ruby & sapphire

by richard w. hughes

RUBY & SAPPHIRE is a journey into one of mankind's most fascinating subjects.

A technical work that elicits anything other than yawns is always a scarce item. But *Ruby & Sapphire* is just such a book—a rare combination of fact *and* fun, the pertinent and the peculiar.

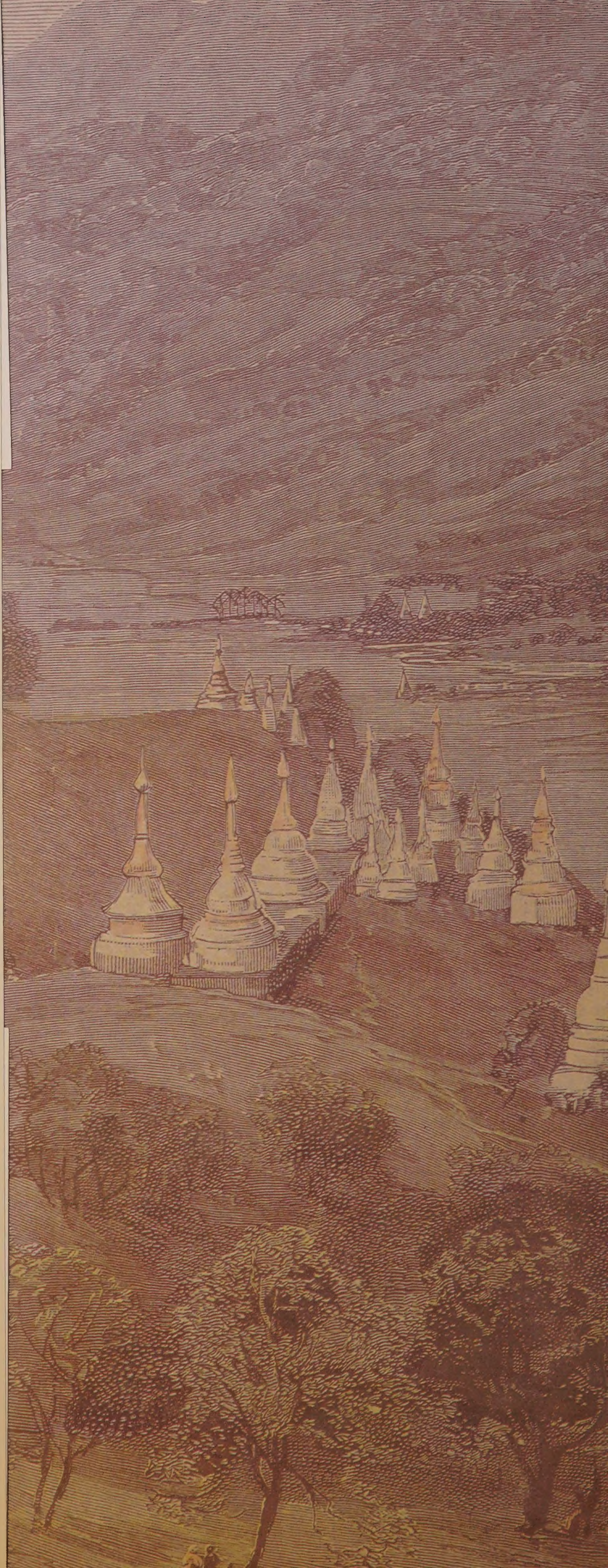
Open *Ruby & Sapphire* and you step into a secret world where, with each page turned, a new adventure awaits. Journey to Burma's Mogok Stone Tract, where pigeon's-blood rubies are pried from both soil and central government control. Marvel over India's maharajahs, the world's greatest gem collectors, for whom no price was too great. Explore the legendary Valley of Serpents, into which pieces of meat were cast to trap rubies. And ascend to the lofty snows of Kashmir, home of storied blue-velvet sapphires. These are but a few of the amazing and colorful tales within.

But *Ruby & Sapphire* is also much more. The product of over 15 years of firsthand experience, it covers every facet of the subject from A–Z. Sources, prices, quality analysis, synthetics and treatments, everything is here, a virtual encyclopedia of the subject.

Ruby & Sapphire highlights:

- Side-by-side photos illustrate color and quality differences, **making it possible even for novices to separate top stones from inferior pieces.**
- Fully illustrated. **Over 350 full-color photos** are included, many in print for the first time.
- Drawings, **maps** and dozens of **rare black-and-white photos** take you direct to the source.
- **Extensive price tables** which cover rubies & sapphires from around the globe.
- Tricks of the trade—**learn how to avoid being taken advantage of** in both buying and selling.
- Exhaustive descriptions and sale prices of important stones make this book **an invaluable research tool.**
- World sources from A to Z—over 50 countries.
- Full discussions on **how to spot synthetic and treated rubies & sapphires.**
- **All key information is tabulated** for quick referral.
- **More than 2400 references**—the most complete list ever assembled.

If you purchase just a single book on precious stones or minerals, it should be *Ruby & Sapphire,* which is nothing less than a tour-de-force of gemological scholarship. **Whether you are a jeweler, gemologist or simply a lover of gems, this book will repay its cost many times over.**



Front cover photo: © Tino Hammid; manipulated by the author in PhotoShop

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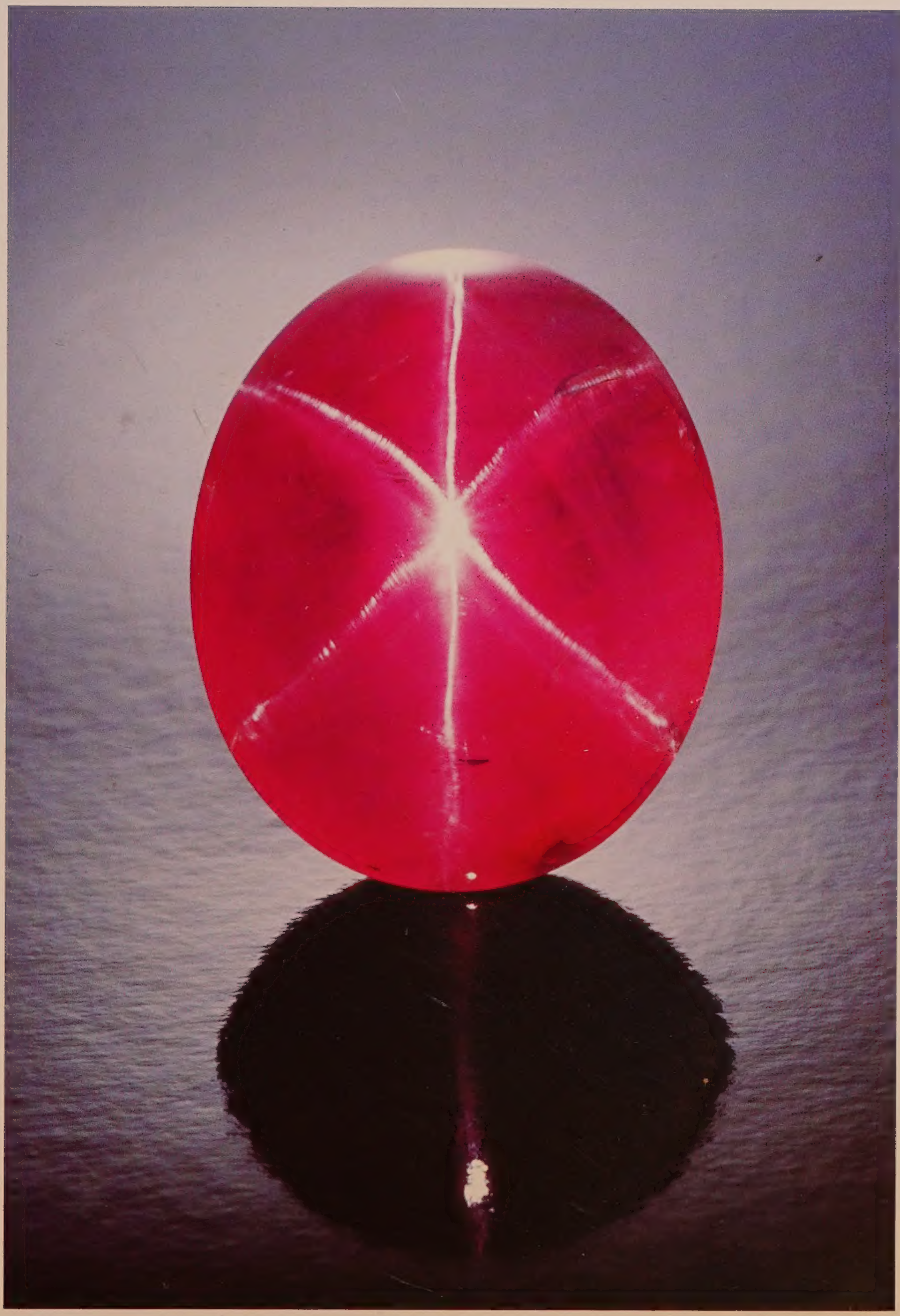
Best wishes from
the author!

R. W. [illegible]

THEY brought me rubies from the mine,
And held them to the sun;
I said, 'They are drops of frozen wine
From Eden's vats that run.'
I look'd again—I thought them hearts
Of friends, to friends unknown;
Tides that should warm each neighbouring life
Are lock'd in sparkling stone.
But fire to thaw that ruddy snow,
To break enchanted ice,
And give love's scarlet tides to flow,—
When shall that sun arise?

RALPH WALDO EMERSON



The 138.7–ct *Rosser Reeves* is the finest star ruby on public display. A product of Sri Lanka's gem gravels, today it resides at the Smithsonian in Washington DC. (Photo: © 1989 Tino Hammid)

THE azure light of Sapphire's stone
Resembles that celestial throne,
A symbol of each simple heart
That grasps in hope the better part,
Whose life each holy deed combines,
And in the light of virtue shines.

MARBODUS

331.05 carats of blue midnight, on a red satin background. (Photo: Harry Winston, New York)

HE that has once the flower of the Sunne
The perfect ruby which we call elixir.

Ben Johnson

Near perfection in a ruby. This untreated 15.97-ct Burma ruby was once owned by Alan Caplan. In 1988, it was purchased at auction for a pretty price—$3,630,000. The per-carat price of $227,301 has yet to be surpassed for ruby. Today the gem is said to be in the personal collection of one of the wives of the Sultan of Brunei. (Photo: Graff, London)

LEGEND OF THE STAR SAPPHIRE

A sapphire, jewel of the skies,
Adorns my lady's hand—
A stone of pure celestial blue
Set in a golden band;
A gem that owes its beauty to
No lapidary's art,
But to the marvel of a star
Imprisoned in its heart.
A star beheld an earthly mind
In ages long ago,
And fell from midnight's spangled vault
To dwell with her below,
And nevermore may it return
To heavenly heights above,
But in a sapphire cell must pay
The penalty of love.

MINNA IRVING

At 563.35 ct, the *Star of India* is one of the largest fine star sapphires in the world. Nearly flawless, its origin is uncertain, but probably emanates from Sri Lanka. Today it rests in New York's American Museum of Natural History, centerpiece of the J.P. Morgan Collection assembled by noted gemologist, George Frederick Kunz.
(Photo: Harold & Erica Van Pelt/American Museum of Natural History)

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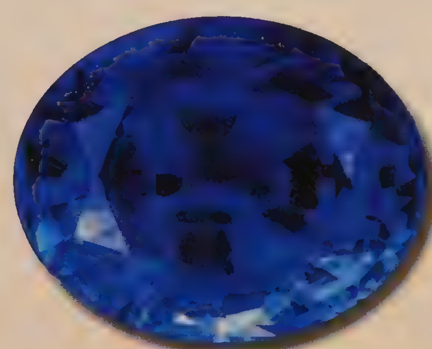

'THE PRICE OF WISDOM IS BEYOND RUBIES' JOB 28:18

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For Wimon and Billie

Remember me, is all I ask.

And if remembered be a task, forget me...

Laurie Anderson

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RUBY & SAPPHIRE

INTRODUCTION

SOMETHING OF MYSELF

> Ship me somewheres east of Suez, where the best is like the worst,
> Where there aren't no Ten Commandments an' a man can raise a thirst…
>
> Rudyard Kipling, *Mandalay*

IT is said that everything has a beginning, a middle, an end. And so it is with *Ruby & Sapphire.* In telling the tale, perhaps it is best to begin with my own story. Like the Judeo-Christian God with his *Bible,* I shall start at the beginning…

University can wait. Seeds of the present volume were sown at age 17, with a classmate's invitation to visit Europe upon graduation from high school. "Let's go! University can wait," Seth teased. "What better way to learn than drink directly from the Fountain of Life? Just imagine, we'll run with Hemingway's bulls, explore life's meaning with Sartre on the banks of the Seine, discover love to a symphony of Crete sunsets. And have a damned good time, to boot. Whaddya say?"

I was captive—swallowing hook, line, sinker and angler's elbow. Two weeks after graduation, we found ourselves aboard Icelandic Airways. Europe and the world lay below. We were all aboard for the first of life's great adventures.

Go East, young man! Asia was not initially in the cards. Seth and I had planned to winter in Israel, and return to Europe in the spring. But, in one of those glorious accidents that changes a life, I met someone in Copenhagen who had just made the overland journey from Asia. As Colin described the wonders of the East, I listened with rapt attention. Istanbul, Delhi, Rangoon, Bangkok—the names rolled off his tongue like a Kipling verse. And then he spoke the magic word—*Nepal.*

Now, one must *understand.* I had grown up in Boulder, Colorado, mountaineering Mecca of America. Reared on *National Geographic* documentaries showing climbers with their army of porters marching towards Everest, the Himalayas represented all one could aspire to. They were the cherry on the sundae, the holy grail, the *pink flamingo on the suburban lawn.* Dangling Nepal out there was like asking a 15-year old if he wouldn't mind showing your nymphomaniac cousin around town while you studied for finals. *It got the blood a pumping!* Then Colin casually mentioned that transport between Istanbul and Nepal would probably run, say… $35. This for a journey of some 5000 km. That sealed it. The die was cast; the hook was set, it was written. I had heard the Sirens' song and would answer the call.

Indeed, he was right. The Eastern lands proved every bit as splendid as described. But in terms of travel expenses, he had erred. It cost me only $25 to travel between Istanbul and Nepal.

Out of Africa. Before jumping straight into Asia, we made a small detour to Morocco, for a taste of the Third World. While waiting for the ferry from Algeciras to Ceuta, Seth and I made the acquaintance of Michael, an African-American from Detroit, who was to become our traveling companion during the next several weeks.

Our days in Morocco were… enlightening. From the moment we crossed the border at Ceuta, we were hassled, hustled, harassed, harangued and otherwise swindled.

Things came to a head in Fez, where we gathered in a decrepit hostelry, plotting escape from the madness. "Ya know, Mike," Seth and I opined, "You could pass for a Moroccan. Particularly if you wear one of those Moroccan *jellabas* (robes) you bought yesterday. Then we can go everywhere without being hassled—the street hustlers will think you're with us." Begrudgingly, Mike agreed the plan was a good one and thus, suitably attired, we headed for the streets. After strolling about a block, with passersby nervously twittering, a voice suddenly cried out from a streetside café: "Hey black man! You're wearing a woman's *jellaba.*"

Ten days after our arrival, weightier in wisdom, but far lighter in coin, Morocco spit us onto the deck of a Tangiers ferry. We landed with an impotent bleat. Our last act in that fair land had been the purchase of a *Herald Tribune*, which proved to be over a week old.

Istanbul is Constantinople. Seth and I parted company in Greece; he headed for Israel and his own personal pilgrimage, I for Asia and mine. My first stop was Istanbul.

The Straits of Bosporus, less than one km wide, mark the physical separation between Europe and Asia. But the chasm of time between these two great continents can be measured in millennia. In Asia, particularly rural areas, one is quickly introduced to life as it was centuries before. A big part of that is precious stones, which remain an integral item of trade in much of the East. From Iran's turquoise, through Afghanistan's lapis lazuli, to the rubies, sapphires and jade of Burma and Thailand, jewels and jewelry are a constant fixture.

India at last. India is best summed up in the comment of one of my fellow travellers, who declared: "It seems to survive in spite of itself." While you either love it or hate it, I found myself doing a bit of both. More than in any other land I visited, I felt transported back to another age.

Since the 15th century, the destination of most overland travelers from Europe was the same—India. I will never forget my first experience. One of the delights of overland travel is that of crossing land borders. Sudden changes in mood and culture always bring surprises. And the Pakistan-India border was a 10. While the Persians had set up an entire museum at the Afghan border to deter smugglers, India took a more subliminal approach. Travellers were set in line, and two handlers brought a psychic out. She slowly approached each traveller and, after a wave of the hand over the forehead, said sternly: "Where is your contraband?" No one broke down into a slobbering heap during my crossing, but later, it was said she was "very good at detecting smugglers."

My friend, Peter, and I took the bus into Amritsar. We had first met in Berlin; later I stumbled upon him on a Khyber Pass-bound bus in Kabul. Over the next several months, we would experience the subcontinent together.

At the Amritsar bus station, *inside the station, in line*, was a cow, seemingly waiting for a ticket on the last bus out. Welcome to India. That night we slept inside the Golden Temple, scene of the Sikh siege in 1984.

Jewels from the mine. My career in gems got off to an ignominious start. Having been offered various and sundry "jewels and priceless relics" from all points east of Istanbul, Peter and I decided to take the plunge in Jaipur. Throwing caution to the wind, we would purchase a small parcel of Indian star rubies for resale. Our search began in a small jewelry shop near Jaipur's *Hawa Mahal* (Hall of Winds).

Clever chaps that we were, Peter and I concluded we simply needed a good ruse. Deep in the core of our being, we just *knew* that the vulpine Oriental venders would hold back the finest goods. Thus we demanded the seller "bring out the good stuff" after each parcel was displayed. Peter, playing the best Abbott to my Costello, would pass a packet across the table for my look-see. Upon poring over a single $1/ct ruby for ten minutes, holding both stone and loupe at arm's length, and checking the star from all directions, I then pronounced judgment: "My good man, this will just not do! We are big dealers, with no time to waste! Show us the good stuff!"

Not even a single *paise* descended from heaven. Instead, following several parcels and several rejections, the seller looked us straight in the eye and, in the vernacular, told us we were full of that which emanates from the rear of a Hindu holy animal. He then proceeded to scold us, explaining that, from the moment we stepped into his shop, it was obvious we were simple tourists, not dealers. Such was apparent merely by the way we handled the loupe and stone papers, not to mention the fact that I had failed to notice the star on one stone because it was upside down. We beat a hasty retreat and, regrouping outside, decided our hiking boots must have given us away.

Kathmandu. Peter and I arrived at Raxaul, on the Nepalese border, at midday. Too late to catch the bus to Kathmandu, but with the Himalayan foothills glistening in the distance, we would not be deterred. We immediately set off for the border. Like so many Asian land borders, the station on one side was a distance from that on the other. Leaving India was, well, Indian—all hassle and uncertainty. Crossing the small creek that delineated the border, one immediately entered another world. "Would the customs agent like to see our bags?" Only if we had a mind to carry them from the horse buggy into the shed. "And would he mind chopping our walking papers anyway?" Of course, with a smile. *Namasté.*

On the Nepalese side, the Himalayas beckoned. We quickly found a truck driven by a Sikh, heading for Kathmandu that very night. "Were we interested?" Would a bear shit in the Vatican? If given the chance, yes. As December's dusk slowly enveloped the surrounding Terai, we set off. The sun's last rays blazed in our wake as we entered the foothills. Midnight came and went and we still headed up, twisting and turning into a Himalayan wonderland, with only our imaginations and the truck's weak headlamps illuminating our path.

Many Indian trucks have a storage space above the cab and so I climbed up to stretch out. It was there that I completed the journey, amidst the pines and stars. As the sun rose, we descended the final hill into the Kathmandu valley. Paradise lost—paradise found. It was pure *magic*. Even today, words seem utterly inadequate, so I will not try. Suffice to say that my stay in the Kingdom lasted several months and included a journey to the Himalaya's inner sanctum. I was hooked, and have since revisited Nepal again and again.

Oh, Calcutta. From Nepal, I beat a swift path to Calcutta, original capital of the British Raj. Anyone who has travelled to India has heard the Calcutta horror stories—the beggars, the cripples, the grinding poverty… Expecting the worst, I arrived at Howrah station at dawn, just slightly tattered, considering I spent the trip in a luggage rack on an Indian train. Instead of despair, I found a vibrant city, one which continues to be my favorite metropolis on the subcontinent.

Burmese Days. Depending on how one worked it, Burma was either the most, or least, expensive country in Asia. Officially, $1 bought six kyat; unofficially, it was closer to thirty. The game was thus: tourists could legally import one carton of cigarettes and one liter of whisky. Obtained at Calcutta's DumDum[1] airport, these would be sold for several times their value in Rangoon. With the exchange of $10 at the legal rate, to satisfy Burmese officialdom, the proceeds were enough to live on for the full week, and then some.

Superficially, Ne Win's Burmese Road to Socialism appeared like the disordered in charge of the disenfranchised, with all in disarray. But evidently somebody was keeping track—six copies were required for every visa application.

Burma represented a topsy-turvy, never-never land where up was down, down was sideways and time moved only slightly above the stall speed of a bicycle. Central government policies had so decimated the manufacturing and agricultural sectors that even basic necessities had to be purchased on the black market. And so ubiquitous was this black market that locals called it the *brown market*. One of Burma's most important products was gems. I recall trading an old and dirty towel for an orange spinel in Mandalay and, to this day, continue to be bewildered that anyone would want that rag. As the saying goes: "In the Land of the blind, the one-eyed man is king."

Bangkok Nights. If Kublai Khan's pleasure dome could be reincarnated in the 20th century, it would rest in Bangkok. Like parched survivors emerging from the Sahara, overland travelers deplaned in Bangkok to a world long-since forgotten. For the first time since Istanbul, one found unheard of luxuries—air conditioning, ice cream, cold beer, *miniskirts*—it was more than a grown man could take. As a mere adolescent, I made sure to get my share. Little did I know it was destined to become my home for over a decade.

Thailand was, is, and probably always will be, one of those glorious places on the planet. A place of enjoyment, a place of warmth, a place of good cheer, a place of *jai dee* (good heart) and *sanuk dee* (good fun). Indeed, it is the Land of Smiles. And a smile is always better than a frown.

Getting down to business. Somewhere it is written that every Bangkok resident should aspire to open either travel agency or jewelry store. Since I was living in Bangkok, and since I cared nothing for the vagaries of ticketing others to paradise, I chose gems. My *entrée* took the form of a gemology class at the newly-minted Asian Institute of Gemological Sciences (AIGS). One thing led to another. Next I knew, I was working at and, soon, managing the Institute. Once again, university could wait.

It was exciting, particularly in the beginning. The school's owners ran one of Bangkok's largest wholesale gem houses. Each morning we would troop in early to check the goods purchased the previous day, with loupe and tweezers our only tools. Buyers came from around the world, particularly Japan—we quickly learned the peccadillos and tastes of each. Best of all, we would play the precious-stone version of *The Price is Right*, guessing the cost of each lot before checking what had really been paid. It was an invaluable experience.

On the border. Weekends were often spent at the Burmese border, particularly Mae Sot. An overnight bus on Saturday night put one in Mae Sot Sunday morning, giving daylight hours for stone purchases. Then it was back on the bus for Bangkok, a quick shower and work Monday morning. When not in Bangkok or Mae Sot, I was off visiting the Cambodian border, Mae Sai, Bo Ploi, Phrae, Chanthaburi, India, Sri Lanka, Burma. Seven days a week, I lived, stroked, inhaled precious stones.

By hook and by book. As all close to me can testify, I suffer a terminal love of books. Thus the first task I undertook at AIGS was creation of a library. But it was a colleague, Bill Spengler, who kindled my interest in antiquarian books. Having grown up in Kabul and Peshawar, Bill was constantly traveling hither and yon. When he returned from one Calcutta sojourn with an Indian edition of Tavernier's *Travels*, I was fascinated. Soon I was doing the same, stocking AIGS and my own library with the obscure, the interesting, the fascinating… along with plotting my own literary career.

Push comes to shove. Inspiration to write came via two contrary channels. The push was two books with which I had fallen in love: Kunz & Stevenson's *Book of the Pearl* and Sinkankas' *Emeralds and other Beryls*. The word *magnificent* does not do these works justice. Their pages put the thought in

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[1] Allegedly named in honor of the fact that it was the first site where dumdum bullets were used.

my mind to do a similar, comprehensive volume on ruby and sapphire.[2] Shove occurred during a particularly distasteful corporate "motivational" retreat. I suppose it worked. Then and there I made the decision to begin doing things for my own welfare.

Love potion number 3.32. Life was not all work and no play. I did find time for other activities. Among my varied duties was working in the closet-like confines of the AIGS lab. It was there, amidst the ever-present odor of di-iodomethane (methylene iodide), that love came to town. My colleague, Wimon, and I were eventually married, and now have a beautiful daughter, Erin Billie. Among other things, we share a passion for precious stones and sashimi. And whenever we smell methylene iodide, we still get all worked up…

The Gemological Enquirer.

> Mark Twain and I are in very much the same position. We have to put things in such a way as to make people who would otherwise hang us, believe that we are joking.
>
> George Bernard Shaw

While the first edition of *Ruby & Sapphire [Corundum]* was in the hands of the publisher, I began work on a periodical, entitled *Gemological Digest.* A better appellation would have been the *Gemological Enquirer*, for, compared to the staid cud typically doled out by test-tube publishers, it must have seemed like a supermarket tabloid. Verily.

In our quest for irreverence, more than a few sacred cows met their maker. I can say with some satisfaction that certain industry figures are still haunted by thoughts of what was printed. Like dealing with the Scud missile, readers either applauded or ducked, depending on the accuracy of our aim. Thankfully, yeas always outnumbered the philistines by a substantial margin.

I will always remember my employer's skittish disposition whenever I brought a new issue over for vetting. After pausing to read it, Henry would cluck and titter like a nervous hen:

> Let's see, this time you've insulted Ne Win, De Beers, the Thai military, the GIA, the Pope, CIBJO, organized religion, the old, the young *and* the restless, atheists, beggars, blind hookers and the entire cast of *Rambo.* Sure you haven't missed someone?

Warming to the task, Henry would then consult his shopworn copy of the *World Registry Of Definable Groups Who Might at Some Future Date Impact Business*, and, with toe extended, gingerly test the waters:

> Hmm. Except the Northern Kerala Mango Growers' Association, I can't find any *new* targets. So I suppose we're safe. But Kee-rist, can't you ditch the disparaging remark about Mother Theresa? And thank god that mango outfit doesn't subscribe!

Thus another issue would be put to bed. Such are the sensitivities of the sensitive. But I must confess, Henry always gave me *plenty* of rope.

Roots. Shortly after the birth of my daughter, I came to realize that 1990s Bangkok was not a particularly nice place for a child. While the people remained as warm as ever, physically, the city had become a monstrosity. Pollution soared to record levels, literally beyond measurement, and an increasing part of each day was spent idling in traffic. The city's worst aspect was its jack-hammer noise, which continued relentlessly, 24-hours-a-day.

Thus the decision to leave was made. Following a brief stay in Vietnam, my family and I returned to Boulder, land of my roots. In the process, I rediscovered some of the beauties of my original home. Clean air, the change of seasons, regular exercise and, most importantly, quiet; are all pleasures relearned, renewed. It is here that I've penned this revision.

Twenty years on. It has now been some twenty years since my first journey to Asia, but the passage of time has done little to dull my thirst for new lands, new experiences. While I have visited more than fifty countries on five continents, the fascination with Asia continues apace.

Many have said about the Himalayas that memories are just not good enough, which is why we are continually drawn back. And so it has been with me and Asia. Whenever I look at a map of that great continent, I see not where I've been, but where I haven't. New adventures await. Land's end continues to be out of sight. All it takes to get started is for someone to say: "Let's go!" Suddenly, I'm 17 again, and university can wait. I'm all aboard for another of life's great adventures.

Richard W. Hughes
Boulder, Colorado, USA
August, 1995

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[2] Amazingly, until the first edition of this book in 1990, there existed not a single volume devoted exclusively to ruby and sapphire.

AUTHOR'S NOTES

Get your facts first, and then you can distort them as much as you please.

Mark Twain (as quoted by Kipling)

MANY in the gemological community take a dim view of non-scientific aspects of the subject. They question the need for details on mystical beliefs, history, even the gem business itself. In the author's view, this is not only unfortunate, but unduly restrictive. Far too many gemological treatises are clinical heartless shells, with any trace of spirit sucked out in the name of science, proper diction or decorum. Considering we are fortunate to work with one of the most romantic products on the planet, this is all the more surprising.

Godehard Lenzen[3] has rightly pointed out that gemology is not merely a subset of mineralogy, but simply knowledge of a certain type of merchandise. I subscribe to the Lenzen view. To my way of thinking, gemology is a rich tapestry of interwoven disciplines. It's threads include not just mineralogy, physics, chemistry, crystallography and geology, but also history, trade, economics, decorative arts, religion, mysticism and magic. Yes, even magic.

Thus, what follows is not merely the science, but also the *gemology* of ruby and sapphire. I hope to convey its romance, its history, its beating heart, its spirit, its *magic*. If I have succeeded in capturing even a portion of that magic, then this book is a success.

3. Lenzen, G. (1970) *The History of Diamond Production and the Diamond Trade*. Trans. by F. Bradley, London, Barrie and Jenkins, 1st English edition, 230 pp.; RWHL*.

Notes on methodology

Before starting our journey into the Land of *Ruby & Sapphire*, a few notes regarding methodology are appropriate, in order that confusion, misunderstandings (and bad reviews) are avoided.

On quotations. *Ruby & Sapphire* features extensive use of quotations, from both primary and secondary sources. Rather than rewriting or paraphrasing the discoveries of others (and, in the process, claiming them as my own), I feel history is better served by exactly transcribing the original, warts and all. In so doing, the danger of misinterpretation is lessened. Unless the meaning of the original is obvious, my own thoughts follow. While this approach may kill a few more trees, it allows readers to make up their own minds on the intent of the original author(s).

Because quotations are faithfully transcribed from the original source, without change, readers may encounter inconsistencies in spelling, punctuation, etc. My approach has been that, unless an obvious spelling error exists, the original stands as printed.

On history. Some may question the need for such extensive historical detail. I include it in an attempt to show the threads of wisdom (and ignorance) connecting us with our past. In today's modern world, it is easy to believe that all worthy knowledge is of recent vintage. Such is not the case and I hope this book, in some small way, will open readers' eyes to the glories and excesses of human tradition and history.

On references. An enormous amount of time has been spent assembling reference materials. Fruits of this research are listed at the end of every chapter (or country listings, in the case of the *World Sources* chapter). Please excuse the small type. When forced to choose between eliminating references or reducing the size of the typeface, I opted for the latter.

Don't you just detest finding an interesting reference, but can't figure out what the damned thing means because it is abbreviated into oblivion? I do. Thus this book's *unabbreviated* bibliographic lists, the most comprehensive ever published on ruby and sapphire.[4] Not all references are actually cited in the text. But they are there for those who wish to explore the subject further.

Why so many references? Wouldn't it be better just to list those cited in the text? No. There's nothing I hate more than just a taste. When it's good, I want it all. Thus the reference lists in this book contain virtually anything the author has encountered pertaining to ruby and sapphire. Obviously some are useless twaddle. But enjoy the feast. To hell with diets.

References feature one of the following notations at the end:

not seen Indicates I have not seen that particular reference.

seen Indicates I have seen, but do not have a copy in my personal library.

RWHL Richard W. Hughes Library; indicates I have an original or photocopy in my personal library. In the case of longer works, I may have a photocopy of only the portions relevant to ruby and sapphire.

* Denotes works of particular merit. Those wishing to explore the subject in greater detail should start with references followed by an asterisk.

On terminology. The following are important notes on the terminology of *Ruby & Sapphire*:

- When units of measurement (inches, feet, lbs, etc.) are converted from another source, they will be converted with the original source's units appearing first and the author's conversions in parentheses.
- *Sapphire*, when alone, indicates blue only. If other colors are described, they will be indicated by the color prefix. *Ruby* includes all red corundums, including those of light red (pink) color.
- The corundum mines of the Thai/Cambodian border region straddle the border. Thus the phrase "Thai ruby" refers to stones from either side of the border.

On computers. This book has been conceived, designed, written, proofed and laid out entirely on Apple Macintosh computers.[5] Software for word processing and layout was *FrameMaker.* The bibliographic database was created using *EndNote Plus.* All line illustrations were drawn by the author, using *FreeHand.* Country maps were imported from *MapArt,* while crystal drawings were generated in *Shape 4.0*, and then imported into *FreeHand.* Photos were scanned and then corrected in *PhotoShop.* Publishing was done by the author, using the services of a commercial pre-press house and printer, with outside expertise brought in when necessary.

This approach has its down side. One must learn to use a number of different software applications, as well as learn about page design and publishing. Oh, but the advantages! By doing everything myself, I have controlled aspects of my work that traditional authors only dream about. No longer am I slave to an anonymous publisher, who knows little of what I write, and cares even less. Free at last, free at last…

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While virtually every magazine in existence contains advertising, the presence of advertising in a book may still be disturbing to some. So let me frame it in a different light: The Harvey Harris book, *Fancy-Color Diamonds,* was published in 1994. At 180 pp., it retails for $175. *Ruby & Sapphire* is 514 pp. and sells for a good deal less. *Capisce?*

On mistakes. This book is a human creation. As such, it is subject to all the errors, prejudices and foibles of the medium and media. Although every precaution has been taken to ensure accuracy, when dealing with a subject of such breadth and complexity, mistakes are inevitable. Should you discover miscues, after cursing my utter ignorance to the highest heavens, forgive me. Then please let me know, so I can correct the mistakes. I can be reached at the following address:

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E-Mail: RubyDick@aol.com

On finality. In the end, this not the last word, but instead, a continuum, an incremental step in a process which has continued for millennia. Or sumthin' like that…. Now I must go. My daughter, Billie, is taking her own incremental steps. She has just learned to balance coins on her knees, and I must bear witness.

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6. These sections are found following Chapters 9 and 11

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MILLENNIA ago, on the island now called Sri Lanka, a *Veddha* (aboriginal) slowly crept down a jungle path. In a land teeming with wildlife, he was headed to a river known to be a popular watering site. As he peered through the thick undergrowth at the river's edge, a *sambur* (elk) stood drinking, oblivious to his presence. Quietly drawing an arrow, the Veddha let it fly with a smooth, practiced motion. Sensing danger, the elk lurched to one side, but too late. The arrow buried itself deep, and the sambur toppled motionless into the water.

Springing from the bush, the Veddha moved to drag it from the stream. Just then he noticed a red flash from the river bottom. Scooping up the stone, he admired its beauty. An incandescent red fire seemed to burn deep within. Today was most auspicious, the Veddha thought to himself. First the sambur, which would feed his family for more than a week, and, now, the red orb. Yes, he had much for which to be grateful. Tonight, he would climb the peak, to give thanks. At dawn, as the great pyramid-shadow spread over the land below, he would offer the glowing crimson orb to *Sumana,* God of Adam's Peak. He was sure Sumana would be pleased.

Anonymous

CHAPTER 1

HISTORY

What is history all about if not the exquisite delight of knowing the details, and not only the abstract patterns.

Stephen Jay Gould, 1991, *Bully for Brontosaurus*

NEXT to diamond, corundum is the most important gem. The species name *corundum,* however, is relatively unknown to lay people. More recognizable are the varietal names, *ruby* (red) and *sapphire* (blue).

Corundum is derived from the Hindu word *kurand* (Streeter, 1892), *kuruvinda* (Tagore, 1879) or *Kauruntaka* (Mitchell, 1979). This was the term used in India to describe an impure form of corundum. Woodward, first in 1714 and again in 1728, refers to this mineral as *nella corivindum* or *tella corivendum,* doubtless derived from the *kurivinda* of the Hindu *Puranas* (Woodward, 1728; Holland, 1898; Barlow, 1915; Shastri, 1978). Henry Yule's *Hobson-Jobson,* Anglo-Indian dictionary *par excellence,* described it thus:

> **Corundum**, s. This is described by Dana under the species Sapphire, as including the grey and darker coloured opaque crystallised specimens. The word appears to be Indian. Shakespear gives Hind. *kurand,* Dakh. *kurund.* Littré attributes the origin to Sanskrit *kuruvinda,* which Williams gives as the name of several plants, but also as 'a ruby.' In Telugu we have *kuruvindam,* and in Tamil *kurundam* for the substance in present question; the last is probably the direct origin of the term.
>
> **Yule's annotations**
>
> ca. 1666.—"Cet emeri blanc se trouve par pierres dans un lieu particulier du Roiaume, et s'apelle **Corind** en langue Telengui."—Thevenot, v. 297.
>
> Henry Yule, 1903, *Hobson-Jobson*

Today corundum is used solely to describe the mineral species consisting of Al_2O_3 crystallizing in the rhombohedral division of the hexagonal system. When pure, corundum is colorless, but this is rare. Impurities give rise to different color varieties, such as ruby (red = Cr^{3+}) or sapphire (blue = Fe^{2+} + Ti^{4+}). The term sapphire alone denotes a blue corundum, while for other hues, the color prefix is used (yellow sapphire, green sapphire, etc.).

Ruby means red, and is derived from the Latin *ruber* ('red') through the late form *rubinus. Sapphire* means blue, and, when first used, described lapis lazuli. Its exact origin is unknown, but may have originated from Sanskrit. It came to the West through the Latin form of a Greek word, *sapphirus.* A similar word is found in both Hebrew and Persian.

The following is the etymology of ruby and sapphire, according to Ayto (1990):

> **Ruby** [14th century] *Ruby* goes back ultimately to Latin *ruber* 'red,' a descendant of the same Indo-European base as produced English *red.* From it was derived the medieval Latin adjective *rubinus* 'red stone.' In due course *rubinus* itself came to be employed as a noun in this sense, and it passed into English via Old French *rubi.* Other English words from the same source include *rubella* [19th century], *rubicund* [16th], *rubidium* [19th], and *rubric* [14th] (headings in ancient and medieval manuscripts were often written in red ink).
>
> **Sapphire** [13th century] *Sapphire* can be traced back through Old French *safir* and Latin *sapphirus* to Greek *sáppheiros* (which seems to have denoted 'lapis lazuli,' another blue stone), but beyond that its origins are uncertain. It may have been acquired via a Semitic language (Hebrew has *sappir*), but it has been suggested that its ultimate source could be Sanskrit *sanipriya,* which stood for a type of dark-coloured precious stone. It meant literally 'precious to the planet Saturn,' and was a compound of *Sani* 'Saturn' and *priya* 'precious.'
>
> Ayto, 1990, *Dictionary of Word Origins*

Figure 1.1 To early humans, the initial attraction to gems was doubtless their rich colors and shiny surfaces. This is exemplified by the magnificent jewel at left, which was fashioned entirely from uncut gems. It contains a mauve Sri Lankan sapphire crystal (5.86 ct), surrounded by four Burmese red spinel octahedra (1.12 ct total) and four alluvial diamond octahedra from Brazil (0.86 ct total). (Photo: Robert Weldon; jewelry: George & Paula Crevoshay/Mellika)

In Hebrew, *sappir* means "the perfect." Thus sapphire is a symbol of perfection (Anonymous, 1952). Another possible derivation is from *sappheiros,* or the isle of Saphirine, in the Arabian Sea (Bank, 1973). Tagore (1879, 1881) states that sapphire was *sappeer* in old Arabic ('to scratch'), probably in allusion to its hardness.

History

Today we know the rich red of ruby and azure-blue of sapphire are nothing but different color varieties of the same mineral, corundum. Such was not always thought to be the case, however. The ancient Sanskrit text, *Garuda Purana,* translated by S.M. Tagore (1879) indicates that in India, at least, this fact may have been known since early times; Western man did not realize this, however, until late in the eighteenth century. Prior to this, in Europe most gems were classified by color alone. Ruby, for example, was found under the heading of *carbunculus* (carbuncle), along with many other red stones, such as garnet and spinel ('balas ruby'). The sapphire was listed under *hyacinthus* (hyacinth) with other stones of a yellow and blue color, such as topaz, quartz, zircon and others.

Theophrastus

Birthplace of democracy, from about 500–300 BC, the Greek city-states gave rise to one of human civilization's most important flowerings of science and culture. While a number of works were written on gems and stones, few have survived. Among these is the *Peri Lithon* ('On Stones') of the Greek scholar, Theophrastus, which dates from about 315 BC. In this brief text, gems were grouped according to color, with different subgroups based on properties. Among these it is probable that the true ruby was found under *anthrax:*

> But there is another kind of stone which seems to be of an exactly opposite nature, since it cannot be burnt. It is called *anthrax,* and seals are cut from it; it is red in color, and when it is held towards the sun it has the color of a burning coal. One might say that it has great value; for a very small one costs forty pieces of gold. It is brought from Carthage [North Africa] and Massalia [Marseilles].
>
> The stone found near Miletus [west coast of Turkey] does not burn; it is angular and there are hexagonal shapes on it. It is also called *anthrax,* and this is remarkable, for in a way the nature of *adamas* is similar.
>
> Caley and Richards, 1956, *Theophrastus on Stones*

It seems likely that, while Theophrastus' *anthrax* may have included ruby, most were red garnets or spinels. The *anthrax* found near Miletus is possibly emery,[1] of which Turkey was a major source. Speculations on the exact meaning of Theophrastus, however, are tenuous, as so much time has passed since the work was written.

1. Emery is a gray to black, impure type of corundum containing magnetite or hematite. It is often used as a polishing or grinding stone.

Figure 1.2 Antique jewelry from the Carthage Treasure (ca. 400 AD), found on the Hill of St. Louis, Carthage (Tunisia), in association with silver dishes and spoons, some with Christian symbols, belonging to the prominent Cresconius family. The jewelry comprises a necklace and earrings of emerald crystals, sapphires and pearls, a gold loop-in-loop necklace with lion-head terminals, a gold ring with a pearl in a claw setting, a plasma intaglio with a bust of Heracles, a nicolo intaglio with a figure of Fortuna and a retrograde Latin inscription meaning, roughly, 'Safe voyage,' and an onyx cameo with a bust of Minerva. The shapes and colors of the sapphires suggest that they probably originated from Sri Lanka. HEIGHT (earrings) 5.7 cm. (Photo: British Museum)

Pliny

More detail was provided by Pliny [23–79 AD].[2] The 37th and last book of the great Roman polymath's encyclopedia, *Natural History,* dealt with gems and stones. Our ruby is most likely found under Pliny's *carbunculus.*

According to Pliny, carbunculus was the most esteemed of all red gems. He stated that they were divided into two categories:

> In all kinds of *carbunculi* those are called male which show a more fiery red and, contrariwise, those that shine less brightly and more faintly are called female. Among the male, some have a clear and pure flame; others are darker and blacker. Some again shine brighter than all others and in the sun show a more marked and a more burning luster, but the very best are those called *amethystizontes* [Almandite: spinel?] because on the crystal points their fire resembles the violet blue of the amethystos [Amethyst]…. As to Indian *carbunculi,* Satyrus says that they are rarely clean as found and indeed are usually befouled. But after they are freed of impurities their brightness is very fiery….
>
> Chapter XXVI
>
> FLAWS OF CARBUNCULUS: THE METHOD OF TESTING IT
>
> In resumé, there is nothing more difficult than to attempt to distinguish these various kinds of *carbunculi* from one another. Further, they are easy to counterfeit and falsify by the art and skill of lapidaries and goldsmiths who put a foil beneath them to make them brilliant and glitter like fire. Some say that the Aethiopians steep their dusky and dark *carbunculi* in vinegar. As a result, in fourteen days, they become pure and lively and remain so for fourteen months. *Carbunculi* are imitated by glass and such imitations at first sight are excellent: but by grinding on a mill, the fraud is immediately discovered as is true with any other artificial or false stone: for the substance of the latter is softer and more brittle than that of the true gem. Further, false *carbunculi* are detected by the lack of hardness of their powder and by their weight: for glass imitations are the lighter of the two. Further, one sees in false *carbunculi* certain small inclusions, that is blisters and vesicules, which look like silver.
>
> Pliny, 1st century AD (from Ball, 1950)

A number of interesting points are raised. The first is employing hardness as a potential test, with Pliny even noticing the hardness of crushed powders made from the stone. Density ('weight') is also mentioned, as are inclusions (gas bubbles) in the glass imitations. This was a savvy

[2] Ever the scientist, Pliny was killed in 79 AD, witnessing the eruption of Mount Vesuvius, which destroyed Herculaneum and Pompeii.

Figure 1.3 The earliest gems were cut as cabochons, simply smoothing over the stones' rough edges. Faceting, which produces scintillation in addition to color, came into vogue only in the second half of the second millennium AD.

The rubies above include a large Burma cabochon (47 ct), along with a 1.38 ct round from North Carolina and a 1.87 ct oval from Tanzania. (Photo: Harold & Erica Van Pelt/ American Museum of Natural History)

observation, particularly considering that he was writing almost 2000 years ago.

Pliny also discussed sapphire, under the heading of *hyacinthos:*

> *Chapter XXVI*
> HYACINTHOS
>
> Next in order, we will speak of the *hyacinthos* [sapphire]. While it differs markedly in some respects from the *amethystos* [amethyst], in luster at least the two stones are much alike, indeed the only difference between them is that in the *amethystos* the violet color is strong and rich, in the *hyacinthos* it is diluted and weaker. The *hyacinthos* at first sight is pleasant and esteemed, but its lovely beauty vanishes before the observer is satisfied. Indeed, it is far from contenting the eye completely and satisfying its pleasure since the color fades sooner than that of the dainty flower also called *hyacinthos,* and the luster weakens rapidly, almost before it comes to the eye.
>
> Pliny, 1st century AD (from Ball, 1950)

It is likely that the sapphires traded in Roman times originated from Sri Lanka. This would explain Pliny's allusion to their pale color. But there is nothing to indicate Pliny was aware that ruby and sapphire were the same material, no doubt because Pliny was so far from the source. Considering just how far away Pliny was, it is amazing he was as accurate as he was.

An additional problem is that traders, then as now, often tried to hide gems' true origin. Pliny, Theophrastus and Solinus (Golding, 1955) mention Turkey and Ethiopia as sources, but these seem improbable in light of today's knowledge. What we do know is that both ruby and sapphire first appeared in Europe in Greco-Roman times. Photographs of these stones suggest that Sri Lanka was the source (see Figure 1.2). But the only sure way of determining their origin is to analyze inclusions and trace-element content on such pieces in museums and collections. Until this is done, all speculations will remain mere conjecture.[3]

Truth is continually diluted as one moves further from the source. This is true even today, *despite* the wonders of modern communications. Imagine what it must have been like during Pliny's era. Corundum has always been, and remains today, largely an Asian gemstone. Thus, to study corundum, we must go to the source, to the Indian subcontinent—where the people had first-hand experience with the occurrence of ruby and sapphire.

3. Proper interpretation of the statements of ancient writers on gems requires both historical and gemological knowledge. For example, Warmington (1928) states that "corundums were sent from India… I take Pliny's Bactrian stones to be Kashmirian sapphires…" (p. 248). As most gemologists know, India's Kashmir mines were not discovered until 1881, quite a bit later than Pliny's time.

Ruby & sapphire in ancient India

—where the gorgeous East, with richest hand, showers on her kings barbaric pearl and gold…

Anonymous (from A.M. & J. Ferguson, 1888)

A number of ancient Sanskrit texts on gems exist, and these have been discussed by Sarma (1984). The Tamil classic, *Shilappakikaram,* written about the end of the 2nd century AD, contains a fascinating description of the South Indian gem market of Madurai. But the earliest to deal solely with gemology was the Buddhist writer Buddhabhatta's *Ratnaparîksâ* (literally *'Gemology'*). Penned about the turn of the sixth century, it was a model for much of what was to come. Indeed, the *Garuda Purana* incorporates the whole text, after a careful removal all traces of Buddhism.

Three works of somewhat questionable authenticity and vintage were the *Agastimata, Agastīya Ratnaparīksa* and *Agastyasamhita.* Although not certain, they were supposedly written by Agastya (Agasti), the legendary sage credited with expansion of Aryan culture beyond the Vindhyas.

Finot (1896) translated (into French) and annotated the *Ratnaparîksâ* of Buddhabhatta, the *Brhatsamhitâ* of Varahamihira, the *Agastimata* and *Agastîyâ Ratnaparîksâ* of Agastya, the *Navaratnaparîksâ,* the *Ratnasamgraha,* the *Laghu-Ratnaparîksâ* and the *Manimâhâtmya.* Tank (n.d.) also mentions the *Vrihat Samhita, Ras Ratna Samuchchaya* and *Kalp Sutra,* but does not indicate in any way the date of these. Brown (n.d.) also mentions the *Graha-gocara Jyautisha* as a Vedic text dealing with astrological gemology.

Probably the best English-language source of Indian lapidaries is S.M. Tagore's *Mani-Málá* (1879,1881). It consists of translations of facts on gems into Sanskrit, Hindi and Bengali, as well as English. While containing information from both European and Arabic-script gemologists, it is largely based up the Hindu *Puranas.* A comparison of his translations with the *Garuda Purana* (Shastri, 1978) shows that this was the source of much of the material.

Puranas (Sanskrit: 'Ancient Lore') are Hindu sacred literature, popular, encyclopedic collections of myth, legend and genealogy, varying greatly as to date and origin. Traditionally a *Purana* treated five subjects: primary creation of the universe, secondary creation after periodical annihilation, genealogy of gods and saints, grand epochs and history of the royal dynasties. *Puranas* are connected in subject with the *Mahabharata* ('Great Epic of the Bharata Dynasty') and have some relationship to law books (*Dharma-sastra*).

Around this core has amalgamated much other material of religious concern during the period of ca. 400 to 1000 AD. *Puranas* were written almost entirely in narrative couplets, in much the same easy, flowing style as the Greek epic poems (*Encyclopedia Britannica,* 1980). Both the *Garuda Purana* and *Skanda Purana* contain material on gems.

Figure 1.4 Sourindro Mohun Tagore, author of *Mani-Málá,* the most important work on gems in India. (From Tagore, 1879, 1881)

In its current form, the *Garuda Purana* probably dates from the 10th century AD (Shastri, 1978), but portions were written as early as 400 AD. It furnishes an unparalleled look at the use and knowledge of precious stones in India. Gems were divided according to their types, with further subdivisions, or castes, based upon characteristics of individual specimens of each type. A large section is devoted to ruby, with a somewhat smaller part on sapphire. While modern translations into English exist (*viz.* Shastri, 1978), I have opted to reproduce the entire ruby and sapphire sections from Tagore's version (see page 486), as he had a greater gemological knowledge.

A number of interesting points are mentioned. As would be expected, Tagore's corundum sources are far more accurate than Pliny and Theophrastus, with Ceylon correctly identified as the major locality. Density ('heaviness') and hardness are both given as methods of distinguishing corundums from glass. We also have a mention of coolness. This is possibly an allusion to the warmth of glass to the touch, when compared with crystals. Like Pliny's mention of soaking of stones in vinegar to improve their color, the *Puranas* discuss a similar process, but state that the gems must be cooked over a fire. One can immediately read into this an early discovery of heat treatment.

Arabic-script mineralogy

After the fall of the Roman empire, Europe declined into Catholic dogma and intellectual darkness. But while Europe slept, the Near East continued the work begun by Egyptians, Greeks and Romans. Despite claims to the contrary (*c.f.* Bandy & Bandy's introduction in Agricola, 1955, p. *v*), learning did not stop between Pliny [d. 79 AD], and Agricola [d. 1555]. The lands from North Africa through Afghanistan were actively involved in trade with the East, and they gave rise to a number of important mineralogical treatises. Among the prominent Arabic-script writings on geology and mineralogy are those of Pseudo-Aristotle [ca. 600–900], Mohammad Ben Mansur, Ibn Sina ('Avicenna') [980–1037 AD], Teifaschi [1184–1253] and Biruni [973–ca. 1050].

The Stone Book of Aristotle is an Arabic-script work erroneously attributed to Aristotle, the famous Greek scientist. The actual author is unknown; it appears to be based on both Greek and later sources. According to Kunz (1915):

> Pseudo-Aristotle, writing some time from the seventh to the ninth century A.D., was the first to define clearly the three leading varieties of the corundum gems (yakut) as the same mineral substance, and differing only in color. These are the ruby, the Oriental topaz (jacinthus citrinus) and the sapphire. Instead of according different medicinal or talismanic virtues to these three precious stones, this writer states that each and all of them, when set in rings or worn suspended from the neck, protected the wearer from danger in epidemics, gave him the honor and good will of his fellow-men, and also the privilege of having his petitions accorded.*
>
> Kunz' annotations
>
> * Rose, "Aristoteles de lapidibus und Arnoldus Saxo," in Zeitschr. für Deutsches Altertum, New Series, vol. vi, p. 386
>
> G.F. Kunz, 1915, *The Magic of Jewels and Charms*, p. 396–7

Kunz also mentioned a Persian treatise on precious stones by Mohammad Ben Mansur:

> A Persian treatise on precious stones was composed by Mohammed Ben Mansur* in the thirteenth century of our era. This work was written for Sultan Abu Naçr Behadirchan, and consists of two divisions, the first treating of precious stones and the second of metals. It is interesting to note in this treatise the recognition of the essential likeness of the Oriental ruby, sapphire, topaz, etc.; these varieties of corundum are all grouped under the single designation "yakut." Ben Mansur writes:†
>
> "The yakut is six-fold: 1, the red; 2, the yellow; 3, the black; 4, the white; 5, the green or peacock-hued; 6, the blue or smoky-hued. Some divide the yakut into four classes: red, yellow, dark, and white, reckoning the peacock-hued and the blue among the dark. The yakut cuts all stones except carnelian and diamond."
>
> Although the Oriental carnelian is hard and difficult to cut or polish, only popular prejudice accounts for this statement, as it falls far short of diamond in hardness.
>
> Kunz' annotations
>
> * Abridgement by Von Hammer in the "Fundgruben des Orients," Wien, 1818, vol. vi
>
> † Ibid., p. 129
>
> G.F. Kunz, 1915, *The Magic of Jewels and Charms*

Although Kunz describes Mansur's treatise as originating from the thirteenth century, Sinkankas (1993) states that he lived in the 9th century AD. If the latter is correct, it represents, along with *The Stone Book of Aristotle*, the earliest documented evidence that those close to the mines were aware that ruby and sapphire were the same mineral.

Another mention is that of the 11th-century Persian, al-Biruni (see box). In his book on mineralogy, Biruni gave a lengthy description of red, yellow, white and blue varieties of *yakut* (corundum), of which the following is but a sampling:

> Of all the stones the *yāqūt* (ruby) has the first place in grade, beauty and rank....
>
> The best variety of the ruby comprises several kinds: the white, dust-colored [blue], black yellow and red. Of these kinds the red is regarded as the best, as the dust-colored and black appear unsuitable upon the face and the skin.... The people of India call it the *padam rak*, and liken it to a stone that is clear and red. It seems *rag* is its name and *padam* is its characteristic. In their language the red water-lily is known as *padam*.... The dust-coloured variety which is called the *nīl* is not used there.... The dust-coloured kind appears red at night, but this red colour is not real; it is imaginary. It reappears as dust-coloured when sunlight shines on it....
>
> It has been said about the pomegranate-like colour of the ruby that, if scarlet blood is sprinkled and spread over a clean piece of silver, the resultant coloration would be like that of the pomegranate-coloured ruby. Scarlet blood is that which is temperate and healthy and besides, flows in the veins. The blood of the right ventricle is scarlet.
>
> al-Biruni, ca. 11th century (Biruni, 1989)

The previous passage is typical of the careful, informed commentary of Biruni, and compares well with Indian descriptions. His description of the color-changing sapphire is particularly accurate.

Among the various Arabic-script works is a well-known treatise written about 1240 AD by Egyptian gem dealer, Teifaschi (Taifashi, Teifashi, etc.) [1184–1253]. Teifaschi's work on gemstones was variously entitled *Kitab al adhjar* [Book of Flowery Thoughts on Precious Stones] or *Azhār al-akfar fi jawāhir al-ahjar* [Blossom of Thoughts on Precious Stones].

Similar to other Arabs writing about gems, Teifaschi places much emphasis on *yaqut* (yakut), a term that at times seemed to embrace several modern gem species, but most often indicated corundum. He delineates its colors, discusses sources and notes that "it is heavier than all other stones of the same size" (Sersen, 1991).

Figure 1.5 Illustration of corundum crystals from India and Burma [some of the above are probably from Sri Lanka]. (From James Sowerby's *Exotic Mineralogy*, 1811, 1817; photo: GIA)

al-Biruni

AL-BIRUNI (b. 973- d. ca. 1050), the 11th-century traveller of Persian parentage, was born in Khwarizm (now Kara-Kalpakskaya, AS–SR). Much of his life was spent living and working in India, primarily the Punjab and the borders of Kashmir. In the process he learned a number of languages, including Turkish, Persian, Sanskrit, Hebrew and Syriac. Biruni died at Ghazna (now Ghazni, Afghanistan).

Like many of the important scientists of the ancient world, al-Biruni was a polymath, expert in a number of different subjects, including history, chronology, math, astronomy, philosophy and medicine. He wrote scores of classic books, including a history of India, as well as works on astronomy, geography, chronology, medicine and pharmacology. One, the *Kitab al-jamahir fi ma'rifat al-jawahir* [literally *The People's Book on the Knowledge of Gems*], was a text of several hundred pages dealing with gems. An English translation of this work was published in 1989 (Biruni, 1989). Biruni writes in a style that even modern readers will appreciate, filling each page with a beautiful mixture of humor, anecdote and scientific observation.

Among the most important of his works was a book on determining the densities of solids, *Maqala fi'lnisab allati bayn al-filizzat wa'l-jawahir fi'l-hajm* [*Treatise on the Ratios Between the Volumes of Metals and Jewels*]. Although this has not survived, portions of it were discussed by other authors. In it, al-Biruni worked out a technique for determining specific gravities of solids of irregular shape, using an ingenious form of balance exploiting Archimedes' principle. He reported precise SG values for eight metals, 15 other solids (mostly gems) and six liquids.

In many respects, Biruni was the prototype of the modern scientist. He was possessed with an extraordinary mind, one which was constantly questioning. While he often refers to the works of others, unlike so many of his contemporaries, Biruni's pursuit of science was not simply repetition, but was based on firsthand investigation and empirical confirmation. Typical were his specific gravity experiments, including the following:

- Red spinel = 3.58
- Blue sapphire = 3.97
- Ruby = 3.85

These are so close to modern values that there is little doubt about which gems he was speaking.

Based on Biruni (1989), Gillispie (1970),
Said & Khan (1981) & Sersen (1991)

Teifaschi also described a source for corundum gems which is undoubtedly Sri Lanka:

> *Yaqut* is brought from a mine named Sahiran which is on an island about forty parasangs beyond Sarandib [Sri Lanka]. The island itself is about sixty parasangs across. There is a large mountain on this island named Mount Rahun. Winds and torrents cause the *yaqut* to descend, after which it is collected [at the foot of the mountain]...
>
> al-Teifaschi (translated in Sersen, 1991)

Obviously, this account appears to be garbled, for there is no island of any size near Sri Lanka. In fact, it appears to be a fairly accurate account of the Ratnapura gem deposits of Sri Lanka, which lie in the shadow of Adam's Peak (Teifaschi's Mount Rahun). Witness the similarity to the account of Abu Zeid al Hasan:

> In the mountains of Serendib [Ceylon] precious stones are found, of various colors, red, green and yellow, most of which are washed from caverns or crevices by rains and torrents... In some places these are dug out of veins like the ores of metals and the rock has often to be broken to come at the precious stones which it contains.
>
> Abu Zeid al Hasan, 850 AD (from Ball, 1922)

In 1832, James Prinsep and Raja Kalíkishen published a fascinating paper in the *Journal of the Asiatic Society of Bengal*. It contained abstracts of three different oriental works, translated into English by Kalíkishen. Prinsep described them thus:

> The information contained in the present notices is extracted from three books, of different ages:
> 1. The *Ajáib-ul-makhlukát o Gharáib-ul-moujudát,* an ancient Persian work on natural history, written by *Zakarya,* a native of *Kufa,* date unknown;
> 2. The *Aqul-i-ashreh,* a work on science, by Mahomed of Berar, An. Hej. 1084 (A.D. 1673;)
> 3. The *Jawáhir-námeh,* a modern anonymous compilation, containing much useful matter in a condensed form: it was probably written at one of the native courts, either Delhi or Hydrabad, since it mentions the opening of recent mines in India.
>
> The two former volumes comprise sketches of all the different sciences known to the ancients. The third, as its name denotes, particularly treats of mineralogy. The Raja has not attempted to give a verbal [verbatim] translation of either, and I shall follow his example in merely gleaning the facts which appear curious, or peculiar to oriental ideas.
>
> RHOMBOHEDRAL CORUNDUM OR SAPPHIRE.
> ARABIC: *yakút;* GREEK: ακανδα? SANSKRIT: *manikya;*
> HINDU: *manik.*
>
> Under the name of *yaqút* are comprised all those stones of the sapphire and ruby species, which are distinguished (or rather connected, as being chemically one) by the epithet *oriental,* in English books of mineralogy, and are now classed together under the general head of corundum, because they are composed of the same earth, alumina, as the corundum or *kúrún* of the Indians. The natives, like our own mineralogists, distinguish four principal species of *yakút;* red, blue, yellow, and white, or colorless.
>
> The first, or ORIENTAL RUBY, ARABIC. *yakút-ahmar,* HINDU. *manik?* exhibits seven varieties of colour, viz. *mihrmátí,* striped *arghwání,* hyacinth; *rumání,* bright-red, or pomegranate; *rúí,* brass-colored; *khamrí,* red-wine colored, the AMETHYST, HINDU. *nagína; lahmí,* flesh-colored; and *khylí,* or asafœtida-colored.
>
> "Not to be deceived in rubies, is a work of great difficulty, because there are spurious ones of polished crystal, which much resemble the true gem; these are called *âyn-ul-raján:* but a skilful lapidary will easily recognize them. When placed in the fire, a true ruby becomes invisible, but when immersed in water, it appears to glow with heat: it also shines like a coal in the dark."

The second is the ORIENTAL SAPPHIRE, ARABIC. *yakút-arzaq,* or *qabúd, safir;* HINDU. *nilam.*

Of this, there are enumerated five varieties, viz.: *taüsí,* peacock-tail blue; *asmání,* azure; *nílí,* indigo; *chaklí,* grey or collyrium; and *sabzí,* greenish.

The third or ORIENTAL TOPAZ, ARABIC. *yaqút-asfar* or *zard,* HINDU. *pokhraj,* has four tints, viz. *narinjí,* orange; *káhí,* straw; *shamâí,* flame or lamp; and *turanjí,* citron-colored. This variety is said to stand the fire better than the others.

If the *yaqút akhzar,* or ORIENTAL EMERALD, be esteemed the fourth variety, then there is a fifth, "of more variegated tints but of less value," comprising probably such as are not transparent, common corundum, adamantine spar, *salam* [*silan,* or *ceylon*] *stone?* &c....

The *Jawáhir-nameh* includes among the varieties of *yaqút,* the *âyn-ul-hireh* (cat's eye) and the *turmali,* from which the latter word may, perhaps, be derived our *tourmaline,* though applied by us to a different mineral.

The *âyn-ul-hireh* (HINDU. *lahsúnia*) is evidently that variety of the sapphire which mineralogists designate *chatoyant,* or *opalescent sapphire,* and which, when cut en cabochon, shews a silvery star of six rays, and is then termed ASTERIA... "The jewellers appraise the value of the *âyn-ul-hireh* according to the number or perfection of the threads (*zanâr*) visible in it, which should give the stone, when turned about, the appearance of a drop of floating water."...

Of the localities of the *yaqút,* it is only stated in two of the works before us, that the gem comes from the hottest part of the globe, "from the south near the equator." In the *Jawáhir-nameh,* however, the large island of Ceylon is said to be its only habitat, where it is generated in caverns from the suppuration and solidification of the essence of water! "The natives dig wells in these places, and wash the *sand* extracted from below, for the various minerals which are disseminated in it."...

In hardness it only yields to the diamond: it is unaltered by the fire, the red and yellow varieties, if any thing, improving in color there-from. The blue, or sapphire, when pure, is of equal value with the diamond. The Arabs are fond of engraving their names upon it.

Besides the *Sílaní* or Ceylon *yaqút,* there is stated in the *Jawáhir-nameh* to be "another ruby, now very much in vogue, which is extracted from a mine in Bengal, near *Tahat-ul-Suráa,* in the vicinity of which is an island, called *Rakhang,* nigh to which is a stream, where also the ruby is procured." *Tahat-ul-suráa* may mean a deep mine; Rakhang is the Arracan of Europeans.[4] "It is greatly valued in *Hindústhan.* Jewellers assert, that its nature is soft, and that fire will dissolve it, but from its appearance or touch no idea can be formed of these defects." This account may refer to the spinelle ruby about to be described, or to a species of garnet.

James Prinsep and Raja Kalíkishen, 1832

The above contains much of interest. Evidence that true ruby and sapphire (corundum) are being described is found in the references to hardness, color range, resistance to fire and sources. The statement that star corundums are judged "according to the number or perfection of the threads" (rays or silk?), may be an allusion to transparency, more opaque being of lower value. Unfortunately, literal translations of the books that formed the basis for the above article never appeared. In any event, it is clear that Arabic-script sources were aware that ruby and sapphire were one and the same, simply different color varieties of a single mineral type.

European learning in the Dark & Middle Ages—Under the yoke of the church

I keep six honest serving-men (They taught me all I knew);
Their names are What and Why and When and How and Where and Who.

Rudyard Kipling

After the fall of the Roman Empire, learning in Europe ground to a halt under oppressive aristocratic and theological rule. Church leaders professed that all knowledge came from God, and, as God's representatives on earth, only they should direct learning. It reality, their motivations were probably no different than those of the aristocracy—privilege and power are more easily maintained with a superstitious and illiterate population. The result was[5] a persecution of anyone with ideas not conforming to the prevailing dogma (*viz.* the Inquisition).

During the Dark and Middle Ages, European "learning" consisted almost exclusively of repetition of Greek and Roman scholarship. Thus, we find little new material of interest on gems from this period. What did exist, was derived mainly from Arab sources (who, in turn, got much of their information from the Greeks and Romans).[6]

The Lapidarium of Marbodus

That said, among the most important European lapidaries of the Middle Ages is that of Marbodus (Marbœuf), abbot and master of the Cathedral School of Anjou from 1067 to 1081 AD, the last year in which he was made Bishop of Rennes.;

According to King (1860), Marbodus' *Lapidarium* poem was mainly derived from Pliny and Solinus [ca. 3rd century AD], the latter of whom he paraphrases entire sentences. Marbodus also borrowed heavily from pseudo-Orpheus [ca. 4th century AD], and, possibly, Damigeron (Sinkankas, 1993). Later authors, such as Camillus Leonardus (1750), borrowed heavily from Marbodus. As with the writings of Pliny and Theophrastus, it is often difficult to ascertain exactly which gem species Marbodus speaks of. We find possible mentions of corundums under *carbuncle* (ruby) and *hyacinths* (various sapphires) (King, 1860):

4. Arracan apparently refers to the Arakan region of present-day Burma.

5. And, unfortunately, continues to be.

6. Among the reasons the *Puranas* and Arabic works are so interesting is because they date from this period when Europe was intellectually asleep.

Adam's Peak

ADAM'S PEAK is known by various names, including Sri Pada ('The sacred footprint'), Samanalakande ('Butterfly Mountain'—where butterflies go to die) or *Shivan Adipatham* ('the creative dance of Siva'). But whatever it is called, it is among the most holy places on the planet, sacred to Christians, Muslims, Buddhists and Hindus alike.

Atop the peak is a small shrine containing a stone with a footprint-like image. This is said to be the footprint of Adam, Buddha or Siva, depending on one's faith. For some Christians and Muslims, the peak is the first place where Adam landed after being expelled from Eden, while certain Catholics say the footprint belongs to St. Thomas, an early Christian apostle who preached in south India. Of course, some Christians also believe that Sri Lanka (Serendib, the isle of paradise) was actually the biblical Garden of Eden. This must be why religion is synonymous with faith, for that is what is so often needed in order to believe some of these conflicting religious accounts. As Mark Twain once said: "Man is the Religious Animal. He is the only Religious Animal. He is the only animal that has the True Religion—several of them. He is the only animal that loves his neighbor as himself, and cuts his throat if his theology isn't straight."

Figure 1.6 Adam's Peak, Sri Lanka. (Photo: William Spengler, Feb., 1981)

Among the more interesting accounts of Adam's peak is that of Friar Odoric, who visited the area between 1316–1330:

> In this country also there is an exceeding great mountain, of which the folk relate that it was upon it that Adam mourned for his son one hundred years. In the midst of this mountain is a certain beautiful level place, in which there is a lake of no great size, but having a great depth of water. This they say was derived from the tears shed by Adam and Eve; but I do not believe that to be the truth, seeing that the water naturally springs from the soil.
>
> The bottom of this pool is full of precious stones, and the water greatly aboundeth in leeches. The king taketh not those gems for himself, but for the good of his soul once or twice a-year he suffereth the poor to search the water, and take away whatever stones they can find. But that they may be able to enter the water in safety they take lemons and bruise them well, and then copiously anoint the whole body therewith, and after that when they dive into the water the leeches do not meddlewith them. And so it is that the poor folk go down into the pool and carry off precious stones if they can find them.
>
> The water which comes down from the mountain issues forth by this lake. And the finest rubies are dug there; good diamonds too are found and many other good stones. And where that water descends into the sea there be found fine pearls. Wherefore the saying goes that this king hath more precious stones than any other king in the world.
>
> Friar Odoric [1316–1330]
> From Henry Yule, 1866, 1913, *Cathay and the Way Thither*

Adam's Peak's pilgrimage season runs from December–April, which also happens to coincide with the clearest views. If one ascends at night (a three-hour climb), upon sunrise you will be treated to one of nature's most glorious sights—the peak casts a perfect triangular shadow on the ground below. On rare occasions, one sees the "Specter of the Brocken"—one's own immensely magnified shadow, projected on distant wraiths of mist, looped by a rainbow halo (Apa Productions, 1983). And if the weather is clear, one can see all the way to Colombo, some 65 km distant. It is no wonder that Adam's Peak has inspired so many divine thoughts over the millennia.

Figure 1.7 Pilgrims atop Adam's Peak admire the view at dawn. (Photo: William Spengler, Feb., 1981)

Marbodus' *Carbuncle*

The *Carbuncle* eclipses by its blaze
All shining gems and casts its fiery rays
Like to the burning coal; whence comes its name,
Among the Greeks as Anthrax known to fame.
Not e'en by darkness quenched its vigour tires;
Still at the gazer's eye it darts its fires;
A numerous race, within the Lybian ground
Twelve kinds by mining Troglodytes are found.

Although Libya is mentioned, we know of no ruby or spinel coming from this area. Once again this points up the difficulty in deciphering such ancient writings. It is likely that Libya was simply a trading locality.

Marbodus specifically mentioned sapphire, but, as in the time of Theophrastus and Pliny, this described lapis lazuli. The modern sapphire is found under *hyacinths* (King, 1860):

Marbodus' *Hyacinths*

Three various kinds the skilled as *Hyacinths* name,
Varying in colour, and unlike in fame:
One, like pomegranate flowers a fiery blaze;
And one, the yellow citron's hue displays.
One charms with paley blue the gazer's eye
Like the mild tint that decks the northern sky:
A strength'ning power the several kinds convey
And grief and vain suspicions drive away.
Those skilled in jewels chief the *Granate* prize,
A rarer gem and flushed with ruby dyes.
The blue sort feels heaven's changes as they play
Bright on the sunny, dull when dark the day:
But best that gem which not too deep a hue
O'erloads, nor yet degrades too light a blue;
But where the purple bloom unblemished shines
And in due measure both the tints combines.
No gem so cold upon the tongue can lie,
With greater hardness none the file defy;
The diamond splinter to th' engraver's use
Alone its hardened stubbornness subdues.
The citron-coloured, by their pallid dress,
Their baser nature openly confess;
With any kind borne on thy neck or hand,
Secure from peril visit every land.
On all thy wand'rings honours shall attend
And noxious airs shall ne'er thy health offend;
Whatever prince thy just petition hears
Fear no repulse, he'll listen to thy prayers,
Midst other treasures to adorn the ring
This gem from Afric's burning sands they bring.

This passage contains several points of interest. First, we have the statement that *hyacinths* may vary in color—one material, but several varieties. This comfortably fits corundum. Second, we see one variety compared to the color of the pomegranate flower, a reference that appears across many cultures with ruby.[7] Third, what we do know of ancient corundum sources suggests that Sri Lanka was probably the major, if not the only, source in early times. Marbodus mentions three colors under the hyacinthus: red (orange?), yellow and sky-blue. It is precisely these three colors which are most common in Sri Lanka. Sri Lanka is also unusual in that all three colors occur in exactly the same hexagonal bipyramidal habit, and sometimes in the same crystal. In hindsight, it would appear most unusual if, at the minimum, miners in Sri Lanka did *not* make a connection between these gems.

Carbunculus of Albertus Magnus [ca. 1200–1280]

CARBUNCULUS (carbuncle), which is *anthrax* in Greek, and is called *rubinus* (ruby) by some, is a stone that is extremely clear, red, and hard. It is to other stones as gold is to the other metals. It is said to have more powers than all other stones, as we have already said. But its special effect is to disperse poison in air or vapour. When it is really good it shines in the dark like a live coal, and I myself have seen such a one. But when it is less good, though genuine, it shines in the dark if clear limpid water is poured over it in a clean polished black vessel. One that does not shine in the dark is not of perfect, noble quality. It is mostly found in Libya; and although there are several varieties, so that Evax says that there are eleven kinds, nevertheless Aristotle, according to Constantine, says that there are [only] three kinds which we have enumerated above—namely, *balagius*, *granatus*, and *rubinus*. And—what surprises many people—he says that granatus is the most excellent of these; but jewellers consider it less valuable.

Albertus Magnus, ca. 1261–63 AD, *Book of Minerals*
(from Wyckoff, 1967)

Marco Polo, Gutenberg and the reawakening of Europe

And the wildest dreams of Kew, are the facts of Khatmandu.
Rudyard Kipling

The reawakening of Europe came slowly at first, but the pace soon quickened, fueled, in part, by exploration of far off lands. Much of this effort was directed towards the East. Although Alexander's army had ventured into India in the 3rd century BC, and the Romans traded freely with the Orient, no European is known to have crossed the Pamirs into eastern Asia until that most famous of travelers, Marco Polo, made the trip in the thirteenth century (Severin, 1976). He blazed a trail through the very heart and soul of the eastern lands, and his memoirs, dictated in a Genoa prison to a fellow inmate, were an instant success. The tales of fabulous lands of wealth and wonder, far advanced to the countries of which Europeans knew, instantly captured readers' imaginations.

But the event which had greater impact than any other occurred in the realm of printing. About 1450, Johannes Gutenberg, a diamond polisher from Mainz, invented movable type. For the first time, mass production of books

7. The Thai word for ruby, *taubptim* (ทับทิม) also means pomegranate.

The fantastic Carbunculo

Of all the stories associated with the carbuncle, perhaps none is as fantastic as that of the Carbunculo animal:

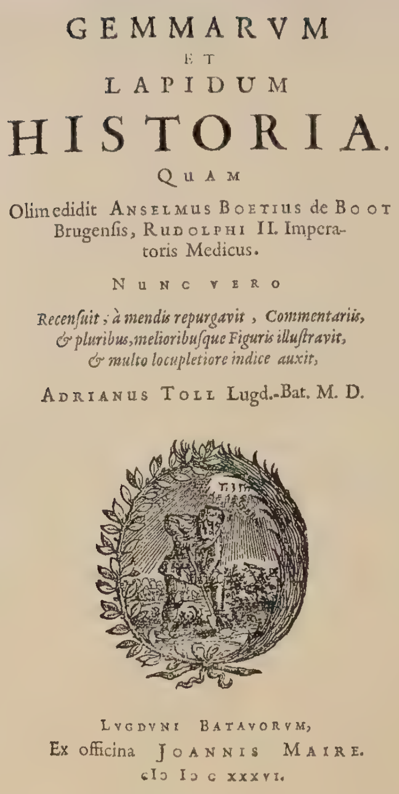
> The fabulous animal called the "Carbunculo," said to have been seen in some parts of Peru, is represented to be about the size of a fox, with long black hair, and is only visible at night, when it slinks slowly through the thickets. If followed, it is said to open a flap or valve in its forehead, from under which an extraordinary and brilliant light issues. The natives believe that the light proceeds from a precious stone, and that any foolhardy person who may venture to grasp at it rashly is blinded; then the flap is let down, and the animal disappears into the darkness. Such are the stories related by the Indians; and it appears that the belief in the existence of the Carbunculo has prevailed in Peru from the earliest times, and certainly before the Conquest; so that its introduction cannot be attributed to the Spaniards. It is even prevalent among most of the wild Indians, by whom the early missionaries were told the stories, which they, in their turn, repeated about the animal. As yet, nobody has been able to capture one; the Spaniards always showed themselves very anxious to obtain possession of the precious jewel; and the viceroy, during the Spanish occupation, in the official instructions to the missionaries, placed the Carbunculo in the first order of desiderata. What animal may have served as a foundation for these fabulous stones, it is difficult to say; probably one that seeks its prey by night, and the flashing of whose eyes, when excited, may have led to such a fable.
>
> William Jones, 1880, *History and Mystery of Precious Stones*

became possible. No longer would learning be the sole province of clergy and nobility. This single development did more than any other to produce the world in which we today live (Roberts, 1993). With it began a flowering of all intellectual pursuits. Freedom to read developed into the principle of freedom of thought. Although unevenly applied, even today, the concept that the State and/or clergy could not legislate against ideas was an important one.

The search for a sea route to Asia soon became the Holy Grail of European explorers. Columbus' famous voyage to the New World in 1492 was in quest of that goal. Finally, in 1498, Vasco da Gama realized the dream, rounding the Cape of Africa and dropping anchor in Indian waters. This ushered in the great European age of Asian exploration and expansion.[8]

For the first time, European travelers to Asia brought back *first-hand* knowledge of Asian gem occurrences. When combined with the burgeoning strides being made in European science, mineralogical knowledge expanded at an exponential rate. Mixed among the facts, however, was a healthy dose of mystical lore, as the following shows:

[8] It is unfortunate that, while Europe moved forward, throwing off its theological shackles, Asia slowly began to regress, burdened by the weight of excess cultural baggage and despotic rulers (Levenson, 1967).



GEMMARVM
ET
LAPIDUM
HISTORIA.
QUAM
Olim edidit ANSELMUS BOETIUS de BOOT
Brugensis, RUDOLPHI II. Imperatoris Medicus.
NUNC VERO
Recensuit; à mendis repurgavit, Commentariis, & pluribus, melioribusque Figuris illustravit, & multo locupletiore indice auxit,
ADRIANUS TOLL Lugd.-Bat. M. D.

LUGDUNI BATAVORUM,
Ex officina JOANNIS MAIRE.
CIƆ IƆ C XXXVI.

Figure 1.8 Title page of the 1636 edition of Anselmus Boetius de Boot's famous book, considered by many the most important lapidary of the 17th century.

> There are Rubies also of manie other sorts, wherof some are white like Diamonds as I said before: other of a Carnation colour or much like white Cherries when they are ripe. There are Rubies found halfe white, halfe red, some halfe Rubies, halfe Safires, and a thousand such other sortes. The cause thereof is because that in the rockes and hils where they grow, their first colour is white, and by force of the Sunne, are in time brought to their perfection and ripenesse, and beeing perfect they are of colour red, like the Carbunckle and Tockes aforesaid, but wanting somewhat of their perfection, and being diffed out before that time, they are of divers colours as I said before, and how much paler they are, and lesse red then the Tockes, so much are they less in valew: for as they are in beautie and perfection, so are they esteemed every one in their kinde. Those that are halfe Rubies, and halfe Safires, which the Indians call Nilcandi, that is to say, halfe Safier, and halfe Rubie, proceed of this that the Rubies and Safiers grow alwaies in one rock, whereby they are oftentimes founde, halfe one, halfe other. The Rubies by the Arabians and Persians are called Iacut,* by the Indians Manica.† The Safiers are of two sortes, one of a darke blew, the other of a right‡ blew.
>
> **P.A. Tiele's annotations**
> * Yâkût (Arab.).
> † Cfr. Sanskrit, manikya; Tamil, manikkam.—[K.]
> ‡ Read: "light".
>
> John Huygen van Linschoten, ca. 1585
> (Tiele, 1885)

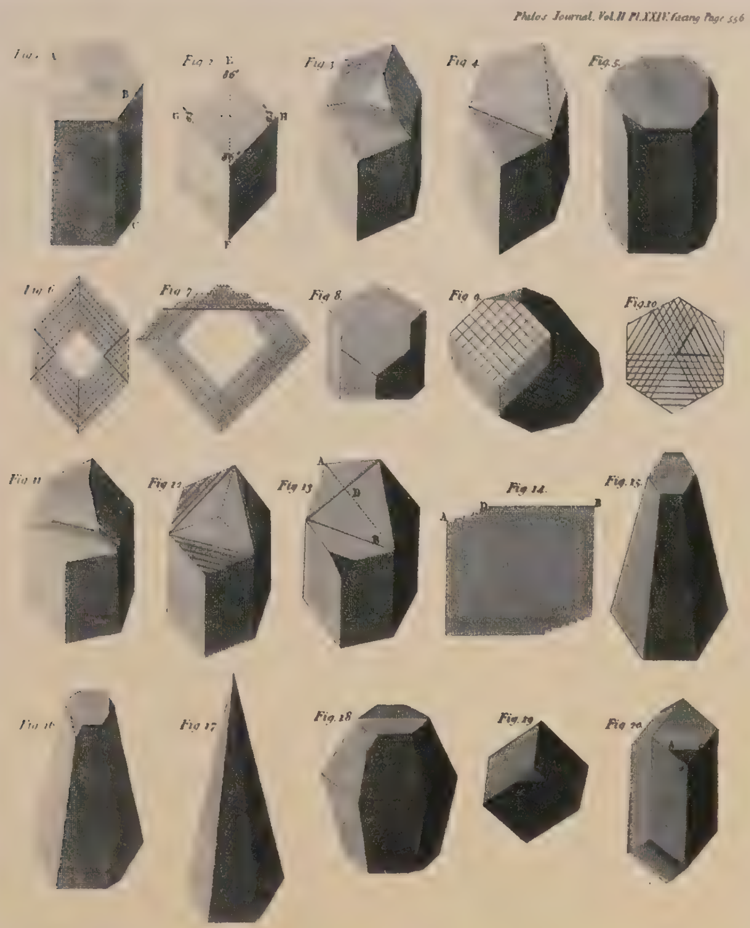


Figure 1.9 Illustration of corundum crystals from Count de Bournon's 1799 paper on corundum.

Anselmus Boetius de Boot [1550–1634]

Among the most famous of early lapidaries is that of Anselmus Boetius de Boot (Boodt). The first edition was published in Hanover in 1609. It was among the most important work on gems of the 17th century and contained a classification scheme considered a precursor to the modern systems (Adams, 1938, p. 162). De Boot listed ruby under the heading of *carbuncolo* (carbuncle, which literally means 'glowing embers'). He described how these stones were held in high esteem in India and Arabia, and that many kings or other nobles would actually glow at night because they wore so many of these jewels. De Boot himself did not actually admit to having seen this. He did say, however, that one could separate a true carbuncle from other red stones by its glow at night. Certainly this sounds like ruby or spinel, both of which fluoresce red to visible light. The concept of ruby emitting a red glow is extremely important and more will be said about it later.

Thomas Nicols

The first independent lapidary to appear in English was that of Thomas Nicols, in 1652. While some of the material is derived from de Boot, much was a product of his own trade experience. Nicols describes in some detail foilbacks and other counterfeits, as well as important source information. Witness the following section under the carbuncle heading:

> **Of the places wherein they are found.**
> The best of these are found in the Isleland called Zeilan [Ceylon], some small ones are found in *Coria, Calecut* [Calicut], *Cambaya* [Cambay], *Bisnager;* there are excellent ones found in the River *Pegu* [Burma], the inhabitants there try them with their mouths and tongues: the colder and harder they are, the better they are; they grow in a certain stony *matrix* of a rosie colour, which if it be transparent is called *Balassium Rubinum* [balas ruby?]; for the most part it is found in the same mine where the *Saphire* is found: and according to the varietie of its nourishment it is found of a mixt colour.
>
> **Of its tincture or Foyl.**
> This though it be a very glorious stone and of excellent beauty, yet a foyl is used to it, as to all other gemms of transparency & perspicuity. The foyl is either made of tinctured Mastick, or of a dyed vitreous substance, or else a red gold foyl is used about it.
>
> Thomas Nicols, 1652

Nicols had an excellent knowledge of ruby (and sapphire) sources, as the above selection shows. He was aware of

Figure 1.10 If not the first, Sri Lanka was certainly one of the first places where corundum gems were found. And the Island of Gems continues to be one of the most important sources of ruby and sapphire, producing such fine examples as the 5 cm- (2 inch) long intergrown crystal at left. (Photo: O. Bauer & J. Beckett/American Museum of Natural History)

hardness, and he seemed to suggest a relationship between ruby and sapphire. All in all, the writings of Nicols show the progress resulting from the expansion of scientific knowledge and first-hand information from Asian sources.

Final unification of ruby and sapphire

The gemological literature from early times through 1700 suggests that first, on the Indian subcontinent, and later, in the Near East, people were aware of the relationship between ruby and sapphire. But this fact was not proven beyond doubt until late in the 18th century. Availability of specimens and adequate source information, along with the tremendous strides made in the areas of analytical chemistry and crystallography, combined to put the final pieces of the puzzle together.

Western mineral science steadily advanced over the 17th and 18th centuries, fueled by specimens sent back by Europeans in Asia. Throughout the 18th century, as European

Figure 1.11 Illustration of corundum crystals and polished cabochon stars. (From James Sowerby's *Exotic Mineralogy*, 1811, 1817; photo: GIA)

colonial empires expanded eastward, mineral specimens from the new colonies were sent back to Europe. British residents in Madras, India sent back samples of crystals used by natives for polishing all gems except diamond. These were termed *adamantine spar* (Greville, 1798):

> *Nella Corivindum* is found in fields where the rice grows: it is commonly thrown up by field rats, and used, as we do emery, to polish iron....
> *Tella Convindum*... Tis a talky spar, grey, with a cast of green: it is used to polish rubies and diamonds....
> *Nella Corivendum* is found by digging at the foot or bottom of hills, about 500 miles to the southward of this place. They use it as emery, to clean arms, &c. it serves also to grind rubies, by making it like hard cement, by the help of stick-lac mixt with it.
>
> Dr. Woodward, quoting Mr. Buckley of Madras (from Greville, 1798)

In 1782, French crystallographer, Romé de L'Isle, was the first European to recognize that ruby and sapphire were crystallographically similar (Ball, 1950). M.J. Brisson published data on the specific gravities of various gems in 1787, including ruby and sapphire (Anderson, 1938):

- Blue sapphire = 3.99
- Ruby = 4.28
- Oriental topaz' (yellow sapphire) = 4.01

With the exception of ruby, these measurements closely agree with modern values.

In 1796, René Just Haüy described ruby and sapphire as a single species, *tetesia* (or 'perfection') (Ball, 1950, p. 275). But the real credit for the discovery went to Count de Bournon and Charles Greville, who, in 1798 and 1802, published two landmark papers in the *Philosophical Transactions of the Royal Society of London* (Greville, 1798; de Bournon, 1802). Haüy added the final chapter in 1805, when he formally united all varieties under the name corundum (Barlow, 1915).

Prior to this date, the term *oriental* was used to indicate a superior hardness in the precious stones which we now know as corundum. Thus our blue sapphire was termed *oriental sapphire,* our ruby *oriental ruby,* our yellow sapphire *oriental topaz,* our violet sapphire *oriental amethyst* and our green sapphire *oriental emerald.* The *oriental* prefix was derived from the fact that the Orient (countries east of the Mediterranean Sea) was the major source of these gems. Count de Bournon (1802) described it thus:

> Although the epithet oriental has been for a long time used by the lapidaries, to express, in gems or precious stones, a degree of hardness superior to that of other stones, (the diamond excepted,) which made them capable of taking a more brilliant polish; and although, following the example of the lapidaries, naturalists had employed the same term by way of distinguishing them, there still remained a great uncertainty, respecting the nature of the analogy which really existed between the various stones to which the above epithet was applied.
>
> Count de Bournon, 1802
> *Description of the corundum stone…*

This nomenclature was not due to any mineralogical knowledge, with the result that a number of different species, related only in hardness and color, were united together. Slowly, however, mineralogy progressed to the point where the true nature of these substances could be ascertained.

As mineralogists began to study these impure specimens of corundum, as well as others of ruby and sapphire, clues linking them together were found in their crystal symmetry. Eventually Greville and de Bournon fit into place the final piece of the puzzle.

> It is, in fact, among those gems or stones, now known by the names of sapphire, oriental ruby, &c. that corundum ought to be placed; but the progress by which we have arrived at this degree of knowledge was necessarily very slow, and was impeded by continual obstacles: for the scarcity and smallness of the crystals of corundum, and the impression naturally made upon our minds by the various appearances it exhibited to us, were by no means likely to lead us to form a true judgment respecting it.
>
> Count de Bournon, 1802

De Bournon was able to unite all of these dissimilar substances under the name of corundum by a combination of keen observation and shrewd application of tests such as specific gravity, hardness and chemical analysis:

> The substance treated here of, has hitherto presented itself to our notice under two appearances, which differ so much from each other, in the greater number of those characters which most forcibly affect our senses, particularly those which concern the organ of sight, that we cannot be much surprised to find that mineralogists feel some reluctance, at the idea of uniting together substances which appear so very dissimilar.
>
> Under one of these appearances, in which it is known by the name of corundum, this substance presents itself either in fragments, or in crystals of a pretty large size; sometimes, indeed, of a very considerable one. The surface of these crystals is generally dull and rough; their texture, which is very much lamellated, is shown to be so by their fracture, which is obtained without much difficulty, as the adherence of their crystalline laminæ to each other is not very strong, and is easily overcome; and the crystal or fragment may always be brought to the rhomboid, its primitive form. Their colour, which is most commonly rather dull, is a whitish, greenish, and sometimes yellowish gray. Specimens of a purplish red, or of a blue color, have always been extremely rare; indeed, a short time since, no such specimens were known, excepting a very few, preserved in the collection of Mr. GREVILLE, and some small fragments he had given away; but the specimens which have been lately sent from the district of Ellow, have contributed to increase their number.
>
> Under the other appearance, (in which this substance is known by the names of sapphire, ruby, &c.) it offers itself, on the contrary, in crystals which are generally of a very small size, and have a smooth and brilliant surface. Their transparency is often very great; and it seldom happens that they are not semi-transparent, in a greater or less degree. They are more difficult to break in the direction of their crystalline laminæ; and this difficulty increases, in proportion to their purity and their brilliancy. Their colours are much more beautiful, more variegated, and more lively.
>
> With respect to the name of this substance, as, in its most common state, it is known in India, (its native country,) by the name of corundum, and as that name has been generally adopted in Europe, I have thought proper to continue it, and shall distinguish, by the terms *perfect* and *imperfect,* the two different states in which it presents itself to our observation.…
>
> From what has been said it appears, that the analogy existing between the stones hitherto known by the names of corundum, sapphire, oriental ruby, oriental hyacinth, &c. is so strong and complete, as no longer to permit us to doubt that they ought all to be considered merely as varieties of the same substance, to which I have given the general name of corundum.
>
> Count de Bournon, 1802

Thus it was, in the year 1802, that ruby and sapphire were formally united under the heading of *corundum.*

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Yule, H. and Burnell, A.C. (1903) *Hobson-Jobson.* London, Routledge & Kegan Paul, 1st ed., 1886; 2nd ed. 1903 by William Crooke, reprinted 1995, AES, New Delhi, 1021 pp. (see Ava, pp. 40–41; Balass, p. 52; Capelan, p. 159; Ceylon, pp. 181–190; Coromandel, pp. 256–258; Corundum, p. 259; Tenasserim, p. 914); RWHL.

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CHAPTER 2

CHEMISTRY & CRYSTALLOGRAPHY

He builded better than he knew;—The conscious stone to beauty grew.

Ralph Waldo Emerson [1803–1882], *The Problem. Stanza 2*

IN a series of ground-breaking articles, Charles Greville (1798), Count de Bournon (1798, 1802) and Richard Chenevix (1802) identified corundum as a distinct mineral species, formally uniting ruby and sapphire under this heading for the first time. Not only were the physical properties measured, but also the chemical and crystallographic features were laid out with surprising accuracy. This finally proved what many had long suspected—ruby and sapphire were actually the same material, corundum.

Chemical composition

Chemically, corundum consists of crystallized alumina, e.g. aluminum oxide (Al_2O_3). All other elements present are impurities. When corundum is pure, colorless sapphire results; the color of ruby is due to traces of chromium; blue sapphire from traces of iron and titanium.

Chenevix's analyses (1902) first established the composition of this new species. They are reproduced below:

Blue perfect corundum, or sapphire		Red perfect corundum, or ruby	
Silica	5.25	Silica	7.00
Alumina	92.00	Alumina	90.00
Iron	1.00	Iron	1.20
Loss	1.75	Loss	1.80
Total %	100.00	Total %	100.00

These analyses were surprisingly accurate, but with one flaw. Preparation of material for analysis entailed crushing samples in an agate mortar and pestle. The far-harder corundum abraded the agate, causing contamination of the samples with silica. It was not until 1840 that the mineralogist Heinrich Rose [1795–1864] realized that corundum was more than 99% alumina. (Frazier & Frazier, 1994).

Table 2.1: Electron microprobe analysis of blue sapphires from Elahera, Sri Lanka (in wt%)[a]

Element	Sample number			
	1	2	3	4
SiO_2	0.06	0.03	n.d.[b]	0.06
Al_2O_3	99.43	99.71	99.49	99.48
Na_2O	n.d.	n.d.	n.d.	0.01
K_2O	n.d.	n.d.	n.d.	0.02
MgO	n.d.	n.d.	n.d.	0.05
CaO	0.02	n.d.	0.01	n.d.
FeO	0.15	0.17	0.12	0.22
MnO	n.d.	0.03	0.01	n.d.
TiO_2	0.01	0.01	0.01	0.02
Total	**99.67**	**99.97**	**99.64**	**99.86**

a. Table 2.1 data from Heilmann & Henn (1986)
b. n.d. = not detected

Table 2.1 gives modern electron-microprobe analyses of corundum, while Table 2.2 lists those obtained via proton-induced x-ray emission (PIXE).

The corundum structure

Chemically, corundum is an oxide, meaning a naturally occurring mineral compound in which oxygen is combined

Figure 2.1 Hand-colored plate of corundum crystals. (From James Sowerby's *Exotic Mineralogy*, 1811, 1817; photo: GIA)

with one or more metals. As with hematite, to which it is related, the ratio of metal to oxygen in corundum is X_2O_3.

Hematite group	
Hematite	Fe_2O_3
Corundum	Al_2O_3
Ilmenite	$FeTiO_3$

Hematite-group mineral structures are based upon hexagonal closest packing of oxygen atoms, with cations in octahedral coordination between them (see Figure 2.3). Corundum's basal projection shows that only two-thirds of the octahedral spaces are actually occupied by Al^{3+} cations. Electrostatic valence (e.v.) or bond strength of the Al^{3+}–O^{2-} bonds is related to the presence of one-third octahedra without central Al^{3+} ions. Because Al^{3+} ions are surrounded by six oxygen atoms, the e.v. of each of the six Al–O bonds equals one-half. Each oxygen is shared between four octahedra, meaning that four bonds (of e.v. = one-half) can radiate from an oxygen position. Within the basal plane {0001}, this allows for only two Al-O bonds from each oxygen, which is indicated by the geometry of two octahedra sharing one oxygen corner.

Table 2.2: PIXE weight % analysis of natural and synthetic rubies[a]

Origin	Number of specimens tested	Element											
		Ca		Cr		Fe		K		Ti		V	
Natural ruby													
Afghanistan	1	0.063		0.490		0.109		0.018		0.004		0.010	
Burma	40	0.030	(022)[b]	0.439	(314)	0.098	(122)	0.010	(010)	0.021	(032)	0.046	(035)
India (locality 1)	28	0.033	(024)	0.359	(084)	0.182	(065)	0.009	(006)	0.013	(035)	0.011	(005)
India (locality 2)	10	0.036	(012)	0.870	(213)	0.187	(083)	0.006	(004)	0.200	(402)	0.009	(006)
Kenya	10	0.069	(091)	0.476	(051)	0.049	(069)	0.053	(047)	0.026	(013)	0.031	(012)
Sri Lanka	5	0.044	(030)	0.148	(029)	0.545	(459)	0.027	(028)	0.046	(032)	0.019	(022)
Thailand	39	0.013	(011)	0.314	(111)	0.413	(108)	0.006	(006)	0.019	(011)	0.002	(002)
Synthetic ruby													
Chatham	7	0.008	(004)	0.528	(087)	0.006	(003)	n.d.[c]		0.004	(002)	n.d.	
Inamori	2	0.007	(002)	0.303	(003)	n.d.		n.d.		n.d.		n.d.	
Kashan	6	0.030	(023)	0.163	(075)	0.031	(019)	0.012	(010)	0.034	(016)	n.d.	
Knischka	1	0.011		0.247		0.159		n.d.		0.005		n.d.	
Ramaura	5	0.010	(008)	0.329	(286)	0.037	(046)	0.008	(006)	0.002	(001)	n.d.	
Seiko	1	0.005		0.386		0.006		n.d.		0.002		n.d.	
Unknown	5	0.006	(006)	0.179	(013)	0.004	(004)	n.d.		0.007	(001)	n.d.	

a. Data in Table 2.2 is from Tang & Tang *et al.* (1991b)
b. Values in parentheses represent one standard deviation from the mean concentration.
c. n.d. = not detected

Figure 2.2 While the American state of Montana is famous for sapphires, the occasional ruby, such as the crystal pictured above, is also found. (Photo: Mike Havstad/GIA)

Table 2.3: Corundum unit cell dimensions

Morphological unit cell of corundum		
Rhombohedral angle	=	85°42⅔'
Hexagonal cell axes ratio *a:c*	=	1:1.3652
Structural unit cell of corundum		
Rhombohedral cell		
a_r	=	0.5128 nm
a_α	=	55°17
Hexagonal cell		
a_h	=	0.4758
c_h	=	1.2991
c_h/a_h	=	2.73

The arrangement of Al^{3+} ions and of the omitted cations in a vertical section of the corundum structure is shown in Figure 2.3. Each octahedron shares a face between two adjoining layers in the vertical stacking of octahedra. The Al^{3+} cations within those octahedra that share faces will tend to move away from the shared face because of the repulsive forces between them.

Chromium enters the corundum lattice in the form of a trivalent ion, Cr^{3+}, isomorphously replacing some of the aluminum ions. Each Cr^{3+} ion is surrounded by six oxygen ions. The Cr^{3+} ions possess a radius of 0.065 nm, somewhat greater than that of Al^{3+} ions (0.057 nm). Upon isomorphous replacement of Al^{3+} by Cr^{3+}, certain lattice parameters (a and c) are increased.

Crystallography of corundum

Corundum crystallizes in the trigonal subdivision of the hexagonal system, belonging to the ditrigonal–scalenohedral class $\bar{3}2/m$. This class has the following elements of symmetry:

- One three-fold axis, which also represents a three-fold inversion axis.
- Three two-fold axes perpendicular to the three-fold axis described above.
- Three planes of symmetry perpendicular to the two-fold axes and intersecting along the axes of higher order.
- A center of symmetry.

Unit cell dimensions

The *unit cell* is the fundamental building block of a crystal, i.e. the smallest part which still possesses all the characteristics of the whole crystal. Before the discovery of x-rays, crystallographers determined unit-cell dimensions by studying a crystal's external shape ('morphology'), and by analyzing and measuring faces and angles. Unit cells determined in this way are termed *morphological cells,* and differ somewhat from structural cell dimensions determined through x-ray

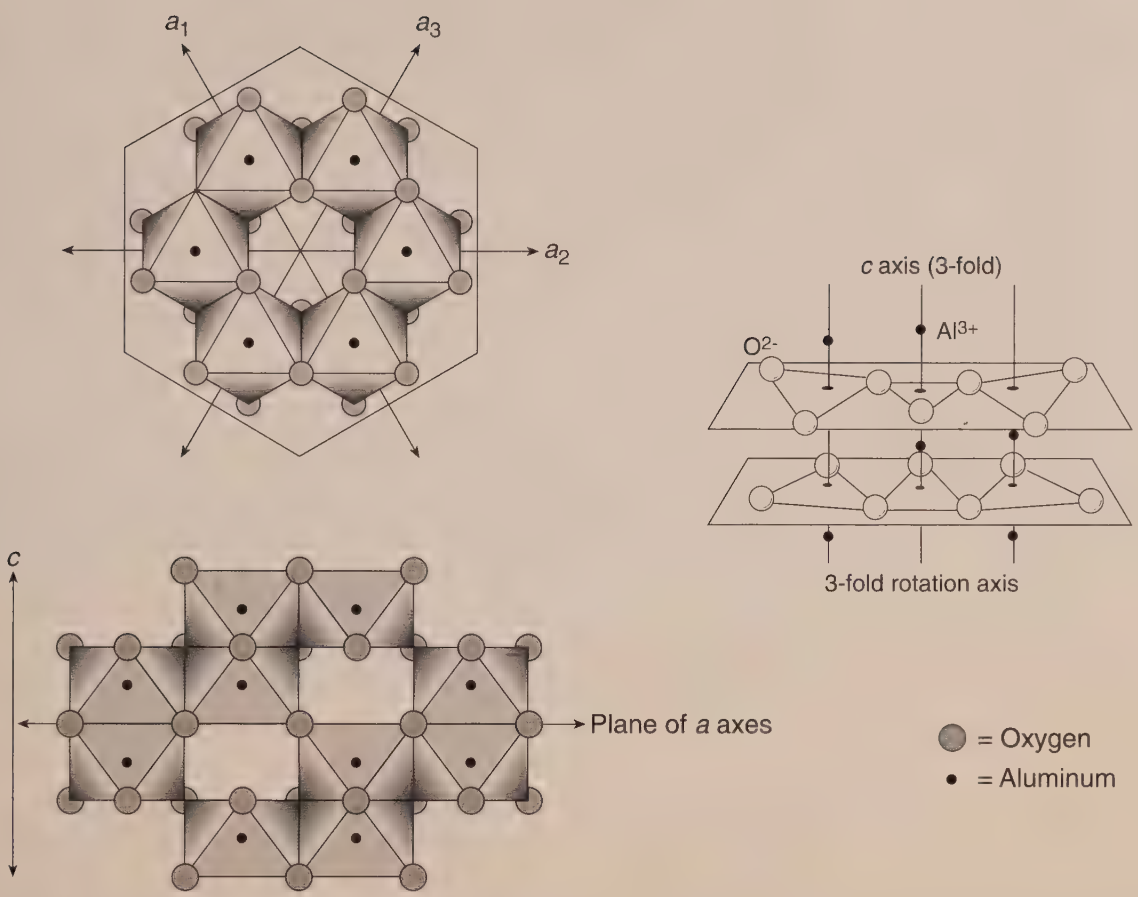

Figure 2.3 Three different views of the structure of corundum. The top illustration shows the structure looking down the *c* axis, while below is a view perpendicular to the *c* axis. At right is a perspective view.

studies. The dimensions of each are given in Table 2.3 (after Belyaev, 1980).

Crystal forms

Form refers to a specific type of crystal face. Possible forms depend on the shape of the unit cell. Within the $\bar{3}2/m$ symmetry class there are two general forms (groups of *like* faces).[1] According to Bravais-Miller notations, these two simple forms are (Klein & Hurlbut, 1993):

- Rhombohedrons: $\{h0\bar{h}l\}$ and $\{0h\bar{h}l\}$
- Ditrigonal scalenohedrons: $\{hk\bar{i}l\}$ and $\{kh\bar{i}l\}$

Of these, the scalenohedron is unique to class $\bar{3}2/m$. Thus it is known as the *hexagonal-scalenohedral* class.

Rhombohedra and scalenohedra of this class may combine with forms found in classes of higher hexagonal symmetry. Thus one may encounter hexagonal prisms, dihexagonal prisms, hexagonal bipyramids (dipyramids) and basal pinacoid, as follows:

- Pinacoid (basal pinacoid): {0001}
- Hexagonal prisms: $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$
- Dihexagonal prism: $\{hk\bar{i}0\}$
- Hexagonal bipyramid: $\{hh\bar{2h}l\}$

Face indexes & angles

Indexing of crystal forms (faces) varies slightly between the morphological and structural unit cells. The choice of which to use depends upon the application. Structural unit cells are used in studies involving the electron microscope or x-ray topography, while the morphological cell is used when studying enlarged manifestations of plastic deformation (twinning or gliding) or cleavage, and determining orientation by the back-reflection Laue technique.

For the gemologist, external morphology is of primary crystallographic interest. The types of faces and their angles of intersection can be of great use in identifying corundum, not only as crystals, but also as cut stones, for internal growth

[1] Each face of the same form has the same position in relation to the symmetry elements and crystallographic axes, as well as displaying similar appearances (luster, striations, etch marks, etc.) and properties. This is because all faces of the same form are underlain by the same types and arrangement of atoms.

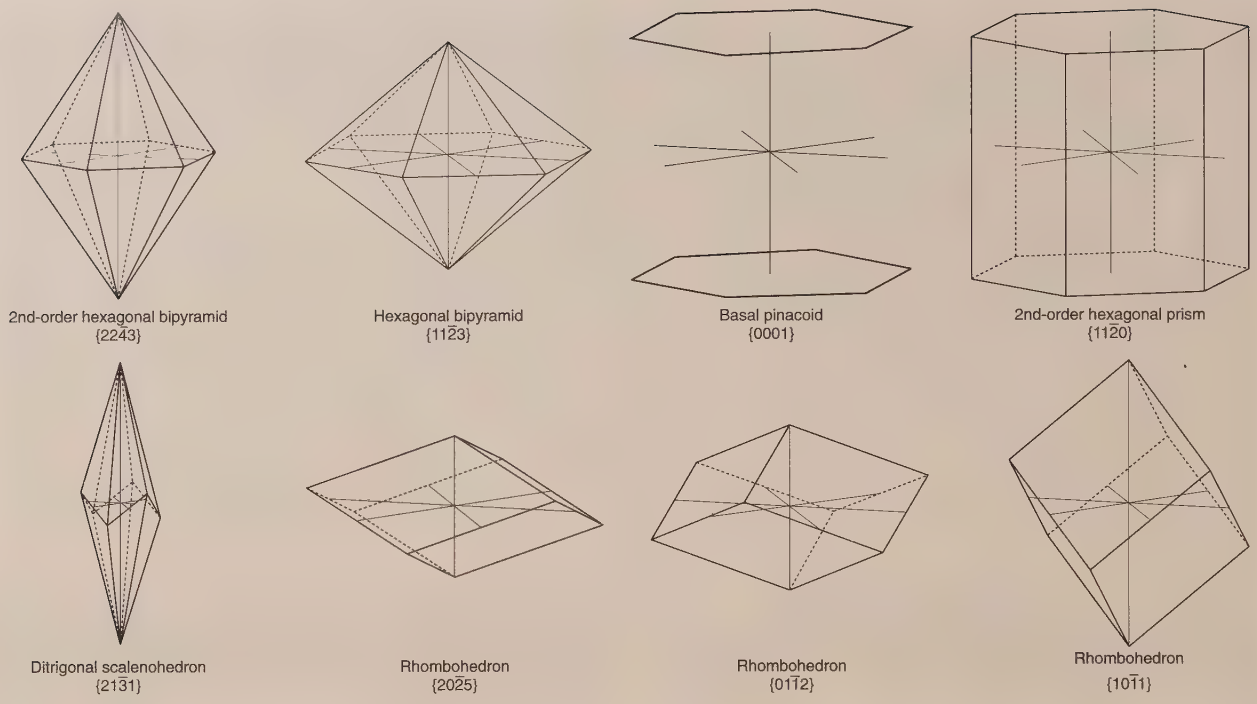

Figure 2.4 Idealized drawings of some of the possible crystal forms of corundum.

planes and color zones always lie parallel to crystal faces. A technique for separating natural and synthetic corundum based on growth-line angles is discussed on page 185.

The common faces of corundum and their angles of intersection are shown in Table 2.4.

Twinning in corundum

Under certain conditions, crystals may form symmetrical intergrowths, known as *twins,* in which the crystal lattice of one part bears a definite crystallographic relationship to that of the other section.

Twin crystals may be classified into one of three categories according to the cause:

- **Growth twins:** Formed via a mistake during growth, where atoms take up incorrect positions on the growing crystal. This results in a change in growth direction, and formation of a twin crystal.
- **Transformation twins:** These are 'secondary twins' which occur in a pre-existing crystal. They occur when a crystal formed at high temperatures is cooled and subsequently rearranges its structure from the high-temperature form. This is common in feldspars, but is not found in corundum.
- **Glide or deformation twins:** Also a type of secondary twinning, these result from a deformation of the crystal due to mechanical stress. If the stress produces slippage (gliding) of atoms on a small scale, twins may result; large slippage may cause slippage without twinning, eventually resulting in fracturing.

  This type of twinning is exemplified by calcite, where pressure from a razor blade on the rhombohedron edge produces glide twins right before one's eyes. It is also common in corundum, and typically occurs repeatedly throughout a crystal.

Twinning in corundum is of the first and third types. Growth twins are common in corundum from certain localities, such as Sri Lanka and Kashmir. However, most twinning in rubies and sapphires is secondary twinning due to deformation. When a crystal is repeatedly twinned, with many or all of the twin planes lying parallel to one another, it is known as *polysynthetic twinning* ('lamellar twinning').

Polysynthetic twinning in corundum commonly occurs on the rhombohedron $\{10\bar{1}1\}$ faces, or, more rarely, along the basal pinacoid {0001}. According to Belyaev (1980), rhombohedral twinning occurs at low temperatures and high deformation rates. This is why rhombohedral twinning is more common than the basal twinning, which requires higher temperatures (>1000°C, according to Heuer, 1966).

Viewing twinning in corundum. Twinning in corundum is best observed by immersing the specimen in di-iodomethane (methylene iodide) and examining it between crossed polars with magnification. Under these conditions, twin planes stand out as bright planes fringed with interference colors. In contrast, sharp color zoning, which is sometimes confused with twinning, remains dark.

Boehmite (γ-AlO·OH) needles also indicate the presence of twinning. The long white needles of boehmite are formed through exsolution at the junctions of the rhombohedron twin planes. Like the rhombohedral twin planes, boehmite needles meet at angles of 86.1° and 93.9°. They make an

Table 2.4: Angles (in decimal degrees) between face normals of corundum

c																				
{0001}	*m*																			
90.00	{10$\bar{1}$0}	*a*																		
90.00	30.00	{11$\bar{2}$0}	*q*																	
32.23	57.78	62.49	{20$\bar{2}$5}	*r*																
57.62	32.39	43.01	25.38	{10$\bar{1}$1}	*t*															
80.99	9.02	31.21	48.76	23.39	{40$\bar{4}$1}	*d*														
38.25	71.97	57.59	33.97	47.00	64.62	{01$\bar{1}$2}	*R*													
38.25	51.76	57.59	6.02	19.38	42.75	36.07	{10$\bar{1}$2}	*γ*												
17.51	81.36	74.91	27.52	50.37	72.67	20.75	32.64	{01$\bar{1}$5}	*s*											
72.40	61.54	34.37	59.34	55.66	58.81	34.16	57.83	54.91	{02$\bar{2}$1}	*S*										
72.40	17.61	34.37	40.17	14.80	8.59	57.83	39.08	64.43	56.93	{20$\bar{2}$1}	*p*									
42.31	54.35	47.70	20.54	27.34	46.25	19.67	19.67	28.28	38.82	38.82	{11$\bar{2}$3}	*n*								
61.22	40.62	28.79	35.70	26.0	34.41	32.01	25.53	46.58	29.66	29.66	18.92	{22$\bar{4}$3}	*l*							
76.52	23.24	17.27	46.59	25.74	19.26	50.35	41.25	63.69	39.54	18.85	35.40	18.35	{21$\bar{3}$1}	*L*						
80.02	17.05	18.88	48.98	25.83	13.75	56.03	43.29	68.26	45.31	15.49	40.09	24.12	6.19	{31$\bar{2}$1}	*y*					
76.52	42.69	17.27	53.90	41.79	40.32	41.25	50.35	60.09	18.85	39.54	35.40	18.35	21.19	26.66	{12$\bar{3}$1}	*w*				
69.89	35.59	20.13	43.57	29.44	31.03	39.34	39.34	55.08	28.47	28.47	27.59	8.67	12.35	18.54	12.35	{11$\bar{2}$1}	*f*			
84.77	30.42	5.24	57.52	39.01	30.01	52.74	52.74	69.74	31.84	31.84	42.47	23.55	13.55	16.65	13.55	14.88	{44$\bar{8}$1}	*z*		
79.63	31.59	10.38	52.66	35.34	29.60	48.03	48.03	64.67	29.95	29.95	37.33	18.41	11.11	15.85	11.11	9.74	5.15	{22$\bar{4}$1}	*v*	
74.65	33.38	15.37	47.98	32.11	29.97	43.53	43.53	59.76	28.83	28.83	32.33	13.43	10.72	16.61	10.72	4.76	10.14	4.99	{44$\bar{8}$3}	*g*
85.52	30.30	4.49	58.22	39.57	30.12	53.43	53.43	70.48	32.16	32.16	43.21	24.30	14.03	16.89	14.03	15.64	0.75	5.89	10.88	{14 14 $\overline{28}$ 3}

Face definitions

Common symbol	Index	Name	No. of faces	Common symbol	Index	Name	No. of faces
c	{0001}	Basal pinacoid	2	*m*	{10$\bar{1}$0}	First-order hexagonal prism	6
l *L* *y* *x*	{21$\bar{3}$1} {31$\bar{2}$1} {12$\bar{3}$1} {24$\bar{2}$3}[b]	Ditrigonal scalenohedron	6	*a*	{11$\bar{2}$0}	Second-order hexagonal prism	6
q *r* *t* *d* *R* *γ* *s* *S* *b* *k*	{20$\bar{2}$5} {10$\bar{1}$1} {40$\bar{4}$1} {01$\bar{1}$2} {10$\bar{1}$2} {01$\bar{1}$5} {02$\bar{2}$1} {20$\bar{2}$1} {10$\bar{1}$7} {30$\bar{3}$2}	Rhombohedron	6	*p* *n* *w* *f* (ω) *z* *v* *g* (ν) *h* *j*	{11$\bar{2}$3} {22$\bar{4}$3} {11$\bar{2}$1} {44$\bar{8}$1} {22$\bar{4}$1} {44$\bar{8}$3} {14 14 $\overline{28}$ 3} {22$\bar{4}$9} {44$\bar{8}$9}	Second-order hexagonal bipyramid	12

a. Based on the morphological cell where *a:c* = 1:1.3652. Angles were calculated using *Shape 4.0* (Dowty & Richards, 1993).
b. Face reported but not contained in the above table.

angle of 32.4/57.6° with the *c* axis. Since they usually only form along twin planes, their presence often indicates the presence of twinning.

Twinning in synthetic corundum. Verneuil synthetic corundum also displays a form of polysynthetic twinning due to the rapid cooling of the boule. Termed *Plato lines,* these are found parallel to the hexagonal prism faces (see page 153). On rare occasions, boehmite needles and rhombohedral twinning have been seen in Verneuil and floating-zone synthetic corundum.

The boehmite needle-rhombohedral twinning combination provide one of the best means of separating natural corundum from the *flux-grown* synthetic. While rhombohedral twinning has been seen in the flux-grown synthetic, the boehmite-rhombohedral twinning *combination* has not.

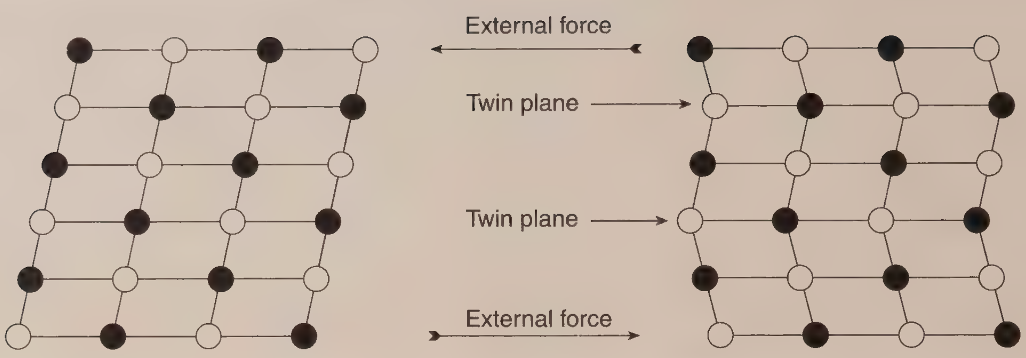

Figure 2.5 Two-dimensional atomic model of glide twinning. Opposing forces cause planes of atoms to slip or glide into a twinned position.

Table 2.5: Face frequency (after Belyaev, 1980)

Frequency of faces for natural corundum crystals	Based on Donnay-Harker law	According to Hartmann (1980)	
		Number of free bonds for F-face	
		Per cell (volume)	Per unit surface
$\{0001\}$	$\{10\bar{1}1\}$	$\{10\bar{1}1\}$	$\{10\bar{1}1\}$
$\{10\bar{1}1\}$	$\{01\bar{1}2\}$	$\{0001\}$	$\{11\bar{2}0\}$
$\{22\bar{4}3\}$	$\{11\bar{2}0\}$	$\{02\bar{2}1\}$	$\{01\bar{1}2\}$
$\{11\bar{2}0\}$	$\{0001\}$	$\{01\bar{1}2\}$	$\{22\bar{4}3\}$
	$\{22\bar{4}3\}$	$\{11\bar{2}0\}$	$\{20\bar{2}5\}$
	$\{02\bar{2}1\}$	$\{22\bar{4}3\}$	$\{02\bar{2}1\}$
	$\{11\bar{2}3\}$	$\{20\bar{2}5\}$	$\{0001\}$

Other types of twinning may also be found in the flux synthetic corundums, but without the accompanying boehmite needles. See Chapter 7 for more details.

Morphology (face probability) & habit

In normal English usage, form refers to shape, but in crystallography, shape is designated by the term *habit*. Crystallographic *form* is used in a restricted sense, indicating a specific type of face, or group of *like* faces. A crystal's habit (overall shape) describes the relative development (or lack of development) of a form, or combination of forms.

A number of factors beyond the unit cell dimensions may influence the habit, or shape, of a crystal. These include all the external influences during growth, such as the chemical composition of the growth melt or solution, temperature, pressure and cooling rate, direction of solution or melt flow, and availability of open space for free growth.

While crystals have many potential faces, certain forms occur with greater frequency. Faces are most likely to grow parallel to the lattice planes which have the highest density of lattice points. This is known as *Bravais' Law*, and while Donnay & Harker (1937) and Hartmann (1980) found exceptions, it is generally true.

Describing habit. Habit is often indicated by *dominant form*. Thus a crystal which displays mostly bipyramid faces might be described as *bipyramidal. Massive* describes specimens displaying no outward evidence of their internal symmetry (such as rolled pebbles).

The habit of ruby often differs from that of sapphire. Rubies tend to grow as tabular hexagonal prisms in which every other corner is truncated by rhombohedron faces. As a result, many rubies, particularly those from the Thai/Cambodian border region, are faceted with overly shallow pavilions. In contrast, sapphires are generally found as barrel- or spindle-shaped hexagonal pyramids and bipyramids. These are best illustrated by the sometimes enormous specimens unearthed in Sri Lanka. Stones faceted from such crystals differ from most rubies in that the pavilion is often excessively deep.

Prismatic and pyramidal or bipyramidal-shaped crystals frequently display horizontal striations at right angles to the *c* axis. These result from oscillatory growth, where the conditions are just right for the growth of both the pinacoid and pyramid or prism faces. Thus, the growth alternates, with each face growing for just a short time, creating a striated appearance. The horizontal striations create a characteristic appearance which allows corundum crystals to be easily identified in most cases. Of the corundum look-alikes, only quartz displays similar horizontal striations, but the vast differences in specific gravity between quartz and corundum allows easy separation.

The most common habits of corundum from major worldwide localities are as follows:

Ruby habits

Afghanistan. Tabular hexagonal prism and pinacoid combinations with well-developed rhombohedron faces. Also elongated prisms and bipyramids. Crystals are often embedded in a white marble matrix. Polysynthetic twinning along $\{10\bar{1}1\}$ is common. Traces of blue color zoning are often

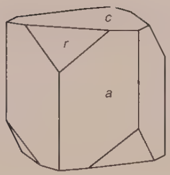

Figure 2.6 Crystal habits of rubies from Jagdalek, Afghanistan.

seen, similar to rubies from Vietnam and Mong Hsu (Burma).

Burma. Tabular hexagonal prisms, often showing a terraced or stepped appearance due to oscillation between the basal pinacoid and pyramid, prism or rhombohedron faces. Rarely barrel and spindle shapes. Development of the rhombohedron faces is also common. Crystals are usually somewhat waterworn and silky, and may be confused with spinel, which is found with ruby. Specimens attached to the marble matrix used to be rare, but now are more common because of the use of dynamite in mining the marble matrix. Spinel crystals in the marble matrix are also being recovered in this manner.

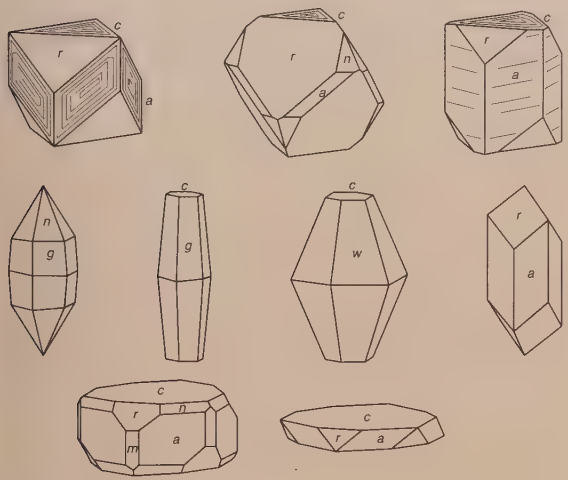

Figure 2.7 Crystal habits of rubies from Mogok, Burma.

Rubies from Mong Hsu generally consist of pyramids or bipyramids, with little development of the hexagonal prism. Most distinctive are the blue cores generally present (these often disappear after heat treatment).

Kenya. Tabular to blocky hexagonal prisms, often with adhering matrix. Also elongated hexagonal spindles. Polysynthetic twinning is common.

Sri Lanka. Similar to Sri Lankan sapphires (see Figure 2.19 for an illustration).

Figure 2.8 Rubies from Mogok, Burma. The cut stone weighs 11.55 ct, while the crystals range from 16.65 to 278.50 ct. Note the adhering marble on some specimens. (Photo: Robert Kane/GIA)

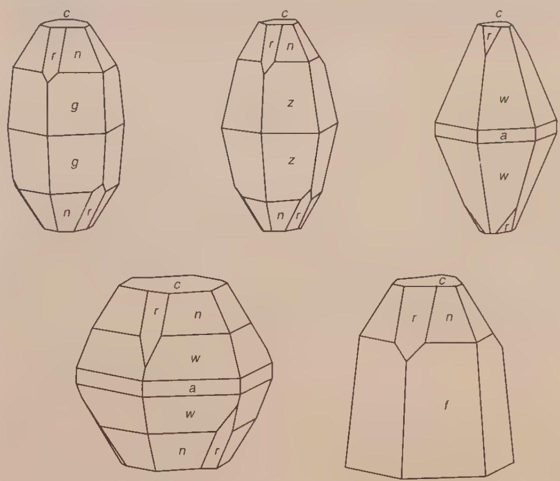

Figure 2.9 Common crystal habits of rubies from Mong Hsu, Burma. (After Smith & Surdez, 1994)

Tanzania (Morogoro). Mainly basal pinacoid and rhombohedron faces, with slight development of the hexagonal prism. Superficially, they resemble spinel octahedra, but can be separated by reference to the different growth marks on different forms.

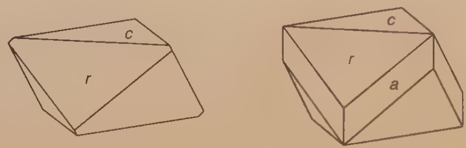

Figure 2.10 Crystal habits of rubies from Morogoro, Tanzania.

Thailand/Cambodia. These rubies occur as tabular prism/rhombohedron/pinacoid combinations which are always extremely rounded. Rhombohedron truncations at the three opposite corners on each side may create triangular pinacoid faces. Matrix specimens are not found. Polysynthetic twinning is quite common.

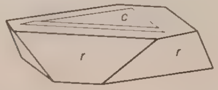

Figure 2.11 Typical crystal habit of rubies from the Thai/Cambodian border.

United States (North Carolina). Rubies from this locality are often combinations of prism and pinacoid, modified by the rhombohedron and bipyramid. Twins on the basal pinacoid have also been reported (Hidden, 1902). Crystals may have embedded garnet crystals.

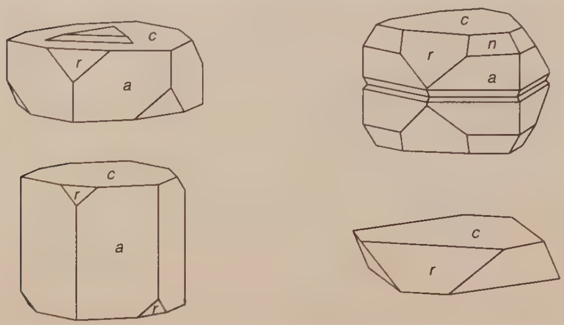

Figure 2.12 Typical crystal habits of rubies from Cowee Creek, North Carolina (USA). The crystal at upper right is a twin on {0001}.

Vietnam. Mostly rounded pebbles of irregular shape. Also bipyramids topped by small pinacoid faces. These may be modified by the rhombohedron. Blue color zoning is often present, similar to Jagdalek (Afghanistan) and Mong Hsu (Burma) rubies. Polysynthetic twining along $\{10\bar{1}1\}$ is common.

Sapphire habits

Australia. Similar to Thai material. Barrel shapes and pyramids or bipyramids are most common. Crystals often show corroded surfaces which appear to be due to alluvial action, but which actually result from corrosion during the volcanic eruptions which brought the crystals to the surface ('magmatic corrosion').

Burma. Mostly waterworn fragments and blocky-to-tabular hexagonal prism/pinacoid combinations of even coloration. Pyramids terminated by the basal pinacoid are also common. Due to the tabular shape of the rough, cut Burmese sapphires tend to be shallow. Polysynthetic twinning on $\{10\bar{1}1\}$ is common. Matrix specimens are rare, but some crystals possess a thin brown matrix skin.

Figure 2.13 4.75 cm long ruby crystal from Luc Yen, Vietnam. Note the rhombohedral twinning striations, which are common on many corundum crystals. (Photo: Tino Hammid/GIA)

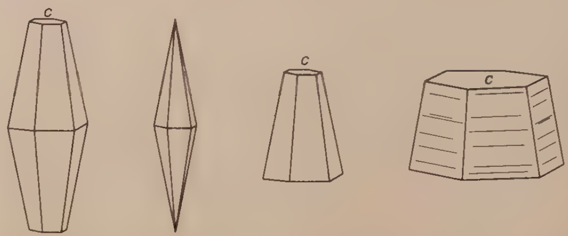

Figure 2.14 Crystal habits of sapphires from Australia.

Cambodia. Similar to Thailand, Australia and Nigeria. Barrel shapes, pyramids and bipyramids, or waterworn fragments are most common. Basal parting is also common. Magmatically-corroded surfaces (see 'Australia', p. 56) are common.

Kashmir (India). Spindle-shaped hexagonal bipyramids of light blue color with deep blue tips and partially corroded

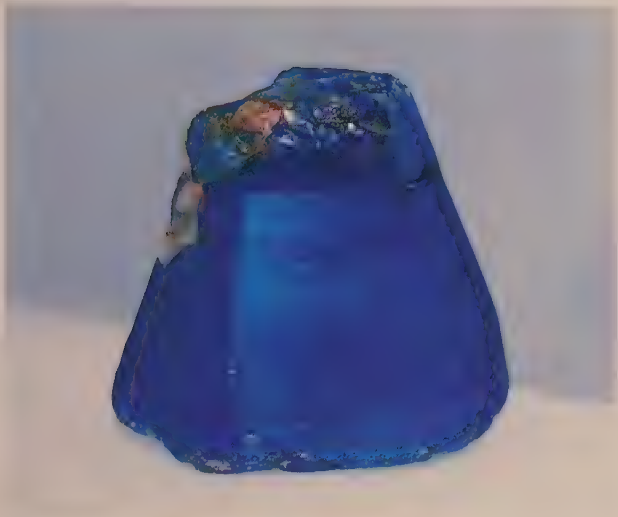

Figure 2.15 The outside world rarely gets a glimpse of Burmese sapphire rough. Since most stones are smuggled out of the country, it makes more sense to cut them first. The stone above, which is a particularly fine example, weighs 502 ct, and was unearthed at Kabaing, near Gwebin, in the Mogok Stone Tract. (Photo: U Khin Mg Win; specimen: U Hla Win)

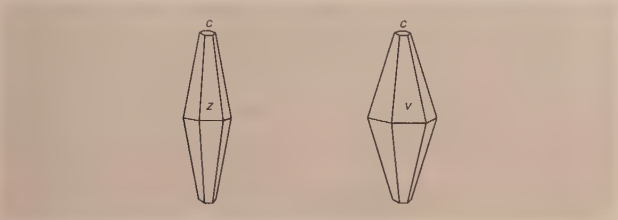

Figure 2.16 Crystal habits of sapphires from Kashmir, India.

surfaces. Some may show slight development of the pinacoid, and many are flattened along an *a* axis. Growth twins are common, with crystals occasionally twisted around one another. Virtually all sapphires from this source (near Sumjam) possess a tenacious white clay-like crust adhering to the

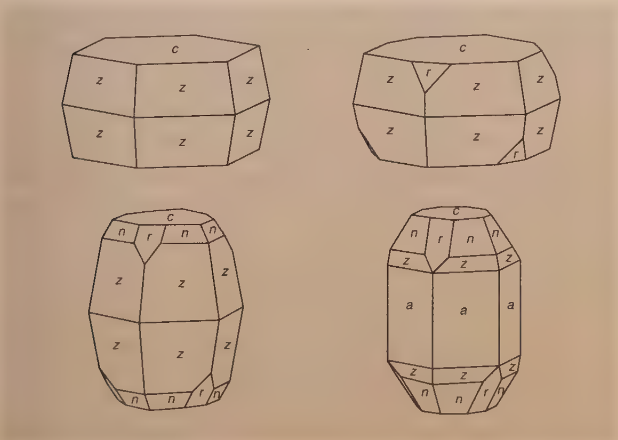

Figure 2.17 Common crystal habits of sapphires from Nigeria.

surface. Crystals may be intergrown with dark tourmaline prisms.

Nigeria. Similar to Thailand, Cambodia and Australia. Crystals often display rounded surfaces which result from magmatic corrosion.

Figure 2.18 The classic, bipyramidal Sri Lankan sapphire habit is displayed by this 1,873.60 ct specimen. Note the two growth twins. (Photo: Bart Curren/ICA; specimen Hans Anton Van Starrex)

Sri Lanka. Sri Lanka is the most prolific source of corundum crystal specimens, with the classic shape being a spindle-shaped hexagonal bipyramid. This is often flattened along one of the *a* axes. Hexagonal prism/pinacoid combinations are also found.

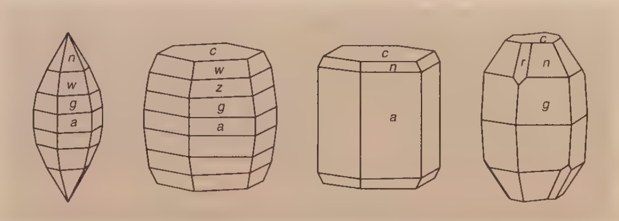

Figure 2.19 Crystal habits of sapphires from Sri Lanka.

Tanzania (Umba Valley). Umba sapphires occur as tabular crystals showing pinacoid and hexagonal prism faces, but without pyramid faces. Basal pinacoid faces typically show polysynthetic twin striations that divide them into small triangles. Color zoning is often as a colorless hexagonal 'tube' parallel to *c* axis. This tube may be black in rubies.

Thailand. Most common are barrel shapes and hexagonal pyramids and bipyramids (spindles). Many crystals are polysynthetically twinned along $\{10\bar{1}1\}$. Basal parting is often seen, especially in black star sapphires. Material may be euhedral or somewhat waterworn.[2] Matrix specimens are virtually unknown.

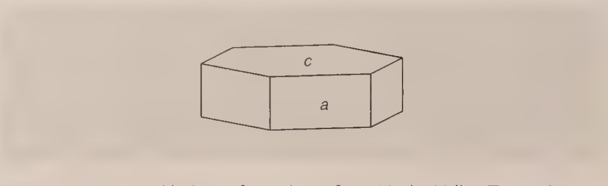

Figure 2.20 Crystal habits of sapphires from Umba Valley, Tanzania.

Figure 2.21 Corundum crystals often display raised triangles on the pinacoid face, resulting from oscillation between the rhombohedron and pinacoid. Such triangles are in opposite position on each end of the crystal. If the crystal is transparent and thin enough, the triangles create a "Star of David" effect, such as that shown above in a 2.5-ct Yogo (Montana) stone. (Photo: John Koivula/GIA)

United States (Montana). Yogo stones display a distinctive habit of thin rhombohedron/pinacoid combinations, some of which are corroded. Raised triangles are sometimes seen on pinacoid faces (reversed on opposite ends of the crystal).

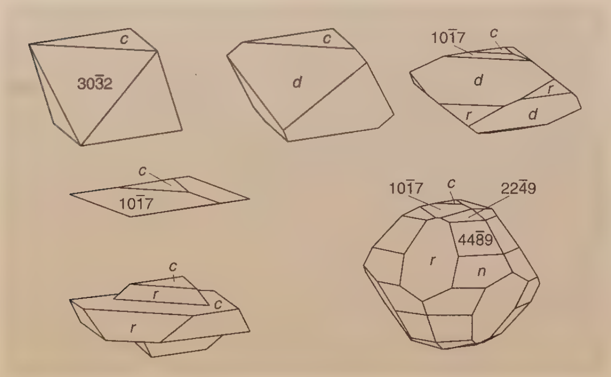

Figure 2.22 Crystal habits of sapphires from Yogo Gulch, Montana, USA.

Sapphires from Rock Creek tend to occur as rounded ball shapes. Those from the Missouri River and Dry Cottonwood Creek are often hexagonal prism/pinacoid combinations. These may be modified by the rhombohedron.

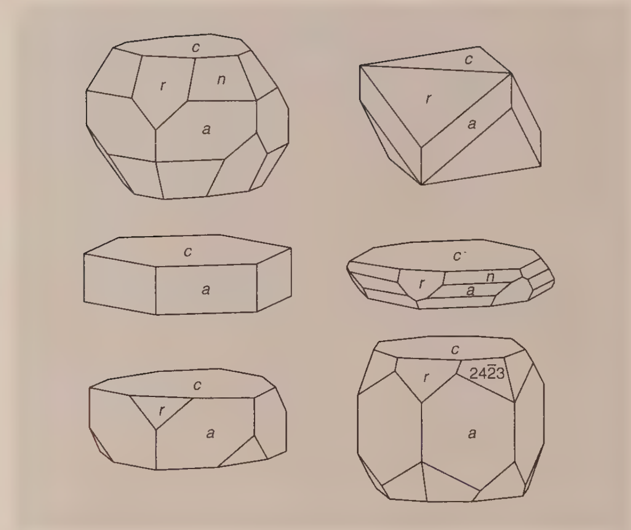

Figure 2.23 Crystal habits of sapphires from the Missouri River, Dry Cottonwood Creek and Rock Creek, Montana, USA.

Taxi driver

The end of the fight is a tombstone white
with the name of the late deceased,
And the epitaph drear: "A Fool lies here who tried to hustle the East."

Rudyard Kipling, *The Naulahka*, Chapter 5

LIVING in Bangkok, one quickly becomes inured to the tourist scams, shams and various rip-offs. But one I'll never forget is the day I stepped into a taxi on my way to work. Now understand that a Bangkok taxi ride provides much fuel for thought, conversation and otherwise, since, due to traffic, most time is spent going absolutely nowhere. One particular morn, as I sat contemplating the possibility of life elsewhere on the planet, the driver leaned back and handed me a stone paper. "Excuse me, but my last passenger dropped this. Do you know what it is?"

Obviously he did not realize he was speaking to one of the world's preeminent gemologists. Loupe in hand, I quickly identified the gems as Verneuil synthetics. Arriving at my destination, I stepped out, informing him that the gems were synthetic, of little value, and that he should discard them. Several days later, in another cab, I was asked to evaluate yet another parcel of synthetic sapphires, left behind by yet another passenger. Seems they all had pockets full of holes. It was then, upon reflection in my morning coffee, that the coin finally dropped. Guess I'm a slow learner.

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2. The rounding so common in volcanic-derived sapphire is generally due to magmatic dissolution, as opposed to actual alluvial action.

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CHAPTER 3

PROPERTIES

Archimedes, as he was washing, thought of a manner of computing the proportion of gold in King Hiero's crown by seeing the water flowing over the bathing-stool. He leaped up as one possessed or inspired, crying, "I have found it! Eureka!"

Plutarch [AD 46–120], *Pleasure Not Attainable, According to Epicurus. 11*

CORUNDUM is among the most durable of all gemstones. With a hardness surpassed only by diamond, and an absence of easy cleavage, corundum is able to withstand tremendous amounts of punishment. This is borne out by the fact that most gem corundum is recovered from alluvial deposits where, despite eons of weathering, crystals still display much of their original shapes.

Figure 3.1 Parting in corundum

A. Rhombohedral parting, typical of ruby, arises from exsolution of boehmite along the rhombohedron {10$\bar{1}$1} faces (left).

B. Basal parting, typical of black-star sapphires from Chanthaburi (Thailand) and Australia, arises from exsolution of platy hematite along the basal pinacoid {0001} (right).

Cleavage, parting and fracture

The properties of cleavage, fracture and parting involve a crystal's reaction to external pressure or force. This is intimately related to bonding and atomic structure.

Cleavage

Cleavage describes the tendency of a single crystal to break along atomic planes. As atomic planes form crystal faces, cleavage always takes place parallel to a possible crystal face. It is described according to the following factors:

- The face it parallels (rhombohedron, pinacoid, etc.)
- Smoothness of the cleavage surface (perfect, imperfect)
- Ease with which the break is effected (easy, difficult)

Gemological texts have traditionally denied the existence of cleavage in corundum (*c.f.* Bauer, 1904). Instead, the smooth flat breaks have been attributed to parting, a weakness due to structural defects. However, work performed in Russia on synthetic colorless sapphire (Belyaev, 1980) suggests that cleavage *is* present. Large sapphire plates grown via direct crystallization were found to split along large mirror planes, and further testing showed that the breaks were not associated with twinning or other defects. Cleavage was found along the morphological rhombohedron {10$\bar{1}$1} as well as the prism {11$\bar{2}$0}. Rhombohedral cleavage was detected more often, and the surfaces were also larger, while the prismatic cleavage steps were deeper and visible to the naked eye. At times, both rhombohedral and prismatic cleavages formed simultaneously, giving macro-steplike relief to cleaved surfaces. Cleavage in synthetic corundum was found to manifest itself best in crystals grown under conditions ensuring high purity and low defect concentration (Belyaev, 1980).

Parting

The end-result of parting is identical to cleavage—splitting along a plane of weakness. Like cleavage, this tends to produce a distinctive, step-like fracture surface. However, parting is due to structural *defects,* rather than the basic

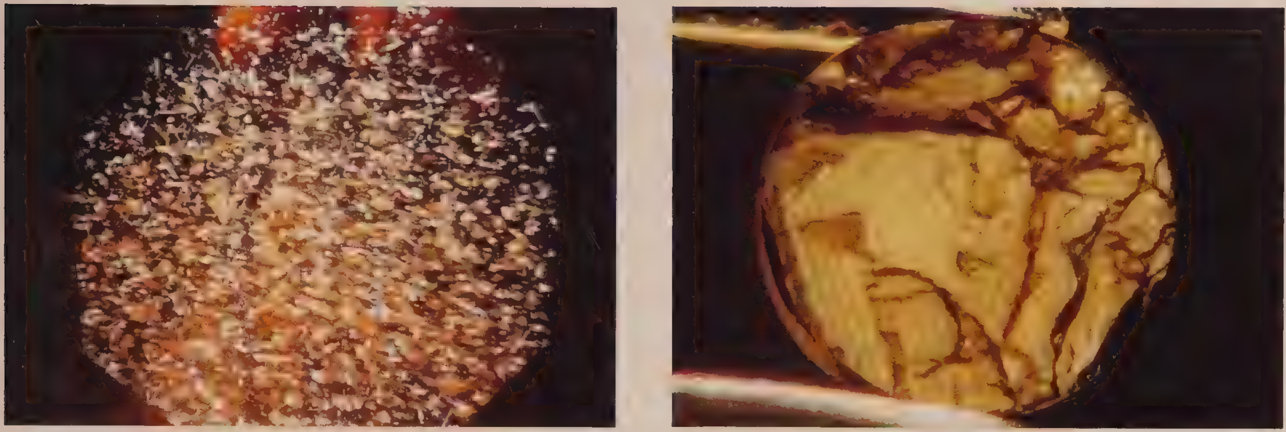

Figure 3.2 Black-star sapphires owe their asterism not to rutile needles, as in the stars from Burma and Sri Lanka, but to tiny plates of hematite. This platy hematite 'silk,' which colors the stones dark brown, results in parting ('false cleavage') parallel to the basal pinacoid (parallel to the cabochon's base in a properly oriented stone).
Left: Hematite silk in a faceted yellow sapphire from Chanthaburi (Thailand). (Photo by the author)
Right: Basal parting on the cabochon base of a black-star sapphire from the same source. (Photo: Tony Laughter)

structure *design,* as with cleavage. Thus, the number of possible partings is limited to the number of defective planes present. A useful analogy is to imagine a house struck by an earthquake. If the house collapses due to a faulty architectural design, this is cleavage. But if it collapses because the builders did not follow the architect's drawings properly, it is parting.

Not only has the idea of cleavage in corundum been reexamined, but also that of parting. Judd (1895) precisely described the partings of corundum and classified them into three categories: basal {0001}, rhombohedral $\{10\bar{1}1\}$, and prismatic $\{11\bar{2}0\}$. This disputed the then-contemporary view that such partings were actually cleavages. In Judd's opinion, the partings were due to solution planes. Until 1979, the modern view was similar, but attributed such partings to twinning.

In 1979, J.S. White published a study suggesting that twinning is not the cause of corundum parting. After examining twins in a number of different minerals, he found that twin planes were not necessarily planes of weakness. Instead, twinned crystals tended to break at points *other than along twin planes.* This led him to question the idea that the easy parting found in many corundum crystals was directly due to twinning.

With both optical and electron microscopes, White studied corundum specimens showing rhombohedral parting from three different US localities. He found that partings were not simply planar fractures, but were actually thin seams of exsolved boehmite ($\gamma AlO{\cdot}OH$), unmixing along the rhombohedron $\{10\bar{1}1\}$. If enough boehmite is exsolved in a single plane, it may produce a lack of adhesion. Thus the parting of corundum. Since boehmite typically exsolves at the junctions of crossing twin lamellae, it was mistakenly thought that twinning produced the parting.

Black-star sapphires found in Thailand's Chanthaburi province also display parting, but along the basal pinacoid {0001}. In this case, the culprit is hematite-ilmenite silk (Weibel & Wessicken, 1981). Such hematite-ilmenite silk exsolves in the basal plane, and produces both the star effect and deep brown color. When enough hematite is present in a single plane, it can lower cohesion enough to lead to parting.

If hematite-ilmenite silk causes basal parting, then why doesn't rutile silk, which also unmixes in the basal plane, do the same? The answer is found in the silk's crystal habit. Rutile tends to unmix as slender needles, while hematite-ilmenite exsolves as plates.

Fracture

When broken along directions other than cleavage or parting planes, corundum exhibits a conchoidal ('shell-like') to sub-conchoidal fracture. In terms of tenacity, rubies and sapphires are relatively brittle, although much less so than other species, such as spinel or zircon.

Hardness

The resistance that a smooth surface of a mineral offers to scratching is its *hardness.* The classic scale of hardness for minerals was developed by Frederick Mohs in 1824 and is still in use today. Corundum is nine on this scale, and, among naturally-occurring minerals, is surpassed only by diamond. Mohs' scale of hardness is qualitative, not quantitative. In other words, Mohs' scale does not indicate how much harder one mineral is than another. Absolute hardness scales attempt to quantify hardness. Figure 3.3 compares Mohs' scale with absolute hardness. The difference between

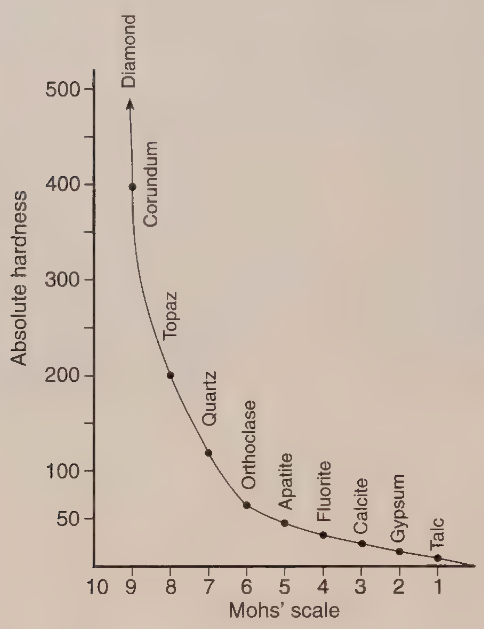

Figure 3.3 The absolute hardness of corundum (9) compared with other minerals on Mohs' hardness scale. The difference between diamond (10) and corundum is greater than that between corundum and talc (1).

diamond (10) and corundum (9) is greater than the difference between corundum and talc (1).

Like all crystalline materials, single crystals of corundum also exhibit differences in hardness along different directions. Belyaev (1980) reported that in melt-grown synthetic corundum, the basal plane possessed the lowest hardness, with prism planes coming next. Maximum hardness was observed in planes forming an angle of 60° with the *c* axis. Slight differences in hardness have also been observed in different color varieties. Ruby is slightly softer than blue sapphire, and star sapphires are slightly harder than the transparent varieties.

According to Belyaev (1980), the hardness of corundum on Knoop's scale is 1370 kg/mm^{-2} with a 1 kg load and random indenter direction. Djevahirdjian (n.d.*a*), however, gives the Knoop's hardness as 1800 at 90° to the *c* axis and 2200 parallel to the *c* axis. The modulus of elasticity was stated to be 4.4×10^6 $kg/cm^{-2} \pm 1\%$ Young's *E*, while Vickers hardness is given as 2500–3000 kg/mm^{-2}. Other sources list the Vickers hardness at 1570–1750 (RSA Le Rubis S.A., n.d.).

Table 3.1 lists the indention hardness values of synthetic corundum of various types and orientations.

Thermal properties

Table 3.2 compares the thermal properties of corundum with those of some ruby look-alikes, such as pyrope, almandine and spinel.

Table 3.1: Microhardness (Knoop scale) of synthetic corundum crystals (Kg/mm^{-2})

Material	Orientation of diamond point	Before heat treatment	After heat treatment
Colorless sapphire (melt grown)	⊥ to *c* axis // to *c* axis	2720 2350	2720 2150
Colorless sapphire (Verneuil)	⊥ to *c* axis // to *c* axis	2280 2350	2370 2450
Ruby (Verneuil)	⊥ to *c* axis // to *c* axis	2750 2900	2750 2730

Thermal inertia. The thermal inertia probe is commonly used by jewelers to separate diamond from diamond simulants, but they also have utility in other separations. Such probes function by heating a probe tip to a selected temperature and measuring how quickly it cools when the tip comes into contact with the gem. The more rapid its rate of cooling, the higher the thermal inertia of that material.

Table 3.2 shows that corundum's thermal inertia values are almost twice those of spinel, and more than three times those of the red garnets. By using a well-designed thermal inertia probe, corundum can be separated from these ruby simulants.[1] Of the naturally-occurring minerals which resemble corundum, only topaz (0.138–0.177) and kyanite (0.171–0.176) have thermal inertia values above those of spinel. Thus, this test can prove useful in separating corundum from other minerals.

Thermal expansion. When a material is heated, it expands, actually growing in length and width. The number describing this increase in volume is known as the *coefficient of thermal expansion,* and for crystalline materials, it varies with direction.

Other than techno-weenies, who *really* cares? If you are a bench jeweler, you should. Gems that expand far more along one axis than another easily crack when heated. Even the heat of a jeweler's torch can produce fractures. So before you heat a mounting, find out what gems are in it.

The thermal expansion (deg^{-1}) of single crystals of corundum is given by Belyaev (1980) as follows:

20 to 50°C	= 6.66	×	10^{-6} (// to *c* axis)
20 to 1000°C	= 9.03	×	10^{-6} (// to *c* axis)
50°C	= 5.0	×	10^{-6} (⊥ to *c* axis)

Sinkankas (1981) states that this is behind diamond and beryl. However, corundum displays a smaller difference between its expansion along the *c* and *a* axes than does beryl. The tiny volume changes of both diamond and corundum mean that they can be safely left in their mountings while undergoing high-temperature repairs. Beryl and quartz,

[1] The dichroscope will also do the job, as both spinel and garnet are singly refractive.

Table 3.2: Thermal properties of corundum (from Hoover, 1983)

Material and direction tested	Thermal conductivity (cal cm^{-1} °C s^{-1})	Specific heat (cal g^{-1} °C^{-1})	Thermal diffusivity (cm^2 s^{-1})	Thermal inertia (cal cm^2 °C s$^{1/2}$)
Corundum				
• *c* axis	0.0834	0.206	0.101	0.262
• *a* axis	0.0772	0.206	0.0937	0.252
• *c* axis (other)	0.0600	0.206	0.0728	0.222
Spinel (locality unknown)	0.0281	0.216	0.0358	0.148
Spinel, Madagascar	0.0227	0.216	0.0288	0.133
Almandine, New York (USA)	0.00791	0.2	0.0101	0.0789
Pyrope, Arizona (USA)	0.00759	0.2	0.0101	0.0754

however, expand much more along the *c* axis than the *a* axes, increasing the danger of heat-induced fractures.[2]

Melting and boiling points and solubilities

According to Belyaev (1980), the melting point of corundum is 2030°C, but other sources give 2050°C. Belyaev gives corundum's boiling temperature as 3500°C. Its solubility in 100 g of water is 9.8×10^{-5} g at 29°C. Corundum dissolves slowly in boiling nitric acid and in orthophosphoric acid to 300°C, while dissolving well in borax at 800–1000°C, and in potassium bisulfate at 400–600°C. *Due to the ability of fluxing agents such as borax to dissolve corundum, extreme care should be exercised when heating borax in close proximity to corundum, such as when repairing jewelry articles.*

Density and specific gravity

Density and specific gravity are essentially synonymous, but there is a difference. *Density* describes the weight of a specific volume of material (usually g/cm^3), while *specific gravity* (SG) is a ratio comparing the weight of a substance to the weight of an equal volume of water at 4° C. Thus specific gravity has no units. Water has an SG of 1.0 (unity) and is the medium of comparison. A material with an SG of 4.0 would weigh four times more than an equal volume of water.

Corundum's density is usually given as 3.98g/cm^3. Webster (1983) puts the SG of colorless sapphire (pure corundum) as 3.989, while ruby and blue sapphire are approximately 3.997, with little locality variation. SGs of stones rich in either Fe or Cr have been reported as high as 4.06. For information on the SGs of gems from individual sources, see the country descriptions in Chapter 12.

Electrical properties

As the name implies, electricity involves electrons. Materials which have free electrons available for movement (such as copper and most other metals) are termed *conductors*. Those lacking free electrons pass electricity only begrudgingly, if at all, and are termed *insulators* (dielectrics).

2. Corundum may also be cleaned ultrasonically without problem, unlike emerald, where there is a real danger of breakage (not to mention the loss of clarity caused by removal of oil from fractures).

"Le Saphir Merveilleux" and other wonders

THE remarkable coldness of the Sapphire to the touch, due to its great density,[a] gave rise to the notion recorded by Epiphanius of its power to extinguish fire, or natural antagonism to heat. This was improved upon by mediæval credulity into the doctrine that "the Sapphire worn in a ring or in any other manner is able to quench concupiscence, and for that reason is proper to be worn by the priesthood, and by all persons vowed to perpetual chastity." (Vossius, De Phys. Christ. vi. 7.) And furthermore, "the Sapphire is said to grow dull if worn by an adulterer or lascivious person." Hence its adoption to adorn the episcopal ring of office from the commencement of the Middle Ages down to the present time: the ring of the Abbot of Folleville, the oldest ecclesiastical jewel extant, is set with a large native Sapphire.

C.W. King, 1865

The idea of sapphire as a indicator of virtue and faithfulness formed the basis of "Le Saphir Merveilleux," a story penned by Mme. de Genlis. This was based on a sapphire in London's South Kensington Museum. Previously owned by Count de Walicki (a Polish nobleman) and Philippe Egalité (former Duke of Orleans), it displayed a blue color in daylight, but changed to an amethyst hue in candlelight. In Mme. de Genlis' story, the sapphire is used as a test of female virtue, changing color when worn by the unfaithful. If the owner of the stone wished to prove a woman innocent, she would be made to wear the gem for three hours of daylight, but if guilt was the desired end, the test was timed such that it began in daylight and ended in candlelight (Kunz, 1913).

A number of marvelous properties have been attributed to the ruby, not least of which was its ability to protect the wearer from harm. Witness the following from that master of gemological esoterica, G.F. Kunz:

> The gorgeous ruby, the favorite gem of Burma, where the finest specimens are found, is not only valued for its beauty, but is also believed to confer invulnerability. To attain this end, however, it is not thought to be sufficient to wear these stones in a ring or other jewelry, but the stone must be inserted in the flesh, and thus become, so to speak, a part of its owner's body. Those who in this way bear about with them a ruby, confidently believe that they cannot be wounded by spear, sword, or gun.*

* Taw Sein Ko, communication from his "Burmese Necromancy."

G.F. Kunz, 1913, *The Curious Lore of Precious Stones*

a. In fact, corundum's coldness to the touch has to do with its high thermal conductivity, not its density.—RWH

Table 3.3: Electrical properties of corundum

Property	Value & conditions
Electrical resistance	10^{11} Ω/cm^{-1} at 500°C 10^{6} Ω/cm^{-1} at 1000°C 10^{3} Ω/cm^{-1} at 2000°C
Dielectric constant	10.6 // to *c* axis at 300°K; 10^{6} Hz 8.6 ⊥ to *c* axis at 300° K; 10^{6} Hz
Dielectric loss tangent	$<10^{-4}$ at 10^{10} Hz at 300°K
Dielectric strength	480,000 V/cm^{-1} at 60 Hz

Single crystals of colorless sapphire are among the best insulators known. This fact, coupled with their high chemical, mechanical and thermal stability, allows colorless sapphire to be used in harsh environments, such as outer space. Among other industrial uses, synthetic colorless sapphire is today employed as a substrate material for integrated circuits and for the windows of powerful laser wave-guide systems.

Some of the more important electrical properties of Verneuil synthetic corundum are listed in Table 3.3 (based on Djevahirdjian, n.d.*a;* RSA Le Rubis S.A., n.d.).

Optical properties

The beauty of precious stones is largely related to visual phenomena—the way in which they affect light. Light returned to the eye is *reflected,* while that which bends passing through a material is *refracted.* Selective absorption of white light results in color. Color can also be produced by spreading (*dispersion*), interference (the colors on oil slicks), diffraction (the colors of precious opals and butterfly wings) and scattering (the blue color of the sky). If, at room temperature, a material is able to absorb one type of energy (visible light is visible energy) and convert it into *visible* energy of another type, it is *luminescent.* These are but a few of the optical phenomena that affect the appearance of gems.

Refractive index, birefringence, optic character and sign

Refractive index (RI) is a ratio comparing the speed of light in air with its speed in a second medium. In the case of doubly refractive stones, such as corundum, the difference between the highest and lowest RIs is the *birefringence.* Because corundum crystallizes in the trigonal division of the hexagonal system, its optic character is doubly refractive and uniaxial. Light entering in all directions except along the optic axis (corresponding to the *c* axis) is split into two rays—termed *ordinary* and *extraordinary.* Maximum double refraction occurs when light travels at 90° to *c* axis; birefringence decreases to zero as the direction of travel approaches the *c* axis.

The RI for light travelling parallel to the *c* axis is termed the *ordinary* or *omega* (n_{ω}) index, while that measured for the other ray when light travels perpendicular to the *c* axis is

Figure 3.4 Uniaxial interference figures seen on drops of liquid on a Thai/Cambodian ruby (viewed // to the *c* axis between crossed polars). Most natural corundums are cut with the *c* axis perpendicular to the table, and so the figure is seen straight through the table. Shallow stones will show larger figures than those cut deep. (Photo by the author)

termed the *extraordinary* or *epsilon* (n_{ε}) index. Since in corundum the o-ray travels slower (has a higher RI) than the e-ray, it is negative in sign.

Ordinary (ω) ray
- Constant RI (n_{ω})
- Always vibrates at 90° to the *c* axis

Extraordinary (ε) ray
- Variable RI (n_{ε})
- Vibrates in a plane containing the *c* axis
- When light travels perpendicular to the *c* axis, the e-ray vibrates parallel to *c.* Its RI then reaches its maximum difference from n_{ω}
- When light travels parallel to *c* (along the optic axis), the e-ray vibrates at 90° to *c*

While the RIs of corundum may vary slightly from one locality to another, the birefringence is extremely consistent at 0.008. According to Webster (1983), pure corundum gives readings of 1.7606 for the e-ray (n_{ε}) and 1.7687 for the o-ray (n_{ω}). Generally the e-ray gives readings between 1.758 to 1.772 and the o-ray between 1.766 to 1.780. Iron and/or Cr content appear to be the major cause of variation. Fe-poor gems (such as from Sri Lanka) tend to fall into the low end of this range while Fe-rich yellow, green and blue sapphires from Thailand and Australia tend to possess higher indices. High Cr content also elevates readings. Despite the slight variations for gems from different localities, refractive index is not a reliable method of determining origin. This holds true for synthetic corundums, as well as natural.

Determining optic character and sign

One method of determining optic character is by reference to the interference figure. This requires a polariscope or

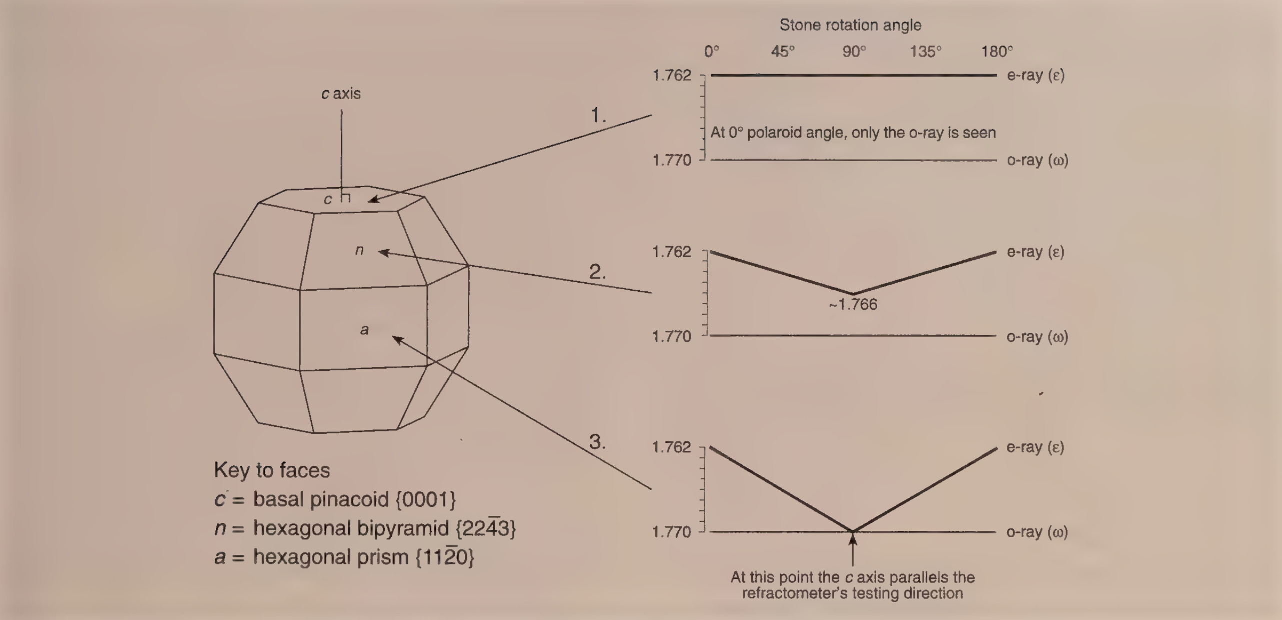

Figure 3.5 RI readings of corundum for facets of different orientations (through 180° rotation).

1. Facets lying ⊥ to the *c* axis (on the basal pinacoid) will produce two constant readings at 1.762 (n_ε) and 1.770 (n_ω). To determine the optic sign of such stones, the eyepiece polaroid should be oriented with its transmission direction parallel to the refractometer scale lines (termed a 0° polaroid angle). In this position, only the o-ray will be seen (the high RI in corundum, revealing the stone to be negative in sign).
2. If the facet tested lies oblique to the *c* axis, one constant (o-ray) and one variable (e-ray) RI will be seen. The variable curve does *not* meet the constant curve. This pattern is also possible in biaxial crystals, but they can be separated by determining the polaroid angle of the constant curve. For biaxial stones with this RI pattern, the polaroid angle of the constant curve exactly equals 90°. In uniaxial gems, the polaroid angle of the constant curve can be anything *except* 90° when this pattern is seen.
3. If the facet tested is parallel to the *c* axis (parallel to the hexagonal prism faces), one constant and one variable RI will be seen. The variable curve will meet (but not cross) the constant curve. This occurs at the point where the *c* axis lies parallel to the testing direction of the refractometer (parallel to the length and surface of the hemicylinder).

polarizing microscope and a glass bulb. In most cases, the ordinary uniaxial figure is seen. However, heavily twinned specimens sometimes display a pseudo-biaxial figure. To separate the two, rotate the stone while watching the dark "brushes." In true uniaxial stones, these turn in the same direction as the stone, while in biaxial stones the brushes rotate counter to the stone's rotation.

Most natural corundums are cut with the *c* axis at 90° to the table facet. This makes locating the interference figure easy, as it will be seen straight through the table. With shallow stones (such as Thai/Cambodian rubies), it is even easier (see Figure 3.4). In the Verneuil synthetic corundum, the *c* axis is usually parallel to the table. This requires more skill to see the interference figure. A lens placed on the upper polaroid, such as that from the refractometer eyepiece, makes locating the figure much easier. In difficult cases, such as when the optic axis is parallel to the table, a drop of oil or honey on the spot where interference colors are seen will produce a tiny interference figure on the drop surface.

Optic character and sign may also be determined by plotting refractive indices on a graph as the gem is rotated through 180°. Depending upon just how the tested facet is oriented with respect to the *c* axis, one of three patterns will be seen (see Figure 3.5).

1. *c* axis at 90° to facet tested
2. *c* axis parallel to facet tested
3. *c* axis at an oblique angle to facet tested

The optic sign is easily determined in examples 2 and 3, as the 1.770 index is constant, but in example 1, another facet must be tested, or the polaroid plate used, to determine optic sign. Because the o-ray always vibrates at 90° to the *c* axis, orienting the transmission direction of the eyepiece polaroid at 90° to the *c* axis (parallel to the scale division lines on the refractometer scale) will allow only the o-ray to be seen. In corundum, this will reveal the higher index only, thus proving the stone to be negative in sign.

Dispersion ('fire'): In the seventeenth century, the noted British scientist/physicist, Isaac Newton, discovered that sunlight could be split into its colored components when passing through a prism. This is termed *dispersion* ('fire'), the breaking up of white light into its component colors of red, orange, yellow, green, blue and violet, when passing through two non-parallel surfaces (see Figure 3.6).

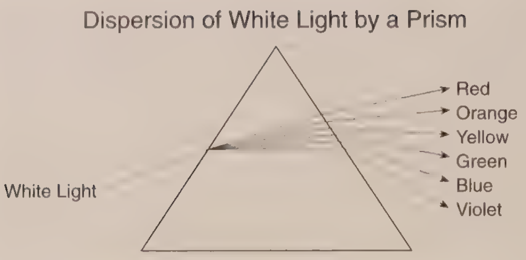

Figure 3.6 When white light passes through two non-parallel surfaces (such as the prism above), it will be split into its component colors.

Dispersion can also be defined as the variation of a gem's refractive index with wavelength. Because RI varies with wavelength, the RI of a material is always given for yellow light of a wavelength of 589.3 nm, which corresponds to the Fraunhofer sodium 'D' line in the solar spectrum.[3] Dispersion is determined by taking the difference in RIs, measured first using light of the Fraunhofer 'B' line (686.7 nm) in the red, and then light of the Fraunhofer 'G' line (430.7 nm) in the blue. This gives a numerical value of the stone's ability to spread or disperse light across the visible spectrum.

According to Webster (1983), the B–G interval dispersion of corundum is 0.018, which is relatively low when compared with gems of similar RI. It is easily visible only in pale stones, particularly those of large size. The rich body color of most rubies and sapphires completely masks what little fire there is.

Luster

Luster is the quality and quantity of light reflected by a gem's surfaces, both external and internal. Internal luster is termed *brilliance,* while surface luster is simply called *luster.*

Surface luster

Surface luster depends upon the stone's refractive index, polish quality and surface cleanliness (which determines the amount of light that can be reflected). There are three major factors that affect surface luster:

- **Polish quality**: The better the polish the better the surface reflections, and thus, luster (see Figure 3.7). Similarly, the cleaner the surface, the better the luster.
- **RI**: Determines the amount of reflection at the surface. The greater the RI difference between air and the gem, the greater the reflection. High gem RIs yield higher lusters.
- **Surface cleanliness**: Dirt distorts reflections. Oils also lower the RI difference between air and gem, thus lowering luster.

Corundum displays a surface luster which is greater than glass (vitreous), but less than diamond (adamantine), and so is described as *vitreous to subadamantine.* Since polish quality can vary greatly from one specimen to another, or even from facet to facet, if well-polished surfaces are not available, luster should be judged on a smooth crystal face or freshly broken fracture surface. The best means of doing this is with a microscope and an overhead light source. Provided the gem has a well-polished surface, relative-reflectivity meters (such as the *Jeweler's Eye*) may also be used to determine luster.

Internal luster (brilliance)

Brilliance (or *brilliancy*) is the quality and quantity of light returned to the eye from reflections within the gem. There are four main factors which affect brilliance:

- **Polish and surface cleanliness**: The higher the polish the better the surface reflections (luster). Similarly, the cleaner the surface, the better the luster.
- **RI**: Determines the size of the critical angle, which in turn influences the amount of light returned from pavilion facets.
- **Transparency (clarity)**: Affects light transmission, which influences brilliance.
- **Proportions**: These strongly influence the amount of light returned (via total internal reflection) or lost (via unplanned leakage).

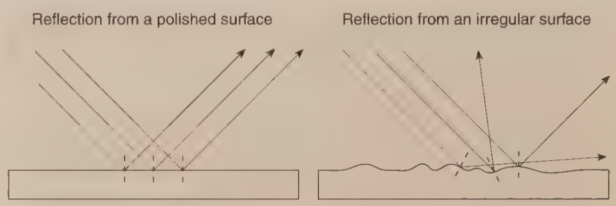

Figure 3.7 The luster of a gem is greatly affected by surface quality. Well-polished surfaces yield specular reflections (left) and thus higher lusters, while poorly polished surfaces (right) produce diffuse reflections with lower lusters.

Optical phenomena

> The prismatic crystals of corundum, as well as the pyramidal ones, when their extremities are terminated by faces which are perpendicular to their axes, very frequently have those terminal faces *chatoyant*.… To the above property must also be referred, that beautiful reflection of light, in the form of a star with six rays, which is frequently given, by cutting, to oriental rubies, sapphires, &c. and which causes those stones to be then called by the name of *star-stones.*
>
> Count de Bournon, 1802

Optical phenomena may arise from the following causes:

a. Reflection from oriented inclusions (chatoyancy, asterism or aventurescence).
b. Unusual selective-absorption behavior (change-of-color).
c. Interference and/or diffraction (iridescence, schiller, orient, play-of-color).
d. Scattering from multitudes of microscopic or sub-microscopic inclusions (girasol).

[3] In 1814, Joseph von Fraunhofer passed sunlight through a thin slit, and thence into a prism. He discovered that the solar spectrum contained a number of dark lines, produced by absorption of light by elements in the gases surrounding the sun and earth. These lines were mapped and given letter names.

Table 3.4: Optical phenomena in corundum

Phenomenon	Appearance & cause	Gem examples
Chatoyancy (cat's eye)	A single band of light resulting from reflection off a single set of parallel needle inclusions.	CORUNDUM CAT'S EYE (rare) Chrysoberyl cat's eye
Asterism (star)	Two or more intersecting bands of light, due to reflection from intersecting sets of needle inclusions.	STAR CORUNDUM (6 or 12 rays) SYN. STAR CORUNDUM (6 rays)
Change-of-color	Color change from greenish (daylight) to reddish or purple (incandescent light). Caused by the light source's spectral composition, and the stone transmitting equally in both the green and red parts of the spectrum.	COLOR-CHANGE CORUNDUM COLOR-CHANGE SYN. CORUNDUM Alexandrite chrysoberyl
Girasol (opalescence)	A subtle billowy light caused by scattering of light from impurities in opal.	GEUDA-TYPE CORUNDUM Common opal (opal with no play-of-color)

The optical phenomena displayed by corundum include asterism, chatoyancy, change-of-color and girasol. Of these, chatoyancy is extremely rare. Table 3.4 lists the phenomena found in corundum.

Asterism

Asteria, or star stones, are among the most marvelous of all corundums. In seventeenth-century Germany, they were the *Siegstein* ('Victory Stone'). To others, their crossing bands of light represented faith, hope and destiny. Star sapphires were commonly used as talismans to protect against the "evil eye" and the Sinhalese used them to guard against witchcraft of all kinds. The famous English orientalist, Richard Francis Burton, possessed a large specimen which he claimed brought him good horses and prompt attention wherever he went (Kunz, 1913).

Asterism in corundum is due to reflection from multitudes of exsolved needle inclusions (termed 'silk'). Silk in most varieties consists of rutile (TiO_2), which forms along the second-order prism $\{11\bar{2}0\}$, while in black-star sapphires, it is made up of hematite (Fe_2O_3) or ilmenite ($FeTiO_3$) mixtures, which form along the first-order prism $\{10\bar{1}0\}$. Such needles are arranged along three directions in the basal plane, which intersect at 60/120° angles. Light is reflected in a band perpendicular to each of these directions, thus forming a 6-rayed star in suitably oriented cabochons. To exhibit asterism, stones must be cut with the *c* axis perpendicular to the cabochon base.

Twelve-rayed stars are also known. In these, both types of silk are found in the same stone (see Figure 12.140). Occasionally one encounters a double star stone where two individual stars (with parallel rays) are offset slightly, due to either parallel growth or twinning (Benson, 1960; Koivula & Kammerling *et al.*, 1993).

Chatoyancy

Ordinary chatoyancy has yet to be found in corundum. However, a chatoyancy of sorts is possible if a stone containing closely spaced planes of silk is cut with the cabochon base parallel to the *c* axis, or if groups of closely-spaced parallel liquid films are present (*Cf.* Kammerling, 1995). Cat's eye corundums are rarely encountered, though, as suitable gems are oriented for asterism instead of chatoyancy.

Change of color

The change-of-color (alexandrite) effect may be found in both natural and synthetic corundums. Due to these stones' unusual light absorption, they display a low saturation blue-green color in daylight (or cool fluorescent light) and a purplish red under incandescent light.

Gübelin & Schmetzer (1982) noted that all color-change stones display similar absorption features, namely a balanced transmission of the blue-green and red, and absorption of the yellow. The greater the contrast between areas of transmission and the yellow absorption, the stronger the color change. Due to the combination of daylight's balanced spectral composition and the higher sensitivity of the human eye to green light, the gem appears blue-green under this illuminant. In contrast, incandescent bulbs possess little in the way

Color-changing ruby

IT is worthy of notice that the true Oriental Ruby foretells to the wearer, by the frequent change and darkening of its colour, that some inevitable misfortune or calamity is not far off; and in proportion to the greatness of the evil, so does it assume a greater or less degree of darkness and opacity—a thing which I have heard frequently from persons of the greatest eminence, and have, alas! experienced in my own person. For on December 5, 1600, as I was travelling from Stutgard to Calloa, in company with my beloved wife Catharine Adelmann, of pious memory, I observed most distinctly during the journey, that a very fine Ruby, her gift, which I wore set in a ring upon my finger, had lost once or twice almost all its splendid colour, and had put on obscurity in the place of splendour, and darkness in the place of light, the which blackness and dulness lasted not for one or two days only, but several: so that being above measure alarmed, I took the ring off my finger and locked it up in my trunk. Wherefore I repeatedly warned my wife that some grievous misfortune was impending over either her or myself, as I had inferred from the change of colour in my Ruby. Nor was I deceived in my forebodings, inasmuch as within a few days she was taken with a mortal sickness that never left her till her death. After her decease, indeed, its former brilliant colour again returned spontaneously to my Ruby.

Wolfgang Gabelchow, 1600 (from King, 1865)

Table 3.5: Summary of corundum properties

Property[a]	Values	Property	Values
Composition	Al_2O_3	**Crystal structure**	
		Crystal system	• Hexagonal-Trigonal
		Crystal class	• $\bar{3}2/m$ (ditrigonal-scalenohedral)
Chemical properties		**Physical properties**	
Corundum is completely inert with respect		Density	• 3.986 g/cm³
to acids and bases up to 300° C		Specific gravity	• 3.98–4.06
Nitric acid	• Weakly dissolved in boiling nitric acid		
Orthophosphoric acid	• Weakly dissolved in boiling ortho-phosphoric acid		
Electrical properties		**Mechanical properties**	
Electrical resistance	• 10^{11} Ω/cm^{-1} at 500°C	Mohs' hardness	• 9
	• 10^{6} Ω/cm^{-1} at 1000°C	Knoop's hardness	• 1800 // to *c* axis
	• 10^{3} Ω/cm^{-1} at 2000°C		• 2200 ⊥ to *c* axis
Dielectric constant	• 10.6 // to *c* axis at 300°K; 10^6 Hz	Cleavage (not easy, imperfect)	• Rhombohedral {10$\bar{1}$1}, prismatic {11$\bar{2}$0}
	• 8.6 ⊥ to *c* axis at 300° K; 10^6 Hz	Parting	• Rhombohedral {10$\bar{1}$1}, basal {0001}
Thermal properties		**Optical properties**	
Boiling point	• 3500°C	Refractive index (N_D 589.3 nm)	• n_ω = 1.762; n_ε = 1.770 (+0.008, –0.004)
Melting point	• 2030–2050°C	Birefringence	• 0.008–0.009
Softening point	• 1800°C	Doubling strength	• 0.0026 (from Schell, 1993)
Thermal expansion		Dispersion	• n_{B-G} = 0.018; n_{F-C} = 0.011
• // to *c* axis	• 20–50°C = 6.66 × 10^{-6}	Dispersing strength	• 0.0083 (est. based on Schell, 1993)
• // to *c* axis	• 20–1000°C = 9.03 × 10^{-6}	Transmission	• Visible region = Excellent
• ⊥ to *c* axis	• 50°C = 5.0 × 10^{-6}		• 0.75–4.5 µm = ≥85%
Other thermal properties (see Table 3.2)			• 0.25–0.4 µm = ≥60%

a. The above data has been collected from various sources (mainly Verneuil synthetic colorless corundum) and is approximate only. Considerable deviation from these values may be found.

of blue or violet wavelengths, but are rich in yellow, orange and red. Thus, under incandescent light, the balance is tipped to the longer wavelengths, producing a purplish red color.

Most color-change sapphires[4] are simply blue-violet stones which become purple in incandescent light. They owe their color to a mixture of the elements that create red (Cr^{3+}) and blue (Fe^{2+} + Ti^{4+}). The change-of-color thus produced is not generally of good quality. Better quality color-change sapphires display a daylight color on the green side of blue. This occurs most often when vanadium is present. The problem is, vanadium is rarely present. Although a V-colored Verneuil synthetic corundum is common, it is extremely rare in nature. Only from Burma and Tanzania's Umba Valley has the author seen this type in nature. The presence of vanadium is indicated by a line at 473 nm in the spectrum, in addition to the change-of-color.

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CHAPTER 4

COLOR, SPECTRA & LUMINESCENCE

By convention there is color, but in reality there are only atoms and space.

Democritus, 460 BC

WHILE bats detect objects by reflected sound, and snakes spot their prey by reflected heat, humans detect objects via reflected/transmitted/emitted light. In our world, few phenomena are more remarkable than color. It pervades every moment of our lives, from the red-orange sunrise upon waking, to the depths of our dreams. We weave its imagery into our arts, and, with fanciful prose, sing its praises in poetry. Even our deepest feelings reflect the sensation of color. We "feel blue," grow "green with envy," and "red with anger." Precious stones are among the most richly-colored objects on the planet. Thus it is not surprising that these, too, are intimately associated with color. *Emerald green*, *ruby red* and *sapphire blue* are but a few of the common English color terms associated with gems.

Color in ruby & sapphire

Considering the diverse range of colors found among the corundum gems, it is indeed remarkable, and surely must have seemed so to the ancients, that all are the same mineral. Few other gem species display such a range of color. From pigeon's-blood red to cornflower blue to lemon yellow, every color of the rainbow is represented. Perhaps the only color not found is a true emerald green, although a less intense olive green is often encountered. But who knows? Some day one lucky miner may unearth this "missing link," too.

One reason for corundum's broad range of colors concerns its chemistry. Certain minerals possess inherent color, because the coloring agent is a basic component of their chemical make-up. These are termed *idiochromatic* ('self-colored'). Turquoise, whose complete chemical formula is $CuAl_6(PO_4)_4(OH)_8{\cdot}5H_2O$ is an example. Copper, which is an integral component, also creates the ubiquitous blue-green hue for which turquoise is famous.

In contrast, most minerals are inherently colorless, with their colors resulting from minor impurities. These are termed *allochromatic*. Corundum, beryl and quartz are examples. Corundum is composed of aluminum oxide (Al_2O_3) which, in its pure state, is completely colorless. But pure corundum is rare in nature. Instead, a small number of impurity metals may impart color, either individually, or in combination.

Transition elements

In synthetic corundum, many different coloring agents have been used, but with natural corundum the number is limited. Although there remains much to be learned regarding the true causes of color in corundum, in most cases a clear picture has emerged. Most colors result from a peculiar group of elements termed *transition elements*, which also produce color in many different substances besides minerals. These elements lie at the center of the periodic table and are unusual because their electron structure contains inner unpaired electrons. Such unpaired electrons can be excited to higher energy levels. In these transition elements, transitions correspond to absorption of *visible* light. Among the first series of transition elements are chromium, iron, titanium, vanadium, manganese, and copper. These are the most important instigators of gemstone coloration, in themselves

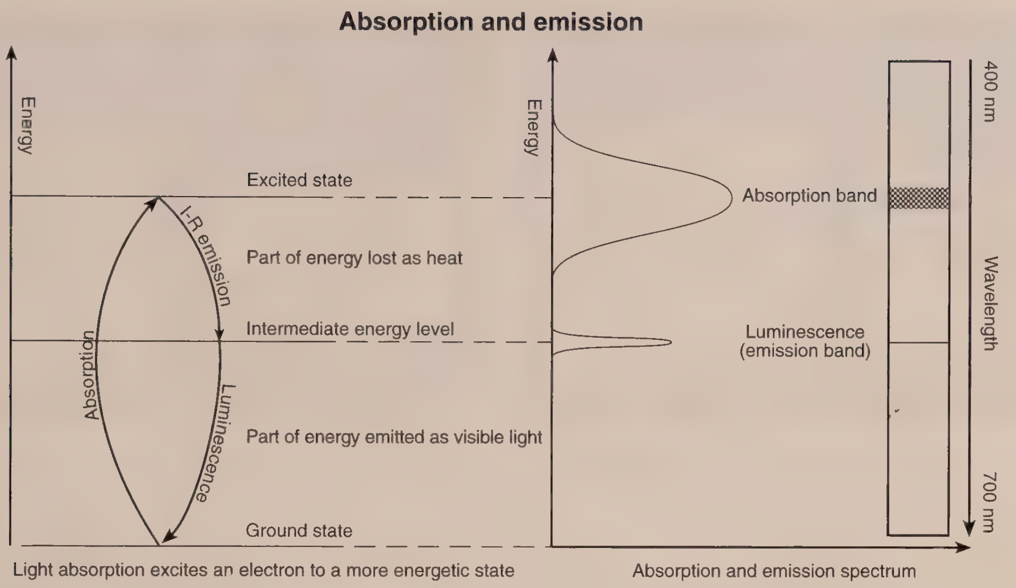

Figure 4.1 Comparison of electron excitation in a crystal (left), with the corresponding spectral graph generated by a spectrophotometer (center), and as viewed with a direct-vision spectroscope (right). (After Fritsch & Rossman, 1987)

responsible for the color of ruby, sapphire, emerald, alexandrite, tanzanite, tsavorite, and a plethora of others.

Causes of color

Introduction to color

Before discussing the interactions of these elements with corundum, we must first examine the mechanism of color itself. White light, or sunlight, is made up of a balanced mixture of the spectral colors—violet, blue, green, yellow, orange, and red. An object does not really possess color itself. Instead, it is merely a perception based upon interaction between the light source, object and eye.

White and black are not colors in the scientific sense of the word. Instead, the sensation of white is created by relatively balanced amounts of all the wavelengths of colored light (400–700 nm) striking the eye. Black is simply a lack of visible wavelengths reaching the eye. An object appears colored because of selective absorption of visible light. Some colors (wavelengths) are absorbed, while freely transmitting or reflecting others. The actual color seen depends on our eyes' interaction with the wavelengths which strike the eye and is the *complementary* color of the light absorbed (this is actually the definition of complementary).

In the simplest terms, grass appears green because, when white light illuminates it, the colors *not absorbed* combine to produce green. If one were to illuminate the grass with red light, it would appear black, because red light is absorbed by grass. Thus, no visible light reaches the eye.

From these examples it is clear that grass appears green not just because of the way it absorbs light, but also because of the physiology of our eyes and, of equal importance, the spectral composition of the light source by which it is illuminated.

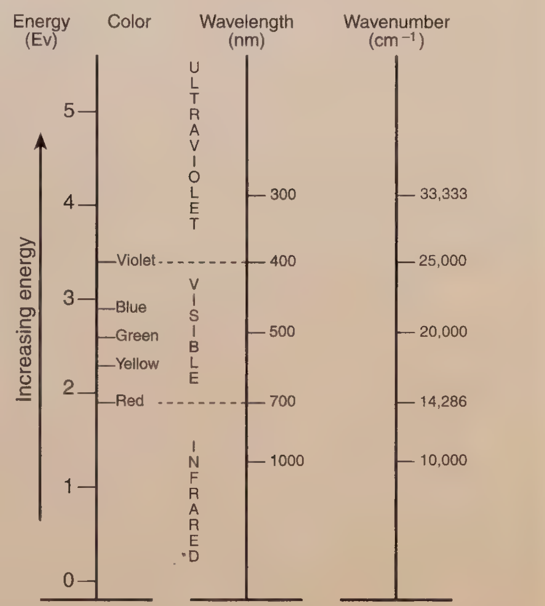

Figure 4.2 The visible portion of the electromagnetic spectrum, with three different ways of numerically describing color. Wavenumbers express the number of wavelengths per unit length (cm). (Illustration by Billie Hughes; modified from Klein & Hurlbut, 1993; based on Nassau, 1983)

With this in mind we will now look at the specific situations in corundum.

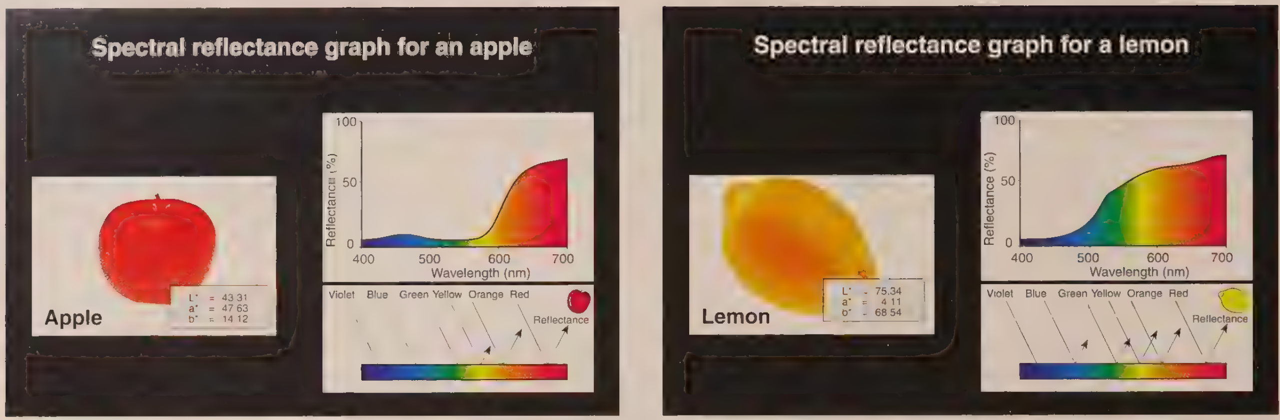

Figure 4.3 Spectral reflectance graphs for an apple (left) and lemon (right). The apple returns mainly red light, and so appears red, while the lemon returns a combination of green, yellow, orange and red, resulting in a yellow color overall. (Illustrations modified from those of Minolta USA)

Ruby

The color of ruby (and red spinel) is one of those magnificent accidents of nature. Not only is the body color red (due to absorption), but ruby also fluoresces red to daylight. This supercharges the hue into levels of intensity not matched by other red stones.

Ruby's rich crimson hue is due to electron transitions involving the Cr^{3+} ion, which substitutes for Al in amounts approximating 1–3%. This ion's ability to absorb visible light is due to its outer electron suborbitals, whose energy gaps correspond to the energy of visible light.

Electromagnetic radiation is commonly specified by referring to its wavelength, with different types of radiation having different wavelengths, ranging from the long broadcast waves to the extremely short x-rays and γ rays. Another way of specifying the type of radiation is by its energy, usually given in electron volts (eV). The shorter the wavelength, the higher its energy.

In order for an atom to absorb visible light, its electron energy levels must correspond to the energy of visible light. With ruby, two absorption mechanisms occur when white light passes through it. One involves an electron transition from the ground state $^4A_2$ to the $^4T_2$ level. 2.2 eV radiation is thus absorbed, corresponding to yellow-green light. The second involves a transition to the $^4T_1$ level, absorbing 3.0 eV radiation, or violet light. These absorption areas are actually bands rather than narrow lines and overlap somewhat. Thus, there is only slight transmission in the blue, but strong transmission in the red, giving ruby its rich red color with slight purplish overtones.

Conservation of energy laws state that energy is never lost, so energy used in elevating the electron to higher levels must reappear again when the electron falls back to the ground state. Rather than returning directly to the ground state, however, it first falls to the ^2E level, giving off energy of 1.2 eV from the $^4T_1$ level, and 0.4 eV from the $^4T_2$ level. Both of these correspond to the infrared region, resulting in the release of an insignificant amount of heat. But as electrons continue their journey to the ground state, the release of 1.79 eV occurs. This gap falls in the visible region (red), causing emission of red light. Thus the rich crimson fluorescence of ruby, which, when strong, adds visibly to the color. This is the *carbuncle* of the ancients, a stone within which a fire was said to burn.[1]

Blue sapphire

The blue of sapphire results from an entirely different mechanism than ruby—*intervalence charge transfer.* Its mystery was not discovered until fairly recent times. Auguste Verneuil, father of the synthetic ruby, was the first to discover that titanium and iron were responsible for the blue color, but the actual mechanism eluded detection until later.

By itself, a few hundredths of a percent of titanium in corundum produces no color whatsoever, while the same amount of iron alone imparts only a pale yellow color. But if both are together, a rich blue results.

Iron and titanium both substitute for aluminum in the corundum structure. Iron resides either in a *ferrous* (Fe^{2+}) or *ferric* (Fe^{3+}) state, while titanium is found as Ti^{4+}. If both Fe^{2+} and Ti^{4+} lie in close proximity, a blue color results. When stimulated by light, a single electron hops from iron to the titanium ion. This is illustrated by the following equation.

$$Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+}$$

The intervalence charge transfer mechanism which produces a blue color in sapphire is a far more efficient colorant than the Cr^{3+} ion in ruby. Ruby requires about 1–2% of

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1. Iron has the effect of quenching this fluorescence. Thus the iron-rich rubies from the Thai/Cambodian border show little, if any, fluorescence. The result is a dark, garnet-red color.

Table 4.1: Causes of color in corundum

Color	Cause(s)	Reference
Red (including pink)	Electronic transitions on dispersed Cr^{3+} ions in octahedral coordination which have replaced Al^{3+} in the corundum structure.	Fritsch & Rossman (1987)
Blue	Intervalence charge transfer ($Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+}$; sometimes written $Fe^{2+}–O–Ti^{4+} \rightarrow Fe^{3+}–O–Ti^{3+}$), where the Fe^{2+} and Ti^{4+} have replaced Al^{3+} in the corundum structure and are in close proximity to one another.	Ferguson & Fielding (1972) Fritsch & Rossman (1988)
	Intervalence charge transfer ($Fe^{2+} \rightarrow Fe^{3+}$), where the Fe^{2+} and Fe^{3+} have replaced Al^{3+} in the corundum structure and are in close proximity to one another.	Schmetzer, K. (1987)
Yellow	Ion pair transitions on individual ions of a pair ($Fe^{3+}—Fe^{3+}$).	Ferguson & Fielding (1972)
	Color center (point defect) hole pair resulting from insufficient charge when any divalent impurity (such as Mg^{2+}) replaces Al^{3+} in the corundum lattice. When sapphire is heat treated under highly oxidizing conditions, a hole (missing electron) is created, resulting in a charge of $^{+1}$. This hole combines with the divalent impurity, producing the $^{+3}$ charge needed at the lattice site. Apparently this divalent impurity-hole pair absorbs light.	Emmett & Douthit (1993)
	A variety of color centers of unknown structure.	Nassau & Valente (1987)
	Color associated with an unknown element diffusing outward from exsolved particles of unknown composition.	Koivula (1987) John Emmett, pers. comm. (July 5, 1994)
	Unreported mechanism involving dispersed Ni ions (synthetic only).	Nassau (1980)
Orange	Combination of red color (Cr^{3+}) *and* one or more of the yellow causes above.	Emmett & Douthit (1993)
Violet/purple	Combination of red color (Cr^{3+}) *and* one or more of the blue causes above.	Fritsch & Rossman (1988)
Green	Ion pair transitions on individual ions of a pair ($Fe^{3+}—Fe^{3+}$), *plus* intervalence charge transfer ($Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+}$), as described above.	Emmett & Douthit (1993)
	Unreported mechanism involving Co (strong reducing conditions), V and Ni ions which have replaced Al^{3+} in the corundum structure (synthetic only).	Nassau (1980)
	Combination of one or more of the blue and yellow causes described above.	K. Nassau (pers. comm., Aug. 19, 1994)
Color-change	Electronic transitions of dispersed V^{3+} ions in octahedral coordination which have replaced Al^{3+} in the corundum structure. Due to balanced transmission in both the red and blue-green, the gem shifts color depending on the composition of the light source.	Schmetzer & Bank (1980)
Dark Brown	Mechanical color due to dark brown color of exsolved hematite plates (mainly black star sapphire).	Weibel & Wessicken (1981)

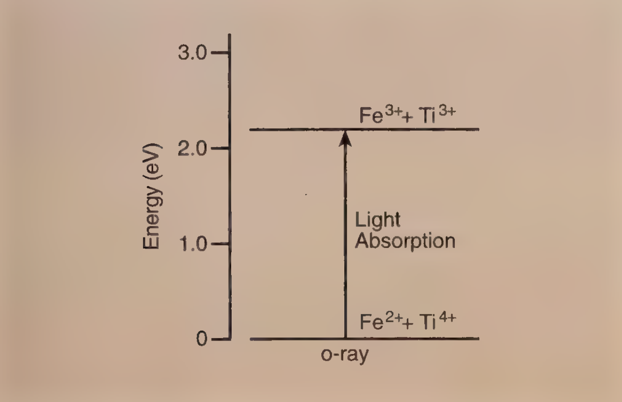

Figure 4.4 Energy transitions from the ground state to an excited state in blue sapphire. Through a molecular charge-transfer process, an electron jumps temporarily from Fe^{2+} to Ti^{4+}, resulting in light absorption. (From Nassau, 1983)

chromium for a deep red color, while only a few hundredths of one percent of iron and titanium are needed to achieve a similar depth of color in sapphire.

Many sapphires possess the necessary iron and titanium for a deep blue color, but the iron is in the wrong state. Heat treatment under reducing conditions changes Fe^{3+} to the necessary Fe^{2+}. At the same time, heating may cause diffusion of titanium from rutile silk into the surrounding corundum. Now both the Fe^{2+} and Ti^{4+} needed are present. Thus, a pale and cloudy stone becomes clear, with a deep blue color. This and other processes for heat treating corundum are discussed in detail in Chapter 6.

Yellow & orange sapphire

In yellow and orange sapphires, color can originate in one of several ways. With Thai and Australian yellow sapphires, Fe^{3+} appears to be the cause, although this is not necessarily substitutional iron. Yellow stones from these localities show prominent iron absorption bands in the spectrum.

Figure 4.5 A cornucopia of corundum colors. The wide range of hues in which corundum is found has made it the envy of many lesser gem species. (Photo: © Tino Hammid; gems: Nafco, Scottsdale, AZ)

Color centers. With Sri Lankan yellow sapphires, the cause of color is not only due to Fe^{3+} but also to color centers. Color centers involve one electron missing from an atom, producing a *hole color-center,* or one extra electron, in a vacancy, producing an *electron color-center.* Irradiation causes an electron to be ejected from an atom, simultaneously creating both a hole center and an electron center. Either or both of these electrons may then become excited and absorb visible light.

Yellow sapphires from Sri Lanka contain both fading and nonfading color centers. Apparently the nonfading type was created by millions of years of low-level doses of radiation while in the ground. The nonfading color centers, coupled with the Fe^{3+}, are responsible for the color seen. In the padparadscha, Sri Lanka's delicate pinkish orange sapphire, chromium is also present, adding a pink tint and thus producing a pinkish orange color.

Heat treatment is currently used to produce both yellow and orange sapphires from lightly-colored Sri Lankan material. The resulting colors are often so deep as to be totally unlike those produced in nature from this locality. It is believed that their color is not due to color centers, but instead results from an unknown element diffusing outward from exsolved particles of undetermined composition.

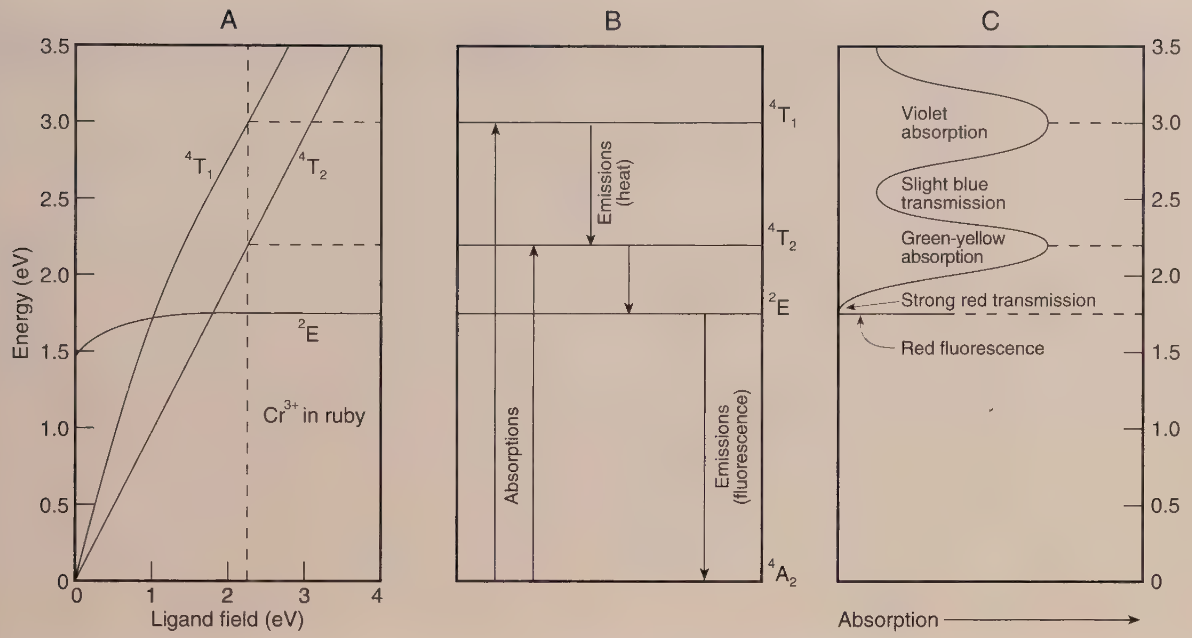

Figure 4.6 Color in ruby
A. Term diagram of Cr^{3+} in a distorted octahedral ligand field.
B. Energy levels and transitions in ruby.
C. The resulting absorption spectrum and fluorescence of ruby.
(Modified from Nassau, 1983)

Evidence of this is seen as these stones always contain multitudes of minute exsolved particles, with the color concentrated around them. In Chapter 6, the mechanisms involved in treated corundums are taken up in greater detail.

Black-star sapphire

Black-star sapphire differs from other corundums, in that its color is not due to impurity ions in solid solution or color centers. Instead, it results from the color of inclusions of exsolved hematite-ilmenite silk (Weibel & Wessicken, 1981). Similar to the Cr-green mica plates in aventurine quartz, this silk imparts a deep brown-black color to an otherwise blue, green or yellow sapphire. This is termed *mechanical coloration*—color by inclusions.

Not only is the hematite-ilmenite silk responsible for color, but these platelike inclusions also produce a six-rayed star effect. When it occurs in an otherwise blue or green sapphire, the rays of the star appear white. Rarely however, the hematite unmixes in a yellow sapphire, and the star takes on a golden-yellow color. Such *golden-star* black-star sapphires are mined at Bang Kha Cha and Khao Ploi Waen in Chanthaburi Province, Thailand, and are highly prized. This is evidenced by their high prices, which may command up to $100 per carat in the local (Thai) market.

Other sapphire colors (see Table 4.1)

Luminescence

Corundum, particularly ruby, displays several forms of luminescence. These include:

- Fluorescence: Emission of visible light when exposed to higher energy radiation
- Phosphorescence: Continued emission after the stimulating source is removed
- Thermoluminescence: Emission of visible light when the specimen is heated
- Triboluminescence: Emission of visible light when the specimen is rubbed

The most important of these from the gemological standpoint is *fluorescence*. Fluorescence results when a stone absorbs higher energy (visible light, ultraviolet light or x-rays), and then re-emits it as lower energy in the *visible* region.

Ultraviolet (UV) light is most often used to stimulate fluorescence. Two different wavelengths are typically used—366 nm (long wave) and 253.7 nm (short wave). The viewing cabinets used in conjunction with these light sources provide a dark background and isolate the reaction from stray room light. It is best to grasp the stone with tweezers rather than holding it in the hand, again so that the reaction is seen against a perfectly black background. The gem should be grasped table-to-culet and held as close as possible to the light, for fluorescence diminishes in direct proportion to the distance the stone lies from the light.[2] Examine the gem across the girdle, where it is thickest, to see the strongest

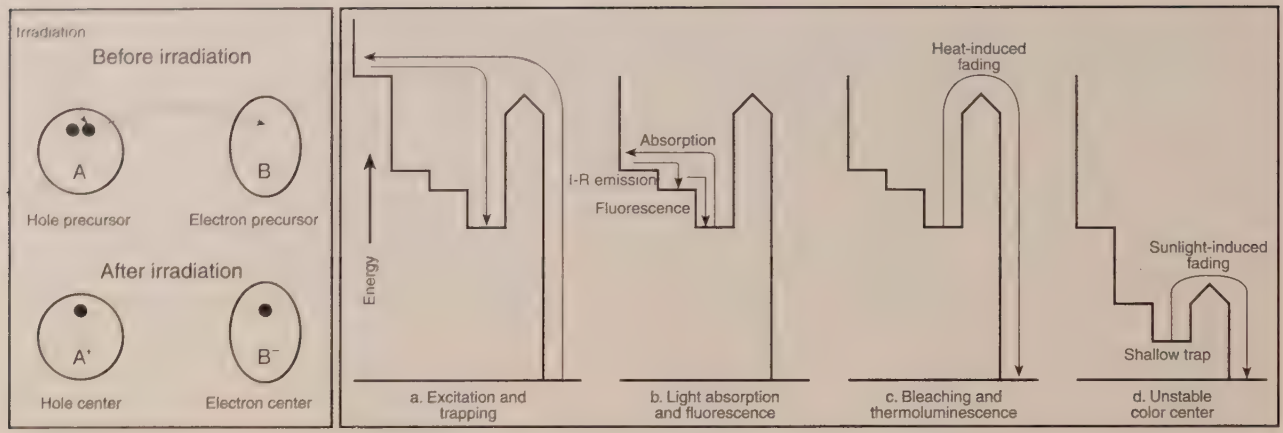

Figure 4.7 Sri Lankan yellow/orange sapphires owe part or all of their color to color centers, which may occur naturally or via human-induced irradiation. Some of these color centers are unstable and even sunlight may cause bleaching.
Left: Simultaneous creation of hole and electron centers. Irradiation ejects an electron from an atom, ion, molecule, impurity or other defect (A). This is received by the electron precursor (B), which may also be an atom, ion, molecule, impurity or other defect. Now both hole and electron centers possess unpaired electrons. Either or both may absorb visible light when excited.
Right: Formation of color centers in gemstones.
a. Irradiation causes excitation and subsequent relaxation may trap the electron.
b. Once trapped, daylight may cause more excitation, resulting in absorption of visible light (the precise wavelengths absorbed depend on the size of the step). Subsequent decay occurs in steps and generally releases heat. If one of the steps falls into the visible region, fluorescence (visible emission) results.
c. Heating the gem may cause the electron to return to its original location, thus bleaching color and producing thermoluminescence.
d. In some stones, energy produced by sunlight alone may cause fading. (Modified from Nassau, 1983)

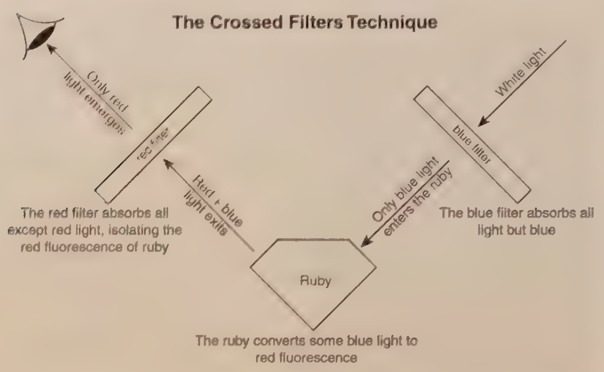

Figure 4.8 B.W. Anderson's crossed filters technique for observing fluorescence in ruby.

reaction. Check fluorescence from all sides, as some gems fluoresce in one area only. Protective eyewear is needed for short-wave UV, to prevent damage to the eyes from this more energetic source.

A feature which should be incorporated into UV cabinets is a magnifying lens. Magnification allows one to pick out small fluorescent features, such as growth zoning, which would otherwise go unnoticed. Although less than satisfactory, the removable magnifying eyepiece lens of certain refractometers can be used for this task.

There is no better technique of observing fluorescence in ruby than B.W. Anderson's *crossed filters* method. It requires two complementary filters—a blue filter to absorb all red, orange and yellow light, and a red filter to absorb all green, blue and violet light. When "crossed," the entire visible spectrum is absorbed, from violet to red, permitting no light to pass. Plastic or glass filters of the above colors usually work well, as does a strong solution of copper sulfate (for a blue filter).

In the test, a fiber-optic light (or another focused light) is directed through the blue filter onto several rubies. Now observe the gems through the red filter. An amazing sight awaits, with the rubies appearing as glowing red coals on a jet-black background. Because of the blue filter, only blue light falls onto the stones. They convert this blue light into a slightly lower form of energy—red light, emitted from the gem at the fluorescent doublet of 692.8 and 694.2 nm. This can be confirmed by examining the stones through the crossed filters with the spectroscope. A bright fluorescent doublet will be seen at the end of the red, silhouetted on a black background. It is a magnificent method of demonstrating exactly the principles of fluorescence, in this case, fluorescence to *visible* light. While long-wave UV is the most efficient stimulating energy, visible light also produces substantial fluorescence, as shown in Figure 4.11.

Although fluorescence is a useful gemological test, some caution must be used in interpreting the reactions. Fluorescence usually is caused by impurities within the stone, with

2. The inverse square law. Halving the distance increases illuminance by a factor of four.

Luminous rubies of lore

RUBY has long had the reputation of being self-luminous. Witness the following selections from G.F. Kunz (1913):

> The luminous "ruby" of the King of Ceylon is noted by Chau Ju-Kua,* a Chinese writer of about the middle of the thirteenth century and hence a contemporary of the Arab Teifashi. He says: "The king holds in his hand a jewel five inches in diameter, which cannot be burned by fire, and which shines in the night like a torch." This gigantic luminous gem was also believed to possess the virtues of an elixir of youth, for we are told that the king rubbed his face with it daily and by this means would retain his youthful looks even should he live more than ninety years.
>
> Kunz annotations
>
> * See the English translation of his "Chu-fan-chï," by Friedrich Hirth and W.W. Rockhill, St. Petersburg, 1911, p. 72.
>
> G.F. Kunz, 1913, *The Curious Lore of Precious Stones*

The famous Portuguese physician, Garcia da Orta, who lived in Goa from 1534–64, published a classic work on the medicinal products of India. In this volume, which was said to be the third book ever printed in India, da Orta discussed self-luminous rubies (Orta, 1913):

> ...it is true that a lapidary told me that he counted on a table a few very fine rubies from Ceylon, very small, such as we call score rubies, because they are sold at twenty the *vintem*. One got between the folds of a table, and at night, in the dark, the table seemed to have a spark of fire, so that it was like a candle. A very small ruby was found, and when it was taken up the spark no longer appeared on the table. I do not know whether this is the truth or a lie. But I know that the lapidary who told me this professionally, told lies sometimes, as he found them profitable in his trade, and he got so used to it that he occasionally related marvels of his own accord.
>
> Garcia da Orta, 1563
>
> *Coloquios dos simples e drogas he cousas medicinais da India [Colloquies on the Simples and Drugs of India]*

only tiny fractions of one percent being necessary in many cases. Since the impurity content can vary a great deal from stone to stone, the fluorescent reactions may also vary. Thus, fluorescence should never, never be solely relied upon to establish the identity of a gem. Instead, it provides only a rough indication, even under the best of circumstances. Far too many rubies and sapphires have been misidentified by gemologists who put too much faith in the colorful glows seen under ultraviolet light.

Table 4.3 is an admittedly weak attempt at setting out the typical fluorescent reactions for the different varieties of corundum. It should by no means be considered the last word on the subject. Variations in the trace element content can produce entirely different reactions; thus, this can be considered only as a general guide. For individual reactions, see the tables for each type in Chapter 7 (synthetic) and Chapter 12 (natural).

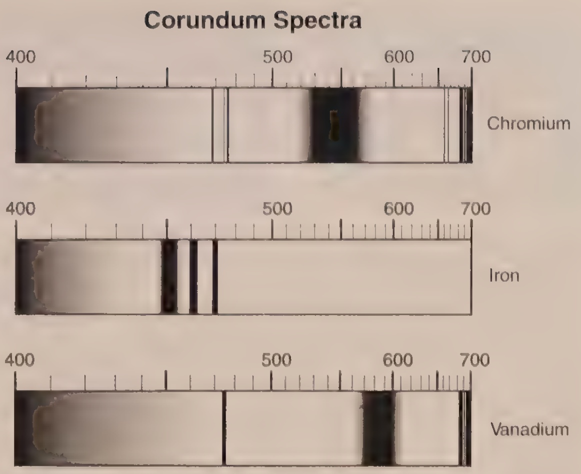

Figure 4.9 Visible absorption spectra of corundum. Depending on the coloring agents present, these three spectra may occur in various combinations.

UV phosphorescence. *Phosphorescence* refers to a continuing of fluorescence after the stimulating radiation source has been switched off. A common example is the green glow exhibited by many light switches after the light is turned off.

According to Webster (1939), both natural and synthetic (Verneuil) rubies display a weak phosphorescence to UV light. But because this after glow lasts just a fraction of a second, it is of limited diagnostic use. Cr-rich Burmese and synthetic rubies tend to show a slightly longer phosphorescence than Thai/Cambodian rubies, where Fe quenches the effect.[3]

Absorption spectra

Visible region

Among B.W. Anderson's many contributions to gemology, that which will be remembered longest is his work in the field of spectroscopy. Beset with a degree of color blindness, Anderson was forced to avail himself of other means identifying gems, rather than relying on characteristic colors. One of his greatest innovations was introducing gemologists to an instrument which had long been used in analytical chemistry—the hand spectroscope. In a series of 40 ground-breaking articles in *The Gemmologist*, Anderson and C.J. Payne laid down the absorption spectra for virtually every major gem material. So comprehensive were these articles that, even today, they remain the most important source of data on visible-region spectra (Anderson & Payne, 1953–1957).

A spectroscope gives a direct display of the visible spectrum from 400–700 nm. It does this by splitting light, either with prisms or a diffraction grating, and laying this out so as to be viewed with the eye. White light is first passed through the stone and then into the instrument. Certain wavelengths

3. Are you reading these footnotes? Good.

Figure 4.10 UV fluorescence in blue sapphire
Top: Sri Lankan sapphire in normal light (left) and fluorescing red under LW UV light (right). (Photos: Tony Laughter)
Bottom: A strong light source is sometimes enough to stimulate fluorescence. In this heat-treated blue sapphire from Sri Lanka, a fiber-optic light guide placed next to the stone produces a brilliant red-orange glow from a colorless portion of the stone. (Photo: Wimon Manorotkul; 10×)

may be absorbed, and others freely transmitted, creating an absorption spectrum consisting of bright colors and dark absorption bands and lines. The position of these bands of broad absorption and lines of narrow absorption have diagnostic value. Their position can be roughly measured by means of a wavelength scale, or estimation by reference to the colors or known lines of a sample filter or stone. Even using a spectroscope with a built-in wavelength scale, however, yields only approximate measurements.

There exist three basic spectra in natural corundum, due to the elements chromium, iron and vanadium. Those of chromium and iron spectra are extremely common, while that of vanadium is rare. They are shown in Figure 4.9.

The absorption spectrum of ruby is derived principally from the element chromium, with iron occasionally playing a small part. Chromium produces a distinctive spectrum which will easily separate ruby from all other minerals; however, synthetic ruby is also colored by chromium and so shows an identical spectrum.

Using the hand spectroscope

The direct-vision spectroscope is one of the most difficult instruments to master. But in the hands of an experienced observer, the information gained can be of great value. Thus, it is vital that anyone aspiring to the title of gemologist be well versed in this instrument's use. While it is beyond this book's scope to describe the use of this instrument, a few brief tips are called for:[4]

Successful use of the spectroscope is largely a question of path length. Longer light paths allow more absorption, thus strengthening faint lines; shorter paths produce less absorption and so allow distinction of individual lines within areas of heavy absorption. Path length is determined by the following:

- **Position of the stone:** Stones must be carefully positioned so that only light passing through them reaches the spectroscope. Due to the arrangement of facets or inclusions, light may exit the stone in several different directions; the stone should be positioned so that the maximum amount of light passes out towards the spectroscope. Placing one's hand around the stone in different positions allows one to determine exactly where the light is headed. Oval stones should be positioned so that the broad side faces the spectroscope. The stone's position must also take into account color zoning. Absorption lines normally result from color, so the stone should be positioned so that light passes through deeply-colored areas, to maximize absorption.
- **The light source and its position:** The light source itself is of tremendous importance. It must be intense, and focusable to a narrow spot. Fiber optic illuminators of 150 watts or more work well for spectroscopy. The light may be positioned to allow transmission directly through the stone from below, or reflected from above. In most cases, the reflection method is superior, for it allows a longer path through the stone and, thus, more absorption. If too much absorption is seen, the path should be shortened by moving the light and/or the stone to lessen the absorption. For example, shortening the path in Fe-rich Thai/Cambodian rubies may allow one to pick out the iron lines at 451.5, 460, and 470 nm, in addition to the Cr spectrum. Lengthening the path intensifies faint lines, which

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4. An excellent description of the use of the spectroscope can be found in Anderson's *Gem Testing* (1990).

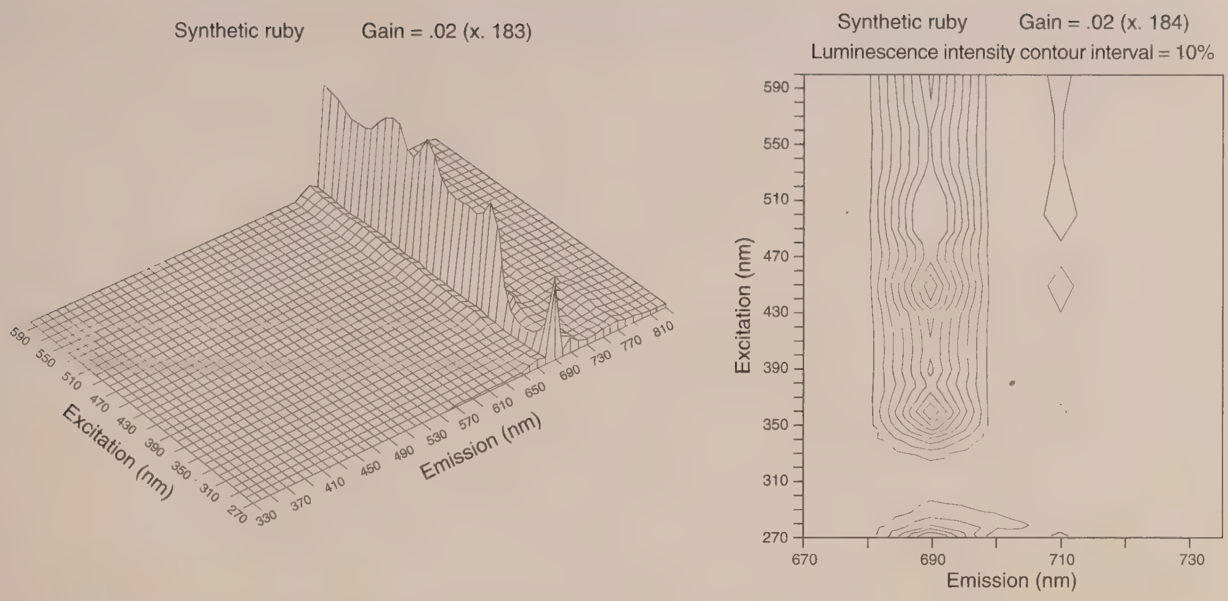

Figure 4.11 Excitation vs. emission diagram for a synthetic ruby. Note the substantial fluorescence generated by light in the visible region. (Illustration courtesy of Don Hoover)

allows one to see the 451.5 nm complex in heat-treated Sri Lankan sapphires, where it is normally weak.

- **Spectroscope adjustment and position:** First the instrument is centered on the spectrum by rocking it up and down with the slit only slightly open. Once the spectrum is located, the slit is adjusted just enough to allow the spectrum to appear (not too much!). Adjust the drawtube focus for each individual area, as different colors come into focus at different points. In locating faint lines, much skill is needed. Like a pinball machine, one learns through practice how to finesse the instrument. Try not to look directly at a faint line, but instead peer out of the corner of the eye. Open and close the slit rapidly and rock the instrument up and down at the same time. This will help to resolve the faint lines which are so often encountered.
  Once one understands the implications of path length, it is simply a question of positioning the instrument in the proper position to catch the light. When both light and stone are correctly positioned, the instrument itself still needs to be correctly placed. This involves moving the spectroscope into the light path exiting the stone. Always make sure the instrument is firmly anchored with the holder supplied on table models, or with modeling clay or plasticine. Although the instrument is called the hand spectroscope, the fact is that it just cannot be used effectively in the hand alone. A holder to anchor the instrument is absolutely essential.

Non-visible spectra

Spectrophotometers are able to detect spectral features outside the visible region. Those areas studied for gemology include the ultraviolet and infrared regions. While studies have indicated this area warrants further research, the expense of the instrumentation involved means that only the most well-heeled gemologists have access to such tools. The result has been a paucity of studies in these regions. Too often, when such studies have been published, they involve but a handful of stones. Until more comprehensive studies involving large numbers of stones from a variety of sources are published, the following data must be viewed as work-in-progress.

Table 4.2: Krüss UVS 2000 spectra

Natural corundum (Type I)	**Accuracy**
Ruby Lines 1 and 2 stronger than line 8	>90% (121 stones)
Blue sapphire Lines 1 and 2 stronger than line 8 (without line 10)	>92% (109 stones)
Synthetic corundum (Type II, except some blue sapphires)	**Accuracy**
Ruby Line 8 equal or stronger than lines 1 and 2	>74% (118 stones)
Blue sapphire Lines 1 and 2 stronger than line 8 (with line 10) *or* line 8 stronger than lines 1 and 2	>86% (26 stones)

Ultraviolet (UV) spectra

Blue sapphires also display absorption lines in the UV region and these can be useful in separation from Verneuil synthetics. As this region is invisible, however, special instruments or techniques are required to observe these lines. Absorption lines are present in natural blue sapphires at 379 and 364 nm and are said to be due to ferric iron. These can

Table 4.3: Fluorescent reactions of untreated corundums

Variety	Long wave UV (366 nm)	Short wave UV (253.7 nm)[a]	X-rays
Ruby (including pink) • Burma, Sri Lanka, Vietnam, Afghanistan, Kenya, Tanzania • Thailand/Cambodia	• Moderate to extremely strong red to orangy red • Weak to moderate red to orangy red	• Moderate to strong red to orangy red • Inert to moderate red to orangy red	• Moderate to strong red • Inert to moderate red
Blue sapphire • Sri Lanka, Kashmir (India) • Australia, China, Colombia, Nigeria, Thailand, Cambodia	• Inert to strong red to orange • Inert	• Inert to strong red to orange • Inert	• Dull red or yellowish orange • Inert
Purple & violet sapphire • Burma, Sri Lanka, Vietnam	• Weak to strong red to orange red	• Inert to strong red to orange red	• Inert to strong red
Yellow & orange sapphire • Australia, Thailand • Sri Lanka • Vietnam	• Inert • Inert to strong orange • Not reported	• Inert to weak red • Inert to strong orange • Not reported	• Inert • Weak to strong orange • Not reported
Green sapphire • Australia, Thailand	• Inert	• Generally inert; rarely weak red to orange	• Inert
Colorless sapphire • Sri Lanka	• Inert to strong orange to red	• Inert to moderate orange to orange red	• Inert to moderate red or orange

a. Heat treated gems often display a chalky blue-green fluorescence under SW. Generally it is the colorless areas of the gem which show this fluorescence. Dyed gems may display a fluorescence concentrated in the cracks (where the dye is located). This fluorescence may differ from that of the stone itself.

be found even in Sri Lankan sapphires where the 451.5 nm line is not present (Anderson & Payne, 1948). These UV lines are absent in Verneuil synthetics. Nautiyal & Mukherjee (1958) reported lines at 388 and 375 nm for natural sapphires. As they used more sophisticated measuring apparatus, their wavelength measurements are probably more accurate than Anderson's.

UV spectra have proven useful in separating natural corundums from a variety of synthetics. Unfortunately, the cost of UV spectrophotometers is out of reach of most labs. However, Krüss of Germany has manufactured a cheaper UV spectroscope that will allow many separations to be made. The Krüss UVS 2000 makes use of a mercury emission lamp which has a total of 17 emission lines ranging from about 260 nm in the UV to 580 nm in the visible region. Krüss has numbered these lines, and those numbers are used in Table 4.2, which is based on Montgomery (1991b).

By use of a fluorescent screen, the UVS 2000 allows one to see whether a gem transmits light in the region from 260–580 nm. Any lines not visible indicate absorption of that area by the gem in question.

Infrared (IR) spectra

Peretti & Smith (1993) reported that Russian hydrothermal synthetic rubies show a number of sharp lines between 3000 and 3800 wavenumbers, in addition to the normal infrared spectrum of corundum. Smith & Surdez (1994) found a number of sharp lines between 3100 and 3400 wavenumbers in Burmese rubies from Mong Hsu.

Pleochroism

Corundum crystallizes in the trigonal division of the hexagonal system. Lattice points are equally spaced along the horizontal plane, but differently spaced in the vertical plane. This type of symmetry in the distribution of electron clouds means that light will behave differently, depending on its direction of travel.

In corundum and other uniaxial gems, light entering in any direction except parallel to the *c* axis is split into two rays. Because of differences of atomic symmetry, and subsequently, vibration direction, each ray may be absorbed differently. Thus, one ray takes on one color, while the other takes a different color. This difference in color with direction is termed *pleochroism* ('multicolored'). Uniaxial materials possess two vibration directions (ω and ε), and so, potentially, two different colors, one corresponding to each vibration direction. As a result, uniaxial gemstones, such as corundum, are *dichroic*. Because pleochroism results from the difference in vibration directions, it varies in a manner similar to the refractive indices.[5] The color corresponding to the ordinary ray (o-ray) is constant throughout the crystal, while that corresponding to the extraordinary ray (e-ray) is variable. Parallel to the *c* axis (optic axis), the e-ray color matches that of the o-ray. Thus no pleochroism is seen in this

5. Surprisingly, Denning & Mandarino (1955) found in a study of synthetic ruby that, while the pleochroic pattern was similar to the RI variation, it did not match exactly. In fact, for light of 486 nm, there was noticeable pleochroism even parallel to the *c* axis. But the above model is close enough for our purposes.

Table 4.4: Visible spectra of corundum

Variety	Spectra description (from 400 to 700 nm)[a]
Ruby (including pink)	• Broad absorption from ~400–450 nm • Blue transmission from ~450–500 nm • Narrow absorption lines at 468.5, 475 and 476.5 nm • Broad absorption band centered at about 550 nm. This band is stronger for the ordinary ray.[b] • Strong orange and red transmission from about 600 to the infrared • Narrow absorption lines in the red at 659.5 and 668 nm (weaker) and 692.8 and 694.2 (stronger). These may reverse into fluorescent (emission) lines. Note: Fe-rich rubies may display Fe lines, in addition to the above. This has not been reported in synthetic corundum.
Blue sapphire	• Slight absorption in the deep violet • Three lines of decreasing strength at 451.5, 460 and 470 nm; in Fe-poor stones, only the 451.5 nm line may be seen. The lines are stronger for the ordinary ray. Only a weak 451.5 line has been reported in synthetic sapphires, and this is rare. Thus the full 3-line complex is proof of natural origin. • Broad band of weak absorption centered about 560 nm in some deeply colored specimens. This has no diagnostic significance, being seen in both natural and synthetic corundums. It is due to the ordinary ray. • Crowningshield (1959) reported on a natural blue sapphire with the normal 451.5 nm line, but also with lines at 500 and 510 nm, and a fine line at 610 nm. This has never been reported elsewhere. Anderson (1980) reported that Verneuil synthetic blue sapphires may have even weaker bands on either side of that at 451.5 nm, which are nearly impossible to see. A vague blur is seen, or sensed, at about 490 nm, just where the green ends and the blue begins. The other is an even weaker blur in the violet at about 428 nm. Note: Cr-rich natural or synthetic blue sapphires may display a weak Cr spectrum (fluorescent lines at the end of the red).
Violet/purple sapphire	• Combination of the Fe and Cr spectra above. Only rarely has a weak 451.5 line has been reported in synthetic sapphires.
Yellow sapphire	• Fe spectrum (see blue sapphire above); some gems may show a weak Cr spectrum • Heat-treated Sri Lankan yellows may show complete absorption from 400 to 450 or 500 nm. This is of no diagnostic value, as it is also found in some Verneuil synthetic corundums. • On rare occasions, a weak line at about 455 nm has been reported in Verneuil synthetic yellow sapphire.
Orange sapphire	• Combination of Fe and Cr spectra (see blue sapphire and ruby above) • Heat-treated Sri Lankan oranges may show complete absorption from 400–450 or 500 nm. This is of no diagnostic value, as it is also found in some Verneuil synthetic corundums.
Green sapphire	• Strong and complete Fe spectrum (see blue sapphire above). This is virtually always present in natural stones, but is not found in synthetic green sapphires. • Some synthetic green sapphires show a line at 500, 530, 635 and 690 nm. This may be due to a combination of cobalt, vanadium and nickel.
Colorless sapphire	• Generally not diagnostic; may display extremely weak Fe and/or Cr spectra
Color-change sapphire	**Vanadium spectrum** (common in synthetic corundum; rare in natural corundum) • Broad absorption from 400–450 nm • Single absorption line at 473 nm • Broad absorption band centered about 690 nm • Strong transmission through the orange and red. A narrow fluorescent (emission) line may be seen at about 680 nm (this gives the gem a change of color). **Cr/Fe spectrum** (common in natural and Verneuil synthetic corundum) • Combination of Fe and Cr spectra (see blue sapphire and ruby above)

a. All wavelengths are approximate only.
b. Pleochroism can have a slight effect on the absorption spectrum. By rotating a polaroid plate over the spectroscope eyepiece, the spectra of both the ordinary and extraordinary rays can be viewed independent of one another.

direction. In intermediate directions, as the direction of travel deviates from the *c* axis, the e-ray's color steadily diverges from that of the o-ray. The e-ray color reaches its maximum divergence when light travels perpendicular to the *c* axis. Thus the strongest pleochroism in uniaxial stones is seen at 90° to the optic axis.

Not all doubly refractive minerals display pleochroism, because, in some, the difference in absorption between the two rays is not enough to be detected with the eye. Most varieties of corundum do display strong pleochroism, but its strength may vary with the stone's depth of color. Generally, the greater the specimen's depth of color, the greater its pleochroism, and vice-versa. No pleochroism is observed in colorless stones, or in colored stones when looking parallel to an optic axis.

Table 4.5 lists the pleochroic colors of different corundum varieties.

Pleochroism with the dichroscope

To observe pleochroism, a dichroscope is used. This makes use of either specially-configured polaroid or calcite. The calcite type is preferable because it is colorless, and so allows finer gradations of color to be distinguished. Furthermore, some of the polaroid types tend to go bad over time, losing their ability to show pleochroism.

Observing corundum's pleochroism with the dichroscope will reveal two colors in all directions except parallel to the optic axis, where only one is seen. The key is to examine the stone at 90° to the optic axis, where the e-ray reaches its maximum divergence from that of the ordinary ray.

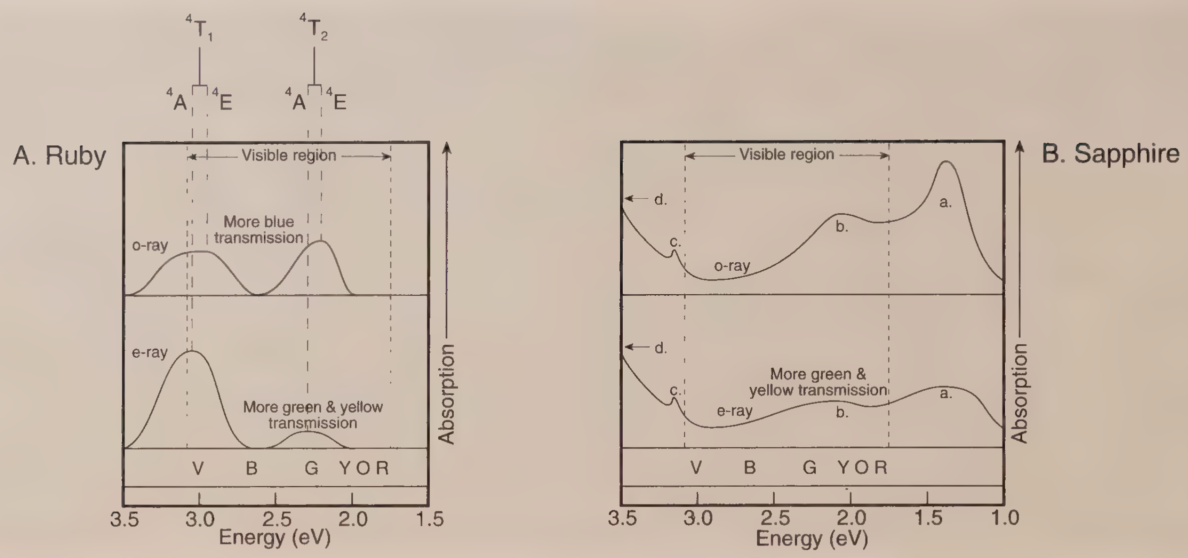

Figure 4.12 Spectral absorption curves of ruby (left) and blue sapphire (right) for both the o-ray and e-rays illustrate the differences in absorption for each ray across the visible region. Such differences indicate pleochroism.

A. Greater blue transmission of the o-ray gives it a purplish red color. Higher green and yellow transmission gives the e-ray a slightly orangy red color.

B. Greater transmission of the green and yellow gives sapphire's e-ray a more greenish blue color. For sapphire, band (a) is derived from $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer, band (b) from $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer, band (c) from a ligand field transition in Fe^{3+}, and band (d) from $O^{2-} \rightarrow Fe^{3+}$ charge transfer. (Modified from Nassau, 1983)

Table 4.5: Pleochroism of corundum

Variety	Ordinary-ray color (w)	Extraordinary-ray color (ε)	Strength
Ruby	Slightly purplish red	Slightly orangy red	Moderate to strong
Blue sapphire	Slightly violetish blue	Slightly greenish blue	Moderate to very strong
Violet & purple sapphire	Bluish purple to violet	Yellowish purple to greenish blue	Strong to very strong
Yellow & orange sapphire	Slightly reddish yellow to orange	Slightly greenish yellow	Weak to very weak
Colorless sapphire	Colorless	Colorless	Very weak to none

Pleochroism in cut stones

In uniaxial gems, when light passes straight down the *c* axis, there will be no pleochroism. Observation through a dichroscope proves this. However, light does not pass in straight lines through faceted gems. Pavilion facets cause gems to change direction at least twice. As a result, color variations due to pleochroism can be visible, even if the gem is cut with the *c* axis perpendicular to the table. This is illustrated and explained in Figure 4.14.

For a description of pleochroism in Verneuil synthetic corundums, see Figure 7.9 on page 148.

The business of pleochroism

Because of corundum's strong pleochroism, it must be taken into account during cutting. With both ruby and sapphire, the better of the twin colors is the o-ray. For this reason, cutters attempt to orient the gem so that the *c* axis is perpendicular to the table facet. This produces the lowest e-ray dilution.

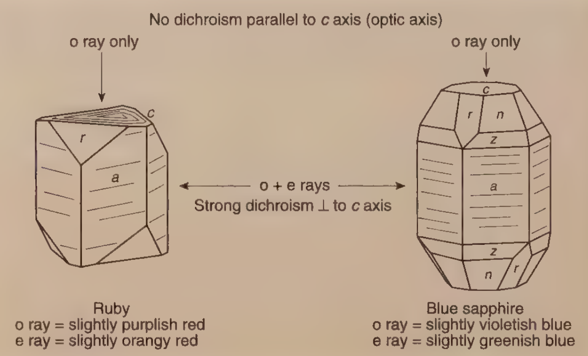

Figure 4.13 Pleochroism of natural corundum

In directions parallel to the *c* axis, only the more intense o-ray color is seen. However, at right angles to the *c* axis, the o-ray is diluted by the less intense e-ray. Thus most natural corundums are cut with the *c* axis at 90° to the table facet, in order to obtain more of this intense color.

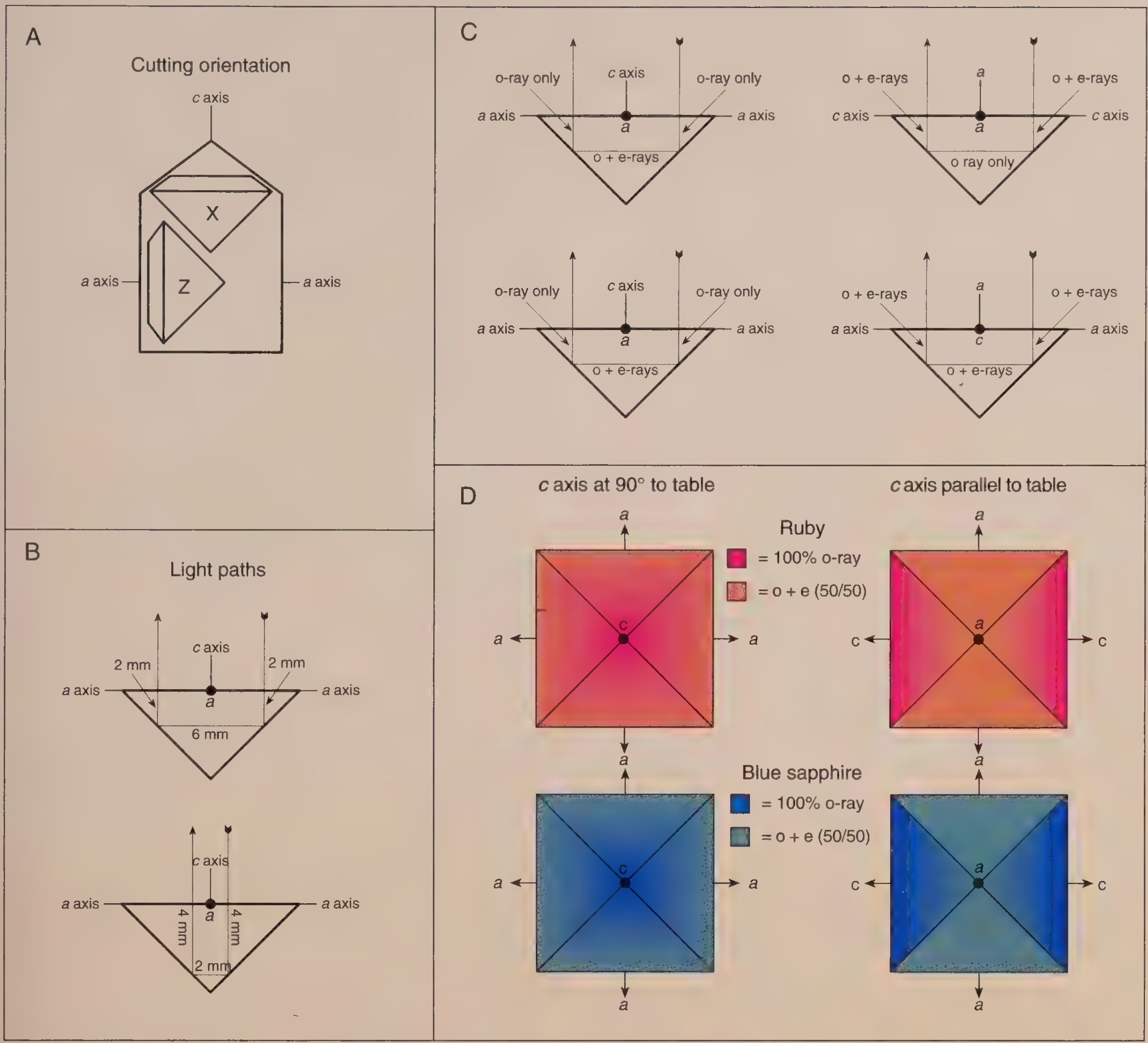

Figure 4.14 The visual effects of pleochroism on the appearance of corundum

A. Stone X is cut with the *c* axis 90° to the table facet, while in stone Z, it is parallel.

B. Where light strikes the pavilion can have a dramatic impact on the o-ray/e-ray mixture. If the *c* axis is perpendicular to the table, maximum o-ray color occurs when light strikes near the culet, because virtually the entire path is parallel to the *c* axis. In contrast, light striking near the girdle will consist of a 50/50 mixture of o-ray and e-ray colors, because virtually the entire path is in the plane of the *a* axes.

C. Light paths for cut stones of two different orientations, those with the *c* axis at 90° to the table (left), and those with the *c* axis parallel to the table (right). Note that when the *c* axis lies parallel to the table, the girdle will show full o-ray color parallel to the *c* axis. This decreases to a 50/50 mixture at the culet.

D. The visual effects of pleochroism in ruby (top) and sapphire (bottom). When the *c* axis lies perpendicular to the table (left), maximum o-ray color is found on all facets at the culet. This decreases to a 50/50 mixture at the girdle. When the *c* axis lies parallel to the table, facets lying along the a_2 line will show a uniform 50/50 mixture across their entire surface. But for facets lying along the *c* axis line, the situation is more complex. Light at the culet shows a 50/50 mixture. O-ray content increases to 100% at the girdle.

(Note: for simplicity, only two *a* axes are shown. Hexagonal crystals actually have three *a* axes, which meet at 60°. Color differences have been exaggerated slightly for clarity.)

In a perfect world, all corundums would be cut with the *c* axis perpendicular to the table facet, for this orientation allows for maximum o-ray strength. But it is not a perfect world. The lapidary's job is not to produce ideal color, but to obtain the greatest *total stone value*. For example, due to the shape of the rough, or location of color zoning and/or inclusions, ideal orientation may result in excessive weight loss. It is far better to cut a 2 ct sapphire worth $750/ct than a 1 ct stone worth $1200/ct. One does encounter variations from the ideal orientation, but such variations are *not* necessarily evidence of a lack of skill on the part of the lapidary. Instead, they generally indicate an awareness of bottom-line reality.

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CHAPTER 5

UNDER THE MAGNIFYING GLASS: INCLUSIONS

To see the world in a grain of sand, and heaven in a wild flower; hold infinity in the palm of your hand, and eternity in an hour.
William Blake, *Auguries of Innocence.* Stanza 1

ONE of the most fascinating and rewarding aspects of gemology is the study of inclusions. These tiny bits of entrapped foreign debris or structural irregularities reveal much about the gems in which they lie entombed. Often regarded as flaws, which detract from a stone's value, they are actually valuable clues that help unravel the secrets of a gem's past. Not only do inclusions speak to us of the place of formation, but they also serve as hallmarks of the processes which gave rise to precious stones. Flaws? Hardly. Without them the creations of nature would be almost indistinguishable from what Eduard Gübelin (1973) has so aptly termed "the usurpers from the factory."

History of inclusion research

While the study of gemstone inclusions has expanded greatly in the twentieth century, scientists have been peering into crystals for centuries. The great Roman polymath, Pliny, in his first-century AD encyclopedia, stated: "Further, one sees in false *carbunculi* certain small inclusions, that is blisters and vesicules, which look like silver." (Ball, 1950). This is doubtless a reference to the gas bubbles of glass. Al-Biruni, the 11th century Central Asian scholar, specifically mentioned inclusions in *yakut,* the Arabic word for corundum:

> Among the blemishes of the ruby which Al-Kindī has mentioned is the inner strain which, if too conspicuous and deep, cannot be removed. The other is the *khalt-i-hijārah* (admixture of stones) which is called *hurmulliyāt. Hurmal* (harmal or white rue) is white. In Persian it is called *kunjdah.* Another blemish is that of *rīm,* i.e., a kind of dross that is like earth. Still another is that of a perforation which detracts from its clarity and transparency. This appears in the form of a crack which results from the collision of a vitreous object which something and the crack is so wide that water may pass through it. It is physical as well as temporary. Variegation in colour, e.g., greater in one part and less in the other, is counted as a defect. Cloudiness also deducts from the value of the stone. A pearl-like stain may be present on the stone on any part. This blemish is known as *āsin.* If not deep, it would disappear on rubbing [polishing?] the stone. There is no other way in which to do away with this defect, as it is rather deep.
> al-Biruni, ca. 11th century (Biruni, 1989)

One can immediately read into the above, color zoning, included solids, healed fractures (fingerprints) and silk inclusions.

With the invention of the microscope in the 17th century, it became possible for the first time to examine the interior of gems up close. But the modern era of inclusion research did not really begin until the 1820s, with the papers of Davy (1822), Brewster (1826, 1827), Sorby (1858), Sorby & Butler (1869), and Lea (1869a–b, 1876). These works accurately described fluid inclusions, including those of two and three-phases, as well the silk inclusions so common in corundums.

In the modern era, no one has had a greater influence on inclusion research than Eduard Gübelin. While his first book on inclusions was published in 1953, he is largely known for his 1973 masterpiece, *The Internal World of Gemstones.* Here Gübelin combined the observational talents of a master scientist, with the aesthetic sensitivity of an artist and William Blake-like prose. It is one of those rare works which instantly transcends, and transforms, the field. Such was, and is, the

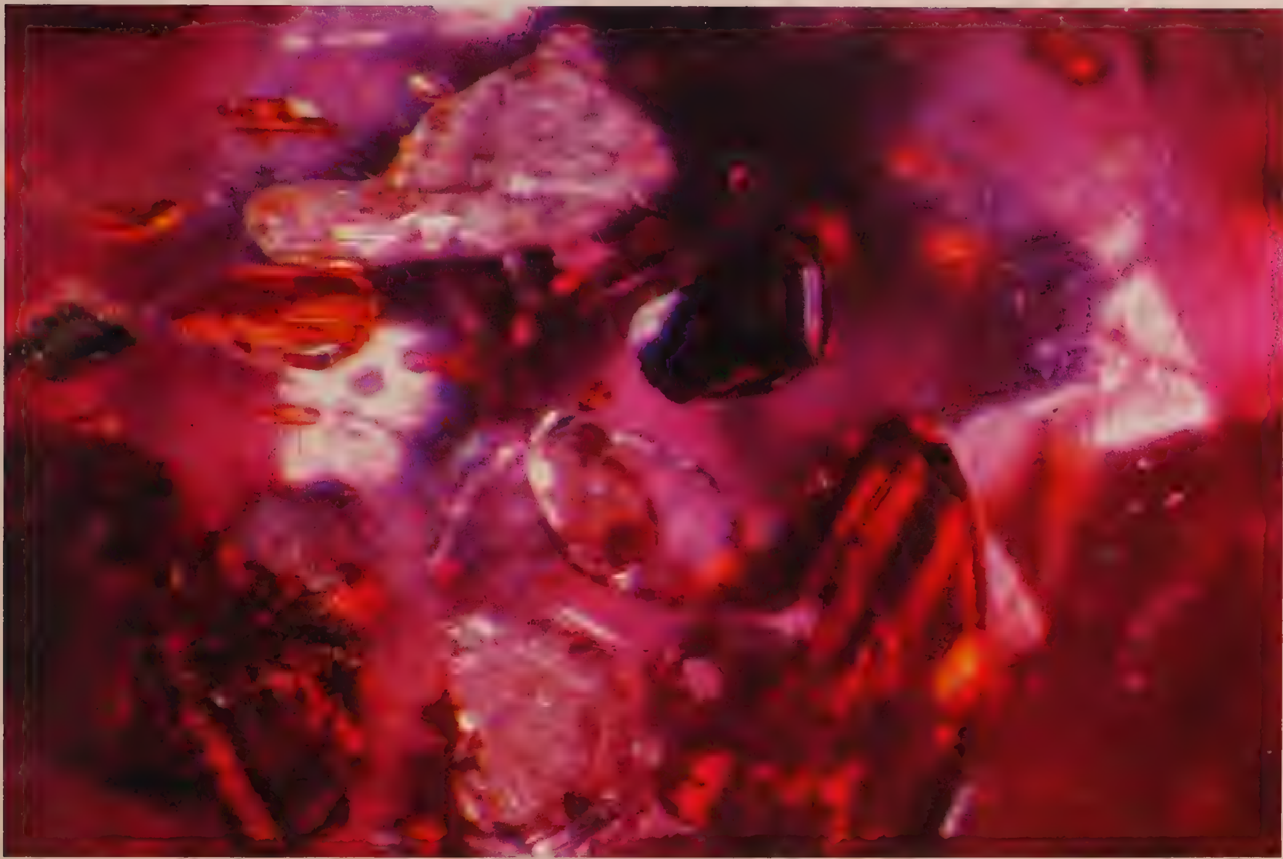

Figure 5.1 Crystals of rutile, sphalerite and calcite explode from the depths of a Mogok ruby. 50×. (Photo: John Koivula/GIA)

influence of this work that no one who has seen this book ever looks at, or describes, the interior of a gemstone in the same way. While it has been superseded by Gübelin's, Koivula's and other's later works, it has not been topped. *The Internal World of Gemstones* remains a gemological *tour de force.*

The microscope— A gemologist's best friend

To view inclusions, a microscope is required. In terms of optics, look for a stereo-zoom head with a magnification range from 10–60× (this can be increased with stronger eyepieces and/or a doubling objective lens). Surprisingly enough, quality of optics is not nearly so important as the microscope base. Many so-called gemological microscopes are lacking in one important area—lighting. Without proper illumination, one sees nothing, even with the best optics. Thus a microscope must possess an extremely strong, built-in light source (a 35-watt quartz halogen bulb is the absolute minimum). GIA/Gem Instruments' *Gemolite* base is one of the best available for all-round use. Even better is that designed by Marc Bogerd and the author for the Asian Institute of Gemological Sciences. The *Gemolite* is greatly improved by modification. Dump the 35-watt bulb and move up to a more powerful model. Use of a bulb with a vertical filament (as opposed to horizontal) produces a wider band of effective illumination. While the stronger bulb may create problems for heat-sensitive gems, it is worth the risk. Once again, if the specimen is not adequately illuminated, you see nothing.

The humble stoneholder is another oft-overlooked aspect of microscope design. A poor-quality stoneholder inevitably results in the "jewelers' prayer meeting"—down on your knees praying to find a stone that has flown out of sight. Surprisingly, many stone holders lack a knurled groove on the inside to grasp the stone's girdle. The best used by the author was that made by GIA/Gem Instruments; however it is no longer made.[1]

Mastering the microscope— Illumination techniques

Dark field

The mainstay of the gem microscope, dark-field illumination brings light from the sides (via a reflector), thus silhouetting inclusions on a dark background. It is good for

[1] The current model is a wire type. While it obscures less of the gem, it is inferior because it lacks the knurling.

David Brewster—Pioneer of inclusion research

ART. XXIV.—*Notice respecting the existence of the New Fluid in a large cavity in a specimen of Sapphire.* By David Brewster, LL. D. F. R. S. and Sec. R. S. Edin.

In two papers which are printed in this *Journal*, I have fully described the physical properties of the two new fluids which occur in mineral bodies. These fluids having been found only in the precious stones,—in quartz, amethyst, topaz, and chrysoberyl, it became interesting to detect them in other minerals, not only with the view of establishing their general prevalence at the formation of this class of bodies, but of ascertaining if they experienced any change in their properties from the mineral in which they are found.

Mr Sanderson lately put into my hands a specimen of sapphire, containing a very large fluid cavity, which, from the expansible nature of the fluid, seemed to resemble that which occurs in topaz. The cavity itself is regularly crystallized, and is about one-third of an inch in length. The fluid occupies about *two-thirds* of its length, and fills the cavity at a temperature of 82° of Fahrenheit. It seems to be more viscid and more dense than I have usually observed it, and in consequence of this property, the capillary margin of the fluid remains distinct and well marked, even at the instant when it fills the cavity. When the temperature descends below 82°, the contraction of the fluid is not accompanied with that violent effervescence which takes place in the deep cavities in topaz.

In the specimen under consideration, the fluid seems to have exerted a high expansive force upon the sides of the cavity, which it has succeeded in opening on both sides. The surfaces of the fissures thus occasioned, are covered with specks of a gelatinous-looking matter, like portions of the second fluid, when in a state of induration. The force, however, was not sufficient to burst the specimen, and the only effect of it seems to have been to expel into the fissures the second fluid, which always occupies the angular and narrow parts of the cavity. This opinion seems to be confirmed by the fact, that none of the second fluid can be seen within the cavity, although this may arise from the difficulty of examining the angular portions of the cavity in the present state of the specimen.

There is another very interesting peculiarity in this specimen of sapphire. It contains at one extremity of the fluid cavity distinct groupes of transparent crystals, which have, no doubt, been deposited by the fluid. What these crystals are, we are not entitled to conjecture, but if the cavity were opened, it might be practicable to ascertain whether or not they are sapphire.

David Brewster, 1827, *Edinburgh Journal of Science*

viewing a variety of solid and fluid inclusions, as well as narrow growth lines. Hand-held fiber-optic lights can also be used to provide dark-field illumination. In many respects, they are superior to the built-in dark-field microscope lighting.

Light field (transmitted light)

Good for locating broad areas of color zoning, as well as checking inclusion transparency. If the iris diaphragm is narrowed to an aperture slightly less than the diameter of the gem, this is also useful for seeing into heavily included gems.

Diffuse light field (white filter)

Diffuse light-field illumination is achieved by placing a frosted white plastic or glass filter over the microscope. It is useful for locating broad growth zoning, and is even better with the addition of an immersion cell and appropriate liquid. Surface-diffusion treated corundums are readily detected by this method.

Diffuse light-field (blue filter)

With yellow and orange sapphires, a special need arises. Many microscopes have light sources with a yellowish tint. When combined with the yellowish color of the di-iodomethane immersion fluid, it is no wonder that curved color banding in synthetic yellow/orange sapphires is difficult to see. Addition of a frosted blue filter counteracts the yellow color of the light and liquid, allowing the growth features of yellow and orange stones to be seen more readily (Hughes, 1988).

Overhead lighting

When surface features are to be examined (either on the stone or on the inclusion itself), overhead lighting is needed. This is obtained either by a built-in overhead light or by using the hand-held fiber-optic light. Generally the fiber-optic light works best. Examination of inclusion surfaces can provide valuable clues as to their identity.

Immersion

Due to a gem's shape, it is often difficult to see its interior clearly. Immersion in a liquid of similar RI (di-iodomethane for corundum) greatly reduces surface reflections. Horizontal immersion microscopes, which allow one to examine the specimen while remaining seated, are popular in Germany. Vertical models are common in the USA. I prefer the vertical models, because manipulation of the stone is far easier and quicker (to change the gem's position in the stoneholder, it is simply placed on the bottom of the cell and picked up in a different position). When looking for subtle features, such as curved growth zoning in synthetic yellow sapphires, one hour or more may be required. The difficulty of specimen manipulation with horizontal microscopes increases examination times by a factor of five to ten. To overcome the comfort problem of using a vertical microscope for immersion, it is best to place it on a low platform, so that one can remain seated while examining the specimen (Hughes, 1989, 1990).

Crossed polars

Examining a gem between crossed polars is the best way to locate the presence of twinning and structural strain. Immersion may also be used together with this method. Twinning planes will appear as bright planes against a dark background as the gem is rotated. Plato twinning in Verneuil synthetic corundum is seen by viewing the gem parallel to the optic axis while immersed between crossed polars. Crossed polars are also useful for separating solid crystals from negative

Tips on proper microscope use

THE most important instrument available to gemologists is the microscope. But just having a microscope does not a gemologist make. You must know how to use it. The following will help you get the maximum out of your microscope.

Rule 1—Clean and adjust the eyepieces
Before you put the stone in the stoneholder, check the eyepieces to ensure they are both clean and properly focused. Like all lenses, eyepieces need periodic cleaning. This should be done with special lens cleaning fluid and lens tissue. Always blow on the lens before using the fluid and tissue, so as to remove any dust particles that might scratch the glass. Then apply a drop of fluid to the tissue and gently clean the eyepiece with a circular motion. But the best cure is prevention. Cover your microscope when not in use. This will ensure that it stays in top condition. If well-cared for, a microscope can last a lifetime.

Eyepieces must also be properly focused. If your eyes are both exactly the same (in terms of focus and strength), the eyepieces should be at the same height. A scale is provided on one eyepiece to show the adjustment position. The zero position is correct for people whose eyes are identical. If vision in one eye is different than the other, you will need to adjust the eyepieces.

To focus the eyepieces, do the following:

1. Place a flat printed object (such as a business card) on the microscope stage. Zoom to the highest power and focus on the dot of an " i " or a period *using the right eye only.*
2. Do not touch the focus again. Zoom to lowest power and, *using the left eye only,* focus by twisting the left eyepiece up or down.

Rule 2—Clean the stone
Such a simple task, but too often ignored. The single most important microscope skill is cleaning the stone before examination. No matter how often hands are washed, some oil remains. Touching the stone applies fingerprints, but not the kind we like to see.

Cleaning is best accomplished with a clean piece of cotton cloth. Cotton has the ability to absorb skin oils, while simultaneously removing dust. Other types of cloth will unfortunately leave either the dust, or grease, behind. This includes most fancy polishing cloths (such as those used for cleaning eyeglasses and the leather cloths for cleaning jewelry). Dipping the gem in alcohol also works.

After the gem is clean, don't touch it again. Pick the stone up directly off the cotton cloth with the stoneholder. Remember, every time a stone is touched, a little oil and dust adhere to it.

Rule No. 3—Examine the stone from all possible directions while varying the lighting conditions
A gemologist's life would be far easier if gems were cut as parallel-sided plates. But they're not. Facets are designed to reflect light back to the viewer, not transmit it. This means light entering the stone from behind (transmitted light) will typically *not* pass straight through. If we want to see inclusions, we must constantly change the light paths through the stone. This is done by changing the position of the stone relative to the light and changing the light relative to the gem.

Change the position of the gem relative to the light: *The stone must be examined from all possible directions.* This is crucial. Locating inclusions has little to do with visual acuity. When the stone is properly positioned, almost anyone can see the inclusion. The difference between expert and novice is that the expert constantly changes the stone's position relative to the light source. So even if you're not an expert, act like one. Check the stone from all possible angles by constantly moving the stoneholder and shifting the position of the gem in the stoneholder.

Change the light relative to the gem: It is not only important to keep shifting the gem's position in the stoneholder, but also to vary the lighting conditions as you do so. Gemological microscopes differ from those used in other fields because specimens are not viewed between two pieces of flat glass. Faceted gems have surfaces that stick out at odd angles; hence the light must enter at odd angles. This is why the lighting setup is so important to a gemological microscope. A good microscope will allow a variety of lighting possibilities (see the following section). Learn to use them.

Rule No. 4—Use a fiber-optic light
The fiber-optic light source is generally the best for occasions which call for either dark-field or overhead illumination. It allows one to view inclusions that were invisible a mere 15 years ago (before the advent of fiber-optic lighting).

Fiber-optic lighting has two main advantages. First, it is both intense and concentrated. In many stones, resolution of inclusion data depends on how much light can be brought to bear on a tiny part of a tiny inclusion. A fan-cooled 150 watt quartz halogen bulb behind a good fiber-optic light guide is tough to beat. Second, the light is mobile— you can move it where it is needed most.

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crystals (solid crystals may display a different extinction from the host, if they are birefringent).

Light field shadowing

John Koivula (1982b) has described a lighting technique which he has dubbed *shadowing.* Shadowing involves opening the microscope to normal light field and passing the edge of an object (such as a business card) between the stone and light. If done properly, detail is enhanced in a narrow part of the stone. This is useful for resolving the fine detail of narrow growth lines, especially those in natural corundum and the curved striae of Verneuil and Czochralski synthetic rubies. Ideally the edge of the business card should run parallel to the growth lines. Another method is to narrow the microscope's iris diaphragm to a size just less than the stone's diameter.

Inclusion types & formation

What is an inclusion?

John Koivula (1991) has provided us with probably the best definition of the word *inclusion:*

> Broadly defined, an inclusion is any irregularity observable in a gem—by the unaided eye or [using] some tool such as a hand

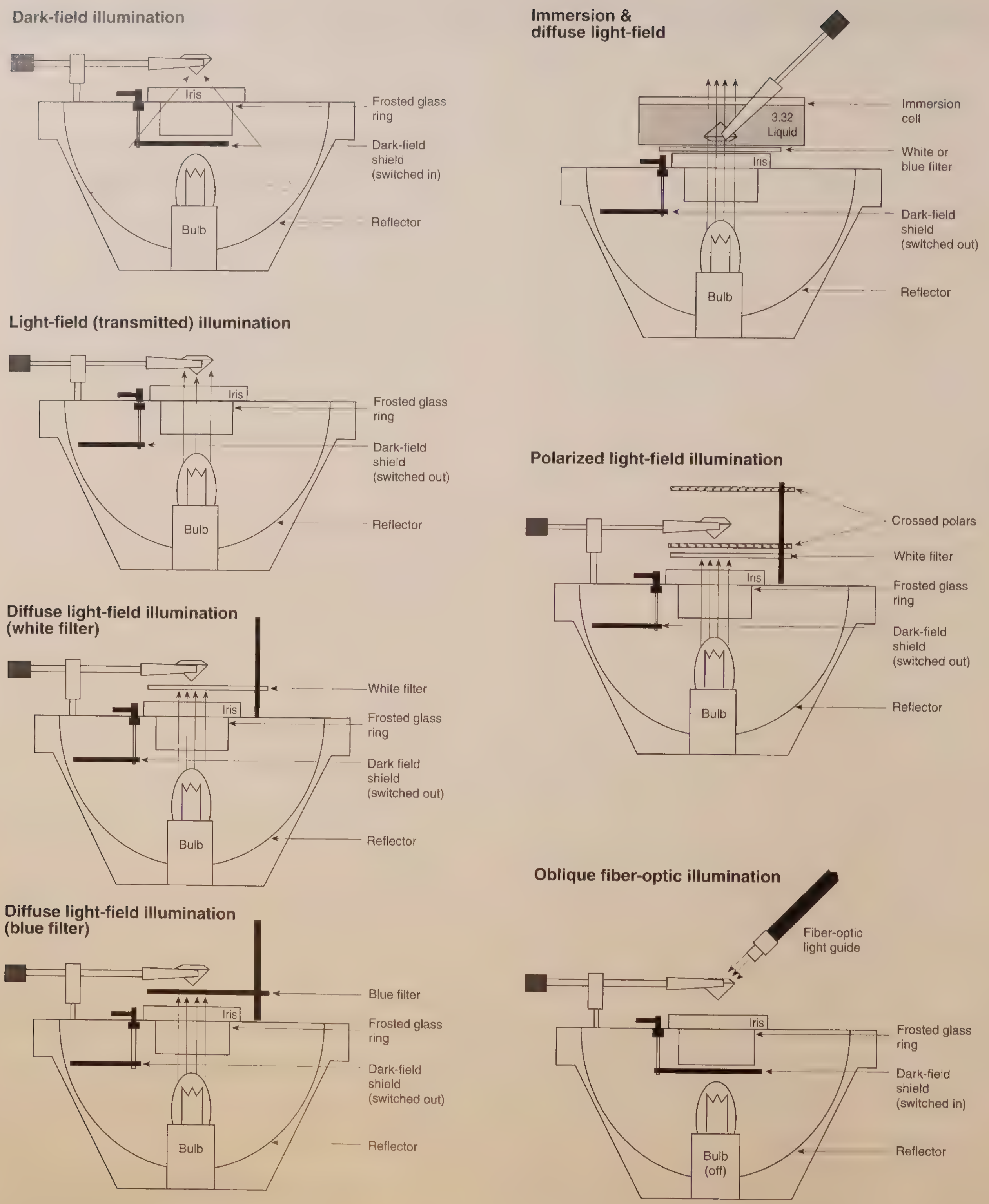

Figure 5.2 One of the keys to successful use of the microscope is mastering the various illumination techniques. Above are shown many of the important lighting methods for gemstones. (Modified from Koivula, 1981)

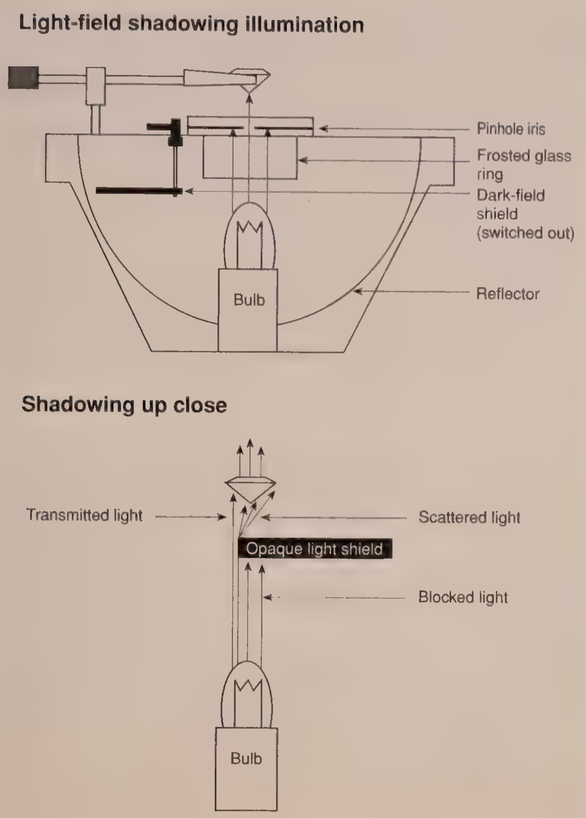

Figure 5.3 Subtle growth features, such as extremely fine zoning, are often brought out via shadowing. Shadowing is effected by using transmitted light, and slowly bringing an opaque object, such as the edge of a business card, between the light and gem. (Modified from Koivula, 1982b)

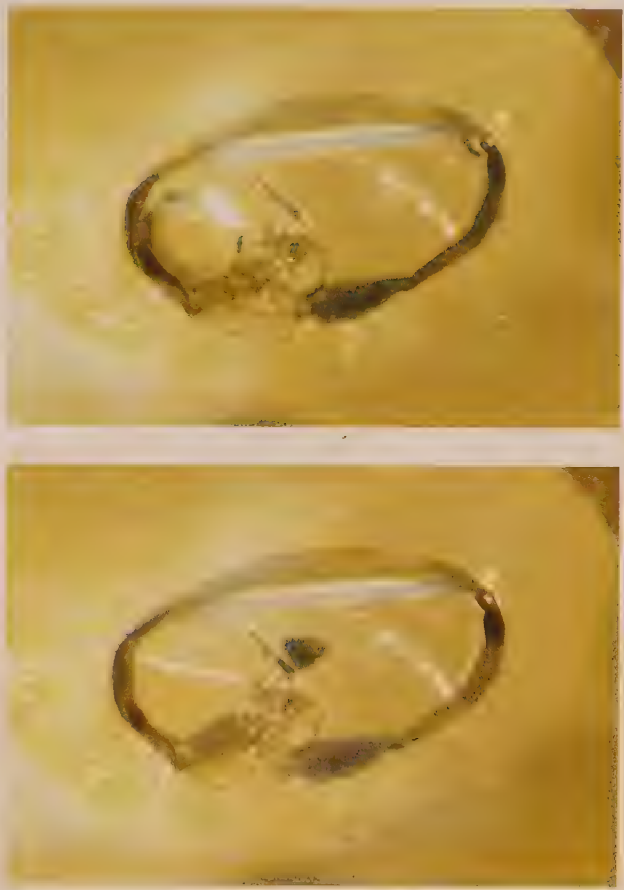

Figure 5.4 Two views of a primary negative crystal in a Sri Lankan sapphire. The cavity contains liquid and gaseous CO_2, along with a mobile graphite crystal cluster. In the top photo, a CO_2 bubble is clearly visible, while in the lower photo the CO_2 bubble has disappeared from the gentle heat of the microscope. The black graphite crystals can also be seen to have moved in the lower photo. (Photos: John Koivula/GIA; 35×)

lens or microscope. The 'irregularity' may be a substance, such as a solid mineral crystal or a fluid filling a cavity, or it may be an unfilled cavity, a fracture, or a growth pattern that produces some optical effect.

Inclusions in gemstones can be classified according to the scheme proposed by Gübelin (1973) and Gübelin & Koivula (1986), which is based upon their age with respect to that of the host crystal. This is as follows:

Pre-existing inclusions (protogenetic)

Inclusions that have formed before the host. These are strictly of a solid nature (pre-existing liquids and gases don't count).

Solid and semi-solid inclusions

Crystals and/or glasses that form before the host and are subsequently trapped. The crystals may appear either as heavily etched or corroded individuals which formed long before the host, or as well-formed crystals which developed just prior to the host

Examples. various, including spinel in ruby. Corundums which formed in metamorphic environments, such as Burmese rubies, are often rich in solid inclusions.

Contemporary inclusions (syngenetic)

Inclusions that have formed at the same time as the host.

Solid and semi-solid inclusions

Crystals and/or glasses that form, and are trapped, at the same time as the host. It is usually impossible to tell from a microscopic examination whether or not a solid inclusion formed before the host.

Examples: Various, including calcite and dolomite in ruby from metamorphic environments (such as Mogok, Burma).

Primary cavities

These consist of cavities formed while the host itself was growing. When they display some semblance of crystal shape, they are termed *negative crystals*. They may be trapped for a variety of reasons (see Figure 5.6), most commonly due to rapid growth. When a crystal grows rapidly, it no longer grows with smooth, flat faces, but instead grows with faces that have channels.[2] Such channels provide perfect pockets for trapping of the growth solution. Primary cavities may be

Figure 5.5 A collection of corundum inclusions from the brush of master photographer, John Koivula
Top left: Spinel octahedra in a blue sapphire from Sri Lanka; 25×
Top right: Iridescent two-phase primary inclusions in Thai/Cambodian ruby, parallel to the basal plane; 25×.
Middle left: Primary rutile crystals (orange) in a sapphire from Rock Creek, Montana; 25×.
Middle right: Secondary, exsolved rutile "silk" clouds in a sapphire from Rock Creek, Montana; 20×.
Lower left: Light yellow apatite crystals in a corundum from Umba Valley, Tanzania; 25×.
Lower right: Discoid fractures caused by heat treatment in an Australian sapphire; 45×.
(Photos: John Koivula/GIA)

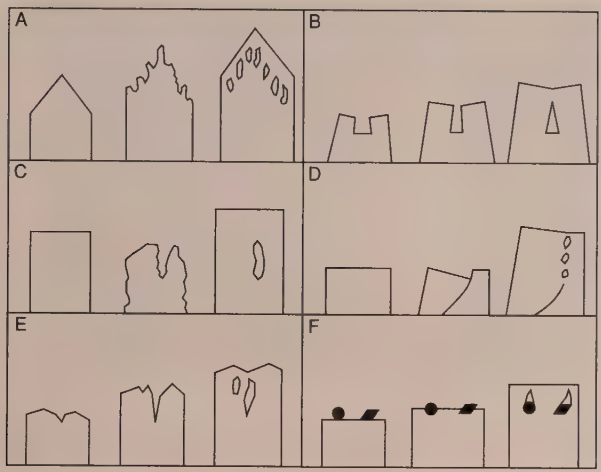

Figure 5.6 Trapping mechanisms of primary fluid inclusions

A. Rapid feathery growth is covered by later solid growth.
B. Subparallel growth traps fluids.
C. Dislocation etched out during partial dissolution is later covered by new growth.
D. Disturbed growth near a fracture in the surface of a growing crystal results in trapping of primary fluid inclusions.
E. Primary fluid inclusions are trapped between or at the centers of growth spirals.
F. Enclosure of any foreign object on the surface of a growing crystal may include some of the growth fluid as well.
(After Roedder, 1984)

filled with liquid alone (single phase), liquid + gas or liquid + solid (two-phase), or liquid + gas + solid (three-phase). At times, the gas bubble of a primary cavity may move. Edwin Roedder (1962) described it thus:

> When the bubble is small enough to respond to statistical irregularities in the number of molecules striking it, and is free of the inclusion walls, it can be seen to wander continuously in a jerky Brownian movement. It is fascinating to watch such a bubble under the microscope and to think that it has been nervously pacing its cell for perhaps a billion years.

According to Roedder (1982), crystals which have grown from metamorphic environments tend to be relatively deficient in primary fluid inclusions. Instead of growing as free crystals, protruding into the fluid from which they grew, crystals in metamorphic rocks have grown in an essentially solid medium by migration of the nutrients via diffusion through other crystals, along grain boundaries, or through a fluid film in the grain boundaries. Space for the growth is found by the dissolution or shoving aside of adjoining crystals. As a result, crystals formed in metamorphic rocks often contain many solid inclusions, but few, if any, fluid inclusions.

Primary cavities generally result where certain areas of the host have grown more rapidly than others, forming, and eventually enclosing, voids. Flat crystal faces, once facing outward, now enclose hollow spaces, and may look just like solid crystals. These voids usually contain a liquid and/or gas bubble trapped at the time of their enclosure. Other solids may also be enclosed (or crystallize later from the trapped fluid). Scientists study such trapped fluids, for they provide important clues regarding the conditions under which the gem formed, being remnants of the original growth solution.

Negative crystals can often be recognized by identical crystal orientation to the host, along with their high relief, due to the liquid or gas filling. More substantial evidence is provided by the gas bubble sometimes trapped within the liquid. It is always delightful to observe a bubble which bobs up and down as the crystal is tilted in the microscope. Such mobile bubbles are quite common in minerals like quartz and fluorite, but less so in corundum (except from Sri Lanka and Madagascar). Heat treatment will often cause explosion of such negative crystals (Koivula, 1980a; 1986).

Examples. Primary cavities are common in all minerals, especially in gems which grow from solution environments, such as quartz, fluorite, beryl, and corundum.

Primary growth phenomena

- **Primary twinning**—Twins that formed at the same time as the host ('growth twins'). These typically occur as single planes only, rather than being repeated throughout the crystal. *Examples:* Spinel and diamond macles (twinned octahedra), penetration growth twinning in Sri Lankan and Kashmir sapphire, etc.
- **Growth zoning**—During a crystal's growth, coloring agents may not be available in consistent amounts. The result is a layered appearance of lighter and darker lines (or bands) which follow the external surfaces of the crystal. This is similar to the growth rings of trees, except that with single crystals, the external surfaces are flat and meet at specific angles. Thus the growth lines of single crystals will always be straight (never curved, unless one looks in directions not parallel to the faces along which they formed). They may form parallel to any of the faces that are, or were, present while the crystal was growing.

  The external surfaces of synthetic single crystals grown by the Verneuil, Czochralski and floating zone processes are not flat, and so the growth lines are not straight. Synthetic gems grown by the flux and hydrothermal processes possess flat faces, and so will display straight growth lines meeting at the face angles.

Secondary inclusions (epigenetic)

Inclusions that have formed immediately, or even millions of years, after the host stopped growing.

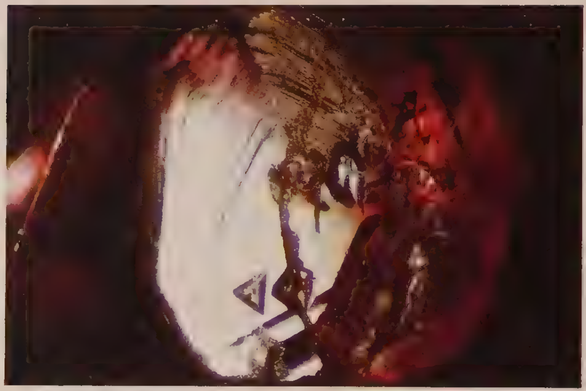

Figure 5.7
Top: Terraced basal pinacoid faces on Burmese ruby crystals. Note the many tiny triangular etch marks (or possibly growth marks). Such stepped surfaces result from oscillatory growth between the basal pinacoid and prism or pyramid/rhombohedron faces, and are often seen on ruby crystals, particularly those from Burma. (Photos: Wimon Manorotkul)
Bottom: A primary cavity in a blue sapphire from Sri Lanka. Note the terraced or stepped growth on the basal pinacoid face. Cavities often display similar growth features to the host and generally are of high relief. The high relief and stepped growth are two ways by which they can be separated from solid crystals. Cavities also are oriented identically to the host (the *c* axis of the host will lie parallel to the *c* axis of the negative crystal). Identifying the basal pinacoid (with its stepped growth) face of the cavity can show its orientation. 120×. (Photo by the author)

Solid inclusions

- **Exsolved crystals**—Exsolution is the "unmixing" of a solid solution. At high temperatures, crystals have more defects, and thus are better able to absorb impurities. As the crystal cools, defects are reduced. This may force impurities to crystallize out. But because of the constraints placed on their movement by the solid host, impurity atoms are unable to travel large distances. Therefore, rather than forming large crystals, they migrate short distances to form multitudes of tiny needles, plates and particles, along the directions in the host where space permits.

  One of the keys to recognizing exsolved inclusions is that they always form in a specific pattern within the host. That pattern may be different for different minerals crystallizing within the same host material (for example, rutile is exsolved in corundum in three directions crossing at 60/120° in the basal plane). Virtually all tiny, oriented needle, particle and platelike inclusions found in minerals are formed via exsolution. These inclusions give rise to asterism and cat's eye phenomena. **Examples:** rutile and hematite-ilmenite silk and needles in corundum.

  Another exsolved inclusion in corundum is boehmite. Consisting of hydrous aluminum oxide (γ AlO·OH), it is produced in corundum by alteration at stress points along the edges of the rhombohedron faces. This occurs along a total of three directions (meeting at 86.1/93.9°), but only two directions occur in the same plane. These planes lie at approximately 30/60° to the *c* axis.

One of the most diagnostic features of corundum is the white clouds of exsolved rutile (TiO_2). According to Gübelin (1940, 1953), Gustav von Tschermak (1878) was the first to identify rutile in corundum. Such clouds vary from dense concentrations which follow, and distort, the crystals' color zoning, to thinly-woven tapestries. At times, only slender threads or particles are visible, while in other cases knife or dart shapes appear (see Figure 5.11 and Figure 12.140). Closer examination reveals many of these to be twin crystals with tiny v-shaped re-entrant angles visible at the broad end. They are flattened so thin in the basal plane that, when illuminated with a fiber-optic light guide from above, bursts of iridescent colors are seen, due to the interference of light from these microscopically-thin mineral lances.

The needle clouds just described are termed *silk*, in analogy to their threadlike pattern and are responsible for the asterism, or star effect. Not only rutile may form silk in corundum; hematite (Fe_2O_3), ilmenite ($FeTiO_3$) or hematite-ilmenite mixtures have been reported. Rutile in corundum tends to unmix parallel to the faces of the second-order hexagonal prism $\{11\bar{2}0\}$, intersecting in three directions at 60/120° in the basal plane (Sahama, 1982). Hematite-ilmenite exsolves in the basal plane parallel to the first-order hexagonal prism $\{10\bar{1}0\}$ (Moon & Phillips, 1984). Thus when both rutile and hematite-ilmenite are present in the same crystal, a 12-rayed star is possible (see Figure 12.140).

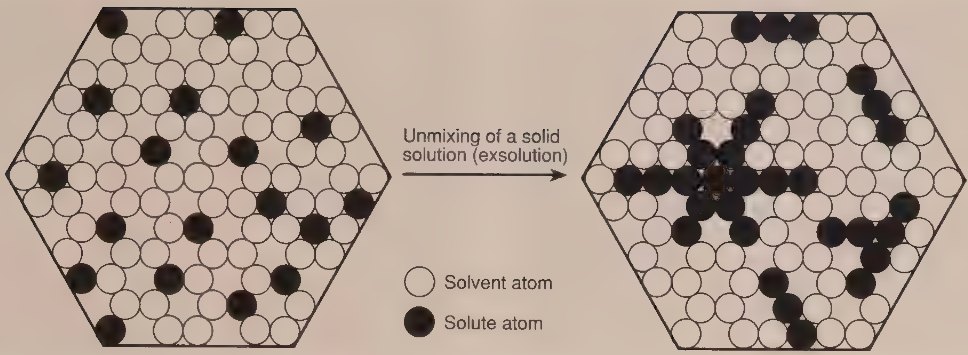

Figure 5.8 Exaggerated and simplified atomic view of exsolution in corundum
During exsolution, solute atoms migrate together to form their own crystals within the host. The orientation of these crystals is governed by the host structure. As a result, they are exsolved in a specific pattern. Within corundum, rutile (TiO_2) unmixes in the basal plane, parallel to the faces of the second-order hexagonal prism {11$\bar{2}$0}, while hematite (Fe_2O_3) or ilmenite ($FeTiO_3$) exsolves parallel to the first-order prism {10$\bar{1}$0}; boehmite (γ-AlO·OH) exsolves along the rhombohedron {10$\bar{1}$1}.

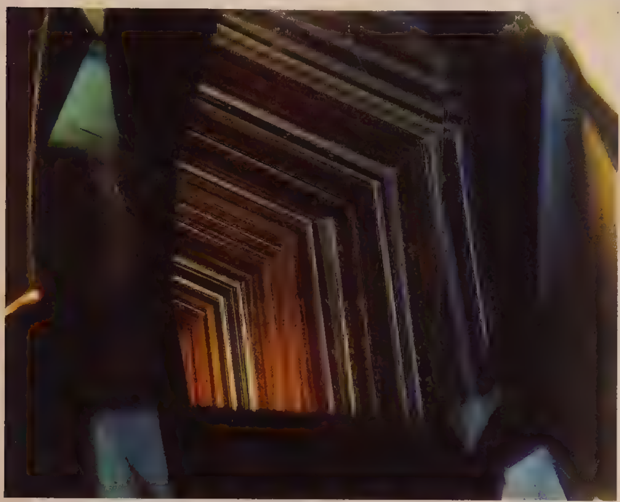

Figure 5.9 Angular growth zoning in a faceted sapphire from Australia. Such zoning may be found parallel to any of the crystal faces. It is never curved if viewed exactly parallel to the crystal face along which it formed. (Photo by the author)

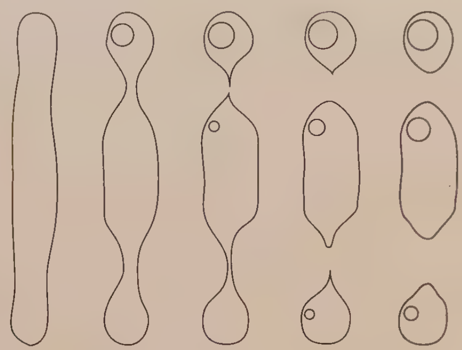

Figure 5.10 The "necking down" of a fluid inclusion with time from its original state (left to right). Each stage occurs at a higher temperature than the one before it. (After Roedder, 1962)

Secondary cavities

These are healed fractures. Any time after the host has grown it may crack. If the conditions are right, growth solutions may enter the crack and dissolve its walls. Dissolved nutrient material is later redeposited on the walls of the crack, causing it to "heal" shut.

Some cracks have healed more than others, but most cracks are in some stage of healing. Healing leaves behind tiny pockets of growth solution which has exhausted its nutrients, and so stopped healing. All that is needed for healing to continue is for the gem to be heated up enough so that the trapped solvent can further dissolve the walls of the cavities. Then the healing continues.

As healing progresses, pockets of trapped solvent become smaller and more regular in shape. Eventually, a healed crack has the appearance of tiny crystals scattered in a "fingerprint" or "feather" pattern. The individual cavities may be filled with a liquid alone, liquid + gas, liquid + solid, or liquid + gas + solid, and may usually be differentiated from primary fluid inclusions by their tiny cavities, curved outlines and fingerprint-like patterns. In contrast, primary negative crystals tend to occur singly, and in larger sizes (Eppler, 1966).

Fractures may develop for a number of reasons, including simple shock, or more likely, from the buildup of strain due to rapid growth or tectonic forces. Immediately, or even millions of years later, the healing process can begin. Should cracks develop as a crystal is growing, the growth solutions penetrate the open wound via capillary action. If the temperature of the surrounding environment is high, healing progresses rapidly; at lower temperatures the pace is slower. The inner walls of the curving fracture are dissolved and solutions redeposit this material, as well as any nutrients carried in by the solution itself, forming flat crystal faces. Slowly, inexorably so, the crack is sealed, leaving behind

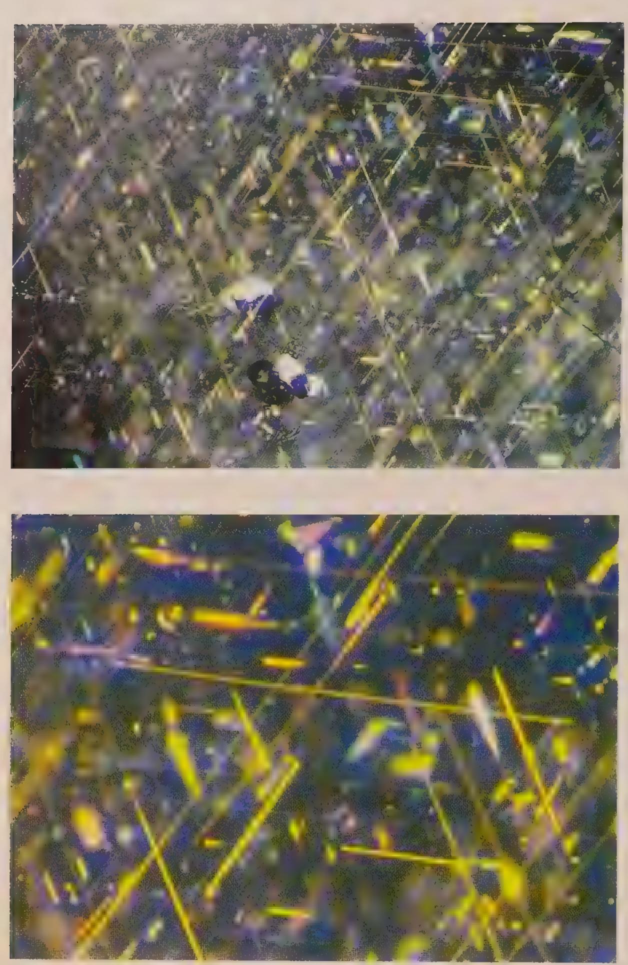

Figure 5.11 Rutile silk
Top: Exsolved rutile "silk" in a Burmese sapphire, viewed parallel to the *c* axis; 45×.
Bottom: A magnified view of the silk above. Note the arrow shapes of the rutile silk. Such perfectly formed silk is proof that a specimen has not been subjected to high-temperature heat treatment.
(Photos by the author, using oblique fiber-optic illumination)

pockets of undigested fluid in fanciful designs termed *fingerprints, feathers, insect wings,* etc.

Should the conditions be favorable, this ongoing process of solution and re-deposition of internal fracture walls eventually results in highly angular pockets of fluid, actually groups of fluid-filled negative crystals arranged in a fingerprint pattern (Roedder, 1962). Experiments performed by Eppler (1966) and others on different minerals, including Verneuil synthetic ruby, have confirmed the above reconstruction of events leading to the formation of healing fissures and negative crystals in gemstones.

In nature, the healing process may take place over millions of years. Thus the resulting cavities are often well developed and display intricate growth features. In corundum, when the fracture was in or near the basal plane, the pockets of undigested fluid often surround hexagonal "islands" of

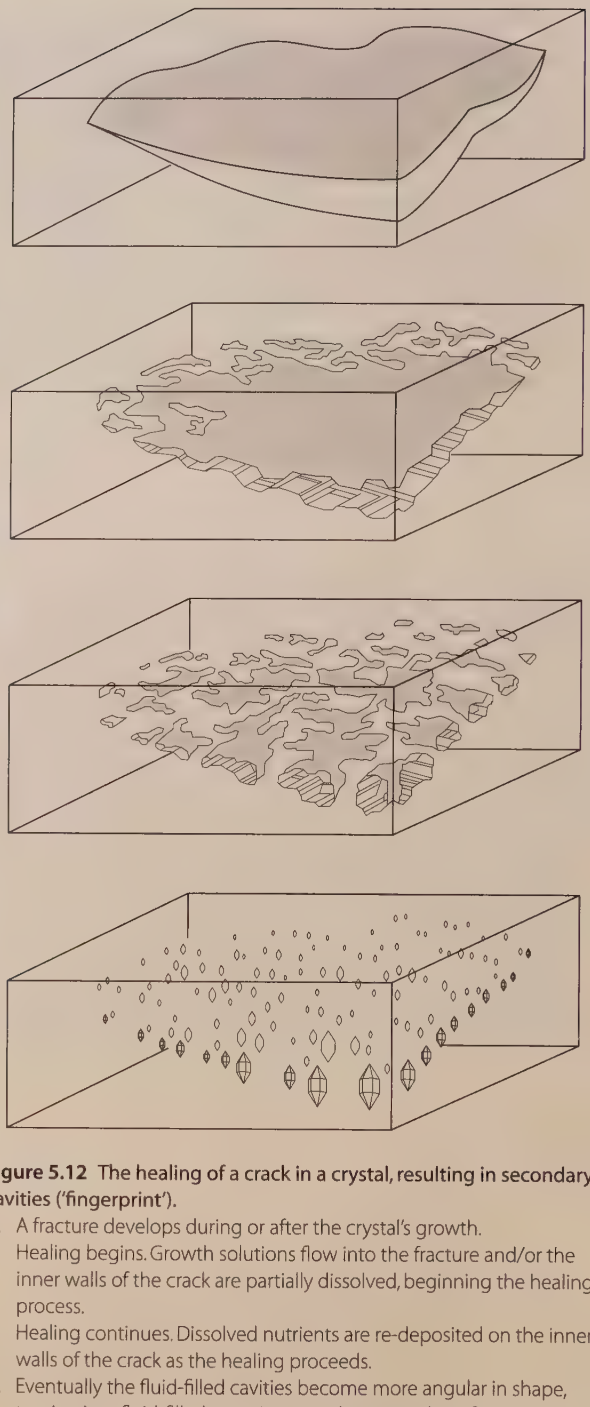

Figure 5.12 The healing of a crack in a crystal, resulting in secondary cavities ('fingerprint').

A. A fracture develops during or after the crystal's growth.
B. Healing begins. Growth solutions flow into the fracture and/or the inner walls of the crack are partially dissolved, beginning the healing process.
C. Healing continues. Dissolved nutrients are re-deposited on the inner walls of the crack as the healing proceeds.
D. Eventually the fluid-filled cavities become more angular in shape, turning into fluid-filled negative crystals arranged in a fingerprint pattern. The fluid that remains behind has been leeched of its nutrients. These pockets containing exhausted growth solutions are smaller along the inner edges and bigger near the outer edges of the original crack. (After Roedder, 1962)

healed material. But if the fracture is along a prism face, such healed islands tend to be rectangular (see Figure 5.13).

Tiny growth steps or "terraces" provide further evidence of the amazing regularity of crystallization processes. In many cases, the residual fluid is so thin that brilliant interference

Figure 5.13 Secondary fluid inclusions (healed fractures, or 'fingerprints') often display the symmetry of the underlying crystal structure in the healed areas. The left photo shows a healed fracture in a Thai ruby which formed parallel to the basal pinacoid. As the *c* axis (3-fold symmetry) runs perpendicular to this face, the healed (dark) areas display distorted hexagonal or triangular (60/120°) outlines. Vertical lines cutting through the fingerprint are repeated twinning striations. In the right illustration, a fingerprint in a Sri Lankan sapphire is shown. Here the fingerprint has formed parallel to the *c* axis, and so the healed (dark) areas show rectangular (90°) outlines, indicating the two-fold symmetry at right angles to the *c* axis.
(Photos by the author using oblique fiber-optic lighting)

colors are seen when illuminated at the proper angle from above (fiber-optic lighting provides an excellent illumination source for such observations). Although flux-grown synthetic corundums may contain flux-filled inclusions formed by a similar healing process, the tremendous detail of nature is missing, because of greater flux viscosity and the far shorter growth times. Thus, the gemologist should carefully study the healing fissures in natural rubies and sapphires under high magnification. They can provide important clues in distinguishing between natural and synthetic corundum.

Secondary growth phenomena

Secondary Twinning—Twinning that has formed after the host. When such twinning occurs repeatedly throughout the crystal, it is termed "polysynthetic twinning."

- **Transformation twins**—At high temperatures, a crystal may be untwinned, but as it cools the resulting strain causes the crystal to be "transformed" into a repeatedly twinned crystal. This is common in the plagioclase feldspars, such as labradorite.
- **Slip or glide twins**—If certain types of crystals are subjected to mechanical stress or pressure at any time after their formation, the bonds between planes of atoms may be broken and the planes "slip" or "glide" across one another into a twinned position, with new bonds immediately formed (if the pressure is too great, however, the crystal just breaks). This type of twinning often occurs repeatedly throughout a crystal, and due to the pressure that produced it, such crystals often contain many cracks (as well as healed cracks). Examples: Rhombohedral twinning in corundum, quartz (amethyst) and calcite.

Within corundum, polysynthetic twinning occurs parallel to the faces of the rhombohedron $\{10\bar{1}1\}$, which intersect each other at angles of 86.1 and 93.9° and meet the *c* axis at 32.4/57.6°. Repeated twinning in corundum is easily observed under the microscope. The planes are only visible when looking exactly along them, and generally pass across the entire stone (although not always). Since polysynthetic twinning takes place on the rhombohedron faces, it is located by looking in directions at about 33/57° to the *c* axis. Most natural corundums are cut with the *c* axis perpendicular to the table facet; in such stones the rhombohedral twinning will be found lying about 33/57° off the table. Immersing a gem in di-iodomethane and examining it between crossed polars allows the twinning to be located most quickly, as it appears as bright planes fringed with interference colors against a dark background. It can be a stunning visual effect (see Figure 5.14).

A final note on inclusion categories

Gems often display inclusions involving combinations of the above categories. For example, so-called "Saturn" inclusions of Thai/Cambodian rubies are actually solid crystals which, when they cooled, created tension resulting in a healed fracture surrounding the crystal. While the host/inclusion age relationship will sometimes be obvious (such as inclusions produced by exsolution, which are always epigenetic), many times it is impossible to determine. So don't worry if you cannot determine a particular inclusion's age relationship to the host.

Identifying solid inclusions

Unfortunately, most publications do not mention exactly how the identity of a solid inclusion was determined. The following are common techniques (based on Hänni, 1987):

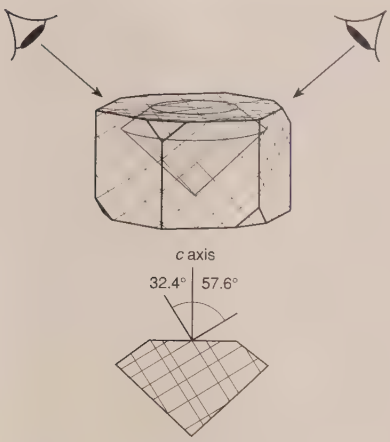

Figure 5.14 Repeated twinning in corundum

Left: Repeated twinning in natural corundum generally occurs parallel to the faces of the rhombohedron $\{10\bar{1}1\}$, which intersect the *c* axis at 32.4/57.6°. As most natural rubies and sapphires are cut with the *c* axis at 90° to the table facet, this means that the twinning will usually be found at about 33/57° to the table. Boehmite needles, which form parallel to edges of the same face (at the junctions of twinning planes), will thus be found in the same directions. They run in three directions (but only two in the same plane) and meet at angles of 86.1/93.9°. Repeated twinning is located most easily between crossed polars with the specimen immersed in di-iodomethane. When seen, such twinning planes often do not penetrate across the entire stone.

Top right: Polysynthetic twinning on the rhombohedron $\{10\bar{1}1\}$ in a Thai/Cambodian ruby, viewed between crossed polars.
(Photo by the author; 30×)

Bottom right: Polysynthetic twinning on the rhombohedron $\{10\bar{1}1\}$ in a Thai/Cambodian ruby, viewed under dark-field illumination.
(Photo by the author)

X-ray powder diffraction method

A small amount of powdered material from a solid inclusion is required. If the inclusion is not exposed at the surface, the specimen is ground to expose it. Using a diamond file or point, the inclusion is scraped to gather material, which is then powdered and used for a powder-diffraction x-ray photo. The resulting diffraction pattern is compared to known samples for identification.

Electron beam methods

When a solid inclusion is exposed at the surface, the scanning electron microscope (SEM) coupled to the electron microprobe (EMP) can be used. A fine beam of electrons is directed onto the inclusion surface. This generates x-rays which are typical in terms of energy or wavelength for each element present. Emitted radiation (fluorescence) can be analyzed using an energy-dispersive system (EDS) attached to the SEM or EMP, with the resulting energy spectrum allowing one to make a qualitative determination of the chemical composition. The SEM has the advantage of being able to strongly magnify the analyzed area and produce pictures of the surface, while the EMP is used primarily for full quantitative chemical analysis. Both techniques are nondestructive, but suffer from an inability to detect the lightest elements.

Raman-laser probe

Solid, liquid or gaseous inclusions can be analyzed with this technique. A monochromatic laser beam is focused on the inclusion, and, via interaction with oscillating molecules, undergoes a frequency change characteristic of the material excited. The resulting spectra, recorded in the infrared region, are compared to reference spectra for known solid, liquid and gaseous phases. Of the methods discussed, the Raman technique is the least-commonly used in gemology.

Optical methods

Inclusions are typically identified by their appearance under the microscope (crystal habit, color, relief, luster, orientation, etc.). This has the advantage of simplicity, but depends entirely on the tester's experience. Only a microscope is needed and inclusions need not be exposed at the surface, but, of all the methods described, it is the least reliable. Unfortunately, for the vast majority of gemologists, it is the only method to which they have access, but by carefully describing the inclusion many problems can be mitigated.

Table 5.1: Inclusions of corundum

Inclusion types	Description
Solids	Solid inclusions (crystals) of various types, usually viewed best in dark-field illumination or via fiber-optic lighting. Crossed polars and immersion may also be useful. The following solids have been identified in corundum: • Allanite (Hänni, 1990a) • Analcime (Gübelin & Koivula, 1986) • Apatite (Gübelin, 1971) • Boehmite (Sahama & Lehtinen *et al.*, 1973) • Brookite (Gübelin & Koivula, 1986) • Calcite (Gübelin, 1953) • Chlorite (Gübelin, 1982a) • Chondrodite (Barthoux, 1933) • Clinozoisite (J.I. Koivula, pers. comm., 1993) • Corundum (Gübelin, 1953) • Diaspore (Smith, 1995) • Diopside (Gübelin, 1971) • Dolomite (Gübelin & Koivula, 1986) • Fassaite (Gübelin, 1973) • Feldspar (alkali, plagioclase) (Gübelin, 1971) • Fergusonite (Gübelin, 1973) • Fluorite (Peretti & Schmetzer *et al.*, 1995) • Garnet (almandine, pyrope, spessartine) (Gübelin, 1953; Du Toit & Charoensrithanakul *et al.*, 1995) • Goethite (Gübelin, 1982a) • Glass (Gübelin & Koivula, 1986) • Graphite (Gübelin, 1973) • Hematite (Gübelin, 1953) • Humite (Barthoux, 1933) • Hornblende (amphibole) (Gübelin, 1973) • Ilmenite (Moon & Phillips, 1984) • Margarite (Gübelin, 1982a) • Mica (biotite, muscovite, phlogopite) (Gübelin, 1953) • Monazite (Gübelin, 1973) • Niobite (columbite) (Gübelin, 1973) • Nordstrandite (Kane & McClure *et al.*, 1991) • Olivine (Gübelin & Koivula, 1986) • Pargasite (amphibole) (Gübelin, 1973) • Pentlandite (Coenraads, 1992a) • Pyrite (Gübelin & Koivula, 1986) • Pyrrhotite (Gübelin, 1971) • Quartz (Themelis, 1992) • Rutile (Gübelin, 1953) • Sapphirine (Koivula & Fryer, 1987) • Scapolite (Kammerling & Scarratt *et al.*, 1994) • Sphalerite (Gübelin & Koivula, 1986) • Sphene (Gübelin, 1973) • Spinel (gahnospinel, hercynite, magnetite, pleonaste) (Gübelin, 1953) • Sulfur (Fritsch & Rossman, 1990) • Thorite (Coenraads, 1992a) • Tourmaline (Gübelin & Koivula, 1986) • Uraninite (Gübelin, 1973) • Uranium pyrochlore (uranopyrochlore) (Gübelin, 1973) • Zircon (Gübelin, 1953) • Zoisite (Themelis, 1992)
Cavities (liquids/gases/solids)	• Primary fluid-filled cavities of various configurations (1-, 2- or 3-phase). CO_2 is a common filling, in both liquid and gaseous forms. • Secondary fluid inclusions in patterns of infinite variety and thickness; often referred to as fingerprints or feathers. CO_2 is a common filling, in both liquid and gaseous forms. Produced by the healing of fractures, their patterns may often be "wispy" or "veil-like," and so are easily confused with flux inclusions in synthetic corundums. Their surfaces should be examined under high magnification with fiber-optic lighting to determine if fluid (natural) or flux (synthetic) fills the small channels. As natural stones healed over a much longer period of time, their healing patterns are often far more detailed. The higher viscosity of a flux also contributes to coarser and less detailed healing in flux-grown synthetics.
Growth zoning	• Straight angular growth lines following various crystal faces, often in a hexagonal pattern and often featuring associated minute exsolved needles or particles following these growth lines. The lines vary in thickness and spacing, are never curved if examined parallel to the face along which they grew, and always lie inside the stone. They are associated with crystal faces, not with cut facets. Sharp lines are seen well with dark-field illumination, or better, immersion with light-field shadowing. Broad bands or hazy clouds are best seen with immersion and diffused light-field illumination.
Twin development	True twinning planes will show interference fringes and appear light against a dark background when the gem is examined between crossed polars. • Polysynthetic twinning along the rhombohedron (in 3 directions, but only 2 in any one plane) meeting at 86.1 & 93.9°. These planes meet the *c* axis at angles of 32.4/57.6°. • Growth twins may also be seen along other faces. Immersion between crossed polars will separate true twinning from sharp color zoning.
Exsolved solids	• Exsolved rutile needles and hematite-ilmenite plates form parallel to the hexagonal prism (3 directions, intersecting at 60/120° in the basal plane). Rutile often forms knife-shaped twins with tiny re-entrants at the broad end. Sizes vary greatly, some being much longer than others, some appearing as mere dots, some broad, some narrow. Overhead fiber-optic illumination is often best, looking down the *c* axis. Exsolved particles are often best seen with the fiber-optic light guide from below or to the side of the stone. Under fiber-optic illumination, rutile silk is often iridescent. • Long white exsolved boehmite needles which form at the junctions of intersecting rhombohedral twinning planes. Thus their directions and angles are the same as that described for Rhombohedral twinning above. The *combination* of rhombohedral twinning with boehmite needles has yet to be seen in flux-grown synthetic corundums and so is extremely important for identification.
Other features	• Rhombohedral parting (due to exsolved boehmite) and basal parting (due to exsolved hematite).

Describing inclusions

In the past, gemologists have done a poor job of describing what they see. Far too often, inclusions have been described only in fanciful terms that do little to tell us what they really are. Words such as "fingerprint," "Saturn" and "silk" may convey the general appearance, but do not identify the exact nature of the inclusion. As John Koivula once said: "The planet Saturn does not occur as an inclusion in gemstones."

Describing inclusions solely in terms of metaphors is a poor way of conveying a gem's internal features. It is better to describe inclusions according to the following:

- **Type:** secondary cavity (2-phase); solid (condition: corroded, euhedral, etc.); exsolved solid, etc.
- **Position relative to the host structure:** parallel to the rhombohedron; random; etc.
- **Appearance:** fingerprint; silk; etc.
- **Other useful information:** lighting conditions used, etc.

Table 5.2: Describing inclusions: Complete and incomplete examples

Incomplete Description	Complete Description
"Silk"	Exsolved knife-shaped needles (probably rutile), 3 directions at ~60/120° in the basal plane, aligned in zoned clouds. Seen best with reflected light along the *c* axis.
"Fingerprint"	Secondary fluid inclusion of random orientation in a "fingerprint" pattern.
"Saturn"	Crystal surrounded by secondary fluid inclusion of random orientation.
"Plato lines"	Polysynthetic twinning on the hexagonal prism ('Plato' type) in three directions at ~60/120°. Viewed parallel to the *c* axis while immersed in di-iodomethane (methylene iodide) between crossed polars.

Overview of corundum inclusions

Table 5.1 a summary of the possible inclusions in corundum. For details and references on the individual occurrences of these inclusions, see the country listings in Chapter 12.

Country descriptions of inclusions

In Chapter 12, the inclusions of corundums are described for each major source, alphabetically by country. It must be stressed that it is often impossible to determine the age of a given inclusion with respect to the host. For this reason, only the type, position and appearance have been described.

The author has not personally collected and tested samples from each and every mine (the only sure way of determining origin). Thus, the descriptions are based on the best-available data, first and secondhand, at the time of writing. The descriptions are *in no way* sufficient for determining the origin of corundums, and even if they were, origin reports in their current form are not something I feel gemologists should be doing. Suffice to say that, similar to humans, all of the corundums to which I have spoken claim planet earth as their home. It may be of academic and historical interest to know where someone comes from, and so it is for gems. But an origin determination of an individual gem *without reference to its quality* is as senseless as applying ethnic generalizations to individual humans.[3]

An additional fly in the origin ointment is that heat treatment often obscures origin information. This may be a blessing in disguise, for it could push the trade into concentrating their efforts on separating natural from treated and synthetic stones, rather than worrying about geographic origin. In this area, the colored stone trade has much to learn from the diamond business. After all, how many customers ask for, say, a Botswana diamond?

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[3]. Because a variety of qualities are found at every source, origin reports divorced from a quality appraisal are meaningless, and open the door to abuse by unscrupulous sellers.

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CHAPTER 6

TREATMENTS

There is hardly anything in the world that some man cannot make a little worse and sell a little cheaper.

John Ruskin [1819–1900]

PRECIOUS stones differ greatly from metals and industrial minerals. Unlike rough gems, which are useless unless of high clarity and cuttable sizes, industrial minerals can be processed to extract the desired product. With industrial minerals, via crushing and smelting, it is possible to separate usable material from the waste. But one of the intrinsic characteristics of gems is their rarity. Their value is derived from the unlikely prospect that such pure specimens exist at all. Thus, out of a mine's entire yield, only a tiny fraction is of sufficient size and quality to warrant cutting. Insufficient size and defects in clarity and color preclude use of the remainder.

Because of the scarcity of gem-quality materials, attempts have been made throughout history to improve inferior samples. Heating or irradiation to improve the color and oiling to hide fractures are but the tip of the treatment iceberg. They constitute a potpourri of recipes aimed at increasing the salability of inferior qualities. By developing treatments, traders have, in part, solved the dilemma in regard to the inability to process lower grades. Thus, treatments allow a larger percentage of the total production to be utilized as gemstones. Some term this "finishing what nature started." If only life were so simple…

In essence, natural gems are valued because *the purest are most rare.* Please read that again: *The purest are most rare.* Since treatments radically distort the relationship between purity and rarity, if natural gems are to remain as viable products, it is crucial that the presence or absence of treatments be clearly disclosed.

Today, when buyers are informed at all, they are given a sugar-coated version of the truth. This creates an unfortunate situation, where color- and/or clarity-enhanced stones compete directly against the natural product. Although many treatments have been practiced for centuries, today's technology produces far more dramatic changes than those of the past. The question then arises of where to draw the line between acceptable treatment and simply producing a fully-synthetic gem. This issue, of whether or not treated gems should be sold as natural, is an item of hot debate in trade circles and will be taken up at the end of this chapter.

History of ruby and sapphire treatments

The history of gem treatments is as old as the gem trade itself. Like much gemological, one of the earliest references to gem treatments is found in Pliny's *History of the World.* The following is a selection:

> …Moreover, I have in my library certain books by authors now living, whom I would under no circumstances name, wherein there are descriptions as to how to give the color of *smaragdus* [emerald] to *crystallus* [rock crystal] and how to imitate other transparent gems: for example, how to make a *sardonychus* [sardonyx] from a *sarda* [carnelian, in part sard]: in a word to transform one stone into another. To tell the truth, there is no fraud or deceit in the world which yields greater gain and profit than that of counterfeiting gems.
>
> Pliny [23–79 AD], from Ball, 1950, p. 195

Another early work mentioning gem treatments is that of an anonymous Egyptian whose writings have survived in the form of two papyri believed to date from the third or fourth

Figure 6.1 The centuries-old technique of blow-pipe heat treatment of ruby in Sri Lanka. While still practiced, it has largely been superseded by more sophisticated methods. (Photo: © Fred Ward)

centuries AD (Nassau, 1984b). The second, known as the Stockholm Papyrus or *Papyrus Graecus Holmiensis,* details methods of counterfeiting and treating gems. Below is but a small sample:

> **19. Production of Ruby**
> The treating of crystal [rock crystal] so that it appears like ruby. Take smoky crystal and make the ordinary stone from it: Take and heat it gradually in the dark; and indeed until it appears to you to have the heat within it. Heat it once more in gold-founder's waste. Take and dip the stone in cedar oil mixed with natural sulphur and leave it in the dye, for the purpose of absorption, until morning.
> **53. Corroding and Opening Up of Stones**
> Grind alum and melt it carefully in vinegar. Put the stones therein, boil it up, and leave them there over night. Rinse them off, however, on the following day and color them as you wish by use of the recipes for coloring.
> E.R. Caley, 1927, *The Stockholm Papyrus*

Heat treatment of corundums has been mentioned in a number of early works. Bhojarajah, whose writings are believed to be based on earlier texts, in the 11th century AD mentions the heating of sapphire. "No one should heat gem stones for testing purposes, or for enhancing their qualities, because if the right temperature is not known a gem becomes polluted through the ill effects of heating and the owner, the examiner and the person who sent the gem for testing all become losers" (Brown, 1956). From this statement it can be surmised that a knowledge of gem enhancement via heat was known.

Arabs also mention the heat treatment of corundums. Teifaschi,[1] in his treatise on gems from about 1240 AD, said:

> In Sarandib [Sri Lanka] and its environs, ruby is treated by fire. People take pebbles from the earth and crush and compress them into a mass with the aid of water. [This mixture] is daubed completely around a dry stone. Then, the whole thing is placed on a rock with other rocks set down around it. Dry firewood is thrown on top, lit and blown upon [with bellows]. The blowing is applied, along with more wood, till any black overtones on the ruby have disappeared.
> The amount of fire and the application of wood depends on the extent of the blackness present. People know this by experience. They heat-treat stones for at least one hour and, at most, twenty days and nights. Then, they carefully extract the ruby, its blackness having disappeared.
> The ruby is not heat treated a second time. After one treatment, its color can neither improve nor diminish.
> Teifaschi, ca. 1240 AD (Clément-Mullet, 1868; Sersen, 1991)

Duarte Barbosa also discussed the heat treatment of Sri Lankan rubies, ca. 1500–1517:

> The King of that island keeps them for his own profit, and when the goldsmiths come upon any which is good they place it in fire for a certain number of hours, and if it comes forth whole its colour becomes very bright and of great value.
> M.L. Dames, 1921, *The Book of Duarte Barbosa,* Vol. 2

In the sixth book of his *Natural Magick,* John Baptist Porta [ca. 1535–1615] of Naples, discusses various methods of counterfeiting and adulterating precious stones. Most interesting is the following description of heat treatment:

> **How to make a stone white on one side, and red or blew on the other.**
> I have seen precious stones thus made, and in great esteem with great persons, being of two colours; on one side a Saphire, and on the other a Diamond, and so of divers colours. Which may be done after this manner: For example, we would have a Saphire should be white on one side, and blew on the other; or should be white on one side, and red on the other: thus it may be done. Plaister up that side which you would have red or blew, with chalk, and let it be dryed; then commit it to the fire, those ways we spoke of before, and the naked side will lose the colour and turn white, that it will seem a miracle of Nature, to those that know not by how slight an art it may be done.
> John Baptist Porta, 1558, *Natural Magick*

Compare the previous two accounts to that from nineteenth century Sri Lanka below, which describes the heat treatment of ruby (also quoted by Tennent, 1859):

> ...the tinge of blue which is frequently found in the stone (giving it the name of *neelakantia*) is easily removed by burning. The process is simple and is as follows:—The stone is enclosed in a thick coating of *chunam* [lime] (that which is used by the natives with their betel-leaves) and then exposed to a strong heat. The operation is repeated until the whole of the blue tinge is removed. But care should be taken to subject only such stones as are perfectly free from cracks to this, for one with cracks, if subjected to heat, is said to crumble down in pieces.[2]
> J.F. Stewart, 1855 (from A.M. & J. Ferguson, 1888)

1. See page 34.

2. *Neelakantia* is a Sri Lankan term for a ruby with a trace of blue in its color. The reference to rubies sometimes cracking from heat treatment may refer to the explosion of CO_2 inclusions, which are common in Sri Lankan corundums.

Figure 6.2 Geuda sapphires
Left: A geuda sapphire crystal from Sri Lanka prior to heat treatment. Note the yellowish "diesel" effect, which tells buyers that the stone will likely turn blue upon heating. (Photo: AIGS, Bangkok)
Right: Geuda sapphire cabochons before (left) and after (right) heat treatment. (Photo: Ted Themelis)

The above are but a few of the historical mentions of corundum treatments. Far from a recent discovery, ruby and sapphire heat treatment has been practiced for centuries, possibly dating back to Roman times. But today's dramatic face-lifts are a far cry from yesterday's subtle changes. It was the discovery that Sri Lanka's *geuda* sapphires could be revitalized via heat that opened the floodgates. The result is that virtually all rubies and sapphires traded today have, at some point, been heat treated. Indeed, certain pieces which would have been worthless a mere two decades ago, can today be transformed into gems worth tens of thousands of dollars.

Modern heat treatment—Enter the *geuda*

> From the adulteration of Metals, we shall pass to the counterfeiting of Jewels. They are by the same reason, both Arts are of kin, and done by the fire. And it is no fraud, saith Pliny, to get gain to live by: and the desire of money hath so kindled the firebrand of luxury, that the most cunning artists are sometimes cheated.
>
> John Baptist Porta, 1558, *Natural Magick*

Heat treatment techniques vary from the modern, using expensive electric ovens, to the primitive, with little more than fire, crucible, and blowpipe. Among the more unusual methods was that described by a Sri Lankan gem dealer. He claimed that most sapphires and rubies are best treated in a fire or oven, but for a small minority, more gentle heating was needed. Eager to learn more about this highly secret art, he was pressed for details. After making sure that no one else was listening, he leaned forward and in a dead-serious voice whispered: "These we feed to our chickens." (Robert Weiser, pers. comm., 1981)

This is not quite so ridiculous as it first sounds. For over two-thousand years humans have been treating pearls by feeding them to chickens, the acidic conditions and grinding action of the crop producing improvements in both whiteness and luster. However, as far as corundum is concerned, it is of no use whatsoever, for the temperatures attained inside a chicken's gullet are far too low.

The modern era of corundum heat treatment began in the mid- to late-1970s, with entrance into the Bangkok market of large quantities of burned *geuda* blue sapphires from Sri Lanka. *Geuda,* a Singhalese word, is used to describe a certain grade of low-quality sapphire which is found mainly in Sri Lanka. Typically pale blue, yellow or pink in color, geuda stones are unsuitable for gems as is, due to an abundance of exsolved titanium in the form of rutile silk clouds.

Before the secret of the geuda was unlocked, their usefulness was limited to employment as abrasives, ornamental stones for rock gardens, and as good luck charms to be buried under the foundation posts in village homes. However, today's ugly duckling is tomorrow's swan, or more properly, yesterday's geuda is today's cornflower blue sapphire. At some point, someone somewhere discovered that the wretched little geuda sapphire, pariah of precious stones, could, with the proper application of heat, be changed into a true beauty. Once fit only for fish tanks, it now festoons the fingers of the upper crust around the world. Why it is even possible that the Sri Lankan sapphire presented to Lady Diana by Prince Charles on the occasion of their engagement first entered this world as a humble geuda. The geuda sapphire is truly the Cinderella of sapphires.

With planeloads of Thais arriving in Colombo to buy geuda, it was only a matter of time before miners in Sri Lanka wised up. First they attempted to heat the stones themselves, but with little success, and so opted for the next best thing—hiking prices of geuda rough to levels only slightly less than that of naturally-blue stones. With detection methods lagging far behind treatment technology, the gem market then committed a crucial error; treated stones were accepted and sold as completely natural, with no distinction made between treated and naturally-colored gems.

A brief history of heat

WHO was first to discover the potential of the *geuda* and when did it happen? No one knows for certain when, but it was not until the 19th century that ovens capable of reaching the necessary temperatures (>1500°C) became available. In answering the question of who, the most convincing account is that related to the author by an old-school Paris dealer (who wishes to remain anonymous).

According to this source, modern heat treatment was developed by Professor and Madame Bron of Company Grasset and Bron, rue Chantepoulet, Geneva. Although not confirmed, it is suspected that the Brons were involved in production of Geneva ruby, a forerunner of Verneuil synthetic corundum. Apparently one result of their experiments with the fusion of natural ruby fragments was the secret of high-temperature corundum treatment.

The first stones heated allegedly originated from the Pailin mines in Cambodia. Treated sapphire rough was given for cutting to lapidaries in the Jura Mountains of Europe at least by 1920 (and possibly as early as 1915). Because the rough was being obtained from the Thai-Cambodian border area, the Brons had contact with people there. At one point, a Thai was hired to help with the work and the secret then spread. Prof. Bron eventually died, but Madame Bron continued her husband's work well into the 1950s. Not without a good deal of guilt, too, for, according to my source, she realized that the family business had committed fraud on a grand scale.

Coldham (1992) gives a slightly different version of the tale. According to him, two Cambodian students came to stay at the Swiss gentleman's house, a then-common practice among wealthy French-speaking Cambodians. During their stay, they learned of the process and upon their return to Cambodia, passed the secret on to dealers in the sapphire fields.

Coldham also mentions a London dealer who bought quantities of both silky and non-silky Australian sapphire in the late 1960s. Cut stones were then sold back to Australia by the same London dealer.

Due to his experience as a cutter, Coldham realized that the volume of clean rough going to London could not account for the quantities of cut stones coming back to Australia. He later learned that the London dealer and the Swiss gentleman had close business associations.

An interesting sideline to the above is given in an article from 1916, which reported:

> It is noteworthy that there has been a strong demand for dark violet-blue stones. These stones are so dark that they appear quite opaque in dull weather, and can only be identified on a cloudless day. In the larger sizes (up to 3 oz. in weight), stones of this colour sell for as much as £5 per oz., although they yield a black stone when cut locally, and it is suspected that the Germans have some method whereby they can modify the colour. It may be suggested that this is probably done by the simple method of heating the stone. Many minerals, such as, for instance, smoky zircon, have their colour modified and their transparency greatly increased after having been heated to redness; and a specimen of Anakie sapphire examined at the Imperial institute showed a greatly increased transparency as a result of this treatment.
>
> Anonymous, 1916
> Sapphire-mining industry of Anakie, Queensland

In 1966, Robert Crowningshield described a blue sapphire reportedly from Thailand that displayed a very weak spectrum and a greenish white SW UV fluorescence. Later, he reported on a fine natural blue sapphire of 18 cts that displayed a zoned greenish white fluorescence under SW UV (Crowningshield, 1966, 1970). While Crowningshield mentioned nothing of heat treatment, today we know that such reactions are common in heat-treated sapphires, particularly those from Sri Lanka. It is highly likely that these were early examples of heated sapphires (Beesley, 1982a).

From this point on, the facts are known. In the 1970s, someone in Thailand began applying the process to low-grade Sri Lankan material on a large scale. By the latter part of that decade, large numbers of heat-treated Sri Lankan sapphires were streaming out of Thai ovens. In the early days of what amounted to the *Great Geuda Rush*, rough could be had for a song and fortunes were amassed overnight. The rest, as they say, is history…

Why this occurred is complicated. In the diamond market there has never been any such question. Naturally colored diamonds, by virtue of their rarity, are worth far more than those colored artificially. However, today the colored gem market faces exactly the opposite situation—treated stones, by virtue of their generally finer color and clarity (on the average), fetch more than the humble natural colors with their obvious defects, because of some crazy notion that heat treatments are somehow "natural." This is despite the fact that the *Random House Dictionary* (1978) defines "natural" as *"formed by nature without human intervention."* Cooking stones in an oven hardly qualifies. Today, the ridiculous is reality in the ruby and sapphire market.

Following the great success achieved in heating Sri Lankan sapphires, Thai burners quickly began pursuing rubies and sapphires from other sources. Many of these, such as Australian blue sapphires and Thai/Cambodian rubies, had a long history of high-temperature treatment, predating that of stones from Sri Lanka, but for others like the Burmese ruby, little had been done. Today, gems from every locality are heat treated to improve the color or clarity, not only in Thailand, but around the world. Few sources show the dramatic changes of the Sri Lankan material, but this is definitely not for lack of effort on the part of burners. Today, the heat-treated ruby or sapphire is the rule rather than the exception.

Geuda rough

All geuda rough is not created equal, with some more valuable than others. The key feature displayed by geudas, as opposed to ordinary rough, is an oily golden appearance inside the stone. It is termed *diesel* because of its resemblance to diesel oil, and is considered an indication that the stone will burn to a blue color. *Young milky* is the term used to describe the well-formed pale blue crystals with a cloudy appearance and a peculiar waxy luster. In transmitted light they display a strong diesel effect and are highly sought after.

The following are some categories of geuda rough, based on direct translations of Singhalese terms used by miners (Wijesuriya, 1985):

- **Blue geuda**: Semi-transparent to sub-translucent material which has a characteristic powder-blue color and slight- to moderate-diesel effect in transmitted light.
- **Diesel geuda**: Semi-transparent to sub-translucent material which has a characteristic tea-color to the diesel effect which is prominent in transmitted light.
- **Milky geuda**: Semi-transparent to sub-translucent material with a characteristic milky appearance. It displays a slight- to moderate-diesel effect in transmitted light.
- **Silky geuda**: Translucent to sub-translucent material with a characteristic silky appearance, due to bands of whitish impurity concentrations that follow the crystal morphology.
- **Waxy geuda**: Translucent to sub-translucent whitish material (often seen as crystal fragments) having a characteristic waxy appearance with a slight diesel effect when observed in transmitted light.

Another category of rough is *ottu*, a Tamil term meaning *to risk* or *take a chance.* This alludes to the hazardous nature of cutting ottu stones, for they possess blue only at the tips, or faces of the crystal, the core being largely devoid of color.[3] Cutting of ottu rough is difficult, as the lapidary must attempt to position the colored portions such that they lie at, and extend across, both sides of the culet. Correctly oriented, the entire stone will face up blue, but if the color lies on one side alone, a large colorless hole or window will result. Some ottu stones are oriented with a single narrow band of color extending across the table or crown. Both types, with the color at the crown or culet, may be mistaken for doublets, as the crown appears colored while the pavilion is colorless when seen from the side. Other terms used to describe geuda rough include *blue geuda, silky geuda,* and *waxy geuda.*

Beginning in 1981, Thai burners made another major discovery with regard to the heat treatment of Sri Lankan sapphires. They found that many sapphires which did not take well to blue burning, could, by varying treatment conditions, be burned to a yellow or orange color. This started another boom and soon deep yellow to orange sapphires began pouring from the ovens of Bangkok and Chanthaburi. Such sapphires displayed an intensity of color which was rare, or even completely unknown, in untreated stones from Sri Lanka. With suitable rough being relatively abundant, the yellow sapphire was then promoted from the realm of a mere collector's stone to that of an important market force.

It should be mentioned that heat treatment of corundum is by no means a sure thing. Included among the many calamities that may befall a "burn" are the melting of stones and/or explosion or cracking of certain pieces. Some lose whatever color they once had, while others may develop unsightly white clouds. If the rough is cheap, this causes little concern. But if one must pay large sums just to obtain the rough, these events can literally put a person out of business and possibly even into the funny farm.

3. Blue sapphire rough from Colombia and Kashmir may also display this *ottu*-type color distribution.

Table 6.1: Factors affecting corundum heat treatment

Factor	Description
Time	• The length of time that the stones are heated at the maximum temperature (soak or dwell). • The rate of temperature ascent and descent (ramp up/down).
Temperature	• The maximum temperature reached.
Atmosphere	• The chemical nature (oxidizing or reducing) of the atmosphere in which the heating is performed, and its pressure.
Chemical nature of the stones	• The chemical elements (major elements and impurities), and their states, present in the stones themselves.
Chemical nature of the surrounding material	• The nature of the material in contact with, or in close proximity, to the stones.

As of the mid-1990s, geuda rough still brings high prices in Sri Lanka, but the stocks built up over centuries of mining are gone. As a result, the Sri Lankan gem market has, to a certain extent, returned to its pre-1975 condition, with good rough being scarce. Certain pieces which Thai buyers are confident will burn well can sell for as much as $50,000 or more. Some burners in Sri Lanka have had success, but the business remains largely in the hands of Thais, who have proven most adept at coaxing color from the geuda.

Heat treatment processes

To understand the effects of heat treatment, it helps to know something of the causes of color in ruby and sapphire. These are described in detail in Chapter 4 (see Table 4.1 on page 73). Pure corundum contains only Al_2O_3, and transmits light from approximately 160 nm in the far ultraviolet to 5500 nm in the infrared. As a result, pure corundum is colorless. Different colors result from impurity atoms (i.e., Cr^{3+} in ruby), or point defects (color centers). Such point defects may consist of missing Al or O atoms (lattice vacancies), extra Al or O atoms (interstitial atoms), or charge carriers such as extra electrons (Emmett & Douthit, 1993).

Theoretically, heat treatment is a simple matter of creating one or more of the above conditions throughout the gem. In practice, it involves a bewildering array of combinations and complex changes, influenced by the following:

Time vs. temperature. According to Emmett & Douthit (1993), at 1700°C, changes in valence of color-producing impurities and rutile dissolution require less than one hour for a 15-ct stone. Corundum's high resistance to thermal

Figure 6.3 Once-primitive furnaces have largely been replaced by high-tech electric ovens
Left: Primitive charcoal oven at Chanthaburi town, used for heating Thai/Cambodian ruby. (Photo by the author)
Right: A sophisticated electric furnace, which allows precise temperature and atmosphere control. (Photo: Ted Themelis)

shock permits heating to 1700°C within one hour and cooling at various rates, without danger of cracking. However many furnace components would be damaged by repeated heating/cooling cycles at such a rapid rate. Thus temperature-time profiles for heat-treatment processes are generally determined more by the desire to preserve oven components (such as muffle tubes[4] and heating elements) than by any question of treatment effectiveness (this does not apply to surface-diffusion treatments, which require extended heating over periods of days or weeks).

In the case of clarity enhancement, treatment times are also influenced by the average inclusion diameter. Small inclusions will be diffused into the surrounding corundum more rapidly than larger ones. Hence gems with coarse silk require longer heating times (John Emmett, pers. comm., 12 July, 1994).

Atmosphere. Of the factors which are subject to human alteration, most important is that of furnace atmosphere. When any oxygen-containing material is heated in an enclosed space to high temperature, a little oxygen gas is either emitted or absorbed. Eventually the surrounding atmosphere stabilizes at a certain oxygen concentration ('equilibrium partial oxygen vapor pressure' or p_o). An *oxidizing* atmosphere can be obtained by adding more free oxygen than that given off by the material at a given stabilized temperature, causing extra oxygen to enter the crystal. If the surrounding atmosphere contains less oxygen than that given off by the material, it is termed *reducing* and there is a net loss of oxygen from the crystal (Themelis, 1992).

The strongest oxidizing conditions are obtained by introducing pure oxygen into the chamber. Reducing conditions are generally obtained by inserting a gas which reacts with free oxygen, and in doing so, removes it from the reaction. Hydrogen is one example, which forms water, as follows:

$$2H_2 + O_2 \rightarrow 2H_2O$$

However, pure hydrogen is dangerous to work with. A safer alternative is 'forming gas,' a mixture of hydrogen (up to 8%) and nitrogen. Charcoal and other carbon-containing substances also allow a reducing atmosphere, resulting in carbon monoxide, as follows:

$$2C + O_2 \rightarrow 2CO$$

The above are but two examples of reactions which may produce the desired atmosphere. For more details, see Emmett & Douthit (1994) or Nassau (1984b).

In some heat-treatment applications, hydrogen is almost a requirement. For example, Ted Themelis (pers. comm., 1994) has reported that a given reaction, which might take six hours with carbon, can be accomplished in approximately thirty minutes using hydrogen-based gas mixtures at the same stabilized temperature and with comparable-sized stones.[5]

[4] To prevent cracking, temperatures for alumina furnace muffles must rise and fall slowly from room temperature to 1000°C. Especially crucial is the region between approximately 450–900°C (Ted Themelis, pers. comm., 1994).

[5] Themelis has also reported that, with Sri Lankan geuda rough, hydrogen-based reduction results in a slightly steely blue, while carbon-based reduction gives a slightly warmer, richer blue (pers. comm., 1994).

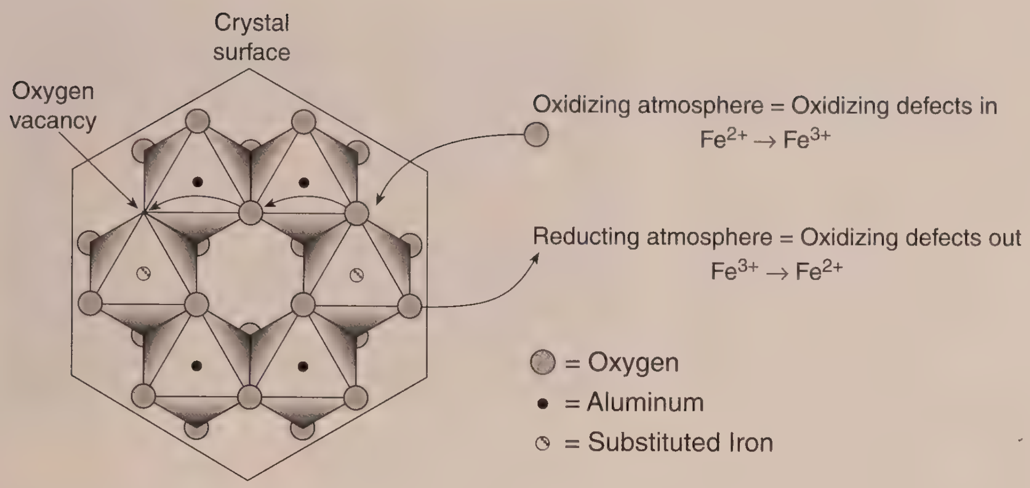

Figure 6.4 The diffusion mechanism

One method by which heat treatment produces changes in color is via *diffusion*. For diffusion to occur, lattice defects are required; the best way of creating such defects is via heating, as defect percentages increase with temperature.

Lattice defects allow the movement, or *diffusion*, of impurity atoms through the gem. Diffusion of oxidizing defects into corundum can change Fe^{2+} to Fe^{3+}, while diffusion of oxidizing defects out of the gem changes Fe^{3+} to Fe^{2+}. This can affect color. Coloring agents themselves (such as Fe, Ti and Cr) may also be introduced into the stone (a process known as *surface* or *bulk diffusion*), but penetration is limited to the gem's surface regions because diffusion rates for such elements are quite slow.

Diffusion rates vary according to the elements involved and their valence. Quadrivalent titanium (Ti^{4+}) diffuses into corundum some 10,000 times faster than either Fe^{3+} or Cr^{3+} because replacement of Al^{3+} by a quadrivalent impurity stimulates formation of defects (John Emmett, pers. comm., 27 June, 1994).

The above illustration shows a view of the corundum atomic structure looking perpendicular to the *a* axes (parallel to *c*). Oxygen does not really move throughout a gem. Instead, through a chain reaction, the movement of point defects (vacancies) allows free oxygen from the atmosphere to produce changes even deep within a gem. Changing the furnace atmosphere produces a net gain or loss of oxygen, which can affect the valence state of iron, thus influencing color.

At high temperatures, changing the p_o (partial oxygen pressure) can change the color by changing the valence state of impurities and/or types and concentration of color centers. Oxidizing atmospheres generally change Fe^{2+} to Fe^{3+}, while reducing conditions move in the opposite direction (Fe^{3+} to Fe^{2+}). Reference to the table on causes of color in corundum shows that these differences in valence are critical for determining color in certain varieties.

Strongly oxidizing conditions result in decreased oxygen vacancies and increased oxygen interstitial defects. At the same time, aluminum interstitials decrease and vacancies increase. Some of these defects are highly mobile and can move entirely through the gem in a chain reaction. This can result in changes throughout the gem, as shown in Figure 6.4.

Hydrogen partial pressure in a furnace is also important, because among the chemically reactive gases, only hydrogen atoms are small enough to diffuse rapidly into a corundum. In fact, some reactions in corundum will not occur at all without hydrogen, regardless of how low the p_o is.

Chemical nature of the stones. Obviously the chemical nature of the stones themselves has a dramatic effect on the success of any treatment. Too little of the necessary element(s) results in little or poor color. Proper heat treatment may be able to liberate coloring agents already within the gem (such as dissolving the Ti from rutile silk), but if the proper elements are not there, one is out of luck (except by surface-diffusion treatment).

Too much of a particular element is sometimes as bad as not enough. For example, attempts to use a reducing atmosphere for Fe-rich sapphires may result in unmixing of iron in the form of iron spinel (hercynite, $Fe^{2+}Al_2O_4$), or metallic iron precipitates. The result is an undesirable cloudy gray stone (Emmett & Douthit, 1993). Excessive reduction may also cause corundum to turn dark brown to black as a result of excessive reduction of the impurities dissolved in the sapphire (John Emmett, pers. comm., 27 June, 1994; Gerald Rogers, pers. comm., 1984).

Chemical nature of the surrounding material. When large lots are heated, gems other than corundum may be mixed in by accident. This can wreak havoc on a burn if those gems melt or liberate elements harmful to the desired reactions. Ideally, the gems should all be corundum of the same type from the same mine. Garnet mixed into a lot by accident is said to be especially dangerous. Other dangerous substances are mica and calcite.

It is also desirable to clean the gems with acid[6] to remove impurities. For high temperature treatments (>1600 °C), it is also advisable to pack the gems in an inert substance of high melting point (such as alpha alumina, α-Al_2O_3), which will provide both insulation and prevent the gems from melting together at their surfaces. Such melting may cause fracturing when the stones are broken apart after the burn, but can be eliminated by proper sorting and cleaning before the burn (Themelis, pers. comm., 1994).

Summary. In summary, the major variables in heat treatment that are subject to human alteration are the oxygen and hydrogen partial pressures and the temperature/time relationship. For more information on the above, see Nassau (1984b), Themelis (1992) and Emmett & Douthit (1993).

There exist several major heat treatment processes which can be performed on rubies and sapphires, based on one or more of the following changes (modified from Emmett & Douthit, 1993):

- Change in the valence state of an impurity, thus changing absorption in the visible region.
- Induce individual impurities to form pairs that absorb differently from unpaired impurities.
- Bring new impurities into solution (where they can affect color) by dissolving pre-existing exsolved impurities.
- Exsolve impurities out of solution, thus changing the combination/proportion of colorants.
- Diffuse entirely new or additional impurities into the gem from outside (via surface diffusion).

The major types of heat treatment are given in Table 6.2 (modified from Nassau, 1981).

A note of caution on treatments

Before attempting any of the processes described, readers should beware. Not only is there risk of damaging the gems themselves, but, because of the high temperatures and sometimes volatile nature of the substances involved, a real physical danger exists to those performing such treatments.

Although the author has attempted to secure accurate information, it is largely secondhand and strictly of a speculative nature. Burners each have their own methods, most of whom take great pains to maintain secret. No guarantee of any kind can be made regarding the reliability of these descriptions given and anyone attempting to follow them in treating gems does so at their own risk. Beware!

Just how dangerous burning can sometimes be is illustrated by the following experience of a Bangkok dealer. About 1981, a fine untreated Sri Lankan blue sapphire of large size was purchased. This was at a time when sapphire prices were at record levels and so the amount paid for the stone was in excess of $50,000. It was an outstanding piece, to be sure, but with one slight defect: just beneath the table facet was a small cloud of silk. Not really distracting, but noticeable nonetheless. The solution? A quick trip to the ovens of his number-one burner. No problem, right? Wrong. Big problem. Color no more. Gone. Vanished without trace into the same black hole that swallowed up Atlantis. One can only imagine that the ensuing conversation between dealer and burner was a goldmine for the student of Thai idiom.

Figure 6.5 African ruby, before (left) and after (right) heat treatment. Heat treatment can often produce dramatic changes, as the above photo shows. The tremendous improvement in color is largely due to the removal of rutile silk. (Photo: World Jewels Trade Center, Bangkok)

Ah, but the story is not yet complete. Our dealer decided to give the dice another throw and burn the stone again, this time with his number-two burner. After all, what else could possibly go wrong, right? Wrong again. Now, no color plus one large crack. At last report, our dealer was said to be considering forsaking the material world and becoming a Buddhist monk.

Removal of silk and developing a blue color— The geuda equation

In the heat treatment of corundum, two elements are of primary concern; iron and titanium. A third element, chromium, also plays a major role in the coloring of rubies and sapphires, but is apparently unaffected by heat. Treatment of geuda sapphires from Sri Lanka requires changes to both iron and titanium, the coloring agents of blue sapphire. The blue color of sapphire is derived from a charge transfer process involving the hopping of an electron from a titanium ion to one of iron when light strikes the crystal,[7] as follows (Ferguson & Fielding, 1972):

$$Fe^{+2} + Ti^{+4} \rightarrow Fe^{+3} + Ti^{+3}$$

Geuda sapphires are typically cloudy, with the clouds consisting of rutile silk, one form of crystallized titanium dioxide (TiO_2). While rutile melts at approximately 1830°C, it is not necessary to actually melt the rutile. Since diffusion into

6. Hydrofluoric acid (HF) works best, as it has the ability to completely dissolve silicates, such as glass (including glass bottles—watch out!), quartz and iron and iron oxides. However, the dangers of working with this acid cannot be overstated. Spills on the skin are generally not apparent until it is too late and the fumes may be deadly, burning the lungs. Hydrofluoric acid should be used only by trained lab personnel under strict laboratory conditions (If you don't know what those are, stay away!). It is among the substances that can etch corundum (see Themelis, 1992, pp. 104–105).

7. This is an instantaneous and ongoing reaction, with the electron immediately returning from whence it came.

Table 6.2: Major corundum heat treatment processes

Process	Treatment conditions	Results
1. Removal of silk	Heat to between 1600–1800°C; cool rapidly to 1250°C, then slowly thereafter.	• Cloudy material becomes clear. Can be used in combination with any process except Process 2.
2. Development of silk	Heat to approximately 1100–1400°C for 1–14 days or more.	• Allows the development of a star in Ti-rich material. Can be used with any process except Process 1. However, this is generally only possible in synthetic corundums where the Ti content is much higher than natural gems (John Emmett, pers. comm., 27 June, 1994).
3. Development of blue	Heat to between 1600–1900°C in a reducing atmosphere.	• Geuda sapphire (Sri Lanka), Kashmir sapphire, etc.—Used in combination with Process 1. Pale, silky stones become clear and deep blue. (Note: A small percentage of Sri Lankan stone turn blue when heated in an oxidizing atmosphere.)
4. Removal of blue	Heat to between 800–1900°C (may be as low as 450°C) in an oxidizing atmosphere.	• While in theory it is possible to lighten the color of dark, "inky" blue Australian, Thai, Cambodian and Nigerian sapphires, the effect is mainly removal of silk, thus increasing transparency. Higher temperatures may be used in combination with Process 1. (Note: A reducing atmosphere has also been reported for this type of heating.) • Removal of the blue component from purplish Thai, Cambodian, Burmese, Sri Lankan, Kenyan, and Tanzanian rubies. Higher temperatures may be used for Burmese, Sri Lankan and East African rubies in combination with Process 1. Blue cores of Mong Hsu (Burma) rubies can also be removed in this way. • Removal of the blue component from green or greenish yellow Australian and Montana (non-Yogo Gulch) sapphires, thus intensifying the yellow color. This is rarely effective.
5. Development of yellow	Heat to between 1600–1900°C in an oxidizing atmosphere.	• White and pale yellow Sri Lankan sapphires become an intense yellow or gold color. Pink stones change to an orange color.
6. Surface (bulk or volume) diffusion (development of color and/or star)	Heat to between 1600–1750°C with the gems packed in a slurry of Ti and Fe or Cr oxides.	• Surface diffusion—Pale gems develop a thin color layer at and just beneath the surface (0.10–0.50 mm deep).
7. Fracture filling	Heat to 1300–1900°C (depending on flux used) with the gem packed in a suitable fluxing agent (such as borax), for 10–20 hours.	• This can be performed on any fractured gem and will result in filling of the fractures, making them less reflective (and so less visible). The gem is also stronger as a result.

solid sapphire is the limiting diffusion rate, at a given temperature it does not matter whether the inclusion is liquid or solid. Needles of 1–5µm diameter will dissolve rapidly into corundum at 1600°C. In this case, the combination of finite solubility of TiO_2 in sapphire at 1600°C and the unusually high diffusion rate of Ti^{4+} determines the apparent rate of dissolution (Emmett & Douthit, 1993). Thus, the heating of any rutile-containing ruby or sapphire to, say 1600–1800°C, essentially dissolves the silk, sending the titanium into solid solution. In order to prevent it from reforming, the stone must be cooled somewhat quickly. This not only removes rutile-induced cloudiness from the stone, but, furthermore, provides the titanium necessary for the coloration of blue sapphires.

The second part of the geuda equation involves reducing the iron to the ferrous (Fe^{+2}) state. If the above heating is carried out in a reducing environment, ferric iron (Fe^{+3}) will be converted to ferrous. Now the gem possesses both the titanium and ferrous iron required for the charge transfer mechanism. Hence, a single heating to between 1600–1900°C in a reducing atmosphere not only clarifies the stone, but also produces a blue color in suitable material. This is the theory behind the heating of geuda sapphires.

One final note on removal of silk. In certain sapphires, the above process removes some exsolved crystals (rutile), but not others. It is probable that those which do not dissolve are of a substance other than rutile (Emmett & Douthit, 1993).

Blue under oxidizing conditions

One Bangkok burner, Gerald V. Rogers, has found that a small percentage of Sri Lankan material will turn blue when heated in an oxidizing atmosphere (pers. comm., 1993). This is in direct contrast to the geuda sapphires, for which a reducing environment is used. Furthermore, the blue color obtained in oxidizing conditions is said to be superior to that produced by the reducing atmosphere. According to Emmett (pers. comm., 27 June, 1994), the reason some stones turn blue in oxidizing conditions is that the silk is comprised of an iron-titanium mineral which contains some of the iron in the reduced (Fe^{2+}) state. Thus no additional reduction is required to form the Fe^{2+}—Ti^{4+} pairs, which produce the blue color. In contrast, stones which turn blue under reducing conditions are those where the silk is primarily titanium dioxide. The iron necessary for a blue color is in solid solution in the sapphire in the Fe^{3+} state. Thus heat treatment proceeds in two steps. First is the dissolution of

Burned

Everybody has been burned before, everybody knows the pain…

David Crosby

EVERY burner has been burned, most more than once. Bangkok treater, Gerald Rogers, related one of his earlier experiences to the author. He had some diamonds upon which he was experimenting. They were placed in the oven and, after the requisite heat treatment, the oven shut down and the results examined. But when the crucible was opened, nothing was there. Nothing, *nada*, not a single stone anywhere near the neighborhood of Mr. Rogers' crucible. He carefully checked the oven—maybe the stones had fallen out of the crucible—but they were gone. Then it hit him, like a rabbit punch straight to the groin: Of course! Diamond is carbon. The stones simply burned up in the oven. Careful examination of the crucible showed a tiny trace of ash at the bottom—all that remained of the once-glittering gems. Children, can you say "Embarrassed?" (Gerald Rogers, pers. comm., ca. 1984).[a]

Ted Themelis also related an early experience of his. After one of his first attempts at heat-treating ruby, his wife, eager to see the results, opened the oven before the gems were fully cooled. He was shocked by a shriek as his wife screamed that the rubies had turned green. Fortunately after fully cooling they became red again. High temperatures had weakened the Cr^{+3} ion ligand field enough to produce a temporary color akin to emerald, which is colored by the same ion. (Ted Themelis, pers. comm., 1994). For a detailed description of this phenomenon, see Nassau (1983).

[a] Note that diamond can be heat treated, but it must be done in the absence of oxygen.

the rutile; second is the reduction of the iron by reducing atmosphere, creating the Fe^{2+}, which reacts with the Ti^{4+}, creating the Fe^{2+}—Ti^{4+} pairs.

Ted Themelis (pers. comm., 1994) has also reported that a small percentage of one lot of silky pink to red Vietnamese rubies turned to a nice blue-violet when heated under full oxidizing conditions at 1700°C. The cause of this change is identical to that just described above (John Emmett, pers. comm., 5 July, 1994).

Development of rutile silk

On paper, it is also possible to perform the reverse of Process 1, recrystallization of rutile silk in Ti-rich stones where the titanium is held in solid solution. Prolonged (1–14 days or more) heating at 1400–1900°C and slow cooling will allow the titanium atoms to unmix from solid solution, forming rutile needles. Thus, star stones, in which the star is weak due to lack of silk, might be heated to strengthen the star. In essence, this is what is done to produce synthetic star rubies and sapphires, but is far more difficult in natural material due to the lack of titanium and presence of high levels of iron.

Removal of blue from rubies

Many mined rubies, particularly those from the Thai-Cambodian border, contain a bluish or purplish tint which lowers their value. Heat treatment can reduce or eliminate this bluish secondary color in what is the reverse of Process 3. This entails heating the stone in an oxidizing atmosphere, which produces the following reaction:

$$Fe^{+2} \rightarrow Fe^{+3}$$

By converting iron to the Fe^{+3} state, the Fe^{2+}—Ti^{4+} pairs that produce blue are no longer present. Instead, a pale yellow color replaces the blue, giving the gem a much purer red color. In some cases, only low temperatures (800–1300°C) are needed to bring about this change, unless it is necessary to remove the silk simultaneously, as is sometimes the case with Burmese, Vietnamese or Sri Lanka rubies. Then, higher temperatures (1600–1900°C) would be indicated. Since the late 1970s, the entire ruby production from Thailand has been burned in the above manner. As a result, Thai/Cambodian rubies traded today are of better color than those in previous times. A very definite improvement is effected by such a treatment, which is not limited to Thai stones alone. Rubies from virtually all other sources are similarly treated.

Improving dark, Fe-rich sapphires

Australian, Nigerian and some Thai blue sapphires generally suffer from being too dark and "inky" in color. This is largely due to the presence of silk, which in stones from these countries may be either hematite (Fe_2O_3), rutile (TiO_2), or another iron-titanium compound such as ilmenite ($FeTiO_3$). The silk affects the color by reflecting and scattering light to such an extent that the pure blue is diluted with white, as well as lowering transparency. Heating to between 1600–1800°C removes rutile silk, effectively improving the color in the process. Since both oxidizing and reducing conditions have been reported for such heating, it would seem that the change is primarily due to the removal of the silk, rather than any lessening of color from the partial oxidation of the iron present.

Green and yellow sapphires from Australian and Thailand are also heated to remove the silk, which in the yellows is frequently present in thin green planes just beneath the upper and lower basal pinacoid faces. In addition, some improvement may also occur as a result of the oxidation of the iron, producing a richer gold or yellow color.

Development of yellow color

Besides the geuda sapphires and the purplish rubies, the other major type of heating performed on Sri Lankan corundum is the development of yellow and orange colors. Success with this process was first achieved in Bangkok during the year 1981. Prior to this, deep yellow and orange sapphires were extremely rare in Sri Lanka, but with the discovery of a method for deepening the color of pale material, intensely

Dick's Law

ONE of the more unusual types of staining seen by the author is that used with Verneuil-produced synthetic blue sapphire. Southeast Asian con artists know that, unlike many natural blue sapphires, no Verneuil synthetic product exists where both blue and yellow are found in the same stone. They also know that, if you are an experienced dealer worth your salt, you know that, too. Thus in order to give us interesting stories to tell in dull sections of the book like this, those clever people take fragments of Verneuil synthetic rough and, after a good tumbling to give the appearance of alluvial wear, apply yellow stains to the outside and into fractures. When you hold that sucker up to the light to check color distribution, you're rewarded with the sight of yellow and blue banding in the same crystal—obviously natural.

> There are many humorous things in the world; among them the white man's notion that he is less savage than the other savages.
>
> Mark Twain, *Following the Equator*, p. 213

Many tender blossoms, newly initiated into the gem trade, are under the impression that the peasant natives of Southeast Asia are, in the main, fools. The natives are thought to wander the jungles with pockets bulging from the weight of valuable rubies, in search of foreigners whom might be willing to lighten their load in exchange for colored beads or, perhaps, a digital wristwatch. Reality sets in when, back home, the purchases prove to be cleverly-disguised Verneuil synthetics. This brings us to the main purpose of this sidebar—*Dick's Law*—which reads as follows:

Basic Statement

The closer you get to the mines, the more synthetics you find.

Postulate No. 1

The quality of synthetic and imitation gems (ease of deception) varies inversely with the distance from the mines, being expressed by the following formula, where d = distance from the mines, q_1 = ease of deception, and k_1 = Dick's constant.

$$q_1 = k_1/d$$

Postulate No. 2

Quantity of synthetics also varies inversely with d, as expressed by the following formula where q_2 = quantity.

$$q_2 = k_2/d$$

So next time you find yourself in some dusty Third-World backwater, about to take that poor native for a ride, remember one thing—the native has the same low opinion of your sophistication as you have of his.

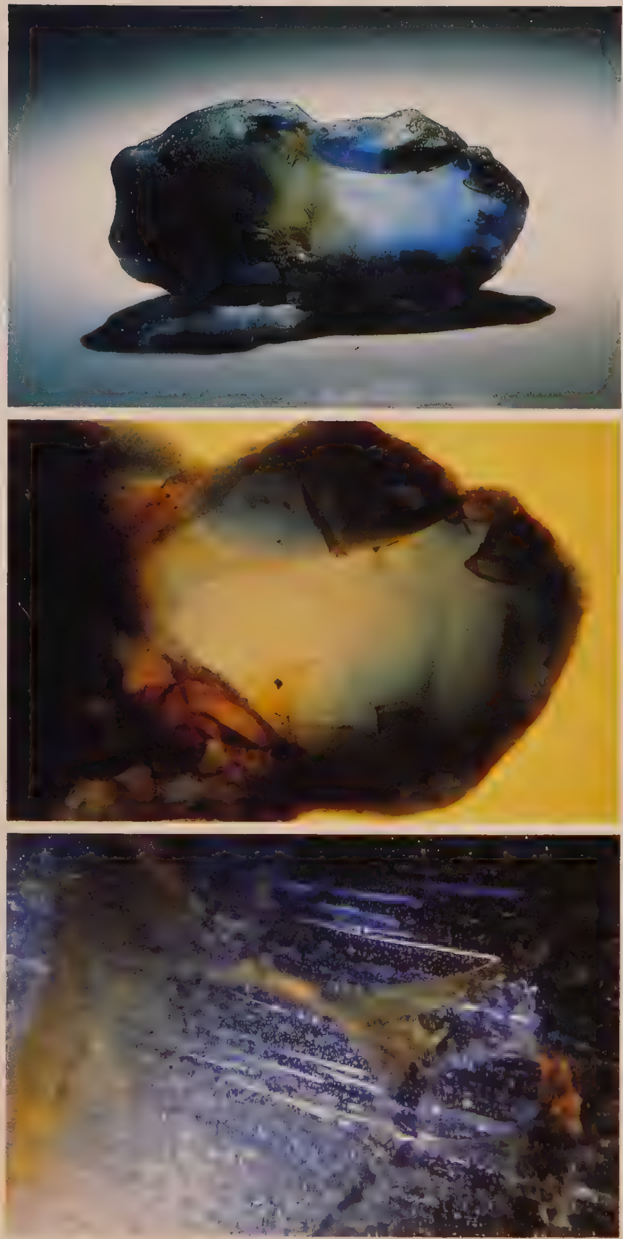

Figure 6.6 Altered synthetic corundum rough
Top: Verneuil synthetic blue sapphire rough which has been tumbled, fractured and stained yellow to resemble natural rough.
Middle: Yellow stains in the cracks are clearly visible, as are the multitudes of gas bubbles
Lower: Curved color banding is clearly visible with immersion.
(Photos: Tony Laughter)

colored gems in these colors soon flooded the market. The treated stones could be produced in depths of color totally unknown up to this time, so much so that prices descended to one fourth or less of the pre-1981 levels. This is rather a shame, for unlike the other heated corundums, a simple test which, to the best of the author's knowledge is 100% accurate, does exist for separating the treated and untreated gems. It was discovered by the author in Bangkok, in 1981, and is described later in this chapter in the section on detecting treatments.

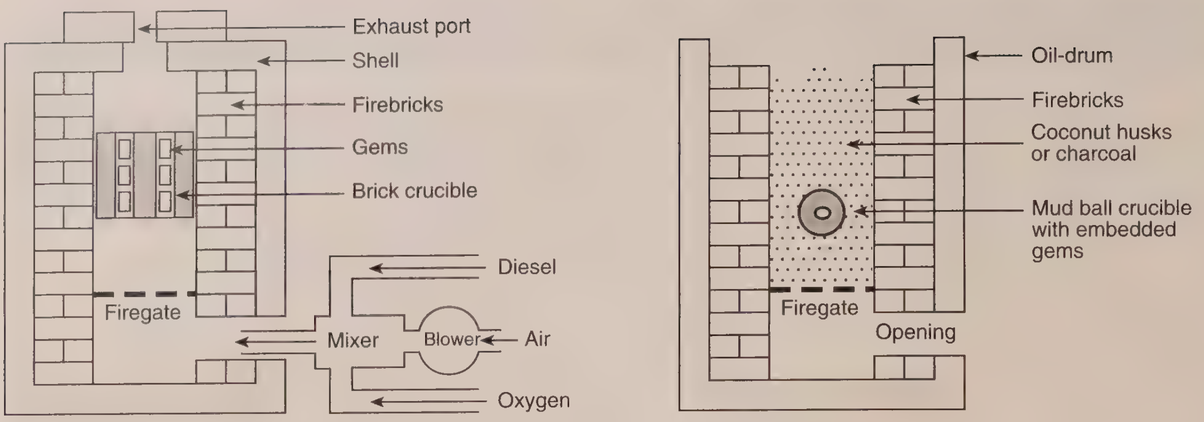

Figure 6.7 Construction of the typical furnaces used for heat treating corundums in Thailand
Left: Furnace for removal of silk and improving color of sapphires.
Right: Simple charcoal furnace for improving color of Thai/Cambodian rubies. (Modified from Themelis, 1992)

The heat treatment of Sri Lankan yellow and orange sapphires is normally performed under oxidizing conditions at temperatures ranging from 1600–1900°C. This apparently causes diffusion of coloring agents outward from tiny exsolved particles of unknown composition, as small haloes of color surround the particles after heating. When present in large enough quantities, there are enough of these colored haloes to impart a pale to deep yellow, orange, or even reddish orange color to the stone, often rendering it slightly cloudy or silky in the process. Under microscopic examination the true nature of the gems' coloration can be seen, for these heated sapphires are strongly zoned, with the most intensely colored regions displaying the greatest concentrations of mineral particles. Of the thousands of burned Sri Lankan yellows examined by the author, all have shown these same inclusions, to a greater or lesser degree, arranged in an identical fashion to the rutile silk of star rubies and sapphires.

Figure 6.8 Evidence of the high temperatures reached during modern heat treatments is found in the above photo of heated Sri Lankan rubies. One can clearly see the melted surfaces, solidified droplets and fragments of stone that have been fused to the surfaces of these stones. (Photo: Adisorn Studio)

Color stability of heat-treated corundum

The stability of the various colors produced by heating corundum has, in the past, been called into question by members of the trade. Certainly the subject of color permanence is an important one, for gems are generally considered as heirlooms to be passed from one generation to the next.

Every so often a report surfaces regarding heat-treated sapphires which have allegedly faded years after being purchased. In most instances the sources are well-meaning lay people or dealers who have simply erred in their recollection of the original color of the stone. This is somewhat akin to an experience every jeweler has doubtless had, that of a customer believing their stone had been switched when in fact the piece had simply been cleaned. However, when experienced colored stone dealers spin this yarn about the fading of heat-treated sapphires it does give one pause for thought.

The following is a typical tale: Famous gem dealer, James Millionaire (a fictitious name) announces to the trade press that heated sapphires should be avoided, for their color is unstable. As "proof," he cites a parcel of heated stones which were purchased five years before and which had lain unnoticed in his safe until recently. Originally all were of a similar fine yellow color, but when examined last week several were found to have faded to near-colorless.[8]

In terms of scientific process, the above cases deserve to be filed with the stories from China about the children who can read with their ears and bend spoons from a distance, as they rely solely on the color memory of the dealer. Considering that the color memory of the human animal is roughly on a

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8. These stones were most likely irradiated Sri Lankan yellow sapphires. Sometimes it is claimed that the stones darkened in color with time. In one recorded instance, they changed from fine blue "Cambodian" sapphires to almost black Australian-type stones (Voynick, 1985)

Figure 6.9 When corundums with Ti-bearing inclusions are heated at high temperatures, Ti may diffuse into the surrounding corundum, thus creating a blue color surrounding the inclusion. The above stone is a Montana sapphire (probably Rock Creek).
(Photo: John Koivula/GIA; specimen: Dee Parsons collection; 20×)

par with that of a politician's memory during public hearings, such tales must be taken with a liberal dose of salt (and wine and whisky and…). When we consider that temperatures ranging from 800–1900°C are necessary to modify the color of a ruby or sapphire in the first place, it seems highly improbable that mere sunlight alone could produce a reversal, let alone a change occurring at room temperature with the stones kept in a stone paper.

Such stories can be simply dismissed. Since such changes require a great deal of energy to effect (>1000°C), similar energy must be applied to reverse them (Kurt Nassau, pers. comm., 19 Aug., 1994). While the same cannot be said about irradiated gems (where fading under sunlight is a possibility), the currently-available evidence suggests that the color of heat-treated corundums is close to forever.

Methods of heat treatment

The heat treatment of corundum is, by nature, a risky operation and those involved often display a penchant for risk-taking similar to the alchemists of days gone by. Although slowly evolving into a science, for many burners it still involves a healthy slice of experimental chemistry, with practices at times more akin to Merlin the magician than modern science.

Like the early alchemists, secrecy is the rule. Asian burners often possesses their own special recipes, discovered through past experiments and jealously guarded. With some it is a magic liquid, for others a paste or powder. In Asia it often seems that the ceremony is as vital as the flame itself. But in other parts of the world, mystery and incantation play no part. Heating corundums is approached with all the rigor and scientific process of a moon shot.

Material may be prepared for burning in one of several ways. Generally the first step is to remove any foreign (non-corundum) minerals from the lot by gemological tests (RI, SG, etc.), hand selection, or both. This is extremely important, as certain types of stones, particularly topaz, beryl, tourmaline and chrysoberyl, may spoil an entire load, causing the corundum to break, or even worse, to melt. Any matrix adhering to the corundum must also be removed for the same reason. This is done with acid or by grinding.

Contrary to what has sometimes been reported, burning is usually done on rough stones. The only grinding is to trim away matrix, or dangerous inclusions such as large crystals and negative crystals that might crack the gem when heated. It would be most foolish to facet the gems first, before burning, as one never knows which areas will achieve the finest coloration. Additionally, it would certainly be a pity to cut a stone, burn and repolish it, only to find its weight to be 1.99 carats. This is not to imply that cut stones are never burned, for they often are, but it is more desirable to perform heat treatment on rough, rather than cut, specimens.

Once the stones have been cleaned and trimmed they are ready for the oven. In order to avoid cracking during the treatment, the gems are placed into a set of nested alumina crucibles which can withstand temperatures up to 1900°C. This is often sealed in the presence of the customer, with the seal being broken only by the customer after the burn is completed, to prevent the theft or switching of material.

One problem with high-temperature treatments involves stones adhering to one another; this often results in fractures when they are later broken apart. It can be avoided by embedding the stones in an inert substance, such as alumina powder or ruby sand. Not only does this allow the gems to be freed without damage, but it also provides insulation against rapid temperature changes that may produce cracking. The crucibles too, may be insulated for the latter reason. One ruby burner in Chanthaburi wraps the crucibles in wet clay obtained directly from the mines themselves, possibly with the belief that it will help the gems to "ripen." It is not known whether or not he also treats the rubies with pesticides and fertilizer.

In addition to preventing sticking and providing insulation, the substances placed in or around the crucibles may also be used to create the desired atmospheric conditions. Charcoal or graphite can be used to create reducing conditions, while various gas combinations can produce either oxidizing or reducing conditions. Other substances used in the crucibles include borax, caustic soda, sodium or potassium hydroxide, glycerin, citric acid, potassium nitrate, buffalo dung, urine, snake legs, etc. In other words, anything goes. Fluxes, such as borax, are said to glaze the surface areas of the stones, producing brighter appearing rough.

Furnaces used in Thailand and elsewhere for the heat treatment of corundum are mainly of three types; electric, gas- or petroleum-fired, and charcoal or coke-fired. Many Thai ovens simply consist of converted oil drums insulated

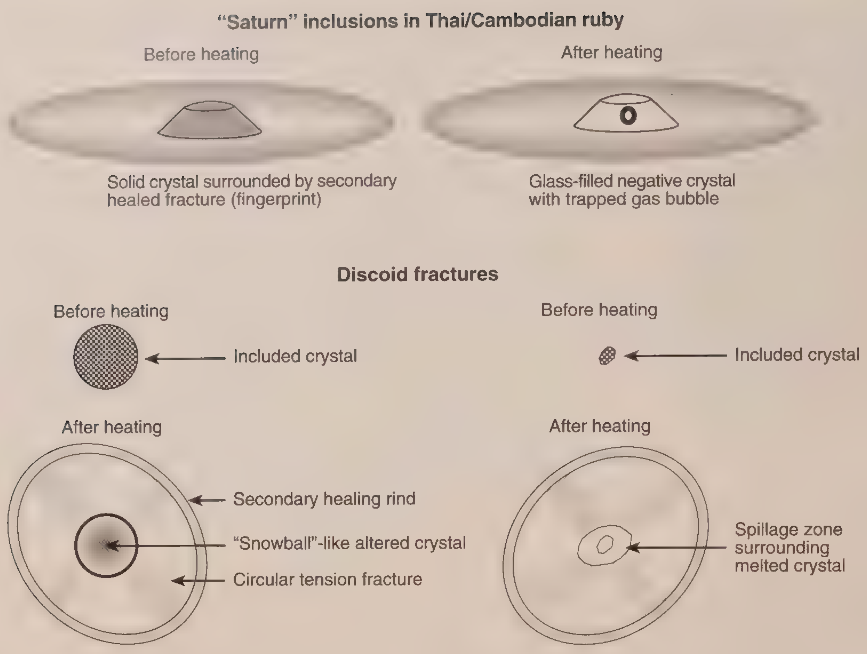


Figure 6.10 Changes in solid inclusions resulting from heat treatment
Top: Solid inclusions in Thai/Cambodian rubies melt during heat treatment, leaving behind glass-filled negative crystals, which often contain gas bubbles frozen in place within the glassy remains of the crystal.
Bottom: When a gem containing crystal inclusions is heat treated, the crystals often expand, creating a distinctive circular tension crack with a shiny luster. If the melting point of the crystal was reached during treatment, a spillage zone will also be seen surrounding the melted crystal. At the outermost edge of the tension fracture, healing may have already begun, creating a secondary healing rind. Inclusions such as this are indicative of heat treatment and are often seen in heat-treated Sri Lankan stones.

with fire bricks. Electric ovens are generally the most costly, but offer the advantage of full control over the oven atmosphere. Thus they are the ovens of choice for heat-treatment experts.

A typical "burn" may run anywhere from 1–24 hours or more, with the more efficient, high-temperature ovens requiring less time. After the oven is shut down, the crucible is allowed to cool slowly to prevent cracking, a process which varies depending on the process and treater. Once completely cool, the crucible is removed and the stones examined. Preliminary burns are often performed on Sri Lankan sapphires to determine how the material will respond. Depending on the results of such trial runs, the gems will then be sorted into groups for developing either blue or yellow colors. Should the results be unsatisfactory on any particular stone, it may be heated several times, possibly by more than one burner, for the cardinal rule of heat treatment is, "if at first you don't succeed, try, try again."

Detection of heat treatment

The almost universal use of high-temperature heat treatments to improve the color and clarity of the corundum gems makes the development of detection methods an area of vital concern. Fortunately, techniques exist that will allow the separation of many heated rubies and sapphires, thus preventing unfair competition between natural and treated gems.

Surface features. High temperatures and the fluxing agents commonly added to the crucible may cause surfaces to become etched or pockmarked. In addition, impurities within the crucible may melt and solidify as droplets on a gem's surface. This means that most gems require repolishing after burning, but lapidaries may miss small areas during the repolishing operation, leaving tiny patches displaying this dimpled or melted appearance. Most common at or near the girdle, they may also be found on the surfaces of pits and cavities because the polishing wheel cannot reach down into such areas. Such evidence is an absolutely positive indication of heat treatment. Use of the hot point can easily separate such phenomena from glue and epoxy droplets (glues will melt) which are also sometimes seen on gems' surfaces.

Double or *multiplane girdles* have in the past been cited as evidence of heat treatment, the logic being that they indicate repolishing or recutting, a necessity after burning (Fryer, 1981). This is unfortunately not the case, as when the girdle is rounded by the freehand methods common to Thailand and other third-world cutting centers, a multiplane girdle results. Thus, the double girdle cannot be considered as indicative of recutting or repolishing, and subsequently, is of no use in identifying heated stones.

Figure 6.11 Tension disks in heat-treated corundums
Left: A circular tension disk resulting from heat treatment in a heat-treated yellow sapphire from Sri Lanka. During heat treatment the included crystal at the center expands, producing a circular tension fracture of often glassy luster. In some cases (as above) the crystal melts, creating an irregular spillage zone immediately surrounding it. Due to the high temperatures involved, the disk begins to heal, creating a secondary healing rind at its outermost edges. Such tension discs surrounding crystals are typical of heat-treated stones from all localities. (Photo by the author)
Right: Glassy tension disk with a snowball-like inclusion at the center in a heat-treated Sri Lankan sapphire. (Photo: Tony Laughter)

Changes in UV fluorescence. Heat treatment may produce changes in the fluorescent reactions of some gems. In a reaction which remains a mystery, some gems display a zoned, chalky, whitish to blue-green reaction under SW ultraviolet after heating. This is similar to the reaction of Verneuil synthetic corundums in the blue to colorless range, in that the colorless areas of the stone fluoresce, while colored areas are generally inert. Thus gems with large colorless areas will show the strongest reactions. Magnification will show that this reaction follows the colorless zoning of the gem exactly (protect your eyes!). Most common in heat-treated Sri Lankan blue sapphires, such fluorescence is also found on occasion in gems from other sources, including rubies (except Thai/Cambodian). Should Cr also be present, orange-red fluorescent areas may also be seen (but are not an indication of heat treatment).

UV fluorescence may help to confirm the identification of the treated Sri Lankan yellow and orange sapphires. Untreated yellow/orange sapphires from Sri Lanka typically display a strong orange ('apricot') fluorescence under both long and short wave ultraviolet light. Heat treatment lessens or completely eliminates this reaction, particularly in deeply colored stones. It is useful to compare the reaction with known untreated control stones of similar body color.

Changes in solid inclusions. Solid inclusions often undergo transformation during heat treatment. All substances expand when heated. The numerical description of this is termed *coefficient of thermal expansion,* and it is unique to each substance. Should an inclusion expand more than the host during heating, the result will be a stress fracture surrounding it. Such stress fractures are generally circular, with a glassy, highly reflective appearance. Such circular fractures generally show a thin, secondary healing rind at the outside edge, because the heat which produced the crack also provides conditions for healing. While such inclusions can also be found in natural gems, they are far more common in heat-treated stones.

Figure 6.12 During heat treatment, solid inclusions will melt if their melting point is below the maximum temperature reached. Due to the rapid cooling rate of the oven, these inclusions generally cool into a glass. Because the glass takes up less volume than the previous crystal guest, gas bubbles form to fill the remaining space. In the heated Thai/Cambodian ruby above, several gas bubbles can be seen in this melted crystal inclusion. (Photo: Wimon Manorotkul)

Solid inclusions may also melt or undergo other transformations during heat treatment. If an inclusion melts, it sometimes spills out into the circular fracture, forming a spillage zone. Other crystals do not melt, but change appearance. Included crystals in Sri Lankan sapphires often turn into round white "snowballs" after treatment. These snowballs may or may not show glassy circular fractures around them.

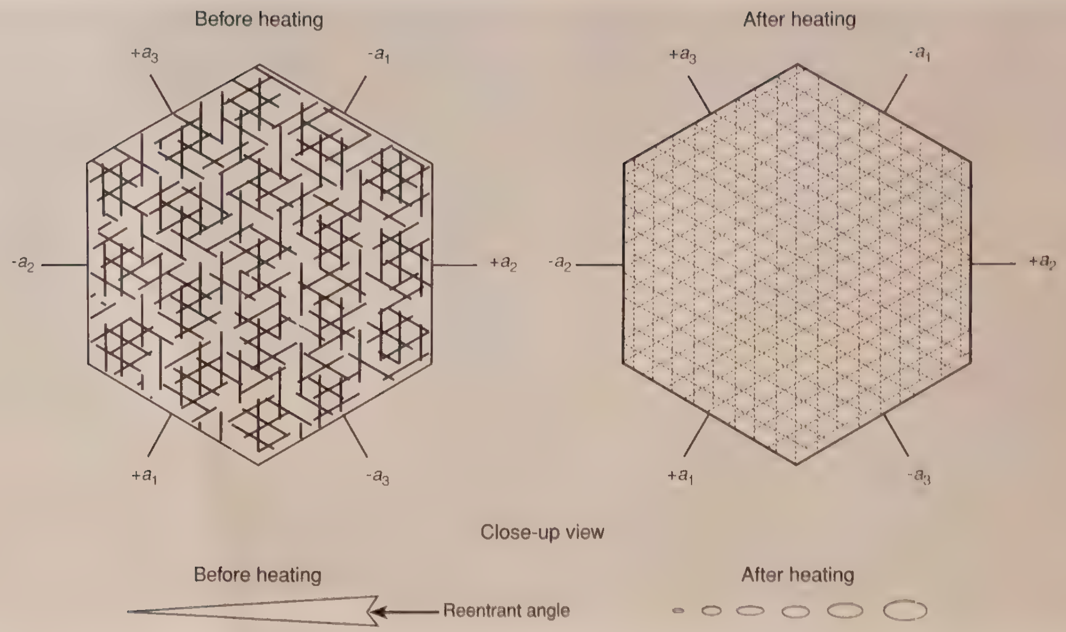


Figure 6.13 Effects of high-temperature heat treatment on rutile silk in corundum

Left: In corundum, rutile exsolves in three directions in the basal plane, parallel to the faces of the second-order hexagonal prism {11$\bar{2}$0}. Before heating, rutile silk consists of needles which, when highly magnified, are often tiny arrow- or dart-shaped twins with small reentrant angles at the wide end. The rutile needles are extremely thin in cross-section and are generally flattened in the basal plane. Overhead fiber-optic illumination with the microscope will reveal such details.

Right: Heat treatment causes the rutile to be partially dissolved into the corundum, but traces remain behind, visible with fiber-optic lighting. Each needle, rather than coalescing into one globule, instead dissolves into a series of tiny droplets arranged in the same pattern as before heating. This *partially-dissolved silk* may be indicative of heat treatment. However, minute exsolved particles, which can occur naturally, may be confused with the partially-dissolved silk of heated gems. The presence of long needles and dart- and arrow-shaped rutile is a strong indication that the gem has *not* undergone high-temperature heat treatment.

Although the temperatures used for the treatment of Thai/Cambodian rubies are, at times, less than those for Sri Lankan sapphires, they still produce changes that can identify the gems as treated. Only one major factor of use in identification has been found to date, but fortunately it is present in most stones. This telltale sign is the alteration of the solid crystal grains which form the center of the so-called "Saturn" inclusion.

A quick glance through the section on Thai/Cambodian rubies in Eduard Gübelin's masterpiece, *The Internal World of Gemstones* (1973), will reveal the types of crystals so typical of the untreated stones of this locality. Opaque brown grains of garnet, yellowish apatites, metallic black pyrrhotites and, more rarely, colorless plagioclase feldspars are all to be found. According to Gübelin (1971), approximately seven out of ten stones from this locality display such crystals. However, these distinctive features are rarely present in the Thai rubies circulating today. Heating melts such crystals, leaving behind high-relief cavities filled with a colorless, or more rarely, a brownish stained glass. These glass-filled voids often contain a gas bubble, frozen in place by the solidified remains of the melted crystal. So common has the heating of Thai rubies become that the author cannot recall having seen more than a handful of unburned rubies with the solid crystals still intact since the early 1980s.

Sapphires from Rock Creek, Montana (USA) often contain primary (non-exsolved) rutile crystals. During heat treatment, such crystals may be cannibalized for their Ti, resulting in blue areas directly surrounding such inclusions. Heating such inclusions may cause a surrounding tension fracture. Ti-oxides liberated from the rutile then rapidly coat the internal surfaces of the fracture and diffuse into the surrounding corundum, producing a blue color in those areas. On cooling, the fracture heals shut, eliminating the reflective interface usually seen in such fractures surrounding inclusions (Emmett & Douthit, 1993). Such included crystals surrounded by color rinds are a good indication of heat treatment.

Changes in cavities. Cavities may be filled with liquids, gases, solids, or a combination of the three. Such cavities in Sri Lankan corundums often contain both liquid and gaseous CO_2; the gaseous phase of CO_2 is eliminated above 31.2°C. Such inclusions form deep within the earth, where pressures exceed 1000 psi or more. Brought to the surface, there is tremendous pressure outward, with little to compensate. Even gentle heating (~270°C has been reported) can

Figure 6.14 Changes in rutile silk in heat-treated corundums
Left: Rutile silk in an untreated Burmese ruby.
Right: Rutile silk in a Burmese ruby after high temperature heat treatment. After heat treatment the individual needles have been partially absorbed by the gem, leaving behind little droplets arranged in a similar pattern. (Photos by the author)

cause such inclusions to explode, damaging the gem in the process. For this reason, burners try to trim away such potentially explosive inclusions prior to treatment. The flip side, of course, is that their presence is an excellent indicator that a gem has not been heat treated. CO_2 inclusions can be identified by reference to the gaseous phase. Below 31.2°C it is present; above that temperature it disappears. Even the heat of the microscope is enough to remove the gaseous phase (Koivula, 1986).

Changes in color zoning. In many untreated corundums, color zoning occurs in extremely narrow, sharp lines. While superficial examination of heated corundums may also show areas of strong zoning, high magnification reveals that, particularly in Sri Lankan blues, such zones are not as sharp as in the untreated stones (Gunaratne, 1981).

Due to the prevalence of treatments, many gemologists today have never seen an untreated Sri Lankan blue sapphire, and so are unable to recognize the difference between the two. Direct comparison between known untreated and known treated gems is necessary for distinction. Shadowing illumination is also useful (see Chapter 5 for details), and allows observation of extremely fine zoning details missed under other lighting conditions. Color zoning in heat-treated Sri Lankan blue sapphires will be noticeably more diffuse and fuzzy at the edges.

Changes in exsolved inclusions. Among the key features for identifying untreated corundums from many sources[9] is the presence of rutile silk. These are not just exsolved mineral particles, but actual needles. Close examination of such inclusions under high magnification (>20×) reveals individual rutile needles consisting of dart-shaped twins with tiny reentrant angles at the broad end. Before burning, both particles and needles may be present; however after high-temperature heating the needles will be gone. Therefore, the presence of actual rutile needles indicates a stone not subjected to high-temperature treatment. With the exception of yellow sapphires, most unburned corundums from Sri Lanka display at least some rutile silk. During heating, rutile silk may not dissolve completely, but instead often coalesces into small droplets arranged in the pattern of the silk. This "partially dissolved" silk is another indication of heat treatment.

Rutile is not the only exsolved substance in corundum. Hematite, ilmenite and boehmite have all been identified as exsolved inclusions in corundum. While rutile may dissolve via heat, apparently some other exsolved inclusions may not. The result in heat-treated Sri Lankan sapphires is white *texture clouds* of unidentified exsolved inclusions which are oriented in a pattern similar to exsolved rutile. Such clouds may show a substructure of minute particles arranged in an identical manner to the rutile silk of untreated gems, while in other instances the clouds are completely smooth throughout.

Previously, heat-treated Burmese rubies were an uncommon occurrence. However, starting about 1984, quantities of heated Burmese rubies came onto the market and many of the Burmese rubies available today have been heated to remove silk. This burned material contains inclusions very different from untreated material. The rutile silk, such a distinctive feature of unburned Burmese rubies, is gone. In place of the knife-shaped needles are little droplets of partially dissolved silk, similar to those seen in heated Sri Lankan corundums. Burners have not had the same success with Burmese blue sapphires, which are not presently treated on a large scale. However, give them a little time…

Heated yellow and orange sapphires from Sri Lanka always contain multitudes of minute, unidentified particles

[9] Sri Lanka, Burma, Kanchanaburi (Thailand), Australia and other sources where exsolved rutile is a common inclusion.

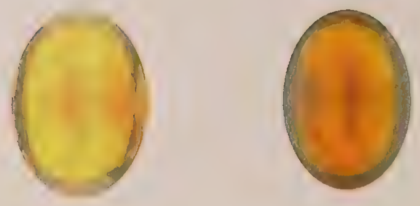


Figure 6.15 Identifying heat treatment in Sri Lankan yellow sapphires
Left: Heat-treated Sri Lankan yellow sapphire at room temperature.
Right: The same stone after being placed within 1 cm of a 150-watt spot light for 15 minutes. Note the darkening and browning of color in the stone at right. This is a positive indication of heat treatment in yellow orange sapphires from Sri Lanka. The change is temporary and the color quickly returns to normal upon cooling. (Photos by the author)

arranged in an identical fashion to the rutile silk. These particles are somehow involved in coloring the stones, for after heat treatment color is found concentrated around them in small haloes. A coloring agent is apparently being diffused out of the particles during heat treatment, but this is probably not iron, as the slow diffusion rates of iron would tend to preclude such large movement during a few hours of heating (John Emmett, pers. comm., 5 July, 1994).

Color banding is found associated with these inclusions; deeply colored stripes occur where concentrations of particles are located. Although particles of a similar nature may also be seen in untreated Sri Lankan stones, color is not necessarily associated with them.

Changes in open and healed fractures. Gems mined from Fe-rich soils, such as rubies from the Thai/Cambodian border, often display rusty red, Fe-oxide stains in their cracks. Heat treatment at high temperatures (1800°C) generally removes such red-orange stains (Sata, 1984; Hughes, 1991a).

Fingerprints are normally an uncommon occurrence in Burmese rubies. The stress of heat treatment, however, may produce fractures which heal. Thus heated stones are often filled with secondary fingerprints and feathers, and overall, bear a strong resemblance to the treated rubies from Kenya.

By embedding the gem in a fluxing agent such as borax (sodium borate, or another borate), heat treatment may produce a partial filling of fractures, where the borax dissolves some corundum, and the resulting mixture solidifies in the fracture (Emmett & Douthit, 1993). Currently there is no simple method of detection for this.

Detecting heat treatment in Sri Lankan yellow-orange sapphires. To date, in only one instance does there exist a simple and reliable test for the identification of heated corundums. This is for the heat-treated yellow and orange sapphires from Sri Lanka, which can be separated by a fade test discovered by the author in 1981 (Hughes, 1987d-e, 1988a).

Before performing this test, the gem should be examined to make sure that no potentially-damaging inclusions (such as CO_2-filled negative crystals which may explode upon heating) are present. The heat of this test may also produce fading in certain gems (the color can be restored by exposure to sunlight) which are otherwise generally stable to light (Kurt Nassau, pers. comm., 19 Aug., 1994). (see 'Fade tests', p. 129)

Some naturally-colored Sri Lankan stones may also fade slightly, but this is not a big problem as they would fade under normal wearing conditions anyway. The fading of some natural yellow/orange sapphires has been reported by miners in Sri Lanka, but fading is said to occur soon after the stone is unearthed. With yellow or orange sapphires from other localities, such as Thailand or Australia, the color remains unchanged by this heat + light fade test. Sri Lankan gems can be separated from Thai and Australian yellows by their lack of strong iron lines (451.5, 460, 470 nm) in the spectroscope, which are always present in the latter.

Figure 6.16 Clouds of minute exsolved particles are seen in a heat-treated yellow sapphire from Sri Lanka (parallel to the *c* axis). When the stone is viewed along the *c* axis, such clouds will line up into a hexagonal pattern, as above. Heat treatment appears to cause exsolution of these particles, arranged in a similar pattern to the silk (three directions at 60/120° in the basal plane). These particles either mechanically color the stone, or are cannibalized for coloring agents.
(Photo: Wimon Manorotkul)

The body color of the treated gems often gives clues for their identification, being unnaturally deep, with brownish overtones. It may grade into *burnt* orange shades of color completely unknown in nature from Sri Lanka.

To perform the test a control stone should be selected which closely approximates the body color of the stone in question. This will serve as a means of comparison to detect any change in color during the test. The gem to be tested is placed on a fireproof surface, such as a metal box, and an

Figure 6.17 Surface-diffusion treated corundums
Left: D-SDTC preform sliced open and polished to reveal the depth of color penetration. Note that much of the color layer will be removed during polishing. Despite claims by manufacturers, the so-called "deep diffusion" process has shown no more color penetration than that claimed in the original Linde patents, i.e. up to 0.50 mm. (Photo: Wimon Manorotkul)
Right: SDTC (left) and untreated sapphire (right), while immersed in di-iodomethane. One can clearly see the dark girdle and highlighted facets and facet junctions of the SDTC. (Photo: Robert Kane/GIA)

intense 150-watt spotlight brought within one centimeter of its surface. After approximately 10 to 15 minutes the lamp is turned off and the color of the control stone is immediately compared to the test stone. Should the test stone be a heat-treated Sri Lankan yellow/orange sapphire, its color will be found to have darkened temporarily, due to the heat of the lamp. As it cools, its color then returns to pre-test levels, so it is important that a comparison is made immediately after the lamp is turned off (see Figure 6.15).

Since 1981, the author has tested thousands of heat-treated yellow and orange sapphires from Sri Lanka in the above manner and has yet to encounter a single heat-treated piece which did not behave in this way. The change is most dramatic in deeply-colored stones and less so in light pieces, but all show a noticeable darkening, or "browning" of their color after a few minutes exposure.

Other possible tests for heat treatment. Emmett & Douthit (1993) have reported that heat treatment of sapphire in a hydrogen-bearing atmosphere results in hydrogen diffusion into the gem. The resulting OH^- molecular ion can be detected by infrared spectroscopy at 3310 cm^{-1} (3021 nm; Eigenmann & Günthard, 1971). This absorption feature has not yet been reported in unheated sapphire.

One final word on the detection of heat-treated geuda blue sapphires from Sri Lanka. Olle Fjordgren (1986) of Sweden has reported that infrared photography can be used to detect heat treatment in certain cases. By photographing a suspect stone under infrared light with infrared film, differences can be seen in the developed photos between untreated and heat-treated geuda blue sapphires. The treated gems are said to appear black or blackish, while untreated stones tend to look rather reddish to violet on IR film. This report has yet to be confirmed, by other gemologists.

Surface diffusion-treated corundums (SDTCs)

To the layman, gem materials such as ruby and sapphire appear to be absolutely solid, impregnable fortresses. This is an illusion, for if an object is of a small enough size, as with certain atoms, it can pass through a gem as easily as sand through one's fingers. The process whereby atoms may be moved through a material is termed *diffusion* and is responsible for a number of the different changes in corundum subjected to heat treatment.

When a crystal is heated, lattice defects are produced in proportion to the temperature reached. Heat it too much and the bonds break completely, producing a truly *defective* crystal. That's melting (and that's tough titty if it's your stone). But if you heat it to just below the melting point, where the maximum defects exist without destroying the specimen, it is possible for atoms to move, or *diffuse*, into the structure, via the point defects. Atoms of a small size, such as hydrogen, diffuse rapidly into corundum. Thus, color changes involving this element can be effected throughout the entire gem in as little as an hour by heating under proper conditions.[10]

Diffusion rates are controlled by the type of ion and structure into which it is moving. Diffusion of oxygen occurs due to a chain reaction involving the movement of point defects (missing oxygen atoms). However, the diffusion of transition metals, such as iron, titanium, and chromium is far slower. Heating the gem at 1800°C for several days will produce a movement of only 0.5 mm or less for titanium, while the diffusion of iron and chromium is as much as 10,000 times slower still.[11] Diffusion of hydrogen and oxygen is common

[10] Actual heating times depend on stone sizes and several other factors.

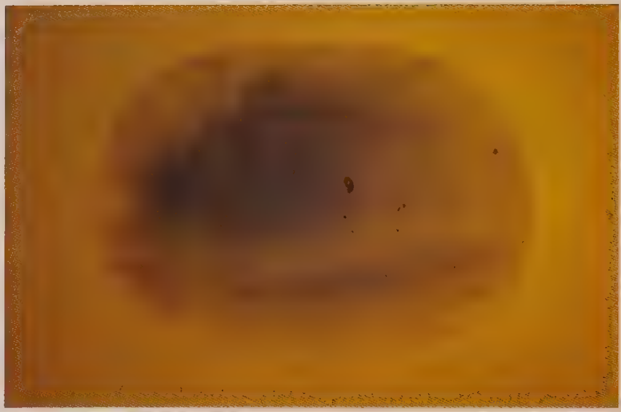
in ordinary heat treatment and may produce changes in color throughout the gem. Diffusion of transition-metal coloring agents takes place only at or near the surface, and thus is termed *surface diffusion* by gemologists. It can be used to induce both color and/or asterism.

The surface-diffusion process is based upon that patented by the Linde division of Union Carbide in 1975 (Carr & Nisevich, 1975–1977). Linde was having problems with lack of silk near the skin of their synthetic star corundums. Surface diffusion was developed to correct this shortcoming. Later it was adapted for use in natural corundums which lacked either color or asterism, and first appeared in world gem markets in 1979 (Crowningshield, 1979).

The surface-diffusion process

Colorless- to lightly-colored corundums are readied for treatment by preforming and cutting, but not polishing, as this inhibits diffusion somewhat. They are then embedded in a crucible containing a powder that consists of alumina, titania, and metallic oxide colorants. Alumina itself has no effect, while Ti aids surface penetration and lessens the formation of color bands (Yaverbaum, 1980). Coloring agents are generally the same as those for dopping Verneuil synthetic corundum. Now the crucible is heated to between 1600–1800°C for prolonged periods of time (days, weeks). This allows atoms within the powder to diffuse into the surface areas, creating a thinly-colored skin which, after a light repolishing, is rarely deeper than a few tenths of a millimeter. Thus, natural rubies and sapphires in which the color is too light, or uneven in distribution, can be treated by the above method to correct these deficiencies. The process is termed *mass* or *bulk diffusion* by scientists in other fields; gemologists refer to it as *surface diffusion.*

Due to the large quantities of clean, lightly-colored sapphire available from Sri Lanka, this material is most often used for surface diffusion. Stones from other localities are used, but less frequently. In terms of the colors produced, the majority are blues, with some rubies (reds), padparadschas (oranges), and yellows being treated. Asterism is also possible. When done properly, the colors resulting from surface diffusion can be nearly equal to nature's finest efforts. However, because the coloring agents have been artificially induced into the gems, and because the color is only at the surface (making it impossible to recut chipped stones without loss of color), diffusion-treated stones have not been accepted by the trade in the same way as the treatments



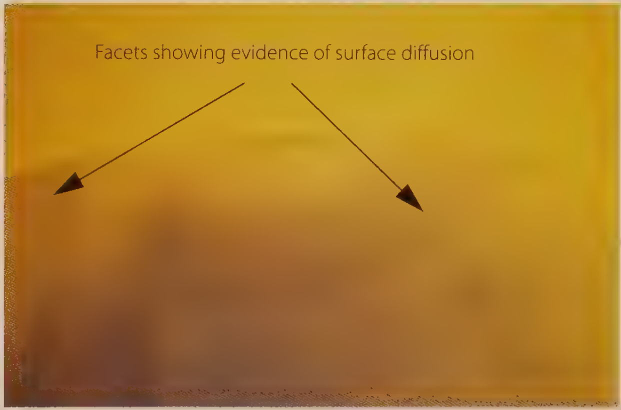


Figure 6.18 In late 1988, more sophisticated SDTCs began appearing in Bangkok. Rather than using colorless Sri Lankan sapphires as starting material, Thai burners began employing strongly zoned Bo Ploi (Kanchanaburi) sapphires. The purpose was simply to provide a more even coloration. Since such stones already contained substantial internal color, detection was more difficult. Evidence of the SDTC treatment is found on those facets where the color concentration follows exactly the facet pattern (see arrows). (Photos by the author)

involving heat alone. Thus, it is imperative that gemologists are able to identify these stones.

Return of the surface-diffusion zombie

Surface diffusion-treated corundums (SDTCs) first appeared in world gem markets in 1979 (Crowningshield, 1979), after the Swiss gem giant, Golay Buchel, purchased the patent rights from Union Carbide. Virtually all were of a blue color. Not only Golay Buchel was involved in the treatment; Thai burners also used the process (Hughes, 1991c). Many stones were passed off as natural until gemologists learned how to identify the material. By 1983, such stones had largely disappeared.

In mid-1988, the author again began to see SDTCs, but this time with a more sinister glint (Hughes, 1991c, 1992). It had always been in the back of his mind that, rather than taking near-colorless sapphires and treating them to a deep color, someday burners would take gems which already had color of their own, but with zoning problems, and, via surface diffusion, smooth such problems away. This is what

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11. The more rapid rate of diffusion for Ti^{4+} in corundum (as compared with Cr^{3+} and Fe^{3+}) is attributed to replacement of Al^{3+} ions with quadrivalent impurities (such as Ti^{4+}), which stimulates formation of the defects required for compensation of the excess positive charge. These defects allow more rapid diffusion (Bessonova & Stanislavskii *et al.*, 1976).

happened in mid-1988, to such an extent that the matter was reported to the International Colored Stone Association (Hughes, 1988b). Unfortunately this whistle blowing did not sit well with certain members of the Thai gem trade. Claims were made that such SDTCs were simply stones which had received *surface heat*.[12] One dealer even went so far as to offer his head for breakfast if his stones were SDTCs (they were, and the breakfast never materialized). Since Bangkok gemologists refused to be cowed, certain burners and dealers then embarked upon a campaign of threat and innuendo, even going so far as to publish an anonymous pamphlet attacking such gemologists (Ploy Sahm See, 1988). Fortunately this had little effect.

The deep-diffusion mutant: Kill it before it mates

Beginning in mid-1989, the author heard about a "new" surface-diffusion process, termed *deep diffusion* (D-SDTCs). In April of 1990, samples were obtained from one company involved. While various claims were made for this material, such as greater penetration of color, little difference was found between D-SDTCs and ordinary SDTCs. The original Union Carbide patents claimed a color penetration of up to 0.50 mm, while the deepest penetration measured to date for D-SDTCs is 0.40 mm (Kane & Kammerling *et al.*, 1990; Hughes, 1991c). D-SDTCs are no different from ordinary SDTCs, in terms of color penetration or identification.

Unfortunately, some people did not see things this way. One producer told the author in June, 1991 that he had received over ten death threats from paranoid Bangkok and Chanthaburi dealers who feared that D-SDTCs would wreak havoc on the sapphire market. Just why this created such a furor when the earlier (ca. 1988), Thai-produced SDTCs made not even a ripple was unstated. It probably had more than a little to do with the fact that the earlier stones were a product of Thai burners, while D-SDTCs were created by heathens from out of town.

Whitewash. A key ingredient of any SDTC is the starting material. Generally this is Sri Lankan sapphire of pale color. But with increased demand for white sapphire from the home shopping networks in the US, prices for the starting material increased significantly. This apparently prompted at least one SDTC producer to look further afield for starting material. According to my source, this company's gaze eventually rested on Czochralski-produced synthetic colorless sapphire. Quantities have apparently been sold, with no reference to the synthetic origin of the sapphire base. It probably just slipped their mind, what with all the worries of running a business.

12. Just how a sapphire receives "surface heat" at 1800–1900°C is one of the great mysteries of science.

Figure 6.19 Red SDTC immersed in di-iodomethane. Note the obvious patchy color concentrated on the surface. (Photo: Tony Laughter)

Seeing red. Ever since D-SDTCs hit the market in 1990, rumors abounded that red SDTCs were in the works. They finally materialized in late 1992, from Richard Pollack of United Radiant Applications, who had a hand in the D-SDTCs (McClure & Kammerling *et al.*, 1993). The reason for the delay in developing the process for red stones has to do with the diffusion rate of titanium relative to chromium, as well as the ability of the coloring agent to color the corundum. Titanium is diffused into corundum far more quickly than either chromium or iron. Once in the gem, it reacts with the iron already present, producing the Ti^{4+}—Fe^{2+} pairs which give a blue color. Only a few hundredths of a percent of titanium is needed to give a rich blue color.

At least one percent chromium is needed to produce a red color of equal depth, but since the color layer is so thin, Cr concentrations approaching fifteen percent or more are necessary in that layer. Such high concentrations actually raise the gem's RI well above the normal range for corundum. When this is combined with the far-slower diffusion rate for chromium, as compared to titanium, it is obvious why red stones are more difficult to create via the surface-diffusion process (John Emmett, pers. comm., 27 June, 1994). An additional conundrum is the fact that the red color begins to become more grayish beyond a few percent Cr concentration, actually becoming green at concentrations beyond about 20% (Nassau, 1983).

Identifying SDTCs (including D-SDTCs)

A visual inspection of diffusion-treated gems is of comparatively little use with regard to their separation from the untreated stones. Deeply colored pieces may at times appear slightly darker around the girdle, due to the concentrations of color at the surface, but natural gems sometimes show a similar appearance.

Identification of SDTCs involves the use of di-iodomethane immersion along with the microscope. The gem is examined with a frosted white filter between the light

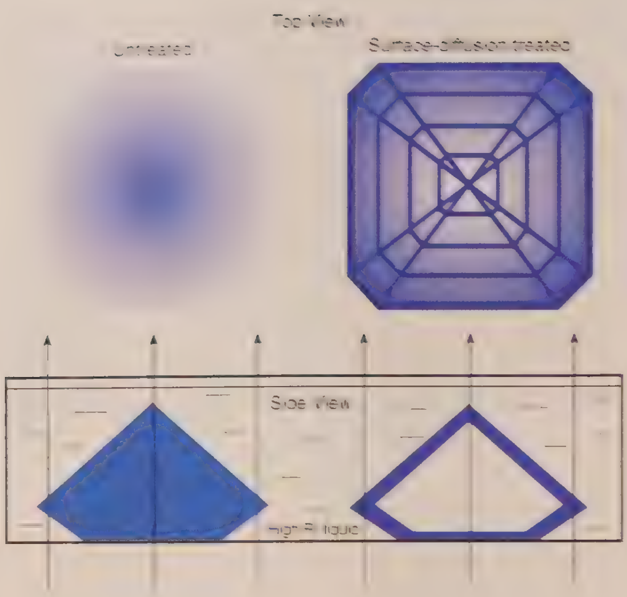

Figure 6.20 When untreated gems are examined while immersed in diiodomethane (left), facet junctions and girdle appear light. If the color is even throughout, color will be darkest at the culet and become lighter towards the girdle because light travels through more and more color towards the center of the gem.

In contrast, the color of SDTCs (right) will be darkest at the girdle because light paths travel through more color at the girdle than anywhere else. Facet junctions will also appear darker because color penetration in the surface-diffusion process is greatest at edges (as opposed to the centers of facets).

and immersion cell (diffuse light-field illumination). Ideally, one will have a known SDTC and a known untreated stone for comparison purposes. One looks for the following features:

- In blue stones, the color tends to be steely, rather than the rich blue of the finest natural stones. This difference, however, is extremely subtle.
- The color of SDTCs will follow the facet pattern of the stone *exactly*. Some facets may be lighter or darker than others, but the color exactly follows the facet pattern of the cut stone. Certain facets may have most, or all, of their color removed by repolishing. Stones may contain substantial internal color, in addition to the thin surface-diffusion color layer just beneath the surface.
- Color is concentrated in a layer at the surface some 0.10–0.50 mm deep (or less). When immersed table down in diiodomethane, this tends to give these stones a darker girdle (unless cutters have tried to avoid detection by heavily repolishing the girdle itself and the girdle facets). *Be careful not to confuse reflections from a thick girdle with the surface color concentrations of a true SDTC.*
- Facet junctions, girdles, culets and other edges will show color concentrations under immersion. This is because color penetration is greater at edges when compared to the center of a facet.
- Pits, cracks, healed cracks (fingerprints) and cavities which break the surface will show a bleeding of color into them. Cracks offer a ready means for penetration of colorants, while pits and cavities are not touched during the repolishing process.
- In addition to the above, one may encounter any of the other features typical for heat-treated corundums. Keep in mind that SDTCs may contain substantial [illegible] color of their own (not resulting from the surface-[illegible] process).

In most cases, immersion will read[illegible] diffusion-treated stones. However, on occasion, [illegible] stones are encountered in which the color is also [illegible] primarily at the surface. Examples of this are the *ottu*-type blue sapphires from Sri Lanka, which when uncut possess a blue skin around a colorless core. Stones of this type should be carefully examined while immersed for color zoning in the surface areas. Although zoning may also be found in the treated stones, it will not be sufficient in quantity to account for the depth of the stone's color, nor will it be located in the deeply colored surface regions. In addition, *ottu* stones do not display color on every cut surface, like most treated stones. If all of the color of the treated gem is removed from some facets during repolishing, it can still be identified because of the highlighted facet junctions and the patchy nature of the remaining colored areas.

Surface repair (surface infilling)

Among those who truly understand the business of gemstones, few will admit an envy for the task faced by the lapidary. Their job involves the creation of the most beautiful gem possible while, at the same time, recovering the maximum amount of weight from the rough. Such is an enormously difficult proposition, considering that each of these ideals can only be achieved at the expense of the other. Thus, success for the lapidary is measured in terms of an ability to strike a delicate balance between beauty and size.

When working with costly materials such as ruby and sapphire, particular attention must be given to weight retention. Because of pressures to squeeze every last point from the rough, cutters may be forced to retain small surface defects, such as pits and cavities. It is simply a case of the lesser of two evils, for although grinding them away completely will make the gem more attractive, this improvement is often not enough to offset the weight loss that results. The presence of surface pits should indicate not a lack of skill on the part of

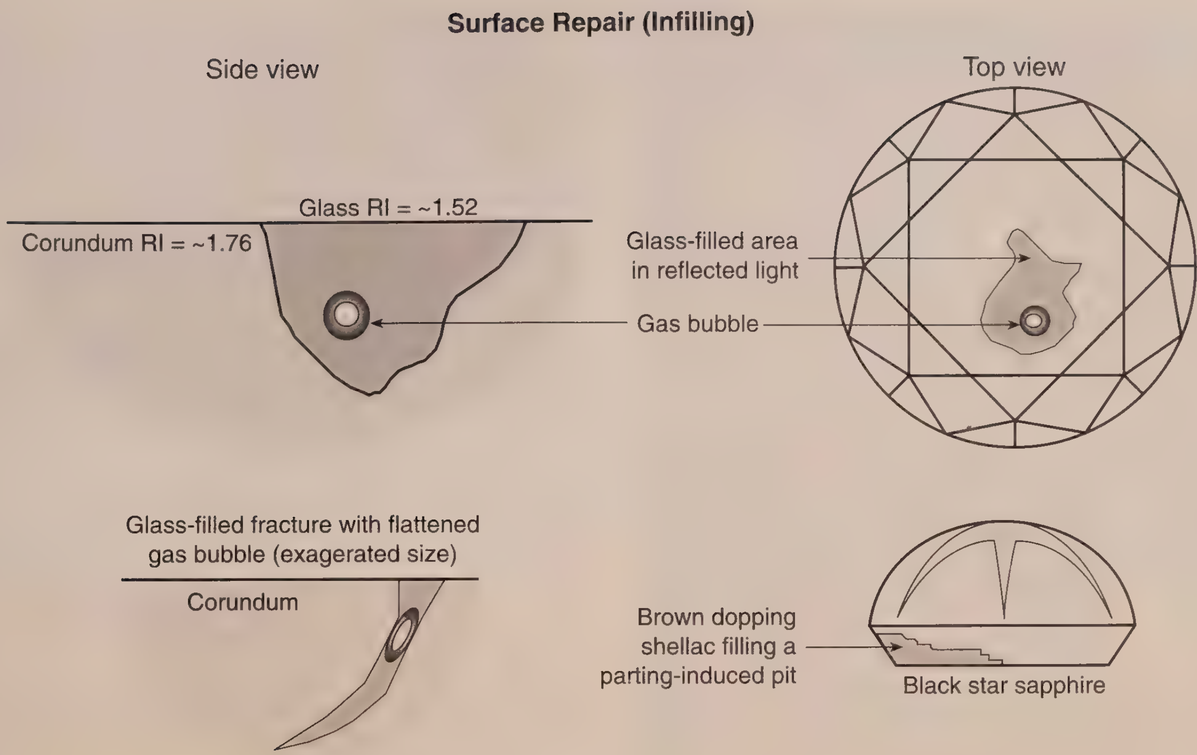

Figure 6.21 Various forms of surface repair (infilling)
Top: Glass-infilled areas on surface-repaired corundum. In reflected light (right), filled areas will show a lower luster than the surrounding corundum, due to their lower RI.
Bottom left: Glass may also be used to infill fractures, thus reducing their visibility. Such filled fractures often have flattened gas bubbles trapped in them.
Bottom right: Brown dopping shellac infilling on black-star sapphire. Such shellac is easily dissolved by soaking in alcohol, and will melt with the hot point.

the cutter, but evidence of the difficulties in turning a profit within this highly competitive business.

While competition is vital in any business, fueling the search for the better mousetrap, not everyone plays by the rules. During the first six months of 1984, Ken Scarratt in London and the author in Bangkok discovered rubies in which the surface blemishes had been filled in with a transparent, colorless glass. (Scarratt, 1984; Hughes, 1984a-c). Dubbed *surface repair* or *infilling*, it represented a new method of dealing with an old problem.

Details regarding the treatment method were supplied to the author by someone who had talked to a man performing surface repair on rubies. This gentleman from Chanthaburi was primarily involved in the heat treatment of yellow sapphires from Sri Lanka and claimed to be the first person in Thailand to treat rubies by surface repair. According to him, surface repair involves applying a silica-based gel to the surface of cut stones with a paint brush in the areas to be repaired. The stones are then heat treated, turning the gel to glass and fusing it into the pits and cavities in the process. He claimed that his surface repair jobs were superior to all others as the glass adhered tightly to the surface, not falling out like those of other burners.

Kane (1984) has reported that analysis of the glass reveals a composition similar to patented processes described in Yaverbaum's *Synthetic Gems Production Techniques* (1980), regarding glossing synthetic corundum and spinel rods. Certain glasses may form solid solutions with or have a chemical affinity to corundum, which means that they easily flow into all narrow nooks and hollows and adhere tightly. Such glasses include oxides of calcium, magnesia, sodium and silica (silicon dioxide), making them perfect candidates for surface repair.

Koivula (n.d.) has suggested that Yaverbaum's book of gem patents represents, in effect, a burner's cook book, which has been steadily explored for new ideas and processes. However the idea of filling in surface cavities with a foreign substance is not totally new to the trade. In the past, a number of different materials including epoxy and dopping shellac have been used to hide unsightly defects, particularly on cabochon-cut black-star sapphires. The basal parting so common in that material often results in breakage during cutting. Such breaks are often disguised in Thailand by infilling with a brown dopping shellac.

To date, almost all of the surface-repaired stones using glass have been rubies, with a handful of blue sapphires also

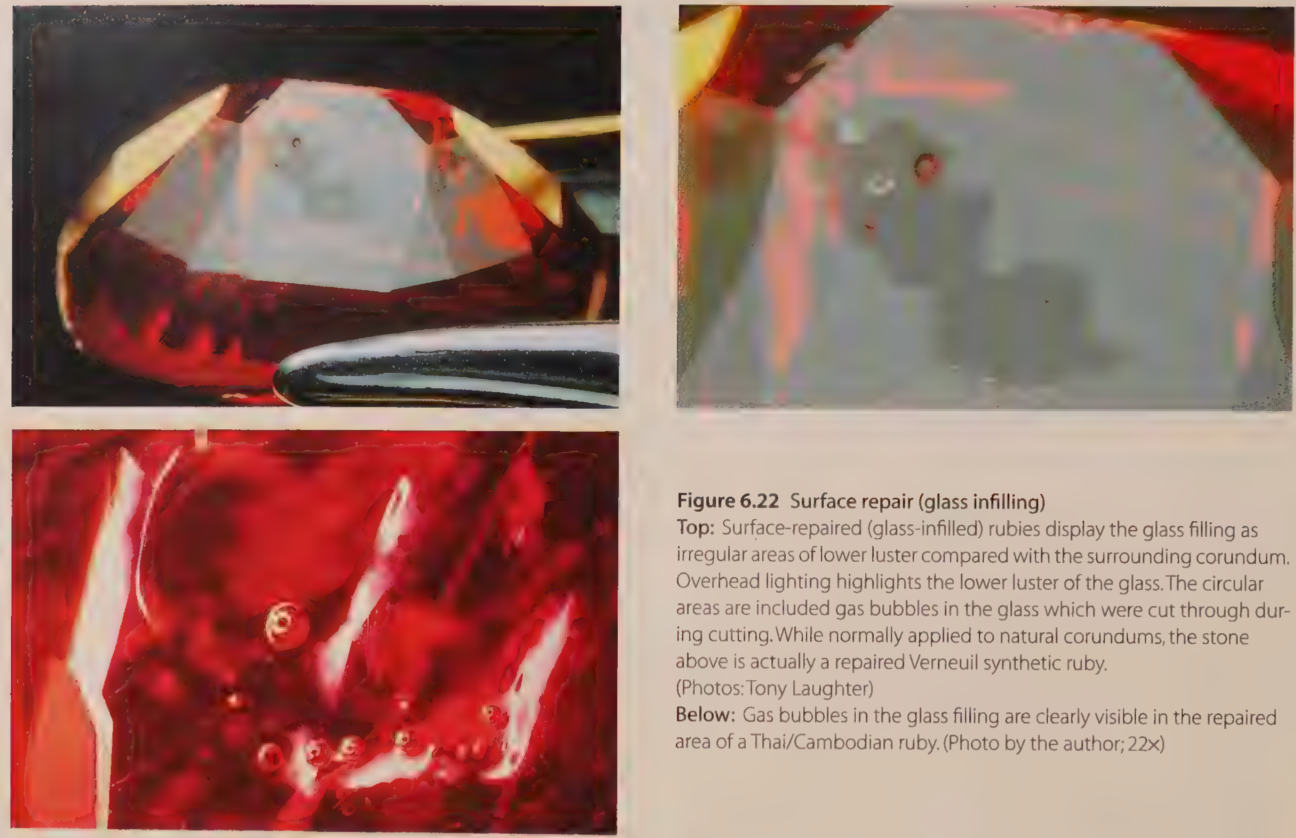

Figure 6.22 Surface repair (glass infilling)
Top: Surface-repaired (glass-infilled) rubies display the glass filling as irregular areas of lower luster compared with the surrounding corundum. Overhead lighting highlights the lower luster of the glass. The circular areas are included gas bubbles in the glass which were cut through during cutting. While normally applied to natural corundums, the stone above is actually a repaired Verneuil synthetic ruby.
(Photos: Tony Laughter)
Below: Gas bubbles in the glass filling are clearly visible in the repaired area of a Thai/Cambodian ruby. (Photo by the author; 22×)

appearing.[13] But any variety of corundum can be treated in a similar manner. Since dealers learned that identification of surface repair is easy, these stones have largely disappeared from the market. Today it is far more common to see accidental infilling (as a by-product of heat treatment, where molten material flows into surface pits) than deliberate.

Identification of surface repair

Since surface repair improves the apparent quality of the stone, reducing or eliminating the visibility of surface defects and increasing the weight of the stone, it cannot be considered acceptable unless the buyer is made aware of its presence and extent at the time of purchase. The detection of surface-repaired rubies and sapphires can be readily accomplished by noting the following factors.

- Differences in luster between the glass filling and the surrounding corundum under an overhead light.
- Differences in relief between the glass (RI = ~1.52) and corundum (RI = 1.762–1.770) when immersed in di-iodomethane.
- Inclusions of spherical gas bubbles within the glass filling.
- The (generally) colorless nature of the glass filling.

Initially, the surface of the suspect stone should be examined under magnification with an overhead light, such as that from a fiber-optic illuminator. Due to their different luster, repaired areas will be visible when the stone and light source are positioned such that light falling on the surface is totally reflected to the eyes. This discrepancy in luster is due to differences in refractive index and polish between the glass filling and surrounding corundum.

Should a surface examination fail to reveal repaired areas, immersion in di-iodomethane is necessary. The difference between the RI of the glass filling and the liquid and gem causes repaired areas to stand out in bold relief at certain oblique angles of viewing. Particular attention should be given to the girdle, culet and pavilion, for it is these areas which most often possess cavities. One must also check all open cavities, for if the glass does not fill them completely, as is often the case, they may go undetected in the initial dry examination.

The colorless nature of the glass filling is not normally apparent in surface-repaired gems. Only if a repaired area penetrates completely the girdle or culet can this be seen, and even in this event the gem must be immersed. Gas bubbles within the glass, however, should be visible during both dry (dark-field illumination) and wet (diffuse light-field illumination) examinations, as well as ordinary dark field. In addition, repaired areas may exhibit spherical cavities formed as a result of included gas bubbles breaking the surface.

Since the original discovery was made, the author has encountered many stones in which repaired areas constitute

13. The first surface-repaired corundum reported was a 16.63-ct heat-treated blue sapphire submitted to the London Gem Testing Laboratory in 1976 (Scarratt, 1983).

only a tiny fraction of the entire gem, having virtually no effect on weight or appearance. The only possible explanation is that infilling occurred accidentally during heat treatment or perhaps such stones were part of a larger lot treated *en masse* while still in the rough state. Hence, after treatment and cutting, the gems would show varying amounts of repaired surfaces, some more, and others less.

Rubies and sapphires are not generally heat treated after cutting, but ideally before cutting. This allows the cutter to make better use of the material, for by cutting the gem after heating, the lapidary can remove flawed areas caused by the burning, or conversely, incorporate areas of fine color and/or clarity which might be removed if the cutting were performed first.[14] If the surface repair was applied to cut stones only, it would then be extremely difficult to explain how such large repaired areas (as have often been found) were produced, because it is not often that a cutter will leave large gaping cavities in prominent areas on a finished gem.

One final note in regard to surface-repaired stones concerns separation of repaired areas from included crystals which sometimes break the surface. Since foreign solids may also show gas bubbles and different luster and relief when breaking the surface, confusion is possible. In such cases it is best to simply indicate the presence and extent of the filled areas, leaving open the question of whether or not they resulted from natural causes, an accidental by-product of heat treatment, or intentional filling of surface defects.

Glass infilling of cracks

Since the *de facto* acceptance of treated corundums in the market in the early 1980s, treaters have busied themselves experimenting with other processes. The author first encountered glass fracture-infilling of rubies in June of 1987 (Hughes, 1988c). Starting in 1993, with the widespread appearance of Mong Hsu (Burma) rubies in Bangkok, gemologists began to encounter rubies containing filled fractures in quantity (Peretti, 1993). This treatment is being performed in Bangkok (Wimon Manorotkul, pers. comm., March, 1994) and is similar to the Yehuda fracture-infilling of cracked diamonds (Koivula & Kammerling *et al.*, 1989). The filling appears to be a glass of unknown composition, and can be identified when it breaks the surface, by reference to its lower luster. Fillings deep within fractures are more difficult to identify. Reference to flattened gas bubbles within the cracks is one method. It should be noted, however, that ruby from the Mong Hsu area of Burma has been found to contain apparently natural fracture fillings of unknown identity (Smith & Surdez, 1994). These can be easily confused with artificially-induced fracture fillings.

14. The exception to this is with extremely dark stones. These may be preformed/cut before heating to reduce heating time and increase the amount of stones which fit into a crucible (Themelis, pers. comm., 1994).

Irradiation

Irradiation-induced color in gemstones results from point defects in a crystal which have the ability to absorb light. These are termed *color centers,* and involve an electron missing from its normally-occupied position (*hole color center*) or the presence of an extra electron (*electron color center*). In order for a material to have color centers, it needs both electron donors (termed *hole-center precursors*) which can eject electrons during irradiation, and electron receivers (termed *electron-center precursors*) to trap the freed electrons. If both centers were originally neutral, the transfer of this electron produces a positive charge in the hole center and a negative charge in the electron center, leaving a single unpaired electron in each. Either or both unpaired electrons can now become excited by absorbing energy from white light, thus creating color (Nassau, 1984b). Currently, further study remains to be done before the exact nature of the color centers in sapphire can be fully understood. Mg impurities have been suggested as a possible source for color centers in corundum by Emmett & Douthit (1993).

The irradiation of the corundum gems involves their exposure to one of three principle types of electromagnetic radiation: shortwave ultraviolet (253.7 nm, 5 eV), x-rays (typically 10,000 eV), and gamma rays (typically 1,000,000 eV). (Nassau, 1984b) This bombardment causes, in suitable varieties, formation of color centers, and a subsequent change in color. Although other types of radiation will produce similar results, it is those just listed which are most often employed with corundum.

The first mention of corundum irradiation was that of Walter (1908), who mentioned experiments performed by Herr E. Ambrecht in London. Exposure of corundum to radium salts was found to deepen the color. Miethe (1912) experimented on a variety of natural and Verneuil synthetic sapphires and found that pale Sri Lankan stones became deep yellow upon exposure to radium salts. Similar, but less dramatic changes were produced in synthetic colorless sapphire. Unfortunately, such changes proved transient, the color fading back to its original state upon exposure to daylight.

Pough & Rogers found similar results in 1947. While studying the color changes produced in gems when bombarded with the, then new, high-intensity x-ray unit, they were completely taken aback by the metamorphoses of Sri Lankan sapphires. After only five to ten minutes exposure, the pale-colored or even completely colorless gems deepened to a rich amber hue. Less dramatic were the changes of more deeply colored varieties. Blue sapphires turned a muddy green, but the light lilac stones acquired a pinkish orange color reminiscent of that most desirable of sapphires, the padparadscha. Later, Webster (1950) found that certain colors of Verneuil-produced synthetic corundum (particularly

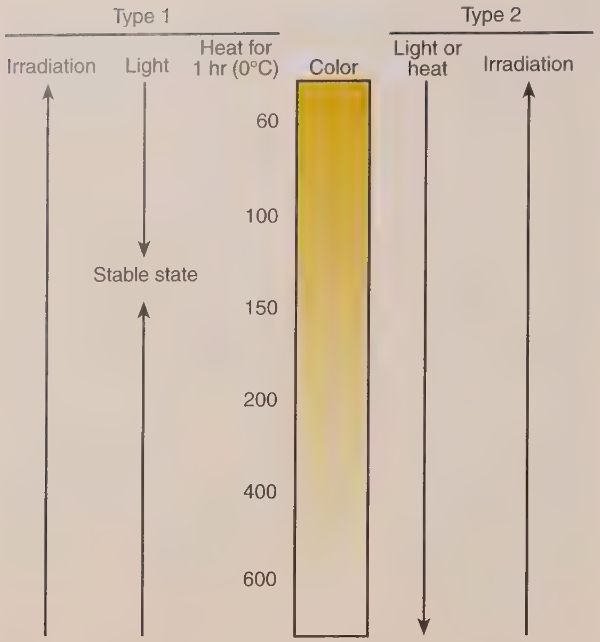

Figure 6.23 The fading behavior of Type 1 and 2 yellow/orange sapphires compared. Type 1 represents a natural stable color center, while Type 2 is a natural or human-irradiated *unstable* color center. In both types, irradiation deepens the color, and heating produces bleaching. But with Type 1 stones, exposure to daylight returns the color to its stable state. (After Nassau & Valente, 1987)

colorless) were also susceptible to irradiation-induced coloration. Alas, the pipe dream ended when it was discovered that in both natural and synthetic corundum the radiation-induced colors were unstable, fading rapidly upon exposure to either heat or light.

The color centers of some minerals, for example amethyst and blue topaz, are strong enough to be completely stable to light. Others, as in *maxixe* beryl, may fade because visible light or mild heating gives enough energy to free the trapped electron, returning it to its original site. In the yellow sapphires from Sri Lanka, both fading and non-fading color centers can be present. Human irradiation of pale yellow or colorless sapphires from Sri Lanka generally produces an intensified yellow color which fades rapidly upon exposure to light or heat. This is the fading color center. Reliable sources in Sri Lanka have also told of yellow sapphires which faded soon after being dug from the gem pits, and others have spoken of temporary fading from the heat of dopping. Yet the color of other deep yellow stones examined by the author has remained intact even after long exposures to the heat and light of a 150-watt spotlight. Apparently the color of certain Sri Lankan naturally yellow sapphires is stable to both light and moderate heat.

If heated to a sufficient temperature, the non-fading color centers can be bleached just like the fading type, but more than 500°C is needed to do the job, compared to 200°C for the unstable kind. In both cases, the color can be restored by irradiation, if the color centers have not been totally destroyed by overheating. Nassau (1982) has reported cases where the stable color centers were accidentally bleached by heating. At his suggestion the sapphires were irradiated, turning them a deep brownish yellow that then faded back to the original stable medium yellow. Thus, in this case, the irradiation created not only the non-fading color center, but also the fading color center. It was this unstable color center that was bleached by the light.

The seven types of yellow sapphire

In 1987, Nassau & Valente completed a detailed study of yellow to orange sapphires. The results suggested that there exist seven different types of yellow/orange sapphires, as follows (typical sources in parentheses):

Type 1	Natural stable color center (Sri Lanka)
Type 2	Natural or laboratory-irradiated fading color center
Type 3	Natural iron-produced stable color (Thailand, Australia, Tanzania)
Type 4	Heat treated stable color (Sri Lanka)
Type 5	Surface-diffused additive color
Type 6	Synthetic with impurity-caused color (Verneuil, Ni-doped)
Type 7	Synthetic with laboratory-irradiated fading color center (Verneuil)

One unusual discovery was that the color of Type 1 sapphires could be altered by either heat or irradiation. Heat (one hour at 150–600°C) produced a fading of the color, while irradiation deepened it. However, in both cases exposing the stone to light (typically two days in the bright California sun, or longer under less bright conditions) caused the color to return to its original stable state. In Type 1 sapphires there apparently exists a stable color state (which may vary from colorless to deep yellow or orange) and sunlight returns the stone to this state no matter whether the color was bleached (via heat) or deepened (via irradiation).

This effect is similar to that reported by Crowningshield (1969). He took a customer's sapphire that had accidentally faded from overheating during jewelry manufacture, and irradiated it with x-rays. At the same time, four pale yellow sapphires from the lab (which had not been heated) were also irradiated. All stones deepened in color. They were then taped to a window for several days' exposure to sunlight. The customer's stone retained its color, but those from the lab faded.

The behavior of both Type 1 and Type 2 yellow/orange sapphires is shown in Figure 6.23.

Radiation sources

When shortwave ultraviolet light is used to irradiate a specimen, only the surfaces are affected, due to the less energetic nature of the medium. This imparts a color which is but "skin deep," causing the gem to appear slightly darker

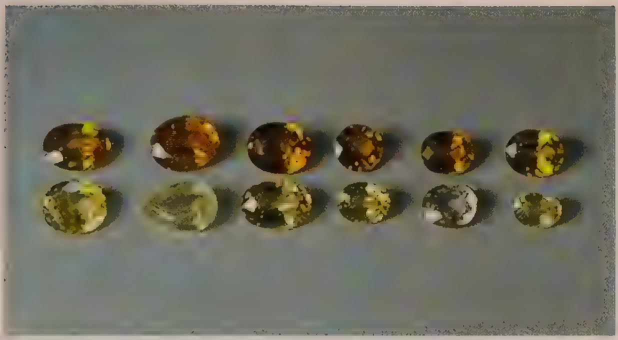

Figure 6.24 Fading behavior of irradiated Sri Lankan yellow sapphires Stones in the top row are pictured before fading and those in the lower row have been subjected to a fade test. (Photo: Tony Laughter)

around the girdle. The same effect can be seen when x-rays are used, but to a lesser degree, as they achieve greater penetration.

Of the various radiation sources commonly used for treating sapphires, by far the most effective is the gamma ray cell, which can color a gem from top to bottom. This consists of a large lead shield surrounding a central cavity, within which are rods, plates, or pellets of a highly radioactive isotope, typically cobalt 60. One hundred times more energetic than x-rays and 200,000 times greater than shortwave ultraviolet, gamma rays can induce a deep golden yellow color into a pale Sri Lankan sapphire in a matter of minutes. Furthermore, the gamma ray-induced color penetrates the gem from top to bottom, whereas that of x-rays or shortwave ultraviolet is largely confined to the surface regions. Indeed, at Colombo Hospital, home of Sri Lanka's only cobalt 60 unit, a steady stream of customers can be found on any given day, their pockets bulging with "patients" awaiting therapy.

Fade tests

Sapphires from Sri Lanka (and the colorless Verneuil synthetics) are most commonly susceptible to irradiation. Even among Sri Lankan sapphires, not all will respond. Best are the colorless or pale yellow stones, which may turn a rich golden yellow. Gems of a pink color, due to traces of chromium, sometimes change to the pinkish orange padparadscha hue. Robert Stevenson, a Bangkok dealer, once told of being shown a truly extraordinary gem by a broker in Colombo; a star padparadscha! Naturally suspicious of such a rarity, he reached for his *Bic*,[15] and with a quick flick, struck the flame. A rather drastic course of action, to be sure, but also revealing. Under the heat of the flame, this once-lovely flower quickly wilted, leaving the broker looking like a boy who had just found a lump of coal in his Christmas stocking. He picked up his fallen beauty and then exited posthaste, mumbling something about an appointment at the hospital.

> [On having the Ptolemaic system of astronomy explained to him] If the Lord Almighty had consulted me before embarking upon Creation, I should have recommended something simpler.
> Alfonso X. (The Wise), King of Castile and Leon [1252–1284]

Unfortunately, facts are not always convenient. Contrary to what the author reported in the previous edition of this book, the fade test cannot determine whether the color of a Sri Lankan yellow/orange sapphire is the result of human irradiation, or natural irradiation in the ground (Kurt Nassau, pers. comm., 25 Aug., 1994). All that can be determined is whether the color is generally stable under normal wearing conditions.

Light-only fade tests. In performing a fade test, only light should be involved, not heat. Subjecting the gem to heat not only runs the risk of damaging the gem through thermal shock (many Sri Lankan sapphires contain CO_2-filled negative crystals which may explode upon heating; see Koivula, 1986), but may also produced fading in gems which are otherwise generally stable to light (Kurt Nassau, pers. comm., 19 Aug., 1994).

A safe fade test (light only) involves placing the gem approximately 15 cm from a 100-watt frosted light bulb.[16] So that it is exposed to light alone, not heat, a small cooling fan (such as that used in electronic devices) is placed next to the stone. 48 hours of such exposure is roughly equivalent to ten years or more of normal jewelry wear (Kurt Nassau, pers. comm., 25 Aug., 1994). Such a test will generally produce some fading in light-sensitive yellow-orange sapphires within a few hours or less. The color of non-light sensitive gems will not be affected. Contrary to some published reports, one should not attempt a fade test by exposure to ultraviolet light, as shortwave UV, in particular, may deepen the color.

Light + heat fade tests. If evidence of heat treatment is seen in Sri Lankan yellow/orange sapphires, confirmation can be found by subjecting the stone to a fade test involving heat and light. Specimens which have had their color altered via high-temperature heat treatment suffer a temporary darkening, as previously described.

Dyes and oils

One of the oldest treatments known is that of dying (staining). Single crystals which are cracked (or polycrystalline materials with grain boundaries) allow penetration of liquids. Colored liquids (dyes) can alter the color of the finished gem. Oils (liquids of higher RI) can help to reduce visibility

15. Butane cigarette lighter.

16. Before performing this test, it is essential that the gem be examined with the microscope to ensure that there are no potentially-explosive negative crystals.

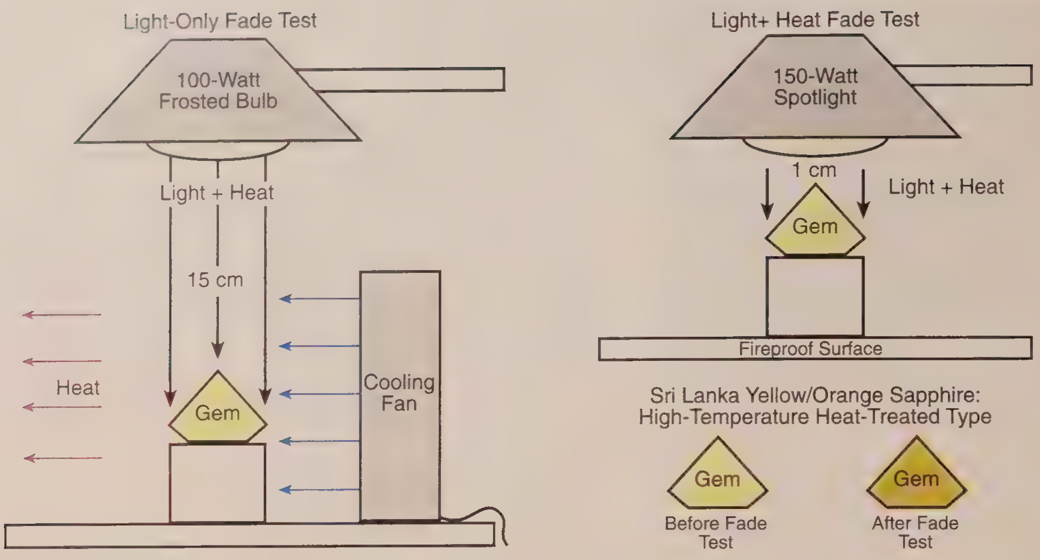

Figure 6.25 Fade tests
Left: In performing a normal fade test, one must ensure that the specimen receives only light, not heat. Thus the gem is placed approximately 15 cm from a 100-watt frosted bulb, with a small fan positioned to cool the gem.
Right: To confirm the presence of high-temperature heat treatment in Sri Lankan yellow/orange sapphires, the gem is placed within 1 cm of a 150-watt spotlight. After approximately 15 minutes exposure, the color of Sri Lankan yellow-orange sapphires which have had their color altered through high-temperature heat treatment will be noticeably darker and more brownish. Note that this technique may cause damage (via thermal shock) or color loss in non-heat treated specimens.

of fractures by replacing air (n = 1.0) with a liquid of an RI (typically n = 1.4–1.6) closer to that of the surrounding gem, thus reducing reflection. Even colorless oils can improve color by reducing reflection from inclusions, thus allowing longer light paths and more absorption. Colored oils may be used as a two-pronged attack on color and clarity.

Figure 6.26 Although much discussed, oiling of corundums is not a big problem, as most stones do not possess the necessary cracks to take the oil. In many Asian gem markets, the oil serves merely to gloss the surface of rough, rather than to deceive. A quick dip in acetone will remove all traces of such surface oiling.
Left: Two different varieties of ruby oil to be found in Thailand's Chanthaburi gem market. (Photo: Mike Havstad/GIA)
Right: Ruby oil and Mong Hsu rubies at the market in Taunggyi, Burma, ca. 1991. (Photo: Tony Laughter)

Contrary to the many trade reports describing colored oils, these treatments are of little importance for ruby and sapphire. The reason is simple—unlike emeralds, rubies and sapphires of good quality do not possess the network of fine cracks necessary for the introduction of dyes and/or oils.

It is true that many lapidary supply shops in the gem-trading town of Chanthaburi, Thailand sell a variety of local-brand ruby oils and other gem elixirs guaranteed to put a smile on your ruby. But these are not generally used with faceted stones. Instead, such oils are applied to rough, not so much to influence the color, which in the case of Thai ruby is already even and intense, as to add sparkle and shine to the otherwise dull, unpolished surfaces.

The application of red oil to rough ruby in Thailand is generally performed in a very high tech manner, by simply pouring it on the stones at room temperature. Again, this is consistent with the aim—to improve the surface luster—rather than to impart color. At the early morning rough markets held throughout Thailand's ruby mining districts of Chanthaburi and Trat, it is not uncommon to see traders putting their stones up on the rack for a quick lube job, and bottles of ruby oil are to be found atop many tables, next to the small piles of uncut ruby. The oiling of rubies in this manner has very little to recommend it, as it rarely penetrates the fractures and so is, for the most part, removed during cutting. If it is feared that the oil is affecting a gem's appearance, soaking the stone in alcohol, acetone, or another suitable solvent should resolve any doubts about its true color. In

Figure 6.27 Dyed corundum
Top left: This multiple strand of 6–7 mm-diameter red beads actually consist of pale sapphires dyed red.
Top right: A bead removed from the above necklace and sliced in two. The right half is dyed, while that at left has had the dye removed with acetone. (Photos: Nicholas DelRe/GIA)
Lower right: Dyed ruby cabochon in normal lighting (above) and with SW UV (below). Dyed red areas tend to fluoresce a chalky bluish white (note that the dye, and thus the fluorescence, is concentrated in the fractures). (Photos: Tony Laughter)

rare cases, rubies have been examined in which oil did penetrate the fractures. This was clearly visible under magnification as dark red stains in the cracks.

The exception is in regard to rubies and sapphires traded in the Indian subcontinent, where dying and oiling are ingrained traditions on the order of scattering one's ashes in the Ganges river. Witness the statement made in Jaipur's *Journal of Gem Industry* (Anonymous, 1976), where it was suggested that, when dealing with dyed rubies, "the packing material used in wrapping these stones never be absorbent, if good customer relations are desired."

Heavily-included rubies and sapphires of pale color from India, Pakistan and Sri Lanka are often dyed with a colored oil to deepen the color. Similarly, Indian star rubies are filled with cracks which allow easy entry for dyes and oils. And let us not forget the strings of ruby beads from India. These often consist of little more than pale sapphires dyed red and strung on a red string (just to make sure).

Immersion in di-iodomethane will uncover dyes (with color concentrated in cracks), as will examination under UV light if the dye fluoresces (the red dyes generally fluoresce a strong orange, with such fluorescence confined to cracks). Regarding the detection of dyes in heavily-included stones, careful use of the hot point will often resolve the issue. Under magnification, when the hot point is applied close to a fracture at the stone's surface, trapped air bubbles in the dye will be seen to move and some dye/oil may even drip out.

If pale material is used, dyed stones will show dichroism inconsistent with the depth of their color, with the dichroism of dyed stones far weaker than undyed stones of similar body color.

Figure 6.28 Surface coating
One of the simplest and oldest treatments is simply applying a surface coating. In the case of the above stone, it was initially represented as an SDTC, but a quick touch on the lap revealed the color to merely consist of a coating. (Photo: Tony Laughter)

On occasion, stones possess cracks containing colored stains of apparently natural origin. At other times, the origin of the stains may be uncertain. Regardless of origin, if the stain does influence the color of the gem, it is important that the buyer be informed, both of its existence and the extent to which the gem's color is affected.

Surface coatings & stains

One of the most simple treatments is to take a pale colored stone and apply a bit of ink or paint right at the culet. The result is an immediate deepening of color. The author saw this on one heat-treated blue sapphire from Sri Lanka where the bottom one third of the pavilion had been coated with a blue substance resembling ink. Although easily detectable, even with a 10× loupe, this crude fraud could fool the unwary, particularly if the stone were mounted.

In Sri Lanka, a common trick is to embed a pale-colored crystal under the surface of the Goraka tree.[17] After several days, the stone is removed, complete with a deceptive yellow surface stain created by the tree's saffron-colored resin. Blue stains are created by rolling the stone in blue carbon paper. Each of these stains may be detected by rubbing the stone with a white cloth wetted with machine oil or some other suitable solvent. The stain will rub off onto the cloth (Coughlin, n.d.).

Disclosure: Rebottling the treatment genie

> A truth that's told with bad intent, beats all the lies you can invent.
>
> William Blake [1757–1827], *Proverbs*, Line 95

To tell or not to tell. That is the question which has haunted so many of those involved in the ruby and sapphire business over the past twenty years. It is a matter of great importance indeed, as a number of countries make disclosure of all treatments a requirement by law. Clearly, the handwriting is on the wall. If the trade does not act on the disclosure issue, governments will do it for them.

There is general agreement that nonpermanent treatments such as irradiation, surface diffusion, surface repair, oiling, and dying should be disclosed. However, many would draw the line at permanent treatments involving heat. Opponents of treatment disclosure feel that it is unnecessary and will only confuse the customer, eventually hurting business. They believe that so long as a treatment is permanent there is nothing to worry about and the whole treatment controversy is so much needless fuss by a group of consumer witch-hunters.

Is it really, though? The most important factor in maintaining the values of precious stones is the rarity. To see that this is true we need only look to the lowly flame-fusion synthetic corundum. A Verneuil-produced synthetic ruby is a ruby in every sense, with the same hardness, durability, color permanence and beauty as nature's own. However, because it is produced in almost limitless quantities, its cost is pennies per carat. The major factor separating it in price from the natural stone is rarity, and should deposits of natural ruby be discovered which yield quantities similar to the synthetic production, we could expect that its price would also drop to a similar level. Fortunately for those who own or deal in natural rubies, this possibility is remote, at best.

Although many would deny it, the additional quantities of ruby and sapphire produced by treating inferior material also have an impact on both supply and thus, price. However, since the amount of treatable rough is limited, this impact is also limited. The heat treatment of yellow and orange sapphires from Sri Lanka was not widely practiced before 1981. Previous to this, a fine, naturally colored, deep yellow/orange sapphire from Sri Lanka of five carats fetched US$400/carat, or more, at the wholesale level. Today, the same stone would bring only a fraction of that amount because it must compete against heat-treated Sri Lankan sapphires. It is an unfair competition, to say the least, for the treatment process yields deep, orangy yellow colors with unnerving frequency, colors that were almost unheard of before 1981. If, however, a distinction were to be made between the natural and treated gems, it could be sold for what it is: a rare, naturally colored, deep yellow Sri Lankan sapphire.

History lesson

Gem treatments are old, ever so. Exactly when it was discovered that the appearance of gems could be altered is lost in the mists of time; certainly it wasn't much after humans started killing one another over these rocks. After all, if one can take a more common, cheaper gem material and pass it off as the rare and valuable type, then why not, right?

17. This tree's leaves and fruit are used in curries.

Cultured vs. natural pearls: What's the difference?

TO many people, treated gems seem little different than the natural. They are convinced that such differences that do exist are largely academic. So just what are the differences? Let me illustrate with the natural vs. cultured pearl. A natural pearl generally consists of 90% or more of nacre, the pearly substance. Nacre is made of layers, with approximately 1000 layers per millimeter. A pearl of 10 mm size (5 mm radius) would thus feature approximately 5000 layers of nacre. As typical growth is 1 mm per year, this would take about ten years to form.

In contrast, cultured pearls feature a shell bead coated by only a thin layer of nacre. The thickness of this nacre layer in today's Akoya cultured pearls averages only 1 mm. Thus a cultured pearl of 10 mm size would have only 500 layers of nacre, ten times less than the natural pearl. It would take but one year to grow.

Now consider the factors which make a pearl valuable. They are essentially beauty and size. Beauty is affected by color, shape, orient, luster, translucency and freedom from blemishes and other defects. For both beauty and size, rarity is important (the more beautiful are more rare, the larger are more rare). Fine color alone is not as rare as fine color combined with large size. If fine appearance (color, shape, luster, etc.) is only found in one out of a thousand pearls, and if only one out of a thousand is above 10 mm in size, the rarity of a 10 mm pearl of fine appearance would be on the order of one out of a million (1000 × 1000). Look at that number again—*it is not an exaggeration.*

Now let's apply this to cultured pearls. The beauty factors and their rarity would be similar to natural pearls, but the size and shape factors are completely different. Since the bead nucleus is perfectly spherical, round cultured pearls are far more common than in nature. Since the size of a cultured pearl is largely dependent on the size of the bead nucleus, cultured pearls of large size will again be far more common. In the 10–14 mm sizes, this frequency is increased literally hundreds of thousands of times. Mention this the next time somebody tells you the only difference between a natural and cultured pearl is that one is started by nature, the other by humans.

Treated gemstones, such as heated rubies and sapphires, are no different. Again, the natural stone is incredibly rare, thousands or even hundreds of thousands of times more so than the treated stone. But the difference in price tends to be small, if any.

Unfortunately, buyers see it differently. Buyers tend to place those who misrepresent adulterated gems alongside highwaymen, tax agents and other types of low-life scum who deserve to be hung by their scrota in the heat of the noonday sun. And since the purchasers of most gems in ancient times were kings or nobles, this was exactly the position in which sellers were often found when they didn't tell their customers that that righteous piece of lapis actually owed its color to blue dye. Although the fate of the jeweler who sold King Hiero the under-purity gold crown that Archimedes tested was not recorded, I don't think he did many lunches with Hiero (or anyone else) after the discovery.

Show and tell

This was how it was in the past. If you were gonna show, you had to tell. The sale of treated stones was regarded as fraudulent if the buyer was not informed of the treatment when the purchase was made. Yes, there were plenty of cases where a particular treatment could not be detected, in which case buyers were ripped off. But you can bet your family jewels that, if and when the buyer did find out, those of the seller would be hangin' high mighty quick.

Misrepresentation of cultured pearls—sowing the seeds of destruction

The first cracks in this policy occurred with the introduction of the cultured pearl early in this century. In the beginning, cultured-pearl producers tried to pass off their product as totally natural. But when it was proved that a cultured pearl was quite different from the natural, the producers took a different tack. Through the use of subtle misinformation they managed to bury the crucial difference between natural and cultured pearls in the minds of the public, the fact that one product is altered by humans, thus distorting its true rarity/value. With that difference gone, the result was swift in coming—the complete and total death of the natural pearl. According to New York dealer, Maurice Shire (1982), from 1880 to the late 1920s, natural pearls represented 80% of the fine retail jeweler's turnover, surpassing even diamonds. Today, they form far less than 1% of the gem and jewelry market. Few of our children will have the opportunity to gaze upon a fine natural pearl, a sublime beauty like no other. Only those who have personally experienced this miracle can testify to the depth of the crime. As Maurice Shire once said:

> In 1928 there had been about three hundred natural pearl dealers in America, by 1960 there were about ten and today [1982], unfortunately, only two or three. Let us pause and think for a moment how the deception, misrepresentation and bad faith of the cultured pearl promoters of that era [1930–1960] actually destroyed a beautiful branch of the jewelry industry.
>
> Maurice Shire, 1982

Death of the natural gemstone

Act Two in the gem treatment tragedy took place in the 1970s in Bangkok, with the large-scale introduction of high-temperature heat treatment of corundum. While treated gems have long been bought and sold, the gem trade never developed clear and unambiguous labeling terminology for such products. Instead, it dealt with them on an individual basis, bestowing the princely kiss on some, while giving the kiss of death to others.

Compare ordinary heat treatment and surface diffusion. Both involve heating corundum to near the melting point while surrounded by other elements. In physical terms, they are identical. But since the surface-diffusion treatment is far more effective, making it possible for virtually any pale sap-

Table 6.3: Arguments for and against treatment disclosure

Arguments against treatment disclosure	For disclosure
Some treatments merely duplicate nature.	All synthetic gems duplicate nature. Does this mean that we can now sell synthetic gems as natural?
Heat treatments merely act upon the potential already existing within the stone.	Any human being has the potential to be a genius. Few live up to it.
The stone could have changed in the ground if it remained buried just a little longer.	I could also be the King of England, but I'm not. If someone believes that a gem could have changed color in the ground, bury it and see just how long it takes.
The colors produced are permanent and will not fade with time.	The colors of synthetic gems are also permanent. Does this mean that we can now sell synthetic gems as natural?
Heat treatment is traditional and has been done for centuries.	Murder is also traditional, having occurred for millennia. Should we legalize it based on this 'historical' basis?
Heat-treated gems are often impossible to separate from totally natural gems; therefore heat treatment need not be disclosed to the buyer.	Almost all synthetic quartz is indistinguishable from natural quartz, using the current methods. Is it now okay to sell synthetic quartz as natural? Because we cannot tell the difference today, does it mean that we will never be able to tell the difference? In the 19th century, humans could not fly; today it is easy.
The customer already knows that everything is treated.	If that's the case, then it shouldn't hurt to tell the customer again.
All gems are treated; cutting and polishing is a treatment.	Whether or not a gem is cut is not typically disputed; it is clearly disclosed to the buyer.
In heat treating corundums nothing is added to the stones; therefore such treatments are acceptable.	If nothing were added or changed, it is obvious that nothing would change. Heat is added, among other things. But the important point is not *how* a gem is altered, but *who* is doing it. If it is altered by humans, it is, by definition, no longer natural.
Heat occurs in nature; therefore heated gems are natural.	Irradiation also occurs in nature; can you imagine what would happen if you sold an irradiated blue diamond as natural?

phire of good clarity to be turned into a gem, the trade has cried foul, demanding that such stones be clearly labeled.

An additional factor is that most jewelers simply did not have surface-diffusion material in their stock when the question arose. On the other hand, by the time most jewelers found out that most rubies and sapphires were heated, they already had an inventory full of the product. It's easy to take a hard-line stance when talking about others, but when changes directly impact one's own business, self-righteousness is more difficult.

If you can't beat 'em, treat 'em

A man's eyes should be torn out if he can only see the past.
Russian proverb

By accepting heat-treated gems as natural, the gem trade has effectively said that it's okay to change the appearance and quality of gems artificially and sell them as natural, if you do it in the right way (defined as the way in which the majority of people in the gem trade do it).[18] The funny thing is, even the gem trade doesn't know what exactly the "right way" is. Thus we have the ludicrous situation where organizations like CIBJO demand that surface diffusion be disclosed, but not ordinary heat treatment. If I were to discover a simple heat treatment tomorrow which could turn any ruby into a top stone, CIBJO[19] would probably demand disclosure, but would still say that you don't need to disclose the oiling of emeralds, because oiling is "traditional."

In the space of just fifteen years, the acceptance of heated gems as "natural" has resulted in the virtual disappearance of untreated rubies and sapphires from the market. Worst of all, working like some deadly virus, market acceptance of heated corundums (as natural) has opened the floodgates for the treatment of all other gems. In my humble opinion, unless drastic steps are taken to correct the situation, the natural gemstone is doomed. Fifty years from now, natural gemstones will be no more than curiosities— ornamental dodo birds—something found only in history books and museums. If this prospect does not bother you, then… then… well, I don't know what, but it sure bothers me.

Technology is moving at an ever-accelerating pace. We can expect that treatments will continue to improve, meaning that the treatability of rough will increase and the appearance of the resulting gems will get better. Thus the difference between what is treated and what is simply synthetic will blur. In truth, the difference between totally synthetic and treated is unimportant. The crucial factor is that both are

18. Thomas Jefferson conceived the United States Bill of Rights to protect individual citizens from just such tyranny and whims of the majority.

19. Or other industry associations.

products of the human hand. Thus they cannot be considered natural.

Defining 'natural'

The source of such problems is that the gem trade has never bothered to clearly define its terminology. A natural place to start is with *natural*. Until the trade clearly defines the term, it will be impossible to decide if something is or is not.

I propose a definition that is essentially the same that one finds in the dictionary, except for one slight addition (cutting and polishing). It will have no problem standing the test of time. Changing technology will not alter it. The gem trade will not have to meet every two years to discuss additions or subtractions from the list. It is simple. It is...

> **natural**—unaltered by humans, except ordinary cutting and polishing (no impregnations, grinding only)

In other words, if humans do anything to the stone beyond cutting and polishing, it isn't natural. *Natural treatment* is an oxymoron.

Red herrings

Over the years, gem dealers and jewelers have used a number of clever arguments for avoiding disclosure of treatments to the buyer. I have summarized the more common ones in Table 6.3, along with arguments against them.

In summary, I want to stress that I personally see nothing wrong with treating and/or selling treated gems of any kind,[20] so long as they are fully described to the buyer at the time of purchase. We must put ourselves in the shoes of the buyer. What would we want to know about the stone if we were considering its purchase? I would certainly want to know if the color and clarity were creations of nature, or if they were synthesized (created) by man.

Failure to fully describe treatments is described perfectly by an English word—*fraud*. Humans will always be able to produce more beautiful gems by treatment, compared with those simply mined from the ground. If no distinction is made, we run the risk of nothing less than total destruction of the natural ruby and sapphire market.

Stamp collecting

LET'S talk stamps. Yes, the little sticky things you affix to envelopes. Daydream for just a moment...

Here's your fantasy: A postage stamp was produced in Thailand in 1945 and is considered the world's most valuable collector's stamp, due to a printing error. It seems the dot on the *i* in Thailand was forgotten in one batch and a few went out before the error was caught. So this is the world's rarest stamp. Now you, being the clever chap you are, get hold of the regular stamps and carefully erase the dot on the *i*. Then you sell them as the rare type. But, horror of horrors, your customers discover the deception and call in the police. As the constables take you away, shrieking and babbling, you protest: "Why me? I didn't add anything. Furs are treated, fruit is treated, everything is treated nowadays." Unfortunately, the cops do not listen. Instead, the one with the twisted grin kicks you into some Black-Hole-of-Calcutta nightmare, shouting down the stairs to the other inmates: "Get ready, little darlings. We've got a live one." The door locks behind, and then a leering voice from the corner snarls: "Why you? *Why you?* Ha, ha, ha, ha, ha, hee, hee, heeeeee............ bend over!"

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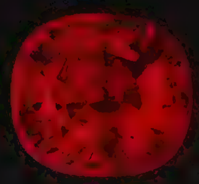

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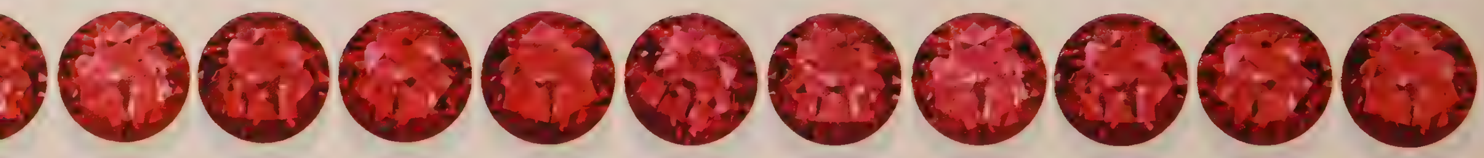

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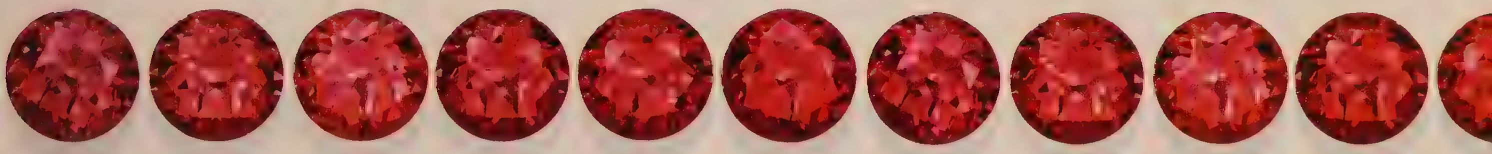

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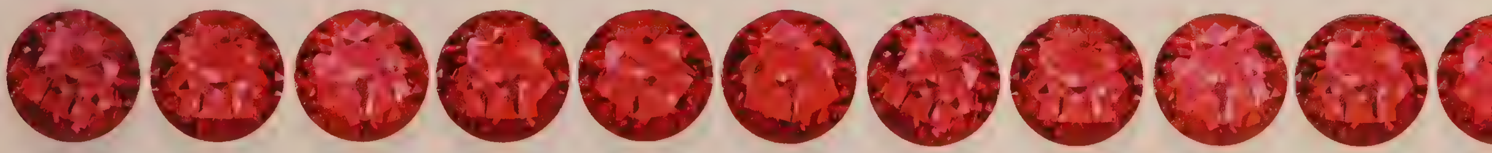

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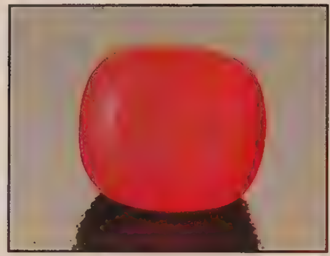

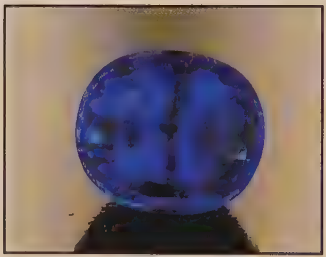

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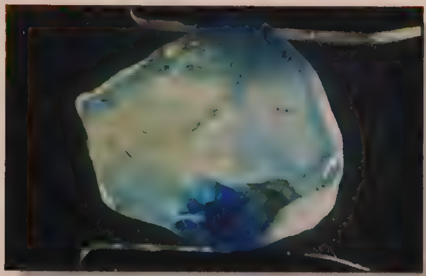
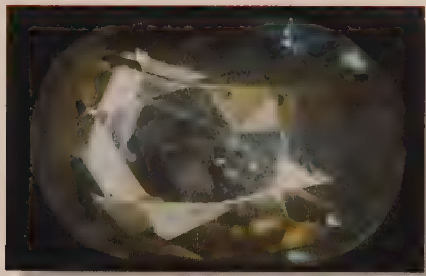

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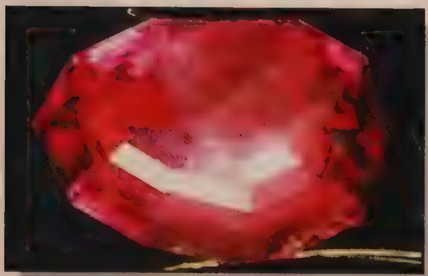
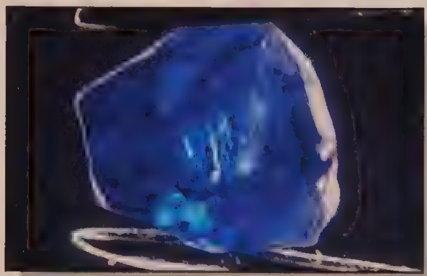


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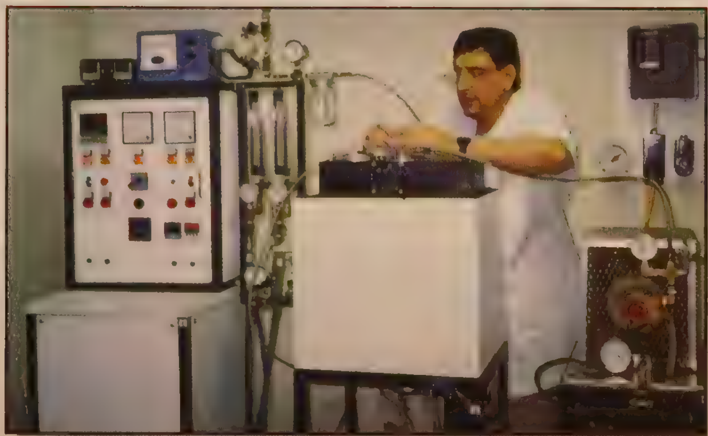

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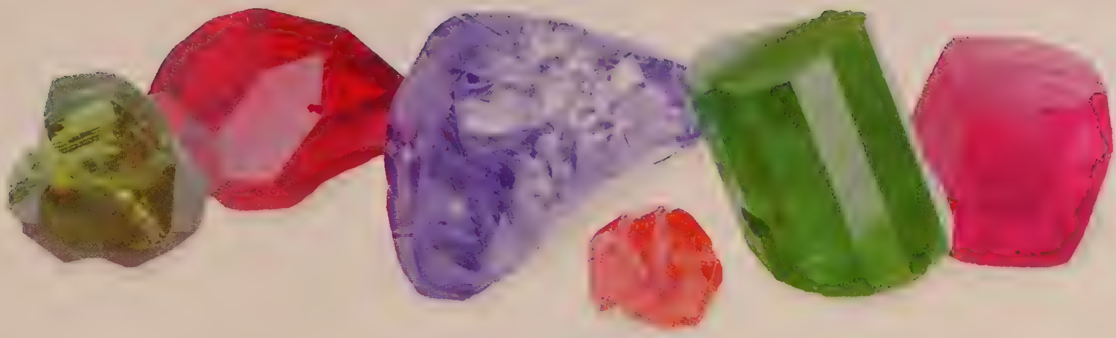

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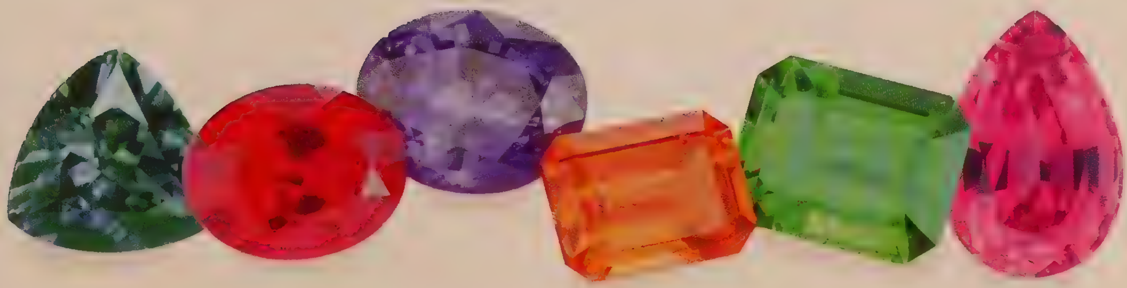

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CHAPTER 7

SYNTHETIC CORUNDUM

Little lamb, who made thee? Dost thou know who made thee, gave thee life, and bid thee feed by the streams and o'er the mead?
William Blake [1757–1827], *The Lamb,* Stanza 1

USE of rocks and minerals for adornment stretches back more than 40,000 years, predating even the mining of ores and coal. Chosen primarily for their vivid colors and rarity, gemstones have played a significant role in commerce and culture throughout history and have long been coveted as among the most valuable of the earth's products.

Precious stones were formerly of much greater trade importance. Prior to development of mechanized transport in the late 19th century, traders were largely limited to goods that could be carried by man or beast of burden. Long-distance trading generally consisted of goods of compact nature and high value. Thus international commerce consisted principally of silks, spices, gems, and other products of a similar nature (Ball, 1950).

One of the oldest trade routes to develop around the traffic in precious stones was that between Afghanistan's lapis lazuli mines and the Egyptian empire. The rich azure hue of lapis lazuli made this stone especially popular in Egypt and, as the only known source was so far distant, demand often exceeded available supplies. Taking advantage of this situation, merchants began to sell steatite (a relatively worthless mineral) that was glazed blue so as to resemble lapis.

A necklace featuring glazed blue steatite beads was excavated at Badari in Egypt and dates to 4000 BC (Elwell, 1979). In the modern sense, this would be an *imitation* instead of *synthetic,* as only the appearance of lapis was reproduced. The discovery is significant, though, for it illustrates just how long humans have been attempting to manufacture the mineral product they needed. In a sense, such early attempts formed the birth of the synthetic gem industry.

Today, the term *synthetic* is properly used only in describing a man-made gem which closely duplicates the chemical composition, crystal structure, properties, and appearance of a naturally-occurring gem. It was not until the 19th century AD that man's knowledge of the chemical and structural makeup of minerals was sufficiently advanced to allow for the true synthesis of gemstones.

Alchemist's dreams

In 1819, E.D. Clarke published details of his experiments with the gas blowpipe:

> ...two rubies were placed upon charcoal and exposed to the flame of the gas blowpipe... after suffering it to become cold... the two rubies were melted into one bead.
>
> E.D. Clarke, 1819 (as quoted by Heaton, 1912a)

The year 1837 saw Marc Antaine Augstin Gaudin [1804–1880], a French chemist, attempt to produce ruby by fusing alum and potassium sulfate in a closed crucible. Ebelman obtained similar results by fusing alumina with borax and later Deville and Caron used aluminum fluoride and boric acid (Heaton, 1912a). Each of these attempts was a type of flux growth. But Gaudin also noticed that, by introducing alumina into the flame of an oxy-hydrogen blowpipe, he could obtain globules of fused alumina similar to the borax beads one makes in the ordinary blowpipe. However, because of a slight difference in specific gravity between his product and the natural, Gaudin concluded that his experiments had produced alumina glass rather than crystalline

Figure 7.1 Plate from Edmond Fremy's book on the synthesis of ruby. It shows a crucible filled with tiny flux-grown rubies. Below is jewelry incorporating small examples of these rubies. (Photo: Robert Weldon/GIA)

alumina (corundum) (Gaudin, 1857, 1869; Heaton, 1912a). Finally in 1870, after many years of work, he abandoned his experiments, still unable to reach his goal.

Fremy. Gaudin's research may not have produced the desired result, but it did prompt others into taking up the challenge. One was Edmond Fremy (Edmund Frémy) [1814–1894], professor and head of the chemistry laboratory at the Museum of Natural History in Paris.[1] He was assisted by C. Feil. The technique employed by Fremy involved dissolving a mixture of alumina and potassium dichromate into a type of solvent known as a *flux*. Through a chemical reaction, the flux causes this raw ruby mixture to dissolve at a temperature far below its normal 2050°C melting point. Then, either by evaporation of flux, or by slowly lowering the temperature, crystals of ruby precipitate out.

Fremy eventually settled upon a flux of potassium hydroxide and barium fluoride, which was dissolved together with the raw materials for ruby in a ceramic crucible at 1500°C. This resulted in rhombohedral crystals of good clarity, in sizes up to 0.30 ct. Their color varied from colorless to red, violet and blue, with the occasional crystal being red on one side and blue on the other (Nassau & Nassau, 1971). Some of Fremy's synthetic rubies were actually mounted in jewelry (both rough and cut stones), while others were employed as

[1] Much of the following is based upon the work of Nassau *et al.* (1969, 1971), who have provided the most detailed history extant of the synthesis of ruby.

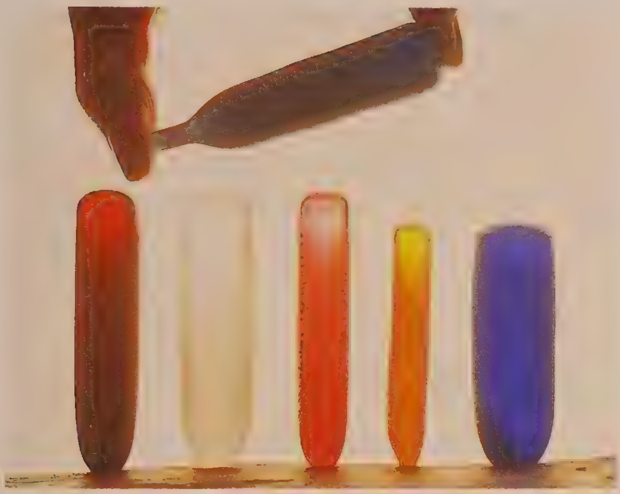

Figure 7.2 Modern Verneuil boules of various colors. (Photo: © Fred Ward)

watch bearings, but their small size prevented his work from being a commercial success. Plans were drawn up for experiments aimed at producing larger stones; however Fremy died before these could be performed. Three years before his death, Fremy published a book (1891) containing illustrations of his synthetic rubies and a summary of his research.

Enter Verneuil

Throughout Fremy's work on the synthesis of ruby he was ably assisted by a number of young men. Chief among these was Auguste Verneuil [1856–1913], the first to develop a commercially viable process for the synthesis of ruby (Nassau, 1980). The method which was developed by Verneuil and which bears his name was truly revolutionary. This is borne out by the fact that, over 100 years after its initial development, the process remains largely unchanged and today is responsible for over 90% of all synthetic corundums produced worldwide.

Verneuil's interest in chemistry grew out of his employment in his father's photographic studio.[2] In 1873, at just 17 years of age, he applied and was accepted as a general assistant at the Paris Museum of Natural History. Upon Feil's death in 1976, Verneuil became Fremy's personal assistant, thus joining Fremy in this alchemists' dream—a quest for test-tube rubies.

Verneuil & the Geneva ruby. It was during this collaboration that an incident allegedly took place which was to completely alter Verneuil's ideas towards the synthesis of ruby:

> In 1886 P.M.E. Jannettaz, a mineralogist and gem expert at the Paris Museum of Natural History, was shown by dealers some small rubies for which a natural origin was at first claimed. These were in fact the "Geneva" rubies which were later also erroneously called "reconstructed" or "reconstituted" rubies. Jannettaz agreed with M. Friedel (a professor at the Sorbonne) and M. Vanderheym (President of the Syndicate of Diamonds and Precious Stones), who had also examined such rubies that the spherical bubbles they contained indicated a synthetic origin, probably by fusion. George F. Kunz in his report to the New York Academy of Sciences, came to a similar conclusion.
>
> Accordingly, Jannettaz discussed the matter with his associates at the Museum to see who might have the appropriate equipment to confirm this conclusion. Verneuil and Claire Auguste Terreil, a chemist, used an oxygen-hydrogen torch in the laboratory of Alexandre Léon Etard to fuse some powdered alumina containing a little chromium. They obtained only tiny specimens, the size of the head of a pin, but Jannettaz nevertheless was able to demonstrate that these were single crystals and gave the same strong fluorescence in Crooke's tube (cathodoluminescence) as the "Geneva" rubies. This was significantly different from the weak cathodoluminescence of natural rubies, thus confirming the fusion origin of the "Geneva" specimens.
>
> Jannettaz "left to these gentlemen the task of reporting themselves how they had performed" these experiments, but they never did so. It appears that this chance request led Verneuil at the age of 30 to try a second approach to the synthesis of ruby, since at that time he was still working actively with Fremy on their joint experiments.
>
> Nassau & Nassau, 1971

Geneva-ruby dealers, however, would not give up without a fight. Barred by law from selling their stones as natural, they protested that, in fact, the stones were manufactured by fusing together small chips of genuine ruby. This resulted in Geneva rubies acquiring the title of "reconstructed rubies," a name they were to carry until the 1960s.

The Geneva process has been described in the literature:

> From the small genuine particles of ruby or "ruby sand" found with the real rubies in Burma I select pieces that are alike in colour and qualities; one of these chips I place upon the top of a "U"-shaped platinum iridium tube. Upon this is focused the heat from two jets of oxygen and hydrogen gas—for the latter can usually be substituted gas from the street mains, as it contains a sufficient proportion of hydrogen gas to qualify it for this use—with the pressure of eight hundred pounds to the inch, producing a temperature of six thousand degrees F [3315°C].[3] As soon as the first chip is melted I introduce into the flame at the end of an iridium holder a second chip, which when it melts flies off and adheres to the first melted chip and they are fused together. The continuation of this process of adding particles results in the production of a genuine ruby of the shape of a pear, resting on its stem—the first chips fused—varying from five to ten carats in weight. The operation lasts from one to two hours, according to the size of the stone produced. The most difficult part of the process is the cooling.... The cooling process is secret and one of the most important factors in the achievement of the reconstructed ruby.
>
> Rudolph Oblatt [Oblat] (from Wodiska, 1909)

2. Verneuil came from a family of watchmaker/mechanics. His father became interested in photography after a chance encounter with early photographer, Louis Jacques Mandé Daguerre [1789–1851], originator of the famous Daguerreotype photography process (Nassau, 1980).

3. Obviously this is an exaggeration.

> The process of producing reconstructed rubies by means of the oxy-hydrogen blowpipe is, roughly, as follows: The residue from cutting rubies and small worthless stones is broken into coarse sand, a small quantity of which is placed on the center of a disk of platinum; this is then carefully brought to the fusion point, care being taken at this stage not to raise the temperature to such an extent as to melt the platinum support.[4] As soon as this mass is fused it serves to protect the platinum, and the reconstructed ruby can be built up on it by adding the fragments of ruby one at a time by means of small platinum forceps. These pieces have to be dropped on with great care in order to secure incorporations with the mass and prevent as far as possible the formation of air bubbles. It will be readily understood that this process is a tedious and laborious one, and, in fact, the formation of masses of sufficient size to yield large stones on cutting is a matter of such difficulty that the cost of production is very high.
>
> Noel Heaton, 1912b

The Nassau-Crowningshield study

In 1969, Nassau and Crowningshield published an exhaustive study of their investigations into the mystery of the Geneva ruby. They examined several Geneva ruby boules[5] and concluded that such appeared to be grown by a precursor of the Verneuil process from purified alumina powder, not crushed fragments of natural ruby, as claimed. Evidence for this was based on the following:

- "Reconstruction" experiments involving the partial melting of small chips of North Carolina (USA) and Mysore (India) ruby resulted in a near-opaque polycrystalline mass of no gem use whatsoever. Thus the conclusion that Geneva rubies could not be formed of partially melted chips of natural ruby.
- Experiments performed by others where crushed natural ruby was used as the feed material for producing flame-fusion boules produced material of low quality.
- Geneva ruby boules showed average iron contents far lower than those typical of natural rubies.

The process as hypothesized by Nassau-Crowningshield involved three separate stages. First, a single gas torch was used to melt a small globule on the top of a cone of sintered ruby powder. This globule was broken off, inverted, and more material then grown on top of it. The final step, which was responsible for the largest amount of growth, involved dropping the feed material onto the boule from above, with two torches to either side providing the necessary heat for fusion.

4. The melting point of platinum is 1772°C.

5. The term *boule*, which is used to describe Geneva and Verneuil crystals, is derived from early crystals, which were somewhat spherical in shape. These resembled the heavy balls used in the French game of the same name. Although modern Verneuil crystals do not resemble balls, they are still referred to as boules.

The Geneva ruby mystery

> He who buys a half share in a secret buys the whole secret
>
> Louis Kornitzer, 1941, *The Jeweled Trail*

Nassau and Crowningshield's study appeared to put an end to the Geneva ruby controversy. However, in 1980 the eminent British gemologist, B.W. Anderson (1980e–f) reopened the debate. Quoting from personal as well as published sources, Anderson told of one Rudolph Oblat (Wodiska's Oblatt) who claimed to have produced Geneva rubies by the fusion of small pieces of "ruby sand" from Burma. That Oblat's claim was no mere boast is given added weight by his detailed accounts, not only of the Geneva process, but also the Verneuil process using purified alumina (Wodiska, 1909). Even more amazing was Oblat's claim that it was none other than Verneuil himself who taught him how to manufacture rubies by the fusion of small chips of natural stones (Kornitzer, 1941).

Louis Kornitzer [1873–1946], a well-known gem dealer and author, related the fascinating story of Oblat, whom he knew during his youth in Paris. According to Kornitzer, Oblat was an ambitious young man working for a Paris jeweler whom he used to meet frequently after work for a glass of wine and a yarn. During one particular conversation, Oblat excitedly related the following tale:

> It appeared during the afternoon the old jeweler had sent him [Oblat] on an errand to the laboratory of Professor Verneuil, a noted French scientist. The simple, kindly professor was pleased to meet a young man who was so enthusiastic and appreciative of his work, and after showing him some of his latest experiments confided that he had just perfected a process for reconstructing rubies by powdering stones of inferior quality, coloring them with a special substance and then fusing them electrically. "There's a fortune in it if I can persuade old Verneuil to part with his secret," said Oblat excitedly, "and I'm practically sure I can. He's too unworldly to care about the commercial side of his discovery. It has apparently never even occurred to him that he might profit by it. He's only interested in it from a scientific point of view. But if I can manage to get hold of the invention I'll make some use of it.
>
> Louis Kornitzer, 1941, *The Jeweled Trail*

Oblat apparently did gain Verneuil's confidence, for a few weeks later he told Kornitzer that the professor not only explained the process, but gave Oblat use of his lab. Oblat eventually obtained the financial backing of a French gem merchant. They bought equipment, rented a lab and were soon turning out rubies. But their stones were costly to produce and their asking prices were so high that orders were slow in coming. At the end of the year they found the enterprise was not profitable, so additional "partners" were enrolled for high premiums and sworn to secrecy. Eventually the plan snowballed to the extent that the rubies were being produced "by the bushel" in a dozen different laboratories

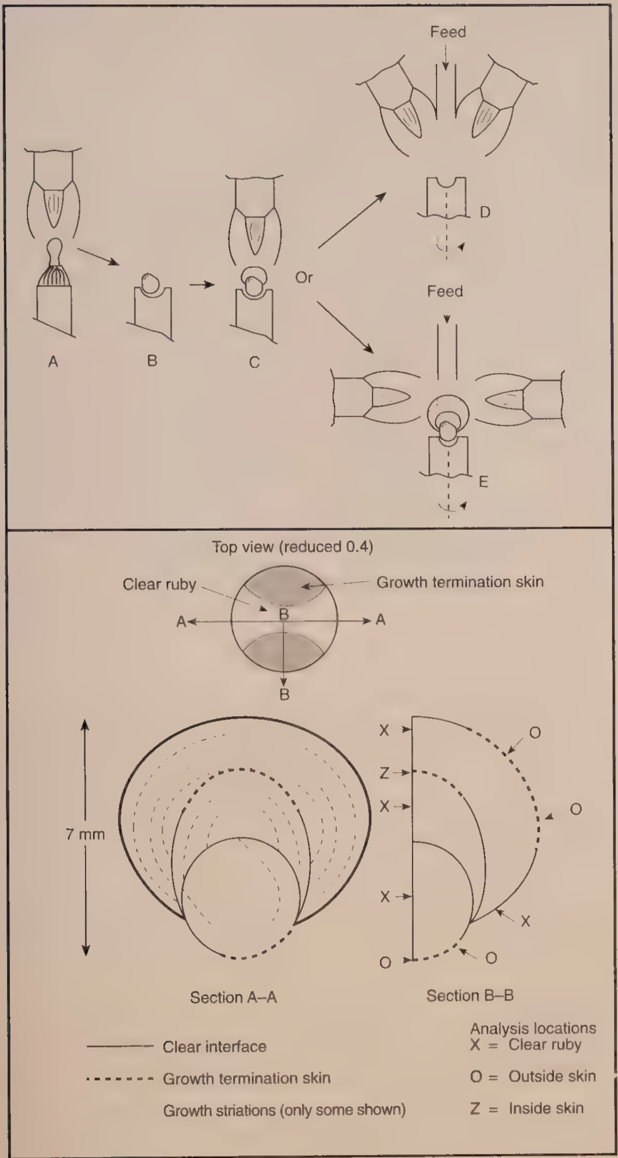

Figure 7.3 The believed manufacturing process and structure of the "Geneva"-type synthetic ruby, an early precursor of the flame-fusion stones of Verneuil. (After Nassau, 1969)

Figure 7.4 Verneuil boule in the furnace just after the torch has been turned off. (Photo: Djevahirdjian)

and the Paris market became flooded with the stones (Kornitzer, 1941; Anderson, 1980e–f).[6]

Questions remain

While the Nassau-Crowningshield study was extremely thorough and a model of scientific inquiry, questions still remain. First, the idea of reconstruction equalling only partial melting is something of a red herring. Never in the literature is there any suggestion or claim that feed material was *not* fully melted during the process. But the linchpin of the Nassau-Crowningshield argument, that the low iron content and appearance of Geneva rubies show that they must have been made with a purified alumina powder, also has problems. Despite the efforts of Nassau and Crowningshield, who did all that was humanly possible to obtain genuine Geneva rubies, none of those studied can be clearly documented as originating from the 19th century. It is within the realm of reason that each of the so-called Geneva rubies tested was merely an example of an early Verneuil-type ruby.

It is also possible that some early experiments involved natural feed material and that these were later abandoned in favor of purified alumina. Mined ruby feed material would seem a natural starting point for anyone attempting to grow rubies that closely match those of Mother Nature. Even today, there is a belief in certain quarters of the crystal growth community that trace elements beyond Cr and Fe make an important contribution to the appearance of natural rubies (Larry Kelley, pers. comm., 22 Feb., 1995).

Oblat, in his description of the Geneva process, did state that small Burmese rubies were used, whereas Nassau and Crowningshield used rubies from North Carolina and India. Burmese rubies contain much less iron than those from North Carolina and India. Because the high iron content was one factor which led Nassau and Crowningshield to disbelieve the reconstruction theory, further questions are raised.

Was Rudolph Oblat in fact the man behind the Geneva ruby, or was he simply attempting to grab headlines with his tale? Unfortunately, due to the deaths of the participants in this drama, the world may never learn the truth of the Geneva ruby mystery.

6. Although Kornitzer claimed that quantities of these stones appeared, little evidence exists to support this view (Kurt Nassau, pers. comm., 3 April, 1995).

MÉMOIRE

SUR LA

REPRODUCTION ARTIFICIELLE DU RUBIS

PAR FUSION,

Par A. VERNEUIL

PARIS,

GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE

DU BUREAU DES LON[illegible]

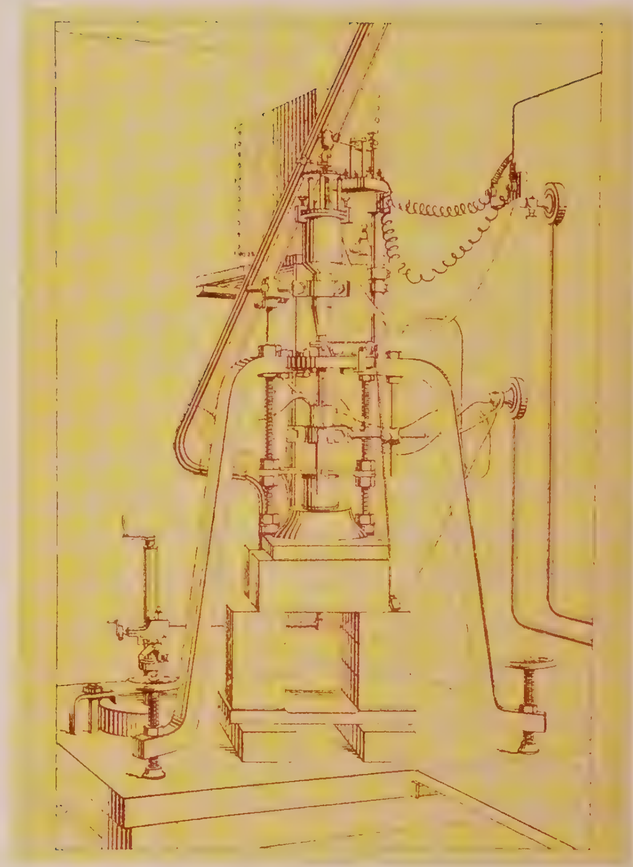

Figure 7.5 Verneuil's landmark paper
Left: Title page from Verneuil's 1904 monograph on flame-fusion growth of synthetic ruby.
Right: Illustration of the furnace apparatus from the same paper. (Photos: GIA)

Verneuil's discovery

Whether Verneuil was already working on the flame-fusion growth of ruby, or whether the appearance of the Geneva stones started him in this direction cannot be known with certainty. In any case, it is evident that sometime about 1886 Verneuil began experiments in this direction (Nassau & Crowningshield, 1969). By the year 1891, he had made sufficient headway to record the major details and deposit them in a sealed envelope with the Paris Academy of Science. Already Verneuil was able to grow crystals of sufficient size, but problems were encountered with the cracking of the boules. This shortcoming was soon taken care of, leading to a second sealed note in 1892.[7] Both were opened in 1910, at Verneuil's request (1891, 1892).[8]

The first hint of what was to come occurred at the Paris World's Fair in 1900, where Verneuil's assistant, Marc Pacqier, displayed several of the new synthetic ruby crystals. But no details of the process were released and it is not known whether Verneuil approved the showing. Finally, in 1902, Verneuil proudly announced to the world that he had succeeded in producing rubies in the lab that were the equal of nature's finest. Not only did his *scientific rubies* replicate exactly the appearance and properties of the genuine article, but most importantly, they could be grown in sizes large enough for use in jewelry. Thus, at long last, the world had its first truly successful synthesis of a precious stone.

Two years later, Verneuil published an extensive article giving the details of his technique. This threw the door wide open for anyone with the right amount of chemical and mechanical training to produce synthetic rubies. Several firms immediately started work and by 1907 the annual production of synthetic ruby soared to over five million carats.

With the synthesis of ruby now behind him, Verneuil focused his attentions on yet another corundum gem, blue sapphire. Synthesis of blue sapphire came late in 1909, after chemical analysis of natural stones by Verneuil revealed traces of iron and titanium in all blue sapphires. Armed with this key piece of information, it wasn't long before blue sapphire was added to the list of successful synthetic gemstones,

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7. In 1892, Verneuil also left the employ of Fremy (Nassau & Crowningshield, 1969).

8. Interestingly enough, Verneuil never mentioned the existence of these notes in any of the many papers on the flame-fusion process (Nassau & Crowningshield, 1969).

Verneuilgate: The missing eight years

WHAT did Verneuil know and when did he know it? Like the Watergate scandal of the 1970s, these are the questions that any modern-day historian would ask. In Verneuil's case, thanks to his sealed notes deposited with the Paris Academy of Science, it is obvious he knew how to grow rubies with a high degree of proficiency no later than 1892. But, like the Watergate tapes, there is that disturbing gap. Richard Nixon's lasted just 18.5 minutes. In Verneuil's case, it lasted eight years. According to the published record, between 1892 and 1900–1902, although active in other areas of science, when it came to growing ruby, he apparently just sat on his hands. Find that hard to believe? I do.

and quantities of the new material soon began pouring out of synthetic ovens around the world. Verneuil eventually received patents for the blue sapphire process (Verneuil, 1911a–b).

Initial market impact

When Verneuil rubies first entered world gem markets after 1904, fears were immediately raised regarding their distinction from natural stones. The situation was similar to that which prevailed with the advent of the Geneva rubies in 1885–86, but with important differences. Although the Geneva ruby did qualify as synthetic corundum, it fell short of the mark in several areas. Due to uneven cooling, Geneva boules were generally filled with fractures and the numerous gas bubble clouds rendered the stones hazy. Furthermore, the color was quite unnatural in appearance and thus the market soon developed methods for their distinction, restoring public confidence and causing a rebound of prices for the genuine article.

In contrast, Verneuil synthetic rubies were revolutionary, being of a color and clarity which equaled or exceeded nature's best. Thus, their appearance in the market created quite a stir. Extensive publicity was given to Verneuil's rubies and their amazing likeness to genuine stones. This interest in the *scientific ruby*, coupled with a severe financial crisis in the USA in 1907, caused demand for natural rubies in the important London market to fall. The years between 1907 and 1914 were particularly bleak. Not only were natural prices and sales down in Europe and the USA, but large quantities of synthetic stones were being shipped to Colombo, Calcutta, Rangoon, and other Asian centers, further eating into profits.

The market acts. Eventually, in the face of falling revenues, the natural ruby industry began to act. In Colombo, the Ceylon Legislative Council imposed a 100 rupee ($33) per-carat import tax on almost all imitation and synthetic gemstones which, in effect, barred their importation. With the aid of experts, in 1912 the Burma Ruby Mines Ltd. prepared instruction charts for separating natural and synthetic rubies. These were then distributed free of charge to jewelers and gem dealers around the world (Kunz, 1913).

Figure 7.6 Alumina powder heading into the drying furnaces prior to the production of Verneuil synthetic corundum.
(Photo: Djevahirdjian)

These tactics soon bore fruit. Competition amongst synthetic manufacturers flooded the market, and in doing so, depressed prices. Demand for natural rubies simultaneously increased as fears regarding their distinction were shown to be unjustified. The natural ruby soon regained its preeminent position.

Thoughts on the future

It is interesting to note that similar fears have again been voiced regarding the ability of detection methods to keep pace with modern growth processes. Consider the answer given to this same question by the German mineralogist, Conrad Oebbeke in the late 1900s:

> Between the natural and the artificial precious stones, the material difference will always exist, that one is a natural, the other an artificial product. Up to the present time, I have not seen *a single artificial precious stone that could not be recognized as such.* The claim that the artificial stones are not to be distinguished from the natural gems, that they are absolutely free from defects, etc., according to my experience, is *not justifiable.* Even if it is possible to produce precious stones having the same crystallographic, physical, and chemical properties as the natural gems, they are nevertheless *not equal in value* to the natural product. No more so than an ever so carefully executed and deceptively similar copy of a work of art, a painting, a piece of sculpture, etc., can be called the original. The artificial products, made in the laboratory, are not formed under the same conditions as the natural article, and for this reason we may rest assured that, even should the present scientific methods of distinguishing the genuine from the artifi-

cial precious stones fail, further scientific investigation will reveal a method that will make the distinction possible. Interesting as may be the success thus far attained in the production of artificial precious stones, and while we may congratulate ourselves on the progress made in chemical techniques in this direction, to the *connoisseur, these articles will always be artificial products* that can never deprive the natural stones of their value. On the contrary, really beautiful natural precious stones will *only be the gainer.* The claim that synthetic stones will ever break the market for real precious stones, is, in my opinion, utterly unfounded.

Prof. Dr. Conrad Oebbeke (from Wodiska, 1909)

It has been nearly a century since these words were spoken, and yet they still ring true.

A close look at Verneuil's process

We will now take a closer look at Verneuil's revolutionary technique. In its basic form, the flame-fusion process involves melting a mixture of alumina powder and a coloring agent in such a way that a single crystal forms. Deceptively simple at first glance, it is in actuality a complex chain of events which took years to perfect.

Purification of raw materials. The first step is purification of raw materials. Chemically, corundum consists of aluminum oxide (Al_2O_3), which is obtained from ammonium alum. Its solubility greatly increased when heated, this alum is dissolved, and the solution brought to the boiling point. After being filtered and cooled, the wet crystals are dried and roasted in furnaces at 1200°C, producing alumina. A fluffy white powder is obtained by gathering the alumina cake and processing it in vibrating sieves. Incredibly, although this white powder is light enough to be inhaled, when melted it solidifies into the glistening gem that is among the hardest of all known substances.

Growth apparatus. Corundum's high melting point (2050°C) provided one of the major barriers in early attempts at its synthesis. Verneuil surmounted this by utilizing an oxyhydrogen blowpipe mounted such that the flame is directed downward onto a ceramic pedestal. This pedestal is lowered by means of a fine screw, allowing the growing boule's upper surface to be kept in the hottest part of the flame.

Feed powder is placed in a screen-bottomed metal basket above the central blowpipe tube. A camshaft causes a hammer to tap the basket at rapid intervals, dropping alumina powder through the flame. Once these grains reach an area of sufficient heat they will be fused.

Cracking the fracture code. The genius of Verneuil is exemplified in how he overcame the problem of cracking. If too high a flame temperature is used, powder will melt immediately upon entering the flame. It then builds up in a molten blob on the pedestal. Because the contact area between the globule and pedestal is so large, the resulting crystal will be a heavily-fractured mass unsuited for gem use. This was the problem of Gaudin and other early researchers.

Figure 7.7 Verneuil synthetic ruby boule still sitting on the sinter cone. (Photo: Mike Havstad/GIA)

Verneuil surmounted the cracking problem by limiting the contact point to a narrow neck. This is done by keeping the flame temperature cool enough so that complete melting does *not* occur when the powder falls through the flame. Instead, only the surfaces of each particle melt. These particles collect on the pedestal, forming a *sinter cone.* Eventually, as the cone increases in size, its tip will reach the hottest part of the flame and melt. From this point onward, all grains which fall onto this molten area will also be fused. Actual growth thus begins from a slender stem. It is vital that this neck be as small as possible, for if the contact area between the boule and its support is too wide, the finished crystal will shatter when the flame is turned off.

Once the neck has formed, the boule grows upward, steadily increasing in breadth as it rises into the hotter and wider portions of the flame. To increase the crystal's diameter, the powder feed rate is increased and the temperature of the flame also boosted by increasing the oxygen flow. Powder continues to cascade downward, drawn through the flame by the force of the gas and onto the glowing crystal, incandescent with heat. Thus the molten mass slowly grows upward by means of thin layers deposited, one on top of another, on the semi-spherical upper surface. Its vertical growth is compensated for by lowering the pedestal at an identical rate, keeping the upper surface in the warmer regions of the flame at all times.

Bubbling over. Should the flame be too hot, the molten top surface will actually boil, causing inclusion of gas bubbles. To avoid these defects, the temperature must be reduced slightly

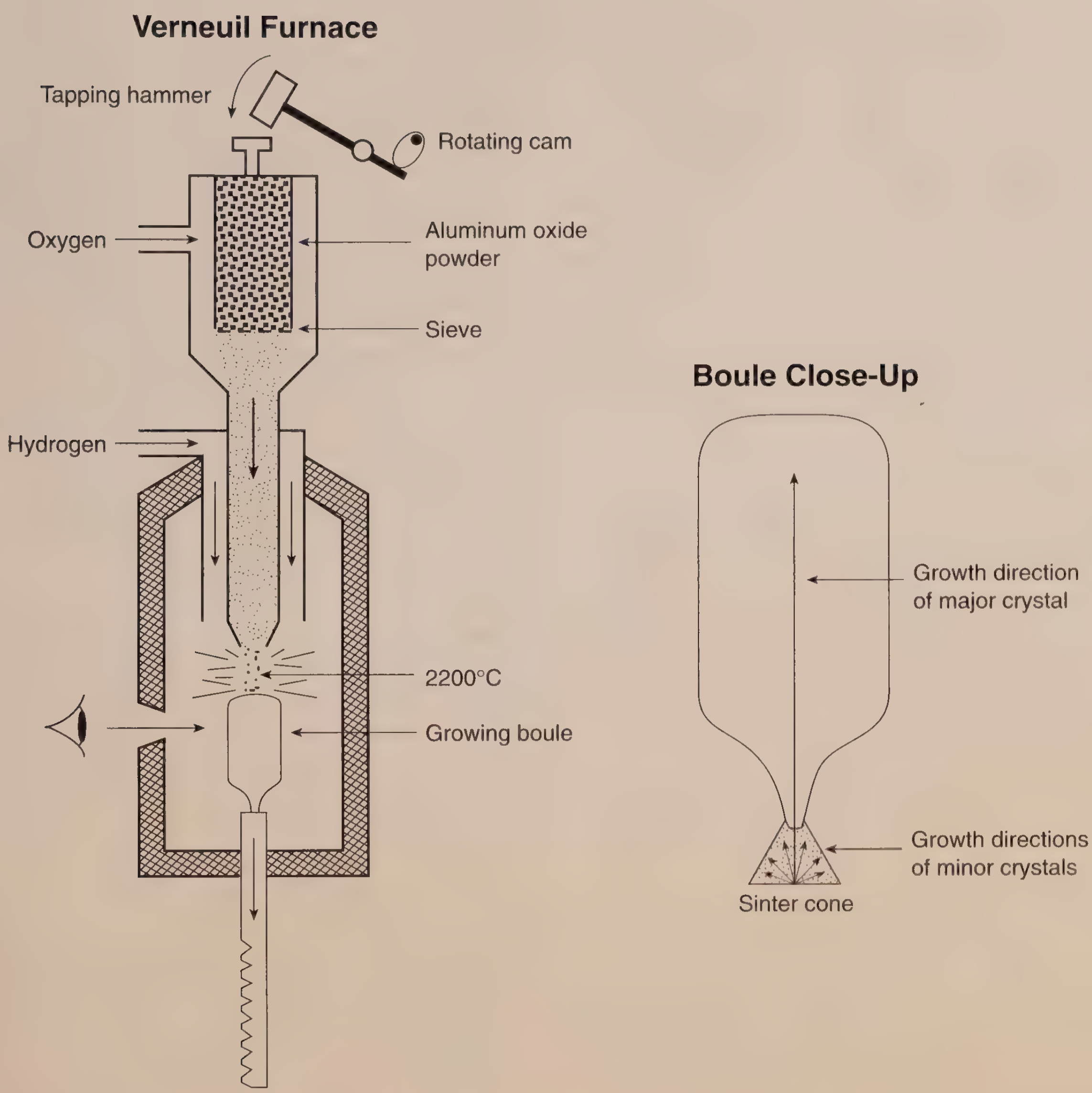


Figure 7.8 Verneuil furnace
Left: Construction of the Verneuil furnace used for producing flame-fusion synthetic corundum. (After Hurlbut & Switzer, 1981)
Right: Close-up of boule and sinter cone. (After Schmetzer, 1986b)

and the boule must be lowered to a somewhat cooler region using the screw device. Monitoring the boule's growth is done through a small window built into the furnace. At last, when the crystal has grown to the desired size, the gases are abruptly shut off. This is the most critical stage, as fractures are here most likely to develop. If the boule has been grown correctly, is well-centered and heated evenly throughout, it can be split vertically into two halves by the gentle tap of a hammer. Due to the observation window cooling one side of the boule more than the other, considerable strain builds up within the finished product (Kurt Nassau, pers. comm., 3 April, 1995). Splitting the boule lengthwise along an incipient parting plane relieves this pressure, which would otherwise cause irregular fractures. For certain industrial uses where whole boules are desired, the splitting can be avoided by rotation of the growing boule, and subsequent *annealing* (reheating). This is performed most frequently on white sapphires for use as cover glasses in watches, gauges, etc., but is not necessary for gem boules.

Crystallographic orientation

Finished boules are usually split lengthwise along an incipient parting plane to relieve the strain which builds up during the rapid growth. If a properly oriented seed rod is used, crystals can be grown with the *c* axis parallel to the boule's length. However, because of the added costs involved, less care is taken in practice and the *c* axis may be inclined, or

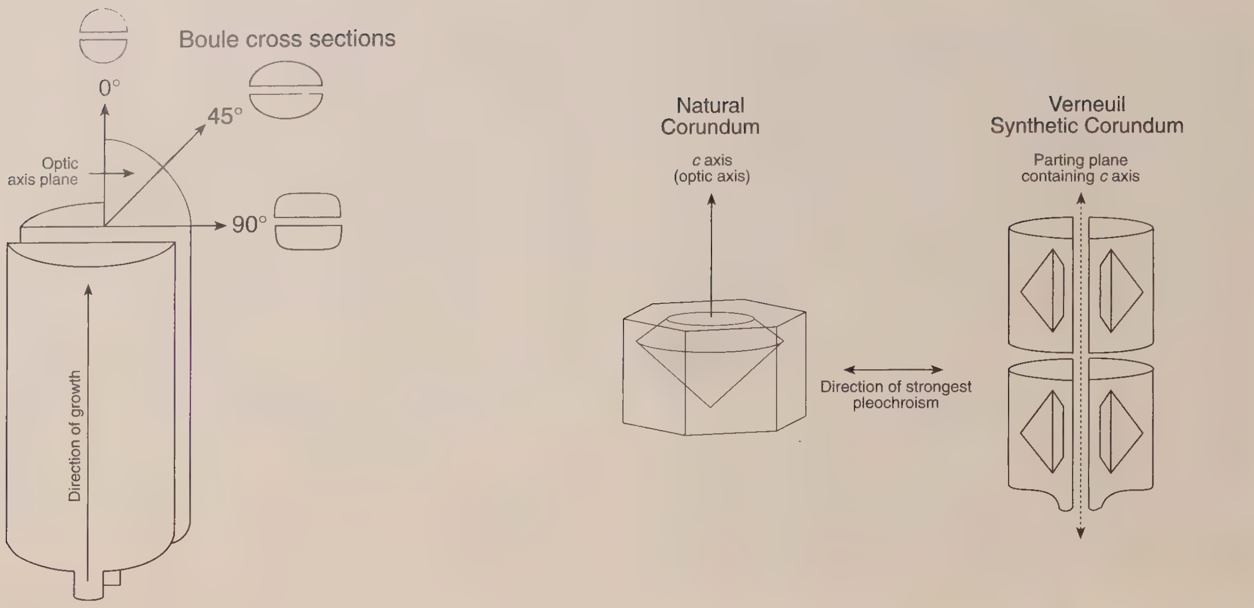


Figure 7.9 Orientation of Verneuil rough
Left: The optic axis (corresponding to the *c* axis) in Verneuil synthetic corundum is *not* always parallel to the boule's length, but always lies within the plane along which the boule is split. Zero-degree boules, where the optic axis is parallel to the length, are roughly circular in cross section. 90° boules, where the optic axis is at right angles to the length, have flattened sides. Most boules have an orientation between 30° and 60°, and are oval in cross section.
Right: Natural corundum is usually (but not always) cut with the *c* axis at 90° to the table facet. This generally produces the richest color and greatest yield. Verneuil boules, however, are split along an incipient parting plane (to relieve tension) before cutting. As color is not of great importance in synthetic corundum (the price is the same no matter how they are oriented), boules are cut for weight retention by slicing them into chunks across the width and then placing the table parallel to the split. Since the Verneuil *c* axis always lies in the plane of the split, it will thus lie parallel to the table of the faceted stone. This results in strong pleochroism at 90° to the table in the Verneuil synthetic, while the same direction (⊥ to the table) in most natural corundums generally shows no pleochroism. Of course this is true only if the stones are cut in the above orientations.

even perpendicular to the boule's length. In all cases, though, the *c* axis will lie within the plane along which the boule has split.

Crystallographic orientation can be controlled by using pre-selected seed rods to initiate growth, with the growing boule conforming to the orientation of the seed. For crystals grown for industry, three major growth directions are used and are designated 0°, 60° and 90° crystals, depending upon the angle between the *c* axis and the boule length. 0° boules appear roughly equidimensional in cross-section, while 30–60° boules are oval and 90° boules almost rectangular (Nassau, 1980). But for gem use, orientation is not important. Among boules produced for use as gems, 90° crystals are probably encountered less frequently than any other type, being found primarily in yellow and orange sapphires. Many boules are random.

Orientation of Verneuil synthetic corundum is of concern not only for industrial uses, but also to gemologists (see Figure 7.9). Natural corundums are generally cut with the *c* axis (optic axis) close, or exactly perpendicular, to the table facet. This is done for two reasons. First, due to the shape of most corundum gem rough, weight loss during cutting is minimized. However, of even greater importance is the fact that, in most varieties of corundum (natural or synthetic), the o-ray color is more intense and beautiful than the e-ray. Thus, when a lapidary cuts natural corundum he usually tries to orient the gem with the table facet, or cabochon base, perpendicular to the *c* axis so that the o-ray color alone is seen, undiluted by the more insipid e-ray hue.

Table 7.1: Common coloring agents

Color	Coloring Agent: Natural Corundum[a]	Coloring Agent: Verneuil Syn. Corundum[b]
Colorless	Pure	Pure
Red, pink	Cr^{3+}	C^{3+}
Dark red	Cr^{3+} + Fe	Cr^{3+} + Fe^{2+}
Blue	Fe^{2+} + Ti^{4+}	Fe^{2+} + Ti^{4+}
Violet, purple	Cr^{3+}/Fe^{2+} + Ti^{4+}	Cr^{3+}/Fe^{2+} + Ti^{4+}
Yellow	Color centers and/or Fe	Ni and/or color centers and/or exsolved hematite
Orange	Cr^{3+}/Fe and/or color centers	Cr^{3+} + Ni
Green	Fe	Co or Co + Ni V has also been reported
Color change	V and/or Cr^{3+}/Fe^{2+} + Ti^{4+}	V
Black star	Exsolved hematite/ilmenite	—

a. See Table 4.1 on page 73 for full description of color in natural corundum.
b. Based on Nassau (1980) and Djevahirdjian (pers. comm., April, 1994).

In contrast, the lapidary is rarely concerned with obtaining the best color when cutting the synthetic. Instead, convenience, speed, and weight retention dictate orientation. Because boules are split lengthwise, most cutters place the table parallel to the flat inner surface of the split. The *c* axis, which always lies in the plane of the split, is thus parallel to the table.

Such orientation differences mean that Verneuil synthetic corundums tend to show a slight color difference compared with the natural, due to the dilution of the o-ray by the weaker e-ray. Examination with a dichroscope clearly reveals this difference. The synthetic displays strong dichroism through the table, while the natural shows little or no dichroism in this direction. Of course, other factors may cause both natural and synthetic stones to be oriented differently. However, in the author's experience, at least 70% to 80% of all natural and Verneuil synthetic rubies and sapphires are cut as described. In the case of large (above 10 ct) synthetics, this increases to perhaps 90% or more.

Coloring agents. Colorless sapphire results from a fusion of pure alumina. For colored gems, small amounts of metallic oxides must be added. Various combinations have been used to produce colored varieties. Those commonly used by modern Verneuil manufacturers are compared with the coloring agents of natural corundum in Table 7.1. In addition to these, others have been tried on an experimental basis.

Both ruby and blue sapphire are made in a range of tones. This is not just to allow stones of different shades to be cut, but also to allow stones of different size to be matched in color, for if two gems which differ greatly in size are cut from the same boule, the larger of the two will have a deeper color. Hrand Djevahirdjian S.A. of Monthey, Switzerland, one of the world's largest manufacturers, produces eleven different shades of ruby (including pink) and six different shades of blue sapphire. Altogether, a total of 32 colors are made, ranging from colorless to red, orange, yellow, green, blue, violet, and purple, as well as a color-change type. In addition to the wide range of single-color gems, bicolor and even tricolor stones have also been made in the past.

Blue sapphire. The growth of blue sapphire presents a greater challenge than ruby, due to a tendency to develop a violet coloration unless strict control over flame temperature and boule position is maintained. Also, as with natural sapphires, the blue color of the man-made stone is more irregular than that in ruby. Verneuil products often show a colorless central core with the blue color restricted to the outer areas close to the surface. Lapidaries have taken advantage of this fact to produce stones which resemble the strongly zoned heat-treated Sri Lankan blue sapphires. The synthetic's uneven color apparently arises from the volatile nature of iron, most of which burns off in the furnace's intense heat. Enough iron remains behind to influence the boule's color, but not the spectrum, as the synthetic stones lack the 451.5, 460, 470 nm absorption complex that is the hallmark of so many natural sapphires.

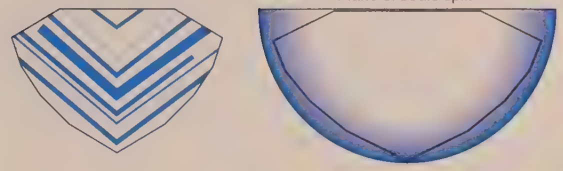


Figure 7.10 Color zoning often differs between natural stones and the "Ceylon"-type blue Verneuil synthetic. In natural stones (right), color zoning is extremely sharp, with dramatic separations between blue and colorless areas. The imitation "Ceylon" type Verneuil synthetic features a colorless core, with a gradual transition between the blue skin and colorless core. Because of the boule shape, the color will wrap around the pavilion facets of most faceted stones.

Modern Verneuil blue sapphires are produced in a wide range of color intensities, of which the zoned type is only one example. These vary from near-colorless to those of the deepest blue, with dense concentrations of gas bubbles often filling the interior of the latter. Spinel is also grown in a range of blues by the Verneuil process.

Crystal sizes. Early flame-fusion crystals were small, averaging perhaps 15 ct in weight. A typical boule of 5–6 mm diameter might yield four or five cut stones of under two carats. However, improvements in the quality of the feed material and the furnace apparatus allow the growth of much larger crystals today. Modern boules can measure up to 9 cm in diameter and faceted stones of well over 100 ct are in existence, but these are rarities. On the average, most Verneuil boules produced today are roughly 6.5 cm in length and weigh between 150 and 200 ct. Because the furnace pedestal is lowered at the rate of 1 cm per hour, the boule's growth rate is the same. Thus, a 6.5 cm boule would require approximately 6.5 hours for its manufacture.

Production and cost. Modern Verneuil plants are capable of producing enormous amounts of synthetic corundum, with an 80 ton per year capacity at the Djeva facility alone. Most material is slated for industrial use, with only a part being cut for jewelry.[9] Due to the enormous quantities involved, prices for the rough material average but a few cents (US) per carat. Blue sapphires cost up to twice as much as rubies, while the green synthetic sapphires fetch ten times more.

Identifying features

Although the Verneuil synthetic ruby represented a tremendous leap forward, amongst the experts who examined them

9. According to Ward (1992), 40 tons go just for watch crystals.

Figure 7.11 The key that unlocks the Verneuil product's identity—curved growth lines and gas bubbles
Top: In rubies and the color-change variety, the curved growth lines are narrow (curved striae), while those in other varieties tend to be broad bands of color (curved color banding). These lines always follow the domed upper surface of the boule, but may be found in various positions in cut stones.
Bottom: Large gas bubbles are often elongated perpendicular to the direction of the growth lines, as exemplified by the Verneuil synthetic ruby at left. In blue stones, gas bubbles sometimes display concentrations of blue color around them (right). (Photos by the author)

there was never the slightest doubt as to their artificial origin. It was Verneuil himself (1904a–d), who systematically described the characteristics by which they could be identified—curved growth lines and gas bubbles.

Desperately seeking striae. The key diagnostic feature of Verneuil synthetic corundum is the curved growth lines. These lines are essentially deposition layers, and result from minute differences in distribution of coloring agents and strain between adjacent layers. With growth taking place vertically, as layer after layer form on top of one another, these lines will follow the contours of the domed top surface of the boule. Thus, in order to see them one must look in directions roughly perpendicular to the boule's length. Since the growth lines of natural corundum are always straight when viewed parallel to the face along which they formed, curved lines represent positive proof of synthetic origin.

The curved growth lines in the red and vanadium color-change varieties are narrow striations resembling the grooves of a phonograph record, and are termed *curved striae*. These have also been found in the green variety (Liddicoat, 1970). In contrast, those found in other colors are usually broad arching bands of color, and so are termed *curved color banding*. A distinction is made because curved striae in stones of a grayish-green color (in daylight) suggest a synthetic color-change sapphire. Lighting conditions for their resolution are also different.

Locating curved growth lines in cut stones may present difficulties, especially with pale colored specimens, or with the yellow, orange and pale red (pink) varieties. Illumination is crucial. Narrow growth lines ('curved striae') are generally resolved best under dark-field illumination, or light-field illumination using the *shadowing* technique (see Figure 5.3). Transmitted lighting with an opaque light shield (such as a business card) inserted between light and stone parallel to the growth lines will reveal details that might otherwise be missed.

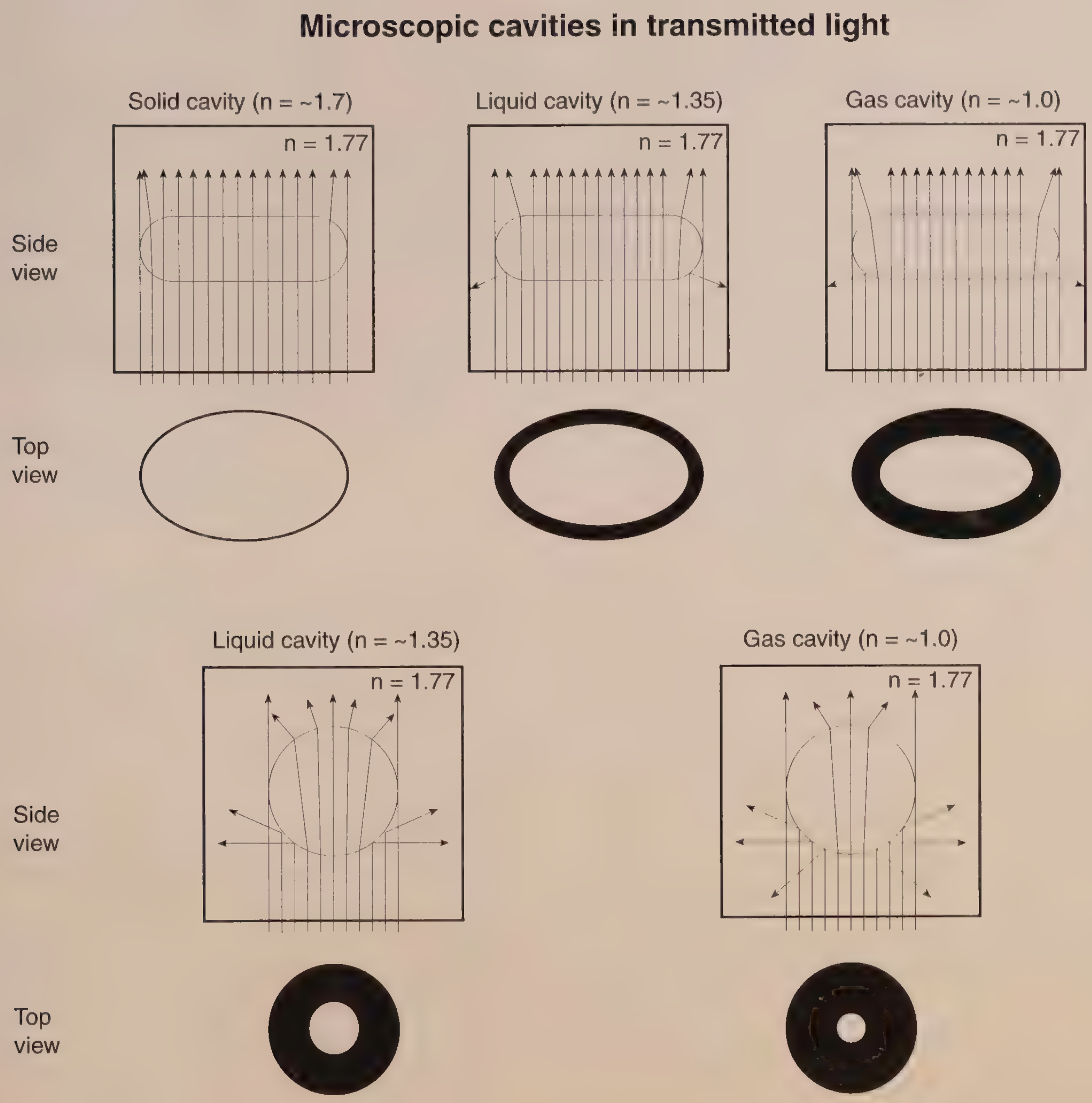


Figure 7.12 Cavities take on different appearances depending on the filling material and shape. If the shape is flattened, the thickness of the black (opaque) rim in transmitted illumination is an indication of the filling's RI. Greater difference between the RI of the filling material and that of the surrounding host results in a thicker opaque rim. Inclusions of more round shape will show a thicker rim still. This is why gas bubbles in synthetic corundums have such high relief. (Modified from Gübelin, 1953)

In contrast to curved striae, the curved color banding of synthetic sapphires is best observed by using dark-field or diffused light-field illumination. This is obtained by insertion of a translucent (frosted) white filter between light source and stone. Keep in mind that the only way to discover which illumination method is best for any given stone is to try them all. If one technique doesn't work, try another. It is also vital that the stone be examined from all possible directions. If you don't see lines in one position, try another (see box on page 89).

One key difficulty is facet reflections, which make it impossible to see growth lines and other inclusions in certain directions. This is overcome by examining the stone in many directions, changing the lighting conditions, or by immersion in di-iodomethane (methylene iodide). Immersion is useful for locating both narrow and broad growth lines, and is often essential in pale varieties. Specimen illumination is generally the same as if examined dry. Pale-colored specimens generally feature broad growth lines and so diffuse light-field illumination is preferred.

Blue for you. In 1981, the author discovered visibility of growth lines in the difficult yellow and orange varieties is tremendously enhanced with a blue filter, such as the #80A or 82A glass filters used with cameras, or simply frosted blue plastic. Due to the yellow bias of tungsten microscope bulbs and the yellow color of di-iodomethane, it can be particularly difficult to locate the color bands in yellow and orange stones. However, inserting a blue filter under the immersion cell, or, if the filter is of good optical quality, just beneath the microscope's objective lens, the yellowish cast can be eliminated (see Figure 7.38). This makes it possible to resolve growth lines in most yellow/orange stones, provided one has the patience to examine the stone in all directions. Dry examinations are also improved by use of the blue filter, making it an important gemological tool. Yellow-green or blue filters also make it easier to locate growth lines in rubies. Experiments have shown that the filter should be the complementary color of the gem tested (Hughes, 1987, 1988).

Growth zoning under UV light. Other tricks exist for locating color zoning in difficult stones. Observation of UV fluorescence (if any) while under magnification is useful for pale stones, especially synthetic colorless sapphire. Low-power magnification (2–6×) can often help pinpoint fine growth details which would otherwise be missed, such as curved banding. This technique makes it possible to locate curved banding even in synthetic colorless sapphire.[10]

Gas bubbles

Gas bubbles result from localized boiling of the top of the boule during growth, due to irregular feed of the powder or too high a flame temperature. They are a common feature of Verneuil synthetics and are of great diagnostic value. Found in a wide variety of shapes and sizes, gas bubbles always appear in high relief, due to the refractive index difference between the gas and surrounding stone. Concentrations vary widely from one specimen to another. Some stones exhibit large numbers, while in others they appear infrequently, or not at all. Bubbles are most common in dark blue stones and least common in the yellow/orange and colorless varieties. In blue stones, blue color concentrations are sometimes seen surrounding the bubbles.

The best illumination for seeing gas bubbles is dark-field, or better yet, fiber-optic lighting.[11] With a good fiber-optic illuminator, bubbles which are nearly invisible under ordinary dark-field illumination can be easily spotted.

[10] Short-wave UV radiation is harmful to the eyes and so protective glasses which block out these rays must be worn when performing this test.

[11] Not all fiber-optic illuminators are created equal. In selecting one for gemological use, one should ensure that the light source is strong enough and the light guide large enough in diameter. Ideal are those utilizing a 150-watt quartz halogen projector bulb with a built-in reflector, along with a flexible light guide of approximately 9–13 mm diameter. Avoid light guides with the goose-neck metal jackets, as they do not provide enough flexibility

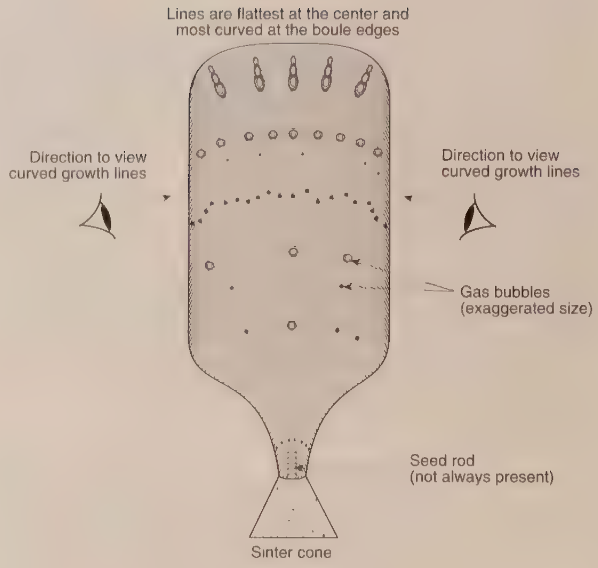


Figure 7.13 Distribution of curved growth lines and gas bubbles in the Verneuil synthetic corundum. Curved growth lines are seen by looking at roughly 90° to the boule's length. Gas bubbles usually occur in layers which follow the curved growth lines. When the bubbles are elongated, this elongation is usually at right angles to the direction of the curved growth lines, with the head of the bubble facing the bottom of the boule.

Bubble shapes. Large examples may resemble doughnuts, due to the manner in which light is reflected from the rounded surfaces. Spherical shapes are most common, with triangular or tadpole shapes also seen, where the head of the bubble points away from the top boule surface, perpendicular to the curved growth lines. One may also encounter irregular, wormlike patterns which resemble the fingerprints of natural stones. These are among the most deceptive features found in Verneuil synthetics and are believed to result from improper calcination of the raw alumina powder (Gübelin, 1953). Separation of gas-filled inclusions from the predominantly fluid-filled forms in natural corundum is achieved by immersion with light-field illumination. Gas bubbles appear dark, while fluid inclusions tend to be transparent and light (see Figure 7.12).

Distribution. Bubble clouds generally follow the curved growth lines and thus reveal the direction of those lines. Within the clouds, some bubbles may be elongated. Because this elongation is usually against the growth structure (perpendicular to the growth lines), their patterns provide an important clue to the direction of the curved growth lines.

Other Verneuil inclusions

All other inclusions seen in Verneuil synthetics are of minor importance compared to the curved growth lines and gas bubbles.

Figure 7.14 Plato twinning lines in a Verneuil synthetic yellow sapphire parallel to the *c* axis, while immersed in di-iodomethane between crossed polars. The Plato lines are a form of repeated twinning parallel to the faces of the hexagonal prism. (Photo: AIGS, Bangkok)

Seed rod. Stones cut from the base of the boule may include part of the seed rod upon which the growth is sometimes initiated. Should the rod's color be different from that of the stone, they will show up clearly under magnification. In addition, the interface between the seed rod and stone often shows a frosted appearance, making the seed readily visible.

In early Verneuil stones, growth was sometimes initiated on natural ruby seeds. An example of this was the boule of B.W. Anderson described by Nassau & Crowningshield (1969).

Plato twinning. It was long believed that oriented planar growth phenomena occurred solely in natural corundum. However, about 1920, Sandmeier, a Swiss gemologist, observed unusual banding in a Verneuil synthetic. His findings were confirmed by W. Plato (1952) of West Germany. These *Sandmeier-Plato* striations, which require special circumstances to see, consist of slip (glide) twins parallel to the hexagonal prism. They form as a result of the rapid cooling of the boule and the relaxation of residual stresses when it is split (Belyaev, 1980).

Plato lines can be found in any of the transparent Verneuil varieties, but only a small percentage of stones actually display them. To observe Plato lines, the stone must be examined under magnification between crossed polaroids. It is also necessary that the stone be immersed in di-iodomethane and viewed parallel to the optic axis. Once the optic axis is correctly positioned, the lines will appear in single, double, or triple sets which intersect at 60° or 120° angles. Irregular shadows similar to the anomalous double refraction effect of glass are also seen between the lines, resulting from strain built up during the boule's formation. These are most notable in areas corresponding to the outer edges of the boule (Eppler, 1964).

Plato lines are normally used only as a last resort, when all other tests have failed to identify the stone. This is because of the rather complicated setup required to locate them and their complete absence in many Verneuil stones. However, if present, they do provide positive evidence of synthetic origin. Although the polysynthetic twin lamellae of natural corundum may resemble Plato lines, they do not run parallel to the optic axis. The only oriented lines found parallel to the optic axis in natural rubies and sapphires are growth lines. Growth lines appear dark between crossed polars and lack the irregular shadows of Plato lines.

Rhombohedral twinning. Rhombohedral twinning is often considered a diagnostic feature of natural corundum. Few people are aware that, in rare instances, rhombohedral $\{10\bar{1}1\}$ twinning has been found in Verneuil stones (Eppler, 1964). In flame-fusion corundums such twins are generally fewer in number and usually in one direction only, but in rare cases they intersect at 87° and 93°. This is not the prismatic Plato twinning just discussed, but instead is rhombohedral twinning identical to that found in nature. Rhombohedral twinning in the Verneuil synthetic also shows interference fringes between crossed polars, and long white needles (boehmite?) may be seen along the junctions of crossing planes.

Mechanical deformation and rapid cooling are believed to be the cause of these deceptive twinning planes, which occur most often in blue, yellow, and orange varieties (but have been found in red stones, too; Hargett, 1989). While rhombohedral twinning is not common in the Verneuil product, one should be aware of the possibility. Even so, the curved growth lines and gas bubbles still allow positive identification.

Secondary healed fractures ('induced' fingerprints). The author first encountered a Verneuil synthetic containing realistic fingerprints and feathers in 1980. Since that date, a small number of such stones have appeared. These possess all the typical features of the Verneuil process, and so are identifiable as such. Yet they contain secondary fingerprints and feathers which, by themselves, are indistinguishable from those found in natural rubies and sapphires. Much speculation has been made as to possible causes of these inclusions, with some gemologists suspecting they have been deliberately induced by cracking the stones and, subsequently, healing these fractures at high temperatures. Koivula (1983) actually did experiments showing how this could be done. Whether these *induced fingerprints,* as they are sometimes termed, result from accidents during growth, or from deliberate attempts to deceive, remains to be proved. Those observed thus far always break the surface of the stone.

Don't get bitten: Watch out for altered synthetic corundum rough

UNSCRUPULOUS traders at mining areas often attempt to process synthetic rough so that it resembles nature. This has been done since the advent of synthetic gems (*cf.* Heaton, n.d., ca. 1912). Such pieces typically involve Verneuil rough, which is used because thieves are cheapskates—they do not like to waste money on more-expensive, flux-grown rough. The rough is buried, broken, tumbled, burned, sat on and shat upon, so as to resemble natural rough. This can often be identified by it's shape, which, even when altered, still resembles a boule fragment, i.e. flat on one side and round on the other. In the case of the blue variety, the color will often be seen wrapping around the round skin (see Figure 7.10).

Occasionally yellow surface stains are applied to simulate the appearance of natural sapphire rough, which often contains yellow areas of color. In other cases, the material may actually be ground into the shape of a crystal, complete with striations on the faces. But unlike natural crystals, magnification of man's handiwork shows rather less attention to detail. Nature never does striations *almost parallel*. And nature never uses a grinding wheel.

Another common trick is to quench-crackle the rough. This involves heat and rapid cooling to induce fractures. Such stones display a characteristic honeycomb fracture pattern quite different from anything encountered in natural ruby or sapphire.

The best way to identify altered rough is via magnification with immersion. This reveals the gas bubbles and curved growth lines so characteristic of the Verneuil product. In the case of red stones, immersion plus shadowing illumination is useful. Ultimately, one should always be suspicious when offered rough corundum of high clarity and good color in mining areas. The fact is that such rough is extremely rare in nature, and not likely to be offered for sale at the mine or on the street. Anyone who finds such a piece of rough knows exactly where to go to sell it—a major dealer. So don't get too greedy—greed is a beast that all too often ends up biting back—right in the wallet.

Figure 7.15 Altered Verneuil synthetic ruby rough tumbled and ground to resemble a natural ruby crystal. Material such as this is frequently offered for sale in Vietnam. (Photo: Maha Demaggio/GIA)

Quench crackling. These are stones which have been heated and then, while still hot, plunged into a cooler liquid. This produces fractures which cause the stones to more closely resemble the natural. Synthetic ruby is most often treated in this way, with the fractures forming a characteristic *honeycomb* pattern. Occasionally oils or other liquids are forced into the cracks in an effort to simulate the fingerprints and feathers of natural stones. The stones may also be heat treated. Quench-cracked Verneuil stones can still be identified, of course, by the curved growth lines and gas bubbles.

Verneuil visible absorption spectra

The spectroscope is an important diagnostic tool, because, with the exception of the microscope, it is the only basic gem-testing instrument which can positively separate natural and synthetic corundum. See Table 4.4 on page 81 for a full description of the visible spectra of both natural and synthetic corundum.

Cr & Fe spectra. Natural and synthetic ruby are both colored by traces of chromium and, hence, generally show identical absorption spectra. However this is not the case with sapphires. The blue color of natural sapphires is caused by small amounts of iron and titanium. This produces an absorption complex of three lines at 451.5, 460 and 470 nm, which collectively are termed *iron lines.* On occasion, only the 451.5 line is seen and, in heat-treated stones, this too may be absent, especially with those from Ceylon.

Verneuil blue sapphires also owe their color to the iron-titanium mixture, but, because of the greater volatility of iron in the Verneuil torch, iron lines are not seen. In rare instances a weak, poorly defined line at ~450 nm has been reported in medium to deep blue synthetic sapphires (Anderson, 1980b). But among the thousands of specimens examined by the author, only a few have exhibited this line. Caution is essential, for a weak 451.5 line has also been observed in Chatham flux-grown synthetic blue sapphires (Kane, 1982). Although the complete series of iron lines can be taken as positive proof of natural origin, a weak line by itself at 451.5 should not. Given their complete absence, the stone in question could be either natural or synthetic.

Iron also colors, in part or whole, most natural yellow, orange, and green sapphires. Hence they, too, may show iron lines at 451.5, 460 and 470 nm. Again, Ceylon stones may show only a weak 451.5 nm line, which is reduced or removed completely by heat treatment. Iron is not used as a coloring agent in Verneuil synthetic sapphires for these colors, so Fe lines will not be seen. Instead, the synthetic yellow is colored by nickel, the orange by nickel and chromium, and the green by cobalt plus nickel and vanadium. In addition to the absence of iron lines, synthetic green sapphires may show a line due to vanadium at 475, or lines at 500, 530, 635 and 690 nm.

Although iron is not normally used to color Verneuil synthetic yellow and orange sapphires, a weak, ill-defined line at 455 nm has also been reported on rare occasions (Anderson, 1980). In the deeper yellow and orangy yellow synthetic, a complete cutoff from about 450 nm, to the end of the violet, may be seen. This is also present with some natural sapphires and so is of no diagnostic value.

On occasion, the 451.5 nm complex has been detected in iron-rich purplish red rubies, particularly those from Thailand/Cambodia. Such stones will also show the normal Cr spectrum, but since the iron lines have yet to be found in synthetic rubies, their presence is proof of natural origin.

Vanadium spectra. The final instance in which the spectroscope is diagnostic is for the Verneuil color-change sapphire. Here vanadium is utilized as the coloring agent and it shows up in features that somewhat resemble those of ruby (natural and synthetic), with a fluorescent line close to 690 nm and a broad absorption band centered at about 580 nm. But instead of three lines in the blue, as shown by ruby, the synthetic color-change sapphire shows a single prominent line at 475 nm. The author has witnessed this vanadium line in only two natural corundums from Mogok, Burma, although it has also been seen in Tanzanian sapphires. Thus it is quite rare in natural corundums, and so, if seen, would strongly suggest (but not prove) a Verneuil synthetic.

Verneuil UV spectra

For a listing of Verneuil UV spectra, see Table 7.2.

Verneuil UV fluorescence

Had Karl Marx been a gemologist instead of writer, he no doubt would have labelled UV florescence "the opiate of gemology." No test is easier to perform, and none comes within hair's breadth of approaching the sense of security one gets basking in the warm red glow of a suspect ruby. The hand is withdrawn from the box, and the mind soars, serene in the knowledge that another synthetic ruby has met its match. But just as with opium and Marxism, the honeymoon is brief. It's a crazy little thing called reality—with the exception of Thai/Cambodian stones, most natural rubies fluoresce just as strongly as their synthetic brethren.

Use of UV fluorescence for the separation of natural and Verneuil synthetic corundum is fraught with danger. Due to the overlap in reactions of natural and flame-fusion synthetics, under no circumstances should it be considered anything other than a weak indication of a stone's identify. That said, in experienced hands, the test can still prove useful. Table 7.2 on page 157 includes a summary of the UV fluorescence of Verneuil synthetic corundum.

Synthetic star corundum

The Verneuil process is also used to grow star rubies and sapphires. Production of asteriated corundum was first achieved in 1947 by Union Carbide's Linde Division. Linde patented the process in 1949 (Pough, 1966).

Asterism in natural corundum is due to reflection of light from sets of microscopic *silk*, which intersect in three directions at 120° within the basal plane {0001}. Most silk consists of rutile (TiO_2), although hematite (Fe_2O_3), ilmenite ($FeTiO_3$), and magnetite (Fe_3O_4), have also been identified. It forms parallel to the prism faces of the host corundum via exsolution (see page 94).

A Linde star is born. While rutile inclusions were identified in asteriated corundum in the nineteenth century and the principles of exsolution were also understood at an early date, it took a chance observation before star rubies and sapphires were synthesized. In 1947, while experimenting with titanium as a coloring agent in synthetic corundum, Linde's J.N. Burdick noticed a trace of silk in one of the boules. Appreciating its significance, he then began experiments which succeeded in developing enough silk to produce a star.

The process involves addition of 0.1 to 0.3% of titanium oxide (TiO_2) to the feed powder, over and above the normal percentages of coloring agents. Then, the boule is grown in the usual fashion, with the titanium entering into solid solution with the alumina. After cooling, it is annealed at between 1100–1500°C for between to 72 hours to 2 weeks, or more. By maintaining this temperature over a lengthy period of time, the titanium unmixes in the form of needles within the synthetic corundum host and a star is born.

Linde's early production suffered from titanium's tendency to move to the outside surface of the growing boule, creating a star in which rays stretched only halfway down the cabochon sides, fading away near the girdle. Other stones showed incomplete stars and transparent areas, due to the uneven silk distribution. The problem was solved by intermittently altering the flame temperature as the boule grows, thus allowing one layer to solidify before the next is deposited. The result is a boule containing layers of uniform titanium distribution, alternating with layers with uneven distribution. As layers are only 0.10 mm thick, the star appears continuous to the eye and the stone can even be recut without problem.

A disadvantage of the torch temperature modification is that boules must be kept smaller in size. The largest cut stone Linde ever produced was a 109-ct star ruby, which was donated to New York's American Museum of Natural History.

Synthetic star rubies went on sale in September 1947 at \$30/ct, and several years later Linde introduced synthetic blue star sapphires. Only cut stones were sold, with cutting performed automatically by Linde. In addition to star rubies and blue sapphires, small quantities of white, gray, purple, green, pink, yellow, brown and black stars were made.

Figure 7.16 Synthetic star corundums

Top left: The engraved ℒ on the back of a Verneuil-grown synthetic star sapphire made by Linde. Note the dense concentration of tiny gas bubbles just below the surface. (Photo by the author)

Middle left: Synthetic star corundums are made in a variety of colors, as evidenced by these four stones. (Photo Mike Havstad/GIA)

Bottom left: Synthetic star ruby boule. Note the colorless seed rod, which is used to produce the desired orientation, with the *c* axis parallel to the boule's length. A faint star is visible on the polished end of the boule. (Photo Mike Havstad/GIA)

Top right: Kyocera/Inamori synthetic star rubies of 1.99 (round) and 1.60 ct (oval). Although many synthetic stars are opaque, some have a degree of transparency similar to fine star corundums. (Photo John Koivula/GIA)

Bottom right: In the near-opaque, "porcelain" variety, orienting the cabochon base parallel to the *c* axis may produce a cat's eye (right). (Photo Mike Havstad/GIA)

Linde enjoyed an early monopoly, but this was short-lived. Sometime before 1957, the Wiedes Carbidwerke of Freyung, [West] Germany, began selling synthetic star corundums ('*Stars of Freyung*') produced by a slight variation on the Linde method. The German stars were more transparent and natural appearing than Linde's. Synthetic star corundum has also been produced in Israel, Japan, Switzerland, and Russia. Currently, synthetic star corundum is produced solely by the Verneuil process. Linde did receive a patent for manufacture of synthetic star corundum by the Czochralski process, but these stones were never marketed.

Reports on the exact identity of the needles in synthetic star corundum differ. Some suggest that they consist of rutile (TiO_2), while others (Nassau, 1968) state that aluminum titanate (Al_2TiO_5) theoretically might also be formed. Today it is understood that they are rutile (Kurt Nassau, pers. comm., 3 April, 1995).

Researchers in Japan during the late 1970s grew Ti-doped ruby by the flux process in an attempt to study and replicate the relatively large exsolved rutile needles found in natural corundums (Takubo & Kitamura *et al.*, 1980). According to this study, rutile typically formed parallel to the first-order

Table 7.2: Properties of Verneuil synthetic corundum[a]

Property	Description
Color range/ phenomena	**Red (including pink)**: Light pink to dark red or purplish red **Blue**: Light to dark blue or violetish blue **Yellow**: Light to deep yellow to orange-yellow **Orange**: Light to deep orange to red-orange **Violet/Purple**: Light to deep purple to violet to violet-blue **Green**: Bright lime green **Colorless** **Color-change (due to V; do not confuse with blue-violet gems)** Daylight—light grayish green to deep bluish green Incandescent light—purplish red **Stars (6 rays)**: All colors
Synthetic process **Location**	• Verneuil (flame fusion) • Various manufacturers worldwide
Crystal habit **Stone sizes** **Prices**	• Round to elongated boules which are split lengthwise in the plane of the optic axis. Such rough may be broken, tumbled, burned, stained, etc., to resemble natural rough. • Cut gems are generally under 20 ct.; cut gems of up to 120 ct have been reported • Prices of cut gems in Bangkok range from US$0.35 to 3.00/ct for transparent material. Reds and yellows are cheaper, blues are up to twice as expensive as reds, and the green material, which is in little demand, may sell for ten times that of the red. **Syn. Star Corundum** • Star material generally wholesales for $1.00–2.00/ct cut
Spectra	**Visible**: • Both natural and Verneuil syn. corundum may show a Cr spectrum, which is of no diagnostic value • A complete Fe spectrum, consisting of a strong line at 451.5, a slightly weaker line at 460 and a still weaker line at 470 nm, has yet to be found in any syn. corundum made by any process. In rare instances, a weak 451 line has been found in the blue variety of Verneuil syn. corundum. Thus the presence of the complete 451.5, 460, 470 Fe spectrum strongly suggests a natural corundum (unheated or heated). • In the color-change variety of Verneuil syn. corundum, a vanadium spectrum is seen, consisting of a single distinct line at 475, a broad band centered at 580 (which gives the stone its color change), and a fluorescent line near 690 nm. While this V spectrum strongly suggests synthetic origin, it has also been encountered rarely in certain natural corundums, particularly those from Mogok, Burma. **Ultraviolet spectra:** • Syn. red to pink— UV transmission (315 nm) generally stronger than visible-region (approx. 550 nm) transmission. 80% show Type II spectra (see Table 4.2 on page 79 for description) • Syn. blue—Lines 1 & 2 stronger than line 8 (with line 10) *or* line 8 stronger than lines 1 & 2 (see Table 4.2 for description).
Fluorescence	**Red (including pink)** • LW: Moderate to very strong red to orange-red; usually quite strong, except in dark-toned stones • SW: Same as long wave, except sometimes slightly weaker. Light-toned stones may show chalky reactions; examination of fluorescence under magnification may help reveal curved growth lines (make sure eyes are properly shielded). **Blue** • LW: Generally inert; stones containing Cr may show weak to strong red to orange-red • SW: Inert to strong chalky blue to green (the colorless portions of the stone fluoresce; blue areas are inert). Examination of fluorescence under magnification may help to reveal curved banding (make sure that eyes are properly shielded). Stones containing Cr may show weak to strong red to orange-red. **Green** • LW: Weak to moderate orange-red, orange or red • SW: Weak to moderate dull orange to brownish red **Orange** • LW: Inert to strong red, orange-red or orange • SW: Inert to strong red, orange-red or orange **Yellow** • LW: Inert to moderate red to orange-red • SW: Inert to moderate red to orange-red **Colorless** • LW: Inert to weak chalky blue to green • SW: Weak to strong white or chalky pale blue; examination under magnification may reveal curved growth lines (make sure eyes are properly shielded) **Violet/purple** • LW: Weak to strong red to orange-red • SW: Weak to strong red to orange-red **Color-change** • LW: Weak to strong orange • SW: Weak to strong orange, chalky blue to green **Stars** Various reactions
Other features	• Verneuil corundum boules tend to be elongated pieces of slightly oval cross-section, split lengthwise to relieve strain. The *c* axis lies in the plane of the split, but does not always follow the boule length. Since the Verneuil product is sold by weight and the price is unaffected by *c* axis orientation, the lapidary concentrates on weight retention. Given a split boule segment which is flat on one side and round on the other, maximum weight retention is gained by placing the table along the split. Since the *c* axis always lies in the plane of this split, this means the *c* axis would lie parallel to the table. In contrast, natural corundums are oriented for best color in addition to maximum weight retention, because the quality of color does impact the price. For most natural and treated corundums, the best color and the greatest weight retention is gained by positioning the *c* axis at 90° to the table. These differences in orientation between the natural and Verneuil synthetics create subtle differences in the face-up color, due to pleochroism. The location of the *c* axis in corundum can be determined by reference to a variety of factors, including RI readings, an interference figure, pleochroism, lack of doubling, the position of certain inclusions, etc. To summarize, certain cutting factors tend to differ between the natural/treated product and the Verneuil synthetic. Just like the fluorescent reactions, if taken by themselves, cutting factors are not reliably diagnostic, because cutting decisions are totally made by humans. But in combination with other features they can represent additional pieces of the puzzle.

Table 7.2: Properties of Verneuil synthetic corundum[a] *(continued)*

Property	Description
Other features (continued)	• Verneuil syn. corundums tend to feature a poorer polish because the price is the same no matter how good the polish (most production is destined for class rings, costume jewelry etc.). A good polish takes time and time is money. Thus it doesn't pay to spend extra time perfecting the polish of a stone where 90% of its cost is in cutting labor. • Cutting styles and shapes sometimes used for the Verneuil product (such as the scissors cut) are rarely seen on natural and treated corundums. Due to the importance of weight retention, natural and treated corundums tend to show more pavilion bulge than the Verneuil product. **Syn. Star Corundum** • Original Linde stones featured an engraved *ℒ* on the polished base of the cabochon
Inclusion types	**Description**
Solids	• Traces of the seed rod (if one was used). The seed rod may have a different color than the rest of the gem and shows a frosted round surface at the rod junction.
Cavities (liquids/gases/solids)	• Gas bubbles, often in clouds following the curved growth lines. When elongated, are usually stretched at 90° to the curved growth lines with the head of the bubble pointing toward the boule's base. Sometimes irregular in shape; large bubbles show pseudo-doughnut shape. In blue stones, bubbles may show concentrations of blue color around them. Bubbles most common in blue stones, least common in yellow, orange and colorless. • Induced fingerprint or feather-like inclusions (secondary healed fractures) **Syn. Star Corundum** • Multitudes of gas bubbles, often arranged in curved layers
Growth zoning	• Curved growth lines at roughly 90° to boule's length, flattest in the center, more curved at outside edges. Narrow lines ('striae'—red, green & color change) seen best in dark-field, or light-field with closed iris diaphragm and shadowing. Broad lines ('banding'—all other colors) seen best in dark-field or diffused light field (white filter). With yellow and orange stones use frosted blue filter. Immersion in di-iodomethane aids in locating all types of growth lines. **Syn. Star Corundum** • Curved growth lines seen parallel to base of cabochon. Sometimes concentric growth lines are seen at 90° to base of cabochon.
Twin development	**Secondary glide twinning** • Plato twinning—seen in groups of one, two or three directions parallel to the hexagonal prism faces (parallel to *c* axis, crossing at 60/120°). To view, immerse in 3.32 between crossed polars and examine parallel to *c*. • Rhombohedral twinning, sometimes with boehmite needles at the junctions of crossing twin planes, identical to natural corundum. Twins cross at 87/93° and are seen roughly 30/60° off the *c* axis. Immersion between crossed polars facilitates the location of twinning.
Exsolved solids	• Extremely tiny needles of exsolved rutile, grouped in dense clouds; the needles run parallel to the faces of the second-order hexagonal prism (3 directions at 60/120°) in the basal plane. Such needles are generally much smaller than in natural gems and may require high magnification (>100×) to resolve. Rutile silk is rare in transparent Verneuil synthetic corundum, but has been seen on occasion. • Boehmite needles occasionally seen at junctions of crossing rhombohedral twin lamellae (possible two directions in same plane, three directions total, meeting at 87 and 93°) **Syn. Star Corundum** • Extremely tiny needles of exsolved rutile, grouped in dense clouds; the needles run parallel to the faces of the second-order hexagonal prism (3 directions at 60/120°) in the basal plane. Such needles are generally much smaller than in natural gems and may require high magnification (>100×) to resolve.

a. Table 7.2 is based largely on the author's own extensive testing of this material, along with the published report of Montgomery (1991b) on UV spectra.

hexagonal prism $\{10\bar{1}0\}$, or more rarely, the second-order prism $\{11\bar{2}0\}$, with the {100} face of the rutile lying in the corundum basal plane {0001}. This differs from other observers, who have found that rutile generally runs along the second-order prism $\{11\bar{2}0\}$ (Sahema, 1982). In any event, Takubo *et al.* were able to grow corundum with exsolved rutile ranging in length up to 5 mm. They reported that, unlike Verneuil star rubies, this rutile was similar in appearance to that found in natural rubies, such as those from Burma.

Identifying Verneuil star corundum

Visual features. Synthetic star corundums can usually be easily identified by appearance and inclusions. Visually, the synthetic products appear too good, with most possessing an extremely sharp star (due to the fine nature of the included silk). In addition, the synthetic stone is often less transparent than the natural, bordering on opaque in the so-called *porcelain* quality. Exceptions are the early Linde and some recent synthetics, which may possess greater transparency, as well as incomplete stars (due to uneven distribution of silk).

In contrast to natural star corundums, synthetic stars are usually characterized by flat, polished bases having no excess weight below the girdle. Original Linde stars featured an engraved *ℒ* (standing for *Linde*) on the base, while the modern synthetics show a partial or complete *bull's-eye* circular zoning pattern on the bottom surface.

Inclusions. Positive identification is afforded by inclusions. Gas bubbles are extremely common, with some found in virtually all specimens. However, due to the usual lack of transparency of the synthetic, they may not be seen clearly under dark-field illumination. Instead, gas bubbles in the near-opaque porcelain-grade stones are often seen better under

Table 7.3: Properties of Geneva synthetic ruby[a]

Property	Description
Color range/phenomena	Medium to dark red
Synthetic process **Location**	• Geneva process (a Verneuil-process variation) • Believed to have been manufactured in a number of European locations
Crystal habit **Stone sizes** **Prices**	• Rounded, shoe button-shaped boules (not elongated) • Generally less than 2 ct cut • No longer manufactured
Spectra	**Visible** • Strong Cr spectrum (same as natural) **Ultraviolet spectra** • Not reported
Fluorescence	Not reported
Other features	Not reported
Inclusion types	**Description**
Solids	None reported to date
Cavities (liquids/gases/solids)	• Gas bubbles (usually present in quantity)
Growth zoning	• Growth termination skins outside of clear core • Three-piece internal structure on full boules • Curved growth lines within each section
Twin development	None reported to date
Exsolved solids	None reported to date

a. Table 7.3 is based on the published reports of Kunz (1886, 1887), Smith (1913) and Nassau & Crowningshield (1969).

light-field illumination, with the iris diaphragm open just enough to allow a small circle of light to pass through the stone near the girdle. Alternatively, gas bubbles also show up clearly if the stone is illuminated from the side or edge with a fiber-optic light.

Curved growth lines. Again, differences exist between the Linde and modern products. Linde stones show widely spaced, easily-visible curved growth lines at 90° to the optic axis. These differ from the tightly packed curved striae of transparent Verneuil synthetic rubies. Non-Linde stars not only show curved lines roughly parallel to the cabochon base, but also display concentric bands which form a complete or partial *bull's eye pattern* on the cabochon base itself. Often a circular, completely transparent space surrounded by gas bubbles is seen. This is not found in Linde stones.

Modern stones may possess a layered distribution of silk and bubbles. When viewed parallel to the optic axis under magnification, silk comes into view first. Then, as the focus is lowered, a layer of bubbles is seen, then silk again, and so forth throughout the stone.

Silk differences. Individual needles of synthetic star corundum are generally smaller and silk clouds more evenly distributed than in nature. Natural silk tends to occur in uneven, strongly-zoned patches, with individual needles easily visible under 10–30×, whereas a minimum of 50× magnification is often required to resolve single needles in the synthetic. Due to differences in respective growth rates, needles in Linde stars are usually longer and more slender, while the non-Linde product contains shorter, more coarse silk of uneven distribution. Differences in needle size, shape and distribution may also cause differences in appearance.

Czochralski (pulling) process

The vast majority of synthetic corundum gems are grown by the Verneuil process. However, certain industrial applications, such as lasers, require crystals of greater perfection at the atomic level. This need led to the growth of corundum by other methods, such as the Czochralski process.

The Czochralski process of pulling from the melt achieves a degree of perfection far greater than that of Verneuil. Although the basic apparatus was developed in 1918 by J. Czochralski, it was not until the advent of lasers in the early 1960s that it was applied to large-scale growth of ruby. Today, in addition to ruby (including pink), colorless, blue, yellow and orange sapphires are also manufactured by the pulling techniques, for use in both jewelry and industry.

Principles of Czochralski growth are simple, but sophisticated apparatus is required. Aluminum oxide[12] plus colorant

12. Feed material at Union Carbide's Washougal, WA plant is synthetic colorless sapphire grown by the Verneuil process.

Figure 7.17
Left: Milan Kokta (left) and Jeff Cooke of Union Carbide's Washougal, WA plant, with two Czochralski-grown synthetic corundum whoppers. (Photo by the author)
Right: A large single crystal of synthetic ruby grown by the Czochralski ('pulling') process. Due to the curved surfaces, stones cut from such crystals contain extremely fine curved growth lines. (Photo: GIA)

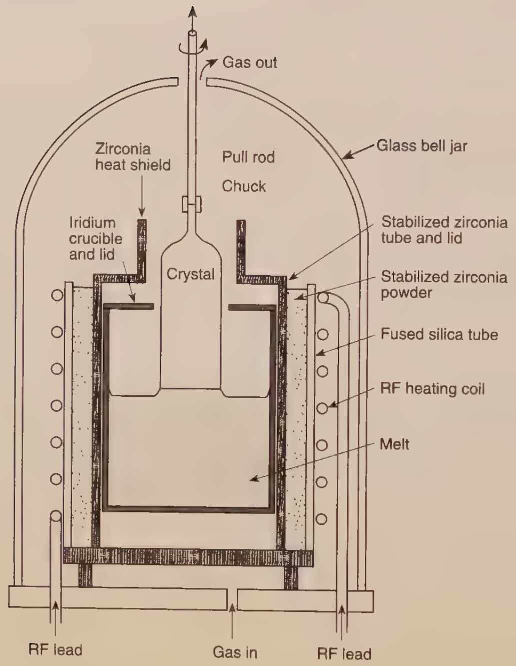


Figure 7.18 Typical apparatus for growing synthetic corundum by the Czochralski ('pulling from the melt') process. (After Nassau, 1980)

(if a colored crystal is desired) are melted in an iridium crucible by means of a radio-frequency (RF) coil heater. An oriented corundum seed crystal attached to a rod is then lowered to touch the surface of the melt. Thermal conduction allows the seed to extend a slight distance into the melt without being dissolved itself. Temperature control is critical—if the melt is too hot, the seed itself will melt.

Pulling begins by simultaneous rotation and slow retraction of the seed. As it is withdrawn, surface tension causes molten alumina to cling to the seed, where it solidifies. Corundum is added continually to the end of the rod as it is slowly lifted out from the crucible. Thus, a single cylindrical crystal up to 20 cm in diameter and 100 cm in length can be obtained.[13]

Pulling rates range from 6–25 mm per hour, with larger pieces utilizing slower rates. It is important that the growing crystal's diameter be kept uniform because sudden changes tend to cause inclusion of gas bubbles and other imperfections. Various methods are used to control the temperature and growth, such as continuously weighing the crucible contents, or even weighing the growing crystal itself (Nassau, 1980).

Czochralski-grown corundum gems are often cut from crystals originally intended for industrial use. These consist of rubies made for lasers, and colorless sapphires for use as watch crystals, among other things. One of the biggest manufacturers of this material is Union Carbide, at their Washougal, WA plant. They have grown material of colorless, red (including pink), blue, and yellow colors in the color depths necessary for gem use. This material wholesales for approximately $4/gram (Milan Kokta, pers. comm., Sept. 1994).

In 1980, Kyocera (Kyoto Ceramics) of Japan began selling faceted Czochralski-grown synthetic rubies, either as loose stones or mounted in their own line of jewelry. Stones are sold under the *Inamori* name, which comes from Kyocera Chairman, Kazuo Inamori. In the USA, they were once marketed under the *Crescent Verte* tag. The Inamori product is far more expensive than that from the Verneuil furnace and

13. There appears to be a physical limit to the diameter of crystals which can be grown by this technique. Larger diameter crystals run into problems because the temperature gradient (difference) between the edge and center of the melt is too great (Milan Kokta, pers. comm., Sept., 1994).

Figure 7.19 Inamori Czochralski-grown synthetic corundum
Left: Inamori synthetic orange sapphire (Photo: Kyocera)
Top right: Inamori synthetic ruby of 0.52 ct. (Photo: GIA)
Lower right: Curved striae and "rain"-like particles (at roughly 90° to the striae) in an Czochralski-grown synthetic ruby. (Photo by the author)

reflects the company's marketing strategy of creating an exclusive image for their line. In 1994, wholesale prices for ruby were approximately $100–150/ct. Other than ruby, Inamori also markets blue and orange sapphires, as well as star ruby. The blue color is sold primarily in Japan.

Czochralski (pulling) identification

Czochralski-grown synthetic corundum is rarely seen in the jewelry trade, probably because it is indistinguishable from the far-cheaper Verneuil product.

Inclusions. To the naked eye, Czochralski stones appear similar to the Verneuil product. Under the microscope, they are often completely clean, but careful examination reveals features allowing positive distinction from both natural and Verneuil synthetics. Foremost are gas bubbles, faint curved growth lines and roughly parallel rows of minute particles of unknown identity which resemble the rain-like flux inclusions found in Kashan flux rubies. Metallic needles and plates have also been seen, mainly at crystal surfaces. They are smaller and far less common than those of Chatham flux-grown synthetic corundum.

Growth striae of Czochralski stones are often tightly curved and so faint that their location may require use of immersion and shadowing. They can normally be seen from several different directions, with color swirls and "cigarette smoke"-type veiling running across the striae. According to Kyocera, feathers resembling a "bundle of twigs" are also found in Inamori gems (Inamori Jewelry Division, 1980). This may actually be a reference to the rain-like particles.

UV fluorescence. Under UV light, Inamori synthetic rubies show an intense red glow unequaled in strength by almost any other ruby, natural or synthetic. This fluorescence is largely responsible for the beautiful crimson color of the Inamori product. The fluorescence of the Inamori synthetic orange sapphire is generally a weaker version of its red cousin, while that of the Inamori blue sapphire has not been reported at the time of writing.

Floating-zone process

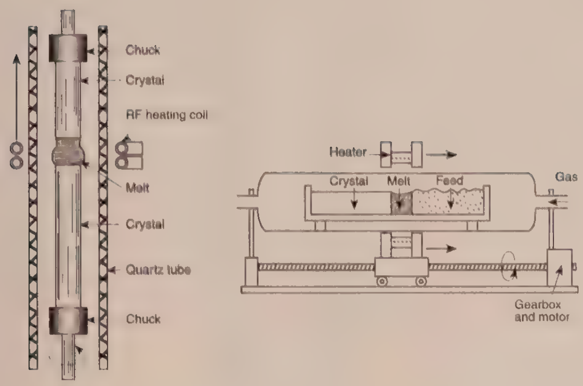
Among the techniques applied to gem corundum synthesis is the floating-zone process. A variation on the horizontal zone-refining method, it was first adapted for the manufacture of corundum gems by the Japanese giant, Suwa Seikosha, maker of Seiko timepieces (Scarratt, 1984).

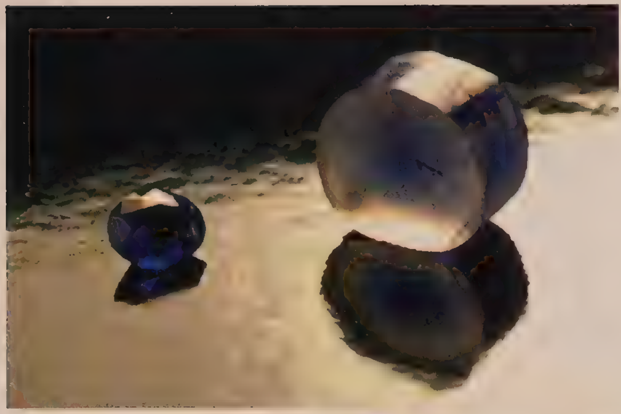
The floating-zone process makes use of a moving temperature gradient (zone of decreasing temperature). In the manufacture of synthetic ruby, a sintered rod of aluminum and chromic oxides is rotated vertically between two chucks. To begin growth, the lower rod end is melted with an infrared radiation convergence heater, forming a narrow molten zone. Then, by slowly lowering the rod past the heater, this molten zone travels along the rod, supported by surface

Table 7.4: Properties of Czochralski synthetic corundum[a]

Property	Description
Color range/phenomena	**Inamori** • Red (including pink): Pink to medium red, strongly fluorescent • Blue: Medium blue • Orange: Medium orange • Red star (6-rays): Medium purplish red **Union Carbide** • Colorless • Red: Pink to medium red, strongly fluorescent • Blue: Medium to deep royal blue • Yellow: Medium yellow
Synthetic process Location	• Czochralski (pulling), melt growth. The manufacturing process of the Inamori syn. star corundum has never been confirmed, but is believed to be Czochralski. • Kyocera, Inamori Division, Kyoto, Japan • Union Carbide, Washougal, WA, USA
Crystal habit Stone sizes Prices	**Inamori** • Lustrous rod-shaped crystals with the *c* axis generally parallel to the rod length. Rough may be cut into cubes for sale. • Mostly small, with few cut stones exceeding 5 ct, and fewer still above 10 ct • 1994 wholesale prices: US$100–150/ct for faceted stones, depending on size and quality **Union Carbide** • Rod-shaped cylinders as above • Crystals may be of enormous size; cut stones of tens of thousands of carats could theoretically be faceted • Approx. $4/gram for rough, with defective industrial material even less. Union Carbide does not sell cut stones.
Spectra	**Visible** • Red (including pink): Cr spectrum, same as natural, of no diagnostic value • Orange: Not reported; probably a weak Cr spectrum • Red star: Cr spectrum, as above **Ultraviolet** • Red (including pink): Generally UV transmission (315 nm) stronger than visible-region transmission. 100% show Type 2 spectra (see Table 4.2 for description).
Fluorescence	**Red (including pink)** • LW: Extremely strong red to orangy red • SW: Extremely strong red to orangy red **Orange** • LW: Moderate orangy red • SW: Moderate orangy red **Red star** • LW: Very strong red • SW: Strong to very strong red with a moderate to strong superficial chalky blue-white overtone **Colorless**: Not reported **Blue**: Not reported **Yellow**: Not reported
Other features	Not reported
Inclusion types	**Description**
Solids	• Fiber-optic lighting may reveal "smoke-like" or "rain-like" wisps similar to the rain-like flux found in Kashan flux-grown syn. rubies. • Small black prismatic crystals of moderate-to-high relief, which probably represent a by-product of crucible corrosion • Metallic silver plates have been seen on the surfaces of some crystals • Traces of seed (roughly hexagonal in shape)
Cavities (liquids/gases/solids)	• Gas bubbles, both round and distorted. These may occur as random individuals, or radially arranged ('stringers') near the skin of the pulled crystals. Other patterns are also possible. • Unusual feather/fracture inclusions have been seen which show early stages of healing • Cracking or crazing near the surface of rough
Growth zoning	• Entire rods show concentric (circular) growth striae parallel to the length of the rod. These lines are much less obvious than in their Verneuil counterparts, and immersion with shadowing may be required to resolve them. While immersed in di-iodomethane with light field, close the iris diaphragm to a size just smaller than the stone's diameter. Then a straight-edged object such as a business card is brought between the iris and the immersion cell. Try to line up the edge of the business card with the general direction of the growth lines for the best effect. • Completely circular lines may not be seen if the stone is cut from just a portion of the rod. From the tightly curved striae of Inamori stones, it would appear that Inamori's rods are rather small.
Twin development	None observed
Exsolved solids	**Red star (Inamori only)** • Clouds of extremely fine white-appearing exsolved rutile. Such clouds appear patchy in places under fiber-optic illumination. Such rutile clouds may require upwards of 400× magnification to resolve individual needles.

a. Table 7.4 is based on the author's research, along with published reports of Gübelin & Koivula (1986), Koivula & Kammerling (1988) and Montgomery (1991b).





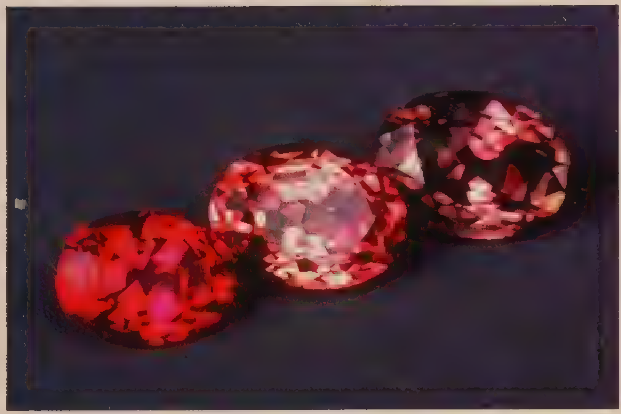


Figure 7.20 Seiko synthetic corundum
Top left: Apparatus used in the floating-zone (zone refining) growth of synthetic corundum. The molten zone's thickness has been exaggerated for clarity. (After Nassau, 1980)
Top right: Rough and cut Seiko blue sapphire. The rough has been sliced. Note the blue color concentration in the center. (Photo: AIGS)
Bottom right: Seiko rubies. The stone at far right is a Seiko synthetic alexandrite chrysoberyl. (Photo Mike Havstad/GIA)

tension. Like a sweeper, impurities tend to remain within the molten zone, and are thus dragged to one end. Once the opposite end is reached, the heater is turned off. A related process, termed *zone refining,* can also be used to purify existing crystals. In zone refining, several passes of the heater may be made.

The floating-zone process was first employed in commercial synthesis of gem corundum by Seiko. Experiments at developing a better watch cover crystal eventually led to the synthesis and manufacture of corundum by their Matsushima Kyogo division. Ruby, blue, and orange sapphires were once produced at the rate of 1,000 ct per month (Scarratt, 1984). Stone sizes were mostly less than one carat cut, to keep prices of finished jewelry down (Brown, 1985). As of 1995, Seiko no longer manufactures material for gem use.

Seiko synthetic corundum was not sold as rough, but was available only in finished jewelry under the Bijoreve trademark. Rough appears as rods with a slight flattening of the sides in a hexagonal pattern. In addition to Seiko, floating-zone gem corundum has been grown in Russia on an experimental basis.

Floating zone identification

Identification of the Seiko product, which includes stones of red, orange, and blue colors is achieved via the microscope. Most are free from inclusions, with the sole features being swirled growth lines and clouds of tadpole-shaped gas bubbles (Scarratt, 1984). In the case of the pink and orange varieties, it may be necessary to immerse the stones in diiodomethane before flow lines become visible. Seiko corundums may also display rhombohedral twinning with long white needles (boehmite?) at the junctions. With the exception of the swirled color zoning, the internal scenery of Seiko stones is similar to Verneuil or Czochralski-grown synthetics. Fog-like swaths of unknown composition may also be seen, along with tiny individual particles (Gübelin, 1988).

Color zoning of Seiko synthetic blue sapphires differs from other varieties in that the color is concentrated in the center of the crystal. The result is an unusual circular blue color spot in the center of the rough and also in the center of many cut stones. In the single piece of blue rough examined by the author, the *c* axis was oriented at 90° to the boule's length. With faceted blue stones, the *c* axis was typically cut parallel to the table, opposite to most natural corundums.

Combination melt techniques

Two other melt processes have been developed in Russia, variations on the three major processes previously described. The first has been labeled *horizontal growth,* and involves a combination of floating zone and Bridgeman solidification in a crucible (Kurt Nassau, pers. comm., 3 April, 1995). Powder is placed in a horizontal boat-shaped container and

Table 7.5: Properties of floating zone synthetic corundum (mostly Seiko)[a]

Property	Description
Color range/phenomena	Red, orange & blue colors have been grown
Synthetic process Location	• Floating zone • Hattori Seiko, Japan • Russia
Crystal habit Stone sizes Prices	• Rods with slightly flattened sides • Cut stones are generally one carat or less • No longer being sold
Spectra	**Visible**: Red: Strong Cr spectrum **Ultraviolet**: Not reported
Fluorescence	**Red** • LW: Strong to extremely strong red to orangy red • SW: Strong red to orangy red **Blue** • LW: Inert • SW: Weak chalky green **Orange** • LW: Moderate red to orangy red • SW: Strong red to orangy red
Other features	Irregular strain pattern between crossed polars (Gübelin, 1988)
Inclusion types	**Description**
Solids	• Tiny individual flux particles have been reported, as well as fog-like irregular clouds of unknown composition
Cavities (liquids/gases/solids)	• Gas bubbles are common
Growth zoning	• Color swirls in a random pattern; blue stones may show a color concentration in the center
Twin development	• Secondary repeated twinning along the rhombohedron faces, which may be accompanied by white needles (probably boehmite) at the intersections of the twin planes • Rectilinear (straight) parting has been reported by Seiko. This is probably a reference to the rhombohedral twinning and boehmite, as described above.
Exsolved solids	• Boehmite needles occasionally seen at junctions of crossing rhombohedral twin lamellae (possible two directions in same plane, three directions total, meeting at 87 and 93°)

a. Table 7.5 is based on the author's own research, along with published reports of Koivula (1984), Scarratt (1984), Brown (1985) and Gübelin (1988).

heat applied to one end. A seed crystal is then brought into contact with the melt, and horizontally drawn away, initiating growth. The heater is then moved slowly to the opposite end several times, resulting in a large synthetic crystal. Approximately two weeks are required for the entire process, which can produce crystals of large size. One rough crystal of 2,817 ct was described by Scarratt (1994). It contained gas bubbles and Christmas-tree like dendritic inclusions similar to those found in devitrified glass. Laughter (1994b) also reported curved striae in this material.

A second technique was also described by Scarratt (1994). This was said to be a combination of the Verneuil and Czochralski methods, but no further details were given. A ruby crystal of 286.44 ct was examined. It was free of gas bubbles and showed a distinctive rippled and silky surface appearance. The only growth structures visible were a series of fine lines running diagonally across the crystal.

"Recrystallized" ruby

In 1995, Larry Kelley of Las Vegas-based TrueGem™ announced he had developed a process for "recrystallizing" ruby and sapphire from natural feed material. The process as described by Larry Kelley (pers. comm., 22 Feb., 1995) involves crushing and acid cleaning natural ruby and sapphire. This material, along with some additional dopant, is placed into a horizontal zone-refining "boat" (see Figure 7.20). Several passes of the heater remove many of the impurities present. The resulting rod is then melted in a Czochralski crucible and a high-grade crystal pulled from the melt. Stones are then faceted.

So why bother? Why not just use purified chemicals? Kelley believes natural ruby's color is not solely due to Cr, but involves a possible interaction of many trace elements found in ruby. Analysis of his stones do show a trace-element content closer to natural rubies than other synthetics. But all is meaningless if the appearance of TrueGem rubies is not

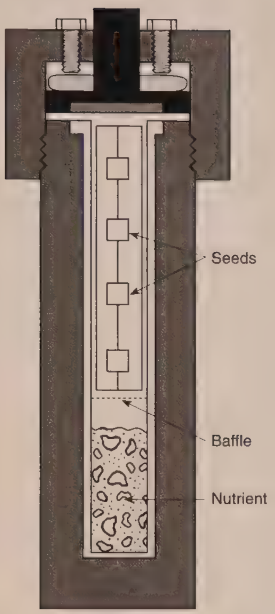


Figure 7.21 Autoclave and other apparatus used in the hydrothermal growth of synthetic corundum. (Modified from Nassau, 1980)

"better" than other synthetics. To answer that question, readers will have to look for themselves.

TrueGem ruby wholesales for \$210–230/ct. Since it is a Czochralski product, it may display features which are characteristic of that process, such as extremely fine curved striae and gas bubbles. Colors range from pink to red.

Solution growth processes

Hydrothermal process

Among the different techniques of corundum synthesis is hydrothermal transport. Otherwise used primarily for the synthesis of quartz and emerald, this process involves growth via solution, rather than melt. Due to the difficulties of growing corundum by this method and high costs involved, to date it has been applied on a small scale only.

Corundum is completely insoluble in water at room temperature, and only slightly soluble at water's boiling point (100°C). However, if a pressurized vessel is used and the temperature is further increased, its solubility rises dramatically (Butcher & White, 1964). This is the principle of the hydrothermal process, the method which most closely duplicates growth of corundum within the earth.

Bombs away. In the growth of corundum, nutrient material is placed in the bottom of a high-pressure vessel known as an autoclave. Autoclaves are typically made of thick steel and incorporate sophisticated closures to withstand pressures which average approximately 3000 atmospheres. So great are the pressures that explosions are a real possibility. Thus the origin of the term *bomb,* to which the autoclave liner is sometimes referred.

Synthesis of ruby requires the autoclave be lined with a suitable metal, such as silver or platinum, for otherwise the iron from the container's walls will color the crystals green. It has been found that the solubility is greatly increased by addition of a mineralizer (flux), such as potassium or rubidium carbonate, which creates an alkaline solution.

Growing with the flow. Seed crystals of either natural or synthetic (Verneuil) corundum are hung from a silver frame atop the vessel and once sealed, the autoclave is then heated on the base. While the temperature at the base is approximately 580°C, in the upper regions (where the seeds are located) it is only 540°C, creating the temperature gradient crucial to the hydrothermal-transport process. Due to the higher temperatures at the bottom, a saturated solution of corundum in the mineralized liquid forms. Although the dissolved corundum increases the density of the solution, this is more than offset by the higher temperatures, which have the opposite effect. Due to its lower density, the saturated solution from the bottom rises in what is known as a *convection current.* Reaching cooler regions near the top, it can no longer hold all the dissolved corundum in solution, and so the excess material crystallizes out on strategically placed seed crystals. Then, the solution is carried back down by convection, and the process repeats itself again and again until the corundum nutrient is depleted. Thus, the origin of the name *hydrothermal transport.*

Growth of ruby by the hydrothermal process is slow compared to melt techniques. Fastest growth takes place on the basal pinacoid at the rate of 0.05 to 0.25 mm per day with linear growth along the *c* axis rarely exceeding 1.0 mm over a period of 14 days (Butcher & White, 1964). Although it is estimated that growth rates and qualities could be improved, due to high start-up costs and the abundance of inexpensive corundum grown by other methods, there has been little incentive for such an undertaking up to the present.

In 1959, Carroll F. Chatham [1914–1983] of San Francisco began marketing synthetic rubies produced by an undisclosed process (Reinecke, 1959). Several reports suggested the stones had been produced by the hydrothermal method (*cf.* Gübelin, 1961a–c). This assumption was based on the presence of seed crystals and other inclusions, which resembled somewhat the published descriptions of experimental hydrothermal rubies grown in 1958 at Bell Labs. However, the actual process used was, and continues to be, a type of flux growth (Tom Chatham, pers. comm., ca. 1986).

From Russia with love. Russia has long been a world leader in crystal growth. With the fall of the Soviet Union and subsequent decline in state funding, many of Russia's crystal growth facilities switched over to commercial activities, with

Figure 7.22 Masterpieces of the crystal growers' art. The 8.77-ct crystal at the rear is a rare example of a near-perfect rhombohedron. In the foreground is a 3.67-ct faceted stone. Both are Ramaura flux-grown synthetic rubies. Unlike melt synthetics, the slow growth of solution processes produces stones which more closely resemble those of nature. (Photo: © 1983 Tino Hammid/GIA)

gem production playing a prominent role. One of the materials to come out of the facility in Novosibirsk was hydrothermal ruby, along with blue and green sapphire (Widener, 1995). It is unknown whether this material was simply old growth, or new production.

Flux process

Flux-grown synthetic corundum, more than any other type, gives gemologists greatest cause for concern. Unlike the Verneuil product, with its distinctive curved growth lines and gas bubbles, flux-grown gems possess inclusions that cleverly mimic those of the natural stone.Only through meticulous study and a continuous honing of diagnostic swords can the gemologist unmask these skillful reproductions.

Flux-grown synthetic corundums were first manufactured by Fremy in the latter part of the nineteenth century. But due to the small sizes of the crystals, the process was soon abandoned in favor of Verneuil's approach. Only in the late 1950s, with the use of ruby in lasers, did researchers return to explore the potential of flux growth.[14] Carroll Chatham, who at age 16 pioneered the commercial synthesis of emerald, was the first to achieve a breakthrough. In 1959, after seven years of experiments he introduced his "cultured" rubies into the market.

Other firms followed and today many are involved in commercial flux growth of gem corundum. Beyond saying that the flux technique is being used, none of these firms release details regarding the method of growth. However, the scientific literature does contain several descriptions of corundum grown from a flux and the following has been taken from these reports (Chase & Osmer, 1970; White & Brightwell, 1965).

The term *flux* refers to a material which, when melted, can dissolve another substance with which it is mixed. Just as sugar is dissolved when mixed with water, a gem mineral can be dissolved when combined with the appropriate flux. Solid at room temperature, a flux becomes a solvent only after melting itself.

14. Interestingly enough, it was again found that flux material was unsuitable for lasers, due to the overly slow growth rates and small crystal sizes.

Table 7.6: Properties of Russian hydrothermal synthetic ruby[a]

Property	Description
Color range/phenomena	• Red: Medium to deep red • Blue • Green
Synthetic process **Location**	• Hydrothermal transport • Novosibirsk, Russia
Crystal habit **Stone sizes** **Prices**	• Not reported • Generally less than 2 ct cut • Not reported
Spectra	**Visible**: Strong Cr spectrum **Ultraviolet**: Series of peaks between 330 and 345 nm in an intensity stronger than any reported for natural ruby **Infrared**: Compared with the IR spectra of natural corundum, additional sharp lines were seen between 3000 and 3800 wavenumbers, with the strongest peaks at 3238, 3310, 3389, 3498 and 3575 cm^{-1}
Fluorescence	• LW: Weak to medium red • SW: Inert to weak red
Other features	Not reported
Inclusion types	**Description**
Solids	• Solids are common and consist of small, highly reflective inclusions of a gold color. These occur as thin to thick plates, in groups, or as single individuals. Two types have been identified: homogenous crystals composed mainly of Cu, with minor amounts of Fe, Ni and Ti; and a more brittle alloy of mainly Cu, with minor amounts of iodine and sulfur. • In one stone, a needle which appeared transparent and colorless was found parallel to the growth zoning.
Cavities (liquids/gases/solids)	• Secondary healed fractures are common, some of which are two-phase
Growth zoning	• Growth zoning is extremely strong and obvious; in some respects it resembles the growth features of Russian hydrothermal synthetic emeralds. Parallel to the basal pinacoid roiled patterns were observed. In one stone, an unusual "Christmas tree" like pattern was seen parallel to the basal pinacoid. Judith Osmer (pers. comm., 7 March, 1995) believes such growth disturbances are due to improper seed preparation, with grinding/sawing/polishing marks or even natural surface irregularities being duplicated by the new growth.
Twin development	None reported
Exsolved solids	None reported

a. Table 7.6 is based on the report of Peretti & Smith (1993b).

Figure 7.23 A platinum ladle is used for dipping into the witch's cauldron in the Chatham laboratory. After several months, this brew will eventually yield flux rubies of fine quality. (Photo: © Fred Ward)

Table 7.7: Fluxes used in flux-grown synthetic ruby

Manufacturer	Flux used
Chatham	Li_2O–MoO_3–PbF_2 and/or $PbO_2Na_3AlF_6$
Douros	Pb-based compound
Kashan	Na_3AlF_6 (cryolite)
Knischka	Li_2O–WO_3–PbF_2 and/or PbO_2: may contain $Na_2W_3O_7$ and Ta_2O_5
Ramaura	Bi_2O_3–La_2O_3–PbF_2 and/or PbO_2
Russia	Lithium tungstate (Li_2O-WO_3)

a. Based on Schmetzer, 1985; Hänni & Schmetzer *et al.*, 1994

Let it grow. To grow corundum by the flux process, a saturated solution is prepared by dissolving the nutrient material (Al_2O_3 + coloring agent) into the flux at a temperature just above the saturation point. Rotation of the crucible may be employed during this stage to ensure the contents are well mixed. Once a complete solution has formed, growth is initiated by gradually lowering the temperature through a range in which corundum will precipitate.

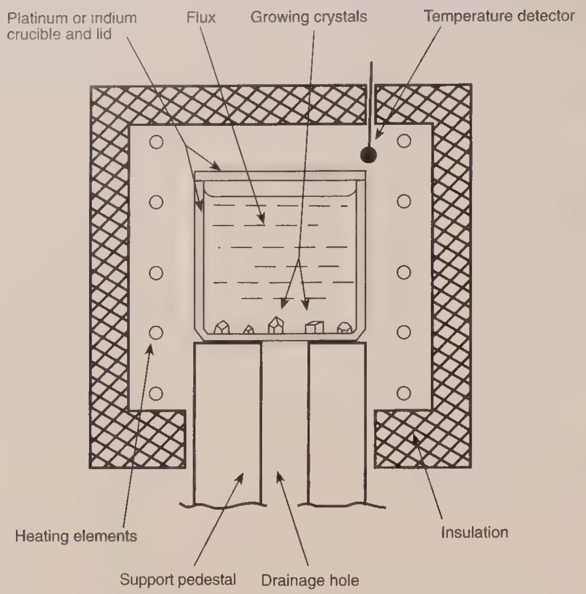


Figure 7.24 Construction of a typical furnace used in the flux-growth of synthetic corundum. (Modified from Nassau, 1980).

Although not mandatory, manufacturers often find it advantageous to keep one region of the crucible slightly cooler, thus causing convection currents to form. Growth usually begins in this cooler area, either on seeds, or by spontaneous nucleation. When crystals reach the desired size, they are removed by pouring off the still-molten flux, or by draining through a hole punched through the red-hot crucible bottom. An alternative method involves cooling the crucible until the entire mass has solidified and then freeing the crystals with boiling acid, which dissolves the flux. But since this may require weeks to accomplish, the former methods are usually preferred (Nassau, 1980).

Ruby's tendency to grow as thin plates from a flux solution is one of the biggest obstacles in the production of usable gem material. Higher growth temperatures seem to help, as does addition of approximately 0.5% of lanthanum oxide to the solution (Elwell, 1979). Higher temperatures also tend to reduce the number of flux inclusions (White & Brightwell, 1965).

Seeds vs. spontaneous nucleation. Use of seed crystals is another method of influencing crystal habit, because seeds allow better control over the growth rate, as well as influencing the crystals' perfection and orientation. Growth rates are directly proportional to the surface area of the seed, and its initial orientation also affects that of the finished crystal. In addition, seeding promotes growth of fewer and larger crystals, rather than multitudes of tiny ones. Thus, by using seeds, a manufacturer can more quickly produce larger crystals, which are also of a more desirable shape for cutting.

Figure 7.25 A 1947 photo from *True Magazine* of Carroll Chatham in his laboratory. (Photo: Chatham Created Gems)

Despite these advantages, some producers (Ramaura, Knischka, Douros) forego the use of seeds, instead allowing growth via spontaneous nucleation. Although growth is less controlled, resulting in crystals of a variety of shapes and sizes, it allows development of extremely clean tabular crystals, the shape most preferred for faceting. If grown on seeds, tabular crystals are usually far more heavily included (Kane, 1983).

Growth rates. It is often reported that many months are required for flux growth (*cf.* Ward, 1992: 9–12 months for Chatham; Brown & Kelly, 1989: 1 year for Knischka). However, the published literature suggests faster growth rates are possible. White & Brightwell (1965) reported growth rates of 0.5 mm per day at 1100° C, with increased rates possible at higher temperatures, while Linares (1965) reported rates of 0.75 mm per day. But this results in more-included crystals. Crystal growers Larry Kelley (pers. comm., 23 Feb., 1995) and Judith Osmer (pers. comm., 7 March, 1995) have told the author that 2–3 months would be all that is required to produce flux crystals of the sizes grown by most commercial manufacturers. Chatham states that their rubies, which tend to be of larger sizes, average eight months (Steve Feldman, pers. comm., 16 March, 1995).

Curved growth lines in flux stones? Only in your dreams

ALTHOUGH Mother Nature possessed far greater patience, the growth rates for the flux and hydrothermal stones are still much slower than most other types of synthetic corundum. The slower growth of flux and hydrothermal stones produces flat, angular faces similar to those on natural crystals. As a result, curved growth lines, so important for identifying melt-grown synthetics, will not be found in the flux or hydrothermal stones, except when flame-fusion seeds are used. Flux and hydrothermally-grown synthetic corundums display straight growth zoning, which runs parallel to the crystal faces and meets at angles, just like the natural.

Typical inclusions. The most common internal features of flux-grown corundums are inclusions of trapped flux. These often resemble the fluid-filled fingerprints and feathers of natural gems and so can create problems for even the experienced gemologist.

Flux inclusions consist of solidified bits of the once-molten flux which was trapped as the crystal grew. They are usually in the form of a singly-refractive glass, and superficially may appear to be fluid, but sometimes show signs of crystallization. This resemblance to fluid inclusions is further increased due to the frequent presence of bubbles within the flux (Burch, 1984). When flux cools, it often contracts, leaving behind a void in addition to the flux (Linares, 1965). Such two-phase flux inclusions are common. However, particularly with larger inclusions, the flux may display flat crystal faces, which are actually flux-filled negative crystals. Moreover, the surfaces are often crossed by irregular tension cracks, especially when crystallization has started at one end of the inclusion (Flanigen & Breck *et al.*, 1967).

Formation of flux inclusions. Flux is trapped in different ways, mostly related to a single factor—overly rapid growth. When growth is too fast, supersaturation of the flux solution decreases at the center of the crystal face. This results in growth primarily along the edges and corners, creating a dendrite-like series of narrow channels. Instead of a flat planar surface, the face develops small depressions, or furrows, which imprison traces of flux. It is in the above manner that the thick flux globules of primary origin have their genesis (White & Brightwell, 1965; O'Donoghue, 1983a).

Rapid growth is also responsible for secondary flux fingerprints and feathers. If a crystal grows too quickly, stress builds. This pressure is released by formation of stress fractures. Such fractures may occur randomly or, more commonly, along directions roughly parallel to major crystallographic faces, such as the rhombohedron, prism, pyramid, and/or basal faces. Growth solutions rush into the fractures, healing them shut and, in doing so, trap small pockets of flux.

This process is identical to that producing secondary fluid inclusions in genuine stones, but differences in the filling material and the relative development of these healed fractures allow a distinction to be made. Fingerprints and feathers within natural corundum contain fluid instead of the solidified flux glass of the synthetic. This fluid is generally more transparent and, as a fluid, cannot show the irregular surface crazing of flux inclusions.[15] In addition, growth details within natural fingerprints are more intricate, thanks to a slower growth rate and lower viscosity of the fluid.

Table 7.8: Manufacturers and varieties of flux-grown synthetic corundum

Manufacturer	Varieties produced
Chatham San Francisco (USA)	• Ruby (first crystal—1952; marketed—1959) • Blue sapphire (first crystal—1972) • Orange sapphire (first crystal—1978) • Yellow sapphire (wrongly reported in 1986, does not exist)
Douros Piraeus, Greece	First offered for sale in 1993 • Ruby
Kashan Austin, Texas (USA)	Kashan Labs formed—1978; filed for bankruptcy in mid 1980s; revived in early 1990s. • Ruby (first crystals, Ardon Industries—1964; marketed—1968)
Knischka Innsbruck, Austria	First marketed—1980 • Ruby
Lechleitner Innsbruck, Austria	First crystal—1983 • *Overgrowths* using natural & Verneuil synthetic seeds—All colors, including color-change
Ramaura Los Angeles (USA)	First marketed—1983 • Ruby
Russia Novosibirsk	First marketed—early 1990s • Ruby

What is the stuff? Rather than trying to separate flux inclusions from fluid inclusions solely by their patterns, one needs to also try and identify the filling. Is it a glassy or crystalline flux (synthetic), or fluid (natural)? Inclusions should be carefully examined under high magnification (100–200×), preferably with a fiber-optic light. Flux feathers are often made up of individual flux grains, none of which are connected to neighboring droplets. In the case of mesh-like flux fingerprints, although channels are interconnected, the flux-free areas between channels show little or no evidence of healing.

In contrast, natural fingerprints usually result from a more highly developed healing process, due to the much slower

15. Filling materials in natural corundums may sometimes solidify, and thus would also be subject to crazing (such as the nordstrandite inclusions of Vietnamese rubies). But this is not so common.

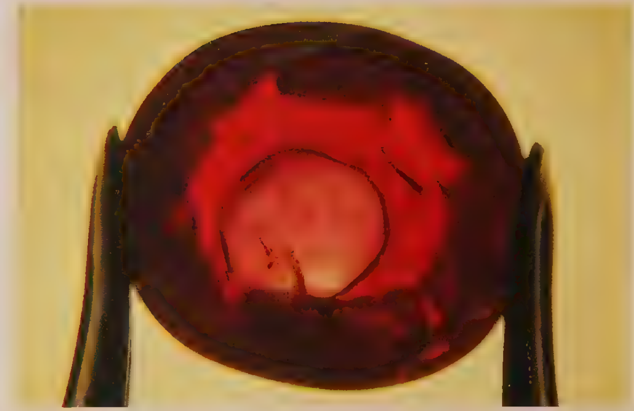


Figure 7.26 Chatham flux-grown synthetic corundum
Top: Chatham synthetic corundum is produced in red (not shown), orange (left) and blue (right) colors. (Photo: Chatham)
Middle left: Various forms of platinum are shown in a flux-grown Chatham synthetic ruby. Such inclusions display a random orientation and are opaque, with a metallic luster. They are believed to result from the partial dissolution of a platinum or platinum-lined crucible. (Photo: AIGS, Bangkok)
Middle right: The seed crystal in a Chatham flux-grown synthetic ruby is clearly visible, surrounded by black planes. Normally the seed would be removed before cutting, but this particular specimen was cut specifically to show the seed. (Photo by the author)
Lower left: Chatham stones often display unusual black growth planes, the composition and cause of which is unknown. Generally they are visible only when looking parallel to the face along which they have formed. At times they appear like black twinning planes, but immersion between crossed polars reveals that they are simply growth lines. (Photo by the author)

growth/healing rate. During or after a natural crystal's growth, fractures can develop. These fractures may then be filled by the growth solution, which crystallizes within the confines of the break, healing it shut. Inevitably the growth solution contains impurities not involved in the crystal's growth. This residual fluid is trapped in thin channels, forming the familiar fingerprint inclusion of natural crystals. But unlike flux fingerprints, which contain a flux glass, these will show evidence of a much slower healing process, in the form of delicate patterns preserved on the walls of the healed fracture. Use of the fiber-optic light reveals details missing in the synthetic product, such as fine growth steps and other marks. Minute fluid mosaics, or tiny "fingerprints within the larger fingerprint" are seen.

Fingerprints within fingerprints. Between large fluid-filled channels there exist smaller ones, forming a "fingerprint within a fingerprint." When illuminated at oblique angles from above, vivid interference colors reflect from tiny growth steps and terraces. In contrast to the fantastic complexity of these thin fluid films, the greater viscosity of the flux and the faster growth rate produces more coarse, less intricate patterns. Interference colors may be seen on occasion, but the wonderful detail of the natural stone is mostly absent in the flux synthetic.

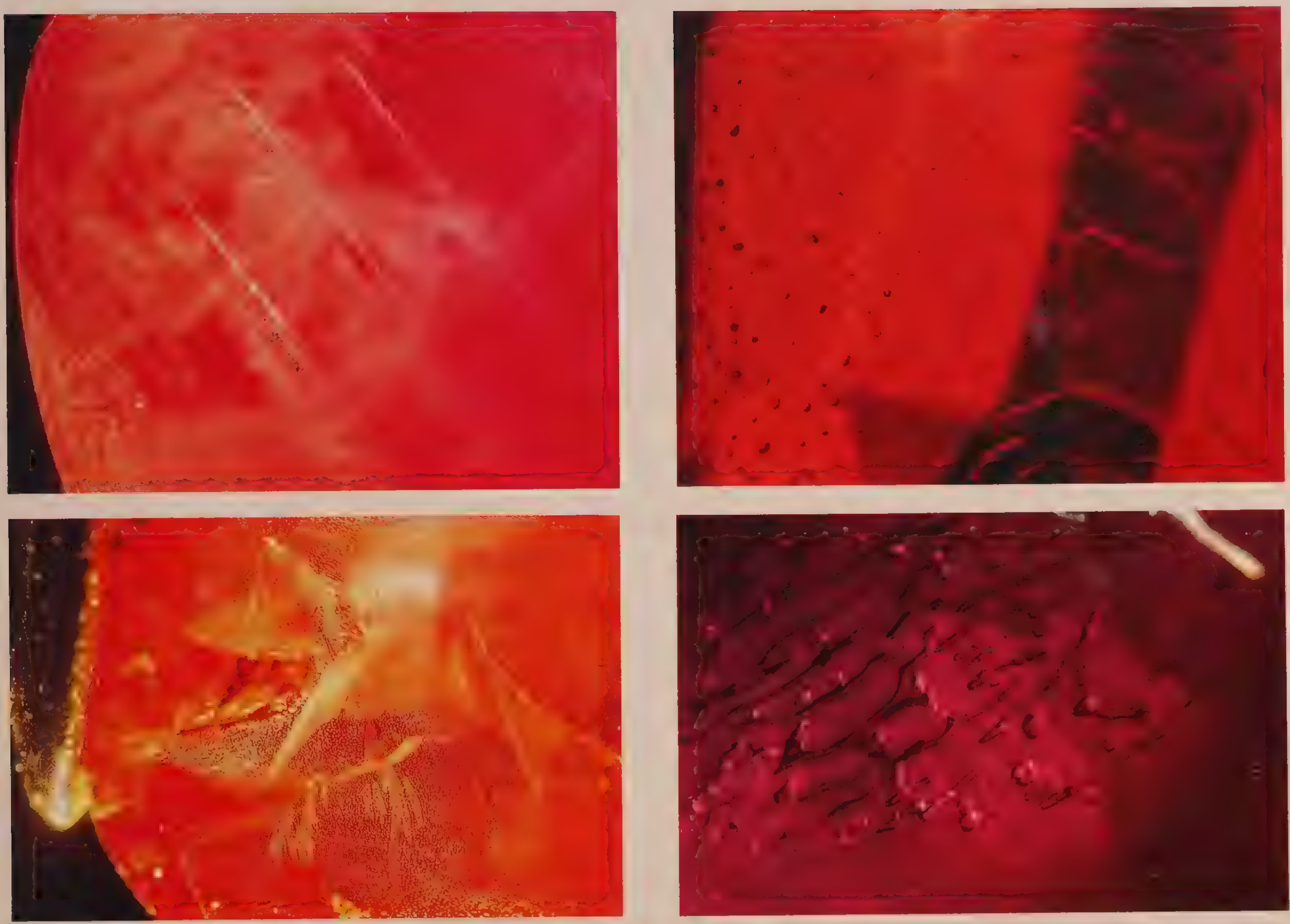


Figure 7.27 All fluxed up
Top left: Is this flux? Sorry. Despite the twisted, wispy veil-like feathers, this is a natural ruby from Mong Hsu, Burma. Note the long white boehmite needles. These have yet to be seen in flux-grown synthetic rubies. (Photo: Tony Laughter)
Top right: The transparency of this inclusion identifies it as liquid, and thus natural. Thai/Cambodian ruby. (Photo by the author)
Below left: Twisted secondary inclusion in a Kashan flux-grown ruby. (Photo by the author)
Below right: A thick secondary fluid inclusion (fingerprint) in a natural ruby from Thailand/Cambodia. In terms of thickness and pattern the appearance is similar to the flux inclusions in flux-grown synthetic rubies. Thus a separation is made not just by reference to the pattern or thickness, but instead, by determining if the filling is a fluid (natural) or a flux glass (synthetic). Unlike most natural liquid inclusions, flux inclusions tend to display a crazed surface appearance under high magnification. Note that this inclusion displays the "fingerprint within a fingerprint" pattern which indicates several stages of healing, as in natural stones. (Photo by the author)

A number of different manufacturers have successfully synthesized corundum on a commercial scale using the flux process. The important ones are listed in Table 7.8.

Chatham

Carroll Chatham was the first to produce and market flux-grown synthetic corundum and his company, Chatham Created Gems, is perhaps the most successful of all. Best know for his pioneering synthesis of emerald, Chatham was a brilliant scientist who did much to advance the synthetic gem industry. His dedication eventually cost him his life when, in 1983 he passed away as a result of the cumulative effects of exposure to beryllium compounds and toxic gases. Today, his two sons, John and Tom, are in charge of his company.

Chatham's initial production was limited to ruby, with blue and orange sapphire following in 1972 and 1978.[16] Current crystals range from 1 to 1500 ct each. This allows faceting of relatively clean stones up to 10 ct. Blue sapphires have been grown, but problems with color distribution and clarity initially prevented their sale, except as small crystal groups unsuitable for cutting. These problems have now been solved (Tom Chatham, pers. comm., 3 Aug., 1995).

The Chatham approach utilizes seed crystals of synthetic corundum. The crucible and wires are apparently made of platinum, as stones frequently display included platinum plates and needles, resulting from the partial dissolution of the crucible walls.

16. *Jewellery News Asia* incorrectly reported in 1986 that Chatham had begun producing flux-grown synthetic yellow sapphires.

Chatham identification

Color range. Chatham currently produces corundum in red (including pink), orange, and blue colors, with Chatham being the sole manufacturer of orange and blue sapphires by the flux process. Rubies tend to resemble Burmese, rather than Thai/Cambodian stones, although darker tones are also seen occasionally. Growth zoning in the red variety is usually apparent only under magnification, while the orange sapphires are more strongly zoned, displaying areas of orange, yellow, and pink, or mixtures of the three. Zoning in Chatham blue sapphires is so strong it has prevented their release into the marketplace, except as non-facet quality crystal groups. Their color ranges from light to extremely deep (almost black) blue.

In pursuit of platinum. Of all Chatham inclusions, most diagnostic is platinum. Not only does it serve as positive means of separation from natural corundum, but also from most other flux synthetics. Platinum inclusions are found in many different shapes and sizes and result from partial decomposition of the platinum-lined crucible/seed wire. Common forms include thin hexagonal or triangular plates, which may be bent or otherwise distorted (Kane, 1982). Large irregular flakes are also seen, as well as spikes, small flat needles, and needles of triangular cross-section. In most cases, platinum is readily separated from similar-appearing natural inclusions by its random orientation, complete opacity, high relief and metallic luster. Platinum has yet to be found in natural corundum.

Some Chatham blue sapphires contain thin, white platinum needles of variable length. These are found as isolated individuals, in small groups, or as extensions of the more typical metallic platinum needles, and occur in both straight and curved forms (Kane, 1982).

Residual flux. The most common inclusion of Chatham corundum is residual flux, which is found in a variety of patterns. Such flux inclusions have caused many a gemologist to cry uncle, due to their uncanny resemblance to the secondary fluid inclusions of natural stones. Flux in Chatham stones ranges from pale yellow (particularly in the blue variety) to white or colorless, and is translucent to opaque and of high relief. If spread thin enough, it may be transparent—but such thin flux is almost always accompanied by thicker, more opaque flux.

Flux patterns are extremely varied, ranging from large primary globules of pale whitish yellow, through thin wispy white veils and thin mesh-like fingerprints of secondary origin. Recently, grid-like patterns of primary flux have been reported (Kammerling & Koivula *et al.*, 1994). In truth, the motifs of flux inclusions are so diverse that identification cannot be based on pattern alone. Many who have tried to do so have failed, for natural rubies and sapphires also frequently contain fluid fingerprints which form similar wispy, veil-like patterns.

Other Chatham inclusions. Platinum and residual flux are the most common and diagnostic features of Chatham corundums, but other inclusions may be found as well. Dense white clouds, composed of tiny dust-like particles, are seen in all varieties and are easily confused with the rutile silk or particle clouds of many natural rubies and sapphires. These clouds in the synthetic are often zoned in straight or angular patterns. Fiber-optic illumination may reveal tiny white needles intersecting at ~120° in three directions within these clouds, again similar to natural stones.

Transparent near-colorless or light pink crystals of low relief and unknown identity are often seen in Chatham stones. In the red and orange varieties they are commonly of low relief, while those found in the blue sapphires tend to be more easily visible. Both the white clouds and the transparent crystals, if considered alone, pose serious problems due to their striking similarity to certain natural inclusions. However they are always found with other, more easily identifiable features, such as platinum and residual flux.

Growth zoning. Unlike melt-grown stones, flux-grown synthetics show straight color zoning which meets at angles. This is similar to the zoning in natural corundum, except that the angles between certain growth planes in flux-grown synthetics may differ from those in the natural, and vice versa. A detailed discussion of the various differences and their usefulness in identification is found on page 185. Chatham rubies may also show irregular color swirls. Known variously as *treacle, heat-wave,* or *scotch-and-water,* the color swirls are reminiscent of those seen in natural rubies from Burma and other localities, and thus are not diagnostic.

Black planes. Black "phantomlike" growth layers are sometimes found in Chatham crystals. These films (platinum-rich?) are seen best looking parallel to their plane, and appear as black edged layers which follow the angular growth lines of the stone. Immersion in di-iodomethane will quickly confirm their location.

Twinning. Twinning is sometimes seen in Chatham corundums along the rhombohedron $\{10\bar{1}1\}$ planes, but lacks the boehmite needles which usually accompany this inclusion in natural stones. In the synthetic, the planes are less numerous and rarely penetrate across the entire stone, as in natural corundums.

Crystal groups. In addition to facetable rough and cut stones, Chatham also markets flux-grown crystal groups in red, orange, and blue colors. These crystal groups, which are not suitable for cutting due to their small size, are coated on the backs and sides with a liquid silica-based ceramic glaze to decrease the chances of breakage. Examination of the glaze

Table 7.9: Properties of Chatham synthetic corundum[a]

Property	Description
Color range/phenomena	Red: Medium to deep red Orange: Light to medium orange, often with orange and pink zoning Blue (non-commercial): Light to deep blue, generally strongly zoned
Synthetic process **Location**	• Flux growth • Chatham Created Gems, San Francisco, CA, USA
Crystal habit **Stone sizes** **Prices**	• Crystals are typically tabular rhombohedra. Contact twins on {10$\bar{1}$0} are common. Less common are twins on {10$\bar{1}$1}. • Largest crystal reported was 2134 ct; cut stones are generally less than 10 ct, but can be larger • Faceted stones: Ruby = $80–300/ct; sapphire = $120–210/ct (wholesale; 1 April, 1994)
Spectra	**Visible** • **Red (including pink)**: Cr spectrum, same as natural, of no diagnostic value • **Orange**: Weak Cr spectrum; no Fe lines present • **Blue**: Weak 415 nm **Ultraviolet** • **Red**: 83% show Type II spectra (see Table 4.2 for description)
Fluorescence	**Red** • LW: Moderate to very strong red to orange-red; usually very strong, except in deeply colored stones • SW: Moderate to very strong red to orange-red; usually very strong, except in deeply colored stones **Orange** • LW: Strong to very strong yellowish orange, orange or reddish orange, with zones of chalky yellow • SW: Very weak to weak, same colors as long wave; also weak pinkish red • X-rays: Variable; strong to very strong orange to reddish orange, with some areas being inert to very weak; may show zoned areas of chalky yellow. No phosphorescence. **Blue** • LW: Inert to very strong chalky greenish yellow to chalky reddish orange to brownish green to sulphur yellow. May be patchy. • SW: Variable; patchy, inert to strong chalky greenish yellow, dull yellowish green, dull chalky greenish white, chalky reddish orange or strong yellow • X-rays: Variable; uneven, inert to moderate chalky yellowish white. No phosphorescence.
Other features	Not reported
Inclusion types	**Description**
Solids	• Platinum plates, needles and crystals, resulting from crucible corrosion. These have a random orientation and are opaque and of extremely high relief. White platinum needles have also been found. • Rounded transparent crystals of low relief and unknown identity.
Cavities (liquids/gases/solids)	• Primary flux-filled negative crystals, often only partially filled (2-phase) and usually displaying crazed surfaces. They are generally of a white or pale yellowish color. Grid-like patterns of primary flux have been observed in pink stones. • Secondary flux-filled negative crystals (healed fractures).
Growth zoning	• Straight color zoning which meets at angles following the faces of the crystal. • Black (but transparent) growth lines which may be layers rich in dissolved platinum. These are visible only when looking close to their edges.
Twin development	• Contact twins on the hexagonal prism. Repeated twinning (on the rhombohedron), but without boehmite needles at twin intersections.
Exsolved solids	• Tiny particles or, more rarely, tiny needles arranged in an oriented pattern within the stone. These particles form clouds which look much like the silk clouds of natural corundums.

a. Table 7.9 is based on the author's own research, along with published reports of Gunawardene (1985b), Kane (1982), Kammerling & Koivula *et al.*, 1994) and Montgomery (1991b).

has revealed the presence of numerous spherical gas bubbles, but these are found only in the glaze and not within the crystals themselves (Kane, 1982).

Visible spectra. Chatham rubies show a strong Cr spectrum, with the pink and orange stones displaying a weaker version. Such spectra are not diagnostic. But Chatham blue sapphires show just a single diffuse band at approximately 451.5 nm, and even this is absent in some specimens. Thus, if the complete series of iron lines is seen at 451.5, 460 and 470 nm, the gem can be assumed to be natural in origin.

Douros

The Douros synthetic flux ruby was introduced to the world in 1993. Brothers John and Angelos Douros of J. & A. Douros Created Gems in Piraeus, Greece, grow the crystals, which are produced via spontaneous nucleation. Properties of this material are detailed in Table 7.10.

Kashan

The Kashan ruby had an unusual genesis, at the Texas-based oil company, Ardon Associates. Beginning in 1963, Ardon's gem-loving CEO prompted company scientists to experiment on flux growth of ruby (Everhart, 1985a–b).

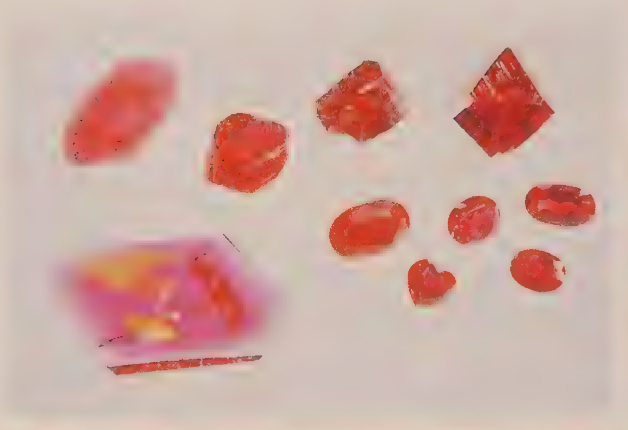


Figure 7.28 Douros flux-grown synthetic ruby
Top left: Rough and cut Douros synthetic flux rubies.
Top right & bottom left: Two-phase flux-filled cavities in a Douros synthetic flux ruby. (Photos: Henry Hänni, SSEF)

Trueheart Brown and two other Ardon scientists set to work. The research was later continued privately and, by 1968, Brown and his two colleagues had succeeded in producing commercial quantities of synthetic ruby, which they sold under the Kashan moniker.

The great Kashan ruby scare. Although the Kashan product was of high quality, it did not achieve widespread recognition until the late 1970s. This coincided with the rise in importance of natural ruby from the Thai/Cambodian border. Renewed interest in the darker-toned Thai rubies produced greater demand for Kashans, due to their similar colors. An additional factor was the rumors circulated that several Kashan synthetic rubies submitted to major gemological labs had been certified as natural. Although these reports were never thoroughly investigated or proven, they did succeed in thrusting Kashan rubies further into the spotlight.

In hindsight, the event probably most responsible for Kashan's shift in fortunes was when Aris "Bob" Mallas joined Kashan and took charge of marketing and cutting. Shortly thereafter, in 1978, Kashan Inc. was formed, and Mallas promoted the stones vigorously. The effect was almost immediate. In just five short years, Mallas turned what was largely a hobby product into a household name.

Kashan identification

Kashan rubies never quite achieve the vivid crimson of the finest Burma-type stones. However, they do possess high clarity and, as a result, the Kashan product can provide a stiff test of a gemologist's abilities.

Color range. Kashan synthetic rubies occur in colors ranging from pale pink to deep red, including dark, blackish reds. In general, they resemble the color of red spinel or Thai/Cambodian ruby, as opposed to the Chatham synthetic, which better simulates the highly-fluorescent red typical of fine Burmese rubies. Contrary to what one might expect, the slightly inferior color of most Kashans has not been a disadvantage. Instead, due to the relative abundance of Thai rubies (as compared to Burmese) in the 1980s market, a steady demand for a Thai ruby look-alike developed and Kashan stones most closely fit the bill.

Crystal habits, stone sizes & shapes. Rough Kashan crystals range from 10–45 grams or more. The tabular crystals show development of rhombohedron $\{10\bar{1}1\}$, bipyramid $\{22\bar{4}3\}$ and basal pinacoid {0001} faces. They are sawed in half before sale, with a further V-shaped cut being made in the center to detach the seed. Non-seeded crystal clusters (rosettes) have been marketed for use in jewelry, being too thin for faceting.

Table 7.10: Properties of Douros synthetic corundum[a]

Property	Description
Color range/phenomena	Red, purplish red, reddish purple
Synthetic process Location	• Flux grown • J. & A. Douros Created Gems, Piraeus, Greece
Crystal habit Stone sizes Prices	• Rhombohedra $\{10\bar{1}1\}$ modified by the pinacoid {0001} and rhombohedron $\{01\bar{1}2\}$; tabular crystals are also seen, some of which are twinned across {0001} or $\{10\bar{1}0\}$. • Crystals typically range up to 20–50 ct; largest crystal reported is 350 ct; largest faceted stone reported is 8.5 ct. • Prices not reported
Spectra	**Visible** • Strong Cr spectrum **Ultraviolet** • Calculated according to the method of Bosshart (1982), the values overlap those of Knischka syn. and natural Burma rubies: o-ray = λ_O and λ/W as 328/6.5; e-ray = 326/5.8
Fluorescence	• LW: Intense orangy red • SW: Moderate red
Other features	Not reported
Inclusion types	**Description**
Solids	None reported
Cavities (liquids/gases/solids)	• Primary and secondary Pb-bearing flux-filled negative crystals. When thick, the flux may have a yellow color. Many flux inclusions contain a gas bubble and show a crazed appearance. Most coarse flux inclusions lie near the crystal surface.
Growth zoning	• Strong zoning parallel to the crystal faces. Color concentrations are found along certain faces. Similar to Ramaura stones, unusual boundaries exist where lines change direction.
Twin development	• Twinning across {0001} and $\{10\bar{1}0\}$ has been found
Exsolved solids	Not reported

a. Table 7.10 is based on the report of Hänni & Schmetzer *et al.* (1994).

Pleochroism. Pleochroism in Kashan rubies is characterized by an overly yellowish red extraordinary ray. When examined with a dichroscope at right angles to the *c* axis, natural rubies typically show purplish red (o-ray) and orangy red (e-ray) colors. However, with Kashans *of comparable body color,* the e-ray color is decidedly more yellowish. This often gives the deeper red Kashans an overall color more akin to red spinel than ruby.

To be meaningful, Kashans must be compared to natural rubies of similar body color. Ideally, the pleochroism of the unknown stone should be compared directly with that of known master stones, both natural and Kashan. The most noticeable difference is between natural and Kashan rubies of a deep red color. As the body color becomes lighter and more pink, the difference becomes less, being least definitive for pale pink stones (American Gemological Laboratories, 1982). The high titanium content of Kashan rubies is believed to cause this unnatural e-ray color.

Inclusions. Unlike Chatham synthetics, Kashan rubies contain no platinum inclusions. Other than growth zoning and twinning, their sole inclusion is residual flux. Analysis of the flux in Kashan rubies has proven it to consist of a sodium aluminum fluoride (Na_3AlF_6), which occurs in nature as the monoclinic mineral cryolite (Gübelin, 1983c). Cryolite flux

Figure 7.29 Rough flux-grown Kashan rubies. Note the V-shaped cuts at the center of each where the seed crystal was originally located. (Photo: Tony Laughter)

in Kashan rubies is typically white in color and stands out in bold relief from the surrounding stone due to its low refractive index (n = 1.338). It may occasionally be transparent, but more often is translucent to opaque, with a *crazed,* or irregularly fractured granular surface texture. This crazed surface texture is useful in separating flux from the fluid inclusions in natural corundum.

Kashan says "Flux you!" to the natural ruby trade

OVER the years, Kashans acquired a reputation for being difficult to identify, due in no small part to the company's marketing tactics. Evidently it was felt that sales would increase if the buying public believed the Kashan product could not be separated from the natural, for difficulties in making such separations were repeatedly stressed in promotional literature. This attitude is vividly illustrated by the following quotations from future Kashan president Aris A. Mallas, Jr., and reprinted for a Kashan sales brochure:

> Kashans are not synthetic, which is really like glass—a haphazard arrangement of atoms. Kashans are like natural crystals which is a precise geometric pattern created billions of times over.... Moreover, I've had them (Kashans) examined by experts who tell me what fine (natural) rubies they are. Kashans are so remarkable they fool these experts—and I don't mean your friendly jeweler down the street, since almost anyone can fool him on gems other than diamonds—I mean top experts.
>
> Bob Mallas (Kashan, n.d., ca. 1980)

Contrary to the above statements, synthetic rubies are not like glass, and Kashan rubies are certainly synthetic. In addition, the Kashan product can be separated from that of nature, provided one becomes familiar with the inclusions found in each.

The saga of the Kashan synthetic ruby took an interesting turn when, in October, 1984, Kashan Inc. filed for bankruptcy amid Brown's charges that Mallas had mismanaged the company (Everhart, 1985b). Over the years, material owned by both Brown and Mallas continued to filter out onto the market. Early in 1994, Texas-based Ruyle Laboratories acquired material from Trueheart Brown and again began selling the material (Laughter, 1994a). Their slogan? "Permissively Grown Stones." Gotta work on that a bit.

Primary flux. Like the fluid inclusions of natural gems, flux inclusions may be of primary or secondary nature. Primary flux inclusions include the large drippy flux globules, as well as the coarse flux rods in parallel alignment, which point outward towards crystal faces. This parallel alignment of flux is significant and typifies the internal scenery in many Kashan stones (Gübelin, 1983c). Closer examination of many flux droplets reveals a two-phase (solid and gas) nature (see Figure 7.30), while flat crystal faces or striations may be seen on the larger flux forms, due to the flux filling of negative crystals. X- and Y-shaped primary flux-filled cavities are common in Kashans.

Let it rain. In addition to large flux inclusions, Kashans frequently contains distinctive arrangements of smaller, dust-like flux particles. Turbid clouds, often termed *fog* or *rain,* consist of finely-disseminated flux particles arranged in roughly parallel zones. Dotted rows of flux particles (*dot & dash* inclusions) U-shaped motifs (*hairpins*), and particle streams emanating from a single larger flux particle (*comets*) are but a few of the euphemisms used to describe flux patterns in Kashan stones. The slender individuals, which resemble (but lack the orientation of) rutile needles in natural corundum, require care in their distinction, as do so many of these particle-type flux inclusions. Fiber-optic illumination is essential for observation of particle flux inclusions, as they may not be visible at all under conventional dark-field light sources.

Secondary flux inclusions. The stress of rapid growth often results in fractures, producing secondary flux inclusions. Like the fingerprints and feathers of natural stones, these are healed fractures, and their appearance can be quite similar. The variety of secondary flux patterns is seemingly endless in Kashan stones, with fingerprints, feathers, wispy veils, nets, flags, folds, to mention just a few. As with Chatham stones, one must look beyond the patterns themselves. Use of high magnification and fiber-optic illumination will separate nature's fluid forms from the flux inclusions of the synthetic, which appear at first glance to be so deceptively similar (see page 169).

Growth features. Besides flux, the only other inclusions in Kashan rubies are growth features, such as growth zoning and twinning. As in the natural stone, Kashan growth zoning is straight and follows the crystal faces. Narrow, well-defined lines are seen in the deep red variety, while, for lighter stones, only diffuse, angular patches are seen.

Rhombohedral twinning $\{10\bar{1}1\}$ is also occasionally found in the Kashan product, just as in natural corundum, but the planes rarely penetrate deep into the stone and are generally less obvious than those of the natural. At times, the color zoning of Kashan synthetic rubies may be so sharp as to resemble twinning. Examination between crossed polars while immersed will allow separation (see page 88).

UV fluorescence. Kashans' fluorescence overlaps with that of natural stones and so is of diagnostic value only in experienced hands. When compared with Thai/Cambodian rubies of similar body color, Kashan short-wave fluorescence is generally of greater intensity. As with the dichroism test, known master stones in a range of body colors from various localities will assist interpretation. However, fluorescence differences between natural and Kashan rubies are so subtle that little faith should be placed in the results.

Knischka

In 1980, Eduard Gübelin introduced the world to a new flux-grown synthetic ruby (Gübelin, 1982c). Produced by Paul Otto Knischka of Steyr, Austria, the Knischka ruby features distinctive inclusions and unusual crystal habits.

Knischka crystals differ from most other natural and synthetic rubies in the large number of faces they display. Among natural rubies it is rare to find a crystal which shows even 20 different faces. However, this new synthetic has been grown with over 40 faces on occasion. Their crystal habits are also unusual, in that some display a pseudo-isometric shape,

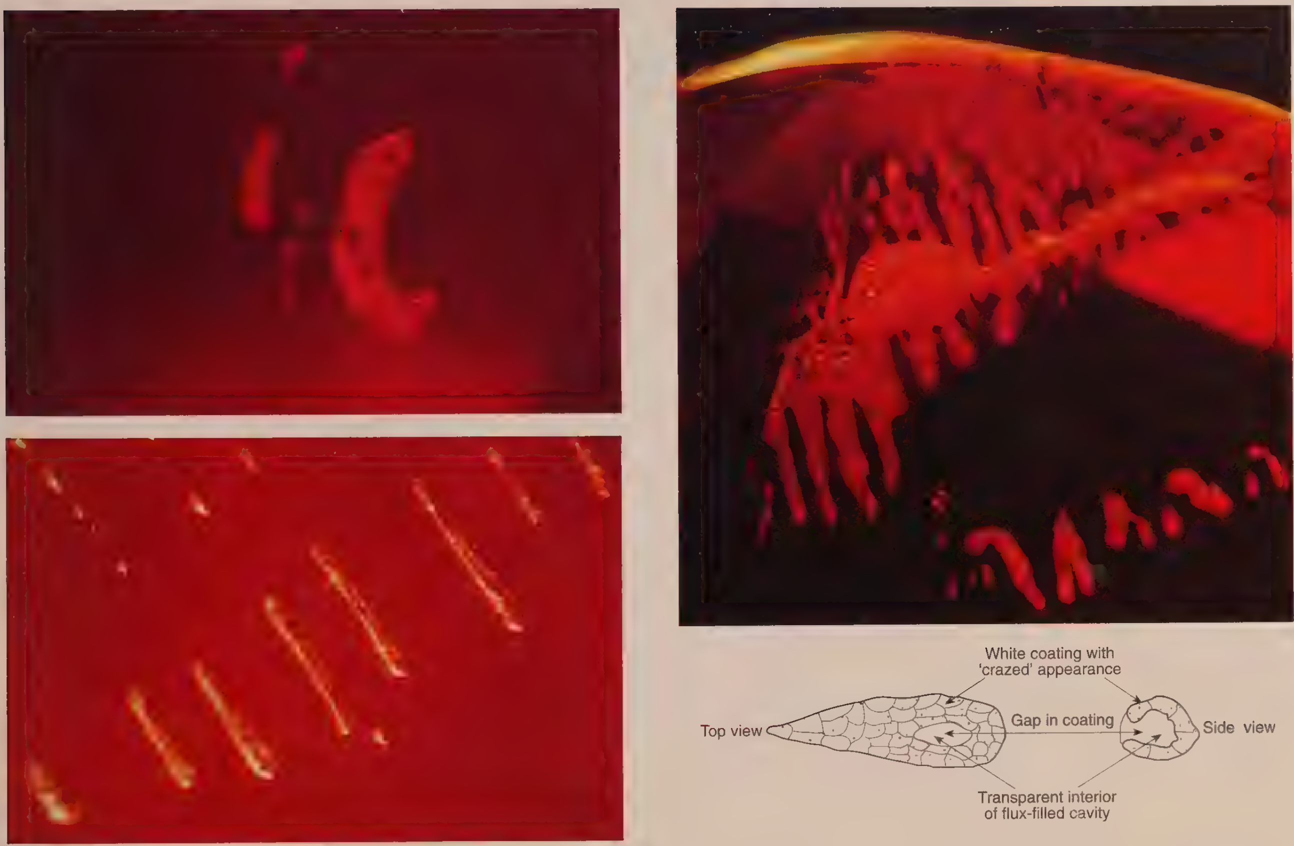


Figure 7.30 Coarse, primary flux-filled cavities in Kashan synthetic rubies. These often show a crazed surface texture and may be two-phase in nature. Such inclusions consist of primary negative crystals partially filled with a flux glass and often are two-phase in nature. This is apparently due to gaps in the flux lining of the cavity. The flux glass also often exhibits irregular surface cracks or "crazing" which are distinctive and often diagnostic in appearance. Many of the cavities in Kashan stones display a parallel alignment, as exemplified by the lower left photo.
(Photos: top left and lower left: Tony Laughter; top right by the author; bottom right drawing: after Burch, 1984)

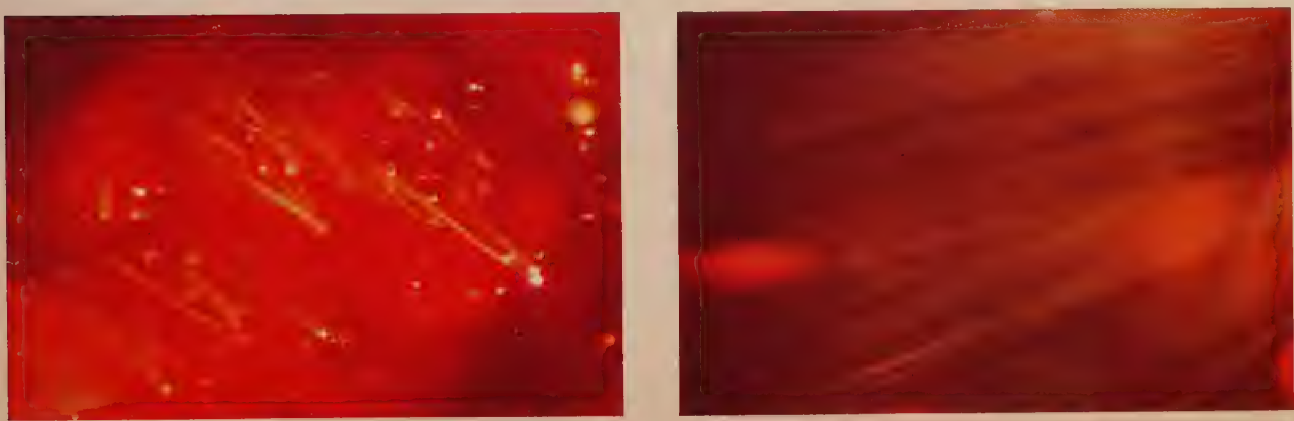


Figure 7.31
Left: Hairpin" or "comet"-type flux inclusions in a Kashan flux-grown synthetic ruby. They are composed of a larger flux droplet and smaller flux particles forming the tails along the growth direction. (Photo: Tony Laughter)
Right: Tiny flux inclusions distributed in a somewhat parallel arrangement in Kashan flux-grown synthetic ruby. Such "rain" inclusions are typical in the Kashans. (Photo: John Koivula/GIA)

Table 7.11: Properties of Kashan synthetic corundum[a]

Property	Description
Color range/phenomena	**Red (including pink)**: Pale to deep red, often with dark, orangy overtones
Synthetic process Location	• Flux grown (cryolite flux) • Austin, Texas, USA (no longer manufactured). Currently marketed by Ruyle Laboratories of Texas.
Crystal habit Stone sizes Prices	• Tabular rhombohedron/pinacoid/bipyramid combinations. These are generally sawn in half, each piece with a V-shaped notch where the seed was removed. • Crystals may weigh several hundred carats. Clean faceted gems are rare over ten carats. • Cut stones generally sell for $35–300/ct, depending on size and quality
Spectra	**Visible** • Strong Cr spectrum **Ultraviolet** • **Red**: 91% show Type II spectra (see Table 4.2 on page 79 for description)
Fluorescence	**Red (including pink)** • LW: Moderate to very strong red to orangy red; intensity is related to depth of body color, with deeply colored stones showing weaker reactions. • SW: Weak to very strong red to orangy red; intensity is related to depth of body color, with deeply colored stones showing weaker reactions. Short-wave reactions of Kashan synthetic rubies are sometimes stronger than long-wave reactions.
Other features	**Pleochroism** • Kashan rubies often display an e-ray color slightly more orangy than the e-ray of a natural ruby of similar depth of color **Refractive index** • RIs for the dark varieties may go as high as 1.779 for the o-ray (Brown, 1981)
Inclusion types	**Description**
Solids	None reported (for flux, see *Cavities* below)
Cavities (liquids/gases/solids)	• "Rain-like" streams of tiny flux particles, generally parallel, but not always • Primary flux-filled negative crystals, often only partially filled (2-phase) and usually displaying crazed surfaces. They are generally of a white color. • Secondary flux-filled negative crystals (healed fractures)
Growth zoning	• Straight growth zoning which meets at angles following the crystal faces
Twin development	• Repeated twinning (on the rhombohedron), but without boehmite needles at the twin intersections
Exsolved solids	None reported

a. Table 7.11 is based upon the author's own research, along with the published reports of Brown (1981), American Gemological Laboratories (1982), Gübelin (1983a), Burch (1984), Schmetzer (1986b) and Montgomery (1991b).

while others are hexagonal bipyramids. Later production often displays striations resulting from oscillatory growth between the hexagonal bipyramids $\{22\bar{4}3\}$ and $\{22\bar{4}3\}$.

To date, Knischka has grown only ruby, which, in terms of color, tends toward a purplish red. Production has remained limited and the stones are rarely encountered. While early production consisted almost entirely of flux-grown rubies on flame-fusion seeds, later material includes crystals grown via spontaneous nucleation. Crystals grown via spontaneous nucleation generally possess better clarity, but tend to yield less after cutting.

In the late 1980s, Knischka raised the temperature of more than a few gemologists by sending out promotional literature describing his rubies as natural. The term natural should be restricted to those gemstones which are formed by nature without human intervention. Knischka rubies, along with all other man-made rubies, are properly termed synthetic.

Knischka identification

In many respects, Knischka rubies resemble those of Chatham. Like the Chatham product, misidentifications can occur if one is unfamiliar with their internal characteristics.

Inclusions. Knischka's most characteristic inclusions are negative crystals, which closely mimic the bipyramidal habit of their host. They may be found alone, or in small groups astride long crystalline tubes (Gübelin, 1982c).

Large gas bubbles are also found within the Knischka rubies. These are actually the gaseous component of two-phase inclusions with indistinct, low-relief outlines. The high RI substance in which they are encased is of an unknown nature and is sometimes irregular in outline with a pale blue, milky texture, or in the form of negative crystals.

In addition to primary cavities, Knischka rubies contain ghostlike clouds of unknown nature. These clouds resemble somewhat the dust-like clouds found in natural Burmese rubies and Chatham flux synthetics, and may result from exsolution.

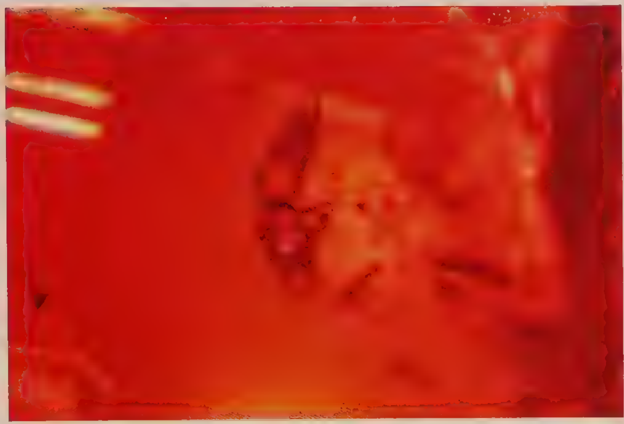


Figure 7.32 I'm PK, you're PK
Left: Twinned Knischka "PK" flux-grown synthetic ruby crystal weighing 40.65 ct. This specimen measures 39.66 mm × 17.90 mm, and exhibits an unusual accordion-like shape. (Photo: Robert Weldon/GIA)
Right: The most distinctive features of Knischka synthetic rubies are glassy, two-phase inclusions. These often exhibit a bipyramidal structure, as shown by the example at the center of the photo. Also common are platinum plates, such as the black triangular example at the photo's left edge. (Photo by the author).

Net-like secondary flux fingerprints and feathers are commonly found throughout the Knischka stones and often form wispy veils similar to those of Chatham rubies. Although usually of high relief, these flux inclusions may sometimes appear less distinct. Their color is generally somewhat white and they range in transparency from semitransparent to opaque.

Platinum plates and needles are a common and highly diagnostic feature of the Knischka product, but are usually smaller than in Chatham stones. Although the manufacturer claims that these can be eliminated, most stones examined have showed the small hexagonal plates throughout (Gübelin, 1982c; Schmetzer, 1987b).

Growth of Knischka rubies takes place on natural Indian, or Verneuil synthetic ruby seeds. It is possible that cut stones could include part or all of the seed crystal and so natural inclusions or curved striae could be found within the seed section. Later production is via spontaneous nucleation (Schmetzer, 1987b).

Growth zoning. In terms of color, the Knischka synthetic rubies tend to resemble natural rubies from Burma more than those from Thailand. Straight, angular color zoning is seen, as are swirled color zones. To date, only intensely red (ruby red) to purplish red stones have been reported.

UV fluorescence. Fluorescent reactions of Knischka rubies may be influenced by the type of seed crystal used. Crystals seeded with natural Indian rubies tend to show slightly weaker fluorescence than those with Verneuil seeds.

Lechleitner's big cover up

Another flux-grown corundum is that of Johann Lechleitner of Innsbruck, Austria. Best known for his work with synthetic emerald, in the 1980s Lechleitner turned to growing corundum. Unlike his emeralds, which were produced hydrothermally, the corundums are grown from a flux bath. They consist of thin flux overgrowths on seeds of Verneuil manufacture, or more rarely, on seeds of natural corundum.

Lechleitner first attempted the growth of corundum in late 1983 (Kane, 1985). Production has consisted largely of ruby and blue sapphire, but also includes orange, green, yellow, violet, purple, colorless, and color-change varieties. Faceted stones examined to date have ranged from 0.50 to 1.50 ct and appear relatively clean to the naked eye, except for a slight cloudiness. To date, most overgrowths are approximately 1 mm in thickness, but covers as thick as 2 mm have been grown.

Verneuil synthetic seeds. In the common type, a flame-fusion seed crystal is used to initiate flux growth. Often there is a total lack of visible separation between seed and flux overgrowth, making it impossible to discern the exact size of the seed and thickness of the overgrowth. Flux veils penetrate deep into the gems, indicating that seeds may be prefractured, allowing flux to enter and heal such fractures during

Table 7.12: Properties of Knischka synthetic corundum[a]

Property	Description
Color range/phenomena	Red: Medium red, slightly purplish red to a deeper red
Synthetic process Location	Flux-grown; both with and without seed crystals. Seeds may be Verneuil or natural. Steyr, Austria (formerly grown at Vienna, Austria)
Crystal habit Stone sizes Prices	• Crystals often display as many as 40 or more faces. Some are modified bipyramids, while others are more tabular, but all possess a unique oscillation between {2243} and {2243}, creating a characteristic striated appearance. • As of 1989, crystals up to 25 ct and faceted stones up to 15 ct were available. Faceted stones up to 67.45 ct exist. • Not reported
Spectra	**Visible**: Typical Cr spectrum of no diagnostic value **Ultraviolet**. Not reported
Fluorescence	• LW: Strong to extremely strong red or orangy red • SW: Moderate to extremely strong red or orangy red. According to Brown & Kelly (1989), some stones may be inert.
Other features	None reported
Inclusion types	**Description**
Solids	• Plates and needles of platinum, due to partial solution of the crucible
Cavities (liquids/gases/solids)	• Primary flux-filled cavities which may be two-phase (flux + bubble). At times these may have a bipyramidal shape, and may be surrounded by irregular milky clouds • Secondary flux-filled healed fractures similar to the fingerprints and feathers of natural stones
Growth zoning	• Straight, angular growth zoning parallel to the crystal faces along which it formed. The most common angle is 122.4°.
Twin development	• Growth twins of unknown orientation have been observed
Exsolved solids	• White particle clouds of unknown composition, possibly due to exsolution, have been seen. These clouds follow the stone's growth structure

a. Table 7.12 is based on the author's own research, as well as that of Gübelin (1982c), Schmetzer (1986c; 1987b) and Kiefert & Schmetzer (1991)

Figure 7.33 Lechleitner synthetic flux corundum overgrowth on a natural seed
Striations and twinning planes visible on the surface (left) and within (right) a natural ruby overgrown with a thin layer of flux-grown synthetic ruby by Lechleitner. The synthetic growth has followed exactly the twinned structure of the underlying synthetic ruby. (Photos by the author)

the growth process. This obviously raises the question of whether Lechleitner's stones are simply a cynical attempt to sell flame-fusion material for flux prices? Considering that most contain no more than a week's flux growth, and a lot less after cutting, I would certainly want this question answered before trading silver for these rocks.

Natural seeds. Stones grown with natural seeds are more heavily included, consisting of thin flux overgrowths on faceted, unpolished seeds. All types display the wispy secondary flux veils that so often characterize flux-grown synthetics. Schmetzer and Bank (1988) reported on Lechleitner material utilizing pale Sri Lankan seeds. We are unlikely to see many of these stones, as the thin overgrowths would have to have an extremely high Cr content. Such high Cr contents will not only increase the RI significantly, making the stones easily identifiable, but, as the concentration of a few percent Cr is reached, will actually lighten the color. Beyond about 20% Cr, the color actually turns green (Nassau, 1983).

Table 7.13: Properties of Lechleitner synthetic corundum[a]

Property	Description
Color range/phenomena	Any; depends on color of seed
Synthetic process **Location**	• Flux-grown overgrowth on natural or Verneuil synthetic seeds • Innsbruck, Austria
Crystal habit **Stone sizes** **Prices**	• Irregular, depends on the shape of the seed; unpolished faces show crystal growth marks, such as striations • Variable; depends on the size of the seed. Most faceted stones seen have been less than 2 ct. • Not reported
Spectra	**Visible**: Variable; depends on seed **Ultraviolet**: Variable; depends on seed
Fluorescence	• LW: Variable; depends on seed • SW: Variable; depends on seed Note: The flux skin may fluoresce differently compared with the seed
Other features	None reported
Inclusion types	**Description**
Solids	• Natural inclusions within the seed, if a natural seed is used • Needle inclusions have been reported in the synthetic seed
Cavities (liquids/gases/solids)	• Thick primary flux inclusions in the overgrowth only • Secondary flux-filled negative crystals (healed fractures) which may penetrate through the overgrowth deep into the seed
Growth zoning	• Straight color zoning which meets at angles following the crystal faces in the flux-grown portion of the stone. Cut stones generally consist of more than 90% seed crystal. • Curved growth lines and gas bubbles in the seed if a Verneuil seed is used
Twin development	Depends on the seed
Exsolved solids	Variable; depends on the seed

a. Table 7.13 is based on the author's research, along with the reports of Kane (1985), Gunawardene (1985a), Schmetzer & Bank (1988) and Brown & Kelly (1991).

Lechleitner overgrowth identification

Lechleitner corundums consists of a flux overgrowth on top of either natural or synthetic seeds. The seeds' colors may not match that of the overgrowth. Overgrowths are generally colorless, or of a similar color to the seed, unless the seed itself is colorless. Those containing Verneuil seeds are termed Type I, while those with natural seeds, Type II.

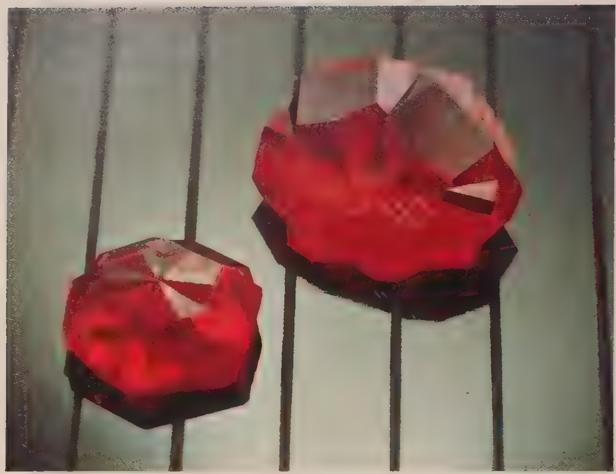
Type I. Type I stones are made in a number of colors, including red, pink, orange, blue, yellow, green, colorless, and color-change varieties. Under the microscope, Type I stones reveal characteristics of both flux and Verneuil processes. Twisted flux veils and fingerprints are common, bringing to mind the secondary flux inclusions of Chatham and Kashan rubies. Curved growth lines and the occasional gas bubble complete the picture. Together with the flux inclusions, they constitute the most easily recognizable inclusion suite among flux-grown synthetics.

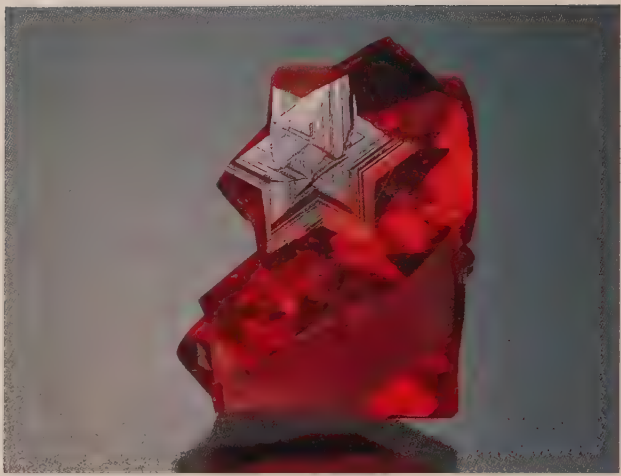
Type II. Unfortunately, the same cannot be said of Type II stones. Consisting of thin flux overgrowths on natural seeds, they display many inclusions typical of nature's own. The author once examined four Type II stones, both before and after cutting. These were flux ruby overgrowths on Thai ruby seeds. In the rough, each displayed a tabular habit, identical to natural rubies, with the exception that faces were extremely well developed, showing none of the weathering traces one would find in natural crystals. Rhombohedral twinning was found in each seed section. This carried through right up to the surface, with the synthetic overgrowth taking on the structural pattern of the seed.

Inclusions varied between those suggesting a natural origin, and flux fingerprints and feathers. Herein lies the danger of Type II gems—one can be mislead by features of the seed. Unless immersed, no junction could be detected between seed and synthetic cover. Even in immersion it was seen only with difficulty, as a colorless region separating the thin, bright red overgrowth from the less-intensely colored seed. During cutting, much of the cover was removed, leaving just a few traces near the girdle and culet. When exposed to long-wave UV and examined under magnification, the synthetic overgrowth glowed bright red, contrasting sharply with the weaker red fluorescence of the seed. Schmetzer and Bank (1988) found similar features in the material with natural Sri Lankan seeds.

Ramaura—Mother fluxers

In a field almost completely dominated by men, it is refreshing to see women get into the act. And such is the case with the Ramaura synthetic ruby. Brainchild of California crystal grower, Judith Osmer, along with partner Virginia Carter, the Ramaura flux ruby first appeared in 1983. It is





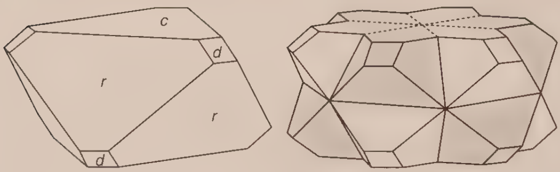


Figure 7.34 Ramaura crystals
Top left & right: Examples of twinned Ramaura crystals.
(Photos: Robert Weldon/GIA)
Below left: Untwinned (left) and twinned (right) examples of Ramaura flux ruby. Faces shown are the basal pinacoid, *c* {0001}, and rhombohedrons *r* {$10\bar{1}1$} and *d* {$01\bar{1}2$}. Twin planes appear as dotted lines. The twin is by rotation around the *c* axis or by reflection across the hexagonal prism {$10\bar{1}0$} or pinacoid {0001}. This form of twinning has not been seen in other natural or synthetic corundums.
(After Schmetzer & Smith *et al.*, 1994)

Figure 7.35 Judy Osmer of Ramaura Created Gems pours incandescent flux out of the crucible, freeing the gems from their fiery womb.
(Photo: © Fred Ward)

grown in various shades of red, including pure red, purplish red, orangy red, and pinkish red, all of medium to high intensity (Kane, 1983). Osmer has also produced blue sapphires, but only on an experimental basis.

Crystal clear. A notable feature of these stones is their high transparency and clarity. This is said to be due to the spontaneous nucleation of Ramaura crystals, which reduces defects, such as impurities and dislocations, that affect the passage of light. Osmer believes the low dislocation density of her crystals is the major reason behind their high transparency (pers. comm., 7 March, 1995).

Ramaura identification

Ramaura flux rubies offer an inclusion suite distinct from both Chatham and Kashan products. Residual unmelted flux is the most prominent feature, while unusual growth features, such as color zoning, also give diagnostic information.

Flux. Ramaura's primary flux inclusions possess a distinctive orange-yellow color. Although they may also appear near-colorless or white, especially if thin, the thick yellow-orange flux provides a positive means of separation from natural rubies. Large flux globules typically occur in "drippy" forms with a crackled or crazed surface texture. They are of high relief and opaque, although transparent patches of lower relief have also been encountered. As with Kashans, flux rods are often found in parallel alignment, with some being two-phase. Flux-filled cavities frequently show flat faces, parallel steps or other growth features aligned with the color zoning, with oblique lighting revealing iridescent patches on these steps. Comet-like inclusions, consisting of large flux grains followed by minute particles trailing out to form a tail, are also seen.

Ramaura's secondary flux inclusions are often indistinguishable from the fluid-filled fingerprints and feathers of natural stones. Flux fingerprints are made up of tiny flux

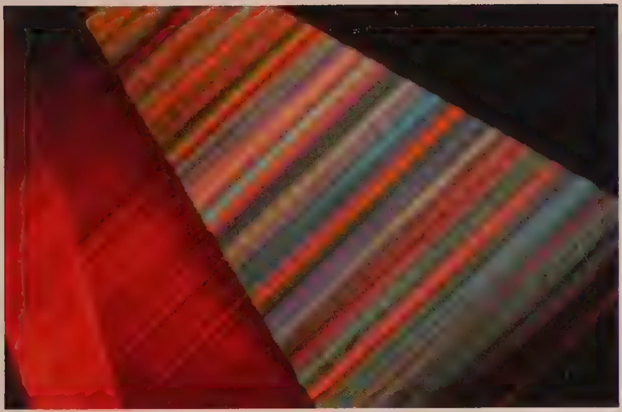


Figure 7.36 Inclusions in Ramaura flux-grown synthetic ruby
Top left: The most distinctive feature of Ramaura stones is their unusual growth zoning. When viewed parallel to the face along which they formed, growth lines are extremely sharp and narrow, in this case actually appearing iridescent. (Photo: John Koivula/GIA; 50×)
Bottom left: When the viewing direction is not exactly parallel to the face (or faces), unusual wispy growth features are seen, particularly at the junctions where the growth lines change direction. (Photo: John Koivula/GIA; 40×)
Top right: Primary flux in Ramaura stones often displays a distinctive yellow-orange color. Note the obvious "crazed" appearance and zoned structure of this large flux inclusion. (Photo: Robert Kane/GIA; 35×)

Figure 7.37 Ramaura stones contain an element (reportedly a rare-earth dopant) which produces a distinctive yellow-orange fluorescence under long-wave ultraviolet light (see above photo). Unfortunately, the element concentrates mainly in the surface regions of the crystal, which are typically removed during cutting. Some crystals, and most cut stones, show no trace of this fluorescence, but when it is seen, it is useful in identifying the Ramaura product. (Photo: Mike Havstad/GIA)

particles. These form twisted or folded white fingerprints which radiate outward from a central point, as well as iridescent fractures and healed fractures.

Thank god for growth features. Although Ramaura's primary flux inclusions provide positive means of identification, many stones are completely free of primary flux, or contain only the deceptive secondary flux. Fortunately the growth features are distinctive enough for reliable identification. All Ramaura stones display some form of growth features. These include straight growth lines, which run parallel to the crystal faces and meets at angles. Natural rubies also show such straight features, but zoning in the Ramaura product tends to be more regular and narrow, almost resembling the curved striae of Verneuil rubies, except it is straight. These straight striae are so narrow as to appear iridescent. Wider bands of color are also seen when the striae are not lined up perfectly. There are also color swirls, similar to the *treacle* or *scotch-in-water* effect common to many natural Burmese rubies. Broad angular patches of color are another common feature (Kane, 1983).

Zoning of Ramaura stones meets at angles, either blurred or sharp, and these junctions are quite distinctive. Single, straight growth planes are sometimes encountered which extend deep into the stone and resemble twinning. Immersion between crossed polars will separate such sharp growth zoning from true twinning. Different types of illumination are needed to observe the growth features of Ramaura stones, and so it is essential that one experiment with various lighting techniques, as well as immersion. Most importantly, the stone must be examined from every possible position (*Hughes' First Law of Gemology*).

Ramaura penetration twins have been seen. Their orientation is by rotation around the *c* axis or by reflection across the hexagonal prism $\{10\bar{1}0\}$ or basal pinacoid {0001}. This

Table 7.14: Properties of Ramaura synthetic corundum[a]

Property	Description
Color range/phenomena	**Red**: Medium to deep red, purplish red and slightly orangy red
Synthetic process Location	• Flux grown; non-nucleated • J.O. Crystal Co., Redondo Beach, CA, USA
Crystal habit Stone sizes Prices	• Three basic rhombohedral habits incorporating {0001}, $\{01\bar{1}2\}$, $\{10\bar{1}2\}$, $\{10\bar{1}1\}$ and $\{22\bar{4}3\}$: 1. Equidimensional rhombohedra which are found attached to the crucible walls 2. Clusters of thin plates growing on the melt surface 3. Similar to the plates above, but thick enough to facet; these grow on the crucible sides and bottom • Crystals may be up to 4 cm across; cut stones are generally under 5 ct; largest rhombohedron as of 1990 was 23.86 ct (Nassau, 1990) • Wholesale prices for cut stones range from $75–300/ct (Jan. 1, 1995)
Spectra	**Visible** • Strong Cr spectrum; same as natural, of no diagnostic significance **Ultraviolet** • **Red**: 100% show Type II spectra (see Table 4.2 on page 79 for description)
Fluorescence	**Red** • LW: A dopant is added to the feed material to produce a characteristic orange fluorescence under LW. However, this may not be absorbed into the crystals at all, and when it is absorbed, it is only on the surfaces, which are generally removed in cutting. Thus this attempt by the manufacturer to simplify the identification of these stones has not been a total success. No phosphorescence. • SW: Weak to strong red to orange-red; slightly bluish white zones observed in some stones. No phosphorescence. • X-rays: Variable; some areas inert, others weak dull chalky red to orange-red. No phosphorescence.
Other features	None reported
Inclusion types	**Description**
Solids	For flux inclusions see *Cavities* below
Cavities (liquids/gases/solids)	• Primary flux-filled negative crystals, often only partially filled (2-phase) and usually displaying crazed surfaces. They are generally of a distinctive yellowish color when thick. • Secondary flux-filled negative crystals (healed fractures) of a white color which are extremely similar in appearance to the secondary fluid inclusions found in natural stones
Growth zoning	• Straight color zoning which meets at angles following the faces of the crystal. Boundaries where growth zoning changes direction have a distinctive appearance and growth lines are often quite narrow and sharp, resembling a straight striae.
Twin development	• Penetration twin by a 180° rotation around the *c* axis, or by reflection across $\{10\bar{1}0\}$ or {0001}
Exsolved solids	• Zoned white clouds composed of minute white particles oriented along the crystal structure of the stone; these are probably produced by exsolution

a. Table 7.14 is based on the author's research, with the reports of Kane (1983), Gunawardene (1984b), Montgomery (1991b) and Schmetzer & Smith *et al.* (1994).

form of twinning has yet to be found in other natural or synthetic corundums (Schmetzer & Smith *et al.*, 1994).

Let it glow. Perhaps most interesting is the Ramaura reaction to ultraviolet light. To ease identification, the manufacturer induces an orange-yellow fluorescence by adding a rare-earth element to the flux. This is notable, for it represents the only case in which a manufacturer deliberately builds an identifying feature into the product.[17] However, it would be wise to consider the following before you put your microscope up for sale and break out the party hats.

Even if this were done with all synthetics, it would not provide the hoped-for panacea, because gemologists would still have to guard against a dishonest manufacturer making stones without the dopant. In any case, the attempt is but a qualified success. The dopant is mainly absorbed in surface regions of the crystals, resulting in the removal of much or all of the fluorescent areas during the cutting process. Judith Osmer emphasizes that one must make side-by-side comparisons between unknown, natural and known Ramaura synthetics if the test is to be meaningful (pers. comm., 7 March, 1995). In summary, if a stone shows large zones of orange-yellow fluorescence it can be considered an indication of synthetic origin. Red fluorescence alone is of no diagnostic use.

Russian (Novosibirsk)

Yet another of the myriad products to come out of Novosibirsk since the breakup of the Soviet Union is a flux-grown ruby. Properties are detailed in Table 7.15.

Summary of flux identification

One of the greatest gemological challenges is separation of natural and flux-grown synthetic corundums. Unlike the rapidly-grown Verneuil and Czochralski stones, slowly-grown flux synthetics develop flat crystal faces. As a result,

[17] The TrueGem synthetic ruby features a laser-inscribed number on the girdle of each stone. However this can be removed by repolishing.

Table 7.15: Properties of Russian (Novosibirsk) flux synthetic corundum[a]

Property	Description
Color range/phenomena	Medium (Type 1) to deep red (Type 2)
Synthetic process Location	• Flux grown • Novosibirsk, Russia
Crystal habit Stone sizes Prices	• Type 1: Elongated tabular prism with well-developed prism {11$\bar{2}$0} faces, and less well-developed rhombohedron {10$\bar{1}$1} and basal pinacoid {0001} faces Type 2: Rhombohedral crystal, with {10$\bar{1}$1}, {11$\bar{2}$0}, {22$\bar{4}$3} and {0001} faces Note: This is the only synthetic ruby where hexagonal prism {11$\bar{2}$0} faces have been reported • Two crystals were examined, weighing 63.8 and 22.6 ct • Prices unknown
Spectra	**Visible**: Strong Cr spectrum (similar to natural ruby)
Fluorescence	• LW: Strong red • SW: Weak red
Other features	None reported
Inclusion types	**Description**
Solids	• Triangular black crystals (probably platinum)
Cavities (liquids/gases/solids)	• Primary and secondary flux-filled negative crystals, which are often two-phase due to flux contraction during cooling. This may appear black. The flux composition is said to be lithium tungstate (Li_2O-WO_3).
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it has formed
Twin development	None reported
Exsolved solids	None reported

a. Table 7.15 is based on the report of Henn and Bank (1993)

they display internal features, such as straight color zoning, which closely mimic the genuine stone. Careful examination of their inclusions will generally allow distinction, but caution is needed if errors are to be avoided. Not only should one have experience with the synthetic, it is of even greater importance to study the natural stone. Neglecting this too often results in an unpardonable sin—condemnation of nature's creation as synthetic. Unfortunately, the author has witnessed this mistake far more frequently than the reverse.

Advanced identification techniques

Due to space limitations, only tests readily accessible to the average jeweler/gemologist have been described. However, with the ever-advancing technology of gem synthesis, it is increasingly important to utilize sophisticated instruments in separating natural and synthetic rubies and sapphires. While these instruments' high costs place them out of reach of all but the most advanced labs, a short description is in order, for it may provide a glimpse of future directions of gem identification.

Growth line angles

Not so long ago, the presence of straight, angular growth zoning was considered positive proof of natural corundum. This changed with the introduction of flux and hydrothermal synthetics. Grown slowly, these stones possess flat crystal faces and, hence, also show parallel or angular color zoning. But due to differences between the crystallization media, synthetic faces (forms) may not match those in natural crystals. Since growth planes reflect a crystal's habit at each growth stage, measuring angles between these planes can help determine the types of crystal faces once present, even after cutting. This information may allow identification. Angle measurement can be made using a protractor-type eyepiece reticule or the stoneholder designed by Schmetzer (1985, 1986a–b).

Table 7.17 lists some possible corundum faces.

Comparing data from Table 7.19, it is clear that zoning parallel to prism faces *a* {11$\bar{2}$0}, and certain bipyramid faces is a strong indication of natural corundum, due to their absence in all synthetics except the Russian flux product. In addition, zoning along rhombohedrons *d* {11$\bar{2}$0} and γ {01$\bar{1}$5} are strong indications of synthetic origin, due to their absence in the natural. Other planes are less conclusive.

Angles of intersection may also provide diagnostic data. With natural corundum the most common angle is 60/120° (between prism faces), 90° (between the pinacoid and prism) and 32.4° (between the positive rhombohedron and prism).

The above would not apply to overgrowths on natural seeds, such as those of Lechleitner.

Spectrophotometry

The spectrophotometer gives us spectral information in the form of a graph. Advantages over the direct-vision

Table 7.16: Summary of synthetic corundum manufacturers

Growth type	Process	Manufacturer	Varieties
Melt growth	Geneva	Europe (manufacturers unknown)	Red
	Verneuil (flame fusion)	Various, worldwide	All colors, star, color change
	Czochralski (pulling)	Kyocera, Japan, Union Carbide (USA) & others	Red, blue, orange, yellow, colorless, red star
	Floating zone	Seiko	Red, blue, orange
	Combination		
	Zone refining/Czochralski	TrueGem	Red
	Floating zone/Czochralski	Russia	Red
	Verneuil/Czochralski	Russia	Red
Solution growth	Flux	Chatham—USA	Red, orange, blue
		Douros	Red
		Kashan (Ardon Industries)—USA	Red
		Knischka—Austria	Red
		Lechleitner—Austria	All colors (overgrowths on natural or Verneuil seeds)
		Ramaura (J.O. Crystal Co.)—USA	Red
		Remeika (Bell Labs)—USA (experimental only)	Red
		Russian (Novosibirsk)	Red
	Hydrothermal	Novosibirsk—Russia	Red
		Various—USA & others (experimental only)	Red, blue, colorless

Table 7.17: Faces and *c* axis angles[a]

Crystal face	Face symbol & index	Degree angle between *c* axis and face[b]
Basal pinacoid	*c* {0001}	90
Hex. prism (2nd order)	*a* $\{11\bar{2}0\}$	0
Rhombohedron	*r* $\{10\bar{1}1\}$	32.4
Rhombohedron	*d* $\{01\bar{1}2\}$	51.8
Rhombohedron	γ $\{01\bar{1}5\}$	72.5
Hexagonal bipyramid	*n* $\{22\bar{4}3\}$	28.8
Hexagonal bipyramid	*w* $\{11\bar{2}1\}$	20.1
Hexagonal bipyramid	*v* $\{44\bar{8}3\}$	15.4
Hexagonal bipyramid	*z* $\{22\bar{4}1\}$	10.4
Hexagonal bipyramid	*f* (v) $\{44\bar{8}1\}$	5.2
Hexagonal bipyramid	*g* (ω) $\{14\ 14\ \overline{28}\ 3\}$	4.5

a. From Schmetzer, 1985
b. Based on the morphological unit cell where a:c = 1:1.365

Table 7.18: Interfacial angles[a]

Intersecting faces	Face normal angles	Intersecting face angles
Rhombohedron ∧ Rhombohedron (*r* ∧ *r'*)	93.9°	86.1°
Bipyramid ∧ Bipyramid (*n* ∧ *n'*)	52°	128°
Prism ∧ Prism (*a* ∧ *a'*)	60°	120°
Bipyramid ∧ Rhombohedron (*n* ∧ *r*)	26°	154°
Rhombohedron ∧ Bipyramid (*d* ∧ *n*)	32°	148°
Rhombohedron ∧ Rhombohedron (*d* ∧ *r*)	47°	133°
Bipyramid ∧ Bipyramid (*z* ∧ *z'*)	58.9°	121.1°
Bipyramid ∧ Bipyramid (*w* ∧ *w'*)	56°	124°
Prism ∧ Pinacoid (*a* ∧ *c*)	90°	90°

a. From Schmetzer, 1985

spectroscope are that it precisely locates areas of strong absorption and transmission, as well as measuring extent and strength. In addition, some models reach into the ultraviolet and infrared, regions beyond normal human vision. Disadvantages are that the human eye is far more adept at picking up subtle absorption features in the 400–700 nm region.

Bosshart (1982, 1983) has published studies of UV transmission behavior of natural and synthetic rubies, establishing different population areas. This not only allowed separation between natural and synthetic, but also permitted distinction between individual sources. Only Ramaura synthetic rubies fell into the natural zone.

X-ray fluorescence (EDS-XRF)

Analysis by the EDS-XRF technique involves study of a gem's fluorescence spectrum while stimulated by x-rays. A beam of primary x-rays is used to bombard the sample material, causing emission of secondary fluorescence-radiation. This produces a spectrum of different fluorescent lines, or energies, corresponding to elements contained by the gem. Roughly 80 elements can be detected by this instrument, ranging from sodium (x = 11) to uranium (x = 92).

If an element is present in sufficient quantities, it can be detected by EDS-XRF. Other than the usual corundum coloring agents, gallium (Ga) has also been detected. Although present in both synthetic and natural corundums, Ga concentrations are, with the exception of Ramaura synthetic ruby, below the instrument's detection limits. Unfortunately EDS-XRF is unable to specify the exact quantity present of a particular element, necessitating use of other methods to separate natural rubies from the Ramaura product (Hänni, 1984).

Table 7.19: Common faces of natural and synthetic corundum[a]

Type	Common faces	Less common faces	Common growth line development with angles	Twin development
Natural corundum	*c, a, r, n*	*n, w, v, z, g* (ν), *f* (ω)	(*a, a'*) = 60/120° (*a, c*) = 90°	{0001} = contact twin—rare {10$\bar{1}$1} = contact twin—rare {10$\bar{1}$1} = repeated twin, often with exsolved boehmite needles at twin intersections—common
Verneuil (flame-fusion) syn. corundum	No faces	—	Curved growth striae or bands following the top surface of the boule. No angles.	{11$\bar{2}$0} = repeated glide twin ('Plato lines')—common {10$\bar{1}$1} = repeated twin with or w/out exsolved boehmite needles at twin intersections— rare
Inamori (Kyocera) Czochralski syn. corundum	No faces	—	Extremely faint tightly-curved striae. May be concentric; no angles.	None observed to date
Seiko floating zone syn. corundum	No faces	—	Indistinct swirls only. No angles.	{10$\bar{1}$1} = repeated twin with or w/out exsolved boehmite needles at twin intersections—rare
Chatham flux-grown synthetic corundum	*c, r, d, n*	—	(*r, n*) = 26/154° (*n, n'*) = 52/128°	{10$\bar{1}$0} = contact twin—common {11$\bar{2}$0} = contact twin—common {10$\bar{1}$1} = repeated twin—common
Douros flux syn. corundum	*c, r, d*	*n*	Zoning is visible along *c, r* and *d*.	Penetration twin around the *c* axis {0001} or by reflection across {10$\bar{1}$0}—occasional
Kashan flux syn. corundum	*c, r, n*	—	(*r, n*) = 26/154° (*n, n'*) = 52/128°	{10$\bar{1}$1} = repeated twin—common
Knischka flux syn. corundum	*c, r, d, n, γ*	{10$\bar{1}$9}	(*r, n*) = 26/154° (*n, n'*) = 52/128°	Growth twins of unknown orientation have been commonly seen.
Ramaura flux syn. corundum	*c, r, d*	*n*	(*r, r'*) = 93.9/86.1° (*r, d*) = 47/133°	Penetration twin around the *c* axis {0001} or by reflection across {10$\bar{1}$0}—occasional
Russia (Novosibirsk) flux syn. corundum	Type 1: *r, a, c* Type 2: *r, a, n, c*		(*a, a'*) = 60/120°	None observed to date
Lechleitner flux syn. corundum overgrowth on natural or Verneuil syn. seed	Depends on seed type	Depends on seed type	Depends on seed type	Twin development follows the seed crystal's structure. {10$\bar{1}$1} = repeated twin—common for natural seeds

a. Modified from Schmetzer (1985). The following face symbols in Table 7.17, Table 7.18 and Table 7.19 were substituted for those in Schmetzer's original tables:
g = ν (second-order hexagonal bipyramid) *f* = ω (second-order hexagonal bipyramid)

Instrumental neutron activation analysis (INAA)

Instrumental neutron activation analysis (INAA) simultaneously determines the presence and quantity of trace elements. As a result, it can separate not only natural corundum from synthetic, but also natural gems of different origins (Hänni, 1984).

With INAA, the sample is first irradiated by exposure to a thermal neutron flux from a nuclear reactor. This forms unstable isotopes, which then release energy through a decay process. Because emissions are distinctive for each element, their measurement (by gamma-spectrometry) allows determination of types and quantities of trace elements.

Unfortunately, INAA has its drawbacks. Neutron bombardment produces potentially-hazardous radioactivity. In the case of ruby, Cr atoms take 30 days to decay to safe levels, and other trace elements may take far longer. Thus gems subjected to INAA must be stored in lead boxes until their radiation no longer poses health hazards. Another problem is the formation of color centers, which may lead to a modification in color. While this does not generally occur with rubies, other corundum varieties may change color from the neutron bombardment, particularly those from Sri Lanka.

Chatham synthetic rubies have been studied using INAA. Early products showed traces of Mo, Pt, and Ir, probably contained in inclusions. This indicates growth from a Li-molybdate flux within a platinum-iridium crucible. Gallium was found in both natural and synthetic rubies, but, with the exception of the Ramaura product, was present in much higher concentrations in natural stones (Hänni, 1984).

Raman spectroscopy

The Indian scientist, C.V. Raman, was the first to observe that scattering of light occurs when molecules are hit by a monochromatic light beam. The frequency change of the excitation radiation can be measured and most substances produce characteristic spectral lines which can be used for identification.

The Raman microprobe is a combination of a microscope, argon gas laser and computer. Any substance which the beam is focused upon can be analyzed, including liquids, gases and solids. However this is limited to molecular compounds; materials such as metallic alloys cannot be identified.

Obviously, such a device has tremendous potential. Liquid inclusions, including CO_2, can be identified, as can various fluxes and impregnations. As the price of this instrument continues to decline, we can expect to see it utilized more and more by gemological labs (Hänni, 1995).

Ma, what's it all mean?

With each of the advanced techniques just described, only a small number of samples has been tested. As more stones are tested, conclusions may change. Much work remains to be done before any of these techniques can be considered reliable for distinction of natural and synthetic corundum.

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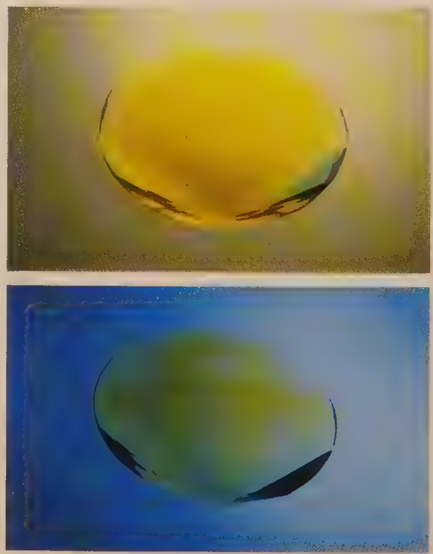

Figure 7.38 Inserting a frosted blue filter beneath the immersion cell makes locating color zoning far easier in yellow stones.
Top: With normal lighting, the yellowish light combined with the yellowish color of the immersion liquid combine to obscure color zoning.
Bottom: Imposition of a blue filter quickly reveals the curved color banding of this Verneuil synthetic yellow sapphire. (Photos by the author)

CHAPTER 8

ASSEMBLED STONES

Carbuncle: Of its Adulteration.

It may be adulterated by a *Rubine* of a very dilute rednesse, by putting a red gold foyl tincture, or colour under it, or by putting some splendent glasse dyed with a red colour under it; And thus without diligent caution it may be taken for a true jewell, and the rather because all are helpt with a foyl. Another way of its adulteration is by a white *Saphire,* or a *Crystall,* or a *Topaz,* or an ordinary *Diamond,* with a red gold foyl placed under it, in its enclosing, either in ouch or ring. Another way they have of adulterating of it, and that is, by glewing two fair *Crystals* together with a little mastick tinctured with a red or crimson colour: In this manner I have seen two pieces of Crystall so glewed together, as that they being once set with a foyl, they could hardly be discerned from a true *Ruby.*

The adulteration of this gemm may be thus discovered, First by the want of sparkling and sending forth of lively rayes. Then by bringing the gemm to the triall of the file. A true *Rubie* will endure the file; but a factitious stone, or a soft counterfeited adulterated stone will not. Another way of discerning the falshood will be this: take the jewell you suspect, and direct your eye from the verge or margine of its inclosure, through the gemm unto the opposite side of its enclosure; and if it consist of two parts with a tinctured foyl betwixt, you will easily perceive the upper part to be void of colour, from whence you may gather that it doth receive its glory from the foyl. Such Artificiall angles and corners will jewellers cut and excavate in the bottome of soft transparent stones (as I have seen) that by the manifold reflection of these lower *Superficies,* into every part of the uppermost *Superficies* of the jewell, a skilfull jeweller shall hardly perceive their craft....

Thomas Nicols, 1652

A Lapidary or, The History of Pretious Stones

BEYOND treated and synthetic corundums, there exist two other types of trickery—imitations and assembled stones. *Imitations* refer to those gems which resemble corundums only in appearance. Spinel and garnet are imitation rubies, as is red glass. Because ordinary gemological tests (such as RI and SG) will easily identify such imitations, and because they are adequately described in standard gemology texts, they will not be described here. But assembled stones are another matter.

Assembled stones typically involve the joining together of two or more pieces of natural and/or synthetic or imitation corundum. As old as the gem trade itself (see the quote from Nicols on this page), they can be so deceptive as to fool even experts.

Assembled stones made of two parts are termed *doublets,* while those of three pieces are *triplets.* Some are made entirely or partly of natural corundum; others may contain no natural corundum whatsoever. Of these, the latter is rarely encountered because, being made entirely of synthetic or imitation corundum, they do not contain the natural inclusions which make assembled stones so deceptive. While those described below are most common, assembled stones can be manufactured from any combination of materials.

Natural–natural doublets

Doublets made entirely of natural corundum are generally manufactured because the shape of the rough is too flat. For example, sapphires from Montana's Yogo Gulch deposit typically occur as thin wafers. Cutting a single stone of good proportions results in excessive weight loss. The solution?

Figure 8.1 The separation plane of a doublet is clearly visible along the girdle of these stones. In this case, the top is natural green sapphire, while the bottom is Verneuil synthetic blue sapphire (left) or Verneuil synthetic ruby (right). While the difference in color between top and bottom is clearly visible in the photograph, one must be careful making a judgement based on this alone, for some non-assembled sapphires may also show such color differences at the girdle, due to pleochroism. Note the curved striae visible in the Verneuil synthetic ruby base of the photo at right. (Photos: John Koivula/GIA)

Glue two thin pieces together to produce a stone of reasonable thickness. Such Yogo sapphire doublets have been produced for many years (*c.f.* Liddicoat, 1969). In September, 1994, the author visited a jewelry store in Missoula, MT, where a number of Yogo sapphire doublets were being offered (as doublets). Prices for two-carat stones went up to $1000/ct, ridiculous when one considers that these were still doublets.

Wafer-shaped rough is also found in the ruby mines along the Thai/Cambodian border. Unscrupulous dealers will sometimes glue, say, two 0.75-ct rough stones together, making a single faceted piece of over 1.00 ct. One of the most deceptive seen by the author consisted of two flat Thai/Cambodian rubies joined together. The finished stone was cut shallow and its color typical of Thai/Cambodian ruby. So natural did this stone appear that experienced dealers would not even think to check it with a loupe. Furthermore, although most doublets are joined at the girdle, this piece was joined below the girdle, with the joint well hidden. All in all, an extremely tricky piece.

Natural–synthetic doublets

More common are doublets featuring a thin slice of natural corundum glued on top of a far-bigger piece of synthetic corundum. Then the whole is faceted, with the join typically placed at the girdle. These can be deceptive, as a quick check with the loupe reveals natural inclusions in the crown. If the top is cut thin enough, the synthetic base need not even be of the same color, but more natural appearing doublets are made with both pieces of the same color. Natural green sapphire is typically used for the top because of its low cost. The pavilion is normally Verneuil synthetic corundum (due to its low cost), but flux-grown synthetic corundum may also be used.

Figure 8.2 Doublet? Not hardly. This stone is an *ottu* blue sapphire from Sri Lanka. The color is concentrated near the cutlet, but because of reflections, it appears that all the color is in the crown. To properly identify an assembled stone, one must locate the separation plane, rather than just a difference in color. (Photo: GIA)

In most cases, the separation plane is perfectly flat and lies at the girdle, but the author did encounter one doublet consisting of Verneuil synthetic ruby which had an irregular chunk of natural Burmese ruby attached with glass. While somewhat deceptive, because the natural portion contained a large area of rutile silk easily visible to the naked eye, magnification quickly unmasked this fraud. But such is the danger of assembled stone—the natural portion may display such obvious "natural" inclusions/features that the stone is not checked carefully.

Synthetic–synthetic doublets

The author once encountered a most unusual doublet, consisting of a crown of synthetic sapphire and a pavilion of Verneuil synthetic Co-blue spinel. Possibly the only reason for such a doublet (with both pieces being synthetic) is that the cobalt-blue color of the synthetic spinel is given a slightly more natural look with the synthetic sapphire crown.

Figure 8.3 Commonly-encountered examples of assembled rubies and sapphires. Other combinations are also possible, but these represent the types most frequently seen.

Certainly if the maker wanted to give the stone the true hardness of corundum, they could have used an entire piece of synthetic corundum. In any case, such a stone is easily identified by the RI difference between the top and bottom pieces.

Coatings

Among the simplest, but most effective, deceptions is to coat a pale stone with colored plastic. So long as the coating is fresh and undamaged, it can look natural. Cabochons, as well as faceted stones, can be coated. One piece seen by the author was an apparent star ruby which showed strong hexagonal zoning and rutile silk obvious to the naked eye. However, microscopic examination revealed the stone to be a pale

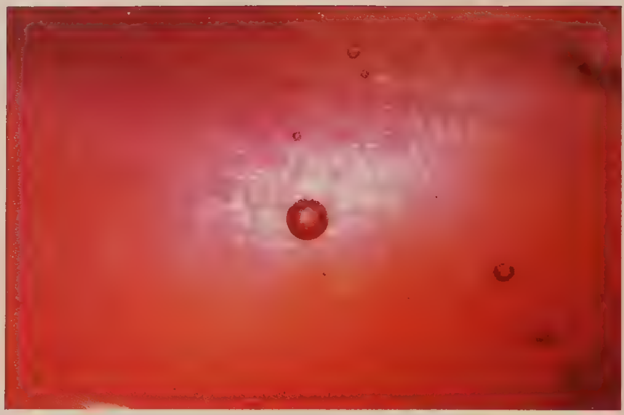

Figure 8.4 Plastic-coated star ruby
Top left: Take a pale-colored star sapphire, coat it with red plastic and, *voilà*, you have a star ruby.
Top right: Under magnification, gas bubbles are clearly visible in the red plastic layer. Rutile silk from the natural star corundum is also visible just below.
Bottom left: Of course, one of the drawbacks of plastic is its lack of durability. This stone was mounted in a ring and the prong tore a hole in the plastic coating. Air has also seeped in around the tear, creating discoloration. (Photos by the author)

(probably light gray) star sapphire completely coated with red plastic. Although a spot RI would immediately reveal the deception, the stone looked so obviously natural that most dealers would never even think to check the stone carefully. Gas bubbles and red color swirls were visible in the plastic under magnification, as was a small hole in the red plastic layer.

One of the oldest frauds is simply painting color onto pavilion facets. When this is applied on all sides of the culet, it can give a rich color to even colorless stones, but it is easily detected. A quick glance at the pavilion under magnification will quickly reveal this subterfuge. For additional information on coatings, See "Surface coatings & stains" on page 132.

Foilbacks & mirrorbacks

Mirror or foil backings were commonly applied to stones set in pre-twentieth century jewelry. Although deceptive, this was a typical trade practice of the day. Today they are rarely encountered, except in older pieces.

Mirrors are sometimes placed on the back of stones to improve their brilliance. In some cases, the mirror may be colored.

Both mirrorbacks and foilbacks are easily identified, generally with a naked-eye examination. If the stone is mounted and the back is not visible, magnification may be needed.

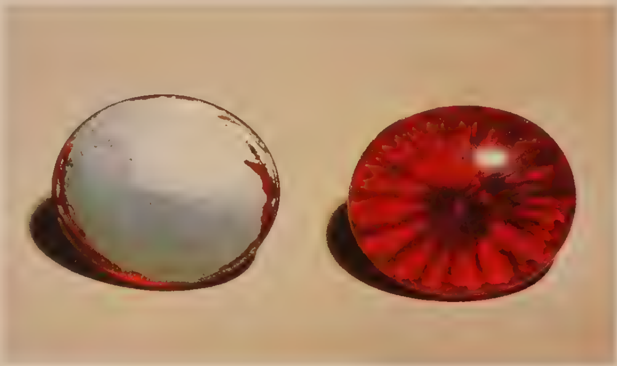

Figure 8.5 Synthetic ruby foilbacks. This type actually consists of a special foil paint applied to increase brilliance. (Photo: Tino Hammid/GIA)

Assembled rough

Just as it is possible to assemble cut stones, it is also possible to assemble rough. A common ploy is to drill a hole in a crystal and fill it with a colored gel. This gives a rich color to an otherwise pale crystal. But the drill hole must be camouflaged. This is generally done by mixing epoxy with fine sand or other rock fragments, to create a matrix-like base. Examination with the microscope under immersion quickly unmasks the filled cavity, which has a different relief and often contains gas bubbles. Use of an appropriate epoxy solvent will also reveal this fraud, but this is a destructive test.

Figure 8.6 A star ruby triplet, complete with mirror. This consists of a transparent synthetic ruby crown atop an engraved mirror, with a piece of low-grade natural ruby on the base to cover up the mirror. (Photo: Mike Havstad/GIA)

One piece seen by the author in Vietnam was superficially a crystal. Closer examination revealed it to consist of a thin slice of natural ruby glued to a Verneuil synthetic ruby. The whole was fashioned to resemble a natural crystal, with the natural portion on the base, giving the silky reflection of a natural stone.

Assembled stars

Faceted stones are not the only problem. Cabochon-cut stars may also be assembled. One type of star doublet is where a slice of asteriated natural corundum is placed beneath a cabochon of transparent natural or Verneuil synthetic corundum. This gives a star effect to the whole piece. By engraving narrow lines in three directions at 60° angles on the back of a transparent natural (or synthetic) corundum cabochon, a star can also be created. The effect is strengthened by placing a mirror backing on the stone.

Probably the most deceptive assembled star corundum seen by the author is the star triplet. A pale star sapphire cabochon of good transparency and good asterism is used as the center piece. Then a Verneuil synthetic ruby or sapphire cabochon is hollowed out so that it fits perfectly over the pale colored star sapphire. A slice of natural corundum is used to seal the back and the stone is then mounted in a jewelry piece which hides the joint. When well made and mounted, this star triplet is difficult to identify.

In such stones, the natural inclusions (silk, hexagonal zoning) of the center piece are often so obvious that it is not checked carefully. However, if the rear of the mounting is closed, hiding the back and girdle of the stone completely, one should be suspicious (usually the back is left open in corundum cabochon mountings, to allow more light through the stone, and so improving the color). Microscopic examination from above will also reveal the deception as the double surface of the synthetic top piece (which is completely transparent) is seen; gas bubbles may also be seen in the glue of the separation layer.

Identification of assembled stones

The identification of assembled stones of all types hinges on one key factor—location of the separation plane. Assembled means joining together—thus identification of these stones involves finding the *joint.*

A warning is in order—difference in color alone between crown and pavilion does not an assembled stone make. The author will always remember the humiliation he suffered during his student days when, in Sri Lanka, he wrongly accused a local dealer of selling sapphire doublets because of a difference in color between crown and pavilion.[1] Unusual reflections, color zoning, or pleochroism may cause the crown to appear differently colored than the pavilion. However, with the exception of coated stones, there must be a visible joint. This is what one should look for.

In most cases, the separation plane is completely flat and is located at the girdle. Glue is normally used to join the pieces together and as the glue (or glass) has a different RI from corundum/syn. corundum, immersion in methylene iodide will quickly reveal the separation plane as a layer of high relief (the corundum will have low relief due to the similarity between its RI and that of the methylene iodide). Immersion will also reveal any color differences between the different layers (a difference in relief will also be seen in corundum-topped doublets where the pavilion piece is something else, such as spinel or synthetic spinel.)

Further clues are found under magnification. Any inclusions present will be seen to stop at the separation plane. In addition, the glue layer often displays brush marks, as the glue is usually applied with a brush. Flat gas bubbles are also frequently seen in the glue layer.

One should always be careful when a stone is mounted with the girdle and/or pavilion completely hidden. This is often an indication that there is something which needs to be hidden.

In summary, the identifying features of assembled stones are as follows:

Doublets/triplets/assembled rough

- *Separation plane:* A distinct joint will be seen completely unbroken around the entire stone. It is generally flat (resulting from grinding on a flat lap), and usually lies at the girdle, but may also be found on the pavilion, or even on the crown.

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1. Whenever purchasing stones, one should generally avoid holier-than-thou proclamations on the fraudulent nature of a stone being offered for sale. This is particularly important if others are looking on. First, there is a good chance you are wrong. Second, it is quite possible that the seller truly believes the stone to be legitimate. Third, if the seller's honor suffers enough, one could be in physical danger. If you are convinced that there is a problem with a stone, select a private moment to gently discuss your concerns with the seller.

Figure 8.7 One of the more unusual assembled stones encountered by the author was that shown above. This featured a small chunk of silky Burmese ruby attached with glass to a Verneuil synthetic ruby. Magnification of the specimen (right; 63×) reveals gas bubbles in the glass. The natural portion is the pinkish area at the upper center of the photo. (Photos: Wimon Manorotkul)

a. The glue layer used to join the two pieces often shows curved brush strokes.
b. Flattened gas bubbles are often seen in the glue layer.
c. Since the glue's RI is quite different from the corundum, it will stand out in high relief when the stone is immersed in methylene iodide.

- At times, a crack may penetrate across the entire stone. This raises the question of whether the stone broke apart during cutting, and was glued back together. Placing the stone in a suitable solvent (acetone or methylene chloride) will dissolve the glue, if present. A less destructive test involves using the hot point under magnification. The hot point may melt portions of the glue, causing bubbles in the glue to expand and contract, revealing the fraud.
- Possible color/pleochroism/luster differences may be seen between one piece and another.
- Inclusions completely change direction/nature at the separation plane. In the case of assembled rough specimens, striations and other growth marks may change at the separation plane.
- Focussing down from the top with the microscope may reveal a second surface just below the first.

Coatings

- *Plastic coatings* (*coatings*, not impregnations): Measurement of RI will quickly reveal the fraud, as plastic has a far lower RI than corundum. Round gas bubbles may be seen in the plastic portion. Focussing down from the top with the microscope may reveal a second surface just below the first. Holes or tears in the coating are often seen under magnification.
- Thin coatings may not produce a different RI, but often show a light interference effect (such as the bloom seen on camera lenses).

Foilbacks/Mirrorbacks

- These will be seen on the back of the stone. They are generally opaque, and quite obvious.
- Lines may be engraved in the mirror or back of the cabochon, to produce a star effect.

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CHAPTER 9

METHODS OF FASHIONING

Besides its use by the armourer, which was formerly a much more flourishing industry in India than now, emery, and the crushed forms of corundum generally, are used largely by the lapidary for cutting and polishing hard stones.

The Indian lapidary (*begri*) uses different kinds of discs (*sán*) for cutting precious stones. Corundum discs of different grades are used for the rough cutting of minerals softer than diamonds, whilst the polishing is done on discs of bell-metal, or pewter, according to the hardness of the stone, the abrading agent being the powder of the stone which is being cut.

Besides the ordinary *begri* or lapidary, there are men whose business it is to bore holes through precious stones, and they are known as *bidhiya*. The *bidhiya* squats on the ground with the stone to be pierced fixed on a three-legged stool in front of him, and proceeds to work with a steel *barma* (gimlet) worked with a *tasma* (leather strap) fixed to a *kamáni* (bow). Water is allowed to drop on to the stone into which the steel gimlet, armed with corundum-dust, gradually erodes a hole.

Corundum is also used by the *náginasaz*, a man who cuts up pieces of coloured glass for false jewellery, and by the *kataiya*, whose business it is to cut into smaller pieces the large masses of crystal imported by the jeweller. The *kataiya* cuts his rocks by means of a heavily loaded bow with wire working in powdered corundum and water. According to Mr. Archibald Constable, corundum is still used in Lucknow for engraving seals. At the end of steel spindles …small discs of copper are fixed. The spindles are placed in an ordinary seal engraver's lathe, and the discs being anointed with corundum powder and oil are made to revolve against the flat surface of the stone to be engraved, which can be manipulated as required. The same process is employed by the *muhar-band* (seal-engravers) of Kashmir.

T.H. Holland, 1898
A Manual of the Geology of India, Part I.—Corundum

ROUGH gemstones rarely possess beauty sufficient for use in jewelry. Instead, most require cutting (grinding) and polishing to unlock the color and luster for which they are known. This is the job of the lapidary.

The earliest method of fashioning gems was simply to polish the flat crystal faces developed by nature. This later gave way to the cabochon, a style of cut imparting a curved upper surface. Still in use today, the cabochon cut is used for star rubies and sapphires, as well as those stones too heavily included to be faceted. Only in the second half of the second millennium AD did we have the development of the faceted cut. This is the style which is most popular today for rubies and sapphires, because it allows their color and brilliance to be seen to best effect.

Cutting basics

The cutting of corundums generally involves four steps:

1. Sawing or cobbing (sometimes omitted)
2. Preforming (shaping and orientation)
3. Facet grinding (omitted for cabochons)
4. Polishing

Typically, the first two steps are performed by one worker, and then the stone is given to another for finishing. The goal is to derive the highest total stone value. This involves producing the most beautiful gem, while at the same time retaining maximum weight.

Sawing and preforming are most important, because they determine, to a large degree, the final appearance and weight. Before any saw cuts are made, rough is examined carefully to

Figure 9.1 Preforming is the most important step in cutting because it is here that the gem is given its essential shape. Pictured is a Thai lapidary preforming blue sapphire on a grinding wheel. (Photo by the author)

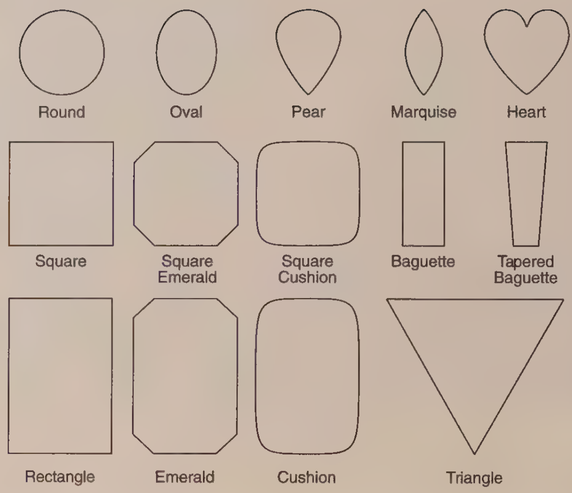

Figure 9.2 Common shapes (girdle outlines).

determine how it can best be utilized. Depending on the size, shape, and distribution of color and inclusions, a decision is made as to how it will be cut. With most corundum, especially the smaller sizes, a single stone only is obtained from the rough and so sawing can be omitted. When made, saw cuts are often placed along cracks or flaws so as to eliminate them at the beginning.

Preforming and orientation

The preforming stage is most important because the gem's essential shape, proportions and orientation are fixed. For this reason, preforming is generally the job of the most experienced worker.

Shape (girdle outline)

The shape of the rough largely determines the shape of the preform, and thus, the finished stone. Most common for corundum are the cushion and oval. Since the cushion provides greater potential brilliance, it is more desirable than the oval. By the same token, the round shape possesses more potential brilliance than the cushion, and so fetches a premium. Rounds are in greater demand, but, due to the greater weight loss in their production, are more rarely seen. This further increases their premium.

Shape can affect desirability, and thus, value. Below are listed the common shapes seen with ruby and sapphire, in general order of desirability:[1]

1. Round
2. Square Emerald
3. Square Cushion
4. Elongated Emerald
5. Elongated Cushion
6. Oval
7. Pear
8. Heart
9. Triangle
10. Marquise

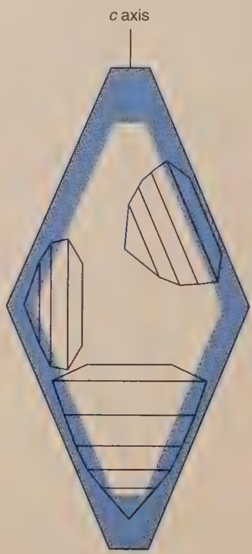

Figure 9.3 In *ottu*-type blue sapphires from Sri Lanka and Kashmir, the blue color lies just below the crystal faces, with a colorless crystal core. For faceted stones to face-up blue, rough is oriented so that the color lies at the culet (preferably on both sides of the culet, reaching as far up the pavilion as possible) or across the crown, preferably extending from girdle to girdle.

In Sri Lanka, weight retention typically takes precedence over color intensity, with the table facet not lying perpendicular to the *c* axis (as it should to achieve the most intense blue color). Thus pleochroism dilutes the color.

Girdle symmetry

Symmetry of the basic girdle shape is also important. Rounds should be absolutely round, preferably with an error not exceeding 2%. As for the desired symmetry of rectangular emerald, rectangular cushion and oval shapes, we can look for guidance to laws developed by Greek artisans over

[1] Other fancy shapes have not been listed because they are rarely used with corundum.

Figure 9.4 Ruby and sapphire cutting in Burma remains primitive
Top left: Ruby cutters polishing cabochons at Mogok, Burma. (From O'Connor, 1905)
Below left and right: Ruby cutting at Mogok, ca. 1992. With the exception of electric power, the methods in use remain little-changed from those of centuries ago. (Photos: Thomas Frieden)

2000 years ago. Comparing length to width, 3:1 proportions yield stones which many find too narrow. Attractive rectangles result from 3:2 proportions, while, for bigger gems, 5:3 proportions are more satisfying.

Orienting for color

Other than shape and symmetry, the main concern of the lapidary is color. Not only its distribution must be taken into account, but also pleochroism, for rubies and sapphires are each strongly dichroic. In shaping the stone, the lapidary is conscious of certain crystal directions along which the color varies. For both ruby and sapphire, the best color is seen along the *c* axis, while at right angles to this direction it is slightly less intense and of a slightly different hue. Thus, the lapidary will strive to orient the rough such that the table facet is perpendicular to the *c* axis. Fortunately, the shape of both ruby and sapphire in the rough usually permits the largest weight retention ('yield'), in just this orientation. Failure to position the *c* axis perpendicular to the table results in a lower color intensity and, subsequently, lower value.

Varying the *c* axis orientation may also help reduce color in overly-dark stones. Some Australian sapphires may be purposely oriented with the *c* axis at 45°, or even parallel to the table, again to lessen the color intensity in overly dark stones. This orientation is often termed *cross-table* by Australian lapidaries.

Variations from the desired orientation may also be due to uneven color distribution. In *ottu* blue sapphires from Sri Lanka, color lies just beneath the faces and at the tips of the crystal. The lapidary tries to orient the stones so that the color is placed at the culet. With most Sri Lankan sapphire rough being spindle shaped, this explains why the cut gems have such deep pavilions. When properly done, with color on both sides of the culet, the entire gem will face up blue. However should the color lie on one side of the culet only, an unsightly *color hole* will be seen in the face-up position.

Should it be impossible to position the color at the culet, the lapidary may lay the crown along one of the faces where the color lies just below the surface. Although the *c* axis is now wrongly positioned to obtain the most intense color, it

Figure 9.5 The faceting method widely used in Thailand today was introduced to the country by a Dutch diamond cutter named Zerner shortly after World War II. Thus the equipment bears a strong resemblance to that used by diamond cutters. The Thai cutter above is dopping the stone prior to faceting. (Photo by the author)

may be preferable to a partial or complete lack of color, or a stone of far smaller size.

Orienting inclusions

Inclusions may also provide reason for the lapidary to veer from the desired orientation. If it will increase the total stone value, the gem may be oriented away from the ideal color to make inclusions less visible. For example, Burmese rubies often contain dense clouds of rutile silk. Individual needles in these clouds are broad and thin, with the flat side lying in the basal plane. In stones cut with the *c* axis at right angles to the table, they are obvious, causing bright reflections. Orienting the table parallel to the *c* axis may make them less visible.

Orientation for total stone value

As one can see, the lapidary must constantly strive to balance desirable and undesirable features, all of which are interrelated. *Total stone value* is the key factor in deciding whether to cut a small, high-quality stone, or a larger, but less costly (per carat) piece. If faced with a decision between cutting a one-carat stone worth $1000/ct or a two-carat stone worth $600/ct, the choice should always be to cut the two-carat piece, due to its higher total stone value.

Faceting

Once the rough has been oriented and the preform ground, it is then given to the cutter for grinding and polishing of the facets. Compared to making the preform, this is a relatively simple task and so is usually carried out by less experienced staff. The cutter will choose a cutting style based upon the type of gem material he or she is working with, as certain styles lend themselves more readily to some gems than to others.

This choice is based largely on two factors: brilliance/scintillation and weight retention. Improving one is generally done only at the expense of the other, and so the cutter strives to achieve balance. Again, the goal is maximum total stone value.

Facets of a cut stone are so placed as to allow light falling on the gem from above to reflect off the internal pavilion surfaces and then return to the eyes. Ideally, the gem should act as a light trap, catching as many rays as possible. This is achieved by the table facet. Then the pavilion reflects them like a mirror, reversing their direction and throwing them upward again where they escape back through the table. Some rays will escape through the crown facets, being *dispersed* (split into colored rays) in the process. With ruby and sapphire, dispersive power ('fire') is low (0.018) and the rich color generally masks what dispersion they do show. Thus, the main aim of the cutting style is to produce brilliance and scintillation.

Scintillation is the twinkling effect seen when either the stone, light source, or viewer's head moves. It is achieved by cutting the stone with many small facets rather than fewer large ones, to break up the light into small angular areas. However, as with everything, balance is necessary; if the facets are too small, blurring, rather than scintillation, results.

Cutting economics 101

ONE often encounters stones which are poorly cut. A natural question is why the cutter didn't do a better job. For example, failure to close the culet is a common problem for rubies and sapphires faceted in Asia. Thus, a stone which is otherwise well proportioned is spoiled by a window at the final row of facets next to the culet. Recutting the gem to remove this window sometimes results in only a slight loss of weight. Hence, it is not a question of weight retention as the cause of the problem; instead, it merely indicates a lack of proper training. But poor cutting does not always suggest lack of skill on the part of the lapidary.

Shape of the rough plays a vital role in determining finished proportions. Due to their bipyramidal shape, rough Sri Lankan sapphires are often cut with deep pavilions. Thai/Cambodian rubies and Yogo sapphires typically feature large windows because of the rough's thin tabular shape. In addition, the high value of ruby forces cutters to sacrifice beauty for weight retention. In fact, large rubies of high quality are typically cut to *poor proportions*. This is not indicative of careless technique, but instead, quite the opposite. Because gems are sold by weight, it is a testament to their prowess at obtaining the maximum stone value.

In the end, one must understand that recutting stones to perfect proportions frequently means losing money, because the increase in quality is not sufficient to offset the decrease in weight. With a five-carat ruby worth $10,000/ct, *every hundredth of a carat is worth $100*. A bit too much pressure on the wheel can result in a small fortune quickly vanishing into dust. Which is exactly what is likely to happen to the lapidary cursed with too heavy a cutting hand.

Figure 9.6 Gem cutting in Sri Lanka
Top left: Kandian Singhalese gem cutters in Sri Lanka, ca. 1930s. (From Kornitzer, 1941)
Lower left: While Sri Lanka is famous for the poor quality of its cutting, since the late 1980s a number of modern factories have opened. Today, the best of Sri Lanka's cutting is on a par with that found in Thailand. The above photo shows Great Northern's Colombo factory, where much Australian sapphire is faceted. (Photo: Great Northern)
Right: Preforming corundum in Ratnapura, Sri Lanka, 1989. Even today, bow-driven apparatus is common, as electricity is still a luxury in many parts of the country. (Photo by the author)

Brilliance refers to the quality and quantity of light returned to the eye by the gem. The most important factor in brilliance is the angle of pavilion facets. If cut too shallow, light passes directly through (instead of reflecting off the rear facets), creating a *window*. Conversely, if the pavilion angle is too steep, light reflects off one side and then passes out through the opposite pavilion facet, creating a dark area known as *extinction* (see Figure 9.7).

Crown height and angle. With crown-to-pavilion proportions, generally the crown height should amount to about one-quarter to one-third of the total table-to-culet depth of the finished stone. The lower value is generally for pale stones, to deepen the color slightly.

According to Soukup (1962), crown main facets should be ideally cut at 37°, but other sources report values ranging from 35–42°. Upper girdle facets should be cut at 41–45°, and star facets at 22–25° (Mike Gray, pers. comm., 25 April, 1995).

Depth percentage. Depth can be expressed as a percentage of the diameter,[2] with ~65% being considered desirable for the finished stone. There are, however, reasons for varying from this ideal. The first concerns the shape of the rough. Thai ruby rough is generally found as flat tabular crystals and because the high price of ruby makes weight retention vital, the cut stones are often far too shallow for maximum brilliance. Similarly, Sri Lankan sapphire crystals are usually long spindle shapes; thus the finished stones end up too deep.

Depth of color is also a factor in depth percentage. Australian sapphires may appear so dark and inky that, if cut to proper proportions, they would be almost black. Thus they are often cut shallow, sacrificing brilliance in order to lighten the color.

Pavilion angle. The ideal pavilion angle for a gemstone depends upon its refractive index, which is a measure of its

[2] Or *average diameter*, in the case of non-round stones.

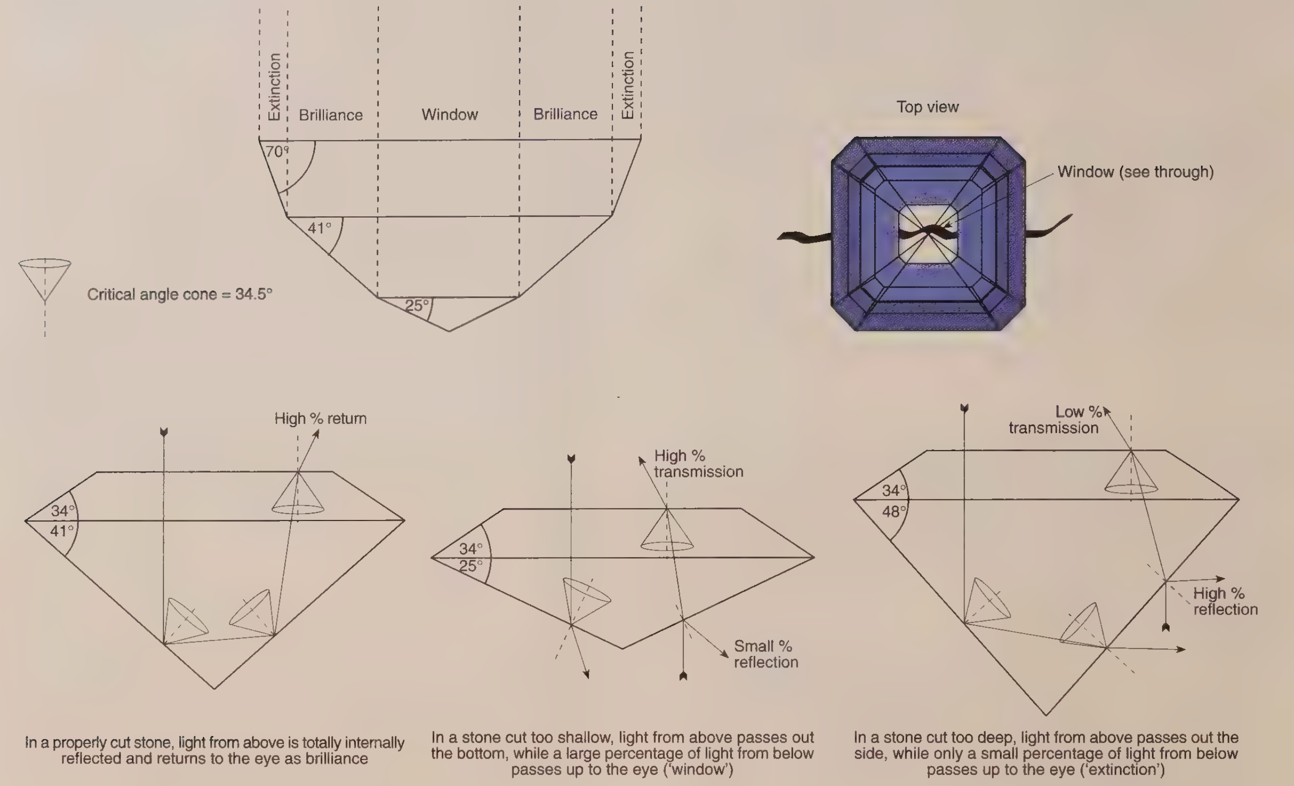

Figure 9.7 Brilliance, windows and extinction
Most corundums are cut with step-cut pavilions and display a combination of three effects. Facets nearest the girdle are too steep and so show extinction, while those next in line are just right and so show brightly colored flashes of brilliance. Those at the culet are too shallow and thus show a window.

- Facets cut at proper angles allow light from above to return to the eye ('brilliance').
- Shallow pavilion facets allow light from above to pass out the bottom. Light from below is mostly able to return to the eye, but because light paths from below are far shorter than on those facets showing brilliance, the color seen is of low intensity ('window').
- If pavilion facets are too steep, light from above reflects across the pavilion and passes out the opposite side. Due to the steep incident angle, much of the light from below is reflected off the first surface. That which does enter the gem is unable to exit the table because it is incident outside the critical angle (in some cases it may exit the table, but is reduced in intensity, due to the shorter light path and loss from reflection as it entered the gem from below). Thus it reflects back around and eventually exits the pavilion. Facets such as these, which are cut too steep, appear dark ('extinction').

brilliance potential. To understand how this influences brilliance, we will look at the concept of *critical angle.*[3]

When light *inside* a gem strikes a facet, whether or not it will exit depends on its angle of incidence and the size of the critical angle formed within the stone. Light within the critical angle will exit, but light incident outside this angle will instead be *totally* reflected back into the gem, where it travels across to another facet and the same situation prevails.

Gems are faceted so that light entering through the table will be totally internally reflected across both pavilion facets and then back towards the table. At the table, light falls within the critical angle, and so exits, creating brilliance. Gems with smaller (lower) critical angles permit less light to escape through the back and sides. As a result, they possess greater *potential brilliance. Actual brilliance* is a function of proportions (pavilion angle, etc.) and critical angle.

Critical angles vary in inverse proportion to the gem's refractive index (RI). The higher a gem's RI, the smaller its critical angle and, thus, the greater its potential brilliance. Since the pavilion angle is largely responsible for a gem's brilliance, the ideal pavilion angle for that gem can be calculated with reference to its refractive index:

	RI	Critical angle	Ideal pavilion angle
Diamond	2.417	24.5°	39.75°
Corundum	1.76	34.5°	40–41°

Should the pavilion facets be cut at an angle less than that of the critical angle, light will pass right through the stone instead of reflecting back, creating a *window,* or area where one can see through the stone, as in window glass.

3. The *critical angle* is the incident angle for the ray which makes a 90° angle of refraction when light travels from a high RI to low RI substance.

Figure 9.8 This was the most unkindest cut of all… one which lowered the value of the stone
Left: When a stone is properly faceted, it will show high brilliance, no window and minimal extinction, such as this fine yellow sapphire. (Photo: Adisorn Studio)
Right: This 179.4 ct yellow sapphire has been cut solely for weight retention. As a result, it displays a large window at the center and much extinction around the edges. Brilliance is almost entirely absent. (Photo: Royal Ontario Museum)

Grease on the back of a stone can substantially reduce brilliance, because it reduces the RI difference between the gem and air, thus shrinking the critical angle. Hence the gem should be perfectly clean in order to see maximum brilliance.

How many facets? Varying the number of facets on a stone can influence both scintillation and color. Maximum scintillation is created by more facets, *to a point*. If the individual facet size is too small, the effect is an undesirable blurring. Thus small stones should have fewer facets, and larger stones more.

To a certain degree, color can be influenced by varying the number of pavilion facets. With pale stones, more facets and steps will deepen the color slightly. Decreasing the number of facets and steps has the reverse effect on dark stones, lightening their color. The shrewd cutter will use this principle to good effect, raising the stone value.

Cutting styles

Brilliant cut. The brilliant cut is much used for diamond, but with corundum it is rarely seen. Although it allows maximum brilliance, only with Montana sapphires is this style common. The reason is that the pavilion facets of the brilliant cut extend all the way from girdle to culet, making it impossible to increase the yield by slightly rounding the pavilion.

Mixed cut. Instead, the cutting style most often used for rubies and sapphires is the mixed cut, so-called because it combines the brilliant cut crown with a step cut pavilion. Its chief advantage lies in the fact that the cutter can retain as much weight as possible by rounding off the steps, or facet rows, on the pavilion. This extra weight retention, however, does not come without a price. If the facet rows nearest the girdle are cut too steep, extinction is created, with light passing out the side instead of returning to the eyes as brilliance.[4]

Step cut. The other major facet style used for corundum is the full step cut, also termed the *trap* or *emerald* cut. It is used on stones of rectangular or square outline, with corners truncated slightly to prevent chipping or fracture. The step cut's long, unbroken facets display the gem's color to maximum advantage. However, since inclusions are more noticeable, this cutting style works best with relatively clean or richly-colored material.

Summary. The brilliant, mixed and step cuts are generally the only faceting styles commonly used for rubies and sapphires. Occasionally, one encounters others, but this is rare.

Native cut—the unkindest of all. The *native cut* is not really a style in itself, but more a lack thereof. *Native cut* is synonymous with "poorly cut" and comes to us primarily from Burma, India and Sri Lanka. It is a crude attempt at one of the major styles and generally results from poor training and equipment. At times these stones bear only the vaguest resemblance to modern faceted stones. Facets are placed in a haphazard manner and, especially with those from Sri Lanka, may not even be flat. Square tables on round stones and rectangular tables on oval stones are the hallmark of native-cut gems from Sri Lanka. They use methods virtually unchanged since ancient times, and you had better believe that the stones show it.

4. Stones cut too deep are also more difficult to mount in jewelry.

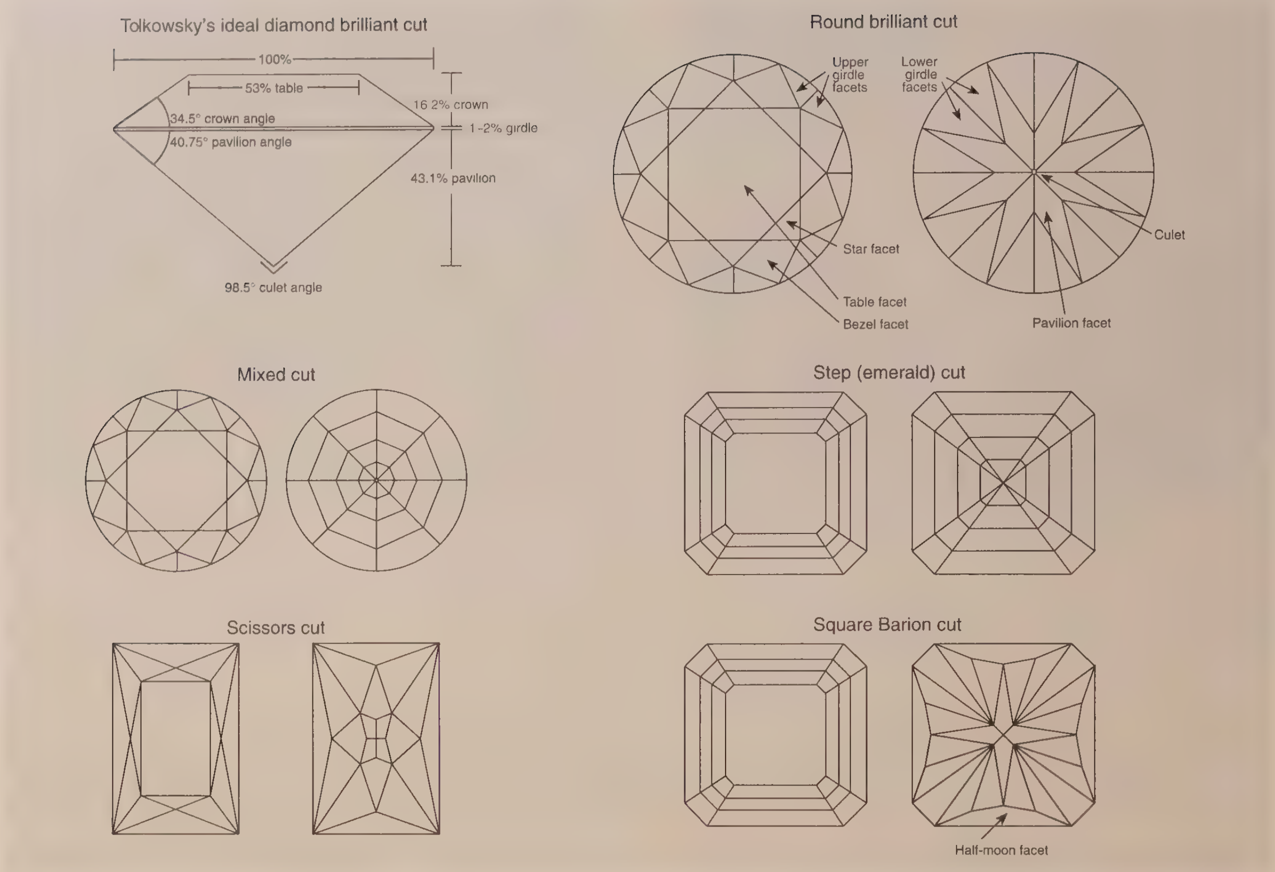

Figure 9.9 Above are shown common cutting styles. Most natural rubies and sapphires are cut with the mixed cut, which features a brilliant-cut crown and a step-cut pavilion. The use of a step-cut pavilion allows greater weight retention. Synthetic corundums are often cut in the scissors style. This is almost never used for natural corundum.

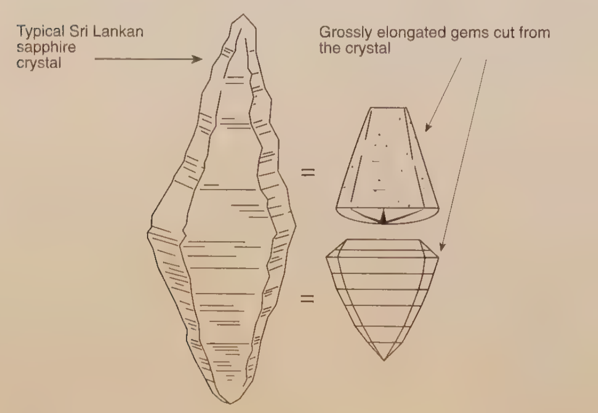

Figure 9.10 In native-cut gems, there is an over-emphasis on weight retention, resulting in grossly misshapen gems. (Modified from Sinkankas, 1968)

This is not to say that only native cuts are produced in these countries. Fine cutting can also be found, but still many stones must be recut if they are to be sold in developed nations. The biggest problem is an over-reliance on weight retention. Proper cutting is just as important as color or clarity in determining the value of a stone, for the best color is seen only in the areas where light returns to the eye. Even the best color is useless if only 10% of the stone's face shows it due to poor cutting.

Buying for recutting. When buying stones which need to be recut, they must be judged or appraised at the estimated weight after recutting to good proportions, just as is done for diamonds. Failure to do so is to risk buying at an inflated price. If a stone weighs 2.50 cts, but after recutting to proper proportions would weigh only 1.50 cts, it must be valued as if it were 1.50 cts, not 2.50. One final tip in regard to purchasing stones for recutting has to do with their proportions. Generally it is better to select stones which are bottom heavy, or lumpy, rather than those which are flat. The weight loss in recutting bottom-heavy stones is usually much less than for flat pieces.

Scissors cut. The scissors cut is used almost exclusively for synthetic and imitation stones. Also known as the cross cut, it possesses side facets consisting of four triangular facets in

Figure 9.11 The round shape is relatively rare in corundum, due to lower cutting yields. But when coupled with high-quality material, such as this untreated Burmese sapphire above, it has a special allure. (Photo: Rattana Angkuanpanit; specimen: World Jewels Trade Center, Bangkok)

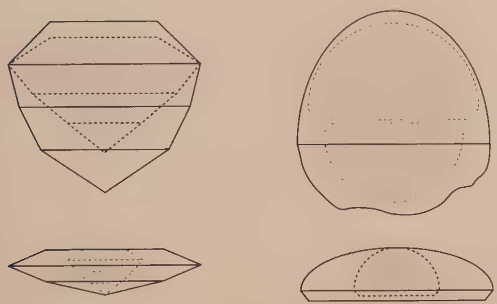

Figure 9.12 In the purchase of "native-cut" (poorly cut) gems, recutting is often necessary. Buyers prefer stones which are overly deep, rather than shallow, because weight loss is generally less. Sri Lankan rubies and sapphires are generally cut too deep, while Thai/Cambodian rubies are usually too shallow. This can be traced back to the original shape of the rough. In recutting Sri Lankan blue sapphires one must also avoid removing areas containing the blue color, for this may result in a dramatic loss of color. At times, it may be advantageous to cut two stones from a single crystal.

an x-pattern on the crown. Large quantities of synthetic ruby and sapphire, synthetic spinel and glass are faceted in this style. So rarely is it used for natural corundum that one should be suspicious of anything cut in this style that is offered as natural.

Barion cuts. Developed by South African diamond cutter Basil Watermeyer, the Barion cuts are an adaptation of the round brilliant style of pavilion facets to angular shapes, such as the emerald, square emerald, kite, triangle, pentagon and hexagon. Their key features are half-moon shaped pavilion facets at the girdle, which allow brilliant-style facets to be placed upon angular-shaped stones. The crown is cut in the standard step-cut style. Barion cuts produce as much or more brilliance than even the standard round brilliant cut, as well as greater weight retention. Unlike step cuts, Barions do not allow rounding of the pavilion (which gives greater freedom in weight retention). Thus they are rarely used for corundum.

Cabochons

One of the oldest methods of cutting gemstones is the rounded shape known as the *cabochon.* This is a French term which itself was derived from the Latin *cabo,* meaning head. Cabochon-cut rubies and sapphires generally fall into two categories: stones which are too heavily included to be faceted, and star stones.

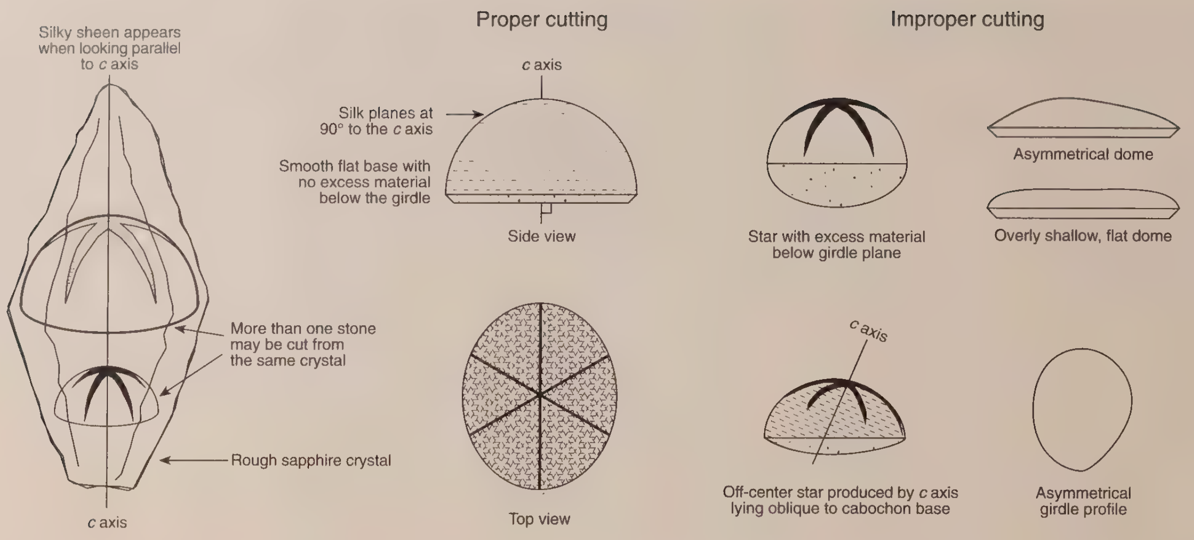

Figure 9.13 Cutting stars and cabochons
For a properly-centered star, the cabochon girdle must be perpendicular to the *c* axis. The base should be smooth and flat, with little excess weight below the girdle. With oval shapes, one ray of the star should follow the oval's length.

Common mistakes include misorientation of the *c* axis, which produces an off-center star, or cutting the dome too shallow, which produces a diffuse star seen only directly above the stone. Native-cut stars from Sri Lanka and Burma often possess excessive material below the girdle plane, but care must be taken in recutting, as loss of color and/or asterism is a real possibility.

The cabochon may be cut in a number of ways. Domes vary from low, almost flat surfaces, through high, steeply curved surfaces. Usually a medium to high dome is preferable. With the more transparent gems, the back of the cabochon is generally flat or slightly convex, and polished. Convex polished bases are used to provide greater brilliance in stones which possess enough transparency. However, should the stone be near, or completely, opaque, a flat base is considered more desirable, as there is no excess weight below the girdle. In any case, excess weight below the girdle should not exceed about 20% of the whole stone, for one must remember that the stone is being paid for by weight. Occasionally stones from Burma, India and Sri Lanka are seen with such heavy bottoms that they look like bowling balls. Just as with faceted gems, these bottom-heavy stones should be valued at the weight they would weigh after recutting to perfect proportions. Overly dark material is sometimes cut as "hollow" cabochons, with the base being concave to lighten the color. This was a common style of cut for the red pyrope/almandine garnets, termed carbuncles, in days gone by. Today it is rarely used for rubies and sapphires.

The symmetry of the top and bottom surfaces on cabochons is easily checked by spinning the stone on a hard flat table. Any wobbling as the stone spins indicates flat spots or a misshapen dome. One should also examine the edges, which should be nicely beveled to prevent chipping.

Double cabochons. Double cabochons with a high-domed crown and low-domed convex base are at times set into jewelry with the low dome facing up. This is done with highly transparent stones, with the aim of increasing brilliance. Light enters easily through the low dome and reflects off the deeper bottom to return to the eyes, just as in a faceted stone.

Star stones

In cutting star material, orientation is all important, for, if done improperly, the star will be off-center or misshapen. Star corundums must be cut so that silk planes lie perpendicular to the cabochon girdle. To do this, the rough is examined under a spotlight or other suitable illuminant, such as direct sunlight. With the light coming just over one's shoulder, the rough is turned until the silky sheen is exactly on top of the stone. Then the line for the girdle is marked so that it lies parallel to the ground. An alternative method utilizes a sticky, viscous liquid, such as honey. When a drop is placed on the rough gem, a miniature star appears on the drop. If the drop is centered perfectly (directly above the *c* axis), the star will appear exactly centered on top of the drop. The girdle is then cut parallel to the floor in this position.

A common mistake in cutting star corundums is misalignment of the rays themselves on oval-shaped stones. When cutting ovals, the lapidary must carefully orient the stone so that one ray is exactly parallel to the length of the oval.

Slightly convex bases may be useful for highly transparent star stones. The convex base allows increased light return, thus strengthening both color and star.

Figure 9.14 Engraved or carved rubies and sapphires are relatively rare. The stone at left is a modern example, along Greek/Roman form. (Photo: Adisorn Studio)

Many star rubies and sapphires are cut with low-domed cabochons, a defect which greatly affects appearance. The cabochon dome acts as a condensing lens to concentrate reflections into a star effect. To be effective, however, the curvature of the dome must be uniform throughout. Low domes generally possess a large flat, or nearly flat area right in the center. This causes the star to appear diffuse, instead of sharp, and it disappears completely unless both the light source and the viewer's eyes are directly above the stone. In contrast, a nicely proportioned dome produces a sharp star that is visible from many angles.

Black-star sapphires. Black-star sapphires from Thailand and Australia owe their asterism to inclusions of hematite/ilmenite, rather than rutile. This hematite/ilmenite silk is included in green, yellow and blue sapphires and is present in such profusion that the stone is colored dark brown or black.

One cause of low domes on black-star sapphires is that the hematite/ilmenite silk is quite platelike (as opposed to the long slender rutile silk found in the star sapphires from Burma and Ceylon). Thus, if a black-star sapphire is cut with a medium to high dome, the star will hardly be seen at all. The lower dome may produce a star that is less sharp and not visible from oblique angles, but at least the star is clearly seen when viewed from directly above. It illustrates well the fact that poor cutting is not necessarily caused by a poorly trained cutter; instead, it may be the opposite, a problem which is hidden by skillful cutting.

Hematite/ilmenite is also the cause of the prominent basal parting common to this variety. So easy does this parting develop that most cutters try to avoid it by cutting the stones as low-domed cabochons. Often during cutting, the high-domed stones chip at the edges of these parting planes.

The tendency of black-star sapphires to chip at the edges often results in unsightly holes on the back of the stone. Thai cutters have come up with a novel, if unscrupulous, technique for hiding these holes—filling them with brown dopping shellac. The result is that many black-star sapphires cut in Thailand possess shellac-filled surface cavities. Most are minor repairs only, but sometimes stones are found with large shellac-filled pits. Removal of the shellac may reveal a stone which is structurally unsound due to the large pits previously hidden by the filling (see Figure 6.21).

Summary of star cutting. To summarize the cutting of star stones, foremost is orientation. They must be properly oriented so that the star is centered directly on the top of the cabochon. Its dome should be medium to high, and without flat spots or other irregularities, allowing the star to be seen even at oblique angles. The girdle outline should be symmetrical and pleasing to the eye, not too narrow or too wide. Oval stones should have one ray placed parallel to the length. The base should be smooth and flat on opaque stones, or slightly convex on more transparent pieces. There should be no pits or cavities present. Watch for cavities hidden by filling with dopping varnish. Finally, weight below the girdle should not exceed 20% of the total.

Carved & engraved rubies & sapphires

Due to its great hardness, only a few examples of carved/ engraved corundums have come down to us from ancient times. These are discussed in Chapter 10 on page 240.

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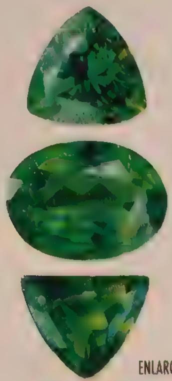

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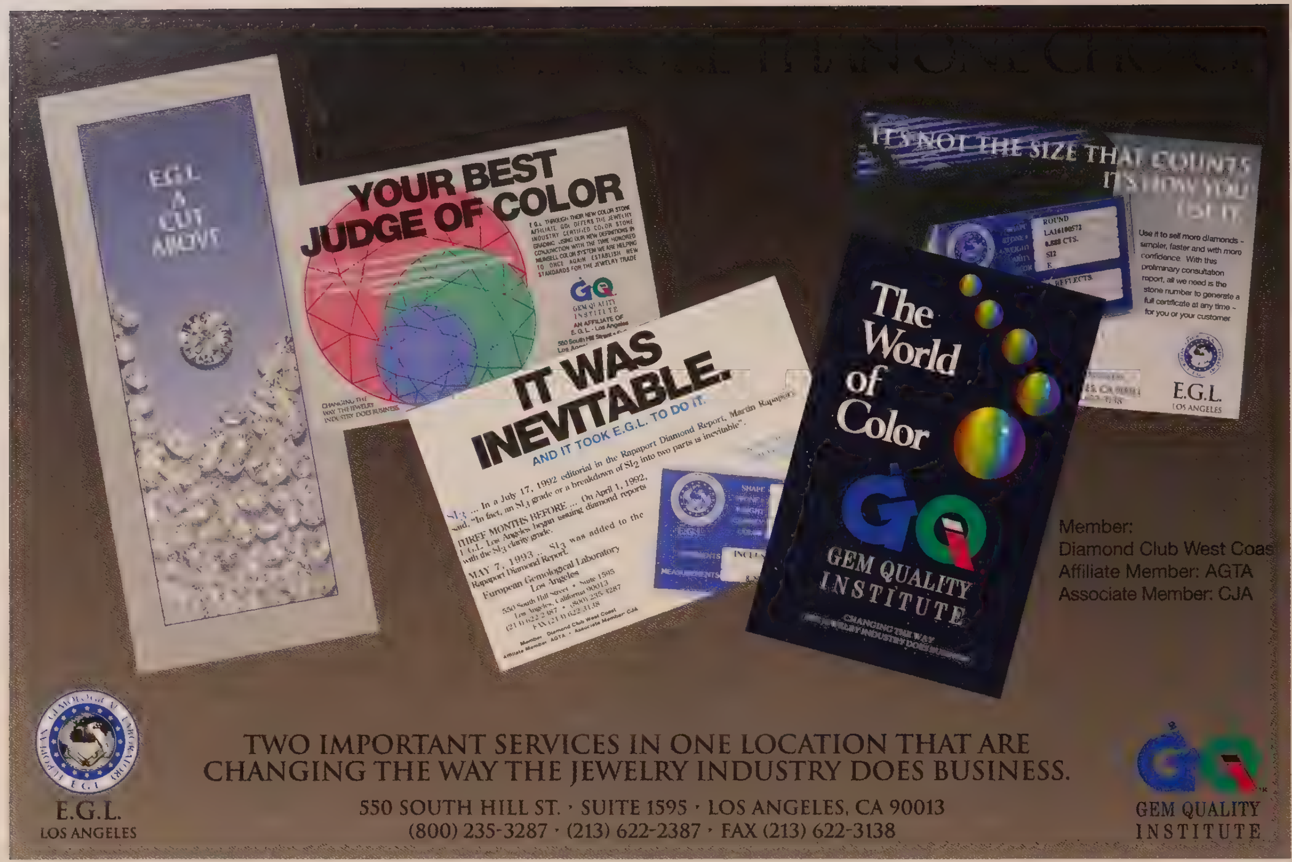

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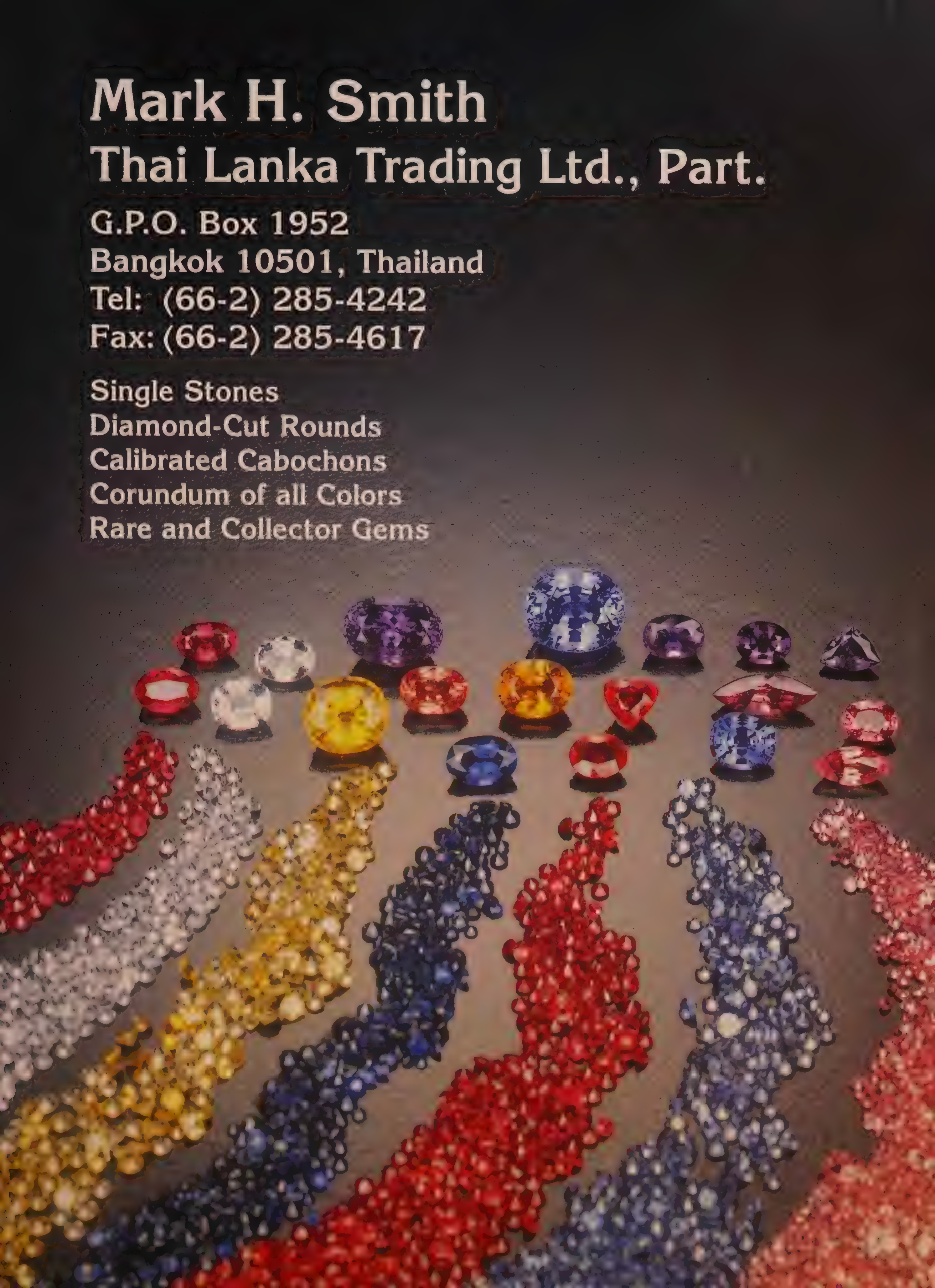
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CHAPTER 10

JUDGING QUALITY: A CONNOISSEUR'S GUIDE

"That which is beautiful is never too costly, nor can anyone pay too much for that which gives pleasure to all," said Abu Inan Farés, Sultan of Morocco, on completion of a beautiful building at Fez. To emphasize his delight, he refused to look at the architect's bill, but tore it up and threw the fragments into the River Fez.

Sydney H. Ball, 1935, *Economic Geology*

I gotta love for Angela, I love Carlotta, too.
I no can marry both o' dem, so w'at I gona do?
Thomas Augustine Daly [1871–1948], *Between Two Loves*

MUCH of human activity concerns discretionary ability. The world is not composed of black and white, but of infinite shades of gray. Not fixed in space and time, these shades undergo continuous change. We are constantly called upon to make qualitative judgements. Such decisions are made daily—they are part of life—and our success in navigating life is closely tied to how we deal with these challenges.

For assistance, society has developed guidelines. While such rules of thumb cannot predict the future of an individual event, if they are based upon the experiences of a large sampling of people, they have utility to the individual over the long haul. But when they are based merely upon "faith," rather than empirical methods, such beliefs constitute dogma.

There is considerable evidence to suggest that many religious and cultural dogmas were at one time based on empiricism. For example, the prohibition against eating pork, so widespread in many cultures, no doubt grew out of the fact that, in early times, those who did eat pork became ill at a higher rate. Unfortunately, when empirical discovery solidifies into immobile dogma, the possibility of future discovery is ruled out. Thus, despite the fact that later human experience has shown that proper cooking can eliminate the illness-producing components present in pork, the ban remains.

Similarly, according to the European thought extant during the time of Columbus, the earth was flat, and it was heresy to think otherwise. This is the difference between empirical beliefs, and those based upon faith alone, i.e., those based on observation and first-hand experience, rather than assumption.

Ruby & sapphire grading: A heretic's guide

Having now committed one heresy, the discussion of religion, I shall proceed to commit another, discussion of colored stone grading.

Comparable to those who opposed the mere thought of Columbus sailing into unknown waters, today many traders and gemologists oppose even a discussion of systematic quality analysis of colored stones. Akin to the priests of the Middle Ages, who fought against translation of the Latin *Bible* into vernacular languages, these high priests of the gem trade apparently feel that only those properly initiated into the "Great Order of Gemmarum et Lapidum" should be allowed to dine at the quality-analysis table. Others less fortunate must be content to scramble for the crumbs of knowledge those on high deem suitable to toss the great unwashed.

Grading systems are as old as the gem trade itself. Witness ancient India's *Garuda Purana,* dating back as far as 400 AD (Shastri, 1978), which classified the then-known gems into categories on the basis of their characteristics. Over the succeeding centuries, these systems have been steadily refined. Diamond grading systems made their appearance in the 20th century, but modern attempts at colored stone grading date from the late 1970s. Problems with some of these early

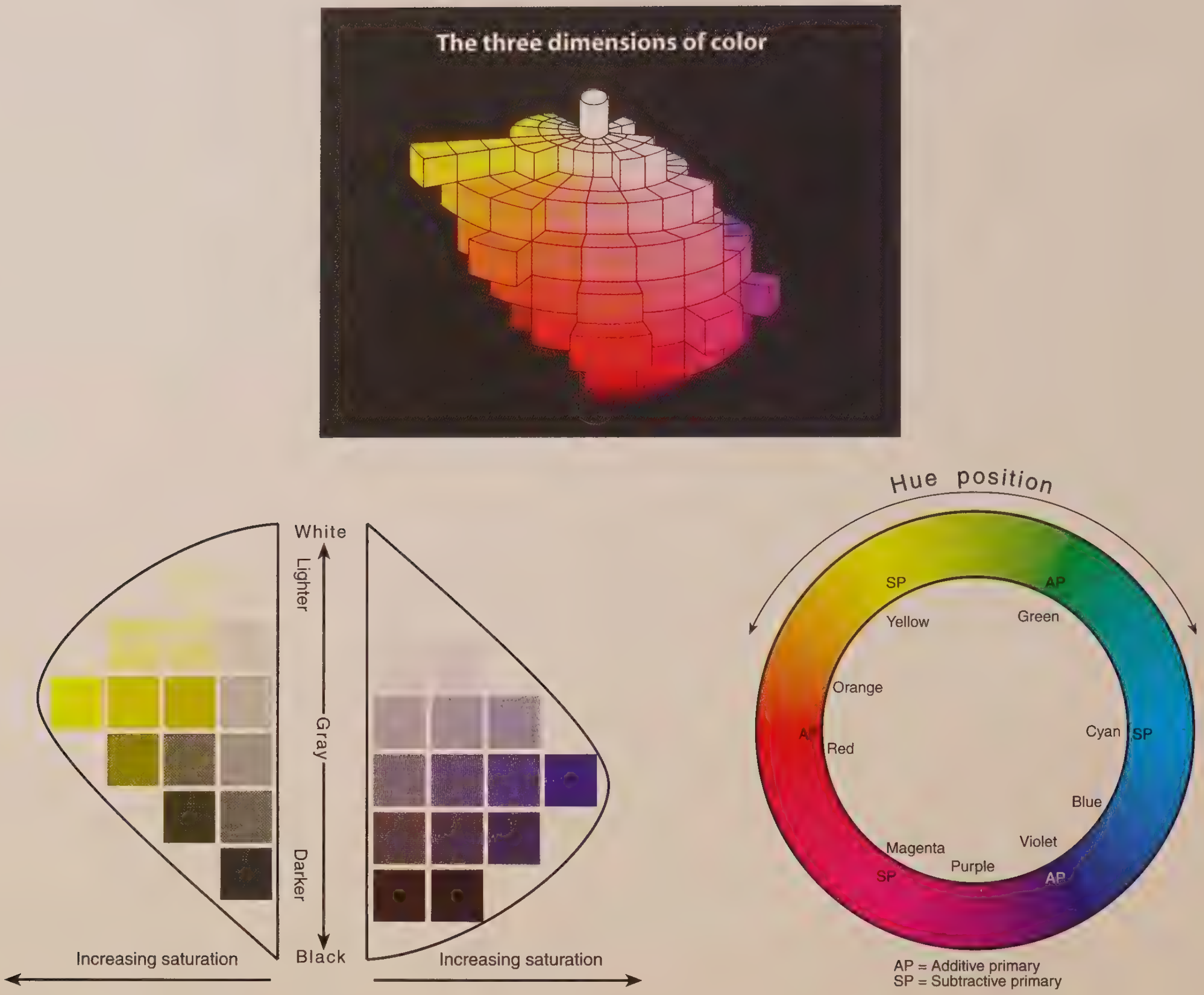

Figure 10.1 The three dimensions of color
Top: Three-dimensional view of a color solid. (Top illustration courtesy of Minolta USA)
Lower left: Vertical slice through the color solid along the yellow-violet axis. Saturation increases horizontally from the center, while lightness/darkness varies along the vertical axis. Note that the highest saturation of yellow is naturally much lighter than that for violet. A slice along the green/magenta axis would show the highest saturations to have a similar lightness.
Lower right: Hue position is illustrated by the color wheel, representing a vertical slice through the color solid (the center is not shown). Mixing equal amounts of the three additive primaries (red-orange, violet, green) produces white, while equal mixtures of subtractive primaries (cyan, magenta, yellow) results in black.

attempts have led many to condemn the very idea of systematic grading. In the author's opinion, this is a mistake.

Early forays into colored stone grading were primitive, and today many problems remain. This is to be found in the development of anything new. Look at the first airplanes. Clumsy and dangerous, they often killed their occupants. Today few would argue against their use, but in the beginning many did: "If humans were meant to fly, they would have been born with wings" was the typical refrain. I suppose if humans were meant to drive, we would have been born with horns and bumpers.

Nelson (1986) cataloged a variety of trade objections to colored stone grading. In the author's (RWH) opinion, the key criticisms are threefold:

- Like the priests who opposed translation of the Latin *Bible* into common languages, dealers are afraid that colored stone grading will remove their trade advantages, thus cutting the *traditional* gem dealer out of the picture.[1]
- In a business where the most complicated and expensive piece of equipment is often an electronic balance, traders dislike the thought of having to send their stones out for lab grading.

[1] The idea of the traditional dealer is one sorely in need of definition, considering that the tradition of many so-called "traditional" gem dealers dates back less than 30 years.

- Many colored stone dealers abhor the thought that their trade might become like the diamond trade, where stones with certificates are traded in an indiscriminate manner, in some cases without ever viewing the gem. As a Geneva dealer once told me: "My five-year old son can trade certificate diamonds. It requires no knowledge, no training." This is a real problem, one which gemologists must answer before they can gain trade support for colored stone grading.

Unfortunately, the advantages to such a system are too often overlooked amidst the bluster and rhetoric. These benefits are the increased consumer confidence and thus, increased sales, which would follow adoption of such standards. Much time would also be saved by adoption of a standardized language for describing the appearance of colored gems.

The key to developing a successful colored stone grading system will be in creating a language useful for communicating the overall appearance of a gemstone. Once a gem is adequately described, it is then up to the marketplace to determine relative value. Attempts to assign relative values to each grade will succeed only if the considerations of the real marketplace are taken into account. To make these decisions, gemologists must work closely with traders.

An unfortunate paradox in the gem world (and one which is also present in many other fields) is that traders, who, by virtue of experience, are generally most qualified to judge quality, must be disqualified from doing so because of their bias. But traders *must* have input into the system for it to succeed.

The elements of quality

Quality is determined by reference to the so-called *3 c's:* color, clarity and cut. While these factors are well defined for diamond, no universally-accepted system exists for colored gems. The following is based on the author's own extensive experience.

Color and appearance in colored gemstones

To the color scientist, given an opaque, matt-finished object, there are three dimensions to color:

- **Hue position**: The position of a color on a color wheel, i.e., red, orange, yellow, green, blue and violet. Purple is intermediate between red and violet. White and black are totally lacking in hue, and thus achromatic ('without color'). Brown is not a hue in itself, but covers a range of hues of low saturation (and often high darkness). Classic browns fall in the yellow to orange hues.
- **Saturation (intensity)**: The richness of a color, or the degree to which a color varies from achromaticity (white and black are the two achromatic colors, each totally lacking in hue). When dealing with gems of the same basic hue position (i.e., rubies, which are all basically red in hue), differences in color quality are mainly related to differences in saturation. The strong red fluorescence of most rubies (the exception being those from the Thai/Cambodian border region) is an added boost to saturation, supercharging it past other gems that lack the effect.
- **Darkness (tone or value)**: The degree of lightness or darkness of a color, as a function of the amount of light absorbed. White would have 0% darkness and black 100%. At their maximum saturation, some colors are naturally darker than others. For example, a rich violet is darker than even the most highly saturated yellow, while the highest saturations of red and green tend to be of similar darkness.

Figure 10.1 is a simplified illustration of the three dimensions of color.

With gems, we are not dealing with opaque, matt-finish objects of uniform color. Thus it is not enough to simply describe hue position, saturation and darkness. We must also describe the color coverage and scintillation.

- **Color coverage**: Differences in inclusions, transparency, fluorescence, cutting, zoning and pleochroism can produce vast differences in the color coverage of a gem, particularly faceted stones. A gem with a high degree of color coverage is one in which color of high saturation is seen across a large portion of its face in normal viewing positions. Tiny light-scattering inclusions, such as rutile silk, can actually improve coverage, and thus appearance, by scattering light into areas it would not otherwise strike. The end effect is to give the gem a warm, velvety appearance (Kashmir sapphires are famous for this). Red fluorescence in ruby boosts this still further.

  Proper cutting is vital to maximize color coverage. Gems cut too shallow permit only short light paths, thus reducing saturation in many areas. Such areas are termed *windows*. Those cut too deep allow light to exit the sides, creating dark or black areas termed *extinction*. Areas which allow total internal reflection will display the most highly saturated colors. These areas are termed *brilliance*.

  Color zoning can also reduce color coverage. Ideally, no zoning or unevenness should be present.

  Pleochroism is sometimes noticeable in ruby and sapphire. It typically appears as two areas of lower intensity and/or slightly different hue on opposite sides of the stone. This is most notable when the table facet lies parallel to the *c* axis.

  In summary, a top-quality gem would display the hue of maximum saturation across a large percentage of its surface in all viewing positions. The closer a gem approaches this ideal, the better its color coverage.
- **Scintillation ('sparkle')**: This is an important factor in faceted stones. A gem cut with a smooth, cone-shaped pavilion could display full brilliance, but would lack scintillation. Thus the use of small facets to create sparkle as the gem, light or eye is moved. In general, large gems require more facets; small gems should have less, for tiny reflections cannot be individually distinguished by the eye (resulting in a blurred appearance).
- **Dispersion ('fire')**: This involves splitting of white light into its spectral colors as it passes through two non-parallel surfaces (such as a prism). The dispersion of corundum is so low (0.028) and the masking effect of the rich body color so high, that it is generally not a factor in ruby and sapphire evaluation.

Clarity

Clarity is judged by reference to inclusions. Magnification can be used to locate inclusions, but with the exception of inclusions which might affect durability, only those visible to the naked eye should influence the final grade.

There are two key considerations in judging clarity. These are:

Visibility

- **Size**: Smaller inclusions are less distracting, and thus, better.
- **Number**: Generally, the fewer the inclusions, the better.
- **Contrast**: Inclusions of low contrast (compared with the gem's RI and color) are less visible, and thus, better.
- **Location**: Inclusions in inconspicuous locations (i.e., near the girdle rather than directly under the table facet) affect value less. Similarly, a feather perpendicular to the table is less likely to be seen than one lying parallel to the table.

Affect on durability

- **Type**: Unhealed cracks may not only be unsightly, but also lower a gem's resistance to damage. They are thus less desirable than a well-healed fracture. As already mentioned, tiny quantities of exsolved silk may actually improve a gem's appearance, and thus, value.
- **Location**: A crack near the culet or corner would obviously increase the chances of breakage more than one well into the gem. Similarly, an open fracture on the crown is more likely to chip than one on the pavilion.

Among the problems of existing colored stone grading systems is that the model chosen is based on diamond. While diamond does share a number of quality factors with ruby and sapphire, others are partly or wholly inappropriate. For example, beauty in diamond is largely a function of the material's brilliance and dispersion ('fire'). Any inclusions which alter the path of light could be detrimental to a diamond's appearance.[2] Perfect clarity is thus the ideal. As described above, perfect clarity is not necessarily the ideal for ruby and sapphire. While fractures and most other inclusions do have a detrimental effect on appearance and durability, *small quantities of finely dispersed inclusions (such as exsolved rutile silk) can actually improve a richly colored gem's appearance*. The watchword here is *small;* too much silk decreases transparency by scattering, reducing color saturation, and thus producing a more grayish color.[3]

Cut ('make')

The function of the cut is to display the gem's inherent beauty to the greatest extent possible. Since this involves aesthetic preferences upon which there is little agreement, such as shape and faceting styles, this is the most subjective of all aspect of quality analysis.

Evaluation of cut involves five major factors:

Shape. This describes the girdle outline of the gem, i.e. round, oval, cushion, emerald, etc. While preferences in this area are largely a personal choice, due to market demand and cutting yields, certain shapes fetch a premium. For ruby and sapphire, ovals and cushions are the norm. Rounds and emerald shapes are more rare, and so receive a premium from about 10–20% above the oval price. Pears and marquises are less desirable, and so trade about 10–20% less than ovals of the same quality. The shape of a cut gem almost always relates to the original shape of the rough. Thus the prevalence of certain shapes, such as ovals, which allow greatest weight retention.

Cutting style. The cutting style (facet pattern) is also a rather subjective choice. Again, because of market demand, manufacturing speed and cutting yields, certain styles of cut may fetch premiums. The mixed cut (brilliant crown/step pavilion) is the market standard for ruby and sapphire.

Proportions. The faceted cut for ruby and sapphire is to create maximum brilliance and scintillation in the most symmetrically pleasing manner. Faceted gems feature two parts, crown and pavilion. The crown's job is to catch light and create scintillation (and dispersion, in the case of diamond), while the pavilion is responsible for both brilliance and scintillation. Generally, when the crown height is too low, the

Background checks

WHEN you are examining a colored gemstone, act like a cop—always do a background check.

The color of the background against which a gem is examined can have a major effect on color. Which is why wily Burmese and Thai miners traditionally offer up rubies to buyers on brass plates or yellow table tops. The yellow color counters the bluish tint commonly present in ruby, making the gems appear more red. Yellow cellophane-lined stone papers or brass tweezers serve the same purpose. Don't be a sucker. For judging color, a plain white background is best.

Figure 10.2 Rough rubies at the mining areas in Burma and Thailand are often displayed on brass plates. The yellow color of the background makes the ruby appear more red than it actually is. (Photo: Olivier Galibert)

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[2] Unfortunately, the current diamond-grading system, largely based on the GIA model, has applied this idea in an overly zealous manner. Thus even a single microscopic inclusion, which in no way affects a diamond's appearance, removes it from the top clarity category. Many of the upper clarity grades have *absolutely no visible difference in naked-eye appearance* (see Hughes, 1987b, 1991).

[3] Stones which look good from a distance, but upon closer examination exhibit clarity problems are termed *bluff stones*

gem lacks sparkle. Shallow pavilions create windows, while overly deep pavilions create extinction. Again, proportions often are dictated by the shape of the rough material. Thus to conserve weight, Sri Lankan material (which typically occurs in spindle-shaped hexagonal bipyramids) is generally cut with overly deep pavilions, while Thai/Cambodian rubies (which occur as thin, tabular crystals) are often far too shallow.

- **Depth percentage:** In attempting to quantify a gem's proportions, reference is often made to depth percentage. This is calculated by taking the depth and dividing it by the girdle diameter (or average diameter, in the case of non-round stones). The acceptable range is generally 60–80%.
- **Length-to-width ratio:** Another measurement that is used for non-round stones is the length-to-width ratio. Overly narrow or wide gems of certain shapes are generally not desirable.

Symmetry. Like any finely-crafted product, well-cut gems display an obvious attention to detail. A failure to take proper care evidences itself in a number of ways, including the following:

- Asymmetrical girdle outline
- Off-center culet or keel line
- Off-center table facet
- Overly narrow/wide shoulders (pears and heart shapes)
- Overly narrow/deep cleft (heart shapes)
- Overly thick/thin girdle
- Poor crown/pavilion alignment
- Table not parallel to girdle plane
- Wavy girdle

Finish. Lack of care in the finish department is less of a problem than the major symmetry defects above, because it can usually be corrected by simple repolishing. Finish defects include:

- Facets do not meet at a point
- Misshapen facets
- Rounded facet junctions
- Poor polish (obvious polishing marks or scratches)

While these guidelines may be useful, one must not become a slave to them. In essence, the cut should display the gem's beauty to best advantage, while not presenting mounting or durability problems. If the gem is beautifully cut, things such as depth percentage or length-to-width ratio matter not one bit. What works, works.

Influence of lighting on color

With any colored gemstone, the color seen depends on the light source used to illuminate it. Over time, gem dealers have come to rely on skylight for their gem buying. Its major advantage is its strength, which ruthlessly reveals flaws. The quantity of light coming through even a modest-sized window is far greater than even the strongest, color-balanced fluorescent tube (or tubes). Another factor appears to be the large radiating area, when compared with the most artificial lights.

Figure 10.3 Lighting can have a dramatic effect on the appearance of any colored gem. Incandescent lighting (left) is rich in red, orange and yellow wavelengths and thus pushes an object's color in that direction. In contrast, skylight (right) is more balanced, pushing the color in the opposite direction. (Illustration: Minolta)

Latitude may also affect a stone's color, simply because skylight is stronger in the tropics. As a result, gems bought in the tropics will appear slightly darker when taken to more temperate climes. It is a slight, but nevertheless, noticeable difference. Surprisingly, north skylight (or south skylight in the southern hemisphere) is actually stronger on cloudy days.

Another factor is the Purkinje shift.[4] In bright light, the eye is more sensitive to red; conversely, in dim light the eye is more sensitive to blue-violet light. Thus the color of blue sapphires would be slightly enhanced in dim lighting.

The question of north skylight

North daylight (skylight, as opposed to direct sunlight) has become the standard, because it produces the least glare, but blind adherence to such gemological dogma is just as bad as blind adherence to religious dogma. If you live north of the Tropic of Cancer (Europe, North America, Japan, China, etc.), north skylight will provide the least glare year round, because the sun always passes through the southern portion of the sky. This is especially true the farther north one goes. The opposite holds true for those who reside south of the Tropic of Capricorn (in the southern hemisphere), where the least glare is found using *south* skylight.

What about those who live in the tropics? If they are north of the equator, north skylight is best, except May–July, when south skylight is preferred. For the tropics south of the equator, south skylight is best, except from Nov.–Jan., when

[4] Johannes von Purkinje, a Czech physiologist, observed while walking in the fields in 1825 that blue flowers appeared brighter at dawn than at midday (Varley, 1983).

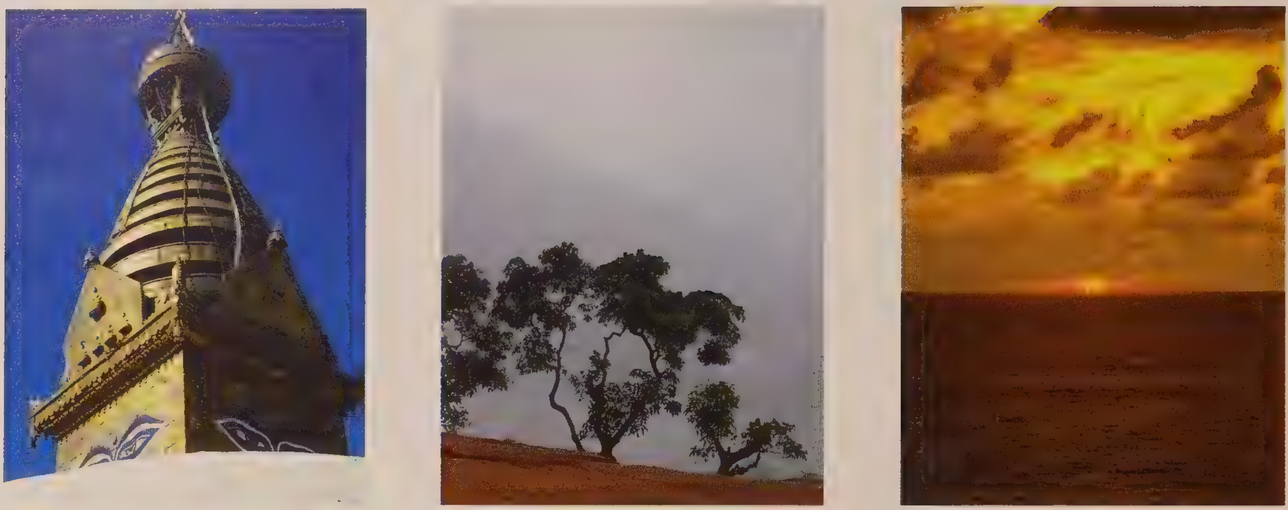

Figure 10.4 Natural light is not constant in spectral composition, but varies according to latitude, time of day, cloud and pollution conditions and whether or not one is using direct sunlight or skylight.
Left: The Buddhist temple at Swayambunath, Nepal, silhouetted against a deep blue sky. It is obvious that such skylight would enhance the appearance of blue stones.
Center: Fog in Sri Lanka's central highlands. The high moisture content gives the light a grayish cast.
Right: Sunset on Sri Lanka's eastern coast. While such sunlight could easily enhance the color of red and yellow stones, it should be noted that direct sunlight is rarely used for examining gems. Typically we use *skylight*, instead. Such skylight is actually *more blue* early and late in the day. Thus blue sapphires will look better at those times. Conversely, when viewed with skylight, rubies will look best around midday, because the skylight is *less blue*.
(Photos by the author)

north skylight is preferred. And if you live right on the equator, use north skylight from Oct.–Feb., and south skylight from April–August. During March and Sept., either north or south skylight can be used.

Time of day

Even skylight changes throughout the day. Generally speaking, rubies (and other red stones) look best during the midday hours. Sapphires, in contrast, look best in the early morning or late afternoon. If you are buying, this means that rubies should be purchased early or late in the day, while sapphires are best bought near midday, thereby preventing a surprise when the stone is examined under another lighting condition.

The above is in contrast to what is often reported (Newman, 1994, p. 38). While direct sunlight is far more red at sunrise and sunset, the *skylight* is actually more blue. Since we use skylight, not direct sunlight, to illuminate gems, blue color will be enhanced early and late in the day. Similarly, the skylight at noon is less blue, thus enhancing the color of rubies in the middle of the day.

Weather and pollution

How might clouds or pollution affect color? Heavily-polluted or cloudy skies will result in more grayish (less blue) skylight, thus improving the appearance of rubies (as opposed to sapphires).

Artificial lighting

Some type of artificial light is obviously the answer to neutralize the above factors. Many dealers today do their buying under special daylight lamps designed to simulate true north daylight, with a color temperature of approximately 5000–6100°Kelvin. Generally speaking, while their color balance is similar to north daylight, the fluorescent tubes used suffer from low light output. A 20-watt fluorescent daylight tube at a distance of 30 cm produces about 1000 lux of illumination, while a north-facing window in Bangkok averages 6000 lux.

The answer appears to be short-arc xenon lamps. While rather expensive (compared to fluorescent lamps), they have a continuous output (like daylight), 6000°K color temperature, and produce illumination levels comparable to north daylight.

For an excellent summary of the entire lighting question, see Sersen & Hopkins (1989) and Sersen (1990), from which the above is derived.

Viewing geometry & background

Gems are designed to be mounted in jewelry and viewed from predetermined angles. This is generally face-up, with the gem viewed in a 180° arc from girdle to girdle. Thus it is only logical that all quality determinations be made with the naked eye under the same viewing geometry. It is important that the gem be rotated through 360° in the girdle plane, so that its appearance is seen from all angles, just as it would be

Figure 10.5 When grading gems, viewing geometry, background and controlled lighting are crucial. The woman above is sorting sapphire rough from Australia. (Photo: Great Northern)

Carat psychology

IN the case of many gems, including ruby and sapphire, psychological (but all too real) price jumps occur at certain weights. For example, a 0.99-ct ruby might be worth significantly less than one which weighs 1.05 ct. The 1.05 ruby would be worth more than one which weighed exactly 1.00 ct, as repolishing (or weighing on someone else's scale) a 1.00-ct stone might send it below the important 1-ct barrier. Similar psychological weight hurdles are found at the 2, 5, 10, 20, 50 and 100-ct levels.

when mounted in jewelry. To ensure reproducibility and repeatability, a standardized light source against a standardized, neutral background (white is best) at a standardized distance should be used. The practice in diamond grading of judging body color through the pavilion facets is madness, and has no place in colored stone grading.[5]

Summary of quality

The appearance of a colored gem is a combination of many separate factors, each of which is related to, and affect, the others. It is precisely the complexity of these intertwined relationships that has bedeviled previous attempts to quantify quality. And yet, every time a dealer buys a gem, a quick mental analysis is made, usually within seconds. In grading any gem, one must be cognizant of, but not become lost in, the details. When all the minutiae has been pored over *ad infinitum, ad nauseam,* take a step back and simply *look at the gem.* In the age of high-powered microscopes this may constitute a radical concept, but one which is necessary.

Fine precious stones are comparable to great works of art. Like a painting, to appreciate it, one must view the whole, not just the parts.

[5] Nor in diamond grading, but that is another subject.

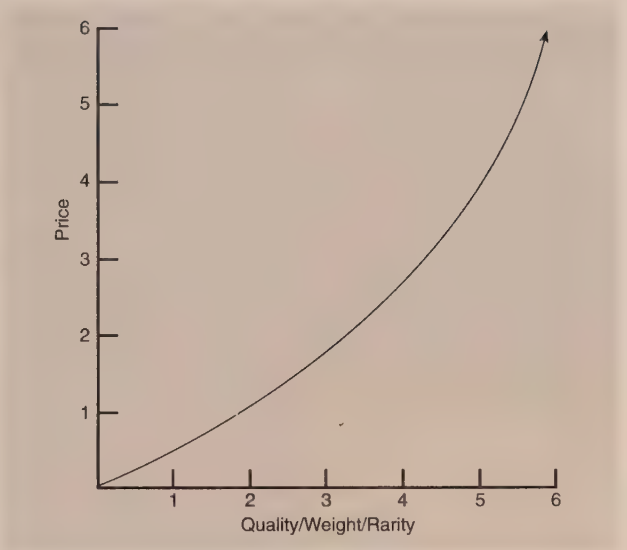

Figure 10.6 Graph representing the relationship between price and quality/weight/rarity. Note that this is not a linear relationship. Price increases more quickly as quality/weight/rarity increases.

Pricing factors

> **Prices of Genuine Jewels**
> The prices of jewels are not stable. There is no law governing their prices, and there is no reason why these prices should not fluctuate with time and place. Each country, each nation carries its own temper. Furthermore, at one time nobles begin to sell them off and at others, to stock them. Stones are plentiful at one time and scarce at another. God grants honour to some and disgrace to others.
>
> al-Bīrūnī, 11th century AD
> *Kitāb al-Jamāhir fī Ma'rifat al-Jawāhir*

One of the great mysteries for novices is the relationship between price and quality. In a perfect world, price would directly relate to quality/weight/rarity. Unfortunately, Planet Gem is far from symmetrical. Market factors can have as much, or even greater, impact on prices as does quality. Prices are influenced by the following factors:

- **Quality:** Better qualities are more rare than lower qualities of the same size (see previous section).
- **Weight:** Bigger stones are more rare, and so more expensive per carat than the same quality of a smaller size.
- **Market factors:** This is the great intangible. Market factors can dramatically affect price.

Weight

Generally, as a gem's weight increases, so does the per carat price. This is shown in Figure 10.6.

Figure 10.7 Thai/Cambodian vs. Burma-type rubies. Due to their lack of both fluorescence and light-scattering inclusions, Thai/Cambodian rubies (left) tend to appear darker and more garnet-like. At right, the Mogok ruby displays far greater color coverage. (Photos: Adisorn Studio, Bangkok)

Such a relationship has long been known, and was first quantified by Villafane in 1572, for diamonds. Today it is most commonly referred to as the 'Indian Law' or 'Tavernier's Law', and works as follows (Lenzen, 1970):

$$Wt^2 \times C = \text{price per stone}$$

Weight of gem	= 5 ct (*Wt*)
Cost of a 1-ct gem of equal quality	= $1000 (*C*)
Calculation: 5 × 5 × 1000	= $25,000 total stone price

The following shows how the price of a gem might increase with this formula applied using a $1000/ct base price.

Weight	Total stone price
1 ct	$1000
2 ct	$4000
3 ct	$9000
4 ct	$16,000
5 ct	$25,000
10 ct	$100,000

Unfortunately, things were not so simple, even for diamonds in the time of Tavernier. The law could not accurately predict the price of diamond below 1 ct, and there were also problems with exceptionally large stones. But it does give a general idea of how prices increase with size.

Market factors

Just a few of the market factors that influence price include:

- **Market supply vs. demand:** Items which are plentiful and/or in low demand will be cheaper than those which are rare and/or in high demand.
- **Financial situation of the seller:** Sellers who need money will obviously be more flexible on price. Similarly, those who are not in need are less willing to reduce their price.
- **Seller's business overhead:** Prices can vary dramatically depending on the seller's overhead. A cup of coffee purchased by a street vendor may cost only a few cents; the same cup of coffee at a 5-star hotel in the same city may cost 10–20 times more, due to the hotel's higher overhead.
- **Buyer's financial situation:** Buyers whose businesses are prospering are often willing to pay higher prices.
- **Buyer's sales prospect:** Buyers who have a customer waiting for an item are often willing to pay higher prices.
- **Buyer/seller personal relationship:** No one likes to do business with unhappy or abusive people. When the buyer and seller enjoy each other's company, they often make special provisions for one another.
- **Personal situation surrounding the sale:** The author has seen buyers pay above-average prices for goods for a variety of reasons. These have ranged from trying to impress one's girlfriend,[6] to buying something simply to prevent a competitor from purchasing the same goods.

For a generalized list of ruby and sapphire prices, see 'Ruby & sapphire prices', p. 491.

Connoisseurship in ruby

Ruby is among the rarest of all the major precious stones, with only a handful of sources producing facet qualities in any commercial quantity. An approximate ranking of important ruby origins is given below. This applies only for the finest untreated qualities from each source and is but a general approximation. In other words, a top-quality Thai/Cambodian ruby can be worth far more than a poor Burma stone.

Quality ranking of rubies by country

1. **Burma:** While Mogok is the traditional source of the world's finest rubies, good stones are rare even from this fabled area. *Pigeon's blood* was the term used to describe the finest Mogok stones (see page 329), but has little meaning today, as so few people have seen this bird's blood. Mogok-type rubies possess not just red body color, but, by a freak of nature, red fluorescence, too. In addition, the best stones contain tiny amounts of light-scattering rutile silk. It is this combination of features which gives these rubies their incomparable crimson glow. In Mogok rubies, the color often occurs in rich patches and swirls, and color zoning can be a problem. Star stones are common. The shape of Mogok ruby rough generally yields well-proportioned stones.

   In 1992, the Mong Hsu mine began producing good material, but most cut stones are under 2 ct. With the exception of the material from the Thai/Cambodian border, virtually any

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[6] Apparently the lady was suitably impressed, for she is now his wife.

Figure 10.8 21.09 carats of Burmese midnight-blue mystery. This stone, an example of Mogok's finest product, was offered in the late 1980s in Bangkok for $10,000/ct. (Photo: Adisorn Studio, Bangkok)

of the sources below can produce material of similar color. The problem is that material clean enough to facet is rare.

2. **Vietnam**: In the late 1980s, this material literally exploded on the world gem market. Although Vietnam's ruby originates from two different mines (Luc Yen and Quy Chau), both sources display similar characteristics. The best Vietnamese ruby is equal to *anything* ever produced in Mogok, and if it had some history behind it, would probably fetch similar prices.
3. **Sri Lanka**: The classic case of giving a dog a bad name. Some of the world's finest rubies have come from Sri Lanka's gem gravels, but, because of the erroneous 'pink sapphire' moniker (see page 401), they have been largely overlooked. Top-grade Sri Lankan reds are virtually indistinguishable from their Mogok brethren, but many stones tend towards purple or pink. As with Sri Lanka sapphires, color accumulates in large stones and so they can be quite magnificent in sizes of five ct or more. Due to the bipyramidal shape of the rough, many stones are cut with overly deep pavilions. This material is strongly fluorescent and stars are common.
4. **Kenya, Tanzania**: Stones from these sources are magnificent when clean, but facet-grade material is relatively rare. Like Burma, much of this material is strongly fluorescent.
5. **Afghanistan**: Jagdalek has produced rubies which rank with the best of Mogok, but facetable material is in short supply. Similar to Vietnamese rubies, many of these stones contain small areas of blue color. Strongly fluorescent.
6. **Thailand/Cambodia**: This material's main attribute is its high clarity, but the flat crystal shapes generally yield overly shallow stones. Due to the high iron content, which quenches fluorescence, most stones tend to have a garnet-red color. An additional problem is the total lack of light-scattering silk inclusions (star stones are not found). Although heat treatment does make improvements, it is not enough. In Thai rubies, only those facets where light is totally internally reflected will be a rich red; the others appear blackish, as with red garnets. Thai stones are actually less purple than most Burmese rubies. However, Mogok-type rubies appear red all over the stone. Not only is a rich red seen in the areas where total internal reflection occurs, but, due to the red fluorescence and light-scattering silk, other facets are also red. This glowing red color is what makes Mogok-type rubies so special.

With the decline in Burma production during the 1962–1990 period, the market became conditioned to Thai/Cambodian rubies, with some people actually tending to prefer them (In the land of the blind, the one-eyed man is king). Thai/Cambodian rubies are acceptable only when good material from the above sources is not available (see box, page 431).

The color purple

IT is a common, but erroneous, belief among many traders and gemologists that Thai/Cambodian rubies are more "purple" than those from Mogok. Using the proper definition of the term purple (i.e., a hue or hues lying between red and violet), we actually find that Mogok rubies are *more purple* than those from the Thai/Cambodian border. Gem dealers know what they are seeing, but do not describe it in terms consistent with the use of those same words in other industries. To the color scientist, purple is merely a hue position. In order to properly describe the color, saturation and darkness must also be defined.

The problem with most dealer descriptions of gem colors is that they try to describe all colors and color differences in terms of changes in hue position and darkness. In fact, when judging the color of gems, saturation of hue is of paramount importance, not tiny nuances in hue position. When a gem dealer says that a Thai/Cambodian ruby is too purple compared to those from Mogok, he is confusing the low-saturation red (grayish red) of the Thai ruby with the higher saturation (but more purplish) red of the Mogok ruby.

Figure 10.9 Which of the above colors is more purple? The answer is neither. Both colors have identical hue positions. However there are differences in darkness and saturation. The color at left has a darkness of 50% and saturation of 100%, while the darkness and saturation values of the color at right are 68% and 63% respectively.

7. **India:** The classic Karnataka (Mysore) Indian locales produce mainly opaque, low-grade star rubies; recently better material has been reported from Orissa, but at the current time, India remains a fringe source.

Connoisseurship in sapphire

Unlike rubies, for which perfection is unknown, even at the 5-ct level, large fine sapphires of 100 ct or more do exist. An approximate ranking of blue sapphires in terms of origin is given below. As with the ruby origin rankings, this applies only for the finest untreated qualities from each source and is but a crude measure. In other words, a top-quality Australian sapphire can easily be worth more than a poor Kashmir stone.

Quality ranking of blue sapphires by country

1. **Kashmir (India):** In the world of blue sapphire, Kashmir is the peak, the quality against which all others are measured. Kashmir sapphires are noted for their rich blue hue and distinctive "velvety" luster, caused by the presence of minute exsolved inclusions. The Kashmir mine, however, produced in quantity only during the years 1881–1890, and has produced little since. For this reason, Kashmir sapphires are generally available only through the estate/auction market. Star stones have been reported, but are rare. Much Kashmir material is strongly color zoned and the bipyramidal habit results in overly deep stones. Thus it can bear a strong resemblance to that from Sri Lanka. Many old Kashmir stones were cut as sugarloaf cabochons.
2. **Burma:** Next to Kashmir, Mogok sapphires are unsurpassed. Although certain Sri Lankan sapphires may rival them in beauty, the Burmese stones are of a deeper, richer color, there being simply more color inside those from Mogok. Moreover, the Mogok stones do not require heat treatment for their beauty, but come out of the ground in living color, a blaze of smoldering, imperial blue. Many fine star sapphires have been found in the Mogok area, some of large size. Crystal habit in Mogok sapphires tends to be more tabular than either Sri Lanka or Kashmir. Thus faceted stones are not so bottom heavy.
3. **Sri Lanka:** For those who prefer slightly lighter, livelier colors, Sri Lanka is the locality of choice. Blue sapphires from Sri Lanka have a unique beauty all their own, the best being a sharp, electric blue. Rakwana stones are of particular note, with their color compared to that found on the tip of a peacock's feather, or that on a peacock's neck, but fine stones are found in many places. Until the spread of heat treatments in the late 1970s, Sri Lankan sapphires commonly reached the richer blues only in stones of ten carats or more. Today deep blues of all sizes are common. Sri Lanka is the world's most prolific producer of giant sapphires (>100 ct). While Mogok stones tend towards a more intense, royal blue, the Sri Lankan sapphire is typically a brighter, cornflower blue, due to less color in the stone. Sri Lanka also produces fine star sapphires, some weighing hundreds of carats, and is the greatest producer of star corundums of all colors. As with all Sri Lankan gems, cutting can be a problem. The typical bipyramidal habit and over-emphasis on weight retention often result in bottom-heavy stones.
4. **All other sources (alphabetically)**

   Australia: Australia is one of the biggest producers of faceted sapphire, but most are dark and inky in color and require heat treatment. The mines of New South Wales produce the better stones, while the Queensland production consists mostly of darker blues. Australian sapphires suffer from bad press. While good quality stones, which can compete with the better Thai and Cambodian material, are occasionally found, they are inevitably sold as anything but Australian.

   Cambodia (Pailin): The Pailin mine in Cambodia has produced a number of fine stones over the past 100 years, although today production is limited, due to political problems. Pailin stones, however, tend to be on the dark side and faceted stones larger than five carats are rare. This is in contrast to Kashmir and Mogok, which have produced a number of sapphire giants. The material is good for cutting stones below two carats, but even the best Cambodian material cannot compete with the best from Kashmir, Mogok, or Sri Lanka. This source has a particular "romance" aspect to it that is not supported by actual quality.

Figure 10.10 One of the delights of the corundum family is the lovely pink-orange *padparadscha*. The example at left weighs 30 ct and is a particularly fine specimen. Traditionally such stones were the color of the lotus flower and came only from Sri Lanka, but today padparadschas have also been found in other localities. (Photo: © Tino Hammid)

Om mani padme hum… Oh, the jewel in the lotus…

China: Material comes from a variety of different locales, but all is iron-rich and tends to be overly dark.

Nigeria: Nigerian material is also iron-rich and tends to be overly dark.

Thailand: In Thailand, the occasional fine stone is produced, particularly from the mines of Bo Ploi, in Kanchanaburi Province. Bo Ploi stones may be of fine color and sometimes reach sizes of 50 ct or more, but most are marred by a certain cloudiness. Many Bo Ploi stones are sold as Sri Lankan, due to their strong color zoning. Sapphires from Chanthaburi and Phrae tend to be overly dark, although some are nice.

USA (Montana): Yogo Gulch in Montana produces sapphires of fine color when found in sizes of greater than one carat, but such stones are extremely rare. The lack of larger stones (one carat or more) and the flat crystal habit (which results in low cutting yields), has kept Yogo from being a source of major importance. Material displays extremely uniform coloration. Most is cut as round brilliants. Other Montana localities produce mainly fancy colors, although heat treatment has changed this somewhat.

Compared to Kashmir, Burma and Sri Lanka, all other sapphires sources are of relatively minor importance for high-end stones.

Fancy sapphires

The term *fancy sapphire* is used to describe corundums other than red or blue. Sri Lanka is king of the hill. Within this small island are found sapphires of virtually every color, including some for which the island is the definitive source, such as the lovely pink-orange *padparadscha*. Tanzania's Umba Valley is also noted for fancy sapphires, as are Montana's mines (non-Yogo).

Yellow & orange sapphire

Yellow sapphires from Sri Lanka are generally of a light to medium hue, without any brownish overtones. Deeper hues are, like the Sri Lankan blues, reached only in larger sizes, or via heat treatment. Heat treatment produces deeper yellows, golds and oranges that are virtually unknown, or rare in nature. The very rare pinkish orange *padparadscha* sapphire is found mainly in Sri Lanka and at Vietnam's Quy Chau mines. While similar gems are sometimes found at Tanzania's Umba mines, most from this locality tend towards the brownish orange. Padparadschas from Sri Lanka sometimes fetch prices that rival even ruby.

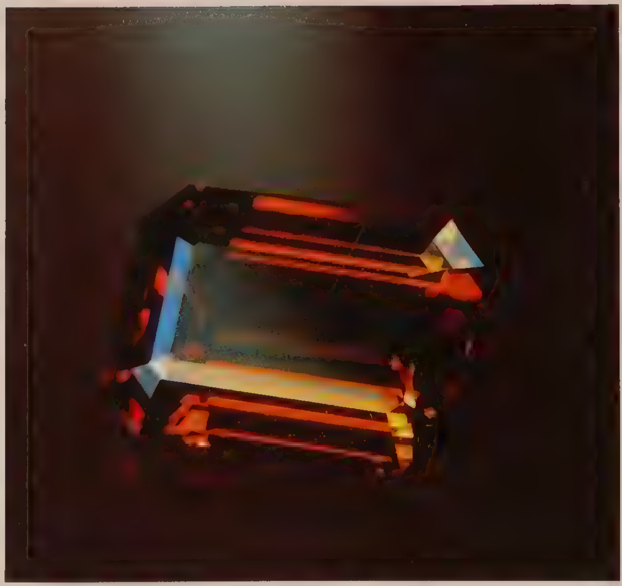

Figure 10.12 Yellow into orange…
Left: Unheated yellow sapphires from Sri Lanka tend to be lighter, brighter and less greenish than those from Thailand or Australia, as this 7.41-ct specimen shows. (Photo: © Tino Hammid; specimen: Intercolor, New York)
Right: Thailand's Chanthaburi mines produce sapphires of the prized "Mekong Whisky" yellow-to-orange color. The stone above is a fine example. (Photo: Adisorn Studio, Bangkok)

Thailand and Australia both produce fine yellow sapphires, with the stones from Chanthaburi in Thailand grading into the highly desirable *Mekong Whisky* golden yellow to orange colors. These bring high prices locally in Thailand and are quite beautiful. Australian yellow sapphires tend to be overly greenish, although fine golden yellows are found in the Queensland mines. Sri Lanka, Thailand and Australia are the only sources which produce deep yellow sapphires in any quantity, although the Mogok area produces the occasional stone.

Green sapphire

The finest green sapphires come from Sri Lanka, but are extremely rare. These stones tend to be of a lighter and more lively green than those from Thailand and Australia. The latter two countries do produce good green sapphires, but most tend towards an impure blue-green or yellow-green which is not very attractive. Green sapphires of good color and clarity over 10 ct in size are relatively scarce, but demand is slow.

Violet and purple sapphire

Violet and purple sapphires are found mostly in places which produce both ruby and blue sapphire. The finest stones come from Mogok, Sri Lanka and Vietnam. Purple stones bordering on ruby color are most valuable and may reach prices approaching those of ruby. Star stones are possible, but relatively rare.

Color-changing sapphire

Among the most unusual sapphires are those which display a change of color. These are judged by the quality of color change, the best going from the green side of blue in daylight to a reddish purple in incandescent light. A number of sources produce such stones, but fine examples are rare. The best are colored by vanadium (just like the Verneuil synthetic corundums) and come from Mogok and Umba, Tanzania. These are extremely rare. More common are Sri Lankan gems which contain a mixture of chromium (red) and iron-titanium (blue). Such stones appear bluish violet in daylight and purple under incandescent light. In the author's opinion, these are marginal as color-change sapphires. Most tanzanite shows a similar color shift.

Judging stars & cabochons

Fine star rubies come mainly from Mogok and Sri Lanka. While Mogok has the reputation for producing the best pieces, the world's finest large example, the *Rosser Reeves Star Ruby*, was mined in Sri Lanka.[7] As for the finest star sapphires, they also come from Mogok and Sri Lanka, particularly the latter. Deeper colors in Sri Lankan stones are mainly (but not always) found in the larger sizes, where the color builds due to the longer light paths.

The best stones will have just enough silk to create the star effect, but not so much as to harm the transparency and color (see Figure 10.13). Such stones are extremely rare and valuable. As for black star sapphires, the most valuable are the golden-star black stars from Chanthaburi, Thailand.

7. This reflect more than just a little on the worth of origin stereotypes.

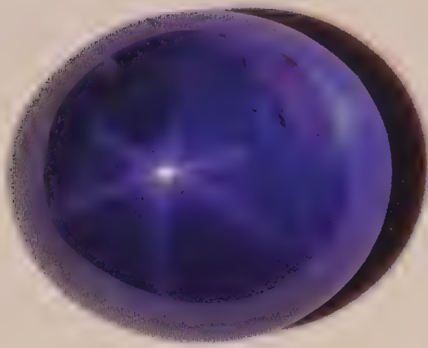

Figure 10.13 Judging stars: It's all in the color
Low-quality stars contain an over-abundance of silk (left photo). While this makes for a sharp star, transparency, and thus color, suffers. Good transparency allows longer light paths, and thus, richer color (right photo). The result is a far more valuable stone.
Left: Stars in the collection of the Royal Ontario Museum. The stone at left weighs 174.75 ct, while the 193.39-ct *Star of Lanka* is shown at right. (Photo: Royal Ontario Museum)
Right: At 101.01 ct, the *Star of Ceylon* is representative of a high-quality star sapphire. Despite the weak star, this gem's high transparency and fine color make it far more valuable than the larger, sharper stars pictured at left. (Photo: Richard Allen/Alan Chappron)

Important factors in evaluating star rubies and sapphires include the following:

- **Color**: This is paramount. One can have an expensive stone with a poor star, but valuable stars of poor color do not exist. Top-dollar colored gems have top-dollar color—it's that simple.
- **Transparency**: If the proper amount of colorant exists in the stone, only good transparency will bring it out. The so-called 'glass body' is the ideal. Too much silk means short light paths, which translates into poor, grayish color.
- **Star**: The star should be complete and sharp, with no missing or broken legs, and each ray should extend to the girdle.
- **Clarity**: Silk should not be concentrated so thick as to harm transparency. Stones containing too much silk will have rather poor color, as silk diffuses the light. Longer needles generally produce a better star than the tiny particles which are sometimes found, but as with all grading, it's the end product that counts, not the conditions which produce it. Like all gems, the ideal is totally fracture-free.
- **Cut**: Only proper cutting releases a gem's beauty. Cabochons need to be cut with medium to high domes (overly flat domes allow the star to be seen only from directly above). The base should be smooth (polished or unpolished), flat (or gently rounded) and the star should be properly centered when the gem rests on its base. Domes should be symmetrical, with no flat spots (which distort the star). Like middle-aged humans, a common problem is excess weight below the girdle. Ideally, less than 10% of the gem's depth should lie below the girdle, but this is rarely found. Due to the bipyramidal shape of many Sri Lankan crystals, local lapidaries often cut them with 50%, or even 80%, of the total depth below the girdle. This is unacceptable, for such stones are extremely difficult to mount in jewelry, and have the face-up size of pieces of much smaller weight.

Ordinary cabochons are evaluated in an identical manner to star stones, except they have no star. While it is a general truth that they are cheaper than faceted goods (because of their typically poorer clarity), cabochons have a special beauty all their own. What they lack in scintillation, they make up in color. In fact, the highest total price ever paid for a single ruby was $5,860,000 for a 38.12-ct Mogok ruby *cabochon* (Anonymous, 1994).

Anatomy of the perfect ruby & sapphire

What makes the perfect ruby or sapphire? The following is the author's somewhat metaphorical take on perfection as applied to ruby and sapphire:

- **Color**: Overall, a priority. The best rubies look like someone painted a swath of fluorescent red across their face. It is a glowing red, diffused throughout the stone, and derives from the unique property of fine rubies, a rich red fluorescence to daylight. For blue sapphire, the color should be a rich blue, verging on the violet, not too light or dark.
- **Clarity**: Generally eye clean, but with the following caveat: it should have a velvet-like softness, as opposed to diamond-like transparency.
- **Cut**: It should show the raw material off to best advantage, without presenting mounting or durability problems. Look for simplicity of design and execution. As the one element of the gem influenced by humans, it should bear the visual signature of its maker.[8] Like a Miles Davis horn line, the cut should be an exquisite balance of economy and intensity.
- **Overall**: The best walk the walk and talk the talk. They wink at you from across the room, call your name, beckon you closer. When you see them, you are driven to possess them and will sell your soul, to Devils or Lords, to call them your own.

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8. For those puzzled by this statement, check out the quartz sphere of Bernd Munsteiner. In the area of fine arts, see Dali, Da Vinci, Goya, El Greco, etc.

Figure 10.14 PDCTP—Pretty Damned Close To Perfect—is how this star sapphire would be described. This stone is over 20 ct and hails from Sri Lanka. (Photo: Rattana Angkuanpanit/World Jewels Trade Center)

Market tastes

While there is general agreement among experienced wholesale buyers about what constitutes the best quality, tastes for commercial goods can vary dramatically from country to country, often related to the purchasing power of their customers. It is impossible to generalize about individual buyers, but is possible to generalize about the tastes of certain consumer markets. In some places, color is paramount; thus buyers are willing to sacrifice on cut and clarity to obtain stones with good color. For other markets, the preference is for high clarity, and so on. Table 10.1 gives some guidelines on these tastes for the major consuming markets.

Buying ruby & sapphire

In every business, there are tricks of the trade, little things that often add up to the difference between profit and loss. Collectively they might be termed *experience,* for that is how they are acquired. Unfortunately these lessons are rarely found in books. Instead, they reside in a small box at the back of every dealer's safe or in some dusty drawer, and are acquired by doing business with someone whose box is bigger still. The lessons in this box consist of mistakes—all the stones and jewelry that can't be sold—things that should never have been purchased in the first place. A description of some of the lessons from the author's box is found in the box on page 226.

Buying parcels

The purchase of lots is more difficult than single pieces, largely because people fail to take the time to properly analyze the parcel. In large lots, although it is impossible to evaluate each piece, one can perform a sample analysis. What one does is to cut a *random* sampling from the lot and evaluate it, dividing the sample into logical quality grades. The

Table 10.1: Major ruby & sapphire market tastes[a]

Market	Preferences[b]
Australia	The Australian ruby taste resembles that of the UK, with preference for darker colors of good cut and clarity. In sapphire, dark Australia-type blues find a ready market, so long as they are clean and well cut. Other sapphire types are also salable.
Far East (China, Hong Kong, South Korea, Taiwan)	These newly-emerging markets have become an important force of late. Typical of many young markets, one finds a range of qualities salable. Cash-rich Taiwan and South Korea are increasingly important for high-end goods. Hong Kong services much of the Far East market.
France	In France, color is paramount. For rubies, it should be a rich, intense red, characteristic of the best Burma-type stones. With sapphire, the preference is a rich blue, similar to Ceylon and Burma-type material. French buyers are often willing to sacrifice clarity and cut for good color. Thus shallow and/or slightly included stones may find a ready market—so long as the color is there.
Germany	Typically, German buyers place great emphasis on perfection in make (cut) and clarity. Color is less important than brilliance, clarity and finish. The preference is generally for lighter, brighter stones, In ruby, this means slightly pinkish red stones, as opposed to dark, garnet reds, while for sapphire it is for bright, Ceylon-type blues.
Italy	Italian taste is similar to the French, with the emphasis on color, as opposed to clarity and cut. Shallow stones ('big face') often find a ready market.
Japan	The rise of Japanese economic power in the 1970s and '80s brought with it a similar rise in demand for luxury goods. This peaked about the time of the Gulf War, and has since flattened somewhat, with the Tokyo stock market failure, Gulf War, and Kobé earthquake. Japanese taste bears a strong resemblance to Germany, with preference for lighter, brighter colors and stones of high clarity and excellent cut. In rubies, this means bright, pinkish reds, while for sapphire it is for bright, Ceylon-type blues. Overly-dark stones find little interest in Japan.
Middle East	While the traditional center of the Middle East gem business is Beirut, the war virtually shut it down. Still, throughout the Middle East the gem trade is largely in the hands of Lebanese traders. Market preferences tend to be schizophrenic, with quantities of both high and low-grade jewels being purchased. The emphasis is often on flash, i.e. big stones and gaudy jewelry. That said, the purchasing power of this region is huge, almost on a par with the US or Japan. Middle-eastern retail buyers are a major presence in the world's retail capitals, such as Geneva, Paris, London, Hong Kong, Tokyo, New York and Beverly Hills.
Switzerland	Switzerland itself is not so much a final consuming market as a supermarket for the world's rich. Most purchases are made by foreigners, with the gems later exported. Buyers come from around the world, but have one thing in common—lots of money. Thus Swiss buyers tend to buy the very best, which means high-saturation Burma-type rubies and Kashmir or Burma-type sapphires. The market is centered in Geneva.
United Kingdom	While certain London jewelers and buyers handle material on a par with the best in the world, the UK market's taste is generally more in line with the country's overall economic decline since the fall of the British empire after World War II. Thus cheaper, darker goods are the norm. This is consistent with dark, garnet-red Thai/Cambodian rubies and dark, Australia-type sapphires.
United States	The US is the world's largest consuming market for all gems, including ruby & sapphire. Because of its melting-pot ethnic and economic composition, virtually all qualities are salable in some segment of the market. That said, preferences are generally for stones with balanced quality—i.e., proportions and clarity are of equal importance to color. In the Northwest (OR, WA, ID, MT), Yogo sapphires are a hot item, and may fetch prices far above those elsewhere. Major urban areas, such as New York and Los Angeles, may cater to many foreign customers.

a. Information in this table is based upon the author's own trade experience and research, along with published reports from Ho (1981) and Sersen (1988b).
b. Note: In each of the world's major luxury retail centers, such as Geneva, Paris, London, New York, Beverly Hills, Hong Kong and Tokyo, buyers from around the world come to buy. Thus the tastes of these centers often may diverge dramatically from the country as a whole.

sample size must be large enough to accurately reflect overall lot quality, but too large a sample simply wastes time. Such a procedure works as shown in Table 10.2.

The trick to the above is accurately estimating the cutting yield and selling price after cutting. How is this done? Experience, pure and simple. Novices should begin by buying only cheap lots, where a mistake in judgment is less costly. By grading the lot, having it cut, checking one's estimates against reality, and repeating the process over and over, one eventually reaches the enlightened, sapient state of eternal profit and bliss. Ideally before the bankroll is finished.

The same method would also be used for parcels of cut stones (minus the cutting charges).

Drawing color. When buying parcels, make sure that stones are examined individually, rather than as a whole. Large parcels will always appear to be of a deeper color than individual stones. This is termed *drawing color,* and results from increased absorption as light travels through several stones, rather than a single piece. Thus to get a true idea of color, stones should be removed from the lot for examination.

Color memory: 'Washing the eyes'

In a word, the color memory of humans is poor. While we can distinguish between millions of colors in side-by-side comparisons, this ability is dramatically reduced if no comparison sample is available. To take advantage of this poor color memory, a typical seller's stratagem is to begin the buying session by showing only low quality goods. As time goes

Business tactics

War talk by men who have been in a war is always interesting; whereas moon talk by a poet who has not been in the moon is likely to be dull.

Mark Twain, *Life on the Mississippi*

EVERY gem trader has his or her own preferred bargaining tactics. Skillful application of such stratagems often translates into business success.

Studied indifference is one common ploy, but difficult to maintain when one's eyes are afire with the sight of a great jewel. In such cases, it helps to use an intermediary. Because intermediaries do not have emotional attachment to the purchase (or sale), they typically achieve better results, which is why brokers are a common feature of the gem business.

Try to camouflage your intentions. When selecting from lots, an effective tactic is the 'bait and switch.' Rather than drooling over the object of your desire, disguise your true objective by asking the prices of other items first. Put the gem you want in with a group of others, ask the price of the group, remove a couple pieces you don't want, again inquire about the price, remove others, add additional pieces, and finally "settle" for the piece you wanted all along.

One of the keys to any negotiation is to get the other party to make the first offer. This is particularly important when haggling over something for which you are unsure of the true market price (there is nothing more deflating than making an offer and hearing a lightning-quick 'yes' issue from the seller's lips). Similarly, if you are selling and the buyer makes an offer you will accept, ponder it a bit before replying.

Among the most unusual bits of advice I've ever been offered was that provided by an old Japanese dealer who had spent most of his life buying gems in Asia. After negotiating several flasks of saké in Bangkok's Soi Ginza, he leaned over to me and slurred in heavily accented English: "Deeek, ze secrets of ze beeziness eez to buy a leettle high, and sell a leettle low." Only the next morning, after my mind had cleared, did I grasp the logic of this statement. By purchasing a little higher than the competition, sellers will approach you first. Thus you obtain the all-important first look. By selling a little lower than the competition, customers will also come to you first.

There is a common tendency when bargaining over a stone to denigrate it, thinking that telling the seller you don't like it will produce a lower price. While it does no harm to gently point out a gem's defects, this should be done in a graceful and subtle manner. Telling someone that their stone resembles "the slime on a lizard's back" not only anger's the seller, making any price reduction *less* likely, but it begs the question of why *you* want to buy something that bad.

In the end, as Bangkok dealer Gerry Rogers has repeatedly lectured me, buying is like selling. When selling, the last thing you want is to upset your customer. And so it is with buying. Complimenting the seller on his good taste in gems is far more likely to produce the desired price than the reverse. If you have to complain about something to the seller, complain that, while you recognize the high quality of the seller's gems, *your customers* lack the ability to understand subtle differences in quality. Thus you have to be careful how you spend your money.

on, the qualities get better and better, until, finally, the *pièce de résistance* is brought forth. Since everything seen up to that time has been of lower quality, it makes the final piece appear even better. This sales technique is termed 'washing the eyes' and is most effective (Halford-Watkins, 1934; W.K. Ho, pers. comm., ca. 1981).

To avoid falling prey to such a ruse, some standard means of comparison is needed. This could be a printed color atlas, a colorimeter (such as GIA's ColorMaster), a set of master stones, or some other medium (like AGL's ColorScan or GIA's GemSet). Many dealers simply carry around two or three comparison stones. Any of the above methods will prove useful.

Auction records

The record-keepers of record-breakers,
The lackers and onlookers of greatness,
Eunuch students of love and peeping Toms.

W.R. Rodgers, 1941, *End of a World*

Next to colored diamonds, rubies are the most precious of gems. Throughout the 1970s, it's highest per-carat price rose steadily. April, 1976 saw a ring containing a ruby of approximately 7.25 ct sell for $230,000 and in October, 1975, a suite of nine rubies from the estate of Geraldine Rockefeller Dodge sold for $690,000 at Sotheby's. On November 24, 1979, in Geneva, a 4.12-ct Mogok ruby sold for $412,000, a fantastic $100,639/ct. During this auction, three separate records were set: the above mentioned ruby; a Colombian emerald ring of 12.46 ct ($48,240/ct), and a Kashmir sapphire of 11.81 ct ($25,815/ct), then a world record per-carat price for blue sapphire.

Not until 1988 were these prices were topped. At Sotheby's New York's October 18, 1988 sale, Alan Caplan's 15.97 ct Burmese ruby sold for $3,630,000, a whopping $227,301/ct. As of 1995, this record still stands. The record for blue sapphire was set at the Feb. 18–20, 1988 sale at Sotheby's St. Moritz, where a 62.02-ct rectangular Mogok sapphire sold for $2,828,546 ($45,607/ct). (Hughes & Sersen, 1988b; Matthews, 1993)

Rubies and sapphires of note

Despite the fact that the corundum gems are the most important, next to diamond, relatively few titled specimens exist. In the case of sapphires, certainly, this is not for want of magnificent specimens of large size. Rubies of large size and fine quality, however, are singularly lacking. While perfect diamonds of many carats abound in history, perfect rubies of even five carats are almost unknown. The simple fact is that when the Gods were dispensing rubies, they did just as we mortals would have—they kept the best for themselves.

Table 10.2: Analysis of 1 kg mine-run lot of Australian sapphire

Analysis	Quality grade of each sample portion (sample = 10% of lot)				Sample total	Lot total (sample × 10)
	1	2	3	4		
Weight of grade (500 ct total)	75 ct (15%)	125 ct (25%)	175 ct (35%)	125 ct (25%)	500 ct	5000 ct
Estimated weight after cutting (20% average yield from rough to cut)	15 ct (3%)	25 ct (5%)	35 ct (7%)	Uncuttable (culls)		
Estimated selling price after cutting	$50/ct	$25/ct	$10/ct	—		
Gross income	$750	$625	$350	—	$1,725	$17,250
Cutting charges (@$2/finished ct)	$30	$50	$70	—	$150	$1,500
Net income	$720	$575	$270	—	$1575	$15,750
Profit (net income – lot price)	Sample price = $1000 total; Lot price = $10,000 total				$575	$5,750

A complete listing of famous rubies and sapphires is tabulated at the end of this chapter. What follows here is a smattering of descriptions and accounts of notable examples.

Rubies described by Tavernier

Jean-Baptiste Tavernier, the famous seventeenth century gem trader and traveler mentions a number of large rubies in his *Travels* (Ball, 1925). Of course Tavernier was writing at a time when almost any red stone was considered as a ruby, so it is likely that the larger stones were actually red spinels ('balas' rubies).

A handful of historic rubies

Burma has been, and continues to be, the source of rubies *par excellence.* Unfortunately, during the many centuries in which the Mogok mines were ruled by the Burmese kings, all stones of large value[9] were considered crown property. This resulted in large stones being broken up into smaller pieces.

Maung Lin Ruby. Among the great Burmese rubies was a stone found by a man or men working on the road to Momeit, during Mindon Min's rule (1853–78). The gem weighed 400 ct in the rough and was secretly disposed of to a trader named Maung Lin for Rs3000 (about £200). It was cut into three pieces: a stone of 70 ct (sold to England); a stone of 45 ct (sold in Mandalay); and a third portion of unknown weight, sold in Calcutta for Rs70,000 (~£4666). (Streeter, 1892; Halford-Watkins, 1934)

J.N. Forster Rubies. According to Tagore (1879, 1881) and Streeter (1892), the two most important rubies ever known in Europe were brought into England in 1875. One, a rich red cushion shape, weighed 37 ct; the other was a blunt, drop-shaped piece of 47 ct. Both stones were later recut by James N. Forster of London, resulting in pieces of 32 5⁄16 and 39 9⁄16 ct (38 9⁄16 ct according to Streeter) respectively. The smaller stone eventually fetched £10,000 and the larger £20,000. Streeter, undoubtedly one of the most competent European judges of rubies of his day, apparently did not examine the stones himself; however he states that experts pronounced them to be unrivaled for rubies of such large size. Perhaps even more authoritative proof of their quality was the fact that their sale in Burma created intense excitement and a military guard escorted the persons taking the stones to the ship. The Burmese King (Mindon Min) was only persuaded to let the stones go because he desperately needed cash. No matter what the king's financial position, however, we can be quite sure that he would not part with the best of his collection, for, as with many monarchs, such a collection has value far beyond money. The royal regalia and associated stones form a vital part of their rule, the foundation of kingly status. Without these trappings a monarch would truly be left without clothes.

Other Burmese rubies. Soon after Thebaw (1878–1885) ascended the throne, a fine stone weighing 100 ct in the rough was found on Pingtoung Hill (Pingu Taung) near Mogok, an area where several "royal rubies" have originated. The stone was presented to Thebaw by Oo-dwa-gee, at the time *Woon* (governor) of the ruby mining district (Streeter, 1892).

King Thebaw, the last Burmese monarch, was reported to have a collection of Burmese rubies unsurpassed in all the world. Of this, there can be no doubt, due to the aforementioned policy that all large stones were the property of the state. John Crawfurd (1829), an Englishman sent on a diplomatic mission to Ava (the then capital of Burma) in 1827, had this to say:

> The King lays claim to every ruby or sapphire which exceeds the value of one hundred ticals; and there is, from all accounts, a large collection of both in the royal treasury; but as they are never sold, and not often disposed of in any way, they can hardly be said to form an effectual portion of the revenue.

What happened to this magnificent collection after the British annexed Upper Burma? The treasury from the Royal Palace at Mandalay now rests at the Indian Museum, South

[9] Above approx. Rs2000 (Halford-Watkins, 1934).

Figure 10.15 And the judges' verdict? 10, 10, 10, 10, 10...
It is impossible to say what is the finest ruby in the world. But this stone is certainly one of the finest, and currently holds the record for the highest per-carat price ever realized for a ruby at auction. Known variously as *Alan Caplan's Ruby* or the *Mogok Ruby*, this 15.97-ct untreated Burma stone was sold by Sotheby's in 1986 for $3,630,000, a whopping $227,301 per carat. It was purchased by Graff of London, who reportedly sold it to the Sultan of Brunei. (Photo: © Tino Hammid)

From karob seed to carat

THE value of gemstones is generally determined by reference to weight vs. quality, with the best qualities always more rare in larger sizes than small. While there is no uniform system for quality analysis, gem dealers have long had a standard weight reference—sort of. Since April 1, 1914, the metric carat has equaled 200 milligrams. Prior to that, things were not so simple. The international carat of 1877 equalled 205.0 milligrams. Like religion, however, not everyone believed. Before the establishment of the standard metric carat, the carat varied anywhere from 188.6 milligrams (in Bologna) to as much as 213.5 milligrams (in Turin). And this is between two cities in the same country. Such variations (as much as 13%) make it extremely difficult to estimate the precise weight of gems described before 1914.

The English word *carat* comes to us from the Greek *keration* ('little horn') and refers to the shape of the seed pods of *Ceratonia silique*, the carob tree (St. John's Bread). Such seeds were used to weigh precious substances because of their relatively consistent weight. Our carat comes through the Arabic *qîrât*, which became in Old Portuguese *quirate*, appearing in modern Portuguese and Spanish as *quilate* (Kunz, 1914).

Kensington, in London, but to look at it, the Burmese king seems to have been a mere pauper. Although there are a number of rubies in the British Regalia, they are of small size or imperfect quality. On 29 Nov., 1885, the British took Mandalay. Guards were posted with orders not to permit anyone to enter or leave the palace. But that night the chivalrous British permitted female servants to come and go freely (see page 314). Throughout the night that is exactly what they did, smuggling the treasure out right under the British soldiers' noses (Stewart, 1972). No doubt, the stones eventually found their way onto the open market in Lower Burma and India, and then into the private collections of the world's wealthy. Thus was lost forever an unrivaled opportunity—public display of the most fabulous jewels of the Burmese monarchs, a collection put together over centuries of rule.

In 1899, the Burma Ruby Mines Ltd. uncovered a giant ruby of 77 ct (rough) which was valued at £26,666 (Brown, 1933). Another stone weighing 36 ct was sold by King Mindon Min, the father of Thebaw, for £30,000 (Brown, 1933). Numerous additional examples of large rubies such as the above exist in the literature, but because we do not know where the stones are today it is difficult to assess their quality, nor know definitely if they were, in fact, rubies. From what we do know today about rubies it can be guessed that most or even all of the large stones (100 ct or more) reported in the possession of the pre-twentieth century monarchs were either flawed or were actually red spinels.

The following are some famous rubies of Burmese origin.

Nga Boh ('Dragon Lord') Ruby. The name given to a ruby found at Bawbadan, weighing 44 ct in the rough, and, when cut, 20 ct. It was said to be the finest of its size ever reported and was given by the finder to King Tharawadi (1837–1846). The stone was among the booty missing from King Thebaw's palace during the British conquest of Mandalay (Streeter, 1892; Halford-Watkins, 1934).

Nga Mauk (Gna Monk) & Kallahpyan Rubies. During the reign of Mindon Min (1853–1878), a man found a rough ruby weighing 7 ticals (560 ct). This was one of the finest Mogok

Iran's Crown Jewels

NO jewelry collection in the world can compare with Iran's Crown Jewels, located in Teheran's Bank Markazi Iran (Central Bank of Iran). Some of the jewels date from the 16th century, when the Spanish began selling new-world emeralds to Asia's great potentates, but the bulk came into Persian hands in 1739, when Nadir Shah sacked Delhi and returned home with sacks and chests of treasure. Included amongst the booty was the most unbelievable jewel ever seen—the fabled Peacock Throne. Commissioned by Shah Jahan, the same Mughal that built the Taj Mahal, the cost of the Peacock Throne was actually twice that of the Taj (Swamy & Ravi, 1993). Unfortunately the original throne was later broken up, but many of its gems are today found in the collection. This collection has been magnificently described by Meen & Tushingham (1968).

After the 1978–9 revolution that toppled Iran's monarchy, the collection was put away, and some of Ayatollah Khomeini's most zealous followers even proposed selling it off. Thankfully this did not happen, and in February of 1992, the collection was quietly reopened to public viewing (Sciolino, 1992).

Rubies

Rubies of great size and quality are quite rare, and Iran's collection is probably the world's finest. Mogok rubies of ten carats or more are extremely scarce in fine qualities, but the Persian collection possesses a number of fine examples. Of particular note is the plaque of 13 magnificent stones described by Meen & Tushingham (1968, p. 118), and matched by another plaque nearby. Each is set in a simple gold ring and all are cabochons, ranging in size from 8 to 16 ct. All are believed to be of Burmese origin.[a]

Red spinels

The world's greatest collection of large red spinels is that of the Crown Jewels of Iran. One piece, a blood-red lump of some 500 ct, is probably the largest fine red spinel extant. A companion piece weighing 270 ct is the more important of the two from an historical perspective, in that the Indian Mughal Jahangir's name is engraved upon it.

The larger of the two spinels in Iran is pierced, but the openings are now plugged. According to one legend, this is the *Samarian Spinel*, which adorned the neck of the Golden Calf. Both stones are believed to originate from the famous balas ruby mines of Badakshan. Numerous other red spinels exist in the Crown Jewels of Iran, many of which exceed 100, and some, even 200 ct in weight.

[a] Although they are stated to be of Burmese origin, no evidence is given to back up this belief. It is possible some may come from other sources.

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rubies ever found (Streeter, 1892; Halford-Watkins, 1934; Keely, 1982; Clark, 1991). But there is a discrepancy in the accounts. According to Streeter and Halford-Watkins, the man's wife traded the stone for a rupee's worth of fish condiments to a man named Nga Mauk, but Keely does not mention such a trade.[10] In any case, the owner of the stone broke it in two, giving one half to the king and secretly sending the other for sale in Calcutta. Discovering the fraud and after learning where the other half had been sent, Mindon Min ordered its return. In the meantime, he ordered the village and its inhabitants burned alive as a lesson to others (this was apparently a traditional punishment under the Burmese monarchy). Eventually, the second half was purchased in Calcutta for an enormous sum and returned to Burma, where it formed a perfect fit with the first. The two stones were cut in Mandalay, one forming a grand stone weighing 98 ct, and named *Nga Mauk;* the other weighed 74 ct and became known as *Kallahpyan,* signifying that it had returned from India. These two pieces disappeared when Upper Burma was annexed by the British in 1885.[11]

Peace Ruby. Few rubies ever generated the excitement that this 42-ct piece of rough produced upon its discovery. Accounts on this stone differ.[12] The author has chosen to use that of Halford-Watkins (1934), who had first-hand experience with the gem. He said:

> This magnificent stone, by far the finest ruby the world has ever seen, was mined in the Mogok Valley on the 30th June, 1919 (the day that Peace was signed). In shape it had the form of an irregular hexagonal prism with a flattened apex, the weight being exactly 42 old carats. The colour was a perfect pigeons-blood, and when in the writer's possession he likened it to a piece of red currant jelly, and used to exhibit it on a small plain white china plate to heighten the illusion. With the exception of a tiny crack near the base, which was removed in the cutting, the stone was entirely without a blemish of any kind. It was purchased in the rough by Chhotalal Nanalal, an Indian gem merchant of Mogok, for £27,500, or £654/15/– per carat, which [was] the highest price per carat ever realised for a rough ruby of any size. It was cut in Bombay into a round brilliant weighing 25 carats, of perfect colour, and absolutely flawless. This brought the actual cost of the material in the finished stone up to £1,100 a carat. The cut stone was disposed of in Paris, and afterwards went to America, the prices realised at the resales being very considerable, but the actual figures are not available for publication.
>
> J.F. Halford-Watkins, 1934, *The Book of Ruby and Sapphire*

The present location of this stone is unknown.

Chhatrapati Manik Ruby. Among rubies, that with the oldest legendary history is the *Chhatrapati Manik.*[13] Legends date back some 2000 years, to the time of Sri Raja Bir Vikramaditya, King of Ujjain (located in present-day Madhya Pradesh, India). Upon his ascension, he proclaimed himself *Chhatrapati* ('Supreme King') and commissioned a new crown befitting his position. Scholars advised him that the crown should consist of nine principal gems (representing

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10. It seems unlikely that anyone living in the Mogok area could fail to recognize such a fine rough ruby, so, in this regard, Streeter may be wrong.

11. For a slightly different version of this story, see page 314.

12. See *Times of London* (Aug. 25, 1919); Brown (1927); Keely (1982).

13. The primary meaning of *Chhatra* is umbrella, but secondary meanings include lord, supreme, shelter, and helper. *Pati* means master, husband or king. *Manik* means ruby, or red precious stone. Thus *Chhatrapati Manik* means 'Supreme Lord of Rubies' (Clarke, 1933).

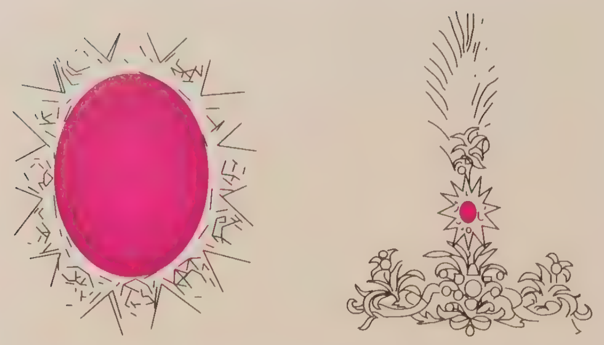

Figure 10.16 A representation of the gem alleged to be the Chhatrapati Manik Ruby, as seen in London in 1934. At left is a close-up view of the gem mounted in a diamond tiara. (Based on Clarke, 1934)

the nine planets). However, ruby, gem of the sun, should have the foremost place, for the sun lords over all other planets. A search of the treasury brought forth the finest gems of each type, but a suitable ruby could not be found. Eventually, a ruby without peer was located in a banker's collection and purchased. As the Maharaja had declared himself *Chhatrapati,* so he called the ruby.

Clarke (1933) gives a further detailed history of this stone, which passed from Vikramaditya's descendants through a variety of merchant's and ruler's hands. These included Sultan Abdul Hossein Qutub Shah, King of Golconda (1672–1687), also known as Tana Shah. He seized the crown and, after unmounting the gems, destroyed it. Tana Shah loved the ruby so much he had his name engraved upon it, and commissioned a book of poetry to extol its virtues. Later, the Great Mughal, Aurangzeb, defeated Tana Shah in battle, taking him prisoner. Leading the troops was Aurangzeb's son, who brought the ruby and book of verses to his father. Aurangzeb ordered Tana Shah's name removed, and his own put in its place.

At Murshidabad, in Bengal, lived a family of bankers, said to be the richest in the world. They often bestowed lavish gifts upon the Mughal. Upon receiving one of these presents, Aurangzeb returned the favor by presenting them with the *Chhatrapati Manik,* along with the book of verses. Later, one Lala Kalkadas of Lucknow traded a number of gems for the ruby and book. Aurangzeb's seal was ground off the gem at this point. During the Indian Mutiny of 1857–8, the book was lost, but Lala Budreedas, son of Lala Kalkadas, managed to keep the ruby. He later moved to Calcutta, where he had it mounted into a new tiara, befitting the ruby that had once graced the head of Vikramaditya, *Chhatrapati* of India.

The stone is said to be a Burmese oval cabochon of good deep color. Its weight is listed variously as about 24 *rati* (~20.68 ct), (Clarke, 1933), or about 40 ct (Clarke, 1934). In 1934, the stone was reported to be in London and was mounted on the front of a diamond tiara.

Star rubies of note

Among star rubies of renown, two immediately come to mind—the *DeLong Star,* an oval stone of over 100 ct, and the *Rosser Reeves Star,* an oval of 138.7 ct. Both are on public display in the United States.

DeLong Star Ruby. This 100.32-ct star ruby is displayed in the American Museum of Natural History in New York. Discovered in Burma during the early part of the twentieth century, it was sold by Martin Ehrmann to Edith Haggin DeLong, who donated it to the museum (Smith, 1994).

Rosser Reeves Star Ruby. At 138.7 ct, this is probably the finest large star ruby in existence. Now at the Smithsonian in Washington, DC, it was named in honor of the donor, Mr. Rosser Reeves. Not only is the stone clearer and more translucent than the DeLong star, but it also possesses a magnificent, sharp six-rayed star. The *Rosser Reeves Star* is also unusual in that it does not originate from Mogok, as with most fine rubies, but from the gem gravels of Sri Lanka.

Rough rubies of note

Famous rough ruby specimens exist in several museums around the world. Extremely large but impure examples have been found in a number of localities. The British Museum possesses a rough hexagonal prism of 10 × 7 inches (25.4 × 17.8 cm) which weighs 34 lb (15.42 kg) and comes from North Carolina. Fine specimens, however, come mainly from Burma. In 1933, the British Museum acquired a remarkable Mogok ruby specimen measuring 12 × 9 × 4 cm and weighing 1.5 lb (3450 ct). Although consisting of a single crystal, it shows the terraced appearance (due to oscillation between the rhombohedron and basal pinacoid) typical of Burmese ruby crystals (Spencer, 1933). Also displayed at the British Museum is the 167-ct *Edwardes Ruby* crystal, which was donated in 1887 by John Ruskin (Keller, 1983).

Another fine Mogok ruby crystal is on display in the Los Angeles County Museum of Natural History (Keller, 1983). Weighing 196.1 ct, it too displays the typical etched and terraced appearance, and is known as the *Hixon Ruby.*

The largest ruby ever found in Thailand was unearthed in 1985. This giant piece of rough weighed approximately 150 ct and was put on public display during a gem fair held in Chanthaburi in 1986.

Famous rubies are summarized in Table 10.3.

Notable red spinels

Among the most famous titled rubies, most are not rubies at all, but red spinels. Two important examples are found in the United Kingdom: the *Timur Ruby,* and the most famous of all, the *Black Prince's Ruby.* Despite the fact that these are actually red spinels, their colorful tales are worth telling.

Black Prince's Ruby. Few precious stones have such a long and storied history as this large, semi-polished, crimson orb.

The slippery SLORC ruby

I guess the government that robs its own people earns the future it is preparing for itself.

Mark Twain, 1912, *Mark Twain: A Biography*

THE Rangoon gem auction had a big star in 1991, a 496-ct golf-ball sized piece of rough. It was dubbed the *SLORC Ruby* by SLORC (Burma's State Law and Order Restoration Committee, the ruling military junta). That's a real pretty name. Kinda catchy, too. SLORC said it was the world's largest ruby, bigger than even the *Star of India*. Although the *Star of India* is a sapphire, and weighs 563 ct, who am I to argue?

SLORC (the ruby) had an interesting birth. Seems she was dug up in February of 1990, at Dattaw, in the Mogok area. Just that year SLORC started allowing ordinary citizens to do legal mining at Mogok. These were joint ventures of the government/private-party type, with the privates doing all the work and giving up a serious piece of the action, on the condition that the government give their blessing to the party. Everything above a certain quality had to be sold at the annual auction in Rangoon. Problem was that some of those private operators didn't like to tell SLORC when they found a nice piece. My daddy always accuses me of the same thing—bad attitude.

Four jailed for life for ruby smuggling

A Burmese martial law court sentenced four people to life in prison for smuggling the world's largest ruby into a neighboring country, state-run radio Rangoon reported.... The 496.5-carat ruby was seized by military intelligence from an unspecified "neighboring country" on August 18, the radio said.... [It] was originally discovered in February by local gem miners near Moegoat township in Burma's northern Mandalay division.

AFP, 1991, *Bangkok Post*

Apparently the miners that found the SLORC thought it better to ship it east to Thailand, instead of south to SLORC. So SLORC slipped a team of stealthy SLORCs into Thailand and seized the slippery SLORC, whereupon it was named the "SLORC" and declared a national treasure. SLORC then proceeded to lecture the masses on the fact that all SLORCs belong to SLORC. Thus those with a SLORC to ship had best not try to slip by SLORC.

SLORC Chairman Senior General Saw Maung inspects world's largest sapphire

YANGON, 4 FEB.—State Law and Order Restoration Council Chairman Defence Services Commander-in-Chief Senior General Saw Maung this morning inspected the raw sapphire, weighing 4,230 ct, mined from Mogok Kyatpyin, west of Pyangbya village. It is the largest sapphire which has commercial value in the world...

Gem poachers mined the raw sapphire in September 1990 and the Defense Services Intelligence personnel seized it on 1 February, 1991 from them while they were making arrangements to sell it off. Six gem poachers and one person involved in the case have been arrested and further investigation is being carried out. Action will be taken against them in accordance with law...

Working People's Daily, 5 Feb., 1991, Rangoon, Burma

Law and justice. My, my, what would the world do without them.

Figure 10.17 The infamous *SLORC Ruby*, from Mogok's Dattaw mine. (Photo: Robert Kane/GIA)

The following is based largely on Orpen (1890), Younghusband & Davenport (1919) and Sitwell (1953).

Although the gem was probably mined at Badakshan's famous balas ruby mines along the Afghanistan border, the gem's first documented appearance is in fourteenth-century Spain. At that time, Spain was ruled by a number of petty kings, one of whom was a Moorish prince, Mohammad, of Granada. Don Pedro the Cruel ruled nearby Seville, and it was to him that Mohammed fled after being deposed by his brother-in-law, Abu Said. Don Pedro's army eventually brought Abu Said to heel. When they arrived to negotiate, Abu Said and his attendants were killed, and their jewels seized. The date was 1366. Among the jewels was a large red spinel octahedron, the size of an egg. It is today known as the *Black Prince's Ruby*.

Don Pedro soon found it his turn to flee, his adversary being none other than his own brother, Henry. In 1366, he fled to Bordeaux, where the Black Prince[14] kept court. Don Pedro beseeched the Black Prince to help, promising untold treasures in return. Henry was duly defeated and the large red stone passed as payment to the Black Prince, in 1367.

The gem reappeared in the hands of the English king, Henry V, at Agincourt, on Oct. 25, 1415. The gallant king, with his army reduced to 15,000 men, was falling back upon Calais when at Agincourt he encountered Duc d'Alençon, the French prince, and his army of 50,000 men. The morning of the climactic battle Henry appeared dressed in most

14. The Black Prince was Edward, Prince of Wales [1330–1376]. His epithet "Black Prince" may reflect the terror he inspired in the French, but it probably referred to the color of his armor.

Figure 10.18 Britain's Imperial State Crown contains more famous gems than virtually any other ornament in the world. These include the Black Prince's Ruby (not shown), the Stuart Sapphire (top right) and St. Edward's Sapphire (below right). (Photos: HMSO, London)

splendid attire, with gilt armor. Upon his helmet was a crown garnished with rubies, sapphires and pearls, including the Black Prince's Ruby.

Henry's helmet was more than mere decoration, for on that day he was set upon by the French prince, Duc d'Alençon. The Frenchman struck his helmet a mighty blow with his battle axe, nearly killing Henry. Others also attacked him, even managing to break away a portion of the crown. Miraculously, though, both the stone and Henry survived. After the battle, a French prisoner retrieved the broken fragment and brought it back to England, an act for which he was duly reimprisoned. The identical helmet worn by Henry at Avincourt is said to reside in Westminster Abbey, shorn of its jewels. Two deep gashes are readily visible, bearing mute testimony to the gallantry of Henry V on that fateful day.[15]

From here the precious gem passed through the hands of numerous British kings, including Henry VIII and his daughter, Elizabeth I, who kept it in her private collection. She did show it to a Scottish envoy, Sir James Melville, however. One evening the Queen took him into her bedchamber, where "she shewed me a fair ruby, great like a racket-ball. I desired she would either send it to my queen [Mary, Queen of Scots] or the Earl of Leicester's picture. She replied 'If Queen Mary would follow her counsels she would get them both in time and all she had, but she would send a diamond as a token by me.'" It was for the Black Prince's Ruby that the envoy begged, but Mary was destined to get neither.

King James I had the stone set in his state-crown, for the Earl of Dorset describes the stone in an inventory of the crown jewels. His description of the imperial crown concludes: "and uppon the topp a very greate ballace [*balas ruby,* or spinel] perced." We know this to be our stone for at some point in time it had been drilled ('perced') at the top with a small hole, so as to be worn suspended from the neck, a common occurrence with oriental gems. Today this hole is capped with a small ruby.

After the coronation of Charles I, by a fortunate occurrence, the great gem was not placed in the jewel house along with the other royal treasures. If it had it would have been lost, for when Cromwell took power and Charles I was exe-

15. As well as the lack of properly sharpened battle axes among the French at Avincourt.

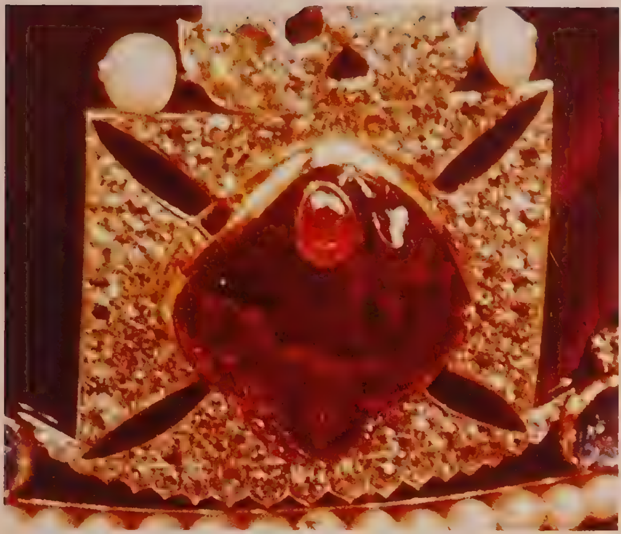

Figure 10.19 Perhaps the world's most famous ruby, the *Black Prince's Ruby*, is actually a large red spinel. Its history is documented back to 1366 AD. Today it is mounted on the front of England's Imperial State Crown, which is located in the Tower of London. (Photo: HMSO, London)

cuted, all the treasures found there were either melted down or sold by order of the Commonwealth. Among the priceless pieces thus lost was the gold filigree crown of Edward the Confessor, which was broken up and sold for its weight of bullion. Orpen (1890) remarked… "Such vandalism is almost enough to make one a Jacobite."

But the Black Prince's Ruby was not among them. According to the Parliamentary sales list of Charles I's Crown Jewels, there is an entry recording the sale, for £4, of a 'perced balas ruby wrapt in paper by itself,' which several authors have identified as the Black Prince's Ruby. Sitwell (1953) believes that this is incorrect, and that the Black Prince's Ruby is more likely to have been that identified as the *Rock Ruby*, which sold for £15.

In any event, in 1660 it was bought by an unknown party, who resold it to Charles II after the restoration of the Stuarts (Michael, 1983). During the reign of Charles II, the stone, by now set in Charles II's State Crown, had another narrow escape. It was nearly stolen by the notorious Colonel Blood, who, unbelievably, was later pardoned by the King.

Once again, in 1841, the crown was almost lost, this time by fire. Only the quick actions of police inspector Pierse saved the day. As the Tower burned, Pierse broke through the iron bars with a crowbar to rescue these irreplaceable object. Again, during World War II, the royal regalia was once more in danger, this time from Hitler's bombers. However, they survived undamaged and today the giant Black Prince's Ruby can be viewed in all its glory in the Tower of London, along with the rest of the English Crown Jewels.

The Black Prince's Ruby is now mounted in the front of the Imperial State Crown, just above the famous Cullinan II Diamond. It is a huge, semi-polished octahedron.[16] Sitwell (1953) states that the stone is backed by a gold foil, as were many ancient gems, to improve its brilliance. This has not been removed for fear of damaging the gem. The stone measures some two inches (5.08 cm) in length and is of proportionate width (Younghusband, 1919). Its exact weight is unknown, but estimates put it at ~140 ct. As earlier stated, it is drilled at one end and a small ruby is set atop the opening.

According to Younghusband (1919), "the question is often asked: 'What is the value of this stone?' And the answer may safely be given that it is priceless, for no amount of money can buy it." It is indeed the most famous gemstone in the world's most famous gem collection.

Timur Ruby (Khiraj-i-alam, or 'Tribute to the World'). The *Timur Ruby* is a large red spinel and rests today in the private collection of the British monarch, mounted on a gold chain along with three other "Indian rubies." It is a large, tabular, semi-polished stone of 361 ct which carries Persian inscriptions in Arabic script. Inscriptions give the names of previous owners, as follows (Twining, 1960):

Ruler	Hirja year	Christian year (AD)	Reigned
Akbar Shah	1021	1612	1556–1605
Jehangir Shah	—	—	1605–1627
Sahib Qiran Sani (Shah Jahan)	1038	1628	1628–1658
Alamgir Shah	1070	1659	1658–1707
Badshah Ghazi Mahamad Farukh Siyar	1125	1713	1713–1718
Ahmed Shah Duri-i-Duran	1168	1754	1748–1772

The Timur Ruby is said to have passed into Timur's hands when he sacked Delhi in 1398. The great Tartar conqueror stayed in India for little over a year, returning to Samarkand with all his booty. Upon his death, the ruby went to his son, Mir Shah Rukh, and in due time to his son and successor, Mirza Ulugli Beg. By this time the Tartar empire was on the wane and during one of the wars between the Tartars and Persians, the ruby came into the hands of Shah Abbas I of Persia. Shah Abbas presented the ruby to his close friend, Jahangir, the Mughal Emperor of India, in 1612. At that time, the gem had the names of Timur's son and grandson, and Shah Abbas himself, engraved upon it, but these inscriptions no longer exist. It is unknown whether they were obliterated over the course of time, or at the behest of Jahangir. In any event, after taking possession of the ruby, Jahangir had his own name engraved upon it, as well as that of his father, Akbar. When his favorite wife, Nur Jahan, chided him for defacing such a magnificent gem, he replied:

16. Prior to the end of the eighteenth century, eastern lapidaries rarely faceted the precious stones on which they worked (Meen & Tushingham, 1968).

"This jewel will more certainly hand down my name to posterity than any written history. The House of Timur may fall, but as long as there is a King, this jewel will be his."

Upon Jahangir's death, the Timur Ruby passed to his son, Shah Jahan (of Taj Mahal fame), who also had his name inscribed on it, and placed it in the famed Peacock Throne. Shah Jahan's son, Aurangzeb (Alamgir Shah), seized control of both the throne and ruby, and added his own name to the inscriptions. The last of the Delhi emperors to inscribe his name upon the gem was Mahomed Farukh Siyar. His successor, Nadir Shah, invaded India and sacked Delhi in 1739. The royal loot carried away to Isfahan included both the Koh-i-Nur Diamond and the Timur Ruby, as evidenced by the following inscription on the Timur Ruby:

> This (is) the ruby from among the 25,000 genuine jewels of the King of Kings, the Sultan Sahib Qiran [Timur], which in the year 1153 [1740 AD] from the (collection of) jewels of Hindustan reached this place [Isfahan].

The jewel's last inscription is that of Ahmad Shah, commonly known as Abdali or Durani, who at the time of Nadir Shah's assassination in 1747 held an important command in his army. Upon hearing of the murder, he attempted to seize the throne, but succeeded in securing only a large amount of booty. This he took with him when he marched south at the head of his Usbeg troops and founded the kingdom of Afghanistan. On his death in 1772, his son, Timur Shah, ascended the Kabul throne, and the ruby eventually passed to the latter's youngest son, Shah Suja. When expelled by Dost Mahomed, he took refuge in the Punjab, where Ranjit Singh, 'Lion of the Punjab,' forced him to surrender both the Koh-i-Nur and the Timur Ruby.

In the end, Jahangir's prediction was born out. When the British East India Company annexed the Punjab in 1849, they also *annexed* the Koh-i-Nur Diamond and Timur Ruby. Both were later presented to Queen Victoria. Despite the occasional protests from India, it is in the British Monarch's hands that they remain (*Times of London,* 1912; Twining, 1960).

Catherine the Great's Ruby. This is the second-largest red spinel of quality on record, at 414.30 ct (or 398.72 ct according to the USSR Diamond Fund, 1972) and is housed in Russia's Kremlin (see box, page 282 for a full description).

A case of mistaken identity

Red spinel is not the only ruby look-alike found in Burma's Mogok Stone Tract. Red tourmaline (rubellite) is also common. This may be the origin of the famous red gem found in Russia's Diamond Fund. The 255 ct "great ruby" was once among the jewels in the imperial treasure in Prague, and was removed by troops under H.C. von Königsmarck in 1648, during the sack of that city in the Thirty Years War. It was later sent to Sweden and, in 1777, presented to Catherine II of Russia by Gustaf III. When examined by A.E. Fersman during his inventory of the Czarist treasure in 1925, he found it to be a pink tourmaline of no particular value or merit. In appearance, it resembles a bunch of grapes (Zenzén, 1930; Fersman, 1947; USSR Diamond Fund, 1972).

Famous titled red spinels are summarized in Table 10.4.

A study in primitive life forms

> What is the difference between a taxidermist and a tax collector? The taxidermist only takes your skin.
>
> Mark Twain, *Mark Twain's Notebook*, Chapter XXXIII

THERE is a particular type of single-cell organism which goes by the name of the government bureaucrat [*bureaucratius simplicius*]. To scientists, it is most easily characterized by its lack of even elementary reasoning, along with a strong desire to possess what is yours. It bears a certain resemblance to other primitive parasites, such as the politician, accountant and lawyer. Indeed, they may be related.

What with the rapid pace of change today, it is easy to conclude that such vermin are a modern phenomenon. But this is not the case, as evidenced by the following tale of a fifteenth-century ruby trader who had occasion to visit Sumatra shortly after his companion had died:

> As soon as our merchandize was landed this chief raised a quibble, asserting that, as my companion was dead, all the said merchandize came to him [the chief], and that he would have it… He thereupon ordered all my property to be seized, and caused all my person to be searched. There were found upon me rubies of the value of three hundred ducats, which I had bought [in Pegu]. These they took, and the chief appropriated them to himself.
>
> *Journey of Hieronimo di Santo Stefano*, ca. 1496 (from Major, 1857)

While extermination has proven impossible, businesspeople have developed certain evasion techniques. One was related to me by a European trader. He told of having to swallow a parcel of particularly valuable gems when forced to transit a land where one variety, the *customs agentus*, was known to be endemic. The ruse succeeded, but this created an additional conundrum. Upon arriving at his final destination, his customer was eager to view the gems. Sadly, he had to be told that there would be a delay, for the gems were still being… er… cleared.

Rubies, spinels & sapphires in the Mughal treasury

No one collected gems like India's Mughals, who lorded over many parts of that land from 1526–1707. A detailed analysis of their treasury has been given by the great Mughal specialist, Abdul Aziz (1942), summarized in Table 10.5.

Famous blue sapphires

Smithsonian

Although large rubies of quality are extremely rare, fine examples of large sapphires are relatively less so. Over the centuries, Sri Lanka has produced more giant sapphires of gem quality than any other source. Several fine examples are found in the Smithsonian Institution in Washington DC.

Bismarck Sapphire. The *Bismarck Sapphire*, weighing in at 98.6 ct, is a faceted gem of Sri Lankan origin donated by Countess Mona Bismarck (Dunn, 1975).

Logan Sapphire. This is the largest sapphire in the Smithsonian collection, a giant of 423 ct, set with 20 diamonds. The stone has a rich blue color but unfortunately is faceted with a large window. It was donated by Mrs. John A. Logan and is considered to be one of the finest large sapphires in existence.

Star of Artaban. Also in the Smithsonian collection is the *Star of Artaban*, a blue six-rayed star sapphire of 316 ct. It is said to be of Sri Lankan origin (Punchiappuhamy, 1984).

Star of Asia. This, too, is in the Smithsonian collection. An extraordinary 330 ct of the richest blue-violet color, it is one of the finest star sapphires in existence.

Star of Bombay. The *Star of Bombay* was bequeathed to the Smithsonian by the famous silent movie actress, Mary Pickford. It weighs 182 ct and is a beautiful blue-violet star (White, 1991).

American Museum of Natural History

Star of India. In New York, at the American Museum of Natural History, is found a fine collection of Sri Lankan sapphires, particularly stars. Largest of these is the *Star of India*, weighing a massive 563.35 ct. This stone is actually of Sri Lankan origin and shows a fine star, although the color is a rather grayish blue. According to Sofianides & Harlow (1990):

> The huge 563-carat Star of India sapphire is one of the [J.P.] Morgan gifts. Its name suggests a story—one might speculate that, after being mined in Sri Lanka in the sixteenth century, it circulated among the treasures of Indian potentates.... George F. Kunz [1913a] recorded only this enigmatic statement: "[It] has a more or less indefinite historic record of some three centuries...." How the gem came into Kunz's hands is unrecorded, but rumor has it that a royal owner needed cash without publicity. An alternate, but doubtful, story is that Kunz had the stone fashioned in New York City in 1900—so much for romance! No matter, the Star of India is magnificent.
>
> A.S. Sofianides and G.E. Harlow, 1990

Midnight Star. Another large star in this collection is the *Midnight Star*, a deep violet Ceylon stone of 116.75 ct. (Sofianides & Harlow, 1990).

Figure 10.20 The *Midnight Star*, weighing 116.75 ct.
(Photo: Harold & Erica Van Pelt/American Museum of Natural History)

British Crown Jewels

Stuart Sapphire. The early history of the *Stuart Sapphire* is somewhat obscure, although it most probably belonged to Charles II, and was certainly among the jewels which James II took with him when he fled to France. From him it passed to his son, Charles Edward, the Old Pretender, who gave it to his son Henry Bentinck, later known as Cardinal York. As the Stuart cause was then dead, he left the sapphire with other Stuart relics to George III.

In Queen Victoria's State Crown this sapphire occupied a prominent position just below the Black Prince's Ruby. It was later replaced by the Second Star of Africa (Cullinan II) diamond, and today is set in a similar position on the opposite side of the same crown.

The Stuart Sapphire is more of historical than real value. Although of a fine blue color, it contains one or two blemishes and is drilled at one end, probably so that it could be worn as a pendant, as was common in earlier times. It is oval in shape, about one and a half inches in length by one inch in width, and is set in a gold brooch (Younghusband & Davenport, 1919).

St. Edward's Sapphire. *St. Edward's Sapphire* is now set in the center of the cross-patee on top of the same crown as the Stuart Sapphire. It is a stone with a history stretching back farther perhaps than even the Black Prince's Ruby. According to tradition, the St. Edward's Sapphire was originally set in the coronation ring of Edward the Confessor, who was crowned in 1042 AD. Special powers were ascribed to this sapphire, including those of curing cramps.

Maharajahs—India's fantastic fetish princes

AMONG the greatest collectors of jewels were India's princes—the *maharajahs*.[a] According to Kipling, providence created the maharajahs simply to offer mankind a spectacle. And what a spectacle it was! Sport and sex were their preferred pastimes, but jewels were their passion.

The Maharajah of Baroda exemplified the princely state of mind. His court tunic was spun of gold, with only one family in his state allowed to weave its threads. The family's fingernails were grown long and then notched like the teeth of a comb, all the better to caress the golden threads to perfection. Among his most precious treasures were a collection of tapestries made entirely of pearls, into which were woven ornate designs of rubies and emeralds.

Jaipur's maharajah lorded over one of the largest and richest of India's princely states. Somewhere in the Jaigarh fort, on a peak above the palace, the private treasure of the Jaipur princes lay buried, guarded by an especially belligerent Rajput tribe, the Minas. Once per lifetime, each maharajah was allowed to visit the treasure and select a single item. Man Singh chose from the private treasure a bird of solid gold studded with rubies of extraordinary fire, so heavy that a woman could hardly lift it. Unfortunately, independence came before the last maharajah, Jai Singh, could choose. Even so, he did not do without. His jewels included a triple-stringed necklace of red spinels, the stones having been contributed by various Mughal emperors, each bigger than a pigeon's egg, along with three huge emeralds, the largest of which weighed 490 ct. Among the world's greatest polo players, Jai Singh died in appropriate form, atop his polo pony, one of the three richest men in England.

None of the Indian princes amassed greater treasure than the Nizams of Hyderabad. Presiding over one of the largest states (half the size of France), their dominion included Golconda, in former times the world's diamond center. They were the first to enter into alliance with the British, but later became indebted, thus allowing the British to gobble up Berar, a valuable part of their domain. For support during the Indian Mutiny of 1857, the British wrote off that debt and awarded the Nizam the Order of the Star of India. Berar, however, remained in British hands, causing the Nizam to remark, "Generosity is uppermost in the minds of my British allies, even though their mathematics are a trifle weak."

Among the titles of the seventh Nizam, Lieutenant General His Exalted Highness Sir Osman Ali Khan Bahadur, were included "Regulator of the Country, Victorious in Battle, the Aristotle of his Age, Shadow of God and Faithful Ally of the British." While Osman Ali may not have been the world's richest man, he certainly qualified as the world's greatest miser. His wealth included two lime-sized diamonds of over 180 ct each; in keeping with his frugal nature, one was used as a paperweight. The Nizam's pearl collection was said to be so vast that it alone would cover the sidewalks of Piccadilly Circus, and he owned over seventy million dollars in gold. But despite his vast assets, visitors to the palace would be presented with only one cup of tea, one biscuit, and one cigarette. After they left, the Nizam would drink any remaining tea, eat the crumbs of the biscuit and smoke the cigarette butts to the end. Over ten million dollars in cash was stashed in his basement, earning negative interest, as rats gnawed their way through thousands each year.

A believer in the *unani* medical system of ancient Greece, Hyderabad became the only place in the world with free clinics and a hospital devoted to unani medicine, which involved good health through ingesting powdered jewels. No maharajah followed this course better than an early prince of Mysore. Informed by a Chinese sage that the finest aphrodisiacs contained crushed diamonds, he succeeded in quickly depleting the state treasuries in his princely quest for potence.

The Nizam of Hyderabad was a Muslim reigning over a largely-Hindu population, but no one could accuse him of lack of faith. Hyderabad law forbade the destruction of any legal records or newspapers in which the name Mohammed had been published. Since many of his Muslim subjects carried this name, the edict created a prodigious amount of paperwork, with wire baskets placed in the streets so the public could properly dispose of papers bearing the prophet's name.

Let us not forget the Maharajah of Patiala. He possessed a breastplate containing 1,001 diamonds. Until the 20th century, it was the custom for him to appear once a year before his subjects, wearing nothing but the diamond-encrusted breastplate, complemented by his sexual scepter, in regal erection.

The seventh Maharajah of Patiala's harem numbered 350. So obsessed was Bhupinder Singh with desires of the flesh, that he devoted an entire wing of his harem to a laboratory, where exotic cosmetics, perfumes and love potions were mixed. A team of British, French and Indian plastic surgeons stood on call, ever ready to alter the proportions of a favorite member of the harem according to the Maharajah's whim. Alas, it was not enough. In the end, Bhupinder Singh died of a most trite cause—boredom.

But India's maharajahs had more on their minds than just jewels and sex. Witness the Maharajah of Gwalior, whose passion was electric trains. His palace was rigged up in a style that would surpass even a schoolboy's most fantastic Christmas-eve fantasies. Guests at his banquets were served by crystal trains running on silver rails, controlled by the Maharajah at an enormous control panel. And if you displeased him during dinner, the dessert train might well pass you by. During one fête in honor of the British Viceroy, the control panel short-circuited, causing food trains to careen wildly, sloshing gravy and other condiments all over the guests. It was, as Collins and Lapierre remarked, "a catastrophe without parallel in the annals of railroading."

Are the maharajahs simply relics of a bygone era? Not really, for they've been reincarnated in the oil sheikdoms of the Middle East. While visiting the European chalet of one of the Middle East's most important jewelers, my host was interrupted by a call from the secretary of an Arab monarch: "Do you remember the blue diamond you sold the King last year? He would like another one just like it, with exactly the same color, to make matched cuff links. The weight is 8.13 ct and its measurements are…" After telling the secretary that such a request was impossible to fill, my host hung up. Alas, the phone soon rang again, with the secretary imploring that the King "*really wants it.*" Turning to me, the jeweler remarked that the monarch wanted to be "more than king." Then he quickly made plans to leave the next morning for Antwerp.

a. This account of the maharajahs is based largely on Lord (1971), Collins & Lapierre (1975) and Allen & Dwivedi (1984).

Figure 10.21 H.H. the Maharajah of Patiala, ca. 1924, in regal splendor. Sikh Sir Bhupinder Singh, the Magnificent, was the seventh Maharajah of Patiala and father of the Chancellor of the Chamber of Princes. His pearl necklace was insured by Lloyd's of London for over $1 million, and he possessed a breastplate made up of 1,001 diamonds. According to Collins & Lapierre (1975): "From his earliest adolescence, Bhupinder Singh demonstrated a remarkably refined aptitude for an equally worthy princely pastime, sex. As he came into maturity his devotion to his harem eventually surpassed even his passions for jewels, polo and hunting. He personally supervised the steady accumulation of its inmates, selecting new recruits with a connoisseur's appreciation of variety in appearance and accomplishment in action. By the time the institution reached its fullest fruition, it contained 350 ladies.

"During the torrid Punjab summers, the harem moved outdoors in the evening to Bhupinder's pool. The prince stationed a score of barebreasted girls like nymphs at intervals around its rim. Chunks of ice bobbing in the pool's water gave the hot air a delicious chill while the Maharaja floated idly about, coming to port from time to time to caress a breast or have a sip of whiskey…." (Photo: from Johnston & Guest, 1937)

St. Edward's Sapphire is today a rose-cut gem, but this was probably not the original style, and it is thought that recutting was performed during the reign of Charles II. It is a stone not only of exceptional color and brilliance, but also with a marvelous legend behind it. The legend states that Edward the Confessor greatly admired St. John the Evangelist. One morning he happened to meet a beggar near Westminster. Having previously given away all his money, he presented his ring to the beggar. Some time later two Englishmen on pilgrimage to the holy land ran into a storm in Syria. Suddenly the path ahead lit up and an old man approached, preceded by two youths bearing candles. On hearing that the pilgrims were English and that Edward was their King, the old man guided them to an inn, where he found them food and lodging. The next morning as they were leaving, he told them he was John the Evangelist and gave them the ring to return to Edward. Bidding them goodbye, John said that he would see Edward in paradise in six months time. The pilgrims eventually returned to England, where they gave the ring and message to Edward. Edward recognized the ring, and thus began preparations for his death. Dying six months later, he was buried at Westminster with the ring on his finger. The tomb was later opened in the twelfth century and the ring given to the reigning King, according to legend (Sitwell, 1953).

Muséum National D'Histoire Naturelle

Ruspoli's Sapphire ('Wooden Spoon-Seller's Sapphire' or 'Great Sapphire of Louis XIV'). E.W. Streeter, in his book *Precious Stones and Gems* (1892), describes a number of fine sapphires. One of these was in the collection of the Musée au Jardin des Plantes, in Paris, and weighed 133.06 ct. The same stone was also described by S.M. Tagore (1879, 1881), who referred to it as the *Wooden Spoon-Seller's Sapphire,* in reference to the poor man who is said to have found it in Bengal, India. Streeter said it was without flaw. This is undoubtedly the same stone that resides today in Paris's Muséum National D'Histoire Naturelle, for it is of a distinctive lozenge shape and possesses only six facets, appearing like a huge sapphire rhomb. It is indeed nearly "without flaw," containing only one small feather and crystal inclusion, and is possibly of Burmese or Sri Lankan origin.

According to the Museum's H.-J. Schubnel (pers. comm., 16 Dec.–5 Jan., 1994–5), its true weight is 135.8 ct. In the museum it is known as *Ruspoli's Sapphire.* During the 17th century, a Roman prince named Ruspoli sold this sapphire to a salesman, who, in turn, sold it to King Louis XIV sometime before 1691. At that time it was the third most prominent gem in the French Crown Jewels.

During the French Revolution, the royal gems were confiscated by the revolutionary government and then stolen by Cadet Guyot. Only a few escaped, including the Ruspoli jewel, probably saved by its peculiar form. In 1796, the revolutionary government allowed the Museum to choose a few gems for educational purposes. Daubenton, the Museum's director, chose the Ruspoli Sapphire, cleverly labelling it as a sapphire crystal. Obviously he was lying, but it was for a noble cause. Today the Ruspoli Sapphire can be viewed in the Muséum National D'Histoire Naturelle (see Figure 10.21).[17]

Figure 10.21 The 135.8-ct *Ruspoli Sapphire* (*Wooden Spoon Seller's Sapphire*), in Paris' Musée au Jardin des Plantes. (Photo: H.-J. Schubnel, Galeria de Minéralogie, Muséum National D'Histoire Naturelle)

State Gem Corporation of Sri Lanka

Probably the finest large star sapphire in existence is the 393-ct piece owned by the State Gem Corporation of Sri Lanka. It is an incredibly rich blue color, much finer than the Star of Asia, and also exhibits a beautiful star. In 1981, this gem went on exhibition at the Festival of Sri Lanka in the Commonwealth Institute, Kensington, England, guarded by a 4.5-foot (137 cm) cobra sentry (Daily Telegraph, 1981).

Other notable sapphires

Catherine the Great's Sapphire. This colossus weighs in at a massive 337 ct. Of unknown origin, it was presented to Catherine II ('the Great') of Russia [b. 1729; d. 1796] in the latter part of the 18th century, by an unidentified admirer. The stone remained part of the Romanoff jewels for more

17. Bank (1973, p. 125) gives a slightly different version. He puts the sapphire at 135.20 ct (or 132¹⁄₁₆ ct). It was supposedly acquired by the Rome's House of Rospoli [sic?], and sold to a German Prince, who, in turn, sold it to the French jeweler, Perret, for 170,000 francs. Morel (1988) states that it was valued at 100,000 livres during the inventory of 1791.

World's largest?

AMONG the most difficult tasks facing the gemologist is that of testing the *world's largest*. 'Tis not a task for the meek; those called upon to test the world's largest somesuch are rarely showered with trust. All specimens are "priceless" and all are "absolutely genuine," having been either family heirlooms, or recently unearthed from someone's backyard or rice paddy. Thus the owner often demands to watch the proceedings, fearing that, if their back is turned for even an instant, the vulpine tester will slide an identical specimen out from under his cloak for the switch.

During the author's many years practicing gemology, people constantly turned up with the "world's largest" this or that. I've been privileged to examine the "world's largest ruby" (a large chunk of battered red glass), the "world's largest imperial green jade" (a large chunk of translucent green glass) and the "world's largest sapphire" (a large chunk of battered blue glass). But perhaps most impressive of all was the "world's largest pearl." So large was this that a fruit scale had to be used to determine its weight. Indeed, it was a pearl of sorts, but, to be frank, that may be an abuse of the term. It actually resembled something extruded from the rear of an enormous oyster, perhaps shortly after a meal of tainted shellfish. No doubt this extraordinary specimen now rests, yoke-like, between the pendulous breasts of a society maiden on the wrong side of 40.

While owners of such gems may genuinely believe them to be priceless, they surface most often from the bowels of unscrupulous dealers' collections, always with an inflated appraisal claiming them to be more valuable than the British Crown Jewels.

This was the case with the infamous *Life and Pride of America Star Sapphire*, which featured in many news reports of 1985 and 1986 (Hughes, 1987a). In a story that would warm the heart of even the most jaded observer, one Roy Whetstine claimed to have bought the 1905-ct stone for $10 at the Tucson gem show. But things turned dour when a reporter discovered that one L.A. Ward of San Diego, who appraised it at the whopping price of $1200/ct, had appraised another stone of the exact same weight several years *before* Whetstine said he found it. Photographs of the "gem" revealed an opaque corundum lump that would be put to better use dressing grinding wheels than windows at Tiffany.

than a century and a half, until sold by Nicholas II to finance a hospital train for the Russian army during World War I. It finally ended up in the US, where it was purchased by Harry Winston for an undisclosed sum. Winston placed the gem in his "Court of Jewels" collection, which toured the US from 1949 to 1953. It was later sold to an unknown buyer (Anonymous, 1951b; Krashes, 1986).

Gem of the Jungle. Next to the velvet-blue sapphires of Kashmir, those from Mogok are the finest. One fabulous 598-ct piece of Mogok rough was purchased by the English dealer and lapidary, Albert Ramsay, in 1928. This fine stone was found near Gwebin, by a miner named U Kyauk Lon (U Hla Win, pers. comm., May 2, 1994). $13,000 was paid for the rough, which came to be known as the *Gem of the Jungle*. Nine different stones were cut from it, ranging from 66.53 to 4.39 ct, and including stones of 20.11, 19.19, 13.15, 12.29, 11.39, 11.18, and 5.57 ct. All were personally cut by Ramsay and were said to be of exceptional color. A marvelous account of the purchase and cutting of this gem is given by Ramsay & Sparkes (1934).

Parure of Queen Marie Antoinette. This is a seven-piece jewelry set containing approximately 29 sapphires, of which 18 are stones of perhaps 20 ct or more. During the French Revolution they vanished, but later reappeared, to be bought by Napoleon, who gave it to his wife, the future Empress Josephine. Upon her death, it went to her daughter, Queen Hortense, who, after the fall of the Bonapartes, sold it to Louis- Philipe, then Duke of Orleans. Since then it has been worn by wives of the successive heads of the House of France, and now belongs to the Count of Paris. Three separate dynasties that have ruled France have owned it: the Bourbons, the Bonapartes, and the Orleans. A fine illustration of the parure is given in Michael (1983). Although most possess large windows due to overly shallow pavilions, together they are magnificent.

Another fine sapphire necklace is pictured in Michael's book; it is the 108-sapphire and diamond necklace of Queen Maria Christina of Spain. Originally from Sicily, she was the wife of Ferdinand VII, her mother's brother. After a terrible civil war, she fell in love with a bodyguard. The scandal of their marriage forced her to leave Spain. She had her portrait painted wearing this beautiful necklace. The jewel was sold by Christie's in 1982 for $297,000 (Michael, 1983).

During the London Exhibition of 1862, two magnificent sapphires were on display (Streeter, 1892). The larger, an oval of somewhat inky color and free from defect, weighed about 252 ct, and was cut in 1840. Although smaller at 165 ct, the second stone was of finer color. According to Streeter, it was by far the finest sapphire of its time to appear in Europe.

Streeter also mentions a fine sapphire in the famous Hope Collection, but no weight was given. It was noted because the gem retained its beauty as well by candle as by daylight. Another, in the Orleans Collection, was called in Madame de Genlis' tale *Le Saphir Merveilleux* (Streeter, 1892). It was violet by candlelight, but blue by daylight.

S.M. Tagore, in his classic work, *Maṉi-Málá* (1879), describes several celebrated sapphires. One of these was a fabulous stone of 951 ct, and was seen by an English ambassador to the Court of Ava (Burma). Tagore also mentions a curious custom among the Hindus of India. They were said to have a prejudice against sapphires, believing the blue gem to be the bringer of misfortune.

Figure 10.23 Engraved rubies of quality are extremely rare. The above is from France, ca. 1700 AD. (Photo: British Museum)

> In consequence of this notion, some of them would invariably keep a stone on trial for several days before they would make final settlement with the sellers. Hence, perhaps, the paucity in the numbers of Sapphires in their possession.
>
> S.M. Tagore, 1879, *Maṉi-Málá*

Famous blue sapphires are summarized in Table 10.6.

Famous fancy sapphires

Few fancy sapphires are described in the literature although there exist many fine examples, particularly from Sri Lanka. Australia, being an English-speaking country, has several well-documented examples.

Anderson's (Willows) Yellow. This was a 21-gram golden yellow stone found on the Willows field in Queensland in 1949. It produced a cut stone of 70 ct, later cut into several smaller gems, the largest weighing 35.75 ct.

Golden Willow (Golden Queen). In 1951, the Willows field again turned up a large yellow. This was named the *Golden Willow,* renamed the *Golden Queen,* and weighed 322 ct in the rough. It produced a 91.35-ct cut stone. The Willows field is noted for large yellow sapphires and a number of yellow-green gems in the 50–100 ct range have been found there.

Queensland. Queensland is famous for producing large black star sapphires. The best known is the *Queensland,* a 1156-ct cabochon giant. Although the inexperienced may believe such a stone to be extremely valuable, this is not the case, for these huge stones are typically heavily included. Their value is chiefly as curiosity items, rather than as true gems.

Although a number of large yellow sapphires have come from Australia, this is not the only source. The author has had the pleasure of examining one of the largest yellow sapphires from Thailand. It was a large emerald cut stone of approximately 75 ct, and owned by a Thai dealer. The stone was too shallow, possessing a rather large window, but in all other ways was magnificent. It was of the preferred *Mekong Whisky* yellow-orange color and without flaw.

In the American Museum of Natural History is what many consider to be the world's largest fine padparadscha. It is an oval stone of 100 ct (Sofianides & Harlow, 1990).

Notable examples of fancy sapphires are summarized in Table 10.7.

Engraved & carved rubies and sapphires

Due to its great hardness, only a few examples of carved/engraved corundums have come down to us from ancient times. Engraved gems were formerly of much greater importance than at present. Numerous books devoted to these magnificent works of art have been written, particularly in the eighteenth and nineteenth centuries. Undoubtedly the most prolific of the authors on this subject was C.W. King.

Writing in the late nineteenth century, King authored a number of books on the glyptic arts. In his *Natural History, Ancient and Modern, of Precious Stones and Gems, and of the Precious Metals* (1865), he describes several examples of both

Figure 10.24 This Burmese sapphire Buddha carving, housed in the British Museum, is a rare example of a quality carved sapphire. Due to the lack of royal patrons, modern artisans seldom have an opportunity to sculpt with such fine material. (Photo: © Fred Ward)

ruby and sapphire which have been engraved, mostly in Roman times:

> …the experienced Lessing (A. Br. lxxix.), and later the Count de Clarac (Cat. des Artistes Gr. et Rom.), altogether deny the existence of any really antique intagli in these harder gems; …Nevertheless, a few works in Ruby of apparently indisputable antiquity have been observed by me amongst the thousands of other gems examined. First, on account of the quality—a large oval slightly convex stone, of the true "pigeon's blood" tint, and weighing apparently about 3 carats—is one in the Devonshire Parure (No. 17 in the Bandeau), engraved with a Venus Victrix—a but poor intaglio in the latest Roman manner.
>
> C.W. King, 1865

King goes on to mention several other engravings done in spinel, but the general impression is that truly ancient intagli done in ruby were decidedly scarce.

Ancient sapphire (*hyacinthus*) engravings were only slightly less scarce. Like ruby, on account of the extreme hardness the ancients mostly employed sapphire as a mere ornamental stone for setting in their jewelry, drilled and semi-polished, but otherwise unengraved and unshaped.

> Amongst the Rutupine antiquities preserved in the library of Trinity College, Cambridge, a portion of a necklace of small rough Sapphires drilled at each end and linked together with gold wire, the exact ornament referred to by the poet Naumachius.
>
> Previous to the Imperial [Roman] epoch, engravings in Sapphire are of the rarest possible occurrence. A small Etruscan scarab, however, on an inferior variety has recently come under my notice, and also a magnificent head of jupiter inscribed IIY, executed in the purest Greek style. This latter had been discovered as ornamenting the pommel of a Turkish dagger, the intaglio turned downwards, and the back of the stone rudely facetted by the Oriental lapidary into whose hands this precious monument had fallen, an additional proof of its genuine antiquity. This stone was one inch in diameter.
>
> C.W. King, 1865

Superior to this as a work of art, and belonging to the same school, was the nearly full face of the Medusa's Head, described by King as one of the chief glories of the famous Marlborough Collection. The carving was said to have been enhanced by the material's fine quality. Most famous, though, was the Signet of Constantius II (then in the Rinuccini Collection), on a perfect stone weighing fifty-three carats. The Emperor is represented as spearing a monstrous wild boar, designated thereon ΞΙΦΙΑΟ (from his sword-like tusks), before a reclining female figure personifying "Cæsarea of Cappadocia," the scene of the exploit. The inscription CONSTANTIVS AVG in the field suggests that this costly stone had been engraved for the actual signet of the imperial hunter. Also mentioned by King was a fine sapphire engraving of Hebe feeding the Eagle. The stone, heartshaped and of fine color, measured 1.5 × 1.25 in (3.81 × 3.175 cm), and apparently belonged to the time of Hadrian.

Modern engraved sapphires were also described by King:

> Of modern works, the finest ever done is the portrait of Pope Paul III., ascribed, no doubt with justice, to the famous Alessandro Cesati, in the Pulsky Collection. It is a beautiful Sapphire 0.75 inch [1.9 cm] square, a truly inestimable gem, both for its fine quality and the spirit and life of the engraving, and was certainly the signet of the Pontiff himself. Inferior to this in point of art was the bust of Henri IV. by Caldoré (with his initials) on a large octagonal stone of pale colour, but possessing great historical interest. A large number of pale Sapphires may be seen in cabinets, engraved with heads of figures, usually but poorly done, in the style of the Cinque-cento. The reason is explained by De Laet (i. 7): —"The sort which is pale, or watery, is painted on the back with indigo, so as to imitate the sky-blue and superior kind, although this method is forbidden to jewellers to employ unless there be something engraved upon the stone, in order that its quality may distinguished.
>
> C.W. King, 1865

Famous engraved rubies and sapphires are summarized in Table 10.8.

Figure 10.25 Sri Lanka has long been known as the source of enormous sapphire crystals, but the world was still stunned when this 40.3-kg giant was unearthed in the 1980s. It was once offered for sale to Michael Jackson, but, alas, the Prince of Pop was not interested (pers. comm., Michael Laframboise & Lilly Rahman, 4 Oct., 1995). (Photo: GIA)

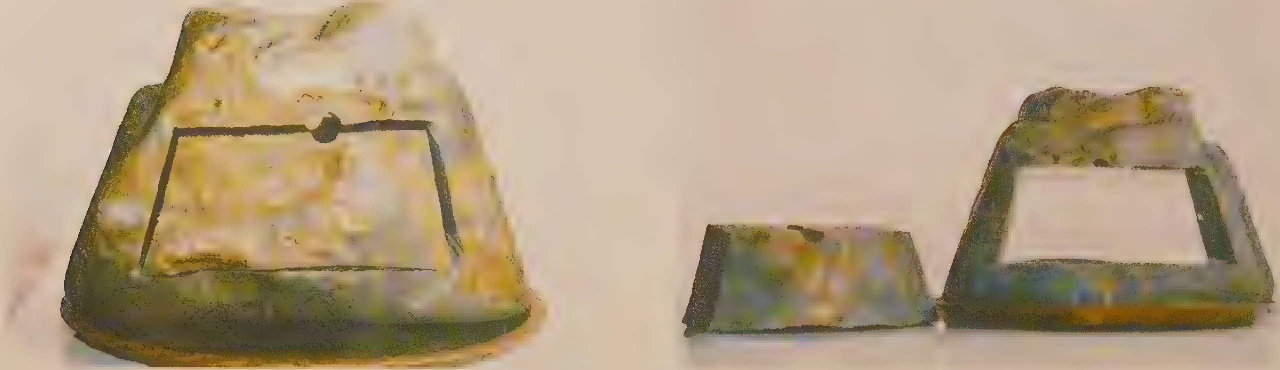

Figure 10.26 This 12.6-kg sapphire giant from Burma is owned by Myanma Gems Enterprise, the Rangoon government gem monopoly. In order to see if something of gem quality might be lurking within, MGE staff disemboweled it with drill and saw. Alas, the interior was just as opaque as the skin. (Photos: U Khin Mg Win/U Hla Win)

Rough corundum giants

Among the largest pieces of rough sapphire ever reported was that found in approximately 1967, at Mogok, Burma (Anonymous, 1967). It was bluish gray in color, measured 27 inches (68.58 cm) across and weighed a massive 63,000 ct (12.6 kg). The Myanma Gems Enterprise., a state-owned concern is the owner of this giant sapphire crystal. But even this is dwarfed by some of the giant crystals unearthed in Sri Lanka. One doubly-terminated specimen tipped the scales at 40.3 kg. Such large crystals are generally not of gem quality. They are summarized in Table 10.9.

Summary of important rubies & sapphires

The following tables list important rubies and sapphires. It is hoped they will assist researchers in locating and identifying stones in the future, particularly those of historical interest. Of course, they are merely the first, not last, word on the subject. Future editions will add further meat to this carcass of history.

Table 10.3: Summary of famous rubies

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Nga Boh Ruby ('Dragon Lord' Ruby) 44 ct rough; 20 ct cut; presented to King Tharawadi (1837–1846)	Bawbedan, Mogok, Burma Found 1837–1846	Unknown	Streeter, 1892 Smith, 1913 Halford-Watkins, 1934
Chhatrapati Manik 25 *rati*[b] (~21.5 ct); later repolished to 24 *rati* (~20.7 ct); oval cabochon; ~1 × 1.25 in (2.54 × 3.175 cm); its weight has also been listed as about 40 ct	Unknown (probably Burma)	Unknown	Clarke, 1933, 1934
Nga Mauk & Kallahpyan Rubies 7 ticals rough; cut stones of 98 & 74 ct	Mogok, Burma Found during reign of Mindon Min (1853–78); possibly 1861	Unknown	Streeter, 1892 Keely, 1982 Clark, 1991
Unnamed 36 ct; sold by King Mindon Min (reign: 1853–78) for £30,000	Burma Date unknown	Unknown	Brown, 1933
J.N. Forster Rubies Two large Burma rubies brought to England in 1875, weighing 37 and 47 ct. These were put on the market by the Burmese royal family and were later recut by Forster to $32\frac{5}{16}$ and $39\frac{9}{16}$ ct (or $38\frac{9}{16}$ ct); one sold for £10,000, the other for £20,000, respectively.	Mogok, Burma Date unknown (before 1877)	Unknown	Tagore, 1879, 1881 Anonymous, 1887 Streeter, 1892 Brown, 1933 Halford-Watkins, 1934
Maung Lin Ruby 400-ct rough; broken into three pieces, two of which were cut into stones of 70 and 45 ct. The third piece was sold uncut in Calcutta for Rs70,000 (£4,666).	Burma Found during reign of Mindon Min (1853–78)	Unknown	Streeter, 1892 Smith, 1913 Halford-Watkins, 1934
Tagoungnandaing Ruby $18\frac{7}{16}$-ct rough; fine color with trace of blue; sold in rough in London for £7,000. Later cut to 11 ct.	Tagoungnandaing Valley Kyatpyin, Burma 1895	Unknown	Talbot, 1920 Halford-Watkins, 1934
Pingu Taung Ruby $8\frac{7}{16}$-ct rough; found in ludwin in Pingu Taung ('Spider Mountain'); sold in London for £1762	Mogok, Burma 1893	Unknown	Halford-Watkins, 1934
Unnamed Rough which yielded cut gems of 98 and 74 ct	Burma Date unknown	Unknown	Smith, 1913
Unnamed 49 ct rough	Burma 1887	Unknown	Smith, 1913
Unnamed ~304 ct rough	Burma 1890	Unknown	Smith, 1913
Unnamed Weight unknown; probably rough; valued at Rs17,000	Burma March, 1893	Unknown	*Nature*, 1893
Mandalay Ruby 48.019 ct; faceted; cushion; offered for sale by Sotheby's New York on Oct. 18, 1988. No bids. In 1988, Sotheby's implied that this may have been the 47-ct J.N. Forster ruby described above (ca. 1877), which is impossible as that stone was recut to $38\frac{9}{16}$ ct.	Mogok, Burma Date unknown (pre-1896)	Unknown	Sotheby's, 1988b Federman, 1988
Unnamed 46¾ ct; oblong form (probably cut); mounted in brooch with four brilliant-cut diamonds; sold (or bought in) at Christie's London on May 7, 1896 for £8000. In 1988, Sotheby's implied that this was identical to the *Mandalay Ruby* above, but many doubt this version.	Probably Burma Date unknown	Unknown	Church, 1905 Sotheby's, 1988b Federman, 1988
Unnamed 77 ct; rough ruby; Sold in India in 1904 for Rs400,000 (£26,667)	Mogok, Burma 1899	Unknown	Holland, 1905 Smith, 1913
Padansho Ruby 13 ct; rough; of secondary color; flat elongated shape; sold uncut in London for £1514	Mogok, Burma 1901	Unknown	Halford-Watkins, 1934
Shwebontha Ruby No. 1 15½ ct; rough; sold uncut in London for £1500	Mogok, Burma 1901	Unknown	Halford-Watkins, 1934
Shwebontha Ruby No. 2 9½ ct; rough; sold uncut in London for £1444	Mogok, Burma 1902	Unknown	Halford-Watkins, 1934
Chaungzone Ruby 23½ ct; rough; sold uncut in London for £2005	Mogok Valley, Burma 1903	Unknown	Halford-Watkins, 1934
Red Hill Ruby 7 ct; rough; sold uncut in London for £534	Mogok, Burma 1904	Unknown	Halford-Watkins, 1934
Taroktan Ruby No. 1 9 ct; rough; sold uncut in London for £635	Mogok, Burma 1904	Unknown	Halford-Watkins, 1934
Taroktan Ruby No. 2 7 ct; rough; sold uncut in London for £490	Mogok, Burma 1906	Unknown	Halford-Watkins, 1934
Unnamed 42 ct rough; 22 ct cut; reportedly bought by Indian dealer named Chodilla for 300,000 Kyat (over $100,000). This has possibly been confused with the Peace ruby (see below).	Mogok, Burma ~1906	Unknown	Ehrmann, 1957

Table 10.3: Summary of famous rubies *(continued)*

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
J.P. Morgan Collection of cut rubies • 47 ct; Burma; irregular cabochon; not clean • 67 ct; faceted; asymmetrical; pink; Ceylon • 8.81 ct; Burma; carved head • 6 rubies together of 6.72 ct; Cowee Valley, North Carolina	Various sources & dates	American Museum of Natural History	Kunz, 1913b Pough, 1964
Kathé Ruby No. 1 22½ ct; rough; sold uncut in London for £1600	Kathé, Mogok, Burma 1915	Unknown	Halford-Watkins, 1934
Thebaw Ruby ('Lucky' Baldwin's Ruby) Originally 26.12 ct; since recut; appeared at auction, Geneva, May, 1971	Source & date unknown (probably Burma)	Unknown	Krashes, 1986, pp. 8–9
Peace Ruby 42 old ct rough; 25 ct cut; faceted round brilliant; sold for Rs300,000 (£27,500)	Mogok, Burma 1919	Unknown	Brown, 1927 Halford-Watkins, 1934 Keely, 1982
Lady Craddock Ruby 22¾ ct; rough; good color, but long narrow shape; sold uncut in London for £4000	Mogok Valley, Burma 1922	Unknown	Halford-Watkins, 1934
Enjouk Ruby 22⅝-ct; rough; not quite the best color; sold in London rough for £2447	Enjouk, Mogok, Burma 1923	Unknown	*Mineral Industry*, 1924 Halford-Watkins, 1934
Kathé Ruby No. 2 21.5 ct; rough; sold uncut in London for £1667	Kathé, Mogok, Burma 1924	Unknown	Halford-Watkins, 1934
Unnamed 96 ct; not stated whether rough or cut; the stone was cracked down the middle, necessitating cutting into two pieces; sold for £7500	Mogok, Burma Aug. 24, 1929	Unknown	*Mineral Industry*, 1930
Unnamed ~100 ct; not stated whether rough or cut	Mogok, Burma Oct., 1930	Unknown	*Mineral Industry*, 1931
Unnamed 19 ct; rough	Mogok, Burma June, 1931	Unknown	*Times of London*, 4 June, 1931
Pama Ruby 32.90-ct rough; sold in rough for £3270; cut in Paris into a square trap-cut stone weighing 9.25 ct.	Kyatpyin, Mogok, Burma 1931	Unknown	Halford-Watkins, 1934
Unnamed 17 ct; rough	Chaunggyi Valley Mogok, Burma April, 1932	Unknown	*Times of London*, 27 April, 1932
Unnamed ~30 ct; rough; valued at £7,000	Mogok, Burma Oct., 1932	Unknown	Anonymous, 1932b Brown, 1933
Unnamed 34 lb (15.42 kg); hexagonal prism crystal (not gem quality)	Corundum Hill, Macon Co., North Carolina, USA Date unknown	British Museum of Natural History	Spencer, 1933
Edwardes Ruby 167 ct; crystal; donated to the British Museum in 1887 by John Ruskin, who named it for Major-General Sir Herbert Edwardes, who is credited for maintaining British rule in India during the Mutiny	Mogok, Burma Date unknown	British Museum of Natural History	Spencer, 1933 Bruce, 1977
Unnamed 3,450 ct (690 g); crystal	Mogok, Burma Date unknown	British Museum of Natural History	Spencer, 1933
Unnamed Nearly 20-ct. rough; 7.5 ct cut; valued at ~£10,000	Mogok, Burma ca. 1933	Unknown	Anonymous, 1933
DeLong Star Ruby 100.32 ct; oval cabochon; star; donated by Edith Haggin DeLong in 1937, who bought it from Martin Ehrmann for US$21,400	Burma Pre 1937	American Museum of Natural History	Anonymous, 1938 Smith & Smith, 1994
Unnamed 310 ct; star ruby (not known whether rough or cut)	Ratnapura, Sri Lanka May, 1941	Unknown	*Mineral Industry*, 1942
Star of Chanthaboon 10.25 ct; transparent, slightly purplish red (not known rough or cut)	'Hill of the Stars' Chanthaburi, Thailand Date unknown	Unknown	Gühler, 1947
12-rayed star ruby 25.2 ct; cabochon; 12-rayed star; deep violet-red color	Ratuapur [sic?], Sri Lanka; ca. 1950?	Unknown (last seen with Fred Pough)	Anonymous, 1950
Stem Cup Cup composed of step-cut rubies set within vertical gold ribs	Source unknown Date unknown	Crown Jewels of Iran	Meen & Tushingham, 1968
Rosser Reeves Star Ruby 138.7 ct; cabochon; star ruby; insured for $150,000 in 1966; this is considered to be the largest fine star ruby in existence	Sri Lanka Date unknown (seen about 1954–6)	Smithsonian	Anonymous, 1966 White, 1991

Table 10.3: Summary of famous rubies *(continued)*

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Unnamed 4.12 ct; faceted; cushion; set in ring with smaller rubies and diamonds; sold at Christie's Geneva on Nov. 24, 1979 for $412,000 ($100,639/ct), then a record price for ruby	Burma Date unknown	Unknown	Rush & Rush, 1979
Unnamed 15.00 ct; faceted; pear shape mounted in a pendant brooch; sold at Sotheby's New York, Oct. 1986, for $1,540,000 (~$102,667/ct), then a record price for ruby	Burma Date unknown	Purchased by private European buyer	Anonymous, 1986 Christie's, 1990
Alan Caplan's Ruby ('Mogok Ruby') 15.97 ct; faceted; sold at Sotheby's New York, Oct., 1988 for $3,630,000 ($227,301/ct). **Auction record per carat price for ruby.**	Mogok, Burma Date unknown	Purchased by Graff for the Sultan of Brunei for an engagement ring for one of his wives.	Keller, 1983 Koivula & Kammerling, 1988 Kapil Malhotra, pers. comm., 6 Feb., 1995
Hixon Ruby 196.1 ct; crystal	Mogok, Burma Date unknown	Los Angeles County Museum of Natural History	Keller, 1983
Unnamed 24.13 ct; star ruby	Sri Lanka Date unknown	Unknown	Punchiappuhamy, 1984
Unnamed 150 ct; rough, ruby	Trat, Thailand 1986	Unknown	Hughes, 1990
Unnamed 8.78 ct; cut; mounted in ring; sold at Christie's New York, April 20, 1988 (Lot 292) for $858,000 ($97,722/ct)	Burma Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 25.70 ct; cut; set in ring; sold at Christie's Geneva, Nov. 1988 (Lot 587) for SFr1,760,000 ($1,205,479; or $46,906/ct)	Source unknown Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 14.00 ct; cushion shape; sold in 1988 for $968,000 ($69,142/ct)	Source unknown Date unknown	Unknown	Christie's, 1990
Unnamed 10.35 ct; cushion shape; sold in 1988 for $1,861,000 ($179,807/ct)	Source unknown Date unknown	Unknown	Christie's, 1990
Unnamed 10.01 ct; cushion shape; sold in 1989 for $1,497,000 ($149,550/ct)	Source unknown Date unknown	Unknown	Christie's, 1990
Unnamed 24.20 ct; cushion shape; sold in 1989 for $3,080,000 ($127,273/ct)	Source unknown Date unknown	Unknown	Christie's, 1990
Unnamed 32.08-ct; faceted, set in ring by Chaumet of Paris; sold on Oct. 26, 1989 at Sotheby's New York (Lot 47) for $4,620,000 ($144,015/ct)	Burma Date unknown	Unknown	Sotheby's, 1989 Matthews, 1993
Unnamed Ruby necklace with diamonds by Van Cleef & Arpels; sold by Sotheby's in 1989 for $3,080,000. **Auction record price for ruby & diamond necklace.**	Source unknown Date unknown	Unknown	Sotheby's, 1989
SLORC Ruby (formerly called the *Nawata Ruby*) 504.5-ct crystal, later trimmed to 496.5 ct	Dattaw (Dattow) Mogok, Burma February, 1990	Myanna Gems Enterprise Rangoon, Burma	*Asiaweek*, 1990 Hughes, 1990b Kane & Kammerling, 1992
Nawarat Tharaphu Ruby 5.25 ct; faceted, cut from 9.70-ct rough	Nawarat, Shan State, Burma Mined on April 23, 1990	Myanna Gems Enterprise Rangoon, Burma	Kane & Kammerling, 1992
Unnamed 8.14 ct; cushion, sold in 1990 for $990,000 ($121,621/ct)	Source unknown Date unknown	Unknown	Christie's, 1990
Unnamed 12.50-ct; cut, mounted in ring; sold at Christie's New York, Oct. 23, 1990 (Lot 443), for $1,045,000 ($83,600/ct)	Burma Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 16.20-ct; cut, mounted in ring; sold at Christie's New York, Oct. 23, 1990 (Lot 445) for $2,750,000 ($169,753/ct)	Burma Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 4.70-ct cut; sold at Feb. 1992 MGE Emporium for $282,000 ($60,000/ct)	Lin Yaung Chi Mogok, Burma Date unknown	Unknown	Kane & Kammerling, 1992
Unnamed 12.10-ct ruby ring; sold at Christie's Geneva, Nov., 1992 (Lot 606) for SFr2,860,000 ($2,000,000; $165,289/ct)	Source unknown Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 9.10 ct; faceted; cushion; sold at Myanma Gem Emporium, Feb, 1992, for $901,000 ($99,011/ct)	Mogok, Burma Date unknown	Purchased by David Gol of Switzerland	Clark, 1992

Table 10.3: Summary of famous rubies *(continued)*

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Crown of Mogok Ruby 10.95-ct rough; 5.56-ct faceted oval	Shwe Pyi Aye Mogok, Burma Date unknown	Unknown	Kane & Kammerling, 1992
Neelanjali Ruby 1,370 ct; cabochon; 12-rayed star	Source unknown Date unknown	G. Vidyaraj Bangalore, India	Matthews, 1993
Eminent Star Ruby Over 30,000 ct in the rough; 6465 ct cut; oval cabochon; star; of poor quality	Source unknown (probably India) Date unknown	Eminent Gems, New York	*ICA Gazette*, 1994
Unnamed 16.51 ct; faceted, cushion shape; sold in 1993 by Sotheby's for $3,000,000 ($181,708/ct)	Burma Date unknown	Unknown	*Colored Stone*, March/April, 1994
Unnamed 38.12 ct; cabochon; sold at 1993 Myanma Gems Enterprise mid-year auction in Rangoon for $5,860,000 ($153,725/ct). **Auction record total price for a single ruby.**	Burma Date unknown	Unknown	Anonymous, 1994 U Hla Win (pers. comm., 2 May, 1994)
Unnamed 26.40-ct star ruby cabochon; sold at Christie's New York, April 12, 1994 (Lot 55) for $1,080,500 ($40,928 per ct). **Auction record for a star ruby.**	Burma Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994)
Unnamed 10.11 ct; faceted, cushion shape; sold at Christie's New York in Oct. 1994 (Lot 317) for $948,500 ($93,818/ct)	Burma Date unknown	Unknown	GAA Market Monitor, 1995
Unnamed 27.37 ct; faceted, pear shape, mounted in diamond pendant by Harry Winston; sold at Sotheby's Geneva in May, 1995 (Lot 469), for $1,500,000 ($122,750/ct)	Burma Date unknown	Unknown	*ICA Gazette*, 1995 *JewelSiam*, 1995
Unnamed 12.22 ct; faceted, cushion shape, mounted in ring; sold at Sotheby's Geneva in May, 1995 (Lot 464), for $4,000,000 ($146,145/ct)	Source unknown Date unknown	Unknown	*JewelSiam*, 1995

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.

b. The *rati* is an old Indian unit of weight. I have converted it into metric carats using Aziz's average jeweler's *rati* of 2.66 grains troy, or 0.8618 metric carats. See Aziz (1942, pp. 119–134) for a full account of Indian weights, which varied slightly over time.

Table 10.4: Summary of titled red spinels

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Black Prince's Ruby Size unknown (approx. 140 ct); semi-polished; drilled; gold-foil backing; mounted in front of Imperial State Crown	Source unknown (Badakhshan?) Dates back to 1366 AD	British Crown Jewels	Orpen, 1890 Anonymous, 1937 Bank, 1973
Timur Ruby (*Khiraj-i-alam*, or 'Tribute to the World') 352.50 ct; semi-polished; engraved with the names of its former owners	Source unknown (Badakhshan?)	British Queen's private collection	*Times of London*, 1912 Twining, 1960
Catherine the Great's Ruby 414.30 ct (or 398.72 ct?); semi polished; mounted in the top of the Grand Imperial Crown (for a full account of this gem, see box, page 282)	Source unknown (Badakhshan?) Possibly early 1400s	Diamond Fund, Moscow	Twining, 1960 USSR Dia. Fund, 1972 Yevdokimov, 1991
Côte de Bretagne Jewel 105 ct; orange-red; carved as an oriental dragon; formerly mounted in the decoration of the Order of the Golden Fleece, along with the French Blue Diamond (Hope Diamond)	Source unknown Dates back at least to 1530 AD	Galerie d' Apollon Louvre, Paris	Patch, 1976
Samarian Spinel 500 ct; blood-red; semi-polished; drilled	Source unknown (Badakhshan?)	Crown Jewels of Iran	Meen & Tushingham, 1968 Bank Markazi Iran, 1971
Katherina & Catherine Spinels 532 ct rough; faceted stones of 146.43 & 27.81 ct	Pamir Mountains Tajikistan	Unknown	Bancroft, 1990

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.

Table 10.5: Summary of rubies and sapphires in the Mughal treasury (from Aziz, 1942)[a]

Description	Weight of cut stone[b]	Price (Rupees)
Akbar's reign (1556–1605 AD)		
• Standard ruby	• 284 *rati* (~244.75 ct)	• 100,000
• Ruby offered by Raja Ramchand of Bhatha to Akbar	• Unknown	• 50,000
• Ruby sent by Prince Daniyal to Akbar	• 104 *rati* (~89.63 ct)	• Unknown
Jahangir's reign (1605–1627 AD)		
• Ruby presented by Jahangir to Prince Parwiz	• Unknown	• 25,000
• Ruby offered by Asaf Khan to Jahangir	• Unknown	• 40,000
• Ruby presented to Jahangir by "Mirza Husain"	• Unknown	• Rs100
• Ruby ring in one piece sent to Jahangir by Murtaza Khan from Gujarat; said to be of good color, substance and water	• 37 *rati* (~31.89 ct)	• 25,000
• Ruby sent by same	• 59 *rati* (~50.85 ct)	"
• *Qutbi* ruby; offered by Vazir Khan	• Unknown	• Unknown
• Ruby offered by Asaf Khan to Jahangir; of beautiful color and well-shaped; Abu'l-Qasim bought it in Cambay for Rs75,000	• 168 *rati* (~144.78 ct)	• 60,000
• Ruby bestowed by Jahangir on Prince Parwiz	• Unknown	"
• Celebrated ruby offered by Rana Amar Singh to Prince Khurram, and by the latter to Jahangir; originally from Raja Maldeo	• 192 *rati* (~165.47 ct)	"
• *Qutbi* ruby presented by I'timadu'd-Daula to Jahangir	• Unknown	• 22,000
• Ruby of the purest water and brilliance offered by Prince Khurram	• Unknown	• 80,000
• Exceedingly beautiful and clear ruby offered by Prince Khurram to Jahangir at Ajmer	• Unknown	• 60,000
• Ruby offered to Jahangir by Mahabat Khan	• Unknown	• 65,000
• Ruby sent by Jahangir to Shah Sultan Khurram	• Unknown	• >30,000
• Ruby purchased by Mahabat Khan from a European and offered to Jahangir	• 286 or 291.5 *rati* (~246.47 or 251.21 ct)	• 100,000
• Fine ruby offered by Prince Shah Jahan to Jahangir; largest ruby in the treasury	• 456 *rati* (~372.10 ct)	• 200,000
• Very fine ruby of good color offered by Prince Shah Jahan to Nur Jahan	• 132 *rati* (~113.76 ct)	• 50,000
• Ruby bestowed by Jahangir on Prince Shah Jahan; Akbar's mother had given it to Prince Salim upon the latter's birth	• 221 *rati* (~190.46 ct)	• 125,000
• Ruby in Nur Jahan's necklace	• Unknown	• 10,000
• A very fine *qutbi* ruby offered by Prince Shah Jahan to Jahangir	• 72 *rati* (~62.04 ct)	• 40,000
• Ruby offered by Asaf Khan to Jahangir	• 300 *rati* (~258.54 ct)	• 125,000
• Engraved ruby of Timurid family sent by Shah 'Abbas of Persia to Jahangir, who then gave it to Prince Shah Jahan. This history was engraved upon it in three inscriptions; later set in the middle slab of the rail of the Peacock Throne	• 288 or 312 *rati* (~248.20 or 268.88 ct)	• 100,000
• Ruby offered by Lashkar Khan	• Unknown	• 4,000
• Ruby offered by Khan Jahan	• Unknown	• 100,000
• Sapphire sent by 'Adil Khan to Jahangir; large and fine, of a beautiful, rich color	• 151 *rati* (130.13 ct)	• 100,000
• *Qutbi* sapphire offered by I'timadu'd-Daula to Jahangir; exceedingly delicate	• Unknown	• Unknown
Shah Jahan's reign (1628–1658 AD)		
• Central ruby of Shah Jahan's *sarpech*; superior in quality even to the much heavier 456 *rati* ruby of Jahangir	• 288 *rati* (~248.20 ct)	• >200,000
Aurangzeb's reign (1658–1707 AD)		
• Bright-colored ruby sent by 'Abdu'l-Aziz Khan of Bukhara to Aurangzeb	• Unknown	• 40,000
• Ruby sent by 'Adil Khan of Bijapur to Aurangzeb	• 125 *rati* (~107.73 ct)	• 20,000
• Ruby offered by Husain Pasha, the ruler of Basra	• Unknown	"
• The favorite, unparalleled 'oriental topaz' (yellow or orange sapphire) of Aurangzeb; of very high color; cut in 8 panels	• 152.16 English ct	• 181,000
• 'Oriental amethyst' (violet sapphire) mounted in the middle of Aurangzeb's chain of pearls and emeralds; a long table; perfect in beauty	• 40 *rati* (~34.47 ct)	• Unknown

a. Many of the above rubies may, in fact, have been spinels, particularly the larger pieces.
b. The *rati* is an old Indian unit of weight. I have converted it into metric carats using Aziz's average jeweler's *rati* of 2.66 grains troy, or 0.8618 metric carats. See Aziz (1942, pp. 119–134) for a full account of Indian weights, which varied slightly over time.

Table 10.6: Summary of famous blue sapphires

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
St. Edward's Sapphire Weight unknown; blue; faceted cushion; mounted in Maltese cross atop the British Imperial State Crown	Source unknown Legends date to 1042 AD	British Crown Jewels, Tower of London	Sitwell, 1953
Stuart Sapphire Slightly over 104 ct; 1.5" (3.81 cm) long × 1" (2.54 cm) wide; oval; mounted on the band at the rear of the British Imperial State Crown	Source unknown Dates to 1214 AD (probably in the crown at the coronation of King Alexander II)	British Crown Jewels, Tower of London	Orpen, 1890 Younghusband, 1921 Anonymous, 1936 Anonymous, 1951 Twining, 1967
Unnamed Oldest known talismanic sapphire existing in western Europe; once served as a clasp for the Imperial mantle covering the sacred remains of Charlemagne; presented to Napoleon Bonaparte when he arrived at Aix-la-Chapell after the conquest of Germany.; mounted in gold, with a splinter of the Cross in its setting, it was supposed to give its possessor dominion over the whole world.	Source unknown Date unknown	Cathedral of Reims (Rheims) France	Abbot, 1933
Catherine the Great's Sapphire 337.10 metric ct; faceted; oval; blue; estimated value at over US$250,000 (1951)	Source unknown Date unknown	Unknown	Anonymous, 1951b Zeitner, 1984 Krashes, 1986
Unnamed 260 ct; once part of the Russian regalia	Source unknown Date unknown	Moscow	Anonymous, 1951a
Unnamed 258.18 ct; faceted; oval-cushion; mounted in brooch; may be the same stone as above	Source unknown ca. 19th century	Diamond Fund Moscow	USSR Dia. Fund, 1972
Ruspoli's Sapphire ('Wooden Spoon Seller's Sapphire' or *'Great Sapphire of Louis XIV')* 135.8 ct; faceted; rhomb shaped (only six facets); said to have been found by a wooden spoon seller in Bengal; sold by the House of Ruspoli (Rospoli?) of Rome to a German prince (salesman?), who in turn sold it to the French jeweler Perret for 170,000 francs. Later purchased by Louis XIV.	Said to be Bengal; probably Burma or Sri Lanka Date unknown	Muséum National D'Histoire Naturelle, Paris Valued at £100,000 in 1791	Tagore, 1879, 1881 Streeter, 1892 Bank, 1973 H.-J. Schubnel (pers. comm., 16 Dec., 1994; 5 Jan., 1995)
Loop Sapphire No. 1 252 ct; oval; dark indigo color; cut in 1840; displayed at London Exhibition of 1862 and Paris in 1867; named after Loop, the London cutter who fashioned it.	Source unknown Date unknown	Unknown	Halford-Watkins, 1934
Loop Sapphire No. 2 Once 225 ct; table cut, recut in 1856 (current weight unknown); displayed at London Exhibition of 1862 and Paris in 1867; sold in Paris for nearly £8000	Source unknown Date unknown	Unknown	Halford-Watkins, 1934
Le Saphir Merveilleux ('Hope Sapphire') Weight unknown; blue in daylight, violet in candlelight	Source unknown Date unknown	Orleans Collection France	Streeter, 1892
Star of India 563.35 ct; blue star sapphire, cabochon; donated as part of J.P. Morgan Collection; reportedly cut by Albert Ramsay ca. 1905 in London; brought to London from India by British Army officer	Sri Lanka Date unknown	American Museum of Natural History	Kunz, 1913a Anonymous, 1935b Sofianides & Harlow, 1990
Midnight Star 116.75 ct; cabochon; star; deep purple-violet color; donated as part of J.P. Morgan Collection	Sri Lanka Date unknown	American Museum of Natural History	Sofianides & Harlow, 1990
J.P. Morgan Collection of sapphires; various cut gems, including: • 188, 158.72, 154 (153?), 69 ct; blue; Ceylon • 14.22 ct; blue; engraved; India • 29 Yogo sapphire (two are above 3 ct)	Various sources & dates	American Museum of Natural History	Kunz, 1913b Pough, 1964 Voynick, 1985, pp. 188–9
Unnamed 951 ct; rough or cut unknown; seen in 1827 in the treasury of the king of Ava	Unknown (Burma?) Date unknown	Unknown	Tagore, 1879, 1881 Smith, 1913
Unnamed 19 ct rough, 8.5 ct cut (cut as a seal); believed to be the second-largest sapphire ever found at Yogo Gulch	English Mine Yogo Gulch, MT ca. 1910	Unknown	Kunz, 1911 Voynick, 1985
Unnamed 10.2 ct cut; believed to be the largest cut Yogo stone in existence	Yogo Gulch, MT Date unknown	Smithsonian	Voynick, 1985, p. 189
F.G. McIntosh collection 83 Yogo sapphires	Yogo Gulch, MT Various dates	Cal-Tech, Pasadena, CA	Voynick, 1985, p. 189
Unnamed Rough, weight unknown; sold for Rs28,000 (£1,870)	Redhill Mine Mogok, Burma, 1917	Unknown	*Times of London*, 11 July, 1917
Unnamed 113 ct; rough; sold for Rs45,000	Bernardmyo, Mogok, Burma, May 10, 1919	Unknown	*Times of London*, 11 July, 1919
Unnamed Weight unknown; rough; sold for Rs40,000	Mogok, Burma 1919	Unknown	*Times of London*, 15 July, 1919
Unnamed 50 ct (probably cut); sold for £1,200	Source unknown Date unknown	Unknown	*Times of London*, 12 Nov., 1924

Table 10.6: Summary of famous blue sapphires *(continued)*

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Unnamed 570 and 680-ct rough sapphires; sent to be exhibited in the Ceylon Gallery of the Wembly Exposition; many fine stones were found in the same field in a short period of time	Balmadulla, Sri Lanka 1923	Unknown	*Mineral Industry,* 1924
Unnamed Over 40 ct rough; 10.87 ct cut	Bo Ploi, Thailand ca. June, 1927–1929	Unknown	*Mineral Industry,* 1929
Unnamed 437 ct; not stated whether rough or cut; valued at over £11,000	Mogok, Burma 1928	Unknown	*Mineral Industry,* 1929
The King 392.75 ct; star sapphire; seized by US Customs 1916; bought by William G. Willman, New York City, who refused offer of $100,000	Source unknown Date unknown	Unknown	Anonymous, 1935b
Gem of the Jungle 958 ct. rough; cut stones of 66.50 (66.53?), 20.25, 20.00, 13.11, 12.25, 11.33, 11.11, 5.50 and 4.33 ct; purchased by Albert Ramsay for over £13,000	Gwebin, Mogok, Burma August, 1929 (or July, 1930)	Unknown	*Mineral Industry,* 1930 *Mineral Industry,* 1931 Ramsay & Sparkes, 1934 Halford-Watkins, 1935a
Lady Alice Montagu-Douglas-Scott's sapphire ring Oval sapphire engagement ring given by Duke of Gloucester	Kashmir Date unknown	Unknown	Anonymous, 1935a
Star of Bombay 182 ct; cabochon; blue-violet star sapphire; bequeathed to Smithsonian by Mary Pickford	Source unknown Date unknown	Smithsonian	White, 1991
Star of Asia 330 ct; cabochon cut; blue-violet star sapphire; acquired in 1961 from Martin Ehrmann; once said to belong to the Maharaja of Jodhpur	Burma Date unknown	Smithsonian	Desautels, 1972 White, 1991
Logan Sapphire 423 ct; faceted cushion; blue; donated to Smithsonian in 1960 by Mrs. John A. (Polly) Logan	Sri Lanka Date unknown	Smithsonian	Desautels, 1972 White, 1991
Star of Artaban 316 ct; star; donated by Ingram	Sri Lanka Date unknown	Smithsonian	Desautels, 1972
Unnamed 630 ct rough (upon breaking up for cutting, it proved less valuable than expected)	Kathé Mogok, Burma May, 1930	Unknown	*Times of London,* 31 May, 1930 *Mineral Industry,* 1930, 1932 Brown, 1933
Unnamed 293 ct rough	Kathé Mogok, Burma 1930	Unknown	Brown, 1933
Unnamed nearly 1000 ct rough	Gwebin, Mogok, Burma Aug. 12, 1932	Unknown	Brown, 1933
Unnamed 514 ct; rough	Mogok, Burma Dec., 1932	Unknown	Brown, 1933
Unnamed 435 ct; not known whether rough or cut; star sapphire	Kathé, Mogok, Burma 1932	Unknown	*Mineral Industry,* 1934
Unnamed 390 ct; rough; sold for over £3,000	Mogok, Burma 1930s	Unknown	Halford-Watkins, 1935b
Unnamed 18 ct (not known rough or cut); said to be largest fine Pailin sapphire; sold for Tcs. 12,000 (48,000 Baht)	Pailin, Cambodia Date unknown	Unknown	Gühler, 1947
Star of Lanka 193.39 ct; oval cabochon; blue gray color; star	Sri Lanka Date unknown	Royal Ontario Museum Toronto, Canada	Meen, 1963
Star of Ceylon ~101.01 ct; oval cabochon; medium violetish blue	Source unknown Date unknown	Seattle Private collection	Richard Allen, pers. comm., 9 Nov., 1994
Barberini Jewels Antique sapphire and diamond parure; contains 24 cushion-shaped sapphires; ca. 1800; sold at Christie's New York, Nov. 18, 1971 (Lot 139)	Source unknown Date unknown	Unknown	Christie *et al.,* 1971
Bismarck Sapphire 27 × 21.7 × 15.5 mm, faceted squarish oval, blue; donated by Countess Mona Bismarck	Sri Lanka Date unknown	Smithsonian	Dunn, 1975
Big Sky Sapphire 24 ct rough; 12.54 ct; faceted antique cushion; medium blue; one of largest faceted Missouri River sapphires	Missouri River, MT Found in Sept., 1973 by Mac M. Mader	Unknown	Liddicoat, 1975 Zeitner, 1978 Zeitner, 1984
Unnamed 11.81 ct; faceted; cushion; ring; sold at Christie's Geneva on Nov. 24, 1979 for $304,875 ($25,815/ct), at the time a per ct record for sapphire	Kashmir, India Date unknown	Unknown	Rush & Rush, 1979

Table 10.6: Summary of famous blue sapphires *(continued)*

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Unnamed 362 ct; cabochon; blue; star (this may be the same stone as the 393 ct star below)	Sri Lanka Date unknown	State Gem Corp. of Sri Lanka	Wijesekera, 1980
Unnamed 393 (392?) ct; blue star sapphire, cabochon; insured in 1981 for over £1 million; this is probably the finest star sapphire of its size in the world	Sri Lanka Date unknown	State Gem Corp. of Sri Lanka	Daily Telegraph, 25 Aug., 1981 Punchiappuhamy, 1984
Unnamed 58.33 ct; faceted, cushion shape, mounted in 1920s Cartier Art Deco bracelet formerly owned by Marjorie Merriweather Post; sold at Christie's New York, 15–16 Oct. (Lot 454?) for $880,000 ($15,087/ct). This was a world record price for sapphire at the time.	Source unknown (Burma?) Date unknown	Purchased by London buyer	Christie's Magazine, ca. 1982–83
Unnamed ~99 ct; faceted; round; offered in Bangkok in early 1980s for $10,000/ct	Burma Date unknown	Unknown	Author
Blue Princess 114.30 ct; faceted; cushion; mounted in necklace with three large sapphires of approx. 24.09, 40.87 and 26.95 ct; sold at Christie's New York, April 11, 1984 (Lot 487) for $1,320,000	Unknown Date unknown	Unknown	Christie *et al.*, 1984
Unnamed 41.04 ct; faceted; emerald cut; sold at Sotheby's New York, Oct. 1986 for $924,000 ($22,515/ct)	Burma Date unknown	Purchased by American retailer	Anonymous, 1986
Unnamed 152.35 ct; cabochon; round; mounted in panther clip; sold at Sotheby's Geneva, 2–3 April, 1987 (Lot 179) for SFr 1,540,000 ($1,026,667; or $6739/ct); formerly owned by the Duchess of Windsor	Source unknown Made by Cartier, 1949	Unknown	Culme & Rayner, 1987
Unnamed 206.82 ct; faceted; oval cushion; mounted in diamond pendant; sold at Sotheby's Geneva, 2–3 April, 1987 (Lot 119) for SFr 561,000 ($374,000; or $1808/ct); formerly owned by the Duchess of Windsor	Source unknown Made by Cartier, 1951	Unknown	Culme & Rayner, 1987
Rockefeller Sapphire 62.02 ct; faceted, rectangular step cut; mounted in diamond ring; sold to Ralph Esmarian at Sotheby's St Moritz, Feb. 20, 1988, for $2,828,546 ($45,607/ct). Recut by Reginald Miller from 66.03 to 62.02 ct in the early 1970s. **Per carat and total price world record for a single blue sapphire.**	Burma Date unknown	Unknown	Sotheby's, 1988a Hughes & Sersen, 1988b Federman, 1992 Matthews, 1993
Unnamed Kashmir sapphire & diamond bracelet by Cartier; 9 sapphires (8 from Kashmir) from 4.17 to 10.52 ct (49.63 ct total); sold at Christie's New York on April 20, 1988 (Lot 306) for $902,000	Kashmir Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994
Unnamed Kashmir sapphire & diamond bracelet; 8 sapphires (7 from Kashmir) from 4.70 to 10.55 ct (50.95 ct total); sold at Christie's New York on Oct. 19, 1988 (Lot 393) for $1,034,000	Kashmir Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994
Unnamed 204.39 ct; oval; star; fine blue color and transparency; measures 34.40 × 29.15 × 17.34 mm	Source unknown Date unknown	Unknown	Hargett, 1989
Lone Star Sapphire 9,719.50 ct; 6-rayed star; cut in London in Nov., 1989	Source unknown Date unknown	Harold Roper	Matthews, 1993
Unnamed Sapphire & diamond necklace, with sapphires of 36.00, 31.43, 30.91, 14.55 and 10.96 ct. Sold at Sotheby's New York, Oct. 26, 1989 (Lot 58) for $3,520,000. **World record for a single lot of sapphires.**	The 30.91-ct stone is from Sri Lanka; others are from Kashmir.	Unknown	Sotheby's, 1989
Unnamed 337.66 ct; cut; mounted in brooch; sold at Christie's Geneva, May, 1991 (Lot 328), for SFr3,300,000 ($2,340,000; or $6930/ct)	Source unknown Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994
Unnamed 31.12-ct sapphire ring; sold at Christie's Geneva, May, 1992 (Lot 426) for SFr 1,628,000 ($1,130,555; or $36,329/ct)	Source unknown Date unknown	Unknown	Christie's New York, pers. comm., 17 June, 1994
Unnamed 502 ct; rough, pyramid-shaped crystal, silky, of good color	Kabaing, Mogok, Burma Feb. 22, 1994	Unknown	U Hla Win, pers. comm., 22 June, 1994
Unnamed 6.28 ct; faceted cushion; sold at Christie's New York, Oct., 1994 (Lot 240) for $233,500 ($37,182/ct)	Kashmir Date unknown	Unknown	GAA Market Monitor, 1995

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.

Table 10.7: Summary of famous sapphires other than blue

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
• 100.18 ct; faceted oval; orange ('padparadscha'); Ceylon (considered among the finest pad-paradschas of its size in existence) • 75, 100, 151 ct; yellow; Ceylon•73.5 ct; golden yellow; Ceylon • 33 ct; violet; Siam	Various, mostly Sri Lanka	American Museum of Natural History	Kunz, 1913b Pough, 1964 Crowningshield, 1983
H.C. Maxwell Stuart collection 2,384 sapphires of every color, shade and tint; sold on June 22, 1921 at Christie's for £3,000	Various sources & dates	Unknown	*Times of London*, 23 June, 1921
Stonebridge Green 195 ct. rough; sold for A$30,000	Rubyvale, Queensland, Australia, 1938	Mr. Wilhelm Litz	Anonymous, 1981
Anderson's (Willows) Yellow 28 dwt.,[b] 3.5 grains (~218 ct); rough; yellow; later cut to several gems (biggest = 35.50 ct)	Willows field, Queensland Australia; 14 Aug., 1946	Unknown	Morton, 1946 Monteagle, 1979
Clifton-Parr Golden Flower 13.5 dwt. (104.89 ct) rough; 21.25 ct cut; faceted; yellow; found by Eleanor Pacey; reportedly sold ca. 1970 for A$9000	Pacey's Ridge, Anakie, Australia, Oct. 13, 1946	Unknown	Monteagle, 1979
Donovan's Yellow 21 dwt. (163 ct); rough; reddish yellow	Rubyvale, Anakie Australia; 1949	Cliff Donovan	Monteagle, 1979
Golden Willow (*Golden Queen*) 322 ct rough; 91.35 ct. faceted; yellow; value estimated at A$150,000	Willows field, Queensland Australia; 1952	Unknown	Anonymous, 1952c Anonymous, 1965
Unnamed Weight unknown; green; 6-rayed star	Willows field, Queensland Australia	Unknown	Anonymous, 1952b
Unnamed 179.41 ct; faceted cushion; yellow	Sri Lanka Date unknown	Royal Ontario Museum, Toronto,	Meen, 1963
Unnamed 43.95 ct; faceted cushion; greenish yellow	Mogok, Burma Date unknown	Royal Ontario Museum, Toronto	Meen, 1963
Unnamed 28.61 ct; faceted; near square; orange ('padparadscha')	Source unknown Date unknown	Royal Ontario Museum, Toronto	Meen, 1963
Black Star of Queensland 1,165 ct rough; 733 ct cut; black star sapphire; rough was used as a door stop for many years; purchased by Kazanjian Brothers and cut in 1948	Klondyke ridge, Anakie, Queensland, Australia 1938	Unknown	Norwood, 1968 Scholler, 1985
Unnamed Black star sapphire; above 100 ct rough; 67 ct cut	Willows field Queensland, Australia	Peter Laws (1968)	Norwood, 1968
Unnamed 195.45 ct; faceted; oval; yellow; sold at Christie's Geneva, Oct. 2, 1969 (Lot 246)	Source unknown Date unknown	Unknown	Christie *et al.*, 1969
Pride of Queensland 471 ct; rough; possibly cut into a 169 ct stone; yellow	Reward Claim Anakie, Australia; 1975	Unknown	Monteagle, 1979
Australian Sun 396 ct rough; yellow	Anakie, Australia 1976	Unknown	Monteagle, 1979
Centenary Gem 2019.50 ct; rough; yellow-blue parti-color	Anakie, Australia 17 Feb., 1979	John Richardson Anakie, Australia	Monteagle, 1979
Unnamed 30 ct; faceted oval; pinkish orange ('padparadscha')	Source & date unknown (probably Sri Lanka)	Unknown	Crowningshield, 1983
Unnamed 1,126 ct; rough crystal, pinkish orange, 'padparadscha' color; crystal later cut into several gems, the biggest of 47.00 ct	Sri Lanka Date unknown	Unknown	Crowningshield, 1983 Fryer, 1986
Kingsley Sapphire 162.26 ct; rough; bi-color, yellow and green	Fancy Stone Gully Anakie, Australia Date unknown	Unknown	Koivula and Kammer-ling, 1989

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.
b. Dwt. is the abbreviation for pennyweight (1 pennyweight = 7.776 ct).

Table 10.8: Summary of famous engraved/carved rubies & sapphires

Name, weight, description and sale price[a]	Source & carving date	Current location	Reference
Rubies *Queen Elizabeth I Ruby Cameo* Mounted on engraved rock crystal ewer	Made in Milan's Miseroni workshop about 1600	Exhibited at Burghley House, London, April, 1985	Norman, 1985
Unnamed Ruby cameo of the head of Mme de Maintenon (1635–1719); 2.2 cm dia.; mounted in gold ring	ca. 1700	British Museum	Tait, 1986, p. 224
Unnamed Ruby engraved with a chimera; said to be the largest engraved ruby known	Source unknown Date unknown	French Crown Jewels?	Jones, 1902
Ecce Homo ('Behold the Man') 2,890 ct; star ruby; carved in the image of a man	Rough from Mozambique	Unknown	Anonymous, 1959
Carved rubies from Tanzania (ruby in zoisite) • *Liberty Ruby*: ~8500 ct; carved in the shape of the US Liberty Bell • *Mercy Ruby*: 22,000 ct; • *Good Samaritan*: 6.25 × 5.25 in (15.875 × 13.335 cm) These are but a few examples	Rough from Tanzania (ruby in zoisite)	Unknown	Slawson, 1976 Zeitner, 1976 Zeitner, 1984
Sapphires *Great Sapphire of the Karlsruhe Museum* 24 mm diameter; engraved with the head of Zeus	Source unknown. 3rd century AD	Karlsruhe Museum Germany	Duchamp, 1994
Ring of Saint Louis	15th century	Karlsruhe, Germany	Duchamp, 1994
Hercules	Unknown	Karlsruhe, Germany	Duchamp, 1994
Le Sceau de France	Unknown	Karlsruhe, Germany	Duchamp, 1994
Crucifixion Sapphire 20 × 18 mm; cameo	Unknown	Kunsthistorisches Museum	Duchamp, 1994
Seal of Alaric Sapphire 20.6 × 16.7 mm; engraved ('ALARICUS REX GOTHORUM')	Unknown	Vienna Museum Austria	Duchamp, 1994
Sapphire Ring of the Vienna Museum Ring carved from a single piece of sapphire; external diameter = 24 mm (internal = 13 mm)	Unknown	Vienna Museum Austria	Duchamp, 1994
Pertinax Sapphire Octagonal intaglio of the Roman emperor Pertinax (126–193 AD); measures 5.5 × 7 × 5.5 mm	16th century?	National Library Paris, France	Duchamp, 1994
Unnamed Sapphire intaglio; engraved with the face of Helios; from the Baron Roger de Sivry collection	18th century?	Unknown	Duchamp, 1994
15 ct; perfect blue; carved; one side shows leaves radiating from a central stem; thought to have come from India	Unknown	Unknown	Anonymous, 1932b
Unnamed Image of Buddha carved in blue sapphire; mounted on gold pin	Unknown	British Museum of Natural History	Aziz, 1942
Unnamed Engraved sapphire showing woman dressed in a drapery; the gem's color zoning was used to great effect, with one color used for the head, the other for the drapery	Unknown	Formerly in the Russian crown jewels; current location unknown	Anonymous, 1952a
Head of the Roman emperor Caracalla [188–217 AD] Engraved sapphire	Unknown	Unknown	Anonymous, 1952a
Seal of Constantine II 50 ct; engraved sapphire	Unknown	Unknown	Anonymous, 1952a
Portrait of Empress Marie-Theresa Engraved sapphire; fine quality; by Carlo Costanzi	Engraving done in 1705	Unknown	Anonymous, 1952a
Sapphire intaglio made by Jacques Gay upon the recovery of the Dauphin in 1752	1752	Unknown	Anonymous, 1952a
Royal Sapphire of Burma 375 ct; carved blue sapphire; elongated oval, engraved on one side with a petals suggesting a lotus bud, on the other with three concentric circles of lotus, suggestive of a Buddhist emblem; drilled with three tiny holes (probably for suspensions as an amulet); sold at Christie's Geneva, 19 Nov., 1970 (Lot 314) for SF310,000; formerly in Nizam of Hyderabad collection.	Burma Date unknown	Unknown	Christie *et al.*, 1970
Kazanjian Sapphire Carvings • Abraham Lincoln: 2302 ct rough; 1318 ct carved • George Washington: 1997 ct rough; 1056 ct carved • Thomas Jefferson: 1743 ct rough; 1381 ct carved • Dwight Eisenhower: 2097 ct rough; 1444 ct carved • Martin Luther King Jr.: 4180 ct rough; 3294 ct carved • Madonna of the Star: 1100 ct rough; 545 ct carved	Reward Claim Anakie, Australia Commissioned by the Kazanjians	Kazanjian Foundation of Calif.	Anonymous, 1952a Norwood, 1968 Monteagle, 1979

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.

Table 10.9: Summary of rough corundum giants

Name, weight, description and sale price[a]	Source & date found	Current location	Reference
Unnamed 312 lb (141.5 kg; 707,500 ct); opaque, red and blue crystal (not gem quality)	Franklin, NC Before 1882	Shepard Collection Amherst College, USA	Kunz, 1892
Unnamed Over 10 lb (4.5 kg); sapphire crystal	Mogok, Burma 1928	Unknown	*Mineral Industry*, 1929
Unnamed 335 lb (152 kg) hexagonal bipyramid crystal (not gem quality); 2 ft, 3 in (68.58 cm) in width. **This is the largest known corundum crystal on record.**	Leydsdorp, Northern Transvaal, South Africa Date unknown	Geological Survey Museum, Pretoria, South Africa	Spencer, 1933 Anonymous, 1951a
Unnamed 136.5 lb (61.92 kg); rough brown & cream crystal; 15 × 7 × 12 in. (38 × 18 × 30 cm)	18 km from Santa Barbara, MG, Brazil Date Unknown	Natural History Museum, London (#BM1935, 1060)	Roger Harding, pers. comm., 16 May, 1995
Unnamed 42 lb (19 kg); crystal said to be in the shape of the island of Sri Lanka	Sri Lanka Date unknown	American Museum of Natural History?	Anonymous, 1936 Wijesekera, 1980
Unnamed 63,000 ct (12.6 kg; 27.783 lb); rough crystal, bluish gray pyramid (not gem quality); 27 × 14.25 × 6.75 in (68.58 × 36.195 × 17.145 cm)	Mogok, Burma ca. 1967	Myanma Gems Enterprise, Burma	Anonymous, 1967
Unnamed 40.3 kg; rough, doubly-terminated bipyramid crystal	Rakwana, Sri Lanka Date unknown	Unknown	Koivula & Kammerling, 1989a
Unnamed 4,230 ct; rough; bluish bipyramidal crystal; not gemmy	Lokekhet ('Kadegadar') Mogok, Burma Sept. 1990	Myanma Gems Enterprise, Burma	*Working People's Daily*, 5 Feb, 1991 Clark, 1991, p. 68

a. On April 1, 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only (see box on page 228). All dollar prices in US dollars unless stated otherwise.

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CHAPTER 11

GEOLOGY

By Richard M. Allen, AG (AIGS), Certified Professional Geologist (AIPG) and Richard W. Hughes

> We come now to the geological part. This is the one where the evidence is not all in, yet. It is coming in, hourly, daily, coming in all the time, but naturally it comes with geological carefulness and deliberation, and we must not be impatient, we must not get excited, we must be calm, and wait. To lose our tranquility will not hurry geology; nothing hurries geology.
>
> Mark Twain, 1905–1909, *Was the World Made for Man?*

ALUMINUM and oxygen are among the planet's most abundant elements. So why is the world not awash in corundum, which is simple aluminum oxide? The finger of blame must be pointed at the spoiler—silicon. Next to oxygen, silicon atoms are more common than any other. And silicon likes to *do it.* Anywhere, anytime—it just can't wait to mate. Lacking even the most basic sense of moral propriety, silicon bonds immediately whenever aluminum and oxygen waltz down the pike.

The elemental mating game

Unfortunately for ruby and sapphire aficionados, silicon readily mates with aluminum and oxygen. Poor corundum. This most beautiful of gems is positively scarce when compared to silicon-based minerals. Its sole chance to grow is when the silicon is previously engaged. Only when free silica is in short supply does corundum stand a chance. The idea of desilication as a necessary factor is fundamental in understanding corundum formation, and will be discussed in detail later in this chapter.

The big bang (and other parlor tricks)

In order to put those primary elements in perspective, let's examine the makeup of the earth itself before we look directly at corundum deposits.

Several theories exist regarding the earth's formation and evolution of its crust, but evidence favors the idea that our planet accreted from pre-existing solid particles—the same materials which formed our sun and other planets in our solar system. The origin of these particles is another question. Heavier elements apparently saw their beginnings in earlier stars, with those stars themselves being products of the births and deaths of other stars. This recycling of matter forms a chain of events that can be traced back to the "Big Bang" of popular physics lore.

Compositional differences between the sun and planets may have resulted from the temperature differential between the center of the accreting cloud (now the sun) and its outer edges, and possibly non-homogenous accretion processes.

Journey to the center of the earth

Based on current geologic evidence, the earth has existed as an individual planet for some 4.6 billion years. In the early period, gravity and internally-generated heat slowly reorganized the molten mass into different layers. While metallic elements and heavier compounds sank towards the core, lighter compounds rose to the surface, eventually cooling into a solid, non-luminous crustal layer. This *crust,* a dynamic, constantly moving and fractured skin, surrounds a 13,000-km diameter sphere. The sphere, composed of heavy minerals, was itself organized into two major parts. These divisions are the *mantle,* a layer about 2900 km thick (thought to be made up primarily of the mineral olivine), and the still-molten *core,* approximately 7000 km in diameter (theoretically composed mainly of nickel and iron).[1]

1. *Theoretically,* because, the Jules Verne classic notwithstanding, no human has yet to journey anywhere near the center of the earth.

Figure 11.1 One of the ways in which ruby forms is via metamorphic processes. The above specimen shows ruby crystals embedded in a gneiss matrix from Mysore (Karnataka State), India. Height: 4.2 cm. (Photo: © 1993 Jeff Scovil)

Tales from the crust

The earth's crust is believed to have existed for approximately 3.7 billion years, but there remains much study to be done. Hence no consensus exists as to how the continents and the ocean-basin crust physically separated. Still it is important to note that less dense minerals comprise the continental masses, with heavier minerals forming the oceanic basin floor.[2] Like ships at sea, continental masses essentially float on top of heavier, less viscous material—the lower layer of the crust and the mantle.

Silicon and aluminum, together with oxygen, form the bulk of the minerals of the continental crust. Hence geoscientists term these rocks *sial* (from silicon and aluminum). Continental rocks (sial) are therefore rich in aluminum. In contrast, the dense rocks underlying the sial of the continents and forming the crust directly under the oceans are rich in silicon and magnesium. These are termed *sima* (from silicon and magnesium).

Rock types. Geologists categorize all rocks into three general types: igneous, sedimentary and metamorphic. *Igneous* rocks are those formed from molten minerals, with the molten mixture referred to as *magma* by geologists. *Sedimentary* rocks are formed from eroded particles and fragments of pre-

2. Together with a thin layer beneath the continents, these heavy layers are considered part of the crust proper.

existing rocks deposited by the action of water or wind. *Metamorphic* rocks are formed when existing rocks (of any type) are altered by heat and/or pressure, thus forming new rocks.

These three rock types exist within a dynamic cycle over geologic time. All can be, and are, recycled versions of pre-existing types. Sedimentary rocks have all been either igneous, metamorphic, or even other sedimentary rocks before having been deposited. Igneous rocks are melted and cooled versions of pre-existing sedimentary, metamorphic, or even other igneous bodies. Metamorphic rocks can also be reworked igneous, sedimentary, or other metamorphic rocks. The cycle goes on, with the earth's crust constantly modified and renewed.

Crust composition. The crust, which makes up less than 1% of the earth's mass, has a mean thickness of 17 km. Its upper 16 km consists of 95% igneous and metamorphic rocks, and 5% sedimentary rocks (Clarke & Washington., 1924; as quoted by Mason & Moore, ca. 1982). Of the elements present (by weight), oxygen is most common (46.6%), silicon second (27.7%), and aluminum third (8.1%). Although aluminum and oxygen are abundant—corundum (Al_2O_3) is not. This is due to certain geochemical reactions, which have taken, and continue to take place in the continental rocks.

Ruby, oh ruby, wherefore art thou ruby?

To gain a better understanding of how corundum forms, we will look at *where* it is found on the surface of the crust. Because of variations in deposits, the geology of corundum will be examined from the standpoint of the basic source-rock types.

Readers are advised that the following examples of corundum genesis are described only in the broadest terms.[3] Keep in mind that current theories are often in direct conflict. Geology is a science, but, as with any science, ideas are constantly modified and, in some cases, completely discarded.

Born of fire: Corundum in igneous rocks

Igneous rocks can be separated into two broad categories based upon their mode of formation. Those which cooled slowly deep within the earth (and so are coarse grained) are termed *intrusive,* while those which cooled rapidly at the surface (and so are fine grained) are *extrusive.* The latter includes volcanic lavas.

Due to rapid cooling of extrusive rocks, gem corundum crystals cannot form within them. However, they often act as a carrier for crystals formed deeper down, which is why many corundum deposits are associated with extrusive igneous rocks.

Figure 11.2 Ruby in a syenite matrix from Vietnam's Luc Yen mine. (Photo: Nguyen Dang Khoa/GIA)

Corundum has been found in a wide variety of igneous rocks; these include alkaline basaltic lavas, intrusive ultramafics, pyroclastics, and pegmatite bodies.

If there is any underlying thread tying together the composition of corundum-bearing igneous rocks, it is their deficiency in silica (SiO_2). While much literature exists regarding the geology of corundum deposits, it is difficult to piece together a single pattern beyond that.

When aluminum, silicon, and oxygen (among other elements) exist together in a magmatic melt, geochemical reactions favor the formation of feldspars.[4] Hence feldspars are the most common crustal minerals. Sodium and calcium feldspars, which exist together in a solid-solution series, are known as *plagioclase,* while potassium ('potash') feldspar is known predominantly as *orthoclase.* Because sodium and potassium were known in the classification scheme of the last century as alkali metals, sodium-rich plagioclase (*albite*) and orthoclase are known as *alkali* feldspars.

When a low-silica igneous melt is in the process of cooling and crystallization, feldspars are formed only until the free silica is depleted. From that point on, minerals which require less silicon begin to grow. Such minerals are termed *feldspathoids,* and are never found together with free silica (SiO_2—quartz). The most common feldspathoids are nepheline, leucite, cancrinite, and sodalite. Nepheline, especially, is indicative of corundum-favorable geochemistry.

Igneous rocks which contain these feldspathoids are called alkaline igneous rocks, hence the terms *alkali basalt,*[5] or *alkaline magma.* The names of these minerals serve as modifiers to the main composition, such as in *nepheline syenite.*[6]

3. Specifics can be found in references in the chapter's bibliography.

4. Feldspars are complex aluminosilicates (compounds containing aluminum, silicon and oxygen) and also contain sodium, potassium, and calcium.

5. In a general sense, basalt is a fine-grained, dark igneous rock.

Within these rocks, if conditions are just right, aluminum and oxygen may combine to form alumina (Al_2O_3—corundum). When the proper trace elements are present, ruby or one of the colored sapphire varieties results.

Intrusive ultramafic rocks. An excellent example of an *in situ* ('in place') igneous deposit is the Yogo sapphire deposit in Montana, USA.

Until the last decade, the Yogo deposit has historically been referred to as the "Yogo dike." Because of its surface expression, early miners and geologists thought that sapphire-bearing magma had simply been injected into a long narrow crack within the surrounding rock units, and then cooled. A *dike* is what geologists call a tabular body of rock which has cut across or through pre-existing formations. It now appears that the dike-like structure may only be part of the picture. The dike could actually be connected to a technically different and more deeply rooted type of formation.

At Yogo Gulch, sapphire crystals occur within an igneous rock known petrologically as an *ouachitite,* a type of ultramafic lamprophyre.[7] During the Tertiary period (2–65 million years ago), this lamprophyric magma pushed upwards from great depth. The *diatreme* theory would add that this occurred explosively, along with water vapor and other escaping gases, through a narrow volcanic pipe. Dispersed throughout the ouachitite are crystals of corundum, virtually all of the same, uniform blue hue.

Rocks within the Yogo deposit have been altered by solution activity, rearranged somewhat by collapse of the surrounding formations and subsequent phases of magmatic activity, and subjected to considerable weathering.

Yogo source rock is of igneous origin, and evidence suggests that the sapphires actually formed at great depth. The lamprophyric rock merely acted the role of an elevator, lifting the gems to the surface. Indeed, the Yogo sapphires could have formed as a result of metamorphic processes deep in the earth. Thus, technically, these sapphires would then not be the product of igneous formation, although they are found in an igneous deposit.

Corundum-bearing basalts. Basaltic rocks yielding gem-quality corundum in significant amounts are found throughout southeast Asia, and in parts of Australia and Africa. In each of these places, corundum appears to have originated in basalts that eventually flowed at the surface. For example, along the Thai/Cambodian border, strongly alkaline basalt erupted during the Quaternary period.[8] Indications show that it had its source either deep in the crust or in the upper mantle. Today the ruby and sapphire crystals are found there only in secondary deposits, where they ended up after having been eroded out of the basaltic rocks.

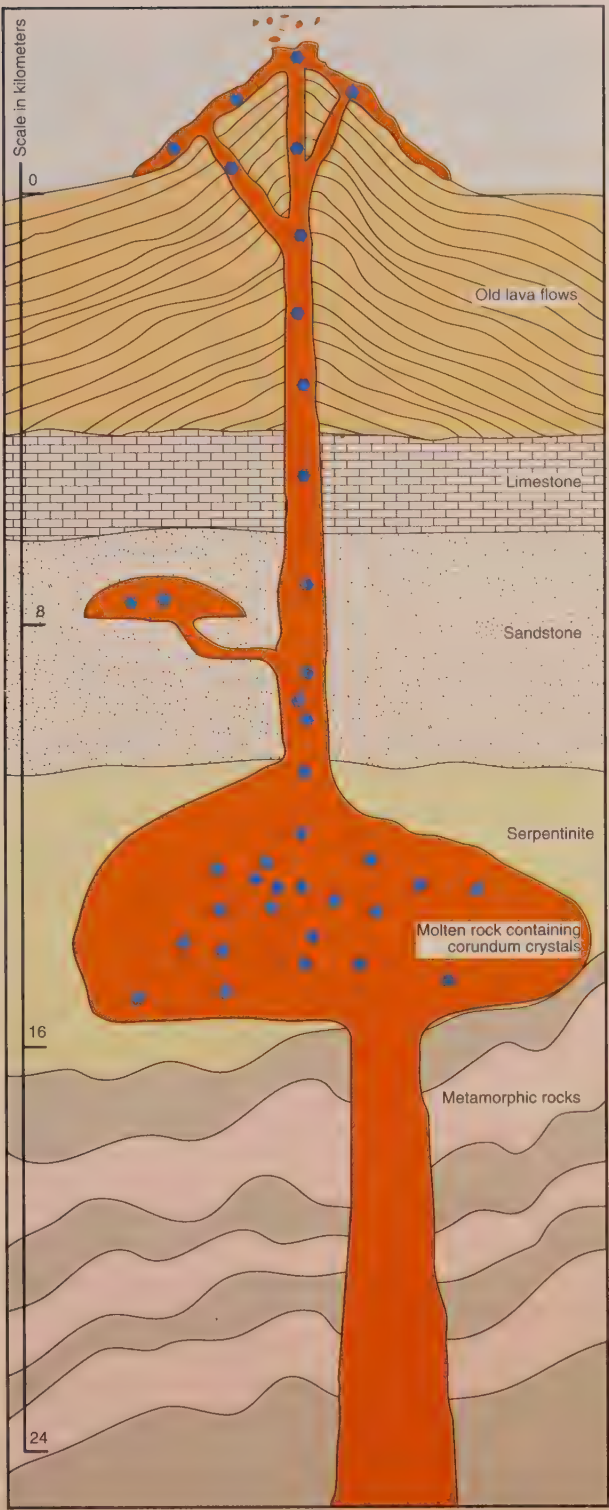


Figure 11.3 Corundum crystals often form far below the surface, but are carried up by extrusive igneous rocks. (Modified from Keller, 1990)

6. Syenite is an igneous rock composed of alkali feldspar and accessory minerals such as hornblende or biotite.

7. *Ultramafic* rocks are those composed mainly of ferromagnesian silicates. *Lamprophyre* describes an igneous rock in which dark minerals occur as phenocrysts within a dark or light ground mass.

8. The most recent geologic period—from approximately several million years ago.

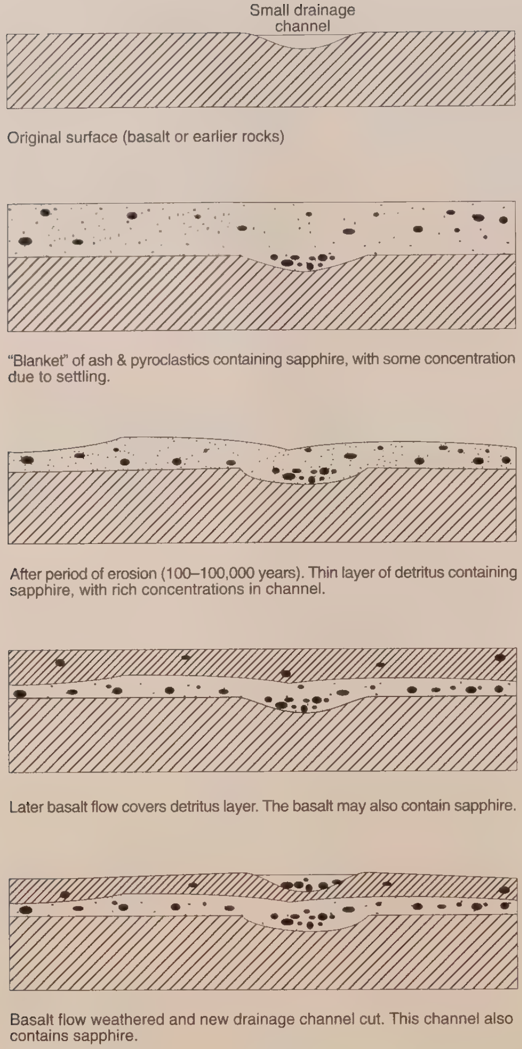


Figure 11.4 Hypothetical formation of detrital sapphire deposits in Australia. (Based on drawings supplied by Terry Coldham)

Flows vs. pyroclastics[9]. The question of flow versus pyroclastic surface transport of corundum continues to be hotly debated in geological circles. Australian Terry Coldham believes basaltic corundum formation will eventually prove to be a combination of both. The following is his theory:

During the period of Tertiary volcanics, with which Australia's sapphire deposits are associated, large pyroclastic eruptions were followed by lava flows. Each may have contained sapphire, distributed like plums in a pudding. Periods of perhaps thousands of years between a pyroclastic event and a subsequent lava flow would have allowed most of the ash-like material to be removed by erosion, leaving a thin layer of detritus containing a high proportion of heavy minerals, including corundum. Cyclic events of pyroclastic

Figure 11.5 Sapphire crystals from Loch Roag, Isle of Lewis, Outer Hebrides, Ross and Cromarty, Scotland. They are embedded in a dike rock with a composition similar to lamprophyre.
(Photo: Alan Hodgkinson/Ian Combe)

and magma eruptions would lead to successive layers of basalt with weathered "fossil eluvial" surfaces between. This is exactly the sort of situation found in volcanic sapphire deposits, be they in Australia, Thailand or China.

Such a proposal would explain the difficulty in finding concentrations of *in situ* corundum sufficient to account for the richness of adjacent alluvial deposits. A thin horizon, be it a few centimeters or a meter, between two layers of hard basalt would be difficult to find or define, and yet could easily release, over eons of weathering, sufficient corundum to account for the commercial deposits. Even more likely is that in any one area a multitude of discontinuous horizons, each of which is not particularly rich in its own right, might be simultaneously weathered and add its share of corundum to the deposit (Terry Coldham, pers. comm., 16 Sept., 1994). Figure 11.4 illustrates this scenario.

Ch-ch-changes: Metamorphic rocks

As with igneous rocks, the key to corundum formation and distribution in metamorphic rocks is a lack of silica in the host rock. Again, one must remember that some metamorphic rocks may simply be the products of the alteration of previous igneous rocks. Thus there may be considerable variation in the particulars of each deposit.

Broadly speaking, there are two types of metamorphism. One occurs when a rock formation, or group of formations, is regionally subjected to heat and/or pressure. This heat and pressure usually results when the rocks are buried by overlying layers. This subjects them to the weight and pressure of the upper rock masses at the same time they are heated, because temperature increases significantly with depth. Tectonic[10] factors also add to metamorphism. These can result,

9. Pyroclastics are rock fragments expelled during volcanic eruption or aerial expulsion from a volcanic vent.

10. *Tectonism* refers to geologic instability within the crust.

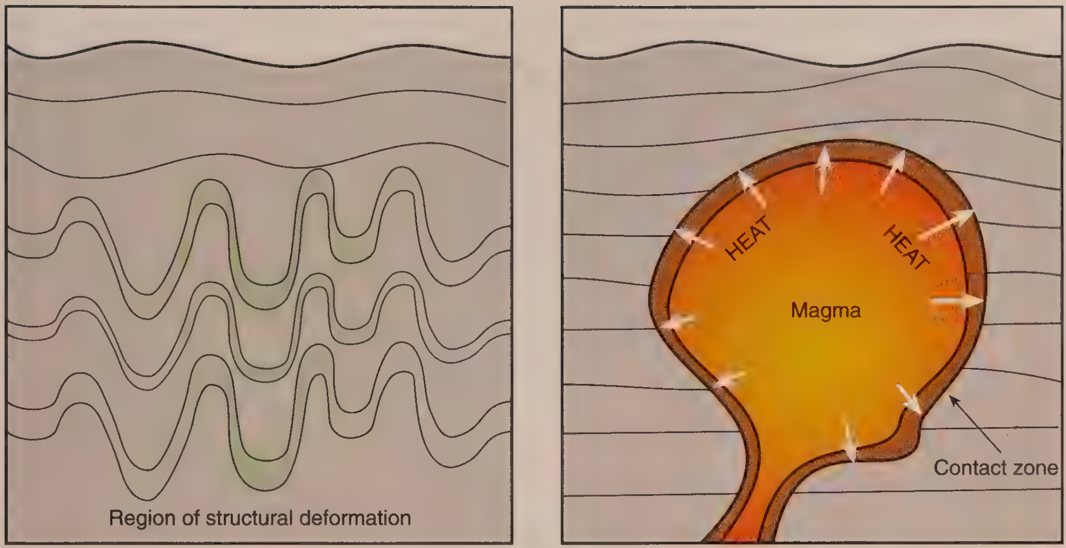


Figure 11.6 Metamorphic rocks result from different processes of change caused by heat and pressure. Regional metamorphism occurs deep in the crust where regions are strongly deformed by accompanying heat and pressure. This is usually precipitated by large-scale tectonic events. In contrast, contact metamorphism is localized, resulting from the heat of igneous intrusions. (After Press & Siever, 1994)

for example, from continents smashing into each other as a result of continental drift, the rocks along the zone of collision being subjected to great amounts of stress and pressure over geologic time. Geologists call these types of rock alteration *regional metamorphism.*

The other type of metamorphism is known as *contact metamorphism.* This occurs when a magma intrudes into, or cuts through, other rock formations. Such heat "bakes" them, creating new minerals which require higher temperatures for their formation. The intruded rocks can be changed chemically to a new composition, their makeup altered through geochemical reactions with the molten material. This is termed *metasomatism.*

The igneous rock itself can also undergo a compositional change, as minerals within react with the intruded rocks to form new compounds. Strictly speaking, it is only the intruded rocks which can be said to have been metamorphosed—they were not molten to begin with. The igneous rock can only be said to have been altered. But it is important to remember that both intruding material and host rock can undergo compositional change.

Regional metamorphism. In order to demonstrate the geochemical relationship between silicon, aluminum, and oxygen within a regionally metamorphosed rock (say a metamorphosed shale), we need to consider the original makeup of the rock.

Shale is a laminated sedimentary rock. It is composed of clay-sized particles usually deposited by water, such as in an ancient river delta or lacustrine (lake) basin. If oxygen, silicon and aluminum were present (in the form of feldspars) in the original eroded rock, *kaolinite* would be a major constituent mineral of the shale. Kaolinite is one of the simplest and most common of the clay minerals. Silica (in the form of quartz particles) could also be present if the original eroded rock also contained silica, or if silica was introduced during the sedimentary process.

Eventual burying, heating and metamorphism of the kaolinite/silica-bearing shale formation could result in a new metamorphic rock, now called a slate, phyllite, or schist, depending on the intensity of the metamorphism. One of its main components would be a new mineral, pyrophyllite. However, if there were no silica present, the breakdown of kaolinite would result only in a partial formation of pyrophyllite. The remaining aluminum would bond with the available oxygen to form another constituent —alumina. Thus regional metamorphosis of a shale with this composition could result in a corundum-bearing rock.

By itself, this type of corundum formation is of relatively little concern when dealing with rubies and sapphires; no significant deposits of gem-quality corundum are known which derive solely from this scenario. It is mentioned only to show how certain rocks can become enriched in alumina. Such Al-rich rocks may be involved in subsequent corundum formation via a different mechanism.

Contact metamorphism. To see how contact metamorphism might result in corundum formation, consider another hypothetical case—one where a molten magma is intruded into surrounding rocks. This process actually has features of both metamorphic and igneous rock formation.

Figure 11.7 Some of the world's finest rubies are formed in a marble matrix, via metamorphic processes. The example at left comes from Afghanistan's Jagdalek mines.
(Photo: Harold & Erica Van Pelt/American Museum of Natural History)

Suppose an igneous melt rich in both aluminosilicate minerals and quartz was injected from its parent magma body into surrounding cold rocks, in the form of a dike. Depending on its texture, this dike could be a *pegmatite*.[11]

Let us also assume that the intruded rock formations are silica deficient—rocks such as serpentine, peridotite, limestone, or even marble (which is metamorphosed limestone). As the pegmatite intrudes and reacts with the surrounding rocks, geochemical reactions will cause the silica from the pegmatite to react with the minerals outside the pegmatite and form new compounds richer in silicon content. The result is a de-facto desilication of the pegmatite fringes.

In turn, this desilication means that some of its silicon, which could have resulted in the formation of feldspar crystals, is now gone. Aluminum can now combine only with the left-over oxygen to form corundum. As might be imagined, the boundaries of such pegmatitic alteration may not be well defined. The corundum-bearing zone may grade into the intruded rocks, as well as back into the pegmatite.

Many of the world's major ruby and sapphire sources have contact metamorphism to thank for their bounty. While there may be considerable variety in the specifics of the deposits, a few examples of classic gem locales will illustrate the importance of contact metamorphism. Please note that at these places, the stones are actually being mined mostly from secondary deposits. The source rocks themselves are usually either hypothesized or are uneconomical to mine.

Mogok, Burma (Myanmar). The Mogok region, home to perhaps the world's greatest treasure trove of gem corundum, is a complex geologic situation where igneous dikes and intrusions cut through marble, limestone beds and metamorphic rocks in the form of schists and gneisses (schist and gneiss are textural terms for metamorphic rocks). In addition, marble is found interbedded with the gneiss. The Mogok ruby formation was traditionally attributed to contact metamorphism, largely because the source of alumina was unknown. But today we know that some types of limestone could have supplied sufficient alumina for ruby to form. Thus it appears possible that regional metamorphism played the key role. While contact metamorphism tends to occur in isolated

11. *Pegmatite* refers to an intrusive igneous rock of extremely coarse grain size. It results from a process termed *magmatic concentration*, where the most volatile and mobile compounds separate out of the main intrusive mass of magma. This results in a wealth of large crystals, formed via slow cooling of these most residual of the parent magma's minerals. Magmatic concentration allows formation of minerals containing rare elements, such as beryl (beryllium), topaz (fluorine) and tourmaline (boron).

The Valley of Serpents

AMONG the most fascinating ancient stories associated with gem mining is the *Valley of Serpents*. Associated variously with diamond and corundum, this tale was repeated by many early travellers. The earliest known version is that of Epiphanius, archbishop of Salamis in Cyprus (d. 403 AD), who related the following about finding *jacinths* (hyacinths) in Scythia:

> In a wilderness in the interior of great Scythia, there is a valley begirt with stony mountains as with walls. It is inaccessible by man, and so excessively deep that the bottom of the valley is invisible from the top of the surrounding mountains. So great is the darkness, that it has the effect of a kind of chaos. To this place certain criminals are condemned, whose task it is to throw down into the valley slaughtered lambs, from which the skin has been first taken off. The little stones adhere to these pieces of flesh. Then the eagles, which live on the summits of the mountains, following the scent of the flesh, fly down and carry away the lambs with the stones adhering to them. They then who are condemned to this place, watch until the eagles have finished their meal, and run and take away the stones.
>
> Epiphanius, archbishop of Salamis (Cyprus), [d. 403 AD]
> from Major (1857)

Another version is found in Sinbad the Sailor (Burton, 1899). Kunz also discussed it:

> Al Kazwini relates as follows the marvellous tale of the Valley of Diamonds:*
>
> "Aristotle† says that no one except Alexander ever reached the place where the diamond is produced. This is a valley, connected with the land Hind. The glance cannot penetrate to its greatest depths and serpents are found there, the like of which no man hath seen, and upon which no man can gaze without dying. However, this power endures only as long as the serpents live, for when they die the power leaves them. In this place summer reigns for six months and winter for the same length of time. Now, Alexander ordered that an iron mirror should be brought and placed at the spot where the serpents dwelt. When the serpents approached, their glance fell upon their own image in the mirror, and this caused their death. Hereupon, Alexander wished to bring out the diamonds from the valley, but no one was willing to undertake the descent. Alexander therefore sought counsel of the wise men, and they told him to throw down a piece of flesh into the valley. This he did, the diamonds became attached to the flesh, and the birds of the air seized the flesh and bore it up out of the valley. Then Alexander ordered his people to pursue the birds and to pick up what fell from the flesh."
>
> "Another writer states that the mines are in the mountains of Serendib (Ceylon) in a very deep gorge, in which are deadly serpents. When people wish to take out the diamonds they throw down pieces of flesh, which are seized by vultures and brought up to the brink of the gorge. There such of the diamonds as cling to the flesh are secured; these are of the size of a lentil or a pea. The largest pieces found attain the size of a half-bean."
>
> In his version of the tale, one form of which appears in the seventh voyage of Sindbad the Sailor, Teifashi states that the finest corundum gems were washed down the streams that flowed from Adam's Peak, on the island of Ceylon; in time of drought, however, this source of supply ceased.
>
> Now it happened that many eagles built their nests on the top of this mountain, and the gem-seekers used to place large pieces of flesh at the foot of the mountain. The eagles pounced upon these and bore them away to their nests, but were obliged to alight from time to time in order to rest, and while the pieces of flesh lay on the rock, some of the corundums became lightly attached to this, so that when the eagles resumed their flight the stones dropped off and rolled down the mountain side.**
>
> Kunz' annotations
>
> * Dr. Julius Ruska, "Das Steinbuch aus der Kosmographie des al-Kazwini," Beilage zum Jahresbericht 1894–5 der Oberrealschule Heidelberg, p. 35. See Aristoteles De Lapidibus und Arnoldus Saxo, ed. Rose, Z.f.D.A. New Series VI, pp. 364, 365, 389, 390. The "other writer" is probably Ahmed Teifashi.
>
> † The work on precious stones attributed to Aristotle was composed in Arabic probably in the ninth century.
>
> ** Teifashi, "Fior di pensieri sulle pietre preziose," Firenzi, 1818, p. 13.
>
> G.F. Kunz, 1913, *The Curious Lore of Precious Stones*

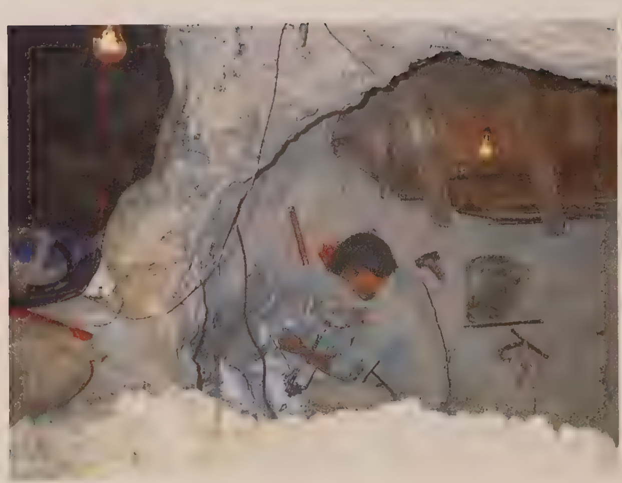
Nicolo Conti described a diamond-bearing mountain in India with a nearby, higher mountain. Men would climb the higher mountain and cast meat onto the diamond mount with catapults. Vultures would then pick up the meat, complete with adhering diamonds. The gems would be retrieved as they fell off the meat (Ball, 1881).

Such beliefs were not limited to India and Sri Lanka. In Burma, the origins of the ruby mines were ascribed to a similar story. Long before the Buddha walked the earth, the northern part of Burma was said to be inhabited only by wild animals and birds of prey. One day the biggest and oldest eagle in creation flew over a valley. On a hillside shone an enormous morsel of fresh meat, bright red in color. The eagle attempted to pick it up, but its claws could not penetrate the blood-red substance. Try as he may, he could not grasp it. After many attempts, at last he understood. It was not a piece of meat, but a sacred and peerless stone, made from the fire and blood of the earth itself. The stone was the first ruby on earth and the valley was Mogok (Kessel, 1960).

Valentine Ball (1881) has stated that the origins of such stories probably result from a common custom in many parts of Asia. When a new mine is opened up, it is common to make an offering to the spirits. Buffalo may be slaughtered and placed on raised bamboo pedestals. It goes without saying that birds would help themselves to such offerings. Ball believed that any outsiders witnessing such sacrifices might well believe this was an integral part of gem retrieval.

A beautiful oriental miniature of the Valley of Serpents, dated 1582, is in the Bibliothèque Nationale, Paris and is reproduced in Bariand & Poirot (1992, p. 236).

Figure 11.8 The valley of Mogok, Burma, Valley of Rubies, and perhaps the source for the legend of the Valley of Serpents. (Photo: Thomas Frieden)



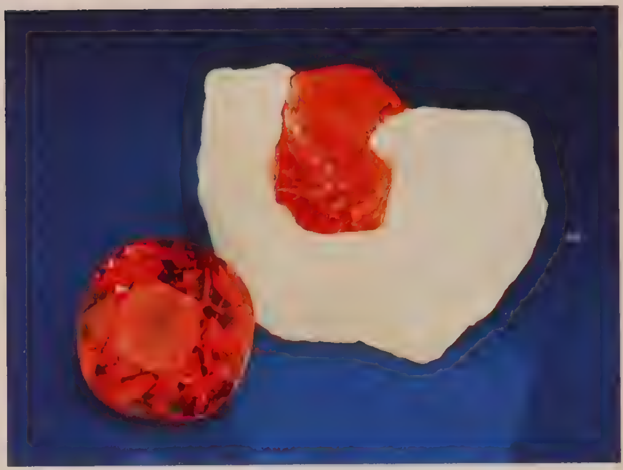


Figure 11.9 Ruby from limestone
Left: At Dattaw, in Burma's Mogok Stone Tract, miners drill straight into the limestone, itself, in search of ruby. (Photo: Robert Kammerling/GIA)
Right: Ruby is not the only gem found in limestone. Many deposits of ruby in marble also contain red spinel. The photo shows a 4.03-ct faceted red spinel alongside a 1-cm spinel octahedra still embedded in its marble matrix. Both specimens are from Mogok, Burma. Because red spinel has a similar appearance and origin to that of ruby, the two gems have frequently been confused throughout history.
(Photo: Harold & Erica Van Pelt/American Museum of Natural History)

areas, Burma's rubies occur over a wide area. Further evidence for regional metamorphism is the ruby matrix, which is inevitably marble. In any event, detailed geologic mapping has yet to be done in the area. Local politics and an obscuring blanket of weathered topsoil and jungle-like vegetation make such studies difficult, at best.

Rubies at Mogok (and many other localities) often occur in association with spinel, with the spinel being more common. Spinel tends to be more common than corundum because it crystallizes under a broader range of temperature and pressure conditions (Delmer Brown, pers. comm., 11 Feb., 1995).

Kashmir, India. One of the world's notable hard-rock deposits of corundum, the Kashmir sapphire deposit is another classic example of the role of desilication caused by contact metamorphism. In this case, some of the world's finest blue sapphires are found high on a Himalayan ridge, where thick strata of marble are interbedded with schists and gneisses. Sapphires occur at the contact zone of a pegmatite intruded into a marble, in association with actinolite-tremolite. They are most abundant where the intrusions are quartz-free and surrounded by the actinolite-tremolite. The crystals are found in lenticular pockets of kaolinized plagioclase feldspar.

Corundum deposits at a number of other sites around the world owe their origin to the processes engendered by contact metamorphism and consequent desilication. Rubies from Afghanistan, southern India, Kenya, Pakistan, Tanzania and Vietnam are all associated with this geochemical scenario, as are sapphires from Umba (Tanzania).

Hard-rock blues

WHILE miners often dream of finding the mother lode, when it comes to ruby and sapphire mining, alluvial deposits are generally a better economic proposition. Montana's hard-rock Yogo deposit is a case in point. Although Yogo sapphires are of high quality, they cannot compete with cheaper alluvial sapphires from Sri Lanka, Thailand, or even Australia. The greater amount of work necessary to separate sapphires from the matrix, higher labor costs in the United States, and small sizes of the stones makes Yogo a marginal business venture.

India's famous Kashmir mine offers another illustration of the difficulties in making hard-rock mining pay. Certainly more attempt would be made to exploit the mine if the costs were not so prohibitive. Besides being a hard-rock deposit, the mine's elevation (4100–4500m) is so high that it can be operated only during summer months. When one adds in the political problems associated with the region, it is understandable why the deposit has largely lain fallow since the 1930s.

Corundum from mixed geology

Some rock formations cannot be assigned completely to either an igneous or metamorphic category. They exhibit properties of both types; the geologic setting in which they are found is the only clue to their genesis.

Consider a sedimentary or metamorphic rock formation buried so deeply and subjected to such long-term heat and pressure that it is virtually melted in the process, retaining little of its stratified or segregated nature. Such a rock would show both igneous and metamorphic characteristics. Depending on their textures and compositions, geologists give these rocks names such as *migmatites*, *granulites* and

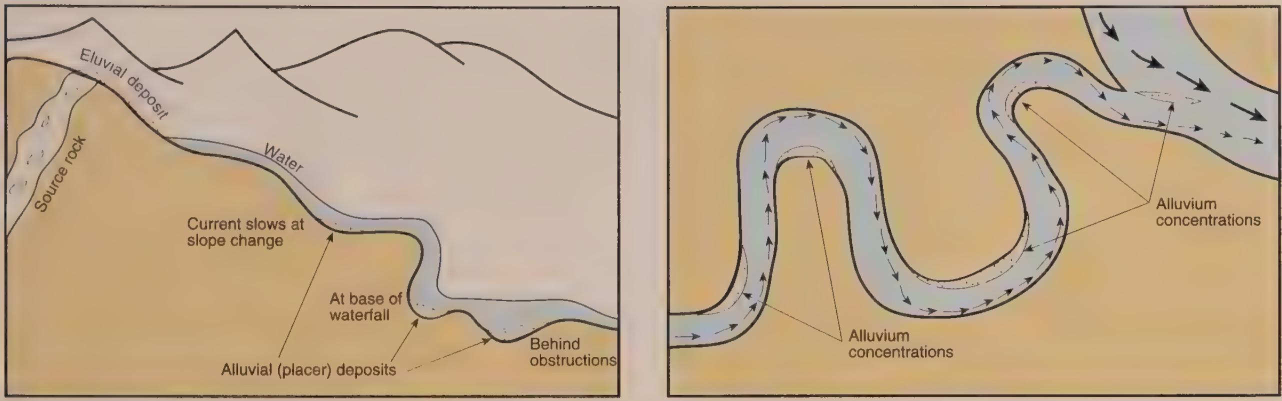


Figure 11.10 Formation of secondary deposits
After weathering from the host rock, alluvial deposits are formed where water velocity drops. This tends to occur where the slope decreases, at the base of waterfalls, behind obstructions and where smaller, faster streams meet larger, slower streams. Alluvial deposits also concentrate on the insides of stream curves.

charnockites. The environment most likely to yield these kinds of rocks is that which occurs where two continental masses of great thickness are colliding with each other, heating and deforming themselves in the process. This occurs at certain plate boundaries.

Geologists have considerable difficulty agreeing on just how to classify these rocks—compositions and textures can vary greatly, and their relationships to adjacent rock formations are not always clear. And there do seem to be places where adjacent groups or strata have more or less blended together as the result of pressure and heat, allowing not only for the types of regional and contact metamorphism described above, but also for intrusions of one molten rock into another.

Hence the situation where aluminosilicate-rich rocks, already low in silica, are further heated in order to enrich them in alumina, and where their emplacement is also adjacent to other types of rocks which can add to their desilication.

Sri Lanka. Since ancient times the Island of Gems has been a prolific source of various gem minerals, not the least of which is corundum. While the actual mining takes place in alluvial deposits, our focus here is on the nature of the rocks from which the alluvium originated.

The corundum-bearing rocks of Sri Lanka (Ceylon) are of Precambrian age. Dating from at least 600 million years, these ancient rocks have yielded fabulous ruby and sapphire riches. Briefly, aluminum-rich sediments apparently accumulated within a large basin. These were then deeply buried and consolidated, only to later be metamorphosed when they, and the continent they were part of, were involved in a collision with another continental mass.

The collision generated tremendous heat and pressure. This mobilized deeper ultramafic (sima) and other continental rocks, which were liquefied and intruded into the aluminous metamorphic rocks.[12] Theoretically, the intermixing of these rocks resulted in desilication of the metamorphosed sediments, yielding corundum crystals which, hundreds of millions of years later, were uplifted and eroded from their host rocks.

In Sri Lanka and southern India, these intermixing rocks are given the name *charnockites;* whether they should be called metamorphic or igneous is still a subject of debate among geologists.

Rock & roll: Secondary deposits

The majority of the gem corundum deposits in the world could be classified as sedimentary in nature. While the term "sedimentary" also applies to one of the three rock types, these deposits cannot be called sedimentary rocks because they have not lithified or solidified. Given enough time, and in the proper geologic setting, they probably would turn into stone.

As we have seen, all the world's known corundum deposits have resulted from igneous, metamorphic, or combined igneous/metamorphic processes. Each of these source rocks would be classified as a "hard-rock" deposit because the ruby or sapphire would have to be extracted from actual rock. But there are actually few hard-rock deposits being mined. Instead, most corundums are recovered from secondary deposits.

Alluvial & eluvial deposits. In gem mining, the two basic types of secondary deposits are alluvial and eluvial. *Alluvial* deposits are secondary deposits of a mineral or minerals which have been transported from their original point of formation by the action of water. *Eluvial* deposits are those which result from an *in-place* decomposition of the original mineral-bearing rocks. In them, the sought-after gems may

12. The actual collision, of course, would take many millions of years.

Figure 11.11 Despite the wonders of modern technology, much gem mining is still performed by simple techniques, such as those used on this hillside mine at Inn Gaung, in Burma's Mogok Stone Tract. (Photo: Thomas Frieden)

still have been sorted somewhat, if even by gravity alone. Scattered throughout many of the world's great corundum-producing areas are places where eluvium is mined.

Alluvial ('placer') deposits, are excellent places to find gem corundum because the ruby or sapphire crystals have already been separated from their host rocks by weathering. *More importantly,* the crystals have been concentrated during deposition. It is for this reason that placer deposits are so rich.

Imagine a rock containing corundum crystals. When this rock has been exposed at the earth's surface by tectonic uplift and consequent erosion, the corundum, because it is so much harder relative to the host rock, remains virtually intact. It is then carried downslope into the valleys via gravity, or, more often, by water.

Along with the corundum moves much other rock material and particles of various sizes: sand, silt and clay. Since corundum has a high specific gravity (4.0–4.15) and thus is heavier than other rock-forming minerals, it settles out first, usually in places where the water velocity slows, or where the current encounters natural obstacles. In this way it is concentrated in certain zones, allowing for easy mining. By studying the shape of the stream course, both ancient and modern, it is possible to predict how to best follow the deposit.

Figure 11.12 Gold and sapphire mining dredge at French Bar, on Montana's Missouri River. (Photo by the author)

Almost all of the world's rubies and sapphires are mined from placer deposits, including those from Sri Lanka, Burma, Thailand, Cambodia, Australia, Africa and even

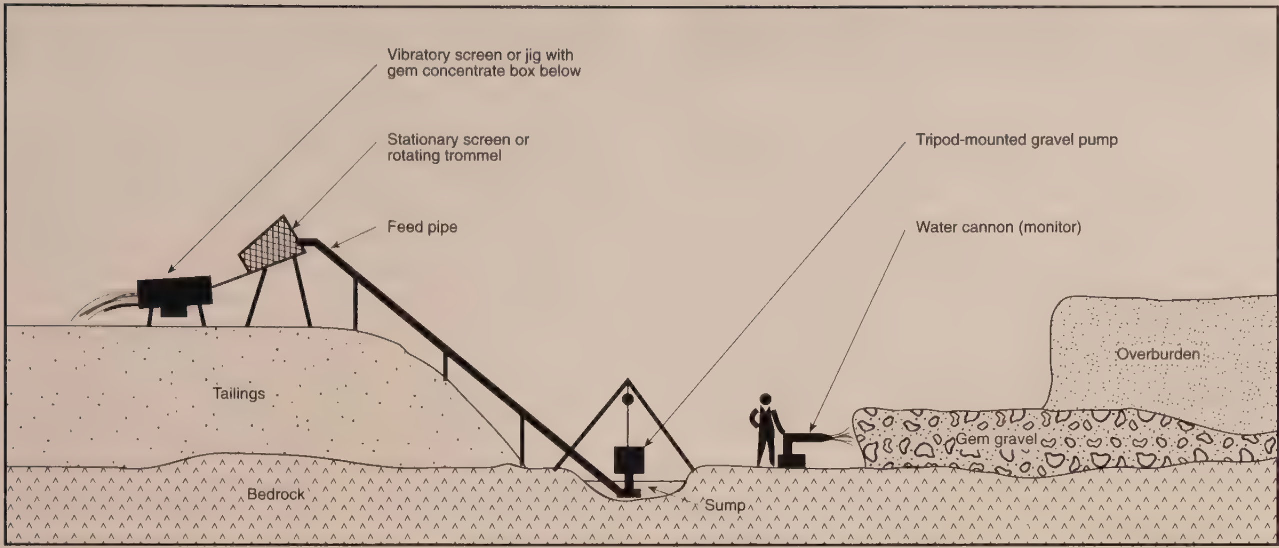


Figure 11.13 Typical layout of a mechanized water cannon/jig-based mine. (Based on Davies, 1975)

Montana (except Yogo). They are easily worked, and more importantly, inexpensively worked.

Placers are worked by a variety of methods ranging from individual human labor utilizing nothing more than shovels, buckets, screens and running water, to large dredges which are literally floating mechanized mills. Primitive hand methods are commonly seen in the Third World (such as Thailand and Sri Lanka), while dredging is employed in more industrialized countries.

Dredging. At Rock Creek, Montana (USA), a large dredge has been used to work an alluvial plain which spreads out from the banks of Rock Creek, one of southwest Montana's finest fishing streams. Here, beneath the deceptively pastoral grass-covered fields and swamps, lie an estimated tens of millions of carats of rough sapphires.[13]

Looking like a small factory building sitting on top of a barge, the dredge is a self-contained operation. It works by digging out in front of itself a depression, which then is filled with water, and upon which the dredge floats. Equipped with shakers, screens and jigs, the dredge utilizes hydraulic currents to separate corundum from the other gravel. The waste is deposited behind as it moves down the plain like a giant snail, keeping its ever-accumulating treasure locked within. Eventually the dredge reaches the deposit's far end, where it turns around and begins a new, adjacent path back up the valley. By this method, just a small crew of workers can process large quantities of material.

Digging in the dirt. When done properly, dredge and placer mining has minimal negative environmental impact. No toxic chemicals are involved in the separation process, and there is no smelting, as in the case of metals mining. In addition, the landscape can easily be restored to its original contours, as ultimately only corundum is removed. This is but a tiny fraction when compared to the mountains of material that must be sorted through to get it.

Unfortunately, the same can not be said of mechanized mining as performed in many third-world countries. Rather than dredges, bulldozers are used to strip away the overburden. Gem-bearing material is then forced into separation jigs via high-pressure water cannons. Indiscriminate use of such water cannons often creates environmental havoc, as mud and sediment wash into rivers, polluting the water supply for many kilometers downstream. For this reason, such methods have been severely restricted in many first-world countries. They are allowed only in conjunction with a closed water system with settling ponds.

Exploration: The search for instability

Have all of the world's ruby and sapphire deposits been found? Probably not. But they are getting harder to find.

As we have seen, igneous or metamorphic rocks are the key to corundum formation. Secondary deposits derived from these host rocks are the most economical places to mine. Given these considerations, we can be somewhat more specific about the broad places to look for the gems.

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13. The source rock of this important sapphire mine, the largest known corundum placer in the western hemisphere, has never been found. It lies somewhere at the heads of the valleys that empty into Rock Creek, perhaps eroded away, perhaps buried under the topsoil and pristine evergreen forests of the Sapphire Range. Is it an igneous rock? A metamorphic rock? Or perhaps a hybrid which geologists will try to classify if they ever find it. If so, it will undoubtedly form the basis for many future academic arguments and provide another variation within the general theory of corundum formation.

Pan-based exploration

THE time-tested technique of panning is one of the most common and useful of prospecting methods. In essence, it consists of examining river gravels. Due to its high specific gravity, corundum commonly concentrates in river and stream beds. Exploration involves sampling river gravels, beginning downstream. When even a tiny piece of corundum is found, one steadily works upstream, sampling all the way. Eventually a point is reached where nothing is found. Then the steps are retraced to locate the precise point at which the gem traces begin. From here, further sampling will identify the proper river or stream bank from which the corundum comes. Working uphill will hopefully bring one to the source rock. While simpler in theory than practice, such a method has been used throughout history to locate mineral deposits.

Figure 11.14 Much of the world's ruby and sapphire is recovered by small teams from alluvial deposits. Above, miners wash alluvials for sapphire in Tanzania's Umba Valley area. (Photo: Fred Ward/GIA)

Tectonic belts

Most geologists agree that igneous rock formation is associated with *tectonic belts.*[14] Such belts have formed throughout time and are still being formed today. They are found at ancient or modern-day centers of formation and at junctions of the great crustal plates covering all of the earth. Tectonic belts which are still active today may demonstrate large-scale topographic features, such as the *Cordillera,* the great chain of mountains running from Alaska to southern South America.

Examples of important corundum-bearing tectonic belts include:

- The Himalayan Orogenic Belt: Stretching from the Hindu Kush in Afghanistan, through Pakistan, India, Nepal, Burma and Yunnan (China), this region includes some of the planet's most important ruby and sapphire deposits.[15]
- The Mozambique Orogenic Belt: From Mozambique in the south, through Tanzania and Kenya, to the Sudan and Ethiopia in the north, this belt cuts a 200–300 km-wide swath through east Africa's most productive gem country.

In the middle of present-day continents exist places where ancient continents smashed together and remained joined. These collisions formed ancient mountain ranges, which have since eroded away. Although little evidence of these collisions is now visible, at one time such zones were unstable. Instability equals geologic activity. Within the belts are places where molten magma from the depths was injected into surrounding rock formations or erupted onto the planet's surface. Since corundum formation is tied either to the igneous rocks themselves, or the rocks the igneous melts penetrate and alter (via contact metamorphism), past or present tectonic belts are where the hard-rock deposits are going to be.

A zone of regional metamorphism favorable for formation of gem corundum would be one similar to that of Sri Lanka, with its attendant charnockites. But again, the Sri Lankan zone lies where two ancient continental masses collided—another tectonic belt.

Where to begin looking. Geologists are constantly learning more about the belts around the world where tectonic activity has taken, and is taking place. The specific rock origins in many remote areas have yet to be deciphered, and there are likely places hidden under snow or jungle that have the rock types necessary for corundum genesis. Looking within tectonic belts, though, is essential.

Corundum deposits are becoming harder to find because most areas where placer deposits are located are also those areas with greatest population density—the tropics. Thus many of these placers have already been located.

Placer deposits are the easiest places to look. Remember that economical extraction of any mineral depends on its concentration within the host deposit. Placers are also the most concentrated of deposits, and much of the ground has been gone over. In remote tropical areas there are probably still small undiscovered placers. But, while electronic instruments exist for locating metallic minerals, there are no geophysical instruments that can remotely sense corundum-bearing gravels. The best one can do is use a magnetometer to locate significant concentrations of magnetite, which often occurs with corundum.

In summary, the best areas to look for new ruby and sapphire deposits are those showing past or present tectonic

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14. Belts of crustal instability. *Orogenic* belts are those associated with mountain-building ('orogenic') processes.

15. This belt precipitated the collision of the plate containing India and Sri Lanka (the Indian *subcontinent*), with the Asian mainland. Once far south of the equator, India raced north in a mere 30 million years (breathtaking speed in geologic terms), slamming into the Eurasian plate. Not only did this give rise to the planet's mightiest mountain range, it also resulted in rich gem deposits along the belt.

Do most gems come from the tropics?

ARE there really more gems in the tropics? The ancients thought so, and a cursory glance of a map of world gem deposits might seem to bear this out. In former times this was believed to be due to the closeness of the sun, as gems were thought to "ripen" more quickly in a warmer climate. Since the ancients obtained most of their gems from the Indian subcontinent (India, Sri Lanka, Burma), the origins of this myth are evident, as the following selection from Garcia da Orta (1913), the 16th century Portuguese physician at Goa, shows:

ORTA

...There are other white rubies in many shades. Others are slightly encarnadine, or of a whitish cherry colour. Others half-white half-vermilion, others half-sapphire half-ruby....

RUANG

Can you excuse me for asking the cause of this variation in the colour of the rubies?

ORTA

That which I have heard said, that is most conformable to reason, is that the ruby in the rock, when it is near its birth, is white, and that as it matures it reaches to the perfection of vermilion. As this perfection cannot be acquired at once, sometimes stones are found becoming red, as I said, and sometimes with bands of yellow and white. As they say that the ruby and sapphire come from one rock, there are other stones that become a mixed blue and red, like a true composition of dark blue and vermilion, and almost red. In some languages of India they call such a stone NILACANDI, which is as much as to say "ruby and sapphire."

Garcia da Orta, 1563
Colloquies on the Simples and Drugs of India

Today we know that, while gems don't necessarily occur more often in tropical areas, certain gems are more easily mined there.

Gems such as corundum are durable and corrosion resistant. This allows them to withstand the pounding of alluvial action. When of high density, they tend to sink faster and so travel shorter distances, concentrating in layers where water velocity slows. This occurs at the bottoms of slopes, at obstructions on a stream bottom, where a fast-flowing stream meets a larger, slower one, and on the inside edges of river bends (Keller, 1990).

Weathering can be important in the recovery of gems, particularly those which occur in pegmatites, for gem concentration in such deposits varies wildly from one spot to another. Even a slight increase in ore grade or a small decrease in mining costs can make a huge difference in that crucial business element—net profit. Not only is the uneven concentration of gems in pegmatites a problem, but also actual extraction. The blasting in hard-rock mining injures brittle gems; for this reason controlled blasting using widely spaced charges is used to decrease the shock.

Weathering is nature's jig, gently separating, sorting and concentrating the gems in certain places. Deposits subjected to large flows of water, in the tropics or elsewhere, will feature well-sorted sediments. Gems are mined much more easily from well-sorted sediments, as Mother Nature has already done much of the work. In such placers, gems are typically sorted by size and density.

Climate can also be important for certain gems. Turquoise, like all principal disseminated copper ore bodies, is confined to arid or semi-arid regions (Ball, 1922).

activity which are far from people, and far from the intense effects of weathering. Frozen places like Antarctica or Mongolia, for example, might have significant corundum-bearing geology. Economically mining them, however, would be another matter entirely.

Hiding in plain sight. An alternative to locating entirely new deposits is to reexamine those already known. History is replete with examples of mines abandoned as "uneconomical," which are later successfully revived. Case in point is Thailand's Bo Ploi mines. Discovered in 1918, by the early 1980s the area was being worked only sporadically. But detailed geologic surveying showed that much payable ground remained. By the late 1980s, the Bo Ploi area was one of the world's largest sapphire producers.

Where not to look. Some areas of the continents, called *cratons,* are really too old and have been regionally metamorphosed too much to yield gem corundum. These areas might be considered continental "cores." Tectonic activity has been confined to their edges since Precambrian times. The rocks of the cratons themselves are extremely deformed, and any gems would have been obliterated long ago. Cratons are large in area. Examples of cratonic terrain include most of northern Canada east of the Mackenzie River and much of eastern Siberia.

Conclusion

As previously mentioned, readers in search of more specific information on individual deposits should consult the geologic reports for that area. It is impossible to summarize geologic details of every deposit while maintaining the connecting thread presented here—specifically, the relationship between silicon, aluminum and oxygen within the earth's rocks.

Just as that thread should now stand out against the wide variety of corundum-producing terrains, climates and rocks, it should be even more apparent how rare and exotic these beautiful gems are. Considering the truly vast amounts of other silicon, aluminum and oxygen compounds that form our planet's crust, ruby and sapphire are simply glorious accidents of nature.

Summary of world corundum occurrences

Table 11.1 on page 274 describes the most important occurrences of gem quality corundum around the world, along with their geologic origin. Remember that the geologic origin for many corundum deposits has not been studied in detail and thus is subject to modification as more evidence comes to light.

Figure 11.15 The quest for ruby and sapphire increasingly involves heavy equipment and sophisticated prospecting methods. Australia is among the world leaders in corundum mining and exploration. The photo above shows drilling operations at Subera, in Queensland's Anakie fields. (Photo: Great Northern Mining)

World Sources of Ruby & Sapphire

1. Afghanistan
2. Australia
3. Bolivia
4. Brazil
5. Burma (Myanmar)
6. Burundi
7. Cambodia
8. Canada
9. China
10. Colombia
11. Czech Republic
12. Finland
13. France
14. Germany
15. Greece
16. Greenland
17. India
18. Italy
19. Japan
20. Kenya
21. Laos
22. Macedonia
23. Madagascar
24. Malawi
25. Mexico
26. Namibia
27. Nepal
28. New Zealand
29. Nigeria
30. Norway
31. Pakistan
32. Russia
33. Rwanda
34. Sierra Leone
35. South Africa
36. Sri Lanka
37. Sweden
38. Switzerland
39. Tajikistan
40. Tanzania
41. Thailand
42. Turkey
43. United Kingdom
44. United States
45. Vietnam
46. Zaire
47. Zimbabwe

Table 11.1: World occurrences of gem corundum

Locality	Mode of occurrence	Varieties
Afghanistan/Tajikistan a: Jagdalek b: Gharan c: Dharipiche d: Turakuloma (Tajikistan)	a: Ruby *in situ* in metamorphosed dolomitic limestone cut by granitic intrusions of Oligocene age (Bowersox, 1985) b: Ruby and red spinel in deposits of unknown origin; probably marble (Hughes, 1994) c: Yellow sapphire in deposits of unknown origin (Hughes, 1994) d: Ruby found in mineralized zone of marbles (Bank and Henn, 1990)	a: Red b: Red c: Yellow d: Red
Australia a: New England b: Anakie c: Lava Plains d: Hart's Range	a–c: Sapphires found in eluvial and alluvial gravels derived from alkali basalts and pyroclastics (Coldham, 1985; Pecover, 1987a) d: Ruby found in amphibolite (McColl and Warren, 1980)	a–c: Blue, green, yellow, black star d: Red
Bolivia a: Unknown locality	a: Sapphires from an unknown locality (Jaroslav Hyrsl, pers. comm., 15 June, 1995)	a: Blue
Brazil a: Río Coxim b: Indaiá	a: Sapphires found in alluvial deposits of unknown origin (Eppler, 1964) b: Sapphires found in alluvial or colluvial deposits of unknown origin (Epstein & Brennan *et al.*, 1994)	a–b: Blue
Burma (Myanmar) a: Mogok b: Mong Hsu c: Sagyin Hills d: Thabeitkyin e: Yet-Kan-Zin-Taung f: Namsèka g: Naniazeik h: Mong Hkak i: Nawarat & Namhsa	a: Ruby occurs in contact or regionally metamorphosed limestones cut by clay bands. Sapphires occur in alluvial deposits derived from granitic pegmatites, or rarely corundum syenites (Keller, 1990; Kane and Kammerling, 1992) b: Ruby occurs *in situ* in marbles and alluvial deposits derived from the same (Hlaing, 1993a) c: Ruby occurs *in situ* in marble (Penzer, 1922) d: Alluvial deposits of unknown origin (Gyi, 1938) e: Ruby in deposits of unknown origin (U Hla Win, pers. comm., 27 June, 1994) f: Ruby in deposits of unknown origin (Noetling, 1891) g: Ruby in residual deposits derived from crystalline limestones surrounded by granite intrusions (Penzer, 1922) h: Sapphire in secondary deposits associated with metamorphic (schist, gneiss) and igneous (granite, basalt) country rocks (Hlaing, 1993b) i. Ruby in deposits of unknown origin (Kane & Kammerling, 1992)	a: Red, blue, purple, violet, yellow, stars b: Red c: Red d: Red, blue, stars e: Red f: Red g: Red h: Blue i: Red
Cambodia a: Battambang (Pailin) b: Ratanakiri (Bokéo) c: Phnum Chnon, Phnum Thmei d: Chamnop	a: Sapphires and rubies found in eluvial and alluvial gravels derived from alkali basalts (Berrangé & Jobbins, 1976) b: Ruby and sapphire in deposits of basaltic origin (Berrangé & Jobbins, 1976) c: Sapphire in eluvial and alluvial deposits of basaltic origin (Berrangé & Jobbins, 1976) d: Sapphire in eluvial and alluvial deposits of basaltic origin (Berrangé & Jobbins, 1976)	a: Red, blue, green, yellow, black star b: Red, blue c: Blue d: Blue
Canada a: British Columbia b: Northwest Territory c: Ontario d: Yukon Territory	a: Ruby and green sapphire in alluvial deposits of unknown origin (Sinkankas, 1959, 1976) b: Sapphire in deposits of unknown origin (Sinkankas, 1959, 1976) c: Corundums of a variety of colors from metamorphosed limestones and other deposits of unknown origin (Sinkankas, 1959, 1976) d: Sapphire in deposits of unknown origin (Mark Mauthner, pers. comm., Sept. 23, 1994)	a: Red, green b: Blue c: Red, blue, green, black stars d: Blue to green
Czech Republic a: Jizerska Louka b: Ceské Stredohorí Mtns.	a: Blue sapphire in alluvials possibly derived from granites or basalts (Jaroslav Hyrsl, pers. comm., 15 June, 1995) b: Ruby & sapphire in deposits of unknown origin (Jaroslav Hyrsl, pers. comm., 15 June, 1995)	a: Blue b: Red, blue
China a: Wutu, Shandong b: Penglai, Hainan Island c: Mingxi, Fujian d: Ailao Mtns, Yunnan e: Nanjiang, Sichuan f: Kalpin, Xinjiang	a: Sapphire in secondary deposits derived from alkali basalts (Jinfeng Guo & Fuquan Wang *et al.*, 1992) b: Sapphire in secondary deposits derived from alkali basalts (Wang Furui, 1988) c: Sapphire in secondary deposits derived from alkali basalts (Keller & Keller, 1986) d: Ruby in deposits of unknown origin (Anonymous, 1991) e: Ruby in deposits of unknown origin (Chikayama, 1986) f: Ruby in deposits of unknown origin (Keller & Fuquan, 1986)	a: Blue, green, yellow b: Blue, green, yellow-green c: Blue, green, yellow d: Red e: Red f: Red
Colombia a: Mercaderes—Río Mayo	a: Secondary deposits derived from an unidentified source rock (Keller & Koivula *et al.*, 1985)	a: Variety of fancy colors
Finland a: Kittilä (Lapland) b: Ammänkallio, Lojo (Maila)	a: Ruby in amphibolite (Hunstiger, 1989–90). b: Corundum in limestone (Barlow, 1915)	a: Red b: Unknown colors
France a: Le Puy-en-Velay b: Chantel, Haute Allier c: La Mercredière, Brittany	a: Sapphire from volcanic rocks (Rambosson, 1870) b: Ruby in amphibolite (Hunstiger, 1989–90) c: Blue star sapphire in deposits of unknown origin (Barlow, 1915)	a: Dark blue b: Red c: Blue star
Germany a: Various localities	a: No gem material reported to date (Barlow, 1915)	
Greece a: Stirigma, Xanti b: Various	a: Ruby in marble (Hunstiger, 1989–90) b: Emery (Barlow, 1915)	a Red b: Black; not gem
Greenland a: Fiskenæsset	a: Ruby in an amphibole-rich rock (tschermakitic) (Peterson & Secher, 1993)	a: Red

Table 11.1: World occurrences of gem corundum *(continued)*

Locality	Mode of occurrence	Varieties
India		
a: Sumjam, Kashmir	a: Sapphire *in situ* and in secondary deposits derived from a pegmatite associated with actinolite-tremolite lenses (Atkinson & Kothavala, 1983)	a: Blue, purple
b: Karnataka	b: Ruby from deposits derived from anorthosite-gabbro ultramafic complexes (Viswanatha, 1982)	b: Red
c: Kalahandi, Orissa	c: Ruby from deposits of unknown origin (Kuriyan, 1993)	c: Red, stars
d: Kangayam, Tamil Nadu	d: Ruby from deposits derived from the contact of pegmatite and ultramafic rocks (Viswanatha, 1982)	d: Red
e: Andhra Pradesh	e: Ruby from deposits derived from sillimanite-garnet ultramafic complexes (Viswanatha, 1982)	e: Red
f: Madhya Pradesh	f: Ruby from deposits derived from sillimanite-cordierite-garnet graphite gneisses (Viswanatha, 1982)	f: Red
g: Rajasthan	g: Ruby from deposits derived from sillimanite-kyanite-quartz graphite schists (Viswanatha, 1982)	g: Red
Italy		
a: Lonedo, Venice	a: Sapphire and ruby in sands of unknown origin (Barlow, 1915)	a: Blue, red
b: Piedmont and Lombardy	b: Non-gem corundum of unknown origin (Barlow, 1915)	b: Unknown colors
Japan		
a: Hida metamorphic belt	a: Ruby in gneiss, formed via contact metamorphism (Hunstiger, 1989–90)	a Red
Kenya		
a: Morogoro	a: Ruby derived from desilicated pegmatites cutting serpentinite (Penny Lane mine) and contact between the serpentinite and the pegmatite (John Saul mine). (Keller, 1992)	a: Red
b: Turkana	b: Sapphire in alluvial deposits apparently derived from alkali basalts (Themelis, 1989; Keller, 1992)	b: Blue, green, stars
c: Kinyiki Hill	c: Sapphires derived from desilication of rafted gneisses in ultramafic serpentinite (Keller, 1992)	c: Blue
d: Garba Tula	d: Sapphires of possibly volcanic origin (Bridges, 1982)	d: Blue, yellow
Laos		
a: Ban Huai Sai	a: Sapphires and rubies found in eluvial and alluvial gravels derived from alkali basalts (Hughes, 1992)	a: Blue, green, black star
Madagascar		
a: Behara (near Fort Dauphin)	a: Sapphire in deposits thought connected with pegmatitic activity (Henry Hänni, pers. comm., 10 Oct., 1994)	a: Blue
b: Iankaroka (Tulear)	b: Bi-color sapphires occurring along contact zones between granites and migmatites (Koivula & Kammerling *et al.*, 1992)	b: Blue, green, orange, red (often banded)
c: Various localities	c: Corundums found in a variety of other localities	c: Various colors
Malawi		
a: Chimwadzulu Hill	a: Corundums *in situ* in an epidotized amphibolite, embedded in a coarse aggregate of hornblende crystals, which is itself enclosed in a fine-grained granular matrix of epidote and plagioclase (Rutland, 1969)	a: Various colors
Mexico		
a: San Geronimo, Estada de Oaxaca	a: Sapphire of unknown origin (Kunz, 1883)	a: Blue-yellow
b: Baja	b: Sapphire of unknown origin (Johnson, 1963)	b: Blue
Namibia		
a: Ussab	a: Sapphire found embedded in a crystalline limestone at the Ussab gold mine (Barlow, 1915)	a: Deep blue
Nepal		
a: Ganesh Himal	a Ruby *in situ* in dolomite (Dudley Blauwet, pers. comm., Sept. 14, 1994)	a: Red
b: Dhankuta, Taplejung	b: Ruby of unknown origin (Harding & Scarratt, 1986)	b: Red
New Zealand		
a: Rimu, Kanieri, Whitcombe creeks, South Island	a: Ruby *in situ* in a Cr-bearing mica rock locally termed "goodletite" (Delmer Brown, pers. comm., 12 Dec., 1994)	a: Red to bluish red
Nigeria		
a: Nisama & Jemaa	a: Sapphire in alluvial and residual deposits from alkali basalts (Kanis & Harding, 1990; Kiefert & Schmetzer, 1987)	a: Blue, yellow
Norway		
a: Fröland	a: Non-gem ruby *in situ* in a biotite-sillimanite gneiss (Hunstiger, 1989–90)	a: Red
Pakistan		
a: Hunza	a: Ruby and sapphire *in situ* in calcitic or dolomitic marble (Gübelin, 1982)	a: Red, violet, purple, blue
b: Nangimali, Azad Kashmir	b: Ruby *in situ* in marble (Anonymous, 1992)	b: Red
Russia		
a: Kootchinskoye ore complex	a: Ruby *in situ* in a magnesium-calcium marble (Koivula & Kammerling, 1991)	a: Red
b: Rai-Iz, Polar Urals	b: Ruby from plagioclasites (Evseev, 1993)	b: Red
c: Azov region	c: Ruby in a sillimanite-corundum gneiss (Hunstiger, 1989–90)	c: Red
d: Khitostrov, North Karelia	d: Rose corundum *in situ* in highly metamorphosed rocks of amphibolite type (Gromov, 1993)	d: Rose color
Rwanda		
a: Kamemba/Changungu	a: Sapphire in deposits of unknown origin (Barot *et al.*, 1991)	a: Blue, geuda
South Africa		
a: Mashishimala	a: Ruby in marble (Barlow, 1915)	a: Red
b: Oliphant river	b: Sapphire associated with a mica belt (Barlow, 1915)	b: Blue
Sri Lanka		
a: Various localities (particularly in the Highland Series), including Ratnapura, Rakwana, Elahera, Okkampitiya, etc.	a: Alluvial gravels derived from source rocks formed via granulite facies metamorphism (De Maesschalck & Oen, 1989). It is thought that intrusions of basic charnockites of basaltic chemistry into the Al-rich sediments caused their desilication, resulting in the formation of corundum (Rupasinghe and Dissanayake, 1985).	a: All varieties

Table 11.1: World occurrences of gem corundum *(continued)*

Locality	Mode of occurrence	Varieties
Sweden a: Baron mine at Gellivare-Mamberg	a: Non-gem corundum in both magnetite and hematite with syenite (Barlow, 1915)	a: Non-gem corundum
Switzerland a: Campo Longo, Tessin b: St. Gotthard c: Velle d'Arbedo & Locarno d: Passo Campolungo	a: Corundum in dolomite (Barlow, 1915) b: Ruby and sapphire in dolomite (Barlow, 1915) c: Ruby in amphibolite (Hunstiger, 1989–90) d: Ruby in marble (Hunstiger, 1989–90)	a: Red, blue, gray b: Red, blue c: Red d: Red
Tanzania a: Umba Valley b: Longido c: Morogoro area d: Mbinga district of Ruvuma (Songea)	a: Ruby and sapphire *in situ* in desilicated pegmatites cutting a serpentinite pipe and from alluvials derived from that pipe (Solesbury, 1967) b: Ruby *in situ* in a Cr-green zoisite and amphibole-bearing rock (anyolite) lying within a peridotite intruded into a sequence of high-grade metamorphic rocks (Dirlam & Misiorowski *et al.*, 1992) c: Ruby as alluvial deposits or as lenses in calc-silicate rocks within marbles (Dirlam & Misiorowski *et al.*, 1992) d: Ruby and sapphire in secondary deposits of unknown origin (Suleman & Zullu *et al.*, 1994)	a: All varieties; no stars b: Red c: Red d: All varieties; no stars
Thailand a: Chanthaburi/Trat b: Kanchanaburi c: Phrae d: Si Saket e: Sukothai f: Phetchabun	a–e: Sapphires and rubies found in eluvial and alluvial gravels derived from alkali basalts (Vichit & Vudhichativanich *et al.* 1978)	a: Blue, green, red, yellow, black star b: Blue, green, yellow c: Blue, green d: Red e: Blue f: Blue
Turkey a: Aidin province	a: Emery (Barlow, 1915)	a: Black; not gem
United Kingdom & Ireland a: Loch Roag, Scotland	a: Sapphire found in a monchiquite of lamprophyric affinities (Jackson, 1984)	a: Blue
United States a: Idaho b: Montana (Yogo) c: Montana (non-Yogo) d: North Carolina	a: Sapphire and some ruby possibly derived from a basalt dike cutting gneiss (Sinkankas, 1959, 1976) b: Sapphire *in situ* and from alluvials derived from a lamprophyric rock intruded into limestone (Brown, 1982) c: Sapphire in alluvials believed derived from igneous dikes of unknown composition (Clabaugh, 1952) d: Ruby from alluvial deposits derived from peridotites (Pratt, 1906)	a: b: Blue, violet, purple c: All varieties; no stars d: Red
Vietnam a: Luc Yen (Yen Bai) b: Quy Chau (Nghe An) c: Di Linh/Binh Dien (Lam Dong) d: Phan Thiet (Thuan Hai) e: Gia Kiem (Dong Nai)	a: Rubies found in alluvial Quarternary gravels derived from mineralized marble (Kane & McClure *et al.* 1991) b: Rubies found in alluvial gravels from unknown source rocks (probably marble). (Kane & McClure *et al.* 1991 c–e: Sapphires found in alluvial gravels derived from alkali basalts (Kane & McClure *et al.* 1991)	a: Red b: Red, orange c–e: Blue
Zaire a: Kivu region	a: Ruby and transparent sapphire found in deposits of unknown nature (Minerals Yearbook, 1952; Newman, 1994)	a: Grayish blue
Zimbabwe a: Barauta b: O'Brian's Claims	a: Sapphire in alluvials derived from a pegmatitic source rock (Sweeney, 1971) b: Ruby *in situ* in marble (Hunstiger, 1989–90)	a: Blue b: Red

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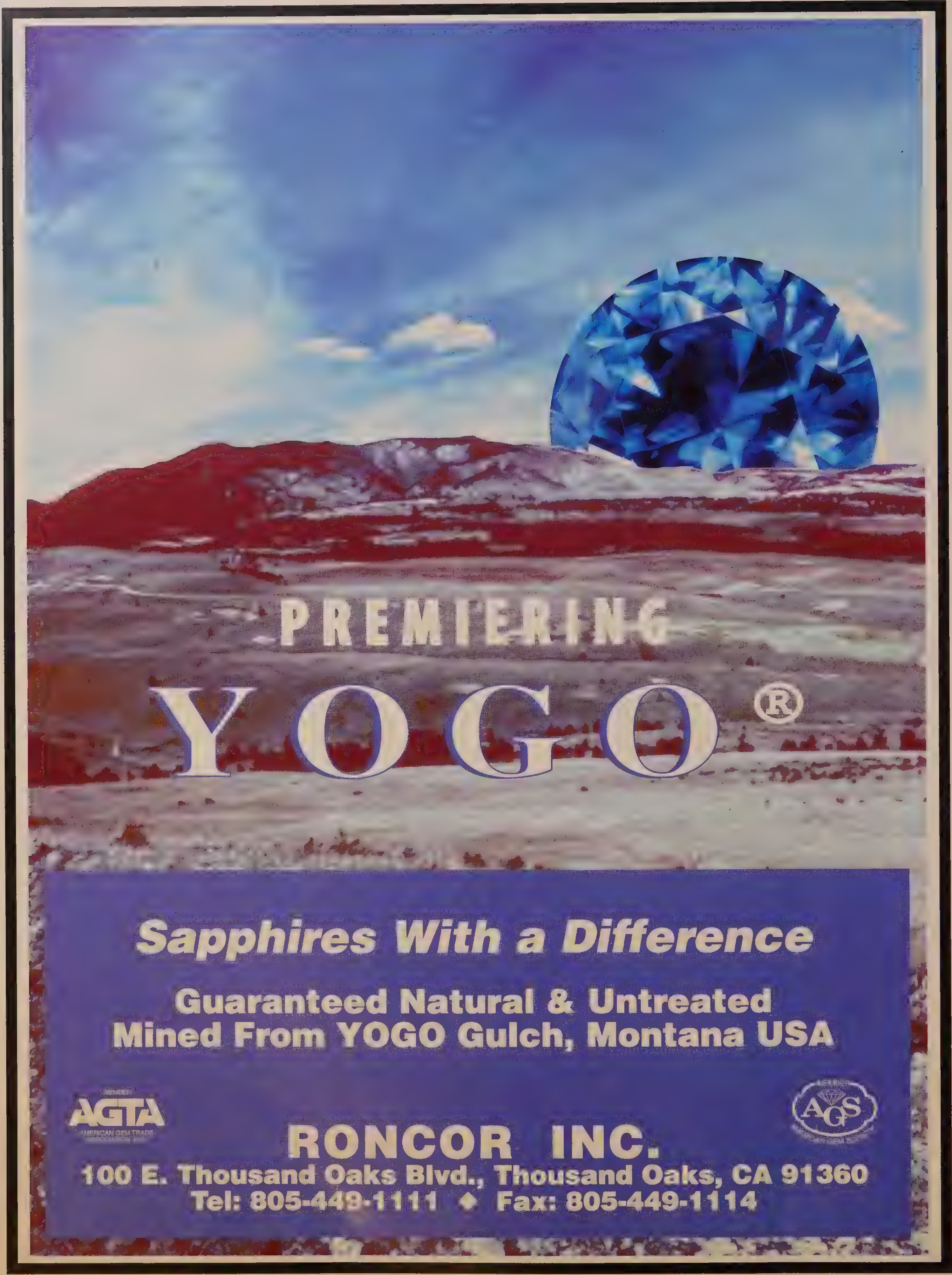
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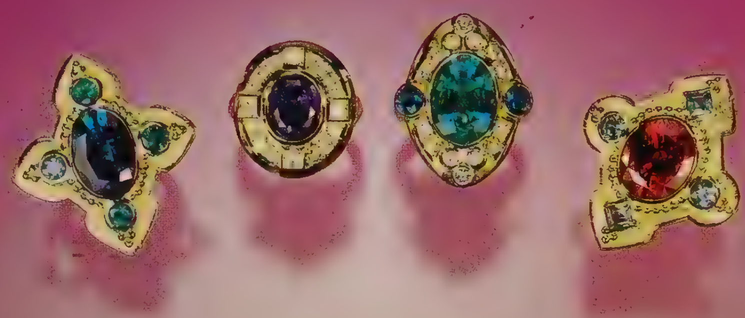

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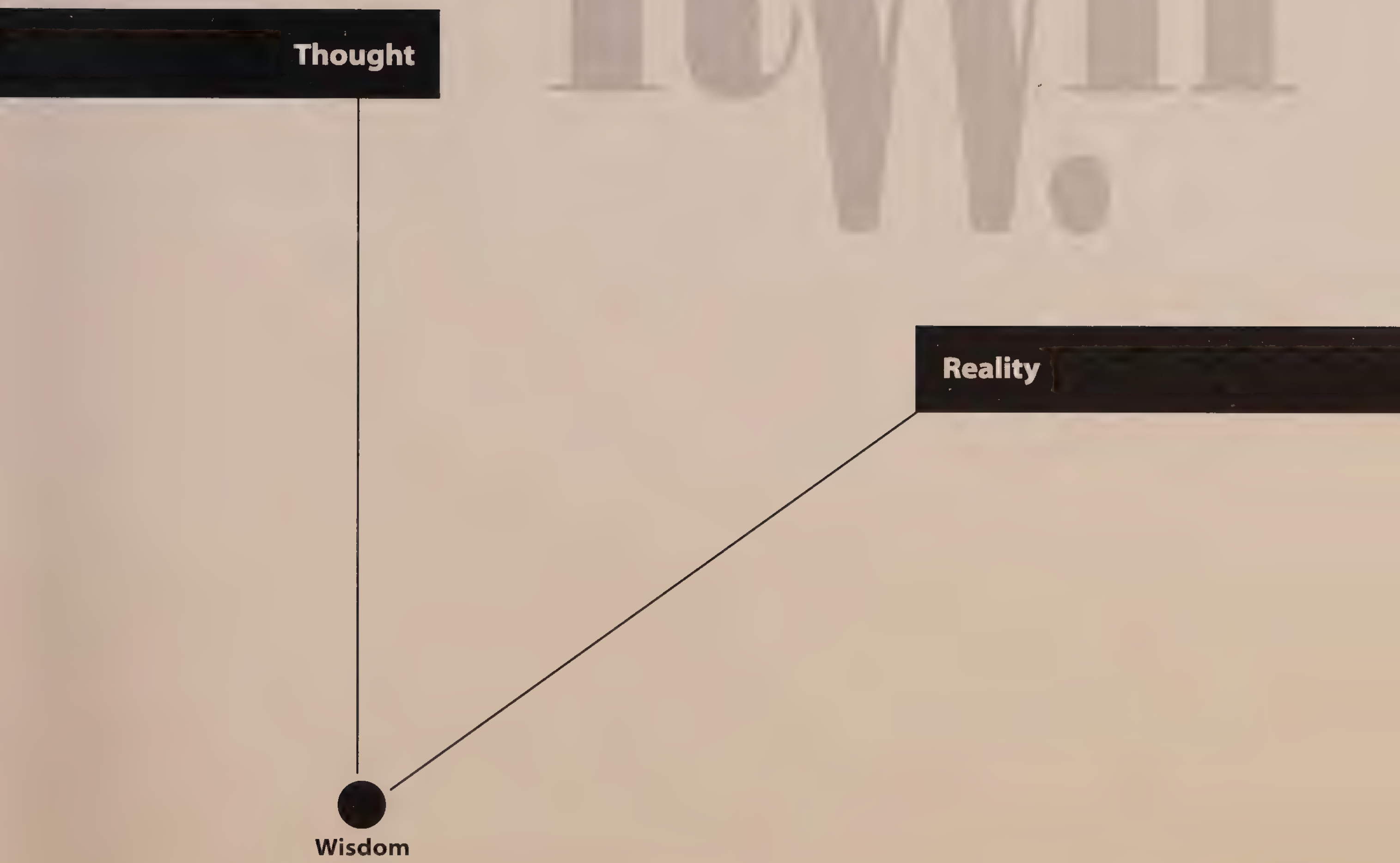

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CHAPTER 12

WORLD SOURCES OF RUBY AND SAPPHIRE

The earth was made round so that we would not see too far down the road.

Isak Dinesen, *Out of Africa*

AND for to seeke out gemmes and some little stones, we strike pits deep within the ground. Thus wee plucke the very heart-strings out of her and all to weire on our finger, one gemme or pretious stone, to fulfill our pleasure and desire. How many hands are worne with digging and delving, that one joint of our finger might shine againe. Surely if there were any devils or infernal spirits beneath, ere this time verily these mines for to feed covetousness and rowt would have brought them up above ground.

C. Plinius Secundus, 23–79 AD, *The Historie of the World*
Philemon Holland translation, 1661
(From S.H. Ball, 1931)

The quest for precious stones does not rank high on humankind's list of worthy or redeeming activities. You'll find no mention of it in the Boy Scout handbook. And you'll not see it prescribed by priests as a path towards forgiveness, for in the struggle to possess the earth's booty, far too many a sinner is born and even more falsehoods are fabricated. We cannot look to gemstone mining for useful homilies. There is no lesson via process, no consolation in the journey. The only reward is the reward itself—to possess, to claim as one's own. Gem mining's attraction is thus: grasp the purest of the pure, tap God's current, the power of all creation. Hold the earth's bounty in one's *own* hand… and damn anyone who shall stand in your way.

Anonymous

Afghanistan/Tajikistan

The great enigma: Afghanistan's ruby/spinel mines

Afghanistan's ruby/spinel mines are one of the great mysteries of gemology. Historically, rubies and red spinels have been produced from four areas: Burma, Sri Lanka, the Thai/Cambodian border (ruby only; no red spinel) and Afghanistan. While extensive accounts exist regarding the other deposits, little has been written about the rubies/spinels of Afghanistan in the 20th century. Indeed, many are totally unaware of the Afghan occurrences.

Although the author has visited Afghanistan and has examined many rubies from Jagdalek, he has not visited either of the two major deposits described. Thus the following has been assembled from historical sources, with much of the primary research on inclusions in Jagdalek stones coming from the author's own research. In terms of historical data, rather than rewriting or paraphrasing what others have found and, in the process, claiming it as his own, the author believes history is better served by repeating their words exactly, warts and all. Hence the extensive use of quotations from the primary literature (including the original footnotes from those sources).[1]

[1] All footnotes attached to quotations are those of the original authors, and are indicated with symbols (*, †, etc.). My own footnotes are at the bottom of the page and are numbered—RWH.

Early history: 1000–1895 AD

Afghanistan's ruby/spinel mines were mentioned in the Arabic writings of many early travelers, including Istakhri (951 AD), Ibn Haukal (978 AD), al-Ta'Alibi (961–1038 AD), al-Muqaddasi (ca. 10th century), al-Biruni (b. 973; d. ca. 1050 AD), al-Teifaschi (1240 AD), and Ibn Battuta (1325–1354 AD).

Mohammad Ben Mansur, writing in the 12th century, stated during the time of Abbaside (caliphs who ruled from 750 to 1258 AD), a hill at Chatlan was broken open by an earthquake and within a white rock in the fracture was found the *'Laal-Bedaschan'* (balas ruby). Women of the neighborhood apparently tried to extract dye[2] from the red stones, and failing, threw them away. Later a jeweler recognized their value (Ball, 1931).

Although Marco Polo (ca. 1254–1324 AD) apparently did not visit the mines, he passed nearby. In Yule's definitive version of Marco Polo's travels is the following:

> **Polo's text**
>
> BADASHAN is a Province inhabited by people who worship Mahommet, and have a peculiar language. It forms a very great kingdom, and the royalty is hereditary…
>
> …It is in this province that those fine and valuable gems the Balas Rubies are found. They are got in certain rocks among the mountains, and in the search for them the people dig great caves underground, just as is done by miners for silver. There is but one special mountain that produces them, and it is called SYGHINAN. The stones are dug on the king's account, and no one else dares dig in that mountain on pain of forfeiture of life as well as goods; nor may any one carry the stones out of the kingdom. But the king amasses them all, and sends them to other kings when he has tribute to render, or when he desires to offer a friendly present; and such only as he pleases he causes to be sold. Thus he acts in order to keep the Balas at a high value; for if he were to allow everybody to dig, they would extract so many that the world would be glutted with them, and they would cease to bear any value. Hence it is that he allows so few to be taken out, and is so strict in the matter.*
>
> **Henry Yule's annotations**
>
> *—I have adopted in the text for the name of the country that one of the several forms in the G. Text which comes nearest to the correct name, viz. *Badascian.* But *Balacian* also appears both in that and in Pauthier's text. This represents *Balakhshán*, a form also sometimes used in the East. Hayton has *Balaxcen*, Clavijo *Balaxia*, the Catalan Map *Baldassia*. From the form *Balakhsh* the Balas Ruby got its name. As Ibn Batuta says: "The Mountains of Badakhshan have given their name to the Badakhshi Ruby, vulgarly called *Al Balaksh.*" Albertus Magnus says the *Balagius* is the female of the Carbuncle or Ruby Proper, "and some say it is his house, and hath thereby got the name, quasi *Palatium* Carbunculi!" The Balais or Balas Ruby is, like the Spinel, a kind inferior to the real Ruby of Ava. The author of the *Masálak al Absár* says the finest Balas ever seen in the Arab countries was one presented to Malek 'Adil Ketboga, at Damascus; it was of a triangular form and weighed 50 drachms. The prices of *Balasci* in Europe in that age may be found in Pegolotti, but the needful problems are hard to solve.
>
> No sapphire in Inde, no Rubie rich of price,
There lacked than, nor Emeraud so grene,
Balès, Turkès, ne thing to my device.
(Chaucer, *'Court of Love.'*)
>
> L'altra letizia, che m'era già nota,
Preclara cosa me si fece in vista,
Qual fin *balascio* in che lo Sol percuoto.
(*Paradiso*, ix. 67)
>
> **Henri Cordier's annotations**
>
> ["…d'Ohsson translates a short account of Badakhshan by Yakut (+1229), stating that this mountainous country is famed for its precious stones, and especially rubies, called *Balakhsh.*" (Bretschneider, *Med. Res.* II. p. 66.)—H.C.]
>
> The account of the royal monopoly in working the mines, etc., has continued accurate down to our day. When Murad Beg of Kunduz conquered Badakhshan some forty years ago, in disgust at the small produce of the mines, he abandoned working them, and sold nearly all the population into slavery! They continue to remain unworked, unless clandestinely. In 1866 the reigning Mír had one of them opened at the request of Pandit Manphul, but without much result.
>
> The locality of the mines is on the right bank of the Oxus, in the district of Ish Káshm and on the borders of SHIGNAN, the *Syghinan* of the text. (*P. Manph.; Wood*, 206; *N. Ann. des. V.* xxvi. 300.)
>
> [The ruby mines are really in the Gháran country, which extends along both banks of the Oxus. Barshar is one of the deserted villages; the boundary between Gháran and Shignán is the Kuguz Parin (in Shighai dialect means "holes in the rock"); the Persian equivalent is "Rafak-i-Soumakh." (Cf. Captain Trotter, *Forsyth's Mission*, p. 277.)—H.C.]
>
> Yule & Cordier, 1920, *The Book of Ser Marco Polo*

The famous Moorish traveller, Ibn Battuta (Batuta) (1325–1354 AD), mentioned the following:

> People generally attribute the lapis-stone [lapis lazuli; Arabic *lazward*] to Khurasan, but in reality it is imported from the mountains of [the province of] Badakhshan, which has given its name also to the ruby called *badakhshi* (pronounced by the vulgar *balakhshi*)…
>
> H.A.R. Gibb, 1971, *The Travels of Ibn Battuta*, Vol. 3

An early mention of the rubies of Badakshan is found in the writings of the Spaniard, Ruy Gonzalez de Clavijo, who visited the court of Timur,[3] at Samarkand in the years 1403–1406 AD.

> The lord [Timour] caused all the Meerzas and nobles in the land of Samarcand to come to this festival; amongst whom was the lord of Balaxia, which is a great city, where rubies are procured; and he came with a large troop of knights and followers.
>
> The ambassadors went to this lord of Balaxia, and asked him how he got the rubies; and he replied that near the city, there was a mountain whence they brought them, and that every day they broke up a rock in search of them. He said that when they found a vein, they got out the rubies skilfully, by breaking the rock all round with chisels. During the work, a great guard was set by order of Timour Beg; and Balaxia is ten days journey from Samarcand, in the direction of India.
>
> Ruy Gonzalez de Clavijo, 1403–6 AD (Markham, 1859)

In 1832, James Prinsep published a fascinating paper in the *Journal of the Asiatic Society of Bengal.* This contained abstracts of three different oriental works, translated into

2. Lapis lazuli, also from Badakshan, was an important source of pigment in ancient times (*viz.* ultramarine, which is made by crushing lapis). Thus the actions of these women are understandable. However, corundum and spinel, unlike lapis, are colored by impurities. Thus their streak, and their color when crushed, is colorless.

3. Tamerlane is an English corruption of *Timur i leng* ('Timur the lame'), as Timur was crippled in battle when about 27 years old (Collins, 1968).

Figure 12.1 Major gem deposits of central Asia. Corundum is found at Sumjam (India), Hunza (Pakistan), Jagdalek (Afghanistan) and Gharan (Afghanistan/Tajikistan), as well as along the China/Tajikistan border.

English by Raja Kalíkishen,[4] some of which covered the ruby/spinel deposit of Badakshan:

Dodecahedral Corundum or Spinelle Ruby
Persian: *lâl;* Hindu: *manik?* or *lâl.*

"The mine of this gem was not discovered until after a sudden shock of an earthquake, in *Badakshan**, had rent asunder a mountain in that country, which exhibited to the astonished spectators a number of sparkling pink gems of the size of eggs. The women of the neighborhood thought them to possess a tingent quality, but finding they yielded no coloring matter, they threw them away. Some jewellers, discovering their worth, delivered them to the lapidaries to be worked up, but owing to their softness the workmen could not at first polish them, until they found out the method of doing so with *mark-i-shísá,* marcasite or iron pyrites. This gem was first esteemed more than the *yaqút,* but as its color and hardness were found to be inferior to the latter, it became less prized."...

In a manuscript history of Cashmír and the countries adjacent, by Abdúl Qádir Khan, Benares, 1830, is the following description of the manner of extracting rubies from the *Badakshan* mines: it professes to be taken from an oral account by Mirza Nazar Báki Bég Khán, a native of *Badakshán,* settled at Benares.

Having collected a party of miners, a spot is pointed out by experienced workmen, where an adit is commenced. The aperture is cut in the rock large enough to admit a man upright: the passage is lighted at intervals by cotton *mashúls* placed in niches; as they proceed with the excavation, the rock is examined until a vein of reddish appearance is discovered, which is recognized as the matrix of the precious gem. This red colored rock or vein is called *rag-i-lál,* or, the vein of rubies; the miners set to work upon this with much art, following all its ramifications through the parent rock. The first rubies that present themselves are small, and of bad colour: these the miners called *piadehs* (foot soldiers): further on some larger and of better colour are found, which are called *sawars* (horse soldiers); the next, as they still progress in improvement, are called *amirs, bakshis,* and *vazirs,* until at last they come to the *king jewel,* after finding which, they give up working the vein: and this is always polished and presented to the king. The author proceeds to describe the finest ruby of this kind that had ever fallen under his observation. It belonged to the Oude family, and was carried off by Vizir Ali; he was afterwards employed in recovering it from the latter: it was of the size of a pigeon's egg, and the color very brilliant; weight, about two tolas; there was a flaw in it, and to hide it, the name of *Julál-ud-dín* was engraved over the part; hence the jewel was called the *lál-i-jaláli.* A similar ruby to this, but considerably larger, is in the possession

[4] The information was extracted from three books, of different eras: 1, the *Ajáib-ul-makhlukát o Gharáib-ul-moujudát,* an ancient Persian work on natural history, written by *Zakarya,* a native of *Kufa,* date unknown; 2, the *Aqul-i-ashreh,* a work on science, by Mahomed of Berar, An. Hej. 1084 (AD 1673) and 3, the *Jawáhir-námeh,* a modern anonymous compilation, containing much useful matter in a condensed form; the latter was probably written at one of the native courts, either Delhi or Hyderabad, since it mentions the opening of [then] recent mines in India (Prinsep & Kalíkishen, 1832).

Figure 12.2 Although facet-quality rubies from Jagdalek are somewhat scarce, they are magnificent when found, as the above stone shows. (Photo: Bart Curren/ICA)

of *Runjit Sinh*, and has the names of five emperors engraved upon it.

Prinsep & Kalíkishen's annotations

[*] The *Manaif-ul-ahjár* dates this occurrence "350 years ago," but the date of the work is not given: the *lál* is not mentioned by *Zakarya*. Since the above was written, Mr. H.H. Wilson has favored me with a sight of another work on jewels, entitled *Khawás-ul-hejár*, translated by himself, in which the *lál* is treated of under the name of *balaksh* (*Balakshan* being synonymous with *Badakshan*). This leaves no doubt as to the origin of the word Balas…

James Prinsep & Raja Kalíkishen, 1832

The inscriptions mentioned on the ruby owned by Ranjit Singh ('Runjit Sinh') suggest that this was the Timur Ruby now in the personal collection of the British monarch (see box, page 282).

In 1836, Captain John Wood began an epic journey to trace the headwaters of the Oxus River. He did attempt to visit the ruby mines in Badakshan, but due to inclement weather was unsuccessful. The following is his account:

> The ruby mines are within twenty miles of Ish-kashm, in a district called Gharan, which word signifies caves or mines, and on the right bank of the river Oxus. They face the stream, and their entrance is said to be 1,200 feet [366 m] above its level. The formation of the mountain is either red sandstone or limestone largely impregnated with magnesia. The mines are easily worked, the operation being more like digging a hole in sand, than quarrying rocks.… The galleries are described as being numerous, and running directly in from the river. The labourers are greatly incommoded by water filtering into the mine from above, and by the smoke from their lamps, for which there is no exit. Wherever a seam or whitish blotch is discovered, the miners set to work; and when a ruby is found it is always encased in a round nodule of considerable size. The mines have not been worked since Badakhshan fell into the hands of the Kunduz chief, who, irritated, it is supposed, at the small profit they yielded, marched the inhabitants of the district, then numbering about five hundred families, to Kunduz, and disposed of them in the slave market. The inhabitants of Gharan were Rafizies, or Shiah Mohamedans, and so are the few families which still remain there.
>
> John Wood, 1841, *A Journey to the Source of the River Oxus*

A mention of the Badakshan mines was also made by Pandit Manphúl, in a report dated 1867. His report is important

Famous balas rubies— Blood-red souvenirs of conquest

AMONG the most storied stones of history are the large balas rubies found in museums and gem collections throughout the world. The Diamond Fund in Russia has a number of representative examples. Noted Russian gemologist/mineralogist, Alexander Fersman, remarked "…in the Diamond Fund these spinels have a significant place. One of such stones, weighing 100 carats, speaks to us of the sands of Ceylon, but the majority of them come from Afghanistan, from the mountains of the province of Badakshan. In old Russian manuscripts it was called 'lal Badakhshan.'" (Fersman, 1946, p. 374).

Prominent among spinels in the Diamond Fund is the massive red orb atop the Imperial Russian Crown. This crimson colossus tips the scales at 414.30 ct (Twining, 1960). A rather fanciful description of the stone's history has been given by Yevdokimov (1991). It was said to have been found by Chun Li, a Chinese-mercenary member of Timur's[a] army that looted Samarkand. Unfortunately for Chun Li, he failed to turn in some of the booty, and so was exiled in slavery to the ruby/spinel mines of Badakshan. Finding the stone, he crept away in the night and made his escape. But his attempt to present it to the Chinese emperor was thwarted when a palace guard found the stone and killed him for it. This guard was similarly killed when a jeweler he tried to sell the stone to turned informant. Thus the gem passed to the emperors. In 1676, the ruby was purchased "at a pretty price" from emperor Kon Khan by Nikolai Spafari, at the behest of Alexei Mikhailovich, second Czar of the Romanov dynasty. Upon the ascendancy of Catherine II ('The Great') to the throne in 1762, she had the stone mounted on the top of her crown, where it remains today (Yevdokimov, 1991).

Another famous spinel is the Timur Ruby, or Khiraj-i-alam ('Tribute to the World'). Timur was the last of the great nomad kings to overrun the world. When not conquering far-off lands he made his base at Samarkand, where legendary feasts and orgies were held, some of which went on for days (Collins, 1968).

The Timur Ruby weighs 352.5 ct and is currently in the private collection of Queen Elizabeth II. It carries several Persian inscriptions written in Arabic, the longest of which reads: "This is the ruby among the twenty-five thousand jewels of the King of Kings, the Sultan Sahib Qiran." The ruby is said to have passed into his hands when he sacked Delhi in 1398 and, after the usual pillage and extortion, was later obtained by Ranjit Singh, the 'Lion of the Punjab.' The British annexed the Punjab in 1849. Along with the province, they also "annexed" the Koh-i-Nur diamond and the Timur Ruby. Both were later presented to Queen Victoria (Twining, 1960).

a. Also known as Shah Qiran; b. 1336?; d. 1405]

Figure 12.3 Not even war slows the quest for precious stones. Here Afghan miners drill the limestone in search of ruby at Jagdalek, Afghanistan.
(Photo: Gary Bowersox)

for, unlike most others, Manphúl seems to have examined actual specimens. He said:

> The Ruby Mines are situated in *Ishkásham,* bordering on *Shighnán.*... The Ruby mines have not been worked for the last twenty years and upwards. They were then given up in consequence of the labour spent on them not having been sufficiently rewarded; whether the mines had been exhausted, or whether the workers were unskilful, or managed to steal the more precious stones, is not certain. The present Mír, who had one of the mines worked last year (A.D. 1866), at my request, made over to me some of the best specimens brought to him. They are not the best of their kinds, unless the one encased in a nodule turn out to be so. The Mír, depreciating the skill of the present workers, who are natives of the country, and, according to an established usage, labour for nothing, is anxious to secure the services of competent miners.... It is believed that the mines are still stealthily worked by the people living near them, with, or without the countenance and connivance of the servants of the Mír charged with their management. The mines are known to have yielded rubies of six different colours, viz. red, green, white, yellow, violet, and rosy. The specimens with me are white, violet, and rosy.
>
> The ruby (*lál*) has given Badakhshan a lasting celebrity in the world of Oriental poetry.
>
> The Sohanmakkhi* also comes out of the Ruby Mines.
>
> **Yule's annotations**
>
> * [Query, corundum?]
>
> Pandit Manphúl, *Badakhshán and the Countries around it* (see Yule, 1872)

Valentine Ball (1881), Irishman *extraordinaire,* former head of the Geological Survey of India and editor of *Tavernier's Travels in India,* also remarked on the mines, under the topic of spinel:

Afghanistan.—In the year 1879 the so-called ruby mines of the late Amir of Afghanistan, Shir Ali, which are situated near the village of Jagdalak in Kabul, were visited by Major Stewart of the Guides. Two specimens of stones, called *yakut* by the natives, and samples of the matrix, were forwarded to the office of the Geological Survey for examination. The stones proved to be spinel, and the matrix a crystalline micaceous limestone. Major Stewart* states that the Amir kept a strict guard over the mines and only allowed particular friends of his own to work them.

Badakshan.—The balas ruby mines of Badakshan are situated on the banks of the Shighnan, a tributary of the Oxus. They have been known by reputation for very many centuries, and the name balas is derived from Balakshan, another form of writing the name of the country or from Balkh the capital town.† This may possibly be the origin of the common mistake made in English works on precious stones, namely, that these mines are situated in Balochistan!...

* Prog. As. Soc. Bengal, 1880, p. 4.

† Prinsep J. Jour. As. Soc. Bengal, Vol. I, p. 359

Valentine Ball, 1881
A Manual of the Geology of India, Part III: Economic Geology
pp. 429–430

Ball claimed the Jagdalek stones were spinel. While spinel could also possibly occur there, a later analysis reported by F.R. Mallet (1887) proved that the two specimens collected were, in fact, rubies.

Bauer (1904) describes both the Jagdalek and Badakshan deposits. Of the latter, Bauer said:

> The ruby mines of Badakshan were famous in olden times, and they supplied some of the vast store of treasure amassed by the Great Mogul. They are situated in Shignan, on the bend of the Oxus river, which is directed to the south-west, in latitude about 37°N. and longitude 71.5°E. They lie between the upper course of the Oxus and its right tributary the Turt, near Gharan, a place the name of which is said to signify "mine," sixteen miles [26 km] below the town of Barshar, in the lower, not the higher, mountain ranges....
>
> It is possible that the rubies and spinels which have recently come into the market through Tashkent, and which, according to the merchants, were mined in the Tian-Shan Mountains, are in reality from these same mines. There is no reliable information as to the existence of ruby mines in the Tian-Shan Mountains or in Tibet, so that the 2000-carat ruby recently received by Streeter, and said to come from Tibet, may also have been found in these mines on the Oxus.
>
> Max Bauer, 1904, *Precious Stones*

There is little mention of the Badakshan mines after Bauer, possibly because they lie on the border of, or inside, Tajikistan, a region of the former USSR little visited by foreigners. Barthoux (1933) discussed the mines, stating they lay near the village of Siz, in the area of *Ghâran,* on the right bank of the Oxus. He reported that huge, translucent, purplish pink octahedrons (*'le rubis balais'*) over 20 cm in size were extracted at that locality. Almandine garnet was said to occur on the left bank. Barthoux also stated that a more important occurrence of ruby was at Jagdalek ('Djagdalik').

Badakshan ruby/spinel: Myth or reality?

FROM the historical record, it is clear that the Badakshan mines were of great importance during the period from 1000–1900 AD. While it is impossible to speculate about ruby, it is safe to say that, based on the numerous historical accounts, the Badakshan mines were the source of many of the finest early red spinels in gem collections around the world, such as those in the crown jewels of Iran, the collection in Istanbul's Topkapi, Russia's Diamond Fund, and England's Tower of London.

Unfortunately, in modern times, these mines are largely overlooked. 20th-century gemologists persist in the belief that the only source of big red spinels is Burma (Kammerling & Scarratt *et al.*, 1994). This is not based upon any particular evidence, such as inclusion studies; for these studies do not exist, either for Burma spinels or for those from Badakshan.[a] Instead, it simply rests upon the belief that what is today, has always been.

While evidence for the existence of the Badakshan mines is not direct, it is substantial. We have the name *balas ruby,* which is apparently derived from an ancient word for Badakshan, we have numerous detailed accounts of the mining, we have spinels with Arabic inscriptions and we have historical names, such as the *Timur* ruby. Circumstantial? Indeed. But if circumstantial evidence was of no value, the world's jails would be empty.

[a] Occasional photos of inclusions in Burmese and Sri Lankan spinel have been published. But since no *in-situ* collecting has been done at the Badakshan mine, and little in Burma, it is impossible to say whether similar inclusions will be found at each deposit. Remember, rutile silk has been found in rubies from virtually every deposit except Thailand/Cambodia. Similar inclusions are often found in stones from different mines.

The larger pieces were mostly massive, but smaller pieces showed traces of "$p\{10\bar{1}1\}$, $a\{0001\}$, $d\{11\bar{2}0\}$ and $e\{22\bar{4}3\}$." They were found with spinel and most were pink in color. Also occurring with the rubies were humite, chondrodite, phlogopite, fuchsite, rutile, sphene, hematite and pyrite (Barthoux, 1933; trans. by Olivier Galibert, June 3, 1994).

After Barthoux, discussion of Afghan rubies was restricted to the Jagdalek mines. During the Soviet occupation, mining of all Afghan gem and mineral deposits was controlled by the state (Boa, 1987). However, since many mines lay in inaccessible areas, such mining became an important source of income for the rebels. With the Soviet pullout, modern exploration and exploitation might become possible, thus increasing the output from Afghanistan.

Other Afghanistan localities

Streeter (1892) did mention a ruby of 10.5 ct brought to England from mines at Gandamak, about 20 miles (32 km) from Jagdalek. Due to the proximity of these localities, it is possible that the stone actually came from Jagdalek. Griesbach (1892) reported rubies 20 miles (32 km) west of Tatang in a coarse, micaceous marble.

Figure 12.4 An Afghan miner stands outside one of the limestone galleries at the Jagdalek ruby mines, near Kabul.
(Photo: Gary Bowersox)

Gary Bowersox reported that gem-quality ruby had been found northeast of Kabul (Koivula, 1987). No further details are available. Ghaggi has also been reported as a source of ruby. About 1986, American dealer Dudley Blauwet purchased a large, euhedral yellow sapphire crystal said to have originated from Dharipiche, Kunar Province, northeastern Afghanistan (pers. comm., Sept. 19, 1994).

Tajikistan

In the late 1980s, large reddish spinels were reported from the Pamir mountains of what is now Tajikistan. One 532-ct rough yielded cut gems of 146.43 and 27.81 ct (Bancroft, 1989, 1990). It is not known if the mine that produced these specimens is the same as the Badakshan mine described above (Peter Bancroft, pers. comm., June, 1994). Ruby was also reported in eastern Tajikistan, near the border with China, in the early 1980s (Bank & Henn, 1990; Henn & Bank *et al.,* 1990). The mine is said to be located at Turakuloma, some 40 km northwest of Murgap, at 4500 m above sea level, in a mineralized zone of marbles. However, this deposit is far from the Afghan border.

According to Dr. Jaroslav Hyrsl (pers. comm., 10 May, 15 June, 1995), the location of heavy mineralization is in eastern Tajikistan is within the Muzgkol metamorphic complex. This consists of gneisses, marbles, pegmatites, etc. Ruby in marble and gemmy violet scapolite crystals (up to several cm in length) in hydrothermal veins are found. The best pegmatite is said to be at Kukurt Lake, near Murgap; elbaite, blue topaz, danburite and jeremejevite are found there. Pink spinel occurs with gemmy clinohumite and white forsterite and black graphite grains (all together in massive pyrrhotite) at Kuh-i-lal ['the place of ruby/spinel']. This is the same name as that applied to the famous Badakshan mine, no doubt because the stones found there are the same.

Summary of the historical record

The above accounts clearly describe two separate mines for ruby and/or spinel. One, located at Jagdalek (spelled variously, *Jagdalak* or *Jegdalek*), 51.5 km (32 miles) east of Kabul, and another further north in Badakshan, on the banks of the Shignan, a tributary of the Oxus (Amu Darya), near Gharan, just north of Ishkásham. According to Alexander Fersman (1946–47), noted Russian mineralogist/gemologist, "From the mines at the mouth of the Kuga–Lial River, the East for a thousand years has been getting its red stones—bright rubies and pinkish-red spinels, called *lal*."[5] Gary Bowersox has told the author that the Afghan name of the Badakshan mine is *Kuh-i-lal* ['the place of ruby/spinel'] (pers. comm., July 1, 1994). Undoubtedly the localities described by Fersman and Bowersox are identical.

Political difficulties and rugged terrain make Afghanistan a difficult country to explore, and Tajikistan is no better. Until someone manages to visit the Badakshan mines, and lives to tell the tale, we must be content with mere speculation.

Characteristics of Afghanistan ruby (Jagdalek)

Nothing exists in the literature regarding the gemological characteristics of rubies or spinels from Badakshan, primarily because no 20th-century eyewitness accounts exist of the mines. In addition, gemological descriptions of the important specimens of history, such as the Timur and Black Prince's rubies, have never been published.

The situation at Jagdalek is somewhat better. Material has filtered out throughout the 1980s. In the early part of that decade, the author acquired a number of faceted and rough specimens from Jagdalek.

Occurrence. Afzali (1981) reported the Jagdalek mine to lie in Kabul province at 34° 26' N, 69° 49' E. The most complete description of the mine is that of Brückl (1937, in German). Rubies are said to occur embedded in a regionally-metamorphosed marble cut by granitic intrusions of Oligocene age.

Color range. Rubies from Jagdalek are only rarely encountered in faceting quality, but when clean can be magnificent. In terms of color, Jagdalek rubies resemble most the gems of Vietnam, Burma and Sri Lanka, being strongly fluorescent and often of a slightly pinkish or raspberry-red hue similar to rubellite tourmaline. A small percentage are of violet hue.

Figure 12.5 A beautiful example of a ruby from Jagdalek, Afghanistan. (Photo: Bart Curren/ICA)

Solid inclusions. Common are colorless blocks displaying rhombohedral cleavage, most likely calcite. Inclusions of calcite are not surprising, considering that Jagdalek rubies are found in a marble matrix, just as in Burma. Transparent plates and books of hexagonal outline are also seen. Their anisotropic character between crossed polars and prominent basal cleavage suggest mica. Other platelike inclusions consist of irregular distorted shingles which are opaque and black or slightly gold in color. These also display a somewhat micaceous appearance. Rounded colorless grains of low relief were also seen and, in one specimen, corroded blocks of yellow color. Several specimens examined by the author contained deep red-orange prisms of square outline and submetallic luster. Some were knee-shaped twins with obvious re-entrant angles, indicating rutile.

Cavities. Both primary and secondary fluid inclusions are seen, the latter responsible for the lack of clarity most of these rubies display. Irregular, fluid-filled cavities with jagged edges (much like those in Colombian emeralds) are found. However, the cavities of the Jagdalek rubies are somewhat thicker. The fingerprints and feathers which fill these stones often show a ragged appearance, with coarse tubes that can easily be confused with the flux inclusions in flux-grown synthetics.

Growth zoning. Color zoning in Jagdalek rubies is extremely sharp and narrow, forming in the typical hexagonal pattern when viewed parallel to the *c* axis. Interesting features of Jagdalek rubies are the small spots or zones of sapphire-blue color. Such blue zones may be angular in outline, or consist of narrow bands, but all show a sharp division between red

[5] *Lal* is the Persian word for balas ruby. In Chinese, it is *la* (Bretschneider, 1887).

Table 12.1: Properties of Jagdalek (Afghanistan) ruby[a]

Property	Description
Color range/phenomena	• Near colorless to a deep red, often slightly purplish, strongly fluorescent. Violet stones are seen on occasion.
Geologic formation	• Ruby is found embedded in a regionally metamorphosed marble cut by granitic intrusions of Oligocene age
Crystal habit	• Most crystals are hexagonal prisms (short or long) with development of rhombohedron and pinacoid faces. Spindle-shaped bipyramids are also sometimes seen.
RI & birefringence	n_ε = 1.762; n_ω = 1.770 Bire. = 0.008
Specific Gravity	~4.00
Spectra	**Visible region**: Strong Cr spectrum (similar to rubies from other localities)
Fluorescence	**UV**: Strong red to red-orange fluorescence (LW stronger than SW)
Other features	May be dyed or heat treated
Inclusion types	**Description**
Solids	• Apatite (Beesley, 1986) • Calcite; rhombs (Beesley, 1986) • Chondrodite (Barthoux, 1933) • Dolomite (Brückl, 1937) • Garnet (Brückl, 1937) • Graphite (Brückl) • Hematite (Barthoux, 1933) • Humite (Barthoux, 1933) • Mica (fuchsite, phlogopite); books (Barthoux, 1933) • Pargasite (hornblende) (Barthoux, 1933) • Pyrite (Barthoux, 1933) • Spinel (Brückl, 1937) • Rutile; prisms, knee-shaped twins (Barthoux, 1933) • Sphene (Barthoux, 1933)
Cavities (liquids/gases/solids)	• Primary cavities and negative crystals • Secondary healed fractures are common. They occur in a variety of patterns and thicknesses • Iron oxide stains are common in cracks (these may be removed during heat treatment)
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle'-like swirls in other directions. Blue color zones are intermingled in most stones, similar to Mong Hsu (Burma) and Vietnamese rubies. Growth zoning is extremely sharp and prominent.
Twin development	• Growth twins of unknown orientation • Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Dense zoned clouds of (often, but not always) tiny particles (probably rutile), parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.1 is based on the author's first-hand studies, supplemented by those of Bowersox (1985), Barthoux (1933), Beesley (1986), Brückl (1937) and Themelis (1988).

and blue. Similar blue zoning is seen in rubies from Vietnam and Mong Hsu (Burma).

Twin development. Rhombohedral polysynthetic twin lamellae are seen in most specimens, inevitably accompanied by long white boehmite needles meeting at 86.1/93.9°.

Exsolved inclusions. While exsolved rutile needles have not been found, clouds of tiny exsolved particles of what may be rutile have been seen. The lack of true silk means that star rubies are not produced. Cabochons may show a silvery sheen, though, from reflection off the particles. Exsolved boehmite needles are common at the junctions of intersecting rhombohedral twin lamellae.

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Australia

Although Australia's interior is largely composed of desert wastelands, beneath the surface of the continent's eastern fringes lies some of the planet's most important sapphire deposits. Unfortunately, most are of lower commercial grades, so much so that the term *Australian sapphire* has become synonymous with dark, inky-blue sapphires. While Australia does produce small quantities of better stones, these are rarely exported. Even when they do leave the country, due to market prejudices, they are inevitably sold in Bangkok as Thai or Cambodian goods.

While Australia's best cannot compare with the finest Kashmir, Burmese and Sri Lankan sapphires, over the past 30 years the country's mines have produced the majority of the world's calibrated sapphires. In fact, in terms of carat weight, Australia is perhaps the largest producer of sapphire in history (Terry Coldham, pers. comm., 16 Sept., 1994).

Occurrence of sapphire in Australia closely resembles deposits in Thailand, Cambodia, Nigeria and China, with iron-rich sapphires found associated with alkali basalt flows.[6]

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[6] In 1987, corundum crystals were discovered in the Inverell-Glen Innes area of NSW in tuffaceous rocks (Pecover, 1987). Tuff refers to a rock composed of volcanic ash.

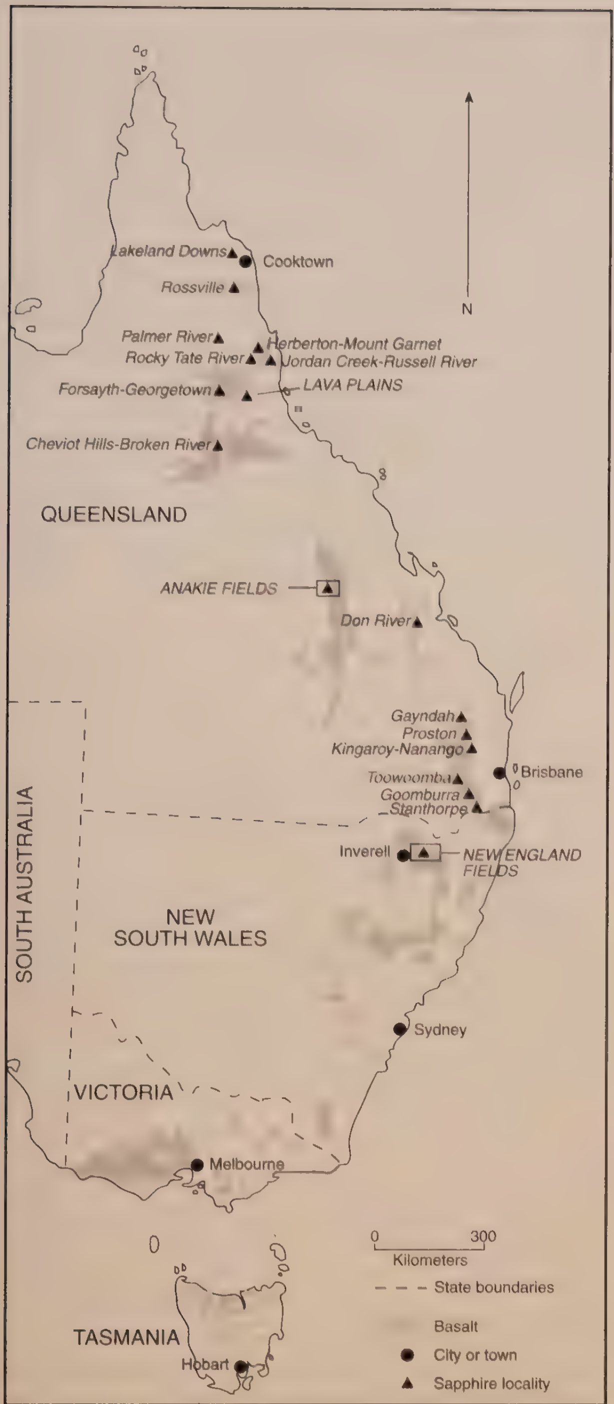

Figure 12.6 The sapphire mines of Australia. Most production is centered around the Anakie and New England fields, with the latter producing the best quality stones. At present, little is being produced from Lava Plains. (Modified from Coldham, 1985)

The Anakie fields in central Queensland and the New England fields in New South Wales (NSW) produce the lion's share. Of these, the New England district produces the finest blue gems while Anakie, which also produces quantities of blues, is noted for fine yellow and green sapphires. Blue sapphire of fine color is also found in the Lava Plains area of Queensland and poor-grade ruby has been found in the Harts Range, Northern Territory. Black-star sapphires are found in many Queensland and NSW localities.

History of Australian sapphire

New South Wales (NSW)

Sapphires were first discovered in Australia in 1851, when Samuel Strutchburry, a state geological surveyor observed their presence in a gold sluice on the Cudgegong and Macquarie rivers in NSW (Broughton, 1979). A few years later, in 1854, W.B. Clark noted sapphires in the tin sluicing concentrates of the Inverell mining district. This is the site of today's mining operations in NSW, and the discovery predated that in Queensland by over 20 years.

Although the initial discovery was known to be sapphire, they were considered of no value. Later, in 1869–70, larger amounts were discovered via gold mining operations in several localities. Nothing came of this until much later.

Commercial mining operations began for the first time in 1919, on Fraser Creek, near Inverell. This was the site of the small abandoned village of Sapphire, so named because of the richness of the sapphire alluvium in the area. Only eight ounces were recovered that year, but this was enough to spur further development. Mining soon progressed in the area of Inverell and Glen Innes, with the gem-bearing gravels of Fraser's Creek, Horse Gully and Mary Anne Creek (near Inverell and Sapphire), and Reddistone Creek (north of Glen Innes) being exploited. The sapphire industry was relatively stable until the Great Depression (1930s), after which production virtually ceased until the early 1960s (Broughton, 1980).

One of the richest areas ever found is that of King's Plains, New England District, NSW. As of 1994, this area was said to be Australia's main producer, and was being worked by Great Northern Mining. While the average mechanized miner on the NSW fields would be happy with a yield of US$30/m^3, the King's Plains field has for years averaged US$100/m^3; during 1993–94, the average was an astounding US$1500/m^3 (> 1 kg of corundum per m^3). Yields such as this are remarkable anywhere in the world. The richness of this deposit is thought to be due to the fact that it lies in an ancient valley undisturbed since the original volcanic eruptions (Terry Coldham, pers. comm., 16 Sept., 1994).

Anakie, Queensland

The discovery of sapphire in Queensland is attributed to A.J. Richardson, a State Government Surveyor (Walda L. Scholler, pers. comm., 22 April, 1995). He found some small red zircons on Retreat Creek near the town of Anakie ca. 1873–1875. Believing them to be rubies, he sent the red pebbles and their gravel concentrate off for testing. They proved to be zircons, but other pebbles included sapphires.

Timeline of Australian corundum[a]

1851	Samuel Struchbury finds sapphire in the Cudgegong-Macquarie rivers district of NSW, during gold dredging.
1853	Rev. W.B. Clark reports sapphires and other gems associated with stream tin in the vicinity of Green Swamp (now known as Inverell). Alluvial gold is the main motivation for prospecting, until it begins to run out in the 1860s.
1870	Joseph Wills starts a tin rush and wrote of "four or five places of sapphire." Tingha and other mining camps, including Stannifer, Kimberly, Wrighton, Stanborough, Elsmore and Gilgai spring up around Inverell; miners uncover other gems, including diamond and sapphire.
ca. 1873–75	Archibald John Richardson finds sapphire near the town of Anakie in Queensland.
1880	The Anakie field becomes established, with most early production going to Czarist Russia via German buyers. Average price is A$2 per ounce.
1900	One thousand miners employed at Anakie. Germany imports an increasing proportion of production. Average price is A$20 per ounce.
1919	Commercial mining commences in the New England District; 1,150 ct are obtained near the town of Sapphire. Mining later comes to a halt due to World War I and the collapse of Czarist Russia.
1960s	Sapphire mining begins again in response to increasing demand from Asian cutting centers (particularly Bangkok), when production from traditional sources, such as Burma and Cambodia, declines. Thai buyers begin visiting the fields in the late 1960s (probably as a result of their new-found heat-treating abilities).
1970s	Boom time in Australia's sapphire industry, with dozens of sapphire plants in operation, particularly in NSW.
1978	Ruby of poor quality is discovered in the Harts Range, Northern Territory. Mining is later abandoned due to the low quality of production.
1980s	Production begins to decline as the richest gravels are exhausted. In 1987 the Australian government attempts to ensure that a larger percentage is cut and treated in Australia. The policy generally fails.
1989	A single miner, Tom Nunan, dominates the industry, producing as much as 80% of Australia's total sapphire production. His plans to cut and treat a percentage of his production himself offshore, as well as expand mining at Anakie, however, come to naught. By 1992 he is forced to seek outside investors and eventually sells out to Great Northern Corp, while retaining a seat on the board.
1990s	NSW' production declines dramatically from its late 1970s peak. Much mining shifts to Queensland.
1993	Production from Great Northern's Kings Plains mine in Inverell increases to 800 kg/month (Bruce Davidson, pers. comm., July 18, 1994).

a. Based on Coenraads, 1992, Coldham, 1992, and others.

Richardson eventually became a partner in a sapphire-mining company. The company extended its prospecting to nearby areas, eventually expanding the gemming area to 28 sq miles (41 km^2). Production began in the 1890s, but was sporadic, with most stones going to Czarist Russia via German buyers (Coldham, 1985).

Initial 19th-century production at Anakie was minimal due to lack of incentives related to low prices (Broughton, 1979). Many mines closed down at the end of the century, but later reopened as new markets developed for the dark blue gems. A number of the early immigrant prospectors came from Germany, and Germans tightly controlled the selling and marketing in the years up until World War I. Stones were exported to Germany for sorting, cutting and eventual sale to the lucrative Imperial Russian Court market (Broughton, 1979). It is said that the deep inky-blue stones, which today are considered inferior, held a fascination for the Russian nobility, one unmatched by sapphires from other sites. To this author it seems that their low price may have held the greatest fascination, but this is not mentioned by other authors.[7] Anakie produced mainly blues, but also fine yellows and greens. These fancy colors were not then appreciated by gem buyers and so were used primarily by industry, including watch bearings and as an abrasive for polishing shell casings and manufacture of wire (Broughton, 1979; Walda L. Scholler, pers. comm., 22 April, 1995).

World War I brought an end to German domination in Anakie. Unfortunately, it also brought an end to the lucrative Imperial Russian market. Despite this setback, sales fueled by demand from Europe and the US rose after the war's end, a boom that continued until the Great Depression.

Popularity of Anakie sapphires descended to an all-time low from 1930–60, due in part to the harsh conditions on the fields. High summer temperatures and little water equalled little production (Walda L. Scholler, pers. comm., 22 April, 1995). During 1957, a paltry $100 worth of sapphires was mined. Only in the mid-1960s did the flagging market revive, primarily because of the discovery in Thailand that heat treatment could improve a stone's appearance. Like the Thai ruby, which was considered inferior by nearly all experts of the late 19th and early 20th centuries, the Australian sapphire today largely owes its market share to the skill of burners in improving its appearance. According to Coldham (1985), "without heat treatment to clear (remove the silk from) the stone, the mining of Australian sapphire would not be commercially viable."

In 1994, rumblings about the Subera area (just east of Rubyvale, near Anakie) were heard. This deposit is being worked by Great Northern Mining, with the rough being sent to Sri Lanka for cutting. Unconfirmed reports put potential production at up to 600 kg per month. Subera material is said to be slightly lighter than the average Inverell blue after heat treatment (Bruce Davidson, pers. comm.,

7. An additional factor may have been that stones were being heat treated in Germany to lighten their color (see Chapter 6 box 'The history of heat').

Figure 12.7 Illustrations of Queensland corundum crystals and cut stones from Dunstan's landmark 1902 paper, "The sapphire fields of Anakie." (Photo: Robert Weldon/GIA)

18 July, 1994). In October of 1995, Great Northern suspended their Subera operations, reportedly because of the poor yields (Walda Scholler, 10 Oct., 1995).

Lava Plains, Queensland

Another Queensland sapphire locality is at Lava Plains. Material given the author by Barry O'Leary displayed a rich, deep blue color reminiscent of stones from Bo I Rem (Thailand) and Pailin (Cambodia). Unfortunately most is small and cracked. Mechanized mining has taken place, including one mine owned by a Thai (Terry Coldham, pers. comm., 16 Sept., 1994).

Other Queensland localities

Sapphire has been found at a number of other sites in Queensland. These include (north to south) Rossville, Lakeland Downs, Palmer River, Herberton-Mount Garnet, Rocky Tate River, Jordan Creek-Russell River, Forsayth-Georgetown, Cheviot Hills-Broken River, Don River, Gayndah, Proston, Kingaroy-Nanango, Toowoomba, Goomburra and Stanthorpe (Cooper, 1994).

Mining methods

While some amateur hand digging and sieving is still to be found, Australia is one of the world leaders in modern commercial sapphire processing techniques. In fact, such mechanized mining techniques were adopted some twenty years earlier than in Thailand (Terry Coldham, pers. comm., 16 Sept., 1994).

Mechanized mines are dotted over an area of some 4000 sq km in the New England district of NSW, with each miner working a creek or river often hundreds of acres in area (Coldham, 1985). After samples are taken, mining then proceeds in a systematic manner. In contrast, Anakie-district claims are much smaller due to state mining laws which limit their size. Miners work almost on top of each other in an area only a few sq kms in size. Anakie miners are also more

Figure 12.8 Rough sapphire from Australia, showing the typical range of colors produced Down Under. (Photo: Great Northern Mining)

concentrated because the gem gravel tends to occur in thicker and richer deposits (Coldham, 1985).

Both districts feature gem gravel covered by 2 to 80 ft (0.6–24 m) of barren overburden, which is typically removed by either backhoes or bulldozers. After removal of the overburden, the gem-bearing wash is excavated and loaded onto trucks for removal to the processing plants. Some parts of the Anakie fields are reserved for hobbyist miners, or *fossickers,* who mine by sinking small shafts. This is controlled by strict mining laws (Terry Coldham, pers. comm., 16 Sept., 1994).

Gravel brought to the processing plants is tipped into dump boxes, where it is washed into a trommel with high-pressure water hoses. The trommel consists of a revolving screen similar to those used at Nong Bon in Thailand, where a coarse gravel is found. This normally has two different size screens; the first sieves out fine, sand-sized particles while the second takes 0.75–1 inch (1.9–2.54 cm) material. Larger gravel passes into rock bins for return to the excavations. The middle sizes of 0.0625 to 1 inch (0.16–2.54 cm) pass into a pulsator jig for separation. It is from this pulsator that most gems are recovered. Recovery rates are said to be as high as 90–95% (Coldham, 1985).

Figure 12.9 Faceted blue and yellow sapphires from the Kings Plain region of Australia's Inverell District.
(Photo: Great Northern Mining)

Unlike Thailand, Australia has strict conservation laws requiring reclamation of mined areas, particularly in NSW. All processed gravels are returned to the sites for infilling and are then covered with the original overburden and top soil. This process prevents the land devastation that occurs in Thailand, a country that should adopt similar measures.

At day's end, the concentrate is removed from the pulsator for selection. In addition to corundum, zircon, pleonaste and other minerals are found. Only the sapphire and zircon are of gem use. Separation of the sapphire involves drying the concentrate and passing it through a magnetic separator to remove iron-rich minerals, such as black spinel. The remainder contains the corundum, which represents only 10% of the whole before magnetic separation. Workers then carefully hand-select the concentrate over mirrors to remove the gems, mirrors allowing light to reflect back through the gems, thus exposing them more readily (Coldham, 1985).

Blue sapphires are typically placed into a separate mine-run parcel, consisting of all qualities except the largest and finest stones, which are sold separately. Approximately 95% of the total corundum production consists of blues (Coldham, 1985).

Occasionally the mine run is sold *as is,* but at other times it is divided into firsts, seconds and thirds, with each category further sieved into separate sizes. These are then sold, typically, by the carat or Troy ounce, with industrial grades sold by the kilo. The exact range of qualities will depend on the individual mine's grading, which varies from place to place and person to person. Other colors, such as greens, yellows and particolors, are sold separately in small lots, since they represent but a few percent of the entire output.

Stone types and sizes

According to Coldham (1985), a typical Inverell mine run parcel contains about 10–20% of stones above 2 ct, 40–60% of 0.5–2.0 ct-sizes, and 30–40% of 0.20–0.50 ct sizes. Mine runs from Anakie are of a slightly larger stone size overall (20–40% are above 2 ct). Most cuttable Australian sapphires are under 2 ct in the rough, with clean stones above 10 ct being rare today.[8] Large pieces (up to 1,000 ct) were once recovered, but today are rare because the large gravel is removed by the trommel. At Anakie, large stones are still occasionally recovered from the areas restricted for individual pit miners without heavy equipment. This is particularly true at the Willows field, which is noted for fine golden yellow stones (Broughton, 1979).

Blue sapphires make up 90–95% of total production. Those of Anakie tend to be dark, almost black at times, while finer blues are found in NSW. In NSW, the best material is said to hail from Reddistone Creek and production from this mine may reach a quality comparable to that from Pailin, Cambodia. In fact, the term *Reddistone Creek stone* is used worldwide to indicate the best of Australian sapphire (Terry Coldham, pers. comm., 16 Sept., 1994).

Most Australian material, however, tends toward the inky-blue shades. This dark material may be deliberately cut slightly, or far off, the pure blue *c* axis. Although this dilutes the pure ordinary ray, making the stone more greenish, it is preferable to a black stone. Such an orientation, where the table parallels the *c* axis, is termed *cross-table* in Australia.

8. Large stones are still found occasionally, some by hobbyists and tourists, who check out the heaps of oversized material left by the mechanized miners' trommels (Terry Coldham, pers. comm., 16 Sept., 1994).

Figure 12.10 Australia's sapphire industry is among the most modern in the world. High-pressure sluicing of gravel is shown at left, while Great Northern's Chris Shaw controlling a color sorter at Inverell (NSW) at right. (Photos: Great Northern Mining)

Be all you can be

OTHER than blue, the most common variety in Australia is a blue-green. Two other colors that are often found are yellow and green. While NSW is acknowledged as the source of Australia's finest blue sapphires, Anakie in Queensland is said to produce the finest greens and yellows. Green stones occur in a wide range of hues, from bluish green to yellowish green, but all suffer from the typical green sapphire malady—a lack of color intensity. Most are of an army-green color, so perhaps the world's military leaders would consider the following—adoption of green sapphire as the official gem of those under arms. Now we just need to find another stone for those countries where khaki is standard battle dress. Perhaps a fine Libyan desert glass…?

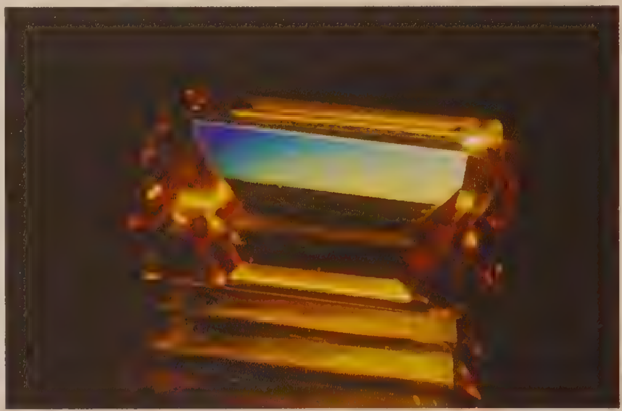

Figure 12.11 Faceted yellow sapphire from Subera, Anakie. (Photo: Great Northern Mining)

Australian yellow sapphires may be of very high quality but, like the yellows of Chanthaburi (Thailand), large quantities are not available. These stones range from greenish yellow through pure yellow to the highly prized golden yellows. Occasionally these latter stones may resemble the prized whisky-yellow stones from Chanthaburi. Like the blues, such stones can be heat treated to remove rutile silk; pale stones often become a rich gold or even orange (Terry Coldham, pers. comm., 16 Sept., 1994).

In addition to green and yellow sapphires, an unusual variety is found which is of a yellow-green to green-yellow color. It is termed *wattle*, due to its resemblance to Australia's national flower and is popular locally. Pink, purple and mauve stones are rarely encountered in the Australian gem gravels. Some of these may show a weak color change from grayish green in daylight to purplish in incandescent light. Black-star sapphires, featuring both six and twelve rays, are also found, including the rare *golden-star* black-star sapphires. These are similar to those mined in Thailand.

Marketing of Australian corundum

The lion's share of Australian sapphire production is bought by Thai buyers in Australia. This situation originally developed in the late 1960s because of the Thais' ability to perform both heat treatment and inexpensive cutting. Rough is typically shipped to Bangkok for treatment and cutting. International buyers purchase cut stones in Bangkok, for worldwide distribution and jewelry manufacturing. In the mid-1980s, Thailand developed an important jewelry manufacturing business of its own, so many stones are mounted in Thailand before export.

Similar to Sri Lanka, Thai dominance of Australia's sapphire industry has created intense local resentment and jealousy. The Thai dealers' propensity for ignoring government

Figure 12.12 Sapphire separation plant in Australia. (Photo: Great Northern Mining)

duties and laws, along with certain strong-arm tactics when threatened, are cited by locals. But to be fair, we must also acknowledge the Thais' genius for coaxing maximum beauty via heat treatment, as well as their ability to produce a better cost vs. quality ratio. An uneasy partnership exists. While Australian miners continually complain that they are not getting enough of the finished-sapphire pie, the fact remains that, with the high cost of Australian labor, offshore processing is more competitive.

Unfortunately, because most Australian production is treated and cut in Thailand, and due to existing market prejudices, inferior stones of both countries often end up being sold as *Australian,* while better stones are sold as *Thai* or *Cambodian.* This might change if more Australian rough were treated and sold in Australia, but such a prospect is unlikely. Barring new discoveries, Australia will probably retain its reputation as a supplier of dark, commercial-grade sapphire.

Ruby in Australia

In 1978, Australia's first commercially significant discovery of ruby was made in the Harts Range, Northern Territory. According to McColl & Warren (1980), the host rock is an amphibolitic complex, interpreted as a development from a terra rossa soil profile formed on a limestone contaminated with pyroclastics and interlaminated with lavas and tuffs.

The ruby occurs as well-formed crystals, but little faceting material has been found. In the early 1980s a company mined the deposit, and a Bangkok lapidary workshop was set up specifically to cut the material. Unfortunately, those involved had little gem experience and did not recognize that red color alone does not a viable ruby make. The material's poor clarity made it suitable only for the lowest cabochon grades and the company soon floundered.

Table 12.2: Properties of NSW & Anakie (Australia) corundum[a]

Property	Description
Color range/phenomena	• Blue: light to extremely dark, inky blue, due to high Fe content • Green: light to dark blue-green to green; generally dark • Yellow (particularly from Queensland): medium to deep yellow to greenish yellow; sometimes deep orange yellow similar to the color of whiskey • Black star: 6 & 12 rays, similar to those from Chanthaburi, Thailand • Orange to pink to mauve: rare
Geologic formation	• Secondary deposits derived from weathered alkali basalts.
Crystal habit	• Subhedral to rounded; crystals may be pyramids ('dogtooth' shape), bipyramids, barrels (bipyramids with pinacoid) or tabular hexagonal prisms ('flats') • Crystals often display rounded edges, due to chemical corrosion, probably resulting from the magma which carried the crystals to the surface
RI & birefringence	n_ε = 1.761–1.765; n_ω = 1.769–774 Bire. = 0.008–0.009 RI increases with increasing Fe content
Specific Gravity	3.97 to 4.02
Spectra	Weak to strong Fe spectrum (generally strong)
Fluorescence	**UV**: Generally inert; orange, pink or mauve stones may show some red under LW
Other features	Virtually all are heat treated
Inclusion types	**Description**
Solids	• Columbite (niobite), black prisms (Coenraads, 1992a) • Feldspar (alkali), may have stress haloes (Coldham, 1985; Coenraads, 1992a) • Gahnospinel (Fe, Zn spinel) (Coenraads, 1992a) • Hercynite (Fe spinel) (Coenraads, 1992a) • Hornblende? (Coldham, 1985) • Ilmenite (Coenraads, 1992a) • Magnetite (Fe spinel), black octahedra • Mica? (Coldham, 1985) • Niobium-rutile (Coenraads, 1992a) • Primary iron-rich melt inclusions (Coenraads, 1992a) • Pyrrhotite (Coenraads, 1992a) • Pyrrhotite-pentlandite intergrowth (Coenraads, 1992a) • Thorite (Coenraads, 1992a) • Uranium pyrochlore, red x-tals (Gübelin & Koivula, 1986) • Zircon, transparent, may have stress haloes (Gübelin & Koivula, 1986)
Cavities (liquids/gases/solids)	• Secondary healed fractures are common
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; this can take on a wide variety of forms, from extremely sharp bands to those which are diffuse and cloudy. On crystals, greenish or yellowish cores with blue rims are often seen. Red and pink cores are less common.
Twin development	• Growth twins of unknown orientation • Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$
Exsolved solids	• Rutile needles in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°). These planes lie in the basal plane. • Brownish hematite needles & plates along the first-order hexagonal prism (shorter and more platy than rutile). These are often found concentrated in thin green zones. Ilmenite or hematite-ilmenite mixtures are also found in Anakie stones. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Information in Table 12.2 is based on the author's own research, along with the published reports of Coenraads (1992a–b), Coldham (1985), Gübelin & Koivula (1986), Kiefert & Schmetzer (1991), and Moon & Phillips (1984).

Characteristics of Australian (NSW & Anakie) corundum

While the two major sapphire deposits of Australia, Inverell (NSW) and Anakie (Queensland) are in completely different parts of the country, little information exists about the characteristics specific to each. Thus, out of necessity, they are described together.

Sapphire

Varieties and occurrence. Australian sapphires typically occur in an inky-blue color, typical of corundums formed in Fe-rich, alkali basalts. Other colors found include green, yellow (which ranges into a whisky-yellow) and black-stars. Rubies (including pink) are known, but rare.

Solid inclusions. Solid inclusions in Australian sapphires resemble those from other alkali basalt-derived deposits, such as Thailand and Cambodia. Colorless rounded or euhedral crystals of feldspar have been reported by Schubnel (1972). These may be surrounded by glassy tension halos (possibly due to heat treatment) or simply stress fractures, as well as being accompanied by comet-like tails. At times, heat treatment appears to melt these or similar appearing crystals, for gas bubbles may be found frozen in place within these crystals. Red or orange crystal grains are sometimes found, as well, often accompanied by comet-like tails. While uranium pyrochlore crystals have been identified in Australian sapphire, they are not so common as in Pailin sapphires. Stubby rods and plates of hornblende and mica, respectively, have been reported in Anakie sapphires by Coldham (1985).

Cavities. Secondary fluid inclusions (healed fractures) are found in Australian corundums, but are not as common as those in Sri Lankan and Burmese sapphires.

Growth zoning. One of the most distinctive features of most basalt-derived sapphires is the prominent growth zoning. Straight, angular color zoning is a common feature of blue and green stones, with many showing extremely sharp, fine banding of alternating blue and colorless, or blue and yellow, bands under magnification. This follows the usual hexagonal pattern of the crystal when looking down the *c* axis, but angles will vary depending upon crystal habit and the direction of viewing. In some, a triangular zoning is seen at the crystal center.

In yellow gems, zoning is more difficult to detect (use of a blue filter improves this somewhat). Typically, it is seen most easily parallel to the basal pinacoid {0001}. Since most gems are cut with the table parallel to the pinacoid, this zoning is generally seen parallel to the table. Green concentrations in yellow stones are often seen just beneath the pinacoid surfaces. Such green zones often contain concentrations of exsolved hematite silk. Anakie yellow sapphires often display a sawtooth pattern of green zoning surrounding a yellow core.

Twinning. Rhombohedral twinning is found in Australian sapphires along with the boehmite needles formed at the edges or junctions of these planes, through the exsolution of excess hydrous alumina or by the alteration of the corundum itself. In yellow stones these do not generally penetrate deeply into the specimen.

Exsolved inclusions. Like the blue sapphires from Chanthaburi, the silk in Australian sapphires does not appear to be solely rutile, but instead is also hematite, with only small amounts or rutile present. The hematite occurs as thin plates or very stubby needles of a gold color, parallel to the faces of the first-order hexagonal prism. The rutile is found as longer needles aligned parallel to the second-order hexagonal prism. Gübelin & Koivula (1986) have identified epitaxial intergrowths of ilmenite needles and hematite plates in Anakie sapphires. Moon & Phillips (1984) stated that acicular mixed crystals of the trigonal isomorphous series hematite-ilmenite are responsible for the asterism and color of most Australian black-star sapphires.

Fiber-optic illumination often reveals clouds of tiny exsolved particles following the color banding. These particles are the residue left over after heat treatment. Virtually all Australian sapphires are heat treated to remove silk. Without such treatment, most of the production would be unsalable.

Exsolved boehmite is commonly found at intersecting rhombohedral twin junctions.

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Table 12.3: Brazilian corundum localities

State and deposit descriptions
Bahia • Anagé: Green sapphires, sold locally as Oriental emerald. Opaque pink to red crystals also are found in the area (Themelis, 1992). • Near Capim Grosso: In 1970, this mine yielded several hundred kilos of sapphire (Sauer, 1982). Opaque ruby crystals are also found in the area (Themelis, 1992). • Río de Contas: Ruby, opaque, non-gem quality (Themelis, 1992). • Salobro River: Sapphire found in the diamond alluvials (Sauer, 1982). • Jacobina: Ruby (Sauer, 1982). • Sitio da Jibóia (near Barra Ingedinho): Ruby (Sauer, 1982). • Vitória da Conquista: Ruby of low quality (Themelis, 1992).
Mato Grosso • Jauré and Quilombo, Río Coxim: Blue sapphire first discovered around 1960. The material tended to be dark blue in color, with RIs of 1.762–1.770 (0.008). SG varied between 3.952–4.052. Opaque brown cubes of unknown identity were found as inclusions, along with primary and secondary fluid inclusions, some two-phase (Eppler, 1964). • Ruby (Sauer, 1982).
Mato Grosso do Sul • Coxim River, near Jauru: Blue sapphires, dark, found together with diamonds in alluvial deposits. Average weight of rough is 1–2 grams (Themelis, 1992).
Minas Gerais • Conceicao do Dentro: Opaque greenish sapphire (Themelis, 1992). • Datas, Diamantina and Sapucaí-Mirim River: Small pieces of sapphire found in the gold and diamond alluvials (Sauer, 1982; Themelis, 1992). • Guanhães: Ruby (Sauer, 1982). • Indaiá: Blue sapphire. This is probably the most important sapphire deposit in Brazil (Epstein & Brennan *et al.*, 1994). • Ipatinga (42° 20' W, 19° 36' S), in the hilly areas surrounding Caratinga, east of Belo Horizonte: Sapphire—This material cuts faceted stones up to 0.5 ct and cabs to one ct or more. Only a small percentage of the rough is usable gem material (Themelis, 1992). • Jequitinhonha River: Small blue sapphires have been found along the extended banks and tributaries of this river (Themelis, 1992). • Malacacheta, some 160 km NW of Teófilo Otoni: Blue sapphire—This mine produces blue to blue-green sapphire. Most faceted stones are under 0.5 ct, and rarely exceed two carats. Color-change sapphires are also reported (Themelis, 1992). • Paraguaçu and Coxim Rivers: Ruby (Sauer, 1982). • Triângulo Mineiro: Ruby (Sauer, 1982).
Para • Along the banks of the Río Gurupi, in the northeast corner of the state: Ruby, probably the best in Brazil. Some are waterworn crystals, of good color, transparent, and generally weigh between 1–2 grams each (Themelis, 1992).
Río de Janeiro • Serra dos Órgãos, Petrópolis: Sapphire, dark bluish gray, opaque (Themelis, 1992).
São Paulo • Itaqui Range: Sapphire (Sauer, 1982).
Other Brazilian localities • Corundum has also been reported from Santa Catarina (Lages), Esperito Santo, Goiás, and Ceará States (Themelis, 1992).

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Bolivia

Dr. Jaroslav Hyrsl has reported to the author that sapphires were found at an unknown locality in Bolivia some 40 years ago (pers. comm., 15 June, 1995). No other information on this occurrence is available.

Brazil

Corundum in Brazil was first reported by Hussak (1907). Since that time, it has been reported from several different localities, but little of gem quality has turned up. In 1994, the Indaia deposit of Minas Gerais was described (Epstein & Brennan *et al.*, 1994). It is said to be the country's most important occurrence.

Table 12.3 summarizes Brazil's corundum deposits.

Characteristics of Indaiá (Brazil) corundum

Indaiá (Minas Gerais). The following is based on the report of Epstein & Brennan *et al.* (1994). Indaiá Creek, where the sapphires are found, is located about 30 km by road southeast of Ipatinga, in Minas Gerais. Blue stones had been known to local residents for many years, but it was not until 1984 that they were positively identified as sapphire. Exploration of the area then began. As of 1994, the only diggings were of the primitive type.

Table 12.4: Properties of Indaiá corundum (based on 27 specimens)[a]

Property	Description
Color range/phenomena	• Medium to dark blue to violet/purple. • Some material shows a weak color shift.
Geologic formation	• The source rock has yet to be found. Sapphires are recovered in alluvial or colluvial deposits believed derived from Pre-cambrian basement rocks.
Crystal habit	Most are broken, subhedral pieces; elongated hexagonal crystals are sometimes found.
RI & birefringence	n_ε = 1.760–1.762; n_ω = 1.768–1.772 Bire. = 0.008–0.010
Specific Gravity	4.00 to 4.02
Spectra	Three specimens examined showed a weak 450 nm band.
Fluorescence	LW: Inert SW: Moderate to strong bright red in some specimens (generally those with slightly violetish color)
Other features	Not described
Inclusion types	**Description**
Solids	• Rounded crystals w/halos (zircon?) • Reddish brown crystals of mica (biotite?)
Cavities (liquids/gases/solids)	• Primary and secondary fluid inclusions have been found, some three-phase; secondary fluids were found in all specimens.
Growth zoning	Straight angular growth zoning was found.
Twin development	• Lamellar twinning of unknown orientation was reported (but the photo of this twinning appeared to be rutile silk).
Exsolved solids	• Exsolved rutile silk was reported.

a. Table 12.4 is based on Epstein & Brennan *et al.* (1994).

Figure 12.13 Sapphires from Colombia and Brazil. (Left to right: 4.61, 1.06 and 4.47 ct) (Photo: Robert Weldon/GIA)

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Burma (Myanmar)

Corundum has been found in a number of different areas of Burma. These include Sagyin (near Mandalay), Thabeitkyin, Naniazeik (near Myitkyina), Mogok and, most recently, Mong Hsu (central Shan state). Most famous is the Mogok Stone Tract, which has remained the world's premier source of ruby for more than 800 years.

> Far away in a remote corner of the earth is a town of mushroom growth, called Mogok.… It has but one industry, the recovery of rubies from mud and sand. You may be ever so hungry or thirsty, the first things offered or mentioned to you are rubies. No matter what business may have brought you to Mogok, the natives all assume you are there for rubies—rubies, nothing but rubies.… It is said that a king would be ruling at Mandalay today if it had not been for rubies…
>
> Anonymous, 1905, A city built on rubies

When one speaks of ruby, the Mogok Stone Tract in Upper Burma immediately springs to mind. Lying approximately 644 km (400 miles) north of Rangoon, Mogok has for the past 800 years been the premier source of fine rubies. It is an area steeped in legend and its story embraces not only gems, but also the early exploration and expansion of the European colonial empires into Asia.

Figure 12.14 Kipling called it a "beautiful winking wonder." It is Rangoon's Shwedagon Pagoda, symbol of Burma, the *Golden Land.* Ralph Fitch, the great English traveler of the 16th century, described it thus:

"...it is called Dogonne, and is of a wonderfull bignesse, and all gilded from the foot to the toppe....It is the fairest place, as I suppose, that is in the world."

In addition to the numerous solid gold plates, the upper reaches are embedded with literally thousands of diamonds and other precious stones. Atop it all rests a 76 ct diamond orb. (Photo by the author, 1980)

Figure 12.15 Pigeon's blood
Left: The 196-ct Hixon Ruby of the Los Angeles County Museum of Natural History is one of the finest Burmese ruby crystals on public display. Unfortunately, such crystals are all too rare—most are immediately cut, since the market for cut stones is far larger than for mineral specimens. **Right:** These extraordinary rubies, at 5.56 and 5.25 ct, represent a lifetime's toil. They are mounted in the traditional Burmese manner, with the gold setting improving the stone's color, as well as acting as a mirror to increase the gems' brilliance. (Photos: Fred Ward)

The town of Mogok (1500 m) is located in the Katha district of Upper Burma. Consisting of heavily-jungled hills rising to a height of 2347 m (7700 ft) above sea level, the ruby mines district covers about 400 sq miles, although only a portion (70 sq miles) is gem bearing. Considered one of the most scenic areas in Burma, it is home to a number of colorful ethnic groups, as well as a variety of wildlife, including elephants, tiger, bear and leopard.

History

The exact date when rubies were first discovered in Mogok is unknown. No doubt the first humans to settle the area found rubies and spinels in the rivers and streams. Kunz (1915) mentions a Burmese legend from the ruby mines.

> According to this legend, in the first century of our era three eggs were laid by a female naga, or serpent; out of the first was born Pyusawti, a king of Pagan; out of the second came an Emperor of China, and out of the third were emitted the rubies of the Ruby Mines.
>
> Taw Sein Ko, as told to G.F. Kunz (1915)

A similar story is related by Tin and Luce (1960):

> At that time spirits carried away a certain hunter. When they reached the place where the Naga had laid her egg, the hunter finding the egg bore it away joyfully. But while he was crossing a stream, swollen by a heavy shower of rain till it overflowed its banks, he dropped it from his hand. And one golden egg broke in the land of Mogok Kyappyin and became iron and ruby in that country.
>
> P.E.M. Tin & G.H. Luce, 1960
> *The Glass Palace Chronicle of the Kings of Burma*

Early humans at Mogok

Vague references (Ehrmann, 1957) exist suggesting, on the basis of stone relics unearthed, that the area was first settled by Mongolians about 3000 BC. However it is likely that humans moved into the area long before that date. Halford-Watkins (1934) stated that stone, bronze and iron-age tools fashioned from a variety of jadeite have been found in alluvial diggings throughout the Mogok area.

The karst (sink-hole) topography, with its numerous underground caves, makes the Mogok area interesting for students of ancient man and prehistoric animal life. Karst topography has yielded important finds of Peking Man and younger extinct human types in China, as well as many fossil anthropoid apes. While no important archeological finds have been found at Mogok, this probably has more to do with the xenophobic attitude of the Burmese government since 1962 (and the subsequent decline in all types of academic activity), rather than a lack of study material. Interesting animal specimens did come to light before the area was closed off to outside study and it seems likely that further work will reveal further discoveries (de Terra, 1943).

Hellmut de Terra (1943) made a detailed report on the Pleistocene in the Mogok area in 1937–38 as part of a study on early man in Burma. No Pleistocene fossils were found,

Figure 12.16 Map of Southeast Asia, showing the important gem localities, particularly those of Burma.

Timeline of ruby and sapphire in Burma

Middle Pleistocene Ruby is probably discovered in the Mogok region by stone-age humans inhabiting the area.

6th Century One of the seven sons of Kun-Lung, founder of the Shan dynasty, is said to rule a state, probably Momeit,[a] near which ruby mines existed. His tribute to the central government was two *viss*[b] yearly (G.S. Streeter, 1889a).

1200s Talaing chronicles speak of a kingdom of Kanpalan [Kyatpyin?] (Mason, 1850; Halford-Watkins, 1934).

1419–1444 Nicolò di Conti visits Ava (Penzer, 1929).

1495–1496 Hieronimo di Santo Stefano, a Genoese merchant, visits Pegu. Ava is described as a land lying fifteen days' journey from Pegu. Rubies and many other precious stones are said to "grow" there (Major, 1857).

1500–1517 Duarte Barbosa does not visit, but describes Ava and Capelam [Kyatpyin?] and the ruby trade (Dames, 1918).

1502–1508 Ludovico di Varthema visits Pegu and describes the source of rubies as Capellan. In return for a present of coral, di Varthema received from the king of Pegu about 200 rubies in return: "Take these for the liberality you have exercised towards me" (Temple, 1928).

1563 Cæsar Fredericke visits Pegu, describes the ruby trade, and buys rubies for later sale in Ceylon (Hakluyt, 1903–05).

1586 Ralph Fitch, the first Englishman to reach Burma, visits Pegu and describes the ruby trade. He mentions Caplan as the source (Hakluyt, 1903–05).

1597 Burmese king, Nuha-Thura Maha Dhama-Yaza forces the Momeik *sawbwa* (prince) to trade Mogok and Kyatpyin for Tagaungmyo (George, 1915).

1617 The British East India Company makes its first contact with Burma, when Henry Forrest and John Staveley are sent to recover the goods of a company servant who had died at Syriam (Stewart, 1972).

1629–1637 Fray Sebastien Manrique visits Arakan, where he said the market was well-stocked in such things as rubies, sapphires and even "gray" amber (Luard, 1926–27).

1631–1668 Jean-Baptiste Tavernier makes six separate voyages to Asia. Although he does not visit Burma, his memoirs mention that ruby comes from Capelan (Ball, 1925).

1780 King Bodawpaya sends thousands of captives from the Manipur war to Mogok, to work the mines. Thereafter the mines become a quasi-penal colony (Halford-Watkins, 1932).

1783 King Bodawpaya extends the tract boundaries to encompass Mogok, Kyatpyin and Kathé (Brown, 1927).

1795 Michael Symes visits Ava, and mentions ruby mines at a mountain called Woobolootaun opposite to Keoum-meoum (Symes, 1800).

1824–1826 The first Anglo-Burmese war is won by Britain. The treaty of Yandabo cedes Arakan, Assam and Tenasserim to the East India Company (Stewart, 1972).

1830 A runaway English sailor in the employ of King Phagyidoa is sent to blast a rock at a royal ruby mine at Tapambin. He either died at the mines or slipped quietly away, for nothing was heard of him again (G.S. Streeter, 1889).

1833 Père Giuseppe d'Amato, an Italian Jesuit, visits Chia-ppièn [Kyatpyin] and describes the ruby mines. His account (published posthumously in 1833) is the first documented eyewitness description of the ruby mines (d'Amato, 1833).

1852–1853 Britain annexes Pegu, which is taken with few losses in the second Anglo-Burmese war (Stewart, 1972).

1853 Henry Yule's mission to Ava. He describes, but does not visit, the ruby mines (Yule, 1858).

1853–1878 The reign of King Mindon Min. In 1863, payments in silver are offered Mindon Min for the sole rights to purchase gems at Mogok. This forced increasing persecution of miners, resulting in large-scale depopulation of the area by the time of the British annexation (George, 1915; Halford-Watkins, 1932).

1870 A German mining engineer named Bredemeyer is put in charge of the ruby mines at Sagyin, near Mandalay (E.W. Streeter, 1892).

1878 King Thebaw takes the throne upon the death of Mindon Min (Stewart, 1972).

1879 Rival members of the royal family are murdered in Mandalay. Britain withdraws its resident (Stewart, 1972).

1881 A party of Frenchmen under an engineer in Thebaw's employ visit Mogok (G.S. Streeter, 1889).

1882 April: Burmese mission to Simla, in British India, declares to the French Consul from Calcutta that a Frenchman just obtained from King Thebaw the concession for the Burma ruby mines. This was probably just a proposal (Preschez, 1967; trans. by Olivier Galibert, June, 1994).

1883–1885 French and Italian speculators negotiate with Thebaw for mining concessions at Mogok. In Feb., 1884, a French engineer, Alexandre Izambert, goes to Mandalay to solicit concession for the ruby mines of "Monieh and Rapyen." He offers Rs300,000 for the concession, which would cover 750 m on both sides of the road between Mandalay and the mines that his company proposes to build. The deal falls apart, due to a secret agreement between a Burmese minister and an Italian consular agent (Preschez, 1967; trans. by O. Galibert, June, 1994). Further massacres in Mandalay (Stewart, 1972; Keeton, 1974).

1885 Britain uses the pretext of Mandalay palace massacres and a timber dispute between the Burmese government and the Bombay-Burma Trading Corp. to invade Upper Burma. The real reason was fear of French influence in an area thought vital to British interests. Mandalay is taken on Nov. 29. In December, Edwin W. Streeter becomes interested in obtaining the concession for the mines (Stewart, 1972; E.W. Streeter, 1892).

a. Mong Mit state is often written as Momeit or Momeik.
b. In those days all payments were made in roughly cast discs of silver, with rupee coins not coming into general use until about 1874. One *viss* of silver weighed 3.6 lb (1.6 kg), and was then worth about Rs100. It was subdivided into 100 ticals (Halford-Watkins, 1934).

Timeline of ruby and sapphire in Burma *(continued)*

1886 Jan. 1: Britain formally annexes Upper Burma. Shortly thereafter, E.W. Streeter forms a syndicate with Charles Bill and Reginald Beech. They approach the India Office to obtain the concession for the Mogok mines. Lord Dufferin puts the lease out to tender, which the Streeter syndicate wins with a bid of Rs400,000 (E.W. Streeter, 1892).
Dec. 26: British military force reaches Mogok area. On Jan. 27, 1887 they enter the town of Mogok. Accompanying the expedition were G.S. Streeter (E.W. Streeter's son), Col. Charles Bill, Reginald Beech and engineer Robert Gordon (G.S. Streeter, 1887a).
The period between annexation and the first arrival of British troops is the golden age of local mining. For the first time in centuries, mining is free and stones can be sold without restrictions (George, 1915).

1887 C. Barrington Brown is sent to Mogok by the Secretary of State for India to determine the value and conditions of the mines. His report represents the first systematic description of the deposits (Brown and Judd, 1896).

1889 The Streeter syndicate joins with the Rothschilds to form the Burma Ruby Mines Ltd, which is floated on Feb. 26. Pandemonium reigns as the offer is oversubscribed fourteen times and ordinary shares rise to a 400% premium. The £1 founders' shares trade at £350 (P. Streeter, 1993).

1895 Warth examines ruby mines at Naniazeik, some 80 km west of Myitkyina (Kachin State) (Penzer, 1922).

1889–1896 Period of the Burma Ruby Mines Ltd first lease, with a profit shown only during 1895–1896 (Brown, 1927).

1897–1904 Period of the second lease, generally profitable (except 1897–98 and 1903) (Brown, 1927).

1905–1912 Period of the third lease, generally profitable (except 1909). A.H. Morgan's drainage tunnel is finished in 1908, allowing mining of once-flooded alluvials (Brown, 1927).

1913–1925 Period of the supplementary agreement. Losses mount as rich areas are exhausted and the market slumps due to World War I. Profit is shown only in 1913, 1918 and 1920. Morgan's drainage tunnel is damaged in 1925 and never reopened. The company goes into voluntary liquidation on Nov. 20, 1925 (Brown, 1927).

1926–1931 No buyers take the lease. The company continues small-scale mining until June 30, 1931, when the lease is surrendered (Halford-Watkins, 1932a).

1926–1947 Mining is performed largely by native methods. European-style mining is limited to a few leased mines.

1938 U Khin Maung Gyi (1938) reports on the Thabeitkyin stone tract west of Mogok. Sporadic mining had apparently been done for at least 50–60 years previously.

1942 May 7: Japanese occupy Mogok. Organized mining stops until the British reoccupation (March 15, 1945), but small-scale digging continues (Ehrmann, 1957b).

1948 Jan. 5: Burma achieves independence from British.

1962 General Ne Win stages a military coup, plunging Burma into isolation. Thus begins one of the 20th century's cruelest and longest-running dictatorships, where Ne Win rules in a manner akin to the 19th-century Burmese kings.

1969 March 12: Burmese Ministry of Mines bans exploration and mining of gems, effectively nationalizing the country's gem mines. Ruby and jade mining licenses previously issued to prospectors are revoked (*Mining Journal*, Annual Review, June, 1970).

1968–1980s Smuggling increases, with only a fraction of the total output ending up in government coffers. More Burmese gems are on offer in Bangkok than Rangoon.

1988 Anti-government riots wrack the country. The government crushes the opposition, with thousands gunned down in Rangoon, Mandalay and other cities.

1989–94 To quell mounting discontent, the military junta begins to liberalize the economy (including mining) while still maintaining total political control. The name Burma is changed to Myanmar; Rangoon is changed to Yangon.[c]

1990 March 9: Private/government mining joint ventures are opened for tender at Mogok (Kane and Kammerling, 1992). However, smuggling remains widespread as the government's share of profits is 51.4%.

1991 Rubies are found at Mong Hsu (Shan State). The Thai border town of Mae Sai becomes the main smuggling point for these gems (Hlaing, 1991). The first foreign gemologists in over 25 years visit Mogok (Ward, 1991).

1994 The government reduces the export tax on gemstones to 15% (U Hla Win, pers. comm., May 2, 1994).

1995 Dismayed by the continued smuggling of Mong Hsu rubies, the Burmese government closes all ruby markets at Taunggyi, moving legal trading to Rangoon (U Hla Win, pers. comm., 14 Mar., 1995).

c. A common Asian belief is that a change of name will help put a stop to a run of bad luck. Thus Ne Win, a notoriously superstitious man, ordered the names of the capital and country changed after the riots.

mainly because intensive mining had not spared even the smallest limestone fissures. However, in one cave a lower human jaw was found, believed to be that of a female human prehistoric cave-dweller dating well before the present people settled the Mogok area. Many Neolithic stone implements were also found, from the surface of old lake terraces approximately 3.2 km (2 miles) east of the town of Mogok, or from cave entrances. Certain caves were found to be inhabited by Buddhist hermits, who had installed shrines in them. One cave was even used as a cemetery. According to De Terra, "There is no question that the first people to settle in this area took refuge in the caves, because most of them face a valley that must have offered a most favorable habitat in prehistoric times. A lake, several streams and plenty of game, in addition to fertile loamy soils covering several square miles of flat ground at the valley bottom, would have offered plenty of inducement to early settlers. Here the chase could have been combined either with food-gathering or with agricultural practices."

It is unlikely that any human could live in the Mogok area for long, particularly in caves, and not discover the gems which have made the area so famous. No doubt, the first

The dragons of Mogok

In the vicinity of the Mogok Caves the inhabitants relate many tales of buried dragons and underground spirits, which at one time are supposed to have taken refuge underground. The association of these beasts with the cavities presumably traces back to some sort of worship, but today the people are chiefly after gem bearing deposits, cave loam and sand. In the course of these mining operations the miners often find fossils, teeth of elephants and deer, or other bones belonging to animals now extinct. To the local people fossils are known as "nagá ajó" or dragon bones. They distinguish several types of dragons, although none of these seem to fall within the range of zoölogical nomenclature. A miner upon finding a fossil will present his find as a sort of religious offering to a near by monastery or Buddhist shrine, and here it will be placed before an image. In some cases I learned that fossil teeth of large size, such as elephant molars, are worshipped as "Buddha's teeth," but the monks themselves do not approve of this practice. Quite possibly the magic cult came from China where "dragon bones" continue to play an important role in native pharmacology and superstitious customs.

During my stay at Mogok, it was generally believed by the natives that I had come to search for a special kind of dragon bone. The result was that after a week's stay, prices for fossil bones soared, until an elephant's molar was valued as highly as a five carat ruby! This attitude did not make it easy for us to acquire much of the cave fauna. At Leu Village, where I made an attempt to excavate one of the larger caves, the headman told me that years ago, near Pinpyit, miners had come across large bones. They had been so frightened at the sight of the huge animal remains that they gave up their work, closing the entrance with a stone wall so that the dragon might not walk out and ravage their village!

Hellmut de Terra, 1943
The Pleistocene of Burma
Transactions of the American Philosophical Society

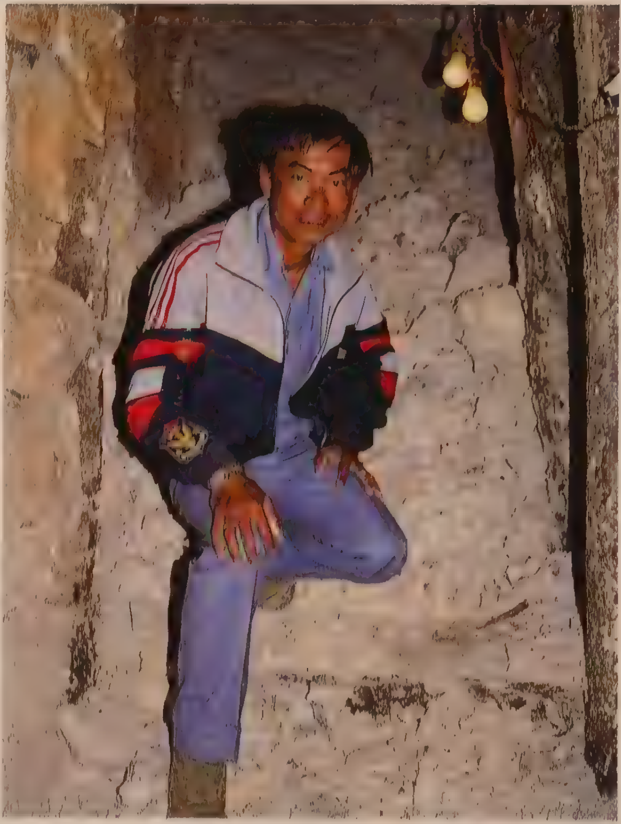


Figure 12.17 Tunnelling into the limestone in search of rubies at the Thyaungchi mine in the Mogok area. (Photo: Thomas Frieden)

gems collected would be the well-formed red spinel crystals today termed *anyan-nat-thwe* ('spirit polished') by locals. Such lustrous crystals need no fashioning to display their beauty and could not help but attract attention.

Modern history of Mogok

According to G.S. Streeter (1889a), one of the sons of Kun-Lung, founder of the Shan Dynasty, is said to have governed a state in the 6th century AD, near which there were ruby mines, and to have paid an annual tribute of 2 viss (about 3.3 kgs) of rubies to the central government. However, this has not been documented. Ehrmann (1957) describes a local legend stating that modern Mogok was founded in 579 AD by headhunting tribesmen from nearby Mong Mit (Momeik). After losing their way they discovered a "mountain break full of beautiful rubies" when investigating a commotion made by many birds. This story is similar to that told of many gem deposits and is believed to derive from Sinbad the Sailor's "valley of precious stones" in Sri Lanka, or perhaps al-Kazwini's relation of Alexander's valley of serpents and diamonds in India (Kunz, 1913). In the Burmese version, a fever- and serpent-ridden valley was found teeming with rubies. Far too dangerous for mere mortals to enter, the stones were obtained by casting lumps of fresh meat into the abyss. This attracted large birds of prey who snatched up the meat and brought it out, along with the rubies adhering to it. They were then retrieved from the birds' nests and droppings (see box, page 265).

The first Europeans arrive

From the earliest times of European contact with East Asia, Burma has been associated with rubies. Nicolò di Conti, the first European visitor to Ava, described the king of Ava thus:

> The King rideth upon a white Elephant, which hath a chayne of golde about his necke, being long unto his féete, set full of many precious stones.
>
> Nicolò de' Conti, 1419–1444
> from Frampton's Elizabethan translation (Penzer, 1929)

Figure 12.18 Spoils of the jungle
A variety of wild game is found in the heavy forest surrounding the Mogok ruby and sapphire mines. Here Burmese miners return from the hunt with a slain leopard. (From O'Connor, 1905)

Ludovico di Varthema visited Pegu between 1502 and 1508:

> The sole merchandise of these people is jewels, that is, rubies, which come from another city called Capellan [Ruby Mines District in Burma], which is distant from this thirty days' journey; not that I have seen it, but by what I have heard from merchants.... Do not imagine that the King of Pego enjoys as great a reputation as the King of Calicut, although he is so humane and domestic that an infant might speak to him, and he wears more rubies on him than the value a very large city, and he wears them on all his toes. And on his legs he wears certain great rings of gold, all full of the most beautiful rubies; also his arms and his fingers all full. His ears hand down half a palm, through the great weight of the many jewels he wears there, so that seeing the person of the king by a light at night, he shines so much that he appears to be a sun.
>
> Ludovico di Varthema of Bologna (Temple, 1928)

Di Varthema and his party offered the king coral as a gift. This act of generosity so impressed the king that he gave them over 200 rubies (Temple, 1928).

Duarte Barbosa, visiting Burma about the same time, gave one of the best accounts of rubies:

> CAPELAM
>
> And yet further inland beyond this city [Ava] and Kingdom there is another Heathen city whith its own King, who nevertheless is subject and under the lordship of Ava; which city or Kingdom they call Capelam. Around it are found many rubies which are brought in for sale to the Ava market, and are much finer than those of that place.
>
> OF RUBIES
>
> In the first place rubies are produced in the Land of India and are found chiefly on a river called Pegu. These are the best and finest, and are called *Numpuclo*' by the Malabares, and when they are clean and without flaw they fetch a good price. To test their quality the Indians put them on the tongue; those which are finest and hardest are held to be the best. To test their transparency they fix them with wax on a very sharp point and looking towards the sun they can find any blemish however slight. They are also found in certain deep pits in the mountains beyond the said river.
>
> In Pegu they know how to clean but not how to polish them, and they therefore convey them to other countries, especially to Paleacate, Narsinga, Calicut and the whole of Malabar, where there are excellent craftsmen who cut and mount them.
>
> **Dames' annotations**
>
> ' *Pegu Rubies.* The name *Numpuclo* here stated to be used for the Pegu rubies in Malabar is explained by Mgr. Dalgado in his *Glossario.* He considers that the initial letter is wrongly given owing to a copyist's mistake, and that the word should be read *chumpuclo*, as in Malayalam the name of the ruby is *chuvappukallu* from *kallu* "stone" and *chuvappu* "ruby," literally "ruby-stone." For the places where these rubies are found see p. 107 and p. 108.
>
> Duarte Barbosa, ca. 1500–1517 (from Dames, 1858)

The first Englishman to visit Burma was Ralph Fitch, in 1586, whose journey led to the founding of the British East India Company. He said:

> Caplan is the place where they finde the rubies, saphires, and spinelles: it standeth sixe dayes journey from Ava in the Kingdome of Pegu. There are many great high hilles out of which they digge them. None may go to the pits but onely those which digge them.
>
> Ralph Fitch, 1586 (in Hakluyt, 1903–05)

Figure 12.19 A stunning 1714-ct (1743-ct ?) Mogok ruby crystal sits atop the marble which nurtured it into existence. (Photo: Thomas Frieden)

Not only did Fitch comment upon the rubies, but also told of a curious local custom mentioned by many of the early European travelers to the area:

> In Pegu, and in all the countreys of Ava, Langeiannes, Siam, and the Bramas, the men weare bunches or little round balles in their privy members: some of them weare two and some three. They cut the skin and so put them in, one into one side and another into the other side; which they do when they be 25 or 30 years old, and at their pleasure they take one or more of them out as they thinke good... The bunches aforesayd be of divers sorts: the least be as big as a litle walnut, and very round: the greatest are as big as a litle hennes egge: some are of brasse and some of silver: but those of silver be for the king and his noble men. They were invented because they should not abuse the male sexe for in times past all those countries were so given to that villany, that they were very scarse of people.
>
> Ralph Fitch, 1586 (in Hakluyt, 1903–05)

Just how such balls would prevent masturbation or homosexuality is unclear. But the custom continues into the present day. During one 1980s visit to Burma, William Spengler met a man who claimed that he had pearls implanted in his genitals, to heighten sexual pleasure (very pers. comm., 20 March, 1995).

Alexander Hamilton (1744), who traveled to India and Burma in the 18th century, also had some interesting remarks about the Burmese. In reference to the sarongs worn by ladies, he said:

> Under the Frock they have a Scarf or 'Lungee' doubled fourfold, made fast about their Middle, which reaches almost to the Ancle, so contrived, that at every Step they make, as they walk, it opens before, and shews the right Leg and Part of the Thigh.
>
> This Fashion of Petticoats, they say, is very ancient, and was first contrived by a certain Queen of that Country, who was grieved to see the Men so much addicted to 'Sodomy,' that they neglected the pretty Ladies. She thought that by the Sight of a pretty Leg and plump Thigh, the Men might be allured from that abominable Custom, and place their Affections on proper Objects, and according to the ingeiuous Queen's Conjecture, that Dress of the 'Lungee' had its desired End, and now the Name of Sodomy is hardly known in that Country.
>
> Alexander Hamilton, 1744

Hamilton also mentioned the products of Burma:

> The Product of the Country is Timber for building, Elephants, Elephants Teeth, Bees-wax, Stick-lack, Iron, Tin, Oyl of the Earth, Wood-oyl, Rubies the best in the World, Diamonds, but they are small, and are only found in the Craws of Poultry and

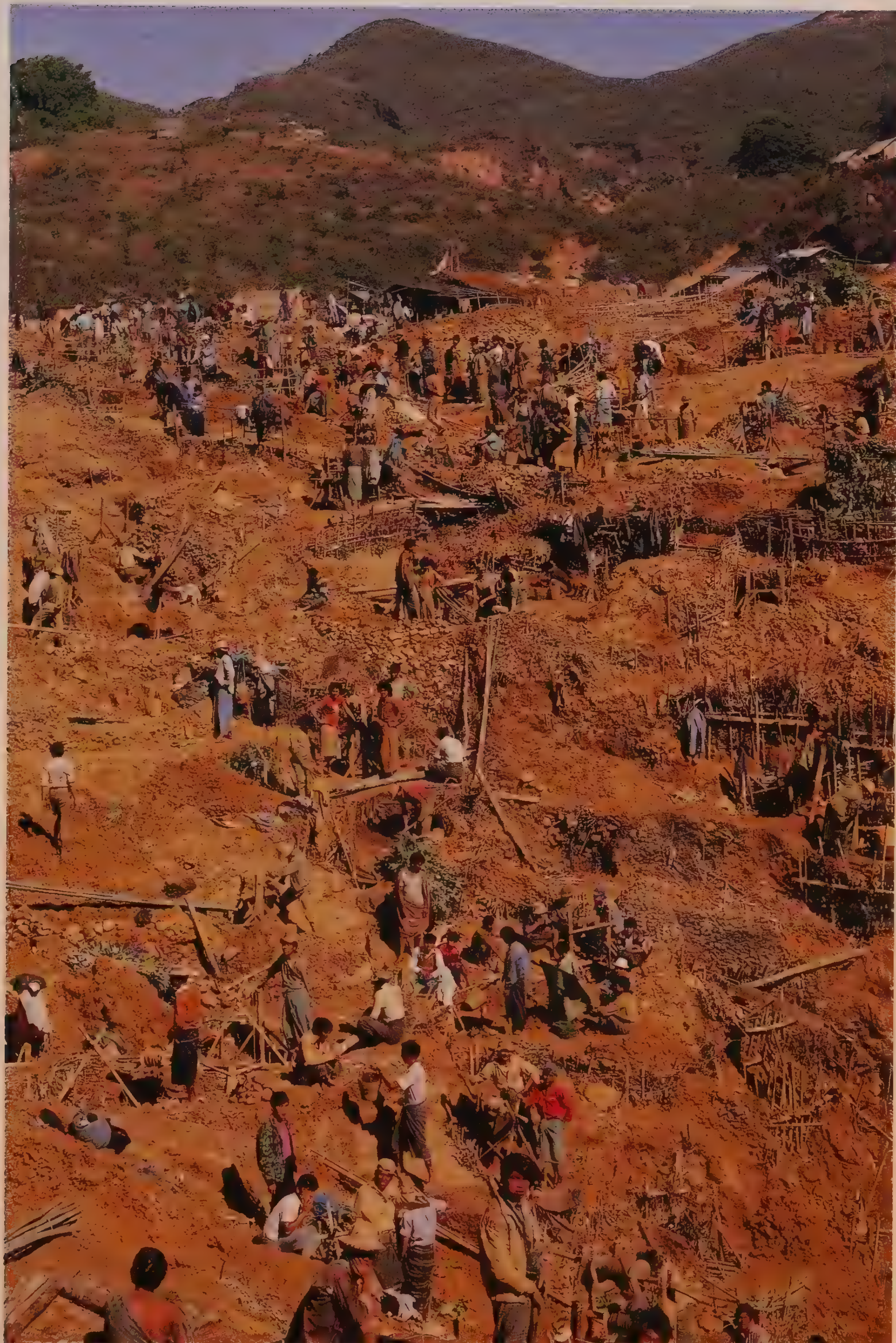


Figure 12.20 Although hillside deposits were largely ignored during the British period, today they represent virgin ground. Here, at Inn Gaung ('Big Hole Mine'), in the Mogok area of Burma, miners tunnel like ants, occupying an entire hillside in their quest for the red stone. This drama has been played out throughout human history, a continuum of our species' pursuit of dreams, ego, wealth and power. Some make it big; too many others are left with only the dream. (Photo: Thomas Frieden)

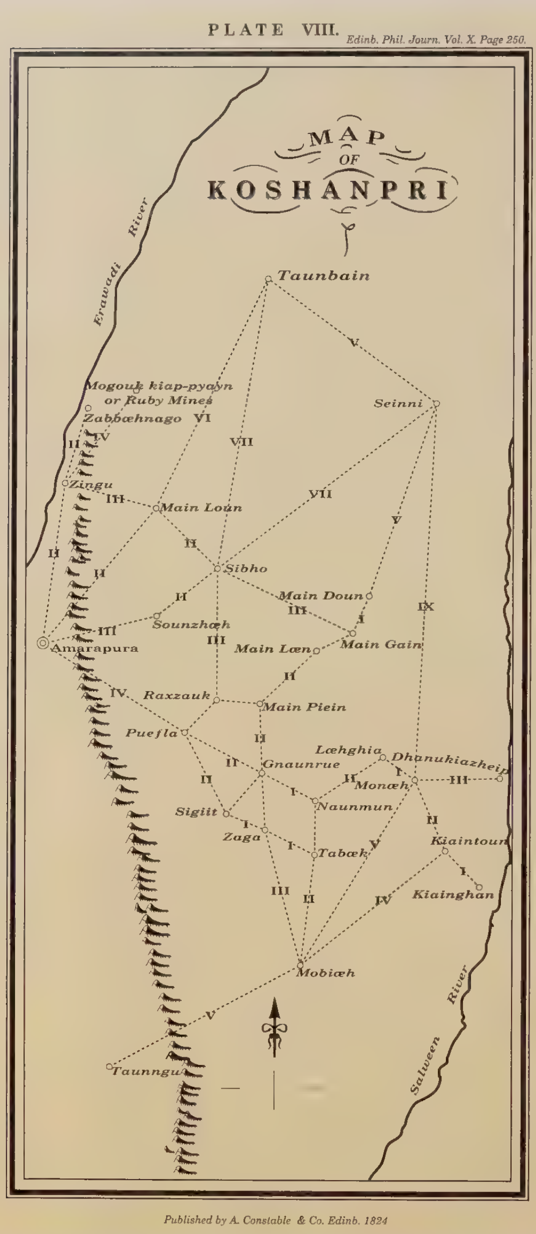


Figure 12.21 One of the earliest European maps to show the position of the ruby mines, based on information provided by a Burmese slave to Francis Hamilton in 1824. Roman numerals indicate the average number of stages (walking days) between points. Although the distances are relatively accurate, Mogok ('Mogouk') actually lies further east from Amarapura (near present-day Mandalay). (Redrawn by the author from Hamilton, 1824)

> Pheasants, and one Family has only the Indulgence to sell them, and none dare open the Ground to dig for them... About twenty Sail of Ships find their Account in Trade for the limited Commodities, but the Armenians have got the Monopoly of the rubies, which turns to a good Account in their Trade; and I have seen some blue Sapphires there, that I was told were found on some Mountains of this Country.
>
> Alexander Hamilton, 1744

Figure 12.22 Native gem diggers at Mogok about the turn of the century. (From O'Connor, 1905)

Such tales certainly contributed to the European view of the Orient as a place of wonder and exotic mystery. But these were nothing compared to that related by the famous French traveler and diamond merchant, Jean-Baptiste Tavernier, about the King of Bhutan.

> There is no King in the World more fear'd and more respected by his Subjects then the King of Boutan; being in a manner ador'd by them.... One thing they told me for truth, that when the King has done the deeds of nature, they diligently preserve the ordure, dry it and powder it, like sneezing-powder: and then putting it into Boxes, they go every Market-day, and present it to the chief Merchants, and rich Farmers, who recompence them for their kindness: that those people also carry it home, as a great rarity, and when they feast their Friends, strew it upon their meat. Two *Boutan* Merchants shew'd me their Boxes, and the Powder that was in them.
>
> Jean-Baptiste Tavernier, 1677–8

That is one banquet in which this beggar would decline to partake. *Down Satan!* But it is interesting that the passage was apparently so shocking to Victorian British that it was removed from the later editions edited by Valentine Ball.

Of the many accounts of the gems of Pegu, as Burma was then known, perhaps most interesting was that of Cæsar Fredericke of Venice, who journeyed to Asia in 1563. The following is his description of the gem trade in Pegu.

Men of the cloth

CÆSAR Fredericke of Venice, who journeyed to Asia in 1563, gave one of the earliest accounts of the fascinating Asian technique of negotiating prices in secret by covering the hands of the buyer and seller with a cloth.

> There are many Marchants that stand by at the making of the bargaine, and because they shall not understand howe the Jewels be solde, the Broker and the Marchants have their hands under a cloth, and by touching of fingers and nipping the joynts they know what is done, what is bidden, and what is asked. So that the standers by knowe not what is demaunded for them, although it be for a thousand or 10. thousand duckets. For every joynt and every finger hath its signification. For if the Marchants that stande by should understand the bargaine, it would breede great controversie amongst them.
>
> Cæsar Fredericke, 1563, (in Hakluyt, 1903–05)

Figure 12.23 Traders offer jadeite, sapphires and rubies in Rangoon's Shwebontha Street gem market. (Photo by the author, 1992)

> ... it is a thing to bee noted in the buying of jewels in Pegu, that he that hath no knowledge shall have as good jewels, and as good cheap, as he that hath practized there a long time. There are in Pegu foure men of good reputation, which are called Tareghe, or brokers of Jewels... through the hands of these foure men passe all the Rubies: for they have such quantitie, that they knowe not what to doe with them, but sell them at most vile and base prices. When the Marchant hath broken his mind to one of these brokers or Tareghe, they cary him home to one of their Shops, although he hath no knowledge in Jewels: and when the Jewellers perceive that hee will employ a good round summe, they will make a bargaine, and if not, they let him alone... when any Marchant hath bought any great quantitie of Rubies, and hath agreed for them, hee carieth them home to his house, let them be of what value they will, he shall have space to looke on them and peruse them two or three dayes: and if he hath no knowledge in them, he shall alwayes have many Marchants in that Citie that have very good knowledge in Jewels; with whom he may alwayes conferre and take counsell, and may shew them unto whom he will; and if he finde that hee hath not employed his money well, hee may returne his Jewels backe to them who hee had them of, without any losse at all. Which thing is such a shame to the Tareghe to have his Jewels returne, that he had rather beare a blow on the face then that it should be thought that he solde them so deere to have them returned.
>
> Cæsar Fredericke, 1563 (in Hakluyt, 1903–05)

Thus "spake" Cæsar Fredericke. After reading his tale, one can only wish and sigh that modern-day gem merchants would be so understanding. Perhaps businessmen haven't really changed all that much. Fredericke was no doubt just an example of a species still in flourish. Had he made his journey in the present day, Fredericke may have returned to Europe with wooden elephants—in addition to his gem purchases.

Ralph Fitch also mentioned the *Tareghe,* and said that if they failed to pay a merchant in a timely fashion, the merchant could "take [the Tareghe's] wife and children and his slaves, and binde them at your doore, and set them in the Sunne; for that is the law of the countrey." A noble custom, and perhaps one which could be applied today to politicians, tax collectors and sundry dictators.

In the year 1597 AD, the Burmese King Nuha-Thura Maha Dhama-Yaza ratified a royal edict exchanging small

Guiseppe d'Amato's description of Mogok

FROM 1597 AD onwards, Mogok was part of Burma proper. The first European to actually visit the mines in the Mogok area and write about them was a Portuguese priest, Giuseppe d'Amato, sometime before 1833. D'Amato arrived in Burma sometime in 1784, and spent the rest of his life there. He resided at Moun-lha (Mon-lhá), some 30 miles (48 km) northwest of Ava, where he died in 1832 (Burney, 1832). His brief account of the ruby workings at Kyatpyin was published posthumously in the *Journal of the Asiatic Society of Bengal* and is reproduced in its entirety below:

IV.—Short Description of the Mines of Precious Stones, in the District of Kyat-pyen, in the Kingdom of Ava.

[Translated from the original of PÈRE GIUSEPPE D'AMATO]

The territory of *Kyat-pyen** (written *Chia-ppièn* by d'Amato) is situated to the east, and a little to the south of the town of *Mon-lhá*, distant 30 or 40 Burman leagues, each league being 1000 *taa*, of seven cubits the *taa*†; say 70 miles [113 km]. It is surrounded by nine mountains. The soil is uneven and full of marshes, which form seventeen small lakes, each having a particular name. It is this soil which is so rich in mineral treasures. It should be noticed, however, that the ground which remains dry is that alone which is mined, or perforated with the wells whence the precious stones are extracted. The mineral district is divided into 50 or 60 parts, which, beside the general name of "mine," have each a different appellation.

The miners, who work at the spot, dig square wells, to the depth of 15 or 20 cubits, and to prevent the wells from falling in, they prop them with perpendicular piles, four or three on each side of the square, according to the dimensions of the shaft, supported by cross pieces between the opposite piles.

When the whole is secure, the miner descends, and with his hands extracts the loose soil, digging in a horizontal direction. The gravelly ore is brought to the surface in a ratan basket raised by a cord, as water from a well. From this mass all the precious stones and any other minerals possessing value are picked out, and washed in the brooks descending from the neighbouring hills.

Besides the regular duty which the miners pay to the Prince, in kind, they are obliged to give up to him gratuitously all jewels of more than a certain size or of extraordinary value. Of this sort was the *tornallina* (tourmaline?) presented by the Burman monarch to Colonel Symes. It was originally purchased clandestinely by the Chinese on the spot; the Burmese court, being apprized of the circumstance, instituted a strict search for the jewel, and the sellers, to hush up the affair, were obliged to buy it back at double price, and present it to the king.

You** may ask me, to what distance the miners carry their excavations? I reply, that ordinarily they continue perforating laterally, until the workmen from different mines meet one another. I asked the man who gave me this information, whether this did not endanger the falling in of the vaults, and consequent destruction of the workmen? but he replied, that there were very few instances of such accidents. Sometimes the miners are forced to abandon a level before working to day-light, by the oozing in of water, which floods the lower parts of the works.

The precious stones found in the mines of *Kyat-pyen*, generally speaking, are rubies, sapphires, topazes, and other crystals of the same family, (the *precious corundum*.) Emeralds are very rare, and of an inferior sort and value. They sometimes find, I am told, a species of diamond, but of bad quality††.

The Chinese and Tartar merchants come yearly to *Kyat-pyen*, to purchase precious stones and other minerals. They generally barter for them carpets, coloured cloths, cloves, nutmegs and other drugs. The natives of the country also pay yearly visits to the royal city of Ava, to sell the rough stones. I have avoided repeating any of the fabulous stories told by the Burmans of the origin of the jewels of *Kyat-pyen*.

There is another locality, a little to the north of this place, called *Mookop*, in which also abundant mines of the same precious gems occur.

Note.—While I am writing this brief notice, an anecdote is related to me by a person of the highest credit, regarding the discovery of two stones, or, to express myself better, of two masses (*amas*) of rubies of an extraordinary size, at *Kyat-pyen*. One weighed 80 *biches*‡, Burmese weight, equivalent to more than 80 lbs.! the second was of the same size as that given to Colonel Symes. When the people were about to convey them to the capital to present them to the king, a party of bandits attacked *Kyat-pyen* for the second time, and set the whole town on fire. Of the two jewels, the brigands only succeeded in carrying off the smaller one; but the larger one was injured by the flames: the centre of the stone, still in good order, was brought to the king. I learned this from a Christian soldier of my village of *Mon-lhá*, who was on guard at the palace when the bearer of the gem arrived there.

Prinsep's annotations

* The *Kyat-pyen* mountains are doubtless the *Capelan* mountains mentioned as the locality of the ruby, in Phillips' Mineralogy—"60 miles from *Pegue, a city in Ceylon*." Though it might well have puzzled a geographer to identify them without the clue of their mineral riches.

† Estimating the cubit at $1^1/_2$ feet, the league will be 10,500 feet, or nearly two miles;—about an Indian *kos*. [The cubit is an ancient measure of length based on the forearm]

** The letter seems to have been intended for some scientific friend in Italy.

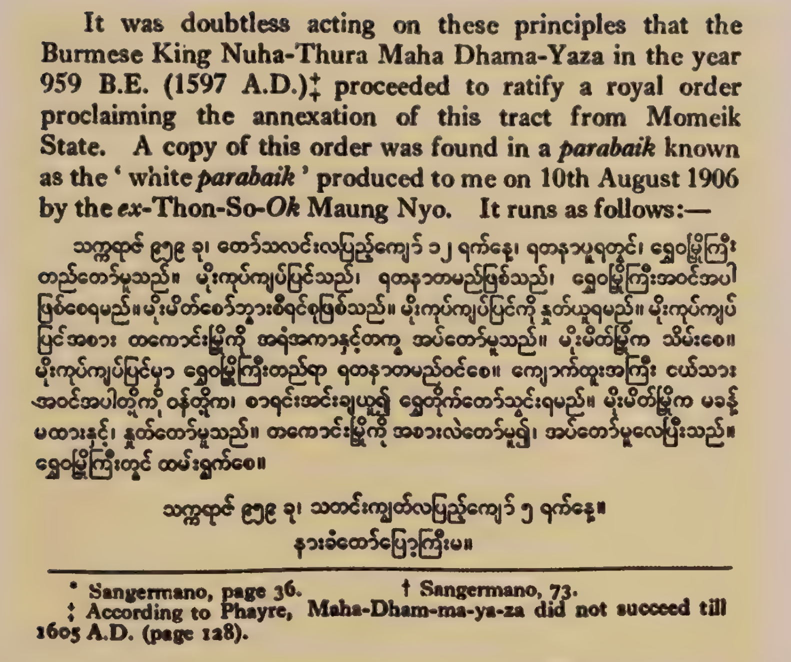
†† Probably the *turmali* or transparent zircon, which is sold as an inferior diamond in Ceylon. [Vide vol. i. page 357.]

‡ The Père d'Amato's *biche* is the *bisse* of Mendez Pinto, and the old travellers, and the *biswa* or *vis* of Natives of India. The Burmese word is *Peik-tha*, which is equivalent to $3^1/_2$ lbs., and to a weight on the Coast of Coromandel called *vis*. B.

Père Giuseppe d'Amato, 1833 (with notes from James Prinsep)

parts of Burma under his control for the Mogok Stone Tract, previously under the control of a Shan *saopha* (Burmese = *sawbwa;* or prince). Both the Burmese text of this order and an English translation are reproduced in Figure 12.24 (George, 1915).

According to Halford-Watkins (1934), the town of Mogok did not exist at that date, the name merely being applied to a mining area and series of paddy fields situated some five miles (8 km) from Thapambin village. Due to the difficult nature of the country, the journey between the two places could not be completed before nightfall, which is *mochok* in Burmese. Thus the name Mochok ('nightfall camping ground'), which was later corrupted to Mogok. Another possible derivation of the name is that it is the place where the mountains meet the sky, in allusion to the mountain tops being hidden in the clouds during the rainy season.



It was doubtless acting on these principles that the Burmese King Nuha-Thura Maha Dhama-Yaza in the year 959 B.E. (1597 A.D.)‡ proceeded to ratify a royal order proclaiming the annexation of this tract from Momeik State. A copy of this order was found in a *parabaik* known as the ' white *parabaik* ' produced to me on 10th August 1906 by the *ex*-Thon-So-*Ok* Maung Nyo. It runs as follows:—

သက္ကရာဇ် ၉၅၉ ခု၊ တော်သလင်းလပြည့်ကျော် ၁၂ ရက်နေ့၊ ရတနာပူရတွင်၊ ရွှေဝမြို့ကြီး တည်တော်မူသည်။ မိုးကုပ်ကျပ်ပြင်သည်၊ ရတနာတမည်ဖြစ်သည်၊ ရွှေဝမြို့ကြီးအဝင်အပါ ဖြစ်စေရမည်။ မိုးမိတ်စော်ဘွားစိရင်ရာဖြစ်သည်။ မိုးကုပ်ကျပ်ပြင်ကို နုတ်ယူရမည်။ မိုးကုပ်ကျပ်ပြင်အစား တကောင်းမြို့ကို အရံအကာနှင့်တကွ အပ်တော်မူသည်။ မိုးမိတ်မြို့က သိမ်းစေ။ မိုးကုပ်ကျပ်ပြင်မှာ ရွှေဝမြို့ကြီးတည်ရာ ရတနာတမည်ဝင်စေ။ ကျောက်ထူးအကြီး ငယ်သား အဝင်အပါတို့ကို ဝန်တို့က၊ စာရင်းအင်းချယူ၍ ရွှေတိုက်တော်သွင်းရမည်။ မိုးမိတ်မြို့က မခန့် မထားနှင့်၊ နုတ်တော်မူသည်။ တကောင်းမြို့ကို အစားလဲတော်မူ၍၊ အပ်တော်မူလေပြီးသည်။ ရွှေဝမြို့ကြီးတွင် ထမ်းရွက်စေ။

သက္ကရာဇ် ၉၅၉ ခု၊ သတင်းကျွတ်လပြည့်ကျော် ၅ ရက်နေ့။
နားခံတော်ပြော့ကြီးမ။

* Sangermano, page 36. † Sangermano, 73.
‡ According to Phayre, Maha-Dham-ma-ya-za did not succeed till 1605 A.D. (page 128).

Figure 12.24 The Royal edict of 1597 AD transferring the Mogok Stone Tract from a Shan *saopha* (*sawbwa* in Burmese) to the Burmese King. (From George, 1915)

Translation

Shwe-Wa-myo (Ava) was established on 12th Tawthalin Labyigyaw of 959 B.E. It is the Ratna Pura (Ratna=Gem, and Pura=City). Mogok and Kyatpyin are names for Gem. They should be included in the Shwewamyo. These two were part of Momeik Sawbwa's State but should be excluded and Tagaung Myo with its surrounding villages be included in the State instead.

It is ordered that the Momeik Sawbwa take possession of Tagaungmyo and that Mogok and Kyatpyin be given over to Shwewamyo. The Wuns concerned must take over the rubies with a list of all descriptions (big and small) and pay into the Government Treasury.

No appointments whatever are therefore to be made by the Sawbwa to Mogok and Kyatpyin which have been given to Shwewamyo in exchange for Tagaungmyo.

NAKHANDAWPYAWGYIMA
5TH THADINGYUT LABYIGYAW, 959 B.E.

One might wonder why the Shan *saopha* would agree to such a one-sided deal, where a relatively worthless piece of land was traded for the world's greatest ruby mines. It is indeed strange what people will do with a knife at their throat.

Burmese monarchs worked the Stone Tract as a royal monopoly, in a thoroughly despotic manner. All rubies above the value of Rs2000 were considered Crown property and failure to surrender them was punishable by torture and death. Father Sangermano, an Italian priest who lived in Ava between 1783 and 1806, discussed this:

> With regard to precious stones, a few inferior sapphires and topazes are sometimes found; but it is the rubies of the Burmese Empire which are its greatest boast, as both in brilliancy and clearness they are the best in the world. The mines that contain them are situated between the countries of Palaon and the Koè. The Emperor employs inspectors and guards to watch these mines, and appropriates to himself all the stones above a certain weight and size; the penalty of death is denounced against any one who shall conceal, or sell, or buy any of these reserved jewels.
>
> Father Sangermano, 1893
> *The Burmese Empire a Hundred Years Ago*

But conceal them they did. The story of the *Nga Mauk Ruby* provides an example. Nga Mauk, a poor miner, uncovered a large fine ruby which was later divided into two excellent pieces along an incipient flaw. One half was given to the king, but the other secretly sold. The king learned of the deception when he proudly showed his half to the dealer who had bought the other part (Keely, 1982). Enraged, he sent his minions to exact punishment. All area villagers were placed into a makeshift stable and burned alive. Even today, some 150 years later, the remains of this horrible cremation can be seen at a spot called Laung Zin, which means "fiery platform."[9] Daw Nann, his wife, is said to have watched his blazing death from a hill near Kyatpyin which is today called *Daw Nann Kyi Taung* ('the hill from where Daw Nann looked down'). As for the famous Nga Mauk ruby, it disappeared from the palace the night the British conquered Ava in 1885 (Keely, 1982; E.W. Streeter, 1892; Clark, 1991).[10]

Figure 12.25 "An' I seed her first a-smokin' of a whackin' white cheroot…" (Rudyard Kipling, *Mandalay*) (Photo: Thomas Frieden)

9. George (1915) has reported that the name Kyatpyin, from which the Capelan of early European travellers is derived, comes from the fact that the people slept on platforms, with fires underneath to keep them warm at night.

Figure 12.26 A native miner at a *twin-lon* mine, near Mogok, Burma. (From O'Connor, 1905)

Figure 12.27 King Thebaw and Queen Supayalat, the last monarchs of Burma. (From the *Illustrated London News,* 16 Jan., 1886)

In wars with the neighboring kingdoms of Manipur and Assam, prisoners were taken. During the latter part of the 19th century, production from Mogok declined drastically due to the despotic rule and heavy handed policies of the Burmese monarchs' agents. In their quest to extract as much tax as possible, they effectively drove people from the area.

Empire building

On the road to Mandalay, where the old Flotilla lay,
With our sick beneath the awnings when we went to Mandalay!
Oh the road to Mandalay, where the flyin'-fishes play,
An' the dawn comes up like thunder outer China 'crost the Bay!
Rudyard Kipling, 1892, *Mandalay*

The British move into Burma came slowly, but inevitably. Disputes on the border with British India led to the first Anglo-Burmese war in 1824–6. As a result, Arakan, Assam and Tenasserim were ceded to the East India Company. Pegu was annexed after the British won the second Anglo-Burmese war of 1852–3. In 1885, commercial disputes and reported corruption and massacres at the Court gave the British the needed excuse to annex all of Upper Burma, including the Mogok Stone Tract.

Mandalay was taken on Nov. 29, 1885. While the British expedition quickly took the capital, it was over one year before Mogok was occupied and five long years of skirmishes before the rest of Upper Burma was secured.

Unfortunately, the fabulous jewels of King Thebaw were never recovered. When the British took Mandalay, they sealed the palace, but Thebaw's ministers requested permission for Queen Supayalat's ladies to come and go as they wished. General Prendergast, leader of the British expedition, agreed over the objections of G.S. White. White wrote: "Colonel Sladen… sent me word that the ladies might be allowed to come and go freely. I entered a protest that everything of small size and great value would be passed out by the ladies.… [as a result] thousands of pounds of booty were, I am sure, lost to the army." (Stewart, 1972)

Halford-Watkins (1934) felt the magnitude of the royal treasure was highly exaggerated, pointing out that there is not a single written first-hand description of these gems:

10. For a slightly different version of this story, see page 228.

Figure 12.28 British camp at Mogok. (From the *Illustrated London News*, 19 Feb., 1887)

...[the monarchs'] persons were regarded as being so very sacred that such regalia had to be viewed from a very respectful distance, so that it was quite impossible for anyone even to judge of the genuine nature of the stones, much less to estimate their value. [I have] talked with several of the old officials and habitués of the palace of the times of both King Mindoon Min and Thebaw, and has been assured that the majority of these tales are pure invention, and that most of the stones worn were of quite ordinary quality, and sometimes very poor, quality; while many of the large gems attached to the robes and other regal paraphernalia were merely coloured glass.

This rather calls to mind the stories of the valuable ruby trousers buttons worn by my friend the Sawbwa of Momeit during his visit to London, which were made so much of at the time by a certain section of the press. The Sawbwa invariably wears his native costume, in which his trousers do not possess a single button of any kind, much less ruby ones.

The fact that only a comparatively few gems of any importance were found in the possession of King Thebaw at the taking of Mandalay confirms the statements made by these old officials. And it is a known fact that when Queen Supayalat left she carried with her all her personal gems wrapped in a handkerchief which was so small that she dropped it as she was boarding the steamer, and did not miss it until it was returned by a soldier who had picked it up. Of course it was said that the majority of the treasure had been buried as the British advanced, and there has since been much excavating and searching done in and around the square mile of Fort Dufferin, in some of which [I have] taken an active part. But so far the result has been a total blank, as the old officials always said that it would be, owing to nothing having been buried, and but comparatively little stolen, for the simple reason that it was not there to be made away with.

J.F. Halford-Watkins, 1934

Shortly after the annexation of Upper Burma in December, 1885, London jeweler, Edwin Streeter, was breakfasting in Paris and happened to overhear two men discussing the Burma ruby mines. After introducing himself, he found that a French firm, Bouveillein & Co., had arranged a provisional lease of the ruby mines from King Thebaw. With the British annexation, this lease was then worthless.

Upon his return to London, Streeter contacted the India Office with the prospect of obtaining the lease. A syndicate was formed, consisting of Streeter, Charles Bill, Reginald Beech and Streeter's son, George Skelton Streeter. Captain Aubrey Patton was selected to travel to Rangoon for negotiations. He departed from London in January, 1886. On Patton's arrival in Burma, it was found that Gillanders, Arbuthnot & Co. of Calcutta and Rangoon, in conjunction with an unknown London jewel broker, had already offered

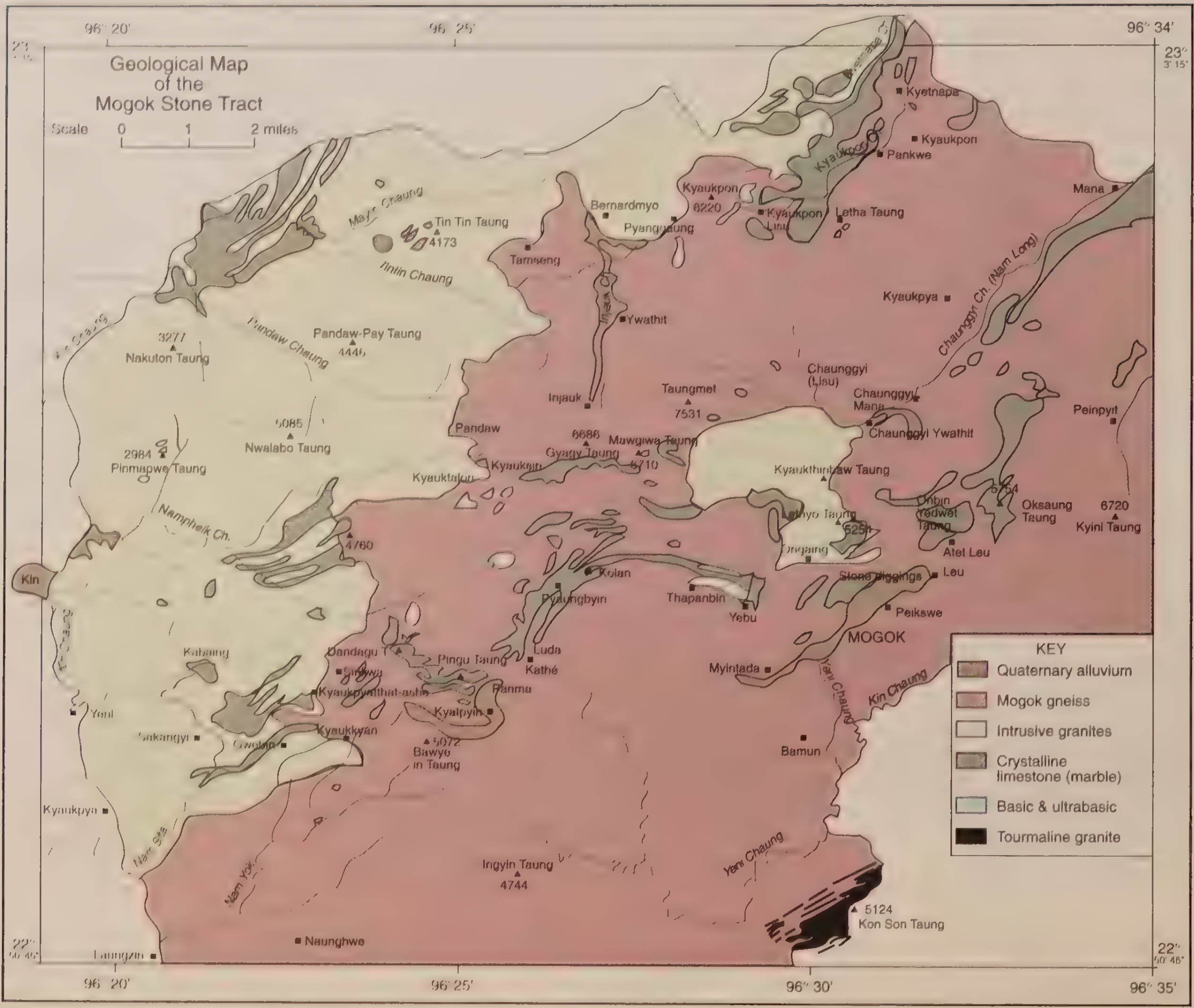


Figure 12.29 Geological map of the Mogok Stone Tract in Upper Burma. Most gems are recovered from alluvial deposits situated near the towns of Mogok and Kathé. (Modified from Iyer, 1953)

two lakhs[11] of rupees for the lease. The Streeter syndicate countered with an offer of three lakhs, which Gillanders, Arbuthnot & Co met. The government then decided to offer the lease for public tender. In respect of the further competition, Streeter increased the offer to four lakhs (£30,000) for a five-year lease, which was provisionally accepted, pending investigation into native mining rights (E.W. Streeter, 1892; *Times of London*, Aug. 17, 1887). Meanwhile, as per the British Indian government's suggestion, Streeter dispatched his son, along with Bill, Beech and Rangoon engineer, Robert Gordon, to accompany the British military expedition to Mogok, which left Mandalay in November, 1886 (E.W. Streeter, 1892).

Mogok was occupied by British troops in December, 1886. In February, 1887, Mr. F. Atlay arrived at the mines to act as agent for the Streeter syndicate. He subsequently became mine manager, a position he continued to hold under the Burma Ruby Mines Ltd.

It was not until 1889 that the lease actually began. The reasons for the delay were entirely political. Edward Moylan, a disbarred barrister, managed to convince many in London that the lease holder, E.W. Streeter, had acquired it through dishonest means (such as bribery). Moylan, who was then Burma correspondent for the *Times* of London, succeeded in raising enough questions to cause the lease to be reexamined. In the end, his true motive was revealed; he was working for Gillanders, Arbuthnot & Co, who hoped to win the lease themselves[12] (Stewart, 1972).

11. One lakh equals 100,000 rupees

12. A Mr. Danson was reportedly sent to Mogok at one stage to report on the mines for Gillanders, Arbuthnot & Co. (George, 1915).

At this point, enter one Moritz Unger, a Paris jeweler. He claimed to represent a powerful European syndicate with the London Rothschilds at the head, and in March, 1886, applied for the lease. Unfortunately, he could produce no evidence of this syndicate's existence, and soon disappeared from the scene (London *Times,* Aug. 17, 1887).

In light of the controversy surrounding the lease, the British government decided to send a trained geologist to report on the mines. C. Barrington Brown reached Mogok on January 10, 1888. His was the first detailed geologic study of the Mogok area (Brown and Judd, 1896). Brown's report was eventually received by the Secretary of State and the lease was put up for renewed tender (E.W. Streeter, 1892).

By this time, the London Rothschilds were involved. N.M. Rothschild and Sons, through their Exploration Co subsidiary, had written to the Secretary for India, asking if they could bid for the mines. Eventually the Streeter syndicate joined with N.M. Rothschild and the Exploration Co., and together they floated the Burma Ruby Mines, Ltd. A fresh offer was tendered and was accepted on Nov. 27, 1888. The lease was signed on February 22, 1889, giving the company seven years, with a renewal option, at an annual rent of Rs400,000, plus one sixth of net profits (E.W. Streeter, 1892; P. Streeter, 1993). Streeter and his associates later sold the lease to the Burma Ruby Mines, Limited for £55,000 (Brown, 1927).

The Burma Ruby Mines, Ltd.

The *Times* of London published the prospectus for the company on Feb. 27, 1889. That morning, extraordinary scenes were witnessed at the company's offices, as the following extract shows:

> If St. Swithin's Lane had been a ruby mine itself the scene witnessed there yesterday morning could not have been more remarkable. The crowd around New Court was so dense that Lord Rothschild and other members of the house were unable to get in by the door. So a ladder had to be got, and the spectacle was seen of a number of great financiers entering their own office in a burglarious fashion. The clerks had to be smuggled in by a back entrance behind the Mansion House. The surging crowd in front drove a telegraph boy right through the window of a baker's shop opposite, the poor fellow being rather severely hurt. The fortunate possessors of Ruby Mine application forms, which were being hawked at five shillings, had to pass between files of policemen to hand in their applications. The next time the Messrs. Rothschild make an issue, it would be well for the police to arrive on the scene before the stags.
>
> *Financial News,* London, Feb. 28, 1889

Within hours, the issue sold out. General public and company directors alike were under the mistaken impression that fabulous riches were just waiting to be unearthed in Mogok. No one gave a thought to the difficulties of mining gems in such an inhospitable and remote location. Instead, they could see but one thing—rubies—pigeon's blood rubies.

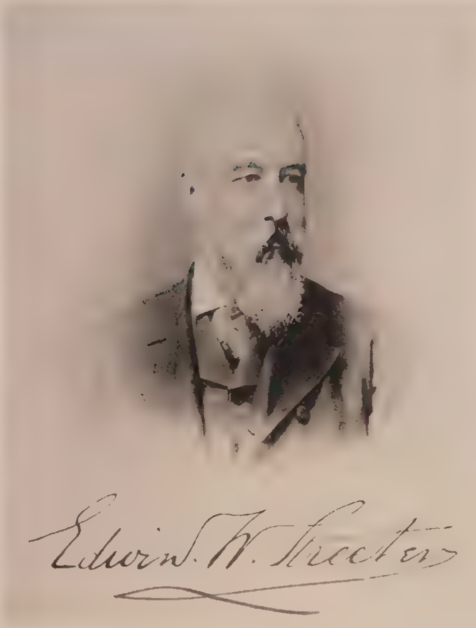


Figure 12.30 Edwin Streeter, the London jeweler and author who was involved in the early history of the Burma Ruby Mines, Limited. (From Streeter, 1892)

> **London Mine Gambling**
>
> London has periodical investment or gambling crazes. At one time it is railway "securities," so called, at another the bonds of some bankrupt State, at still another some South Sea bubble in the shape of Indian or African gold mines. At present the fever is African and Burmese....
>
> The latest London craze was finely exhibited at the recent allotment of shares in the Burmese ruby mines, concerning which our well-informed London correspondent wrote us February 15th: "The mines may be immensely valuable, or perhaps not; no one can tell as to this until a year's work has been done upon them." All London rushed to get the prospectus, and the crowd began to collect in front of the Rothschild's offices long before they were open in the morning. The £1 shares went immediately to £4, and the total amount of stock offered was applied for many times over.
>
> These shares are "a pure gamble," even more than is usual in mining, though they have this advantage over most of the London mining stocks, that there is a *possibility* that they will pay, and pay largely, while the average London mining stock is absolutely certain never to pay anything.
>
> Editorial, *Engineering and Mining Journal*
> New York, March 16, 1889

The Company started its career with a paid up capital of £150,000 and a highly exaggerated view of potential production. All kinds of unforeseen difficulties were encountered during the first years, with an unusual amount of time spent in preliminary operations. The annual rental fee to be paid to the Government of India was originally fixed at the high sum of £30,000 per year plus 30% of any profits made, in return for the sole rights to mine with machinery. Native mining was also allowed by native methods in areas not

Mogok—A city built on rubies

MOGOK has always been known as the city of rubies. Just how true this is was brought home when geologists and engineers first began to study the gem deposits of the area. They found that some of the richest alluvials lay right beneath the town itself and so in 1902, and again in 1908 and 1909, parts of the town were purchased and the people settled elsewhere (Brown, 1933).

Figure 12.31 High street in Mogok about 1905. (From O'Connor, 1905)

utilized by the Company, for which a tax of 30% on all finds was collected. This tax soon proved unworkable and so a fee per workman was charged instead. Revenue from native workings later became an important source of funds, but in the beginning little was collected.

Tremendous difficulties were encountered from the outset. First, a road had to be constructed from Thabeitkyin to Mogok, through nearly 100 kms of densely-jungled hills[13] (George, 1915). Machinery had to be imported; diseases took their toll of men and livestock; flooding was common in the rainy season; these were but a few of the problems. Power generation was yet another obstacle. Coal was not practical as it would have had to have been brought from Thabeitkyin (Talbot, 1920). Steam pumps were used at first, but required too much timber. Since Mogok had plenty of water, it was decided to construct a hydroelectric plant. This was completed in 1898, the first of its kind in that part of Asia (Brown, 1933).

Although water helped in electricity generation, it remained the nemesis of miners at Mogok, continually flooding the workings. The company's engineer, A.H. Morgan, proposed a tunnel through the rock some 100 ft (30 m) below the surface and more than a mile (1.6 km) in length. Construction began in 1904 and finished in 1908. The tunnel was immediately successful in dewatering the diggings.[14] Unfortunately, its completion coincided with a downturn in the gem market, in part brought about by the development of Verneuil's synthetic ruby.

Introduction of cheap Verneuil synthetic rubies hurt sales, as did the economic downturn resulting from World War I. With losses mounting, the Company renegotiated its lease with the Government several times, but it was not enough. In 1925, faced with mounting losses, the Company went into voluntary liquidation. No buyers were forthcoming and so in 1931 the lease was surrendered. Thus ended the first attempt at mechanized mining of the world's richest ruby deposits.

Figure 12.32 Bottom of the ramp at the Burma Ruby Mines Ltd. mine at Mogok, with both British and native workers. (From Claremont, 1906)

Company postmortem

Many have speculated about the reasons for the Company's failure (Halford-Watkins, 1932a–d), most concluding that it was just not meant to be, the difficulties being too great to surmount. But evidence uncovered by the author suggests the Company owed its failure less to the difficulty of the task and more to that old devil we know—human greed. In a confidential report written to the Government of India on the future of mining at Mogok, the head of the Geological Survey of India, J. Coggin Brown, pointed his finger straight at the De Beers diamond cartel:

13. Starting as a mule track, it was later widened for carts until its fully-metalled completion in 1901–2. Before its completion, one convoy of carts took over six weeks to make the journey (George, 1915).

14. Heavy rains in 1925 caused a fall, blocking the tunnel, causing the valley to revert to its former state of a series of large lakes, which is how it remains today.

Marching on Mogok

It was anticipated that we should not reach this unknown country without meeting with some opposition, and on Nov. 15th [1886] a force of Shans was found stockaded in our front on the Kodan River. The ground they had chosen was a spot on which two years previously an army of Theebaw's had been completely routed. A successful flanking movement, however, cleared them out completely in a little over an hour, several dead and wounded men being left behind.

No more opposition being met with, Sagadoun at the foot of the hills was reached and occupied, and a halt was made for a few days. From here, 6000 feet above us, glittering in the sun, could be seen the peaks of Shwee-ov-Toun, which were promptly christened Sheba's breasts, from their supposed likeness to the hills that guarded King Solomon's mines, and lesser peaks covered with jungle forest, from which peeped out a native village or a green patch of cultivation.

On Dec. 18th the march up the hills began. The only transport that could be used along these mountain tracks was that of pack mules and ponies, and hard work these poor beasts found it, often ascending 2000 feet in a day, and many a man wondered as he tramped along if his kit and food would reach him before midnight. At each camp new and curious views would open themselves out before us; at one point the plains and hills between us and Bharno could be seen stretching for miles and miles in the bright evening sunlight; next morning the same country would be covered with white clouds floating far below our position, appearing like some huge snow field. Again, at another camp would be discovered away to the east some mountain range of Yunnan veiled in blue mist.

As the force proceeded, the Shans and Dacoits fell back, evacuating one strong stockade after another, till at last, on the morning before Christmas Day, we reached a point at the end of a narrow valley where the hills rose high above us, and through which two narrow passes lead directly into the Ruby Mine district. It was found that these passes were strongly stockaded, and held by the enemy in force.

General Stewart determined to attack the position on our right front first, as it would otherwise command our flank. A few shells were first dropped into it, and then an attacking party moved forward; in about an hour a ringing cheer informed us that the stockade was taken, and soon its former occupants could be seen scuttling over the hills, conspicuous in their white jackets and large straw hats. It was too late, however, to give proper attention to the stockade on our left which commanded the road to Mogok; so camp was pitched, and on the order bugle sounding it was found that we were to spend a quiet Christmas Day, for the last few days' work had exhausted both men and beasts. At an elevation of about 6000 feet, the morning of Dec. 25th dawned in quite an English fashion; a heavy white frost covered the ground, and bitter were the complaints at the coldness of the night. The popular Padre of the force held divine service and the day passed quietly. Next morning the column started early, but only to discover that the series of stockades on our left had been abandoned: they had been most carefully constructed and cleverly masked, and would, properly held, have formed a very formidable obstacle to the advance....

...[Due to the head man absconding with the payroll], the opposition against us evaporated and we entered the Ruby Mine valleys of Burma without firing another shot. On the morning of January 27th the last ridge overlooking Mogok was reached and the town lay at our feet.

G. Skelton Streeter, Mogok, March 8, 1887
(From Streeter, 1887a, *Murray's Magazine*)

At this juncture I cannot refrain from writing an opinion which I have already expressed verbally, that the influence of the De Beers diamond concern has had more to do with the present [1927] position of mining for coloured gems in Burma than appears on the surface. The reasons for this are obvious, and it is significant that there has always been a powerful representative of the Great South African concern on the Board of the Burma Ruby Mines, Limited.

J. Coggin Brown, 1927
Gem Mining in the Mogok Stone Tract...(confidential report)

Brown was referring to the competition for a share of the gem market between De Beers and the Burma Ruby Mines Ltd. Apparently, he believed that the Burma Ruby Mines Ltd. was sabotaged by De Beers. This idea is not as far-fetched as it might seem. De Beers was not always the huge and powerful monopoly of today. It has taken over eighty years of monopolistic practices and masterful marketing to reach such a position of dominance.

Early in the 20th century the diamond market faced the real problem of oversupply, due to discovery of vast new deposits in South Africa. It takes no great leap of faith to see that, from De Beers' perspective, the potential success of the Burma Ruby Mines Ltd. represented a substantial threat. Of course, one cannot sell rubies if they are not being mined and effectively marketed. According to Brown, poor decisions taken by the Board of Directors of the Burma Ruby Mines Ltd. greatly contributed to the venture's eventual failure.[15]

In his summary, Brown discussed the future potential of ruby mining in Burma:

> The operations of the Company, apart from an abortive attempt to mine gems from the limestone, and one or two half-hearted efforts to prove the hill deposits, have consisted entirely in working the valley alluvials, confining their attentions to the Mogok, Kyatpyin and Kathe Valleys. There are, however, other valleys in the stone tract and the question arises whether these have been sufficiently explored. It is exceedingly doubtful if they have, in particular the Kin and Khabine [Kabaing] deposits. It is notoriously difficult to prospect this type of mineral deposit and no two geologists of experience would agree as to the reliability of the results so obtained. But it was surely the duty of the Company to put these questions beyond doubt. This has not been done, not through any fault of the local technical command but owing to the inhanition of the Board of Control...
>
> It has been stated to me repeatedly, and I see no reason to doubt the fact from my own view as a geologist, that there are great possibilities in the hillside deposits. They will certainly be more difficult to evaluate and occasional failures might result, but, in a speculative business like gem mining perhaps this does

15. This opinion was probably only expressed by Brown because his report was confidential. In his public writings on the Burma ruby mines, Brown said nothing about it.

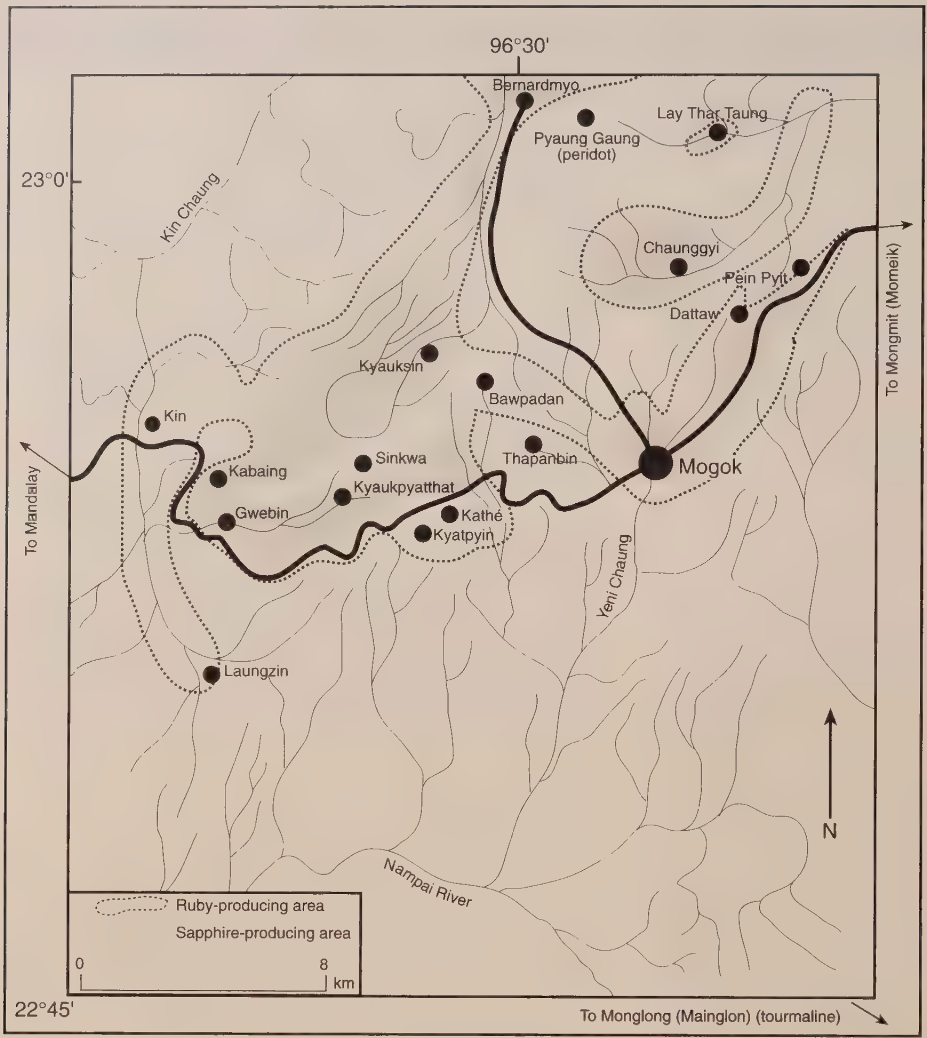


Figure 12.33 Map of the sapphire-producing regions of Burma's Mogok Stone Tract. (Modified from Halford-Watkins, 1935b)

not matter much.... The history of the Company proves that time after time the selection of a field for a new enterprise instead of being a matter of scientific certainty, has been a pure speculation, based for the most part on reports and rumours of the success of native miners.

J. Coggin Brown, 1927
Gem mining in the Mogok Stone Tract... (confidential report)

Burma after the company

In the years after the failure of the Company, the working of the mines reverted to the age-old methods of native miners. Company machinery lay fallow and eventually became useless. The fantastic drainage tunnel designed by A.H. Morgan was damaged by heavy flooding in 1925 and never repaired, resulting in the formation of two large lakes which today dominate the landscape of Mogok.

New rules for mining took effect in 1930, which allowed homesteading upon payment of a Rs10 per miner fee (Ehrmann, 1957b). The result was a proliferation of small mines. Some machinery and the electric plant were sold to A.H. Morgan and a Mr. Nichols (or Nicols; Meen, 1962). Morgan later died, but Nichols continued to supply electricity to the area at least through 1962. By 1957, some 1200 individual mines were in operation, employing anywhere from 2–50 people each. Miners were also shareholders, splitting the profits with mine owners, which helped to eliminate theft (Ehrmann, 1957b).[16]

In 1962, a military coup brought General Ne Win to power and plunged the country into isolation. Ne Win called the new direction the "Burmese road to socialism," but many thought the "Burmese road to poverty" a more apt label. With the exception of roadside food stalls, most industries were nationalized.

Gem mining was fully nationalized in 1969 (*Mining Journal,* June, 1970) and private trading of gems outlawed. In fact, mere possession of loose stones was a crime.[17] After

16. The above has been taken from the accounts of Martin Ehrmann. Readers should be aware that Mr. Ehrmann was not the most reliable of authorities; while his articles are rich in detail, they are also riddled with errors and misspellings. Unfortunately, his are virtually the only non-geological accounts for the period 1930–1960.

nationalization, the government worked the mines in a rather desultory fashion. Mechanized mines were operated, but with little success, as the generals placed their military cronies in positions of power, rather than trained engineers and administrators. The little output that did fall into government hands was sold at the annual auction in Rangoon, operated by the state-run Myanma Gems Enterprise (MGE).[18] Illegal mining also took place and accounted for the lion's share of production. These stones eventually found their way onto the world market through the porous borders of Thailand, China and India.

Smuggling became the norm, so much so that the Burmese black market was dubbed the "brown market" by locals, due to its ubiquity. At Mandalay's night market one could find all manner of smuggled foreign goods openly on sale, while, at the jade mining and trading town of Hpakan, the goods offered were even more exclusive. French cognac and champagne, American cigarettes, perfume from Paris, all were readily available for those willing to pay the price (Lintner, 1989).

Burma today

In 1988, anti-government riots wracked the country and were ruthlessly crushed. Realizing the degree of popular discontent, the years following the riots have seen an ever-so gradual loosening of controls on the country's economy. In 1989, MGE began to accept privately-owned gem and jewelry consignments for offer at the annual auction and at its retail shops. Private-government joint ventures in gem mining were started, as were joint ventures with foreign companies for jewelry manufacture. The holding of foreign currency was also legalized, eliminating the need for sacks of the local kyat, which is available in small denominations only. In April, 1994, the gem export tax was reduced to a near-reasonable 15% (U Hla Win, pers. comm., May 2, 1994). But in today's highly competitive business climate, only when such restrictions are entirely eliminated can smuggling be erased.

Today, the seed of a local jewelry-manufacturing industry in Burma has been planted, but it will take years to bear fruit. As of the present writing, Burmese jewelry cannot compete with that manufactured elsewhere; most foreign buyers of Burmese jewelry are strictly interested in the gems, with the settings being used for scrap once out of the country.

From the developments of the past few years, it is clear that big changes are afoot in Burma's gem and jewelry industry. The world will certainly welcome such moves if they lead to true economic and political freedom.

Figure 12.34 The search for crimson infects both young and old. Inn Gaung ('Big Hole Mine'), Mogok. (Photo: Thomas Frieden)

The current situation in Mogok

Prior to 1991, information on Mogok's mining situation was difficult to obtain. The biggest problem was the totalitarian nature of the Burmese government, which regards even mundane details about the country as state secrets. Until 1991, foreigners were not permitted to travel to Mogok. E.J. Gübelin (1963, 1965, 1966) was one of the last foreign gemologists to visit the area, in the early 1960s.

During the mid-1980s, the author had a chance to discuss the, then current, mining situation with a longtime resident of Mogok. Photographs were also obtained, revealing that little had changed in Mogok since the early 1960s. Private mining had long been banned throughout Burma, but in a town of several thousand people whose sole means of income is mining gems, the government was forced to turn a blind eye. Just as in former times, a gem market was held once a week in Mogok at the parade grounds and traders came from far and near to attend. Cheaper goods were displayed openly, while more expensive stones were sold behind closed doors in small sheds which lined the edges of the grounds.

17. To circumvent this ban, Burmese gems were typically traded in cheap, base-metal settings, both in Burma and at the Thai border (based on the author's OFE; post-1970s; number of stones observed: plenty).

18. Myanmar Gems Corp. was founded by the Ministry of Mines on April 1, 1976. It was renamed Myanma Gems Enterprise in 1989 (Kane & Kammerling, 1992).

Borderlands

BURMA is home to one of the planet's richest sources of gem mineral wealth. Since 1962, it has also achieved notoriety of a different sort—home to one of the planet's most repressive regimes.

The country today known as Myanmar (Burma) was, before the British colonial period, a patchwork of tributary states populated by diverse ethnic groups, including Shan, Kachin, Karen, Karenni, Pa-O, Mon, Wa and others, loosely ruled by the Burmese monarch. Under the Burmese monarchs, such groups paid tribute, but the capital had little direct influence. British rule succeeded in uniting the country, but when it became clear that colonialism was at an end, long-simmering dreams of ethnic independence quickly boiled over. In order to prevent fragmentation of the country, a constitution was drawn up allowing any of the member states to secede from the Union of Burma if they felt it necessary. It was only by adding this clause that the non-Burmese ethnic states agreed to join the Union.

Independence came in 1948, but problems arose almost immediately, with the ethnic states feeling neglected in terms of development money and support. The Karens were the first to resort to armed struggle, shortly after independence. In 1958, the Shans followed, and, in 1961, the Kachins. This was the beginning of the still-ongoing civil war (Lintner, 1990).

Many rebel groups use smuggling to raise revenue. Whether by foot, road, river, rail, elephant or mule, manufactured goods from Thailand and elsewhere travel into Burma, while gems, narcotics, gold, silver and other raw materials move outward in a never-ending stream.

Smuggling routes from Burma's gem mines to the outside world are varied and constantly changing. From Mogok, gems may pass by road east through Kengtung, to reach Mae Sai in northern Thailand. This route has, of late, become particularly popular for the new ruby from Mong Hsu. Another popular route, which has been eclipsed to some degree, takes one by rail or road to Moulmein, south of Rangoon. From here, it is but a short 1–2 day walk to Mae Sot in Thailand's Tak province. Still another route leads westward into India or Bangladesh.

With the opening up of China's economy, much jade now proceeds directly from the mines in Kachin State, to Kunming, capital of China's Yunnan province. And reports have it that rubies and sapphires are also finding their way along this route (Robert Frey, stolid comm., May 3, 1994).

Current government policy is to make peace with the ethnic guerilla groups. As of May, 1994, a number of them had laid down their arms (Lintner, 1994a–b).

Figure 12.35
Top left: The Moei river separating Thailand from Burma at Wang Kha, near Mae Sot in Thailand. On the opposite bank, the bamboo blind hid a bustling market with close to 1000 people from all over Asia. Wang Kha was one of several smuggling camps operated by Karen rebels along the Thai border.
Top right: Porters leave Wang Kha, bound for Moulmein with Thai manufactured goods. This camp was once a major transit point for Burmese gems smuggled into Thailand, but several years after this photo was taken the Burmese military attacked the site and burned it to the ground. All that remain today are a few charred timbers amidst the ever-encroaching jungle.
Below: Elephants arrive at Wang Kha. After this photo was taken, the two *mahouts* climbed down off their rides and undid their *longyis* (sarongs), revealing special cotton belts with slots containing silver bars. (Photos by the author, 1979–81)

Beginning in 1991, foreigners were again allowed to visit Mogok (Ward, 1991; Kane & Kammerling, 1992). What they found was little changed from the time of the Burma Ruby Mines Ltd. Today, just as in the time of the company, mechanized mines coexist with traditional workings, and smuggling continues to be a big problem.

Mining areas

It is somewhat fruitless to describe precise mining areas because the situation is constantly in flux. As with most mining areas, mines continually close and new ones open, as deposits are exhausted and new ones discovered. Illegal mining (and cutting) generally takes place in more inaccessible regions and is sometimes supported by armed rebel groups. As of 1992, the Burmese government was operating eight mechanized mines in the Mogok area, seven for ruby/sapphire and one for peridot. Both open cast and tunneling are being used. MGE operates two tunneling operations, one at Lin Yaung Chi for ruby and another at Thurein Taung for sapphire. *Byon* from the various mines is either separated on site, or transported to the MGE Central Washing Plant (Kane & Kammerling, 1992).

In addition to government mines, since 1990, the government has allowed private/government joint ventures, which as of 1992 numbered in the hundreds. A number of joint-venture primary-source mines operate near Kyauk Saung, as well one at Dattaw (Dat Taw).[19] The later is famous as the source of the SLORC ruby (Kane & Kammerling, 1992).

The mine at Myintada, near the town of Mogok, is famous for fine quality star rubies and sapphires, with facetable ruby and fancy spinels also being found in quantity. Near the town of Kathé (famous for sapphires) is the government mine at Pingu Taung ('Hill of Spiders'), where fine sapphires are found. To the west of Pingu Taung is another government mine at Kyaukpyatthat-ashe. In addition to sapphire and ruby, a number of other gems, and even uranium, are also mined.

These are but a few of the localities where mining is proceeding today. Rubies are found in virtually all of these localities, along with spinels and zircons.

Burmese sapphires

Although rubies are found with much greater frequency at Mogok (rubies form about 80–90% of the total output), sapphires may reach larger sizes. Cut gems of over 100 carats are not unknown. Large fine star sapphires are also found at Mogok, in addition to star rubies. Near Kabaing, at Kin, is located a mine famous for star sapphires.

The sapphires of Burma occur in intimate association with rubies in virtually all alluvial deposits throughout the Mogok area, but are found in quantity at only a few localities, particularly 8 miles (13 km) west of Mogok, near Kathé (Kathe) (Halford-Watkins, 1935b). At Kyaungdwin, near Kathé, in 1926 a small pocket was discovered that yielded "many thousand pounds' [sterling] worth of magnificent sapphires within a few weeks." (Halford-Watkins, 1935b)

According to Halford-Watkins (1935b), the majority of fine sapphires were derived from the area between Ingaung and Gwebin. One magnificent Gwebin gem mined in 1929 was scratched up just below the grass by miners preparing a site for digging. It was a water-worn, doubly-truncated pyramid weighing in at an incredible 959 ct, and was named the *Gem of the Jungle.* Purchased and cut by Albert Ramsay, it produced nine fine stones, ranging in size, from 66 to 4 carats (see page 239).

Sapphires have also been found near Bernardmyo:[20]

> Bernardmyo itself at one time produced large quantities of sapphires, many of which were of magnificent colour and quality, though a number were of a peculiar indigo shade, which appeared either very dark or an objectionable greenish tint by

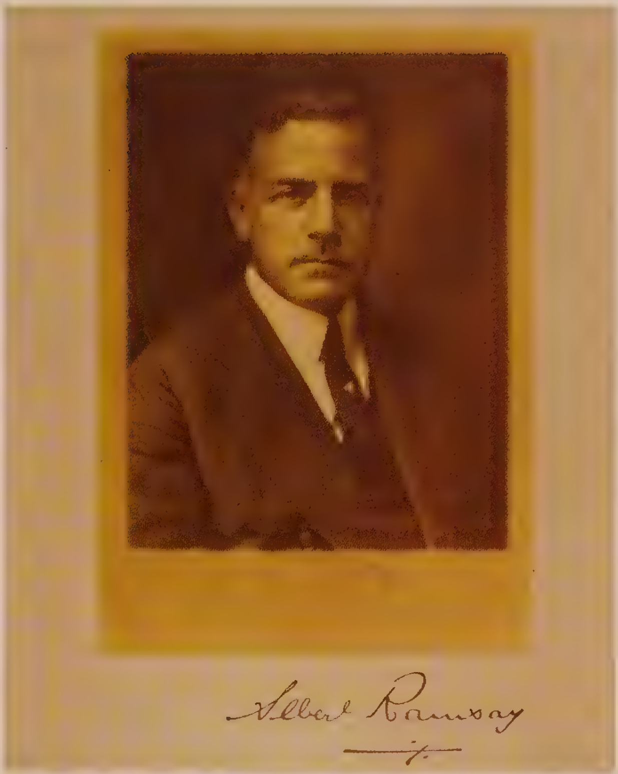


Figure 12.36 Photo of Albert Ramsay, who purchased and cut the *Gem of the Jungle.* (From Ramsay, 1925)

19. This is probably the Dató of de Terra (1943). The name is said to mean "mercury." De Terra explored several rich cave deposits at Dató.

20. The plateau of Bernardmyo was chosen by the first British expedition to Mogok as a suitable place for a sanitarium for British troops. It was thought the climate better suited Europeans and hoped that the place would eventually develop into the Simla of Burma. Bernardmyo was christened after the first British Chief Commissioner of Upper Burma, Sir Charles Bernard (G.S. Streeter, 1887b, 1889). Today it is also home to the local airport.

Table 12.5: Gem species of the Mogok Stone Tract (other than corundum)

Gem type	Gem type
• Amblygonite/Montebrasite—colorless, yellow • Andalusite—orange • Apatite—green, yellow and light blue, including cat's eyes • Beryl—aquamarine • Chrysoberyl—alexandrite, colorless, yellow • Cordierite (Iolite)—good violetish blue colors • Danburite—colorless, fine yellow and, rarely, pink and green • Diopside—green, including cat's eyes • Enstatite—green to yellow (including brown) • Epidote • Feldspar (*Myaw myo kyauk*) Albite: colorless, white, yellow and cat's eyes Moonstone (*Myaw*)—near colorless, with distinctive rainbow or blue schiller, found east of Mogok • Fluorite—violet/purple, green, yellow • Garnet (*U Daung*)—pyrope, almandine, spessartine and hessonite (grossular) • Kornerupine—green, yellow-green, blue and stars • Kyanite—blue • Lazurite (Lapis Lazuli) (*Pa la dote Hta*)—blue	• Painite—dark red-brown; very rare (only three crystals found to date, two from Ongaing) • Pargasite—gray; very rare • Peridot (*Pyaunggaung sein*)—green; world's finest and largest, from Bernardmyo • Phenakite—colorless, has been found • Quartz (*Sa lin*)—colorless, yellow (*Sa lin wa*), brown (*Sa lin nyo*), violet (*Sa lin swe*) and rose (formerly *Thu Yaung*; today termed *Sa-Lin-Nhin-Zee*) • Scapolite (*Myaw-ni*)—colorless, pink, yellow and violet cat's eyes and faceted gems • Sillimanite (Fibrolite)—fine blue gems, including cat's eyes • Sinhalite—yellow-brown; rare • Sodalite—blue • Sphene—orange-brown • Spinel (*Am nyunt pan*; from *am nyunt*—'poor'—in reference to spinel's lower hardness compared to corundum)—the world's finest red, pink and orange spinels, plus fancy colors and stars • Spodumene—colorless • Taaffeite—colorless, pale violet; rare • Topaz (*Hatat ta ya*)—colorless and other colors • Tourmaline (*Pa ye u*)—yellow, red, brown, orange, green and colorless • Zircon (*Gaw meik*)—yellow, green, orange and red

artificial light. During an extensive native mining rush to Bernardmyo in 1913 a number of these stones were placed on the London market.

Many of the stones found in this area were coated with a thin skin of almost opaque indigo colour which, on being ground off, revealed a centre sometimes of a fine gem quality, but in many cases of greenish shade. The method of occurrence was different from that anywhere else as the majority of stones were taken from a hard black iron-cemented conglomerate, which was found layers a few inches thick, often only a few feet below the surface. This area now appears to be exhausted, and little mining is carried on there to-day except for peridots, which are abundant.

Another isolated local deposit which has produced some fine sapphires occurs at Chaungyi, four miles north of Mogok, and about a thousand feet higher.

J.F. Halford-Watkins, 1935b

Other than blue, sapphires also occur in violet, purple, colorless and yellow colors at Mogok. The violet and purple stones may be fine; yellows tend to be on the light side and are not common. Green sapphires are known, but rare.

Other gems from the Mogok area

Other than corundum, the Mogok area produces fine gems of many species. In this regard, Mogok is, next to Sri Lanka, probably the most prolific source of gems in the world. Chief among these is the spinel, which historically was often confused with ruby. Although occurring in many colors, Mogok produces the world's finest reds (including pink) and oranges, bar none. Not only are the cut stones magnificent, but the area also furnishes the world's finest crystal specimens. Locally termed *anyan-nat-thwe* ('spirit polished'), the perfection of these crystals is such that they are often set into jewelry as is. At Kabaing, pink spinels are mined, while just south from Kabaing, at Sakangyi, hot pink rubies are obtained. Near the town of Kyatpyin are obtained the world's finest red spinels, while many kilometers north, at Pandaw, the best pink spinels are found.

Probably the world's finest peridot is mined at Pyaung Gaung, near Bernardmyo, with cut gems sometimes larger than one hundred carats, while the world's rarest gem mineral, painite (named after its finder, longtime Mogok resident, A.C.D. Pain), has been found near Ongaing.

Figure 12.37 *Twin-lon* mines and native miners at Mogok, Burma. (From Iyer, 1953)

The following are among the species mined in the Mogok Stone Tract, based on the author's own research, on Kammerling & Scarratt *et al.* (1994), and U Hla Win (pers. comm., Feb. 1994). In parentheses are the Burmese names for the gems.

Mining methods

The rubies of Mogok occur in a crystalline limestone (marble) matrix believed to result from a combination of both contact and regional metamorphism. In contrast, the sapphires are derived from a number of different igneous rocks, including biotite gneisses, urtite veins intruded into marble (Kane & Kammerling, 1992), or pegmatites (Iyer, 1953). Weathering has transported both rubies and sapphires down from the hills to the valley floors where they have settled in the bottom of the streams and rivers to form part of the alluvium. It is from these ancient river gravels that the majority of the stones have been recovered.

Figure 12.38 Washing gem gravels in a stream in Burma's Mogok Stone Tract. (Photo: Robert Kammerling/GIA)

Four traditional types of mines exist in Mogok:

- The *Twin-lon,* or pit method, for mining the valley alluvials.
- The *Hmyawdwin,* or open trench method, for excavating hillside deposits.
- The *Ludwin* system for the extraction of gem-bearing materials that fill limestone caves.
- Quarrying (tunneling) directly into the host rock to extract rubies and sapphires.

Since the time of the Burma Ruby Mines Ltd., these have been supplemented by open-cast mechanized mines.

Twin-lon. *Twin-lon* or "twin" mining involves the sinking of a small round shaft or hole down to the gem-bearing gravel, which is locally termed *byon.* Miners believe that an area is rich in rubies where big chunks of quartz are found in the byon (Iyer, 1953). Each mine is generally worked by two to three men, similar to traditional gem mining in Thailand and Sri Lanka. Two of the men take turns digging the shaft while the third stands above-ground lowering a small basket to haul up the earth. This basket is attached to the end of a long bamboo pole with a counterweight, or a hand-cranked winch, to assist in lifting the earth. Depths of these twins vary with the depth of the gravel and range from 3–24 m (10–80 ft). Light is provided by ingenious manipulation of a looking glass or reflector at the shaft's mouth so that a beam is thrown down to the bottom. Candles may also be used.

Figure 12.39 A Burmese miner at Mogok dewatering an excavation using an ingenious bamboo pump. (From O'Connor, 1905)

Once a layer of byon is reached, horizontal tunnels are driven for distances of up to 9 m (30 ft) to remove as much paydirt as possible. Shallow shafts need no shoring up, but the deeper ones are firmed with posts. Even with these precautions cave-ins do occur on occasion and may be fatal. Flooding from groundwater is a constant problem and the first job each day is to remove the previous night's accumulation of water. Ingenious pumps made from bamboo have been devised for this purpose. Today these are supplemented by diesel-powered pumps. Generally, twin-lon operations can only be carried on in the dry season (Nov.–May).

Larger excavations, shored up by timber, twigs and leaves, are termed *lebin* and *kobin,* and the biggest, *inbye.* These are used in areas where the earth is not compact enough for twinlons. The *inbye* is rarely seen due to the expense of the timber needed (George, 1915, p. 77).

Hmyawdwin. *Hmyawdwin* mining consists of open cuttings on the sides of hills. J. Coggin Brown was earlier quoted as feeling that great potential still remained for this type of mining. A stream of water, sometimes brought from great distances via bamboo or plastic channels, is directed to the upper end of the working under pressure. This carries the mud into the tail race of the excavation, with the lighter material being swept away. The heavier concentrate is then carried to a suitable site for washing. As this method requires plenty of water, it is used mainly in the rainy season (June–October).

Ludwin. *Ludwin* ('loo') is the least common of the three traditional methods of mining in Mogok. These are excavations into the sides of the hills, following the gem-bearing material through the crevices and caves in the limestone. European methods were applied to these deposits by the

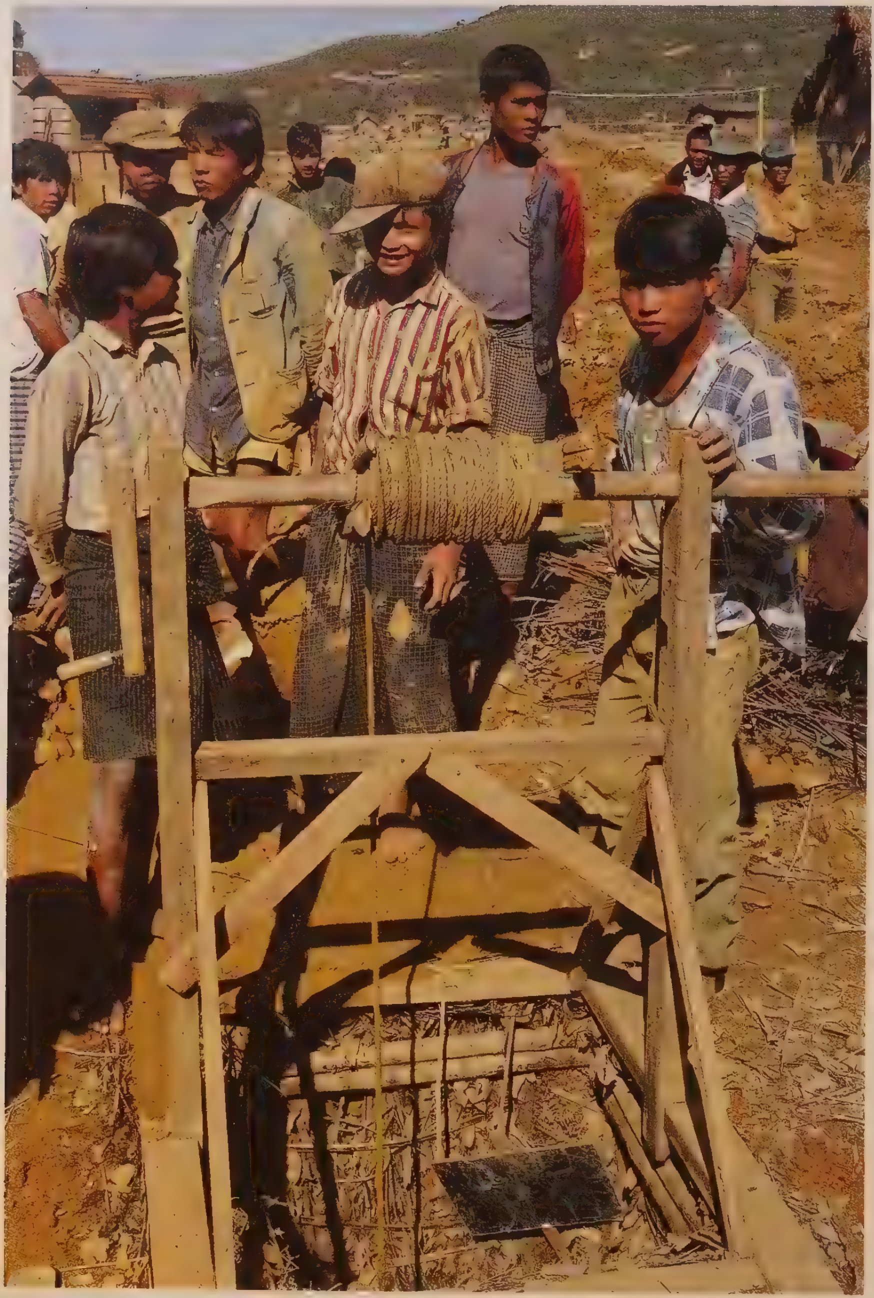


Figure 12.40 Raising gravel from a *lebin* (square pit) at Mogok's Inn Gaung ('Big Hole Mine'). Note the foil reflector at the pit entrance, which is designed to direct light to the pit's bottom. (Photo: Thomas Frieden)

Company at one time, but failed. It is within these caverns and crevices that some of the richest finds have been made. One cavern proved so vast in size and the depth of the byon so great, that hmyawdwins and twins were actually set up inside the cavern itself. Unfortunately the roof caved in, putting an early halt to the proceedings (Halford-Watkins, 1932a). According to George (1915, p. 76), the danger attending this method was overstated. However, just before Kane and Kammerling's 1992 visit, they were told that several miners had died in a cave-in at a ludwin at Than Ta Yar.

Such caves form as a result of impurities in the limestone. Groundwater dissolves the limestone, forming cavities. More resistant minerals, such as rubies and other gems, concentrate in the loamy soil on the cave bottoms. Miners will crawl through tiny crevices in the limestone to reach concentrations of byon. This will then be hauled to the surface for washing.

Quarrying

C. Barrington Brown (Brown and Judd, 1896) described a fourth method of mining—quarrying or tunneling into the host rock itself, which is a slight variation on the ludwin. One particularly rich ludwin near Bobedaung (Bawpadan) was termed the "Royal Loo."[21] At the time of Brown's visit in 1887, miners were using a gunpowder of local manufacture.

Figure 12.41 When miners do find something, their market is close at hand. Here a small trader awaits the results of a *byon* washing session at Inn Gaung ('Big Hole Mine'). (Photo: Thomas Frieden)

However, this often damaged the gems. Today, more sophisticated types of blasting are used to extract both ruby and sapphire from their host rock (Kane & Kammerling, 1992).

Mechanized mining

During the time of the Burma Ruby Mines Ltd., mechanized mines were operated at a number of different locations. The largest, at Mogok's Shwebontha mine, opened in April, 1894, and operated for years thereafter. These were generally open cuts, with the excavations being made by hand. First, a pit 10 sq ft (0.93 sq m) was sunk to a depth of 25 ft (7.62 m). This served as a water sump, and a centrifugal pump was lowered into position to remove the water. Near this hole coolies would attack the byon by digging a hole and working outward on all sides, breaking down the walls and loading the earth into trucks. As the hole widened, it became possible to sink lower and lower. Workers dug away at the toe of the wall, and as the bank caved in, transferred the earth to trucks, with water being diverted to the pump pit. The trucks were hitched to an endless rope, which would haul the earth up a ramp to the washing plant, where it is tipped into screens and falls into the washing pans (Talbot, 1920).

[21] I refuse to comment on the British meaning of that term.

Figure 12.42 Native *kanase* women washing ruby gravel at Mogok, Burma, ca. 1905. (From Anonymous, 1905a, *Booklovers Magazine*)

At Shwebontha, this simple process developed into a huge gaping hole in the surface of the valley nearly a mile (1.6 km) in length. While not deep, it was mining on a grand scale. From January, 1895 to February, 1904, 4,820,000 truckloads of byon were taken out of the ground at Shwebontha, and its extension at Schwelimpan. These resulted in gems worth over £485,000 (Talbot, 1920).

Washing the *byon*

Once sufficient byon has been obtained, it is transported to the washing area. A shallow circular enclosure is formed with big rocks, the floor of which slopes slightly at one end. Into this the byon is placed and a stream of water directed onto it while the whole mass is stirred. Water and lighter debris flow out a small opening at the lower end, leaving behind the gems and heavier material. Eventually the opening becomes clogged with heavy gravel. This gravel is then removed for further washing on circular bamboo trays, similar to the method used in panning for gold (Halford-Watkins, 1932b).

Output from mechanized mines goes to a washing plant, to be separated by machine. In the days of the Burma Ruby Mines Ltd., two separate washing plants were operated at Shwebontha, three at the Redhill mine, and one at Padansho, near Kyauklongyi (Brown, 1933). Today, the government operates a washing plant, where byon from government mines which do not have a plant on site is washed.

Figure 12.43 British sorters at the Company mines, at Mogok, Burma. (From O'Connor, 1905)

The *kanase* (*kanes*) custom

Almost inevitably, some of the gems escape and are carried away to the tailings. According to local custom, these tailings may be searched through by anyone, with any stones found becoming the property of the finder. Under the Company, however, this was later restricted to women only; any man who raised a stone from the ground, unless a worker or license holder, was subject to imprisonment. Thus, it is the women who search in this way. They are termed *kanase* women. According to Halford-Watkins (1932b), this custom resulted in the wholesale theft of large numbers of stones from Company mines, as well as providing a convenient method for the disposal of stolen goods. The way it worked was as follows: a dishonest workman may catch sight of a stone. He would then pass it secretly to a nearby kanase woman or tell her where to search for it. Moments later, there is a shout of joy from the woman as she has just "uncovered" a stone which, by custom, is hers to keep. The Company went to great lengths to prevent the theft of stones, enclosing the sorting areas, requiring workers to wear steel masks so that stones could not be swallowed, etc. However, all this was to no avail because of the kanase custom.

Sorting and trading

Final sorting of the gravel is normally done by the mine owner, his relatives or other trusted staff, with another person present to keep him honest. All others are kept away. As stones are found they are placed into a bamboo container, or today, a plastic bag. At the end of the day, the contents are put into a packet, which is sealed on the spot if the owner has partners who are not present. This seal will only be broken in the presence of all the partners, again to keep everyone honest.

In the morning, stones found during the previous day's work are placed onto a polished brass plate for grading in direct sunlight. First the inferior material, termed *sonzi,* is removed and separated into three types: ruby, sapphire and spinel. This is later crushed for use as abrasive (Halford-Watkins, 1932b).

Those left on the plate are now graded roughly, by hand or sieve, according to size. The owner himself removes the best stones, for personal grading at a later time, with the remainder graded by sorters. First, lower qualities are arranged in small piles, then better stones. In the end, all are passed to

To catch a thief

IN a gem mining operation, it is absolutely vital that theft be kept to a minimum (it can never be eliminated entirely). If a significant portion of the production is stolen, these stones will appear in the marketplace, always undercutting the prices asked for legitimate production. The author was once told of one unique method of dealing with this problem. Two brothers purchased a gem mine in Africa. While one brother handled the daily affairs at the mine, the other set himself up incognito at the nearby town as a gem buyer, purchasing all of the stones stolen by his workers. Although they were buying stones that were rightfully theirs, the brothers were happy with the arrangement for it allowed them to control the entire production of the mine, and thus, to better influence the price.

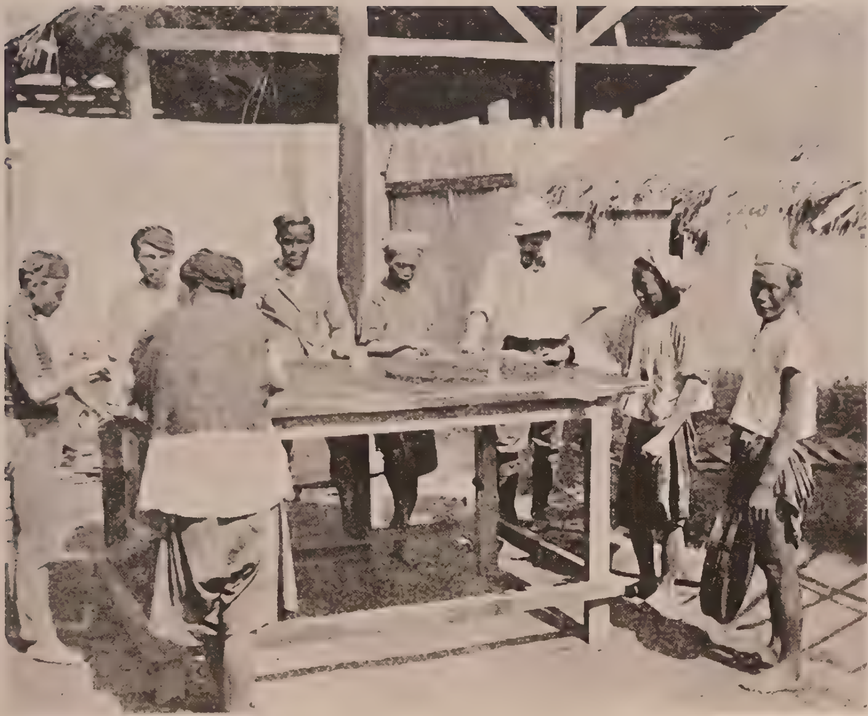


Figure 12.44 Native workers under British supervision at the Company mines at Mogok, Burma. Despite close watch, theft was a constant problem. (From O'Connor, 1905)

the owner for final classification, assisted by the ubiquitous brokers, who play an important role in the valuation and sale. Valuations and bids are all done with the secret hand language so quaintly described earlier by Cæsar Frederick.

The role of brokers is important, both at Mogok and further north at the Hpakan jade mines. Each dealer employs them to act as his eyes and ears. Their job is not only to assist in valuations and sales, but also to obtain intelligence about what valuable stones have been recently mined, who the owners are, and, just as importantly, who the stones are being offered to and the prices bid. Owners of valuable stones do their best to keep details secret, for if a piece is bid upon, when the spies of other dealers learn of the bid, no one will offer more (Halford-Watkins, 1932b; W.K. Ho, pers. comm., ca. 1982). In other words, if one dealer believes it is worth only 50,000 Kyat, then why offer more? This situation results in purchases taking place in a cloak-and-dagger atmosphere as both buyer and seller seek to conceal their activities. Stolen stones in particular may be offered at remote jungle rendezvous', sometimes in the dead of the night with only a hand torch as illumination. Legitimate goods may also be offered in this way, being represented as stolen in the hope that this would increase the buyer's feeling that he is getting a *steal* of a deal (Halford-Watkins, 1932b).

Perhaps the best summary of the gem business in Burma was that of British officer, Major F.L. Roberts (Chhibber, 1934). Although speaking in reference to the jade business, he could just as easily have been discussing the ruby trade:

> From the time jade is won in the Jade Mines area until it leaves Mogaung in the rough for cutting there is much that is underhand, tortuous and complicated, and much unprofitable antagonism. In my opinion the whole business requires cleansing, straightening and the light of day thrown on it.
>
> Major F.L. Roberts,
> former Deputy Commissioner of Myitkyina

Judging from the tone of his statement, it sounds like Major Roberts would have been just the man for the job, too.

Pigeon's blood: Chasing the elusive Burmese bird

The Burmese term for ruby is *padamya* ('plenty of mercury'). Other terms for ruby are derived from the word for the seeds of the pomegranate fruit.[22] Traditionally, the Burmese have referred to the finest hue of ruby as "pigeon's blood" (*kothway*), a term which may be of Chinese (Anonymous, 1943) or Arab origin. Witness the following from al-Akfani, who described thus the top variety of ruby:

> *Rummānī* has the colour of the fresh seed of pomegranate or of a drop of blood (drawn from an artery) on a highly polished silver plate.
>
> al-Akfani, ca. 1348 AD (from Sarma, 1984)

Some have compared this color to the center of a live pigeon's eye (Brown & Day, 1955). Halford-Watkins described it as a rich crimson without trace of blue overtones (Anonymous, 1943). Others have defined this still further as the color of the *first two drops* of blood from the nose of a

[22] The Thai word for ruby, *taubptim* (ทับทิม) also means pomegranate.

Local classification of gems

THROUGH the many generations of trading in Mogok, a local classification system has evolved as follows (based on the author's interviews with Burmese and Thai traders; George, 1915; Halford-Watkins, 1932):

Thai names:

- *Gim baw siang* (กินบ่เสี้ยง): A Thai word describing a Burmese cabochon ruby with calcite matrix (literally 'more than enough to eat', in reference to the belief that this stone brings prosperity)

Burmese names

Individual stones are termed *lon-bauk*. Ruby parcels are graded by size and color.

First-water stones (deep rich crimson)

- *Anyun*: Two ct and over
- *Lethi*: Average 1.75 ct
- *The-bauk* (*haibauk*): Average 0.75 ct
- *Saga-the*: Average 0.50 ct
- *Ame-the*: Average five stones per carat (0.20 ct each)

Second-water stones (bright crimson)

- *Ani-gyi*: 2–6 ct weight

Third-water stones (bright light crimson)

- *Ani-te*: 2–6 ct weight (also known as *Bombaing*, because they were fancied in Bombay, India)

Fourth-water stones (*Ahte-kya*)

- *Ahte-kya* (literally 'fallen from the top'): Mixed stones of the above grades but slightly defective in shape or water
- *Kyauk-me*: Very dark stones which were sold mainly in Madras, India

Parcels of lesser-quality stones

- *Gaungsa* or *Yawya*: Pale inferior stones of mixed sizes (up to 6 ct)
- *Asa-yo*: Dark inferior stones of mixed sizes (up to 6 ct)
- *Asa-yo kya*: Inferior to *Asa-yo*
- *Akyan-the*: Similar to *Asa-yo* but smaller
- *Apya*: Flat stones of fine quality
- *Apya-kya*, or *Apya-sa*: Flat stones of second quality
- *Apyazone*: Third-quality flats
- *Awa*: Large defective stones
- *Gair*: Large, impure, almost opaque stones
- *Ani-the*: Small stones of second water and good quality
- *Akyaw-the*: Small, pale, good
- *Apyu-the*: Small, pale, inferior and rough
- *Atwe*: Rough and impure
- *Zon-si*: Spinels and rejections from other classifications
- *Mat-sa*: Opaque sapphire
- *Thai*: Tiny stones (literally 'sand')
- *Pingoo-cho*: First-quality star rubies (literally 'spider's thread')
- *Pingoo* or *Pingoo-sa*: Silky rubies (with or without star)
- *Gaw-done* or *Gaw-cho*: Star sapphires
- *Am nyunt*: Ordinary mixed waterworn spinels
- *Am nyunt-nat-thwe*: Rose spinel octahedra of perfect luster and crystallization (literally 'spinels polished by the spirits')
- *Am nyunt-seinche*: Tiny spinels of the same type as *anyan-nat-thwe* above
- *Nila*: Large sapphires
- *Nila-sa*: Mixed inferior sapphires

---

freshly slain Burmese pigeon. But the *piece de resistance* of pigeon's-blood research has to be that of James Nelson (1985):

> In an attempt to seek a more quantitative description for this mysterious red colour known only to hunters and the few fortunate owners of the best Burmese rubies, the author sought the help of the London Zoo. Their Research Department were quick to oblige and sent a specimen of fresh, lysed, aerated, pigeon's blood. A sample was promptly spectrophotometered.... The Burmese bird can at last be safely removed from the realms of gemmology and consigned back to ornithology.
>
> James B. Nelson, 1985, *Journal of Gemmology*

After that, the only question remaining is whether or not "spectrophotometered" is a genuine English verb.

Color preferences do change with time. The preferred color today is not necessarily that of a hundred, or even fifty, years ago. In the author's experience, the color most coveted today is that akin to a red traffic signal or stoplight. It is a glowing red color, due to the strong red fluorescence of Burmese rubies, and is unequalled in the world of gemstones. Thai rubies may possess a purer red body color, but the lack of red fluorescence leaves them dull by comparison. It must be stressed that the true pigeon's-blood red is extremely rare, more a color of the mind than the material world. One Burmese trader expressed it best when he said "...asking to see the pigeon's blood is like asking to see the face of God." (Nordland, 1982)

The second-best color in Burma is termed "rabbit's blood," or *yeong-twe*. It is a slightly darker, more bluish red. Third- best is a deep hot pink termed *bho-kyaik*. This was the favorite color of the famous Mogok gem dealer, A.C.D. Pain. U Thu Daw, longtime Mogok dealer and a contemporary of Pain's, has stated that bho-kyaik is not so much a color term, as an overall quality description. To qualify, a ruby must fulfill six requirements. First, it must be at least one carat. Second, the color must be of the third quality (exceeded only by *kothway* and *yeong-twe*). The table facet must be perpendicular to the *c* axis, it must be well cut, of good luster and eye clean. The literal meaning of bho-kyaik is "preference of the British" (U Hla Win, pers. comm., 2 May, 22 June, 1994).

Fourth-best is a light pink color termed *leh-kow-seet* (literally 'bracelet-quality' ruby). At the bottom of the ruby scale is the dark red color termed *ka-la-ngoh*. This has an interesting derivation for it means literally either "crying-Indian quality" or "even an Indian would cry," so termed because it was even darker than an Indian's skin. Most dark rubies were sold in Bombay or Madras, India. Ka-la-ngoh stones were said to be so dark that even Indians would cry out in despair when confronted with this quality.

Burmese rubies compared

Until the discoveries in Vietnam in the late 1980s, Burmese rubies were without peer. Other sources, such as Kenya and Afghanistan, produced the occasional stone which could stand with Burma's best, but such stones were extremely rare. Discovery of ruby in Vietnam changed all that. For the first time in hundreds of years, a viable alternative to Burma presented itself. Only time will tell if the Vietnamese mines can

Figure 12.45 U Hmat, the "Ruby King," at the town of Mogok, in Burma. (From O'Connor, 1905) According to O'Connor…

> U Hmat was great here in the days before any Englishman had come within sight of Mogôk. He is not a foreigner… but a native of the soil. He lives some distance from the market-place in a rambling wooden house on piles.… At one end he has built himself a strong-room of brick, in which lie hidden, according to popular tradition, rubies of extraordinary value. U Hmat is seldom seen abroad. He goes, it is said, in terror of his life; and his courtyard is thronged with retainers, who make for him a kind of personal bodyguard. But in bygone days he travelled every year to Mandalay with a present of rubies, and was received in audience by the king. He is a builder of many monasteries and pagodas; but is said to be less lavish in this respect than most of his compatriots in Burma. He is believed accordingly by his European neighbours to have 'his head screwed on the right way.' His character for economy is the topic of very favourable discussion at the dinnertables of the settlement, and it is a commonplace of opinion that he is the only Burman at the mines who is not a fool. Let it be added that he is the father of a pretty daughter, whose jewels are the despair of every other woman in Mogôk, and that he keeps her in strict seclusion, lest some adventurous youth should steal away her heart, or her person, or both. He has been good enough, however, to show me some of her most beautiful jewels.
>
> V.C. Scott O'Connor, 1905, *The Silken East*

continue to produce, but, historically speaking, Burmese rubies are in a class by themselves.

The color of a fine Burmese ruby is due to a combination of two factors. First, the best stones have high color intensity. This results from a mixture of the slightly bluish red body color and the purer red fluorescent emission. It is this red fluorescence which is the key, for it tends to cover up the dark areas of the stone caused by extinction from cutting. Thai rubies possess a purer red body color,[23] but lack the strong fluorescence. In Thai rubies, where light is properly reflected off pavilion facets (internal brilliance), the color is good. However, where facets are cut too steep, light exits through the side instead of returning to the eye, creating darker areas (extinction). All stones possess this extinction to a certain degree, but in fine Burmese rubies, the strong crimson fluorescence masks it. The best Burmese stones actually glow red and appear as though Mother Nature brushed a broad swath of fluorescent red paint across the face of the stone. This is the *carbuncle* of the ancients, a term derived from the glowing embers of a fire.

A second factor is the presence of silk. Tiny exsolved inclusions tend to scatter light onto facets that would otherwise be extinct. This gives the color a softness, as well as spreading it across a greater part of the gem's face. Thai/Cambodian rubies contain no rutile silk, and thus possess more extinction.

In actuality, rubies from most sources possess a strong red fluorescence and silk similar to those from Burma, with the Thai rubies being the exception. However, those from Sri Lanka are generally too pale in color, while, with other sources, such as Kenya, Pakistan and Afghanistan, material clean enough for faceting is rare. Thus the combination of fine color (body color plus fluorescence) and facetable material (i.e., internally clean) has put the Burmese ruby squarely atop the crimson mountain. Some old-timers consider Burma to be not just the best source, but the *only* source of stones fit to be called ruby. When one considers that today probably 90% or more of newly-mined rubies owe a good measure of their clarity and color to heat treatment, this statement does not seem so outlandish (unfortunately, most Burmese rubies are today heat treated).

Burmese sapphires compared

Although it is rubies for which Burma is famous, some of the world's finest blue sapphires are also mined in the Mogok area. Today the world gem trade recognizes the quality of Burmese sapphires, but this was not always the case. Edwin Streeter (1892) described Burmese sapphires as being overly

23. Purer in the sense that the hue position is closer to the center of the red (relative to purple and orange).

Figure 12.46 Gem-set Buddhist icon at Burma's Zay Kyaung monastery. (Photo: Robert Kammerling/GIA)

dark. Unfortunately this error was later repeated by Max Bauer and others. G. Herbert Smith wrote…

> While the Burma ruby is famed throughout the world as the finest of its kind the Burma sapphire has been ignominiously, but unjustly, dismissed as of poor quality. In actual fact nowhere in the world are such superb sapphires produced as in Burma.
> G.F. Herbert Smith, 1972, *Gemstones*

While this statement must be qualified by adding that the finest Kashmir sapphires are in a class by themselves, those from Burma are also magnificent. J. Coggin Brown said this:

> It has been stated that Burmese sapphires as a whole are usually too dark for general approval, but this is quite incorrect; next to the Kashmir sapphires they are unsurpassed. Speaking generally, Ceylon sapphires are too light and Siamese sapphires too dark, and it is more than probable that many of the best 'Ceylon' stones first saw the light of day from the mountainsides of the Mogok Stone Tract.
> J. Coggin Brown & A.K. Dey, 1955, *India's Mineral Wealth*

Not all Burma sapphires are deep in color. The best display a rich, intense, slightly violetish blue, but some are quite light, similar to those from Sri Lanka. The key difference between Burma and Ceylon sapphires is *saturation*, with those from Burma possessing much more color in the stone. Color banding, so prominent in Ceylon stones, may be entirely absent in Burma sapphires.

Namsèka rubies: Salt of the earth?

ONE Burmese locality that has received scant mention is that of Namsèka. Located 24 km (15 miles) southwest of Mainglôn (which is just south of Mogok), in the narrow valley of the Nampai, it was described by Fritz Noetling in 1891.

At the time of his visit the deposit had apparently not been worked for some time. The exact occurrence is said to be less than 1 km northwest of the small village of Namsèka. According to Noetling, the first samples of ruby brought to the attention of the Government of Burma were of high quality and were provided by Lieutenant Daly, Superintendent of the Northern Shan States. However, Noetling spent three full days with twelve coolies working the deposit, and found not even a single fragment of ruby. Only some dark purple spinels turned up.

According to a story told to Noetling…

> When the Thibaw Sawbwa sent one of his officials to Namsèka to get samples of good stones from the mines, none could be procured. The man therefore went over to Mogôk, where he purchased the stones which were handed over to the Sawbwa as "Namsèka rubies."

Noetling told the local Sawbwa about his doubts regarding ruby occurring at Namsèka. The Sawbwa proceeded to produce a plate of stones which included both rubies and other gems, with the rubies matching those of Lieutenant Daly perfectly.

In the end, Noetling had to conclude that he just wasn't sure about rubies at Namsèka. It was possible that the mine was originally salted in an attempt to sell the mining rights, but it was equally possible that the rubies occurred in irregular concentrations which would be uncovered only by sustained work at the site. Since Noetling's report in 1891, nothing more has been heard of the rubies of Namsèka.

Other Burma corundum localities

Gem-quality rubies and sapphires are found in a number of other areas, all of which are in upper Burma. These include:

- Sagyin, near Mandalay, where poor-quality rubies have been mined from the marble quarries.
- Thabeitkyin, along the Irrawaddy river, west of Mogok, for ruby.
- Yet-Kan-Zin-Taung, 50 miles (80 km) from Mandalay along the Mogok road, for ruby.
- Namsèka, south of Mainglôn, for ruby.
- Naniazeik, Myitkyina district, Kachin State, for ruby.
- Mong Hsu, Southern Shan States, for ruby.
- Mong Hkak, Southern Shan States, for sapphire.
- Nawarat (Pyinlon), Shan State, for ruby.
- Namhsa, 15 km north of Nawarat (Shan State), for ruby.

Sagyin Hills

In the Sagyin Hills, just 26 km north of Mandalay and 3.2 km from the Irrawaddy river, rubies were once obtained from the detritus of clay-filled hollows and fissures in the crystalline limestones. Such hollows were said to yield sapphires, spinels and amethysts, in addition to rubies (Penzer, 1922). This locality is famed for fine marble, as well.

Figure 12.47 Mong Hsu rubies revitalized Burma's moribund gem industry when they first hit world gem markets in the early 1990s. The above two stones, weighing 2.59 ct total, are superb examples of just what all the fuss was about. (Photo: © 1994 Tino Hammid; stones: Amba Gem Corp., New York)

Apparently the mines had been worked for many years. King Mindon Min was said to have obtained Rs30,000 worth of rubies in one month from an old cave-working and pit in the adjoining alluvium, which were called the *Royal Loo* [24] (Holland, 1898).

About 1870, the mines were under the supervision of a German engineer named Bredemeyer, who stated that stones were best when the detritus was of a yellow color. In 1873, Captain G.A. Strover, described the Sagyin rubies in the *Indian Economist* as being lighter in color that those from Mogok (Penzer, 1922).

According to Penzer (1922) and Chhibber (1934), a Sir Henry Hayden inspected the tract in 1895. He found the rocks to be gneisses and schists, with bands of crystalline limestone in them. The latter were considerably altered, and contained numerous minerals, including spinel and ruby overlying the crystalline limestone. Moisture moved through the joints between the limestone and surrounding rocks, dissolving the limestone and creating fissures and hollows. These open spaces later trapped the more resistant and insoluble clayey materials, including rubies.

At the time that Penzer described the deposit (1922), little work was being done and it appears that little work has been done since.

24. The "Royal Loo" was also mentioned by Brown and Judd (1896), but described it as being at Bobedaung, near Mogok. It seems likely that the name was applied to more than one deposit.

Buying at the source

BEFORE the discovery that Burmese rubies could be heat treated, the presence and relative abundance of fluid fingerprints and feathers was useful in determining whether or not a particular ruby originated from Burma. The author recalls examining large numbers of suspected Burmese rubies brought for examination. A quick look in the microscope, however, revealed numerous fingerprints and feathers. Looks of anticipation turned to frowns when told that the only thing "Burmese" about the gems were the nationality of the sellers.

In the same vein, a story regarding an acquaintance comes to mind that speaks volumes about the efficiency of modern transportation. This gentleman journeyed all the way from Bangkok to Peshawar, Pakistan for the purpose of buying Afghan gemstones. He bought several lots of rubies from Afghan refugees who had just crossed the border, eager to raise cash for purchasing weapons to drive the Russian infidels out of their homeland. Back in Bangkok I examined his purchases and was forced to relay the information that his journey had been for naught. Most of the rubies were from Thailand.

Thabeitkyin (Thabeikkyin)

Burma's Thabeitkyin area has received little notice. The following is based on the 1938 report of U Khin Maung Gyi (Gyi, 1938).

Thabeitkyin township is located on the Irrawaddy river north of Mandalay. In former years, access to Mogok was via

Figure 12.48 Mong Hsu rubies
Left & top right: In their untreated state, Mong Hsu rubies typically display a bluish core.
Below right: Heat treatment removes the bluish core, leaving white clouds in its place. (Photos: Tony Laughter)

river steamer to Thabeitkyin. From there, the road heads east to Mogok, some 60 km away (today a road heads directly to Mogok from Mandalay).

Rubies at Thabeitkyin were reportedly mined as early as the 1870s, though no valuable stones were found until the reign of King Thebaw [1878–1885]. U Yauk, from Ye-nya-u village, is said to have found a ruby the size of a hen's egg.[25] Since all large finds were considered the property of the king, the stone was duly delivered to the palace. This was how the king came to learn of rubies at Thabeitkyin, and from that point on a ruby tax was levied on the villagers of the area.

Old mining sites at Thabeitkyin are west of Wabyudaung, at Twindawgyi, Kyaukpya, Ohnbaing and Ye-nya-u Pandwin. In the 1930s, ruby was found at Kyet-saung-taung, Zaneechaung and Nyaungbintha. Kyet-saung-taung lies roughly 5 km southwest of Wabyudaung.

In addition to rubies, blue and star sapphires have been recovered from Thabeitkyin. Nothing is known about the present mining situation.

Yet-Kan-Zin-Taung

Corundum is said to occur at Yet-Kan-Zin-Taung village, which lies on the east side of the Mandalay-Mogok road, some 50 miles (80 km) towards Mogok, near the village of Let-Pan-Hla (U Hla Win, pers. comm., 27 June, 1994). Good-quality ruby is said to occur along with red spinels. The locality is also notable for its production of red star spinels. Mining is said to be difficult due to the rocky nature of the soil.

Naniazeik (Nanyaseik)

In the early 1890s, ruby was found at Naniazeik, Myitkyina district, Kachin State. Naniazeik lies some 80 km west of Myitkyina and 19 km west of Kamaing. According to Penzer (1922), Warth examined the deposit, in 1895. "He [Warth] stated that rubies, sapphires, and spinels were obtained from the detritus afforded by the disintegration of crystalline limestones surrounded by intrusive masses of granite."

The most complete description of this occurrence is that of Chhibber (1934), with Tanatar (1907) and Bleeck (1908) also weighing in with reports. Chhibber (1934) examined the deposit in the early 1890s. He described the major localities as being in the neighborhood of Mawthit and Marrawmaw. Shan women would wash for gold, while the males would work for rubies and other gems. In addition to ruby, spinel is also found. Their color was said to vary from a near-opaque, dark green to a bright, translucent red, with the latter color being rare. Metamorphosed limestones were thought to be the source of origin for both the rubies and spinels.

[25] Rubies the size of "a hen's egg" have been frequently reported in the literature. The author is still waiting to see his first fine specimen of such a size.

Table 12.6: Properties of Mong Hsu (Burma) ruby[a]

Property	Description
Color range/phenomena	• Generally medium to deep red. Before heat treatment, crystals display cores of a blue to violet color. Such blue cores are eliminated during heat treatment. Star stones have not been reported.
Geologic formation	• Found in primary metamorphosed crystalline limestone (marble), as well as secondary deposits derived from the same
Crystal habit	• Well-formed crystals consisting of pyramids/bipyramids terminated by the basal pinacoid. Development of the hexagonal prism is generally slight.
RI & birefringence	RI readings may vary depending upon the area of the crystal tested, with higher RIs found in the crystal center. It has been hypothesized that this is due to higher Cr concentrations in crystal centers. • n_ε = 1.760–1.770; n_ω = 1.768–1.778 Bire. = 0.008 to 0.009
Specific Gravity	3.97 to 4.01
Spectra	• **Visible**: Strong Cr spectrum, identical to other natural and synthetic rubies • **Ultraviolet**: Differences were found between the UV spectra before and after heat treatment. Heat-treated specimens showed dramatically increased transmission from 340–280 nm. • **Infrared**: Sharp peaks were recorded at 3189, 3233, 3299, 3310, 3368, 3380, and 3393 wavenumbers. Such peaks have not been found in rubies from other sources.
Fluorescence	**UV**: Moderate to very strong red (LW stronger than SW)
Other features	Not reported
Inclusion types	**Description**
Solids	Many Mong Hsu rubies possess no solid inclusions. When they are found, they tend to occur near the surface, making them rare in cut gems. Those identified to date include the following: • Apatite (Smith & Surdez, 1994) • Chlorite: Mg-rich (Peretti & Schmetzer *et al.*, 1995) • Diaspore: in veins. These were not found in heat-treated specimens and are easily confused with glass infilling (Smith, 1995). • Dolomite: colorless, rounded to subhedral grains (Smith & Surdez, 1994) • Fluorite: euhedral crystals (Peretti & Schmetzer *et al.*, 1995) • Mica: white (Peretti & Schmetzer *et al.*, 1995) • Rutile: red-brown crystals (J. Koivula, pers. comm., 28 Feb., 1995)
Cavities (liquids/gases/solids)	• Secondary fluid inclusions (healed fractures) are common, in a variety of patterns
Growth zoning	• Straight angular growth zoning parallel to the crystal faces is present in all specimens. Irregular 'treacle'-like swirls in other directions. Zoning can be extremely sharp (use shadowing illumination). • Many crystals display zoned blue cores (such areas actually alternate blue and red) at their center. Such blue zoning may also be found in other parts of the crystal. Heat treatment eliminates such blue areas.
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$ is often present • Twinning has also been seen on the first-order hexagonal prism $\{10\bar{1}0\}$
Exsolved solids	• Clouds of tiny exsolved inclusions of unknown identity are common. As with all exsolved inclusions, these follow the growth structure of the crystal, and are concentrated relative to the original impurity content of the crystal at that stage of growth. • Extremely fine, short rutile needles have been rarely seen

a. Information is Table 12.6 is based on the published reports of Smith (1995), Smith & Surdez (1994) and Laughter (1993a–b).

The author is unaware of anything published on this deposit since Chhibber in 1934.

Mong Hsu

In 1991, U Tin Hlaing first reported on the occurrence of ruby at Mong Hsu. The following is based largely on his reports (Hlaing, 1991, 1993a, 1994).

Rubies at Mong Hsu were said to have been discovered by a local resident who had worked as a miner at Mogok. While bathing in the Nam Nga stream, which runs near the town of Mong Hsu, he stumbled across rubies among the pebbles on the banks. Thus began the most recent of Burma's ruby rushes. Fortune seekers flocked to the area and the population swelled from 8000, to over 30,000 at the peak of mining activity. This tapered off, however, as between April and June, 1993 the price for Mong Hsu ruby rough dropped by half (Hlaing, 1994).

Mong Hsu is one day's drive northeast of Taunggyi, (173 km by road; 83 km as the crow flies). It lies between the Nam Pang and Salween rivers. Typical of many areas in Burma's Shan States, the population of the Mong Hsu area consists of Shans in the valleys, with hill tribes (Palaungs at Mong Hsu) living at higher elevations. These Palaungs were involved in tea cultivation before the discovery of ruby (Hlaing, 1994).

Mining was initially restricted to valley alluvials, but later moved into the *in-situ* marble deposits in the surrounding

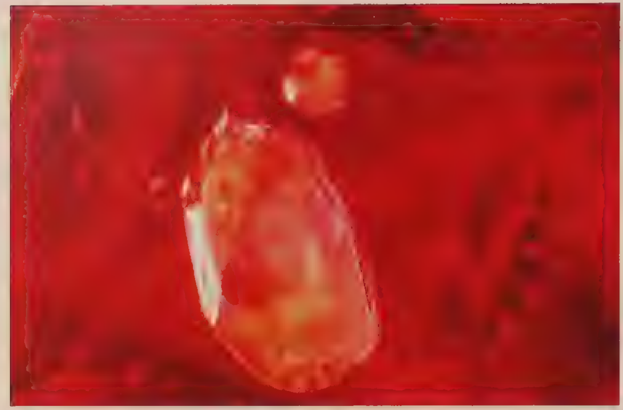


Figure 12.49 A large crystal of calcite in an unheated Mogok ruby, in polarized light. Calcite is suggested because of the intersecting twinning planes visible within the included crystal. Such calcite crystals containing repeated glide twinning are often seen in Burmese rubies, which were formed in a calcite (marble) matrix. (Photo by the author)

limestone hills. Minerals associated with the ruby are flattened quartz, green tourmaline, red-brown garnet, staurolite, pyrite, and radiating acicular tremolite (Hlaing, 1993a).

In early 1994, the Burmese government was said to be considering joint ventures with foreign firms for the mining of ruby at Mong Hsu (Ted Themelis, pers. comm., Feb., 1994). Similar noises were made in 1989–90 about allowing foreigners to mine at Mogok, but turned out to be nothing but a pipe dream.

Much of the material mined at Mong Hsu makes its way into Thailand, particularly through Mae Sai. Initially the deposit has shown great promise. Only time will tell if such promise is of lasting quality.

Characteristics of Mong Hsu (Burma) corundum

Since the discovery of ruby at Mong Hsu, good reports of their characteristics have been published. These are summarized in Table 12.6.

Mong Hkak

Vague reports of a Kengtung Stone Tract have existed for years (Halford-Watkins, 1934). In 1993, U Tin Hlaing (1993b) gave specific information on a sapphire deposit in that area. Located in the Southern Shan States, 75 km east of Mong Hsu and just north of Kengtung, sapphires are said to occur in a secondary deposit associated with surrounding metamorphic (schist, gneiss) and igneous (granite, basalt) country rocks. The gems were found near the village of Wai Hpa Fai, 5 km from Mong Hkak, with ethnic Wa mining sapphire from open pits. Mong Hkak sapphires are said to have an average length of 1.5 cm, with gem-quality material being "much smaller (about 0.3 mm in size)" (Hlaing, 1993b). This description of the size of the gem material may be a typographical error, for unless larger material were forthcoming, the deposit would seem to have little potential. Blue-green bi-color sapphires are also said to be found at Mong Hkak (Hlaing, 1993b).

Nawarat & Namhsa

Kane & Kammerling (1992) reported on two additional areas where ruby has been found. Nawarat,[26] also known as Pyinlon, lies in the northern Shan State, near the Chinese border; Namhsa is some 15 km north of Nawarat. Mining in this area has apparently been ongoing since 1990. Immediately after the 1991 MGE emporium, a 5.25-ct faceted ruby "of exceptional color and clarity" was shown to Kane & Kammerling. This gem was later christened the *Nawarat Tharaphu*, and was reportedly cut from a 9.70-ct piece of rough found on April 23, 1990 at Nawarat.

Features of Mogok (Burma) corundum

Ruby

Mogok's famous rubies display a distinctive internal picture, often allowing separation from rubies of other sources. Typical are both euhedral ('well-formed') and rounded crystal grains, along with dense clouds of rutile silk. Rhombohedral twinning is common, as is straight/angular color zoning, at times in a swirled pattern termed *treacle*. Generally absent, or in small numbers only, are the fluid-filled inclusions so common in Thai/Cambodian and Sri Lankan rubies.[27]

Varieties and occurrence. Mogok rubies range from lightest pink, through bright red, to deep garnet-red. Most tend to be slightly purplish-red in hue position, and grade into purple and violet sapphires. Fine star rubies are also found. Twelve-rayed star rubies have been reported, but are extremely rare.

Mogok rubies are derived from a crystalline limestone (marble) matrix, resulting from either contact or regional metamorphism.

Solids. Crystalline solids of many types are characteristic of Mogok rubies. They typically form clusters of rounded and/or euhedral grains of a light color (or colorless), often concentrating in the center of the crystal. The most common guests are calcite, spinel, corundum, apatite, rutile and zircon.

Calcite is present as both rounded and angular rhombs, recognizable by its cleavage and polysynthetic glide-twin lamellae. Twinning striations may also be found in included corundum crystals, which occur as tabular or rounded individuals of extremely low relief. These corundums included in corundum typically show a *terraced*, or step-like, appearance from multiple development of the basal pinacoid. Spinel

26. Literally 'nine gem talisman,' which is related to the nine planets of Vedic astrology. Ruby, the gem of the sun, is traditionally placed at the center.

27. After heat treatment, Burmese rubies may contain numerous fingerprints and feathers, a result of stress-induced fracturing and subsequent healing in the oven.

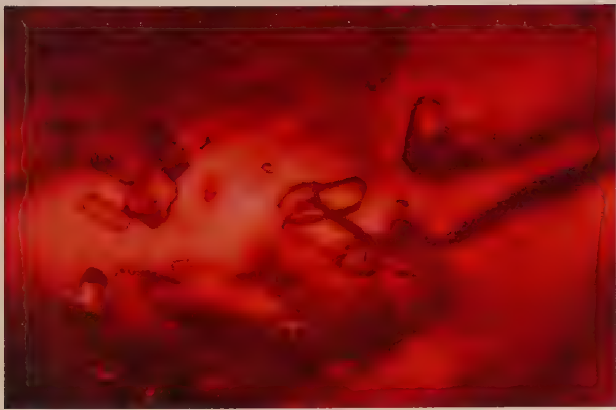


Figure 12.50 Rounded crystal grains are a common feature of Mogok rubies, such as those seen above, which are probably apatite. (Photo: Wimon Manorotkul)

crystals occur as both octahedra or, more often, as rounded irregular forms of low relief.

In addition to lightly colored or colorless mineral inclusions are guests with distinctive colors. Primary rutile crystals of deep red color and metallic luster stand out in high relief. Their square outline and knee-shaped twin or prismatic habit indicate their identity. Bright to pale yellow, partly resorbed crystals of low relief may be apatite; Eduard Gübelin (pers. comm., May 5, 1994) has reported that apatites in Mogok rubies tend to be rounded, while apatites in Sri Lankan stones often show distinct faces.

Yellow crystals of high relief suggest sphalerite or sphene. Rounded, partly resorbed grains of olivine are pale green. Deep-green prisms of a vanadium-bearing amphibole, pargasite $[NaCa_2Fe_4(Al,Fe)\ Al_2Si_6O_{22}(OH)_2]$ have been seen by the author in one spectacular vanadium-colored Mogok specimen (courtesy of Valaya Rangsit, ca. 1985). Dark brown to opaque slabs/plates suggest phlogopite mica. Zircon is also found, with and without stress halos.

Primary cavities. Primary fluid-filled cavities are not particularly common in Mogok rubies. This is said to result from the metamorphic processes in which they grew, which combine extremely slow growth rates with a fluid-poor environment (Roedder, 1982).

Negative crystals in Mogok rubies exhibit similar faces and habits as their host. Typical examples show a terraced appearance made up of numerous steps, the result of alternating development of pinacoid and pyramid (or rhombohedron) faces. Some are well-formed, with flat faces, while others are rounded. Negative crystals can be separated from solids because negative crystals show the same orientation as their host. In other words, the pinacoid face of each negative crystal is exactly parallel to the same face of the host and to any other negative crystals present in the stone.

When seen, negative crystals in Mogok rubies are often two phase. Eppler (1976) identified the filling as gases containing hydrogen sulfide. This constituent was recognized by its odor when the gems were crushed, opening the cavities. He speculated that gas bubbles within the growth solution perched on a face as the crystal grew. This provided an obstacle to the growth at that point on the face, while adjacent areas continued to grow. Eventually the surrounding gem engulfed the bubble completely, trapping it while simultaneously creating the negative crystal.

Secondary cavities. Untreated Mogok rubies contain far fewer secondary fluid inclusions (healing fissures or *fingerprints*) than rubies from Thailand/Cambodia, Sri Lanka or Kenya. Heat-treated Burmese rubies may, however, contain many secondary fluid inclusions formed during the heat treatment process.

Figure 12.51 While strong color zoning is rare in Mogok sapphires, it is common in the rubies from this area. A fine example is shown above, viewed parallel to the *c* axis. (Photo: Tony Laughter)

When secondary fluid inclusions are found in untreated Mogok rubies, they tend to be well healed, with angular negative-crystal pockets sometimes containing gas bubbles. Others may be fractures where little healing has occurred. Generally lacking are the intermediate-stage, lacy fingerprints with narrow fluid tubes common to rubies from Thailand/Cambodia, Sri Lanka and Kenya. Heat-treated Mogok rubies, however, contain far more fingerprints and secondary-fluid inclusions, making the identification of origin more difficult.

Growth zoning. Straight, angular growth zoning is common in Mogok rubies, as with rubies from sources other than Thailand/Cambodia. The zoning is always found parallel to crystal faces. When looking parallel to crystal faces, the bands of color line up into sharp narrow zones; however, in other directions they may appear in irregular swirls termed *treacle*, from their resemblance to the swirls in syrup.

Table 12.7: Properties of Mogok (Burma) ruby[a]

Property	Description
Color range/phenomena	• Colorless to a deep red; the red of Burmese rubies is generally *more* purple than Thai/Cambodian rubies; some stones are of a 'garnet' red color. Most are strongly fluorescent. • Six-rayed stars are common; 12-rays are known, but rare. • Color-change stones (colored by vanadium) are rarely found. These have a color change similar to the Verneuil synthetic.
Geologic formation	Found in metamorphosed crystalline limestones (marble) and secondary deposits derived from the same.
Crystal habit	• Typically stubby crystals consisting of prism/pyramids terminated by pinacoid faces and modified by the rhombohedron. Crystals often display a terraced appearance due to oscillation between the pinacoid and rhombohedron. Triangular depressions may be seen on pinacoid faces.
RI & birefringence	$n_ε$ = 1.760–1.766; $n_ω$ = 1.768–1.774 Bire. = 0.008 to 0.009
Specific Gravity	~4.00
Spectra	**Visible**: Strong Cr spectrum; V spectrum has been seen on rare occasions.
Fluorescence	• Strong to very strong red to orangy red (LW stronger than SW). Heat-treated gems sometimes show chalky fluorescence from colorless patches.
Other features	None reported
Inclusion types	**Description**
Solids	Various, often in dense concentrations, including: • Apatite, hexagonal prisms (Gübelin, 1973) • Calcite, transparent, often with rhombohedral glide twinning (Gübelin, 1969b) • Dolomite (Gübelin & Koivula, 1986) • Corundum (Gübelin, 1953) • Garnet (Gübelin, 1953) • Graphite flakes, black (Kammerling & Scarratt *et al.*, 1994) • Mica (muscovite) (Gübelin, 1953) • Olivine (Gübelin, 1973) • Pargasite, bright green crystals (Gübelin, 1973) • Pyrite (Gübelin & Koivula, 1986) • Pyrrhotite (Gübelin & Koivula, 1986) • Rutile prisms (not silk), dark red to black (Gübelin, 1953) • Scapolite, well-shaped crystals (Kammerling & Scarratt *et al.*, 1994) • Sphalerite, brown (Gübelin, 1973) • Sphene, yellow-orange, high dispersion (Gübelin, 1969b) • Spinel group minerals (Gübelin, 1953) • Sulfur (Fritsch & Rossman, 1990) • Zircon (Gübelin, 1953)
Cavities (liquids/gases/solids)	• Primary negative crystals (rare) • Secondary negative crystals (healed fractures) are rare, except in heated stones. They often lack the lovely 'lacy' appearance of Sri Lankan stones; typically they have fluid-filled channels which are widely spaced.
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle' like swirls in other directions
Twin development	• Growth twins of unknown orientation • Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Rutile silk in dense clouds of (often, but not always) short needles, parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.7 is based on the author's own extensive experience, along with published reports of Eppler (1976), Fritsch & Rossman (1990), Gübelin (1973), Gübelin & Koivula (1986) and Kammerling & Scarratt *et al.* (1994).

Twin development. Rhombohedral twinning is common, and may feature long, white exsolved boehmite needles at intersecting twin junctions.

Exsolved solids. One of the most diagnostic features of Mogok rubies is the dense white clouds of exsolved rutile. At high temperatures, when atomic spacing is greater, titanium enters into solid solution with the host corundum. As the corundum cools, however, its crystal lattice contracts, literally squeezing the titanium atoms out of solution, where they join with oxygen atoms to form minute crystals of rutile (TiO_2). This process is known among mineralogists as *exsolution*—the unmixing of a solid solution. Because of constraints on their movement by the solid corundum host, titanium atoms are unable to travel large distances. Therefore, rather than forming large crystals, they migrate together to form thousands of tiny slender needles where space permits. For rutile in corundum, this space is parallel to the faces of the second-order hexagonal prism, intersecting in three directions at 60/120° in the basal plane.

At times, only long slender threads are visible, while in other cases knife or dart shapes appear. Closer examination reveals many of these to be twin crystals with tiny v-shaped re-entrant angles visible at the broad end. They are flattened so thin in the basal plane that when illuminated with a fiber optic light guide from above, bursts of iridescent colors are seen, due to the interference of light from these microscopically-thin mineral lances.

Rubies from Mogok usually contain at least some rutile silk. It is found in dense white clouds made up of relatively

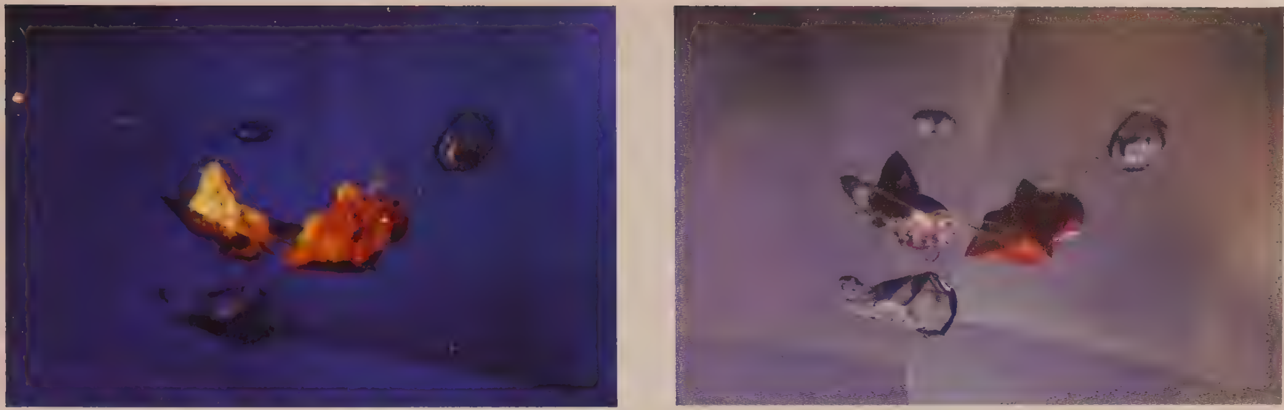


Figure 12.52 Two views of a secret…
Two different looks at unknown red crystal inclusions in a Burmese sapphire from the Mogok area. (Photos by the author)

Figure 12.53 Although Burmese sapphires share a number of similar features with their cousins from Sri Lanka, polysynthetic twinning is generally not one. The rhombohedral twinning in the Mogok sapphire above is rather rare in Sri Lankan sapphires. (Photo by the author).

short individuals, whereas in Sri Lankan corundums the rutile silk tends to be longer and less densely woven.[28]

Along with the rutile silk in Mogok rubies are clouds of minute particles of an unknown nature. These particle clouds, like the silk, also appear to result from exsolution, and are arranged in an identical pattern. At times, it has been noticed that heat treatment removes the rutile silk, but not the particles. Thus, in some cases at least, they may be composed of a mineral other than rutile. Due to their arrangement, they also influence the star effect of asteriated gems. In asteriated gems where silk clouds consist mainly of particles, the star is diffuse and lacking in definition. Conversely, where clouds contain a preponderance of needles, the star possesses better definition. Both needle- and particle-dominated stars can be found in Burmese corundums.

Boehmite. Mogok rubies display one additional type of exsolved needle inclusion: boehmite. Boehmite needles are long white inclusions which form at the junction of intersecting twinning planes and, as a result, lie parallel to faces of the rhombohedron $\{10\bar{1}1\}$. Where planes meet, they intersect at angles of 86.1° and 93.9° (three directions total, two in the same plane). If one understands the vast differences in orientation and appearance, there is little likelihood that boehmite needles be confused with rutile silk.

Boehmite results from pressure-induced exsolution. This pressure also is responsible for the *gliding* (slipping) of atomic planes, creating polysynthetic twins. Since pressure also causes stress fractures, low-grade corundum is generally filled with these twin planes and the accompanying boehmite needles.

Boehmite needles are often long, running completely across the stone. When intersecting in the above manner, they appear like a sort of lattice framework, or creation from Mother Nature's erector set. At times, close examination shows the appearance of narrow fluid fingerprints and frequently one observes narrow stress fractures extending outwards from the needles at 45° angles in a spiral fringing appearance. When twin planes run through secondary fluid inclusions, the boehmite needles often divide them into parallel sections.

Together, the rhombohedral twinning/boehmite needles combination provide one of the best methods of separation from the synthetic stone, for they are seen in a large percentage of natural corundums from all sources. Although rhombohedral twinning and boehmite needles have on rare occasions been found by the author in Verneuil synthetic corundum, curved growth lines and gas bubbles allow separation. Nothing resembling this combination occurs in flux synthetics, making it important in the battle against sophisticated factory products. Twinning is sometimes

28. It has been suggested by some that the length of the rutile needles and density of its clouds can be useful in separating Mogok and Sri Lankan rubies, but this is a test the author would not want to undergo.

Figure 12.54 Rutile silk in a Burmese sapphire from the Mogok region. (Photo by the author)

found in flux synthetics, but without the accompanying boehmite needles.

Within Mogok rubies, rhombohedral twinning with boehmite needles is seen, although not as often as in Thai/Cambodian rubies.

Features of Mogok (Burma) sapphire

In certain respects, the inclusions in Mogok sapphires differ from their red relatives. These differences can be accounted for by the different modes of origin for each. Although mined in close proximity to one another, the sapphires are believed to have originated in pegmatites and nepheline-corundum syenites, while the rubies formed in a metamorphosed crystalline limestone.

Like the rubies, Mogok sapphires contain dense clouds of rutile silk, and a number of fine star sapphires in various shades of blue have been unearthed. Included crystals, however, are less common in the blue gems than the red, while secondary fluid inclusions are far more abundant. Finally, the color of Mogok sapphires is exceptionally even, and banding is not found in some specimens, even under immersion. The lack of sharp zoning (and presence of rhombohedral glide twinning) helps to separate Mogok sapphires from those of Sri Lanka, where it is less common.

Varieties/phenomena. See Table 12.8.

Occurence. See Table 12.8.

Solids. With the exception of exsolved minerals, solid inclusions are somewhat rare in the sapphires from Mogok. Zircon has been identified as rounded grains, both with and without halos, as well as magnetite (spinel group) octahedra, large single rutile prisms and pyrrhotite (magnetic pyrite) crystals. One specimen examined by the author possessed a highly corroded tabular crystal of low relief with a pale green color. This might possibly have been olivine. Other crystal inclusions reported are apatite, monazite, fergusonite and phlogopite mica.

Cavities. Negative crystals are common in sapphires from the Mogok Stone Tract, although most appear to be of secondary, rather than primary, origin. Healing fissures, in all their glory, are usually profusely distributed across the stones. These range from fingerprints with slender, worm-shaped fluid channels, to curving concentrations of angular negative crystals, some two phase in nature. At times, fluid-filled fingerprints are superimposed upon these arrangements of negative crystals, suggesting two separate stages of fracturing and healing. Characteristic are the fingerprint patterns which appear folded or crumpled like flags in the wind.

Growth zoning. The color distribution of Mogok sapphires is exceptionally even; this is one of the key differences between Mogok and Sri Lankan blue sapphires. In gems from each locality the blue hue is equally fine, but one can never get too much of a good thing and Sri Lankan stones normally contain substantial areas without color. Thus, the even coloration of Mogok sapphires gives them an intensity lacking in most Sri Lankan stones. So well dispersed is the color in the former that, in many cases, even close scrutiny while immersed in di-iodomethane fails to yield evidence of the zonal banding. In the author's experience, only with the small blue sapphires from Yogo Gulch, Montana and those from Mogok is the banding often lacking.

Table 12.8: Properties of Mogok (Burma) sapphire[a]

Property	Description	
Color range/phenomena	• Near colorless to rich, deep blue almost verging on the violet. Despite the stereotypical 'intense blue' Burma sapphire, many Burmese sapphires are quite light in color, wholly resembling those from Sri Lanka. The blue color of Burmese sapphires is often just slightly more violet than those of Sri Lanka. • Purple to violet. • Yellow, generally a light, straw yellow. • Green has been reported (U Hla Win, personal comm., 1994), but is relatively rare. • Six-rayed stars are common in many colors; 12-rayed stars are rare.	
Geologic formation	• Burmese sapphires have been found in a variety of environments, including pegmatites, corundum syenites, gneisses and urtites. Gems are generally recovered from secondary deposits.	
Crystal habit	• Unlike sapphires from most other sources, Burmese blue sapphire crystals tend to be rather tabular, consisting of short prism/pyramids with large pinacoid faces. The result is cut stones which are often flat.	
RI & birefringence	n_ε = 1.757–1.765; n_ω = 1.766–1.774	Bire. = 0.008–0.009
Specific Gravity	~3.95–4.10 (higher readings in darker stones)	
Spectra	Visible: Weak to strong Fe spectrum.	
Fluorescence	Generally inert (LW & SW). Cr-bearing stones may show a weak red under LW.	
Other features	To the best of the author's knowledge, Burmese blue sapphires are not heat treated. This is not for lack of trying, but because the treatment secrets of this gem have yet to be unlocked. But give them time…	
Inclusion types	**Description**	
Solids	• Apatite (Gübelin, 1973) • Brookite, yellow crystals (Gübelin & Koivula, 1986) • Dolomite (Gübelin & Koivula, 1986) • Fergusonite (Gübelin, 1973) • Monazite (Gübelin, 1973) • Mica (phlogopite) (Gübelin, 1973)	• Pyrrhotite (rare) (Gübelin, 1973) • Rutile, dark red prisms (Gübelin, 1953) • Spinel group (magnetite) (Gübelin, 1973) • Unidentified green crystal • Zircon (Gübelin, 1973)
Cavities (liquids/gases/solids)	• Secondary healed fractures are quite common (unlike Mogok ruby); they take on a variety of patterns and thicknesses. • Fractures may be lined with reddish secondary limonite stains (Gübelin & Koivula, 1986)	
Growth zoning	• Growth zoning is generally rare; occasionally broad areas of zoning are seen.	
Twin development	• Growth twins	• Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Rutile in dense clouds of (often, but not always) short needles, parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane. Rutile is reportedly rare in yellow and green stones (U Hla Win, pers. comm., May 2, 1994). • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°).	

a. Table 12.8 is based on the author's own extensive experience, along with published reports of Eppler (1976), Gübelin (1973), Gübelin & Koivula (1986) and Kammerling & Scarratt *et al.* (1994).

Twin development. Polysynthetic twinning along the rhombohedron faces is common in Burma sapphires. Often accompanying these lamellae are long white boehmite needles. Such twinning is comparatively rare in Sri Lankan stones.

Exsolved solids. Rutile silk in Mogok sapphires is similar to that of the Mogok rubies. Compared with Sri Lankan stones, the silk tends to be shorter and more densely packed, and can be recognized by its spike or dart shapes. These needles lie in the basal plane and run parallel to the faces of the second-order hexagonal prism, intersecting at 60/120° angles.

The author has observed in certain Mogok sapphires what appears to be a second type of silk, differing from the rutile silk in several respects. Its color tends to be more brownish or yellowish than the rutile. Although it is oriented along three directions at 60/120° angles in the basal plane, these directions are offset 30° from that of the rutile, running parallel to the faces of the first-order hexagonal prism, not the second-order. Differences in shape are also apparent, with the new silk occurring as ultra-thin elongated plates of a distorted hexagonal outline. Possible identities include hematite, ilmenite, or a hematite/ilmenite intermixture, such as has been identified in Thai, Australian and Umba sapphires. Rarely, 12-rayed star sapphires have been found in Mogok. These possibly result from near-equal presence of both rutile and a second type of silk, as described above.

Again, like Mogok rubies, zoned clouds of minute exsolved particles are common in Mogok sapphires. While it seems possible that, in some cases, they are merely smaller versions of rutile silk, in others, differences between the silk and the particles can be seen. At times, the particles produce a pinkish reflection with overhead fiber-optic lighting. In others, the reflection is simply white. Apparently, like the

Pilgrimage to Mogok

EVERYONE has their own personal Mecca, their own pilgrimage to make. For myself, it has been Burma's Mogok Stone Tract. I waited patiently for over 15 years for this door to open. In April of 1996, it happened.

Mogok was everything I expected, and more. The town itself is no longer a small village of a few thousand inhabitants, but a bustling city. Today, the entire district probably contains 300,000–500,000 inhabitants. These consist of Burmese and Shan (Buddhist), Nepalese Gurkhas (Hindu), Lisu (Christian and Animist), along with a smattering of Muslims, Sikhs and those of Eurasian origin. The region's population has swelled tremendously in recent years, following the Burmese government's liberalization of the gem trade.

Today, urban Mogok encompasses everything from Myintada in the southwest, to On Bin, in the northeast. One valley over, the town of Kyatpyin has merged with Kathe. Many areas, which were once distinct villages, are now simply urban appendages of either Mogok or Kyatpyin.

During my visit, in addition to Mogok/Kyatpyin, I visited mines at Ah Chauk Taw, Chaungyi, Dattaw, Inn Chauk, Inn Gaung, Lay Oo, Lin Yaung Chi, On Bin, Ongaing, Pingu Taung, Pyaung Gaung, Shwe Pyi Aye, Thurein Taung, and Yadanar Kaday Kadar.

Today, the easily accessible valley alluvials have been exhausted and thus mining has largely moved to hillside and hard rock deposits. During the author's five days in Mogok, not a single twinlon was seen, with the only valley mines observed consisting of *lebins*.

Hard rock mining takes place at a number of localities, including Dattaw, Thurein Taung, and Lin Yaung Chi, among others.

Perhaps the most exciting part of my journey was a visit to a *loodwyin* at Thurein Taung. The indefatigable Dr. Saw Naung Oo, who resides in nearby Kyauk Pyatthat, guided us through thin cracks deep inside the mountain. These represented solution cavities and fissures within the marble, and provide places for gems to concentrate. Small wooden channels have been constructed to carry the overburden and *byon* out for washing. While most loos consist of narrow cracks, in places these widen out into limestone caverns. Dr. Saw Naung Oo told us of one chamber at Yadanar Kaday Kadar which was nearly as big as a football field.

Another fascinating day was spent traveling to Bernardmyo. Transport was Willy's Jeep, ca. 1950, but the road was strictly 19th century ox cart path. Indeed, while it takes 1.5 hours by jeep, one can walk it in less than six. This gives some idea of the speed of the jeep. Thankfully, while the jeep sometimes carries as many as 20 passengers, ours had only five.

Halfway to Bernardmyo is the fascinating Inn Chauk mine, where rubies are pried from beneath towering marble pillars. Due to weathering, such marble outcrops feature a black skin, and are common throughout the Mogok area.

At Pyaung Gaung, peridot is obtained by blasting in a peridotite. Bernardmyo itself is a small village inhabited by Chinese and Lisu. Nearby is a cemetery, where tombstones bear mute witness to early trials of British soldiers in this area. Most graves date from 1888–1892.

My pilgrimage to Mogok was a dream come true. It is a Mogok tradition that one wishes the owner luck when leaving a mine. Thus, to the people of Mogok I wish them luck. *Kyauk Gyi, Kyauk Gaung, Yaba Zay*. Good luck. May the stones you find bring you as much happiness as my visit to Mogok brought me.

Mining areas and trading

While a variety of stones are found in most deposits, local inquiries revealed that certain areas are famous for a particular variety.

Locality	Varieties
• Ah Nauttaw	Good star rubies
• Balongyi	Best star rubies
• Dattaw	Good TP rubies
• Ho Mine	Best TP rubies
• Inn Gaung	Good star rubies
• Kyauk Sin	Good fancy spinels
• Kyauk Pyatthat	Good blue sapphires
• Lebin Sin	Best TP rubies
• Lin Yaung Chi	Good TP rubies
• Mainglong	Tourmaline
• On Bin	Best red spinels; good fancy spinels
• Pyaung Gaung	Best peridot
• Sakangyi	Quartz, topaz
• Shwe Pyi Aye	Good TP rubies
• Sinkwa	Good star blue sapphires
• Thurein Taung	Best TP blue sapphires
• Yadanar Kaday Kadar	Best star blue sapphires Good TP blue sapphires

The Mogok area also features several regular gem markets, which have certain specialties and times of operation.

Market & time	Specialty
Kyatpyin town	
• Cinema hall area 9:00–11:00, 14:00–17:00	All kinds of gems from the western part of the Mogok Stone Tract
• Inn Gaung 15:00–18:00 (every 5th day)	Various kinds of rough
Mogok town	
• Lay Oo 7:00–9:00	Small rough of all kinds
• Myintada 15:00–18:00	Small rough
• Peik Shwe 9:00–12:00; 14:00–17:00	All kinds of rough and cut stones. This is the biggest market in the Mogok area (3 kyat entrance fee)
• Yoke Shin Yone (Cinema Hall) 15:00–17:00	Fine gems. Also a meeting place for exchanging information on mining and trading
Bernardmyo village Every fifth day	Peridot, enstatite, diopside and other semi-precious stones

The best stones are not offered in the markets at all, but are shown to customers in private homes.

In the past few years, trading in Burma has undergone a revolution. Just four years ago, private gem trading was illegal; today, both rough and cut stones can be freely purchased by foreigners with dollars from licensed traders, with only a 10% export tax to be paid. And most importantly, such licenses are cheap and easy for locals to obtain. Thus, for the first time in over 30 years, private trading and export of gems is both simple *and* legal.

In a land where private business was once the sole province of the *tatmadaw* (military), these changes are nothing short of remarkable. Make no mistake, the tatmadaw still has their fingers in many pies, but, for the first time in decades, they are allowing others to have a taste, too.

Figure 12.55
Foreign buyers examine rough jadeite at the 1992 gem emporium at Rangoon's Inya Lake Hotel. Such emporiums were once the only legal way to do business in Burma, but today trading is possible via licensed private gem dealers. (Photo by the author)

two types of silk, there exist at least two types of exsolved particles in Mogok sapphires.

Exsolved boehmite needles are common. They differ radically from the orientation of the exsolved rutile silk, lying not in the basal plane, but instead along the rhombohedron faces, at the junctions of crossing twin planes. Their angles of intersection are 86.1/93.9°, as they follow the edges of the rhombohedron faces.

Future prospects for Burma

Production from Burma's mines has never been great, a fact consistently overlooked by those seeking to exploit the deposits.[29] Although mining methods have improved over the past few years, production remains small. This has pushed prices for Mogok rubies and sapphires to record levels. Prospects for the future appear no better than the past. While it is likely that material remains in the ground waiting to be mined, only a change in government seems destined to bring about a total revitalization of Burma's gem and jewelry industry. In the meantime, other sources, such as Thailand, and recently Vietnam, fill, to a degree, the world's appetite for ruby. This may push away the pangs of hunger, but it does not satisfy the heart's longing for the storied stones of history. Thus the world is forced to wait, with bated breath, for the day when the glowing red stones of Burma will again take their rightful place as the world's premier ruby.

29. Witness Samuel Chappuzeau, who in 1671 wrote of Burma: "Nothing comes thence but *Rubies,* and not in so great quantities as is believed, seeing that every year there comes not out to the value of an hundred thousand Crowns, and amongst them you'll very rarely find a Stone of four or five Carrats that is fair…"

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Burundi

In 1989, Campbell Bridges reported the discovery of a large volcanic deposit of sapphire in Burundi, near the Rwanda border. Some of the material is of good color, while some is described as being of *geuda*-type, which is believed suitable for heat treatment (Koivula & Kammerling, 1989).

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Cambodia (Kampuchea)—see Thailand/Cambodia.

Canada

While Canada does have important deposits of industrial corundum, little of gem quality has been found. Table 12.9 is a brief summary, based largely on Sinkankas (1959, 1976).

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Table 12.9: Canadian corundum localities

Province and deposit descriptions
British Columbia
• Tiny ruby grains have been found in some of the tributary creeks of the Tulameen River. A gem-quality green sapphire pebble was found in gold gravel in the Pend Oreille River, a tributary of the Columbia in West Kootenay District.
Northwest Territories
• Deep blue sapphire crystals up to 0.5 inches (1.27 cm) in diameter have been found at the Philmore Mine on the Fox Group of islands near the east-central end of Great Slav Lake in the Mackenzie District. The material may be suitable for cabbing.
Ontario
This province contains Canada's most important corundum deposits.
• Bancroft: gray- to black-star sapphires have been cut from material found at Egan Chute, near Bancroft.
• Hastings County: Rose and blue corundum occurs in metamorphic limestone in northern Burgess Township; Small blue gems have been cut from material recovered east of York River in Dungannon Township.
• Peterborough County: Near the border of Methuen and Burleigh townships, grayish green corundums (sometimes with blue cores) have been found. Most is of cabochon grade; some will show asterism.
• Renfrew County: Material similar to that from Peterborough County is found at Craigmont, Raglan Township.
Yukon Territory
• The author has been informed of an occurrence of gem-quality sapphire at an undisclosed location in the Yukon. Material is said to be similar to that found at Rock Creek, MT, with faceted stones of two carats or more possible (Mark Mauthner, pers. comm., Sept. 23, 1994).

China

I can resist anything except temptation.

Oscar Wilde

Historically, China has viewed the outside world with the jaundiced eye of the professional virgin—having heard of the pleasures of love, she is fascinated by the thought, yet abhors the idea of foreign penetration. Thus for much of her history she has watched the world from afar, a voyeur, content in the knowledge that she alone is pure.

Cathay has never lacked for suitors. Since the time of Marco Polo, her silks, tea and jade tugged at the West like a siren song, but the dragon lady never encouraged foreign trysts. Indeed, a 2400-km long chastity belt was constructed about 220 BC to keep the barbarians at bay. But like so many empires, too much sophistication, too much class, *too much civilization* took their toll. Plied with opium by European traders, China's resolve weakened slowly, from the inside out. In the mid-19th century, tiring of the coquettish games of love, French & British troops burst in with a vengeance. A small expeditionary force marched through the heart of the most-populous nation on earth and, with virtually no resistance, deflowered the maiden on her palace bed.

Under Mao Tse Tung, the Middle Kingdom's boudoir door slammed shut. But as the 20th century draws to a close, with the yoke of dogmatic communism shed, outside fertilization is again welcomed. In our lifetime, for perhaps a brief moment, a window has opened into an area little explored by foreigners. Thus far, this has yielded a tantalizing glimpse of China's mineral wealth, suggesting that much remains to be discovered. The virgin is again flirting with the world....

History

China proper has never been considered an historical source of ruby or sapphire. Vague mentions of corundum in Tibet exist (Gregor, 1803), but none have been confirmed. The author has been unable to find any evidence of historic deposits of gem corundum in China proper, but there is evidence that impure material was used as an abrasive material due to its hardness (Needham, 1959).

Still, the Chinese were aware of ruby and sapphire from outside the country. While never noted as great travellers, historically they have ventured outside their borders on military or diplomatic missions, or for religious pilgrimage (Bretschneider, 1887). Fa Hien (Fa Hsien) was selected by the Chinese emperor to travel to India to obtain accurate information on Buddhism. In the account of his journey, which occurred during 399–414 AD, he did mention the occurrence of many precious stones in Ceylon (Legge, 1965). One Chinese author, Thao Tsung-I, wrote a brief treatise on the precious stones known about 1366 AD. A short section of this was translated by Bretschneider (1887). In this, *la* (balas ruby, or spinel) is described, as well as *yakut* (*yaqut*), which is Persian for corundum.[30] Thus it is apparent that some in China were aware of the corundum gems from abroad, but domestic occurrences were not reported until the late-1970s, when economic and political reforms made it possible to openly discuss "bourgeois" subjects, such as gems.

Tu Wan's *Stone Catalogue of Cloudy Forest* dates from about 1126 AD (Schafer, 1961). This book contains descriptions of various stones known to the Chinese in the 12th century, but apart from the banded blue-green "Stone of the Office of the White Horse" (*Ho-nan-fu*), none accurately describe corundum.

According to Liu Guobin (1981), the finest historical work on precious stones in China is the *Lapidarium Sinicum* of H.T. Chang (1921). The author has not yet seen this book. In the 1990s, gemological periodicals have appeared in

30. According to Bretschneider (1887), the Chinese word for ruby is *hung pao shi* ('red precious stone'), while that for blue sapphire is *lan pao shi* ('blue precious stone').

Figure 12.56 Corundum localities of China. Gem deposits are found in Fujian, Hainan, Heilongjiang, Jiangsu, Qinghai, Shandong, Sichuan, Xinjiang and Yunnan Provinces. Note that the position of some localities is approximate only.

China, but as the author cannot read Chinese, this section is drawn from sources using the Roman alphabet.

Corundum in China

Information on Chinese localities is difficult to come by, as access often involves obtaining permission from the Chinese military, which controls most mines. A second factor is location: many mines are in remote areas where travel is difficult. The following information is as accurate as present circumstances will allow.

Ruby and sapphire have been reported from a number of areas in China. Of these, most important are the sapphire occurrences of Shandong, Fujian and Hainan in eastern China. In each of these places, sapphires occur in alkali basalts as dark, inky-blue material similar to that mined in Australia.

Hainan Island

The following is based on the reports of Wang Furui (1988) and Galibert (1990).

Figure 12.57 French dealer, Olivier Galibert, inspects rough sapphires at Penglai, Hainan Island, China. (Photo: Olivier Galibert)

Getting there. Hainan Island is located in the South China Sea, due east of Vietnam. Reached by air from Guangzhou (Canton) and by air or (irregular) boat from Hong Kong, Haikou, the island's provincial capital, is the jumping off point for trips to Penglai, where the mines are located.

Access from the provincial capital of Haikou is typical for third-world backwaters: several hours on a livestock-infested bus along what the charitable term "roads." The December-February rainy-season flooding, which turns the Penglai area into a swamp, will give travelers further fuel for spinning porch-side yarns in the twilight of their lives ('I remember when I was on the road to Penglai…').

Penglai's sapphire mines lie 2 km southeast of the town of the same name, covering some 25 km^2, in the northeast corner of Hainan Island. Due to the difficulty of getting there, few foreign gem dealers visit. Fortunately, the journey is not the only reward: the Penglai area produces some of China's finest sapphires.

Mining and cutting. Sapphire was first discovered on Hainan Island in the early 1960s by a local farmer, Zhang Changde, who found a beautiful stone on the ground near where his animals were grazing. Fascinated, he began collecting more, but apparently must seek his reward in heaven, for upon turning the gems over to the local geological team, received just 1.6 yuan (~$1.00) for his trouble (Wang Furui, 1988).

In 1982, an exploration team was sent to study the deposit (Wang Furui, 1988), but since Olivier Galibert's first trip to the area in 1987, only Hainan-Island natives have been involved in mining. Digging generally takes place in the evenings by farmers (and even government officials), particularly after a heavy rain. Excavation methods are primitive, along the lines of traditional corundum mining in southeast Asia. What sapphire is recovered is often kept in small bags sewn into the miners' trousers.

Apparently one of the major reasons why the deposit has not been worked on a larger scale is the "she loves me-she loves me not" policies of local officials, who are seemingly unable to decide just who will be blessed with the princely kiss. This is common among mining projects in Third-World nations, where local officials do everything possible to both retain authority and sell it to the highest bidder.[31] At the time of Galibert's last visit in 1990, most production was being sold to Thai and Hong Kong dealers; no sapphire-cutting factories existed on the island.

Gemology of Penglai sapphires. Alkali basalt is thought to be the source rock of the sapphires, which are recovered at a depth of 2–3 m, alongside pyrope garnet, black spinel, pyroxene, olivine and zircon. Penglai sapphires tend to occur as small- to medium-sized hexagonal prisms and fragments. Average size is 2–5 mm, with the largest reported at 35.5 ct. Colors are mostly blue, with stones varying through bluish green, green and yellow-green. Most are dark. Stones containing traces of Cr have also been found, but are rare.

Gemological properties are typical for sapphire. Straight, angular color zoning is common, with associated clouds of unidentified silk. Solid inclusions may be opaque and black; white crystals have also been found. Both types may be surrounded by tension haloes. Like most sapphires, Penglai stones are commonly heat treated (Wang Furui, 1988).

Fujian

The following is based on the report of Keller & Keller (1986). Sapphires were first discovered near the town of Mingxi in 1980, during diamond exploration. Mining takes place approximately 10 km northwest of town in secondary deposits derived from alkali basalts.

Colors of the material range from yellow-green, green, through greenish blue to blue, with rough averaging 2 ct in size. The largest faceted gem reported was 2.1 ct. Virtually no information is available on the inclusions of this material.

31. Or bidders. During the author's (RWH) residence in Vietnam, he heard of several cases where the "exclusive" rights to mine a deposit did not "exclude" native digging on the same land.

Figure 12.58 Sapphire diggings at Penglai, Hainan Island, China. (Photo: Olivier Galibert)

Crystal habits tend to be barrel and dog-tooth shapes, similar to sapphires from Australia (which the material strongly resembles).

Shandong

The following is based on the report of Jinfeng Guo & Fuquan Wang *et al.* (1992). Sapphire was discovered near Wutu, Changle County, Shandong Province in the late 1980s, first in alluvial gravels, later *in situ* in alkali basalts. Mining is taking place in the secondary deposits, while primary deposits are worked for mineral specimens. Similar to other basaltic sapphire, crystals tend to be barrel-shaped prisms. Many show rounded, etched surfaces due to partial solution by magma during their eruptive trip to the surface.

Most stones are dark blue; some range from greenish blue to yellow in color; most are strongly zoned. While material ranges in size from 5–20 mm, larger stones are overly dark. Solid inclusions identified in Shandong sapphire include U- and Th-rich zircon crystals of orange-red color, Ti-rich columbite (niobite; black, metallic), Na-feldspar, apatite, ilmenite, and Mg-Fe spinel. Silky specimens are found, but the identity of the silk has yet to be reported. Virtually all are heat treated.

Other Chinese localities

Yunnan. Ruby in marble was discovered in the Ailao Mountains of Yunnan Province in the late 1980s, with placer deposits being mined (Qian Tianhong & Luo Yiqing, 1992). Shortly after the find was made, people descended on the area in droves, possessed with "ruby fever." This was not exactly the type of "resettlement policy" the central government had in mind, and a quick halt was put to the proceedings.

The exact locality is 25 km southeast of Yuan Jiang. Material is similar in color to that from Burma and Vietnam, but facetable rough is quite scarce (Terry Coldham, pers. comm., 21 Dec., 1995).

In Yunnan, the Shunning Fu prefecture was described as a source of sapphire, ruby and green sapphire; these gems were said to occur in other parts of that province, as well (U.S. Consular Reports, 1990).

Heilongjiang. Ruby and volcanic sapphire has been reported from Heilongjiang (Anonymous, 1989). Weather conditions are difficult, allowing mining only 3–4 months of the year. The army is said to control the area, and little is being recovered, with most stones of small sizes. Ruby is also found in this province.

Jiangsu. Low-quality (dark) blue sapphire is said to occur in Jiangsu, but the reports of ruby are thought to have been confused with garnet, which is of good quality.

Qinghai. Both ruby and sapphire have been reported from Qinghai (Dong Bingyu, 1993). Mining is difficult due to the 3000 m elevation of the Qinghai plateau. Translucent ruby of pale pink to medium red is said to occur in an oligoclase-biotite gneiss. Star rubies are also possible (Anonymous, 1991b).

Sichuan. Ruby has been reported from Nanjiang, Sichuan Province (Chikayama, 1986).

Xinjiang. Ruby has been reported at Kalpin, far western Xinjiang (Keller and Fuquan, 1986). Sapphire has also been reported from Taxkorgan in Xinjiang (Chikayama, 1986).

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Figure 12.59 Rough sapphires from Penglai, Hainan Island, China. (Photo: Olivier Galibert)

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Figure 12.60 A 1.48-ct blue sapphire from the Mercaderes-Río Mayo area of Colombia. (Photo © 1985 Tino Hammid/GIA)

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Colombia

Sapphire from Colombia was first mentioned by G.F. Kunz (1908). During 1907 he was shown rolled sapphire crystals from an unknown Colombian locality. They were described as hexagonal crystals, flat and barrel-shaped, of white, colorless, yellow and pale blue color, and were said to resemble sapphires from the Missouri river deposits of Montana (USA). Kyanite and spessartine garnet were found with the sapphires. Codazzi (1927) described pale gem-quality sapphire and ruby from the sands of the Río Mayo.

The deposit is located on the border of the departments of Cauca and Nariño, near the village of Mercaderes, some 143 km southwest of Popayán. Since the early 1980s small quantities of sapphires from the Mercaderes—Río Mayo area in southwest Colombia have appeared in the gem trade. This material tends to have a color range similar to that from Umba, Tanzania. Blue and brownish green stones are most common, but yellows and reds (including pinks) have also been found. Many stones show a color shift from blue to violet. The largest faceted stone reported was a 16-ct light blue stone (Keller & Koivula *et al.,* 1985).

Characteristics of Colombia sapphire

Characteristics of this material are summarized in Table 12.10.

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Table 12.10: Properties of Colombian sapphire[a]

Property	Description
Color range/phenomena	• Similar to corundums from Umba Valley, Tanzania. This ranges from blues and greens (with a brownish cast), with yellows and pink to red stones also found. Many stones have yellowish cores.
Geologic formation	Secondary deposits derived from an unidentified source rock (possibly an alkali basalt)
Crystal habit	Rounded, tabular to elongated hexagonal prisms. Basal parting is common
RI & birefringence	$n_\varepsilon = 1.762$; $n_\omega = 1.770$ Bire. = 0.008 (based on three specimens only)
Specific Gravity	3.99 to 4.02
Spectra	Visible region • Most stones display a weak Fe spectrum. Some also show a very weak Cr spectrum.
Fluorescence	**UV** SW: Inert LW: Weak to moderate orange to red (particularly in color-shifting stones); sometimes patchy
Other features	Many stones may display a weak color shift from bluish towards reddish
Inclusion types	**Description**
Solids	• Apatite, small prisms (Keller & Koivula, *et al.*, 1985) • Rutile, euhedral prisms (Keller & Koivula, *et al.*, 1985)
Cavities (liquids/gases/solids)	• Iron oxide stains are common in cracks (this may be eliminated during heat treatment)
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; many stones have yellowish cores
Twin development	• Polysynthetic glide twinning on the rhombohedron is common
Exsolved solids	• Rutile needles in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°). These planes lie in the basal plane. Star stones are occasionally found. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.10 is based on Bank & Schmetzer *et al.* (1978) and Keller & Koivula *et al.* (1985).

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Czech Republic

Information on the corundum deposits of the Czech Republic has been provided by Jaroslav Hyrsl (pers. comm., 15 June, 1995). The most famous locality is Jizerska Louka in northern Bohemia, which is said to produce some of the finest sapphires in Europe. Written reports on alluvial mining at Jizerska Louka date from the beginning of the 16th century, when Italian prospectors were sent there by the emperor Rudolf II, a noted gem and mineral collector. The sapphires are generally small (up to 5 mm), blue to blue-green and only rarely suitable for cutting. Accessory minerals include ilmenite, black spinel, zircon and, rarely, red spinel. Ruby has also been mentioned from this locality, but has not been confirmed. Both granites and basalts have been mentioned as the source rock; this also awaits confirmation.

Rarely, both sapphire and ruby have been found in the Ceské Stredohorí Mountains during the mining of the famous Bohemian garnets, together with zircon and spinel. Corundums seldom exceed a few millimeters.

Finland

Ruby has been reported from Finnish Lapland, at Kittilä, in amphibolite (Hunstiger, 1989–90). Translucent pyramidal crystals of corundum have also been found in Lojo at Ammänkallio (Maila), in limestone (Barlow, 1915).

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France

Although France has never been known as a source of gem corundum, in medieval times the volcanic deposits of du Puy en Velay produced quantities of inferior sapphire. These were designated as 'sapphires de Puy' or 'saphire de Podio' in medieval jewel inventories, to distinguish them from their more valuable Asian cousins (Holmes, 1934; Byrne, 1935).

Ruby in amphibolite has been reported from Chantel in the Haute Allier region of France (Hunstiger, 1989–90). Blue star sapphire has been reported from at La Mercredière, in the Loire Inférieure department of Brittany. Low grade corundum has been reported in many other parts of France (Barlow, 1915). These include:

- Hautes-Pyrénées near Cauterets
- Le Croustet and the volcano Le Coupet, in basalts
- In granite between Puzac and Ordizan
- Gèdres, Lac de Caillaouas, in Haute-Garonne Department
- Arignac in Ariège
- Menet, in Cantal
- Haute-Loire Department
- Puy-de-Dôme of the Puy de Saint-Sandoux
- Col des Cadènes in the massif of Pic St. Barthélemy
- Volcanic district of the Auvergne Mountains
- Pont Paul, near Morlaix (Finisterre department)

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Germany

To date, gem-grade corundum has not been found in Germany. However their are many German occurrences of impure corundum. According to Barlow (1915), these include:

- Rhine basin, in the Siebengegirge and Eifel districts
- Königswinter
- Unkel on the Rhine
- Steinheim, near Frankfort-on-the-Main
- Niedermendig and Mayen
- Baden, northerly from Schenkenzell
- Horberig, in the Kaisertuhl
- Wildenreuth, in Bavaria
- Fulda, in Hesse
- Michaelstein, in the Harz mountains
- Near Hinter-hermesdorf, in Saxony
- On the ochsenkopf at Brockau, near Schwarzenberg
- Mittelberg, near Waldheim
- Teiplitz
- Goldberg, in Silesia
- Frankenstein

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Greece

Greece has never been noted as a source of gem corundum, but a number of Greek islands have been historical sources of emery.[1] Many of these deposits have been mines since ancient times. Most important are the mines on the island of Naxos. Other islands which have deposits include Samos, Nicaria, Heraklia and Sikinos (Barlow, 1915).

Ruby in marble has been reported from Stirigma in the Xanthi region of northern Greece (Hunstiger, 1989–90).

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Greenland

Ruby was first found in Greenland in the mid-1960s, in the Fiskenæsset area of southwestern Greenland. The rubies, which occur in an amphibole-rich rock (tschermakitic), are found in a variety of red shades and may contain inclusions of pargasite (Gübelin & Koivula, 1986). Unfortunately, the high cost of mining in Greenland currently makes these rubies too expensive to be of commercial importance. Most are of cabochon-quality only. Pink corundum has also been found in the area north of Godthåbsfjord (Nuup Kangerlua) and Kangerdluarssuk Fjord (Peterson, 1993).

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[1] Emery is a gray to black, impure type of corundum containing magnetite or hematite. It is often used as a polishing or grinding stone or abrasive.

Figure 12.61 Ruby in matrix from Greenland. (Photo: GIA; specimen: A. Ruppenthal)

India

India has long been synonymous with precious stones. Beryls, pearls, carnelians and Golconda's storied diamonds were but a few of the precious substances which had drawn visitors to the subcontinent for millennia. To the ancient Romans, the East, specifically India, was the repository of all wealth. India not only sold her mineral treasures to Rome, but were leaders in developing the technologies that allowed them to be exploited. India's rulers were also the world's greatest gem collectors, amassing riches of incalculable value.

No land save Sri Lanka has venerated the corundum gems longer than India. In fact, the term corundum is derived from the Sanskrit word *kurand* (see page 29). Since the earliest times, ruby and sapphire in India have ranked among the *Maharatnani* ('great gems'). India's ancient jewelers divided gems into two main groups: *Maharatnani* ('great gems') and *Uparatnani* ('secondary gems'). In the former class was placed diamond, pearl, ruby, sapphire and emerald. Early Sanskrit texts dealt with *ratnapariksa* ('investigation of gems,' or 'gemology'), and divided blue sapphire (*'nilamani'*) into two varieties, *indranila* and *mahanila*. The former was described as rarer and more precious, displaying a rainbow blue, while the latter apparently included stones of a darker hue (Brown, 1956). According to Holland (1898), three classes of sapphires were recognized by Indian jewelers: deep blue, those with a tinge of green (*subj-pun nílá*) and those with a tinge of red (*lál-pun nílá*).

Supernatural powers were attributed to gems in India. One way this was manifested was the interdependence between gems and planets. Ruby, associated with the Sun, was the Lord of Gems, for the Sun lorded over all the planets. Sapphire was associated with Saturn (Wojtilla, 1973).

The earliest Sanskrit texts mention only Sri Lanka as a source of ruby and sapphire. Somewhat later, Kalinga (northeast India, between the valleys of the Mahanadi and Godavari rivers) and Kalpur (Kalpura; in central India) are added, but neither are today sources of corundum. About 1884, a buried treasure of some sixty rough sapphires was unearthed from a mound amongst the temples atop the sacred hill of Mahendragiri, in the Ganjam district of Kalinga. They were probably placed there as a votive offering at some unknown date in the past. After being cut in Madras, they were examined in by the Geological Survey of India, and pronounced to be of good quality. (Brown, 1956).

While India's use of impure corundum as an abrasive appears to stretch back at least a millennia or more (see page 199), the country's history of *gem* corundum production is relatively brief. Low-grade ruby has been mined for an indefinite period, but India did not enter the major leagues of gem corundum production until the 1880s, with the discovery of sapphire in Kashmir. It is to these mines that we now turn.

Kashmir sapphires—blue velvet

The famous sapphires of Kashmir are mined from a remote region high in the Great Himalayan mountains of northwestern India. Lying at an elevation of approximately 4,500 m, they are located in the small Kudi ('rock') Valley, near the hamlet of Sumjam (Soomjam), in the Padar (Paddar) region of Kashmir. The district of Zanskar, which has been incorrectly listed as the source of the sapphires, lies just to the north (Ball, 1885b; Steve Karpa, pers. comm., 1990).

History of the Kashmir mine

Exactly when sapphires were first discovered in Kashmir is unknown. Ball (1885b) lists it as about 1879 or 1880, but La Touche (1890) gives 1881 or 1882. The following is one of the earliest accounts of the discovery of sapphires in Kashmir:

> There are two versions of the discovery of the corundum deposits at Sungchang in Zanskar, one being that they were exposed by a hill-side slipping, the other that they were discovered by hunters. Their value was so little known that the villagers bartered them for a trifle to Lahouli traders, who in their turn vainly endeavored

Figure 12.62 A selection of both rough and cut sapphires from the famous Kashmir mine. The cut stones range from 6–14 ct. (Photo: Henry Hänni/SSEF)

to exchange them for grain in Kulu. On their value becoming known, there was a rush of jewelers from Delhi and other places; and they speedily rose to 100 rs. per tola = about £20 stg. per oz., for good specimens, at which rate they have remained; at present none are to be had, all the stock brought down has been sold, and the mine is strictly guarded by one of the Maharajah's Dogra regiments. So far as I can learn, the matrix is a schistose or slaty rock....

The Maharajah has recently released from prison and largely rewarded two native hunters, who had been imprisoned for dealing in sapphire, on condition of their showing him two other deposits, one of *blue* and the other of *red* corundum. I have no information regarding these deposits. A small fragment of the red corundum has, however, found its way to Kulu; it is true oriental ruby, perfectly clear, and of a beautiful water.

A. Grahame Young, Kulu, Aug. 8, 1882
(from Shepard, 1883)

Another version of the discovery was told to Albert Ramsay (1934):

In India my eyes have been dazzled by such jewels as never have been seen in the Western world. When I was last in the Srinagar palace of the Maharaja of Jammu and Kashmir thirty trays were brought before me, and if I were to say that any one tray, sent to market, would fetch a million dollars, I would be giving only a faint impression of the astonishing wealth and beauty of those treasures of an Indian gentleman.

A handsome man is Colonel His Highness Maharaja Sir Hari Singh. In the afternoon he had shown me his sapphires and told me the story of how they were found.

It seemed that in the old days a band of men with beards dyed red found some blue stones exposed by a landslide in the hills of Kashmir. These men had come from Afghanistan, part of a mule caravan on its way to Delhi. The stones, as curiosities, were put away in the bags on one of the mules, and then, in Delhi, they were traded for salt. Thereafter they were sold to someone who recognized them to be rough sapphires: and they were resold and resold and resold, until finally, in Calcutta, they brought in rupees a price which was equal to $400,000. The news of this transaction got back to the maharaja of that time, who discovered that the sapphires had been picked up in his own Kashmir hills. In great wrath he went to Calcutta and demanded them. Every single transaction in the long train had to be undone. The man who had sold the sapphires gave back the $400,000, and so it went through many towns, until, at Delhi, a merchant received back a few bags of salt. Today, I should think, those Kashmir sapphires are worth $3,000,000. One of them is as large as an egg-plant. For one of the smaller fragments I offered His Highness $25,000. He just laughed at me; he does not want to part with any object in his beloved collection, but, oh, how I should like to buy some of those treasures!

Albert Ramsay (with Boyden Sparkes), 1934

Still another version is that of T.D. La Touche (1890):

The existence of sapphires in considerable quantities in some part of the North-West Himalayas was first brought to light in 1881, or early in 1882, when some were brought into Simla by traders from Lahol, who stated that they had been obtained from a spot among the mountains on the borders of Zanskar, where a land-slip had laid bare the rocks beneath the soil, and disclosed the

Timeline of Kashmir sapphire

1879–82	Blue sapphires are first discovered in the Padar region of Kashmir, allegedly where a landslip had uncovered their occurrence (Mallet, 1882; Shepard, 1883; Ball, 1885b; La Touche, 1890).
1882	Sapphires begin to appear in Simla. The Maharajah of Kashmir intervenes by sending a regiment of sepoys to take control of the mines (Ball, 1885b). Delhi jewelers buy up more than two lakhs (£20,000) worth of stones (Mallet, 1882).
1882–87	The glory days of the Kashmir sapphire mine. During this period, crystals as large as 5″ (12.7 cm) long by 3″ (7.62 cm) wide are found (La Touche, 1890).
1887–88	Declining revenues cause the Maharajah of Kashmir to ask the British Indian Government for assistance. T.D. La Touche is dispatched to the mines to undertake the first detailed geologic survey of the area. He finds the "Old Mine" exhausted and turns his attention to placers on the valley floor, where systematic sampling via pits is done. Placer yields are found to decrease at the lower end of the valley, and below the 1 m level. During 1887, his team finds one parti-colored piece of rough weighing ~6 oz (933 ct)[a] (La Touche, 1890).
1889–1905	Official mining halts, but local poachers continue to dig (*Minerals Yearbook*, 1906).
1906–1908	C.M.P. Wright and the Kashmir Mineral Co. lease the mines. Wright reworks the placer deposits and obtains a number of fine stones. He digs a trench a few hundred meters south of the Old Mine, but eventually gives up, due to the difficulties of mining in such an inhospitable area. Wright's trench later becomes known as the "New Mine" (Middlemiss, 1931). One stone reportedly sells for £2000 (Heron, 1930).
1911	Lala Joti Parshad visits the mines as Mining and Prospecting Officer. He mines the southwest opening of the New Mines, but results are poor (Middlemiss, 1931).
1920	Sohnu Shah of Jammu leases the mines, with poor results. This apparently confirms the belief that the mines are exhausted (Middlemiss, 1931).
1924	Pandit Labhu Ram, Junior Assistant Superintendent Mineral Survey, maps the area of the Old and New Mines. This results in much useful information on where sapphire is found *in situ* (Middlemiss, 1931).
1926	Lala Jagan Nath of Jammu is given a prospecting license and obtains 5,500 tolas (~64 kgs) of sapphire. His license is revoked due to certain irregularities (Middlemiss, 1931).
1927	Lala Joti Parshad and Pandit Labhu Ram of the Kashmir government extract 39,029 tolas (~454 kgs) of material from Lala Jagan Nath's trench at the New Mines in 15 days. Cutting the material, however, produces disappointing results (Middlemiss, 1931).
1928–32	With the exception of poachers, no mining is done (Brown & Dey, 1955).
1933–1938	Systematic mining again commences. Average annual production is 641,656 ct (128 kgs). (Brown & Dey, 1955)
1939–1943	Outbreak of World War II results in declining production (Atkinson & Kothavala, 1983).
1944	Geologist R.V. Gaines and R.C. Rice, on leave from the US Army in Calcutta, visit the mines. Theirs is the first trip by Western geologists in many years. They find the mine guarded by a team of police (Gaines, 1946).
1945–51	Sporadic mining by private lessees, with little of quality found (Atkinson & Kothavala, 1983).
1952–1959	Sporadic mining by the Kashmir state government (Atkinson & Kothavala, 1983).
1960	The mine is taken over by Jammu & Kashmir Minerals Ltd., a state government concern. They continue to operate at least through 1979 (Anonymous, 1978).
1961	Kashmir government geologist, B.K. Raina, makes a detailed, but confidential, survey of the mines (Raina, 1961).
1966–67	Raina and M.L. Parimoo undertake a detailed, but confidential, mapping of the mines (Parimoo & Raina, 1968).
1967	The Maharajah of Kashmir's political power is broken (Atkinson & Kothavala, 1983).
1977–79	The Indian government discusses leasing the mines, without success (Anonymous, 1977b, 1978, 1979a, 1979c).
1981	D. Atkinson and R.Z. Kothavala make the first visit by outside geologists to the area in many years. Their reports are the best accounts of the mines published to date (Atkinson & Kothavala, 1983, 1985).
1982–present	Government continues to discuss leasing the mines, but without success. Muslim guerrilla activity in the mining area increases and, as of 1994, the mining region was considered rebel territory (Cap Beesley, pers. comm., Dec. 5, 1994).

a. Although La Touche did not specifically say so, it is assumed these are Troy (apothecary) ounces.

presence of the gems. Various stories are told of the original discovery; according to one of these, which was told me on the spot, a certain shikari, having lost the flint from his gun while out hunting, or, as is the custom of the natives when in want of a light for their pipes, looking for a handy fragment of quartz or other hard rock to strike a light with, picked up a small sapphire, and finding that it answered his purpose better than the ordinary fragments of quartz he was in the habit of using, carried it about with him for some time, and eventually sold it to a Laholi trader, by whom it was taken to Simla, where its value was recognised. Enquiries were then made, which resulted in the discovery of the spot where the shikari had picked up the stone, and for some time, until guards were posted near the locality by the Maharajah of Kashmir, in whose territory it lies, large quantities of the stones were brought to Simla and sold at absurdly low prices, the Laholis only asking about one rupee per seer for them. Another story runs to the effect that a number of traders who had arrived in the Simla bazaar with borax from Rupshu were emptying their baskets in a merchant's shop, when a stone fell out and was thrown by the merchant into the street. The well-known jeweller, Mr. Jacobs,[2] happened to be passing at the time, and, so the story

2. No doubt this is Alexander M. Jacob, for whom the 162-ct *Jacob ('Imperial') diamond* is named. Variously supposed to be a Persian, Jew, Armenian, Russian and/or a British agent, he was then the most important trader of jewels and antiquities in India. Said to be a master of white magic, he operated out of a small, incense-filled shop in Simla, summer capital of the British Raj. Jacob was the inspiration for Lurgan Sahib in Kipling's *Kim*, as well as F. Marion Crawford's *Mr. Isaacs* (Crawford, 1882; Lord, 1971).

Figure 12.63 View of the Kashmir sapphire mines. Taken in 1887–8, this is among the earliest photos of the fabled deposit. (From La Touche, 1890)

> goes, was struck by the stone. Picking it up, perhaps with the intention of returning it, he saw what it was, and on the merchant's claiming it, when he saw that there was something unusual about it, bought it for a small sum. This latter story, if it is to be relied on, would seem to point to the existence of another and as yet unknown locality for the gems, somewhere in Rupshu; otherwise it would be difficult to account for the presence of the sapphire among the borax, which is brought to Simla along a route that does not pass anywhere near the known locality in Padar. Various stories have been circulated of the discovery of sapphires in Kulu and other portions of the North-West Himalayas, but up to the present time none of these have been confirmed.
>
> T.D. La Touche, 1890

In the beginning, sapphires were so abundant that one person reported seeing about 1 cwt. (~50.8 kg) of them in the possession of a native (Brown, 1956).

> Gradually, as they were carried by traders to distant points, especially to Simla, their value became known, and the agents of jewellers commenced a brisk competition, till most of the available stones had been bought up. The Maharajah of Cashmere then intervened by sending a regiment of sepoys, with their officers, to take possession of the mines; and, it would appear, with *carte blanche* to harry the inhabitants who had, or who were suspected of having, any of the stones in their possession. Indeed, so thoroughly did they fulfil their mission, that any one they laid hands upon who was found to have money, was suspected of either having sold or being about to purchase sapphires, was thereupon despoiled, and if not arrested and confined, was placed under observation.
>
> The effect, as described by the few Europeans, principally missionaries, who live in the country, has been to cause those who knew, or thought they knew, other localities where similar stones were to be found to remain silent, and to conceal evidence of their knowledge so as to escape oppression.
>
> Valentine Ball, 1885b

Theft of stones was a constant problem, and remains so today, with "gangs of hardy smugglers" appearing out of nowhere, ever ready to take advantage of the extreme remoteness of the locale to pilfer stones (Middlemiss, 1931). Due to the altitude, conditions were difficult at the mines. Even in the best years, mining was limited to the three short summer months of July-September, being covered in snow at other times. Some years, barely 30 days of mining were possible, due to snow.

In the year 1887, on finding a steady decrease in revenues from the mines, the Maharajah approached the Government of India for assistance in assessing and developing the site. T.H.D. (T.D.) La Touche, a trained geologist, was dispatched to the site in September of that year. His account (La Touche, 1890) was the first scientific description of the area.

Upon his arrival, La Touche found that material was obtained from two different sites. The first of these, now

Figure 12.64 This 3.03-ct Kashmir sapphire illustrates the color and velvety texture which has made stones from this locality so famous. (Photo: ©1986 Tino Hammid; gem: Meyer & Watt)

termed the "Old Mine," was a group of shallow pits sunk into an actinolite-tremolite rock containing small pegmatite lenses, high on the northeast wall of Kudi Valley. The vast majority of fine stones were found in these lenses. Sapphires were also mined from the placers 250 m below the Old Mine, on the valley floor, but were generally of lower quality.

La Touche also traced the pegmatite-bearing rock through the ridge to the north side, and did discover large blocks of corundum-bearing granite. However, despite La Touche's ingenious attempt to create a landslip to trace the source of these blocks, it was not found. Since that time others have also attempted to locate sapphire-bearing lenses on the opposite side, but without success.

At the time of La Touche's visit, the Old Mine was practically exhausted. Although another site (termed the 'New Mine'), was later found, it produced little. What this means is that virtually all of the large fine Kashmir sapphires in existence were taken from the site known as the Old Mine during the period from 1881–1887. In just six years, this mine produced such a quantity of fine stones that they achieved a reputation second to none among sapphires. So fine was their quality that, today, they remain the standard against which all others are measured. Utterly incredible, but absolutely true.

Finding the Old Mine exhausted, La Touche turned his attention to the placers below, and worked them with mostly mediocre results. One success, however, was the discovery of a 6 oz (933 ct) parti-colored giant. In 1888, he was back for another try, but found little.

From 1889 to 1906 there was a lull in official mining, with the only digging being that of poachers. In 1906, the Maharajah leased the mines to private interests. C.M.P. Wright reworked the placers after much study and obtained many fine stones. 1907 brought the discovery of the New Mine, a few hundred meters southeast of the Old Mine. Wright, however, was eventually forced to abandon his efforts, due to the many difficulties encountered in mining in such an inhospitable region. Active efforts did not resume until 1924.

In 1926, Lala Jagan Nath reopened the New Mine and extracted over 60 kg of corundum. His license was revoked for irregularities just one year later. 1927 was to be the last gasp of the Kashmir sapphire mines. Over 450 kg was taken from the New Mine in just 15 days, but few fine cut stones above 10 ct resulted. Middlemiss, in his report of 1931, had great hopes for the mines. These were based, in part, on the potential of discovering the sapphire outcrop on the opposite side of the ridge. Unfortunately, his hopes were never realized.

Figure 12.65 The sapphire washing apparatus constructed by La Touche at the Kashmir mine. Taken in 1887–8, this is the earliest photo known of mining at this storied location. (From La Touche, 1890)

In 1944, geologist R.V. Gaines and R.C. Rice, both on leave from the US Army in Calcutta, visited the mines. They found most openings had been walled up and sealed to prevent poaching. As a further hindrance, in addition to the permanent police post at Kudi, a platform was erected on the ridge overlooking the mines. This platform was named the "Black House," in allusion to the bleak and lonely life of the three policemen stationed there (Gaines, 1946). It later burned and has not been rebuilt (Atkinson & Kothavala, 1983).

Today the adits are heavily barred to prevent entry and the entire valley is closely watched by a small team of police stationed at its mouth year round (Atkinson & Kothavala, 1983; Steve Karpa, pers. comm., 1990).

Since 1927, the mines have been worked intermittently, but with no real success. Every few years the Kashmir Government makes noises about leasing out the mines, but so far these attempts have not come to fruition (Anonymous, 1977b, 1978, 1979a, 1979c).

Description of the deposit

Mining methods at the Kashmir mines have always been primitive, due to the altitude and remote location. Still today, the mines remain accessible only by foot or helicopter. The closest roadhead is at Kishtwar, 6–8 days' march from the mines. Much of the journey is over narrow mountain paths fit only for man and small pack animals. In many places large rivers must be crossed, spanned only by hanging bridges not designed for large loads. This, as much as anything, has ensured that mining methods remain primitive.

The sapphires of Kashmir occur in outcrops high on the wall of the Kudi Valley. Within an actinolite-tremolite rock, small pegmatite lenses occur, and it is within these lenses that the sapphires are found. Originally a landslip exposed the sapphires at the surface, allowing discovery. At first, huge

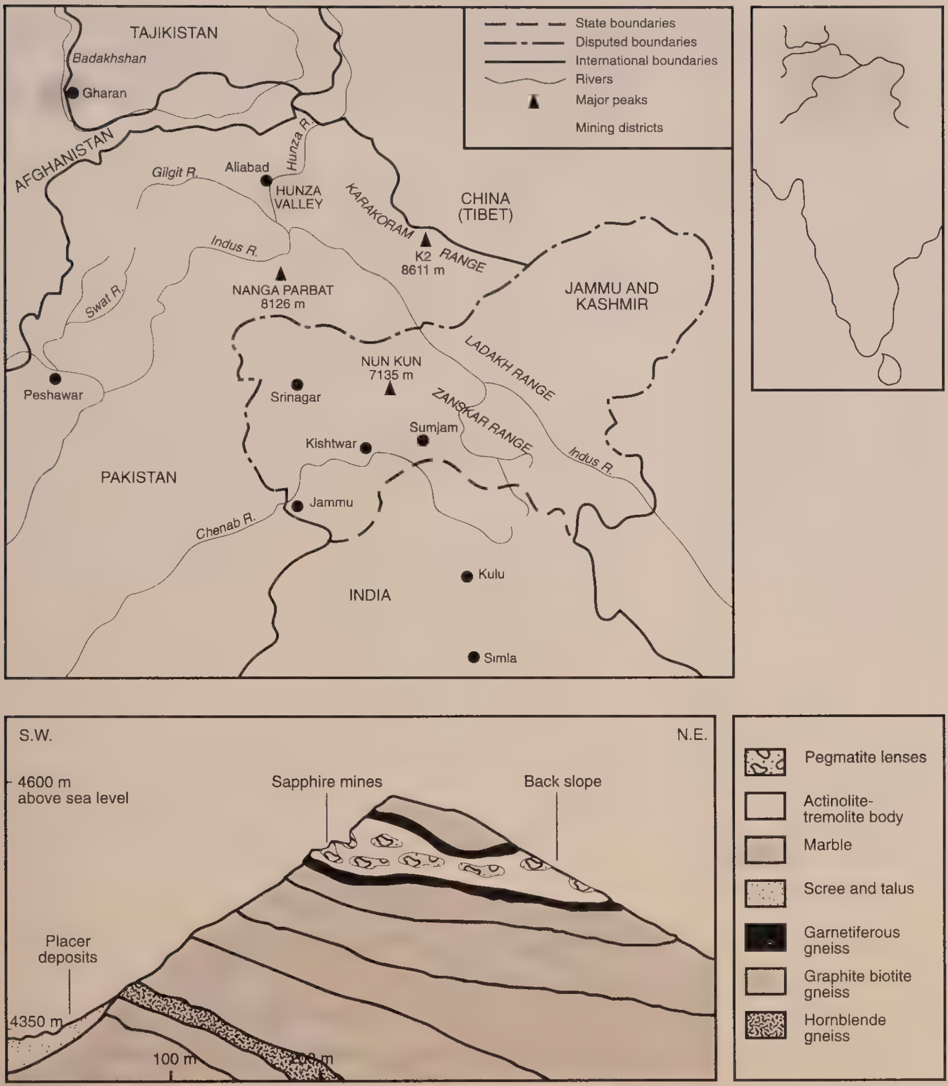

Figure 12.66 The location and geology of the famous Kashmir sapphire mines near Sumjam. Rubies are mined near Gharan in Afghanistan/Tajikistan, as well as near Aliabad in Pakistan. (Modified from Atkinson & Kothavala, 1983; based on Middlemiss, 1931)

quantities were obtained by simple digging. In places they were as thick as "plums in a pudding," and sometimes of enormous sizes. Many of the finest stones were obtained by the Maharajah and were stored at the Kashmir State Treasury. A number of authorities reported that large sacks and chests containing literally a king's ransom worth of rough and cut sapphires lay hidden away in the Kashmir State Treasury Chambers. The material, culled from 40 years' production, was quite literally the cream of the crop. C.S. Middlemiss (1931) described this hoard as follows:

> We are aware that one of these outcrops, namely that of the Old Mine, continued yielding gemstone [sic] for an appreciable time, and gave an extremely good output of very large stones from about the year 1881 to about 1887. This is a historical fact and is well known to many living people. A few specimens of sapphire then collected are still preserved, jealously guarded by the State, in the *toshakhana* [treasury], and have been seen by the writer. Of these there is at least one large piece, bigger than a polo or croquet ball, and others smaller all of a rich blue colour. There are also many cases of cut gems of pendant size which are superficially as large as florins.
>
> C.S. Middlemiss, 1931

Incredible! Bigger than a croquet ball. What became of these stones? We just do not know. Although many merchants visited Jammu and Srinagar with the intention of purchasing some or all of these stones, their offers were refused (Halford-Watkins, 1935). The present author recalls reading about a caretaker trying to steal this treasure about 1978–82, taking one piece each day in his lunch pail. He was caught and the stolen goods apparently recovered. Since then, nothing further has been heard of the "hoard of Kashmir." All we can do is wait and hope.

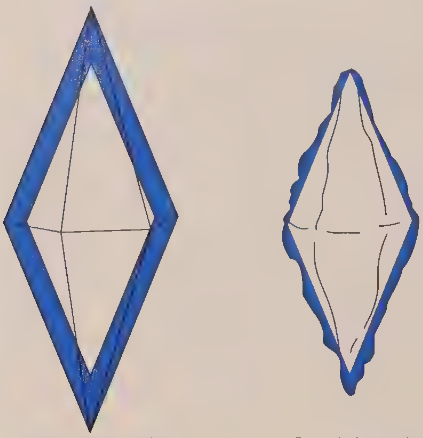

Figure 12.67 The famous Kashmir sapphire mines produce two different types of rough. Some of the crystals display heavily corroded surfaces, while in others the original crystal surfaces are largely intact. Like the *ottu* sapphires from Sri Lanka, the color in Kashmir sapphires lies mainly along the crystal faces, with the core of the crystal being colorless. Unfortunately, in the corroded crystals this vital color layer is largely absent, making them poorly suited for cutting. Both corroded and uncorroded crystals have proven satisfactory for heat treatment. (Redrawn by the author from Middlemiss, 1931)

Middlemiss also discussed the failure of all the first geologists on the scene to describe the actual occurrence from which these fine stones emanated:

> But of the details of the *in situ* rock occurrence whence these magnificent trophies were won we unfortunately know hardly anything, nor have we any recent descriptions by the Mineral Survey or Mining Engineer of the nature of the quarry, pits or other openings made by the early pioneers at this place. It is a curious fact that all the geological and mining men who have visited and reported on these mines, from La Touche downwards, though agreeing as to the position of the Old Mine workings, have one and all seemed to shirk any description of them. Are they rock-face workings, irregular burrowings, tunnels, pits or what, what is their extent and how deep from the surface do they go? We simply do not know! La Touche, in his published paper simply says "here the face of the rock has been laid bare by a landslip, and at first the sapphires were taken out of the granite itself: but when I visited the mines this patch of rock had ceased to yield any for some time, nor did the closest search bring any more to light". Labhu Ram in his report says "the Old Mine is also located in the same actinolite-tremolite mass that contains the New Mines.... No trace of pegmatite veins is found near it and the mine has not yielded any stones for very many years since the late eighties". Later on in his report he discusses the point whether or not the sapphire may have had a different source altogether to that of the New Mines "having been derived either from the garnetiferous gneiss bands found exposed above and below the mine, or directly from the actinolite-tremolite schist".
>
> None of the others who visited the mines, including the Mining Engineer, have anything to say at all on this matter.
>
> This is all very unsatisfactory; but at least we may conclude that very large sapphire pieces were got from this point of the rectangular area mentioned above, although details as to its matrix, mode of occurrence and the nature of the workings remain obscure.
>
> C.S. Middlemiss, 1931

Evidently, those who did have a chance to observe the workings at the Old Mine were so impressed by what was found that they completely forgot to describe the workings. This means that we know little about how these incredible stones were obtained. Today all that remains of the Old Mine are a few shallow burrows dug into the rock.

About 100 m from the Old Mine are a series of shallow adits distributed over a small area. In the early 1980s, much blasting had been done to get at the sapphire-bearing pegmatite (Atkinson & Kothavala, 1983).

Kashmir sapphires compared

Overview. In the 30–40 year period during which the mines were intensively worked, Kashmir sapphires achieved a reputation second to none. Today, with the exception of estate sales, fine Kashmir sapphires are virtually unobtainable, mute testimony of the degree to which they are coveted. Outside the collection seen in the Jammu and Kashmir State Treasury, few cut stones of greater than 65 ct have been reported (Schwieger, 1990). Crystals are sometimes of enormous size. Mallet (1882) reported on one which measured 1 ft (30 cm) in length.

Color. Kashmir sapphires range from near colorless through a deep blue, with the occasional pink to purple stone found. The large fine gems of years gone by were generally cut from the blue areas of much larger crystals. Those specimens that possess smooth faces contain this blue layer intact. However, many pieces feature heavily corroded surfaces and thus the blue layer is only partially present, if at all. The following description of Kashmir sapphire by Jaipur gem trader, Rajroop Tank tallies well with the author's experience:

> KASHMIR:—The Sapphires of Kashmir form an exclusive class of their own. In the Jewel trade it is customary to attach the appellation 'Kashmir' to any fine Sapphire regardless of its geographical origin. This is an indication of the outstanding qualities of Kashmir Sapphires. The colour of these Sapphires resembles the beautiful hue of the peacock's neck. Even a small concentration of that fine colour illuminates the entire structure of the Gem.

The treasures of Kashmir—Mother lode, or mother of futility?

IS the Kashmir mine played out, or do riches still await those patient enough to explore further? The possible answer lies in the nature of the occurrence. Kashmir sapphires occur as the result of pegmatites cutting through a limestone. Heat from the intrusion has resulted in metamorphism of the limestone to marble, with corundum forming at the fringes. Such heat does not normally occur in one area only. Thus the discovery of sapphire in Kashmir is possibly more widespread than what has so far been discovered. While La Touche reported that placer yields were found to decrease at the lower end of the valley, and below the 1 m level. it is possible that he was testing only the fringes of the deposit (Delmer Brown, pers. comm., 30 Nov., 1994). Similarly, the primary pockets in which the sapphires are found are probably scattered throughout the fringes of actinolite-tremolite band. Typically, the nature of such pocket-based occurrences is feast or famine, and history is replete with examples where such mines were abandoned just a few meters or days' work short of paydirt.

In the case of the Kashmir sapphire mine, a logical course of exploration would involve mapping the extent of the intrusions within the limestone. Then it would be a matter of bringing in appropriate equipment and getting down to work. As the Russians have shown with their Siberia diamond mines, extreme weather is not a barrier for those who have the drive to succeed. A road could be constructed from the mine to a lower-altitude area with plentiful water for washing the sapphire ore. This ore could then be stockpiled in the winter months, for later washing in summer. But with the Kashmir mines, location and access are just convenient excuses for a lack of action. The real barriers to mining in this area are the backward economic policies of the central government, and the political problems which have resulted from the conflicts with Pakistan. Until these problems are solved, the famous sapphires of Kashmir will continue to repose in their icy tomb.

> It may, however, be noted that the product of the Kashmir mines suffers more from flaws and blemishes than that of many other mines. The Gems of Kashmir mines often have window, hole, or cavity in their texture, and they also suffer at times from ambiguity of colours. It requires special skill to cut the Jewels as the crystals are covered with a hard crust of earth and it is difficult to know beforehand the internal structure. If a specimen is free from cavity or window and does not exhibit ambiguity of colour it can be cut into an excellent Gem. The produce of the old mine in Kashmir did not suffer from so many blemishes, but the Sapphires of that mine are no longer available.... Kashmir Sapphires generally remain thick after cutting. Stars are not found in them.
>
> Rajroop Tank, n.d., *Indian Gemmology*

New Mine & placer sapphires. Sapphires found at the New Mines differ in one important respect from those of the Old Mine, and this difference is important in understanding Kashmir material. New Mine material comes in two types, both of which are coated with a tenacious white clay. In almost all, the blue color is found mainly at the outer crystal edges, especially the tips. Virtually all are spindle-shaped hexagonal bipyramids, as shown in Figure 12.67. Other than the blue tips and faces, the rest of the crystal is typically colorless (the New Mines also produce the occasional stone with blue tips and a pink core). What this means is fine blue stones must be cut from the tips of the crystals, similar to the way in which Sri Lanka's *ottu* sapphires are cut. Witness the statement by Parkinson (1952):

Figure 12.68 Kashmir sapphires, such as the stone above, are often cut as sugarloaf cabochons. Note also the blackish color, which many Kashmir sapphires display. (Photo: Mouawad, Geneva)

> I am quite satisfied that many of the so-called "Kashmir sapphires" are actually of Ceylon origin; certainly they are not mined in Kashmir.

To this author, it seems that Parkinson saw a stone that *looked like* it was from Ceylon, and so assumed it was. Many faceted Kashmir sapphires bear a certain resemblance to Sri Lankan *ottu* stones.

One of the ways in which *ottu* stones are typically cut is to lay the table facet parallel to a pyramid face, along the intensely colored area at that face (see Figure 9.3 on page 200). While this produces a larger stone, it also produces an overly blackish color, as well as losing the velvety softness. Many Kashmir sapphires display this color.[3]

In the vast majority of New Mine and placer stones, the blue faces have been corroded away. Rather than having flat, well-formed faces, most have deeply pitted faces; thus the colored areas are, by and large, missing due to surface corrosion. When the faces are intact, fine stones can be cut. This fact alone may account for the great scarcity of fine Kashmir sapphires, as the Old Mine, where evenly-colored stones

3. An illustration of this is in 12.68. Contrast it with Figures 12.62 and 12.64, which shows the classic Kashmir color and velvety luster. See also Figure 3 in Schwieger (1990), which shows 22 faceted Kashmir sapphires, nearly all of which display this blackish color.

Figure 12.69 Blue velvet—Inclusions of Kashmir sapphires
Top left: Most distinctive of the Kashmir sapphire inclusions are the rounded zircon crystals with tiny accompanying black uraninite crystals.
Top right: Healed fissure with flat, strongly recrystallized cavities (negative crystals) in a Kashmir sapphire. Some of these cavities contain tiny opaque crystals of unknown identity. 50×.
Below left: Pargasite crystal in Kashmir sapphire.
Below right: Tiny hexagonal crystals with thin-film satellite haloes in a Kashmir sapphire. These are similar to those found in Thai/Cambodian rubies.
(Photos: Henry Hänni/SSEF)

were apparently more common, has produced virtually nothing since 1887.

Old Mine sapphires. Probably the only detailed description ever recorded of Old Mine material was that of Grahame Young of Kulu, which is reproduced here:

> ...The vein consists of
> I. Ordinary quartz crystals, some very large.
> II. A few crystals of amethyst.
> III. Deep blue corundum of a beautiful water, very rough externally, no crystal more than 4 inches [10 cm] long; sp. gr. 3·985.
> IV. Corundum, sapphire-colored only in the middle, shading lighter until both base and apex are perfectly limpid.
> V. Perfectly limpid corundum.
> VI. Black corundum.
> VII. Opaque white corundum, sapphire tinge in places, small black crystals (probably tourmaline) imbedded. All the above are beautifully crystallized, apex very acute.
> VIII. Massive corundum, both black and opaque white.
> IX. Chlorite, crystals imperfect.
> X. A little magnetite.
>
> ...The facts I have collected regarding the first discovered deposit are derived from an examination I made of about an hundred weight [1 cwt. = 50.8 kgs] of the crystals; their owner would not allow me to apply any tests, but I used a compound lens magnifying 30 diameters.
>
> A. Grahame Young, Kulu, Aug. 8, 1882 (from Shepard, 1883)

The above was written prior to the discovery of either the New Mine or valley placers. Extrapolating, we can surmise that at least *some* Old Mine material contained substantial internal coloration (nos. III. and IV. above). From this location of color in the crystal, we can further extrapolate that the polished shapes of those Old Mine stones with substantial internal color would differ from New Mine stones. In fact, many of the Kashmir sapphires today sold at auction are cut as "sugarloaf" cabochons. While this is in contrast to Tank's statement that Kashmir sapphires generally remain thick after cutting, he was probably familiar only with New Mine material. The author's own experience with New Mine material also agrees with Tank's, in that gems are often strongly zoned and cut with deep pavilions, similar to

Sri Lankan *ottu* sapphires. But apparently the Old Mine produced some material which would allow both more even coloration and, thus, stones cut to normal proportions.

In summary, it is impossible to say, based on evenness of coloration and shape, that an individual stone came from the Old or New Mine. Both mines produced the *ottu*-type material so similar to that from Sri Lanka. But based on the historical record, the Old Mine appears to have produced far more of the top-grade, evenly-colored material.

Heat treatment. Heat treatment can produce dramatic results with Kashmir sapphire. One large lot examined by the author both before and after burning showed a success rate better than even the best Sri Lankan *geuda* material. Nearly every piece had been transformed to a rich blue color. Why aren't we seeing this material in the market? The answer is simple. No rough. Even low-grade material is scarce, and no mining is being done at present.

Characteristics of Kashmir sapphire

The following is based on the studies of Gübelin (1953, 1973), Gübelin & Koivula (1986), Hänni (1990a), Phukan (1966) and Schwieger (1990), as well as the author's own studies on a 1 kg lot of Kashmir material.

Crystal habit. Kashmir sapphires bear a strong resemblance to those of Sri Lanka, with almost all being spindle-shaped hexagonal bipyramids. Some of these are flattened slightly. However, the Kashmir stones often consist of intergrowths, with one crystal twisted around another, or even as multiple intergrowths of as many as ten or more crystals grown together in a single mass. Kashmir sapphire rough is easily recognized due to its distinctive mode of occurrence. Coated with a white clay-like matrix, which fills the pits of heavily corroded surfaces, this clay-like material also appears to be included in many stones with irregular cavities just beneath the crystal surfaces. So tenaciously does it cling to the skin that hydrofluoric acid is required for its removal.[4] Most crystals are small, in the 1–4 ct range, and some feature small brown tourmaline prisms[5] and mica flakes adhering to their surfaces, or intergrown with them.

Solids. Kashmir sapphires contain solid inclusions of a number of types, but these are generally small, requiring magnifications of up to 100× to resolve their morphology. Most distinctive are the small, slightly corroded, colorless crystals of zircon. Commonly adhering to these are tiny black crystals of uraninite. Uraninite also occurs alone, typically with radiating stress fractures.

Occurring with the sapphires are dark green and brown prisms of tourmaline. These may be found growing right up against the sapphire and are occasionally included within the gem itself. Euhedral allanite crystals have also been encountered, as well as long needles of pargasite (amphibole). Specimens examined by the author have also displayed inclusions of what appears to be mica. Unidentified brown crystals of large size have been seen by the author in one specimen.

Figure 12.70 The turbid, silk-based zoning that is the hallmark of Kashmir sapphires. (Photo: Henry Hänni/SSEF)

Cavities. Among the most distinctive inclusions of the Kashmir sapphires are the negative crystal guests. These tend to occur in patterns and in many cases contain small black crystals growing within. These black crystals are prismatic in habit and may possibly be tourmaline. The negative crystals containing black crystals within represent the most distinctive inclusion feature of the Kashmir sapphires examined by the author.

Growth zoning. Due to the irregular distribution of color in Kashmir rough, cut stones will also often display strong color zoning, similar to Sri Lankan material.

Exsolved inclusions. The hallmark of the Kashmir sapphire is its velvety texture, a slight haziness which, under magnification, is revealed as numerous fine lines intersecting in three directions at 60/120° in the basal plane. The identity of these tiny exsolved inclusions has in the past been the subject of much dispute (see Phukan, 1966; Gübelin, 1953) While their exact identity is still yet to be determined, today it is generally accepted that they consist of exsolved rutile (Hänni, 1990a; Schwieger, 1990).

The silk of Kashmir sapphires differs from that of Burma and Sri Lankan stones in terms of the size of the needles. Many appear as tiny dots in snowflake patterns, and magnification of 40× or more is often required to resolve individual needles. Due to its extremely fine nature, Kashmir silk provides subtle light scattering without materially affecting transparency, giving these gems their velvety appearance.

This haziness is present in virtually every piece examined by the author, but is not the sole province of the Kashmir stone. Sapphires from Sri Lanka, Thailand (especially

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4. See page 110 for cautions on the use of this acid.
5. Termed "coal" by local miners (La Touche, 1890).

Table 12.11: Properties of Kashmir sapphire[a]

Property	Description
Color range/phenomena	• Near colorless to a deep blue (almost black), including a highly prized, rich 'velvety' blue that is considered sapphire nirvana to connoisseurs • Rarely pink to purple • Six-rayed stars are known, but are rare
Geologic formation	• Sapphire occurs at the contact zone of a pegmatite intruded into a marble, in association with actinolite-tremolite. They are most abundant where the intrusions are quartz-free and surrounded by the actinolite-tremolite. The crystals are found in lenticular pockets of kaolinized plagioclase feldspar.
Crystal habit	Spindle-shaped hexagonal bipyramids are most common, sometimes terminated by the basal pinacoid. Most crystals are coated with a tenacious white kaolin clay. Dark brown tourmaline crystals are often found adhering to the crystal surfaces. The color generally lies near the tips and exterior surfaces of crystals, similar to *ottu* sapphires from Sri Lanka. Two distinct crystal types are found: • Euhedral crystals, with flat faces, where the color layer is intact • Corroded crystals where the color layer has been partly or completely dissolved. The blue color of such crystals often appears as mottled blue spots.
RI & birefringence	n_ε = 1.762; n_ω = 1.770 Bire. = 0.008 (based on one specimen only)
SG	4.03 (based on one specimen only)
Spectra	• Weak to moderate Fe spectrum. Cr-rich stones may display a weak Cr spectrum superimposed on this.
Fluorescence	**UV**: Generally inert (LW & SW)
Other features	May be heat treated
Inclusion types	**Description**
Solids	• Allanite, euhedral crystals (Hänni, 1990a) • Feldspar (plagioclase in strongly corroded crystals (Hänni, 1990a) • Pargasite (amphibole), needles & prisms (Gübelin, 1973) • Tourmaline (dravite): prisms, green to brown color (Gübelin, 1973) • Uraninite, black crystals often embedded in zircon. When alone, they may have stress fractures around them. Uraninite crystals are distinctive and important in separating Kashmir sapphires from other sources. (Hänni, 1990a) • Zircon: corroded crystals, sometimes long needles (Phukan, 1966)
Cavities (liquids/gases/solids)	• Primary cavities and negative crystals • Secondary negative crystals (healed fractures) are distinctive and may contain black crystals (uraninite in the cavities)
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed. In Kashmir stones this is often composed of alternating clear and turbid zones. Such turbidity is responsible for the 'velvety' appearance of many Kashmir stones. • Color zoning is often restricted to the areas just beneath crystal faces; such stones are termed "ottu" in Sri Lanka
Twin development	• Growth twins of unknown orientation • Polysynthetic glide twinning on the rhombohedron (not common)
Exsolved solids	• Rutile in fine clouds of generally tiny needles, parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane. This rutile tends to be much finer than that found in Burmese and Sri Lankan sapphires. Often only tiny particles are seen; these may occur in tiny 'snowflake' patterns. • Clusters of dust-like inclusions (probably rutile) which may resemble snowflakes

a. Table 12.11 is based on the author's first-hand experience, along with published reports of Gübelin (1953, 1973), Gübelin & Koivula (1986), Hänni (1990a), Phukan (1966) and Schwieger (1990).

Kanchanaburi) and Pailin may also exhibit a certain milkiness, making confusion a real possibility. The haziness in Kashmir stones, however, is extremely fine in nature, not enough to seriously degrade the clarity, but just enough to impart the distinctive velvety luster to the stones (see Hänni, Fig. 1, p. 69, for an excellent illustration of this effect).

Other corundum localities in India

Kashmir is not the only locality in India producing corundum. Other sources exist, but are of lesser importance in world markets, due to the lower qualities of production. Other Indian corundum localities are given in Table 12.12 (based on Iyer & Thiagarajan, 1961, Kuriyan, 1993a–b, Viswanatha, 1982).

Indian ruby

For many years India has been the world's biggest supplier of low-end ruby cabochons and star rubies. These localities include:

Andhra Pradesh. Low-quality ruby (including stars) has been reported from a number of areas in Andhra Pradesh state. These include Anantapur, Krishna, Kurnool, and Warangal (Fernandes & Joshi, 1995).

Bihar. Facet-grade ruby has been reported from an unknown locality in Bihar. The percentage of facet-grade material has been reported up to 25% of total production (Durlabhji, 1994).

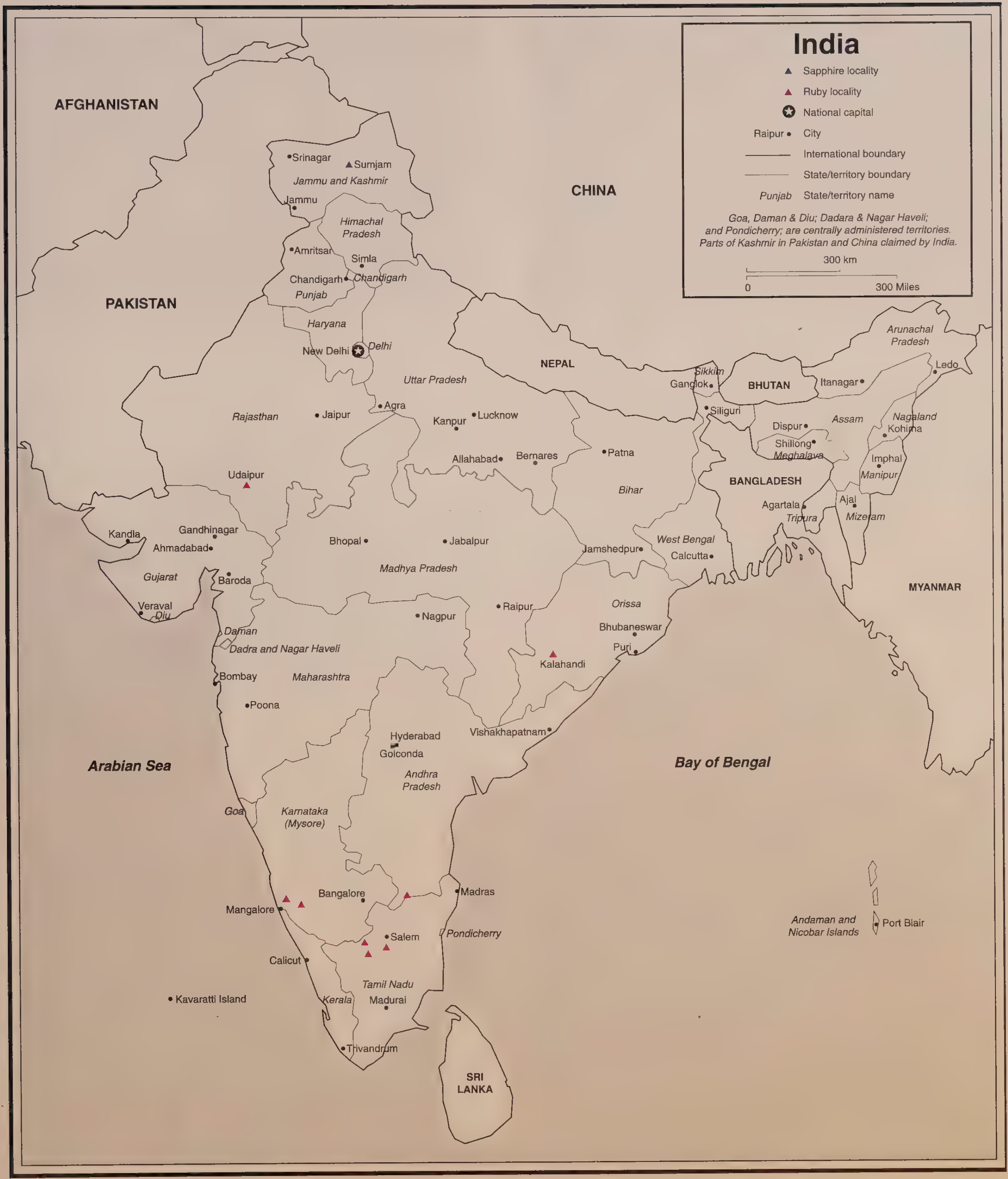

Figure 12.71 Map of India showing the principle corundum localities. Major mines are located in Kashmir, Orissa, Karnataka and Tamil Nadu States.

Figure 12.72 Fine rubies have recently been found in India's Orissa State, as the above photos show. (Photos: Bart Curren/ICA)

Kangayam (Tamil Nadu). Facet-grade ruby occurs in the Kangayam area of the state of Tamil Nadu, of which Madras is the capital. Stones from this area are of a reddish color with a slight darkish tint, but are generally heavily included. This source also produces star rubies.

Karnataka (including Mysore). Another important ruby source in India. Gems come mainly from the Channa-Patna area, but lack transparency and so are suitable only for cabochons and beads.

The Indian star rubies are generally heavily included, and so of poor color and transparency. They do possess sharp stars; however due to the lack of transparency the color is poor, and so they are usually but a few dollars per carat, or less.

Orissa. In the early 1980s, important gem strikes were made in Orissa, eastern India. These included both ruby and sapphire. Ruby is found at Jhillingdhar, Hinjhrilbahal, Charbati, Rabaandangar and Odashali in Kalahandi district, while sapphire is found at Amera and Karlakot in Kalahandi, and Sangamara in Balangir district. To date, with the exception of the ruby mine at Jhillingdhar, most mining is done by small teams of locals (Kuriyan, 1993a–b). Rough ruby is of variable shapes, from distorted hexagonal crystals to rolled pebbles. They often have a coating of greenish-black or brown material. Facetable material is said to be relatively rare. Sambalpur district has also been reported as a source of ruby in Orissa (Durlabhji, 1994).

Because of their poor clarity, Indian star rubies they are often dyed and oiled. Most are filled with cracks, polysynthetic twin lamellae and parting planes which allow penetration of oils and/or dyes. The Indian trade magazine, *Journal of Gem Industry* (Anonymous, 1976), suggested that "the packing material used in wrapping these stones should never be absorbent, if good customer relations are desired." Perhaps even better customer relations would result from omitting these dyes and oils altogether.

Figure 12.73 A large, low-quality star ruby from India's Mysore district. While such material is a staple of the low-end gem trade, today India also produces some better material. (Photo: Royal Ontario Museum)

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Table 12.12: Other corundum localities in India

Gem tracts
Andhra Pradesh • Anantapur, Khammam, Krishna, Kurnool, Nellore, Visakhapatnam and Warangal districts • Guntur district: Ruby • Bellary district: Sea-green sapphire
Assam • Nongryniew, Khasi Hills: Clear colorless corundum
Bihar • Unknown locality: Hexagonal ruby crystals coated with a blackish material
Karnataka (including Mysore) • Bangalore, Bellary, Chikmagalur, Chitradurga, Coorg, Hassan, Kolar, Mandya, Raichur, Shimoga and Tumkur districts
Kerala • Travancore district
Madhya Pradesh • Betul area
Orissa • Kalahandi and Balangir districts
Rajasthan • Udaipur district
Tamil Nadu • Kangayam–Karur–Palni areas in Coimbatore, Madurai and Tiruchirapalli districts • Salem district

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Figure 12.74 Mining for ruby in Kenya's Tsavo National Park. (Photo: E.J. Petsch/ICA)

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Italy

Sapphire and ruby have been reported in the sands of Lonedo in Venice. Corundum also occurs at a number of localities in Piedmont and at Monte Aviolo, on the slopes of Adamello in Lombardy.

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Japan

Non-gem ruby in gneiss has been reported from the Hida metamorphic belt of Japan. It is thought to have formed via contact metamorphism (Suzuki, 1970; as quoted by Hunstiger, 1989–90).

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Kenya

Many gemologists and traders believe Africa to be the source of the future. A huge continent with large areas still unexplored, it has tremendous mineral potential. Since the early 1960s, we have begun to get a taste of African corundum, with new discoveries of great importance. Nowhere on the continent is this more true than in East Africa's Mozambique Orogenic Belt, particularly Kenya and Tanzania (see page 410).

Kenya is a land of fabulous game reserves and a relatively liberal economy. It is also a land of untold gem wealth, much of it just beginning to be tapped. Included in Kenya's gem riches is ruby. With the world's important ruby deposits numbering less than the fingers of one hand, the discovery of gem qualities in Kenya was important in its own right.

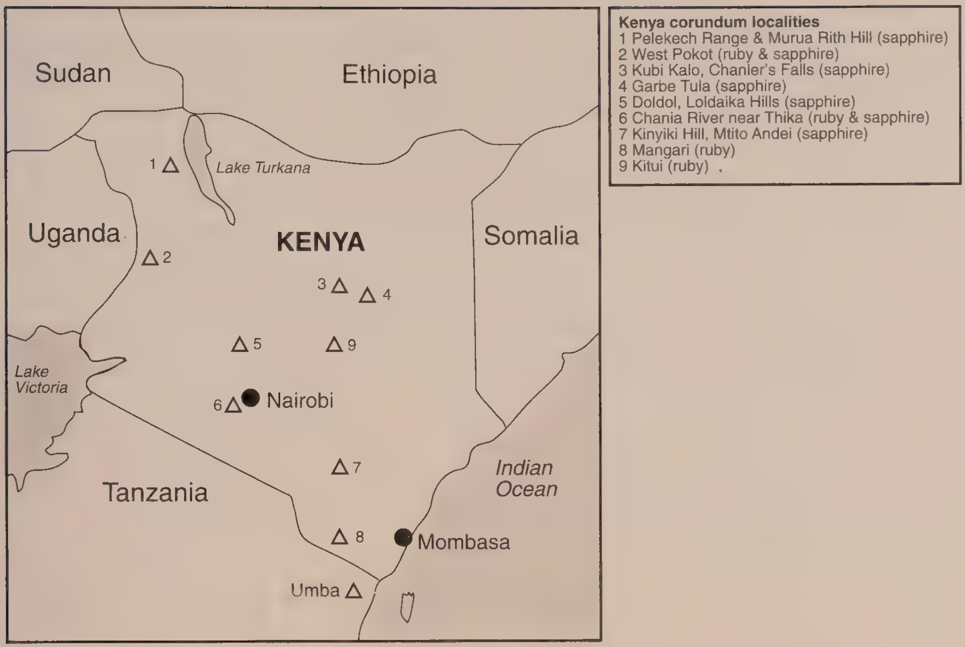

Figure 12.75 Map of Kenya showing the important corundum localities.

However, it was for an entirely different reason that the discovery made world headlines in 1974.

Two geologists' dream: Their own ruby mine[6]

In 1973, American geologists John Saul and Elliott ('Tim') Miller were prospecting in Kenya's Tsavo West National Park for chromium and vanadium-bearing gemstones when they found what has become one of the world's richest deposits of ruby. Saul, a long-term Kenya resident, did what any miner would do—he obtained a fully legal permit to mine the deposit. In Kenya, however, things did not work like elsewhere. Thinking that local participation would smooth the way, they shrewdly offered 51% ownership to a group of high-ranking Kenyans. Little did they know that their find would set off a controversy spanning two continents (Anonymous, *Time*, 1974; Mohr, 1974).

Unfortunately for Saul and Miller, others soon learned of the find. One was Beth Mugo, then President Jomo Kenyatta's niece and unofficial lady-in-waiting to his wife, Mama Ngina. Another was a wealthy resident of Greek extraction, George Criticos. Criticos was a friend of Kenyatta's and involved with his wife in running the Kenya Trade and Development Corporation. Saul and Miller charged that Mugo and Criticos encouraged other leading Kenyans, including Mama Ngina, to demand a larger share of the take. Saul and Miller agreed, increasing the Kenyans share to 72%, but it was not enough.

Within a matter of days, the total "requests" by influential Kenyans came to exceed 150% of the ownership, with no end in sight. June of 1974 saw Saul suddenly declared a "prohibited immigrant" and given less than three hours to leave the country. Miller, who had been out of the country, returned, but found it advisable to go into hiding. After a month on the lam he, too, left. Kenyatta, in an oblique reference to the ruby mine, publicly declared after Saul's expulsion that no foreigner should be allowed to exploit Kenya's resources for his own private benefit. Laudable as his stand was, in this instance it rang hollow; the wealth of the mine was apparently intended exclusively for Kenyatta and his cronies.

Perhaps Kenyatta should have supplied paper weights to the Ministry of Natural Resources. The record of Saul and Miller's original claim[7] mysteriously disappeared about the same time a different claim for the mine appeared, this time in the name of George Criticos. No doubt the exchange occurred during a particularly ill wind. This was *after* a local court issued an injunction forbidding Criticos from working the deposit. But even the court injunction did not stymie Criticos, for he continued to mine the claim. After all, why worry about such trivial matters as court orders when one is tight with the President and his family?

6. Much of the information in this section has been provided by a party who wishes to remain anonymous.

7. Saul deposited duplicate copies of the claim with then US ambassador to Kenya, Anthony D. Marshall.

Despite protests by the US ambassador and a lawsuit by Saul and Miller in the Kenyan courts, the mines were never returned to their rightful owners, although some compensation was paid. But the mine's legacy lives on in the minds of the people of the region. Today the deposit is known as the "John Saul" mine (Bridges, 1982), and its classic color is termed "johnsaul color."

Description of the Mangari deposit

Kenya's most important ruby mines lie approximately 80 km northwest of Tanzania's Umba corundum deposits, in the area of Mangari, just within the north-eastern tip of the southern section of Tsavo-West National Park. Here, at the junction of the seasonal Mwatate and Bura rivers, are the ruby mines which initially generated such controversy. There are actually two mines, consisting of altered ultra-basic intrusive bodies lying about 3.2 km apart. Although close together and of similar geologic occurrence, the quality of rubies found at each is distinctly different.

The more easterly deposit is known as the *Penny Lane Mine,* while the westerly pipe is termed the *John Saul Mine.* The ruby occurrence has been described as follows (Pohl & Niedermayr *et al.,* 1977, as quoted by Bridges, 1982):

- In desilicated veins cutting through altered and serpentinized ultramafic rocks (Penny Lane).
- In or near the contact zone (of the serpentinized pipe) associated with desilicated pegmatoidal segregations (John Saul).

At Penny Lane, large open-cast pit diggings have been made into a yellowish green, tremolite-actinolite, talc, chlorite rock, following narrow mica-rich (sericite, vermiculite?) veins, with which kyanite and crystalline limestone segregations are sometimes found (Bridges, 1982). The rubies occur in pocket-like clusters along these veins, especially where mica is concentrated. Mica adheres to the rubies' surfaces and, when removed, reveals euhedral to subhedral ruby crystals of a dark red to dark pinkish red color. These stones fluoresce a strong crimson under ultraviolet light and, like most rubies, improve greatly when illuminated by incandescent light. However, almost all are heavily included and so are suitable for cabochons only. Dark green tourmalines are also found in the pegmatites of the area (Bridges, 1982).

Rubies found at the John Saul Mine occur within the contact zone of a rhomb-shaped pipe measuring about 200 m across. Plumastic pegmatites occur in this zone and are sometimes "riddled with rubies" (Bridges, 1982). The pipe itself consists of a greenish "rotten" rock, similar in appearance to the blue ground of a diamond pipe. Where chlorite is present, ruby is also encountered. Considerable eluvial reserves of ruby are said to exist in the area due to its flatness and the millions of years of weathering that have occurred.

Tim Miller has described the plant at the John Saul Mine as probably the most modern, expensive and efficient of any gem mine in East Africa (Bridges, 1982). Like most, it works on a heavy media separation principle and was chosen because it can process and sort large quantities of material. Also, with ore fed in at one end and cleaned ruby returned at the other, there is little chance for theft of stones, a major concern at any gem mining operation.

Characteristics of Mangari ruby

Relatively little has been published on Mangari ruby, which is unfortunate, for fine pieces are sometimes found. The following is based on the reports of Bridges (1982), Crowningshield (1974), Keller (1992), Key & Ochieng (1991a), and the author's own study of the material.

Overview. The author has encountered faceted Kenyan rubies up to 20 ct. Rubies of the John Saul Mine tend to be lighter and brighter than those of Penny Lane, displaying a rather strong pink to purple-pink element (Bridges, 1982). The vast majority of the stones are of fine cabochon to sub-cabochon grade, but occasionally a fine small clear piece is found. All are intensely fluorescent under UV light and at times resemble Burmese rubies. However, the Kenyan stones are generally filled with thick, wispy fluid fingerprints and feathers, unlike unheated stones from Burma.[8] Such inclusions have caused many Kenyan rubies to be misidentified as flux-grown synthetics. This is unfortunate, for they are easily identified by reference to included crystals and the ubiquitous boehmite needles along polysynthetic twin lamellae.

Many Mangari rubies are brought to Bangkok for heat treatment, cutting and eventual sale. Like most rubies, their appearance is greatly improved by heat treatment, and many would be unsalable without it. Better qualities (i.e., better clarity) are often passed off as Burmese rubies, due to their strong fluorescence. Separation is usually straightforward, as the Burmese stones contain actual rutile silk and generally lack fluid fingerprints. However, recently, large numbers of Burmese rubies have been heat treated to remove this silk. This also produces numerous fingerprints and feathers which were previously rare in Burmese stones, making separation of heat-treated Burmese and Mangari rubies more difficult. Both show the obvious signs of heat treatment, such as exploded or melted crystals with tension haloes, but heat treatment obscures the origin.

Solids. Solid inclusions are less common in Kenyan rubies. White or colorless crystals of unknown identity are seen, either euhedral or heavily corroded. Some of these may show a carbonate reaction when exposed to HCl (John Koivula, pers. comm., March, 1995).

Cavities. Large numbers of fluid fingerprints and feathers are the hallmark of Kenyan rubies. Coupled with the clouds of exsolved inclusions, these give a slightly turbid appearance

[8] Today many Burmese rubies are heat treated. This process introduces multitudes of secondary healed fractures not present before treatment.

Table 12.13: Properties of Mangari (Kenya) ruby[a]

Property	Description
Color range/phenomena	• Light to deep red to purplish red; often a rich, highly fluorescent red • Six-rayed stars are possible
Geologic formation	Mangari rubies formed during regional metamorphism under upper amphibolite to granulite facies conditions. They occur: • In desilicated veins cutting through altered and serpentinized ultramafic rocks ('Penny Lane' mine) • In or near the contact zone (of the serpentinized pipe) associated with desilicated pegmatioidal segregations ('John Saul' mine) Associated minerals include muscovite, phlogopite, plagioclase, xenotime, kyanite, margarite, tourmaline, zircon, pyrite and spinel. Ruby crystals are often coated with mica.
Crystal habit	• Idioblastic hexagonal prisms and elongated hexagonal spindles up to several centimeters in diameter
RI & birefringence	Not reported
SG	Not reported
Spectra	Strong Cr spectrum
Fluorescence	Strong to extremely strong red to orange-red (LW stronger than SW), due to a high Cr and low Fe content
Other features	Most gems are heat treated
Inclusion types	**Description**
Solids	• Muscovite mica, Cr-green grains (Key & Ochieng, 1991a) • Phlogopite mica (Hunstiger, 1989–90) • Pyrite? • Rutile (Key & Ochieng, 1991a)
Cavities (liquids/gases/solids)	• Secondary fluid inclusions (healed fractures) are extremely common and often have a thick, wispy appearance which is easily confused with flux inclusions in synthetic flux rubies
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$ is extremely common
Exsolved solids	• Fine to dense clouds of rutile silk in the basal plane (3 directions at 60/120°) • Boehmite: Long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.13 is based on the author's own research, along with the published reports of Crowningshield (1974) and Key & Ochieng (1991a).

to most stones, making them suitable only for cabochons. Even faceted gems generally possess this sleepy overall look, somewhat like *lai thai* rubies (see page 441), but with extremely strong fluorescence. Many fingerprints appear thick and wispy, making confusion with the flux-grown synthetic products a real possibility. However, along with the fluid inclusions are boehmite needles and lamellar twinning, allowing a separation to be made. In heavily included gems such as the Kenyan rubies, it may be necessary to open the microscope's light source to light-field and close the iris diaphragm until it is just smaller than the stone, to examine the stone's interior.

Close examination of the fluid pockets of these fingerprints reveals a two-phase appearance in some cases. Others are seen to be tiny negative crystals which have resulted from the healing of cracks. Primary negative crystals are also found, both as well-formed individuals and as irregular cavities. These again may be confused with flux inclusions.

Growth zoning. Color zoning is common and appears both as large diffuse zones and as sharp and narrow color bands. Rhombohedral twinning is also common and is accompanied by long white boehmite needles along the edges and junctions of these planes.

Twin development. Polysynthetic twinning on the rhombohedron is extremely common.

Exsolved solids. Contrary to what the author previously reported (Hughes, 1990),[9] rutile silk is found in Mangari rubies. Thus star stones are possible (Key & Ochieng, 1991a). After heat treatment, the rutile is partially dissolved, leaving behind concentrations of minute exsolved particles arranged in an identical pattern. At times, these particles are relatively coarse, while in other cases they may be so fine that the individual particles cannot be discerned. Instead, some show only diffuse white "texture" clouds somewhat similar to those found in certain heat treated blue sapphires from Sri Lanka. These texture clouds follow the hexagonal zoning of the crystal structure.

Overall. The internal appearance of rubies from Kenya is characterized by large numbers of fluid inclusions bounded and crisscrossed by rhombohedral twin lamellae and boehmite needles. This is similar to many Thai rubies, but without the "saturn" type crystal formations and with turbid areas of exsolved matter and strong fluorescence. Immersion

9. Yes, just call me stupid.

Figure 12.76 Star sapphires from Kenya. While such stones display sharp stars, they contain too much silk to be valuable. (Photo: Bart Curren/ICA)

reveals color zoning; this and the strong red fluorescence allow separation from Thai rubies. At times, chalky white patches are also seen under shortwave, among the red areas. The color of Kenyan rubies may resemble Burmese stones, but the large numbers of fluid inclusions common to Kenyan rubies are lacking in those from Burma (unheated). Despite the major internal differences, the author continues to see Kenyan rubies being sold as Burmese. In the world of colored gemstones, there is so much in a name.

Other Kenya ruby localities

Rubies occur at several other localities in Kenya. In the mid-1970s, a joint Kenya-Austria mineral survey uncovered ruby in the Taita Taveta Hills near Nairobi (Anonymous, 1979). According to Bridges (1982), there is a definite north-northwest striking belt that traverses both Kenya and Tanzania. Cabochon-grade ruby of pinkish color has been reported from Kitui (Taawajah claim), some 50 miles (80 km) east of Mt. Kenya (Barot & Harding, 1994). The deposit was first discovered in 1969, but mining did not begin until 1989. Material from Kitui is heavily fractured and often dyed. Common inclusions are rhombohedral twinning and concentrations of rutile silk. Most is exported to India. Sizes range from 2 to 20 ct.

Sapphire in Kenya

Sapphire has been discovered in Kenya at a number of different locations. According to Pohl and Horkel (1980), sapphire was discovered in 1936 at Kinyiki Hill, which is near Mtito Andei, on the Nairobi–Voi highway. In 1939, corundum crystals approaching 1 m in length were found. When broken up, small gemmy areas were found.

The sapphires occur in pockets with vermiculite and asbestos and are thought to have formed from desilication of gneiss at a serpentinite contact. Most production, however, has come from alluvial and colluvial deposits at the base of Kinyiki Hill. Production is said to be small and sporadic (Keller, 1992).

About 80 miles northeast of Mt. Kenya, at Garba Tula, are found dark blue sapphires of an inky color which strongly resemble those from Australia. It does not appear that these are being exploited, presumably because large enough quantities of facetable stones have not been found. Some fine yellow sapphires have also been recovered from this locality (Bridges, 1982).

DuBois (1970) has reported gem sapphire from Kubi Kalo in the area of Chanler's Falls, as well as the Doldol area in the Loldaika Hills. Other Kenyan sapphire localities include The Chania River gravels near Thika, and Mugeno Ridge (Keller, 1992).

In the mid-1980s, star sapphires from the area west of Lake Turkana in northwestern Kenya appeared in the local market (Barot & Flamini *et al.*, 1989). Since that time, a quantity of both faceted and star blue sapphire has been mined. The material appears to be of vocanic origin, but the actual source rock is yet to be located. Some material improves with heat treatment (Barot & Flamini *et al.*, 1989; Themelis, 1989b). Solid inclusions in Turkana sapphires include rutile silk, crystals of corundum and rutile/brookite. Color zoning is prominent. Most unusual are narrow planes of black hematite needles (Barot & Flamini *et al.*, 1989; Hughes, 1989).

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Figure 12.77 And the river flows… The mighty Mekong at Ban Huai Sai separates Laos from Thailand.
Inset: The Gems City sapphire mine just outside the Lao town of Ban Huai Sai. (Photos: David Squires)

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Laos

The land-locked country of Laos[10] lies as a buffer between Thailand and Vietnam. While Laos does share small borders with Burma and China, the country has traditionally been dominated by either Thailand or Vietnam, with French rule [1893–1953], providing but a brief lull. Largely mountainous, in the 1990s Laos remains a backwater, little touched by the outside world.

The major corundum deposit is at Ban Huai Sai. Rumors have circulated for some time of both sapphire and ruby

10. *Laos* is a plural French/English corruption of the more proper *Lao.* Similarly, the capital, *Vientiane,* is a corruption of *Viang Chan.*

deposits in the southern part of the country, but the exact localities still remain unknown to this writer.

Ban Huai Sai (Ban Houay Xai)

Ban Huai Sai is situated on the banks of the Mekong river in Laos, directly opposite the Thai town of Chiang Kong. This is the infamous "golden triangle," where the borders of Thailand, Laos and Burma meet.

History. In 1890,[11] Shan diggers discovered *nin* (นิล) (black spinel, an accessory mineral of corundum) at Chiang Kong, (Ban Huai Sai), which lies just across the Mekong river from Thailand, in Laos. With typical patience they carefully prospected the area and eventually found sapphires. Mining then proceeded but soon stopped due to the low quality of the stones found.

According to H. Warington Smyth (1898), a Thai official at Chiang Kong (Kawng) also discovered small red fragments of garnet at the mines. Taking them to be rubies and, in expectation of royal support for mining, he went out and bought the best ruby he could afford. This was duly sent to the King with a note stating it was found by the aforementioned official at Chiang Kong.

Smyth, then in the employ of the Thai Department of Mines, was sent by the King to report on the deposit. But suspicions were soon aroused, as miners claimed that not even a single ruby had been found in the area. The report sent back to Bangkok certainly did little to advance the career of the Chiang Kong official.

Discussion. While the occurrence at Ban Huai Sai has been known since the late 1800s, due to the sapphires' overly dark color, little mining occurred until the early 1970s. Like many another sapphire mine, modern heat treatments make salable what was once too dark. Thus the 1970s and 1980s saw a small-scale revival of sapphire mining at Ban Huai Sai, which was worked with Czech assistance in the early 1980s. As of June, 1995, an Australian company had begun mining just outside of Ban Huai Sai (David Squires, pers. comm., 28 June, 1995). Dark blue sapphires are found in secondary deposits believed derived from a small basalt plug (Bernard, 1975; Vichit & Vudhichativanich *et al.,* 1978). Most stones seen by the author have been less than 2 ct cut, and tend to be inky in color. Material is generally smuggled across the Mekong River for sale in Thailand.

Yellow, green and black star sapphires are found, in addition to blues. Accessory minerals include red and black spinel, and zircon (Bernard, 1975).

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Macedonia (formerly Yugoslavia)

The most complete English account of Macedonian corundum is that of Ruzic (1972), upon which the following account is based. Corundum was first reported from Prilep, Macedonia in 1925 by Dr. Erdmannsdörffer, a German geologist. At that locality, a near-gem quality ruby is found in a dolomitic marble.

Prilep lies approximately 100 km south of Macedonia's capital, Skopje. The corundum occurs in dolomite marble on the southern and southwestern slopes of Sivec Mountain (1134 m), some 8 km northeast of Prilep. The marble quarries of Prilep are quite famous and produce the purest white color. The corundum occurs in red (including pink), blue and white colors. Most are heavily included and suitable only for cabbing. Crystals are recovered secondary deposits in the fields surrounding the marble quarries. As of 1972, farmers collected the crystals during the spring plowing and sold them to tourists and mineralogists.

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[11] Bernard (1975) lists this date as 1880.

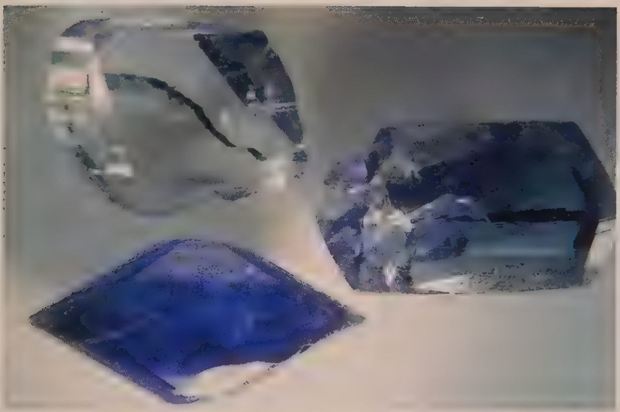

Figure 12.78 Three sapphire crystals from Madagascar. (Photo: H.A. Hänni/SSEF).

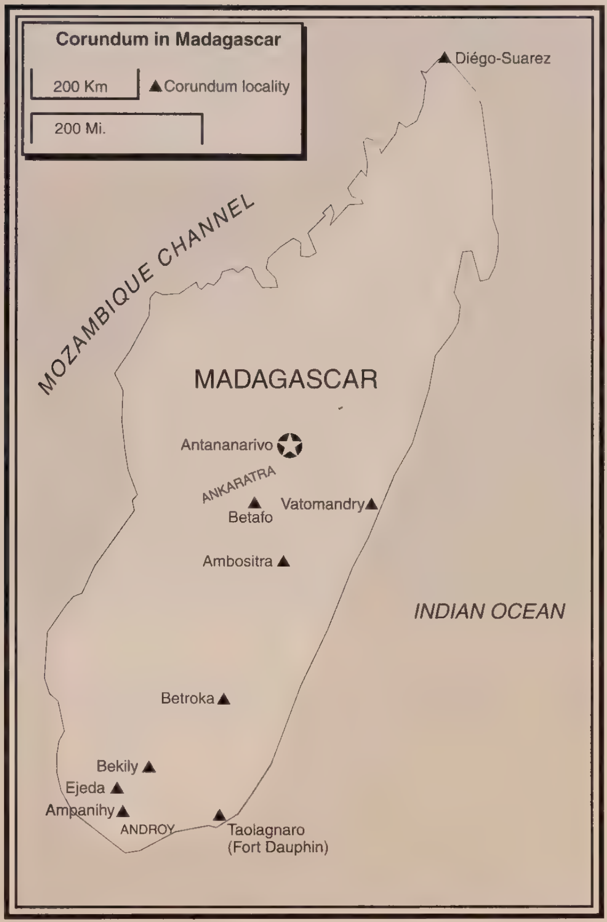

Figure 12.79 Map of Madagascar's corundum localities.

Madagascar (Malagasy Republic)

Madagascar has long held a reputation as a source of precious stones. In 1547, Captain Jean Fonteneau visited the island and mentioned its gems, but it was only after 1891, when M.A. Grandidier gave the Muséum d'Histoire Naturelle in Paris some specimens of rubellite, sapphire and zircon, that the potential was recognized (*Mineral Industry,* 1921).

Corundum has been reported from several localities on the island of Madagascar (Malagasy), most in the south. Some of this is of gem quality. Lacroix (1922) has provided the most detailed account of the minerals of the island, including corundum. Deposits are located at Mevatanana, Ambositra and Betafo; the stones are mostly dark blue, but also colorless, red and green. Black corundum pyramids have been found associated with basaltic tuffs near Diégo-Suarez. At Betsiriry, bluish to grayish corundums are found associated with muscovite (Barlow, 1915).

Lacroix visited one alluvial gold locality southwest of Ambositra, in the bed of the small Ifèmpina river, where rolled corundum pebbles were found. While most were opaque, transparent colorless pieces up to 500 grams were reported. But the deposits richest in ruby and sapphire were north on the volcanic massif of Ankaratra, where corundums of basaltic origin were obtained (Barlow, 1915).

Ruby has been reported from Vatomandry, Ankaratra and Gogogogo (Hunstiger, 1989–90), and at Ampanihy (Mike Gray, pers. comm., 27 Sept., 1994). Other localities in Madagascar where corundum is said to occur include Beforona (Ambohitranefitra), Ejeda and Sakeny (Besairie, 1966). The Smithsonian has a blue sapphire crystal from the Androy region in the south.

In 1990, Pierre Stéphane Salerno described to the author a sapphire occurrence southwest of Betroka, at Iankaroka (Tulear Province). These are termed *polychrome* sapphires, due to their unusual banding, which occurs in blue, green, brownish orange and red (including pink). Crystal habits are typically elongated to tabular, barrel-shaped bipyramids. The gems are said to occur along contact zones between granites and migmatites, along with iolite, green tourmaline and biotite. Inclusions of CO_2 and octahedra of what is probably magnetite (the gems are attracted to a horseshoe magnet)

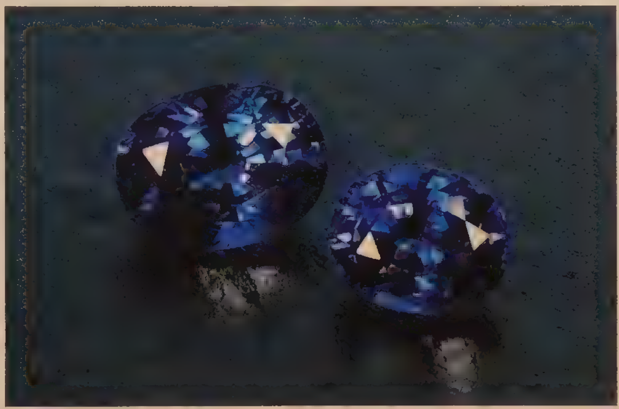

Figure 12.80 Blue sapphires from Madagascar's Behara/Bekily area. (Photo: Bart Curren/ICA).

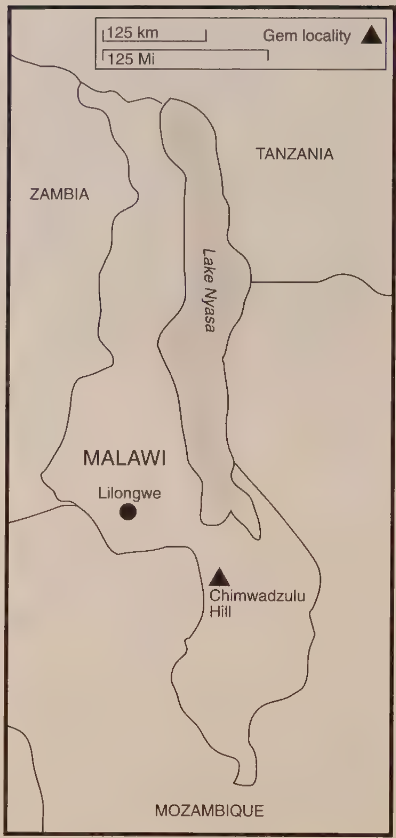

Figure 12.81 Malawi corundum
Left: Faceted sapphires from Malawi's Chimwadzulu Hill mine. (Photo: Bart Curren/ICA).
Right: Map of Malawi, showing the location of Chimwadzulu Hill.

have been reported (Koivula & Kammerling *et al.*, 1992; John Koivula, pers. comm., March, 1995).

In 1994, an important sapphire occurrence in Madagascar became known. This material ranges from pale to rich blue and is said to be suitable for heat treatment. Some pieces are colorless with blue cores; many are strongly zoned. The deposit, which is thought to have been formed in connection with pegmatitic action, is around Behara or Bekily (NW of Fort Dauphin, *aka* Taolagnaro) in the southwestern part of the island. The scattered occurrence lies in flat savanna terrain, with most stones collected by rural people from the surface, or from thick layers of decomposed rock (Henry Hänni, pers. comm., 10 Oct., 1994). Crystals are said to be of similar morphology to those from Kashmir (Eliezri & Kremkow, 1994).

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Malawi

Malawi is a landlocked country in eastern Central Africa. Formerly the British protectorate of Nyasaland, it achieved full independence in 1964. Bloomfield (1958) was the first to report gem-quality corundums from Malawi. The occurrence is the Chimwadzulu Hill area of Malawi, some

Table 12.14: Properties of Malawi sapphire & ruby[a]

Property	Description	
Color range/phenomena	• Red to orange to yellow	• Blue to green
Geologic formation	Recovered in situ from an epidotized amphibolite. Crystals are embedded in a coarse aggregate of hornblende crystals, enclosed in a matrix of epidote and plagioclase.	
Crystal habit	Tabular shapes consisting of pinacoid and rhombohedron combinations. Some may show triangular markings on the basal pinacoid. Many crystals show distinct basal parting.	
RI & birefringence	n_ε = 1.759–1.770; n_ω = 1.768–1.780 Bire. = 0.008–0.010 Higher values result from increasing Cr and Fe content.	
SG	3.96 to 4.05; higher values result from increasing Cr and Fe content	
Spectra	**Visible**: Cr spectra, Fe spectra, or a combination of the two	
Fluorescence	**UV**: Generally inert; red stones may show a weak red (LW stronger than SW)	
Other features	May be heat treated	
Inclusion types	**Description**	
Solids	• Hornblende (Henn & Bank, 1990) • Plagioclase (anorthite) feldspar (Henn & Bank, 1990) • Rutile prisms (?)	• Unknown, black, opaque inclusions (Henn & Bank, 1990) • Zircon prisms (Henn & Bank, 1990)
Cavities (liquids/gases/solids)	• Secondary fluid inclusions (healed fractures). These may be three phase	
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed	
Twin development	• Polysynthetic glide twinning on the rhombohedron {10$\bar{1}$1} is common	
Exsolved solids	• Fine to dense clouds of short to long rutile needles, parallel to the second-order hexagonal prism (3 directions at 60/120°) in the basal plane • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)	

a. Table 12.14 is based on the author's research, along with the studies of Henn & Bank (1990), Henn & Bank *et al.* (1989, 1990) and Grubessi & Marcon (1986).

50 miles (80 km) south of Lake Nyasa, near the western Mozambique border. Both ruby and fancy-colored sapphires occur in situ. This is in an epidotized amphibolite, embedded in a coarse aggregate of hornblende crystals, which is itself enclosed in a fine-grained granular matrix of epidote and plagioclase. Most stones are yellow, green or blue, with many parti-colored sapphires found (Rutland, 1969).

In the early to mid-1980s, an Italian firm was said to be working the deposit. The material viewed by the author ranged from blue to orange, pink and red and much of it was facetable, with most cut stones under 2 ct. As of 1994, the status of the deposit is unknown.

Figure 12.82 A fine orange sapphire from Chimwadzulu Hill, Malawi. (Photo: Bart Curren/ICA)

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Mexico

G.F. Kunz was the first to report corundum from Mexico. While examining a parcel of rolled pebbles of jasper, agate and chalcedony from San Geronimo, Estada de Oaxaca, Mexico, he found one piece of translucent, mottled blue and yellowish-white corundum (Kunz, 1883). Opaque blue sapphire was reported to occur in the central part of the Sierra Juarez of Baja California, about 70–80 miles (113–129 km) south of the US border. No gem material from this locality has yet to be reported (Johnson, 1963).

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Myanmar—see Burma

Namibia (formerly Southwest Africa)

Deep blue corundums have been found in a crystalline limestone at the Ussab gold mine, Namibia (Barlow, 1915).

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Nepal

In 1982, the author purchased a few poor quality Nepalese ruby and sapphire cabochons from a Kathmandu shop. During the same visit the author was shown specimens of beautiful intergrown ruby crystals. These were not of gem quality. These were said to originate in Ganesh Himal. Also in 1982, Toshira Baba reported on ruby from Nepal. It was said to occur with topaz in the Taplejung District, Dhankuta Zone of eastern Nepal (Harding & Scarratt, 1986).

In 1993, Mark Smith of Bangkok reported being shown translucent purple to pink corundums said to originate from mines at 3,000–4,500 m in Ganesh Himal (Koivula & Kammerling *et al.*, 1993). The locality is the Chumar mine (4,343 m), Laba Panchayat (district), near Dhading, where ruby occurs in dolomite with fuchsite. Sixty meters above the Chumar mine is the Riyal mine, where ruby is found in a soft gray graphite (Dudley Blauwet, pers. comm., Sept. 14, 1994). As of 1994, Nepal has produced only mineral specimens and cabochon-grade ruby and sapphire.

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On the stoop of the Third World

No one who has spent time in the Third World will tell you that doing business is easy. In 1987, one well-known foreign gemologist, who had resided in Nepal for a number of years, described to the author just how tough doing business in the abode of the snows could be.

In a feeble attempt to improve the cutting standards of Nepalese gems, he decided to import modern machines. So far, so good… until the machines arrived at Nepalese customs, where it was determined that the import duty would be greater than the machines' actual cost. This gentleman, being of high moral fiber, refused to pay the duty as a matter of principle. And so the machines languished in a customs warehouse, the amount due increasing relentlessly. After over one year in hock, moral fiber had turned to spaghetti. When his Nepalese partner asked him how badly he wanted these machines, "Badly" was the answer. "Are they worth $1000 to you?" "Yes," came the reply. Thus money changed hands.

The next morning, as the sun rose above the mighty Himalayas, its rays illuminated several cutting machines resting peacefully in their boxes on the stoop of the foreign gemologist's home. And the gemologist, minus a bit of moral fiber, could finally begin to introduce Nepal to modern gem cutting. His partner had paid thieves to steal the machines out of the customs compound.

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New Zealand

The following is based on the work of Delmer Brown (pers. comm., 12 Dec., 1994). Ruby has been reported to occur in the old gold districts near Rimu, Kanieri and Whitcombe creeks, south of Hokitika, on New Zealand's South Island. The ruby is of deep color, often having a slight bluish tone. It occurs in a rock locally termed "goodletite," which is largely composed of fuchsite mica, margarite, and possibly other Cr-bearing micas. Most rubies are of small size, but large crystals are occasionally seen. Small tourmaline needles have been found as inclusions. Some material is cabbed or faceted, but much is slabbed, with the ruby contained in the green rock matrix, similar to the ruby-in-zoisite from Longido.

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Figure 12.83 Nigerian corundum localities. Deposits are situated near Jos, at Nisama and Jemaa.

Nigeria

Dark blue sapphires have been known to originate from Nigeria since the late 1960s, but it was only in the early 1980s that the deposit was exploited commercially. Sapphires have been reported from two different localities in Nigeria. The first is Nisama, situated between Gidan Waya and Agombe Lafixa in Kaduna province (Bank, ca. 1986). This site is said to lie some 45 km northeast of Jos in central Nigeria. Weathered alkaline basalts are thought to be the source rock of the sapphires, which are mined via primitive methods from alluvials in holes and depressions up to a depth of 0.5–1.0 m (Kiefert & Schmetzer, 1987a–b).

Kanis & Harding (1990) also reported an occurrence of alkali-basalt derived sapphire and zircon at the village of Jemaa, some 50 air km SW of Jos. Jemaa sapphires were first discovered in 1968 by a tin-mining company. Due to the dark colors and lack of knowledge of heat treatment, the deposit was not exploited further until the early 1980s. Most material is said to be smuggled out of Nigeria by Senegalese and Mali traders.

Characteristics of Nigerian sapphire

Table 12.15 details characteristics of Nigerian sapphire.

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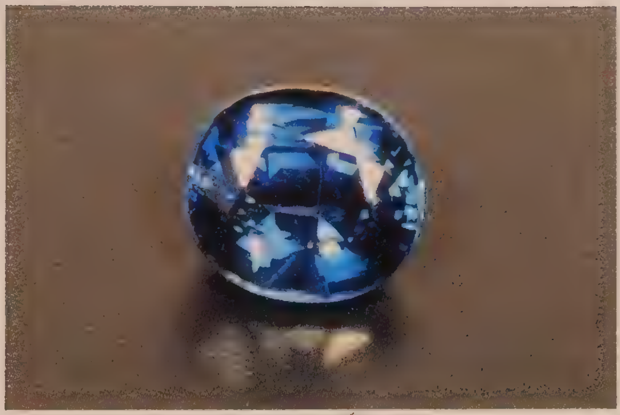

Figure 12.84 Blue sapphire from Nigeria. (Photo: Bart Curren/ICA)

Kiefert, L. and Schmetzer, K. (1987b) Blue and yellow sapphire from Kaduna Province, Nigeria. *Journal of Gemmology*, Vol. 20, No. 7/8, pp. 427–442; RWHL*.

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Norway

Non-gem quality ruby has been found in matrix at Fröland, which lies 11 km northwest of Arendal, in south Norway. The ruby occurs in a biotite-sillimanite gneiss, along with plagioclase, disthene, and fuchsite (Hunstiger, 1989–90).

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Pakistan

Ruby has been found in the Hunza District of northern Pakistan. While Gübelin (1982b) speculated that the local populace probably knew of the deposit for many years, the first documented mention of the deposit occurred when Hermann Bank received for appraisal a suite of Hunza marble specimens containing ruby in 1971 (Okrusch & Bunch *et al.*, 1976). Shortly thereafter, Piat (1974) gave a brief description of the deposit. Once work began on the Karakoram Highway in the early 1970s, specimens began to trickle out (Gübelin, 1982b).

Hunza: Land of the "Great Game" and eternal life

Welcome to Hunza, where the populace is reputed to live longer than anywhere else on earth and some locals are said to descend from a mutinous band of Alexander the Great's army.

Table 12.15: Properties of Nigeria sapphire[a]

Property	Description
Color range/phenomena	• Blue to greenish blue; typically inky • Yellow
Geologic formation	Secondary deposits derived from weathered alkali basalts
Crystal habit	Most crystals have dull, corroded surfaces with rounded edges, due to chemical weathering during the rise to the surface during volcanic activity. Many crystals show distinct basal parting. Their shapes include... • Tabular shapes, consisting of the basal pinacoid {0001} and hexagonal bipyramid {22$\bar{4}$1}, sometimes modified by the rhombohedron {10$\bar{1}$1} • Barrel shapes consisting of pinacoid, bipyramids {22$\bar{4}$1} and {22$\bar{4}$3}, hexagonal prism {11$\bar{2}$0} and rhombohedron
RI & birefringence	n_ε = 1.759–1.768; n_ω = 1.768–1.776 Bire. = 0.008–0.009
SG	3.98 to 4.01
Spectra	**Visible**: Strong Fe spectra. In addition, weak Cr spectra have been observed in some specimens.
Fluorescence	**UV**: Generally inert (LW and SW)
Other features	Most stones are heat treated to improve color and clarity
Inclusion types	**Description**
Solids	• Apatite (Henn, 1986) • Feldspar: slightly rounded, albite prism-negative crystal combinations, surrounded by thin fluid films lying parallel to the basal pinacoid. These appear identical to those seen in Thai/Cambodian rubies. (Kiefert & Schmetzer, 1987b) • Margarite (?) • Mica (muscovite) (?) • Unknown corroded hexagonal plates • Uranium pyrochlore, red with stress haloes (Kiefert & Schmetzer, 1987b) • Zircon (Henn, 1986; Kiefert & Schmetzer, 1987b)
Cavities (liquids/gases/solids)	• Primary cavities & negative crystals • Secondary fluid inclusions (healed fractures) and poorly-healed fractures, which may contain iron-oxide stains
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed. This is quite obvious in most stones.
Twin development	• Polysynthetic glide twinning on the rhombohedron {10$\bar{1}$1} (not common)
Exsolved solids	• Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1/93.9°)

a. Table 12.15 is based on the reports of Bank (ca. 1986), Henn (1986) and Kiefert & Schmetzer (1987a–b).

Figure 12.85 Pakistani ruby in a green muscovite mica matrix. (Photo: Robert Weldon/GIA)

Even in the 1990s, access is tumultuous. Hunza lies just south of the Wakhan corridor, a thin, 19th-century finger of Afghanistan created to keep the world's great powers, China, Russia and the British, away from each others' throats. Much of the modern world has yet to penetrate this great wilderness area, and as anyone who has traveled the "Karakoram Highway" (KKH) can testify, the use of the term "highway" in describing this route is an abuse of the English language. During the author's 1977 visit to the Khumbu region of Nepal, two British engineers described how it took fifty years to build a road in the Himalaya. The Karakoram Highway has obviously yet to reach its golden anniversary. Rockslides, which pose a constant danger, are the major difficulty. Then there is a small matter of highway robbers, which operate according to the "fee enterprise" system.[12]

Hunza's corundum deposits lie just north of Rakaposhi (7,788 m; 25,551 ft). Rubies and blue sapphires are found in marble bands below the Mutschual and Shispar glaciers in the district around the villages of Aliabad and Karimabad.

The marble forms concordant intercalations within sillimanite and garnet-bearing biotite-plagioclase gneisses and mica schists. These marble bands are generally 1–5 m thick (although some may reach 10 m), and consist largely of calcite, although dolomite was found in one case. Gem-quality spinel has also been found, in red (including pink), violet and blue colors (Okrusch & Bunch *et al.*, 1976).

12. After paying your fee, consisting of all your valuables, you are allowed to pass.

Table 12.16: Properties of Pakistan (Hunza) ruby and sapphire[a]

Property	Description
Color range/phenomena	• Red to purplish red • Blue • Violet to purple
Geologic formation	Primary deposits consisting of a corundum-bearing marble enclosed in gneisses and mica schists
Crystal habit	• Generally prisms, rhombohedra or bipyramids with some development of pinacoid faces
RI & birefringence	$n_\varepsilon = 1.762$; $n_\omega = 1.770$ Bire. = 0.008
SG	3.99 to 4.00
Spectra	**Visible**: Strong Cr spectrum
Fluorescence	**UV**: Strong to extremely strong red to orange-red (LW stronger than SW)
Other features	None reported
Inclusion types	**Description**
Solids	• Apatite, hexagonal crystals (Gübelin, 1982b) • Calcite, in medium to large masses, sometimes as euhedral crystals with polysynthetic twinning (Gübelin, 1982b) • Chlorite, distinctly green (Gübelin, 1982b) • Dolomite, resorbed crystals (Gübelin, 1982b) • Margarite, feather-like inclusions (Gübelin, 1982b) • Mica (phlogopite), widely scattered to thickly massed concentrations of red-brown flakes (Gübelin, 1982b) • Pyrite, sometimes altered to goethite (Gübelin, 1982b) • Pyrrhotite (Gübelin, 1982b) • Rutile (Gübelin, 1982b) • Spinel (Gübelin, 1982b)
Cavities (liquids/gases/solids)	• Primary cavities and negative crystals • Secondary healed fractures are common. They occur in a variety of pattern and thicknesses. • Iron oxide stains are common in cracks (this is eliminated during heat treatment)
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle' like swirls in other directions
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$
Exsolved solids	• Rutile silk has not been reported • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.16 is based upon the published reports of Gübelin (1982b), and Gübelin and Koivula (1986).

Other Pakistan corundum deposits

In 1992 it was reported by C.R. Beesley that ruby had been found in an area of Pakistan-controlled Kashmir (Azad Kashmir). (Anonymous, 1992; American Gemological Laboratories, n.d.) The following is based on his reports.

Located in a remote area called Nangimali, not far from the China border, the deposit was first discovered in 1988. So far, it has produced mineral specimens and cabbing rough, along with a small amount of facetable material. Color varies from pink to deep red and pyrite is said to occur with the ruby.

At the site, the ruby occurs in a marble bed some 30 to 40 ft (9–12 m) thick. The mine's elevation is between 13,500 and 14,000 ft (4115 to 4267 m), with the lower area said to be most promising. This makes mining possible only during the summer months of June through August. A further complication is the site's proximity to the ill-defined and disputed India-Pakistan border, making access difficult.

Figure 12.86 View of the Hunza Valley, site of Pakistan's most important ruby mines. New ruby mines are located in the white patches on the brown hillside at the center of the photo. (Photo: Dudley Blauwet)

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Rhodesia—see Zimbabwe

Russia

In a country as large as Russia, one would expect some corundum occurrences. And this is the case. However, due to the Cold War and the fact that details on most Russian localities are written in the Russian language, the outside world has little information on such occurrences. Hopefully this will change with the end of the Cold War.

Corundum was first found in Russia at Borzovka. Crystals are found in the Ilmenskie Mountains and near Lake Irtyash (Evseev, 1993a).

Small rubies of excellent color and transparency were found in 1979 in a magnesium-calcite marble in the "Kootchinskoye" ore mine complex, located in the South Ural Mountains north of Magnitogorsk. If larger stones can be mined, this locality promises to be an important one (Koivula & Kammerling, 1991).

Ruby has also been reported from the Azov region, in a sillimanite-corundum gneiss (Serdynchenko & Polynovskyi, 1971; Hunstiger, 1989–90). Specimen-quality ruby is being mined from plagioclasites at Rai-Iz, about 60 km northwest of Salekhard in the Polar region of the Ural Mountains (Evseev, 1993b). A small quantity of gem material is also said to be found at Rai-Iz. Rose-colored corundum is found at Khitostrov, North Karelia, embedded in highly metamorphosed rocks of amphibolite type (Gromov, 1993). Bright to dark blue crystals have been reported from Khibiny. Corundum has also been found at Khit Island, Karelia (Evseev, 1994), and dark blue sapphire has been reported from near Chita in southeastern Siberia (Eliezri, 1994).

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Rwanda

Blue sapphire and heat-treatable geuda similar to that of Lodwar, Kenya, has been found in the Kamemba/Changungu area close to the border of Rwanda and Zaire. A few tens of kilos of this material has reportedly been exported from Burundi to Thailand. Material suitable for stars is apparently not found (Barot & Kremkow, 1991). It was later reported that the source is an alluvial deposit near Lake Tshohohaw in southwest Rwanda (ICA Gazette, 1995).

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Sierra Leone

Large quantities of low-grade ruby have been reported from an unknown locality in Sierra Leone. The barrel-shaped crystals range up to 4 inches (10 cm) in length, and are cut into beads, cabochons and, occasionally, stars (Eliezri & Kremkow, 1994).

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South Africa

While gem qualities have yet to be found in South Africa, the country does possess a number of corundum occurrences. Ruby in marble has been reported from Mashishimala, South Africa. Mashishimala lies some 18 km ESE from Leydsdorp in Northern Transvaal. Sapphire associated with a mica belt has been reported in an area some 12 km from the Oliphant River. Impure corundum has also been reported from Swaziland, as well as in the gold fields in the vicinity of Pretoria (Barlow, 1915).

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Sri Lanka (Ceylon)

> Sītā: "What now is this land which is like unto an unbroken expanse of rainbows?" Vibhīsana explains: "See in front of you the territory of the Simhalas, which has the Ocean as the moat, which is adorned, as it were, with a beautiful crest by means of the Rohana Mountain of which the ground is formed of precious stones, where the water of the Ocean, passing through the womb of oysters, is transformed to the condition of charming jewels which are adornments on the limbs of damsels having the complexion of the shoots of the *dūrvā* grass. And more. People who produce the nectar of (sweet) speech, the Rohana Mountain which produces gems and the Ocean which produces pearls—these three are not found together anywhere else but in the Island of the Simhalas".
>
> *Balaramayana*, Act 10 (from Paranavitana, 1958)

Ratna Dweepa —The Island of Jewels

The island now known as Sri Lanka[1] is thought to have first been settled by humans about 500,000 BC. While stone cultures emerged about 10,000 BC, the legendary history of Ceylon goes back to 3000 BC, when Rama, an incarnation of the Hindu god Vishnu, supposedly conquered Ceylon. The story, told in the Sanskrit epic *Ramayana*, tells of Rama's beautiful wife, Sita, being kidnapped by Ravana, the demon king of Ceylon. Rama invaded Ceylon with an army of monkeys and killed Ravana, rescuing Sita (Tresidder, 1984).

Figure 12.87 The famous Panther Brooch was made by Cartier for the Duchess of Windsor, Wallis Simpson. It features a 152.35-ct Sri Lankan sapphire. (Photo: © Fred Ward)

Vijaya, a Bengali prince, led the Indo-Aryan Sinhalese,[2] to the island about 500 BC. About 300 BC, the Tamils, of Dravidian origin, arrived on the island. The *Mahavamsa*, a Sinhalese chronicle written in the 5th century AD, tells the history of Lanka (Ceylon) from its settlement by Vijaya and his followers in 543 BC to the death of King Mahasena in 325 AD.

For over 2000 years Sri Lanka has supplied the world with fine rubies and sapphires. In fact, Sri Lanka was most probably the original source of these gems. Burma may produce

[1] In the Bible Sri Lanka was *Orphir*, to ancient Rome it was *Palesamundi*, while Greeks referred to it as *Taprobane*. Arabs called it *Serendib* or *Zeylan*, it was *Seilan* to Marco Polo and *Ceilao* to the Portuguese, *Zeilan* to the Dutch, and finally, *Ceylon* to the British. The English word "serendipity," the faculty of making fortunate discoveries by accident, was coined with Sri Lanka in mind by 18th Century English writer, Horace Walpole. In *The Three Princes of Serendip* Walpole told of a prince with a facility for stumbling upon bags of treasure.

[2] The name *Sinhala* is in honor of Prince Vijaya's father, allegedly the son of a lion; thus the Sinhalese, or Sinhala, are the "lion people."

Figure 12.88 The greatest boast of the Isle of Gems is its rubies and sapphires, as exhibited by the stunning pair above. The sapphire is untreated, and weighs 4.78 ct, while the heat-treated ruby is 3.15 ct. But does weight really matter? Beauty comes in every size. (Photo: Robert Weldon/GIA; specimens: C. Keenan)

finer qualities, but only Sri Lanka has produced rubies and sapphires in such large sizes for so long a period of time. All varieties are found here, including some such as the *padparadscha,* for which Sri Lanka is the premier locality.

History

Historical evidence suggests gemstones were an important item of commerce in Sri Lanka from early times. Tennent (1859) quotes the *Mahavamsa* as mentioning a gem-encrusted throne owned by the Naga king before the Aryans conquered the island in 543 BC. Indeed, Buddha himself is said to have had to intercede when two kings fought over this throne. And legend has it that King Solomon, the epitome of biblical wisdom, had precious stones brought from Ceylon to woo the beautiful Queen Sheba (Wijesekera, 1980).

Written accounts of the island do not go back earlier than 543 BC. However, with our present knowledge of Sri Lanka it is possible to make a few assumptions regarding the first discovery of corundum on the island. The deposits lie scattered across the southern two-thirds of the island, in literally thousands of different locations mostly connected with rivers and drainage systems. They appear in such abundance that it is not stretching the truth to say that they were probably discovered shortly after humans first reached the island from the Indian mainland. In fact, many stone implements have been discovered from the caves and gem pits of Sabaragamuva Province, of which the gem center of Ratnapura is the capital. These implements and tools date back to the Stone Age (Anonymous, 1968). This means that Sri Lanka is, if not the oldest, then one of the oldest sources of gemstones in the world, having produced continuously since Stone Age times.

Sapphires and rubies from Sri Lanka first appeared in Western jewelry among the Etruscans (600–275 BC), and were used by the Greeks and Romans from approximately 480 BC onward (Ball, 1931). C.W. King (1860) described a sapphire cameo of Hadrian's time (117–138 AD) from Sri Lanka or India with a hole drilled in it, apparently for use as an earring or in a necklace. Oval sapphire beads are a common feature in jewelry from Roman times on. Their oval shape and pale blue color match perfectly the crystal habit and color of Sri Lanka's sapphires, which is no doubt the source from which they originated.

With the arrival of the Aryan conqueror Vijaya, in 543 BC, exploitation of gem deposits undoubtedly increased. Pliny (77 AD) states that in the time of Emperor Claudius (41–54 AD) ambassadors of the Island of Taprobane (Sri Lanka) boasted of the fine precious stones it produced. Ptolemy, the Greek astronomer, refers to beryl, sapphire and gold among the products of the island in the second century AD:

> Cory, a promontory of India is opposite the promontory of the Island of Taprobana, which formerly was called the Island of Symondi, now by the natives Salica. Those who inhabit it, in the

Figure 12.89 Taprobane is noted for its star stones, such as this stunner. (Photo: Robert Weldon; specimen: Ray Zajicek/David Cohen)

Ceylon! Ceylon! 'tis nought to me how thou wert known or named of old,
As Ophir, or Taprobane, by Hebrew king, or Grecian bold—
To me thy spicy-wooled vales, thy dusky sons, and jewels bright,
But image forth the far-famed tales—But seem a new Arabian night.
And when engirdled figures crave, heed to thy bosom's glittering store—
I see Aladdin in his cave; I follow Sinbad on the shore.

Miss Jewsbury
(from A.M. & J. Ferguson, 1888)

common language, are called Salae; all of the women are covered with hair.

Among these rice, honey, ginger, beryl, amethyst, also gold, silver, and other metals are found. It produces elephants and tigers.

Claudius Ptolemy, ca. 90–168 AD, *The Geography* (1991)

Chinese accounts also tell of the gems of Sri Lanka (Ball, 1931). Fa-Hien, the Chinese Buddhist traveler of the 5th century AD, claimed that Ceylon was visited by gem traders before Buddha's time (624–544 BC). He also said:

The kingdom is on a large island, extending from east to west fifty yojanas, and from north to south thirty. Left and right from it there are as many as 100 small islands, distant from one another ten, twenty, or even 200 le; but all subject to the large island. Most of them produce pearls and precious stones of various kinds; there is one which produces the pure and brilliant pearl*,—an island which would form a square of about ten le. The king employs men to watch and protect it, and requires three out of every ten such pearls, which the collectors find.

* Called the mani pearl or bead. Mani is explained as meaning 'free from stain,' 'bright and growing purer.' It is a symbol of Buddha and of his Law. The most valuable rosaries are made of manis.

Fa-Hien, 399–414 AD, (Legge, 1886)

From this point onward, references to the famous gemstones of Serendib (Sri Lanka) are numerous. Among the more famous references to Sri Lanka are those in the Travels of Sinbad the Sailor from the Arab epic work, *Tales of Arabian Nights*, as well as the travels of Marco Polo (Yule, 1920). Polo had this to say about the gems of Serendib:

Marco Polo's text

WHEN you leave the Island of Angamanain and sail about a thousand miles in a direction a little south of west, you come to the Island of SEILAN, which is in good sooth the best Island of its size in the world....

Now I will quit these particulars, and tell you of the most precious article that exists in the world. You must know that rubies are found in this Island and in no other country in the world but this. They find there also sapphires and topazes and amethysts, and many other stones of price. And the King of this Island possesses a ruby which is the finest and biggest in the world; I will tell you what it is like. It is about a palm in length, and as thick as a man's arm; to look at, it is the most resplendent object upon earth; it is quite free from flaw and as red as fire. Its value is so great that a price for it in money could hardly be named at all. You must know that the Great Kaan sent an embassy and begged the King as a favor greatly desired by him to sell him this ruby, offering to give for it the ransom of a city, or in fact what the King

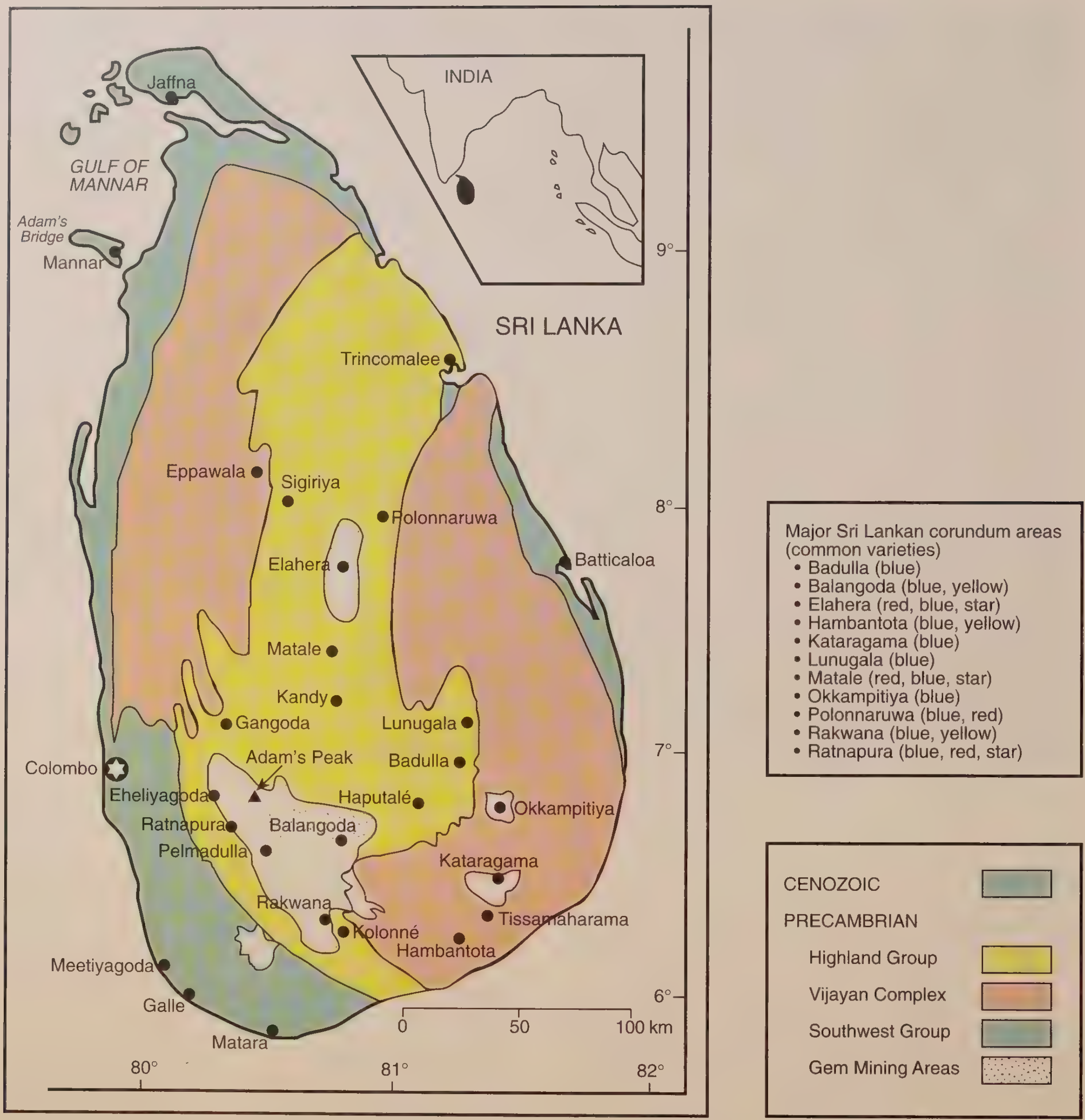

Figure 12.90 Geological map of Sri Lanka showing the major gem-producing areas. (Modified from Zwaan, 1982; Zoysa, 1982–1983)

would. But the King replied that on no account whatever would he sell it, for it had come to him from his ancestors.*

Henry Yule's annotations

* There seems to have been always afloat among Indian travellers, at least from the time of Cosmas (6th century), some wonderful story about the ruby or rubies of the king of Ceylon. With Cosmas, and with the Chinese Hiuen Tsang, in the following century, this precious object is fixed on the top of a pagoda, "a hyacinth, they say, of great size and brilliant ruddy colour, as big as a great pine-cone; and when 'tis seen from a distance flashing, especially if the sun's rays strike upon it, 'tis a glorious and incomparable spectacle." Our author's contemporary, Hayton, had heard of the great ruby: "The king of that Island of Celan hath the largest and finest ruby in existence. When his coronation takes place this ruby is placed in his hand, and he goes round the city on horseback holding it in his hand, and thenceforth all recognise and obey him as their king." Odoric too speaks of the great ruby and the Kaan's endeavours to get it, though by some error the circumstance is referred to Nicoveran instead of Ceylon. Ibn saw in the possession of Arya Chakravarti, a Tamul chief ruling at Patlam, a ruby bowl as big as the palm of one's hand. Friar Jordanus speaks of two great rubies belonging to the king of SYLEN, each so large that when grasped in the hand it projected a finger's breadth at either side. The fame, at least, of these survived to the 16th century, for Andrea Corsali (1515) says: "They tell that the king of this island possesses two rubies of colour so brilliant and vivid that they look like a flame of fire."

Sir E. Tennent, on this subject, quotes from a Chinese work a statement that early in the 14th century the Emperor sent an officer to Ceylon to purchase a carbuncle of unusual lustre. This was fitted as a ball to the Emperor's cap; it was upwards of an ounce in weight and cost 100,000 strings of cash. Every time a grand levee was held at night the red lustre filled the palace, and hence it was designated "The Red Palace-Illuminator." (*I.B.* IV. 174–175; *Cathay*, p. clxxvii.; *Hayton*, ch. vi.; *Jord.* p. 30; *Ramus.* I. 180; *Ceylon*, I. 568).

Timeline of corundum in Sri Lanka

10,000 BC	The first stone-age culture emerges in Sri Lanka. Such aboriginal peoples were related to early settlers in Australia, the Nicobar Islands, Malaysia, etc. (Tresidder, 1984).
543 BC	The *Mahavamsa* chronicles are authored. They contain many mentions to Sri Lanka's precious stones (Geiger, 1912, 1929).
500 BC	Vijaya moves into Sri Lanka from India. Thus begins the first advanced civilization in Sri Lanka (Tresidder, 1984).
300 BC	Tamils make their first appearance in Sri Lanka (Tresidder, 1984).
300 BC	Megasthenes mentions the pearls of Ceylon (Ball, 1950).
45 AD	Four Sri Lankan envoys visit Rome. Pliny thus learns of the island's gems, pearls and corals (Punchiappuhamy, 1985).
ca. 60 AD	The *Periplus of the Erythraean Sea* states that transparent gems are produced in Taprobanê (Schoff, 1912; Ball, 1950; Casson, 1989).
168 AD	Ptolemy mentions that Taprobana produces beryl and amethyst (Ptolemy, 1991).
ca. 250 AD	Caius Julius Solinus states that precious stones are abundant in Taprobane (Golding, 1955).
399–414 AD	Fa-Hien of China mentions Sri Lanka's pearls and precious stones (Legge, 1886).
545	Cosmas of Alexandria visits India and mentions that the hyacinth (jacinth) is one of Ceylon's principal products and that the great hyacinth, an object of reverence, lies on a high peak (Dames, 1921).
850–910	Soleyman and Abouzeyd's *Voyages of the Two Mahometans* mentions the occurrence of gems in Ceylon (Wadia & Fernando, 1945).
1100–1300	Arabs Edirisi (1100s), al-Kazwini (1200s) and al-Teifaschi (1240) refer to the pearls and gems of Ceylon (Wadia & Fernando, 1945; Clément-Mullet, 1868).
1254–1324	Marco Polo visits Seilan (Ceylon) and describes the island as the source of rubies (Yule, 1920).
1316–53	Friar Odoric of Pordenone and John de' Marignolli visit Ceylon and describe a pool of gems at the base of Adam's Peak (see 'Adam's Peak', p. 38) (Yule, 1913).
1333–1341	Ibn Battuta visits Ceylon, and describes Kunakār as the center of gem production (Beckingham, 1994).
1505	The first Portuguese arrive; they soon occupy the island's coastal areas (Tresidder, 1984). One Portuguese official, Duarte Barbosa, gives a detailed account of Sri Lanka's precious stones (Dames, 1918, 1921).
1629–43	Fray Sebastien Manrique visits Taprobane and describes rubies, sapphires and other gems found there (Luard, 1926).
1656	The Dutch push the Portuguese out, after both sea and land battles (Tresidder, 1984).
ca. 1660–80	Robert Knox, an English sailor captured by the King of Kandy, tells of the island's precious stones (Knox, 1681).
1796	Holland surrenders Sri Lanka to the British, who have become interested in Trincomalee's fine harbor (Tresidder, 1984).
1832	The British finally bring the entire island under their control (Apa, 1983).
Mid 1970s	Thais begin arriving in Sri Lanka to purchase *geuda*.
1983	Full-scale war breaks out between the Tamil minority and the Sinhalese majority (Wheeler, 1984).

Henri Cordier's annotations

[…In the Chinese work *Cho keng lu,* containing notes on different matters referring to the time of the Mongol Dynasty, in ch. vii. entitled *Hwui hwui shi t'ou* ("Precious Stones of the Mohammedans") among the four kinds of red stones is mentioned the *si-la-ni* of a dark red colour; *si-la-ni,* as Dr. Bretschneider observes (*Med. Res.* I. p. 174), means probably "from Ceylon." The name for ruby in China is now-a-days *hung pao shi,* "red precious stone." (*Ibid.* p. 173.)—H.C.]

Yule & Cordier, 1920, *The Book of Ser Marco Polo*

Regarding the "Red Palace Illuminator," which was mentioned by many visitors to Ceylon, the story is not as mad as it first seems, since some incredibly large corundums have been unearthed in Sri Lanka. During the author's visit to Sri Lanka in 1986, a stone of fantastic proportions had just been unearthed from the gem gravels. Its weight was 40 kg.

Ibn Battuta, the great Moor traveler, visited Sri Lanka sometime between 1333–1341 AD. Amidst the tales of "flying leaches" and the climb up Adam's Peak, he also provided a detailed account of the ruby mines:

> *Description of the rubies.* The marvellous rubies called *bahramān* [carbuncles] are found only in this town [Kunakār]. Some are taken from the channel, and these are regarded by them as the most valuable,* and some are obtained by digging. In the island of Ceylon rubies are found in all parts. The land is private property, and a man buys a parcel of it and digs for rubies. He finds white stones, deeply-cracked, and it is inside these that the rubies are formed. He gives them to the lapidaries who scrape them down until they split away from the ruby stones. Some of them are red, some yellow, and some blue, which they call *nailam.*† Their custom is that all rubies of the value of a hundred *fanams* belong to the Sultan, who pays their price and takes them; those of less value belong to the finders. A hundred *fanams* equal in value six gold dinars.
>
> All the women in the island of Ceylon have necklaces of rubies of different colours and wear them also on their arms and legs in place of bracelets and anklets. The Sultan's slave-girls make a network of rubies and wear it on their heads. I have seen on the forehead of the white elephant seven ruby-stones each larger than a hen's egg, and I saw in the possession of Sultan Ayrī Shakarwatī a bowl as large as a man's hand made of rubies, containing oil of aloes. When I showed my astonishment he said: 'We have things larger than that.'

C.F. Beckingham's annotations

* Mzik (p. 360, n. 12) notes that the precious stones were found in the detritus deposited in the pools at the edge of the stream.
† Sapphires.

Ibn Battuta, ca. 1333–1341 AD
(from Beckingham, 1994)

The Chinese, Ma Huan, who published his observations in 1433, also gave a fascinating account of Sri Lanka's gems:

> The interior of this mountain produces red *ya-ku,* blue *ya-ku,* yellow *ya-ku,* blue *mi-lan* stones, *hsi-la-ni, k'u-mo-lan,** and other such [stones]; they have each and every precious stone. Whenever heavy rain occurs, the water rushes out of the earth and flows down amidst the sand; they search for and collect [the stones], and that is how they get them. There is a common saying that the

Table 12.17: Sri Lankan gem nomenclature

Variety	Local term and description
Ruby	• *Ratha* (Singhalese): General term for ruby • *Suryakanta mani* (Sanskrit): Ruby (also *manik*) • *Nilakantia*: Ruby with a tinge of blue • *Padmaraga* (Sinhalese): Pinkish ruby; rare and prized as highly as ruby • *Rathu keta* • *Gona ratne* • *Lohitaka* • *Coovangoo*: Defect of cloudiness in a corundum • *Mola neero*: Dark spots in the stone's body
Sapphire (all colors)	• *Nila* (Singhalese): General term for blue sapphire. The Thai term for low-grade blue-gray star sapphire is *yila* or *nila* (ยีหลา or นิหลา) and is probably derived from this word, which is Sanskrit for blue. • *Indra nila*: Best quality of sapphire, which is blue with a trace of violet • *Puspa raga* ['flower king'] (Singhalese): General term for yellow sapphire. The Thai word for yellow sapphire, *busarakam* (บุษราคัม) is probably derived from this. • *Ratu puspa raga*: Bright yellow with a reddish tinge (more valuable) • *Kaha puspa raga*: Pure bright yellow • *Geuda*: Cloudy corundum of little value (today valued, due to heat treatment) • *Ottu*: Blue sapphire crystal where the blue color is confined to a layer at and just below the surface

precious stones are in truth the crystallized tears of Buddha their patriarch.

Mills' annotations

* Red *ya-ku* means a ruby, blue *ya-ku* a deep blue sapphire or corundum of the first quality, and yellow *ya-ku* a yellow corundum or sapphire known to jewellers as Oriental topaz. The *mi-lan* (Giles, nos. 7802; 6732) is no doubt the *ni-lan* (Giles, nos. 8211; 6732) of T'ao Tsung-i, a pale blue sapphire of medium quality; Ibn Battuta called it *nailam*, the Persian equivalent for the Hindi word *nilam* derived from Sanskrit *nila*, 'blue'.

The *hsi-la-ni* (Giles, nos. 4105; 6653; 8197), "of Ceylon", has not been identified; it had a dark red colour. The *k'u-mo-lan* (Giles, nos. 6276; 8016; 6732), T'ao's *ku-mu-lan*, is an unidentified stone of 'red-black-yellow' colours; Bretschneider suggested it might be an opal, but this stone does not appear to be found in Ceylon (compare Williams, p. 364). See Husain, p. 220, and Bretschneider, vol. 1, pp. 174–5, quoting from ch. VII, f. 5V of the *Cho-keng lu*, 'Records [written] while the Plough rests', composed by T'ao Tsung-i in 1366.

Ma Huan, 1433, *The Overall Survey of the Ocean's Shores* (1970)

Robert Knox, a sailor in the service of the English East India Company, was captured by the King of Kandy in 1660. Spending nearly twenty years in the country, his account is most interesting:

> In this Island are several sorts of Precious Stones, which the King for his part has enough of, and so careth not to have more discovery made. For in certain places where they are known to be, are sharp Poles set up fixed in the ground, signifying, that none upon pain of being stuck and impaled upon those Poles, presume so much as to go that way; Also there are certain Rivers, out of which it is generally reported they do take Rubies and Saphires for the Kings use, and Cats eyes. And I have seen several pretty colored stones, some as big as Cherry-stones, some as Buttons, and transparent, but understood not what they were. Rubies and Saphires I my self have seen here.

Robert Knox, 1681, *An Historical Relation of Ceylon*

Duarte Barbosa

ONE of the most fascinating and authoritative accounts of the gems of Asia was that of Duarte Barbosa. A Portuguese civil servant who resided in Asia from about 1500 to 1517, his memoirs included detailed accounts of a number of Asian gems, including Indian diamonds, Sri Lankan rubies, sapphires and topazes (yellow sapphires), as well as Burmese rubies. The following is an edited version of his commentary on Sri Lankan corundums. Note his description of heat treated sapphires being drilled for identification.

Of the Rubies found in the Island of Ceilão

In the Island of Ceilão, which lies in the second India, are found many rubies which the Indians call Maneca,* the more part whereof never attain in colour to the perfection of those treated of above [Burma rubies], inasmuch as although red they are pale; they are notwithstanding very cold and hard, and the better of them are much esteemed among these peoples. The King of that island keeps them for his own profit, and when the goldsmiths come upon any which is good they place it in fire for a certain number of hours, and if it comes forth whole its colour becomes very bright and of great value. When the King of Narsinga can obtain any such he has them cunningly bored on the lower side, but so that the perforation does not reach beyond the middle, nor does he allow them to be exported from the Kingdom.† For the reason mainly that it is known that they have undergone the aforesaid test, they are worth more than those of Pegu even with all their sparkle and transparence....

Of Sapphires

The best Sapphires come from the Island of Ceilão, they are very hard and fine....

Of Topazes

Natural topazes are found in the Island of Ceilão, by the Indians they are called *Purceragua*.** The stone is very hard and cold and of the same weight as the ruby and Sapphire, all three being of the same species. Its perfect colour is yellow like beaten gold, and when the stone is perfect and clear it is worth at Calicut, be it great or small, its weight in fine gold, and this is usually its price. When they are not so perfect they are worth their weight in *fanam* gold, which is a half less; if white they are worth much less, and with them they counterfeit small diamonds.

Mansel Longworth Dames' annotations

* *Ceylon Rubies.* The name *Maneca* is thus explained by Mgr. Dalgado in his *Glossario*:
"Duarte Barbosa tells us that *Maneca* is a ruby, but its original Singalese, *menika*, Sanskrit *manika*, means simply a 'precious stone.'"

† This passage is given as follows in the former edition:
"So that the hole reaches to the centre, and they do not pass it, because the stone can no longer leave the Kingdom, and that it may be known that it has been tried in the fire. And so also these are worth more than those of Peygu....

** *Topaz.* "*Purceragua* is Malayālam Pusparāgam, Sanskrit *pusparāga*, a topaz" (Dalgado).

Duarte Barbosa, 1518, *The Book of Duarte Barbosa* (Dames, 1918, 1921)

Figure 12.91 Scenes from Serendib
Left: Ratnapura—City of Gems. (Photo by the author)
Right: River mining utilizing long-handled *mamoties* (rakes) in Sri Lanka. (Photo: Ted Themelis)

Chappuzeau, whose writings are believed to be based upon Tavernier's notes, described Sri Lanka's gems thus:

> The second place of the *Indies* from whence they bring Stones of Colour [the first being Burma], is in a great River of the Isle *Ceylon;* they are found in the sand at low water, three or four moneths after the rains have past, and the poor people are employed in seeking for them. The Stones which they ordinarily find there are clear, more lively than those of *Pegu,* and of a very high colour, especially the *Topaz.*
>
> Samuel Chappuzeau, 1671, *The History of Jewels*

Strachan (1701) discussed the rubies of Sri Lanka:

> Upon the coast betwixt *Gale* [Galle] and *Gindere* lies *Os Sepie* and in the River at *Catoene* there are found Rubies, and if one is desirous, and seek among the Sand in the Water, he will find above a drop weight of Rubies in the space of one hour, but they are very small, for 20 of them will scarcely weigh a grain weight, so that it is not worth a mans while.

From these accounts, it is clear that Sri Lanka is a vast storehouse of precious stones. In fact, the island contains the greatest concentration of gem deposits in the world. Not just rubies and sapphires, but some forty other gem species, including spinels, garnets, beryls, tourmalines, quartz, moonstones, topaz, taaffeites, ekanites, sinhalites, and others too numerous to list. With the sheer number and variety of stones found, the moniker "Island of Gems" is no accident.

Ruby & sapphire varieties

Virtually all varieties of corundum are found in Sri Lanka. Table 12.17 gives some traditional Sri Lankan nomenclature terms for corundums (based mainly on Ferguson, 1888; Mahroof, 1992; Clarke, 1933).

It is the blue sapphire that is Sri Lanka's pride and joy. Today, with the prevalence of huge quantities of heat treated Sri Lankan blues on the market, one may not realize that formerly the island was not a major source of blue sapphires. In olden days, before the rise of the *geuda,* Sri Lanka did not produce many fine blue sapphires in the smaller sizes. The reason is that the rough material is unevenly colored. Instead, good stones with a rich *and* even blue color mostly came in larger (above 5 ct) sizes only. With the advent of heat treatment, however, stones of smaller sizes and good color became available, so much so that today, Sri Lanka is the major source of fine blues in all sizes.

Over the years Sri Lanka has produced some fantastic natural blue sapphires of large size, both faceted and stars. These include top-quality gems in the 100–300 ct range. Many of the largest sapphires in museum collections around the world have originated from the gem gravels of Sri Lanka.

Origin of Sri Lanka's corundum deposits

One of the great geological mysteries of the past was the origin of Sri Lanka's gem deposits. While opaque corundums have occasionally been found *in situ,* virtually all gem material has been mined from secondary deposits. In the 1980s, a number of different studies were done on the possible genesis of Sri Lanka's gem minerals. The following scenario is based mostly on Rupasinghe & Dissanayake (1985):

Charnockites (orthopyroxene-bearing granites), which make up an integral part of the gem-bearing Highland Group, are thought to have played a key role. It is hypothesized that aluminous sediments derived from weathering and transportation of material from an Al-rich continental crust were deposited in the Highland Basin. Such pelitic sediments were subsequently deformed and metamorphosed under granulite-facies conditions caused by continental collision. Contemporaneous intrusions of basic charnockites of basaltic chemistry into the Al-rich sediments caused their desilication, resulting in the formation of corundum, spinel cordierite and sapphirine. The pegmatites, with which gem

Figure 12.92 Mining in Sri Lanka—it's the pits. (Photo by the author, 1981)

minerals like beryl, chrysoberyl and tourmaline are associated, are thought to be derived from a charnockite parent.

Mining areas

The corundum-producing areas of the island are located primarily in the southern two-thirds of the island. In Sri Lanka, Pre-Cambrian metamorphic rocks dominate, with the exception of the northwestern coastal belt (Zoysa, 1981). Cooray (1967) describes the division of the Pre-Cambrian rocks into three types, known as the Highland, Vijayan and Southwest Groups. It is within the Highland Group that most of the major gem fields are located. Topographically, Sri Lanka is divided into three peneplains as follows, with most of the gem deposits lying in the second peneplain:

- 1st Peneplain: Coastal plain, up to 30 m above sea level
- 2nd Peneplain: Average of 480 m above sea level
- 3rd Peneplain: Average of 720 m above sea level

The corundums of Sri Lanka are mined almost entirely from alluvial gravels. In only a handful of cases have they been found *in situ*. These *in situ* occurrences have been in pegmatites and gneisses, but were of low quality only and so of little economic importance.

Gem mining in Sri Lanka has traditionally been centered in and around the town of Ratnapura, the "city of gems" (*ratna* = gems; *pura* = city). But it is not confined only to this area. Mines are found scattered over the entire lower portion of the island, and every few years a new area is opened up. What makes Sri Lanka singular in the world is not simply the widespread gem occurrences, but also the fact that at most localities a number of different gem species are found, many unique to Ceylon. To date, more than forty different gem species have been found.

Ratnapura, Rakwana, Balangoda, Okkampitiya, and Morawaka are the main alluvial gem beds found in Sri Lanka. Although many different species are found at each location, each site is famous for one in particular, as follows (Zoysa, 1981; Fazli, 1995):

• Balangoda	Yellow sapphire
• Lunugala	Blue sapphire
• Morawaka	Chrysoberyl
• Okkampitiya	Blue sapphire, hessonite garnet
• Rakwana	Blue sapphire
• Ratnapura	Ruby, blue sapphire

Other areas where corundum has been found include:

• Elahera	Ruby, blue sapphire, stars
• Gampaha	Orange sapphire
• Koswatta (Rajagiriya, Colombo)	Orange sapphire
• Pelmadulla	Blue sapphire

Mining methods—It's the pits

Mining techniques in Sri Lanka are similar to those of other corundum placer deposits in Burma and Thailand, with one important exception—mechanized mining is banned. Gem placers are formed through the weathering action of the natural elements. Weathering releases the gems from their host rock and carries them to streams and rivers. Whenever a river loses velocity suddenly, it deposits its load of coarse sediments and stones carried in suspension. This occurs at the outlet of rivers entering the plains from the mountains, at hollows in the river bed, at the junction of a smaller stream with a large river and at concave sections in the bends of rivers. Gem placers are also found beneath the surface of rice paddies where rivers once flowed. It is from such alluvial sites that gems are mined.

The depth of the gem gravel, or *illam,* in Sri Lanka generally varies from 3–20 m; at Pelmadulla it may reach 40 m. Some areas contain only one gem bearing horizon while others contain two or three different layers of illam. The age of the alluvial deposits at Ratnapura has been determined to be middle to late Pleistocene (Zoysa, 1981).

Residual gem deposits occur in the Elahera area, which is one of the major gemming areas of Sri Lanka. Blue sapphire, ruby and star stones are found here. The Elahera deposits lie at a depth of between 3–10 m. The third major type of gem deposit in Sri Lanka is eluvial. These are found in the Horton Plains area. Depth of the gravel here is between 5–10 m.

The search for gems is a highly speculative operation and is usually carried out by a group of native workmen on a share basis. One fifth goes to the owner of the paddy field, another fifth to the financier, with the rest going to the actual workers.

Figure 12.93 Washing the *illam* in Sri Lanka's Ratnapura area. (Photo by the author)

After selection of a likely spot for mining, the ground will be tested from time to time as the pit deepens using a long steel rod sharpened and tempered at the point (Adams, 1927). By pushing the rod into the soft earth and twisting it round and round and by tapping the rod and carefully listening to the sound, an experienced operator can tell at what level the illam lies, its thickness, and its character. When the point of the rod passes through the illam and strikes the underlying decomposed bedrock, clay will be found adhering to its point; if the rod's surface is scratched this would indicate the presence of quartz or corundum, the two most common constituents of the illam.

To reach the illam, a shaft is sunk until either a blackish rock called *ralu ratta* or a rocky gravel of whitish color called *thiruvana* is reached. This indicates to the miners that the next layer is illam. If, after the illam they come to a layer of clay, called *malawa,* they cease digging (Ratnavira, 1939).

Shafts are round in the case of smaller pits, and square for larger pits. The shaft will be lined with small branches and vertical poles driven down into the mud to prevent cave-ins. One or two men work at the bottom of the pit shoveling the

The princely kiss of *padparadscha*

What's in a name? That which we call a rose by any other name would smell as sweet.

—William Shakespeare

JUST what is in a name? Plenty when it comes to the *padparadscha*. The debate over its use pits those who believe that romantic terms are vital sales aids, against others afraid that buyers will be taken advantage of if the padparadscha brush is too broad.

Today, padparadscha is narrowly defined by Western gemologists as a Sri Lankan sapphire of delicate pinkish orange color (Crowningshield, 1983). But the original use of the term was somewhat different. *Padparadscha* is derived from the Sanskrit/Sinhalese *padmaraga*, a color akin to the lotus flower (*Nelumbo Nucifera* 'Speciosa'). Most lotus blossoms are far more pink than orange, and in ancient times, padmaraga was described as a subvariety of ruby (*cf.* the *Garuda Purana*; Shastri, 1978). Even today, in Sri Lanka the term is used to describe stones more pink than orange. Just why the Western definition of a Singhalese term should be more acceptable than the way the Sinhalese use it themselves is a question deserving an answer.

A big part of the padparadscha problem is that some gemologists and dealers (including those who abhor the very idea of colored stone grading) use terms like padparadscha and chrome tourmaline as quality descriptions. They fail to realize that traditional gem varieties (such as 'ruby' or 'sapphire') encompass a broad range of both high and low qualities. *Sapphire* alone takes in the palest Sri Lankan blues and the darkest Australian stones. The gem trade and gem-buying public seem to have no problem with this variety description, because it is simple and based on hue position alone, not lightness/saturation. If it is blue, it is sapphire.

And yet there is no agreement with padparadscha, largely because people attempt to use the term to describe color quality (lightness/saturation) rather than just hue.

Another problem with names like padparadscha is that they are intrinsically associated with the localities where they were first found. When a rhododendron-colored garnet was first discovered in North Carolina, G.F. Kunz, who was well aware of the marketing value of an attractive name, dubbed it *rhodolite*. Upon finding that garnets of similar color could be found in other locales ('rhodolite'-like garnets had been mined for over two millennia in Sri Lanka), gemologists attempted to "prove" that true rhodolites were unique and locality-specific, even going so far as to identify the rhodolite variety not just by color, but by refractive index (RI). This led to the ridiculous situation where garnets of identical color and composition were labelled differently. One point too high or low on the RI meant a gem was not the coveted rhodolite, but a lowly almandine or pyrope.

Locality is not a practical way of defining gem varieties. Even if it were possible to determine, it becomes meaningless when a new source producing equal or better qualities is discovered. The best "padparadscha" this author has seen was unearthed in Vietnam, not Sri Lanka. However, should the gem trade decide that the name padparadscha is worth keeping, it would be far better to simply define the accepted color range. A gem could then be simply compared to a set of printed color references to see if it merited the princely padparadscha kiss.

Figure 12.94
Left: An oriental lotus blossom (*Nelumbo Nucifera* 'Speciosa'), from which padparadscha takes its name. (Photo by the author in Sri Lanka)
Right: While this 1126-ct Sri Lankan crystal displays a color which many non-Sri Lankan gem dealers consider that of the "true" padparadscha, note that it differs visibly from that of the lotus blossom at left. In Sri Lanka, the name padparadscha has been traditionally applied to stones which are far more pink than orange.
(Photo ©1983 Tino Hammid/GIA)

clay and mud into a small bamboo basket, which when filled is adroitly thrown upwards and into the waiting arms of another man at the surface. Deeper pits utilize a rope winch or bamboo pole lift. Due to the accumulation of water, bailing (or pumping today) is needed.

When the illam is reached, it is broken up with an iron rod called the *illam kura.* It is then brought to the surface and placed on a clean flat piece of ground prepared in advance. Work in the gem pits is hot and extremely muddy; miners wear nothing but a tiny loin cloth, fitting attire for those working in the shadow of Adam's Peak, a major pilgrimage site. The peak is said to have the footprint of Adam (or Buddha or Mohammad, depending on one's faith) at the summit, but even for the atheist a trip to the summit is definitely worthwhile. At sunrise, the mountain casts a huge shadow in the form of a perfect pyramid on the ground below. Definitely on the tourist map of those who believe in pyramid power. See page 38 for more on Adam's Peak.

Not all mining takes place in paddy fields. River beds are also mined. For river mining a small dam of reeds is constructed across the river below the area marked for mining (Punchihewa, 1983). Special long handled rakes are then used to scrape the gravel off the river bottom and towards the embankment. Thereafter, washing and sorting is done as usual.

By law, only the simplest of equipment is allowed for gem mining in Sri Lanka. Small floating sluices for use with scuba divers have been employed. Divers suck up the gravel in what amounts to a big vacuum cleaner; this is piped to the floating sluice for separation. Several of these are in use today in Sri Lanka. Beyond this, the only modern equipment used is the gasoline operated pump for dewatering the pits.[3] Overall, however, the gem industry in Sri Lanka today remains a primitive, "poor man's" business. This is not necessarily bad, though, for it has, and apparently, will continue to provide employment for thousands of needy villagers for many years to come. Countries such as Thailand, which is going through her gem deposits at breakneck speed, would do well to carefully examine the potential benefits of such a policy.

Washing the *illam*

Once sufficient illam has accumulated, washing can begin. This is carried out in a nearby stream or pond constructed specifically for the purpose, and is similar to the method employed at Mogok, in Burma. Each man stands waist deep in water with a basket filled with mud. A circular motion is employed, like panning for gold, to remove all lighter sediments, leaving the *nambuwa* (concentrate) at the bottom of the basket. When this is done the basket is brought to the shore. After several baskets have been thus prepared, another man, expert in the recognition of rough gems, examines each carefully in succession. The basket is tilted up so that the sun's rays shine upon the gravel and the man then invokes a prayer to the gods to give him good luck. With a rapid motion he sweeps the gravel back and forth, picking out the large fine precious stones, which are termed *jathi* (Leslie Punchihewa, pers. comm., 1982). The residue left behind after all jathi is removed is termed *toura-mali,* a word from which our tourmaline is derived.

Figure 12.95 Despite improvements over the past decade, much gem cutting in Sri Lanka is still performed by traditional, inefficient methods. (Photo by the author, 1989)

As the better stones are found, they will be handed to the man who finances the operation for safe keeping. This banker is always present during washing to ensure that theft is kept to a minimum (it can never be eliminated entirely). When one man finishes sorting a basket it will be handed to another for resorting so that nothing is missed. Once all of the illam is washed, the gems are taken to the market for sale, with the proceeds being divided pro rata among the partners in the claim (Adams, 1927).

The market in Sri Lanka

With so many fine gems being found in Sri Lanka, one might expect the island's gem trade to be a big business, but government regulation and the attitudes of local traders have combined to limit the volume of trade. To put it bluntly, it is difficult to do business in Sri Lanka, compared with other Asian gem centers such as Thailand and Hong Kong.

Sri Lanka's importance increased dramatically with the discovery of geuda heat treatments in the mid 1970s. By 1980, literally hundreds of Thai buyers were streaming into the country to purchase the once lowly geuda. Sri Lankan miners profited greatly from this situation, but dealers and other middlemen became increasingly jealous. This jealousy reached a peak in 1984, when Ratnapura and Colombo dealers petitioned the government to restrict the visas of Thais,

3. The government, however, has permitted mechanized mining of areas scheduled for inundation due to dam construction.

Sri Lanka's gem industry: Tangled up in red (tape)

CONSIDERING the above, it would seem correct to assume that Sri Lanka's gem industry is huge, but such is not the case. Government restrictions and the local peculiarities of doing business in Sri Lanka have combined to strangle the local gem industry. Sri Lanka has been, and continues to be, a difficult place to transact business.

Government red tape is only part of the problem. As is common throughout Asia, bargaining is the norm in Sri Lanka. However, the first asking price in Ceylon is usually ridiculously inflated, with the local dealer or miner hoping to make a killing on every sale. Since no one can possibly be an expert on every type of stone, buying the unfamiliar in Sri Lanka is an invitation to fiscal disaster. Those who cannot sell what they have purchased, do not return to try their luck again.

Dealers in Hong Kong and Thailand show greater foresight. More reasonable asking prices not only save time, but also ensure repeat business. When this is coupled with the minimal government red tape, it is not difficult to understand why business prospers in these places. Sri Lanka is a different story. Despite the production of raw materials, the gem business remains largely a cottage industry. It will only realize its true potential when the government removes all restrictions, and more importantly, when the local dealers and miners reduce their expectations to a legitimate level. By asking such high starting prices, they kill the goose that lays the golden egg, i.e. the customer.

Of course, Thai and Hong Kong dealers are only too happy to see the present conditions continue in Sri Lanka, for they are the winners. The most important factor in a country's gem industry is not local production of gem rough. One need only look at Burma and Sri Lanka to see the fallacy in this line of thinking. No, what is most important is the overall business climate. The government in Sri Lanka must remove restrictions and the dealers must begin to look at customers as other than mere "walking wallets" if business is to prosper. Apparently this message is finally beginning to get through, for in May, 1994 Sri Lanka began reducing certain government restrictions on the gem trade (Kremkow, 1994).

Figure 12.96 Dealers in Ratnapura eye a specimen while waiting for customers. (Photo by the author)

claiming that they were breaking currency regulations, and others laws banning the export of rough gemstones. These claims were true to a large degree, with currency and rough smuggling rampant. Typical of the prevailing attitudes among Sri Lanka's gem traders is the following:

> …we must take appropriate action in order that the country may gain the full benefits of the trade. These should include prohibition, a central trade organization, and facilities for training and research.… Several sources of income and employment are being created as a result of the *geuda* trade, and geuda sellers have benefited the most. Land owners and house owners receive more than their money's worth. Many girls who are engaged as prostitutes to Thai men, earn larger amounts than they could ever earn by being employed. Initially, most of these beneficiaries used to be academically not qualified to be employed elsewhere. Socio-economists label them as school 'drop-outs', but they make more money than an employed graduate! Sadly, today even some highly qualified professionals are also among those beneficiaries.
>
> W.A. Ratnasekera, 1988

Unfortunately, many of these same conditions existed long before Thai traders set foot on the island of gems. Witness the following from 1950:

> The City of Gems itself, Ratnapura, is also a city of adventurers as is to be expected.… Unfortunately the lure of gems, which attracts adventurers, attracts also women whose personal virtue is suspect. The harlots of Ratnapura are an island proverb and the place itself is known by a word meaning Womantown.
>
> Harry Williams, 1950, *Ceylon: Pearl of the East*

The answer to these problems, is not to simply bar Thais from Sri Lanka, as local dealers might wish. In order for the gem business to prosper, local dealers, cutters and treaters must become more competitive.

Sri Lanka's lapidary industry provides a perfect example. In 1939, a government committee published a study of the gem industry in Sri Lanka, listing problems and giving suggestions for improvement (Anonymous, 1939). One of the suggestions was to improve local cutting, the chief complaint being that cutters place too much emphasis on weight retention. Nothing has changed. All too often, Sri Lankan cutting is the standard to which all other *poorly* cut stones are compared. The government, in an effort to protect the local cutting industry, bans export of rough gems. But instead of protection, it merely perpetuates the low standards of

Ruby or pink sapphire? A lesson from the past

THE rubies of Sri Lanka can be extremely fine, approaching the best Burmese stones in quality. Most, however, tend to be less intense, more pink than red. In the past, such pink stones were termed *female rubies*, as opposed to the deeper red stones that were called *male rubies*. A search of the gemological literature reveals that the term *pink sapphire* did not appear until the beginning of the twentieth century. Prior to this, all corundums of a red color (pink is merely a light red) were referred to as rubies. Typical was the following from 1873:

> The colour of the ruby varies from the lightest rose-tint to the deepest carmine. Those too dark or too light are not esteemed.
>
> Harry Emanuel, 1873, *Diamonds and Precious Stones*

Then someone decided, incorrectly, that pink was not red. Early in the 20th century, the term pink sapphire makes its first appearance:

> The tint of the red stones varies considerably in depth; jewellers term them, when pale, pink sapphires, but, of course, no sharp distinction can be drawn between them and rubies.
>
> G.F. Herbert Smith, 1913
> *Gem-Stones and their Distinctive Characters*

Exactly where does one draw the line? Neither gemologists or traders can agree, which has led to the ridiculous situation of stones being brought to labs solely to determine if they are rubies or pink sapphires. We don't have this problem with blue sapphires; light or deep blue, they are still blue sapphires.

Our corundum conundrum has resulted from a quirk of language. In English, the hue "red" is broken up into two separate words. To the layman, "pink" is synonymous with "rose" and refers to pale or light reds (Kornerup & Wanscher, 1978), while "red" encompasses deeper tones and intensities only. However, to the color scientist, pink is a subvariety of red. Since ruby is defined as being red, someone mistakenly decided that pink must be a sapphire and problems began.

A comparison can be made to the Thai language, which features two distinct words for blue. *See fah* (สีฟ้า) refers to light blue, while *see num ngun* (สีน้ำเงิน) covers only dark blue. If Thais used the same logic for blue sapphire as some apply for ruby/pink sapphire, then a light blue sapphire would have a different name than those of a dark blue color.

Make sense? Not to this writer, but many gemologists and gem dealers apparently think so because this is exactly how they subdivide red corundums.

In the author's opinion, all corundums of a red color, regardless of its depth or intensity should be termed rubies, just as was done prior to the twentieth century. This would eliminate the above problem. In 1989, the International Colored Gemstone Association (ICA) adopted just such nomenclature. Unfortunately, the term pink sapphire continues to be used by many Western gem dealers and gem labs, who apparently cannot look past the ethnocentricities of their own language.

Figure 12.97 The red color of corundum ranges from near colorless to deep crimson. While many might disagree, the author would classify each of the above stones as ruby. These stones, the largest of which is 0.36 ct, are from Luc Yen, Vietnam. (Photo: Tino Hammid/GIA)

cutting, hurting the industry in the long run. While things have begun to change, room for much progress remains.

In 1971, the State Gem Corporation of Sri Lanka was set up with the aim of promoting the local gem industry. However it has merely added to, and become, a major cog in the overwhelming bureaucracy of the trade. By law, all exports must be channelled through the Corporation, which wastes precious time, one more reason for avoiding Sri Lanka.

The following steps are necessary to improve Sri Lanka's gem and jewelry industry:[4]

- Remove all restrictions on the export of Sri Lankan gems, both rough and cut. This will force the local cutting industry to match international standards. And if Sri Lanka cannot compete? As one much wiser than I once said: Life is tough—wear a cup.
- Eliminate all import duties on the materials necessary to produce modern jewelry. This includes cutting and jewelry manufacturing tools, as well as precious metals and gems. Eliminate means *eliminate*, not reduce. Cut the bureaucrat totally out of the loop. Don't give them the opportunity for graft.
- Dump the State Gem Corporation. The lack of such a bureaucracy hasn't hurt Thailand's gem trade and won't hurt Sri Lanka's. Take the employees and put them to work building a first-class gemological school and laboratory. The curriculum should include classes on modern gem cutting and jewelry

[4] While specific to Sri Lanka, these could apply equally to a number of gem-producing nations.


Figure 12.98 Zircon is one of the most common solid inclusions found in Sri Lankan corundums. These tiny crystals often display tension haloes, which are believed to result from expansion of the zircon due to metamict (radioactive breakdown) processes. (Photos by the author)

Figure 12.99 Crystal inclusions dart through the interior of a sapphire from Sri Lanka. 31×; polarized light. (Photo by the author)

manufacture, as well as traditional gemology. Publish a journal, so that the rest of the world can learn of, and about, Sri Lanka's gem riches.
- Encourage Sri Lankans to travel abroad to other gem centers, to learn about their successes (and failures).
- Teach local businesspeople that there is greater gain in repeat business with a 20% mark-up than one-time business with a 200% margin. Customers who are overcharged do not return again.

Nature has endowed Sri Lanka with mineral and gem wealth greater than any other country of similar size. It is indeed a shame that the country's people have yet to realize the full benefits of this resource. Hopefully the residents of Sri Lanka, Sinhalese, Tamil, and Muslim alike, can put aside their differences, for the diversity of the island's peoples has the potential to become Ceylon's strongest asset.

Characteristics of Sri Lankan corundums

Overview. No matter what the color (and virtually all colors are found), corundums from the island of Sri Lanka tend to be similar internally. These include exsolved rutile silk, a variety of solid inclusions (apatite, rutile, zircon, spinel, etc.), primary negative crystals and secondary healed fractures in an extraordinary plethora of patterns.

Ceylon rubies and sapphires are noted for the many types of fluid inclusions they contain. Fingerprints, feathers, web and mesh-like patterns, these and so many others await discovery within the Sri Lankan corundums. No other source produces such varied and complex types of fluid inclusions.

Other important features include negative crystals of high relief which are often two-phase and mimic the bipyramidal habit of their host. Polysynthetic twinning is somewhat rare compared with other sources, while strong color zoning and solid inclusions of a number of different types, including zircon, mica and apatite, are characteristic.

Due to the widespread practice of high temperature heat treatment of corundums, internal features can be drastically altered. The effect of such treatments on inclusions is taken up in Chapter 6, while here are described the features of untreated gems.

Solids. Sri Lanka's rubies and sapphires are rich in mineral inclusions. Among the most important of these are rounded grains of zircon surrounded by tiny tension fractures, creating a halo. These halos are thought to have formed by the increase in volume of the zircon as it decays to the amorphous metamict state. Brownish stains may also be seen within the tension cracks.

Other common mineral guests in Sri Lankan rubies and sapphires are dark red prisms of rutile, hexagonal prisms of apatite, spinel octahedra, and corroded brown slabs of biotite and phlogopite mica. Also identified are crystals of tourmaline, pyrite, pyrrhotite, garnet, graphite, corundum and calcite.

Heat treatment often turns included crystals into round white "snowball" inclusions. These are commonly sur-

Figure 12.100 Sri Lanka has historically been the source of the largest gem sapphire crystals. The 3965-ct fist-sized example above was valued ca. 1991 at over $1 million, and was estimated to yield a number of cut gems in the 50–100 ct range. (Photo: Fred Ward)

Figure 12.101 A phantom crystal rears out of the depths of a Sri Lankan sapphire. (Photo by the author)

rounded by glassy circular tension discs, with secondary healing rinds at the outermost edges.

Cavities. Well-formed negative crystals are a frequent guest within Ceylon corundums. At times, two-phase fillings are seen, while in one case witnessed by the author, a sand-like debris was contained in a negative crystal that stretched from one end of the host crystal to the other. Incredibly, when the spindle-shaped crystal was inverted, the sandy debris ran slowly down to the opposite end, just like an hourglass. So large was this cavity that the entire performance could be observed with the naked eye (now if we can just get Sri Lanka to produce these in calibrated sizes).

The filling material in these negative crystals has proven to be combinations of liquid and gaseous CO_2. In some cases, a solid phase is also present. Most consist of graphite (Gübelin & Koivula, 1986), but diaspore has also been identified (Schmetzer & Medenbach, 1988).

Negative crystals in Ceylon stones may be either primary or secondary. Two shapes are common; the hexagonal bipyramid, which is sometimes extremely elongated, and the tabular hexagonal bipyramid terminated with pinacoid faces. They can be distinguished from solid crystals by their high relief and identical orientation, with identical faces of each negative crystal running parallel to those of the host corundum.

Sri Lankan corundums possess healing fissures in great abundance. These occur in every shape, size and pattern, turning the stones' interiors into tapestries of fluid droplets. Gazing into Ceylon sapphires, we see fluid filaments spun into dazzling webs of incomparable beauty. Insect wings, fingerprints, mesh-like healing nets, veils, all are present, each one a testimony to the natural forces which shaped these gems deep within the earth. The full spectrum of healing is found, from open cracks with no signs of healing, to completely healed inclusions consisting of tiny negative crystals in fingerprint patterns.

You go from form
Into the formless
Into the void…
It is eternally quiet
It is eternally quiet
It never was…
Richard Alpert, *Be Here Now*

Figure 12.102 Into the void of a Sri Lankan sapphire. (Photo by the author)

In transmitted light, the fluid filling of these secondary cavities may at times appear pale yellow in color, while reflected light from a fiber optic light guide reveals details of the healing process on the surfaces of the residual fluid canals. Close examination under high magnification shows each channel to be a tiny fluid-filled negative crystal. Where the fluid is thin enough, vivid interference colors arranged in geometrical patterns of tiny steps can be seen. During the healing process, as more and more material builds onto the inner walls of the fracture, irregular voids are gradually reduced in size, eventually taking on crystal outlines of tabular hexagonal shape. Such flattened negative crystals in fingerprint groupings frequently display inverted triangular growth steps on the top and bottom basal pinacoid faces, as well as horizontal striations along the prism or pyramid faces. Also observed in Sri Lankan sapphires are extremely thin iridescent fluid films in parallel planes (usually with their broad side parallel to the basal pinacoid).

Growth zoning. Strong color zoning is the norm. Most Sri Lankan ruby and sapphire crystals are unevenly colored, with large areas altogether devoid of color. In blue sapphires, crystal cores are often colorless, with blue concentrated just below the crystal faces, in thin layers. Such crystals are locally termed *ottu,* meaning "to risk," for the color bands must be carefully placed during cutting to achieve an even color, itself a risky operation. A Sri Lankan ruby once shown to the author possessed a medium red color around the edge and a deep red hexagonal pupil in the center.

Before heat treatment, color zoning in Sri Lankan corundums generally has razor-sharp edges. However, after burning, the edges become slightly dulled or diffused, with much of the detail of the narrow, sharp growth striae gone.

Twinning. Secondary polysynthetic twinning is rather uncommon in corundums from the gravels of Sri Lanka. Instead, twins are typically growth twins and are generally found as single planes, rather than the multiple glide twins of corundums from other sources.

Exsolved solids. Within unheated stones, rutile silk is common, although high temperature treatments will remove most, if not all, of this rutile. Compared with Burmese gems, the silk in Sri Lankan corundums tends to be longer and less tightly woven, but this is not a reliable means of separation.

The prevalence of silk is illustrated by the large number of star rubies and sapphires produced from the island's gem gravels. At times, the needles are accompanied by elongated or irregular thin plates which also appear to be rutile. In addition to needles and plates, clouds of tiny exsolved particles are common.

Although rutile silk can be found in Sri Lankan stones of all colors, it is somewhat less common in the yellow sapphires, which tend to contain exsolved particles rather than needles. Heat treatment of Sri Lankan yellow sapphires apparently diffuses the coloring agent from these particles into the corundum. This is confirmed by the intensification of color where the particles are in greatest concentration and the color rinds surrounding the particles after heating.

In addition to exsolved silk/particles, clouds are also found in which the constituents are so small and evenly distributed that even high power magnification (100× or more) cannot resolve them. Sometimes termed "texture clouds," they are often a brownish yellow color in transmitted light and display a roiled, milky appearance. Dealers in Sri Lanka refer to this effect as "diesel," due to its oily appearance. *Geuda* sapphires show it best and traders look for the diesel effect when selecting rough for heat treatment. After heating, texture clouds of a somewhat similar nature are commonplace in Sri Lankan blue sapphires. Texture clouds may consist of the non-titanium residues from the rutile, which diffuse into corundum at a far slower rate than titanium (see page 121).

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Table 12.18: Properties of Sri Lanka corundum[a]

Property	Description
Color range/phenomena	Virtually all colors found, except emerald-green • Red: colorless to a rich, purplish red (strongly fluorescent) • Blue: colorless, through bright blue, to a dark blue • Violet/purple: colorless to a rich violet or purple • Yellow: colorless to a rich yellow • Orange: colorless to a rich orange to pinkish orange. • Green: rare, generally light in color • Six-rayed stars in virtually any color are quite common; 12-rayed stars are known (Anonymous, 1950a), but rare.
Geologic formation	Secondary deposits thought to be derived from charnockites (orthopyroxene-bearing granites) and associated rocks
Crystal habit	Variable; typically spindle-shaped hexagonal bipyramids. Some of these may be modified by pinacoid faces. Hexagonal prisms are also found.
RI & birefringence	n_ε = 1.759–1.763; n_ω = 1.767–1.771 Bire. = 0.008
SG	3.99–4.02
Spectra	**Visible** • Red, purple, violet stones: Cr spectrum Combinations of the above may also be seen • Blue stones: weak to moderate Fe spectrum
Fluorescence	**UV**: Variable, depending on body color • Blue: LW—inert to strong red to orange; SW—inert to moderate red to orange. Heat treated gems often show a zoned chalky blue-green SW fluorescence. • Red, violet, purple: LW—moderate to strong red to orange; SW—same, but weaker • Yellow, orange, colorless: LW—moderate to strong orange; SW—moderate to strong orange
Other features	Most are heat treated; yellow, orange and colorless gems may be irradiated to produce a deep yellow to orange color (such irradiation may also modify the color of other varieties)
Inclusion types	**Description**
Solids	Various, including… • Apatite prisms (Gübelin, 1969) • Boehmite (Sahama & Lehtinen *et al.,* 1973) • Calcite (Gübelin, 1953) • Chalcopyrite (Gübelin, 1973) • Corundum (Gübelin, 1953) • Feldspar (albite) (?) • Garnet (Gübelin, 1953) • Graphite, black crystals (Gübelin & Koivula, 1986) • Hematite (Gübelin, 1953) • Ilmenite (Gunawardene & Rupasinghe, 1986) • Mica (biotite, phlogopite, muscovite) (Gübelin, 1953) • Pyrite (Gübelin, 1953) • Pyrrhotite (Gübelin, 1969) • Rutile; rod-like crystals (Gübelin, 1969) • Spinel octahedra (pleonaste, gahnospinel, etc.) (Gübelin, 1953) • Tourmaline (?) • Uraninite octahedra (Gübelin, 1973) • Zircon crystals (often with stress halos) (Gübelin, 1953)
Cavities (liquids/gases/solids)	• Well-formed primary cavities ('negative crystals') are common and often display habits typical of Sri Lankan sapphires (bipyramids); these are often two or three phase and may contain graphite and/or CO_2. Liquid and gas phases will be homogenized at 31.5°C, proving CO_2 composition. Diaspore has also been identified as a solid phase in cavities in Sri Lankan corundum (Schmetzer and Medenbach, 1988). • Secondary negative crystals (healed fractures) are also common and often display lovely 'lacy' appearances; these probably display a greater variety of patterns and beauty than corundums of any other source
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; generally associated with clouds of rutile silk. Sri Lankan stones are notable for their obvious growth zoning. In unheated specimens this zoning has extremely sharp edges; after heat treatment the edges of individual zones is somewhat fuzzy. • Color zoning is often restricted to the areas just beneath crystal faces; such stones are termed *ottu* in Sri Lanka
Twin development	• Various types of growth twins are common. Contact twins on {0001} and {$10\bar{1}1$} have been reported (Schmetzer, 1987b). • Polysynthetic glide twinning on the rhombohedron is rare
Exsolved solids	• Fine to dense clouds of short to long rutile needles, parallel to the second-order hexagonal prism (3 directions at 60/120°) in the basal plane

a. Table 12.18 is based on the author's own extensive experience, along with published reports of De Maesschalck & Oen, 1989; Gübelin, 1940, 1942–3, 1953, 1968, 1969, 1973; Gübelin & Koivula, 1986; Gunawardene & Rupasinghe, 1986; Hoagland, 1952; Koivula, 1980, 1980–81, 1986; Sahama, 1982; Schmetzer & Medenbach, 1988; Schrader, 1985; and Zwaan, 1967.

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Sweden

Non-gem corundum has been reported at the Baron mine at Gellivare-Mamberg, in Lapland. Here it occurs in both magnetite and hematite with syenite.

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Switzerland

Corundum in dolomite has been found on the Campo Longo, at Tessin, Switzerland. The color ranges from pale red to blue, gray and colorless, with specimens being transparent to translucent. Clear prisms of up to 10 cm in length have been reported. Red and blue corundum are said to occur in dolomite at St. Gotthard (Barlow, 1915).

Ruby has also been found in amphibolite at Valle d'Arbedo and northern Locarno, and in marble at Passo Campolungo (Hunstiger, 1989–90).

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Tajikistan—
see Afghanistan/Tajikistan

Tanzania

Tanzania, the largest country in East Africa, was created in April 1964 by the union of Tanganyika and the island of Zanzibar. It became independent in 1961 after being successively under Arab, German and British control. The area has a long trading history. Kilwa, a coastal trading community in southern Tanzania, was visited by Ibn Battuta in 1331. Vasco da Gama landed on Zanzibar in 1499 and David Livingston explored the country in 1871 in his famous search for Henry Morton Stanley. Site of the Leakys' discovery of *Homo sapiens* earliest ancestors and home to Africa's highest peak, Mount Kilimanjaro (5,894 m), Tanzania is also an important source of ruby and sapphire.

Despite Tanzania's enormous gem wealth, the local gem industry is largely a product of the twentieth century, particularly from 1950 on. But the industry remains primitive, mired in government red tape. In 1971 the government nationalized the first gem mines; the policy throughout the 1970s and 80s was total state control. Needless to say, this did not produce a healthy local industry, with most gem rough fleeing across the long and porous border with Kenya. As of 1992, the government had liberalized the trade substantially (Dirlam & Misiorowski *et al.,* 1992). If the present trend continues, Tanzania's gem industry has great potential.

The Mozambique Orogenic Belt—East Africa's cauldron of gem creation

> Proclus in his book of Sacrifice and Magick, saith, That the antient Priests were wont to mix many things together, because they saw that divers Simples had some property of a God in them, but none of them by it self sufficient to resemble him. Wherfore they did attract the hevenly influences by compounding many things into one, whereby it might resemble that One which is above many.
>
> J.B. Porta, 1658, *Natural Magick*

Tanzania's corundums are largely a product of the Mozambique Orogenic Belt, which cuts a 200–300 km-wide north-south swath through the eastern part of the country. Running all the way from Mozambique in the south, to the

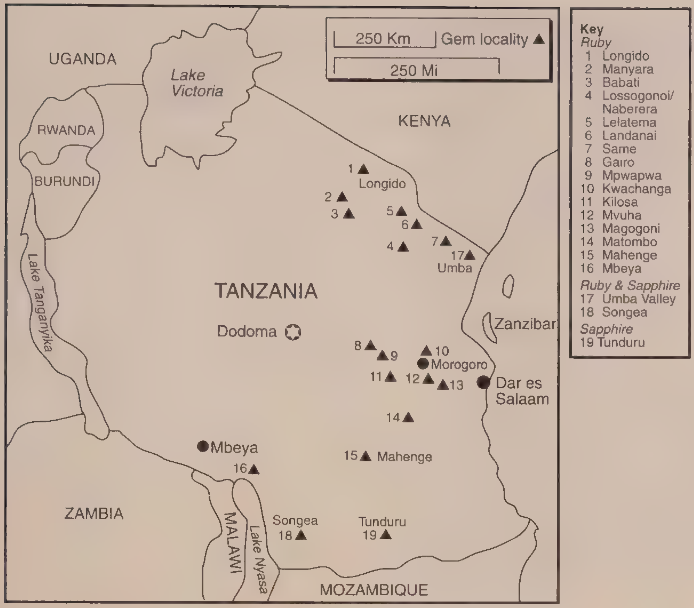


Figure 12.103 Corundum deposits of Tanzania (modified from Dirlam & Misiorowski *et al.*, 1992; Keller, 1992; and Bassett, 1993).

Sudan and Ethiopia in the north, this belt is home to many of East Africa's most important colored gemstone finds.

Rocks in this belt underwent several different cycles of tectonism, as well as extensive metamorphism, plutonism, folding and faulting. The metamorphism produced granulite complexes,[5] which, when combined with major crustal movements, formed a witch's brew of unusual minerals and color varieties. In the granulitic cauldron, pressure and hot fluids cannibalized minerals for their chromophores—vanadium, chromium, manganese—where they were absorbed by existing minerals. At other times, minerals were simply dissolved and built anew. The result is one of the richest gem belts on the planet (Dirlam & Misiorowski *et al.,* 1992).

Localities

Although corundum has been found in many different areas in Tanzania, the most important deposits are as follows:

- Umba River Valley: Ruby & sapphire in many different colors
- Morogoro area: Ruby
- Longido: Ruby in a chrome-green zoisite
- Mbinga District of Ruvuma (Songea): Ruby & fancy sapphire
- Tunduru: Ruby & sapphire in many different colors

Umba River Valley

Originating in the Usambara mountains of northeast Tanzania, the Umba River flows eastward towards the coast. Corundums, garnets and a number of other gems are found at a place where it passes along the western edge of the Gilevi Hills. Although rubies are mined at Umba, it is the cornucopia of sapphire colors for which this locality is famous. Oranges, yellows, violets, blues, bi-colors, color-changing stones and hues, for which words cannot do justice, are all present at Umba. John Saul once made a reference collection of 108 distinct sapphire colors from Umba, excluding grays, parti-colored stones and color-changing stones (J. Saul, pers. comm., 1987).

Figure 12.104 Like insects, miners tear at the earth in their quest for sapphires at Tanzania's Umba Valley. (Photo: © Fred Ward/GIA)

Corundum was discovered at Umba in 1960. George Papaeliopoulos ('Papas'), a young Tanzanian of Greek origin made the original find. Claims were subsequently pegged by

5. Sets of metamorphic mineral assemblages resulting from high pressures and temperatures.

Figure 12.105 Mechanized washing plant at a ruby mine one hour south of Mahenge, Tanzania. (Photo: © Fred Ward/GIA)

Figure 12.106 A fine ruby crystal from Tanzania. (Photo: Robert Weldon/GIA; specimen: M. Chung)

Papaeliopoulos' company, Umba Ventures, Ltd. (Solesbury, 1967; Sarofim, 1970; Dirlam & Misiorowski *et al.*, 1992). This company mined an area of 2,350 acres from 1961 until 1972, when it was nationalized. The Tanzanian government took over until 1982, when Gupta Exploration & Mining was given the rights. In 1989, Asia Precious Stones and Equipment Co. of Thailand obtained a license. This company formed a joint venture (Africa-Asia Precious Stones and Mining Co.—AAPS) which obtained exclusive rights to Umba (Dirlam & Misiorowski *et al.*, 1992).

Geology and occurrence. The source of Umba corundums is in and around a grayish-green serpentinite pipe measuring about 2.4 km in a north northeastern direction by 1.2 km wide (Bridges, 1982). Pegmatitic veins striking generally north northeast and dipping almost exclusively eastwards, cut and lie within the pipe. Associated with the pegmatite are vermiculite, chlorite, actinolite and sometimes corundum. The country rock consists of amphibolite-garnet gneisses, biotite gneisses, siliceous granulites, and crystalline limestones carrying small flakes of phlogophite and graphite. Corundum occurs mainly in the limestones, but gem-quality stones are found almost exclusively in the pegmatitic areas within or bordering the pipe where it is associated with vermiculite and chlorite. The main mine extended 100 m below the surface, with tunnels radiating from the primary shaft on the gem-bearing levels. Gem material is also mined from alluvial gravels and this has been the main source since mining first began (Bridges, 1982). As of 1992, most mining was in secondary deposits (Dirlam & Misiorowski *et al.*, 1992).

Under normal conditions, corundum will not form in pegmatites, due to the presence of silica. However, Umba corundums are thought to have formed in granitic pegmatites, via desilication, as they intruded the silica-poor serpentinite. This theory is born out by the following factors:

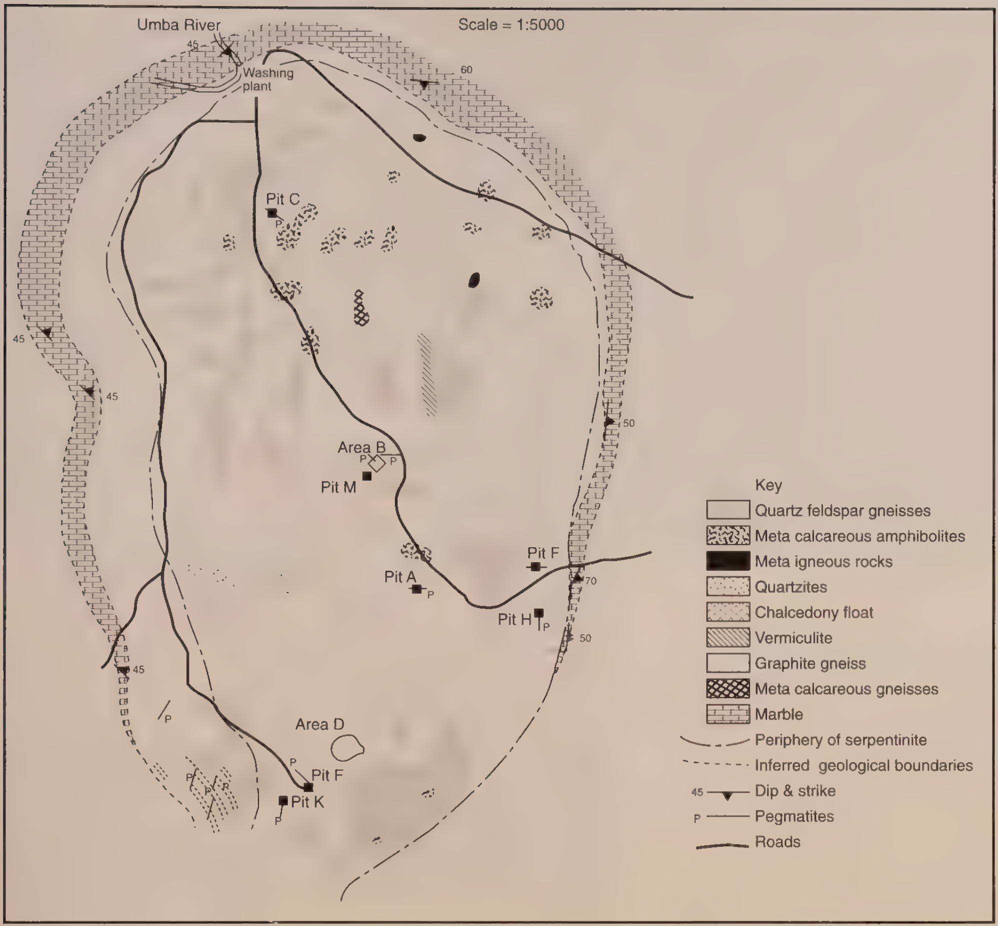


Figure 12.107 Corundum deposits of Umba River, Tanzania. (From Solesbury, 1967)

- There is never any quartz in association with corundum.
- When present the feldspar consists of plagioclase (generally oligoclase to bytownite).
- The association of the pegmatites with a basic or ultrabasic host.

The sapphire occurrence at Umba is unique. Stones are found around the aforementioned pipe, being brought up in shafts scattered in a perimeter of over 3.2 km. Ten different shafts were found scattered around the pipe, each producing only one color of sapphire. Matrix collected from the shafts is processed by knocking them to reduce their size, before being milled and then extensively treated in tumblers. This causes disintegration of the agglomerate, thus freeing the sapphires (Sarofim, 1970).

Production. Production in 1969 was said to be 100,000 ct per month. Of this, over two-thirds was produced by the company while small miners found less than 20,000 ct. A large proportion of the corundum mined at Umba is large rough of a facetable grade (Sarofim, 1970). Rough that yielded cut rubies as large as 20 ct was occasionally found during the 1960s and 1970s. The largest faceted ruby was a stone of 69 ct (Roland Naftule, pers. comm., 11 Dec., 1994). Faceted sapphires as large as 40 ct and cabochons up to 90 ct have been reported (Dirlam & Misiorowski *et al.*, 1992).

About 1965, the Naftule family (Roland Naftule of Phoenix, AZ-based Nafco Gems and Naftule Fils of Switzerland) purchased a substantial quantity of Umba material. So much, in fact, that, barring a run on Umba sapphires, the Naftule hoard is said to be sufficient to last well into the next century (Federman, 1988).

Varieties. True ruby-red colors, although scarce, do occur at Umba. But most of the reddish stones found tend towards orangy red and magenta shades, which traditionally have not been classified as ruby. Instead, it is the multihued sapphires which are Umba's forté. These range from light to deep blue (most with a violet tinge), pink, orange, yellow, purple, green, peach, lavender, lilac, violet and even color-changing varieties. Parti-color stones are also found. One such specimen described by Campbell Bridges (1982) had a diameter of 4" (10 cm), passing in color from deep pink through orange, yellow, green and blue. It is said that at least six of the major color-producing ions (Cr, Fe, Mn, Ni, Ti, V) are

Figure 12.108 Rough and cut sapphires from Tanzania's Umba Valley. (Photo: Bart Curren/ICA)

present in the Umba pipe and its environs. This appears to be one of the key factors in explaining the tremendous color variation of Umba sapphires.

One of the more interesting varieties found is the color-change sapphire, which changes from a greenish to grayish blue in daylight to a purplish color under incandescent light. Vanadium plays an important role in causing the shift of color, similar to the Verneuil synthetic and certain Burmese stones; such stones may show a vanadium spectrum.

Another unusual variety is the orange sapphire. While many Umba orange sapphires tend to be darker and more brownish than their Sri Lankan brethren, stones identical in color to the delicate pinkish orange *padparadschas* of Serendib are also found. Some have suggested that this term be strictly reserved for Sri Lankan stones, but this is both impractical and illogical. Even if it were possible to determine the provenance of every stone, it is a needless complication to doing business. Furthermore, when the gem trade itself cannot agree upon just what the color range of padparadscha should be, it is difficult to accept the arbitrary definition of one dealer and not another.

Characteristics of Umba Valley corundum

Umba sapphires possess a distinctive internal appearance. Most are crisscrossed by rhombohedral twinning planes and the accompanying boehmite needles. Along with these long boehmite needles are multitudes of tiny thin plates or films which have also formed along the rhombohedron planes. These appear to be microscopically thin plates and needles of another mineral formed through alteration or exsolution, and give a dazzling iridescence when illuminated by a fiber optic light guide.

Extremely common are crystals of zircon. Apatite is also a frequent guest in Umba stones. These may range in size from large euhedral or rounded individuals to tiny plates or even fragments. Some stones may feature large numbers of these hexagonal apatite prisms.

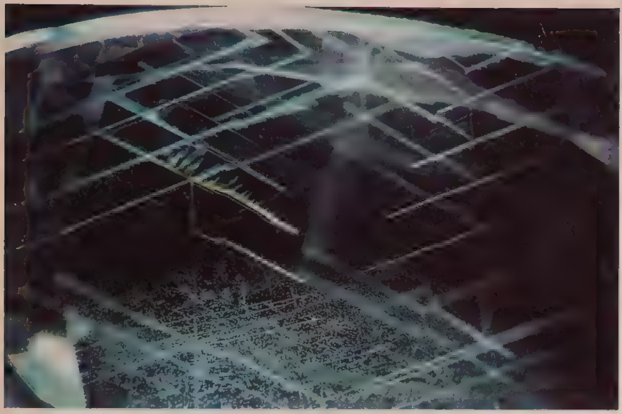
Morogoro

The Morogoro region, 120 km west of the capital of Dar-es-Salaam, began producing ruby in the 1970s. Although actually a large province with a town of the same name, rubies from anywhere in the region are termed "Morogoro" ruby (Dirlam & Misiorowski *et al.*, 1992).

Mines in the area include Matombo, Kitonga, Epanko, Ruaha, Lukande, Mayote and Kitwaro (Hänni and Schmetzer, 1991). The rubies are found in either alluvial diggings or associated in agglomerates of mica and kyanite. Gravel containing the rubies is usually collected from the surface or extracted from shallow pits. It is then washed in the typical manner of such workings and the rubies selected out by hand. Small amounts of spinel are also found. When the ruby occurs in the mica/kyanite agglomerate, the matrix is either crushed or tumbled to free the gems. Morogoro rubies are said to be of a pinkish color somewhat reminiscent of some Burmese rubies (Sarofim, 1970).

Longido

The following is based on the accounts of Sarofim (1970) and Dirlam & Misiorowski *et al.* (1992). Tanzania's first corundum discovery dates back as far as the early 1900s. A German officer stationed along the Kenya border at Mt. Longido found red stones in the area which subsequently proved to be rubies. The outbreak of World War I, with the Battle of Merkerstein, fought close to the deposit, put an end to his exploration, but at war's end he returned to continue the search. In 1924 he formed the Tanganyika Corundum Exploration Corp. Ltd., which operated sporadically until 1971, when the Tanzanian government nationalized the



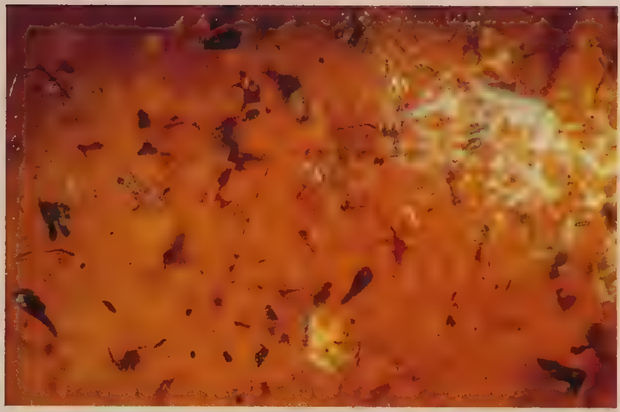


Figure 12.109 Inclusions of Umba Valley sapphires
Top left: Boehmite needles. (Photo: Henry Hänni/SSEF)
Top right: Zircon and garnet crystals lie amidst the silk of an Umba corundum. (Photo: Henry Hänni/SSEF)
Left: Ultra-thin hematite plates and needles seen in a sapphire from Umba Valley, Tanzania. 63×. (Photo: Shane McClure/GIA)

Figure 12.110 Rubies from Tanzania's Morogoro area. The three cut stones at left range from 0.51 to 3.31 ct, while the crystals at right range from 5.65 to 8.55 ct. (Photo: Shane McClure/GIA)

mine and subsequently closed it. Reopened in 1988, it is now operated by the Longido Gemstone Mining Co.

The company's concession covers more than 700 acres, consisting of two hills at the foot of Mt. Longido. Here the ruby displays a unique origin. It is found as hexagonal red crystals of sometimes enormous size (for ruby) encased in *anyolite* (derived from a Masai word for green), a rock consisting of chrome-green zoisite and dark green to black amphibole. Explosives and pneumatic drills are used to reach the anyolite, which is brought to the surface from 100 m-deep galleries sunk into the hills.

Anyolite occurs in a "reef" about 0.5–1.0 m wide and 500–600 m long. This reef itself lies in a weathered peridotite that was intruded into a sequence of high-grade metamorphic rocks including marble. Invariably it contains black hornblende concentrations, which appear to affect not only the color of the rock, but also that of the rubies. The best rubies are said to be found in the light colored anyolite, while the darker rock yields darker rubies.

Upon reaching the surface, the anyolite is hammered to free the ruby crystals, which vary in diameter from small sizes to more than 20 in (50 cm). Cobbing of the rough is performed, as all the rubies are heavily included. Each stone is broken down until it begins to transmit some light. Those which upon cobbing to 2 mm size still fail to transmit light are then discarded. Prior to export, the rough rubies are commonly tumble-polished to remove cracked sections.

According to Sarofim, the percentage of usable gem ruby rough to anyolite is said to be on the order of 80 ct per

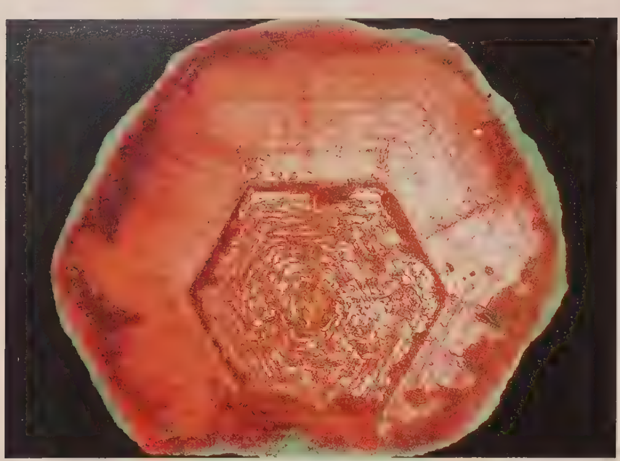


Figure 12.111 Longido ruby
Left: Ruby at Longido occurs in *anyolite*, a rock composed of chrome-green zoisite and dark green to black amphibole. (Photo: GIA; specimen: A. Ruppenthal)
Right: Tanzania's Longido mine produces mostly carving material. Rare examples of cuttable material from this mine are shown above. The faceted stone is 0.19 ct, while the cabochon weighs 2.10 ct. (Photo: Robert Weldon/GIA; specimens: Allen Bassett)

metric ton. Of this, only 1% is of cabochon grade, with even less being facetable; the rest is suitable only for carving. Most rough is less than 5 mm in size. Faceted stones seldom exceed one carat.

Longido stones tend to be of a deep brownish red color, somewhat similar to the better grades of Indian ruby. Some of the mine's output goes to gem carvers. The carved material often incorporates the original chrome-green zoisite matrix. Cabochons are also fashioned out of the matrix, and when rubies are present, are sold as "ruby-in-zoisite."

Songea

Starting in 1994, small, pastel-colored sapphires began appearing from a remote area in the Mbinga District of Ruvuma, in southern Tanzania This deposit is generally known as Songea. (Suleman & Zullu *et al.*, 1994). Most are blue, but fancy colors are also found, along with color-changing stones and some approaching a ruby color. The closest village to the deposit is said to be Amanimakoro (Kammerling & Koivula *et al.*, 1995).

Tunduru

In 1995, the SSEF reported on sapphires from another deposit, located at Tunduru, next to the Muhuwesi Forest Reserve where the Muhuwesi and Mtetesi rivers meet. River gravels were being worked for a number of different gems. The corundums ranged from blue, through pink, purple, green, brown and gray (ICA Gazette, 1995).

Bangkok's Mark Smith reports that this material is much finer than that from Songea, with the color range resembling that found in Sri Lanka. He had seen 1000-ct parcels of 1–2 ct purples. One 3-piece parcel of pink-purple sapphire weighed over 35 ct. Some pink gems have been heated to a *padparadscha* orange. In addition to corundum, alexandrite

Figure 12.112 In 1994, sapphires such as these from Tanzania's Songea region began to appear in world markets. (Photo: Bart Curren/ICA)

and cat's eye chrysoberyls, diamonds, garnets and spinels are also mined in the Tunduru area (M. Smith, pers. comm., 20 Sept., 1995).

Other Tanzanian localities

A number of other areas in Tanzania produce ruby. Ruby in anyolite occurs at Naberera and Lossogonoi. The latter, on the Masai Steppe, produced several thousand carats of superb darkish rubies during a few weeks of digging in the late 1960s. Ruby is also found at the north end of Lake Nyasa (Bassett, 1993) and ruby in marble has been reported at Ngorongoro, Tanzania (Hunstiger, 1989–90). The area near Handeni has produced quantities of cabochon-grade ruby crystals of tabular habit. Small amounts of ruby have been found with the alexandrite and emerald deposits at Lake Manyara (Dirlam & Misiorowski *et al.*, 1992).

Table 12.19: Properties of Umba Valley (Tanzania) corundum[a]

Property	Description
Color range/phenomena	• Virtually all colors found, but usually of low saturation. When deep colors are found, they generally lack the saturation of fine gem corundums. Colors include deep red-oranges, light blues, blue-greens and greens, and light yellows. Color is often lighter at the crystal core, or vice versa. The color may be influenced by sometimes extensive hematite exsolution. • Color-change gems are known; star stones have not been reported.
Geologic formation	Weathered deposits derived from pegmatite veins which have cut a serpentinite body
Crystal habit	• Sapphire: Generally tabular hexagonal prisms terminated with basal pinacoids and with no development of pyramid faces. Traces of rhombohedron-pinacoid oscillation may result in non-intersecting triangular markings on pinacoid faces; solution of boehmite along rhombohedral twin planes may result in intersecting striations. • Ruby: Similar to the sapphire, but with a more rhombohedral habit (Webster, 1961)
RI & birefringence	Higher values with increasing Cr or Fe content n_ε = 1.760–1.769; n_ω = 1.768–1.778 Bire. = 0.008
SG	3.97 to 4.06
Spectra	**Visible**: Cr or Fe spectra, or a combination of the two. Rarely, V spectrum.
Fluorescence	**UV**: Generally inert. Cr-rich stones may show a weak to moderate red to red-orange (LW stronger than SW).
Other features	Certain varieties may be heat treated
Inclusion types	**Description**
Solids	• Apatite (Zwaan, 1974) • Calcite (Hänni, 1987) • Feldspar (plagioclase) (Gübelin & Koivula, 1986) • Graphite (Zwaan, 1974) • Hematite (Hänni, 1987) • Mica (vermiculite) (Zwaan, 1974) • Monazite (Hänni, 1987) • Pyrrhotite (Zwaan, 1974) • Spinel (Zwaan, 1974) • Zircon (Zwaan, 1974)
Cavities (liquids/gases/solids)	• Primary cavities and negative crystals • Secondary healed fractures are common
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed
Twin development	• Polysynthetic glide twinning on the rhombohedron is common
Exsolved solids	• Rutile needles in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°), in the basal plane • Brownish hematite needles & plates along the first-order hexagonal prism (shorter and more platy than rutile) • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.19 is based on the author's own experience, along with the studies of Hänni (1987) and Zwaan (1974a)

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Table 12.20: Properties of Morogoro area (Tanzania) ruby[a]

Property	Description	
Color range/phenomena	• Weak to rich red to purplish red	• Six-rayed stars are found on occasion
Geologic formation	Alluvial deposits or as lenses in Calc-silicate rocks within marble	
Crystal habit	Mainly rhombohedron {10$\bar{1}$1} and pinacoid {0001} combinations. Some may be modified slightly by the hexagonal prism {11$\bar{2}$0}. Crystals may be confused with spinel octahedra.	
RI & birefringence	n_ε = 1.761–1.762; n_ω = 1.769–1.770	Bire. = 0.008
SG	3.99 to 4.01	
Spectra	**Visible**: Strong Cr spectrum	
Fluorescence	**UV**: Strong red to orange-red (LW stronger than SW)	
Other features	Most stones are heat treated	
Inclusion types	**Description**	
Solids	• Apatite, small prisms (Hänni & Schmetzer, 1991) • Garnet (pyrope) (Hänni & Schmetzer, 1991)	• Spinel octahedra (Hänni & Schmetzer, 1991) • Zircon, rounded to prismatic (Hänni & Schmetzer, 1991)
Cavities (liquids/gases/solids)	• Primary voids and pseudo-secondary healed fractures • Iron oxide stains are common in cracks (this may be eliminated during heat treatment)	
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle' like swirls in other directions	
Twin development	• Polysynthetic glide twinning on the rhombohedron {10$\bar{1}$1} is common	
Exsolved solids	• Rutile needles in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°). These planes lie in the basal plane. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)	

a. Table 12.20 is based on Hänni and Schmetzer (1991).

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Thailand/Cambodia

Thailand (*Prathet Thai;* ประเทศไทย) was known throughout most of its existence as Siam. Located in the center of mainland Southeast Asia, today it shares borders with Burma, Laos, Malaysia and Cambodia. Among the aforementioned countries, Thailand was the only one to escape European colonization. The Thais, which are ethnically related to the Shans of Burma and the Tai tribes of Vietnam and southern China, established their first kingdom at Sukothai early in the 13th century. The present capital of Bangkok (*Krung Thep;* กรุงเทพฯ) was established in 1782, several years after the previous capital at Ayutthaya was sacked by Burmese invaders. Large-scale immigration from China occurred in the late nineteenth and early-twentieth centuries and today most business, including that of gems, is in the hands of Chinese.

Present-day Cambodia (Kampuchea) traces its history back over 2000 years. The great kingdom of Angkor (of *Angkor Wat* fame) rose in the ninth century and at one time ruled an empire stretching from the Burmese border to the South China Sea. In the 15th century, in decline, it was

Timeline of corundum in Thailand & Cambodia

1408	Chinese traveler Ma Huan mentions a market in eastern Siam where inferior rubies are sold (Phillips, 1887).
1548	Portuguese Fernand Mendez Pinto visits Siam and says rubies and sapphires are abundant (Pinto, 1645; Gühler, 1947).
1608	Captain William Keeling is told by the Siam ambassador to Bantam (Java) that precious stones are cheap and plentiful in Siam (Wright, 1908; Gühler, 1947).
1617–1640	Manual de Faria's description of Portuguese Asia states that Siam has ruby and sapphire mines (Ball, 1931).
1688	Nicolas Gervaise mentions blue stones from the jungles of Siam (Gervaise, 1688).
1738	The *Cronica de la Apostolica Provincia de San Gregorio* mentions that Siam abounds in mines of rubies and sapphires (Anonymous, 1738, as quoted from Gühler, 1947).
1863	Western Cambodia, including the Pailin mines in Battambang Province, is ceded to Siam (*Encyclopedia Americana*, 1984).
1885	According to a Dr. Richardson, rubies are found in a stream near Muang Haut (Zimmé area), Northern Thailand (Colquhoun, 1885).
1890	Sapphire is found at Chiang Kong (actually Ban Huai Sai, Laos) by Shan diggers (Smyth, 1898).
1890s	The mines of Chanthaburi/Trat/Pailin are highly active (Smyth, 1898). Two different British firms are given concessions (Black, 1896).
1907	Battambang Province, with the important Pailin mines, is returned to Cambodia (French Indochina). (*Encyclopedia Americana*, 1984).
1918	Sapphire is found at Bo Ploi, Kanchanaburi (Graham, 1924).
1939	Gem corundum is discovered in the basalt of Muang Long, Phrae (Anonymous, 1939; Gühler, 1947). The name Siam is changed to Thailand (Hoskin, 1987).
Late 1940s	L.W. Zerner, a Dutch diamond cutter, opens first modern lapidary shop in Thailand (*Europa Star*, 1983).
1960s	Mining in Thailand is revived as production from Burma and Cambodia declines, due to the political situation in those countries.
1987	Large-scale mechanized mining begins at Bo Ploi. Production increases dramatically (Hughes & Sersen, 1988).
Early 1990s	Production from Chanthaburi-Trat declines as areas are exhausted. Much mining moves across the border to Cambodia, where the deposits have not been so heavily exploited.
1993–94	Production from Bo Ploi declines as the areas are exhausted (Delmer Brown, pers. comm., Oct., 1994).

pressed on each side by Thais and Vietnamese. Eventually, in 1863, the French moved in and added the territory to their Indochina empire. Cambodia achieved independence from French rule in 1953.

The rubies and sapphires of this region are principally derived from the Thai-Cambodian border region, with mines lying on both sides of the frontier. For this reason, the deposits of both countries will be discussed together. References to the mines in eastern Thailand should also be understood to include those across the border in Cambodia.

History

The earliest reference to the gems of Siam (Thailand) was that of the Chinese traveller, Ma Huan, in 1408 AD (Phillips, 1887; Gühler, 1947):

> A hundred *li* (twenty miles) to the S.W. of this Kingdom there is a trading place *Shang-Shui*, which is on the road to *Yun-hou-mên*, [possibly a canal between Chanthaburi and Trat Provinces in eastern Thailand]. In this place there are five or six hundred foreign families, who sell all kinds of foreign goods; many *Hung-ma-sze-kên-ti* stones are sold there. This stone is an inferior kind of ruby, bright and clear like the seeds of the pomegranate."[6]

In Manual de Faria's (1617 to 1640 AD) description of Portuguese Asia it is stated that Siam has "mines of sapphires and rubies" (Ball, 1931). Nicolas Gervaise, writing in 1688, also mentions what may have been an occurrence of sapphire in Siam:

> ...there are blue stones found in certain parts of the jungle in the uplands. This stone resembles the *Lapis* which is usually found in gold mines.

Gervaise, however, seemed interested more in gold than precious stones, for this is his only reference to gems (Gervaise, 1688).

Ulrich Gühler (1947) has given us an authoritative account of the history of gems in Thailand, unfortunately in an obscure Thai journal, beginning with Ma Huan. From the fifteenth century onwards, various travelers to Thailand mention, in passing, that rubies and sapphires are found near Chanthaburi. Also included are the sometimes humorous descriptions of the gems, as well as the local people and their customs. Witness the statements of early French missionaries to Thailand (Cartwright, 1908) from before 1770 on the former Thai province of Laos:

> In the province of Laos from whence the kingdom takes its name, there is a deep mine whence rubies and emeralds are extracted. The King possesses an emerald of the size of an ordinary orange.

De la Loubere (1693), French envoy to Siam in 1687, described Thailand as "abounding in mines of rubies and sapphires." He added that the stones usually found their way into the possession of monks, who were secretive as to the gems' origin, and who employed them as charms.

The nineteenth century

John Crawfurd, British envoy to Siam and Cochin China (1828) provides greater detail, much of it accurate:

6. The Thai word for ruby, *taubptim* (ทับทิม) also means pomegranate.

Figure 12.113 The corundum-producing localities of Thailand, eastern Cambodia and Laos. (Modified from Vichit & Vudhichativanich *et al.*, 1978)

The only gems which are ascertained to be minerals of Siam, are the sapphire, the Oriental ruby, and the Oriental topaz [yellow sapphire]. These are all found in the hills of Chan-ta-bun [Chanthaburi], about the latitude of 12 degrees, and on the eastern side of the Gulf. The gems, from what we could learn, are obtained by digging up the alluvial soil at the bottom of the hills, and washing it. The gravel obtained after this operation is brought to the capital for examination. Both the ruby and sapphire of Siam are greatly inferior in quality to those of Ava [former capital of Burma]. Several specimens were shown to us during our stay, but none of them of any value. The mines of Chan-ta-bun, not withstanding this, are a rigidly guarded monopoly on the part of the King.

John Crawfurd, 1828

Pallegoix (1854) also gave an account of the mines:

Precious stones are found without doubt at several places in the Kingdom of Siam, as, when travelling, I often came across them in the beds of streams and amongst the gravels of rivers, but nowhere are there so many as in the province of *Chanthaburi*. The Chinese, who plant pepper all around the large mountain of *Sabab* collect them in quantities. In the high mountains, which surround the habitations of the *Xong* tribe, and in the six hills west of the town these stones are hidden in such quantities that the planters of tobacco and of sugarcane, who have established themselves at the foot of these hills, sell them by the pound: those of the smallest size cost 16 francs per pound, those of medium size 30 francs and those of the largest size 60 francs. The principal stones, which the Governor of *Chanthaburi* has shown me, are the following: large and perfect rock crystals, cat's eyes the size of a small nut, topazes, hyacinths, garnets, sapphires of a deep blue and rubies of various tints. One day I went with a number of our Christians for a walk through the hills in the neighborhood of *Chanthaburi* and I found scattered over them black and greenish stones, semi-transparent (corundum), amongst which were garnets and rubies; within one hour we had collected two handfuls of them. As there are no lapidaries in the country, the inhabitants, who have collected some precious stones while planting their tobacco or sugarcane, do not know what to do with them and sell them at a low price to Chinese travelling traders, who forward them on to China. Yet, it must be noted that the King of Siam has reserved for himself certain localities where the best stones occur in greatest abundance; the Governor of *Chanthaburi* is charged with the exploitation and sees to it that the stones reach the palace, where some second-rate Malay lapidaries polish them and cut them into brilliants.

Mgr. Pallegoix, 1854 (modified from Gühler's translation)

Pallegoix's description accurately summed up the situation during the first half of the nineteenth century. Henry Louis (1894) visited the mines in 1892, but the most authoritative accounts of nineteenth-century Chanthaburi are those of H. Warington Smyth (1898, 1934), an Englishman employed by the Department of Mines of Siam from 1891–1896. Much of the following is based on his accounts.

About 1857, Shan traders from Mogok (Burma) rediscovered Chanthaburi's mines, starting a gem rush which still continues. The rush supposedly began after a certain Nai Wong went fishing. Instead of prawns and fish, his net brought up gravel containing rubies. He exchanged these for clothes from Shan (*Gula;* กุหล่า) traders and the rush was on (Gühler, 1947). Thousands of Burmese Shans, who are ethnically related to the Thais of Siam, made their way to Chanthaburi, Trat and Pailin. These Shans developed the mines and their descendants hold prominent positions in Chanthaburi's gem trade even today.

In 1857, Shan speculators leased the mines from the government and brought in their own men from Burma. However, there was little success until the appearance in 1880 of a financial genius named Mong Keng. Gathering all the mines into his hands and gaining control of the opium and gambling monopolies, too, he worked the mines profitably for many years, eventually becoming known as the *King of Precious Stones*. With his fame also spread the fame of Pailin's blue sapphires, not only in Siam, but also to India and Europe. In the early 1890s, however, the Government made a concession of parts of the district to a British firm, turning the *Sapphire King* into a serf almost overnight. Later, in 1895, another British firm, Siam Exploring Co., Ltd., received from the King of Siam the exclusive right to work the Pailin mines. They later also bought out the claims of the previous British company (Black, 1896).

French kiss

IT is often interesting to read the tales of foreigners visiting other cultures. Below are a few examples, courtesy of some rather straightlaced French priests prior to 1770. Regarding the local Lao males, they said (Cartwright, 1908):

Unbridled in their desires for the opposite sex, they seem to live merely for reproduction.

Not only did the Lao receive the scorn of the European clergy of the day, but also the Burmese.

Generally speaking, they [the Burmese women] are gentle in their way, but very voluptuous. Lewd and licentious, they have quite abandoned all sense of shame.

With regard to doing business in Southeast Asia, a quaint custom which tourists everywhere might wish to revive is described:

If someone is convicted of breach of trust, the creditor is allowed by law to seize their wives, children and slaves and to expose them to the glare of the sun at his door."

Certainly many Burmese and Lao might wish the same upon those French missionaries after reading such excerpts. But we'd better be getting back to our gems.

Nineteenth century mining and trading

Smyth (1898) has provided us with a fascinating picture of mining in Chanthaburi and Pailin during this period:

The Shân seems by nature designed for the pursuit of gems. He is bitten with the roving spirit, and in addition he has the true instinct of the miner, to whom the mineral he lives to pursue

Figure 12.114 A magnificent slice of the Orient. When it comes to Thai/Cambodian ruby, few can match this 2.98 ct stone. (Photo: © 1986 Tino Hammid; specimen: Reginald Miller, New York)

possesses a subtle charm, which constrains him never to rest or weary of its search against all odds. The sentiment is quite different to the avarice of the victims of a gold mania. The skill of the Gula [Shan] is no less than his energy. He detects color and recognizes quality with a rapidity and accuracy to which few attain. No Siamese, no Lao, no Chinaman can compete with him. The Burman is about his equal, but has not his industry or constitution, and is therefore chiefly found in the capacity of middleman, buying and exporting.

At first whole parties were decimated by the fever. Not one in thirty returned to the sea alive. But there were others to take their place, and gradually the clearing of the jungle, the improvement of communications, the superior shelter, and the comforts which were introduced had their effect; and although the mines still have an evil name, and the opening up of each new district calls for further sacrifices, the rate of mortality among the Shans is now comparatively moderate….

Should the Shâns therefore leave for any reason, there is no other force which can be utilized to do the necessary work. The departure of these people would doom the mines. They are necessary, if only to bury the others….

The Gula digger is proud and independent. He cherishes the freedom of his life, and he brooks not much official interference. Restraints which may be applied to the African negro will not do for him. When the [Siam Exploring] Company came to Nawong, diggers were notified (*inter alia*) that if they worked on the company's territory they must sell stones to its agents, at prices to be settled by the latter. This was felt to be an infringement of the right to sell in the open market, and was resented. Thereafter the company attempted to enforce the right of search

Figure 12.115 Map of the Thai gem districts of Chanthaburi (Chantabun) and Trat (Krat), along with Pailin (in present-day Cambodia). (From Smyth, 1898)

on the persons and belongings of the diggers. Rather than submit they left *en masse,* some for the Pailin mines, others for their homes in Burma. The result was that, out of two thousand eight hundred diggers whom the company found in and about Nawong, a couple hundred were left when we visited the place; and at Bo Yaw, instead of twelve to fifteen hundred men, there were fifty-four at our visit.

Thus the Gula will be seen to be an individual whose susceptibilities must be taken into some consideration.

H. Warington Smyth, 1898, *Five Years in Siam*

Smyth also discusses the mining methods in some detail, as well as providing a fascinating account of the buying of gemstones:

In buying stones, it is well to remember you are entering the arena to pit your knowledge against the other man's. He regards it as a sporting contest, and he would fleece or ruin his dearest friend as part of the game, if his dearest friend were fool enough to let him do it. The moment you bargain about a stone, a trial of strength (or knowledge) has begun between you, as much as if you were boxing or fencing. Everything is forgotten but the object in view, to protect yourself and get home on the person of your opponent.

Your eye must be in training too, and if you have not looked at a stone for six months, get some one else to do your buying for you, or you will be badly hit.

H. Warington Smyth, 1898, *Five Years in Siam*

The above is one of the best descriptions of the bargaining process, and is typical of the accurate and informative commentary provided in the writings of Smyth.

The twentieth century

In 1907, Battambang Province, containing the valuable Pailin mines, was returned to the French in Cambodia. Up until that time, Pailin supplied as much as 90% of the

Figure 12.116 Showing off the family jewels at Bo Rai, Thailand. (Photo: Olivier Galibert)

world's fine sapphires. Although production continued to pass through Chanthaburi and Bangkok, after 1907 Thailand's production of sapphires dropped dramatically from the loss of Pailin. Discovery of new sapphire mines in Kanchanaburi and Phrae helped somewhat, but with the loss of Pailin, Thailand lost a major portion of its sapphire mining potential. The decline of Burmese ruby production during 1962–1992 and subsequent rise of the Thai ruby, however, has ensured the importance of Bangkok and Chanthaburi as a trading center for rubies and sapphires.

In Cambodia, the rise of the bloody Khmer Rouge regime in Cambodia (Kampuchea) halted for several years all mining activity. With the installation of the Vietnamese-sponsored government in 1979 mining was again started.

The war in Cambodia inflicted tremendous suffering on civilians in Vietnam, with food and goods of all kinds being in short supply. This resulted in black humor among foreign aid personnel stationed there. The following is a sample, courtesy of Bangkok writer, John Hoskin:

Vietnamese cable to Moscow:	Please send aid!
Soviet reply:	Please tighten belts.
Vietnamese answer to Moscow:	Please send belts.

While Vietnamese troops have now left Cambodia, the country continues to be wracked by guerrilla warfare between the central government and Khmer Rouge. The jungles surrounding Pailin remains a bastion of the Khmer Rouge, ably assisted by the Thai military and traders, who profit from the situation.

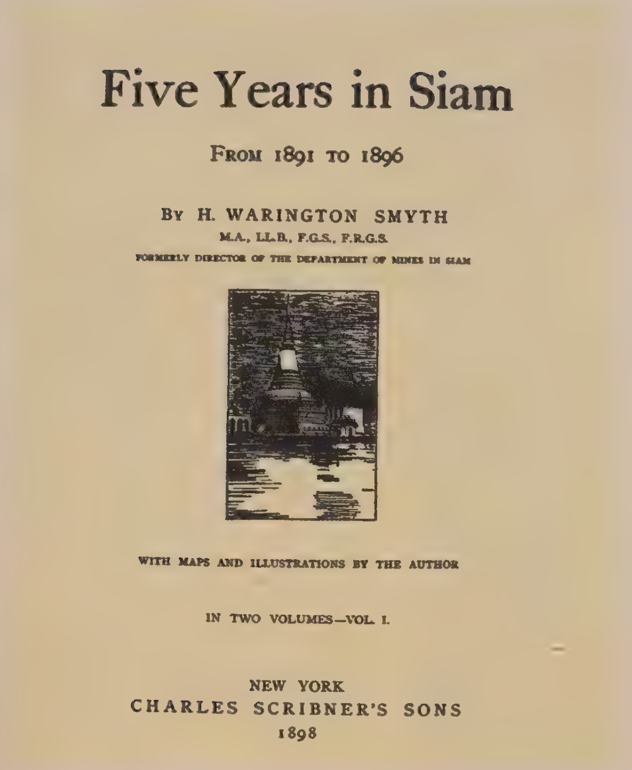
Mining areas

Table 12.21 lists the locations of gem-quality corundums in Thailand, Cambodia and Laos (based on Jobbins & Berrangé, 1976; Coenraads & Vichit *et al.,* 1995).

Chanthaburi, Trat and Pailin deposits

Khao Ploi Waen & Bang Kha Cha

At Khao Ploi Waen (literally 'Hill of Gems') and Bang Kha Cha, blue, green, yellow and black-star sapphires are found in small amounts. Ruby is entirely absent. Khao Ploi Waen is located just 6.5 km west of Chanthaburi and consists of placers derived from an isolated butte some 70 meters above the surrounding plains. This is said to have been the first place in Thailand where corundum was found. The hill



Five Years in Siam

FROM 1891 TO 1896

BY H. WARINGTON SMYTH
M.A., LL.B., F.G.S., F.R.G.S.
FORMERLY DIRECTOR OF THE DEPARTMENT OF MINES IN SIAM

WITH MAPS AND ILLUSTRATIONS BY THE AUTHOR

IN TWO VOLUMES—VOL. I.

NEW YORK
CHARLES SCRIBNER'S SONS
1898

Figure 12.117
Left: Title page of H. Warington Smyth's *Five Years in Siam* (1898). This two-volume work contains the best nineteenth-century account of the ruby and sapphire mines of Thailand/Cambodia.
Right: A *Gula* (Shan) horseman at Pailin, Cambodia. (From Smyth, 1898)

consists of a volcanic plug and sapphires are mined from placers derived from the lava. Mines are scattered all around the base of the hill. Most are simple pit mines, but mechanized mines have sometimes operated.

The blue sapphires found here are of a pure blue color, but suffer from being too dark. Good black-star and green sapphires are found, but the mine is most famous for producing yellow sapphires of a characteristic *Mekong Whisky* golden-yellow to orange color. This color is much in demand in the local market and fine stones sell for as much as US$500–1000/ct or more. The rare "golden-star" black-star sapphires are also found here and fetch good prices locally. A golden-star black-star sapphire results from hematite silk unmixing in an otherwise yellow sapphire. The more common, white-rayed black-star sapphires contain hematite silk in blue or green sapphires. Twelve-rayed black-star sapphires are common, and result from both hematite and rutile silk in the same stone.

The placers of Bang Kha Cha are located but a few kilometers from Khao Ploi Waen and produce an identical suite of colors. They are situated on a flat swampy plain on the Khlong Hin River estuary, which is underlain by alluvium. Not only are the swamps mined, but also the river bottom. Zircon and pyrope garnets are also found at both localities.

Wat Tok Phrom, etc.

The second major corundum zone is found behind the granite mountain of Khao Sabab, which dominates the view from Chanthaburi. These mines are right on the border between Chanthaburi and Trat Provinces, and include:

- Bo Waen—ruby only
- Bo Na Wong—ruby only
- Wat Tok Phrom—ruby only
- Ban Bo I Rem—mainly blue sapphire

Although transportation to, and roads within, this area are poor, a number of large mechanized mines can be found. Mostly ruby is mined, with the exception of I Rem, where sapphires dominate. The sapphires are of a deep, pure blue color and resemble those from nearby Pailin. This material is good for cutting small sizes (one-half carat or less) because it holds the color well, but larger stones tend to be too dark. As with the other mines in Thailand, the deposits are alluvial or eluvial in nature. Output of ruby from this district forms a significant portion of Thailand's ruby exports.

Bo Rai & Nong Bon

The third major area is further to the east, in Trat Province, and includes the large and well-known mechanized mines at Nong Bon and Bo Rai. These are the largest ruby mines in Thailand and are accessible by good roads. Only ruby is found here, with larger stones found at Nong Bon, but with finer colors coming from Bo Rai.

The mines at Bo Rai and Nong Bon are mechanized, with bulldozers, earth movers and other heavy equipment in use; those across the border in Cambodia, however, are usually primitive pit mines only, due to the ongoing war.

Figure 12.118 A miner repairs a jig at Bo Rai, eastern Thailand. (Photo: Wimon Manorotkul)

In terms of stone sizes, Thai rubies, like all other rubies, are found in much smaller sizes than sapphires. With the tremendous increase in mining in recent years, larger gems have been unearthed, including several of fine quality in the 10-ct plus range. The biggest ever found in the area was a 150-ct giant (in the rough) unearthed in 1985 in Trat Province. Due to the even coloration of Thai rubies, most cut gems above 5 ct tend to be overly dark.

Pailin, Cambodia

The following is based on the reports of Berrangé & Jobbins (1976). Further east, across the border in Cambodia, are the famous Pailin gem fields. Lava flows here have formed four separate hills around which the mines are situated. Westernmost are those of Phnom O Tang and Phnom Ko Ngoap, rising about 40–60 m above the surrounding plain. These two areas produce primarily ruby, with small amounts of sapphire. The rubies here are identical to those found in nearby Thailand. To the east at Phnom Yat, near the small town of Pailin, the situation is reversed, with sapphires dominating. It is from this locality that most of the famous Pailin sapphires have been unearthed. The fourth lava outcrop, located in a coffee plantation, is only 200 meters in diameter and is thought to be a volcanic pipe.

One interesting feature of the corundums from the Pailin area is the virtual absence of colorless, yellow and green sapphires. Local diggers only occasionally find a yellow stone; the other varieties are not found at all. Color-change sapphires are found with some frequency, as in Thailand, and can often be had for a song as they are mixed into parcels of inferior rubies. These stones appear a light to deep-greenish violet in daylight and change to a purplish pink in incandescent light, similar to those from Umba.

Although the rubies from Pailin are of good quality after heat treatment (similar to those from Thailand), it is the blue sapphires that are its boast. In fact, the word for blue sapphire in the Thai language is *pailin* (ไพลิน), its name being taken from this important locality. Ranging in color from a medium to deep blue, the material is particularly fine in small sizes. Pailin sapphires strongly resemble those found at Bo I Rem in Thailand, except that the latter tend to be darker. This is also the major flaw with most Pailin stones; it does mean, however, that small stones (below 0.50 ct) hold their color well. Star sapphires have been found at Pailin but are rare. Zircon and pyrope garnets are found, in addition to corundum.

Table 12.21: Corundum occurrences in Thailand/Cambodia/Laos

Locality	Geologic occurrence	Gem corundums found	Accessory minerals
Chanthaburi Province, Thailand Tha Mai District • Khao Ploi Waen, Khao Wua, Bang Kha Cha	• In residual basaltic soil, eluvium and alluvium	• Dark blue, green, yellow, black star (6 & 12 rays)	All localities: Black spinel (*pin ta-ko*; นินตะโก), clinopyroxene (*nin sian*; นินเสียน) (clinopyroxene > spinel); garnet (*ko main*; โกเมน), zircon (*pay thye*; เพทาย) (garnet > zircon); biotite or phlogopite mica is common at Khao Wua/Khao Ploi Waen
Chanthaburi/Trat Province, Thailand Klung and Khao Saming District • Bo Welu, Ban Si Siat, Tok Phrom, Bo Klang, Nong Pla Lai, Ang Et • Bo I Rem • Bo Na Wong, Nong Bon Noi	All localities: In residual basaltic soil, eluvium and alluvium	• Ruby, sapphire • Sapphire only • Ruby only	• Clinopyroxene, garnet (traces), zircon (abundant) • Traces of zircon • Clinopyroxene, with traces of garnet and zircon
Trat Province, Thailand Bo Rai District • Nong Bon • Bo Rai area • Rubywell Mine	• In residual basaltic soil, eluvium and alluvium. • In alluvium • In alluvial gravels	• Ruby only; bigger stones are found at Nong Bon • Mainly ruby; traces of sapphire • Mainly ruby; traces of sapphire	• Garnet, clinopyroxene, ilmenite, magnetite and hematite • Clinopyroxene, garnet; ilmenite and magnetite at Ban Thung Satharana • Black spinel, garnet, sapphirine and ilmenite
Phrae Province, Thailand Denchai/Wang Chin District • Ban Bo Kaeo, Huai Mae Sung	• In stream and terrace gravels	• Mainly sapphire; traces of ruby	• Black spinel, clinopyroxene (spinel > clinopyroxene), zircon, garnet (traces)
Sukothai Province, Thailand Si Satchanalai District • Ban Huai Po, Ban Pak Sin, Ban Sam Saen	• In stream and terrace gravels	• Sapphire only	• Black spinel
Phetchabun Province, Thailand Wichianburi District • Ban Khok Samran, Ban Marp Samo, Khlong Yang	• In residual basaltic soil and stream gravels	• Sapphire only	• Black spinel, clinopyroxene (spinel > clinopyroxene), zircon, garnet (traces)
Kanchanaburi Province, Thailand Bo Ploi District • Bo Ploi, Ban Chong Dan	• In alluvium, eluvium and residual basaltic soil	• Mainly blue sapphire; also yellow; traces of ruby	• Black spinel (abundant), clinopyroxene (abundant), garnet (traces), sanidine
Ubon Ratchathani/Si Sa Ket Province, Thailand Nam Yun and Kantharalak Districts • Ban Saen Thawon, Ban Ta Kao, Ban Ta Koi, Ban None Yang, Huai Pho • Huai Ta, Aek, Lam Som	• In alluvium • In stream gravels	• Ruby and sapphire • Ruby and sapphire	• Zircon (abundant) • Zircon
Battambang Province, Cambodia Pailin area • Phnom Ko Ngoap, Phnom O Tang • Phnom Yat	All localities: In alluvium, eluvium and residual basaltic soil	• Mainly ruby, color-change • Mainly blue sapphire	All localities: Zircon, pyrope garnet, clinopyroxene, magnetite, ilmenite, olivine, feldspar
Ratanakiri Province, Cambodia • Bokéo (Bo Loi, Bo Noac, Bo Tum)	• Eluvial and alluvial gravels	• Ruby and sapphire	• Zircon (especially blue after heating), garnet, black spinel
North of Rovieng, Cambodia • Phnom Chnon, Phnom Thmei	• Eluvial and alluvial gravels	• Sapphire	• Zircon
Cardamom Mountains, Cambodia • Chamnop	• Eluvial and alluvial gravels	• Sapphire	• Zircon
Laos • Ban Huai Sai	• Eluvial and alluvial gravels	• Sapphire, black star	Not reported

Geology of the Chanthaburi/Trat/Pailin area

The corundums of this area occur as both eluvial and alluvial gravels derived from Tertiary to Pleistocene basalts intruded into older sedimentary or metamorphic rocks. In many ways they resemble the corundum bearing basalts of Australia.

Corundum deposits of Thailand and Cambodia differ from those of nearby Burma in that the matrix of the latter is a crystalline limestone (ruby) or pegmatite or syenite (sapphire), rather than basalt. Study of the xenocrysts from Thailand and Cambodia by Jobbins & Berrangé (1981) suggest that the corundums, clinopyroxenes, garnets, spinels and other associated minerals originally formed at great depths by metamorphism and/or metasomatism on the edges of a basic pluton. They were then intruded rapidly with the magmas at a much later date.

Basalts of Indochina may be divided into two broad groups—small and large. The smaller bodies carry corundum, zircon and garnet, whereas the larger are barren of corundum, containing only zircon. It has been hypothesized

Figure 12.119 "I've found one!" A sapphire miner at Khao Ploi Waen (Chanthaburi Province), Thailand, holds up the sapphire fragment she has just unearthed. (Photo by the author)

that the larger bodies, which are also older, may have initially contained corundum, but that later eruptions were barren and the gems lie buried under later lavas.

Evidence of corundum origin in basalt is given by the distribution of the gems. Ruby and sapphire are found in gem gravels weathered from the lavas, with rich concentrations in the *in situ* weathered basalt (eluvial deposits) and soil profiles overlying the basaltic bodies. However, rubies and sapphires in the basalt matrix are rare. This suggests a sparse distribution of corundum in the lavas themselves, with a marked increase in concentration in the gravels due to weathering. Euhedral crystals are relatively rare, with most exhibiting a slight to large degree of rounding of the crystal faces, due to partial corrosion by the lava. A high surface polish is common in grains recovered near the vents.

The exact origin of corundum in the basalts has yet to be fully explored. Barr & Macdonald (1977) speculated that corundum-bearing basalts could have been generated in the mantle. However, the alumina content of the basaltic magma is problematic. Instead, Vichit (1978) has suggested that corundum could crystallize in the latter stages from a basaltic magma generated at depths of 65–95 km by partial melting of mantle materials. This magma could then move upward to a depth of 25–35 km, with fractionation processes increasing the alumina content substantially, as well as increasing the percentages of nepheline normative minerals. Wall-rock contamination is one possible factor involved. At this point, a decrease in temperature could produce crystallization of corundum, with an eruption carrying the magma to the surface, where it would be quenched. This would explain the origin of corundum samples embedded in a basalt matrix, as well as the lack of corundum in accompanying samples of schist, gneiss and syenite.

The corundum varieties found in the Chanthaburi/Trat area are mainly ruby, blue, green and yellow sapphires, along with black stars. Accessory minerals include pyrope, zircon, quartz, spinel (mostly black), and a number of opaque black stones locally termed *nin.*

In 1979, Dr. P. Aranyakanon noted that certain corundum varieties are distributed along four distinct zones

Figure 12.120 Miner's village at Na Wong, Chanthaburi/Trat, Thailand. (From Smyth, 1898)

between Chanthaburi and Pailin. The first zone is located less than 5 km due west from Chanthaburi town and includes mines at Khao Ploi Waen and Bang Kha Cha. Various sapphire varieties are found here, while ruby is absent entirely.

The second zone is situated astride the border separating Chanthaburi and Trat Provinces, behind the mountain of Khao Sa Bap. Mines stretch from Ban Welu Klang in the north through Ban Na Wong in the south, and include Tok Phrom and Bo I Rem. This is the *Muang Klung* region in Bauer (1904). In the second zone ruby and sapphire are found, with the exception of Bo I Rem, where deep blue sapphires are mined in some quantity.

Zone 3 is situated in Trat Province and the deposits actually stretch across the border into Cambodia, near Pailin. The mines are situated in particular around the towns of Nong Bon and Bo Rai. Only ruby is found in the third zone, with sapphire being almost entirely absent.

Zone 4 lies directly at the town of Pailin, where sapphires greatly outnumber rubies.

In Chanthaburi and Trat Provinces, the thickness of the gem bearing gravels varies from place to place, depending upon the nature of the bedrock and slope of the deposits. At Khao Ploi Waen sapphires can be found at the surface or at depths of between 3–8 meters.

The gem bearing soil at Bo Rai is from 4–10 m deep or more, while the author has witnessed mining at Ban Nong Bon reaching depths of 20 m or more. The thickness of the gravel layer ranges from 0.3–1.0 m.

Figure 12.121 The traditional method of mining is to sink a pit down to the gem-bearing layer. All that is needed is a partner, a few simple tools and, most importantly, the dream of finding sapphires. Here, miners work in the shadow of Khao Ploi Waen, the "Hill of Gems."
(Photo by the author)

Ratanakiri, Eastern Cambodia

Cambodia is famous for producing blue zircon (via heat treatment), but little has been mined since the Khmer Rouge takeover in 1975. The most important deposits are situated in Ratanakiri [literally 'Hill of Gems'] Province in the far

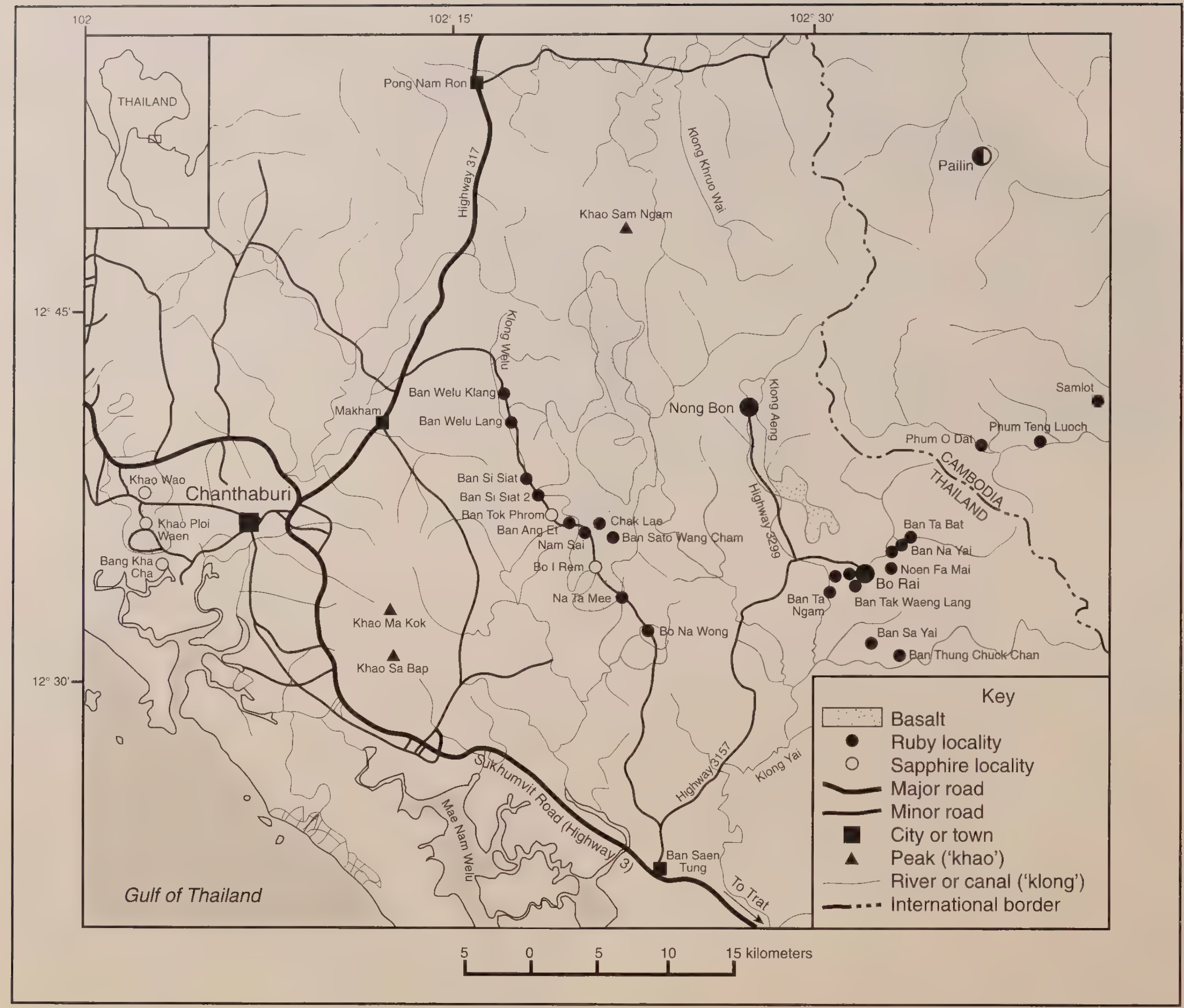


Figure 12.122 Corundum sites in Chanthaburi and Trat (Thailand) and Battambang (Cambodia). (Modified from Vichit & Vudhichativanich *et al.*, 1978)

eastern part of Cambodia, along the Lao and Vietnamese borders. Biggest of the mines is at Bokéo, with others at Voeune Sai and Bo Kham. The mines do produce the occasional ruby and sapphire. Sapphires and rubies are found at Botum and north of Ban Noy (near Bokéo) and at O Panat. Sapphires only are found at Phnom Kaloeu at Boi Loi (Lacombe, 1970).

Bo Ploi, Kanchanaburi, Thailand

When Pailin was ceded to French Indochina in 1907, Thailand lost its key source of quality blue sapphires. This has been compensated for, to some degree, by the output from Bo Ploi, in Kanchanaburi Province, better known as site of the famous World War II "Bridge on the River Kwai."

In 1918, blue sapphires were discovered near the town of Kanchanaburi in western Thailand (Graham, 1924). This created a minor gem rush, and the small town of Bo Ploi was founded near the mines. Not much was found in the first few years, but in early 1929 rich finds were made in the northern part of the field. The mining output exceeded $3,000 during the first few months of that year. Over 100 sapphires mined, weighing more than 3,300 ct, were valued at $4,250 (Gühler, 1947). Later, however, the mines were abandoned, believed to be exhausted. Mining did not recommence until well after World War II.

In 1978 a new sapphire deposit was found 6 km north of Bo Ploi, at Ban Chong Dan, and several hundred people, including some large operators, started mining there. Shortly thereafter Bo Ploi become Thailand's major source of blue sapphire, especially for large stones. (S.A.P. Mining, 1988).

The Bo Ploi deposit lies about 30 km north of Kanchanaburi town and consists of a group of low basaltic hills covered by large boulders. Weathered basalt forms a characteristic red soil which has accumulated at the foot of the hills. In this soil are found black spinels (magnetite—

Give me Burma, or give me death

WHEN supplies of Burma ruby were cut off in the early '60s, for the first time in 800 years, the world was forced to look elsewhere. Their ravenous gaze settled on the oft-denigrated stones of the Thai/Cambodian border. Although other sources produced rubies of better color, only the Thai/Cambodian mines produced enough facetable material. And with improvements in heat treatment, it was not long before the mines supplanted Burma as the world's major ruby supplier.

The Thai/Cambodian mines do occasionally produce rubies of good quality, but most are lackluster, with blackish overtones, due to the lack of fluorescence and light-scattering silk. Gühler aptly summed up the differences between Thai and Burmese rubies:

> The color of the Siamese ruby is inferior to that of the Burmese ruby. The color tends to be purplish or even brownish and generally it is too dark. A Siamese ruby inspected under natural or artificial light will show its color only on those facets which are directly hit by the light. Those facets in the shade [today termed 'extinction'] will appear almost black. A Burmese ruby will appear red throughout, even on those facets which are not directly exposed to the source of light. It goes without saying that on the markets of the world a Siamese ruby is less valued than a Burmese ruby. It should, however, be stated that there are sometimes found at Chanthaboon [Chanthaburi] rubies which are entirely similar to those of the famous Mogok mine in Burma.
>
> Ulrich Gühler, 1947

In the 1970s and 80s, the ruby market found itself in an unusual situation. Fully 95% of all faceted rubies originated from a source which every major writer on the subject 50 years before condemned as producing stones of inferior color. But in a world starved of ruby, all that matters is that it's red and it's corundum.

This ruby famine resulted in customers becoming conditioned to the dark, garnet-like colors of the Thai mines, so much so that fine Burma or Sri Lankan rubies were often rejected for being "too light." De Beers, with their "champagne-sounds-so-much-better-than-brown" Argyle diamond ad campaign, understands the impact of long-term conditioning. In the ruby market, the dearth of fine color goods means that today's buyers salivate at the sound of the Thai/Cambodian bell.

But not me. Although I may be forced into a Salman Rushdie-like existence for saying so, I prefer my sugar sweet. When it comes to ruby, give me *ruby*, not garnet. Give me Burma, or give me death.

Figure 12.123 Thai/Cambodian versus Burma-type rubies
Left: An 8.02-ct Burma-type ruby. Note the rich, fluorescent-red color and high degree of color coverage.
(Photo: Bart Curren/ICA; specimen: Centerstone, Ltd.)
Right: A Thai/Cambodia-type ruby. Note the dark appearance and large black areas of extinction. (Photo: Adisorn Studio)

strongly magnetic), which are locally termed *nin* (นิล)and are faceted into inexpensive gems. Sapphires are rarely found attached to the basalt matrix; most are mined from eluvial and alluvial deposits.

The mines of Bo Ploi and its surroundings produce mostly blue sapphire, along with the occasional yellow, pink and star sapphire. Gühler described them thus:

> Very transparent [actually they are somewhat milky] with perfect color; reddish tints are rare. Lighter colors are more frequent. Large specimens are frequent. Rather less flaws than Pailin, except zonar striations which are very common and frequently seen in hexagonal arrangement. Star sapphires of poor quality are sometimes found.
>
> Ulrich Gühler, 1947

The situation at Bo Ploi began to change in a big way around 1987. Geologists carefully prospected the area and discovered that the gem-bearing gravels were more widespread than was previously thought, with many too deep to reach by pit mining. This started a mining boom, with the operation of several huge mines, making Bo Ploi one of the world's biggest sapphire mines (Hughes & Sersen, 1988). As of 1994, most of the deposits had been exhausted and

Figure 12.124 In the quest for the red stone, entire hills have been torn asunder, such as this ruby mine at Nong Bon, Trat Province, Thailand. (Photo by the author)

mining had been substantially reduced (Delmer Brown, pers. comm., Oct., 1994).

Heat-treated Kanchanaburi sapphires strongly resemble those from Sri Lanka, particularly with regard to their strong color zoning. Because market demand for Sri Lanka sapphires is greater, most Kanchanaburi stones end up mixed into parcels of Sri Lankan stones and sold as the latter. This is indeed a shame, for the stones from Bo Ploi are quite beautiful in their own right. Were it not for the slight milkiness that they display, these Thai stones would be the equal of many from Sri Lanka, or even Burma. As mentioned, large sizes (20 ct or greater) are frequently found at Bo Ploi. The author has seen several fine pieces larger than 20 ct, including one heart-shaped 66-ct giant (Hughes & Sersen, 1988). Gühler mentioned one faceted stone of fine color and fancy shape which weighed 51 ct. Others of top quality cut from a single crystal weighed 28 and 16 ct respectively. The rough which produced these two stones was originally bought for $600, a not inconsequential sum of money forty years ago.

Bo Ploi stones are easily separated from those of Sri Lanka and other localities by reference to the concentrations of minute exsolved particles always present. These particles impart a distinctive "milky and silky" look to the stone. They follow the hexagonal color zoning and are most heavily concentrated where the color is deepest, with colorless areas generally particle-free. Virtually all Bo Ploi stones are heat treated. Other than corundum, the only additional facetable gem mineral found at Bo Ploi is the previously mentioned black spinel (*nin*).

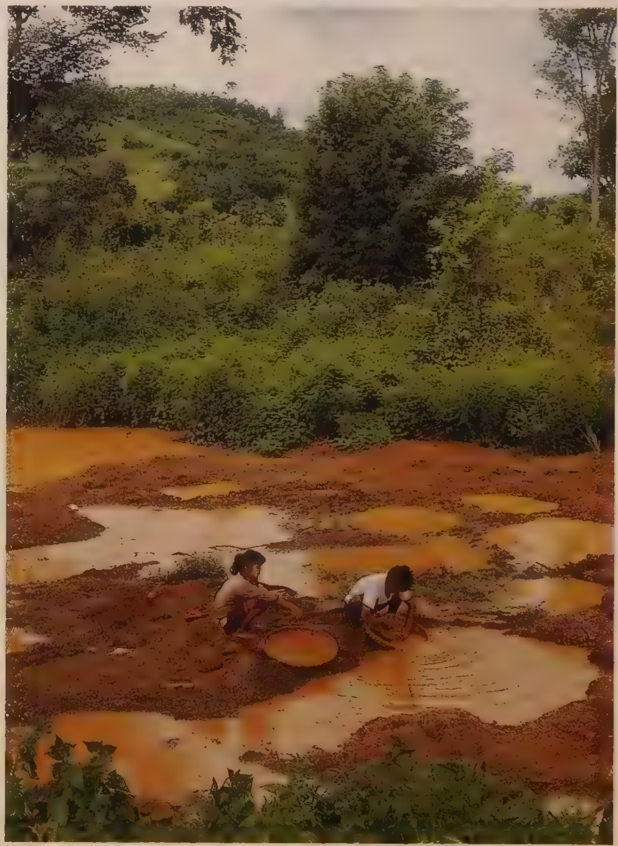


Figure 12.125 The Phrae deposits in northern Thailand produce blue sapphire, but have been little exploited. Here miners wash gravel at Ban Bo Kaeo. (Photo by the author, ca. 1987)

Phrae Province, northern Thailand

The corundum deposits of Phrae in northern Thailand are located in Den Chai District. Although known since the

Figure 12.126 A miner at Bo Rai, Trat Province, Thailand, uses a water cannon to force the ruby-bearing soil into the separation jig. (Photo: John Rouse, ca. 1983)

1920s, the deposits have only been worked since the 1970s. Phrae basalt is the largest of the corundum-bearing lavas in Thailand. Bisected by the Nam Yom River, deposits are found on both banks, with the most important at Ban Bo Kaeo and Huai Mae Sung. At the time of the author's visit to the area in 1984 and 1987, the mines of Bo Kaeo had been largely abandoned, with work proceeding only at Mae Sung. All deposits in the area consist of recent alluvium in the streams. Blue and green sapphires are found associated with black spinel, sanidine, augite, olivine and zircon, but only the sapphires are of economic importance.

The blue sapphires of Phrae are a deep, inky blue-violet color. Large sizes (5 ct or more) are rare, but the deep color does lend itself to cutting melee. Green sapphires are also found, as well as the occasional poor-quality ruby and red spinel. Of the various working corundum mines in Thailand, Phrae is among the least important in terms of production, but the occasional fine blue stone turns up every now and then. The best Phrae sapphires have a distinctive deep blue color that verges on the violet, with blackish overtones. Most, however, are too dark.

Si Saket, Thailand

Small deposits of sapphire and ruby have been found along the Thai/Cambodian border near the town of Si Saket. But mining is complicated by the mines' location in an off-limits area just inside the Thai side of the Cambodian border. If hostilities ever cease in Cambodia it is possible the deposits will be more carefully prospected and worked.

Mines are located at Ban Ta Koi, Ban Khok Sa-Ard, Plon Thung Yao and Huai Ta-Ak. As with other basalt-derived deposits, the suite of gems here consists of dark blue, green and yellow sapphires. There are also dark red zircons (which can be heat treated to blue or colorless), red garnets and black spinels. Small quantities of ruby have also been found.

A visit with the Khmer Rouge

BOTH Bo Rai and Nong Bon lie less than 10 km from the Cambodian border and ruby deposits lie on both sides of the line. Due to nearby fighting between the Khmer Rouge and Cambodian army, shelling is often audible.

At times, thousands of miners have made the daily journey across the border to mine, since the Cambodian side has not been as heavily worked. This is not without its danger. Roving bandit gangs take a steady toll of miners, and those not killed outright may be seriously injured by land mines and booby traps. Were this not enough, the area's thick jungle is home to some of the world's worst malaria.

In the mid-1980s, the author and friends decided to explore the border area near Bo Rai more closely. Suitably equipped with jeep, map and camera, we bounced down a muddy path that was a known mining artery into Cambodia. After a few minutes, passing many miners trekking to Cambodia, we rounded a corner, only to find a bamboo pole blocking our way. Familiar with the geography of the area, we realized that we were still well inside Thailand; thus it was a shock to see a teenage soldier in green uniform, a red star firmly affixed atop his hat, Chinese AK-47 in hand. As we approached, in halting Thai he told us to wait and quickly returned with a Thai plainclothes political officer from the military camp located just out of sight. We explained we were researching gem mining in the area, but he politely stressed that it would be best if we went back from whence we had come. Which we did.

Later the same afternoon, possessing the bravado possible only of those who have yet to experience war at close range, we decided to make a further foray to the camp. The same Khmer Rouge guerrilla was present at the barrier, but he now returned with a different Thai political officer. We again started to explain our purpose, but were cut off in mid-sentence: "I know why you're here. Go back. There is no mining." "What about all the people walking up the road with pick and shovel?" we asked, but were told in no uncertain terms that there was *no mining in the area*. As we pondered this message, the forest stillness was broken by a sound in the undergrowth and several miners emerged from a jungle path just behind us. "What about them?" we inquired. Casting a cynical glance in the direction of the miners, the Thai officer said "I don't see anything. Neither did you. Get lost."

Mining methods

There are two basic types of corundum mining in the region: primitive pit mining and mechanized mining.

Pit mining

The earliest and simplest type of mining is pit mining. It is utilized to a certain extent at all localities, particularly those producing sapphires. A narrow circular pit, roughly one meter in diameter, is sunk down to the gem-bearing gravel.[7] In places the gem-bearing layers are just a meter or so beneath the surface, while in others they may lie as deep

7. This gravel is termed *kee ploi* (ขี้พลอย) or *kasa* (กะสะ), and in most localities consists of small round nodules of a hardened clay

The wild, wild east

SIMILAR to the frontier mining towns in 19th century America, a lawless atmosphere pervades eastern Thailand's ruby-mining towns of Bo Rai and Nong Bon. Gun-toting police officers stand nearby, ever ready to restore order should the need arise, which it often does. 1981 saw over 50 murders in Bo Rai, a small town with a population of 10,000. According to Bo Rai's then chief of police, Major Anan Rakmitr, most of the killings were over conflicting land and mineral rights. There were 140 police officers in Bo Rai for the town's population, but Rakmitr claimed it was not enough. This attitude was understandable, considering that his predecessor was killed in an ambush by gunmen. Today police carry M-16 rifles and people do not get so angry at them. "They hate each other too much," Major Rakmitr explained (Nordland, 1982).

Figure 12.127 The ruby-mining town of Bo Rai in Thailand's Trat Province. Mountains in the distance form the border between Thailand and war-torn Cambodia. (Photo: Wimon Manorotkul)

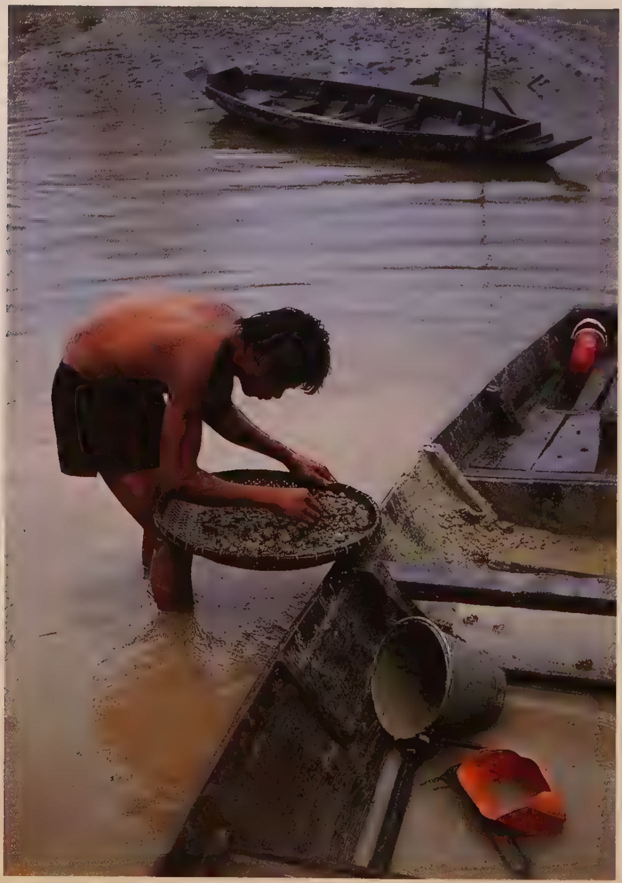


Figure 12.128 Washing the sapphire-bearing mud from the Khlong Hin River estuary at Bang Kha Cha, Chanthaburi Province, Thailand (ca. 1981). Divers scrape the mud from the bottom of the river estuary and place it in shallow boats. It is then brought ashore for washing. (Photo by the author)

as 20 m or more. Access in shallow pits is via steps cut in the pits' sides to allow access. At Bo Ploi, where the gravels are deepest, pits are shored up with strips of bamboo to prevent cave-ins, and bamboo ladders are used for access.

One worker removes the earth at the bottom of the pit. Another man above works the bamboo lift, a simple type of crane which brings the earth to the surface (at Bo Ploi, rope winches may be used). After a sufficient quantity of earth has been brought up, it will be taken to a small man-made pond for washing.

Washing is done with a bamboo tray similar to that used for husking rice. Waist deep in water, the washer moves the tray round and round, allowing mud and lighter materials to wash away. Once the gravel is clean, the tray is then tilted upwards and the gravel spread out. Any gem fragments can then be picked out as they catch the sunlight. In earlier times, pit mining was the only method of mining.

Variations on the above are found depending on local conditions. At Bang Kha Cha in Chanthaburi Province, divers scrape gem-bearing mud from the bottom of the river and load it onto a small boat. It is then brought ashore for washing. Washing of the alluvial gravels from river beds is also done at Pailin in Cambodia. Open cuts are also made by hand and the overburden is removed in rectangular areas which descend in steps to the gem gravels. The gravel is then removed for washing. These open cuts are made at a number of sites in Thailand. At Pailin, the only modern equipment used up until 1975 was small gasoline pumps for dewatering. All other mining was done by hand. With simple pit methods, the theft of stones is a real problem; one mine owner at Pailin estimated that up to 40 percent of his production was lost through theft (Davies, 1975).

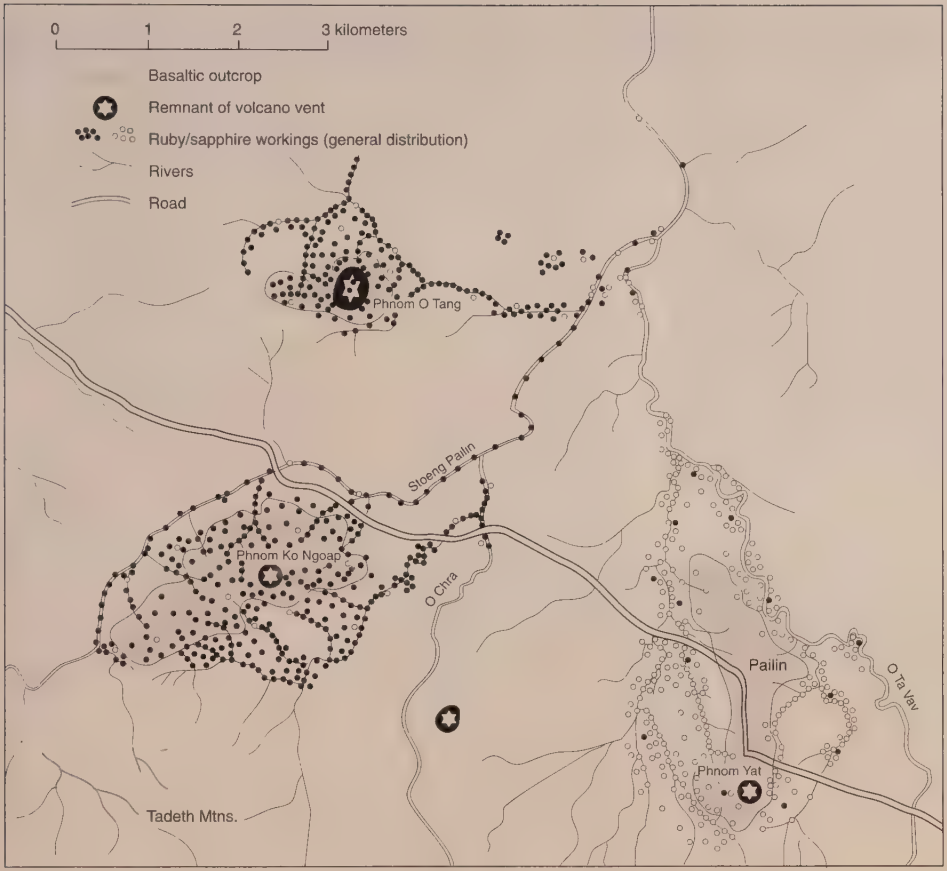


Figure 12.129 Distribution of ruby and sapphire mines at Pailin, Cambodia. (Modified from Jobbins & Berrangé, 1981)

Overall, pit mining offers an inexpensive method suitable for small teams of workers. It is, however, inefficient and has been largely replaced by mechanization.

Mechanized mines

Mechanized mining allows processing of much greater quantities of earth in a more efficient manner. It has thus replaced most of the simpler pit mining in the region. Bulldozers first strip away all the overburden, exposing the gem-bearing soil. This is then scraped into a big hill, where water cannons gradually force it into a pump. The pump carries the soil to a jig modified from that used for mining tin in southern Thailand. As the mud passes over the jig, heavier minerals are trapped while the lighter material is carried away. At the end of the day, the pump is turned off and the gems are selected from the gravel trapped by the jig. Small screened troughs are also used for washing the gem gravel, in conjunction with high-pressure water cannons.

There is one problem with jigs. If the water current is too strong, it can take away not only mud, but also the smaller gems. Alluvial mining is a fine science and requires precise conditions to maximize recovery. A critical factor is the water velocity through the jig, as well as the jig angle. In other countries, iron shot is loaded into the jig to assist in trapping the gems, but the author has yet to witness its use in Thailand. American mining engineer Delmer Brown estimated that he could increase the recovery from the average Thai mechanized mine by 10–20 percent with just a few simple changes (pers. comm., April, 1994).

Even under ideal conditions, recovery of gems is small. A typical day's work yields only a tiny handful of gems of mostly inferior qualities and sizes. Witnessing the day's production at a ruby mine is a humbling experience, giving a real appreciation of the true rarity of a large, fine ruby.

Mining requires relatively large amounts of water, so the best time is during the rainy season (June-October), when plenty of water is available for washing. Unfortunately, the rainy season is also the best time for mosquitoes, and, as a result, the incidence of malaria among miners is high. This is doubly true of those that try their luck across the border in Cambodia. Chanthaburi and Trat are among the wettest areas of Thailand and so water is less of a problem than at Bo Ploi in Kanchanaburi, which is dry much of the year.

Miners at big mines earn less than $3–4 per day. The thousands of peasants from surrounding areas, who dig at

The Tao of ruby mining

FROM a knoll above Bo Rai, one can spy the thickly-jungled hills of Cambodia. The air is punctuated by the occasional thump of artillery fire from the direction of that war-torn land, but the gently rolling hills surrounding the town of Bo Rai rock to another kind of activity—ruby mining. Once covered in forest and farmland, the land today has been stripped bare. In the quest for red—green is gone—only brown remains.

Bo Rai and Nong Bon are awe-inspiring places. Like a war zone, destruction is everywhere as the soil is ripped asunder in the quest for the tiny red gems. Towns are little more than collections of lean-tos, with permanent dwellings shunned, and for good reason—they lie on ruby-bearing soil. Thus, as other areas are exhausted, miners stare with little-disguised lust at the virgin soil the houses are built upon. At Nong Bon, the author witnessed mining directly on both sides of the town, with drainage tunnels carrying the gem-bearing mud from under one of a small group of houses to the jig on the other side.

Many years ago, when mining tunnels threatened to undermine the structure of the Buddhist *wat* (temple) at Khao Ploi Waen, monks were forced to halt mining on, and under, temple grounds. At Nong Bon, where a Chinese temple sat atop a small hill, priests were more pragmatic. Mining had cut down the surrounding land more than 30 m on every side, save one, with the only access by a narrow strip with a big drop on either side. Eventually a compromise was struck. The wily Chinese monks traded the temple land for a piece of barren property, with the provision that miners fund construction of an entirely new temple. The gods thus assuaged, mining quickly removed all traces of the old temple.

Figure 12.130 Ruby mining in Thailand proceeds at a frantic pace, sometimes even beneath miners' huts. Here, miners at Nong Bon (Trat Province) use a water cannon to pump the ruby-bearing soil into a tunnel running right beneath their homes. On the other side, a jig will separate the rubies and heavier minerals from the worthless overburden.
(Photo by the author, ca. 1983)

random in the forest, find barely enough to eke out a living. But there is always the chance of finding the big one, and everyone knows of somebody who has. It is this dream which fuels their search.

Impoverished people are also found at each of the mechanized mines, washing gravel by hand. This gravel may at times be dug from nearby pits. Smaller gravel, trapped by the jig, can also be purchased for approximately $20 per barrel, but of course, only tiny rubies are obtained from such jig sand. Poor women and children may also be seen washing the mud as it flows out of the jig. Again, only small stones are obtained this way, as the author can testify, since he tried it one day at Nong Bon. After an hour's work, a tiny pile of ruby "sand" had been found; the only large red stones were pyrope garnet, which is common at Nong Bon.

Ecological consequences. Mechanized mines are not without their down side. Miners make use of bulldozers, backhoes and other heavy equipment to move large quantities of earth. The jungle has thus been stripped from huge tracts of land to get at the gems below, creating an ecological disaster. Problems with deforestation forced the Thai government to ban the use of all heavy equipment, but this did nothing to stop the destruction. Mine owners merely operated during the night and today they work openly during the day.

Figure 12.131 While one might slurp noodles from a white table top, rubies in Bo Rai's early morning market are traded only upon yellow tables, which enhance their red color. From 7:00–9:00 AM every morning rough rubies are traded on the main streets of most major mining towns in Chanthaburi/Trat Provinces. (Photo by the author, ca. 1985)

An additional problem is the unrestricted use of water cannons, which pump large quantities of earth and silt into local rivers, thus polluting the water supply. Modern mines in other countries use settling ponds to allow the silt to settle, as well as recycling all water in a closed system. Unfortunately, with Thailand's free-trade-even-if-it-kills-us economy, such safeguards are rare. Worse still, Thailand is today exporting its ecologically-disastrous behavior to neighboring countries (see Hughes, 1993).

In Sri Lanka, the government forbids the use of heavy equipment. Their reasoning is that gem mining has provided employment for more than 2,000 years and hopefully will continue to do so for many years to come if worked slowly. Unfortunately, with world demand and prices for ruby at such high levels, mining in Thailand proceeds at a frantic pace. It can only be hoped that foresight and reason will overtake the desire for immediate profits. If not, Thailand may soon exhaust this precious and non-renewable resource.

In fact, exhaustion is the biggest problem facing Thailand's ruby mines. Fewer and fewer stones are found. Since the

Figure 12.132 Heavy media separation jig at Bo Rai, Trat Province, Thailand. Ruby-bearing earth is pumped into the jig where the heavy minerals, such as ruby, are separated from the lighter waste. (Photo: Wimon Manorotkul, ca. 1983)

author's first visit to these mines in 1979, he has not seen a single new deposit opened. Instead, the same ground is worked again and again, with ever-diminishing returns. Although accurate statistics are not available, the general consensus is that production is declining rapidly. Unless new deposits are unearthed, it appears that the already-rare ruby will become even more scarce. Even worse, since the land has generally not been properly reclaimed, it is useless for farming. Although land reclamation laws exist, enforcement is lax, for ruby mining provides employment and badly needed foreign exchange. Thus the rape of the land continues unabated.

Land ownership

The land upon which the mines are situated in Thailand varies in ownership. Much is privately owned and leased out to mining companies, who may then sublease it to smaller groups. In other cases, the land is owned by the government. All miners must possess a mining license, which is easily obtained at low cost.

Trading and cutting

From the time that the stones are won at the mines to the point of export from Thailand, they may pass through as many as seven or eight different pairs of hands, steadily increasing in value along the way. Once a stone is found, the miner need not venture far to find a buyer, as many small dealers wait patiently at the mines for just such an event. Each morning in mining towns such as Bo Rai and Nong Bon, a rough stone market is held where miners and dealers exhibit their wares. It is a colorful scene, with buyers and sellers crowding around small tables examining stones. These markets are mainly for smaller miners, while the big firms sell direct to cutters in Chanthaburi and Bangkok, or cut the

Down the drain—Mining Bangkok's alluvials

Figure 12.133 A Thai boy searches the drains of Bo Rai town in the search for rubies. (Photo: Olivier Galibert)

FOR much of Asia's population, life is a constant battle for survival. But few have it tougher than those Bangkok residents whose job it is to climb down into sewers and drains and cleanse them of society's offal and castaways.

Work begins at dawn, with the removal of the first grating. Down someone goes, a blackened rope the only lifeline to the world above. Even at street level, the stench makes one wince. But he is beyond smell, beyond light. Slowly he moles into the dark, tugging the rope. Eventually, the charcoal form slowly emerges from another drain a few paces away. One hand still clutches the rope, but the other's fingers wrap even more tightly around a different buoy—a small bag of debris collected along the way. He has been mining the city's alluvials and, like those upcountry, the heavies are the most valuable.

So it goes, until the sun's last rays force their way into Bangkok's acetylene sunset. Then the day's production is laid out on a soiled blanket. A few swipes with a blackened toothbrush bring forth life, luster. Here a fragment of silver, there a bit of gold and, if it has been a particularly good day, a scrap of jewelry.

Passersby bend down to examine the finds. One pays particular attention to a silver coin. With the toothbrush, he slowly works away the years of grime and, as he does so, his mind's eye slowly smiles. It is a rare coin from the colonial days, much sought-after by local collectors. Quickly mixing it into a pile of common coins, the haggling begins. They finally settle on 900 baht—about $36.

So it goes. No matter how low the drain cleaner's caste, in the end, he manages some dignity. That, and a few more baht, a bit of sweet relief, a bit of light at the end of the tunnel, until the next day's descent. As the customer walks away, the drain cleaner also smiles inside. He thinks he'll get a few more of those coins from that Chinatown workshop where they are made. They seem to be popular.

Figure 12.134 Offering prayers to the ruby gods
Children search for stones which might have been dropped in Bo Rai's early morning rough market. (Photo: Olivier Galibert)

stones themselves. Smaller sizes and cheaper qualities are offered in large lots, with more expensive pieces sold singly.

From Chanthaburi, Trat and Cambodia, gems flow to the town of Chanthaburi for cutting, heat treatment and eventual sale. Every Thursday through Sunday a cut stone market is held, with Bangkok-based dealers descending on the town to look over the week's finds. Along Treerat Road the business is fast and furious, with little time for contemplation.

Brokers (runners) are used to offer stones, for they can hide the owner's identity, as well as ask higher prices without feeling embarrassed. An offer is made, the parcel is sealed, and off goes the runner to consult with the owner. In time the runner reappears, usually with a counter offer, and so it goes until a deal is made. Payment is normally by a three-day post-dated check to allow the buyer to test the stones in Bangkok and cancel the check if a stone turns out to be synthetic. Most stones, of course, are genuine, but should a newcomer try to buy he must first wade through the many synthetic stones that suddenly appear from the broker's pockets. Passing this "initiation test" allows them to proceed to the real thing. Failure (the purchase of synthetic gems)

Table 12.22: From mine to consumer

Distributor	Gem Purchase Price Per Carat	Gem Purchase Price Total	Mark-up %	Gem Selling Price Per Carat	Gem Selling Price Total
Miner	5 ct rough ruby extracted by the miner		—	$100/ct rough × 5 ct	$500 total
Small-time rough buyer	$100/ct. rough × 5 ct	$500 total	30%	$130/ct rough × 5 ct	$650 total
Cutter	$130/ct. rough × 5 ct	$650 total			
	Cutter cuts rough gem: rough to cut = 20% yield; 5 ct rough = 1 ct cut				
			30%	$845/ct cut × 1 ct	$845 total
Chanthaburi dealer	$845/ct cut × 1 ct	$845 total	20%	$1014/ct cut × 1 ct	$1014 total
Bangkok dealer	$1014/ct cut × 1 ct	$1014 total	28%	$1300/ct cut × 1 ct	$1300 total
US buyer	$1300/ct cut × 1 ct	$1300 total	40%	$1820/ct cut × 1 ct	$1820 total
US jewelry manufacturer	$1820/ct cut × 1 ct	$1820 total	50%	$2730/ct cut and set	$2730 total
US retail jeweler	$2730/ct cut + price of setting	$2730 total + price of setting	100%	$5460/ct cut and set	$5460 total
US consumer	$5460/ct cut + price of setting	$5460 total	—	—	—

Jungle economics

SOME may gaze at the above pricing tables and immediately decide to drop wife, kids and family dog for the next plane to the mines to get themselves a piece of that ten-times mark-up between mine and consumer…

"Yeah, baby, scratch my back, I can see it now… I just park my ass for a few days out there at them mines… cherry pick a few ripe reds… let's say in the 5-ct range… pay the sandman a couple bucks to grind 'em fine & make 'em shine… then I just place my bod' on that Concorde silver rod to the Big Apple, right down to Fifth Av-A-New, where I dump 'em for ten times more! Count it baby, ten times profit! Yessir, sure is a wonderful world… Honey-buns, can ya scratch the other side, too?"

If life were so easy, do you really believe I would be penning this prose at pennies a page? No, it just ain't so. While it is possible to become a small-time rough buyer and purchase gems at the prices quoted in the table above, you've got to be prepared to sit on a pox-ridden jungle trail for days on end, buying the day's production from every Tum, Tik and Harrychai… for an average of 50 Baht ($2) per day… and if Tum's mother just died you gotta be there for the funeral, with a donation… and at sundown the mosquitoes make their appearance, and they do carry the world's worst malaria… and your only company will be people who ask you over and over again if you can speak Thai, and when you speak your five words of Thai, they will all say exactly the same thing: "Khun poot Thai geng!" ('You speak good Thai!').

I think you get the point. Every member of the supply chain performs a service of sorts—that's what they get paid for. In the case of the small-time rough buyer, they get paid for spending the better years of their life in some god-forsaken jungle for weeks at a time, with only malarial mosquitoes and occasional Khmer Rouge guerrilla for company. Sounds like fun, eh?

suddenly produces large numbers of brokers, all eager to sell. Definitely not a good place for the inexperienced.

The Chanthaburi market is almost exclusively devoted to the sale of cut stones; when rough is offered it is inevitably a cleverly beat-up Verneuil synthetic. Not only are Thai rubies and sapphires sold, but also heat-treated Sri Lankan sapphires and other corundums from around the world. This is because many are brought to Chanthaburi for cutting and heating. Even stones from Bangkok may be sent to Chanthaburi for sale, since it is where many buyers are found. From Chanthaburi, the stones proceed to Bangkok for sale to international gem buyers and then pass into the major consumer markets of Japan and the West.

From mine to consumer

Table 12.22 illustrates the typical distribution chain of ruby and sapphire. A 5 ct rough stone sold by the miner for US$500 ($100/ct) could cost the final consumer ten times that amount at retail. This is by no means an extreme case, but represents average mark-ups throughout the chain of distribution.

Characteristics of Thailand/Cambodia ruby

The rubies produced in Thailand and Cambodia originate from deposits straddling the border of these two nations, just north of the Gulf of Thailand. Thus, the internal features of rubies are identical. To simplify matters, these stones will hereafter be referred to as Thai rubies, even though, in fact, they may have been mined across the border in Cambodia.

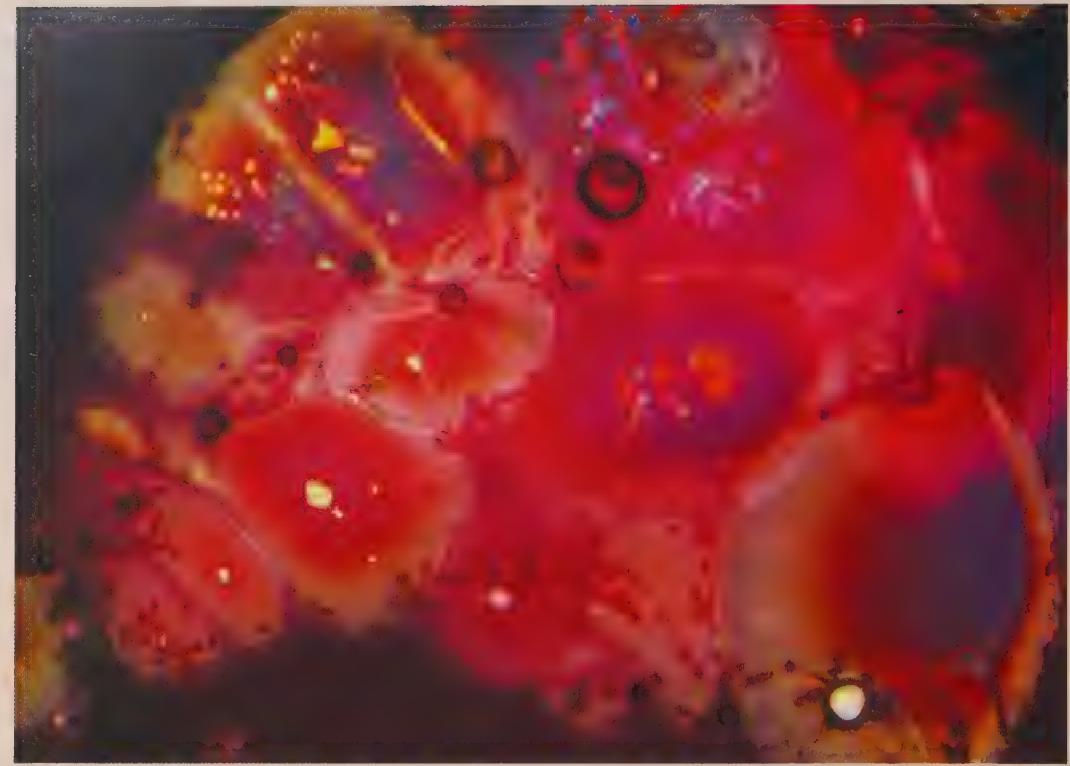


Figure 12.135 Like eyes, tiny two-phase inclusions peek out from the interior of a Thai/Cambodian ruby. Oblique fiber-optic illumination; 35×. (Photo: John Koivula/GIA)

Overview. Thai rubies are characterized by a complete lack of rutile silk. As a result, star rubies are not produced from these deposits. The long white needles commonly found in Thai rubies form parallel to the edges of the rhombohedron faces at the junctions of intersecting polysynthetic twinning planes. It was once hypothesized that these might consist of fluid-filled tubes (Gübelin, 1953, 1973). Today we know they are the mineral boehmite, γAlO·(OH), which exsolves along intersecting twin lamellae (Koivula, 1981; Gübelin & Koivula, 1986).

Most distinctive in Thai rubies are the solid crystals surrounded by fluid fingerprints or feathers. Dubbed *Saturn* inclusions by gemologists due to their unique appearance, they are a common sight. Other features include fluid inclusions of both primary and secondary origin, of which the latter are present in almost every specimen. Color zoning of any kind, however, is rarely seen in Thai rubies.

Separation of Thai rubies from those of Burma and Sri Lanka can be made by reference to the lack of exsolved silk and/or particles in Thai rubies. The only acicular inclusions seen are the slender boehmite needles found lying at the junctions of the rhombohedral twinning planes. These intersect at 86.1/93.9° angles and often run through fingerprints, dividing them into banner-like sections. Boehmite needles and the accompanying polysynthetic twinning are extremely common in Thai rubies and are among the most useful features for distinguishing them from the flux-grown synthetic rubies. In cases where the twinning planes do not extend across the entire stone, the often irregular edges of these planes are sometimes traced by white boehmite needles, as well.

Solids. Common solid inclusions in Thai rubies are rounded crystals with flat ends that sit perched upon the rhombohedron or basal planes, surrounded by fingerprints. The solid portion of these Saturn inclusions may be almandine garnet (brown, opaque), apatite (yellowish), pyrrhotite (black with metallic luster), plagioclase feldspar (colorless, transparent), olivine, or diopside. Negative crystals also form Saturn inclusions.

Today virtually all Thai rubies are heat treated to remove the bluish tint from their color. Heat treatment generally melts these solid crystals, leaving behind a high-relief void filled with the glassy remains of the guest mineral. At times, it leaves a gas bubble frozen in place within the glass-filled void. The brownish stains so often found in the surrounding fingerprint also disappear upon heating. As these Saturn inclusions are present in 50–80% of all Thai rubies (Gübelin, 1971), they make it possible to detect the heat treatment.

Cavities. Thai rubies posses an abundance of both primary and secondary fluid inclusions. Gübelin (1971) has suggested that the flat fluid fingerprints in Thai rubies represent

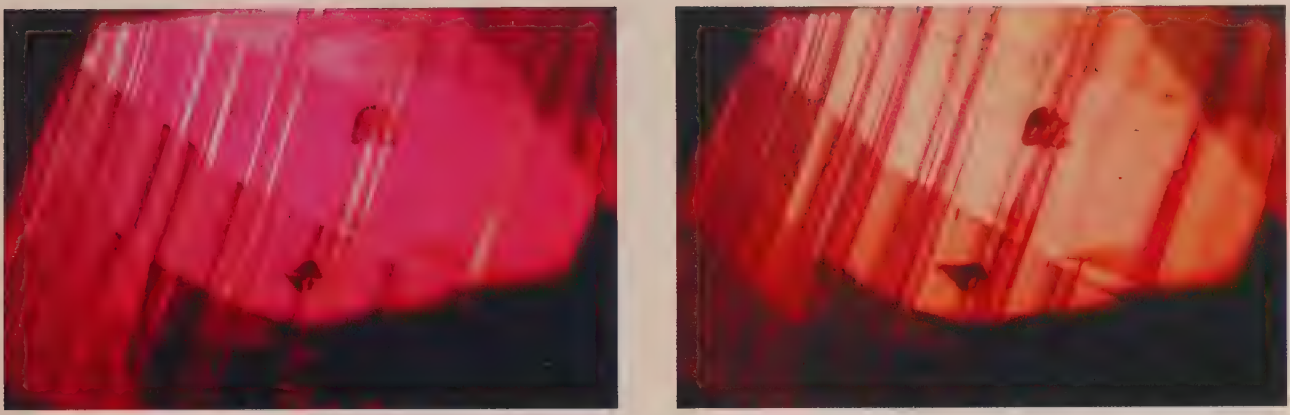


Figure 12.136 Twin sisters
Thai/Cambodian rubies frequently contain polysynthetic twinning lamellae parallel to the rhombohedron {10$\bar{1}$1}. Since each section is in reverse position to the other, one will see reversed pleochroic colors. Rotation of a polaroid plate above the stone will again reverse these colors; 60×.
(Photos by the author)

exhausted residual solutions left behind after the crystallization of the mineral grain. Forming on a crystal face during a temporary lull in the ruby's growth, the guest mineral sucked out all of the nutrients from the fluid. The mineral was subsequently trapped when the host again started growing.

The primary fluid inclusions are found as described above, or as ultra-thin films surrounding tiny two-phase negative crystals which lie parallel to the basal pinacoid. The latter are similar to those found in sapphires from Yogo Gulch, Montana. Primary CO_2-filled inclusions were trapped when the Yogo sapphires crystallized at great depth (and high pressure). Later as the sapphires were carried upward, under the lower confining pressure, these primary cavities sometimes cracked. This allowed fluid to escape into the fracture, where it caused healing and the trapping of many tiny secondary CO_2 inclusions. The result is "atoll-like" inclusions consisting of primary negative crystals sometimes surrounded by secondary fluid inclusions (Roedder, 1972, 1984).

In Thai/Cambodian rubies, these tiny two-phase negative crystals are surrounded by extremely thin fluid films in fingerprint patterns which often possess a triangular or hexagonal outline. Since natural rubies are generally cut with the *c* axis perpendicular to the table facet, these films will usually lie parallel to the table. It is this parallel alignment which allows easy separation of these primary fluid inclusions from secondary fluid inclusions produced by healing.

Thin primary fluid films may also be found along the rhombohedron planes in Thai rubies, but are much less common than those in the basal plane. By utilizing reflected light from a fiber optic light guide, the films appear as brightly iridescent fingerprints stacked one on top on another in the basal plane. Tiny bubbles are often seen in the center. Under transmitted or dark-field illumination, only the two-phase negative crystals are seen, not the surrounding fluid films.

Thai rubies may also contain secondary fluid inclusions ('healing fissures'). These are commonly found parallel to the basal pinacoid and rhombohedron faces, as well as in random directions. One type of Thai/Cambodian stone that deserves mention is the *lai thai* ruby. Such stones are characterized by fine red color and large numbers of wispy, thick, secondary cavities.[8] The name *lai thai* (ลายไทย) means literally Thai "design" or "motif," because the twisting, wispy patterns of the fluid inclusions resemble the designs seen on Thai silks and other local arts and crafts.

Lai thai rubies often give gemologists fits. Their thick and twisted fingerprints and feathers bear a strong resemblance to the primary and secondary flux inclusions common in flux-grown synthetic rubies. One must remember that the patterns of natural fingerprints and feathers may, at times, be identical (wispy, mesh or veil-like) to flux inclusions. Thus, separation is achieved not through reference to patterns, but by close examination to determine the identity of the filling material (fluid vs. flux glass), and by reference to the other inclusions present.

Lai thai rubies inevitably contain lots of polysynthetic twin lamellae and boehmite needles. Twinning alone is seen in flux-grown synthetic rubies, but not twinning with boehmite needles at the twin junctions.[9] Thus since nothing resembling this combination is found in the flux-grown synthetic rubies, a positive distinction is possible. Natural rubies which contain lots of secondary fluid inclusions invariably contain rhombohedral twinning and boehmite needles, too, because the pressure which caused the glide twins and boehmite to form also produced fractures that were later healed.

8. Stones such as these, which have fine color and look good at first glance, but which upon closer inspection have clarity problems, are termed "bluff stones" by dealers.

9. The twinning/boehmite combination has been seen in Verneuil synthetics, but these can be identified by their curved growth lines and gas bubbles.

Figure 12.137 Saturn in rouge
Thai/Cambodian rubies often contain opaque crystal inclusions surrounded by fingerprints ('Saturn' inclusions). During heat treatment, these crystals typically melt, forming glass-filled negative crystals of high relief with flat ends (usually parallel to the basal pinacoid or rhombohedron faces). One such glass-filled negative crystal is shown at left. In some cases, gas bubbles may be found within the glass filling, frozen in place (not shown). 87×. (Photo: Wimon Manorotkul)

Hence one should be suspicious of rubies which contain multitudes of what appear to be secondary healed fractures (i.e., fingerprints), but lack the twinning/boehmite combination.

Without magnification, *lai thai* rubies may appear, at first glance, somewhat similar to Burma-type rubies. This is less a resemblance of body color and more a product of clarity. The color of *lai thai* rubies is slightly more yellowish than most Thai stones. Inclusions, scatter the light in random directions, bringing in some of the yellowish red extraordinary ray, even when the *c* axis is perpendicular to the table facet. Rutile silk often has the same effect in Burmese rubies. The wispy inclusions in *lai thai* stones effectively mask extinction which would otherwise be present, again like the rutile silk of Burmese stones. The presence of obvious extinction in Thai rubies and the comparative lack of it in Burmese gems is a major difference in appearance between the two sources. In Burmese gems, silk and strong fluorescence effectively mask the extinction. Wispy inclusions in *lai thai* gems have a similar effect, but at a price: dramatically-reduced clarity.

The secondary fluid fingerprints and feathers of Thai rubies often display beginning and intermediate stages of healing, but rarely the latter stage (where well-formed negative crystals are arranged in a fingerprint pattern, such as within Sri Lankan rubies). Reflected light from a fiber-optic light produces bright interference colors that reveal intricate surface details of these healing fissures. Narrow growth steps give the appearance of terraced farmlands seen from the air. Between the coarse fluid tubes, extremely minute channels are found, resembling tiny fingerprints within larger fingerprints. When fluid channels are broad and flat, light is easily transmitted from below. With Thai rubies in particular, when a fingerprint lies along the basal plane, the fluid channels surround "islands" of healed corundum whose outlines are slightly distorted, or even perfect, hexagons. These hexagonal islands within fingerprints are also common in primary fluid films.

Growth zoning. Other than the ubiquitous repeated twinning, growth features, such as color zoning, are quite rare in Thai rubies. Of the thousands of Thai stones examined by the author, only a handful have ever shown irregularities in color distribution. None have displayed narrow color banding. Instead, the most irregular color disturbances found are broad areas of color concentration with diffuse borders which are, at best, difficult to resolve. Immersion between crossed polars may help to locate banding at times, particularly if the stone is examined exactly parallel to the *c* axis. The lack of color irregularities in Thai rubies contrasts greatly with the flux-grown synthetic rubies, most of which display sharp angular growth lines.

Characteristics of Thai/Cambodian sapphire

Thai sapphires are often described as a single entity, but originate in fact from three different major deposits, each located in an entirely different part of the country. Thus stones from each deposit possess unique inclusion suites.

The major sapphire-producing localities of Thailand and Cambodia are as follows:

- Bo Ploi, Kanchanaburi Province (100 km west of Bangkok)
- Khao Ploi Waen & Bang Kha Cha in Chanthaburi Province and Ban Bo I Rem, on the border between Chanthaburi and Trat Provinces
- Ban Bo Kaeo & Huai Mai Sung, Phrae Province (approximately 500 km north of Bangkok)
- Phnom Yat at Pailin, Battambang Province, Cambodia

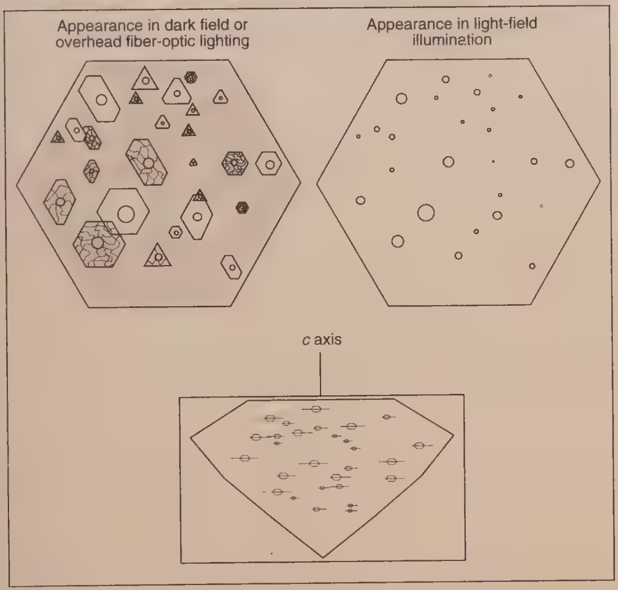


Figure 12.138 Ultra-thin primary two-phase fluid films in Thai/Cambodian rubies, which form parallel to the basal pinacoid. Since most natural rubies are cut with the table parallel to the basal pinacoid, they will generally be seen parallel to the table facet. Overhead fiber-optic lighting will reveal them as bright, iridescent films with triangular or hexagonal outlines, but in light field, only the central bubble is seen. This has caused many novice gemologists to mistake these inclusions for the gas bubbles found in some varieties of synthetic corundum. (Photo by the author)

Bo Ploi, Kanchanaburi

Among the three major sapphire-producing districts of Thailand, the most important in terms of both production and quality is Bo Ploi. The sapphires of Bo Ploi in Kanchanaburi are virtually all of a blue color (with an occasional yellow found). They possess distinctive inclusions which allow them to be quickly recognized.

Solids. Included crystals of a number of types are found in sapphires from Bo Ploi. Gunawardene and Chawla (1984) identified transparent colorless crystals of feldspar and long prisms of hornblende. Also found were submetallic grains of pyrrhotite. The author has seen heavily corroded black crystals of dull luster, sometimes containing gas bubbles frozen in place. This could be the result of heat treatment, to which all Bo Ploi sapphires are subjected. Heating may melt the crystal, leaving behind a void containing a bubble within the solidified remains of the former included crystal. Glassy circular tension halos have also been found around included crystals, likely another by-product of heat treatment.

Jingfeng Guo & Griffen *et al.* (1994) reported on a Co-rich spinel inclusion surrounded by a glass rim. It was

Table 12.23: Properties of Thai/Cambodian ruby[a]

Property	Description
Color range/phenomena	• Near colorless through rich red, to a dark garnet-red. Generally weak in fluorescence. • Star rubies are not found.
Geologic formation	• Secondary deposits derived from weathered alkali basalts.
Crystal habit	• Tabular hexagonal prism/rhombohedron/pinacoid combinations. Most stones are so heavily weathered that no faces can be discerned. Due to the tabular habit, most cut stones are flat.
RI & birefringence	n_ε = 1.762–1.768; n_ω = 1.770–1.776 Bire. = 0.008 RI increases with Fe content.
SG	• Not reported; believed to be near 4.00.
Spectra	**Visible** • Cr spectrum in all stones; if enough Fe is present, a weak Fe spectrum may be superimposed on the Cr spectrum.
Fluorescence	Generally weaker with increasing Fe content and depth of color. • LW: weak to moderate red to orange-red • SW: inert to weak red to orange-red
Other features	Virtually all stones are heat-treated; some may contain glass infilling.
Inclusion types	**Description**
Solids	Typical are solid crystals surrounded by secondary healed fractures ('Saturn' inclusions). Such crystals include: • Apatite, typically yellow (Gübelin, 1971) • Garnet (almandine, pyrope) (Gübelin, 1971) • Diopside (Gübelin, 1971) • Feldspar (plagioclase) (Gübelin, 1971) • Olivine (Gübelin, 1971) • Pyrrhotite/chalcopyrite (Gübelin, 1971) • Sapphirine, blue (Koivula & Fryer, 1987) Heat treatment of the above inclusions melts the solids (often turning them to glass), creating distinctive, transparent glass-filled negative crystals. Gas bubbles may be found frozen in the glass. This is not to be confused with glass infilling (surface repair). Glass inclusions reportedly occur naturally, due to the melt environment of Thai/Cambodian rubies.
Cavities (liquids/gases/solids)	• Primary thin fluid films which often appear to be two-phase and which lie parallel to the basal plane. Light field illumination makes these inclusions appear similar to the gas bubbles in syn. corundum; use oblique fiber-optic illumination from above to see these thin fluid films in their entirety. The outline of these films is often hexagonal or triangular. • Secondary healed fractures are extremely common. They occur in a variety of patterns and thicknesses. • Iron oxide stains are extremely common in cracks (this is eliminated during heat treatment).
Growth zoning	• The only type of growth zoning seen in Thai ruby is vague, broad areas of slight color variation. Even this is extremely rare.
Twin development	• Polysynthetic glide twinning on the rhombohedron (3 directions, meeting, at 86.1 and 93.9°) is extremely common.
Exsolved solids	• Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°).

a. Table 12.23 is based on the author's own extensive studies, along with those of American Gemological Laboratories (1982), Gübelin (1971, 1973), Gübelin & Koivula (1986) and Koivula & Fryer (1987).

thought that the glass rim resulted naturally from magmatic heating, rather than human heating.

Cavities. Negative crystals are seen, but appear to be secondary rather than primary in origin, as they are associated with healing fissures. These fluid-filled voids form most often in the basal plane, occurring as flattened individuals with triangular growth markings in some cases. Secondary fluid inclusions in fingerprint and feather patterns are present in most Bo Ploi sapphires. The fluid channels are relatively coarse at times, forming curved and folded patterns of great beauty. Yellowish stains have been seen in some healing fissures; others are iridescent in reflected light where the fluid is thin enough to cause interference.

Growth zoning. Zoning in sapphires from Bo Ploi include uneven color banding parallel to the faces of the hexagonal prism. This banding appears much like that of heat treated Sri Lankan sapphires, except for the exsolved particles which always accompany it. In Sri Lankan sapphires, minute exsolved particles may also be found. However, the particles in Ceylon sapphires are often found in colorless areas, as well as with the color banding. In Bo Ploi stones, the particles are always found to follow exactly the color banding.

Twin development. Polysynthetic twinning is also a common feature, along with long white boehmite needles running parallel to the edges of the rhombohedron faces.

Exsolved inclusions. To the naked eye, Bo Ploi stones, with their uneven color zoning, appear much like, and are often sold as, heat-treated Sri Lankan stones. However, the Bo Ploi sapphire is slightly milky, due to concentration of minute exsolved particles along the blue color zones. These particles are found in every stone, but concentrate only in the blue bands, being entirely absent in colorless areas. Rutile silk, of

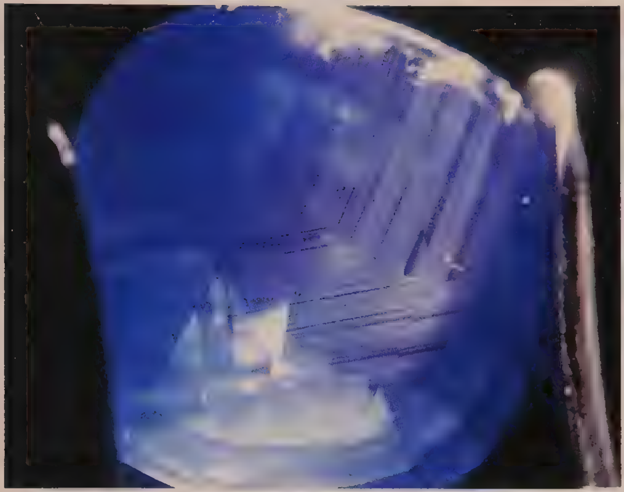



Figure 12.139 The milky, silky world of Bo Ploi sapphires
Left: The fine blue color of some Bo Ploi sapphires is evident in this photo. Also seen are the tiny exsolved particles which give the stones their distinctive "milky & silky" appearance; 18×; oblique fiber-optic illumination. (Photo by the author)
Right: Minute exsolved particles seen through the table in a Bo Ploi (Thailand) blue sapphire. In Bo Ploi sapphires, such particles are always present and lend a certain cloudiness to the stone. They differ from Sri Lankan sapphires, where concentrations of particles may be found in colorless areas; in Bo Ploi stones the concentrations of particles follow exactly the blue colored areas; where there is no color there will be no particles, and vice versa; 17×; oblique fiber-optic illumination. (Photo: Wimon Manorotkul)

characteristic knife- or dart-shapes, with tiny re-entrant angles at the broad end, is found in Bo Ploi stones. But unlike the silk of Sri Lankan sapphires, which is virtually pure rutile (TiO_2), individual needles of Bo Ploi stones are thought to be solid-solution mixtures of rutile and ilmenite ($FeTiO_3$). Titanium diffuses into corundum some 10,000 times faster than iron. Thus when Bo Ploi gems are heated, the titanium is dissolved into the corundum, leaving the iron behind. The result is a pattern of tiny exsolved particles in the same pattern as the rutile (see Figure 6.13 on page 118).

The exsolved mineral particles in Bo Ploi sapphires, which give them a distinctive turbidity, generally allow separation from sapphires of other sources. These particles, which are relatively coarse in size, are arranged in an identical fashion to the silk, intersecting in three directions at 60/120° in the basal plane. Their distribution is distinctive, as they concentrate in dense accumulations which exactly follow the blue bands of color; colorless regions are devoid of particles. Thus, deep blue stones contain large numbers, while in light blue stones they are present in fewer numbers. When one looks parallel to the *c* axis with an overhead light source, intense silvery bands are seen due to reflection off the particles. Transmitted light in the same direction produces alternating bands of blue and colorless, with the blue zones showing a characteristic powder-blue milky appearance. The blue color is pure and deep, at times equaling that of good quality Burmese or Sri Lankan sapphires, except for the trace of milkiness. Many Bo Ploi stones, however, will be oriented slightly off the *c* axis to avoid the strong color zoning in that direction. This gives such stones a slightly more greenish color due to the increased e-ray presence. Transmitted light in directions at oblique angles to the *c* axis displays the color in tiny rows of blue dots intersecting in three directions.

Chanthaburi/Trat

The production of sapphires from Chanthaburi and Trat has traditionally been small compared with Bo Ploi. Bo I Rem yields sapphires of a pure, but deep blue color. Bang Kha Cha and Khao Ploi Waen are known for yellow, green and black-star sapphires, including the famous *Mekong Whiskey* yellow sapphires and *golden-star* black-star sapphires. Dark blue sapphires are also found here.

Blue sapphires. Inclusions are similar to those from the famous Pailin mines (which lie but 30 km. distant across the border in Cambodia). Most distinctive are small red and orange octahedra that, according to Gübelin (1973), consist of the rare mineral, uranopyrochlore. The extremely intense deep blue color may display just the slightest trace of milkiness, due to extremely fine exsolved particles which scatter the light. Other features are secondary healing fissures and polysynthetic twinning with boehmite needles.

The color of these stones is especially distinctive in the microscope. Growth zoning in a hexagonal pattern is sharp and well-defined, with a lovely deep blue visible parallel to the *c* axis. In transmitted light, slightly turbid, yellowish texture clouds are seen with sharp boundaries. Fiber-optic illumination reveals the cause of the slight cloudiness to be extremely minute exsolved particles. They appear white in reflected light, but brownish or yellowish in transmitted light when in thick planes. This yellow color is diffused

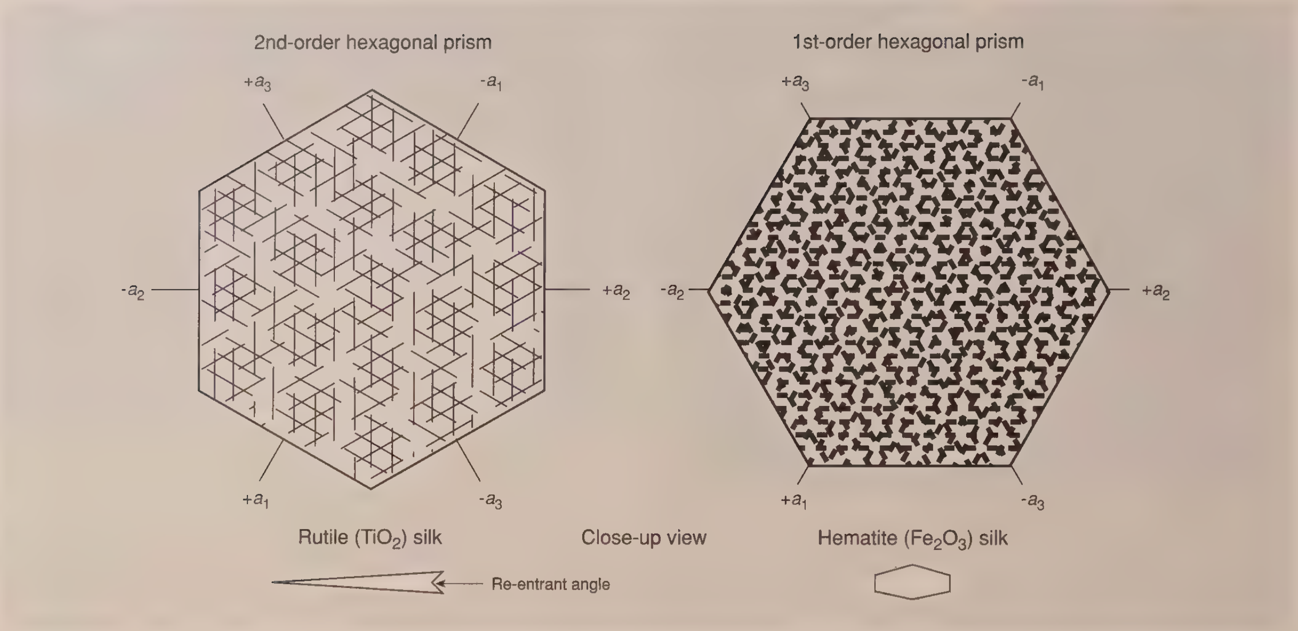


Figure 12.140 Silk in natural corundum is exsolved along three directions (parallel to the hexagonal prism) in the basal plane, meeting at 60/120°.
Left: Rutile silk forms parallel to the faces of the second-order prism {11$\bar{2}$0}, and tends to occur as dart- or arrow-shaped twins with tiny reentrant angles at the broad end. Rutile silk is commonly found in corundums from a variety of sources, particularly Burma and Sri Lanka.
Right: Hematite forms parallel to the faces of the first-order prism {10$\bar{1}$0}, and tends to be more platy (rather than slender needles). Hematite silk is common in Fe-rich sapphires, particularly those from Thailand and Australia. Some Thai black-star sapphires (from Khao Ploi Waen and Bang Kha Cha) may contain both hematite and rutile silk, and thus can be cut into 12-rayed star stones.

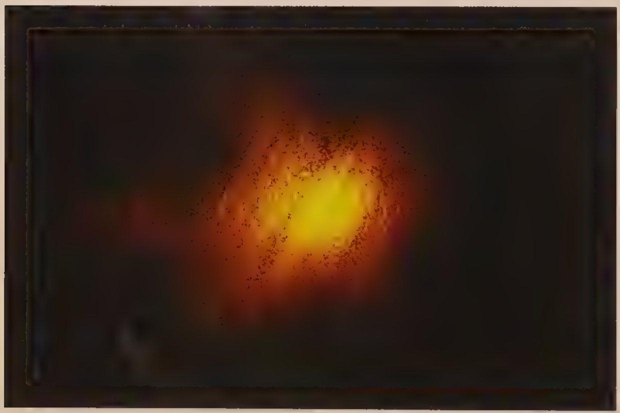


Figure 12.141 The star of a golden-star black star sapphire from Thailand's Chanthaburi Province. This golden-colored star results from exsolution of hematite silk in an otherwise yellow sapphire. 63×.
(Photo by the author)

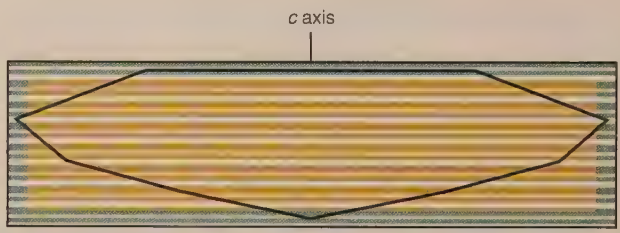


Figure 12.142 Color zoning as found in Thai yellow sapphires. Zoning is best viewed parallel to the basal pinacoid. Due to the flat shape of most rough, stones are usually cut with the table parallel to the pinacoid. This means zoning will generally run parallel to the table facet. Crystals often have green skins, containing thin concentrations of exsolved hematite silk. In cut stones, these will generally be found near the table and culet.

throughout the stone, giving an eerie greenish overtone to the intense blue color in certain positions. So fine are these particles that the sharp zoning may take on a waxy appearance.

Yellow and green sapphires. Zoning in the green sapphires is generally sharp alternating bands of yellowish green and blue, while in the yellow sapphires are seen bands of green and yellow. The yellow crystals are tabular and thin, with green banding lying just beneath the upper and lower pinacoid faces. Cut stones are often shallow, with green bands just under the table and culet, as a result. The banding of these yellow sapphires is unusual for corundum in that sharp parallel zoning is visible along the basal pinacoid, but less so parallel to the *c* axis (parallel to the hexagonal prism faces). The hexagonal zoning parallel to the *c* axis, however, can be determined by the banding of the silk.

Unlike Thai rubies, the twinning and accompanying boehmite needles in Chanthaburi's yellow sapphires tend not to penetrate the entire stone. Instead, they are found mostly near the gems' surfaces.

Silk is found only in narrow planes within the green bands, usually at the table and culet. This silk consists mostly

Figure 12.143 A red-orange crystal shoots through the azure depths of a Pailin sapphire. Once considered unique to Pailin sapphires, we now know that such uranopyrochlore inclusions are found in sapphires from many sources. 80×. (Photo: John Koivula/GIA)

Figure 12.144 An unidentified white crystal is frozen in the interior of a Pailin sapphire. 63×. (Photo by the author)

of extremely short, "hairy" hematite needles of a brownish color, intersecting in three directions at 60/120° angles along the first-order hexagonal prism. With a fiber-optic light, small amounts of rutile silk can also be detected. Rutile needles are longer and more slender than hematite; in addition, they lie parallel to the second-order hexagonal prism. This situation also applies to the blue, green and black-star sapphires.

Black-star sapphires. The dark brown-to-black color of black-star sapphires results from dense concentrations of hematite silk, mechanically coloring the stone. When included in an otherwise blue or green stone, a white six-rayed star results. However, if the hematite is present in a yellow sapphire, the rare and desirable *golden-star* black-star sapphire is produced, where the rays of the star take on a deep, golden-yellow tint. These golden stars are far more valuable than the ordinary white stars, but are little known outside of Thailand.

Close examination of black-star sapphires often reveals a strong 6-rayed star due to hematite silk, and a weaker 6-rayed star offset 30° from the other, due to rutile silk. Many black-star sapphires from Chanthaburi display this to some extent. Should enough rutile be present, a 12-rayed black-star sapphire results. Bang Kha Cha and Khao Ploi Waen produce relatively large numbers of these gems. At times, six rays may be yellowish or blue, while the other six appear white.

The heavy concentrations of platy hematite silk in black-star sapphires weaken them considerably. As a result, they tend to break along the basal pinacoid plane (basal parting). This parting is identical to cleavage, except the number of possible partings is limited to planes where the hematite silk is sufficiently concentrated to affect structural adhesion. Rutile does not have the same effect (due to its less platy nature). Hence the lack of basal parting in Burmese and Sri Lankan star stones containing concentrations of rutile silk.

Parting is often visible on the back of cabochons as extremely flat surfaces exhibiting a step-like appearance. The pits produced by basal parting are often disguised by filling with dopping shellac (see Figure 6.21 on page 125).

An unusual feature of both the blue and black-star sapphires from Chanthaburi/Trat is the extremely tiny disc inclusions found scattered through some stones. These discs

Table 12.24: Properties of Bo Ploi sapphire[a]

Property	Description	
Color range/phenomena	• Blue: near colorless to deep blue, somewhat inky (but less than other Thai sapphires), often rich blue but strongly zoned • Yellow: near colorless to medium yellow • Six-rayed stars are known, but not common	
Geologic formation	• Secondary deposits derived from weathered alkali basalts	
Crystal habit	• Generally tabular hexagonal prisms; cut stones are often flat as a result	
RI & birefringence	n_ε = 1.762–1.764; n_ω = 1.770–1.772	Bire. = 0.008
SG	• Not reported; probably near 4.00	
Spectra	**Visible**: Medium to strong Fe spectrum always present	
Fluorescence	**UV**: Generally inert; may occasionally show weak chalky blue-green (SW)	
Other features	• Generally heat treated; may be surface-diffusion treated	
Inclusion types	**Description**	
Solids	• Feldspar; transparent, colorless (Gunawardene & Chawla, 1984) • Hornblende; long prisms (Gunawardene & Chawla, 1984) • Pyrrhotite; submetallic grains (Gunawardene & Chawla, 1984)	• Spinel, Co-rich, surrounded by glass rim (Jingfeng Guo & Griffen *et al.*, 1994) • Unknown corroded black grains
Cavities (liquids/gases/solids)	• Secondary fluid inclusions are common	
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; generally associated with dense clouds of rutile silk, where the silk is concentrated in the blue areas. Heat treatment dissolves this silk, leaving behind minute particles. Colorless areas will be found to be devoid of such particles.	
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$	
Exsolved solids	• Rutile silk in dense clouds. Heat treatment dissolves this silk, leaving behind minute particles. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)	

a. Table 12.24 is based on the author's own extensive research, along with published report of Gunawardene & Chawla (1984).

appear to have resulted from exsolution and are visible only with a fiber optic light guide. They are flattened in the basal plane, but otherwise appear to be randomly distributed. Such inclusions could easily be mistaken for gas bubbles, which they strongly resemble, except for their flat shape.

Solid inclusions. A variety of solids are found in blue and green sapphires from Chanthaburi and Trat, but are rarely, if ever, found in the yellows. Most distinctive are red and orange octahedra of either garnet or uranopyrochlore. These may be surrounded by small fingerprints containing yellow stains. Also seen are slightly rounded colorless crystals surrounded by circular flat tension fractures which are highly iridescent in reflected light. Some stones show small opaque black crystals of triangular outline and metallic luster which strongly resemble the platinum plates found in certain flux-grown synthetic rubies. Other crystals seen are colorless blocks of what may be feldspar surrounded by flat glassy tension halos and opaque black blocks (niobite?).

Other inclusions. Chanthaburi sapphires of all colors display secondary fluid inclusions, although these are less common in yellow sapphires. These occur in the form of fingerprints, feathers, etc. Polysynthetic twinning and the accompanying boehmite needles are also commonplace in all varieties. In addition, the sapphires of this region show basal parting due to concentrations of hematite silk. This is most evident in the black-star sapphires, but is also a prominent feature within the blue and green stones as well. Basal parting is readily observed on the rough material; however it is also seen occasionally in cut stones. Some of these parting planes have been subjected to healing processes; thus one frequently observes fingerprints and feathers lying along the basal plane.

Phrae

Stones from these mines tend to be dark blue in color, with some tending towards a deep, slightly violetish blue to blackish violet hue. Other varieties found include some green sapphire, but almost all of the production is blue.

Hexagonal color zoning is strong and prominent in Phrae stones, similar to those from Australia. Some stones display central or core hexagonal zones of pale yellow to colorless with the outer areas of the crystal being blue. "Diesel-type" oily appearances may be seen in transmitted light before heat treatment. Polysynthetic twin lamellae with boehmite needles are common. Exsolved particles and silk of an unknown nature are also seen. Most Phrae sapphires are heat treated.

Table 12.25: Properties of Thai yellow sapphire (Chanthaburi)[a]

Property	Description
Color range/phenomena	• Yellow: medium yellow to greenish yellow to deep yellow-orange, sometimes similar to the color of Thailand's *Mekong* whiskey • Golden-star black-star sapphires are found
Geologic formation	• Secondary deposits derived from weathered alkali basalts
Crystal habit	• Generally tabular irregular fragments. As a result, cut stones are usually flat.
RI & birefringence	n_ε = 1.764–1.770; n_ω = 1.772–1.778; Bire. = 0.008 RI increases with Fe content
SG	Not reported
Spectra	**Visible**: Strong Fe spectrum always present
Fluorescence	**UV**: Generally inert; some stones may show weak red under SW
Other features	—
Inclusion types	**Description**
Solids	• Non-exsolved solids are rare
Cavities (liquids/gases/solids)	• Generally rare; when seen they consist of secondary healed fractures
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; generally seen best parallel to the basal pinacoid; often consists of green bands
Twin development	• Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Rutile needles intersecting in 3 directions at 60/120° (parallel to the 2nd-order prism), in the basal plane • Brownish hematite needles & plates along the first-order hexagonal prism (shorter and more platy than rutile). These are often found concentrated in thin green zones just beneath the basal pinacoid faces (on cut stones often just under the table & culet). • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.25 is based on the author's own research.

Large stones (10 ct +) of fine quality are sometimes found, but at the time of the author's visit to the mines in July of 1988, little mining was taking place.

Pailin (Cambodia)

Varieties and occurrence. The famous Pailin mines in western Cambodia produce only ruby and blue sapphire, with other varieties almost nonexistent. Rubies from this district are identical internally to those found across the border in Thailand and so will not be discussed separately. It is the blue sapphires, however, for which Pailin is noted. Of a pure and intense blue color, in smaller sizes (>3.00 ct) they are considered among the world's finest.

Solids. Internally, Pailin sapphires resemble those from the Chanthaburi/Trat mines near I Rem. Distinctive are the red crystals of uranium pyrochlore (*a.k.a.* uranopyrochlore). When large, these octahedral crystals appear black, but smaller examples display a deep red or orange color. At times they are found concentrated in rows following the host's growth structure, but most appear as individuals, often ahead of comet-like trails of minute fluid droplets. Others may be surrounded by fingerprints containing a red- or orange-stained fluid, possibly due to heat treatment.

Other crystal guests are also found. Colorless or white prismatic or tabular, crystals of moderate relief are common. These may display striations across their faces and are often surrounded by circular glassy tension halos. Feldspar is a possible identity. Also seen are euhedral hexagonal prisms looking much like corundum itself, or possibly apatite.

Cavities. The fluid-filled fingerprints and feathers of Pailin sapphires are numerous and create delicate patterns of great beauty, somewhat akin to those of Thai and Cambodian rubies. They often exhibit detailed healing, with tiny hexagonal areas surrounded by residual fluid. So thin are these fluid tubes that a vivid iridescence is seen in reflected light, truly a splendid sight. Coarse negative crystals are also found, but whether they have resulted from actual growth or simply from the dissolution of a solid inclusion via heat treatment is not sure. As some display gas bubbles frozen in place, it would appear the latter is more likely, at least in some instances. Such inclusions could have a natural origin, due to the heat of the magma which brought the gems to the surface (John Koivula, pers. comm., March, 1995).

Growth zoning. Color zoning in Pailin sapphires is extremely sharp and follows the hexagonal contours of the crystal. At times, thin concentrations of minute exsolved

Table 12.26: Properties of Thai sapphire (Chanthaburi & Phrae, except yellow)[a]

Property	Description
Color range/phenomena	• Chanthaburi/Trat: Green to blue, generally dark and inky • Phrae: Green to deep blue, generally dark, but slightly violet • Black stars, 6 & 12 rays, are common. Other colors are less so. Golden-star black-star sapphires are found.
Geologic formation	• Secondary deposits derived from weathered alkali basalts
Crystal habit	• Hexagonal bipyramids, as spindles or modified by pinacoids (barrel shapes)
RI & birefringence	n_ϵ = 1.764–1.770; n_ω = 1.772–1.778; Bire. = 0.008 RI increases with Fe content
SG	Not reported; probably near 4.00
Spectra	Visible: Strong Fe spectrum always present
Fluorescence	Generally inert
Other features	• Basal parting is common when exsolved hematite is present
Inclusion types	**Description**
Solids	• Feldspar (plagioclase) (Gübelin, 1973) • Garnet, red to orange, surrounded by tension haloes (Gübelin & Koivula, 1986) • Niobite (columbite), black euhedral crystals (Gübelin, 1973) • uranopyrochlore?, red-orange octahedra
Cavities (liquids/gases/solids)	• Secondary healed fractures are common
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; this can take on a wide variety of forms, from extremely sharp bands to those which are diffuse and cloudy
Twin development	• Growth twins of unknown orientation • Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Rutile needles in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°). These planes lie in the basal plane. • Brownish hematite needles & plates along the first-order hexagonal prism (shorter and more platy than rutile). These are often found concentrated in thin green zones. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.26 is based largely on the author's own research.

particles or yellowish texture clouds are also distributed along these zones, similar to stones from Chanthaburi. Rarely, one encounters phantom growths formed by the deposition of a thin layer of a foreign substance upon earlier crystal faces. This produces a perfect outline of the crystal at a previous stage in its development. In Pailin stones, these are often of stunning beauty.

Twin development. Rhombohedral twinning is common.

Exsolved solids. While rutile silk has been seen in Pailin sapphires, it is generally not well-developed. Instead, most silk clouds consist of tiny particles rather than well-developed needles. Thus star sapphires are not of high quality. White boehmite needles, however, are often seen, lying at the junctions of rhombohedral twinning planes.

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Table 12.27: Properties of Pailin (Cambodia) sapphire[a]

Property	Description
Color range/phenomena	• Blue: light to deep blue, often a rich blue, but without the strong inkiness common to most other basalt-derived, Fe-rich, sapphires • Red: see Thai/Cambodian ruby • Stars are known, but not common (except black stars)
Geologic formation	• Secondary eluvial and alluvial deposits derived from weathered alkali basalts
Crystal habit	• Rounded, angular to subangular outline. Many crystals display glossy surfaces, particularly those recovered from near volcanic vents. This is due to partial dissolution by the carrier magma and is common in sapphires of volcanic origin.
RI & birefringence	n_ε = 1.760–1.762; n_ω = 1.768–1.770; Bire. = 0.008
SG	3.993 to 4.007
Spectra	**Visible**: Moderate to strong Fe spectrum
Fluorescence	**UV**: Inert (both LW & SW)
Other features	Virtually all Pailin sapphires are heat treated
Inclusion types	**Description**
Solids	• Feldspar (plagioclase), colorless grains (Gübelin, 1973) • Thorite (Gübelin, 1973) • uranopyrochlore, distinctive octahedral red crystals (Gübelin, 1973) • Unidentified euhedral crystals resembling quartz or apatite (RWH)
Cavities (liquids/gases/solids)	• Secondary healed fractures are common; these often surround solid inclusions
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; beautiful phantom growth patterns are also seen
Twin development	• Polysynthetic glide twinning on the rhombohedron
Exsolved solids	• Rutile silk in thin planes, parallel to the second-order hexagonal prism (3 directions at 60/120°). These planes lie in the basal plane. The rutile often consists of dense clouds of tiny particles, rather than needles. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.27 is based on the author's research, along with published reports of Gübelin (1973) and Gübelin & Koivula (1986).

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Turkey

While Turkey has never been a source of gem corundum, since the 19th century it has been an important source of emery. Turkish emery is obtained chiefly from the province of Aidin. As of 1915, the major source was from the slopes of the Gumuch Dagh, 19 km southeast of the ruins of Ephesus (Ayasaluk), and farther from Ak Sivri (161 km southeast of Smyrna). Emery has also been found at Kulah on the river Hermes, not far from the ancient city of Philadelphia; near Adula, west of Kulah; at Manser, north of Smyrna; in the vicinity of Smyrna, at Baltizik, Azizich, Cosbunar and Kulluk (Barlow, 1915).

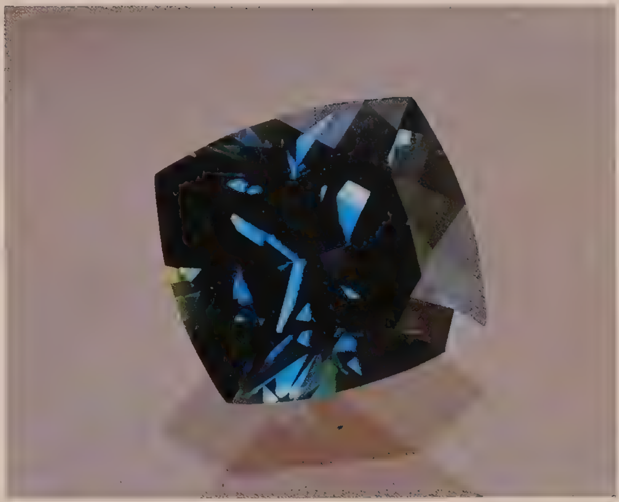

Figure 12.145 The United Kingdom's finest sapphires are found near Loch Roag on the Isle of Lewis. This 9.6-ct Loch Roag blue sapphire is believed to be one of the largest ever from the UK. (Photo: Alan Hodgkinson/Ian Combe)

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United Kingdom (UK) & Ireland

Low-grade corundum has been found in a number of different locations in the British Isles. In England, it occurs at Dartmoor (Devonshire), as rolled fragments in the Avon river, at Beaumont (Essex) and at Carrock Fells (Beaumont), while in Ireland it has been found in Wicklow county (Barlow, 1915).

More important are the sapphire deposits of Scotland. Low-grade material comes from many places, including Aberdeen, Banff and Forfar (Barlow, 1915), but better material comes from Loch Roag on the Isle of Lewis in the Outer Hebrides (Jackson, 1984). At this locality, blue sapphire of facet quality has been found in a monchiquite of lamprophyric affinities.

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United States of America (USA)

While it is unknown if the American Indians made use of corundum, the first documented mention of this mineral in the United States dates to 1819, when John Dickson, a teacher at Columbia, SC, and former student of famous American mineralogist, Benjamin Silliman, sent him a lot of specimens he had collected in the Carolinas. Among these specimens was a perfect hexagonal crystal of blue sapphire (Pratt, 1906). Deposits were later found throughout the stretch of country from North Carolina, South Carolina, Georgia and Alabama.

Localities of gem corundum exist in the states of Idaho, Montana and North Carolina. Following these sections, a summary of gem corundum occurrences in other states is given.

Idaho

Corundum has been found at a number of different sites in Idaho, but nothing of commercial importance has appeared. Low-grade corundum has been found in many of the gravel deposits in the vicinity of Pierce, Shoshone County, Idaho. Pratt (1906) stated that they were discovered by Victor C. Heikes, in connection with black-sand investigations at Portland, OR, but did not specify a date.

Sinkankas (1959, 1976) reported occurrences in gold placers near Resort, Idaho County. In Adams County, placers at Rock Flat, five miles (8 km) northwest of McCall, near the towns of Meadows and New Meadows, have produced small quantities of gray, violet and blue sapphire, and even some ruby. Star corundums were also found. A basalt dike cutting gneiss is said to be the source rock.

Similar corundums have been found in the Burgdorf area 22 miles (35 km) by road north-northeast of McCall. Sapphires have also been found in gravels of the Ruby Meadows area three miles (4.8 km) southeast of Burgdorf. Blue and pink crystals are said to have been found near a thulite (zoisite) deposit on Tunk Creek, Okanogan County.

Themelis (1992) reported that sapphires have been found at Flatwood Drainage (elev. 2100 m; 6900 ft), east of the town of Clarkia, Clearwater County. While white to light blue, *geuda*-like, material from this deposit has been heat treated, little of commercial interest has appeared to date.

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Montana

> Two roads run between Helena and Great Falls, Montana. One, a finishing-school clean four-lane blacktop, traces the west bank of the Missouri River. It'll have you in Great Falls within 90 minutes, via Texaco and Emily Post. The other cuts through the gulches. Little separates the two. Just a few miles, about a hundred years, and the things people dig out of the ground.
>
> Like moths to a flame, the blaze of gold and silver first lured the white man to Montana. And it continues to do so. Heading into the gulches through Diamond City takes you through the very heart of the American West. Once a thriving metropolis of thousands, with churches outnumbered only by saloons, today nothing but tailings and a few parched timbers remain. But on a lonely night, if you listen hard enough, you can still hear the tinkling of a honky-tonk piano. A dealer lays out a straight flush, the bell rings and another round of whisky is bought for the house. Hear that? The Chinaman just made a new find in Confederate Gulch. Nuggets are on the bar, they're falling out the windows—and even the one-eyed jacks are dancing on the tables. Whores are arm-in-arm with preachers and, suddenly, Jesus is nowhere to be found.
>
> The boom days are long gone, but hope still springs eternal. Prospectors continue to be drawn to Montana. The gulches still hold a few panners, still there, still digging. But they find more than just gold and silver. They also find blue pebbles—sapphires. A cold wind blows, but they still dream. Ride through the gulches at dusk and you come across them, ear cocked to the ground. They are listening, listening hard… they hear the tinkling of a honky-tonk piano… and Jesus is nowhere to be found.
>
> Anonymous

Of all American corundum localities, Montana reigns supreme. While rubies are only rarely found, facet-quality sapphires are mined at a number of different locations. Fine blue gems have been mined in central Montana, at Yogo Gulch, but cut gems over one carat are rare. In terms of color, Yogo stones can compete with some of the best of Asian sapphires, but their small size has kept them from succeeding in world markets.

Further west, fancy sapphires are found associated with the placers of the Missouri River, and at Dry Cottonwood and Rock Creeks. These deposits produce larger material, but the colors tend to be pale. In the past, these saw mostly industrial usage, but with successful development of heat-treatment technology, the 1990s have seen renewed interest in Montana sapphires.[1]

Yogo Gulch

It is the blue sapphires of Yogo which are Montana's major boast, and so it is to this site that we will turn first in our

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1. Montana Sapphire™ is a registered US trademark owned by Tom Lee.

Figure 12.146 Sapphires are Montana's greatest boast, and this collection shows some of the various colors that the state's mines produce. Unfortunately, such colors and qualities are all too rare, even with modern heat-treatment methods. (Photo: © 1994 Tino Hammid; specimens: American Gem Corp.)

exploration of the Montana sapphire deposits. Yogo Gulch is situated in Judith Basin County, central Montana, with the nearest town being Utica, 11 miles (18 km) to the northeast. Sapphires were first discovered at Yogo in 1894 (Voynick, 1985). It was not the blue of sapphire which first brought miners to the area, though, but a mineral of a different color—gold. Yogo City was founded in 1878 and the population quickly grew to over 1,000. But the boom was short-lived. The gold was soon gone, and with it, the townsfolk. By 1881, Yogo had become a virtual ghost town, peopled with only a few hardy souls who refused to give up the search. Notable among these was Minnie Ringgold, an emancipated slave with a double row of front teeth, who ran the local saloon and hotel (Voynick, 1985).

Another who remained was Jake Hoover. A sometime prospector, Jake was a hard-drinking, womanizing raconteur in the best tradition of the old American West. Hoover's main claim to fame was his crackerjack hunting skills. None was more skilled with a Winchester; twice he took out four bears at a single sitting (Voynick, 1985). But today Hoover is remembered not for his prowess with rifle and hunting knife, but something quite different. In the fall of 1894, Jake Hoover found himself prospecting a section of Lower Yogo Creek and, in the process, stumbled across the azure pebbles of Yogo.

Although it is likely that the sapphires of Yogo were found by prospectors some 15 years earlier, Hoover was the first to recognize their true nature. Prospectors along Yogo Creek

Timeline of sapphire at Yogo Gulch[a]

English Mine

- 1894 Autumn: Gold prospector, Jake Hoover, discovers sapphires while washing for gold along lower Yogo Creek, near the almost-abandoned town of Yogo City.
- 1895 Summer: Hoover collects a cigar box of blue pebbles along Yogo Creek. He and his partners send the box off to G.F. Kunz, noted gemologist at Tiffany's, New York. A check for $3,750 is returned, along with a letter declaring the stones "sapphires of unusual quality."
- 1896 February: Jim Ettien is herding sheep just east of Yogo Gulch when he notices gopher heaps all in a line, stretching for over a mile. Suspecting the soft earth where the gophers had tunnelled to be a mineral-bearing vein, he washes some of the earth, turning up blue sapphires. Ettien then files two lode claims on his vein, soon to become known as the Yogo Dike. Hoover and his partners later purchase Ettien's claim for $2,450 (Brown, 1982).
- 1897 Hoover and others form the New Mine Sapphire Syndicate to mine at Yogo. Hoover sells his interest for $5,000. That same interest is sold in August to the London jewelry firm of Johnson, Walker and Tolhurst for $100,000. The British company acquires all shares by 1901.
- 1898–1922 The English Mine, as it is now called, produces steadily. Charles Gadsden arrives from England in 1902 to take charge of the mine. The English mine is generally profitable, but with post-war demand lagging, is put up for sale in 1922 for $150,000.
- 1923 July 26: Severe rain damages much of the mine workings.
- 1929–1954 Charles Gadsden devotes the remainder of his life to the Yogo mine, dying in nearby Lewistown in 1954.
- 1955–1965 With Gadsden gone, the deposit languishes. Rock hounds freely roam the property, keeping what they find.
- 1965 Siskon Inc. purchases the Yogo property for $75,000. They lease it to Arnold Baron, who briefly works the mines.
- 1968–1973 August: Siskon sells the property to a group of California investors, including Herman Yaras and Chikara Kunisaki. They embark on a grand plan to sell real estate to rock hounds ('Sapphire Village').
- 1973–76 Kunisaki buys out the interests of the other partners. The *Kunisaki Tunnel*, a 3,000-ft (914 m) long hole is driven into the dike at the old American Mine site, but his company, Sapphire International Corp., fails in the fall of 1976.
- 1978–79 Victor di Suvero, leases the Yogo property, but fails, relinquishing the lease in late 1979.
- 1980 April: Intergem leases the property for $6 million from Roncor, Kunisaki's company (Voynick, 1993).
- 1981–86 Intergem develops and carries out a vertically-integrated plan which includes mining, cutting, jewelry manufacturing and marketing. In 1986, due to a banking crisis, Citibank abruptly pulls out their financing, causing the company's failure.
- 1987–1992 Roncor conducts limited mining (Voynick, 1993).
- 1993 April: AMAX takes a two-year lease on the main section of the dike (Voynick, 1993).
- 1995 AMAX surrenders their lease.

American Mine

- 1896 July 4: John Burke and Patrick Sweeney file six lode claims in Yogo Gulch and Kelly Coulee, west of the English Mine, naming their property the "Fourth of July" claim.
- 1901–4 A New York company, American Gem Syndicate, leases the Burke and Sweeney claims. Unable to raise capital, the claim reverts back to Burke and Sweeney, who exploit the deposit themselves. Their operation becomes known as the American Mine, to distinguish it from the English Mine. In 1904, Burke and Sweeney sell out to the American Sapphire Co., for $100,000.
- 1913–14 Fall: The struggling American Mine is put up for sale.
- 1914 Spring: Owners of the English Mine purchase the property for ~$80,000, giving them control of the entire dike's length.

Vortex Extension

- 1984 A group of local prospectors stumbles across a long-abandoned western extension of the Yogo dike. Claims are filed.
- 1984–1994 Vortex Mining is formed and the group steadily mines their claims, sinking a shaft to the 200-ft (61 m) level by 1994.

a. Based on Voynick, 1985, except where otherwise noted)

found little gold, but noted small blue wafers clogging the riffles of their sluices. These were discarded. Initially, Hoover, too, simply dropped them back into the creek. Only after the gold was played out did he begin to collect the little blue pebbles, no doubt aware that sapphire had been found in Montana along the Missouri River. Eventually a cigar-box of them was sent off to New York, to Tiffany & Co, where the noted gem expert, George Frederick Kunz, immediately recognized them for what they were—fine blue sapphires. The cigar box of sapphires never returned. In its place came a check for $3,750, along with a letter stating that the stones were "sapphires of unusual quality" (Voynick, 1985). Unlike the off-color stones already being mined along the Missouri River, these were of a rich blue color, making the discovery at Yogo the most important occurrence of gemstones in the United States. Kunz, in his reminiscences of 1927–28, stated that the mine produced more gem wealth "than all the other sapphire mines in America put together."

At the little town of Yogo, the rush was on. Arrival of the Tiffany check brought attention to bear on sapphires rather than gold. Initially, sapphires were found in placer deposits only below the point where the dike cut across the creek. However, in 1896, the actual primary dike rock was uncovered by sheep rancher, Jim Ettien, who noticed a strange coincidence—gopher holes arranged in a perfect line.

The British are coming, the British are coming

In 1896, Hoover and his backers formed the New Mine Sapphire Syndicate, eventually buying out Ettien's claims. Although the mining, which made use of high pressure water jets and wooden sluices, was successful, marketing the rough

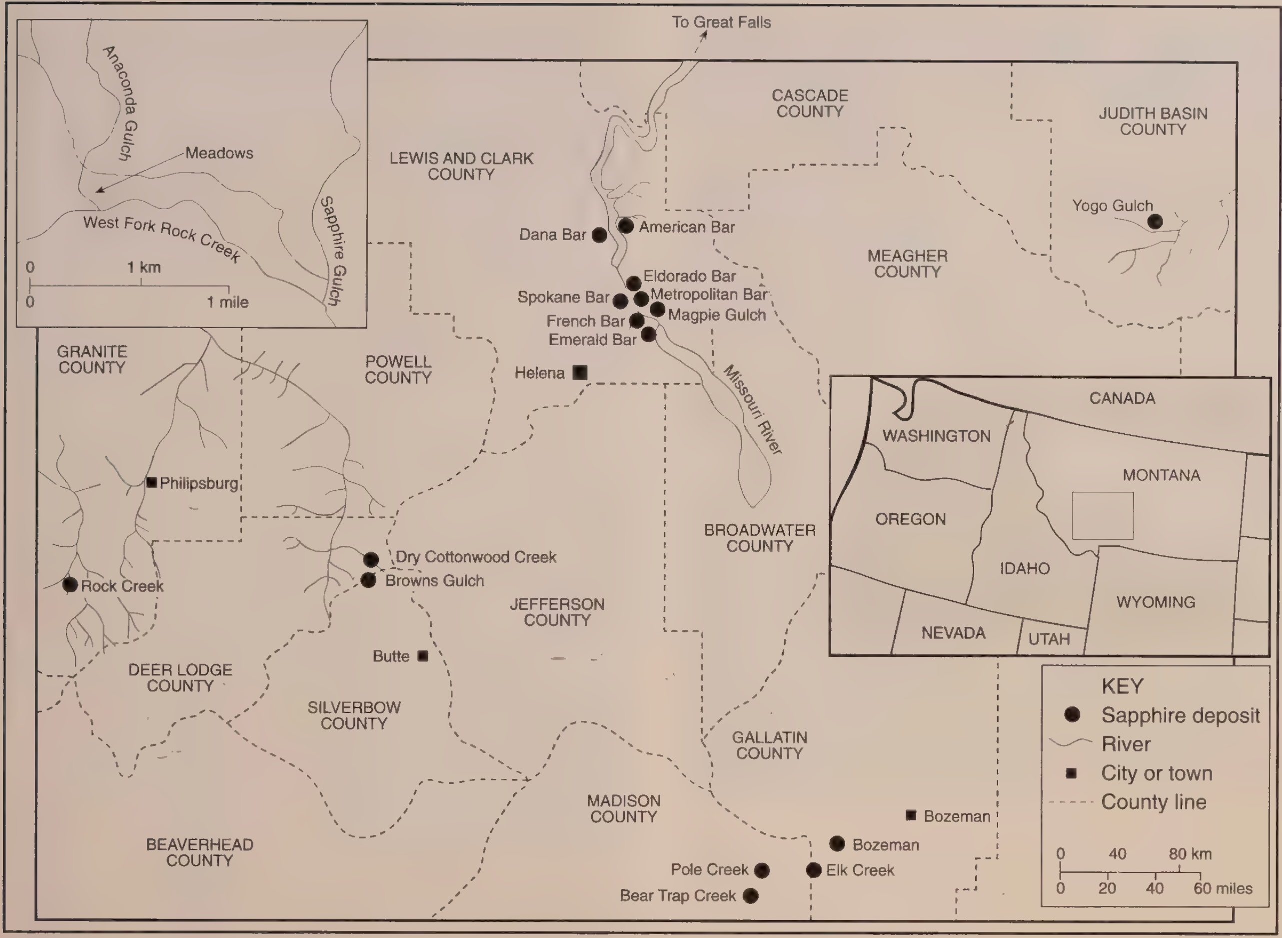

Figure 12.147 The corundum deposits of Montana
Major mines are located at Yogo Gulch, along the Missouri River, at Rock Creek and at Dry Cottonwood Creek. (Modified from Clabaugh, 1952 and Emmett & Douthit, 1993)

stones was not. This difficulty caused the Syndicate to approach a respected London jewelry firm, Johnson, Walker & Tolhurst.

Johnson, Walker & Tolhurst was already involved in mining sapphires in Sri Lanka and Burma and envisioned setting up a De Beers-style sapphire monopoly. The offer to become sole agents for the sale of Yogo sapphires was thus readily accepted. Thus began the most profitable period for the Yogo sapphire mine.

In 1902, the company dispatched an Englishman, Charles Gadsden, to oversee operations. His wife, Maude, joined him in 1903, beginning a relationship with the Yogo mine which was to be severed only by his death in 1954. By 1902, the British firm had acquired full ownership of the mine and Gadsden was given complete authority. Yearly production soon topped one million carats and the ten percent which was of gem quality accounted for seventy-five percent of the $100,000 annual income (Voynick, 1985). Gadsden wrote a report in 1948, stating that the average production was 22 ct per ton of processed dike rock (Marc Bielenberg, pers. comm., Nov. 1994).

Initial mining at Yogo consisted entirely of working the accumulated placer deposits, as well as surface workings on the dike itself. Gadsden, however, soon undertook underground mining. Hardrock miners recruited from nearby Butte brought the dike rock to the surface, where nature lent a hand. Although hard at first, after a year's exposure to surface weathering, the dike rock softened and was ready for washing.[2] Sluices were then used to separate the sapphires. As efficient recovery was vital, Gadsden decreed the tailings be rewashed a second and even third time. This paid off when, in 1910, the largest Yogo sapphire ever found, a crystal of nineteen carats, was discovered.

2. While most of the dike rock crumbles upon exposure to weathering, a certain percentage does not. Unusually, the dike rock that resists weathering apparently contains a higher than average yield of sapphires (Delmer Brown, pers. comm., Dec., 1994).

Figure 12.148 Excavations in the sapphire-bearing dike at Yogo Gulch, Montana. (From Claremont, 1906)

Figure 12.149 G.F. Kunz, of New York's famous Tiffany firm, was sent a cigar-box full of Yogo sapphires by Jake Hoover in 1895. Thus began the story of the most important sapphire deposit in North America. The Tiffany brooch above, ca. 1900, contains numerous Montana sapphires (probably most are from Yogo).
(Photo: © 1986 Tino Hammid; brooch: Ralph Esmarian, New York)

The British company was not alone at Yogo. While they worked the dike's eastern end (known as the 'English Mine'), starting in 1896 the steep western end was also worked by various American groups. As a result, this became known as the 'American Mine.' Although much money was spent developing the American Mine, including underground workings and a modern processing plant, the lack of effective marketing doomed it to failure. Eventually, in 1914, the American Mine was bought by the British, giving them control of the entire dike. It never reopened, but the $80,000 purchase price was soon recovered by the shrewd Charles Gadsden, via reworking the old tailings (Voynick, 1985).

During World War I, production dropped, but soon returned to high levels. 1921 was a record year for the English mine, with 300,000 carats of gem sapphire being mined. But this was to be its last gasp. In 1923, a severe cloudburst flooded the underground workings and destroyed the surface facilities. The English mine never recovered, and in 1929 was closed permanently. In thirty-nine years, the deposit had produced 2.5 million carats of gem sapphire said to be worth as much as $25 million (Voynick, 1985). After the closure of the English mine there followed a long period of inactivity where the only mining taking place was that of local residents and rock hounds working illegally with simple tools. The world, it seemed, had forgotten Yogo.

But gems were still there to be had. In 1933, a news item in a local paper told of an odd discovery—a double handful of blue sapphires were found in the gizzard of a turkey purchased at a market in Judith Basin County (Blodgett, 1981).[3]

Commercial mining resumed in 1958, but quickly failed and did not begin again until 1965. 1965–1979 saw no less than six separate mining ventures, each ending in failure (see timeline for details). (Voynick, 1985)

[3] No doubt this story is an exaggeration, but nevertheless a great tale.

Figure 12.150
Left: Maude and Charles Gadsden in the front yard of their home at Yogo Gulch, Montana, ca. 1914. (Photo by D.B. Sterrett, USGS)
Right: Washing for sapphires at the New Mine, Yogo Gulch, Montana. (From Claremont, 1906)

Sapphire Village: Rock-hound heaven?

BY far the most unusual idea in the history of Yogo-sapphire mining was Sapphire Village, the brainchild of Herman Yaras of Oxnard, CA. In 1969 he decided to sell small plots of land adjoining the dike to holidaymakers who would be able to mine sapphires during their leisure hours (Yaras, 1969; Voynick, 1985). It was something like a rock-hound version of Club Med. Located at the east end of the dike, properties were sold with the rights, in perpetuity, to dig sapphires along a one-mile (1.6 km), "virgin" stretch of the Yogo dike, but mining was limited to 100 lbs (45 kg) of ore daily. While Yaras' firm soon went the way of so many other Montana sapphire-mining companies, its legacy remains. A small group of trailers are still to be found at the Sapphire Village, their occupants happily whiling away their time washing the ore and faceting their finds. But all is not peaches and cream in rock-hound heaven. Low yields have led some Sapphire Villagers to suggest that the one-mile stretch of 'virgin' dike may have been deflowered by an earlier suitor.

Enter Intergem

In 1980, Harry C. Bulloch, a mining engineer, formed American Yogo Sapphire, Ltd. (later Intergem, Ltd.) with the idea of reviving the Yogo mine. The lack of adequate operating capital had killed many earlier ventures at Yogo, but Intergem was well-financed, having raised $7.2 million. Finally it seemed that the Yogo sapphire might again grace the necks and fingers of the world's upper crust.

Delmer Brown, a geological engineer, was brought in to study the deposit. Those studies indicated that the sapphire-bearing dike extended deep into the earth's crust, making Yogo the largest proven sapphire deposit in the world. Unfortunately, the yield was not uniform throughout the dike. Brown found that ore richness varied anywhere from five to fifty carats per ton. Interestingly enough, the lower grade ore generally contained bigger stones, making it more profitable to mine. Some areas of the dike were almost entirely barren of ore (Voynick, 1985).

In addition, it was theorized that average stone size would increase with depth. Corundum's higher density relative to the carrier magma would mean that only the smaller, flatter stones would have sufficient buoyancy to reach the dike's surface. Larger and more rounded stones might be found deeper within the dike. The question, of course, was how much deeper? It has yet to be answered.

From these studies, Bulloch and Brown formulated a plan to begin working the dike surface and eventually to extend mining underground. But as work proceeded, Intergem realized it would take more than just getting sapphires out of the ground to make the Yogo mine a paying proposition. Vertical integration provided the answer. Rather than simply selling the rough material to dealers and cutters, as is done at most gem mines, Intergem planned to integrate the mining with cutting, and finally, jewelry manufacture. This would allow Intergem to take a percentage of the markup for each stage, from the processing of raw materials, through cutting, to the finished jewelry (Delmer Brown, pers. comm., 1994).

A novel approach to marketing the finished product was also developed, with large magazine advertisements billing the Yogo gem as the world's only guaranteed unheated sapphire. Only with Yogo sapphires could this claim be made, as the entire mine production was controlled by Intergem. In contrast to sapphires from other localities, Yogo stones needed no treatment, for they came straight from the ground in a fine blue color and of high clarity.

Azure dreams—The Vortex saga

All great discoveries are made by men whose feelings run ahead of their thinking.

Charles H. Parkhurst

WHILE Intergem was busy mining and marketing, a group of local prospectors from nearby Utica, MT were poking around the fringes of the Yogo dike. Charles ('Chuck') and Marie Ridgeway and their friends, Lanny and Joy Perry, were area residents who had done some gold mining in the mountains surrounding Yogo. Knowing of the existence of the sapphires, they had the idea that the dike might outcrop beyond the claims of Intergem. Thus, after some study of maps, they made plans to visit an area along the cliffs of Kelly Coulee, just across the gulch from the American Mine.

The night before their planned excursion, Chuck Ridgeway dreamt of a ledge, high on a cliff, covered with sapphires. Upon awakening, he excitedly told his partners, but rather than generating enthusiasm, his story elicited only disbelief and derision. Fixing them with the cold glare of a man scorned by his friends, Chuck stated he would go to Kelly Coulee alone, declaring: "Although you were all in my dream, I don't need you." Guiltily, the others joined him.

Arriving at Kelly Coulee, the dreamscape unfolded. As they made their way across the heavily-forested ridge, a cliff appeared. Just below lay a small ledge. From above, Lanny Perry lowered himself onto the ledge, but rather than sapphires, found only a one-hundred foot drop to the floor of Yogo Gulch. His friend trapped, Chuck Ridgeway, scrambled down to help, but slipped, nearly falling in the process. Looking down, he saw a sight that will be forever etched in his memory—the slip had uncovered a small section of dike rock. Each member of the party greedily scooped the weathered ore into their packs. At the Perry's cabin that evening, dirt was screened and washed by the weak glow of a kerosene lantern. When all was said and done, a single blue pebble winked up at them from the bottom of the screen—signaling that they had just found a new offshoot of the Yogo dike.

The Ridgeways and Perrys filed claims on 300 acres of property and formed Vortex Mining to exploit the deposit. In the beginning, small placers were worked above the cliff. Later, a shaft was sunk. Keith Mychaluk (1992) from the University of Calgary has written a thesis on the Vortex section of the dike. According to his thesis, it differs somewhat from the main dike, with its origin as a diatreme (blow-out pipe). (Mychaluk, 1992)

At the time of the author's visit in June, 1994, the shaft had reached the 200-foot level and Vortex was finding that, in some cases, dreams do come true.

Figure 12.151 200-feet down in the Vortex shaft at Yogo, mine co-owner Lanny Perry (left) and visiting geologist Richard Allen examine sapphire-bearing dike rock. (Photo by the author, June, 1994)

Figure 12.152 Mining for sapphires at Yogo Gulch, Montana, around the turn of the century. (From Claremont, 1906)

Unfortunately, Intergem's advertising won it few friends in the gem trade. With stocks full of treated gems, jewelers and dealers did not need anyone telling the public the truth about the frequency of gem treatments. As a result, Intergem's sales were not as strong as expected, creating cash shortages. In the mid-1980s, a banking crisis occurred, and Intergem's financing was pulled out by Citibank.[4] This brought the downfall of Intergem and an end to the experiment. In 1986, the mines at Yogo again closed, with underground mining having barely begun. Another chapter in the Yogo sapphire saga came to a fitful close.

Other Montana corundum localities

In addition to the famous mine at Yogo Gulch, gem sapphires are also found at other localities in Montana. These include the gravel bars of the upper Missouri River (near Helena), at Dry Cottonwood Creek (north of Butte) and further west, along Rock Creek (near Phillipsburg). Most of these mines were traditionally worked for gold, with sapphires recovered as a byproduct. Amateur sapphire mining (fee digging) also takes place.

Gem corundum has also been found at Bear Trap Creek and Pole Creek (Madison County) and near Bozeman and at Elk Creek (Gallatin County). (Clabaugh, 1952)

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4. Citibank was paid back with a combination of Yogo rough, cut stones and jewelry. This stock had largely been liquidated by 1993 (Delmer Brown, pers. comm., 14 Sept., 1994).

Missouri River Sapphire

1865 Sapphire is first discovered in Montana by gold miner Ed R. Collins, while working on one of the gravel bars just above the Missouri River, near Helena (Kunz, 1894).

1869 A.C. Hamlin mentions sapphires and a ruby sent to him from Eldorado Bar (Hamlin, 1866–70).

1873 The first published record of Montana sapphires appears, describing rolled sapphire pebbles from gravel bars along the Missouri River (Smith, 1873).

1891–98 In London, the Sapphire and Ruby Company of Montana Ltd. is formed to exploit 8,000 acres of Missouri-River sapphire property. The company is surrounded by charges of fraud and is taken over in 1898 by the Eldorado Gold and Gem Co. of Montana Ltd. (P. Streeter, 1993).

1900–1960s Many of the original bars are partly or completely submerged in lakes (such as Lake Hauser) formed by the construction of dams along the river. Any mining that takes place is for gold, with sapphires recovered as a by-product only (Clabaugh, 1952).

1993 American Gem Corp. acquires mining and dredging rights for one portion of Eldorado Bar (Verbin, 1994).

1993–94 Tom Lee acquires mining rights near Hauser Dam (pers. comm., 10 Nov., 1994).

Missouri River deposits

Sapphires were first found in Montana in the gravel deposits along the Missouri River. The original discovery was made by a gold prospector, Ed R. Collins, in the year 1865, somewhere along the Missouri River. This did not create a great deal of excitement, however, as most stones were pale blue-green. Over the years a number of companies have tried their hands at mining along the Missouri river, but none have met with success. The main reason for mining is gold, with any sapphires found considered gravy.

The area where mining has taken place along the Missouri River includes (working upstream, north to south) American Bar, Dana Bar, Spokane Bar, Eldorado Bar, Metropolitan Bar, French Bar, Magpie Gulch, Cheyenne Bar, Emerald Bar, and. Sapphires have been found as far downstream (north) as Beartooth, but have not been found in quantity north of American Bar (Pratt, 1906). Ruby Bar, a locality mentioned by Kunz (1893) and Pratt (1906), was thought by Clabaugh (1952) to be the same as French Bar. About the turn of the century, many Chinese immigrants were working at French Bar; today the only reminder of this bygone era is the occasional Chinese coin unearthed in the diggings (Delmer Brown, pers. comm., Sept., 1994).

Missouri River sapphires are found in gravel deposits lying on terraces of argillite rock of the Pre-Cambrian Belt series. Locally termed *bars*, most actually lie as much as 200 ft (60 m) above the river (Clabaugh, 1952). In 1890, George Kunz described the Missouri River sapphires as follows:

Figure 12.153 Joy Perry cleans the jig for sapphires at the Vortex Mine, Yogo Gulch, Montana. (Photo by the author, June, 1994)

> The Montana specimens rarely exceed 0.25–0.50 inch in length. They are brilliant but usually of pale tints. The gems are usually of a light-green, greenish-blue, light-blue, bluish-red, light-red, and the intermediate shades. They are usually dichroitic, and often blue in one direction and red in another, or when viewed through the length of the crystal, and frequently all of the colors mentioned will assume a red or reddish tinge by artificial light. A fine piece of 9 carats was found of a rich steel blue. A very beautiful piece of jewelry, in the form of a crescent, was made of these stones by Tiffany and Co., in 1883; at one end the stones were red, shaded to bluish-red in the center, and blue at the other end; by artificial light the color of all turned red. Perfect gems of from 4 to 6 carats each are frequently met with. Occasionally crystals are found which would afford ruby and sapphire asterias [stars] of a poor quality.
>
> George F. Kunz, 1890 (as quoted by Clabaugh, 1952)

According to Clabaugh (1952) and Zeitner (1978), most stones are pale in color, with deeper hues being rare. Pale blue-green, blue and green are most common; pale purplish-blue sapphires are not all that rare; very attractive amethyst and green stones have been cut from the darker pieces. Deep blue, pink, reddish purple, yellow and orange gems are rare. Color-changing gems have also been found on occasion. The biggest gem reported from the Missouri River deposits was an 18-ct cut stone (Marc Bielenberg, pers. comm., May 30, 1994). A 24-ct blue rough found in 1973 was later cut into a 12.54-ct faceted stone called the *Big Sky sapphire* (Liddicoat, 1975; Zeitner, 1978), while, in 1939, a piece of rough found on the dredge resulted in a 12.86 ct cut stone (Marc Bielenberg, pers. comm., Nov., 1994).

The sapphire crystals from the Missouri River commonly exhibit a faint zonal distribution of color with the lightest zone in the center along the *c* axis. Some have more brightly colored central spots and others show distinct bands of color.

Figure 12.154 A selection of Montana sapphires (probably mostly Missouri River). (From Streeter, 1892)

Many exhibit a silky sheen, due to exsolved mineral particles, and star stones have been cut (Zeitner, 1978).

In terms of crystal habit, most are slightly rounded and worn, but crystal faces can be recognized. The crystals generally show development of the basal pinacoid, hexagonal prism, bipyramid and rhombohedron faces. Some are of the thin wafer shape so common at Yogo Gulch, but others are barrel shapes or hexagonal prisms, which are better for cutting.

During 1988, the author was shown several parcels of blue sapphires obtained from the Missouri River. The stones originated from a gold mine located on a ranch opposite the Eldorado Bar on the Missouri River, with the sapphires being a byproduct of gold mining. As mined, their colors were said to be transparent light blues and greens, with no cloudiness or silk present. But after heat treatment and cutting, the color had metamorphosed to a more rich, intense blue. The best piece was priced at $400/ct (wholesale price in Bangkok). Most of the material cuts stones of less than one carat. However, material which cuts good stones of up to five carats has been found. Proper heating yields stones of definite commercial value.

Rock Creek

Sapphires of various colors are also found in the Rock Creek area, which, in terms of concentration and size, is the state's richest deposit. Located 16 miles (26 km) southwest of the town of Phillipsburg, in Granite County, mining is centered chiefly along two tributary gulches of the west fork of Rock Creek, Anaconda Gulch and Sapphire Gulch (formerly Myers Gulch). Farther north, some mining has also been conducted along Quartz Gulch and Cornish Gulch.

Figure 12.155 Rough sapphires from Spokane Bar, along the Missouri River, with the gem-bearing gravel beneath the plate. The colors shown in the photo are typical for most Missouri River production, which is why the deposits are generally worked on a fee-digging (tourist) basis. Commercial operations are mainly for gold, with any sapphires found considered "gravy."
(Photo by the author, Sept., 1994)

Figure 12.156 Ted Smith stands in front of his Gem Mountain property at Rock Creek, Montana. This site was later sold to American Gem.
(Photo by the author, June, 1994)

According to Kunz (1893):

> During the past year sapphires have also been found in Granite County, 30 miles west of Phillipsburg, on the west fork of Rock Creek. The sapphires are steely blue, green, yellow, and a few pink or reddish stones. From 10 to 20 stones are found in every pan of gravel.
>
> George F. Kunz, 1893
> *Mineral Resources of the United States, 1892*

Montana mining madness

IN 1890, at the invitation of Montana miners, F.D. and A.N. Spratt, London jewelers E.W. Streeter[1] and Horatio Stewart traveled to that state to quietly inspect the Missouri River deposits (Voynick, 1985). Upon their return to London, the Sapphire and Ruby Company of Montana Ltd was formed to exploit 8,000 acres of Missouri-River sapphire property. Founded in September of 1891, the high-powered list of subscribers included assorted dukes, earls, barons and knights, designed to induce investors to purchase stock. Streeter was the company's gem consultant. Unfortunately, charges of fraud quickly arose, when it was found that the blue-bloods had not paid up their subscriptions, being shareholders on paper only. According to the *Engineering and Mining Journal* (Sept. 9, 1893), "...Mr. Streeter was misled in his examination by the promoters, by resort to a method not unknown in mining circles." Just what was that method? Salting. The rubies and sapphires Streeter was shown on his visit actually originated in the Orient (Voynick, 1985a).

Mining did take place, but due to the poor color of the stones recovered, it was not a success. In 1898, the company was saved from ignominy by being taken over by the Eldorado Gold and Gem Co. of Montana Ltd. (P. Streeter, 1993). This was but the first chapter in what was to become a Montana tradition, where the only money made is in selling the property to new investors, those blinded by the word "sapphire."

[1] Of Burma Ruby Mines, Ltd. fame

The sapphires were reportedly found in a gravel bed 4 ft (1.2 m) thick, overlain by 3 ft (0.9 m) of loam. At first, they were extremely plentiful, with as many as 60 pieces found in every pan of gravel (Kunz, 1894). Like the Missouri River deposits, various companies were floated to work the claims. The period of 1906–43 saw continuous mining, with most stones destined for industrial use due to their poor color. During this period, approximately 38 tons of sapphire were recovered from Anaconda and Sapphire Gulches alone. However, widespread adoption of synthetic sapphire for industrial use ended mining at Rock Creek. Today small-

Figure 12.157 Paydirt. Rough sapphires from the Vortex Mine, Yogo Gulch, Montana, complete with adhering matrix on some pieces. (Photo by the author, June, 1994)

scale commercial mining is proceeding, as well as fee-basis amateur diggings. Most Rock Creek sapphires are now heat treated to improve color and clarity.

Rock Creek produces sapphires similar to those found along the Missouri River, except that a somewhat wider range of colors is common, with some stones of deeper hues obtained. During the years 1899–1901, it was reported that about six percent of the sapphires mined were suitable for cutting, but Clabaugh (1952) doubted that such a large percentage was so classified in later years. Overall, the yield from Rock Creek is among the highest in Montana. Now if only someone could fix the color…

Rock Creek stones are generally pale; some are dull and translucent, and many show irregular or zonal distribution of color, with a brightly colored spot near their center. Particolor sapphires are sometimes found and are locally termed *pinto* sapphires. The most common colors are pale blue, blue-green, green, pink and yellow. Blue or blue-green sapphires with a central orange or yellow spot are also seen. In many ways, the large assortment of odd colors at Rock Creek brings to mind the fancy sapphires of Umba Valley, but Rock Creek stones generally show less color intensity.

According to Clabaugh (1952), Rock Creek sapphires are similar in size and shape to those from the Missouri River. Some crystals are sharp and distinct, with pitted surfaces, while others are abraded and rounded. Most are hexagonal plates, many are roughly equidimensional, and a few are prismatic, with greater length than width. Crystal forms include the basal pinacoid, rhombohedron, hexagonal prism, and hexagonal bipyramid.

Rock Creek

ca. 1892	Sapphires are found at Rock Creek, near Phillipsburg (Kunz, 1893).
1899–1900	Two seasons of hydraulicking yield half a million carats, 25,000 of which are gem quality (Voynick, 1985).
1905–1936	American Gem Mining Syndicate of St Louis mines the deposit. Their claims cover the three main areas, including Anaconda, Maley and Sapphire Gulches and the meadows area along the west fork of Rock Creek. Most stones are used for watch bearings (Voynick, 1985).
1964	Marc Bielenberg acquires property at Rock Creek.
1979	Winter: Chaussee's Sapphire mine is sold, and renamed Gem Mountain (Maggart, 1981).
?	Skalkaho Grazing Inc. acquires the "meadows" section of Rock Creek.
1993	American Gem Corp. takes an option on the upper part of Gem Mountain (Verbin, 1994).
1993–94	Tom Lee acquires mining rights at Rock Creek (pers. comm., 10 Nov., 1994).

Dry Cottonwood Creek

According to Kunz (1904), sapphires were first found at Dry Cottonwood Creek about 1889. The mine is located on the South Fork of Dry Cottonwood Creek, in Deer Lodge County, some 13 air miles (21 km) northwest of Butte. It is accessed south from Deer Lodge, 14 km via Highway 90 to the Galen exit, then east on County 273 to US Forest Service Road (USFSR) 85, then about 10 km to USFSR 8634. After about 0.4 km, one reaches USFSR 608, which follows the South Fork of Dry Cottonwood Creek up to the site (American Gem Corp., 1994).

About 1893, some 25 lbs (11 kg) of sapphires were recovered during a season's work. Between 1902 and 1911 the

Marc Bielenberg: Mr. Montana sapphire

ANY history of sapphire in Montana would be woefully incomplete without mention of Marc Bielenberg. Although personally involved with mining at Rock Creek and Dry Cottonwood Creek, the breadth of his work stretches far beyond those bounds. Indeed, the history of Montana itself is inextricably intertwined with the Bielenbergs, one of the state's true 'pioneer' families. They were deeply involved in Montana's early development as an important mining territory, but also played a role in agriculture and ranching. The legendary Grant-Kohrs Ranch near Deer Lodge, now a US national historic site, was developed by Con Kohrs & the Bielenberg family.

For more than half a century, Bielenberg—as miner, prospector, gemological researcher, archivist, historian and teacher—has worked tirelessly to educate the world about Montana's unique deposits, the quality of the stones, and the lore and legends surrounding their early discovery and mining. It is not an exaggeration to say that every mining company and individual involved with Montana's sapphires today owes Marc Bielenberg a professional debt of gratitude and appreciation.

Tom Lee, Gem River Corporation

Figure 12.158 Marc Bielenberg at Dry Cottonwood Creek. American Gem's property is up the valley at right, while that in the background is owned by Gem River. (Photo by the author, May, 1994)

deposit was worked sporadically, for both gold and sapphire, and again between 1914–16. A temporary revival in interest occurred during 1942–43, due to the war demand for industrial sapphire, but nothing came of it (Clabaugh, 1952; American Gem Corp., 1994).

Color percentages at Dry Cottonwood Creek average as follows: green (60.3), yellow (17.8), blue (11.1), white (5.7), red & pink (3.1), orange (1.1) and lavender (0.9). (Tom Lee, pers. comm., 10 Nov., 1994) Dry Cottonwood stones are noted for their high degree of clarity.

Figure 12.159 Ya gotta start 'em young...
The author's daughter, Billie, mining sapphires at Dry Cottonwood Creek. (Photo by the author)

Dry Cottonwood Creek

1889	Sapphires and some gold are found at Dry Cottonwood Creek (Kunz, 1904).
1902	Northwest Sapphire Co. of Butte, establishes a short-lived hydraulicking operation (Voynick, 1985).
1907	Variegated Sapphire Co. mines with a floating mechanical gold dredge (Voynick, 1985).
1910–11	Consolidated Gold and Sapphire Mining Co. of Butte mines the deposit with a smaller dredge, but to no avail. The deposit was then inactive until the 1940s (Clabaugh, 1952; Voynick, 1985).
1940s	Demand for industrial sapphire during World War II temporarily revives interest in Dry Cottonwood Creek sapphires, but there is no production (Clabaugh, 1952).
1950s	Marc Bielenberg acquires property at Dry Cottonwood Creek.
1964	Marc Bielenberg acquires mineral rights on the entire Dry Cottonwood Creek Property (Bielenberg, pers. comm., Nov., 1994).
1993	American Gem Corp. acquires mining rights on the upper part of Dry Cottonwood Creek (Verbin, 1994).
1993–94	Tom Lee acquires mining rights and properties at Dry Cottonwood Creek (pers. comm., 10 Nov., 1994).

Characteristics of Montana corundums

Mineralogy of the Yogo sapphire

Yogo sapphires differ from other sapphires around the world in a number of important respects. Chief among these differences is the fact that the Yogo stones are recovered from the original rock matrix; this has given scientists an unparalleled opportunity to study their genesis. With the exception of color, Yogo sapphires share a number of characteristics with the rubies found along the Thai/Cambodian border. Color zoning is all but unknown, the crystals tend to be

Montana's De Beers... or just another victim of the blues?

Are you ready to be heartbroken? Are you ready to bleed?

Lloyd Cole

IN 1991, Greg Dahl, sometime lawyer and former Minnesota politician, read about Montana sapphires in *National Geographic* magazine (Ward, 1991). Excited at the prospect of the state's gem potential, he formed American Gem Corporation in 1993 to exploit Montana's considerable sapphire holdings. Mining rights were purchased for properties at Gem Mountain (Rock Creek), Dry Cottonwood Creek and along the Missouri river (a portion of Eldorado Bar, including dredging rights to Hauser Lake). It was not long before American Gem owned the rights to some 70,000 acres, a healthy slice of Montana's alluvial sapphire deposits. Attempts have also been made to purchase properties at Yogo, so far unsuccessfully. While the company's stated goal is to gain control over all of Montana's sapphire deposits, this seems an unlikely prospect, since each of the four major mining districts is broken up into a myriad of smaller claims. As of July, 1994, American Gem had made approximately $10 million in long-term property commitments (Greg Dahl, pers. comm., July 1, 1994).

American Gem also acquired the high-powered heating talents of John Emmett's Crystal Research, for a cool $3 million. Company directors believe that, with improvement in heat-treatment technology, proper capitalization and effective marketing, they have a real contender. Unfortunately, while treatment technology has increased the potential yield compared with 50–100 years ago, mining in Montana today is also far more expensive, due to government and environmental red tape. A further complication is the weather. With the exception of underground workings at Yogo and the Missouri-River mines, sapphire season in Montana is essentially limited to the summer months of May–September. But as Greg Dahl's Minnesota-farmer father once told him, "You make hay when the sun is shining." With Montana's long hours of summer daylight, two shifts are possible.

In the state's 100-year sapphire mining history, countless companies have sallied forth, lured by the same siren song— big enough, blue enough... only to founder on the brutal shoals of Montana-sapphire reality—almost big enough, almost blue enough. Can American Gem succeed, where the best efforts of so many other companies were not good enough? Will the Charles Gadsdens, Edwin Streeters and Jake Hoovers soon be dancing a jig up in heaven, thumbing their noses at the nay-sayers and non-players? Or must they find solace in yet another funeral dirge, yet another swan song, perhaps a slow blues...

All the things that your eyes once promised, I see an urge too. Now your eyes are red from crying.
Almost blue, flirting with this disaster became me, it named me as the fool who only aimed to be.
Almost blue, it's almost touching, it was almost good...

Elvis Costello

Is it possible to make Montana's sapphires pay? The best answer I can come up with is Mark Twain's remark about how uncertainty is what makes horse races.

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extremely flat, and their inclusions are also similar. Further study is needed to determine what possible links might exist between the genesis of the corundums from these two deposits.

Color range. Yogo sapphires are characterized by two features—excellent color and clarity. Their rich blue hue is deeper than many untreated sapphires from Sri Lanka, but lighter and less inky than those of Australia. In faceted stones of at least one carat or more, the color is close to ideal. Unfortunately, stones of this size are extremely scarce.

More amazing than the color itself is its consistency across mine-run lots. Virtually all are of the same blue, with about 3% being of a lilac hue. Their color uniformity makes them excellent for matching in jewelry. Delmer Brown, chief geologist for Intergem, discovered just two rubies and ten green sapphires out of 300,000 carats of Yogo rough, and these odd colors were all stones too small to facet (Brown, 1982).

The clarity of Yogo sapphires is also outstanding. What is it, then, that has kept the Yogo sapphire from being the world's most desirable sapphire? The answer is simple—size. Field investigations have shown that less than ten percent of the stones recovered exceed one-carat weight in the rough. The largest cut Yogo sapphire on record is a mere 10.2 ct. Were it not for this fact, the Yogo stones might indeed be the most renowned of blue sapphires.

Geologic formation/occurrence. Yogo sapphires occur in a lamprophyric rock, altered to reddish, yellowish, purplish and greenish clay minerals, with pyroxenes, carbonates, zeolites and chlorite present. The occurrence consists of a vertical dike roughly 5.6 km long and 1–7 m wide, and is thought to have been emplaced in several geologic events. While the gems are found *in situ,* studies on trapping pressures of negative crystals suggest the sapphires crystallized at depth, with the dike rock representing a carrier mechanism having no relationship to the sapphires themselves (Roedder, 1972, 1984; D. Brown, pers. comm., Aug. 24, 1994).

As recovered from the jig concentrate, Yogo sapphires sometimes possess a thin, hard, black outer coating of what is hercynite. This is believed to originate from a late magmatic stage reaction of the magma with the previously-formed sapphires. Great care must be used in the sorting stages if this coating is not to obscure the crystals themselves (Brown, 1982).

Crystal habit. In addition to their small size, Yogo sapphires exhibit a very flat, tabular crystal habit, making it more difficult to recover large stones in cutting. One possible explanation for the prevalence of so many thin crystals is that mining is occurring only on the topmost portion of the dike. While the dike rock has a specific gravity of ~2.5 and the sapphire is 4.0, like thin sheets of mica floating on water, flatter crystals would have greater buoyancy and so would tend to

Figure 12.160 Rough and cut Yogo sapphires showing the full color range. These stones are from the J.P. Morgan collection in New York's American Museum of Natural History. (Photo: Harold & Erica Van Pelt/American Museum of Natural History)

be found on top. In fact, Charles Gadsden claimed that at the 250-ft level, the crystals tended to become more equidimensional (Delmer Brown, pers. comm., 14 Nov., 1994).

Crystals are typically combinations of large basal pinacoids and smaller rhombohedron faces. Rhombohedron faces often develop such that the pinacoids take on a triangular shape, with reverse orientation on opposite sides of the crystal. Occasionally, triangular pinacoids are raised slightly above the surface. When equally-developed triangles are present on each end, observing the stone parallel to the *c* axis gives the appearance of a six-pointed "Star of David."

Many faces exhibit deep etching, believed to result from magmatic dissolution as the sapphires, which formed at depth, were brought to the surface. This etching, however, has, in most cases, not completely destroyed the crystals' symmetry, but merely rounded their edges. In some cases, this magmatic rounding has destroyed all traces of the original crystal symmetry.

Figure 12.161 Primary rutile crystals in a sapphire from Yogo Gulch, Montana. Yogo stones do not contain exsolved rutile, but may contain primary rutile; 30×. (Photo: John Koivula/GIA)

Table 12.28: Properties of Montana sapphire (Yogo Gulch)[a]

Property	Description	
Color range/phenomena	• Blue: light to medium blue; fine, rich blue in larger (1 ct +) stones • Violet: light to medium violet ('lilac' color)	
Geologic formation	• Yogo sapphires formed in the upper mantle, but are mined from a lamprophyric rock intruded into limestone	
Crystal habit	• Tabular pinacoid-rhombohedron combinations. Repeated growth of the rhombohedral and pinacoid faces often results in raised triangles on the pinacoid faces. These will be in reverse position on opposite sides of the crystal	
RI & birefringence	Not reported	
SG	3.98 to 4.013; bright blue stones have the highest SGs, violet colors the lowest	
Spectra	**Visible**: Weak Fe spectrum; Violet stones may show Fe-Cr combination spectrum.	
Fluorescence	**UV**: Generally inert. Lilac-colored stones may show a weak to moderate red (LW stronger than SW)	
Other features	• Most faceted gems are round brilliant cuts. Cut gems are rarely larger than 0.50 ct. • Yogo stones are not generally heat treated • Due to the thin shape of Yogo rough, doublets made of two pieces have been seen	
Inclusion types	**Description**	
Solids	• Analcime (Gübelin & Koivula, 1986) • Calcite (Gübelin & Koivula, 1986) • Mica (biotite); long, irregular, brownish (Dunn, 1976) • Pyrite (Gübelin & Koivula, 1986)	• Rutile; rods and knee-shaped twins (Dunn, 1976) • Spinel; light brown, partially resorbed (Dunn, 1976) • Zircon (Gübelin & Koivula, 1986)
Cavities (liquids/gases/solids)	• Primary CO_2-filled negative crystals are sometimes found. These may be surrounded by small "islands" of secondary cavities.	
Growth zoning	Generally absent; the only zoning observed is extremely vague, similar to that of Thai/Cambodian ruby	
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$ has been found	
Exsolved solids	• Contrary to what has been reported (*cf.* Gübelin & Koivula, 1986), rutile silk is *not* found in Yogo stones (Delmer Brown, pers. comm., March, 1994) • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)	

a. Table 12.28 is based on the author's own research, along with published reports of Allen (1991), Brown (1982), Dunn (1976), Gübelin & Koivula (1986) and Roedder (1984).

Due to the thin crystal habit, doublets have been fashioned out of two thin Yogo pieces (Liddicoat, 1969).

Inclusions

Yogo sapphires are notable for their high degree of clarity. Although fluid and solid inclusions do occur, for the most part they are entirely absent. In some respects, the inclusions tend to resemble those found in Thai rubies. Color zoning is absent and included crystals often appear atoll-like, surrounded by secondary healed fractures.

Solids. Most common are tiny crystal grains of various types. Dark red crystals of metallic luster have been seen. These occur in rod shapes and knee-shaped twins, often surrounded by fingerprints, and are rutile (Dunn, 1976). Colorless crystal grains have also been found surrounded by very thin fingerprints of hexagonal outline in the basal plane. These strongly resemble the primary fluid inclusions of Thai rubies. Tabular colorless crystals of what may perhaps be corundum or negative crystals are surrounded by partially healed fractures containing reddish stains. Long irregular inclusions of mica, as well as light brown, partially resorbed crystals of spinel are also found (Dunn, 1976).

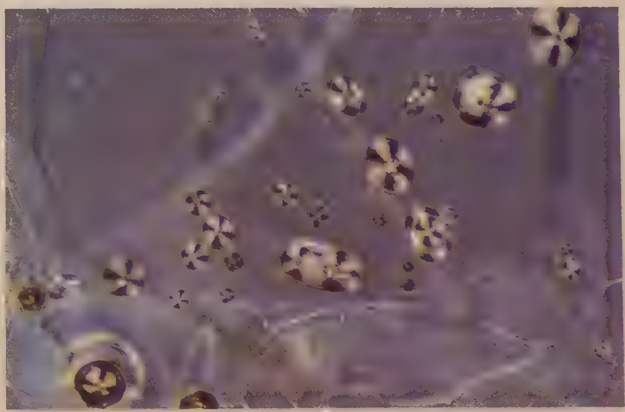

Figure 12.162 Natural glass inclusions in an unheated sapphire from Rock Creek, Montana. Between crossed polars, each inclusion acts as a condensing lens, producing a tiny uniaxial interference figure when viewed parallel to the optic axis; 50×. (Photo: John Koivula/GIA)

Cavities. Inclusions of other types are scarce in Yogo stones, many being entirely clean. At times, irregular cavities filled with a whitish or yellowish fluid have been found. Primary CO_2-filled inclusions have also been reported, trapped when the Yogo sapphires crystallized at great depth (and high

Figure 12.163 Exsolved boehmite inclusions in a sapphire from Eldorado Bar, Missouri River, Montana; 30×. (Photo: John Koivula/GIA)

pressure). Later as the sapphires were carried upward, under the lower confining pressure, these primary cavities sometimes cracked. This allowed some fluid to escape into the fracture, where it caused healing and the trapping of many tiny secondary CO_2 inclusions. The result is "atoll-like" inclusions consisting of primary negative crystals sometimes surrounded by secondary fluid inclusions (Roedder, 1972, 1984).

Growth zoning. Color zoning, which disfigures many a sapphire from other localities, is entirely absent, indicating a slow rate of growth deep within the earth.

Twin development. Rhombohedral twinning, although not common, has been found in Yogo sapphires.

Exsolved solids. Exsolved rutile silk is not found in Yogo stones; thus the absence of star gems from the deposit. Boehmite needles are sometimes found at the junctions of intersecting rhombohedral twin lamellae.

Characteristics of other Montana corundums

The author has not examined many Montana sapphires other than those from Yogo Gulch. One interesting feature of Rock Creek corundums is the tendency for color to be concentrated in hexagonal cores at the center of the crystal. Primary rutile is a common feature of Rock Creek sapphires. During heat treatment, the titanium from such rutile crystals often diffuses into the surrounding corundum, creating a blue halo around the included crystal. If the crystal expands enough to fracture the corundum, titanium rushes into the plate-like fracture, coating the walls. The fracture heals during cooling, leaving a blue disc surrounding the crystal (Emmett & Douthit, 1993).

One of the most unusual inclusions ever seen in sapphire was that of a Rock Creek stone photographed by John Koivula (pers. comm., June 6, 1994). It contained numerous small inclusions of natural glass, each of which contained a gas bubble. When viewed between crossed polars, each glass inclusion acted as a condensing lens, producing a tiny uniaxial interference figure (see Figure 12.162).

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Table 12.29: Properties of Montana sapphire (Missouri River, Dry Cottonwood Creek & Rock Creek)[a]

Property	Description
Color range/phenomena	• Blue: near colorless to a medium blue; rarely dark blue • Green: near colorless to a medium green • Purple, pink to red • Yellow: near colorless to medium yellow, greenish yellow or orangy yellow to orange. • Six-rayed stars are possible
Geologic formation	• The source rock is unknown for each of these deposits
Crystal habit	• Tabular to columnar hexagonal prisms • Rhombohedron-pinacoid combinations • Many crystals are rounded by alluvial or magmatic weathering into ball-like shapes (particularly Rock Creek)
RI & birefringence	Not reported
SG	Not reported
Spectra	Not reported
Fluorescence	Generally inert. Cr-rich (reddish) material may show weak to moderate red (LW stronger than SW)
Other features	Material from each deposit is commonly heat treated
Inclusion types	**Description**
Solids	• Clinozoisite (Dry Cottonwood Creek) (John Koivula, pers. comm., 1993) • Garnet (almandine) (Dry Cottonwood Creek) (Koivula & Fryer *et al.*, 1991) • Primary rutile, which may develop surrounding blue haloes after heat treatment (Rock Creek) (Emmett & Douthit, 1993)
Cavities (liquids/gases/solids)	• Primary and secondary fluid cavities are common • Natural glass (all localities)
Growth zoning	• Straight, angular growth zoning parallel to the crystal faces is common • Rock Creek gems often display hexagonal cores of concentrated color. This effect may be increased with heat treatment • After heat treatment, Rock Creek gems often display blue color haloes surrounding included crystals
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$ is common
Exsolved solids	• Exsolved rutile silk has been observed in sapphires from each deposit • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.29 is based on the author's own research, along with published reports of Emmett & Douthit (1993), Gübelin & Koivula (1986), Koivula & Fryer *et al.* (1991) and Themelis (1985, 1992).

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Figure 12.164 2.53-ct ruby crystal from Macon County, North Carolina. (Photo: John Koivula/GIA)

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Figure 12.165 Consolidated Ruby Co. mine in Cowee Valley, North Carolina, Nov. 1914. (Photo by D.B. Sterrett, USGS)

North Carolina

While industrial corundum has been mined in many North Carolina localities, gem material occurs primarily in Macon, Jackson (in the vicinity of the town of Sapphire), Clay, Yancey and Alexander counties in the western part of the state. Corundum was first discovered in Macon County, North Carolina in 1870 at the Corundum Hill Mine, some 8 miles (13 km) southeast of Franklin, Macon County (Pratt, 1906). The area surrounding Franklin, particularly Cowee Creek, is the major deposit, and is famous for alluvial ruby, along with rhodolite garnet. It was worked by Tiffany's of New York about 1910, but abandoned due to the low quality of gems recovered (Delmer Brown, pers. comm., Aug. 30, 1994). While faceted gems of up to 3–4 ct have been faceted from Cowee Creek rough (Pratt, 1906), the deposit has not produced enough of these stones to make it commercially feasible. Today the area is worked strictly on a fee-digging basis for tourists.

Cowee Creek rubies range from pink to dark red. They often contain striking red inclusions of garnet, as well as tiny masses of primary rutile and exsolved silk. Star stones have sometimes been cut. In terms of habit, they are generally tabular hexagonal prisms modified by the rhombohedron and basal pinacoid. Longer prisms are sometimes found (Judd & Hidden, 1899), and basal twinning {0001} has also been reported (Hidden, 1902).

Sapphires of a variety of colors are also found in North Carolina, including one described by Kunz (1892) of an emerald-green color. None of the sapphire deposits are currently of commercial significance.

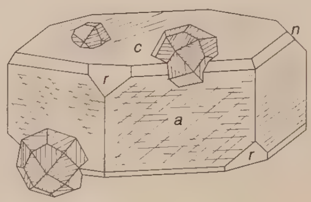

Figure 12.166 Ruby crystal from Cowee Valley, North Carolina, with embedded garnet crystals. Such garnet inclusions are typical of this locality. (From Judd & Hidden, 1899)

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Table 12.30: Other US corundum localities

State and deposit descriptions
Alabama • Black star sapphires have been found near Bradford, Coosa County
Alaska • Star sapphires of a grayish color and star rubies have been found on the Copper River in the Juneau Indian Reservation, southeastern Alaska (Sinkankas, 1959)
Colorado • Deep blue sapphires were reported in the late 19th Century in Colorado (Kunz, 1892). The occurrence is at the old Calumet Iron Mine, near the ghost town of Turret, approximately 20 km from Salida. The crystals occur as flat hexagonal plates up to 0.25 inch (0.635 cm) in diameter. The locality is not of any commercial significance.
Georgia • Corundum has been found in most northern counties of this state, but little of gem quality has turned up. The Laurel Creek Mine in Rabun County has produced translucent ruby which is suitable for cabbing (Sinkankas, 1959).
Indiana • Black star sapphires have been found as waterworn pebbles in the glacial gravels of Morgan County (Sinkankas, 1959)
Iowa • An unusual sapphire was found in 1912 along the shore of Lake Okobji in Dickinson County. First though to be a piece of blue bottle glass, it later proved to be a sapphire which cut a fine gem of ~1.38 ct (Sinkankas, 1959).
New Jersey • Red and blue corundums have been reported in the limestone quarries at Newton, Franklin and Sparta (Sussex County) (Sinkankas, 1959)
Pennsylvania • Farms near Morgan Station and Black Horse, Delaware County, have produced some black star sapphire. Similar material has been found near Shimersville, Lehigh County (Sinkankas, 1959).
Washington • Blue and pink corundum crystals with small translucent to transparent areas have been found near a thulite (zoisite) deposit on Tunk Creek, Okanogan County (Sinkankas, 1959)

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USSR (former)—see Russia

Vietnam

Why can't somebody dig up rubies somewhere pleasant? Say Hawaii, or maybe the French Alps? But it never happens. Rubies seem to come only from the most god-awful places. Name a place riddled with pox, poverty and/or war and that's where to look for rubies. So true, in fact, that savvy prospectors don't bother with geological maps—they use the Amnesty International report on human rights violations. Their divining rod is a rolled up copy of the World Health Organization's list of diseased places.

And now they've really done it. Yep. They've gone and found rubies in Vietnam. Just our luck.

Discovery of rubies in Vietnam took the entire world by surprise, not the least this author. In 1989–90 I heard the first rumblings that the reds had the reds. "Ha," said I. "Refugees, maybe. Rubies? No way." Way. Slowly, ever-so-slowly, the realization came that I might be mistaken. First was the sudden deluge of "Burma"-type rubies in the Bangkok market. Second was the Bangkok announcement of a Vietnamese ruby auction. At last, after watching planeloads of Thai gem dealers disembark at Bangkok's airport wearing cone-shaped hats, I was forced to admit that they had not been working as extras in a Vietnam-War movie.

Enter *Doi Moi*

The good news is that the Vietnam war has been over since 1975. And since the late 1980s, the central government has initiated economic reforms, which they spell *D-O-I M-O-I,*

Figure 12.167 Ruby crystal group from Luc Yen, Vietnam. (Photo: Bart Curren/ICA; specimen: Pala International)

but which many would spell C-A-P-I-T-A-L-I-S-M, were they taking place anywhere else.

In the late 1980s, Vietnam underwent a number of political and economic changes. Communism was recognized as a dead end, as was the nation's occupation of Cambodia. Along with the removal of troops came economic liberalization. Private business was legitimized and public-sector businesses were privatized. Overall, this brought tremendous changes. Formerly a net rice importer, within two years Vietnam became one of the largest rice exporters in the world.

But Vietnam still displays numerous vestiges of its communist past. Foreign visitors arriving in Hanoi (Ha Noi) or Ho Chi Minh City (Saigon) must register with the police within 48 hours. Many parts of Vietnam remain completely off-limits to foreigners, unless they have special permits. This includes both of the important ruby-mining districts (Luc Yen, north of Hanoi, and Quy Chau, to the south).

Figure 12.168 Corundum localities of Vietnam. (Modified from Kane & McClure *et al.*, 1991, and Smith & Kammerling *et al.*, 1995).

History

An obscure reference to rubies found with iron ore and lead east of the Mekong river in French Indochina is the first mention of ruby in Vietnam (*Engineering and Mining Journal,* 1899; Bel, ca. 1899). However, beyond a few dark red-orange zircons, Vietnam has never been known as an important source of gems.

According to Phan Truong Thi, rubies at Luc Yen were already known by the early 1970s (Widener, 1994). Gold and tin prospectors were probably first to find corundum in the modern era. It was not until the gems were shown to retired Thai civil servant, Boonsin Jatoorapreuk, and his Vietnamese wife, Hang, in 1987, that their potential was recognized (see box, page 479).

Luc Yen

The first major discovery of ruby in Vietnam was made at Luc Yen. Located in Yen Bai Province, some 243 kms north of Hanoi, the gems are recovered from alluvial gravels

Figure 12.169 Rough ruby on sale at the government gem market at Luc Yen, north of Hanoi. (Photo: Robert C. Kammerling/GIA)

washed down from marbleized limestones in the foothills of the Bac Bo Mountains (Kammerling & Keller *et al.*, 1994).

Eleven valleys in the Luc Yen area have been identified as gem bearing, with stones found including ruby, fancy sapphire and spinel. Due to the karst-like topography, the gems have concentrated in depressions typically no more than 3 km^2-size in the valley floors. It is these depressions which have largely been mined. Unfortunately, many of the most promising areas have been exploited. Difficult access to remote areas and lower yields in more easily accessible areas have combined to sharply reduce production compared to the early 1990s peak (Kammerling & Keller *et al.*, 1994).

At Luc Yen, in addition to corundum, red (including pink) and pale blue spinels are also found. This spinel, much of which is of gem quality, makes up as much as 70–90% of the gem material at some sites. In addition to spinel, small yellow and green tourmalines and garnets have been found (Kane & McClure *et al.*, 1991).

Quy Chau (Bu Khang District)

Rubies were reportedly first found in the Quy Chau area about 1965. Geologist Phan Truong Thi was mapping the area when the find was made. Thi wrote his first report on the ruby deposit in 1970, but at the time the government was interested only in industrial minerals, such as tin and iron (Widener, 1994). Thus the "bourgeois" ruby lay fallow. Only after the mid-1980s move to a market economy, and the subsequent development of the Luc Yen mine, did eyes turn again to Quy Chau. It is rare for any country to develop a world-class ruby mine. Vietnam, within a span of just a few years, suddenly had two.

Figure 12.170 The horror, the horror…
Vinh, south of Hanoi, is the jumping-off point for trips to the Quy Chau ruby mines. The city was scene of some of the most terrible destruction of the Vietnam conflict. But the worst came *after* the fighting was over, when the city was rebuilt with East German assistance, producing something akin to a tropical East Berlin. (Photo by the author, May, 1992)

The Lonely Planet guidebook, *Vietnam, Laos & Cambodia* (1991) said this about Nghe An Province:

> Nghe Tinh [Nghe An] Province is endowed with poor soil and some of the worst weather in Vietnam. The area frequently suffers from floods and devastating typhoons. Nghe Tinh is one of the places about which the locals say: 'The typhoon was born here and comes back often to visit'. The summers are very hot and dry while during the winter the cold and rain are made all the more unpleasant by biting winds from the north.
>
> Lonely Planet, 1991, *Vietnam, Laos & Cambodia*

Upon hearing this, the author recognized Nghe An as bona fide ruby country. And so, in April of 1992, he

Figure 12.171 A sampling typical of the fine rubies which have come from Vietnam since the late 1980s. These stones have come from the Luc Yen and Quy Chau mines, and range from 0.17 to 1.94 ct. Many of the stones contain orangy iron-oxide stains, which are typically removed during heat treatment. (Photo: Shane McClure/GIA)

followed Vietnam's ruby trail to Quy Chau. The following is largely based on that visit (Hughes, 1992b).

Horrors of war

War is horrible—everyone knows that. Nghe An province, with its capital, Vinh, was home to some of the Vietnam War's worst destruction. Start off with French firebombing, then add a bit of scorched earth, courtesy of the Vietminh. Now top it off with good old US high-tech bombing, to really do things right. But the worst was yet to come. After the war, East Germans were brought in to rebuild Vinh, producing what one visitor described as "a tropical East Berlin." If Marlon Brando saw Vinh today, he would have only one thing to say: "The horror… the horror…" Today, Vinh is the center of ruby trading for Quy Chau gems.

The road to Quy Chau

The provincial capital of Vinh is the major jumping-off point for trips to Quy Chau. It is accessed from Hanoi over 200 kms of what the charitable call "Highway 1," a slender piece of asphalt-cum-bullock track stretching all the way from Hanoi to Ho Chi Minh City (2000 km to the south). From Vinh, the mines are another 80 kms further west into the bush, towards the Lao border. As we bumped and bounced our way from Hanoi towards Vinh, the author tentatively inquired as to the condition of the road to the mines. With a toothsome grin my Vietnamese host declared: "This Highway No. 1. That Highway No. 10." Then he cackled with raucous laughter. I did have to ask…

The mines are located some 70 kms west of Highway 1 and a few kilometers southeast of Quy Chau. Six police

Figure 12.172 Miners at Vietnam's Quy Chau ruby deposit. (Photo by the author, May, 1992)

checkpoints were spread between Vinh and Quy Chau district. Travellers must have their documents in order.

Nghe An province not only is the birthplace of Ho Chi Minh, but also the road and railhead of the Ho Chi Minh Trail. Both the railroad, which crosses the road frequently, and the road were major military targets during the war.

The mining area consists of gently-rolling hills bisected by the Hieu river, near the village of Cho Bin. Northeast of the river, the hills are thought to be limestone, but the rubies come from the hills on the southwest bank. These were said to consist of weathered granite, interwoven with pegmatites, with the rubies originating in the pegmatites. Other geologists, however, have told the author that it is more likely that the rubies originated in the limestone (Delmer Brown, pers. comm., Aug., 1994). Whatever the source rock, the rubies have been concentrated in alluvial gravels in the valley bottom and along the hillside streams. Valley-floor alluvials were not being worked at the time of the author's visit, due to problems with water seepage. Modern mining techniques would solve these problems (Ken Connell, pers. comm., April, 1992).

There were four mining areas operating at the time of the author's visit. Heading up the road towards the Lao border, the first is a small digging at Quy Hop. Then come the second and third operations, termed "Billionaire" and "Millionaire" hills, respectively, in reference to the value of material taken out of each, with the fourth nearby, at Ban Dung (Kammerling & Keller *et al.*, 1994). A short distance further on is the small town of Quy Chau.

The graveyard shift

Once the word spread that the valuable red stones of Luc Yen could be also dug around Quy Chau, a wild-west type gem rush descended on the area. The population soared as one of the poorest provinces in Vietnam suddenly became one of the richest. At one stage it was estimated that the district was inhabited by anywhere from 50,000 to over 300,000 miners, but these figures are probably greatly exaggerated.

They came to dig, and dig they did, tunnelling hither and thither. As relentless as ants, they furrowed and burrowed into the hills, many becoming rich in the process. Brand spanking new "ruby" homes now dot the landscape, containing items of previously unheard of luxury, such as VCRs. This in what was once Vietnam's poorest province. But all was not well in the Land of Red. Holes yielded riches for a lucky few, but turned into graves for some unfortunates. In a single accident in 1991, over 60 people were said to have perished from a massive cave-in.

Peace in Cambodia meant trouble back in Vietnam. Tens of thousands of Vietnamese soldiers were discharged. Many made the transition back into civilian life without problem, but a few turned their guns on the local populace, robbing those who travelled along remote roads, including the Quy Chau area. Such security problems, along with the mining accidents, forced the central government to step in. Illegal (i.e., non-concession) mining remains, but is now done largely by natives of Nghe An province, rather than outsiders. The gem-bearing area has been mapped by geologists and the most-promising sites auctioned off to Vietnamese "companies," which means different, and often competing, divisions of both the national and provincial government.

Gem material seen consisted largely of ruby, with smaller amounts of blue/violet and orange sapphire, and one piece of yellow chrysoberyl. Spinel and garnet are also said to occur at Quy Chau (Kammerling & Keller *et al.*, 1994). The ruby is similar in appearance to that from Luc Yen, featuring distinctive blue zones of color. Other than from Luc Yen, this has been seen in rubies from Jagdalek (Afghanistan) and Mong Hsu (Burma).

Figure 12.173 I'll bet it tastes just like chicken... Dinner for sale in the market of Vietnam's Quy Chau ruby mines. (Photo by the author, May, 1992)

Figure 12.174 An independent miner washing sapphire-bearing gravels in the Ma Lain area of Binh Thuan Province of southern Vietnam. (Photo: Robert C. Kammerling/GIA)

Other Vietnam corundum localities

Luc Yen and Quy Chau are not the only localities where corundum has been reported in Vietnam. Corundum-bearing basalt flows are common in southern and central Vietnam. Those that show gem potential include Di Linh/Hinh Dien (Lam Dong Province), Phan Thiet (Binh Thuan Province), and Gia Kiem (Dong Nai Province, at Xa Vo and Tien Co). Typical of alkali basalt-derived deposits, most sapphires are of a dark blue to green color. Yellow sapphires have also been recovered (Kane & McClure *et al.,* 1991).

In 1994, a new strike of sapphire was made in the central highlands area of Dac Lac Province, resulting in a major gem rush. The locality is at Truong Xuan, which lies some 100 km from Ban Me Thuot. Dac Nong Province has also been mentioned as a source of sapphire (*JewelSiam,* 1995).

In Bangkok, the author has also seen cobalt-blue spinel of gem quality from an unidentified Vietnamese locality.

The disappearing auction

BOONSIN Jatoorapreuk and his wife, Hang, formed B.H. Mining to exploit the Luc Yen deposit, in partnership with Aphichart Fufuangvanich and several other Bangkok dealers and a Vietnamese-government consortium, Vinagemco (Anonymous, 1991c). Some three years were spent in digging and shoveling, digging and shoveling, with breaks only for the endless meetings with government officials that are *de rigeur* in third-world countries. In time, a substantial quantity of material was amassed and safely ensconced in the state bank, and marketing plans were formulated. Ultimately it was decided by the powers-that-be that an auction was the most fitting method of sale. Like their cousins from Burma, Vietnamese rubies would be publicly sold to the highest bidder.

To promote this grand event, reporters from various international wire services were invited to a pre-auction viewing at the bank. But when the canvas sack said to contain the best stones was opened, only fish-tank grades and empty plastic bags tumbled out. Photographers snapped merrily away as pandemonium reigned, with charges and countercharges flying round the vault. Scapegoats were quickly conjured; Steve Reynolds, B.H. Mining's marketing manager, soon found himself labeled a CIA agent and was forced to get the hell out of Dodge, er, Hanoi.

Naturally, the above events resulted in much government and company hemming and hawing. After the requisite ego (and, presumably, wallet) massage, it was decided that all was rosy in the land of big red. Vinagemco-B.H. Mining's lease was restored, although in severely truncated form. And yes, with trumpets trumpeting, Luc Yen was "officially opened," the skeletons of the past three years of digging and shovelling apparently safely stowed in the closets of foreign banks.

Auction dates were set and postponed, time and again. Eventually the grand affair was held, beginning May 20, 1992. While experienced buyers scratched their collective heads in wonder, two Japanese golf-course developers plunked down US$827,000 for a quantity of overpriced ruby rough, and then promptly disappeared from sight, never to be heard from again.

Figure 12.175 As the above stone shows, Vietnam produces rubies as good as anything from Burma. But the machinations and intrigue surrounding the gem business in that country have left this potential largely unexploited.
(Photo: Bart Curren/ICA; specimen: Rafco International Gem Co.)

Figure 12.176 Weird scenes inside the goldmine
When the preview for the first Vietnamese ruby auction was held, representatives of the international press flocked. But when canvas sacks containing the best stones were opened, the cream had already been skimmed. Inside, plastic bags were either empty, or filled with "replacement"-grade material. (Photos: Steve Reynolds)

Figure 12.177 Sapphires and rubies from Vietnam, ranging in size from 0.28 to 0.42 ct. (Photo: Tino Hammid/GIA)

Mining methods in Vietnam

Mining methods in Vietnam are similar to other corundum mines in Southeast Asia. While nominally illegal, the time-honored practice of pit mining is alive and well throughout Vietnam. These are operated mainly in remote areas or on the fringes of mechanized mines. Such mining involves sinking a shaft down through the overburden to the gem-bearing gravels. These are then raised to the surface for washing.

Like ruby mines in Thailand and Cambodia, bulldozers or backhoes are also used for excavation. The earth is then forced into a separation jig by the use of water cannons and pumps. Once in the jig, the 'heavies' (higher-density minerals) are sorted by hand to remove the rubies. Vietnam is still new to the gem business and many mistakes are made in the mining techniques and operation of such mechanized mines (Ken Connell, pers. comm., April, 1992).

Characteristics of Vietnamese corundums

The properties of Vietnamese rubies from Luc Yen and Quy Chau are described in Table 12.31, while those of sapphire from southern Vietnam are found in Table 12.32.

Vietnam's gem industry: Thoughts on the future

The quality of Vietnam's ruby is as good or better than that found anywhere else in the world. And yet Vietnam's gem industry finds itself in the doldrums, largely because of heavy-handed government policies and unrestrained greed on the part of locals. While Vietnam ranks among the world's poorest nations, for the foreigner, Hanoi is a far more expensive city to live in than Bangkok.

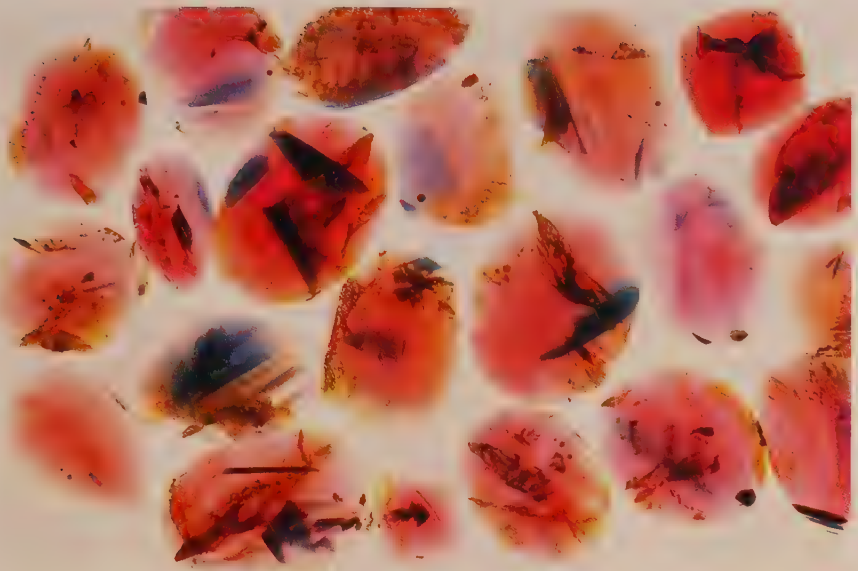

Figure 12.178 When immersed, many Vietnamese rubies contain distinctive blue color patches. (Photo: Shane McClure/GIA)

One of Vietnam's biggest problems is the tax structure. Workers in foreign-run factories may make $35–100 per month, but the government takes as much as 70% or more in tax. Thus the worker's only realistic choice is to do their own side business, where income can be hidden from the government. This is done in one of two ways: by simply not showing up for work, or more typically, by working at the foreign office in order to steer customers to their own business.

A number of joint ventures have been set up to tap into Vietnam's gem riches. These are mostly cutting factories. To be successful, such factories require a steady supply of raw materials, but local graft and unrealistic government policies make this impossible. To date, not a single gem-based joint venture has shown a profit; most are forced to rely on raw materials from outside Vietnam. Foreigners do not invest in Vietnam simply for the thrill of it all. They anticipate a reasonable return. If the Vietnamese government expects foreigners to continue investing, they must begin to address some of the above issues.

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Rx: How to kill a gem industry

IT sounded so simple. Add water and watch a gem industry grow right before your eyes. But instead of watching the money roll in, since the late 1980s, Vietnam has been watching the rubies roll out, mostly to Thailand. Big expectations in the ruby business have turned sour in Hanoi. What's going on? It's a crazy little thing called total state control, which, in this industry, is a prescription for death.

The gem business requires something that governments, even those which profess capitalism, are not fond of doing—getting out of the way. Witness Holland. After World War II, the Dutch decided they would get tough with diamond dealers. "No more excuses," said they. "Pay your taxes—or else." Else. The Dutch government no longer has to put up with excuses from diamond dealers—because there aren't any—diamond dealers in Holland. They all moved to Belgium. And you know what? The Belgians haven't complained a bit.

Like so many producing nations before, the Vietnamese government has decided that it has to control where, when and how gems are mined and traded. This is done by a bewildering array of taxes, restrictions and outright bans. In a country where foreigners have to register with the police within 48 hours of their arrival in any city, the concept of free trade is, well, "foreign."

Vietnam has some of the world's best rubies; this is a fact. But it is also true that it is either illegal, or damned tough, for a foreign gem dealer to go there and buy some. The same situation applies to the Vietnamese people themselves. Hence there is smuggling. As Gomer Pyle would say: "Surprise, surprise, surprise!"

Thailand has taken a different tack to controlling the gem trade. It is called decontrol. Rather than chasing after some will o' the wisp substance with bureaucrats and border police, they have wisely decided it doesn't need control. In a series of moves over the past two decades the Thai government has steadily eliminated the import and export taxes on the gem and jewelry industry. Have Thai government revenues fallen as a result? Have the Thai gem dealers taken their booty and fled to Monaco? Hardly. Instead, gem dealers from around the world have moved to Thailand, to take advantage of the free trade.

Today, the amount of taxes contributed by the gem and jewelry trade has never been greater. VAT, payroll taxes, income taxes, profit taxes, gasoline taxes, etc., all derived from these business people living and spending and banking their money in Thailand. As of 1994, Thailand's jewelry industry was the second biggest export earner and the country can say with great pride that it is *Jeweler to the World*.

The Thai government has grasped two important truths. First, the real money is not in mining, but in downstream processing of raw materials, i.e., cutting of gems, manufacture of jewelry, etc. Japan is the epitome of this philosophy. Possessing virtually no natural resources, Japan has proved time and again that its most valuable raw material is its human population.

Second, the Thai government understands that precious stones take the path of least resistance. If a country positions itself at the bottom of the hill, by offering good cutting and trading services and a minimum of taxes and red tape, gems will roll their way, borders or no borders. During the Vietnam War, the US military was unable to prevent smuggling of tanks, cannons and troops down the Ho Chi Minh Trail. But today the Vietnamese government believes it can stop the smuggling of something far more easily concealed. Many would call this "faith." This author would call it something altogether different.

Attempting to stop gem smuggling with bans and police action is akin to legislating against the wind. By hook or crook, Vietnam's gems will blow across the border, no matter what road the Vietnamese government decides to take. But if Vietnam has any plans for building a gem industry from which ordinary Vietnamese themselves might profit, they should study the experiences of other nations. I believe they'll find a country's most important natural resource resides just behind a pair of human eyes. Unfortunately, it is all too rarely mined.

Before enacting legislation affecting an industry not even in existence a decade ago, Vietnam should first explore the experiences of other countries. Look at the successes and failures, talk to experts. Much grief could be saved. Yes, that would mean talking to some of those nasty foreigners. But remember, Lenin was a foreigner, too.

Figure 12.179 Either the spider is quick, or the jeep is slow. Although the Vietnam war ended in 1975, that conflict, added to the effects of 40 years of hard-core communism, has left much of the country moving at about the same speed as the above jeep and bicycle. (Author's photos, May, 1992)

Table 12.31: Properties of Vietnamese ruby from Luc Yen and Quy Chau[a]

Property	Description
Color range/phenomena	• Light pink to a rich purplish red; purple; violet; often with areas of blue zoning. Generally strongly fluorescent. At Quy Chau are found beautiful orange sapphires. • Star stones are found, but are rare
Geologic formation	Secondary deposits derived from: • Regionally metamorphosed marble (Luc Yen) • Pegmatites or metamorphosed marble (Quy Chau)
Crystal habit	• Hexagonal prisms, bipyramids with some development of rhombohedron and pinacoid faces
RI & birefringence	n_ε = 1.759–1.762; n_ω = 1.768–1.770 Bire. = 0.008–0.009
SG	3.97–4.00
Spectra	**Visible**: Strong Cr spectrum
Fluorescence	**UV**: Strong red to orange-red (LW stronger than SW)
Other features	• Most are heat treated; sometimes dyed
Inclusion types	**Description**
Solids	• Apatite; subhedral transparent crystals (Kane & McClure *et al.*, 1991) • Calcite; irregular or rodlike transparent crystals (Kane & McClure *et al.*, 1991) • Mica (phlogopite), brownish orange (Kane & McClure *et al.*, 1991) • Nordstrandite; distinctive yellow-orange formless masses which appear similar to flux in Ramaura syn. rubies (Kane & McClure *et al.*, 1991) • Pyrrhotite; black rodlike forms (Kane & McClure *et al.*, 1991) • Rutile; bright orange crystals (Kane & McClure *et al.*, 1991)
Cavities (liquids/gases/solids)	• Secondary healed fractures in a variety of patterns and thicknesses are common • Iron oxide stains are common in cracks (this can be removed during heat treatment)
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle' like swirls in other directions. Distinctive are the blue color zones intermingled in most stones, similar to Jagdalek (Afghanistan) and Mong Hsu (Burma) rubies. Growth zoning in Vietnamese rubies is extremely sharp and prominent.
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$is common
Exsolved solids	• Rutile in dense clouds of needles, parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane • 'Texture' clouds, composed of such tiny inclusions that their form or composition cannot be resolved. These often appear bluish in certain lighting conditions. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)

a. Table 12.31 is based on the author's own research, along with the published report of Kane & McClure *et al.* (1991).

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Table 12.32: Properties of southern Vietnamese sapphire[a]

Property	Description	
Color range/phenomena	• Pale to deep blue to bluish green. Most stones are of a dark, inky blue typical of Fe-rich sapphires.	
Geologic formation	Secondary deposits derived from alkali basalts	
Crystal habit	• Hexagonal prisms, bipyramids (particularly barrel shapes), with some development of rhombohedron and pinacoid faces	
RI & birefringence	n_ε = 1.760–1.764; n_ω = 1.769–1.772	Bire. = 0.008–0.009
SG	3.99–4.02	
Spectra	**Visible**: Strong Fe spectrum	
Fluorescence	**UV**: Generally inert	
Other features	• Most are heat treated	
Inclusion types	**Description**	
Solids	• Columbite: black, acicular • Feldspar (Plagioclase): transparent, colorless grains • Goethite: filling cracks and cavities • Ilmenite: opaque, black • Kaolinite: filling cracks and cavities	• Pyrrhotite • Spinel (magnetite-hercynite & chromite-hercynite) • Uranopyrochlore: orange-red to black octahedra with stress haloes • Zircon: sometimes with haloes or comet tails
Cavities (liquids/gases/solids)	• Primary negative crystals, sometimes filled with goethite or kaolinite • Secondary healed fractures in a variety of patterns and thicknesses are common • Iron oxide stains are common in cracks (this can be removed during heat treatment)	
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed, sometimes in alternating blue and yellow bands. Distinctive are the colorless cores found in many specimens.	
Twin development	• Polysynthetic glide twinning on the rhombohedron $\{10\bar{1}1\}$is common	
Exsolved solids	• Dense particle clouds of unknown composition, following the crystal faces • 'Texture' clouds, composed of such tiny inclusions that their form or composition cannot be resolved • Lath-like or snowflake-like cloud patterns of tiny particles • Long white needles (probably boehmite) along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°)	

a. Table 12.31 is based on the published report of Smith & Kammerling *et al.* (1995).

Zaire (formerly Belgian Congo)

In 1952, the *Minerals Yearbook* reported that small concentrations of ruby and sapphire had been found in Zaire's (then Belgian Congo) Kivu Province. Newman (1994) also mentioned transparent, grayish blue sapphire in the Kivu region.

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Zimbabwe (Rhodesia)

The following is based on the report of Sweeney (1971). Gem-quality sapphires have been known in Zimbabwe (formerly Rhodesia) since the turn of the century, when they were discovered in the Somabula alluvial diamond diggings. In the early 1970s, material ranging from blue to black star was found to the north and east of Harare (formerly Salisbury). In 1971, a sapphire crystal of 3,100 ct was discovered at the Barauta mine in the northeast corner of the country. This mine was said to produce the best quality sapphires in Zimbabwe. The gems occur as squat hexagonal prisms coated with a thin brown skin and were thought to originate from a nearby pegmatite. While Sweeney waxed ecstatic on the quality of such stones, comparing them to the best from Burma, a photograph displayed two opaque blue crystals. So far, better-quality material has not come to light.

Ruby in marble has been reported in Zimbabwe at the O'Briens' claims, some 56 km NNW of Harare (Hunstiger, 1989–90).

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MANI-MÁLÁ,

OR

A TREATISE ON GEMS.

BY

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KNIGHT COMMANDER OF THE 1ST CLASS OF THE ORDER OF ALBERT OF SAXONY ;
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PART I.

CALCUTTA:

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1879.

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APPENDIX A

TAGORE'S RUBY AND SAPPHIRE

SOURINDRO Mohun Tagore's classic *Maṉi-Málá* (1879,1881) consists of translations of facts on gems into Sanskrit, Hindi and Bengali, as well as English. While containing information from both European and Arabic-script gemologists, it is largely based on the Hindu *Puranas.* Since this book is exceedingly rare, the author has reprinted below many of the relevant sections on ruby and sapphire for the benefit of modern readers.

RUBY[1]

TRANSLATION.

152. According to some authorities, the ruby is found in Ceylon and the lands bordering upon the Indus and the Rávaná Gangá.

153–154. According to others, ruby quarries are found in Ceylon, Kálpur and Tumbura. The rubies of Ceylon are beautifully red; those of Kálpur are yellow, and are called *kuruvinda* (rubicelle); and those of Tumbura are furnished with a blue shade and are hence called *nílagandhi* (violet ruby). That ruby which shoots a gleam green as the leaf of the *asoka* goes by the name of *saugandhika* (spinel).

155. The rubies of Ceylon are good *par excellence,* while those of Tumbura are at the bottom of the scale, the rubies found in Kálpur occupying the middle position. Rubies vary in value in accordance with the place where they are respectively found.

156–159. Of rubies, some are like the *bandhúka* flower (a species of plant), some are like the *gunjá* berry, some like the cochineal, some like the China rose, some like blood, some like the seeds of the pomegranate, some like the flower of the *butea frondosa,* some like red lead, some like the red lotus, some like saffron, some like *alakta* (the red resin of certain trees), some like deep blood, some like deep *alakta,* some like the *kusuma* flower, some like *alakta* with a shade of blue, some like the flower of *asteracantha logifolia* and *kantakárì* (red tree resin), some like vermilion, some like the eyes of the Greek partridge, *cuculus Indicus,* or the Indian crane, and some like the interior of the half-blown red water lily.

160. The saugandhika resembles the crystal in brightness, weight and hardness; and its color is like that of the red-lotus dashed with blue.

161. Of *kuruvinda* rubies, that which is reddish, owes its origin to crystal; still its inner lustre is such as even to surpass the brightest *padmarága* (a kind of ruby).

162. The *kuruvindas* which are produced in the *Rávanagangá,* are red like the *padmarága,* but are not so bright.

163. Rubies have different appellations according to their colors. That which is like the *bándhuli* flower, is called *bandhujíbi,* that resembling the *gunjá* berry, is called *sikhandika,* that which is like the cochineal, is called *indragopi,* that which resembles the China rose, is called *odrapushpaka,* that which is like blood, is called *raktákhya,* that which is like the seed of the pomegranate, is called *kuttima,* that which is like the *kinsuka* flower, is called *parna,* and that which is like vermilion, is called *símantaka.*

164. That ruby the color of which is like mountain slime, is called *gairikákhya,* that which is like saffron, is called *súrjasanga,* that which is like lac, is called *drumámaya,* that which is like the *kusuma* flower, is called *máharájanagandhi,* that which is like *asteracantha longifolia,* is called *gokshura* and that which is like the *solanum jaquini,* is called *kantakárika* (Almandine Ruby).

165. The ruby the color of which is vermilion, is called *manirága,* that which resembles the eye of the Greek partridge, is called *chakaráksha,* that which is like the eye of the *cuculus Indicus,* is called *kokiláksha,* that which is like the egg of the Indian crane, is called *sárasákhya,* and finally that which is like the red-lotus, is called *kokanada.* The earth produces a splendid variety of the kinds enumerated above.

[1] From S.M. Tagore (1879, 1881) *Mani-Málá, or a Treatise on Gems.* Calcutta, I.C. Bose & Co., 1046 pp. Numbers and notes contained within parentheses are those of Tagore. Notes in brackets are those of the author.

166. The *Andhra* country (The modern Telingana. Its people are called *Andaræ* by Pliny.) produces rubies resembling the *kuruvinda* of *Rávanagangá.* These have the same value as *kuruvindas.*
167. The *padmarágas* of Tumbura, which resemble in color crystalline *padmarágas,* are of small worth.
168. Heaviness, coolness, evenness, lustre, thickness, deepness of color and auspiciousness are the principal good qualities of gems.
169. The four-fold division into castes obtains also among rubies. The characteristics of each class I shall now describe.
170. The *padmarága* (Oriental Ruby) is reckoned a Vipra (Brahmin), the *kuruvinda* (Rubicelle) a Kshetriyá, the *Saugandhika* (Spinel) a Vaisya, and the *Mansa-khanda* (Ballas Ruby) a Súdra.
171. Some say that the Vipra rubies emit a shade red like the color of the red-lotus or the red-hot charcoal of the *Acacia Catechu.*
172. The Kshetriyá ruby casts forward a shade resembling in hue a *gunjá,* vermilion, or the flower of the *bandhuka,* the orange, or the pomegranate.
173. From the Vaisya *saugandhika* comes out a shade like vermilion, the flower of the *asoka,* the China rose, or *alakta;* or a red lustre tinctured with yellow.
174. A Súdra *mánsakhanda* emits a reddish, unbeautiful, and glossy shade resembling a piece of flesh (the ruby which is red-white is a *Brahmin,* that which is deep red, is a Kshetriyá, that which is red-yellow, is a Vaisya, and finally that which is red-blue, is a Súdra).

Shades and other Qualities of Rubies.

175. The authorities mention sixteen kinds of shade, four good and eight bad properties of rubies.
176–177. The rubies of Ceylon emit a gleam like the red-lotus, the glow-worm, fire, or the eye of the pigeon, the *cuculus Indicus,* the Indian crane or the Greek partridge. All these shades are auspicious.
178. The *Kuruvinda* shoots a shade resembling red lead, the *gunjá* berry, or the flower of *symplocos racemosa* or of the *butea frondosa.*
179. The *saugandhika* gem scatters a gleam either pale-red or like milk or the water colored by the *crocus Sativus;* —of these, the milky luster blights wealth.
180. The *nílagandi* shines in a halo like the blue lotus or iron.
181. When the ruby is placed over a mirror and is then exposed to the morning sun, the glass will flash with a lustre composed of all the above-mentioned shades.
182. That ruby which, when exposed to the sun 'new risen,' radiates red rays or paints the whole house with crimson, is surpassingly fair.
183. That *padmarága* which, on being cast into a quantity of milk a hundred times its bulk, makes the white mass one entire sheet of red, or sends out a red flame, is nonpareil.
184. That *padmarága* which, like the sun, can destroy even Egyptian darkness, is supremely excellent.
185. That *padmarága* which, when placed on the lotus-bud, anon makes it blossom, is Perfection's self—and is hardly attained even by the Gods.
186. The *padmarága* which is perceptible from a distance like a flame, is entitled *vansakánti,* — it leads to wealth.
187. All those *padmarágas* that, on being thrown into a quantity of milk or of water pure or blue two hundred times their bulk, crimson the liquid, conduce to prosperity though they differ among themselves as regards worth.
188. I shall now describe the eight bad properties of rubies, which have been enumerated by the authorities.
189. *Dwi-chchháyatwa, virúpatya, samveda, karkara, asovana, kokila, jara,* and *dhumra,* are the defects commonly found in rubies.
190. The *padmarága* which emits a two-fold shade is called a *dwi-chchháya.* A *dwi-chchháya* ruby is the death of friends. That ruby which bears a mark like a bird's foot, is called a *virúpa.* A *virúpa* gem always brings humiliation to its master.
191. A *samveda* ruby is one which shows a mark like a rift. This gem renders its owner liable to blows from a weapon. A *karkara* ruby bears in its bosom a gritty fragment. It causes the death of friends and is also fatal to domestic beasts.
192. That *padmarága* which naturally appears as if it were immersed in milk, goes by the name of *asovana;* this gem is the source of a multiplicity of evils.
193. The mark in a ruby which looks like a drop of honey, is called a *kokila.* A *kokila* ruby is inimical to life, wealth and fame, and must be shunned.
194. The quality of being discolored is called *jara.* A *jara padmarága* causes loss of wealth. The color of a *padmarága* which looks like smoke, is called *dhumra* (literally, smoke). A *dhumra*-colored *padmarága* renders one liable to lightning-stroke.
195. The above-mentioned rubies are worthless and pernicious, and should never be treasured up, even were they to be had for the gathering.
196. Those rubies which send out a two-fold shade, bring about loss; and those which are marked with a bird's foot in two several places, are the cause of defeat.
197. Those which bear gritty fragments and are indented, dirty, lack-lustre, rough and discolored, are certainly unlucky, although they may be otherwise good and may belong to a superior caste.
198. If through ignorance, a person happens to wear a defective ruby, loss of friends, destruction of wealth *et cetera,* are the inevitable consequences.
199. The man who keeps in his house a sterling *padmarága,* can with perfect safety, constantly live in the midst of enemies, and is impervious to the attacks of adverse fortune.
200. He who wears a *padmarága* of matchless virtues, need not apprehend any mischief from the foul touch of bad *padmarágas* without number.
201. According to some, as the contact of a single *chandála* (the generic name for a man of the lowest and most despised of the mixed tribes, born from a Súdra father and a Brahmin mother) suffices to contaminate ever so many Brahmins, even so one impure gem serves to pollute pure gems *ad infinitum.*
202. The colors of defective rubies are never like those of good rubies, yet to a certain extent they differ one from the other in color in accordance with their respective mines.
203. Bad rubies should never be worn, although set along with the best rubies—nay, should they happen to be in company with *Kaustuva* itself (The name of a celebrated jewel obtained with thirteen other precious things at the churning of the ocean. It was suspended on the breast of Krishna).
204. *Padmarágas* which resemble in shape a *gunjá berry,* may weigh three, seven or ten *gunjás,* and the heaviest is the most precious.
205. *Padmarágas* resembling the fruit of *Kroshtu* (Terminalia Catappa), may weigh two, eight or twelve *gunjás.*

206. That *padmarága* which is plum-shaped, weighs nine, ten or twelve *máshás* (a particular weight of gold, = five krishnalas = 1/16th suvarna; the weight in common use is said to be about seventeen grains Troy—*Williams*), that resembling the fruit of the Emblic Myrobalam in shape, weighs sixteen, twenty or thirty *máshás.*

207. A *rudrákshya-* shaped *padmarága* (the berry of a kind of tree, Elæocarpus Ganitrus) weighs one, two or three *máshás;* a *támbuli-* shaped *padmarága* (the berry of a plant of the same name) weighs from one to four *tolás.* [1 *tolá* = 180 grains Troy]

208. That *padmarága* which is like a *vimba* (the bright-red gourd of the Momardica Monadelpha plant), weighs six, eight or ten *tolás*— this is the maximum of weight. If any man by good luck happens to obtain a heavier *padmarága,* he will succeed in whatever he undertakes.

209. Some vicious rubies are as beautiful as good ones; but the authorities advise us to shun them carefully.

210. That *padmarága* which is lack-lustre, or which loses its former brightness on being rubbed by cloth, and which betrays a dark shade on its sides on being held between two fingers, is a false and vicious gem, and should never be worn even when it is selling for a song.

211. Should other tests fail in dispelling doubt, the reality or otherwise of a *padmarága* will be indubitably ascertained by rubbing it upon a whetstone or with a *padmarága* of tested genuineness. A false *padmarága* will receive scratches from the process.

212. That *padmarága* which shines out the more, the more it is rubbed, and which is moreover not light, is a pure gem; the others are impure.

213. Excepting *kuruvinda* and diamond, no gem can make scratches upon either the *padmarága* or the *indranila.*

214. A genuine *kuruvinda* is worth as much as a *padmarága* furnished with every quality.

215. A *saugandhika* is worth three-fourth the price of a *kuruvinda.*

216. A súdra *padmarága* is, according to the authorities, worth three-fourth the price of a Vaisya *padmarága.*

217. All gems derive their value from their lustre and their color; accordingly, gems which are found wanting in these two essentials are of small worth.

218. When doubts arise as to the reality of a gem, the infallible test is to rub it with another gem of tested worth. A false gem will be reduced to fragments under the process.

219. The treasuring up of a *padmarága* furnished with every perfection is as meritorious as the celebration of the *Aswamedha jajna,* and leads to wealth, success and long life. (The Horse Sacrifice [is] a celebrated ceremony, the antiquity of which reaches back to the Vedic period. *Vide* hymns 162 and 163 in the first Mandala of the Rig Veda. In later times its efficacy was to entitle the sacrificer to displace Indra from the dominion of Swarga. In it, the horse was generally, if not always, immolated.)

SAPPHIRE

"———Now glow'd the firmament
With living *Sapphires*——— "
Par. Lost. B. IV.

TRANSLATION.

397. The sapphire is found in the country of *Padmákara* near the river *Rávaná Gangá* in Ceylon.

398. All sapphires are not of the same color. Those found in Ceylon resemble one or other of the following objects:—The blue lotus, a cloth dyed in blue, a polished sword, the *Bhramara* (the black bee), Sri Krishna (A God analogous to the Cupid of classical mythology. His color is represented as beautiful gray), Mahádeva's throat (The throat of the Great Destroyer of the Hindu Triad is blue....), the eye in a peacock's tail, the black *aparájitá* (a name applied to several plants, Clitoria Ternatea, Marsilia Quadrifolia, Sesbania Ægyptiaca).

399–400. The 'dark blue ocean,' the peacock's throat, the bubbles of blue water and the throat of the mad *Kokila* (*Vide antè*). These kinds of the Sapphire are generally found.

401–402. A blue Sapphire with a white shade is a Brahmin; a blue one with a red shade is a Kshetrya: a Sapphire of the same color with a yellow lustre is a Vaisya; and finally a blue Sapphire shining in dark lustre is a Súdra.

403. As Rubies are good, middling and bad,—so it is also with Sapphires.

404. That Sapphire whose interior gleams with the iris, is a rare gem of priceless worth.

405. That Sapphire which being thrown into a quantity of milk a hundred times its bulk, paints the whole mass with its native blue, is entitled a *mahánila* ['great sapphire'].

406–407. Of gems, those which are blue, are Sapphires; those which are red, are Rubies; those which are green, are Emeralds; those which are red with a shade of yellow are *Kasáyas;* those which are ash-colored with a yellow shade, are *Pushparágas;* those of the last which are red, are called *Kaurandakas.*

Qualities of the Sapphire.

408. Weight, coolness, depth of color, the quality of being *parsvavarti* (see 411.) and beauty, invest a Sapphire with matchless worth.

409. That Sapphire which combines great weight with small bulk is called *Guru* (literally 'heavy'): such a gem conduces to increase of family. That which always gives out moisture is called *Snigdha* (*vide antè*). A *Snigdha* Sapphire brings on accession of wealth.

410. That Sapphire which, on being exposed to the morning sun, flames in a blue effulgence, is termed *Varnadhya.* It brings prosperity.

411. That Sapphire through which any lustrous substance such as crystal, silver, gold, is seen, is entitled *parsvavarti.* A *parsvavarti* Sapphire brings on fame.

412. That Sapphire which, when placed in a pot, darkens it all through, is called *Ranjaka.* This gem increases wealth and is conducive to fame and increase of family.

Defects of the Sapphire.

413. *Avraka, Trása, C'itraka, Mridgarva, Asmagarva,* and *Raukshya* are the six defects of Sapphires.
414. A Sapphire the surface of which wears a mica-like sheen, goes by the name of *Avraka.* Such a gem brings about loss of wealth and life.
415. That mark in a Sapphire which at first sight looks like a rift, is called *Trása.* A *Trása* renders one liable to bites. That Sapphire which is party-colored, is called *C'itraka:* it causes loss of family dignity.
416. That Sapphire which contains dirt, has the sobriquet of *Mridgarva.* This gem produces a variety of skin-diseases like itching.
417. That which contains gritty fragments, is called *Asmagarva.* This defect is destructive. That which is rough, is called *Raukshya.* Banishment is the consequence of wearing this jewel.
418. A flawless, sterling Sapphire brings its wearer, strength, fame and length of days.
419. The man who wears a Sapphire of spotless chastity, finds favor with *Náráyana* (the Preserver of the Hindu Triad) and acquires longevity, family dignity, fame, understanding and wealth.
420. Those good and bad consequences which follow the wearing of a *Padmarága* combining good and bad qualities, are also produced by the wearing of a Sapphire of a like nature.
421. A Sapphire is distinguishable from glass by weight and hardness only.
422. A shining gem which is found in Sapphire quarries, resembling the *Vramara,* and furnished with a shade, is called *Vramara.*
423. That Sapphire which shows a dash of red, is called *Títtiva* (amethyst). No sooner a woman who is in her family way, wears a *Títtiva* than she is delivered of her child, with perfect ease.
424. The price of the best Sapphire is equal to that of the best *Padmarága.*

The Process of Refining Gems.

55. Acid water refines rubies;...
56. The gruel of *kulathya kaláya* refines the ruby;... blue water, the sapphire;...
57. After mixing up (according to some) the juice of the *Mádára, Manahsilá,* sulpher, and haritál, one should boil them in *putpák* eight times: every other gem except the diamond is thus refined.
58. According to others, rubies, pearls, corals and other gems are refined by boiling them for a *prahara* in a vessel containing the juice of *jayanti,* hung up over a fire.

General Properties of Gems, according to Sanskrit Medical Science.

Particular Properties of the Ruby.

62. The Science of Gems has it that ruby is sweet, cool, specific for imperfect oxidation and biliousness, and very valuable in chemical operations.

Particular Properties of the Sapphire.

68. The sapphire is bitter, warm and good in cold and biliousness, and alleviates the rage of *sani* (One of the stars influencing men's destinies. The astral influence is still undoubtingly believed in by the Hindus.) when worn.

S.M. Tagore, 1879, 1881, *Mani-Málá*

Table A.1: Sanskrit names of corundum gems[a]

Sanskrit name	English translation
Ruby	
Manikya	Ruby
Shona-ratna	Red jewel
Padmaraga	Red lotus-colored gem
Ravi-ratna	Gem of the sun
Blue sapphire	
Nilam	Blue sapphire
Sani-ratna	Saturn's gem
Nila-mani	Blue jewel
Indra-nilam	Royal blue gem
Yellow sapphire	
Pusparaga	Yellow sapphire
Vascaspati-vallabha	Beloved of Jupiter
Pita-rakta-mani	Orange jewel
Guru-ratna	Gem of the guru
Pita-mani	Yellow jewel
Puspa-raja	King of flowers

a. From Brown, R.S. (n.d., ca. 1988) *Handbook of Planetary Gemology.* Hong Kong, McKinney International (Publication Concepts), revised edition, 88 pp.; RWHL.

APPENDIX B

RUBY & SAPPHIRE PRICES

The golden guess is the morning-star to the full round of truth.

Lord Alfred Tennyson [1809–1892], *Columbus*

WHAT'S the price? That is the question on everyone's lips. Unfortunately, the answer seems only to spring from the lips of the seller.[1]

Lack of a universally-accepted system of quality analysis and the numerous *non-quality* factors which can affect price make it extremely difficult to come up with logical price tables for ruby and sapphire. But difficult does not equal impossible. In an attempt to bring ruby and sapphire pricing in from the cold, the author, together with Donald A. Palmieri of *Palmieri's GAA Market Monitor,* [2] has compiled the following tables. Consider this a brave attempt at bringing order to chaos. And when you find inconsistencies and mistakes, just remember that old saying about how you can tell the pioneers by the arrows in their backs.

Market memos—May, 1995

Ruby

Burma (Mogok & Mong Hsu). Mogok rubies continue to bring top prices in the wholesale trade and at auction. There is an ample supply of heat-treated commercial stones, but most of these originate from the Mong Hsu area, not Mogok. Approximately 70–75% of the better-quality Mogok rubies going through certification reveal either low temperature heat or no evidence of heat treatment at all. According to the markets monitored, there is no difference in value for these categories. Of the 25–30% heated to high temperatures, most will sell for up to a 40% discount below the price for the untreated and low temperature heated stones.

Thailand/Cambodia. More than 99% of all Thai/Cambodian rubies have been subjected to high-temperature heat treatment. Fine goods are scarce and Far East demand continues to put upward pressure on prices. Many fine goods remain in the inventories of American dealers.

Blue sapphire

Kashmir. As more heat-treated Kashmir sapphires are found in the market, the question of value differences between heated and unheated Kashmir stones becomes evermore important. Fine Kashmir sapphires are distinctive in color, texture and inclusions and so can often be positively identified as to country of origin. Heat-treatment makes origin determination more difficult, with heated Sri Lankan stones being confused with Kashmir, and vice versa. Extreme caution is recommended when buying, selling or appraising. Market values listed are for untreated stones only. Some dealers will charge the same for a treated stone, and some discount a treated stone up to 30–40%. One thing is certain—a dealer will not pay as much for a treated Kashmir sapphire.

Burma (Mogok). Supplies of Mogok sapphires are as tight as for Mogok rubies. There is little fine material around. Prices are relatively stable, and those who deal in better sapphires buy all they can. Mogok sapphires are being heat treated

1. See 'Pricing factors', p. 217, for a full discussion of the issues involved in pricing.

2. *Palmieri's GAA Market Monitor* is a monthly report on gemstone prices in the US. For subscription information, contact the Gemological Appraisal Association, Inc., 658 Washington Rd., Pittsburgh, PA 15228, USA; Tel.: 412-344-5500; Fax: 412-344-4910.

with increasing frequency. Like their ruby cousins, heat-treated Mogok sapphires are worth less than unheated stones.

Sri Lanka. Today, most Sri Lankan sapphires have been heat treated to improve their color. From about 1975–1985, the market heat treated stocks of *geuda* sapphire which had built up over the centuries. These stocks are now depleted. In addition, heavy rainfall in the early 1990s also hurt production. While mining is today proceeding normally, little fine material is available. In historical terms, this is the *normal* state of affairs for sapphire mining in Sri Lanka. Thus, barring development of new treatments/new mines, we cannot expect to see the availability of Sri Lankan sapphire ever again reach the levels of the early 1980s.

Other blue sapphire sources. This includes sapphires from many localities, including Australia, Thailand, Cambodia, Laos, Nigeria, China, etc. Virtually all sapphires from these sources have been heat treated. Stones from these sources tend to be iron-rich, and of darker, inky-blue colors. Thus they are of lower value than the better stones from Kashmir, Burma and Sri Lanka. Many stones found in investment and barter scams come from these sources. But keep in mind that good and bad come from every mine. A small quantity of fine sapphires are found in Australia, and it would be far better to have a fine Australian sapphire than a poor piece from Kashmir or Burma.

Fancy sapphires

The term *fancy sapphire* is used to describe corundums other than red or blue. When it comes to fancy sapphires, Sri Lanka is king of the hill. Within this small island are found sapphires of virtually every color, including some for which the island is the definitive source (such as the lovely pink-orange *padparadscha*). Tanzania's Umba Valley is also noted for fancy sapphires, as are Montana's non-Yogo mines. But again, Sri Lanka is King, with a capital *K*. The sizes and colors found on that island are enough to make any Montana or Tanzanian miner cry uncle.

Yellow & orange sapphire. Yellow sapphires from Sri Lanka are generally of a light to medium hue, without any brownish overtones. Like Sri Lankan blues, deeper hues are reached only in larger sizes, or via heat treatment. Heat treatment produces deeper yellows, golds and oranges that are virtually unknown, or rare in nature. The very rare pinkish orange *padparadscha* sapphire is found mainly in Sri Lanka and at Vietnam's Quy Chau mines. While similar gems are sometimes found at Tanzania's Umba mines, most from this locality tend towards the brownish orange. Padparadschas from Sri Lanka sometimes fetch prices that rival even ruby.

Thailand and Australia both produce fine yellow sapphires, with the stones from Chanthaburi in Thailand grading into the highly desirable *Mekong Whisky* golden yellow to orange colors. These bring high prices locally in Thailand and are quite beautiful. Australian yellow sapphires tend to be overly greenish, although fine golden yellows are found in the Anakie, Queensland mines. Sri Lanka, Thailand and Australia are the only sources which produce deep yellow sapphires in any quantity, although Montana and the Mogok area produces the occasional stone.

Green sapphire. The finest green sapphires come from Sri Lanka, but are extremely rare. These stones tend to be of a lighter and more lively green than the Fe-rich stones from Thailand and Australia. The latter two countries do produce good green sapphires, but most tend towards an impure blue-green or yellow-green which is not very attractive. Green sapphires of good color and clarity over 10 ct in size are relatively scarce.

Violet and purple sapphire. Violet and purple sapphires are found mostly in places which produce both ruby and blue sapphire. The finest stones come from Mogok, Sri Lanka and Vietnam. Purple stones bordering on ruby color are most valuable and may reach prices approaching those of ruby. Star stones are possible, but relatively rare.

Color-changing sapphire. Among the most unusual sapphires are those which display a change of color. These are judged by the quality of color change, the best ranging from the green side of blue in daylight to a reddish purple in incandescent light. A number of sources produce such stones, but fine examples are rare. The best are colored by vanadium (just like the Verneuil synthetic corundums) and come from Mogok and Umba, Tanzania. These are extremely rare. More common are Sri Lankan gems which contain a mixture of chromium (red) and iron-titanium (blue). Such stones appear bluish violet in daylight and purple under incandescent light. In the author's opinion, these are marginal as color-change sapphires. Most tanzanite shows a similar color shift.

Star stones & cabochons

Prices of star stones and cabochons are generally slightly lower than their faceted brethren of the same quality, but may approach those of faceted stones in the highest qualities. Good quality stars and cabochons must display fine transparency and color (see 'Judging stars & cabochons', p. 222).

Treatments

Virtually all rubies and sapphires sold today have been subjected to high-temperature heat treatment for color and/or clarity enhancement (the exception is stones mined prior to 1975 and not subsequently treated). Today, it is the rare stone which has *not* been heat treated. Telltale signs of this treatment can often be found by experienced gemologists (see page 116). Market values for Thai/Cambodian rubies and most sapphires are based on the assumption that all have been heat treated. Conversely, market values for Mogok rubies and blue sapphires and Kashmir blue sapphires are based on positive gemological proof of country of origin and no detectable trace of any treatment (beyond ordinary cutting and polishing). Fracture-filled rubies are showing up more frequently than in the past, particularly from Mong Hsu (Burma). For blue stones, be aware of surface-diffusion treatments. While experienced gemologists can easily identify this material (via magnification and immersion), it can fool the unwary. Also be aware of synthetic corundums treated by the surface-diffusion process (synthetic colorless sapphire is far cheaper than naturally-mined material).

Buying/Selling/Appraising

The buying, selling and appraising of rubies and sapphires must be undertaken with the utmost care and caution. Know *what* you are buying and from *who* you are buying. Ask about treatments, heat, fracture-filling and otherwise. It may not be important to you until your client finds out from another jeweler or appraiser that the ruby he/she purchased from you has glass-filled cavities. According to the law, ignorance is no excuse. When selling, fully disclose *everything*, including things you take for granted that a judge or consumer affairs reporter would interpret as misrepresentation (even if by omission). When appraising, never identify a stone unless positive evidence is found. If doubt exists, get a second opinion locally or obtain your client's permission to send it to a competent lab for further analysis. This goes for natural vs. synthetic, treated vs. untreated and/or country of origin. The appraisal fee is never high enough to risk one's integrity and reputation on a brief moment of misjudgment. In summary, report everything *you* would want to know if *you* were purchasing the gem.

Category notes

Categories represent broad, integrated quality grades, based on a combination of color, clarity and cutting quality.

Exceptional: These stones are seen only in the finest jewelry, and are rarely encountered. High-end prices for category A represent the highest prices paid at auction. Stones fetching the highest prices are generally those certified as being untreated and of preferred origin (Burma for ruby; Kashmir and Burma for sapphire). All stones in this category will feature exceptional color, with good clarity and cutting.

Very good: These stones are found in high quality jewelry, but are also rarely seen. Such stones feature fine color, with good clarity and cutting.

Good: This category includes stones found in most jewelry. They represent the vast majority of stones traded. Such stones may feature good color, with slight clarity or cutting problems, or be clean and well cut, but have slight color problems (generally lower saturation or overly dark color).

Fair: The upper end of this category represents stones traded in inexpensive jewelry. Such stones often feature color that is overly dark or light, or have serious clarity problems.

Poor: High-end prices for this category represent the lowest quality of stones found in the cheapest jewelry. Low-end prices for this category represent material of little or no gem use. Typically, stones in this category are far too heavily included, or possess the lowest in color saturations.

Price notes

- Prices quoted should be considered average world prices.[3] They represent average cost to retailers from dealers for net cash single stone or small lot purchases. Net cash means payment by bank wire immediately after receipt, or a check within 15 days of receipt. In general, large lot purchases are less expensive while memo and term transactions are more expensive. Matched pairs or suites of any size or shape will almost always cost more than single stones of the same quality.
- All prices are for uncalibrated stones, unless otherwise noted.
- The prices provide only a crude estimate; accurate estimates of the price of an individual stone can only be made by an experienced dealer via personal examination (no pictures, or lab reports!).
- Quality is determined by a combination of color, clarity and cut, relative to probable origin and size. Most stones used in jewelry will fall into the *Fair* to *Good* range.
- In certain local markets, where there is high demand and appreciation for a particular local stone, the price may dramatically exceed that found in the above tables. For example, a fine Yogo sapphire of 2 ct or more may fetch $3000–5000/ct when sold in Montana. If the same stone were taken to Bangkok, it would be difficult to get $2000/ct. Similarly, a fine Mekong Whisky golden sapphire of 5–10 ct from Chanthaburi could fetch as much as $1000/ct or more in the local Thai market, but would receive only a fraction of that price elsewhere.
- Due to the extreme rarity of exceptional rubies and sapphires of 10 ct or more, it is far more difficult to give accurate pricing information. Basically, the price is whatever the market will bear, and non-quality factors (such as those discussed on page 217) begin to influence the price to a far greater degree than stones available in quantity.

Price tables

Tables C.1–3 represent an idealized (i.e. logical or regular) structure to a subject that is influenced by many factors which vary in an irregular manner. Use the information for whatever you can get away with (but don't blame the author if you find inconsistencies; gem prices are never consistent and they certainly don't make sense).

3. It may be a cruel reality for some, but prices do not vary too much from country to country, unless heavy government duties apply.

Table B.1: Ruby (including pink) prices—cut stones

Origin	Size	Quality & price per carat (in US$)				
		Poor	Fair	Good	Very Good	Exceptional
Burma, Mogok (certified, untreated)	< 0.49 ct	$1–25	$25–50	$50–300	$300–600	—
	0.5–.99 ct	$1–60	$60–350	$350–700	$700–3000	$3000–4000
	1.0–1.99 ct	$1–400	$400–800	$800–3500	$3500–4600	$4600–10,000
	2.0–4.99 ct	$1–900	$900–1500	$4000–5300	$5300–11,500	$11,500–125,000
	5.0 ct +	$1–1200	$1500–6100	$6100–13,200	$13,200–144,000	$144,000–225,000
All other sources[a] Afghanistan, Jagdalek Burma, Mogok, Mong Hsu Kenya Sri Lanka Tanzania Thailand/Cambodia Vietnam (all generally heat treated)	< 0.49 ct	$1–25	$25–50	$50–300	$300–500	—
	0.5–.99 ct	$1–60	$60–350	$350–575	$575–2300	$2300–3500
	1.0–1.99 ct	$1–400	$400–650	$650–2600	$2600–4000	$4000–6,000
	2.0–4.99 ct	$1–700	$750–3000	$3000–4600	$4600–7000	$7000–20,000
	5.0 ct +	$1–1000	$1000–5300	$5300–8000	$8000–23,000	$23,000–100,000

a. Note: Due to their lack of fluorescence and light-scattering silk inclusions, Thai/Cambodian rubies will rarely fall into the exceptional category.

Table B.2: Blue sapphire prices—cut stones

Origin	Size	Quality & price per carat (in US$)				
		Poor	Fair	Good	Very Good	Exceptional
Kashmir, India Mogok, Burma (certified, untreated)	1.0–1.99 ct	$1–300	$300–2000	$2000–3400	$3400–4500	$4500–7550
	2.0–3.0 ct	$1–500	$500–3900	$3900–5200	$5200–8700	$8700–11,000
	3.0–4.99 ct	$1–700	$700–6000	$6000–10,000	$10,000–12,700	$12,700–13,500
	5.0 + ct	$1–1000	$1000–11,500	$11,500–14,600	$14,600–15,500	$15,500–45,000
All other sources Australia China Montana, USA Nigeria Sri Lanka Tanzania Thailand/Cambodia Vietnam (all generally heat treated)	< 0.49 ct	$1–35	$35–175	$175–200	$200–300	—
	0.5–.99 ct	$1–200	$200–225	$225–350	$350–500	—
	1.0–1.99 ct	$1–250	$250–450	$400–575	$575–700	$700–1500
	2.0–4.99 ct	$1–500	$500–850	$650–800	$800–1700	$1700–3000
	5.0 ct +	$1–975	$975–1100	$1100–2000	$2000–3500	$3500–10,000

Table B.3: Fancy sapphire prices—cut stones

Variety	Size	Quality & price per carat (in US$)				
		Poor	Fair	Good	Very Good	Exceptional
Orange sapphire		Generally similar to higher end yellow sapphires. Certified Sri Lankan *padparadschas* can reach prices close to those of ruby.				
Yellow sapphire	>2.0 ct	$1–40	$25–60	$75–125	$100–200	$125–250
	2.0–4.99 ct	$1–50	$50–125	$125–200	$200–300	$275–375
	5.0 ct +	$1–75	$75–125	$150–225	$300–450	$400–1200
Purple/violet sapphire	1.0–1.99 ct	$1–50	$50–200	$140–175	$175–250	$200–500
	2.0–4.99 ct	$1–100	$100–400	$400–500	$500–600	$600–1000
Green sapphire	<1.0 ct	$1–10	$10–13	$13–15	$15–20	—
	1.0–2.99 ct	$1–15	$15–18	$18–20	$25–40	—
	3.0 ct +					up to $200
Colorless sapphire	3.5–4.5 mm.	$7–14/each				
Black star sapphire	>1.0 ct	$3–10				
	>1.0–4.99 ct	$10–50				
	5.0 ct +	$30–100 (golden stars may reach $200/ct)				

APPENDIX C

RUBY & SAPPHIRE WEIGHT ESTIMATIONS

DUE to tremendous variation in cutting proportions of ruby and sapphire, it is not possible to estimate weight with the same accuracy of diamond. However, rough estimations can be made. The following tables will assist in such estimations.

Weight estimations of faceted gems

Formulae in Table C.2 are based on stones with thin to medium girdles, no pavilion bulge and well-proportioned shapes (narrow wings and low shoulders). Deviations from these proportions may require percentage modifiers to the final determined value.

Table C.1: Approximate weights of ruby and sapphire

Shape	Size (in mm)	Weight range	Shape	Size (in mm)	Weight range
Round	2.0	.04	Pear	5 × 3	.21–.26
	2.5	.08		6 × 4	.48–.52
	3.0	.13		7 × 5	.74–.90
	3.5	.23		8 × 5	.85–1.00
	4.0	.32–.36		9 × 6	1.45–1.65
	4.5	.52–.56		10 × 7	2.20–2.49
	5.0	.68–72			
	5.5	.75–.85	Rectangular emerald	5 × 3	.20–.36
	6.0	1.10–1.15		6 × 4	.66–.75
	6.5	1.40–1.50		7 × 5	1.20–1.30
	7.0	1.56–1.76		8 × 6	1.90–2.05
	7.5	1.80–2.20		9 × 7	2.90–3.10
	8.0	2.35–2.75		10 × 8	4.00–4.40
Oval	5 × 3	.25–.33	Marquise	4 × 2	.12–.15
	6 × 4	.58–.62		5 × 3	.25–.27
	6.5 × 4.5	.65–.79		6 × 3	.28–.32
	7 × 5	1.00–1.08		8 × 4	.72–.76
	8 × 6	1.58–1.64		9 × 4.5	.96–1.04
	9 × 7	2.20–2.46		10 × 5	1.20–1.40
	10 × 8	3.15–3.70		12 × 6	1.90–2.30
	11 × 9	4.20–4.75			
	12 × 10	5.75–7.10			

a. Based on a table compiled by Chatham Created Gems for synthetic ruby. Weight range is approximate only. Actual weight will vary ±10%.

Table C.2: Weight estimation formulae for faceted ruby and sapphire

Shape	Formula	Modifiers
Round	Average diameter² × depth × 4.00 × 0.0018	**Pavilion bulge** Slight: +3–5% Noticeable:+6–8% Obvious:+9–12% Extreme:+13–18%
Oval	Average diameter² × depth × 4.00 × 0.0020	
Square cushion	Average diameter² × depth × 4.00 × 0.0018	
Rectangular cushion	Average diameter² × depth × 4.00 × 0.0022	
Square emerald	Average width² × depth × 4.00 × 0.0023	**Girdle thickness** Slightly thick: +1–2% Thick: +3–4% Very thick: +5–6% Extremely thick: +7–10%
Rectangular emerald	Length × width × depth × 4.00 × 0.0025	
Square (no beveled corners)	Average width² × depth × 4.00 × 0.0024	
Rectangle (baguette, no beveled corners)	Length × width × depth × 4.00 × 0.0026	
Pear	Length × width × depth × 4.00 × 0.0018	**Shape outline deviation** Slight: +2–4% Noticeable: +5–6% Extreme: +7–10%
Marquise	Length × width × depth × 4.00 × 0.0017	
Heart	Length × width × depth × 4.00 × 0.0018	
Triangle	Length × width × depth × 4.00 × 0.0018	

a. Based on *Palmieri's GAA Market Monitor*, May, 1995.
b. These deviation percentages should be added to the finished weights calculated using the table's fomulae.
c. Average diameter = longest diameter × shortest diameter ÷ 2.
d. Average out horizontal, vertical and diagonal measurements for diameter.

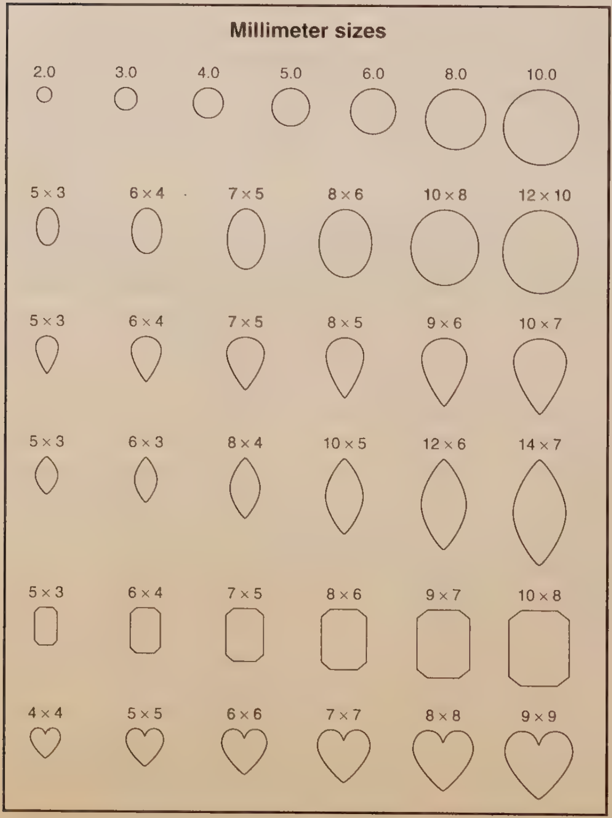

Table C.3: Weight estimation of cabochon corundums (formula = length × width × depth × 4.00 × factor)

	.0029	.0029	.0029	.0029	.0029
	.0025	.0025	.0023	.0024	.0024
	.0026	.0026	.0024	.0025	.0025
	.0027	.0027	.0025	.0026	.0026
	.0028	.0028	.0026	.0027	.0027
	.0029	.0029	.0027	.0028	.0028
	.0029	.0029	.0029	.0029	.0029
	.0026	.0026	.0026	.0026	.0027
	.0027	.0027	.0027	.0027	.0028
	.0028	.0028	.0028	.0028	.0029
	.0029	.0029	.0029	.0029	.0030
	.0023	.0023	.0023	.0023	.0023
	.0023	.0023	.0023	.0024	.0024

	.0023	.0023	.0024	.0025	.0025
	.0023	.0024	.0025	.0026	.0026
	.0024	.0025	.0026	.0027	.0028
	.0024	.0024	.0024	.0026	.0026
	.0026	.0026	.0026	.0028	.0028
	.0028	.0028	.0028	.0030	.0030
	.0026	.0026	.0026	.0026	.0026
	.0028	.0028	.0028	.0028	.0028
	.0030	.0030	.0030	.0030	.0030
	.0024	.0024	.0024	.0024	.0024
	.0026	.0026	.0026	.0026	.0026
	.0028	.0028	.0028	.0028	.0028

a. The above table is based on Newman, 1994 (which was based on a GIA handout).

INDEX

Numbers in italics indicate illustrations.

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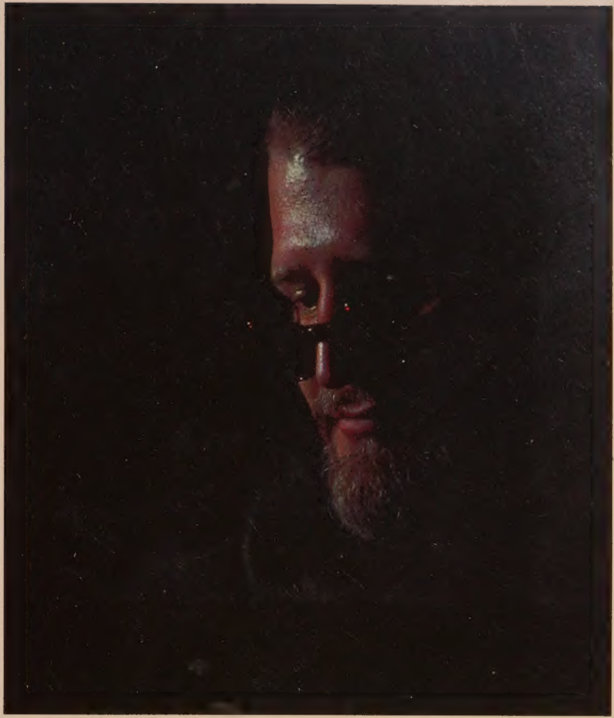
IN this dream I'm on a tightrope
and I'm tipping back and forth
trying to keep my balance.
And below me are all my relatives
    and if I fall I'll crush them.
This long thin line.
This song line. This shout.
The only thing that binds me
    to the turning world below
    and all the people and noise
    and sounds and shouts.
This tightrope made of sound.
This long thin line made of my own blood.
Remember me, is all I ask.
And if remembered be a task, forget me…

Laurie Anderson, *Tightrope*



RICHARD W. HUGHES is one of the world's foremost authorities on ruby and sapphire. A fellow of the Gemmological Association of Great Britain, his first book, the highly-regarded *Corundum,* was published in London in 1990.

While a native of the United States, the author has spent close to half his life in Asia, where his interest in precious stones was first kindled. Richard graduated from Bangkok's Asian Institute of Gemological Sciences in 1979; shortly thereafter he was invited to join their staff. He was later appointed executive vice-president, a position he held for close to a decade. Under his directorship, the institute blossomed into one of the world's leading facilities in gemological education.

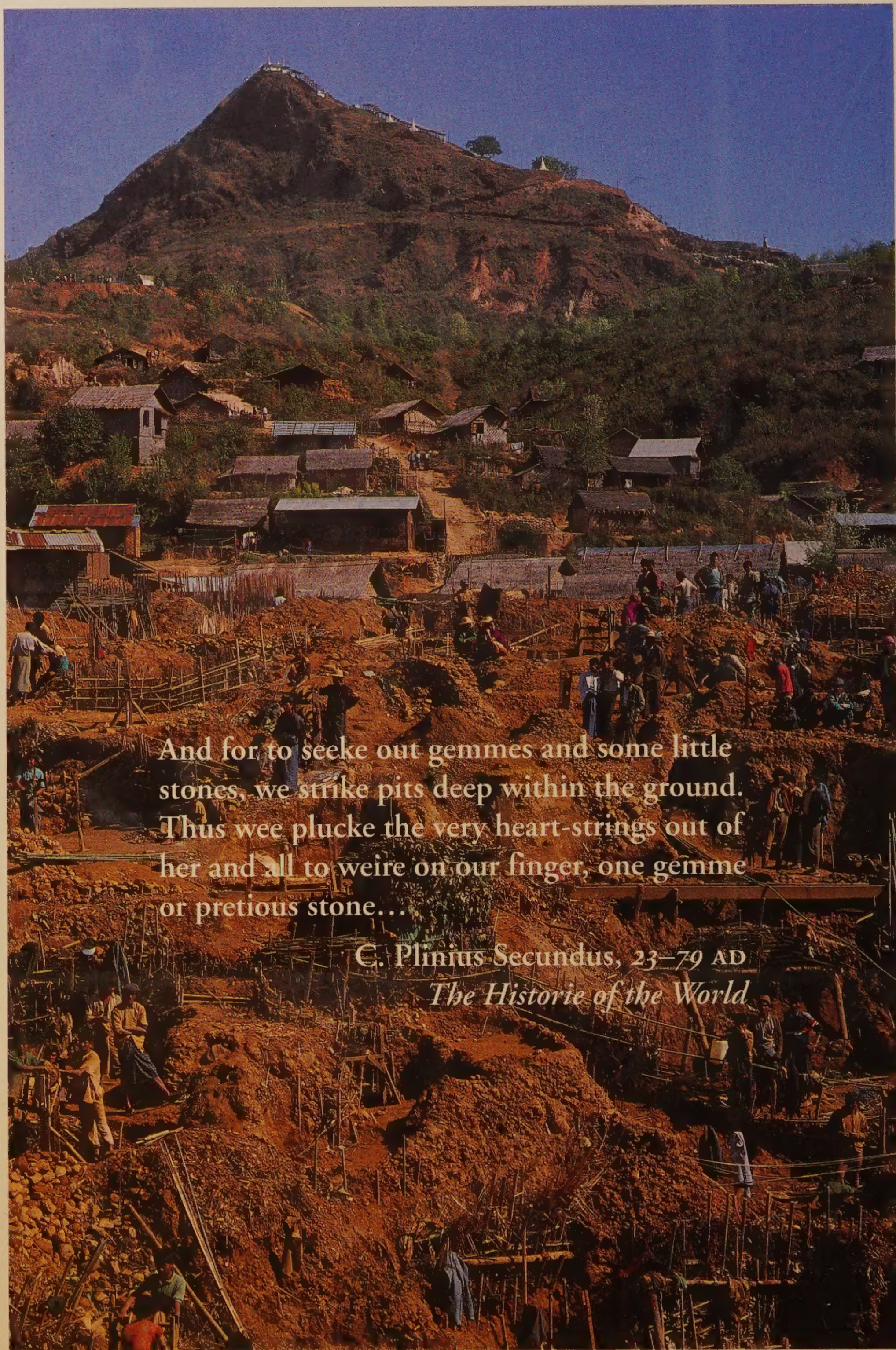
Mr. Hughes has traveled to scores of countries in search of precious stones and authored dozens of articles on all aspects of the gem and jewelry trades. His writings have appeared in major publications throughout Europe, Asia, North America and Australia and his "Devil's Advocate" column is a regular feature of *JewelSiam* magazine.

Richard's irreverent writing style has attracted a widespread following throughout the world, making him much in demand as both speaker and writer. He is recognized for his ability to take complex subjects and make them both compelling and easily understood.

When not visiting ruby and sapphire mines in far-off lands, Mr. Hughes heads up RWH Publishing, which produces books on precious stones. Today, the author makes his home in Boulder, Colorado, where he lives with his wife, Wimon, and daughter, Billie. While he has no family dog, he does admit to having a few fish.

Inside cover: *The ruby mines of Mogok, Burma, as seen by the first British expedition in 1887. (From* The Graphic, *1888, The valley of Mogok—Ruby Mines District, Upper Burmah. London, Feb. 4, 1888, p. 106).*

Rear cover: *In the shadow of Pingu Taung ('Spider Mountain'), in Burma's Mogok Stone Tract, miners tunnel into the hillside in search of rubies. Since early times, Mogok has been the source of the world's finest rubies. (Photo: Thomas Frieden)*



And for to seeke out gemmes and some little stones, we strike pits deep within the ground. Thus wee plucke the very heart-strings out of her and all to weire on our finger, one gemme or pretious stone...

C. Plinius Secundus, *23–79* AD
The Historie of the World

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