GEMS & GEMOLOGY

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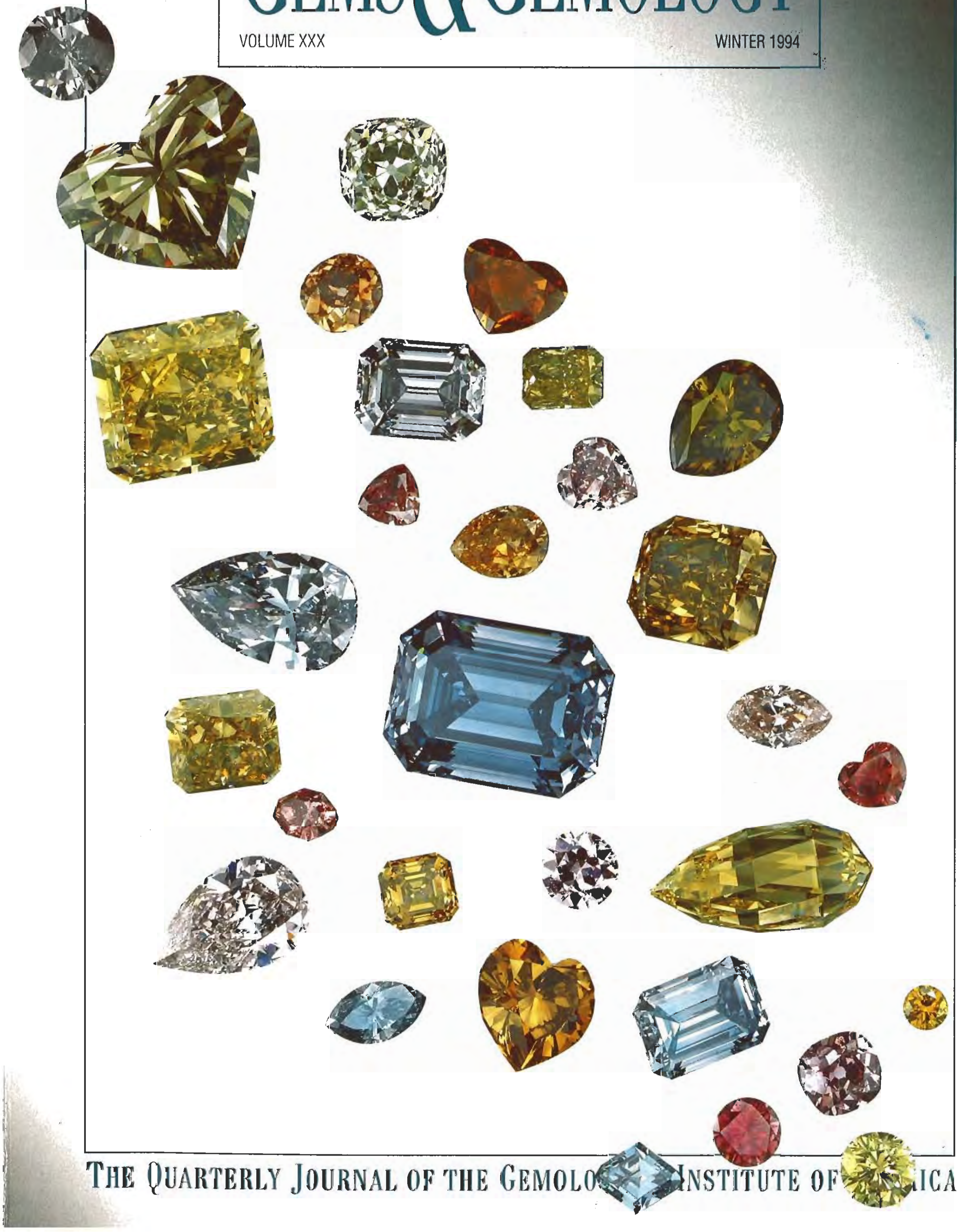

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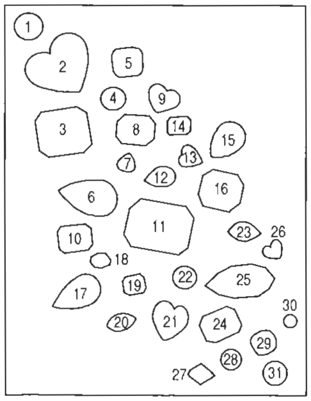

ABOUT THE COVER: Colored diamonds are among the most intriguing and valuable gems. This issue presents, for the first time, a report on how the GIA Gem Trade Laboratory color grades colored diamonds. The diamonds here illustrate some of the exciting colors. They were provided by: American Siba, Cora Diamond Corp., U. Doppelt & Co., Ishaia Trading Corp., I. Wolf, L. Wolf, B. Zucker, and GIA GTL. The descriptions below reflect the color grades that would be given on the new grading reports (due to printing fluctuations, color reproduction may not be exact):

(1) 2.73 ct Fancy black; (2) 22.28 ct Fancy grayish yellowish green ("chameleon"); (3) 20.95 ct Fancy Intense yellow (Internally Flawless); (4) 1.56 ct Fancy Deep orange; (5) 5.30 ct Fancy green; (6) 5.59 ct Fancy gray-blue; (7) 0.46 ct Fancy Intense pink; (8) 5.26 ct Fancy gray-blue; (9) 2.20 ct Fancy Deep brownish yellowish orange; (10) 4.49 ct Fancy Deep greenish yellow; (11) 20.17 ct Fancy Deep blue; (12) 1.49 ct Fancy Intense yellowish orange; (13) 0.87 ct Fancy Intense purple-pink; (14) 1.66 ct Fancy Intense greenish yellow; (15) 4.10 ct Fancy Deep grayish greenish yellow; (16) 9.28 ct Fancy Deep brownish yellow; (17) 3.55 ct Fancy pink; (18) 0.54 ct Fancy Deep pink; (19) 1.15 ct Fancy Deep orangy yellow; (20) 0.77 ct Fancy grayish blue; (21) 3.57 ct Fancy Deep brownish orangy yellow; (22) 0.94 ct Fancy Light pinkish purple; (23) 1.07 ct Fancy orangy pink; (24) 3.09 ct Fancy blue; (25) 11.75 ct Fancy yellow; (26) 0.66 ct Fancy Deep pink; (27) 0.59 ct Fancy blue; (28) 0.53 ct Fancy Deep purplish pink; (29) 1.17 ct Fancy Deep purplish pink; (30) 0.17 ct Fancy Vivid orangy yellow; (31) 0.80 ct Fancy Intense yellow-green. Photo © GIA and Harold & Erica Van Pelt—Photographers, Los Angeles, CA.

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Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in the Fall 1994 issue of the journal, or contact the editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

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GEMS & GEMOLOGY: SIXTY YEARS OF HISTORY AND HISTORY-MAKING

Richard T. Liddicoat, Editor-in-Chief

In 1994, *Gems & Gemology* marked its 60th year of continuous publication. During that time, it has grown in size and impact, becoming a key vehicle for communicating critical information to the international gemological community.

Since its inception, *Gems & Gemology* has had only two editors-in-chief: Robert M. Shipley (from 1934 through 1951) and myself (since 1952). This has been primarily a policy-setting function, with most of the labor-intensive activity carried out by a succession of associate editors and editors. The first was the diminutive Anna Beckley. With her retirement, the job fell to me for a year or two. Following World War II, first Kay Swindler and then Jeanne Martin, Lawrence Copeland, and John Koivula served capably as associate editors. Nevertheless, by 1980, the subscription list was only 1,500. In 1981, the journal was redesigned to its current, larger size, with full-color illustrations throughout and a first-rate editorial board (each article is now reviewed by at least three experts). Under the sure hand of Editor Alice Keller, paid circulation has since leaped to almost 10,000 subscribers in more than 70 countries.

The journal has been influential almost from its beginning. Early issues published much of Edward Gübelin's pioneering gemstone inclusion studies, as well as articles by such other great gemologists as Robert Webster and Lester Benson. Basil W. Anderson and Robert Crowningshield wrote on gem spectroscopy, John Sinkankas described cutting the huge colored stones, George Kaplan contributed on diamond cutting, and Kurt Nassau provided seminal work on gem treatments, to name only a few. These early issues also reported on such new materials as taaffeite, tanzanite, and tsavorite shortly after they were discovered, as well as on important new finds of known gems, including the Siberian diamond discoveries. Through the pages of *G&G*, Mr. Shipley's elder son, Robert Jr., first reported on combining stereoscopic magnification with darkfield illumination to study gems, as well as on his polariscope, which used a thin polarizing sheet in place of Nicol prisms.

Gems & Gemology still endeavors to remain at the forefront of our rapidly developing science. In the past few years, this focus has been evident in articles on such vital subjects as identifying heat, irradiation, and diffusion treatments; separating natural from synthetic gem-quality diamonds and colored stones; and detecting laser drilling and fracture filling in otherwise natural diamonds. As treatments and synthetics have become more sophisticated, *G&G* has introduced readers to the new instruments and higher technologies needed to detect them.

Even though authors are not paid for their contributions, the journal receives more worthy articles than its quarterly allotment of pages can accommodate. We strive to ensure that every issue provides a variety of information that can be applied—now or in the future—in the practice of gemology, and to maintain the high level of professional integrity our readers demand. Our staff and the governors of the Gemological Institute of America are committed to maintaining *Gems & Gemology* as the premier professional publication in its field.

COLOR GRADING OF COLORED DIAMONDS IN THE GIA GEM TRADE LABORATORY

By John M. King, Thomas M. Moses, James E. Shigley, and Yan Liu

The GIA Gem Trade Laboratory (GIA GTL) presents the system it uses to color grade faceted colored diamonds, and the information on which it is based. This system involves a trained grader establishing the characteristic color in a standardized illumination and viewing environment, using various reference materials for color comparison. Here, the Munsell color system is used to illustrate the relationships between the different color terms used. GIA GTL "Fancy grade" nomenclature for colored diamonds has been expanded to better address all colors. This color terminology will soon be incorporated into a new GIA GTL colored diamond report.

Natural-color colored diamonds, traditionally referred to as "fancy colors," hold a special position in the diamond industry. To recall such historic diamonds as the blue Hope, the Dresden Green, or the pink Agra is to conjure up visions of mystery and intrigue, royalty and revolution. Known to many as the "ultimate gem" (figure 1), fancy-color diamonds often command extremely high prices. Perhaps the most celebrated example is the 0.95-ct round brilliant Hancock diamond, first graded "Fancy purplish red" by the GIA Gem Trade Laboratory (GIA GTL) in 1956 (Kane, 1987; Federman, 1992a). Purchased at that time by a Montana collector for US$13,500, in 1987 it sold at auction for $880,000, a record $926,000 per carat. Seven other fancy-color diamonds were sold at auction in the past few years for prices over $250,000 per carat (see list in Giovannini-Torelli, 1993). And in October 1994, a 20.17-ct blue diamond of unknown provenance sold at Sotheby's New York for $9,902,500, or $490,952 per carat (see figure 2 and the cover of this issue).

Whereas colored diamonds were once infrequently encountered, today we see increasing numbers—and a broader variety of colors—in the marketplace (figure 3). For example, during the last decade the Argyle mine in Western Australia has made significantly more colored diamonds available (Hofer, 1985). Some of these diamonds, such as the intensely colored pinks (figure 4), command high prices ($75,000 or more per carat; Federman, 1989a; Cockle, 1994; Winton, 1994); others, such as the brown stones being sold today under the trade names "champagne" and "cognac," provide an affordable alternative to "white" diamonds (Sielaff, 1992; Wagstaff, 1994).

As colored diamonds increased in availability and value, publicity in the trade press also increased (Federman, 1989a and b, 1990a and b; Shor, 1990, 1991; Stephenson,

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See acknowledgments at the end of the article.

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Figure 1. Fancy-color diamonds represent some of the most prized objects in recorded history. These diamonds illustrate some of the colors that diamonds may exhibit naturally, as well as different GIA GTL color grades. For example, the marquise-shaped stone in the ring on the left is a 1.86-ct Fancy Deep blue, whereas the 2.14-ct pear shape is a Fancy blue. The center stone in the other ring is a 1.11-ct Fancy Intense yellow-green. The 12.50-ct briolette is Fancy yellow. The 2.15-ct briolette is Fancy Deep pink, while the 4.43-ct cushion-cut stone to its left is Fancy pink. These six stones are courtesy of American Siba Corp., Ishaia Trading Corp., Moses Jewelers, Isaac Wolf, and Lazar Wolf. Photo © GIA and Harold & Erica Van Pelt.

1992; Bronstein, 1994).[1] This has generated even more interest in colored diamonds and awareness of their special value, further stimulating the market.

In addition, as natural-color colored diamonds have become more prevalent and more valuable, more diamonds that have been color altered by laboratory treatment have also entered the trade. Establishing the "origin of color" of a colored diamond (that is, whether it is natural or laboratory treated) is a great concern for many clients of the GIA Gem Trade Laboratory. Addressing this question has been a major ongoing research effort (involving the examination of several thousand colored diamonds) at both GIA Research and GIA GTL (see, e.g., Ashbaugh, 1992; Fritsch and Shigley, 1989, 1991; Fritsch and Scarratt, 1992; figure 5). As a result, every year thousands of colored diamonds are now submitted to GIA GTL for color-origin determination and, if the stone is found to be of natural color, a color grade on the laboratory report.

GIA GTL recognizes that a means to communicate the colors of such diamonds clearly and consistently is vital to effective commerce. In contrast to colorless-to-light yellow diamonds (i.e., those graded on GIA's "D-to-Z" scale), the value of a colored diamond usually depends more on the rarity of its color than on its clarity, cut, or even its carat weight. In fact, in the words of one prominent diamond cutter, "When you're cutting colored diamonds, you throw away the book" (L. Wolf, pers. comm., 1994). Witness the 0.95-ct Hancock "red" diamond that sold for $880,000; although it was not graded for clarity, inclusions were readily visible. No grading system can completely capture the special character of an individual stone, or its effect on the eye of the beholder. Nevertheless, a meaningful

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[1] *Other sources of information on the mining, marketing, and lore of colored diamonds are the books by Balfour (1992), Blakely (1977), Bruton (1978), Davies (1984), Federman (1988, 1992b), Krashes (1993), Legrand (1984), Orlov (1977), Sinkankas (1993), and Zucker (1984). Information on recent auctions of colored diamonds can be found in the Christie's and Sotheby's sales results, and in pricing guides such as D. Palmieri's* Diamond Market Monitor.

Figure 2. This 20.17-ct Fancy Deep blue diamond recently set a record for the highest per-carat price ($490,952) for a blue diamond sold at auction. Courtesy of Sam Abram, American Siba Corp. Photo © GIA and Harold & Erica Van Pelt.

color description (or "color grade," as it appears on a laboratory report) is a critical communication tool for dealer and consumer alike.

GIA GTL has provided a color description standard for natural-color diamonds for many years. Since the mid-1950s, when GIA GTL began issuing colored-diamond reports, periodic refinements have been made to respond to significant developments—especially treatments and new sources. The system is based on a side-by-side visual comparison of the diamond to one or more "color comparators," under controlled lighting and viewing conditions.

Prompted by the fact that almost every significant colored diamond sold in recent years has been accompanied by a GIA Gem Trade Laboratory report, this article describes the system used by GIA GTL to achieve consistent color descriptions for faceted colored diamonds. Although there are other grading systems for colored diamonds and other gemstones, they are beyond the scope of this presentation.

This article also introduces an expanded "Fancy grade" terminology. Historically, GIA GTL reports have used a series of Fancy-grade terms to describe attributes of certain natural diamond colors. These include *Faint, Very Light, Light, Fancy Light, Fancy, Fancy Intense,* and *Fancy Dark.* In the past, not all of these terms have been used for all diamond colors. In this article, these terms are defined, and two new Fancy-grade terms (*Fancy Deep* and *Fancy Vivid*) are introduced. In addition, *all Fancy-grade terms will be applicable to all natural-color colored diamonds.* GIA GTL will soon introduce a new laboratory report for colored diamonds, which uses this expanded Fancy-grade terminology and includes other improvements.[2]

HISTORY OF DIAMOND COLOR GRADING AT GIA

Since its inception in the 1930s, GIA has played an active role in developing practical color grading systems for diamonds and, more recently, colored gems (Shipley and Liddicoat, 1941; Manson, 1982); this includes the 1988 introduction of a colored stone grading course in GIA education. In the early 1950s, GIA introduced its students to the "D-to-Z" grading system for faceted, colorless-to-light yellow diamonds (Liddicoat, 1955), which comprise the vast majority of diamonds seen in the trade. These letter designations were chosen at that time to differentiate the GIA grading system from other, more loosely defined trade classifications, which typically began with the letter *A*. In the mid-1950s, the GIA Gem Trade Laboratory issued its first laboratory reports using this "D-to-Z" color grading terminology. Since then, several million GIA GTL grading reports have been issued. "GIA has given the trade an objective nomenclature, a living standard that is verifiable through its grading reports," according to diamantaire Martin Rapaport (pers. comm., 1994). This has led to increased consumer confidence in faceted diamonds accompanied by these reports—and to a greatly expanded diamond market.

Each letter in this grading system designates a range of diamond color appearances. Specifically, it describes the *relative absence of yellow color* (e.g., from "colorless"—D, to "light yellow"—Z) seen in the diamond by a trained grader working in a controlled lighting and viewing environment. To establish a letter grade for a particular stone, the grader

Figure 3. This collection represents the dramatic range of colors in which diamonds occur naturally. Courtesy of Aurora Gems; Photo © Harold & Erica Van Pelt.

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[2] *Note that this article contains a number of photos of colored diamonds. Because of the inherent difficulties of controlling color in printing (not to mention the instability of inks over time), the color in an illustration may differ from the actual color of the stone.*

Figure 4. Since the mid-1980s, when the mining operation at Argyle in Western Australia went into full production, the market has seen an influx of attractive, highly saturated pink diamonds. The Argyle diamonds illustrated here were part of a lot of more than 50 stones that were submitted to GIA GTL on a single occasion. Photo © Harold & Erica Van Pelt.

visually compares the color appearance of this stone to that of one or more "master color-comparison diamonds" (often referred to as "masterstones"). He or she views them side-by-side in the same approximate orientation, and predominantly table-down through the pavilion facets. In this viewing position, the effects of facet reflections are minimized, and the subtle bodycolor is more apparent.

By definition, each GIA GTL masterstone designates the position *with the least color* in a given color-grade range along a scale often perceived as linear. For example, a single color description of "E" represents a range of color between the finest "E" and that which is just better than the "F" master; a stone with less color would be graded "D". The boundaries on this scale were established both to provide a simple description terminology and to reflect visual color distinctions made in a practical way within the jewelry industry. Some concepts of the "D-to-Z" grading system formed the basis for GIA GTL's ensuing work on grading colored diamonds. These include boundaries marked by diamond masterstones, color terms applying to ranges of color appearances, and side-by-side comparisons in a controlled lighting and viewing environment.

The "D-to-Z" system was specifically designed for colorless-to-light yellow diamonds, but it proved readily adaptable to include near-colorless to light brown diamonds as well. As we continued to refine the GIA GTL grading system, modifications were made to accommodate those "brown" (relatively common) and also "gray" (less common) faceted diamonds that could be considered equivalent to grades between "K" and "Z". For brown stones, a letter grade plus word descriptions of *Faint*, *Very Light*, and *Light* brown are used for grade ranges

K–M, N–R, and S–Z, respectively. For gray stones, we apply verbal descriptions only of *Faint*, *Very Light*, and *Light* gray for these same three letter-grade ranges. (Those brown or gray diamonds that appear more colorless than the "K" masterstone continue to receive the appropriate letter grade without further description.)

GIA GTL's interest in the color origin of colored diamonds was initially sparked in early 1953, when staff members were first shown diamonds treated to "yellow" by cyclotron irradiation (see reports on diamond irradiation by Custers, 1954; Crowningshield, 1958; and Schulke, 1962). As news of the availability of cyclotron-treated diamonds spread in the trade, GIA GTL began to receive large numbers of colored diamonds from clients wanting to know whether the color had been altered by laboratory irradiation and annealing. Almost as soon as it was introduced in 1956, GIA GTL's origin-of-color report began a process of systematic standardization in describing colored diamonds.

During GIA GTL's early efforts to describe color in faceted natural-color diamonds, two important differences from the "D-to-Z" grading system quickly became obvious. First, the *presence of color* in the diamond, rather than its *absence*, was the important criterion. Second, color was best assessed with the faceted diamond in a *face-up position*, given the potentially great influence of cutting style on color appearance. Diamond manufacturers (e.g., L. Wolf, pers. comm., 1984), like our staff, recognized that diamonds that appeared to have a similar bodycolor when viewed table-down could look noticeably different when viewed face-up.

The most obvious example of this is in the transition area for yellow diamonds from the "D-to-Z" scale to the grades used for colored diamonds. Some shapes (such as the "radiant") may intensify the face-up color appearance to the extent that a diamond that might have been graded in the W-to-X range table-down would grade onto the colored-diamond scale. GIA GTL policy is to assess a diamond's color face-up when that color is more intense than that of the "Z" masterstone face-up.

The term *Fancy* was first used on GIA GTL laboratory reports to describe those natural-color faceted diamonds that exhibited either *a noticeable color appearance when the diamond was viewed face-up, or a face-up color that was other than yellow or brown.* The laboratory's color grading system was further refined in the late 1960s and early 1970s, when GIA GTL added several master color-comparison diamonds for fancy yellow diamonds to its diamond master sets. These new masterstones were used to judge the *face-up color of yellow diamonds;* like "D-to-Z" masterstones, they provided important terminology boundaries. Their use was initially prompted by confusion in the trade about the term *canary*, which lacked an accepted definition (G. R. Crowningshield, pers. comm., 1994). Subsequently, additional Fancy-grade terms were introduced (such as *Fancy Intense*), some for diamond colors other than yellow (i.e., some blue and some brown diamonds were described as being *Fancy Dark*). In addition, we began to articulate on our reports the relative proportions of different colors seen in a diamond (e.g., *greenish blue* means that the overall color is less green and more blue).


Figure 5. Green diamonds are an important subject of ongoing research at GIA regarding the separation of natural-color from laboratory-treated diamonds. This 4.24-ct natural-color Fancy green diamond is surrounded by a suite of yellow to green rough diamonds. The cut stone is courtesy of American Siba Corp.; the crystals are from Cora Diamond Corp. Photo by Robert Weldon.

Whenever possible, in collaboration with the trade, we established important boundary distinctions and added appropriate master color-comparison diamonds. However, we acknowledged early on the practical problems of finding and purchasing all the masterstones that would be needed to cover the wide range of colors in which diamonds occur naturally (again see figure 3). Also significant was the problem of obtaining more than one stone of a specific color for use at laboratory locations in different cities.

The appearance of diamonds with very subtle colors other than yellow posed an additional challenge to our nomenclature system. Some diamonds were encountered that, at first, did not appear to exhibit any color when observed in the face-up position; however, when compared to diamonds associated with the "D-to-Z" color grading scale, they clearly displayed hues different from the yellows (and browns or grays). Thus, they required some form of color grade outside of that scale. For example, a diamond graded as "Very Light pink" would have a "color" similar to that seen in the near-colorless range for yellow diamonds table-down and it would display a very subtle pink color face-up. This need to discriminate such extremely subtle colors by a practical system separates the color grading of diamonds from other gemstones. The relative values associated with particular colors, like pink, are very different for these two groups of stones.

Although the system appeared to work well and was repeatable—e.g., from one grader or laboratory locality to the next—GIA GTL continually sought ways to control the variables involved, such as the lighting and viewing environment and color-comparison standards.

SOME BASIC CONCEPTS FROM COLOR SCIENCE

Evaluating the color of an object (such as a faceted gem) by visual means requires some appreciation of what is actually involved in both observing and describing color. The following paragraphs briefly discuss some of these issues; for further details, see the standard textbooks on color science by Billmeyer and Saltzman (1981) and Wyszecki and Stiles (1982).

Observing and Comparing the Color of an Object. Whenever a person tries to establish the color of an object, or compare the colors of two objects side-by-side, several factors must be considered. Color science methodology (see ASTM [American Society for Testing and Materials] standard D1729-89 and references cited above) indicates the following:

1. One should use a consistent, standard source of light with known illumination characteristics.
2. The observation should take place in an appropriate surrounding environment that is neutral in its color appearance.
3. A rigorously defined geometry should be used between the light source, the object, and the observer.
4. If the object's color is to be compared to that of another object, the latter should ideally be a standard color reference material.
5. Observations must be made by a person with normal color vision.

Because any of these factors can influence the visual perception of an object's color, they all must be controlled if accurate and consistent results are to be obtained.

These factors are particularly important when observing color in a gem material. Illumination and viewing environment were addressed early in the development of the "D-to-Z" color grading scale. GIA designed (in concert with color researchers at Macbeth Instruments; R. T. Liddicoat, pers. comm., 1994) and marketed the DiamondLite. According to Shipley and Liddicoat (1941), the DiamondLite was intended to provide constant daylight-equivalent illumination from a filtered incandescent light source, with a controlled lighting direction and surrounding environment, for color grading colorless-to-light yellow diamonds. Subsequently, a constant, daylight-equivalent, fluorescent-type light source was adopted for the DiamondLite. The use of a carefully controlled light source and viewing environment for diamond color grading has been extensively taught through GIA's educational programs.

Because of its size and design, the DiamondLite is convenient as well as effective for grading the relative absence of color in faceted "colorless" diamonds held in a fixed, predominantly table-down position. As our understanding of the factors that influence color appearance in colored diamonds expanded, however, we recognized the need for a different viewing box. It required the controlled light source and neutral color environment that made the DiamondLite so effective for "colorless" diamonds, yet it had to be large enough to meet the viewing and positioning requirements for evaluating colored diamonds.

The systematic observation of color in a faceted, transparent object also presents challenges in viewing geometry and color comparison that are not typically encountered in other fields of color science. When looking at a faceted gemstone, one sees a mosaic of color sensations, depending on the stone's orientation and the relative positions of both the light source and the viewer's eye. In addition, the pattern and relative size of these sensations varies from one stone to another. Diamond's high refractive index, typical manufacture for brilliance, and precise cutting all affect the path of light through a stone and, thus, its color appearance. The size and cut also affect the total path length of light travel within the stone and, therefore, the amount of light absorption. Likewise, both factors influence the overall distribution of color sensations seen by

Figure 6. The 407.48-ct Internally Flawless, Fancy brownish yellow "Incomparable" diamond is shown here with satellite stones (1.33–15.66 ct) cut from the same piece of rough. Note the range of colors that result from different sizes and different cutting configurations. When GIA GTL examined the original 890-ct piece of rough prior to cutting, it was noted to be essentially uniform in color appearance. Photo by Tino Hammid; courtesy of Christie's New York.

the eye. For example, a large piece of uniformly colored diamond rough will often yield cut stones that vary in color appearance depending on their size and cut (see figure 6). It is the need to determine, from this mix of sensations, which color best represents that of the entire gemstone that most clearly distinguishes the evaluation of color in a faceted diamond from its evaluation in other objects (such as fabrics, glasses, plastics, etc.), which usually present a more uniform color appearance.

Finally, the ability to perceive color varies among people, even those who are not regarded as color blind. Those involved in evaluating colored diamonds should be aware of the characteristics of their own color vision, which can be determined through standard vision testing.

Describing the Color of an Object. Color is a continuum that can be defined and described in terms of three attributes (see figure 7):

1. *Hue,* the attribute of colors that permits them to be classed as, for example, red, yellow, green, blue, or anything in between
2. *Tone,* the relative impression of lightness to darkness of the color (also known as *lightness* or *value* in color science)
3. *Saturation,* the strength or purity of the color (also known as *chroma* or *intensity* in color science)

Figure 8 illustrates these three attributes three-dimensionally, as they appear when combined.

The range of all visible colors is known as a *color space*. A *color-order system* is a method of ordering and specifying the colors in a color space by means of a set of standards selected and displayed so as to adequately represent the whole set of colors under consideration (Wyszecki and Stiles, 1982, p. 506). A number of different color-order systems have been devised in an attempt to describe the colors that surround us.

When observing the colors of several objects one at a time, it is natural to rely on color memory to help distinguish one from another. However, a person's visual color memory cannot provide the degree of repeatability that is necessary to describe color consistently (Burnham and Clark, 1955; Bartleson, 1960). Therefore, color comparators—that is, objects of established color in a chosen color system that are used as standard references—are critical. The most obvious comparator would be of the same material as the sample, to remove appear-

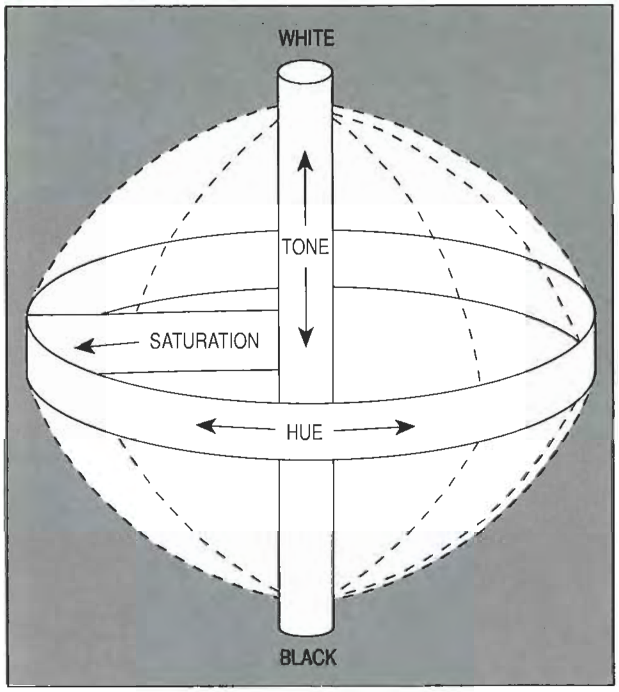


Figure 7. The three attributes of color can be seen here: Hues are located on a circle around a center axis, tone ("lightness" [i.e., toward white] to "darkness" [i.e., toward black]) forms the vertical axis, and saturation forms spokes that radiate outward horizontally from least saturated at the center to most saturated at the rim.

ance variables. As previously noted, however, colored diamonds represent a wide variety of often very subtle colors, some of which are quite rare, and their monetary value may be extremely high. In addition, the color of the stone is influenced by its size and cutting style. Consequently, the cost and time to develop a comprehensive set of diamond color comparators (or masterstones) is challenging. Thus, GIA GTL has investigated other materials that could also function as color comparators.

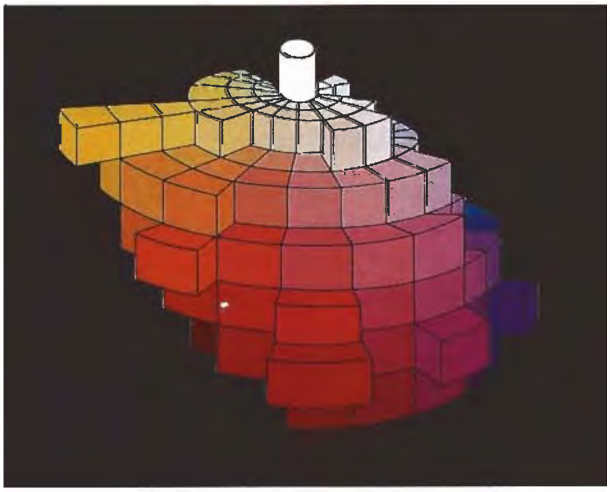
One additional consideration needs to be mentioned. Color descriptions can vary from simple to complex. A rigorous description must involve terms for all the attributes of color—hue, tone, and saturation. The level of detail is referred to as the *fineness* of the description. One of the better-known summaries of the various "levels of fineness" in color terminology is presented by Kelley and Judd (1976). They relate color descriptions to one of six levels of fineness, with each higher level providing for a larger number of color distinctions and having a more complex description terminology (table 1). The needs and level of understanding of the user determine the level of fineness chosen for a color description system. In the case of colored diamonds, a balance must be struck between the need for sufficient detail to describe the color, the need to make the description simple enough to be meaningful to a broad constituency, and the need to describe the color consistently when it is seen in more than one diamond, or in the same diamond on different occasions or in different locations.

THE GIA GTL GRADING SYSTEM

The procedures discussed here for observing and describing color in colored diamonds are primarily based on many years of experience on the part of the GIA GTL staff. In the almost 40 years since the laboratory first began issuing colored diamond reports, staff members have examined and graded tens of thousands of colored diamonds of all colors, sizes, and cutting styles. This cumulative experience has been the most important factor in developing and refining the system described here.

Light Source and Viewing Environment. The current standardized lighting and viewing environment for grading colored diamonds was adopted after the laboratory investigated approximately a dozen possibilities. First, we researched several prototype viewing environments manufactured by GIA GEM Instruments to GIA GTL specifications. We also tested a xenon-type D65 "daylight" light source, which is used as a standard in GIA

Figure 8. Combined, the three attributes of color seen in figure 7 appear as shown here. Note that the saturation steps on the horizontal axis vary with each hue and tone. Illustration courtesy of Minolta Camera Company.



Research. Because GIA is first and foremost a nonprofit educational institution, however, we feel it is important to be able to teach in our training courses what we do in the laboratory. Hence, as our investigation progressed, we recognized that we must use a commercially available viewing box and light source that, if desired, could be purchased by someone in the trade at a reasonable cost. We investigated various alternatives that could be produced by GIA GEM Instruments, but ultimately rejected the concepts of a custom-built viewing environment or the very expensive xenon-type light source. Instead, we turned to products used in other industries, each of which differed slightly in its lighting characteristics. These included viewing boxes manufactured by Macbeth, Pantone, Hunter Labs, and Tailored Lighting (the lighting characteristics of each can be obtained from the respective manufacturers). The viewing boxes we evaluated were reviewed in terms of:

1. The characteristics of its light source—such as lamp type, measured correlated color temperature (a term used to describe the color of a light source) and illuminance (the amount of light energy incident per unit area on a surface, multiplied by the spectral sensitivity of the eye), calculated color rendering index (a measure of the degree to which the perceived colors of objects illuminated by a given light source conform to those of the same objects illuminated by a standard light source) and calculated index of metamerism (a measure of the degree to which pairs of colors with different spectral characteristics appear the same under a standard light source and different under a "test" light source), spectral power distribution, and expected lamp life. These characteristics all contribute to a person's ability to distinguish colors while using the particular light source.
2. The overall illumination level, and evenness of the illumination, within the box.
3. The size and design of the box as it relates to its intended use—that is, grading colored diamonds.
4. The unit cost and ready availability of replacement lamps.

The correlated color temperature of the light sources in these viewing boxes was measured with a Minolta CS-100 Chroma-meter; illuminance level and evenness of light distribution were measured with a Luftron LX-102 light meter. A barium sulfate ($BaSO_4$) plate was used as a white reflectance standard for illuminance-level measurements. In each case, a set of reference colored diamonds were examined in the viewing box by a number of experienced diamond-grading staff members, so project leaders could judge how effectively the color was seen in that viewing environment. Everyone who participated in this experiment was first checked for normal color vision using the Farnsworth-Munsell 100 Hue test.

On the basis of this evaluation, GIA GTL is currently using a viewing box manufactured by the Macbeth Division of Kollmorgen Instruments Corp., and referred to as the "Judge II" (figure 9), for

TABLE 1. The six levels of fineness of the Universal Color Language.[a]

	Level of fineness					
	Color name designations			Numeral and/or letter color designations		
Parameters	Level 1 (least precise)	Level 2	Level 3[b]	Level 4	Level 5	Level 6 (most precise)
Number of color divisions	≈ 13	≈ 30	≈ 270	≈ 1,000–7,000	≈ 100,000	≈ 5,000,000
Type of color description	Generic hue names and neutrals	All hue names and neutrals	All hue names and neutrals with modifiers	Color-order systems	Visually interpolated Munsell notations (from Munsell Book of Color)	Instrumentally interpolated notation
Examples of color description	Blue	Greenish blue	Light greenish blue	Munsell 5B 9/2	4½B 8.3/2.4	

[a] *Adapted from Kelly and Judd (1976).*

[b] *For reporting purposes, GIA GTL uses a level-3 description terminology for colored diamonds.*

Figure 9. The Judge II box provides a standardized viewing environment, with a neutral gray interior color, controlled lighting, and sufficient working distance for making consistent color comparisons of colored diamonds. Photo by R. Weldon.

grading colored diamonds. The box is located in a darkened room to minimize color distractions to the operator. Its interior measures (H × W × D) 20 × 24 × 20 inches (50.8 × 60.9 × 50.8 cm). We have found that the Judge II box offers several specific advantages for observing color in colored diamonds:

1. Its size allows the grader to look at the stone face-up at what, from our experience, is an optimal viewing distance of the stone from both the light source (18 inches, about 45 cm) and the observer (8 to 12 inches, about 20 to 30 cm). At the same time, it provides adequate shielding from extraneous light.
2. The box is deep enough to eliminate color distractions from the surrounding area. We found that graders described the sample colored diamonds most accurately and consistently when they allowed their eyes to color adapt by looking into the box for several minutes and were not subsequently distracted by colors from the surrounding room.
3. The Munsell "N7 neutral gray" interior color reduces color contrasts between the diamonds and the background.
4. One of the light sources available for this box (it comes with several) simulates average daylight with a 6500K color temperature. From our testing, we found that this light source provided superior overall illumination, at a high brightness level, for observing diamond colors at our chosen viewing distance within the box.

Viewing Geometry. As mentioned above, a colored diamond typically has a number of color sensations, and these sensations are often subtle. Therefore, both the position of the diamond in the viewing box, and how the stone is held, are important. We have conducted experiments on various methods of holding the diamond, including the use of tweezers or other metal stone holders and white plastic trays. We have also experimented with holding the diamond in various places within the box to determine where its color is most easily seen. These same considerations apply to the viewing of the color comparators discussed below. Color grading by eye is a subjective process, so decisions on procedural matters such as these were based, after repeated trials, on the recommendations of the grading and technical staff involved.

A faceted diamond's face-up color is evaluated most consistently when the light source is positioned directly above the diamond (figure 10). The stone itself is placed in a grooved, matte-white, plastic tray. (A tray colored gray like the interior of the viewing box tended to make the diamond appear too dark.) Tweezers or other stone holders were all found to potentially influence the diamond's color appearance. In some cases, they add an unwarranted color to that of the stone, especially in paler colors.

Determining the Diamond's Color Grade. GIA GTL uses a three-step process in color grading a colored diamond: (1) determine the face-up color that is to be described; (2) locate the position of that color (first hue, then tone and saturation)—i.e., bracket it—in color space, by visually comparing the stone side-by-side to reference comparators under controlled lighting conditions in the viewing box; and (3) assign GIA GTL color terminology (i.e., the color grade) for that portion of color space.

Characteristic Color. The GIA GTL system describes a single color as being "characteristic" of the diamond as a whole. We define this single color as *the overall color sensation seen when the stone is viewed face-up* (that is not obvious surface reflection, dispersion, windowing ["washed out" or "see through" areas], or extinction ["dark" or "blackish" areas]). To help determine the characteristic color,

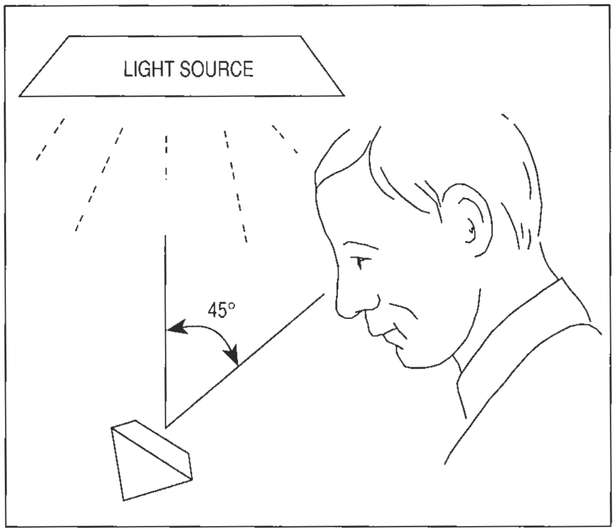


Figure 10. Using a standard viewing geometry such as the one shown here, a trained grader can most readily see and evaluate a faceted diamond's face-up color.

the grader moves the diamond slightly by rocking the tray, so that the stone is viewed from perpendicular to the table facet to perpendicular to the crown facets. In our experience, this process of moving the diamond through a slight angle minimizes the effects of surface reflection, dispersion, windowing, and extinction; for the most part, light enters and returns through the crown facets of the stone (see figure 11).

The "color grade" that a colored diamond receives on a GIA GTL laboratory report is a description of this characteristic color using standardized terms. Figure 12 illustrates various colored diamonds and where the characteristic color is seen in each.

Color Comparators. Once the characteristic color has been determined, it is bracketed in color space by means of a side-by-side comparison with two or more color comparators. As mentioned earlier, it is not always possible to use diamonds themselves as color comparators. However, GIA GTL does use reference colored diamonds for most common diamond colors and, equally important, for significant color distinctions. For example, a substantial distinction that must be made for some blue diamonds is between "Fancy Light" and "Fancy." Therefore, GIA GTL uses a blue diamond at the boundary between these two grades, even though blue is a relatively uncommon diamond color.

Figure 11. The viewing geometry used to grade colored diamonds acknowledges that transparent, high R.I., three-dimensional, faceted gemstones present a range of color sensations, as shown in these two photographs. To determine the characteristic color, the grader rocks the tray through a slight angle, so that the diamond is viewed from several positions. In this particular stone, "windowing" hinders observation of the characteristic color when the table facet is tilted slightly away from the grader (left); rather, the grader sees the color in this stone best when viewing it perpendicular to the table (right). In another diamond, however, the situation might be reversed, or the characteristic color might be most evident with the table at a slightly different angle. Photos by N. DelRe.

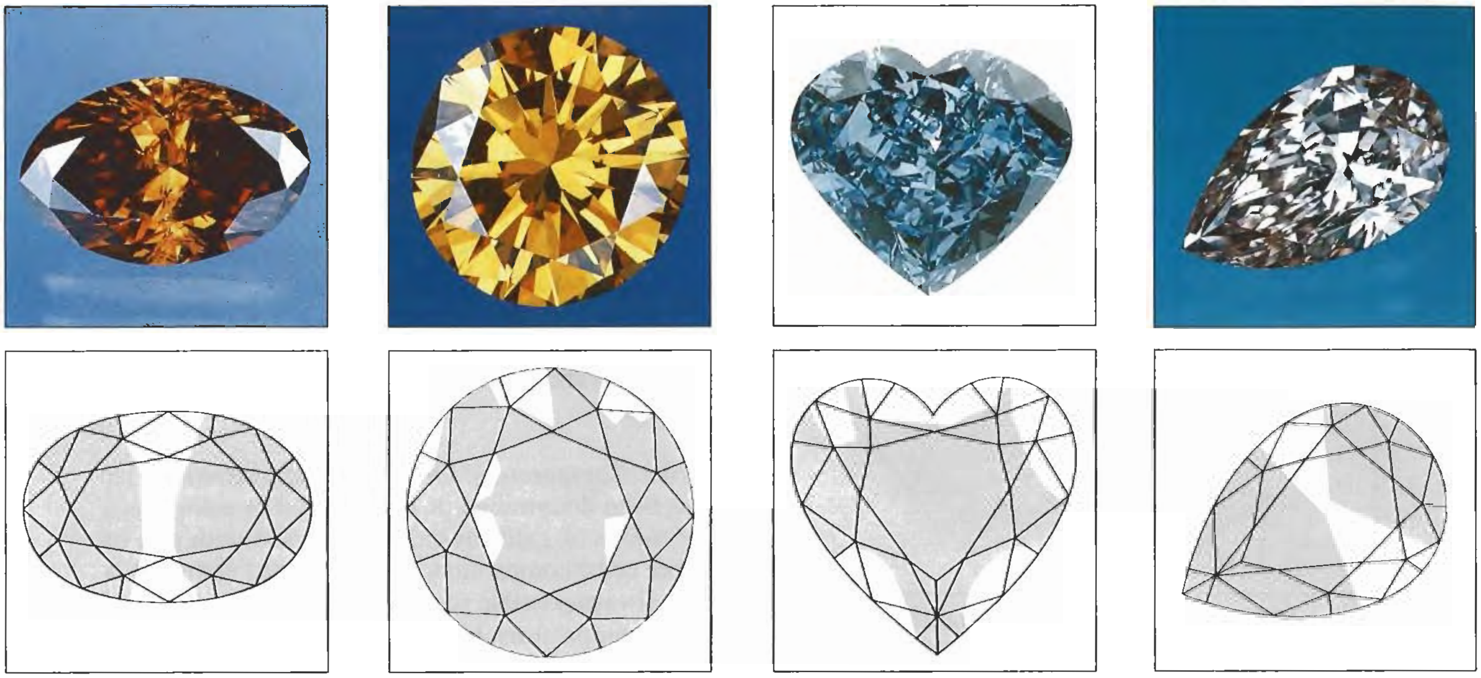


Figure 12. For each of these four fancy-color diamonds, the characteristic color is illustrated by the shaded area on the accompanying drawing. Photos by S. F. McClure and (heart shape) N. DelRe.

To supplement our available collection of colored diamonds and, in particular, to help provide samples for those colors in which diamonds are seen only rarely, we tested comparators from a number of well-known color-order systems. For each system, we considered the commercial availability of the comparators, the number provided and their arrangement in color space, and the range of colors they represented (relative to the colors we know to occur in natural-color diamonds).

We determined that some color-order systems were not compatible for various reasons (for further information on these systems, see Billmeyer and Saltzman, 1981, pp. 25–30; and Wyszecki and Stiles, 1982, pp. 506–507). The first group of systems rejected for our purposes—for example, those of Maerz and Paul, Lovibond, Pantone, and the ICI Color Atlas—are all based on colorant behavior. They employ the principle of systematically mixing various colorants to produce selected color samples (e.g., glasses, plastics, inks, paints, etc.). We found that these comparators are arrayed either too close or too far apart in color space for our purposes.

A second group of systems, represented by that of Ostwald, is based on color-mixing laws; that is, additive mixing of two or more colorants or colored lights in the same proportions yields the same color. Because there is no widely available collection of samples based on this type of system, the comparators in this group, too, were deemed not applicable.

A third group, called "color appearance systems," is derived from the principles of color perception. Here, opaque color chips are used as color comparators, each spaced uniformly in color space in accordance with the perceptions of an observer with normal color vision (Wyszecki and Stiles, 1982, pp. 507–513). This group includes the Munsell Color System, that of the German Institute of Standards (DIN), the Swedish Natural Color System (NCS), Chroma Cosmos 5000, and the Optical Society of America (OSA) Color System. We found that most of these systems were too complex for our specific application. In the course of our investigation, however, we determined that the opaque color chips provided as part of the Munsell system (Munsell, 1905) best suited our needs. This system represents a systematic, three-dimensional, well-distributed sampling of color space (Kuehni, 1983; Billmeyer and Saltzman, 1981, pp. 28–30; Wyszecki and Stiles, 1982, pp. 507–509; Billmeyer, 1987; see also figure 13).

In particular, the distribution of the color comparators in the well-documented and widely used Munsell system along three color attributes (comparable to GIA's terms *hue*, *tone*, and *saturation*) is relatively easy to understand and communicate, which helps its application for our purposes.

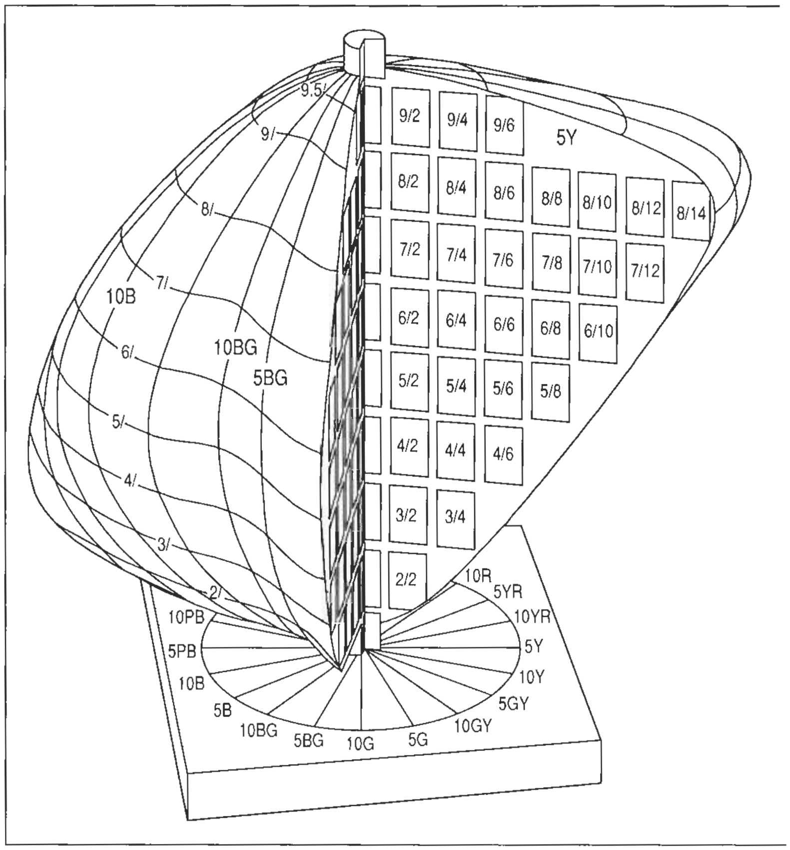


Figure 13. This representation of the Munsell color system shows the arrangement of individual opaque color chips in a color space. Courtesy of the Macbeth Division of Kollmorgen Instruments Corp.

Because locations of the opaque chips in color space can be mathematically translated into other color-order systems, they are compatible to systems used in other countries. These opaque chips are a standard color reference for comparison with other objects (ASTM D1535-89) and are sold commercially as the Munsell "Book of Color," which contains as many as 1,500 chips (figure 14).

It is important to note that each Munsell chip *does not* have a descriptive color name. Rather, it carries only its Munsell notation, which positions it in color space (in the Munsell system, on a Munsell hue page). For example, chip 5Y 8/4 is located on page 5Y at a "value" (i.e., tone) of 8 and a "chroma" (i.e., saturation) of 4 (again, see figure 13). We have correlated our color grading system to the arrangement of these Munsell chips, to illustrate how our description terms relate to one another in this color-order system.

Factors in Assigning the Color Grade. When masterstones are used as color comparators, the grader systematically compares the color of the diamond being graded to the colors of the reference diamonds, bracketing each color attribute in the viewing box (figure 15). At this point in the grading process (i.e., after the characteristic color has been established), the diamonds are held in a fixed position. (This is in contrast to the situation mentioned earlier where the subject diamond is moved slightly to help the grader determine the characteristic color.)

For those less frequent situations where there is not a comparable masterstone, we use the Munsell opaque color chips in much the same way: bracketing by side-by-side comparison of the characteristic color of the diamond with the color of the chip, in the viewing box (see figure 16). ASTM D1535-89 describes the bracketing concept. The grader's goal *is simply to place the characteristic color of the diamond in the proper region of color space,* so the GIA GTL color-description terminology for that portion of color space can be applied to the stone.

An important aspect of the GIA GTL system is the separate analysis of the perceived distribution of color (i.e., evenness or unevenness of color seen face-up). In most cases, unevenness is an effect of the stone's cut; occasionally, the diamond is color zoned. Because this perceived color distribution can affect the diamond's face-up color appearance, it is a

Figure 14. In the Munsell system, opaque color chips are provided in a book, with the chips arranged on what are called Munsell hue pages. Photo by N. DelRe.

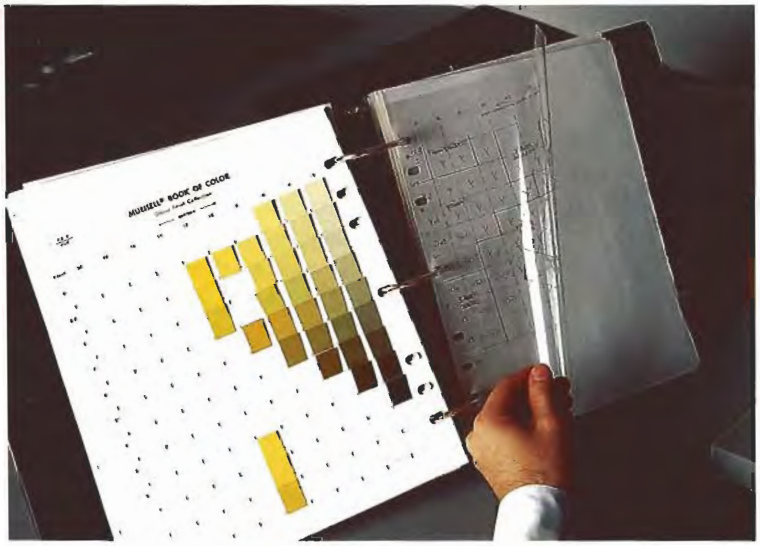
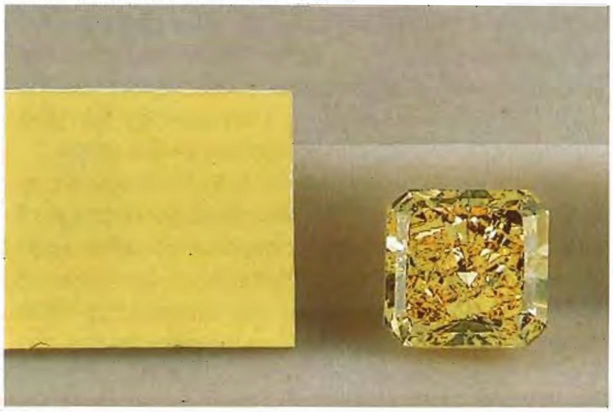


Figure 15. To determine the color description, the grader judges the characteristic color of the diamond against that of color reference diamonds. When comparing the two stones, it is important to place them in the same, fixed viewing geometry and close to each other without touching. Here, a colored diamond (left) is compared to a reference diamond in the viewing box. Photo by S. F. McClure.

factor in how the stone is traded. The grader analyzes color distribution by placing the diamond face-up in a viewing tray and, as with determining the characteristic color, rocking the tray slightly so the stone is viewed from perpendicular to the table to perpendicular to the crown facets. We have found that this rocking motion helps balance the effects of the cut, so the grader is not unduly influenced by the stone's appearance in only one position. The distribution of the color is evaluated in relation to the stone's total face-up area. Most fancy-color diamonds are considered to be evenly colored and are noted as such on the laboratory report (figure 17). In those less-common situations where the characteristic color clearly does not predominate face-up, the color distribution will be called uneven on the report (figure 18).

Figure 16. In some instances, opaque color chips are used as color comparators. As with the reference diamonds, the chips are placed in the same, fixed viewing geometry, close to but not touching the stone. The opaque chip shown here simulates what we consider to be the characteristic color of this diamond. Photo by N. DelRe.



GIA GTL COLOR GRADING TERMINOLOGY

The principles behind GIA GTL's terminology for grading colored diamonds are consistent with those of color nomenclature used in other industries. The Inter-Society Color Council—National Bureau of Standards (ISCC-NBS), when developing their "Method of Designating Colors" (NBS, 1955), used a "level 3" terminology. This level of language was defined by the ISCC-NBS to promote a practical color description terminology *simple* enough to be generally understood by an average person, yet *accurate* enough to be scientifically useful. As shown in table 1, this level includes all hue names (e.g., blue), neutrals (e.g., black, white, and gray), and color modifiers (e.g., light grayish, deep, intense, and other terms that express a related area of tone and saturation values). The GIA GTL system uses a comparable level-3 terminology to describe colored diamonds in terms of hue, tone, and saturation.

GIA GTL is aware that the grader can visually discern more color distinctions than those used in our color grading system. In our experience with colored diamonds, however, a greater degree of "fineness"—i.e., more terms—reduces the consistency and repeatability of the resulting color descriptions. In addition, such color distinctions are only relevant as long as they are meaningful and understandable in the commerce of diamonds; making too subtle or too coarse a distinction is not practical.

Hue Terms. The GIA GTL color-grading system uses 27 hue names (figure 19). *Each name represents a range of color sensations around the hue circle.* In using these hue names, our concern is to mark the boundaries of a given hue—not to designate just a "single" color sensation. We have chosen color comparators to represent the boundaries of each of the 27 hues.

Some of these 27 hue names include a modifying color (e.g., reddish orange); in our grading system, the predominant color is stated last. Note that this hue-naming convention differs from that used in GIA's Colored Stone Grading System (where, for example, green-blue and blue-green are synony-

Figure 17. The color in this 9.05-ct Fancy Vivid yellow diamond is well distributed throughout the face-up appearance of the stone. It would be described as "even" on a GIA GTL report. Courtesy of B. Najjar; photo by R. Weldon.

mous). This is because, in the diamond trade, the final hue name in a stone's color description has significant commercial implications that do not necessarily exist in the colored stone industry (e.g., a green-blue diamond is considered a "blue" stone, while a blue-green diamond is considered a "green" stone, and each has a particular market). These 27 hue names also represent the beginning of what we call our color terminology "grid" for colored diamonds. This grid divides color space into various zones of hue, tone, and saturation; it is helpful in illustrating the relationships among GIA GTL color terms.

Tone/Saturation Terminology. To describe the color of a faceted colored diamond correctly, one must identify its tone and saturation as well as its hue. The Munsell color chips are particularly useful in this regard.

We conducted a series of color-naming experiments for Munsell chips, involving experienced GIA GTL grading staff. We used a special computer program to select approximately 700 chips from the "Book of Color" so that they were at roughly equal distances from one another in color space. Thus, this subset of chips uniformly spanned the portion of color space covered by the Munsell system (which also spanned the range of colors observed in colored diamonds). We then put these chips in a random sequence, and gave them (one at a time) to each of 12 graders very experienced at describing colored diamonds. The experiments were conducted over a period of several days, to prevent eye fatigue on the part of the participants. We asked each grader to look at a single chip in a viewing box under controlled lighting conditions and then to write down a color description of the chip (using GIA GTL terminology) as if it were the characteristic color of a faceted diamond. We used the results of these experiments as one way to relate our color grades to the Munsell system.

Further experiments with the Munsell color chips and over 3,000 colored diamonds, again using trained grading staff and standard color-comparison methodologies (ASTM, 1991, D1729-89), also helped refine the color-comparison process used for grading. Where masterstones are available for color reference, we have located their positions in color space on the terminology grid by means of extensive visual comparison experiments conducted using GIA GTL grading staff. In addition, we have sought advice from members of the diamond trade to ensure the compatibility of our color-grading terminology with current trade usage.

GIA GTL's term for the combined effect of tone and saturation in a colored diamond is referred to as a "Fancy grade." Historically, the laboratory has

Figure 18. The color appearance of this diamond would be described as "uneven" on the GIA GTL laboratory report. Photo by N. DelRe.

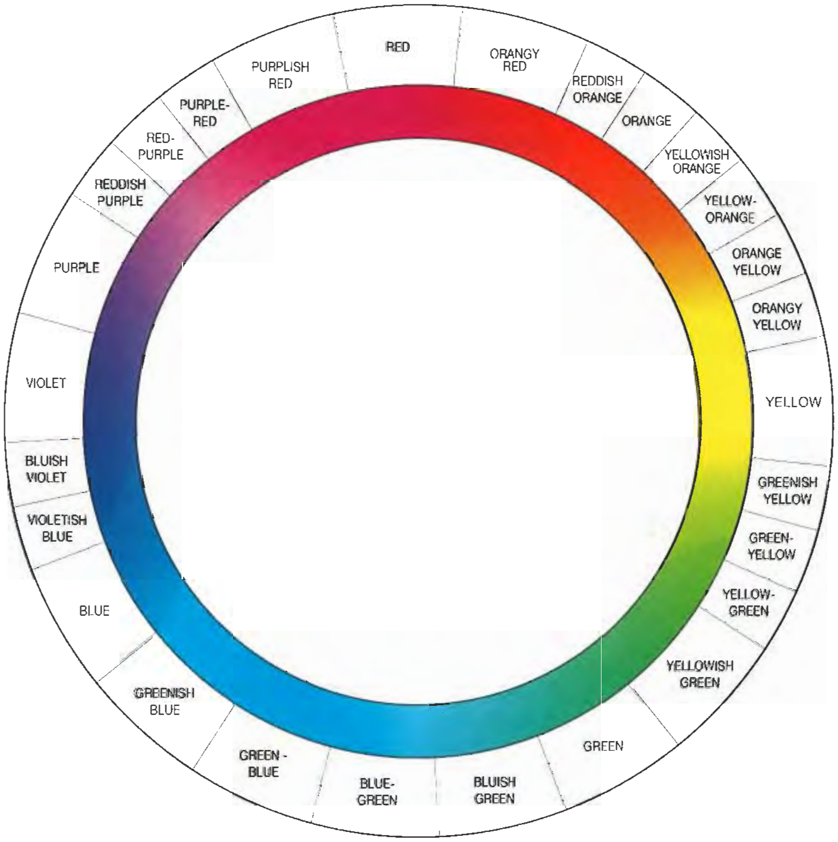


Figure 19. GIA GTL uses 27 hue names on a continuous hue circle to describe colored diamonds. Also shown is the approximate portion of the hue circle to which each name corresponds.

used a series of these Fancy-grade terms on its colored diamond reports; the grade given to an individual stone may have a significant commercial impact. The laboratory's use of these "Fancy" grades is similar to the convention used in the ISCC-NBS system, in which ranges of like tone and saturation values are grouped together and described with the same term (e.g., *light*, *dark*, *strong*, etc.). The Fancy-grade terms used on GIA GTL reports can be depicted by means of our terminology grid (figure 20). According to GIA GTL convention, Fancy-grade terminology is used only to describe the characteristic color in a faceted diamond, and not to describe other aspects of a colored diamond's face-up appearance (such as uneven color distribution).

Using the masterstones, opaque chips, and bracketing process, the grader assigns the characteristic color of the diamond to a "volume" of color space. For illustrative purposes, these volumes can be bounded at the corners by the positions of the Munsell chips (see figure 21). Each volume in the grid is designated by a particular color description (e.g., "Fancy orangy yellow") in our grading system. More than one volume may have the same description.

Using the Terminology Grid. In the grading process, the terminology grid is used as follows. A diamond is first compared to one or more of the colored diamond masterstones. *In most cases, the grader can establish the verbal description of the characteristic color at this stage, which concludes the color grading process.* At a minimum, the grader usually establishes one attribute (hue, tone, or saturation) of the diamond's characteristic color by comparison to these masterstones. If necessary, the grader then uses the opaque chips to refine the location in color space of the remaining attributes. Again, the goal is merely to locate the color between known boundaries—not necessarily to match the diamond's color. By this process, the grader establishes the portion of the terminology grid to which the characteristic color of the diamond belongs, and thus its verbal color description as well.

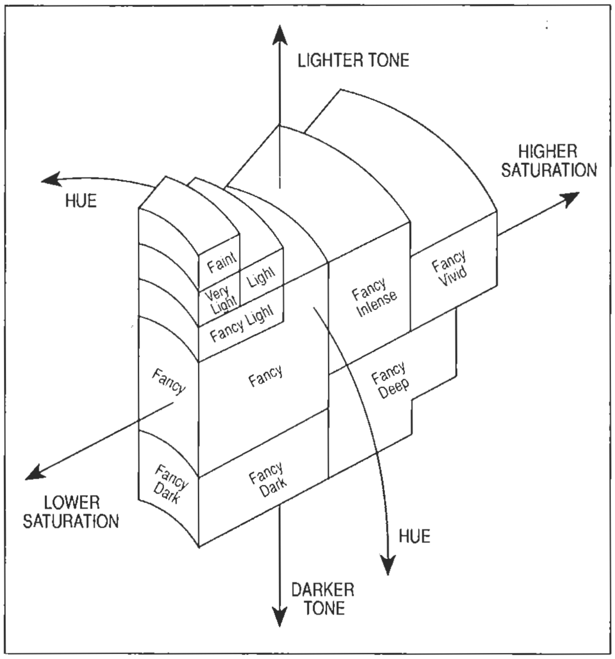


Figure 20. This drawing illustrates the general interrelationship of GIA GTL Fancy-grade terms in color space. The boundaries of these terms shift slightly from one area on the hue circle to another, because not all colored diamonds attain the higher-level saturations. As a result, for some diamonds (such as pink or blue), the GIA GTL grading system gives a paler-colored stone the same Fancy-grade description as a stronger-colored stone with a more common color (such as yellow). Also shown on this illustration are two new Fancy-grade terms, Fancy Deep *and* Fancy Vivid, *and their relationship to the other terms.*

With this grid one can visualize GIA GTL's grading terms by looking at two of the three attributes of color at one time. Specifically:

1. Hue and saturation, where tone is kept constant
2. Tone and saturation, where there is a constant hue

These terminology grids help the grader do two things—assign a hue name and assign a "Fancy" grade.

As shown in figures 19 and 20, portions of color space with the same hue and Fancy-grade terms are not all equal in size. The slight differences in the placement of our terminology boundaries are due to the natural occurrence and relative rarity of various diamond colors. Because yellow is by far the most common, a greater depth of this color is required for a stone to receive a "Fancy" grade. In contrast, colors such as pink and blue are both relatively rare and occur in much narrower (lower) saturation ranges. Thus, a "Fancy" grade is given for a paler stone. Such differences in terminology boundaries are illustrated in figure 22.

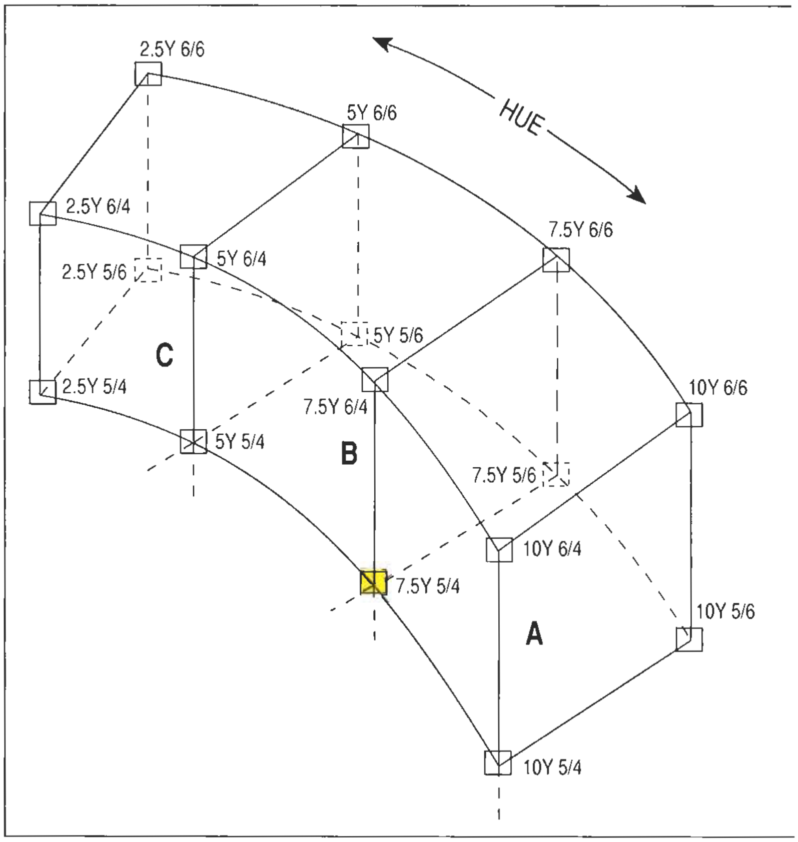


Figure 21. This illustration indicates how a portion of color space can be divided by the arrangement of Munsell chips. Three volumes—labeled here A, B, and C—are shown. By means of the color-comparison and bracketing process, the characteristic color of a faceted diamond can be located within one of these volumes, each of which has been assigned a color grade. In some instances, the grader determines that the characteristic color of the diamond matches that of a particular chip. As the figure shows, however, the chips are actually located at the corners of several different volumes. To prevent any confusion in this situation, the grader uses those terms that represent the highest saturation, lightest tone, and the hue in a clockwise direction around the hue circle. For example, if the match were with chip 7.5Y 5/4—right between A and B—the diamond's color would be described with the terminology that applies to volume A.

GIA GTL selected the color descriptions shown on the terminology grids, and the sizes of their respective areas, to provide both (1) a practical limit to the number of terms that would be used based on visual observation, and (2) precise enough terminology to be useful in making commercial distinctions.

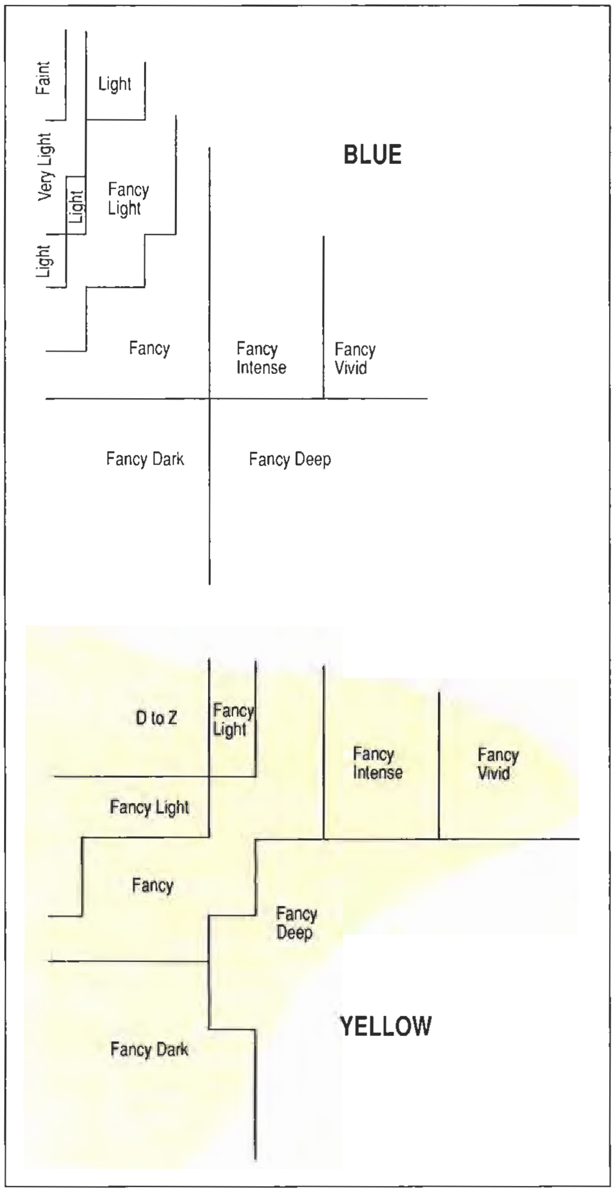


Figure 22. Shown on tone/saturation charts are the Fancy-grade terms for blue and yellow diamonds. Note that the boundaries between terms are different for the two hues. A relatively rare color that typically occurs in lower saturations, such as blue, is assigned certain "Fancy" grades at lower saturation levels than a color such as yellow, which typically occurs in higher saturations. At lower levels, yellow diamonds are graded in the "D-to-Z" range. The shaded areas represent the approximate ranges in which these two colors have been seen to date in diamonds.

Modifications of Hue Terms. There are two kinds of changes that can occur to the 27 hue names, and their boundaries, as one "moves" through the GIA GTL terminology grid. One is a reduction in the number of hue names around the hue circle, and the other is the use of modifying terms as the saturation decreases.

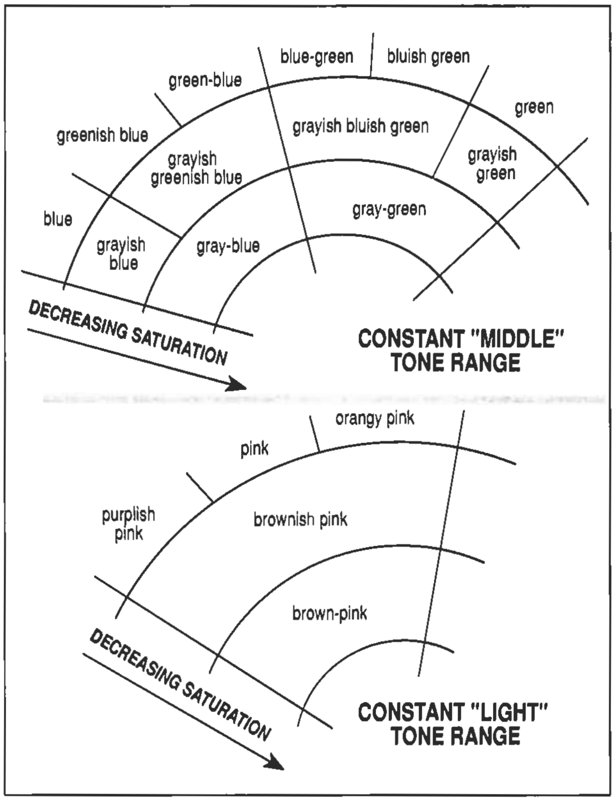


Figure 23. These two hue/saturation grids illustrate the effect that changes in tone and saturation have on the 27 hue names used in the GIA GTL color grading system for colored diamonds. Because the saturation range at very high and very low tone levels is so limited, visual distinctions between these colors become less practical. Consequently, fewer hue names are used in these areas of the two grids. For example, in the bottom illustration, the hue names purplish red, red, and orangy red (shown on the hue circle in figure 19) first become—at this tone and intermediate saturation levels—purplish pink, pink, and orangy pink, respectively. At even lower saturation levels, these three names are combined into just one—first brownish pink, and finally brown-pink. Such a modification in hue terminology is due to the difficulty of discerning the purplish red, red, and orangy red hues at levels of low saturation, and either high or low tone. Similar terminology situations occur throughout the color space used by the GIA GTL colored diamond grading system, as also seen in the top illustration.

At low saturation levels, and at either light or dark tone levels, we recognize fewer than 27 hue names (figure 23) because there is a smaller number of discernible colors. According to industry sources, this parallels how such diamonds are traded: broader distinctions are made between stones in very dark and very light tones, and at low saturation levels. This is analogous to the convention used in other systems, such as the ISCC-NCS, where fewer

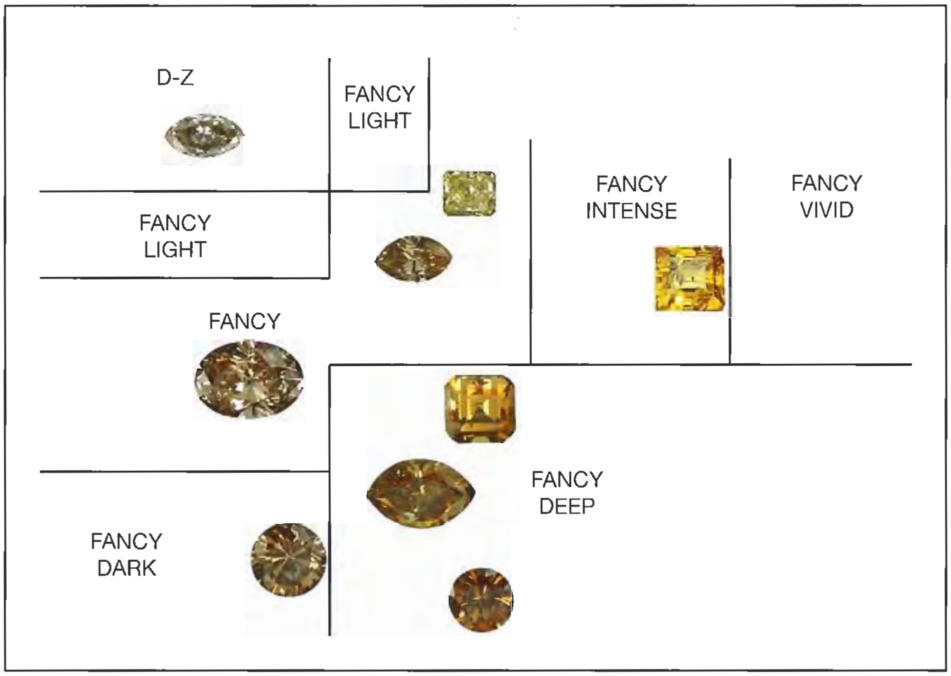


Figure 24. These nine diamonds (0.19–1.06 ct), all in the orange-yellow hue range, are placed on a tone/saturation grid to illustrate the relationship of Fancy-grade terms and color appearance. Note how changes in tone and/or saturation affect the appearance of a hue. Toward the left-hand (lower saturation) side of the grid, brownish *and* brown *are more common in the hue descriptions. Photo © GIA and Harold & Erica Van Pelt.*

hue names are used (i.e., a wider range of colors are grouped together) at lower saturation levels.

When fewer hue names are needed, our 27 hue names are modified in one of two ways. The first is when an English language term is used for paler colors, such as the substitution of "pink" for "red" in the paler versions of "purplish red," "red," and "orangy red" (again, see figure 23). The second way is to modify the hue name by the addition of either "gray/grayish" or "brown/brownish." Some colored diamonds are described in the trade as being brown or, to a lesser extent, gray. In our system, these are not hue terms per se, but they are appropriate color terms to use for the appearance of stones that are at lower saturations of various hues. For example, diamonds in the yellow-to-red hue ranges appear brown when they are particularly low in saturation and/or dark in tone. Most gray diamonds are those that are so low in saturation that no hue is readily perceived, only the light-to-dark tonal changes.

New Fancy-Grade Terminology. One of the recent additions to the GIA GTL colored diamond grading system is the recognition of two new Fancy-grade terms: *Fancy Deep* and *Fancy Vivid.* They supplement the previously existing terminology as follows: *Faint, Very Light, Light, Fancy Light, Fancy, Fancy Dark, Fancy Deep, Fancy Intense,* and *Fancy Vivid* (see, e.g., figures 24 and 25). Referring back to figure 20, *Fancy Deep* represents colors that have a medium to dark tone and a moderate to high saturation (as illustrated in figure 26), while *Fancy Vivid* represents colors that are light to medium tone and very high saturation. With the use of these two new Fancy-grade terms, areas of color space of important, highly colored diamonds will now be given even more accurate and appropriate color descriptions.

OTHER CONSIDERATIONS IN COLOR GRADING

Using Instruments to Measure Color. Certain attributes of color appearance can also be measured with instrumentation, such as a spectrophotometer or a colorimeter (for further general information, see Billmeyer and Saltzman, 1981; chapter 3). Although color measurement may provide finer color distinctions for some materials, questions

Figure 25. These four yellow diamond masterstones (0.39–1.53 ct) mark the most commonly seen lower saturation boundaries of their respective grade ranges (from left to right: Fancy Light, Fancy, Fancy Intense, and Fancy Vivid). The last color grade is a recent addition to the GIA GTL system. Photo by R. Weldon.

Figure 26. All of these diamonds (0.14–0.57 ct) would be graded "Fancy Deep," a recent addition to GIA GTL terminology that encompasses colors of medium to dark tone and moderate to high saturation. Photo by R. Weldon.

have arisen regarding the consistency of such instruments for quantifying the color appearance of faceted diamonds (see, e.g., Collins, 1984) and other gemstones. The many sizes and shapes of fashioned gems influence instrument positioning and path length for light traveling through the stone—and, thus, the accuracy of instrumental color measurements.

An even more fundamental problem is relating the results of instrumental color measurements to the color appearance of faceted gems as observed by eye. Several colorimeters have been marketed for evaluating faceted colorless-to-light yellow diamonds, including the Gran Colorimeter currently being sold by GIA GEM Instruments. If one recalls the factors that influence color observation—the light source, the object, the eye (or, here, the instrument's light detector), and the geometry between these different elements—deriving a consistent set of standards for both visual observation and instrumental measurement of color in gems is a great challenge and, in our opinion, one that has not yet been solved. While instruments such as the Gran Colorimeter do provide useful color measurement data (and can be helpful as back-up for the visual color grading of near-colorless to very light yellow diamonds), the relationship between these data and visual color observations of the same diamond has not been rigorously demonstrated. The challenge is even more profound for fancy-color diamonds. Nevertheless, GIA continues to investigate the use of color measurement instrumentation to supplement visual color grading.

Treated Diamonds. Since GIA GTL first began issuing origin-of-color reports in the 1950s, it has maintained a policy of not color grading diamonds that they have identified as treated. This policy continues today.

Grading Mounted Colored Diamonds. While the most accurate color comparisons are made on unmounted diamonds, practical situations arise that require the color grading of some colored diamonds in mountings. As with mounted diamonds in the "D-to-Z" range, in these instances the color grade is expressed more generally in the form of a range (e.g., "Fancy Light to Fancy yellow") to account for the potential influence of the mounting.

"Additional" Colors. Occasionally, the laboratory encounters diamonds that display an "additional" color that is clearly different from the characteristic color chosen. For example, a blue diamond might contain an orange limonitic (iron oxide) stain in a fracture. In these instances, the additional color component is not included in the color grade but is mentioned as a comment on the laboratory report.

To avoid redundancy in terms (i.e., such as "dark black" or "light white"), natural black and opalescent white diamonds are referred to only as "Fancy" for their Fancy-grade term.

SUMMARY AND PERSPECTIVE

One of the primary goals at the GIA Gem Trade Laboratory is to support the diamond industry with services that protect and enhance the trade, and thus the public trust. That entails a comprehensive program to address all aspects of reporting on the criteria that govern the identification and grading of diamonds. Of significant importance today is the nature of colored diamonds—specifically, their color origin and color grading. This is consistent with the special position that natural-color diamonds have held historically and especially over the last decade (figure 27).

While the "D-to-Z" system used to color grade most diamonds encountered in the jewelry industry (i.e., colorless to light yellow, including light browns and light grays) has been documented, the system used by GIA GTL for colored diamonds has not. Part of the challenge has been to apply scientific, yet practical, time-tested standards to such rarities of nature, and to continuously improve the reporting of such information via laboratory reports.

This article has traced the history and development of GIA GTL's system for describing and grading colored diamonds. This system uses both (1) a controlled viewing and lighting environment to observe the color of faceted natural-color diamonds, and (2) color comparators in the form of colored diamond masterstones and Munsell color chips. These standards help a trained grader identify the characteristic color of a diamond, on the basis of which a descriptive terminology—i.e., a grade—is assigned. The color-grading terminology uses a level-3 fineness, consisting of 27 hue names and possible modifier terms. Supplementing these hue names is a series of Fancy-grade terms that convey information about both the tone and saturation of the diamond's color appearance. The system provided has a basis in color science, yet it is a practical approach to the visual evaluation of colored diamonds.

GIA GTL continues to seek ways to strengthen the system and make it more meaningful. One recent development is the addition of two Fancy-grade terms, *Fancy Deep* and *Fancy Vivid*, to the terminology that will soon appear on GIA GTL reports for natural-color colored diamonds.

Grading the color of colored diamonds is one of the greatest challenges in gemology. The description must be a thoughtful blend of both art and science. GIA GTL's system seeks to use the best of both disciplines, fully describing each subtle color while meeting the practical need to make consistent, repeatable color decisions. It is not an easy process. It requires a robust system with consistent standards. A Fancy yellow diamond must be the same yesterday, today, and tomorrow.

Finally, to neglect history and tradition, or to distance ourselves from the mystique and romance associated with natural-color diamonds, is to do injustice to their beauty. In the end, our responsibility is to study the problem thoughtfully, document the information carefully, and report the results objectively. Recognizing the extremely high values of certain colors in diamond, the system described provides the support necessary to protect and enhance the stability and prosperity of the trade.

Figure 27. Colored diamonds continue to play a special role in the jewelry industry, as they have for hundreds of years. Illustrated here are some jewelry pieces provided by J. & S.S. DeYoung and U. Doppelt & Co. The ring in the lower right contains three Fancy Intense yellow diamonds (1.03, 0.80, and 0.57 ct); the Fancy yellow diamonds in the earrings weigh 7.44 and 7.34 ct, respectively; the nine "greenish yellow-to-green" diamonds in the brooch have a total weight of approximately 21.24 ct; the Fancy Intense orangy yellow oval-cut diamond weighs 1.83 ct; and the 1.54-ct round brilliant-cut diamond is Fancy brownish orangy pink. Photo © GIA and Harold & Erica Van Pelt.

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RUBY AND SAPPHIRE FROM THE SOUTHERN URAL MOUNTAINS, RUSSIA

By Alexander J. Kissin

Primary occurrences of ruby, pink sapphire, sapphires of other colors, and spinel have been found in marbles in the Ural Mountains. This article describes one occurrence, at Kootchinskoye, in the southern Urals, as a model for others in the Ural Mountains. Study of Kootchinskoye also gives some guidelines for predicting other ruby deposits. Although at present, there is no commercial production in this area, it appears to have significant potential.

Following the 1825 discovery of alluvial gold in the Kamenka and Sanarka River basins of the southern Ural Mountains, numerous gem materials were found in the course of gold mining. These include beryl, chrysoberyl, corundum, diamond, euclase, topaz, and tourmaline. As a result, Professor N. I. Koksharov (1855) referred to the region as the "Russian Brazil." Corundum from placers in the area was first reported by Barbot de Marny (1855). The specimens were relatively large (pink and blue sapphire up to 10 × 20 mm; ruby up to 10 mm) but not of gem quality. It was assumed within the geologic community that they originated in pegmatites, which are abundant in the area, although no corundum had been observed *in situ*.

In 1978, the present author postulated in the course of his studies that the ruby may have originated in marbles, which are also widespread in the area. This would be analogous to the occurrence of corundum in marbles at localities such as Mogok, Myanmar (see, e.g., Kane and Kammerling, 1992), from which some of the world's finest rubies are mined. Consequently, in 1979, the author traveled to the Kootchinskoye marble quarry, where he discovered ruby, pink sapphire, and other varieties of corundum *in situ* (figure 1). In 1983, ruby and several varieties of sapphire were found in marble at Chooksinsokoye near the village of Chooksa (here, in alluvial deposits as well as *in situ*) and at Svetlinskoye. In 1988, three additional primary and five alluvial occurrences were found in, or associated with, marbles. The gem-bearing rocks occur in a linear belt about 600 km long (figure 2).

Ruby and sapphire mineralization is now known to occur in marbles within four metamorphic complexes in the Ural Mountains: Murzinsko-Aduiskii, Kochkarskii, Jabyk-Karagaiskii, and Suundukskii (figure 3). On the basis of the known geology, other potential ruby- and sapphire-bearing areas are believed to exist in the Urals. Thus, the Ural Mountains represent an extensive new area of gem corundum mineraliza-

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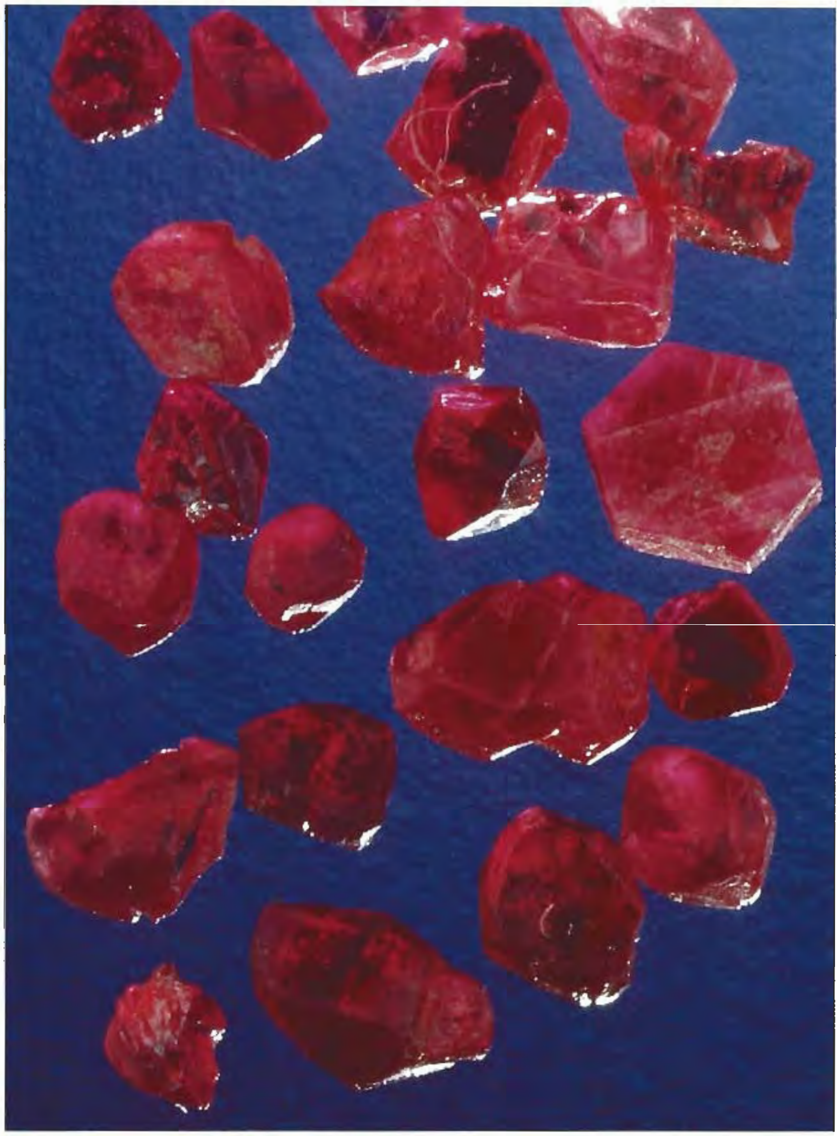

Figure 1. These ruby crystals were found at the Kootchinskoye marble quarry in the Southern Ural Mountains of Russia. They average 1 × 2 mm and belong to the "type A" category of gem corundum from this area. Photo © GIA and Tino Hammid

tion that has been called the "Uralian ruby-bearing province" (Kissin, 1990a). To date, approximately 100–150 carats of facet-grade corundum have been recovered and fashioned at various facilities (Ekaterinburg, Moscow, and an undisclosed location in Czechoslovakia) for evaluation purposes.

This article describes the results of a study conducted to better understand the geologic environment of this gem deposit and provide a basis for further exploration in the area. It reports on the geologic conditions and constraints relating to the formation of the presently known Ural Mountain ruby occurrences, especially at the Kootchinskoye deposit. Also provided are some gemological properties of gem corundum produced to date. Although ruby and sapphire are not yet commercially extracted from this area, it is expected that exploration will successfully find more deposits, some of which eventually will become active mines.

LOCATION AND ACCESS

The Kootchinskoye marble quarry (figure 4), which measures about 100 m × 40 m (330 feet × 132 feet), is located on the eastern side of the Ural Mountains, in the moderately wooded southern part about 50 km from the highest peaks in the range. The region consists of both flat and hilly areas with maximum relief of 300–380 m. Annual temperatures range from –12° to –50°C (10° to –58°F) in the winter, when the ground freezes to a depth of 1.5 m (5 feet), and from 17° to 35°C (63°–95°F) in the summer. Although there are a few small rivers in the area, there are no major rivers or lakes. Plast, about 15 km from the Kootchinskoye deposit, is the largest town in the vicinity (population: approximately 50,000); Chelyabinsk—about 120 km to the north—is the largest city (population: about 1.2 million). The deposits can be reached by auto or train from all major population centers (e.g., Ekaterinburg, Chelyabinsk) in the region.

GEOLOGIC SETTING OF THE KOOTCHINSKOYE OCCURRENCE

Because rubies and sapphires were first discovered *in situ* at Kootchinskoye, it has been the object of more geologic studies than any of the other occurrences in

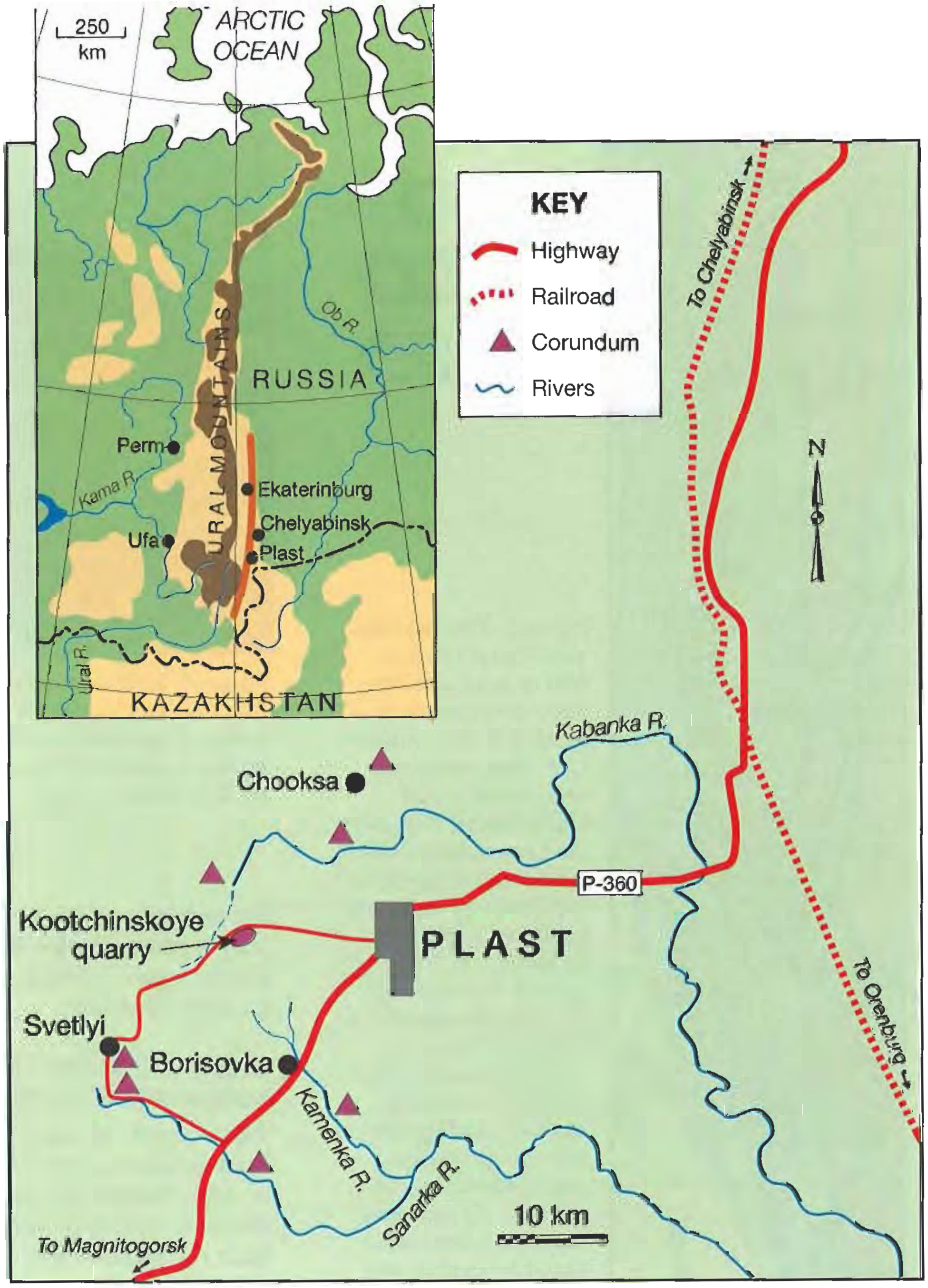

Figure 2. The rocks containing ruby and sapphire occur in a 600-km linear belt (shown in orange on the inset) in Russia's southern Ural Mountains. Most deposits located thus far are near Ekaterinburg and Chelyabinsk. The Kootchinskoye deposit, on which most geologic studies have been conducted, is near the town of Plast.

this region. It appears to be representative of other ruby-bearing marble occurrences in the Ural Mountains. Therefore, it is used here as a model of such occurrences and to describe the geologic conditions under which corundum formed.

The Kootchinskoye ruby/sapphire deposit occurs at the edge of the Kochkarskii metamorphic complex (again, see figure 3), which is of Middle to Upper Paleozoic in age. Metamorphism began about 300 My ago, with the first—prograde (higher pressure or temperature)—stage lasting no more than 30 My, and the last—retrograde (lower pressure or temperature)—stage ending about 260 My ago. Structurally, the complex is characterized by domes between which are tectonically formed depressions known as graben-synclines, which are bounded by formations dipping inward like those of a syncline. The domes usually are formed in gneisses and granites, whereas the graben-synclines characteristically are formed in schists, amphibolites, and marbles; both have numerous fracture and fault zones (figure 5). In places, granite dikes and pegmatites are widespread, as is silicification in the fracture systems, with some occurrence of pink topaz and green tourmaline. Metamorphic amphibolite facies rocks (typical of moderate-to-high pressure and high-temperature regional metamorphism) have been identified in the domal structures, whereas metamorphic albite-epidote-amphibolite facies rocks (formed under lower pressures and temperatures) occur in

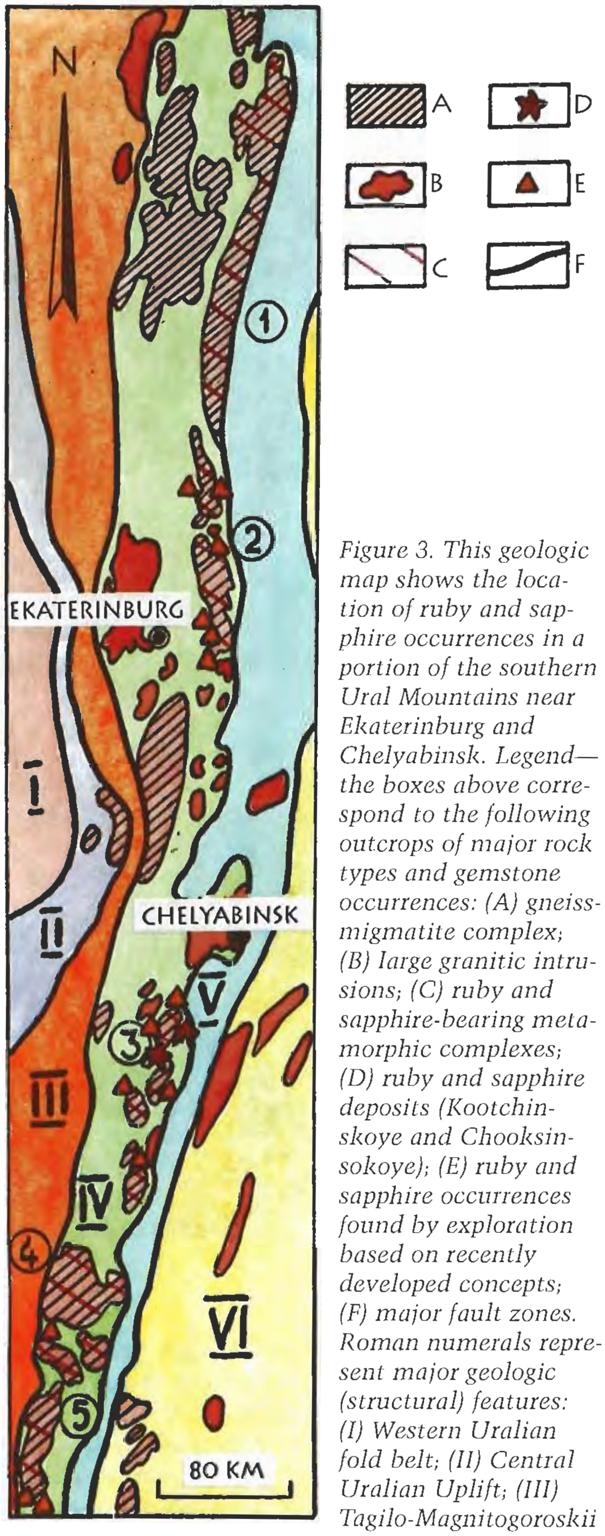

Figure 3. This geologic map shows the location of ruby and sapphire occurrences in a portion of the southern Ural Mountains near Ekaterinburg and Chelyabinsk. Legend—the boxes above correspond to the following outcrops of major rock types and gemstone occurrences: (A) gneiss-migmatite complex; (B) large granitic intrusions; (C) ruby and sapphire-bearing metamorphic complexes; (D) ruby and sapphire deposits (Kootchinskoye and Chooksinsokoye); (E) ruby and sapphire occurrences found by exploration based on recently developed concepts; (F) major fault zones. Roman numerals represent major geologic (structural) features: (I) Western Uralian fold belt; (II) Central Uralian Uplift; (III) Tagilo-Magnitogoroskii trough (downwarp); (IV) Eastern Uralian Uplift; (V) Eastern Uralian trough; (VI) Transuralian Uplift. Circled Arabic numerals refer to gneissic-migmatitic complexes containing marbles with gemstone varieties of corundum: (1) Gaievskii (Sosvinskii and Medvedevsko-Saldinskii)—no gem corundums found yet but potential is good; (2) Murzinsko-Aduiskii; (3) Kochkarskii; (4) Jabyk-Karagaiskii; (5) Suundukskii. Watercolor by A. J. Kissin.

Figure 4. Light-colored calcite marble in Kootchinskoye quarry's north wall is representative of material in which ruby occurs. The quarry is filled with water 5–7 m deep. Photo by A. J. Kissin.

the graben-syncline structures. The Kootchinskoye ruby-sapphire deposit is located in the axial part of a graben-syncline structure in which marbles are particularly abundant.

CHARACTERISTIC FEATURES OF THE KOOTCHINSKOYE MARBLES

Three types of marble have been identified at Kootchinskoye, by means of wet-chemical analyses of 150 marble specimens and semi-quantitative emission spectrographic analyses on 90 marbles. Each represents a different set of metamorphic conditions (or reactions; Kissin 1990b, 1991).

Calcite Marble. This light-colored, massive, medium-grained marble is composed of anhedral calcite crystals. Polysynthetic twinning is rare. It contains less than 0.05 wt.% MgO. Accessory minerals include quartz, adularia, fuchsite (chromian muscovite), green tourmaline, amphibole, graphite, pyrite, pyrrhotite, sphalerite, galena, hematite, and chlorite. Corundum is not found in this type of marble.

Magnesian Calcite Marble. This marble is typically variegated light blue, light green, white, and gray, and is composed of interlocking aggregates of medium- to coarse-grained euhedral calcite crystals that are highly deformed and do exhibit polysynthetic twinning. Magnesian calcite marble occurs inter-

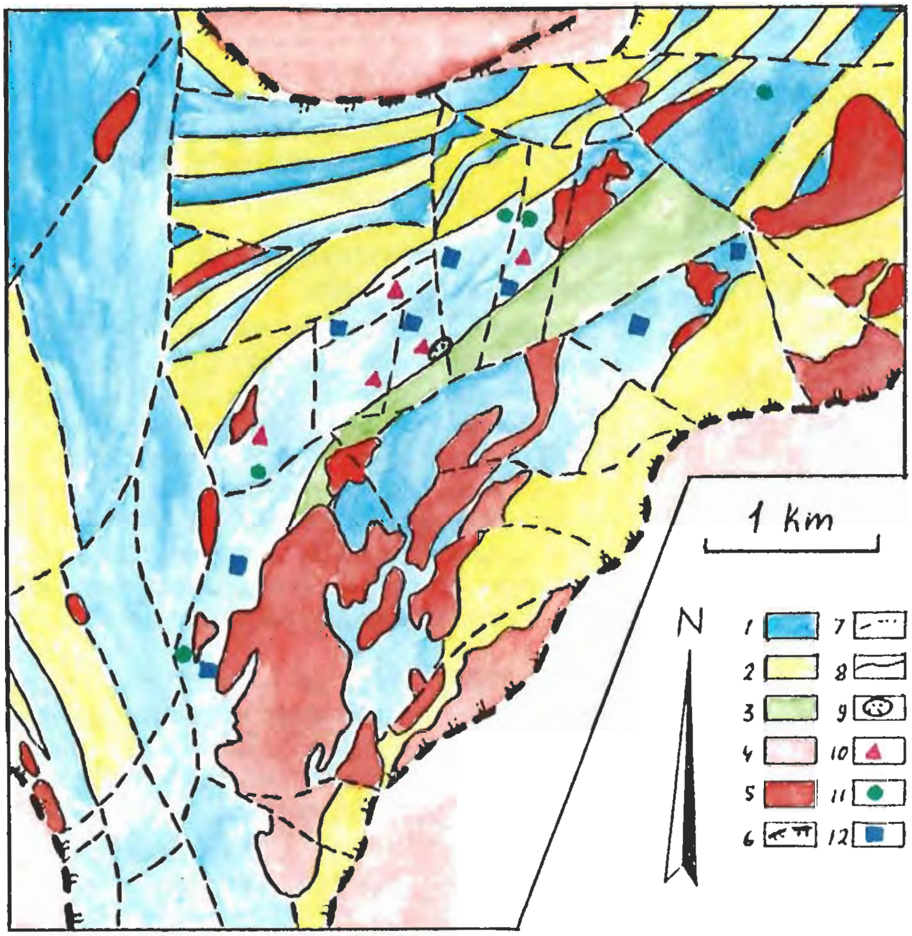

Figure 5. This geologic map of the Kootchinskoye ruby-sapphire occurrence was compiled by the author. The numbered boxes and lines in the key correspond to similar colored areas and lines in the map. The numbers represent: (1) marbles with schist lenses; (2) schists with marble lenses; (3) amphibolites and amphibole schists; (4) gneisses and schists; (5) minor granitoid intrusions; (6) fault zones; (7) fractures; (8) rock-unit contacts/ boundaries; (9) the Kootchinskoye quarry; (10) type-A ruby occurrence; (11) type-B pink sapphire occurrence; (12) type-C sapphire occurrence. Watercolor by A. J. Kissin.

grown with calcite marble; both have gradational boundaries. The MgO content of magnesian calcite marble ranges from 0.1 to 0.9 wt.%. This type of marble does contain corundum and other accessory minerals, such as spinel, apatite, pyrite, pyrrhotite, rutile, fluorite, green tourmaline, Cr-pargasite (an amphibole), sulfur, margarite, diaspore, anhydrite, tsavorite, phlogopite, and Al-chlorite.

Dolomitic Calcite Marble. This white to light-yellow, fine-grained rock has a poikiloblastic texture (i.e., one in which small grains of one mineral occur with larger grains of another mineral). Inclusions (or relicts) of magnesian calcite marble are often observed in the dolomitic calcite marble, which itself occurs as lenses or veins (or occupying fractures) as much as 2 m wide in the magnesian calcite marble. The MgO content of dolomitic calcite marble always exceeds 1.0 wt.% and may reach almost 22 wt.%, depending on the amount of dolomite (pure dolomite contains 21.86 wt.% MgO). This marble also contains corundum, as well as accessory minerals such as spinel, pyrite, rutile, phlogopite, tourmaline, Cr-pargasite, sphene, fluorite, norbergite, graphite, Al-chlorite, and tremolite.

Calcite marble, which is widespread in the Kochkarskii metamorphic complex, formed by recrystallization of limestone during prograde (high-pressure) metamorphism. Magnesian calcite marble is locally abundant at Koochinskoye, intergrown with calcite marble; it formed during prograde metamorphism accompanied by the introduction of fluids. Dolomitic calcite marble formed by magnesium metasomatism in the magnesian calcite marble during retrograde (lower pressure/temperature) metamorphism.

MATERIALS AND METHODS

This study is based on the microscopic examination of approximately 11,000 heavy-mineral concentrates, and approximately 500 insoluble residues, obtained after hydrochloric acid treatment of marbles. The concentrates (see, e.g., figure 6) ranged from several milligrams to a few kilograms. Average grain size ranged from 1.0 to 2.7 mm. Morphological and other characteristics of several thousand corundum specimens from Kootchinskoye were studied.

Figure 6. This sample, which contains ruby, spinel, and chrysoberyl, is representative of concentrate that was obtained from 1 m^3 of gravel recovered from Kootchinskoye. Grain sizes range from 1.0 to 2.7 mm.

Their inclusions were identified primarily by microprobe analysis of thin sections and the morphology of the crystals. Refractive indices were determined on 30 samples using a polarizing microscope with calibrated immersion liquids. In addition, six corundum specimens were analyzed by wet chemistry. For the purpose of this article, microprobe analyses (using a JXA-5 electron microprobe) were performed on 11 pink and red corundum and 11 dark red, purple-red, and pink spinel samples from Kootchinskoye; each was approximately 1–2 mm.

RESULTS: THE KOOTCHINSKOYE RUBIES AND SAPPHIRES

The rubies and sapphires recovered from the Kootchinskoye deposit appear to fall into three categories, designated types A, B, and C (Kissin, 1991). Table 1 lists selected physical and optical properties, as well as chromium content, of the three types of gem corundum. Only types A and B have the color and clarity appropriate for facet-grade material; type C may be suitable for use as cabochons. Table 2 provides the results of the electron microprobe analyses of 11 gem corundums from the same deposit.

Type A (Ruby). This type typically ranges from bright red to purplish red (again, see figure 1) and has a thick, platy habit (figure 7). Crystals are usually well formed, but "case-like" skeletal forms (i.e., hollow crystals filled with the host rock) are often observed. The surfaces of the crystals are frequently highly reflective. Although the crystals are transparent, they have prominent striae. The crystal faces *c* (0001) and *r* $(10\bar{1}1)$ are well developed, as occasionally are *n* $(22\bar{4}3)$ and *a* $(11\bar{2}0)$. Aggregates of crystals are rarely observed and, when encountered, do not consist of more than three individuals.

TABLE 1. Properties of ruby and sapphires from the marbles at the Kootchinskoye occurrence in the southern Ural Mountains.

Property	Type A — Ruby	Type B — Pink sapphire	Type C — Sapphire, pink sapphire, ruby
Color	Red (varies from "crimson" red to red-violet)	Pink (varies from pale to dark pink with local areas of blue)	Light colors to blue, red, and brown or colorless
Habit	Thick, platy; well-formed crystals; striae from rhombohedral twinning common	Typically round; occasional acicular crystals	Massive; rounded; irregular — can be well formed, but rare
Crystal faces	*c* (0001) and *r* (1011) well developed; occasionally *n* $(22\bar{4}3)$ and *a* $(11\bar{2}0)$	*c* (0001) and *a* $(11\bar{2}0)$	None or seldom
Transparency	Transparent	Transparent	Generally translucent to opaque[a]
Fractures	Usually fractured	No fractures	Fractures rare
Inclusions	Octahedral pyrite and apatite, gas	Octahedral and pentagonal pyrite and black rutile, gas	Pentagonal pyrite, red rutile, phlogopite, graphite, gas, liquid, etc.
Typical weight	1 ct	Less than 1 ct	Variable — can be extremely large
Aggregates	Rarely observed; not more than 3 individuals when found	Up to 8–10 individual crystals	May be fine-grained aggregates
Refractive indices[b]	1.771 and 1.760; 1.772 and 1.760	1.767 and 1.758	1.767 and 1.759
Birefringence[b]	0.011–0.013	0.009	0.008
Cr_2O_3 content	1.22–2.81 wt.%	0.11–0.51 wt.%	0.03–0.27 wt.%
Jewelry potential	Very good	Good	Poor; for cabochons only[a]

[a] *Has been found to be transparent, faceting quality at other deposits, such as at Lipovskoye in the central Urals.*

[b] *As determined with a polarizing microscope using refractive-index liquids.*

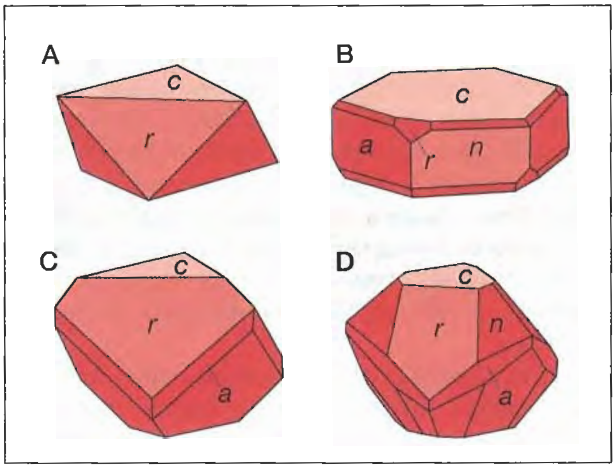

Figure 7. Characteristic crystal forms of type-A (ruby) corundum. Type-A rubies typically occur in "flattened" crystals, whereas type-B rubies are usually rounded.

Inclusions of pyrite (with a combination of octahedron and pyritohedron forms) and apatite have been observed, but no carbonate inclusions were seen in other than the skeletal crystals. These rubies may weigh as much as several carats (the largest so far observed weighed 120 ct); however, those of gem quality typically are 1 ct or less.

Note that the indices of refraction vary with the Cr_2O_3 content, in agreement with published data. Birefringence was considerably higher in the type-A rubies than in their type-B and type-C counterparts. As is to be expected based on the color appearance, Cr_2O_3 content was usually significantly higher in the type-A material than in types B or C, although the author has analyzed some type-C corundum with a relatively high Cr_2O_3 content.

Type B (Pink Sapphire). This type of gem corundum ranges from pale pink to dark pink, with local areas of blue (figure 8). Crystals are typically round; occasionally, however, well-formed elongated crystals with well-developed *c* (0001) and *a* $(11\bar{2}0)$ faces are observed. The crystals are usually transparent and have few or no fractures. Pyrite (with octahedron and pyritohedron faces) and short, black-appearing rutile crystals are typically found as inclusions. Type-B pink sapphire is usually smaller than type-A ruby.

Type C (Other Sapphires). Type-C corundum can be red, pink (figure 9), brown, yellow, blue, violet, or

Figure 8. Type-B pink sapphires from the Kootchinskoye deposit. These crystals average 0.5 × 1 mm. Photo © GIA and Tino Hammid.

TABLE 2. Results of electron microprobe analyses[a] of gem corundums from the Kootchinskoye occurrence.

Oxide (wt.%)	Type A (red)			Type B (pale—dark pink)					Type C (colorless—pink)		
	1	2	3	4	5	6	7	8	9	10	11
TiO_2	0.00	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	96.38	95.69	96.75	98.89	98.33	98.43	98.28	98.11	98.44	98.06	98.33
FeO[b]	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.07	0.00	0.00
MgO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.02	0.00
Cr_2O_3	1.92	2.81	1.22	0.21	0.38	0.11	0.51	0.35	0.07	0.03	0.27

[a] *Analyses were performed by Valentina Gmyra of the Institute of Geology and Geochemistry of the Urals Branch of the Russian Academy of Sciences on a JXA-5 electron microprobe operating at 20 keV, a current of 10 nA; standard ZAF corrections were made. Note that vanadium (as V_2O_3) was checked, but none was found in any specimen.*

[b] *Total iron as FeO.*

Figure 9. This 3-cm-long crystal has the poor diaphaneity associated with type-C corundum from Kootchinskoye. Photo © GIA and Tino Hammid.

colorless. At Kootchinskoye, the crystals are usually irregular in shape and translucent to opaque. Fractures are rarely observed, but the presence of many inclusions (gas, liquid, long red rutile needles, phlogopite, graphite, pentagonal pyrite, etc.) contributes to the typically poor diaphaneity. (Note, however, that facet-grade type-C crystals have been recovered recently from a new deposit at Lipovskoye.) Large specimens (8–10 mm; rarely up to 50 mm) of this corundum have been observed.

CONDITIONS FOR THE FORMATION OF THE RUBY AND SAPPHIRE

The different corundum types appear related to specific types of marble and especially the specific (metamorphic) conditions of temperature and pressure to which the host rock has been exposed. Geobarometry studies conducted by the author (based on the dolomite-calcite technique described by Talantsev, 1981) revealed that the dolomitic calcite marble formed at a temperature in the range of 620°–660°C and a pressure of about 2.5 kbar (Kissin and Talantsev, 1986). These values, which probably represent the highest temperatures and pressures attained in the area, correspond well to the metamorphic conditions determined for the Kochkarskii metamorphic complex by Boltyrov et al. (1973).

Theoretical and experimental studies of the reaction

$$\text{corundum} + \text{dolomite} \longleftrightarrow \text{spinel} + \text{calcite} + CO_2$$

reveal that the temperature and pressure at which the above reaction will proceed, and which mineral(s) will be found in the marbles, depends on: (a) CO_2 pressure, and (b) magnesium activity (roughly proportional to the concentration of magnesium in a rock; magnesium is available in dolomite—Pertsev, 1977; Jansen et al., 1978; Thordarsson, 1981). These studies have shown that as the temperature increases, the reaction moves to the right (spinel is formed), and as the pressure increases, the reaction moves to the left (corundum forms). Further, if the magnesium activity is increased, a corresponding increase in CO_2 pressure is required for the corundum to be stable. Thus, changes in temperature and CO_2 pressure, as occur during the various stages of metamorphism (prograde, retrograde), may have a major influence on the stability of minerals, including corundum.

At Kootchinskoye, type-A ruby formed in magnesian calcite marbles during prograde metamorphism as a result of fluid activity on limestone. During subsequent retrograde metamorphism of the magnesian calcite marble, which resulted in the formation of dolomitic calcite marble, most type-A ruby was converted to spinel. The type-A ruby that survived usually is strongly fractured (as a result of prograde metamorphism) and sometimes shows polysynthetic twinning.

Type-B pink sapphire formed during an early stage of retrograde metamorphism of magnesian calcite and dolomitic calcite marbles. This sapphire formed simultaneously with the marbles; however, where the marble has a high magnesium content, spinel is more likely to have formed than pink sapphire. Because compressive stress was minimal during the retrograde metamorphism, type-B pink sapphire typically does not have fractures.

Type-C sapphire was formed under conditions of decreasing temperature, changes in the fluid regime (increasing role of H_2O), and high CO_2 pressure. It formed in, and filled, fractures in both the magnesian calcite and dolomitic calcite marbles. When the CO_2 pressure decreased, orangy red spinel formed instead of corundum. Thus, spinel is found in both types of marble, where it replaced ruby and pink sapphire that formed earlier. However, the replacement is incomplete and only occurs near (i.e., within 1–2 mm of) fractures in the host marble. Beyond this distance, the corundum and spinel are unaffected.

DISCUSSION

Ruby and sapphire from marble deposits have been known for more than a dozen centuries (see, e.g., Kane and Kammerling, 1992). However, relatively little is known of the origin of these deposits. Based on the study of published geologic data, it appears that the ruby and sapphire deposits in Myanmar (Iyer, 1953; Keller, 1983; Kane and Kammerling, 1992), Pakistan (Okrusch et al., 1976; Gübelin, 1982), Afghanistan (Rossovskii, 1980), and Tanzania (Hänni and Schmetzer, 1991) have many similarities, and may be analogous, to those at Kootchinskoye and elsewhere in the Ural Mountains. All these Russian deposits occur in marble (frequently in several distinct types). Two types of ruby (and sapphire), as well as spinel, have been recognized in most of them (Rossovskii et al., 1982). In the case of the Uralian deposits, of which Kootchinskoye is a representative example, the three types of ruby and sapphire (types A, B, and C) are rarely found together. Although metamorphism (i.e., significant changes in temperature and pressure) is the main geologic factor in the formation of the ruby and sapphire, other factors are also important. In particular, the magnesium content of the marble will have a major influence on whether spinel is the preferred (stable) mineral phase. The Al_2O_3 content of the marble does not seem to be a critical factor, inasmuch as this component is low in all three types of ruby- and sapphire-bearing marble at Kootchinskoye; in fact, the Al_2O_3 content of the gem-bearing marbles (0.08–0.13 wt.%) is lower than that of nearby marble that does not contain corundum (0.15–0.18 wt.%).

Some investigators have suggested that the ruby-sapphire mineralization in marble developed as a result of the contact metamorphic action of pegmatites or granites on aluminum-bearing rocks (e.g., Kievlenko et al., 1974). However, such does not appear to be the case, at least with the Uralian deposits, because at some of these deposits pegmatites and granites are either rare or absent. In the author's experience, where contact zones between pegmatites and marble or aluminum-bearing rocks have been observed, ruby and sapphire are rarely found.

CONCLUSIONS

Rubies and sapphires have been recovered from different types of marbles in the Ural Mountains. The site where they were first discovered, Kootchinskoye, serves as a model for other deposits found in the Urals. On the basis of gemological and chemical studies, the author has identified three types of gem corundum—ruby and various colors of sapphires—which occur in two of the three types of marble that have also been identified in this highly metamorphosed region. The three types of ruby and sapphire recognized at this occurrence are likely to be found in other gem corundum deposits in the southern Ural Mountains. In addition, these corundum deposits have gemological and geologic similarities in common with important deposits elsewhere, such as the ruby and spinel deposits of Mogok, Myanmar (Burma). Therefore, the geologic model for the formation of gem corundum at Kootchinskoye should help in future exploration for rubies and sapphires in marbles.

To date, there is no commercial production of ruby and sapphire in this region, although two large Russian companies recently obtained licenses to mine in the area. A newly discovered occurrence at Lipovskoye, in the central Urals, also shows promise (figure 10). The author believes that there are significant reserves in the area.

Figure 10. This 0.3-ct ruby was recovered from a relatively recent occurrence at Lipovskoye in the central Urals.

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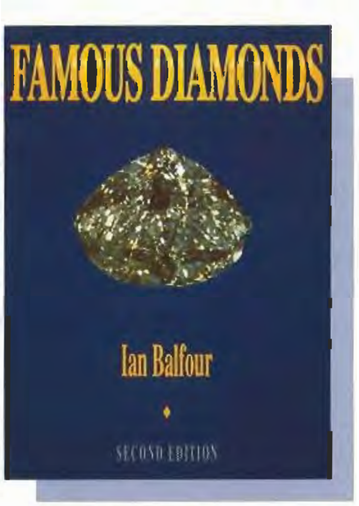

GEM CORUNDUM IN ALKALI BASALT: ORIGIN AND OCCURRENCE

By A. A. Levinson and F. A. Cook

Many deposits of gem corundum are associated with alkali basalt. Best known are the occurrences in Southeast Asia (especially Thailand) and Australia, which are responsible for much of the sapphire and fancy sapphire on the world market today. Yet alkali basalts are relatively uncommon, and corundum deposits are found only in those alkali basalts that occur in association with subduction zones involving ocean-continent plate collisions. This article offers a new hypothesis for the relationship between this rock type and gem corundum. It suggests that gem corundum is formed when certain rocks—such as shales, laterites, or bauxites, with aluminum-rich minerals—are subducted to depths of about 50 km, where metamorphism converts the minerals into corundum and other products that the alkali basalts later carry to the surface. The potential for new deposits is considered.

In 1992, more than 7.2 million carats of fashioned gem corundum were imported into the United States; of this amount, about 2.6 million carats were ruby and 4.6 million carats were sapphire (Austin, 1993). The total dollar value was almost US$153 million, second only to emerald ($213 million) for fine colored stones. These figures reflect the major role that gem corundums play in the jewelry industry.

The vast majority of gem corundums on the world market today, particularly blue and fancy sapphires, come from secondary deposits in Southeast Asia and Australia (figure 1). Although some of these deposits are associated with marbles, such as those in Burma (Mogok and Mong Hsu) and northern Vietnam, most are correlated with the occurrence of alkali basalt, a relatively uncommon type of volcanic rock. According to Olliver and Townsend (1993), until 1988 Australia supplied up to 70% by volume of the world's sapphires (mainly small dark stones); it now supplies about 25%–30%, owing to a large increase in production from Thailand. In both of these countries, the sapphires are recovered primarily from secondary deposits derived from alkali basalts. Yet while much has been published on marble-type deposits (again, as in Mogok) and those associated with peg-

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Figure 1. The approximately 1-ct sapphire in this pendant is typical of some of the fine gem sapphires recovered from alkali basalts. Courtesy of Lindsay-Wasser, Toronto; photo © Tino Hammid.

matitic intrusions (e.g., Kashmir and the Umba River Valley of Tanzania), relatively little is known in the gem industry about the important alkali basalt source of commercial corundum. Thus, in this article we: (1) review various geologic aspects of this rock type and its relationship to gem corundum; (2) offer a theory for the origin of gem corundum in alkali basalts; and (3) apply the information gained to surmise, on geologic grounds, where additional gem corundum deposits of this type might be anticipated.

OCCURRENCE, CLASSIFICATION, AND MINERALOGY OF BASALTS

Basalt is a general term for a dark-colored, mafic (containing minerals with high contents of magnesium and iron), extrusive (volcanic) igneous rock. It is composed predominantly of calcium-rich plagioclase and calcium-rich pyroxene (mainly augite) plus other minerals, depending on the type of basalt (see below). Basalts are by far the most abundant of the Earth's exposed crustal rocks. Not only do they cover essentially the entire ocean floor (usually beneath a thin veneer of sediments), but they also predominate in major "shield-type" volcanoes (which, on occasion, extend above the ocean surface, as is the case with the Hawaiian Islands). In addition, they occur extensively in certain continental settings, such as the Columbia River basalts of the northwestern United States. Basalts also occur abundantly on the moon and on the inner planets, including Mars. Basalts are discussed in all textbooks on igneous rocks (e.g., Williams et al., 1982; Philpotts, 1990).

Basalts can be classified into two broad types—tholeiite and alkali—based on their chemical characteristics and mineralogical composition. They can only be distinguished unequivocally by means of thin-section study with a polarizing microscope or by chemical analysis. Tholeiites constitute about 90% of all exposed basalts. Mineralogical (involving quartz, low-calcium pyroxene, feldspathoid minerals, and olivine) and chemical distinctions between the two types of basalt are shown in table 1.

Alkali basalts never contain quartz as a visible mineral or as theoretical "normative" quartz (a "norm" is a theoretical mineral composition of a rock calculated from the chemical analysis). They are characterized by the presence of silica-undersaturated minerals, including olivine, $(Mg,Fe)_2SiO_4$,

TABLE 1. Mineralogy and chemistry of tholeiite and alkali basalts.

Minerals and chemical content	Present in Tholeiite basalt	 Alkali basalt
Major minerals		
Calcium-rich plagioclase	Yes	Yes
Calcium-rich pyroxene	Yes	Yes
Minor and characteristic minerals		
Quartz (normative)	Yes	No
Low-calcium pyroxene	Yes	No
Feldspathoid minerals	No	Yes
Olivine (e.g., nepheline)	Sometimes	Yes
Chemical content (average)[a]		
SiO_2	48.62 wt.%	46.33 wt.%
Na_2O	2.76 wt.%	3.20 wt.%
K_2O	0.84 wt.%	1.28 wt.%

[a] *Average of characteristic oxides; from Mysen (1987).*

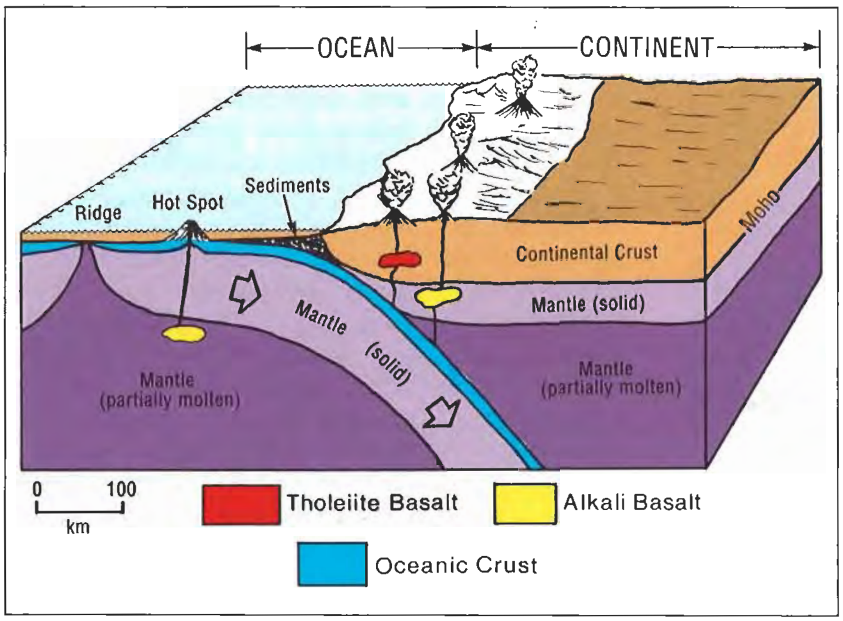

Figure 2. The theory of plate tectonics explains how the Earth's solid outer portion (the lithosphere) is divided into a number of rigid thin segments (plates) which move in various ways. This includes downward movement at certain boundaries, particularly where continental and oceanic plates collide. This figure illustrates the process of subduction (as indicated by the arrows), in which a "conveyor belt" mechanism moves an oceanic plate, comprising mostly basalt with a thin veneer of marine sediment (shale, limestone, etc.), downward beneath a continent into the mantle. This figure also shows the source regions of magmas, which are generated by partial melting of material taken down the subduction zone, that may eventually rise to the surface and crystallize as tholeiite basalt and alkali basalt. Rhyolite and andesite magmas (not shown) would form at even shallower depths than tholeiite. These positions correspond in a general way with increasing depth (which is correlated with pressure) and temperature within the Earth. See text for further details. The Moho, the boundary between the crust and the mantle, is shown here at a depth of about 50 km beneath the surface of the continent. Corundum would form in the range of about 24 to 50 km below the continental surface, depending on the starting materials.

and certain minerals of the feldspathoid group such as nepheline, $(Na,K)AlSiO_4$, in which some of the characteristic alkali elements (Na, K) are found. Undersaturated minerals are those that would, under suitable conditions, react with free silica (quartz) if placed in contact with it to form more-silica-rich minerals. For example, there would be no nepheline in contact with quartz because this feldspathoid would react with quartz to form albite. Consequently, the presence of undersaturated minerals such as nepheline and olivine together identifies the basalt as alkali. Note that tholeiite and alkali basalts are always found in separate and distinct flows.

ORIGIN OF BASALTS

Basaltic eruptions are closely linked with plate tectonics, the generally accepted theory that the Earth's surface is divided into about a dozen large, thick (usually about 100 km) plates that are moving very slowly (about 2.5 cm—1 inch—per year), as illustrated in figure 2. Intense geologic activity, such as earthquakes and volcanism, occurs along the plate boundaries, and the process appears to have been in operation for most of geologic time. Typically, molten basalt (magma) rises from the Earth's mantle to the surface along zones of major rifting (i.e., crustal fractures)—primarily along mid-ocean ridges such as the Mid-Atlantic Ridge, at convergent plate boundaries such as are common along western South America and Japan, and above localized "hot spots" within the middle of plates such as Hawaii. Alkali basalts are found in all the above geologic environments.

To understand figure 2, it is essential to recognize that most rock types are composed of more than one mineral, and each mineral, or combination of minerals, has a specific melting temperature that is influenced by pressure, the amount of water present, and other factors. The process of "partial melting," in which minerals with the lowest melting points within a rock melt first as the temperature rises, allows the generation of various types of magmas (such as rhyolite, andesite, and tholeiite) from some minerals; other minerals with higher melting points (i.e., that are still solid) do not form magmas until they reach greater depths with higher temperatures (as is the case with alkali basalts). By virtue of their greater buoyancy in liquid form, the early-formed magmas tend to rise and become concentrated in locations closer to, or on, the surface where they eventually solidify. In a subduction zone (a long, narrow belt in which one plate descends beneath another), it is unlikely that

Figure 3. A dark blue sapphire xenocryst is seen here embedded in alkali basalt, as it was recovered from Fangshan, Shandong Province, China. Economic deposits with in situ *corundum (i.e., primary deposits) in alkali basalt are rare. The yellow fragments adjacent to the sapphire are weathered ultramafic xenoliths from the mantle (from Guo et al., 1992b, who refer to the sapphire as a megacryst). Photo courtesy of J. F. Guo.*

tholeiitic basalts will form in significant quantities until subduction processes have brought surface (oceanic crustal) rocks down to a depth of about 20–30 km; alkali basalts, however, are not likely to form at depths shallower than 50–60 km (Kushiro, 1987; Perchuk, 1987).

CORUNDUM IN BASALT

Many of the main commercial sources (e.g., Thailand, Australia) of gem sapphires are associated with the occurrence of alkali basalts. This does not necessarily mean, however, that corundum *crystallized* from the alkali basalt magma. This important distinction is explained by the fact that volcanic rocks, and particularly basalts because of the great depths from which they originate (at least 20 km in most areas), commonly carry to the surface xenoliths (rock fragments) and xenocrysts (crystals) of "foreign" origin. Thus, such fragments and crystals have no genetic relationship to the enclosing basaltic rocks (figure 3). For example, recent studies by Righter and Carmichael (1993) showed that all the inclusion-free and unzoned megacrysts (a general term used for large crystals of any type) of augite, feldspar, kaersutite, olivine, and biotite from eight alkali basalts in the western U.S. and Mexico were xenocrysts. The xenocrysts are derived from broken-up or dissolved xenoliths that probably originated from several different rock types at pressures of 5–15 kbar (approximately 15–45 km depth) and were carried to the surface by the alkali basalt magma. Hence, the situation is analogous to diamonds occurring as xenocrysts in kimberlite or lamproite, except that diamonds originate at much greater depths (>110 km; Kirkley et al., 1991). Other gem minerals that are typically xenocrysts, as opposed to primary crystallization products, in alkali basalts include zircon, some garnet, and some spinel. In contrast, olivine (which occurs as the gem variety peridot), as well as some other garnet and other spinel, may be either a xenocryst or a primary crystallization product (Williams et al., 1982; Philpotts, 1990).

Most researchers (see, e.g., Schulze, 1987; Coenraads et al., 1990; Guo et al., 1992b) have concluded that corundum always occurs as xenocrysts in alkali basalts—and does not crystallize from the magma itself—on the basis of three key factors.

1. Experimental studies have shown that corundum cannot be grown from a melt of normal basaltic composition.
2. The surface features—e.g., rounding, etching, and corrosion—of the corundum crystals indicate that the crystals are partially resorbed by the alkali basalt magma (corundum is unstable in this magma, and if in contact with it for a long period probably would be completely resorbed).
3. Certain minerals found as inclusions in corundum, such as zircon and columbite, could not have grown from such a magma.

Significantly, all reported economic, and potentially economic, secondary occurrences of basaltic corundum are spatially associated with the alkali type of basalt. (Coenraads et al., 1990, mention two possible exceptions, in Nigeria and Southern China, but these are not well documented.) Further, most found so far are of Cenozoic age (66 million years or younger), although this may be a result of limited sampling. These observations apply to the occurrences in Chanthaburi-Trat, Thailand (Keller, 1982); numerous other localities in Thailand, Cambodia, and Kampuchea (Coenraads et al., 1990); New South Wales, Australia (Coldham, 1985; Coenraads et al., 1990); three areas of China (Keller and Keller, 1986; Wang, 1988; Guo et al., 1992b); and southern Vietnam (A. S. Keller, pers. comm., 1994). One exception is the little-known deposit in the Mercaderes-Río Mayo area of

Colombia, which is reportedly Cretaceous (66–144 My) in age (Keller et al., 1985).

ORIGIN OF CORUNDUM IN ALKALI BASALT

The main geologic question is: Why are gem corundum crystals found as xenocrysts only in alkali basalts, which represent a relatively small proportion (about 10%) of all basalts? We view the way in which corundum crystals are concentrated in alkali basalts as a two-stage process in the context of plate tectonics theory. The first stage relates to the formation of corundum (separate from the formation of the basalt) deep in the Earth; the second stage relates to the process whereby the alkali basalt magma brings the corundum to the surface.

Stage 1: Corundum Formation. We propose that there are two main mechanisms involving plate tectonics and metamorphism by which corundum can be formed; each involves different starting materials.

Mechanism 1. Aluminum-rich sedimentary rocks, particularly shales (which typically contain such aluminum-rich minerals as muscovite [illite] and kaolinite), are often carried to significant depths in areas of plate-margin interactions such as subduction zones (again, see figure 2). Once the sediments have reached an appropriate depth and sufficiently high temperature by this "conveyor belt" mechanism, they undergo conversion to other minerals that are more stable in the new higher temperature/pressure environment.

Corundum, Al_2O_3, along with potassium feldspar (orthoclase) and water, is a breakdown product of muscovite, a common micaceous mineral found in shales:

Equation 1

$$\underset{\text{(muscovite)}}{KAl_2(Si_3Al)O_{10}(OH)_2} \rightarrow \underset{\text{(orthoclase)}}{KAlSi_3O_8} + \underset{\text{(corundum)}}{Al_2O_3} + \underset{\text{(water)}}{H_2O}$$

The above reaction must take place in the absence of quartz or else aluminum silicates such as kyanite (Al_2SiO_5) instead of corundum will form. Indeed, the fact that kyanite and related minerals are much more common than corundum in metamorphic rocks is evidence that quartz is usually present when muscovite breaks down. Further, if water is present above a certain pressure (about 4 kbar), muscovite will melt rather than form the reaction products shown. Notwithstanding the above restrictions, such reactions are well established. For example, Williams et al. (1982) state that certain aluminous minerals found in basalts, such as spinel, corundum, and cordierite (iolite), represent refractory (i.e., unmelted, unchanged) residues from fractional (partial) melting of shale.

Figure 4 illustrates a phase diagram of the systems muscovite-corundum and diaspore-corundum, which are discussed below. (A *phase diagram* is a graph in which two or more variables, in this case temperature and pressure, are plotted to show the boundaries of the fields, or areas, of stability of various phases; in this case, the phases are minerals. A *system* is that portion of the universe that is being studied, in this case, the mineral conversions of muscovite to corundum and diaspore to corundum.) These phase diagrams can be applied to the breakdown of muscovite and diaspore under conditions of high temperature and pressure, as would be encountered in a subduction zone.

With respect to the breakdown of muscovite, experimental studies have shown that the reaction given above can occur over a wide range of pressures (as indicated by the line separating muscovite from corundum + orthoclase + water in figure 4; pressure is comparable to depth in this case), but in only a relatively narrow range of temperatures (about 650°–725°C; Evans, 1965). Thus, corundum may be expected to crystallize at many different depths or pressures in the Earth's crust if the temperatures are high (*and* if quartz and water are absent). Such conditions occur at shallow depths (characterized by low pressure) in some contact-metamorphic areas where granitic (including pegmatitic) rocks are intruded into sediments, and at greater depths (>20–25 km, characterized by high pressure) in regionally metamorphosed rocks, such as gneiss. However, in a subducting plate, the conversion would take place at depths of about 42 km or greater. It should also be emphasized that the conditions required for this reaction to occur—for example, the absence of quartz, and the absence of water above a pressure of 4 kbars—may be rare in natural situations.

Mechanism 2. With fewer geologic restrictions, corundum could form from other starting materials, particularly hydrated aluminum oxides—such as gibbsite, $Al(OH)_3$, and diaspore or boehmite, $AlO(OH)$. For example, the equation for the formation of corundum from diaspore or boehmite would be:

Equation 2

$$\underset{\text{(diaspore)}}{2AlO(OH)} \rightarrow \underset{\text{(corundum)}}{Al_2O_3} + \underset{\text{(water)}}{H_2O}$$

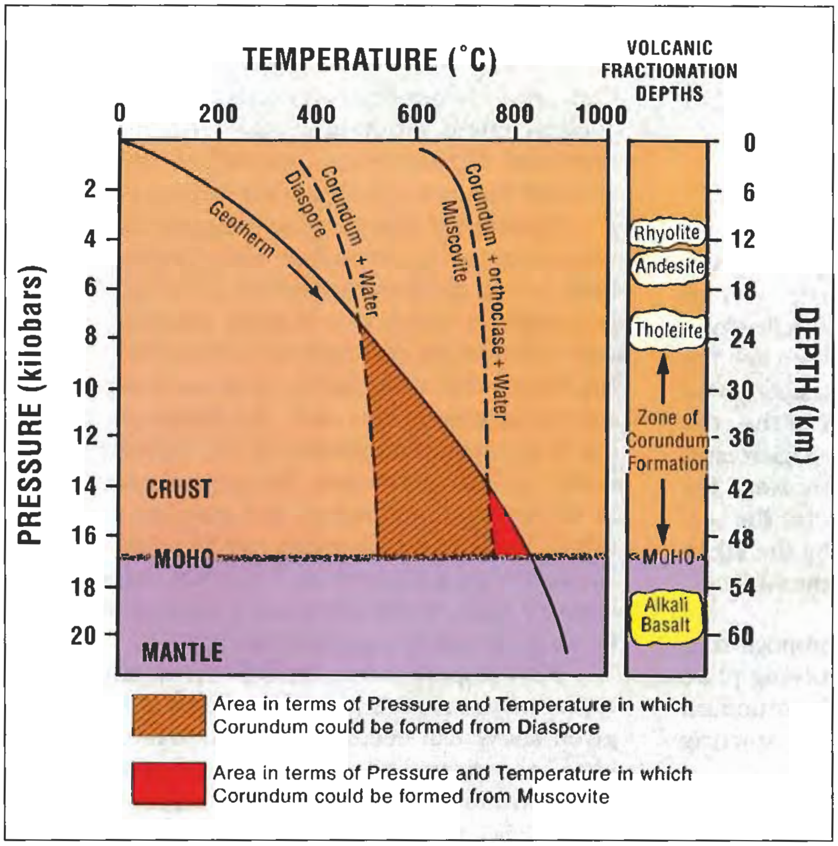

Figure 4. Phase diagrams are shown for conversion of muscovite to corundum (plus orthoclase and water), and diaspore (a constituent of lateritic and bauxitic soils) to corundum (plus water). Stability fields for the minerals are delineated by broken lines (solid where experimentally determined for muscovite), and a geotherm (temperature versus depth line) is plotted for the continental crust. Where the geotherm crosses the stability lines, conditions allow mineral transformation. Thus, corundum can only form from the breakdown of muscovite below about 42 km (cross hatching); however, it can form from the breakdown of diaspore as shallow as 24 km (slanted lines). Also shown are approximate depths of formation for various volcanic rocks. Only alkali basalt forms deep enough to migrate through the zone of corundum formation.

These hydrated aluminum oxides are typical of extensive laterite and bauxite terranes such as are found today in large areas of India, Africa, South America, Australia, and other tropical regions. The pressure and temperature conditions for the breakdown of gibbsite, diaspore, and boehmite also indicate that corundum might form from these minerals deep in the crust by mechanisms analogous to those discussed above for muscovite, except at depths as shallow as 24 km (see figure 4). Gibbsite, diaspore, and boehmite were suggested as possible starting materials for the formation of gem corundum, particularly ruby, in regional metamorphic environments such as at Mogok (Kammerling et al., 1994). Even though these latter deposits are in marbles rather than in alkali basalts, and the methods by which they reached the Earth's surface are distinctly different, the fundamental metamorphic reactions by which corundum is formed from aluminum-rich minerals (see equation 2) are still applicable.

Stage 2: Transport of Corundum to the Surface. The second stage of the process requires a method to bring the corundum crystals to the surface. Key factors in this process are listed below, and the entire process by which corundum forms and is transported to the surface in alkali basalts is illustrated in figure 5.

1. Basalt magmas typically migrate to the surface rapidly (sometimes explosively), in a matter of hours to days. During this short time period, alkali basalt magmas must: (a) incorporate the corundum-bearing xenoliths (figure 6), and then (b) disintegrate and dissolve the xenoliths, thus releasing the corundum and other refractory minerals (e.g., zircon) into the magma as xenocrysts. In most cases, there is at least some resorption of the corundum, as evidenced by characteristic rounding, etching, and corrosion of the surface. At the time it travels upward, the alkali basalt magma is at a temperature of 1100°–1300°C.
2. The depths at which alkali basalts form (> 50 km) require that—to reach the surface—they must pass through the uppermost mantle and deep part of the Earth's continental crust, where corundum crystals may have formed. This contrasts with other extrusives (such as rhyolite and andesite), which typically form at depths of only 10–25 km; this is too shallow to encounter any significant number of corundum crystals, which would have formed in the

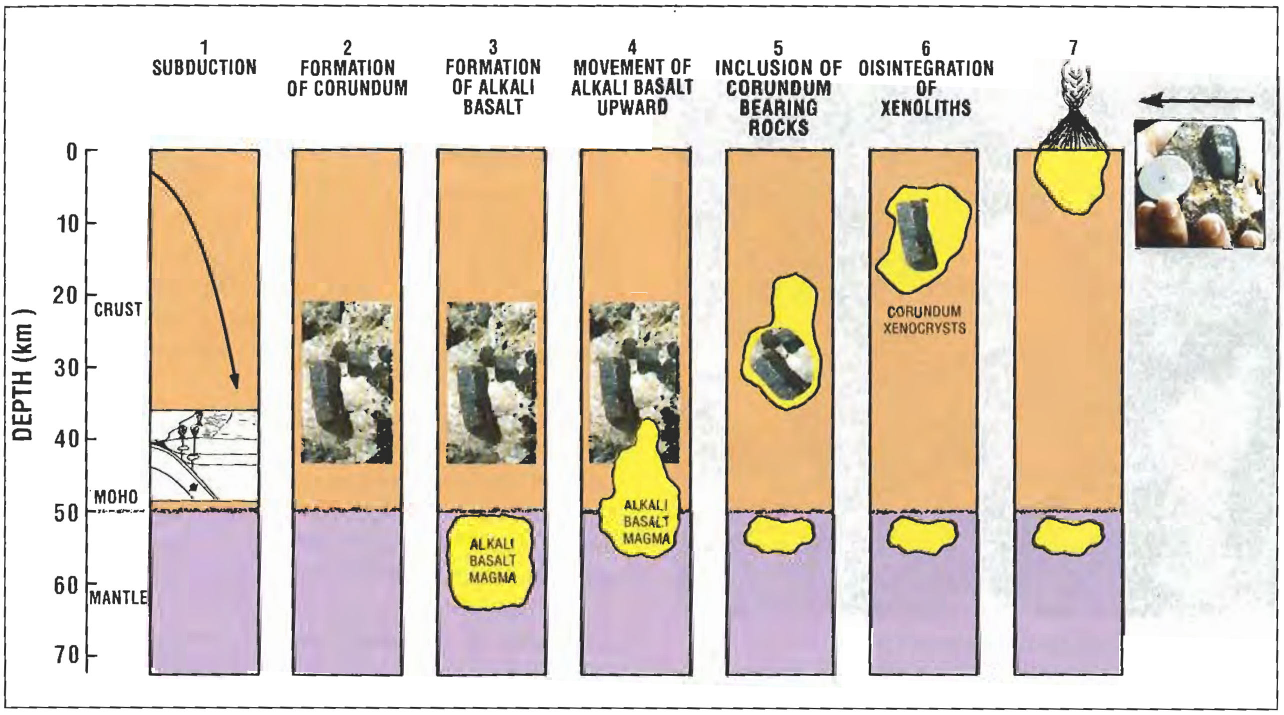

Figure 5. There are several main stages in the formation of corundums and their transport to the surface in alkali basalt: (1) subduction of appropriate starting materials (e.g., aluminum-rich sediments, laterites, bauxites; see figure 2); (2) formation of corundum in appropriate rocks (e.g., gneiss; see figure 6) deep in the crust by means of metamorphism of the starting materials (see figure 4); (3) formation of alkali basalt in the upper mantle by partial melting; (4) movement of alkali basalt upward; (5) inclusion of corundum-bearing xenoliths in alkali basalts (some alkali basalt remains in the mantle); (6) disintegration and resorption of xenoliths, the release of corundum crystals (xenocrysts), and continued transport upward; and (7) volcanic eruption brings corundum crystals to the surface (see figure 3).

Earth's lower continental crust. (Under some conditions of elevated temperatures in the lower continental crust, it might be possible for the geotherm [temperature versus depth line] of figure 4 to intersect the corundum stability field at shallower depths such that corundum could be formed at depths appropriate for transportation by tholeiite or andesite magmas. However, this would likely be rare.)

These various conditions are met, for example, in Southeast Asia (figure 7). Alkali basalts in Thailand, Cambodia, and Vietnam migrated through thick, fractured continental crust (Polachan et al., 1991) and occasionally carry corundum xenocrysts to the surface. Even in this area, however, corundum-bearing alkali basalts are not common.

We emphasize that the formation of alkali basalt magma may occur long after, and may even be unrelated to, the subduction that carried the aluminum-rich rocks to depth. In eastern Australia, for example, the sapphire-bearing alkali basalts are primarily younger than 55 million years, and subduction ceased about 200 million years ago (Veevers et al., 1991). In this region, aluminum-rich rocks may have been carried to depth by subduction and remained part of the lower crust until an alkali basalt magma, or other heat source in the general region, provided sufficient heat to effect conversion of some minerals to corundum. In the case of the alkali basalt magma, the same heat source could subsequently provide a mechanism to bring the corundum to the surface.

ALTERNATIVE THEORIES FOR ORIGIN OF CORUNDUM IN ALKALI BASALT

Only a few theories to explain the occurrence of gem corundum in alkali basalt have been proposed. Hughes (1990) briefly mentioned three: Two suggested that the corundum crystals were xenocrysts of unknown deep origin, whereas the third suggested that the corundum formed, as a primary mineral, in a basaltic magma generated at depths of 65–95 km by partial melting of mantle material.

Because so few corundum crystals have been observed *in situ* in (alkali) basalts in Australia, Pecover (1987) suggested that (alkali) basalt may not be the rock from which corundum is released, at least in that country. Rather, he suggested that

Figure 6. This hand specimen from Gallatin County, Montana, shows gray corundum crystals (longest is about 13 cm—about 5 inches, not of commercial quality) in contact with coarse-grained nepheline (white; a feldspathoid mineral) in a gneiss. The fine-grained areas of gneiss contain muscovite, feldspar, and sillimanite. This rock formed deep in the crust (at perhaps 20–25 km) and was brought to the surface by tectonic activity (not by alkali basalt magma). Although the exact conditions are not known, this rock could have been formed by the mechanism described in this article. Photo © GIA and Tino Hammid

basaltic "tuff" (a rock formed of compacted volcanic fragments), which may represent the surface expression of much deeper pipe-like bodies, may have carried the corundum to the surface.

Two distinctly different theories for the magmatic origin of corundum in alkali basalts, based primarily on the study of deposits in eastern Australia, have been developed: (1) by Coenraads et al. (1990) and Coenraads (1992); and (2) by Guo et al. (1992a, 1994). Both theories recognize that it is unlikely that corundum crystallized from its host alkali basalt and suggest different ways in which corundum may have crystallized from another magma, high in Al_2O_3 content, that is distinct from the alkali basalt that brought the crystals to the surface.

Both of these theories are based, in large part, on the importance attached to certain minerals found as inclusions in Australian sapphires that, like the corundum host, could not have crystallized from an alkali basalt magma. These include zircon, columbite, uranium pyrochlore, thorite, ilmenite, alkali feldspar, and cobalt-rich spinel (the last only from Guo et al., 1994), as well as carbon dioxide–filled fluid inclusions. Thus, they concluded that the sapphires and their inclusions must have grown in an environment rich in "incompatible elements" (those elements, such as Zr, Nb, Ta, U, Th, Ti, and Co, that do not fit into the structures of the common rock-forming minerals), alkali elements (e.g., K and Na), and volatiles (e.g., CO_2).

On the basis of these and other data, such as the presence of iron-rich melt inclusions and the ages of included zircons, Coenraads et al. (1990) developed a model involving two magmas. Basically, this model involves: (1) the ascent from the mantle of a carbonate-enriched mafic magma (first magma) that also contained the incompatible elements; (2) crystallization of corundum and its inclusions within this magma; and (3) later volcanic eruption of alkali basalt (second magma) to entrain the corundum and bring it to the surface.

Guo et al. (1992a, 1994) developed a more complex, multistage model involving four magmas. Their model involves: (1) the ascent from the mantle of a carbonate-enriched mafic magma (first magma) containing the incompatible elements; (2) the interaction of this magma with an alkali-rich felsic (granitic) magma (second magma) in the lower crust; (3) the resulting hybrid magma (third magma) having favorable chemical characteristics (low SiO_2, high Al_2O_3) for the crystallization of corundum; and (4) later volcanic eruption of alkali basalt (fourth magma) to bring the corundum to the surface.

The mixing of two different magmas in the Guo et al. model to produce a third magma with distinctive characteristics is an accepted geologic process (e.g., Williams et al., 1982; Philpotts, 1990), and the mechanism they propose is theoretically possible and may well occur on a local scale. However, we believe that it requires too many special conditions to be applicable to the origin of the widespread corundum deposits of Southeast Asia and Australia. On the other hand, our metamorphic (as opposed to magmatic) model, which uses aluminum-rich sedimentary rocks such as laterite or bauxite as the starting material, provides a simpler explanation for the formation of corundum crystals and all the included minerals (e.g., columbite) that are so fundamental to both of the above models. In particular, our model requires only one magma (alkali basalt)—as a transport mechanism to bring corundum to the surface.

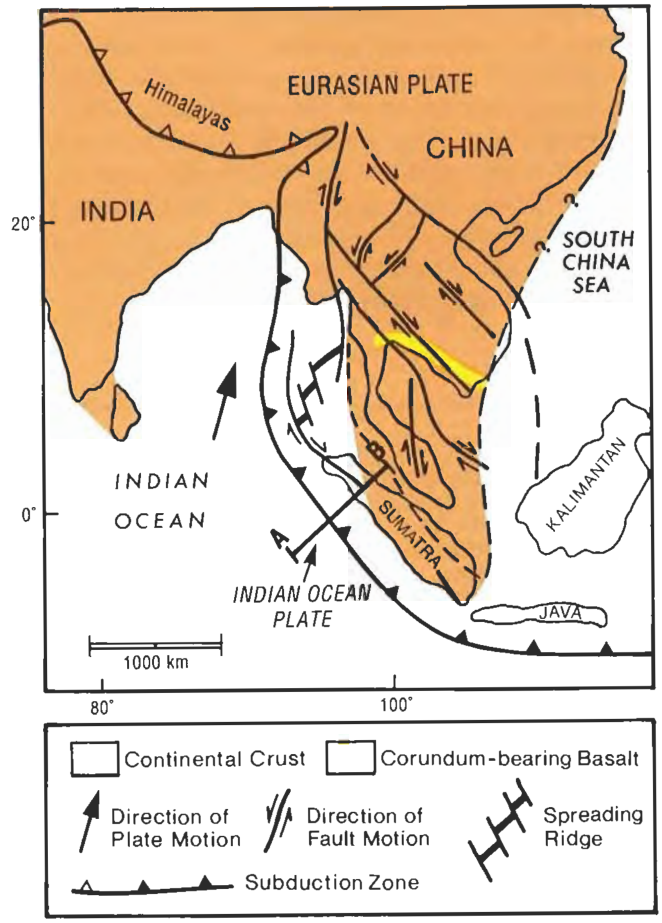

Figure 7. In this generalized tectonic map of Southeast Asia, alkali basalts (yellow area) are located in Thailand, Cambodia, and Vietnam. They occur in old (and probably thick) continental crust in a region that is presently undergoing active faulting associated with the subduction of the Indian Ocean plate beneath the Eurasian plate. A cross-section of the Earth through the crust and upper mantle (line A–B) might approximate the cross-section shown in figure 2. The corundum-bearing alkali basalts are located north of line A–B, where the crust may be thicker and where fractures produce zones of weakness through which the alkali basalt magmas rise to the surface.

Adding support to our proposed metamorphic model is the report by Koivula and Fryer (1987) on the discovery of an inclusion of sapphirine (not sapphire), $(Mg,Al)_4(Al,Si)_3O_{10}$, in a ruby from Bo Rai, Thailand (from alluvial deposits associated with alkali basalts). Sapphirine has also been reported associated with ruby and sapphire in one locality in eastern Australia (Sutherland, 1994). Sapphirine only forms in a metamorphic environment, and Harley (1989) has shown that it crystallizes at pressures and temperatures appropriate for the lower continental crust.

During the formation of laterite and bauxite, certain trace and minor elements may be concentrated in these materials depending on the type of rock material from which they are formed by intensive weathering. For example, all the incompatible elements mentioned above are concentrated to some degree; some, such as Ti, Zr, and Nb may be enriched by as much as fivefold as compared to their parent material (Mason, 1966), which was probably a granite or a syenite. Some laterite deposits developed on mafic rocks—such as in New Caledonia, Australia, and Indonesia—have such large amounts of nickel and cobalt that they are economic to recover (U.S. Bureau of Mines, 1980). Depending on the presence of minor amounts of other minerals (e.g., calcite) in laterites, all other constituents emphasized in both the Coenraads and Guo models can be explained. Clearly, laterites and related weathering products contain the necessary minor and trace elements, in addition to large (or predominant) amounts of aluminum-rich minerals, to be a potential starting material for corundum formation. Not only are large areas of the world covered with laterites today, but it is also likely that equally large areas composed of laterite and similar materials (or weathered products derived from this material) have been subducted into the crust and mantle in the geologic past.

CONCLUSIONS

Although corundum is well known to gemologists, it is relatively rare compared to other minerals primarily because its formation requires an environment that has a low silica (SiO_2) content. Yet silica is one of the most abundant constituents of the Earth. The model presented in this article relates the formation of gem corundum deposits to subduction zones that carry aluminum-rich materials (i.e., quartz-free aluminous sediments, laterites or bauxites), which are naturally silica-depleted, below continental areas. At depths of about 25–50 km, these materials are transformed by metamorphic processes into corundum-bearing mineral assemblages. These assemblages are later brought to the surface by alkali basalt magmas, which form below 50 km. This metamorphic model is simpler than some previous magmatic models which, although they are theoretically possible and might well occur on a limited scale, require numerous special circumstances. The effects of high temperature and pressure on corundum crystals during their transport in alkali basalt magmas are uncertain. However, it is interesting to speculate that they might influence the ultimate color and clarity of the corundum, analogous to some of the commercial enhancement processes currently employed.

At present, significant amounts of sapphire are obtained from secondary deposits derived from alkali basalts in Southeast Asia and Australia. We believe that additional sapphire deposits will be identified not only in the above-mentioned areas but also in other parts of the world where alkali basalts are, or will be, found. On the basis of this model for the origin of the corundum, and the mechanism by which it is brought to the Earth's surface, advances in geologic and geophysical knowledge should enable geologists to locate new areas worthy of exploration for gem corundum.

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DIAMOND, Light Yellow Treated Color

Clients sometimes ask the GIA Gem Trade Laboratory why Origin-of-Color reports are needed for light yellow or brown diamonds—that is, those without sufficient depth of color to fall in the fancy-color range. A 0.91-ct, light yellow round brilliant that came into the West Coast lab this fall clearly showed that one can never be too careful even with such light-colored stones.

This diamond was a moderate blue transmitter, showed a weak green "haze" with no green graining, and had a moderate localized mottled strain pattern. It fluoresced very strong blue to long-wave ultraviolet radiation and strong yellow to short-wave UV; it phosphoresced weakly to both wavelengths. In the desk-model spectroscope, it showed a moderate Cape spectrum, with weak 498- and 504-nm lines, but no 595-nm line was visible. This spectroscopic information (498 with 504 line, but no 595-nm line), combined with the green haze without graining, provoked our suspicions. UV-visible spectrophotometric measurement detected peaks at 451, 477, 496, and 503.2 nm; a possible 546-nm peak; plus a very faint peak at 595 nm. Mid-infrared spectra showed that the diamond was a type IaB>A (high nitrogen). These spectra also showed peaks at 5163 and 4932 cm^{-1}. These H1b and H1c peaks are considered conclusive proof that a type-Ia yellow-to-brown diamond has been irradiated and annealed.

Although color grades are not assigned to treated diamonds, the color of this stone would be in the T–V range. In our experience, it is most unusual to encounter such a light tone, treated-color diamond. Perhaps it represents a failed attempt to improve the diamond's color without leaving a detectable treatment signature.

MLJ, Dino DeGhionno, Patricia Maddison, and IR

Carved EMERALD Fetish

The carved fetish shown in figure 1 was represented to staff members at the East Coast lab as the emerald centerpiece of a pre-Columbian necklace. Although we could not verify the stone's origin, or even when the necklace was fabricated, the primitive carving and crude drilling certainly suggest an early carving technique. However, unlike some other carved gem materials featured in past Lab Notes, the material from which this 39-ct fetish was carved was easily identified as emerald by its "textbook" properties.

Figure 1. This natural emerald carving, measuring 28.25 × 14.05 × 11.15 mm (39 ct), was represented to be part of a pre-Columbian necklace made up of the pieces shown in figure 2.

Specifically, the refractive index was approximately 1.57 (by the spot method). The absorption spectrum, with its chromium lines visible in the hand spectroscope, was diagnostic of emerald. The classic three-phase inclusions also pointed to the carving being natural emerald.

The material was of exceptional quality for a carving, and it showed no evidence of clarity enhancement (e.g., oiling), although microscopy revealed some surface-reaching fissures. This supports the case for the fetish being a genuine pre-Columbian artifact, as it is unlikely that such fine material would escape faceting today.

Although pre-Columbian gold jewelry is not our area of expertise, we could not help but admire the gold figures that accompanied the fetish. Of particular interest were the three shown in the necklace arrangement in figure 2. From their heft, we

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Editor's note: The initials at the end of each item identify the contributing editor who provided that item.

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Figure 2. Note the fine craftsmanship of the reportedly pre-Columbian pieces (including the emerald carving featured in figure 1) shown here as they might have been worn on a necklace.

believe that they are solid, and they appeared to have been cast by the lost-wax technique. The figure above the emerald fetish in the center of the necklace was hollow, but it was most likely also cast by the lost-wax technique. This method was used with a high degree of technical proficiency in the pre-Columbian era. According to Warwick Bray, professor of Latin American Archeology at the Institute of Archeology, London (as was reported in *Gem and Jewellery News*, Vol. 3, No. 3, 1994, on p. 43), "The cast ornaments (Panamanian and pre-Columbian) were generally of a gold/copper alloy, which was easier to cast than pure gold and which could be surface treated with vegetable acids to produce a finer gold colour on the surface—what we call depletion gilding today." This gold/copper alloy, known as *tumbaga*, was alloyed in various proportions. TM

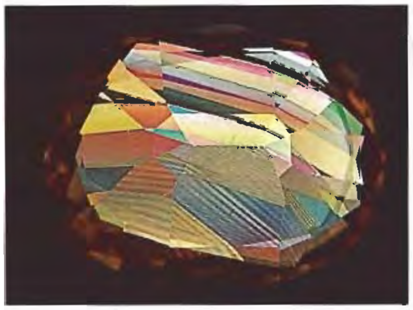
FELDSPAR, Separating Alkali from Plagioclase Species

Faceted yellow feldspars have been coming into the market from a number of localities, including Australia, California, Madagascar, and Oregon. A 5.52-ct faceted stone submitted to the West Coast lab had been represented as sanidine, the potassium sodium feldspar that forms in a high-temperature environment. Although standard gemological tests revealed that the stone was a feldspar, refractive index values of 1.559–1.568 were sufficient to confirm that it was labradorite, not sanidine.

Working with this feldspar reminded us of a comparatively easy test using crossed polarizers that not all gemologists may know about. Although it will not identify the species, it will distinguish some plagioclase feldspars (albite, andesine, anorthite, bytownite, labradorite, and oligoclase) from alkali feldspars (microcline, orthoclase, and sanidine).

When examined with the microscope between crossed polarizing filters, this stone—for example—showed the fantastic, multicolored stripes (figure 3) characteristic of polysynthetic (many-layered) twinning. Polysynthetic twins grow according to twin laws that are only possible in feldspars with triclinic symmetry: microcline and the plagioclases, not sanidine or orthoclase. (Microclines in general are even more twinned than plagioclases and tend to look "plaid" through crossed polarizers.) The stripes in some faceted plagioclases, including the example shown here, are obvious enough to be seen with little or no magnification between crossed polarizers, which makes this a useful field test. Pressed for a quick decision, a gemologist could even look for twinning planes while holding a stone between two pairs of polarized sunglasses placed in the "crossed" position. MLJ

Figure 3. The bright stripes seen in this 5.52-ct labradorite feldspar when viewed between crossed polarizers are due to polysynthetic twinning (parallel twin planes). Such twinning is present in plagioclase feldspars, and separates them from the alkali species microcline, orthoclase, and sanidine.



GROSSULAR-ANDRADITE GARNET from Mali, West Africa

In September, a client brought a piece of yellow-green rough to the East Coast laboratory for identification. The client stated that the stone had been mined in the Republic of Mali, in western Africa, but he had

Figure 4. This 16.30 × 15.45 × 12.40 mm piece of rough, a grossular-andradite garnet, is reportedly from Mali.

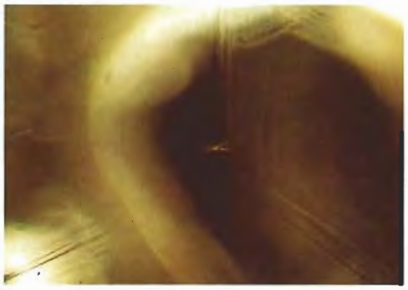


Figure 5. Dodecahedral growth faces (seen here in polarized light) and a small wispy horsetail inclusion are evident in the stone in figure 4 at 50× magnification.

received conflicting opinions regarding its identity (chrysoberyl versus tsavorite garnet).

The transparent material (figure 4) measured approximately 16 × 15 × 12 mm and weighed 25.35 ct. Since it was unmounted and had a fairly flat surface, we were able to determine its optical properties by standard gemological testing. It had a single refractive index of 1.77, but showed strong anomalous birefringence when viewed in the microscope between crossed polarizers. When we examined the piece with a microscope, we saw an unusual pattern resembling dodecahedral growth faces, which was even more pronounced under polarized light; we also found a small, wispy "horsetail" inclusion (figure 5). The spectroscope showed a broad absorption band at 440 nm and a 600-nm line, as well as a possible feature at 500 nm. The specific gravity of 3.65 was determined by hydrostatic weighing. These properties do not fall within the range of properties that characterize either grossular or andradite garnet (e.g., the R.I. is too high for grossular and too low for andradite). Since these findings were not sufficient to identify the material, the stone was sent to the West Coast laboratory for further testing.

X-ray powder diffraction analysis gave a typical garnet pattern. The unit-cell spacing from this pattern and the specific gravity matched the values charted in Deer, Howie, and Zussman's *Introduction to Rock Forming Minerals* (Longman Group, London, 1974) for a garnet intermediate between grossular and andradite, with probable composition 68%–75% grossular, 32%–25% andradite. We confirmed this using EDXRF, which revealed small amounts of Mn, Ti, and V in addition to the major elements Si, Al, Ca (from the grossular component), and Fe (from the andradite). A UV-visible spectrum showed Fe^{3+} peaks at 434, 575.5, and 872 nm. There was no evidence of chromium from either test. Therefore, we concluded that it was a grossular-andradite garnet.

KH, MLJ, and Emmanuel Fritsch

JADEITE JADE

Bleached and Impregnated, with Distinctive Surface Features

We continue to encounter bleached and impregnated jadeite ("B jade") on both coasts, which has enabled us to support and expand the observations in "Identification of Bleached and Polymer-Impregnated Jadeite" (Fritsch et al., *Gems & Gemology*, Fall 1992, pp. 176–187). Consistent and conclusive identification still requires infrared spectroscopy. In some cases, however, careful examination of the surface with a binocular microscope and a variety of lighting techniques may provide useful clues. One such case was a fine-quality bangle bracelet (figure 6) tested at the East Coast laboratory.

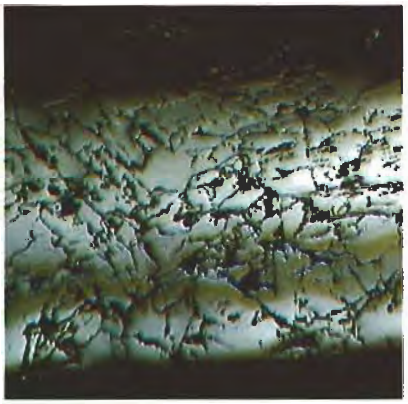
The change in surface texture produced by the treatment was described briefly in the above reference and in greater detail by Ou-Yang Chiu Mei in *Jewellery News Asia*, December 1993, pp. 96–100. The acid treatment removes the usually brown impurities that outline individual crystals of jadeite and detract from the jade's overall appearance. At this stage, the grain boundaries are obvious and, due to the crystal habit of jadeite, may form a honeycomb pattern. Following the "bleaching" step, the jadeite is impregnated with a neutral-color polymer or wax. This substance fills the voids left by removal of the impurities and makes the item appear more uniformly colored and more transparent. In addition, the grain boundaries are less visible after impregnation, although they may still be seen with the microscope. In her article, Mrs. Ou-Yang states that "For more severely treated jadeite, the structure looks like a beehive . . . the changed feature is the fingerprint for identifying type-B." The bleaching process weakens the jade, and both Mrs. Ou-Yang and Mr. Tay Thy Sun (*JewelSiam*, November–December, 1992, pp. 98–100) point out that although impregnation reduces the visibility of the bleaching treatment, it does not restore the original toughness.

We have experimented with different lighting techniques to detect this honeycomb structure after impregnation. Although it may be visible in some pieces with strong transmitted fiber-optic light, we saw it best with reflected light in this bracelet and a cabochon examined recently (figure 7).

In addition, with diffuse reflected light, we detected filled cavities, reminiscent of those seen in treated rubies, in the bracelet. However, these did not have the appearance of a surface residue, which has been noted before in both treated and natural jade; rather, they were actually "finished," or smoothed over, so they were flush with the polished surface. The wax normally used to finish a piece of jade flows and then resolidifies when tested with a "hot point."

Figure 6. Characteristic surface features indicated, and IR spectroscopy proved, that this jadeite bangle bracelet had been bleached and polymer impregnated.

Figure 7. At 40× magnification under diffused reflected light, the surface of this jadeite cabochon shows the unusual texture—actually, the outline of many individual jadeite grains—seen in some "B jade."



However, the material in these filled areas burned slightly when the thermal reaction tester was brought close to their surfaces, a reaction typical of a polymer. To observe the reaction best and to minimize potential damage to the item, we performed this test under magnification.

Corroborative testing with infrared spectroscopy showed strong absorption between 2800 and 3000 cm^{-1}, which is diagnostic of polymer treatment. We tested the bracelet in several areas to see if the filled cavities showed greater infrared absorption than the rest of the bracelet. However, we recorded very strong absorption in all the areas selected. Note, too, that the bracelet floated in methylene iodide, indicating a specific gravity range of about 3.20–3.25, as would be expected for most "B jade" (and lower than the average 3.34 for untreated jadeite).

This bracelet also gave us the chance to use two unconventional tests mentioned in the Fritsch et al. 1992 article. When the bracelet was gently tapped with steel forceps, the sound emitted was clearly muffled or dull, unlike the higher-pitched "ring" that untreated jade would emit. This supports an observation made by some dealers. Also, a drop of hydrochloric acid (HCl) remained intact on the surface; with untreated jade, "sweating" is observed around the droplet on the nearby surface of the stone after only a short time (*Gems & Gemology*, Fall 1992, p. 180). *TM and IR*

Spotted MALACHITE, Imitation and Natural

Many ornamental materials are recognized by their coloration patterns. One obvious example is malachite, which usually has opaque green parallel bands of the same hue but of variable tone or saturation. Two pieces of jewelry, set with material having this characteristic appearance, were submitted to the West Coast lab for identification.

The necklace contained a number of bezel-set 11 × 9 mm stones, with prominent banding that ranged from medium to pale green (figure 8). The material had a spot refractive index of 1.55 and effervesced slightly to a weak HCl solution. It showed conchoidal fracture and fluoresced a weak green to long-wave UV radiation, with a fainter green fluorescence to short-wave UV. Because the material was mounted, we could not determine specific gravity. However, on the basis of the presence of small

Figure 8. Banding can be seen in this 9 × 11 mm segment of a necklace. The swirled appearance of one of the bands helped identify the material as a malachite imitation. Magnified 10×.

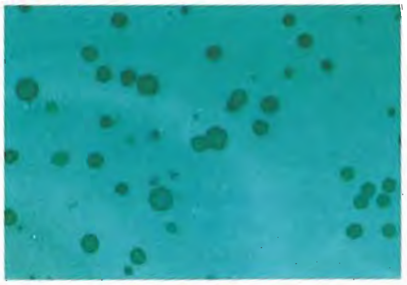


Figure 9. These "spots" on an 18.0 × 3.8 mm segment of a multiple-piece bracelet are similar to those seen on a natural malachite in the GIA collection. Magnified 10×.

bubbles, the "swirly" appearance of one of the bands (again, see figure 8), and the only slight effervescence, we suspected that it was a manufactured substance.

With the client's permission to perform destructive tests if necessary, we applied the thermal reaction tester in an inconspicuous spot: The material turned chalky white, melted easily, and flowed away from the test point. We thus confirmed that it was a malachite imitation.

The second, similar-appearing material was an 18.0 × 3.8 mm polished trapezoid that was set in a bracelet with obsidian, sodalite, imitation sugilite, and imitation turquoise. Given its "swirled" background color banding, the dark green spots on the lighter banded background, and the apparent conchoidal fracture, a first glance would indicate that this could also be a malachite imitation. However, refractometer testing indicated a strong birefringence "blink," and the material effervesced strongly to the weak HCl solution. The darker green spots (figure 9) had a somewhat higher relief (i.e., were more resistant to polishing) than the lighter green background. One dark corner of the background material was slightly translucent, while the rest was opaque. Furthermore, the material was inert to both long-wave and short-wave UV. These test results pointed to malachite as the identity.

We compared this stone to a natural malachite cabochon from the GIA GTL reference collection that also had small green spots with elevated relief on the surfaces of some striped bands. Unlike the response of the imitation malachite described above, the TRT produced a small brown spot where it touched the reference cabochon. When, again with the client's permission, we tested his material with the TRT, a similar dark brown spot was produced. This further confirmed that the unknown material was indeed natural malachite, which had probably been sliced parallel to the plane of the malachite banding.

MLJ, John I. Koivula, and Cheryl Y. Wentzell

PEARLS

Abalone "Mabe" Pearl

"Mabes" made with blister pearls cultured in the abalone shell (*Haliotis rufescens*) from North America were introduced to the participants of the Pearls '94 International Pearl Conference held in Hawaii last May. Thanks to a generous donation to the GIA reference collection, our West Coast laboratory staff subsequently had the opportunity to examine a sample (figure 10).

All of the abalone "mabes" seen thus far have had round button shapes, averaging approximately 9 to 14 mm in diameter. The demarcation line between the abalone blister and the backing was easily seen in our sample because the blister had been backed with ordinary mother-of-pearl shell (figure 11) rather than abalone shell. However, the blisters showed all the qualities that are characteristic of abalone pearls: attractive color combinations in green, blue, pink, and lavender; extremely high, almost metallic luster; and fairly transparent nacre. With high magnification, we noted that the nacre layer showed a fine cellular structure (figure 12). The characteristic appearance of the blister-pearl portion, as well as its strong yellow fluorescence to long-wave UV radiation, proved that it had indeed been obtained from an abalone.

KH

Non-Nacreous Cultured "Pearl"

The Summer 1990 Lab Notes section discussed cultured calcareous concre-

Figure 10. This 12-mm "mabe" has been fashioned from a cultured abalone blister pearl.

Figure 11. Regular mother-of-pearl shell was used to back the "mabe" in figure 10.

Figure 12. The cellular structure of the abalone portion of the "mabe" in figure 10 can be seen at 80× magnification.

Figure 13. This cultured concretion (11.8 mm × 12.7 mm in diameter) was found in a parcel of cultured South Sea pearls.

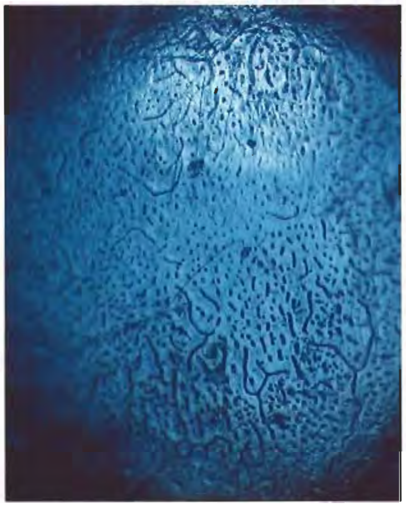


Figure 14. Note the dimples and fine fissures on the surface of the non-nacreous cultured "pearl" shown in figure 13. Magnified 30×.

Figure 15. When the cultured "pearl" shown in figures 13 and 14 was magnified 40×, the unusual lattice-like subsurface structure became apparent.

tions that had been found while harvesting cultured black pearls in the South Seas. Another of these non-nacreous cultured "pearls" arrived at the West Coast laboratory for identification last summer. With a subvitreous luster and no orient, the approximately 11.8 × 12.7 mm "pearl" resembled a shiny black marble (figure 13). When examined with magnification and reflected light, the surface appeared to have shallow dimples and displayed a network of very fine, hairline fissures (figure 14) that corresponded to the subsurface structure of the "pearl." Higher magnification with strong, fiber-optic illumination revealed this structure to be a tightly knit, lighter-colored, lattice-like network covering the entire sphere (figure 15). This structure was more concentrated in some areas, forming faintly eye-visible bands around the circumference of the "pearl." Accompanying the latticework were gray translucent areas that had a distorted honeycomb or cellular structure. These alternated with transparent areas to create an overall patchiness when magnified. The structure near the surface was similar to that of cultured calcareous concretions described in the previously mentioned Summer 1990 Lab Notes section (p. 153).

Because this non-nacreous "pearl" had an appearance different from that of any natural concretion we had seen before, we used X-radiography to reveal its internal structure. The X-radiograph confirmed its cultured origin, evidenced by an obvious bead nucleus surrounded by a thick outer layer.

The owner reported that this "pearl" came from a South Sea black-lipped oyster (*Pinctada margaritifera*), harvested near Rikitea in the Gambier Islands of French Polynesia. If so, it appears to be an unusual product of the usual culturing process, one in which the mantle-tissue graft lacked the critical epithelial cells necessary to produce the nacreous layer. *Cheryl Y. Wentzell*

SAPPHIRE of Unusual Color

Occasionally we see color-change sapphires with the green-to-blue (daylight) and red-to-brown (incandescent light) colors of alexandrite. A 1.83-ct square step cut seen in the East Coast lab was surprising in that it was clearly corundum and had a reddish brown body color similar to that seen in some alexandrite in incandescent light, yet it exhibited no color change. The unusual color appearance was due in part to the presence of pronounced pink and green-blue bands, which were best seen in diffuse transmitted light (figure 16). Part of the color sensation was also influenced by the stone's dichroism. The visible spectrum, viewed through a desk-model prism spectroscope, showed a strong broad band at 450 nm along with general absorption from about 680 to 700 nm. The most notable gemological property was the refractive index of 1.775–1.784. Although rather high, this still falls below the upper limits of 1.785 and 1.794 for natural brown sapphire cited by M. Fleischer et al., in *Microscopic Determination of the Nonopaque Minerals*—U.S. Geological Survey Bulletin 1627 (U.S. Government Printing Office, 1984).

Figure 16. The pink and blue-green banding seen with diffused transmitted light in this 1.83-ct sapphire is partially responsible for the reddish brown body color of the stone. Magnified 15×.

Although sapphires in this color range are seldom encountered at the Gem Trade Lab, we are told by members of the trade that they are not particularly rare, just of little interest commercially.

TM

SYNTHETIC SAPPHIRE, Another Striae Resolution Technique

To get the most from our microscopic examination of gems, we use a variety of lighting techniques: darkfield, brightfield, diffused, oblique-angle fiber-optic, and shadowing, among others. These may be further enhanced by examining the stone while it is immersed (see, e.g., the Winter 1993 Gem Trade Lab Notes, p. 282). Filters can also be useful in resolving growth structures. For example, a white diffusion filter may help resolve curved color banding in blue synthetic sapphires, and a blue diffusion filter may resolve curved color banding in yellow to orange synthetic sapphires (see, e.g., the Summer 1992 Gem Trade Lab Notes, p. 128).

The West Coast lab was asked to identify a transparent pink, 15.58-ct oval modified brilliant. Gemological properties were consistent with corundum, both natural and synthetic. Microscopic examination revealed only minute pinpoint inclusions of an undetermined nature. The method that finally revealed the growth structures that proved its synthetic origin was the Plato test, performed using immersion in conjunction with crossed polarizers.

Figure 17. Examination with short-wave UV radiation at 15× magnification reveals curved growth features in this 15.58-ct pink synthetic sapphire.

As part of our documentation of the stone, we also viewed it under both long- and short-wave ultraviolet radiation. While the even, very strong red fluorescence to long-wave UV was not unexpected, we were surprised to see that the typical strong bluish white reaction to short-wave UV was uneven. To characterize this unevenness better, we examined the stone using magnification in conjunction with short-wave UV illumination (carefully filtering the light coming from the stone to block short-wave UV reflections and thus avoid eye damage). This revealed that the fluorescent reaction was confined to clearly defined curved color bands (figure 17). Preliminary examination of other pink synthetic sapphires from our reference collection has shown the technique to hold promise, as curved growth was also seen in some of these under short-wave UV radiation.

It should be noted that there are precedents for using ultraviolet radiation in the resolution of diagnostic growth features in synthetic gem materials. R. Hughes, in his book *Corundum* (Butterworth's, London, 1990), mentions using low magnification (2× to 6×) and short-wave UV illumination to see growth details in colorless synthetic sapphires. He also cautions that eye protection, such as a short-wave-UV blocking filter, is essential when observing stones under these conditions. The technique also helps characterize growth sectors in synthetic diamonds (see J. Shigley et al., "The Gemological Properties of Russian Gem-Quality Synthetic Yellow Diamonds," *Gems & Gemology*, Winter 1993, pp. 228–248).

RCK, Dino DeGhionno, and Patricia Maddison

PHOTO CREDITS

Shane F. McClure provided figures 1, 2, and 7. Photomicrographs in figures 3, 5, 8, 9, 12, 14, 15, and 17 are by John I. Koivula. Figures 4, 11, and 13 were taken by Maha DeMaggio. Nicholas DelRe supplied the pictures used in figures 6, and 16. Figure 10 is © GIA and Tino Hammid.

GEMNEWS

JOHN I. KOIVULA, ROBERT C. KAMMERLING, AND EMMANUEL FRITSCH, EDITORS
MARY L. JOHNSON AND DINO G. DEGHIONNO, CONTRIBUTORS

DIAMONDS

Native Appalachian diamonds. Occasionally, diamonds are found in the Appalachian Mountains of the United States, including New York, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Alabama, Kentucky, and Tennessee. W. D. Hausel and J. E. Bond, in the November 1994 issue of *International California Mining Journal*, suggest that these diamonds may have local sources, warranting exploration of the Appalachian area. Previous explanations for these diamond occurrences include glacial transport and "deposition by migrating birds from South America."

Diamond developments in Tanzania. Initial surveying is complete on five leases held by Serengeti Diamonds at the Kahama/Shinyanga diamond property. These lag-type deposits (i.e., secondary deposits in which the diamonds are concentrated by wind action) consist of gravels from around the Shinyanga diamond pipes that can occur up to 1 km from those sources. Because of preferential sorting by wind, these deposits tend to be a higher grade than the primary pipes. The Serengeti Diamonds deposits contain an estimated 258,100 carats in two types of gravels: 123,700 metric tons yielding 100 carats per 100 tons, and 1.68 million metric tons yielding 8 carats per 100 tons.

The Tanzanian Parastatal Reform Commission and Willcroft Co. (a subsidiary of De Beers Centenary AG) plan a US$8 million upgrade of the Mwadui mine, including a new diamond recovery plant. Production has declined at the Mwadui pipe, discovered by Dr. John Williamson in 1940, since superficial reserves were exhausted in the 1980s. A second concession near the Mwadui mine is currently being explored. (*Mining Journal*, September 9 [*p. 182*], November 4 [pp. 325, 330], 1994).

Other African diamond mining ventures. United Reef Ltd. of South Africa has reported the results of independent valuation in Antwerp of 417 carats of diamonds from its Bamingui project in the *Central African Republic*: The diamonds average US$150 per carat, making this deposit "among the world's highest in terms of dollar value per carat." (*Mining Journal*, November 4, 1994, p. 325)

After an absence of six years, De Beers plans to begin exploration along a 16,000-km^2 area of the *Sierra Leone* seacoast. (*Mining Journal*, August 19, 1994, p. 137)

Canadian diamond rush bruised but still alive. Despite very poor yields at two major Canadian diamond prospects and a devastating crash in diamond stocks, diamond exploration consultant A. J. A. "Bram" Janse of Perth, Australia, remains cautiously optimistic about several other diamond prospects in Canada. If the sources he cites are correct, it appears likely that at least one prospect will become an operational diamond mine.

The first big blow to the then-booming diamond exploration industry in Canada came on August 5, 1994. RTZ/Kennecott said that their underground sampling of the Tli Kwi Cho kimberlite pipe in the Lac de Gras area of the Northwest Territories had produced unexpectedly low grades of diamond. This immediately devastated diamond stocks on the Canadian exchanges, where investors lost an estimated C$500 million.

The second blow came when resampling of another pipe turned up very disappointing results. This one, the Torrie pipe in the Yamba Lake area, was being worked by Monopros, a joint-venture partner of Tangueray/Mill City Gold (and the Canadian prospecting subsidiary of De Beers).

The bad news about these two kimberlite pipes and the ensuing crash in diamond stocks has hurt investor confidence in geologists' predictions of rich Canadian diamond fields. However, these events have overshadowed another potentially lucrative find, according to research by Dr. Janse. Very encouraging results have been obtained from underground and large-diameter drill-core sampling on the BHP/Dia Met cluster of six pipes—Koala, Panda, Falcon, Misery, Fox, and Leslie. These are located 12 km south of Exeter Lake at about 64°40′N and 110°38′W, in the middle of the Corridor of Hope, which cuts through the Lac de Gras area. BHP/Dia Met is starting to study the feasibility of mining ore from two, three, or possibly all six pipes in the cluster. The company maintains that it expects to start mining diamonds from the 3-hectare (7.5-acre) Panda pipe before the year 2000. BHP has applied for the necessary environmental permits and filed a plan of operations. The company has also made presentations of planned future development to the local Dogrib people (*Northern Miner,* May 16 [p.1], June 27 [p.6], August 15 [p.1], September 5 [pp. 1, 6], 1994; *Financial Post,* Toronto, August 6–8, 1994, p. 1; *Globe & Mail,* Toronto, August 25, p. B6).

In addition, Aber Resources' exploration of diamondiferous kimberlite A-154, located about 25 km south of the BHP/Dia Met cluster, produced unexpected results. Two commercial-size diamonds, 1.75 and 0.25 ct, were found in a single drill core. A drilling barge has been set up to continue work. (*Mining Journal,* May 6, 1994, p. 328; June 24, 1994, p. 460; September 30, 1994, p. 236; December 3, 1994, advertising supplement).

Other Canadian regions with diamond potential include central Saskatchewan, where many companies are actively exploring, and the James Bay Lowlands of northern Ontario, which is now being prospected by KWG Resources (see, e.g., Gem News, Summer 1994, pp. 122–123).

Diamonds found in Finland. Bram Janse also reported heightened interest in diamond prospecting in Finland following Melbourne (Australia)-based Ashton Mining's recent disclosure that they had secured exploration leases covering large areas in northern Finland, found 21 kimberlite pipes, and recovered several diamonds over two carats. For instance, one two-hectare pipe yielded six carats of diamonds from a 23-metric ton sample (*Mining Journal,* September 9, 1994, p. 177). Ashton emphasized that it would still take two or three more years to evaluate these finds fully, but added that costs to develop a mine in Finland should be much lower than in Canada or Russia because of Finland's more advanced infrastructure (*The Australian,* August 31, 1994, pp. 1, 26). Some newspapers have called the finds "secret" (*The Australian,* above) or "sensational" (*Aftenposten,* Oslo, September 8, p. 2). The latter newspaper said that RTZ and De Beers also have large areas under diamond exploration leases.

Encouraged by discoveries in Finland, the Nordic Exploration Group (NordEx) is exploring two 100-km^2 diamond properties: one near Alno and the Swedish Baltic Coast; and the other, called Kalix, near the Finnish border with Sweden. Magnetic anomalies, similar to those associated with Canadian kimberlites, have been discovered in aeromagnetic data from the Kalix region. (*Mining Journal,* November 4, 1994)

Figure 1. This 4.09-ct trilliant-cut amethyst is typical of material being recovered from a mine in northern Namibia. Courtesy of Barker & Co., Scottsdale, Arizona; photo by Maha DeMaggio.

COLORED STONES

Amethyst from Namibia. Amethyst, a staple of the colored stone industry, is always well represented at gem and mineral shows. Typically, it is available in many forms, including faceted stones, cabochons, carvings, cobbed material (i.e., pre-trimmed rough), and mineral specimens as large as hundreds of kilos. Much of the rough material comes from Brazil; Zambia is also a major source.

At shows both this year and last, we also saw material from Uruguay, amethyst-citrine from Bolivia, pale-colored amethyst crystal clusters from the Ural Mountains of Russia (a classic source of amethyst), and even some attractive, medium- to dark-toned faceted material from Namibia (see, e.g., figure 1). According to Hannes Kleynhans, president of Amethyst Mining & Export, Karibib, Namibia, this material comes from a mine on the Burgershof Farm in the Platveld area of northern Namibia, very near the highway that runs from Windhoek to Tsumeb. A dirt ramp leads from the edge of what has become a huge excavated open pit to 150 feet (45 m) below the surface, where a large mineralized vein is being worked.

Mining takes place only during the dry season, roughly from April through September. Groundwater fills the pit during the rainy season, making mining impossible for the remaining six months. The mine is very productive, yielding several tons of material of all qualities annually, according to Mr. Kleynhans.

Chatoyant demantoid garnet. The editors recently examined a most unusual cabochon-cut demantoid garnet loaned by Yoshiko Doi, president of GIA Japan in Tokyo. The 1.94-ct stone (figure 2) displayed distinct chatoyancy in the form of a greenish yellow band, the result of light reflecting from a myriad of more-or-less parallel, fibrous inclusions.

These inclusions do not appear to be arranged in any specific crystallographic orientation within the host, as is normally the case for chatoyant gems (for example, in tourmaline the "eye" is caused by light reflection from

Figure 2. Distinct chatoyancy is displayed by this 1.94-ct (approximately 7.54 × 5.09 × 4.10 mm) demantoid garnet. Photo by Maha DeMaggio.

growth tubes that run parallel to the optic axis of the host). Instead, the "parallel" arrangement of the fibrous inclusions seems to be more random, with some fibers actually curving back on themselves completely (figure 3). This unusual arrangement of "horsetail" inclusions (which creates the "eye") makes the host demantoid garnet a true rarity.

Color-change diaspore from Turkey. Although the editors have known for some time about diaspore from Turkey, material seen thus far has been mostly brown with only a minor color change. However, one of the editors (EF) recently examined rough and faceted samples from a new deposit in Turkey. The best specimens of this new find show a very distinct color change—brownish pink in incandescent light (figure 4) and brownish green in daylight/fluorescent light. The samples were provided by Guven Cankur and Debbie Deatker of Eur-Asia Ltd., North Miami Beach, Florida. The faceted stones that we examined with this distinct color change ranged from 3.38 to 16.44 ct.

Figure 3. Magnification reveals that the fibrous inclusions responsible for chatoyancy in the demantoid in figure 2 are randomly arranged. Photomicrograph by John I. Koivula; magnified 25×.

Other gemological properties were typical for diaspore: refractive indices of $\alpha = 1.700–1.701$, $\beta = 1.723–1.726$, $\gamma = 1.749–1.750$; S.G. (measured hydrostatically) of 3.40; a moderately intense broad line visible at about 450 nm in the handheld spectroscope; inert to long-wave UV radiation, with a weak yellow fluorescence to short-wave UV.

Energy-dispersive X-ray fluorescence analysis detected aluminum—a major constituent of diaspore, AlO(OH)—and traces of titanium, chromium, and iron.

Figure 4. This color-change diaspore from a new find in Turkey appears brownish pink in incandescent light. The cut stone shown here weighs 3.38 ct. Photo by Maha DeMaggio.

Figure 5. Myanmar is the reported source of this 7.91-ct cabochon of plagioclase feldspar with ruby inclusions. Photo © GIA and Tino Hammid.

UV-visible absorption spectroscopy taken in a random orientation also showed features typical of iron (Fe^{3+}) in all gems, which we believe is responsible for the brown color of most gem diaspores from Turkey documented so far. Also detected was chromium. Preliminary investigations indicate that the chromium (Cr^{3+}) is responsible for the color-change behavior (as it is in many gems, such as alexandrite and some color-change pyrope-spessartine garnets). The variable position of the absorption cut-off at short wavelengths was tentatively attributed to charge-transfer phenomena, possibly involving titanium and iron.

Mr. Cankur indicated that exploratory mining revealed good-quality material in many areas, so future production may be significant.

Feldspar with ruby inclusions. In October 1993, Karl Schmetzer of Petershausen, Germany, received for identification some translucent white cabochons with red crystal inclusions (see, e.g., figure 5). X-ray diffraction analysis of the two materials revealed that they were plagioclase feldspar and ruby, respectively. At about the same time, Dr. Schmetzer learned that Martin P. Steinbach, a gem dealer in Idar-Oberstein, Germany, had some 20 cabochons, ranging from 5 to 13 ct. Mr. Steinbach said that the material reportedly came from Myanmar, although he did not know the exact locality. He purchased all of the specimens in northern Thailand, near the Myanmar border.

In November 1993, Michael Gray of Graystone Enterprises in Missoula, Montana, showed one of the editors (JIK) a cabochon of a similar-appearing material, also reportedly from Myanmar but obtained in Europe. Subsequent gemological testing confirmed that this was also a feldspar with ruby inclusions.

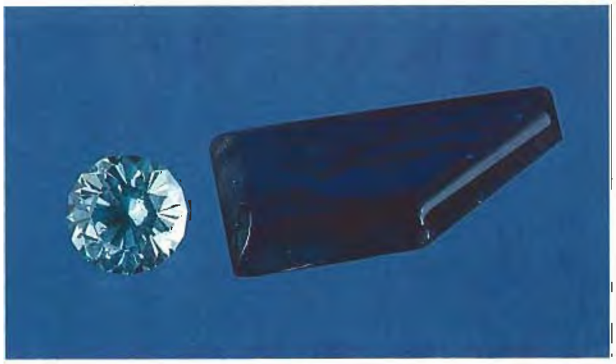
The ruby inclusions have somewhat rounded edges and vary greatly in size. They range in diaphaneity from translucent to transparent. Because some of the inclusions are large (as much as 5 mm long) and often break the surface of the host stone, it is quite easy to determine their refractive indices, absorption spectra, and pleochroism.

Gems from North Carolina. The Summer 1993 Gem News section contained an entry on "emerald matrix" from North Carolina, the only emerald locality in the United States. This material, first seen by the editors at the 1993 Tucson event and again at the one in 1994, was offered by the Emerald City Gem Shop of Spruce Pine, North Carolina. They showed us 152 cabochons, ranging from 2.66 to 31 ct, as well as some attractive unfashioned mineral specimens.

They also distribute other beryls from North Carolina, including pale-colored aquamarines (figure 6) and green beryl cabochons with moderately distinct chatoyancy. They reported that the aquamarine comes from the Hanson Creek Aquamarine mine in Avery County, an abandoned mica mine that the firm purchased in 1992 and subsequently reopened for its gem potential. We saw 125 cabochons ranging from 2 to 22 ct and 58 faceted stones ranging from about 1 to 6 ct.

Another North Carolina gem material offered was kyanite (again, see figure 6) from the Balsam Gap Blue Kyanite mine near Barnardsville. According to co-owner Gary Ledford, kyanite was first discovered at this locality in 1989, but the firm did not start selling it until recently, when they felt they had an adequate supply of fashioned goods. Some of this material is similar to some kyanite from Brazil, the hues ranging from medium greenish blue to blue with colorless areas. However, some of the darker blue material from North Carolina has areas of a darker, more saturated blue than anything we have noted in Brazilian material. We saw two faceted stones (5.38 and 9.58 ct) that were exceptional for their absence of eye-visible inclusions, their transparency, and their well-defined dark blue/colorless bicoloration.

Figure 6. North Carolina is the source of this 1.14-ct faceted aquamarine and 9.88-ct freeform kyanite tablet. Courtesy of Emerald City Gem Shop; photo by Maha DeMaggio.



More on peridot from Pakistan. The Fall 1994 Gem News section contained an entry on a new and potentially significant commercial source of peridot in the far western region of the Himalaya Mountains in Pakistan. Since then, the editors have had an opportunity to study both rough and cut stones from this locality.

At first glance, these orthorhombic peridot crystals may look hexagonal, because of equal sizes among different faces of "columnar" and "pyramidal" shapes. Faces were identified through comparison of these crystals with Goldschmidt's *Atlas der Krystallformen* (olivine group in volume 6 [reprinted by the Rochester Academy of Science, Rochester, NY, 1986]). Faces identified include pinacoids (001), (100), and (010); prisms (120) and (110); brachydome (021), macrodome (101); and pyramid (111). The most prominent of these were the basal pinacoid (001), "columnar" faces (010) and (110), and "pyramidal" faces (021) and (111). While all the crystal faces on the first three uncut specimens we were able to examine closely were etched, striations parallel to the c-axis were clearly visible on the (010) and (110) faces. However, Laura Thompson, president of Shades of the Earth, Phoenix, Arizona, which is marketing the material, reported that many of the crystals recovered are not etched to this extent and actually display lustrous crystal faces. We subsequently saw additional crystals that substantiated Mrs. Thompson's comment (see, e.g., figure 7).

Gemological testing on two faceted stones, a 5.23-ct cut-cornered rectangular mixed cut and an 18.37-ct cushion modified brilliant, gave the following results: color—medium yellowish green; diaphaneity—transparent; R.I.—$\alpha = 1.651$, $\beta = 1.669$, $\gamma = 1.687$; birefringence—0.036; S.G. (determined hydrostatically)—3.35; pleochroism—weak, yellowish green and brownish yellowish green; UV fluorescence—inert to both long and short wave; absorption spectrum—distinct but somewhat diffuse absorption bands at about 453, 477, and 497 nm, as well as a weaker band at about 529 nm (this last absorption feature is typically noted only in fairly large specimens of peridot—see, e.g., Webster's *Gems*, 4th ed. [rev. by B. W. Anderson], 1983, p. 162). All these features are consistent with those reported in the gemological literature for peridot from various localities.

Peridot is the gem variety of the mineral olivine, which is a solid solution between a magnesium end-member, forsterite, and an iron end-member, fayalite. R.I.'s and S.G. vary systematically with composition (see Deer, Howie, and Zussman, *Introduction to Rock Forming Minerals*, Longman Group, London, 1974). On the basis of the R.I. and S.G. values we obtained, the Pakistan material is about 90% forsterite and 10% fayalite.

Magnification did not reveal any inclusions in the two faceted specimens described above. Further, we did not see internal features in any of the other faceted stones we were able to examine briefly (again, see figure 7). However, some of the rough specimens had black rod-like inclusions that, according to Mrs. Thompson, are fairly common in cabochon-quality rough. X-ray diffraction analysis of one such inclusion that broke the surface of a rough specimen revealed a pattern consistent with the magnesium iron borate mineral ludwigite.

Figure 7. A new locality in the far western Himalayas of Pakistan is the source of these rough (128.82 and 393.83 ct) and faceted (18.50–64.61 ct) peridots. Courtesy of Shades of the Earth; photo by Shane F. McClure.

Sapphire from Scotland. In an article in the Winter 1984 *Journal of Gemmology*, Brian Jackson described a then-new occurrence of sapphire in Scotland. Blue sapphire was found as large single crystals (up to almost 5 cm in diameter) in a xenolithic dike at Loch Roag, Isle of Lewis, Outer Hebrides, Ross and Cromarty, Scotland. The dike has a composition similar to lamprophyre, and contains biotite, augite, apatite, sanidine, anorthoclase, and—rarely—corundum. The dike varies from 0.5 to 1.5 m in width, and was exposed over a section 4.5 m high and 24 m in length at an excavation site. Because this occurrence is so unusual, the government immediately declared the

Figure 8. Five stones (0.50–1.02 ct) fashioned from the 242-ct sapphire found at Loch Roag flank what remains of that crystal after cutting. Photo courtesy of Ian Combe and Alan Hodgkinson.

locality a Site of Special Scientific Interest, and mining there was prohibited.

Ian Combe of the Knockan Studio, Sutherland, United Kingdom, reported that a group of gemologists—the Edinburgh Gemmological Group, including himself—was recently permitted to examine loose, fragmentary material at the site. Their discoveries included a heavily fractured 242-ct sapphire crystal and a 39.5-ct fragment. A number of small stones were cut from the large crystal (figure 8), and the fragment produced an attractive 9.6-ct barion cushion-cut sapphire. According to Mr. Combe, the cut stone has the following properties: refractive indices of 1.762–1.770; strong general absorption in the blue region when viewed with a handheld spectroscope; pleochroic colors of blue and green; and no visible inclusions. The color has been described as "medium dark greenish blue"; there is some color zoning, but it is not visible table up. Mr. Combe believes that this is the largest gem sapphire faceted from United Kingdom material.

Update on Montana sapphires. American Gem Corporation (AGC) of Helena, Montana, now controls over 110 square miles (285 km^2) of Montana's alluvial sapphire claims, including Dry Cottonwood Creek, Eldorado Bar on the Missouri River, and Gem Mountain in the Rock Creek area, according to AGC chairman and CEO Greg Dahl. Sapphire yields have averaged 44 to 225 carats per cubic meter in the Dry Cottonwood Creek gravels, with some gravels yielding 1,000 carats per cubic meter, he said. Testing was done for AGC by Watts, Griffis, and McOuat, a Toronto-based consulting firm. Currently, all three claims have a combined resource of over 50 million carats, but Mr. Dahl noted that only 5% of AGC holdings have been tested.

Although usually high in clarity, most stones from these particular alluvial deposits are light in color without heat treatment. Therefore, AGC purchased Crystal Research of Pleasanton, California, to do the color enhancement (see "Heat Treating the Sapphires of Rock Creek, Montana," J. Emmett and T. Douthit, *Gems & Gemology*, Winter 1993, pp. 250–272). This process can intensify or change the color (figure 9). AGC expects production of six million carats of rough sapphire next year from its Montana claims. Before winter conditions halted mining this year, two different mine sites were fully operational. Mining will resume in the spring, Mr. Dahl said.

"Teal" blue cobalt-colored spinel. At the 1994 Tucson show, one of the editors (EF) was drawn to the unusual color of a slightly greenish blue (or "teal") 4.88-ct cushion-cut spinel at the booth of Fu Gemstone Imports, Seattle, Washington (see figure 10). The stone reportedly was from Burma. It was subsequently loaned to us for study, particularly an investigation into the origin of its color.

We recorded gemological properties as follows: R.I.—1.714, with anomalous double refraction; S.G.—3.60; inert to both long- and short-wave UV radiation; red fluorescence to visible light; and a moderate red reaction in

Figure 9. These sapphires (0.66–5.69 ct) are from the Dry Cottonwood Creek, Gem Mountain, and Eldorado Bar alluvial deposits in Montana. All except the pink one have been heat treated by Crystal Research. Courtesy of American Gem Corp.; photo © 1994 Tino Hammid.

Figure 10. This 4.88-ct natural cobalt-bearing spinel is slightly greenish blue because of its unusually high nickel content. Courtesy of Fu Gemstone Imports; photo by Shane F. McClure.

the color filter. This behavior is typical of natural cobalt-blue spinel. Indeed, the handheld spectroscope revealed broad bands at about 460, 550, and 585 nm and total absorption above 610 nm—a spectrum quite typical of such gems (see, e.g., Muhlmeister et al., "Flux-Grown Synthetic Red and Blue Spinels from Russia," *Gems & Gemology*, Summer 1993, pp. 81–98). The stone was essentially clean, except for a few elongated yellow stains in surface-reaching fractures at the corner of the table (which could be mistaken for flux inclusions). The natural origin was confirmed by EDXRF analysis with a Spectrace 5000 spectrometer, which detected large amounts of zinc and gallium, typical of natural spinel. Besides these elements and the main constituents (magnesium and aluminum), EDXRF detected abundant iron, a trace of manganese, and an unusually high nickel content (compared to other natural blue spinels in our data base). As expected, cobalt was not detected (the amount of cobalt typically found in natural cobalt-blue spinels is below the detection limit of our instrument).

Natural cobalt-blue spinels are best known for a saturated, "royal blue" color, not the slightly greenish blue of this gem. UV-visible absorption spectroscopy, recorded with a Hitachi 4001 spectrometer, revealed the small, but significant, difference in absorption that was responsible for the difference in color. Typical natural cobalt-blue spinels have a 490-nm transmission window, which corresponds to the classic "royal blue"; this stone has one at 500 nm, which corresponds to a slightly greenish blue. This 10-nm shift is apparently due to a broad absorption underlying the main Co^{2+} feature. Also, the absorption at 480 nm in this stone is about the same intensity as that at 460 nm; in other natural cobalt-blue spinels, it is usually weaker. We determined that the extra absorption is probably due to nickel (using a Russian flux-grown synthetic Ni^{2+}-doped spinel as a reference). This is consistent with the unusually large amount of nickel found with EDXRF. We believe that this is the first report of nickel contributing to the color of a natural spinel.

Update on Sri Lanka. Unusual weather and other factors are blamed for a general shortage of gems from Sri Lanka, especially good-quality blue sapphires. Nevertheless, that gem-rich country continues to produce attractive and interesting material, including rare examples of gem crystals in matrix, kornerupine, and hessonite garnets.

Five months of heavy rain last winter halted some mining operations during what is usually the most productive time of year, according to Gordon Bleck, of Radiance International, San Diego, California, a gemologist and part-time Sri Lanka resident. Some mines suffered lower production because of other problems. For example, a major South African mining company was authorized to mine the Kalu Ganga, an important river. This caused strong protest from local miners and gem dealers, as well as from residents who lived downstream and feared the environmental impact. As a result, all mechanized mining, small and large, was prohibited—further reducing already faltering production. Terrorism continues to be a limiting factor.

Even so, significant amounts of sapphire, zircon, and spinel crystals in matrix (figure 11) have been found in the Opalle Jungle mining area, about 9.5 km from Wellewatte village in the Kollone electorate, south-cen-

Figure 11. Rare examples of Sri Lankan gems found in matrix include blue sapphire (bottom center), spinel (left, top), and zircon (right). Samples range from 2.5 cm to 7 cm in their longest dimension. Photo by Robert Weldon.

tral Sri Lanka. The material was found less than 1 m beneath the floor of the jungle and adjacent rice paddies. The spinel crystals are dark purple to black, well-formed octahedra, up to 2.5 cm on an edge. They occur in a matrix of large crystals of white calcite, dark green serpentine, and gray forsterite. The zircons are brown, doubly terminated tetragonal prisms and were found on quartz. The blue sapphires were associated with black mica plates in a white rock containing the minerals analcime, albite, and nepheline.

Dark green and some light green kornerupines have been reported before from various areas in Sri Lanka, but this year attractive brown kornerupine was discovered. Gems from this new find range from brown to slightly orangy brown or yellow-brown, with medium to dark tones. Faceted stones weigh from 0.75 ct up to 2.5 ct. All were found in the Dasgiriya area, off the Wellewa road in the Elahera district, in north-central Sri Lanka. Okkampitiya, which has produced some dark brown to black chatoyant kornerupine that is typically under 1 ct, this year yielded an exceptionally large, 10.15-ct dark brown cat's-eye kornerupine.

Gem hessonite garnets up to 110 ct in the rough were discovered in the Balangoda area. They are slightly brownish orange and, because of their generally poor quality, typically yield faceted stones no larger than 6 ct.

"Zebra stone" from Arizona. Soon after a Summer 1994 Gem News entry discussed two "zebra rocks" from Australia, we came across a handsome material banded black and off-white that is called "Arizona zebra stone." Offered by JPS Trading of Tucson, Arizona, this material has a Mohs hardness of about 6 and takes a good polish. Further examination of six variously fashioned pieces of this material (figure 12) and a strand of 15-mm beads revealed that it typically has roughly parallel stripes of varying thicknesses. Other patterns reportedly include lenses, mottled patches, chevrons, and folds.

Figure 12. These pieces of polished "Arizona zebra stone" range from 17.54 to 292.22 ct. Photo by Maha DeMaggio.

The samples we examined consisted primarily of a black material that had a spot R.I. of 1.66–1.67 and an X-ray powder diffraction pattern that matched that of actinolite or tremolite amphibole. The lighter material had a spot R.I. of 1.55 and a diffraction pattern that matched that of calcium-rich plagioclase feldspar. Some pieces contained green alteration patches of epidote, also determined by X-ray diffraction analysis.

According to JPS Trading, this "zebra stone" is quarried near Prescott, Arizona. It is found associated with Precambrian ore deposits containing gold, silver, copper, and zinc. EDXRF analysis of the "zebra stone" revealed significant amounts of zinc and manganese. This material has been subjected to metamorphism; the parent rock was probably greywacke, similar to that being formed today off the west coast of North America.

All patterns are available in pieces weighing up to 500 pounds (227 kg), and some are available in multi-ton pieces, which makes it particularly useful as an ornamental material. JPS Trading also reports that reserves should last for years.

SYNTHETICS & SIMULANTS

"Minkovite" from Russia. At the February 1993 Tucson show, the editors saw examples of what was described by the vendor as a new laboratory-grown gem material from Russia. Although we could not obtain samples for testing at the time, we did obtain a promotional brochure. It said that the material's developers—B. I. Minkov (after whom the material appears to have been named), M. K. Meilman, and V. A. Voloshin—had applied for a patent on it in Russia.

Early in 1994, we received two "Minkovite" samples from Brian D. Kvasnik, president of Gem Resources of Minneapolis, Minnesota. These two faceted stones, a 1.19-ct round brilliant and a 4.50-ct emerald cut (figure 13), were subsequently examined at GIA. Both are a dark, saturated, slightly violetish blue, reminiscent of cobalt-doped synthetic spinel. R.I. values were determined as α = 1.785, β = 1.788, and γ = 1.810, with a birefringence of 0.025. The material was biaxial positive and strongly pleochroic, in light blue, slightly greenish blue, and violetish blue. The samples fluoresced a weak, chalky blue to long-wave UV radiation, and were inert to short-wave UV. Specific gravity values were determined hydrostatically to be 4.47 ± 0.01. Examination with a desk-model prism spectroscope revealed a complex absorption spectrum (see below). With magnification, both stones showed curved color banding. In addition, the larger specimen contained irregular wisps of dark blue color concentrations, one white acicular inclusion, and several small angular inclusions.

Because the specimens' properties did not match

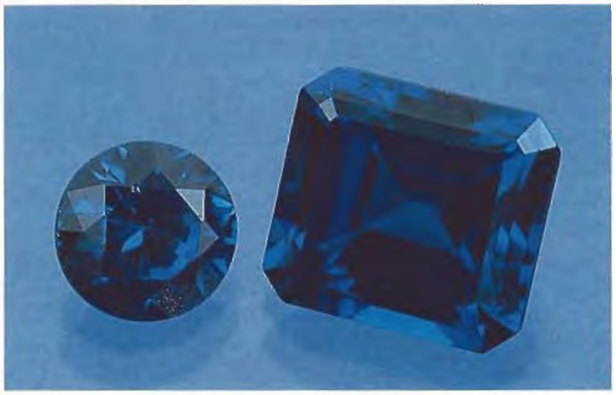


Figure 13. These two laboratory-grown, neodymium-doped yttrium silicate gems (1.19 ct and 4.50 ct) have been promoted under the trade name "Minkovite." Photo by Maha DeMaggio.

those of any known gem materials of natural origin, we conducted additional tests. EDXRF analysis revealed yttrium (Y), silicon (Si), and a trace of neodymium (Nd). A UV-visible absorption spectrum showed several sets of multiple sharp peaks, including sets at 352–365, 528–539, 575–597, 740–766, and 798–816 nm. These are consistent with Nd as a coloring agent. X-ray powder diffraction analysis performed with the assistance of Paul Carpenter at the California Institute of Technology, Pasadena, produced a pattern that matched that of monoclinic synthetic yttrium silicate, Y_2SiO_5.

This is not the first blue synthetic yttrium silicate that the editors have seen. In August 1992, at the 10th International Conference on Crystal Growth in San Diego, California, one of the editors (EF) obtained two faceted samples of such a material for examination (see Winter 1992 Gem News, p. 277). However, those two samples were lighter and less saturated in color, and chemical analyses revealed chromium as the coloring agent.

Figure 14. These synthetic quartz crystals have been hydrothermally grown on a natural quartz base (more than 12 inches—30 cm—across). Photo by Robert C. Kammerling.

Visit to Russian synthetics facility VNIISIMS . . . The Fall 1994 Gem News section described a visit by one of the editors to a new synthetic-gemstone production facility in Novosibirsk, Siberia. On this same trip to Russia, the editor (RCK) also toured a large facility in the Moscow area that is involved in synthetic-gemstone research and production. Located in the city of Alexandrov, about 112 km (70 miles) north of Moscow in the Vladimir region, the Russian Research Institute for the Synthesis of Minerals and Pilot Plant is also known as State Enterprise VNIISIMS. The organization employs about 2,000 people, 1,500 of whom are involved in production and support services. The remainder—including about 60 with doctorates—are engaged in research.

VNIISIMS was founded in 1954 to produce synthetic colorless quartz for various technical applications, and this is still its main product by volume. Two interesting items on display were a large cluster of synthetic quartz crystals grown on a base of natural quartz (figure 14) and hydrothermally grown synthetic calcite (figure 15). The firm also produces synthetic diamond for various technical applications. These synthetic diamond products include diamond powders, diamond-impregnated cutting wheels, and larger crystals—reportedly up to 5-mm long—for use in cutting tools such as diamond scalpels.

The facility also produces a number of materials specifically for gem and jewelry use. The most commercially important (by volume) is synthetic amethyst, but others include synthetic citrine (some in a reddish

Figure 15. The Russian State Enterprise VNIISIMS also synthesizes calcite hydrothermally for technical applications. Note the strong doubling through the smaller of the two crystals on the left. Photo by Robert C. Kammerling.

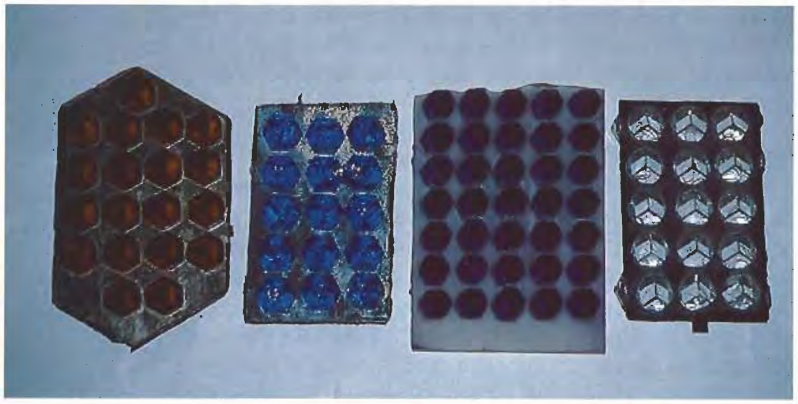


Figure 16. These synthetic quartz crystals were grown on masked, oriented seed plates at the Institute of Experimental Mineralogy, Russian Academy of Sciences. Photo by Robert C. Kammerling.

"Madeira" color), smoky quartz, a dark green type for use as an emerald simulant, a blue in medium-to-dark tones, and a white, translucent (opalescent) type. Seen, too, was a yet-to-be commercially produced synthetic aventurine quartz: synthetic rock crystal containing precipitated platelets of copper.

The facility also uses melt techniques to grow materials for jewelry applications, including cubic zirconia, both colorless and in a range of colors. Production includes nontransparent white and pink CZ for use as pearl simulants, as well as black CZ (see "An examination of nontransparent 'CZ' from Russia, by Kammerling et al., *Gems & Gemology*, Winter 1991, pp. 240–246). A melt technique known as horizontal growth is used to produce YAG in a wide range of colors. Among the most recent gem products are synthetic opal and synthetic malachite.

. . . and two centers in Chernogolovka. The Russia trip also included a visit to two facilities under the direction of the Russian Academy of Sciences in the town of Chernogolovka, 100 km north of Moscow. One, the Institute of Experimental Mineralogy (IEM), is headed by Dr. Vladimir Balitsky. A major focus of this institute appears to be the growth of minerals that may have jewelry applications, especially synthetic quartz in a variety of colors. Of particular interest were quartz crystals on which the largest surface is in the plane perpendicular to the c-axis. To produce this effect, the seed plates on which these crystals were grown had been masked with a metallic-appearing template containing numerous openings, allowing for the simultaneous growth of several parallel crystals (figure 16). Examples seen were synthetic rock crystal, amethyst, citrine, and blue quartz. IEM has also grown synthetic pink quartz, emerald, turquoise, and malachite. Some materials produced at this facility are marketed in the United States by HRI International of Middletown, New York (see "More on Russian synthetics and simulants," Spring 1994 Gem News, p. 57).

Also visited in Chernogolovka was the Institute of Solid State Physics, headed by Professor Gennady Emel'chenko. One current research project involves flux-grown synthetic ruby.

Miscellaneous synthetics and simulants. In addition to the materials described above and in the Spring 1994 Gem News section, the authors have seen a number of other laboratory-grown products this year that are worth noting. These include a saturated, medium-dark blue GGG (gadolinium gallium garnet), reminiscent of the rare gem material haüyne (a small amount of which we have seen recently in faceted form). Also offered was "YAP" (yttrium aluminum perovskite) in several colors. One interesting variety of hydrothermal synthetic quartz encountered lately is predominantly brown with a relatively shallow green layer (parallel to the plane of the seed plate) near the periphery of the crystal. This material was offered as a simulant for andalusite. The editors presume that a gem cut from this material in such a way that it showed both colors might superficially mimic the eye-visible pleochroism of andalusite.

ANNOUNCEMENTS

Visit *Gems & Gemology* at the Basel show. *Gems & Gemology* Editor Alice Keller will be in the *Gems & Gemology*/GIA booth (stand 197, hall 202) at the Basel 95 World Watch, Clock and Jewelry Show. Held in Basel, Switzerland, the show runs from April 26 to May 3, 1995. Drop by to ask questions, share information, or just say hello.

BOOK Reviews

SUSAN B. JOHNSON AND JANA E. MIYAHIRA, EDITORS

HUMBOLDT'S TRAVELS IN SIBERIA (1837–1842) THE GEMSTONES

By Gustav Rose

*Transl. by John Sinkankas, ed. by George M. Sinkankas, 80 pp., illus., Geoscience Press, Phoenix, AZ, 1994. US$25.00**

On the invitation of Tsar Nicholas I, famed German naturalist Alexander von Humboldt conducted a nine-month scientific expedition into the Siberian reaches of the Russian Empire in 1829, accompanied by researchers Gustav Rose and Christian Ehrenburg. A primary purpose of this expedition was to visit sites of geologic, mineralogic, and gemological interest in the Ural and Altai Mountains. Rose served as expedition secretary as well as mineralogist.

In this volume, John Sinkankas presents translated excerpts from the expedition records Rose published in 1837 and 1842. The brief excerpts deal with visits to a number of legendary gem and mineral deposits, some of which remain important even today. These include amber deposits on the Baltic Coast; pegmatite gems such as topaz and tourmaline from Mursinsk and emerald from Takawaja (both in the Urals); and ornamental rocks such as porphyry and jasper from Altai. One of the last localities visited was the site of the newly discovered chrysoberyl deposits, in the same Takawaja River region that produced emerald. This chrysoberyl, which showed a change of color from bluish green in daylight to purplish red in incandescent light, was later named alexandrite.

In addition to a brief introduction describing the purpose of the expedition, Dr. Sinkankas supplies more than 200 explanatory notes on the text. Also provided are some specific locality maps and crystal drawings from other historical publications, as well as sketches of Rose, Humbolt, and Tsar Alexander I prepared by Dr. Sinkankas. A list of references, suggested readings, and an index are included as well.

This is an interesting historical account of an important mineralogical expedition. It is especially relevant in light of the current renewed interest in gem exploration and gem mining in Russia, including the reopening of some of the historic localities. Because many readers are unlikely to be familiar with Russian geography, a map of the expedition's travels would have been useful.

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OTHER BOOKS RECEIVED

Copper Art Jewelry—A Different Lustre, *by Matthew L. Burrkholz and Linda Lichtenberg Kaplan, 160 pp., illus., Schiffer Publishing, 1992. US$49.95.** This charming book focuses mainly on the copper jewelry of Francisco Rebajes and Jerry Fels. A study of the Rebajes Company and Jerry Fels's Renoir of California profiles these two men of vastly different backgrounds. The authors also give a feeling for the diversity apparent in this type of small jewelry business, similar to many set up in post-World War II America.

Rebajes' jewelry, at its peak in the 1940s and early 1950s, reflects the bold emphasis of Art Moderne and the self-reliance of the Arts and Crafts Movement, combined with the highly original vision of the artist himself. Renoir of California reflects Jerry Fels' love of enamels and various themes popular in 1950s America, combined with an enterprising manufacturing spirit. Where Rebajes jewelry emphasizes uniqueness, focusing on facial and animal themes, Renoir jewelry might repeat a single abstract shape many times in different colors and textures.

Also included is a brief history of the early use of copper and a short chapter on other artists of the period and the popularity (and often high quality) of kit-made jewelry. There are more than 300 color photos, a small but valuable bibliography, general price guidelines, and an index .

JO ELLEN COLE
Collection Curator, GIA

Jewelry & Gems: The Buying Guide, 3rd Ed., *by Antoinette L. Matlins and A. C. Bonanno, 262 pp., illus., Gemstone Press, Woodstock, VT, 1993. US$23.95 hard cover, $16.95 soft cover.** This book will be valuable to anyone wishing to refresh their knowledge of gemology in particular, or of jewelry in general. Although the stated audience is the jewelry *buyer,* it is comprehensive enough to benefit those of us in the industry who use this material on a regular basis, particularly if we deal with the public. Both as a learning tool and a review, this work is clear and well-organized, and presents enough of the lore and magic to add interest for the reader and sparkle to any sales presentation.

Aided by 16 pages of illustrations, the authors explore a variety of topics. These include an introduction to gems and gemology, specific sections on diamonds and colored gems, and a discussion on the needs of the buyer, both before and after the purchase. As a designer, I was delighted to see, in this third edition, a section titled "Design and Style: Getting the Look You Want," which provides a glossary of terms related to the structure of a jewelry item, and incorporates the concepts of lifestyle and structural integrity.

My only suggestion for improvement relates to the occasional use of terms that seem mildly inappropriate. While we may call diamonds (within professionally agreed-upon standards of clarity) "flawless" to add value, the use of terms such as "imperfect" or "flaws" somehow devalues the very objects the authors are trying to promote.

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**This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone (800) 421-7250, ext. 282.*

GEMOLOGICAL ABSTRACTS

C. W. FRYER, EDITOR

COLORED STONES AND ORGANIC MATERIALS

A combined magnetic resonance and gamma-irradiation study of some green beryls. D. R. Hutton and G. J. Troup, *Australian Gemmologist*, Vol. 18, No. 10, 1994, pp. 315–317.

This report describes a procedure for determining whether vanadium is present in beryl and, by extension, how to distinguish green beryls colored by chromium from those colored by vanadium. The first step is to record an ESR (electron spin resonance) spectrum of the stone in question and compare it to a similarly oriented reference spectrum of a gamma-irradiated Biron synthetic emerald. If there is a clear match with the latter's vanadium peaks, no further testing is required. When the results are ambiguous, however, the test sample is gamma-irradiated. Such treatment will reportedly increase the intensity of absorption features attributable to vanadium so that they can be detected when another ESR spectrum is run. Using this technique, the authors detected vanadium in three emerald specimens from Colombia. They also found that one sample each from Brazil and Zambia did not contain vanadium. *RCK*

Smoky moonstone: A new moonstone variety. H. Harder, *Journal of Gemmology*, Vol. 24, No. 3, 1994, pp. 179–182.

Moonstones with a "smoky" body color have recently been coming from two localities in Sri Lanka—near Imbulpe in the Central Mountains and in the Balangoda region. Chemical composition revealed a higher iron content than is typical for colorless moonstone. Much of the material is heavily included, mostly with clay minerals. The blue adularescence shows up particularly well when the body color is dark. The author proposes the variety name "smoky moonstone" for this material. *CMS*

DIAMONDS

Alluvial diamond deposits of the Guaniamo Region, Bolívar State, Venezuela. R. R. Coenraads, G. Webb, and B. Sechos, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 287–294.

Over 75% of Venezuela's alluvial diamond production comes from the Guaniamo River and its tributaries, principally the Guaniamito, Guasjualito, Las Nieves, and Quebrada Grande Rivers in Bolívar State. El Milagro, which lies on the Quebrada Grande River, is one of the small villages that depend entirely on diamond mining for their existence. Residents either are miners or are engaged in various support services, from welders to restaurateurs.

The authors describe the primitive living and working conditions in El Milagro, as well as the diamond-mining operations, some of which are no more than 50 m from the village. About 125 teams of four to five miners each work ancient river gravels in the area. The productive gravels, which lie on weathered basement rocks, are in turn overlain by barren sands and fine gravels. Miners first work the overburden with water cannons, producing a slurry that is pumped into the river. When a large-enough diamond-bearing horizon has been exposed, they use picks and water cannons to break up the gravels; these are then pumped to a pulsating jig where the diamonds and other heavy minerals are concentrated. The concentrate is examined, and the diamonds are removed, by hand.

The diamonds recovered, which range up to 13 ct, are sold to local buyers. Gem-quality material is either cut in Ciudad Bolívar, Venezuela, or is exported to Belgium for fashioning. The area produces colorless to yellow stones and fancy colors, including blues and greens; the color of the greens could be traced to radiation staining. A small parcel of stones examined by the authors presented a range of crystal forms as well as extensive surface etching.

This interesting and informative report also includes the results of analyses of gravel samples taken from three sites in the area. There are several good photographs, photomicrographs, and maps as well. It is a welcome addition to the literature on diamond sources. *RCK*

Diamonds and De Beers. Peter Read, *Mineralogical Society Bulletin* (London), No. 104, September, 1994, pp. 7–9.

From the pictures in books on diamonds, I have always had the impression that diamond sorting is a highly skilled occupation, done manually (at least predominantly) by about 5,000 well-dressed individuals (mostly male), sitting at long tables in front of north-facing windows at 2 Charterhouse Street, London.

Now, thanks to this article by Peter Read, I know that diamond sorting is much more automated. Noted for his several books on various aspects of gemology, Mr. Read was technical manager at the Diamond Trading Company (DTC) until his retirement. The DTC, which is part of the Central Selling Organisation, is responsible for sorting and evaluating approximately 80% of the world's rough gem-quality diamonds (of which there must be tens of millions annually in all sizes and categories).

The author chronicles his employment at the DTC, where he started in 1970. Coming from an electronic engineering background, Mr. Read was concerned primarily with automating diamond sorting. This complicated process took five years to perfect because of several technical hurdles. For example, an automatic weighing system had to be designed that had an accuracy of ±0.001 ct and could weigh a diamond every two seconds. The automated sorting process first separates the diamonds into rough weight categories by mechanical sieving; then grades the stones of each weight category by clarity and shape. (Color grading is still done manually.)

The article includes photos of a sieving machine for rough sizing of diamonds, a computer-controlled weigher, and a high-speed rough-diamond counter. Besides the London location, this equipment is also used in South Africa, Namibia, and Botswana.

Hopefully, the release of the information in this paper is a harbinger of more to come on the workings of the CSO. *AAL*

A review of the use and application of mantle mineral geochemistry in diamond exploration. J. J. Gurney, H. Helmstaedt, and R. O. Moore, *Pure & Applied Chemistry*, Vol. 65, No. 12, 1993, pp. 2423–2442.

Until recently, techniques used to explore for primary diamond deposits in kimberlite and lamproite were secrets closely guarded by a few knowledgeable companies and individuals. The last five years, however, have seen an "explosion" of talks at scientific conferences, as well as published papers, on this topic. This article, by acknowledged experts, reviews some of the basic premises and techniques of diamond exploration, particularly those relating to minerals brought up from great depths by kimberlites and lamproites.

The article first discusses: (1) the prediction of regions under which diamonds may have formed, (2) the selection of areas within these regions where diamonds may have been brought to the surface, and (3) the determination of regional tectonic or structural controls (e.g., major fault zones) for the emplacement of the transporting kimberlite or lamproite magma. Geophysical and petrologic techniques are used extensively in this early phase of exploration.

Diamond formation requires the presence of ancient mantle roots (e.g., Archean cratons), where diamonds are stable. However, once these roots have been recognized, it is essential to learn their history over geologic time. To preserve the diamonds, the craton root must have (1) remained relatively cool throughout geologic history, and (2) stayed attached to the craton during subsequent plate motions. Again, geophysical techniques, along with detailed studies in structural geology, are used in this exploration stage.

The main part of the article discusses "indicator minerals." These are resistant minerals that formed in the mantle—such as garnet, ilmenite, and chromite—and were brought to the surface by kimberlite. (Different indicator minerals are associated with lamproite.) They are typically found in soils, gravels, and the like, and they may lead to a source kimberlite. Their chemical composition can then help determine whether the kimberlite is likely to contain diamonds, by providing information on the chemical environment within the kimberlite. For example, the Fe^{3+}/Fe^{2+} ratio in ilmenite can be used to predict whether diamonds are likely to be well-formed or partially resorbed (rounded) crystals, or even converted to graphite or CO_2. Many other examples, accompanied by explicit diagrams, illustrate the extensive use of indicator minerals in diamond exploration. The more than 100 references indicate how large and complex the body of knowledge in this field has become. *AAL*

Electronic era elusive. J. C. Angus and A. T. Collins, *Nature,* Vol. 370, August 25, 1994, p. 601.

If diamond transistors could be developed, they would have immediate uses in high-speed electronics and in devices that could be operated at high temperatures. However, predictions of a brilliant future for diamond in electronics have remained unfulfilled because of the poor quality of synthetic diamond grown from vapor, and inherent problems with doping diamonds to achieve appropriate conductivities—until now.

Researchers at Kobe Steel USA have grown boron-doped, "p-type" synthetic diamond thin films (which conduct by means of mobile "holes," or electron vacancies) by chemical vapor deposition on natural diamond surfaces; these have conductivities and impurity levels comparable to those present in natural type-IIb diamonds. Although researchers in South Africa and Israel have been trying to grow "n-type" diamonds, which conduct by means of mobile electrons, reproducible doping has not yet been achieved. (The electrons in nitrogen, the most-common impurity in diamond, are too tightly bound to produce significant conductivity; phosphorus, the next likeliest electron-donor, is too large to fit easily in the diamond structure.)

In another development, researchers at Waseda University in Tokyo have succeeded in growing highly oriented diamond thin films on silicon carbide. Still, without "n-type" diamond, a computer with all-diamond chips may never be feasible. Nevertheless, diamond electron-emitters may be possible, leading perhaps to diamond-based electron multiplier tubes, discharge lamps, and flat-panel computer and television displays.

Information in this short article came from the Fourth International Conference on the New Diamond Science and Technology, held in Kobe, Japan, in July 1994. *MLJ*

Red diamond, pink diamond and method of producing the same. Sumitomo Electric Industries, Osaka, Japan, European patent application number 94103535.4 (filed August 3, 1994).

This patent application details methods for producing treated-color red, pink, and purple diamonds. First, the starting material is selected: It must be a type-Ib diamond with certain ranges of nitrogen and boron concentrations (less nitrogen for pink target color). Then the crystal is irradiated with an electron (or neutron) beam at an energy of 1 to 10 MeV (density ranges for the irradiation beam are provided; the red color requires a weaker beam). Last, the irradiated diamond is heated in a vacuum or an inert gas atmosphere for at least three hours. For a pink color, the temperature must be between 800° and 1100°C; for red, between 600° and 800°C. When a diamond treated in conditions adequate to produce a red color is heated at too high a temperature, purple results. The pink to red color is due mostly to the creation of the N-V color center (an isolated nitrogen atom associated with a carbon vacancy).

Although this patent application claims (in a section called "Description of the Background Art") that it describes a way of treating "a natural rough diamond," the examples refer only to synthetic diamonds. A number of errors pepper the text. The application claims that the GR1 center produces purple in diamond; in fact, the GR1 absorption gives diamond a blue to green color. The application also states that "a red diamond has been neither naturally produced nor existent"; yet, a small number of natural-color red diamonds have been reported over the last 10 years. The authors also contend that it has been impossible to color a synthetic or natural diamond red or pink, although the reality is that numerous treated-color red and pink diamonds (mostly natural, but some synthetic) have been seen in the trade. *EF*

Shocking pink prices. *Diamond International,* No. 32, November/December, 1994, pp. 61–63.

The 10th tender of Argyle pink diamonds closed on October 4, 1994, establishing a new price record, according to Argyle officials (although the total value was not disclosed). This invitation-only sale offered 47 of Argyle's best pink diamonds for a total of 45 carats. The largest stone was a 3.04-ct Fancy Intense pink emerald cut. Attracting the most attention, though, was a 1.03-ct Fancy purplish red heart shape. The unusual shape was chosen to keep this stone of very rare color above the psychological one-carat mark. One hundred and fifty parties were invited to participate; 70 accepted. The stones were shown in Tokyo, Hong Kong, and Singapore, as well as Geneva, where the event took place.

The entire collection was sold to one buyer, an unnamed international diamond consortium, in what Argyle calls a "global bid"—the fourth successful global bid since Argyle started the tenders

Argyle has found that the tender system has been the most successful approach for selling their best pink diamonds. The approximately 40 to 50 stones offered represent the best of the year's production (from June to May). No stone, no matter how exceptional, is withheld. Over 10 years, 500 diamonds totaling 400 carats have been sold in this fashion. The most desirable shape is the round brilliant. Color constitutes 80% of the value, but cut proportions are important; clarity is a minor factor.

This article states that the price of pink diamonds averages 20 to 25 times higher than that of their colorless counterparts. Smaller, paler, or browner pink stones might be only 10 to 12 times more expensive; however, diamonds in the rarest, most exceptional colors can cost 50 times more. The price of pink diamonds has increased about 5% annually over the last 10 years, according to an "outside estimate." It is interesting to note that although Argyle mines about 90% of the world's pink diamonds, these same pink diamonds represent only 0.001% of Argyle's total diamond production. *EF*

GEM LOCALITIES

Benitoite, San Benito County, California. R. B. Cook, *Rocks & Minerals*, Vol. 69, No. 6, 1994, pp. 392–395.

Benitoite, commonly known to mineral and gem collectors as a transparent blue mineral, also may be white, pink, purple, or near-colorless. Typically, the crystals are color zoned. Crystallographically, they are the first natural examples of the hexagonal ditrigonal-dipyramidal class ever discovered. Benitoite is optically positive with refractive indices of 1.757 and 1.804, has high dispersion (0.046), and has strong dichroism of colorless to dark blue. It fluoresces blue to short-wave ultraviolet radiation. With a composition of $BaTiSi_3O_9$ and a suggested iron chromophore, benitoite is one of the few naturally occurring titanium silicates.

Although benitoite is found in trace amounts at several localities worldwide, the only spectacular specimens come from a single California mine, the type locality, near Coalinga. Occurring in massive compact natrolite, these benitoite crystals are associated with neptunite, joaquinite, jonesite, serandite, djurleite, and digenite.

Because the crystals tend to be flat and included, most faceted stones are relatively small. Cook states that the largest known stone is 7.8 ct, but in another article in the same issue, Michael Gray maintains that the largest is a "flawless 14.52-carat triangle of beautiful cornflower blue."

Benitoite is distinguished from sapphire by its lower refractive indices, higher dispersion, and distinctive fluorescence. *LBL*

A garnet location at Mt. Wyangapinny, near Pittsworth, on the Darling Downs. D. N. Cracknell, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 285–286.

This locality, some 100 km west of Brisbane, Queensland, is one of extensive basalt flows. Lherzolite nodules, believed to be fragments of upper-mantle material, are found scattered throughout the Mt. Wyangapinny Basalt; angular pyroxenite occurs with the lherzolite nodules. As garnet is found in the layered colluvial soil, it is uncertain whether the garnet is associated with the lherzolite or pyroxenite.

Gemological testing on one faceted sample revealed: color—dark brownish red; diaphaneity—translucent; luster—vitreous; S.G.—3.78; R.I.—1.75; absorption spectrum—almost complete absorption; UV fluorescence—inert to both long- and short-wave.

One discrepancy should be noted. The author describes the garnets from this locality as pyropes. However, on the basic of the properties reported and using the classification system proposed by Stockton and Manson (*Gems & Gemology*, Winter 1985, pp. 205–218, they would be classified as pyrope-almandine. *RCK*

Gemstones of California. M. Gray, *Rocks & Minerals*, Vol. 69, No. 6, 1994, pp. 379–384.

This article covers the transparent, facetable gem materials found in California—benitoite, diamonds, tourmaline, spessartine, quartz, and other pegmatite gems. Starting with a brief history of each locality, the author describes the era of most prosperous mining, carat yields, and unusually large stones. In so doing, he captures the mystery and imagery of this unusual state.

Also included are descriptions of some challenging collecting conditions, as well as a section on collector gems in which 17 rare species are listed. As most gem localities are in the thoroughly explored southern part of the state, Mr. Gray thinks that, in general, the greatest potential for new discoveries lies in the less-explored north. He also reminds all field collectors that most of the localities are in private hands, and some are completely off limits: Always ask permission before venturing onto someone else's property to visit a deposit. *LBL*

India's invisible gem rush. Vinod Kuriyan, *Europa Star*, No. 199-4, 1993, pp. 67–70.

This article surveys the rapid development of gemstone mining in Orissa, India. Gems found there include aquamarine, chrysoberyl (cat's-eye and alexandrite), iolite, rhodolite garnet, and ruby. At present, the government is trying to develop mining and establish a cutting industry. The author thinks that Orissa's future as a gemstone producer is promising. This article is part of a dossier covering various aspects of gems and gemology. *RT*

Interstellar oxide grains from the Tieschitz ordinary chondrite. L. R. Nittler, C. M. O'D. Alexander, X. Gao, R. M. Walker, and E. K. Zinner, *Nature*, Vol. 370, 11 August 1994, pp. 443-446.

We usually think of corundum and spinel as coming from two environments: basaltic lavas and metamorphic rocks, especially marbles. However, by virtue of their refractory natures (that is, very high melting temperatures), these minerals sometimes come from a more exotic source: direct precipitation from gases produced by nucleosynthesis (atomic fusion) in stars. Some mineral grains in chondrites—stony meteorites—are older than the Earth, having formed from gases from other stars before our sun condensed.

In this article, the authors describe the results of oxygen and aluminum isotopic studies of 20 corundum grains and one spinel grain from the meteorite Tieschitz. Twelve grains probably came from oxygen-rich red giant stars, five possibly came from massive mass-losing (Wolf-Rayet) stars, and four possibly came from low-mass red giant stars. However, don't expect to see interstellar rubies on the gem market soon. All the grains described in this study were between 0.5 and 2 mm in size, and were selected by examination of over 6,000 refractory oxide grains. *MLJ*

Montana sapphires—the value of color. D. W. Baker, *Northwest Geology*, Vol. 23, 1994, pp. 61–75.

The geologic origin of Montana sapphires has long been a matter of scientific discussion. This article presents new concepts in which the theory of plate tectonics plays an important role. In agreement with previous studies, two distinct types of deposits are recognized: the primary deposit at Yogo Gulch in central Montana, and the secondary (placer) deposits of western Montana.

The author suggests that the Yogo sapphires crystallized from a magma (primary origin), and were not brought to the surface as xenocrysts (in this case, "foreign" crystals formed metamorphically and simply transported by the magma) as has been advocated by others. Evidence for magmatic origin includes: (1) the presence of rare analcime (interpreted as a magmatic, not metamorphic, mineral) inclusions, which are not found in sapphires from elsewhere in Montana; and (2) the thin, tabular shapes of the Yogo crystals, as compared to the barrel-shaped crystal habit typical of metamorphic sapphires.

Dr. Baker provides a detailed model for the formation of the Yogo sapphires in an ultramafic magma into which high-alumina rocks containing kyanite were assimilated. He discusses emplacement of the ultramafic dike at Yogo, and emphasizes the importance of karst-terrain development (e.g., sinkholes in limestone) in determining the present shape and other features of the intrusion. He also discusses geologic differences between Yogo and western Montana, where the placer sapphires are found; he believes that these latter sapphires may have been formed deep in the Earth and then brought to the surface as xenocrysts in volcanic magma.

This article also explains differences in color between the Yogo sapphires ("cornflower blue") and those from the more abundant placer deposits ("steel" blue after heat treatment). Dr. Baker relates these differences to low quantities of iron, as Fe^{2+}, substituting for aluminum in the crystal structure of the "cornflower-blue" Yogo sapphires—as compared to the much greater iron, as Fe^{3+}, in the sapphires from placer deposits. The article also discusses various aspects of mining, including history, particularly at the Yogo deposit. *AAL*

An occurrence of sectored birefringence in almandine from the Gagnon Terrane, Labrador. D. Brown and R. A. Mason, *Canadian Mineralogist*, Vol. 32, 1994, pp. 105–110.

Garnet minerals are generally considered to be optically isotropic, but exceptions occur, especially for the Ca-bearing garnets (grossular, andradite, hydrogrossular); weakly birefringent spessartine is also known. The authors describe a sector-zoned birefringent (0.004 to 0.006) almandine garnet from graphitic schists in metavolcanic rocks of the Gagnon Terrane, Grenville Province, southwestern Labrador.

The garnets studied were 3–5 mm in diameter, "rusty" brown to deep red in color, and predominantly $\mathrm{Alm}_{0.79}\mathrm{Gross}_{0.173}\mathrm{Py}_{0.024}\mathrm{Spess}_{0.015}$ in composition, with typical almandine garnet core-to-rim compositional zoning. A slice cut parallel to the cube-face direction of one garnet showed six pie-shaped sectors with extinction slightly oblique to the [110] (dodecahedral) direction and sector boundaries along the {111}(octahedral) planes. The overall effect resembles six-sided chiastolite. The garnets contained three types of quartz inclusions: small round ones at sector boundaries (occurring with ilmenite whiskers), spindle-shaped ones growing from the center of the zones, and cross-cutting tabular quartz grains close to the garnet surface.

The birefringence was also confirmed by the lower symmetry visible in the X-ray powder pattern as slight splitting of the 400 reflection. The authors dismiss some possible causes for birefringence (Al/Fe ordering, strain due to inclusions), but do not propose alternatives. They do suggest that the sector zoning is due to twinning, probably of the Spinel Law variety. *MLJ*

Origin determination for gemstones: Possibilities, restrictions and reliability. H. A. Hänni, *Journal of Gemmology*, Vol. 24, No. 3, 1994, pp. 139–148.

This article addresses the issues that affect the identification of geographic origin for a particular gemstone. Less common in the U.S., such identifications are an important function of many European gemological laboratories, especially for ruby, sapphire, and emerald. Dr. Hänni provides information from his own extensive experience.

A list of growth conditions and resulting gem features opens the discussion of how to determine gemstone origin, followed by commentary on useful laboratory techniques. Among the most important are high-resolution microscopy and chemical analysis of inclusions.

The most meaningful sections of this article, in this abstracter's opinion, are those on reference samples and limitations. In the former, Dr. Hänni explains that samples from a known locality must be used as references, and that the cautious gemologist will only trust samples collected on-site. Reference samples that are not consistent with historic documentation should be considered suspect. Under "limitations," he reminds us that determinations should be based on more than just one or two diagnostic features. Origin cannot be determined: (1) if there are no diagnostic features present (i.e., features present are not locality-specific or characteristic, or features have been damaged by treatment), (2) if the sample is set in jewelry, or (3) if inadequate information is available on relevant sources. In the course of the discussion, he comments that locality terms should not be used to describe gem color, as it confuses the issue of locality determination. *CMS*

The pearl industry in Queensland and Torres Strait. T. Ward, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 282–284.

This brief but informative article summarizes a report submitted by the author to the Queensland Department of Primary Industries. Following are some of the major points.

The pearl industry in Queensland and Torres Strait has been suffering since 1970, when stocks of both wild oysters and culture stock first suffered high mortality rates. These losses were attributed primarily to over-fishing, although pollution and trawling were also implicated. Local hatcheries for pearl oysters have considerable but as-yet-unrealized potential to increase the number of oysters available to the region; as of June 1992, however, pearl culturing areas in the region held only 42% of their estimated capacity. This most recent understocking is caused partly by the high mortality rates, which are traced to inadequate methods used to transport oysters.

Implantation of bead nuclei and mantle tissue is performed by Japanese technicians working on short-term contracts. Nevertheless, usually less than 10% of the implantations result in gem-quality cultured pearls.

Legislation regarding the industry is complicated, and there is poor communication between the many administrative bodies. Therefore, the author proposes that relevant legislation and administration be coordinated and conducted by a single body. He also feels that the pearl culturing industry in this region will not realize its potential until Australians develop the requisite technical and financial expertise. *RCK*

Pink corundum from Kitui, Kenya. N. R. Barot and R. R. Harding, *Journal of Gemmology*, Vol. 24, No. 3, 1994, pp. 165–172.

A new source for corundum, 50 miles (80 km) east of Mt. Kenya and known as Taawajah, was recently discovered. Primary deposits occur in an assemblage of quartzites, marbles, and other metamorphic rocks. Mining is open-pit, primarily with hand tools, and yields approximately 50 to 100 kg of rough per week. The rough consists of small prismatic crystals, mostly chipped or broken, up to 20 grams in weight. Most crystals are bright reddish pink and heavily included. They usually contain rutile, iron oxide or hydroxide stains (in fractures), fissures, twin planes, and sometimes rounded colorless crystals. Color zoning is common.

The material is suitable for beads and cabochons, and most is fashioned in India. Finished pieces range from purplish pink to reddish pink. Some is also dyed in India, and this material tends to be bright red. Chemical analysis revealed typical ruby composition, with both iron and chromium present. One dyed sample, however, was found to contain no detectable chromium. Crystalline inclusions of pyrope-almandine were also identified. Spectral features are comparable to those of other Kenyan rubies and do not indicate the presence or absence of dye treatment. Dyed material can be identified with the microscope by dense concentrations of color within fissures. Another earmark is pink residue left on a tissue wiped over a stone that has been wet with ethyl alcohol or amyl acetate. *CMS*

Some far northern opal diggings in South Australia. G. Brown, J. Townsend, and K. Endor, *Australian Gemmologist*, Vol. 18, No. 8, 1994, pp. 252–255.

To date, three major localities—Andamooka, Mintabie, and Coober Pedy—have been the significant commercial sources of opal in South Australia. There are, however, other potentially economic areas. After briefly reviewing the major localities and economics of opal mining in general, the authors describe some newer mining localities, east of Mintabie on Lambina Station.

One, called the Lambina diggings, is described in some detail. Here, the host rock is a weathered, white, bleached, porous marine claystone-siltstone above a less permeable, less weathered zone of clay-silt. Stable precious opal is found at depths of less than 10 m as: (1) infillings of joints in a bleached claystone unit; (2) matrix cementing coarse sand interbeds within the claystone; (3) seams at the contact between sand lenses and underlying impervious claystone; and (4) thin veinlets in overlying jasper breccia silcrete. Both white opal and black opal (resembling that from Lightning Ridge) reportedly have been recovered in economic quantities, although information about quantity and quality produced to date are well-guarded secrets of area miners.

Other diggings on Lambina Station include the Broken Leg area. This is reported to be a good source of what is locally known as "rainbow rock," an attractive opalized sandstone that formed when precious opal cemented grains in weathered sandstone.

The article is illustrated with color photographs of each locality described, mechanized mining in progress, and samples of rough opal. *RCK*

Tahiti's black pearl marketing goals—high quality, higher prices. G. Holmes, *Jewelers' Circular-Keystone*, Vol. 165, No. 9, September 1994, pp. 102–106.

Farmers of cultured black pearls in Tahiti have suffered falling prices for the last three years, at a time when farmers of Australian South Seas cultured pearls have seen definite price increases. The Tahitian farmers attribute this price decrease directly to the Tahitian government, which has been freely granting new farming licenses and encouraging exports at a time when the Australian government is exercising tighter control over their pearl products and exportation. In order to maintain quality for the small market share that black pearls have, Tahitian farmers are suggesting that "junk" pearls, which account for 7% or 8% of total production, be used only in decorative items, not jewelry, or be ground up for other uses such as cosmetics and medicinal compounds. To produce a better black pearl, a government plan will focus on lowering mollusk mortality rates, improving hatchery techniques and genetic engineering, and experimenting with cryopreservation. The article also reviews the high financial risk of pearl farming in an area of the world where communication and transportation are basic everyday challenges. *JEC*

Tahiti faces black pearl dilemma. D. Catalano, *National Jeweler*, Vol. 38, No. 20, October 16, 1994, p. 24.

The number of black cultured pearls exported from French Polynesia rose 245% over the last four years, while the price per kilogram fell 39% to $36,900 in 1993, down from $62,696 in 1990. For the first quarter of 1994, the price was reported at $35,728 per kilogram.

This situation gravely concerns the pearl industry of Tahiti and was much discussed at the First International Tahiti Pearl & Jewellery Festival in Papeete in June. Government and industry leaders talked about stopping the issuance of government licenses for new pearl farms, quality control inspections before export, and increased promotion in the Pacific Rim, United States, and Europe.

Black pearl prices peaked in 1987 and 1988. They first slipped during the last quarter of 1989 and have been falling ever since. By 1994, prices of top-quality black cultured pearls had dropped 40%. Average prices for all qualities were down 60%. However, production soared, and black cultured pearls became Polynesia's top export in 1993.

Concessions, originally issued to entice residents to stay on their home islands, had been given to everyone who wanted to get into pearl farming, causing overproduction. In June, the government stopped issuing concessions to establish farms on Manihi atoll, where pearl farming started and most Tahitian farms are located. The government also intends to establish an inspection and export control in 1995. The aim is to export better quality, use middle quality to make jewelry to sell in Tahiti, and retain poor quality for some other industrial use not yet determined. *MD*

Vesuvianite from Bellecombe and Montjobet (AO Italy): A material of gemmological interest. M. Novaga, *Journal of Gemmology*, Vol. 24, No. 3, 1994, pp. 173–178.

Gem-quality transparent vesuvianite occurs in the Valle d'Aosta region of Italy, near Bellecombe and Montjovet. The material occurs *in situ* in metamorphic rodingite of Cretaceous age, within regional serpentines. Facet-grade material ranges from greenish brown to yellowish brown. On the basis of refractive index and specific gravity, two types (not related to specific localities) were identified: one with R.I. = 1.724–1.736 and S.G. = 3.35–3.36, and the other with R.I. = 1.714–1.722 and S.G. = 3.36–3.40. A strong absorption band at 471 nm was present in all samples and is diagnostic for vesuvianite. The samples all contained abundant inclusions, most commonly fluid inclusions in tubes and negative crystals. Chemical composition and other properties are summarized in two tables. The occurrence does not appear to be economically viable. *CMS*

INSTRUMENTS AND TECHNIQUES

A.G.L. Portable Gem Testing Kit. T. Linton, R. Beattie, and G. Brown, *Australian Gemmologist*, Vol. 18, No. 8, 1994, pp. 249, 256.

This Gemmological Association of Australia Instrument Evaluation Committee report describes a portable gem-testing kit being marketed by the Asian Gemmological Laboratory, Kowloon, Hong Kong. The 180 × 150 × 50 mm carrying case, lined with black velvet, held gemstone tweezers, a calcite dichroscope, an OPL diffraction-grating spectroscope, a Chelsea filter, a penlight, a 10× hand loupe, a folding polariscope, an interference-figure sphere, and two gemstone cleaning cloths. The evaluators found all kit components to be of good quality, although they had minor criticisms of a few. For example, they found it difficult to rotate the dichroscope without it slipping from the user's fingers. They concluded that the kit would be useful both to students and the working gemologist in the field. *RCK*

Gem Illuminated Immersion Cell. T. Linton, R. Beattie, and G. Brown, *Australian Gemmologist*, Vol. 18, No. 8, 1994, pp. 247–248.

An illuminated immersion cell from GIA GEM Instruments is the subject of this Gemmological Association of Australia Instrument Evaluation Committee report. The unit consists of a metal casing, internal circuitry with battery-operated krypton lamp, a glass diffusion screen, and a screw-on cap with integral 2× magnifier. Virtually any fluid suitable for immersion may be used with the instrument. After noting the manufacturer's instructions and precautions for use, the evaluators report on gemstone features that were readily identified with the instrument. These include several that are typical of diffusion-treated corundum, luster differences between ruby and "glass repairs" (glass-filled cavities?), curved color banding in Verneuil yellow synthetic sapphire (especially when a blue color-contrast filter was also used), curved and straight color banding in synthetic and natural corundum respectively, and "oiled" fractures in emerald.

The authors conclude that the instrument is well made, easy to use, and comparatively inexpensive. Their one criticism is the limited working life of the batteries, and they recommend that an AC adaptor be made available for laboratory use. *RCK*

Hydrostatic measurement of specific gravity. T. Farrimond, *Journal of Gemmology*, Vol. 24, No. 3, 1994, pp. 161–164.

The author describes his experiments on the viability of determining the specific gravity for small samples hydrostatically, using water as the immersion medium. It is generally thought that water's high surface tension creates inaccurate results for stones smaller than 1 ct. Six stones, ranging from 0.035 to 2.62 ct, were tested. It was found that reasonably accurate S.G.'s could be determined for stones as small as 0.25 ct, and useful approximates could be made for even smaller stones. Results were improved if a small amount of detergent was added to the water. Because the S.G. of water varies little between 4°C and 70°C, no compensation for temperature was considered necessary (unlike with toluene, for example). A final note suggests that the thinnest wire practical should be used to suspend the stone holder. This reduces surface tension at the contact between the water and the wire, thus reducing error caused by the resulting buoyancy. *CMS*

Introducing ESR/EPR spectroscopy to gemmology. D. R. Hutton and G. J. Troup, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 278–279.

This brief report describes the operating principle of electron spin resonance (ESR) spectroscopy, also known as electron paramagnetic resonance (EPR). It then gives a few examples of possible practical applications in gemology, such as in separating natural from synthetic emerald. The article concludes with a proposal for producing a miniaturized unit—about the size of an attaché case—that could be used with a personal computer and monitor. Illustrations include sample spectra and a basic schematic diagram of the proposed portable unit. *RCK*

Pleochroic colours and their related rays. A. Hodgkinson, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 295–297.

Described in this article are useful polariscope and refractometer techniques to relate pleochroic colors in gems to the crystallographic orientation of the rays that carry them. In the first method, the author uses a conoscope to resolve an optical interference figure. The background color of a uniaxial stone against which the optic figure is resolved is that carried by the stone's ordinary ray.

In the second method, the author starts with the standard technique of viewing the instrument's scale through a polarizing filter, which makes it possible to isolate the various rays of both uniaxial and biaxial gems. However, the author illuminates the stone from above, shining an intense beam of light from a fiber-optic illuminator through it. With this method, not only are the readings of the various rays isolated, but the pleochroic colors carried by them are seen as "shadow columns" below (that is, at numerically lower readings than) the R.I.'s shadow edge.

Preliminary efforts by this reviewer to use the second technique with a dark tourmaline appeared to validate the procedure. Readers are encouraged to read this informative report and to experiment with the techniques described therein. *RCK*

Presidium Diamond Fact.™ T. Linton, R. Beattie, and G. Brown, *Australian Gemmologist*, Vol. 18, No. 9, 1994, pp. 279–281.

After describing the operating principles behind this and similar diamond probes, the authors discuss in detail this unit's configuration and operating instructions. They then present their evaluation, which was performed while they staffed a gem identification booth at a week-long gem show. They conclude in this Instrument Evaluation Committee report that the instrument is easy to use, reliable, and efficient in separating diamond from simulants (ranging from 0.01 to over 1 ct). One interesting observation made is that the readings—i.e., where the indicator needle fell within the "simulant" range—on synthetic [colorless?] sapphires varied with the stone's crystallographic orientation. All such readings, however, were clearly in the "simulant" range. *RCK*

PRECIOUS METALS

Gold jewelry sales up. M. Golay, *National Jeweler*, September 16, 1994, p. 4.

According to the World Gold Council (WGC), gold jewelry sales increased in May 1994 over the corresponding period in 1993, rising 5.7% in dollars and 7.6% in units. May sales exceeded $930 million for jewelry in which the primary value was the gold content. Dollar sales rose 5.5% while unit volume was up 6.9%, and sales were up 5.2% for May 1993 year-to-date. May sales increased across all retail channels of distribution, according to the WGC. Analysts said that an upswing in demand for gold, especially in jewelry manufacturing, has made precious metals prices sharply higher in recent months. Optimism should be guarded since speculators putting a lot of cash into gold markets could flee precious metals even more rapidly if upward momentum doesn't continue, according to Jeffrey Christian, a managing director of a New York commodity research firm. *MD*

SYNTHETICS AND SIMULANTS

Australian synthetic periclase. G. Brown, *Australian Gemmologist*, Vol. 18, No. 8, 1993, pp. 265–269.

Magnesite from the large deposit at Kunwarara in Queensland, Australia, is processed at the Queensland Magnesia project into two products: briquettes of sintered magnesia with a periclase structure, and ingots of fused synthetic, periclase. The ingots contain a 10-cm inner rim of facetable material that occurs in three forms: (rare) cubo-octahedral crystals, pseudocubic masses bounded by cleavage planes, and parallel growths of slightly tapering columnar crystals of hexagonal cross section.

This gem-quality material ranges from colorless to yellow to light brown and pale pink. Bulk chemical analyses show the crystals to be composed of >98.5% MgO, 0.1–1.2% SiO_2, 0.3–0.8% CaO, with traces of aluminum, iron, and manganese oxides. Gemological examination by the author revealed the following properties: Mohs hardness—5½; cleavage—perfect cubic, and traces of octahedral; S.G.—3.50; R.I.—1.735; optic character—singly refractive; dispersion—0.014; diaphaneity—transparent; luster—vitreous; Chelsea filter reaction—green; UV fluorescence—all inert to both long- and short-wave (except for the pink material, which fluoresced pale orange to long-wave and dusky pale orange to short-wave UV radiation). No absorption features were noted with a spectroscope, and magnification revealed rare, small negative crystals of cubic habit. Preliminary trace-element analyses indicated that the pinkish hue might be due to Mn^{2+} replacement of some Mg^{2+}. Fe^{2+} (and possibly some Mn^{2+}) substitution is the likely cause of the yellow to brown colors.

This interesting and nicely illustrated article also addresses the tendency of periclase to alter to brucite over time. *RCK*

Russian synthetics examined. K. Scarratt, G. Du Troit, and W. Sersen, *Diamond International*, No. 28, March/April 1994, pp. 45–46, 49–50, 52.

For months, we have been hearing and reading that the "Russians are coming!" into synthetic-gem production. First, synthetics manufacturer Tom Chatham of San Francisco told us that gem-quality synthetic diamonds were entering the jewelry market. Now, in this article, we hear a similar message from Walter Barshai of Pinky Trading in Bangkok. Both have announced that they will sell gem-quality synthetic diamonds to the jewelry industry for a fraction of what natural diamonds cost.

Ken Scarratt, director of laboratory operations, education, and research at the Asian Institute of Gemological Sciences in Thailand, co-authored this brief yet important update on the latest examinations of the newer Russian material. As we first read in the Winter 1993 issue of *Gems & Gemology*, these synthetics are not as easily identified as the Japanese Sumitomo synthetic diamonds. What is most disconcerting about both articles is the implication that near-colorless synthetic diamonds may already exist in the market, but the authors cannot tell us what to look for.

In brief, the *Diamond International* report states that characteristic inclusions will be helpful in identifying the Russian synthetic diamonds. Minute dust-like particles, often randomly oriented, are common. Large, variously shaped metallic inclusions, a result of the flux growth process, are obvious, but not common. The previously reported color growth zones were NOT found in this latest examination. And the fluorescence, which up until now has been quite helpful, was natural in appearance, leaving the authors searching for any slight deviation from the norm to report.

Spectra could give us a clue, as the nickel flux may show a 658-nm line (not found in natural diamonds) with a hand-held spectroscope. This might be just the key for the gemologist, except that annealing (high-temperature heat treatment) may eliminate the 658 line.

Synthetic diamonds are here, and we must read every article available to pick up on any means of identification. If you thought that identifying filled diamonds was a problem, "you ain't seen nothing yet"! *GAR*

MISCELLANEOUS

Microscopic examination of mineral grains in forensic soil samples: Part 1. N. Patraco, *American Laboratory*, Vol. 26, No. 5, April 1994, pp. 35–40.

Even though a few thousand minerals are known, only about 20 are commonly found in soil samples. This article describes how, through the use of polarized light microscopy, one can identify these minerals by means of their optical properties alone. A handy chart describes some common minerals and visual clues useful in identifying them, including color, transparency, cleavage or form, estimated birefringence and relief (degree of shadowing), and refractive index. Köhler illumination and Becke lines (e.g., a white halo around edge of particle in polychromatic light) as identification aids are discussed in the text.

Although the article is written by a retired New York City detective/criminologist for use in using soil as evidence in court, the chart contains minerals and their optic properties that are of interest to gemologists: quartz, feldspar, calcite, garnet, tourmaline, zircon, epidote, hematite, magnetite, and glass. A good list of references is also provided. *CEA*

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SUBJECT INDEX

This index gives the first author (in parentheses), the issue, and first page of the article in which the indexed subject occurs. For Gem News (GN), Gem Trade Lab Notes (GTLN), and Letters (Let) sections, inclusive pages are given for the subject item. The reader is referred to the Author Index at the end of this section for the full title and the coauthors, where appropriate, of the articles cited. The pages covered by each issue are as follows: Spring (1–70), Summer (71–140), Fall (141–218), Winter (219–296).

AUTHOR INDEX

This index lists, in alphabetical order, the names of authors of all articles that appeared in the four issues of Volume 30 of *Gems & Gemology*, together with the inclusive page numbers and the specific issue (in parentheses). Full citation is provided under the first author only, with reference made from joint authors.

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