

Collector's Guide to the
BERYL GROUP



Robert J. Lauf

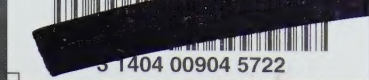


Schiffer

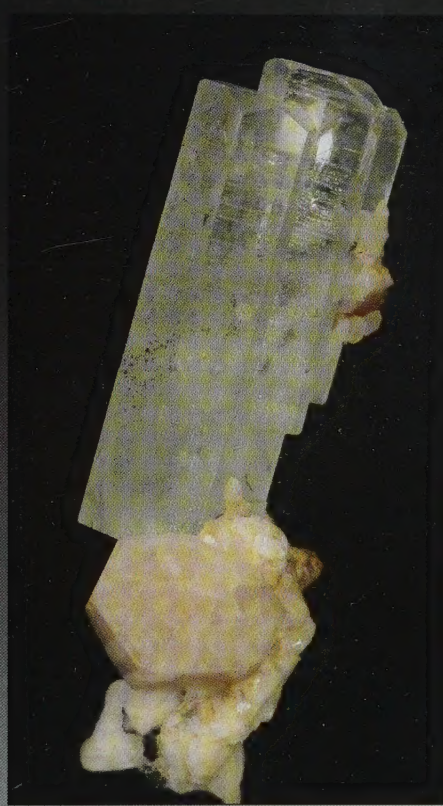
About the Author

The author holds a Ph.D. in Metallurgical Engineering from the University of Illinois. His scientific career included over twenty years at Oak Ridge National Laboratory, where he conducted research on topics ranging from nuclear fuel, coal by-products, materials synthesis, microwave processing, sensors, optical materials, and biomineralization. He has been granted over forty U.S. Patents for his inventions, many of which have become successful industrial products. He is now a Registered Patent Agent and technology consultant.





Collector's Guide to the BERYL GROUP



Schiffer Earth Science Monographs Volume 11



4880 Lower Valley Road, Atglen, Pennsylvania 19310

Robert J. Lauf



Other Schiffer Books By The Author:

Collector's Guide to the Axinite Group. ISBN: 9780764332166. \$19.99.

Collector's Guide to the Epidote Group. ISBN: 9780764330483. \$19.99.

Collector's Guide to Silicate Crystal Structures. ISBN: 9780764335792.
\$19.99.

Collector's Guide to the Tourmaline Group. ISBN: 9780764337758.
\$19.99.

Collector's Guide to the Vesuvianite Group. ISBN: 9780764332159.
\$19.99.

Other Schiffer Books on Related Subjects:

Collector's Guide to Fluorite. Arvid Eric Pasto. ISBN: 9780764331930.
Price: \$19.99.

Copyright © 2011 by Robert J. Lauf

Library of Congress Control Number: 2011932429

All rights reserved. No part of this work may be reproduced or used in any form or by any means—graphic, electronic, or mechanical, including photocopying or information storage and retrieval systems—without written permission from the publisher.

The scanning, uploading and distribution of this book or any part thereof via the Internet or via any other means without the permission of the publisher is illegal and punishable by law. Please purchase only authorized editions and do not participate in or encourage the electronic piracy of copyrighted materials.

"Schiffer," "Schiffer Publishing Ltd. & Design," and the "Design of pen and inkwell" are registered trademarks of Schiffer Publishing Ltd.

Designed by Mark David Bowyer
Type set in Arno Pro / Humanist 521 BT

ISBN: 978-0-7643-3878-6
Printed in China

Schiffer Books are available at special discounts for bulk purchases for sales promotions or premiums. Special editions, including personalized covers, corporate imprints, and excerpts can be created in large quantities for special needs. For more information contact the publisher:

Published by Schiffer Publishing Ltd.
4880 Lower Valley Road
Atglen, PA 19310

Phone: (610) 593-1777; Fax: (610) 593-2002
E-mail: Info@schifferbooks.com

For the largest selection of fine reference books on this and related subjects, please visit our website at www.schifferbooks.com

We are always looking for people to write books on new and related subjects. If you have an idea for a book, please contact us at proposals@schifferbooks.com.

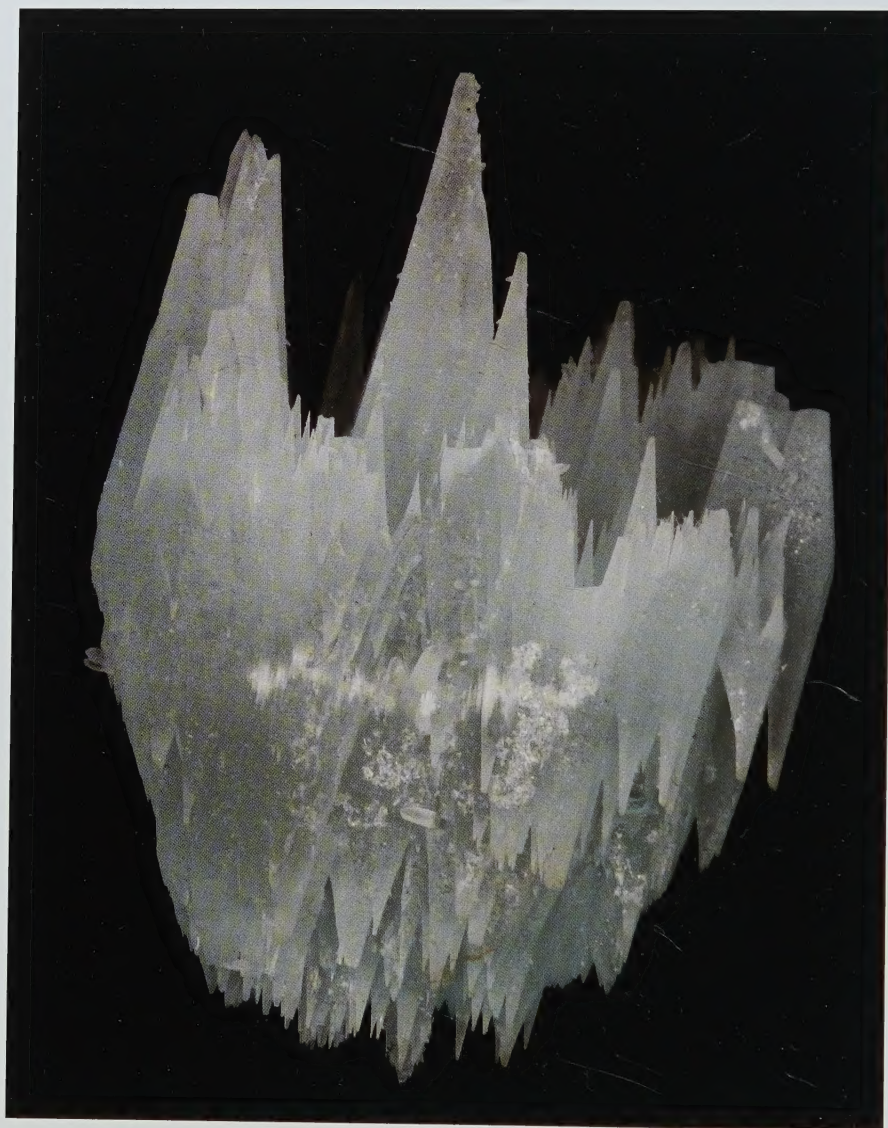
This book may be purchased from the publisher.
Include \$5.00 for shipping.
Please try your bookstore first.
You may write for a free catalog.

In Europe, Schiffer books are distributed by
Bushwood Books
6 Marksbury Ave.
Kew Gardens
Surrey TW9 4JF England

Phone: 44 (0) 20 8392 8585; Fax: 44 (0) 20 8392 9876
E-mail: info@bushwoodbooks.co.uk
Website: www.bushwoodbooks.co.uk

Contents

Preface	5
Acknowledgments.....	7
Introduction	8
Gemology.....	8
Taxonomy of the Beryl Group	13
General formula.....	13
Accepted species and their formulas	13
Crystal structure and morphology.....	13
Chemistry and color	16
Formation and Geochemistry	22
Beryls in igneous rocks.....	22
Beryls in metamorphic rocks	35
The Minerals	40
Bazzite	40
Beryl.....	41
Indialite.....	86
Pezzottaite	88
Stoppaniite	88
References	89



Preface

This volume continues a series of monographs on important groups of so-called rock forming silicates, the purpose of which is to help mineral collectors gain a better appreciation of these complex minerals. Because of the importance of rock forming minerals in geological processes, they are the subject of extensive published research, much of which has been brought together in the five-volume compendium *Rock-Forming Minerals* (Deer, Howie, and Zussman 1962) and the greatly expanded Second Edition thereof. Among rock-forming minerals, the beryl group, although small, is well known to collectors and gemologists through excellent crystals that are found at many localities worldwide. Beryl (particularly the varieties emerald and aquamarine) is a major gem species, and the recently described mineral pezzottaite is a minor gem for the rarity collector.

Members of the beryl group can be found in a variety of rock types, and the interested collector can learn a lot about pegmatites, metamorphism, and metasomatism

by studying these beautiful crystals, their matrices, and their associated minerals. The many types of inclusions in emerald and aquamarine represent a fascinating subject in themselves. Collectors also need to be aware that many cut emeralds and even some mineral specimens may be treated in various ways to enhance their appearance, the controversial “heliodor” crystals supposedly found in Tajikistan being especially notorious at present.

The present monograph is organized as follows: After a brief introduction, the general treatment begins with an explanation of the chemistry and taxonomy of the group. A section on their formation and geochemistry explains the kinds of environments where beryls are formed. Then, a detailed entry for each mineral provides extensive locality information and full-color photos wherever possible so that collectors can see what good specimens look like and which minerals one might expect to find in association with them.



Acknowledgments

The following colleagues kindly provided technical information, literature, and helpful discussions: Dr. Giovanni Ferraris, *University of Torino*; Dr. Lee Groat, *University of British Columbia*; Dr. Jane Howe, *Oak Ridge National Laboratory*. Important specimens and background information were supplied by Laurie Adams, *The Adams Collection*; John Betts; Dudley Blauwet, *Mountain Minerals*; Sharon Cisneros, *Mineralogical Research Co.*; Richard Dale, *Dale Minerals*; Kevin Downey, *Well-Arranged*

Molecules; Shields Flynn, *Trafford-Flynn Minerals*; Pete Heckscher, *The Crystal Circle*; Leonard Himes and Michael Jacob, *Minerals America*; Mohammed Javed, *Javed's International Gem Imports*; Patrick Kelley, *PAK Designs*; Tony Nikischer, *Excalibur Mineral Co.*; Neal Pfaff, *M. Phantom Minerals*; Jeff Schlottman, *Crystal Perfection*; Jaye Smith, *The Rocksmiths*; Scott Wallace, *Majestic Minerals*; and Chris Wright, *Wright's Rock Shop*.

Introduction

The beryl group is a small one, with only five members (if indialite is included), but it is extremely important as a source of gemstones, fine mineral specimens, and industrial raw materials.

Beryl is the main commercial source of beryllium, most of which is used in Be-Cu alloys. Copper alloys, containing about 2.5% Be, are harder and stronger than pure copper while retaining copper's good electrical and thermal conductivity. Beryllium copper is *non-sparking*, making it useful in tools for coal mining as well as the nozzles for gasoline pumps, where steel components would create the danger of explosions. Beryllium is also used extensively in nuclear reactors as a neutron moderator and reflector. Beryllium oxide, BeO, has the interesting property that it is electrically insulating and yet has thermal conductivity comparable to that of copper; it is used in radar tubes and other high power electronic components. In general, industrial grade beryl is produced from pegmatites as a byproduct of mining higher-volume materials such as feldspar, mica, or lithium minerals (Bates 1969).

As a gemstone, beryl was known in antiquity. Emerald mines in Upper Egypt, near the Red Sea, which were re-

discovered and briefly reopened in 1819, were evidently worked as early as 1650 BC and were large enough to accommodate 400 miners working simultaneously. Cleopatra was known to present emeralds engraved with her likeness to favored recipients (Bauer 1904).

In contrast to beryl itself, other members of the group were recognized much more recently: bazzite in 1915, indialite in 1954, stoppaniite in 1998, and pezzottaite in 2003.

Gemology

Gem-quality beryl has been given varietal names based on color: they include emerald (green), aquamarine (blue to blue-green), heliodor (yellow), morganite (pink), goshenite (colorless), and bixbite (deep red). Emerald is the most valuable gem variety, and indeed large, flawless emeralds may command prices comparable to those of fine diamonds. Transparent emerald is typically faceted, but may be cut *en cabochon*. Cabochon cuts are more typical for the less-transparent stones and particularly for chatoyant (cat's-eye) stones.

An unusual type of emerald that has a relatively transparent central zone and a sectorized outer zone is found at the Peña Blanca, Colombia, emerald mine. (Note that in the original report, the locale was erroneously given as the Chivor mine.) It is called “trapiche” (trah-PEE-chay) after the Spanish word for sugar cane crushing gear. Nassau and Jackson (1970) demonstrated that in these specimens, the central core and the green, radiating “arms” represent one

interconnected crystal; the white filling between the arms represents a continuation of this single crystal but with light to massive amounts of albite inclusions. Examples of this type of growth were plentiful, but usually discarded, at Peña Blanca; however, at the Muzo mine, the country rock is black shale, and the trapiches contain black, carbonaceous inclusions between the arms.

Figure 1. Two trapiche emerald cabochons, ~6 X 8 mm, show the distinctive 6-rayed pattern when viewed along the z-axis. Although the only locality given was Colombia, the dark inclusions suggest that the material originated at Muzo. *RJL3846*



Figure 2. A small emerald cabochon, ~3 mm diameter, shows a well-developed cat's-eye caused by parallel, needle-shaped inclusions or channels. *RJL1269*

The blue color of aquamarine is caused by ferrous iron (Fe^{2+}). Any ferric iron (Fe^{3+}) present in the crystal will add a yellowish tint, so greenish-blue stones are typically heat treated at 400 - 450°C to reduce the ferric iron and improve the blue color. *Maxixe*-type beryl has a somewhat different absorption spectrum than aquamarine. Irradiation can improve the color of *Maxixe* beryl, but the resulting deep blue is unstable and tends to fade on exposure to sunlight (Arem 1977).

Bixbite (red beryl) has been known from the Thomas Range, Utah, since around 1905. The unusually rich, rasp-

berry red color was attributed to Mn; it is interesting to note that Mn is also the suspected chromophore in morganite, but the Mn content of morganite is many times lower than that of bixbite (~ 0.005 versus ~ 0.08 wt.%) (Nassau and Wood 1968). The Ruby Violet (or Red Beryl) mine, in the Wah Wah Mountains, Beaver Co., Utah, about ninety miles south of the original find, has been the only commercial producer of red beryl. It is estimated to have produced over 60,000 carats, about 10% of which was facetable (Shigley, Thompson, and Keith 2003).



Figure 3. Aquamarine crystal, ~ 4 cm tall, in pegmatite from the Tripp mine, Alstead district, Cheshire Co., New Hampshire, along with a 6 X 8 mm (~ 1.3 carat) cut stone from the same locale. RJL4028

Pezzottaite, a recently described member of the group, is richly colored in shades of pink to red, and can make colorful faceted gems and cat's-eyes. Large flawless crystals are fairly rare, however, so cut stones tend to be less than about 10 carats for faceted material and 20 carats for cabochons (Laurs et al. 2003; Hawthorne et al. 2004).

Most natural emeralds contain a variety of flaws and internal inclusions, and various techniques have been developed to enhance the appearance (and value) of cut stones. Traditionally, the enhancement involved filling small cracks or fissures with oil whose refractive index was matched to that of emerald. The industry distinguishes between the use of colorless oil simply to hide cracks, which is consid-

ered generally acceptable, and the use of green fillers to enhance the color, which requires the stone to be labeled as "treated emerald." More recently, various types of epoxy or other resins have been used. These have the advantage of a higher refractive index that can more effectively make larger fissures disappear, but in some cases the resin isn't stable; with time it decomposes and turns milky white, making the fissures visible again. In modern practice, oil treatment is preceded by boiling in acid to leach any iron oxides or polishing compound from the cracks so that they can be cleanly infiltrated with oil and become as unobtrusive as possible (Kiefert 2002).



Figure 4. A gemmy pink pezzottaite crystal, ~15 mm wide, from Sakavalana, Madagascar. RJL3761

The demand for gem-grade beryl led to the development of methods to grow synthetic crystals. O'Donoghue (1983) and Schmetzer (2002) review the history of emerald synthesis techniques, beginning with the work of Hautefeuille and Perrey in 1888, and also present examples of the microscopic inclusions that can help the gemologist to recognize synthetic emeralds. Hautefeuille and Perrey used a flux-melt process in which the constituent oxides, along with 0.6% Cr_2O_3 , were dissolved in molten lithium molybdate in a platinum crucible. Flanigen and Taylor (1967) patented a flux-melt process in which several flux compositions were disclosed; their preferred fluxes were acidic lithium molybdates of the type $\text{Li}_2\text{O}_x\text{MoO}_3$, with $x = 2.25$ to 3.25 .

Emeralds have also been synthesized by hydrothermal techniques (Flanigen and Mumbach 1971; Yancey 1973). From a commercial standpoint, a major drawback is the need for high-temperature, high-pressure reaction vessels

in which to maintain the runs over long periods of time (Yaverbaum 1980). Yancey (1973) described a process for growing fairly large crystals in a highly acidic (pH no greater than 0.1) aqueous solution containing sources of Al, Be, and Si oxides and Cl^- ions at a concentration of at least 4 molar. The process was carried out at temperatures of $400 - 700^\circ\text{C}$ under a pressure of $6,000 - 30,000 \text{ lbs/in}^2$. Growth rates as high as 0.6 mm/day were maintained over a period of 13 days.

Flanigen et al. (1967) reviewed the characteristics of fifteen synthetic emeralds, grown by both flux-melt and hydrothermal methods, and compared them to those of natural emeralds. They reported the following properties: density, optical properties, inclusions, fluorescence, chemical composition, structure, and infrared spectra. They concluded that, "the origin of an emerald, natural, synthetic flux, or synthetic hydrothermal, can be defined by determination of characteristic properties."

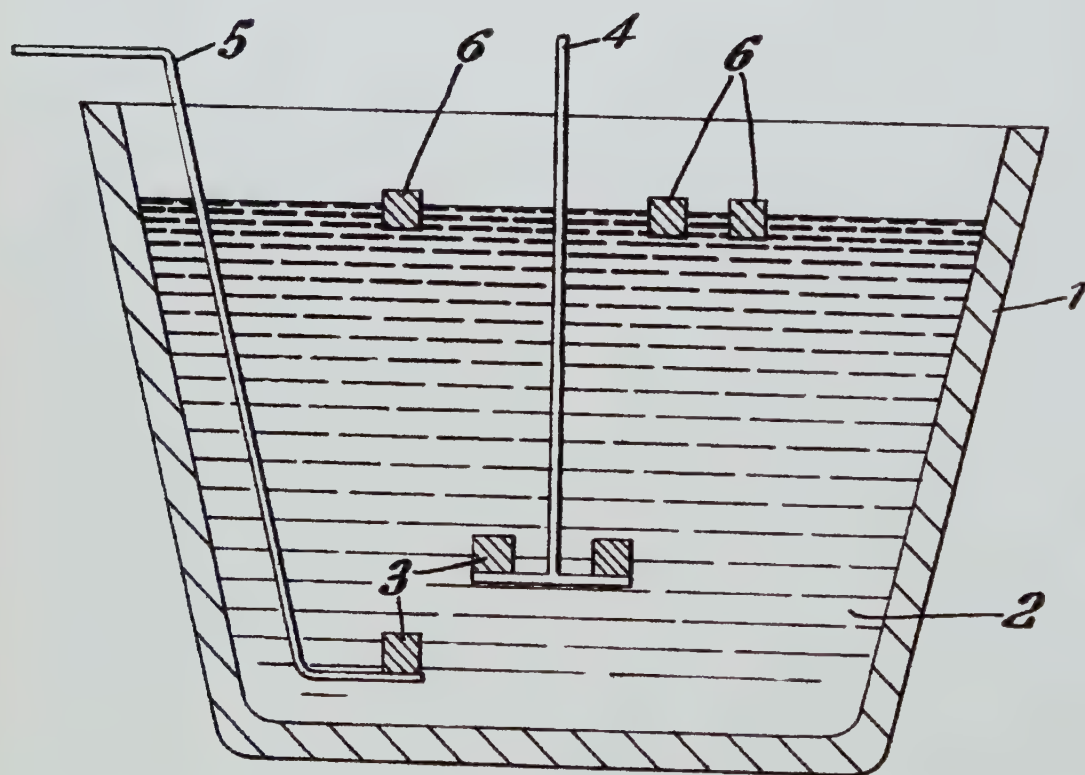


Figure 5. Drawing from U.S. Patent 3,341,302, showing a receptacle 1 containing molten flux material 2. Seed crystals 3 are suspended on hangers 4 and 5 and positioned in a lower zone of the molten flux-filled receptacle. Nutrient source materials 6 are positioned in an upper zone of the molten flux-filled receptacle (Flanigen and Taylor 1967).

Taxonomy of the Beryl Group

General formula

Members of the beryl group have the general formula $\mathbf{A}_{2-3}\mathbf{B}_2[\text{Si}_5(\text{Si},\text{Al})\text{O}_{18}]$ where **A** = Be, Mg, Fe, Cs, Li, or Na; and **B** = Al, Sc, Fe. In addition to beryl, the group includes bazzite, stoppaniite, and pezzottaite (Laurs et al. 2003; Hawthorne et al. 2004). Indialite, a polymorph of cordierite, is generally considered to be a member of the group, and will be so treated here.

Table 1. Accepted species and their formulas

Species	Formula
Bazzite	$\text{Be}_3(\text{Sc},\text{Al})_2\text{Si}_6\text{O}_{18}$
Beryl	$\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$
Indialite	$\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$
Pezzottaite	$\text{Cs}(\text{Be}_2\text{Li})\text{Al}_2\text{Si}_6\text{O}_{18}$
Stoppaniite	$(\text{Na},\square)_2(\text{Fe},\text{Al},\text{Mg})_4\text{Be}_6\text{Si}_{12}\text{O}_{36}\cdot 2\text{H}_2\text{O}$

Crystal structure and morphology

In the structure of beryl, $\text{Be}_3\text{Al}_2[\text{Si}_6\text{O}_{18}]$, hexagonal rings of six SiO_4 tetrahedra form hollow channels parallel to the z-axis of the crystal. Between the rings, octahedrally coordinated Al, surrounded by six oxygens, and Be, surrounded by four oxygens in a distorted tetrahedron, serve to link the rings together into a sort of “honeycomb” structure. In alkali-rich beryls, these large ions (K^+ , Rb^+ , Cs^+) lie inside the hollow channels, as does any water in the crystal (Hawthorne and Černý 1977; Aurisicchio et al. 1988; Artioli et al. 1993; Gatta et al. 2006).

As Laurs et al. (2003) point out, pezzottaite is not strictly isostructural with beryl, but the structures are closely related: “In beryl, the three Be atoms indicated in the formula occupy three symmetrically related positions. In pezzottaite, these three positions are occupied in an ordered fashion by Be_2Li As a result, pezzottaite differs from other members of the beryl group by having a different symmetry (rhombohedral rather than hexagonal) and a larger unit cell.”



Figure 6. Crystal structure of beryl, viewed just off the z-axis or [0001], emphasizing the rings of SiO_4 tetrahedra enclosing hollow channels, octahedrally coordinated Al (pale blue balls) and tetrahedrally coordinated Be (pale green balls with wire bonds). Blue lines indicate the unit cell.

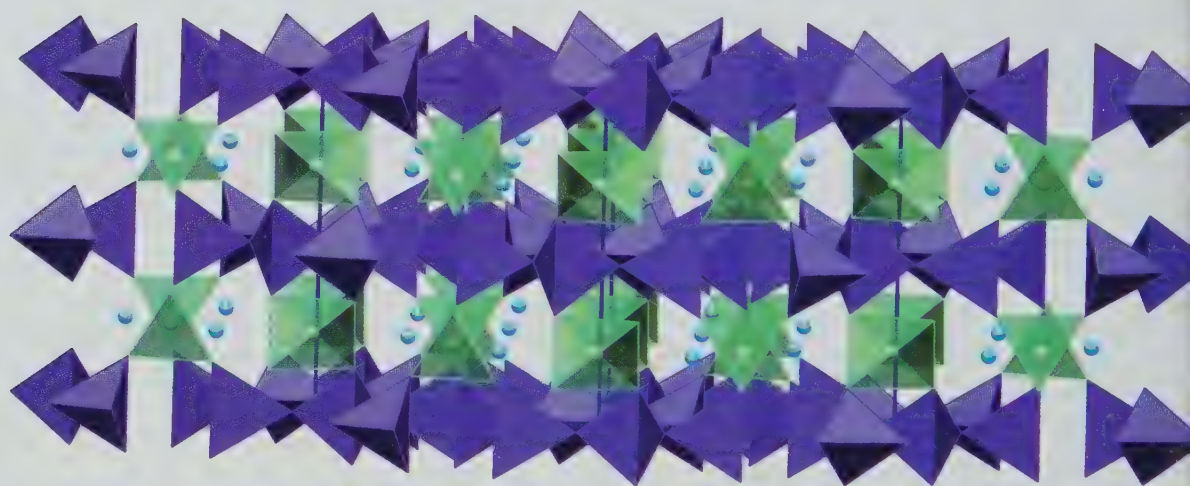


Figure 7. Crystal structure of beryl viewed normal to [0001] to emphasize how the Be (green tetrahedra) and Al (blue balls with wire bonds) connect the silicate rings together.

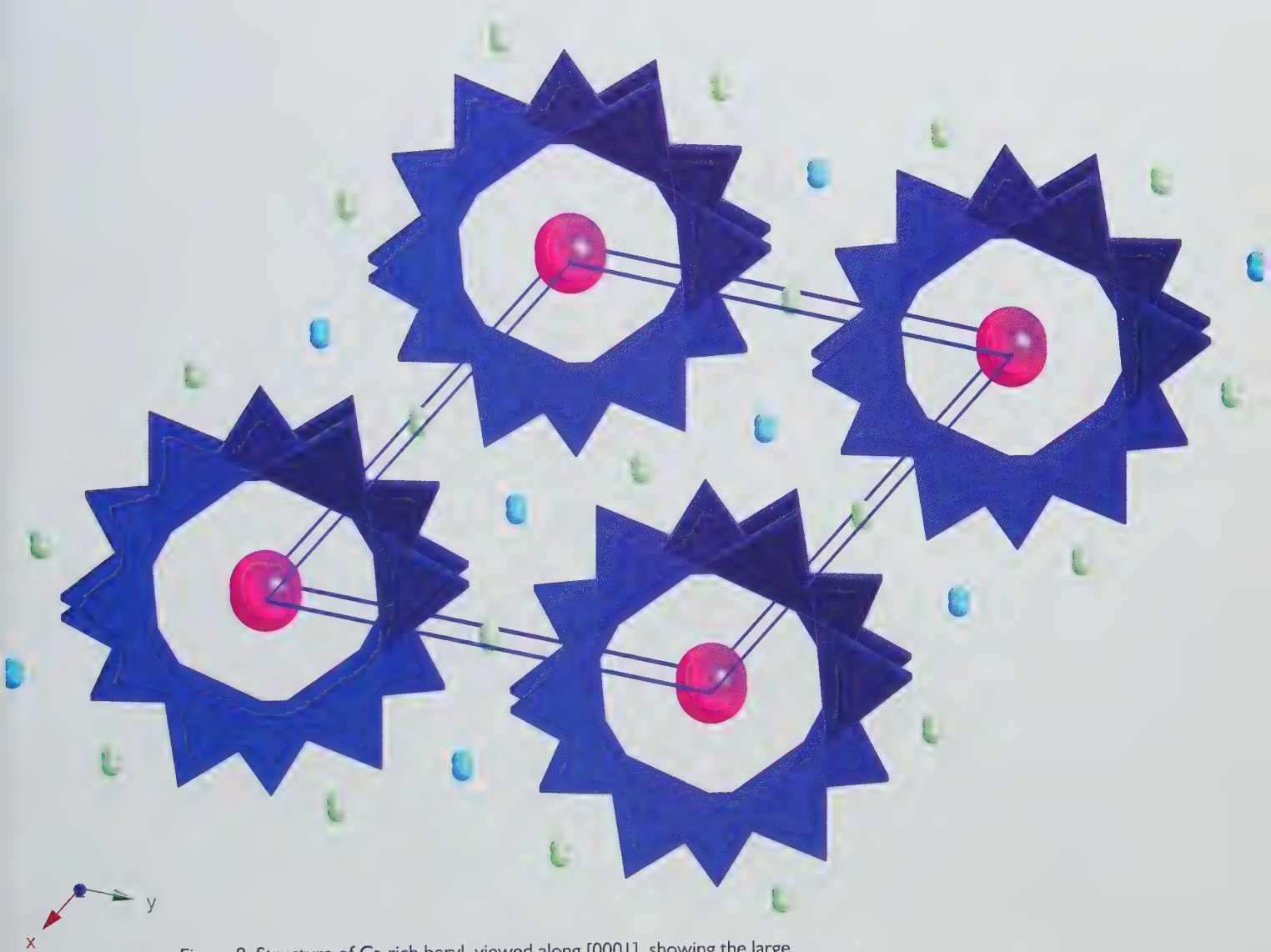


Figure 8. Structure of Cs-rich beryl, viewed along $[0001]$, showing the large Cs^+ ions (magenta balls) lying in the channels formed by the Si_6O_{18} rings.

Goldschmidt (1916) illustrated 160 beryl specimens, from several dozen locales. Beryl crystals tend to be simple elongated or tabular hexagonal prisms. Many show interesting etching structures and other surface figures.

Chemistry and color

The formula $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ implies a theoretical beryllium content of 14% (expressed as BeO); however, most natural

beryl contains somewhat less than this amount because of replacement of some of the Be by alkalis, mainly Na, Cs, and Li (Bates 1969). Although some Na or Li may substitute directly for tetrahedrally coordinated Be, the much larger alkali ions K^+ and Cs^+ cannot be accommodated on these relatively small sites and they locate instead to the large hexagonal channels as shown in Figure 8.

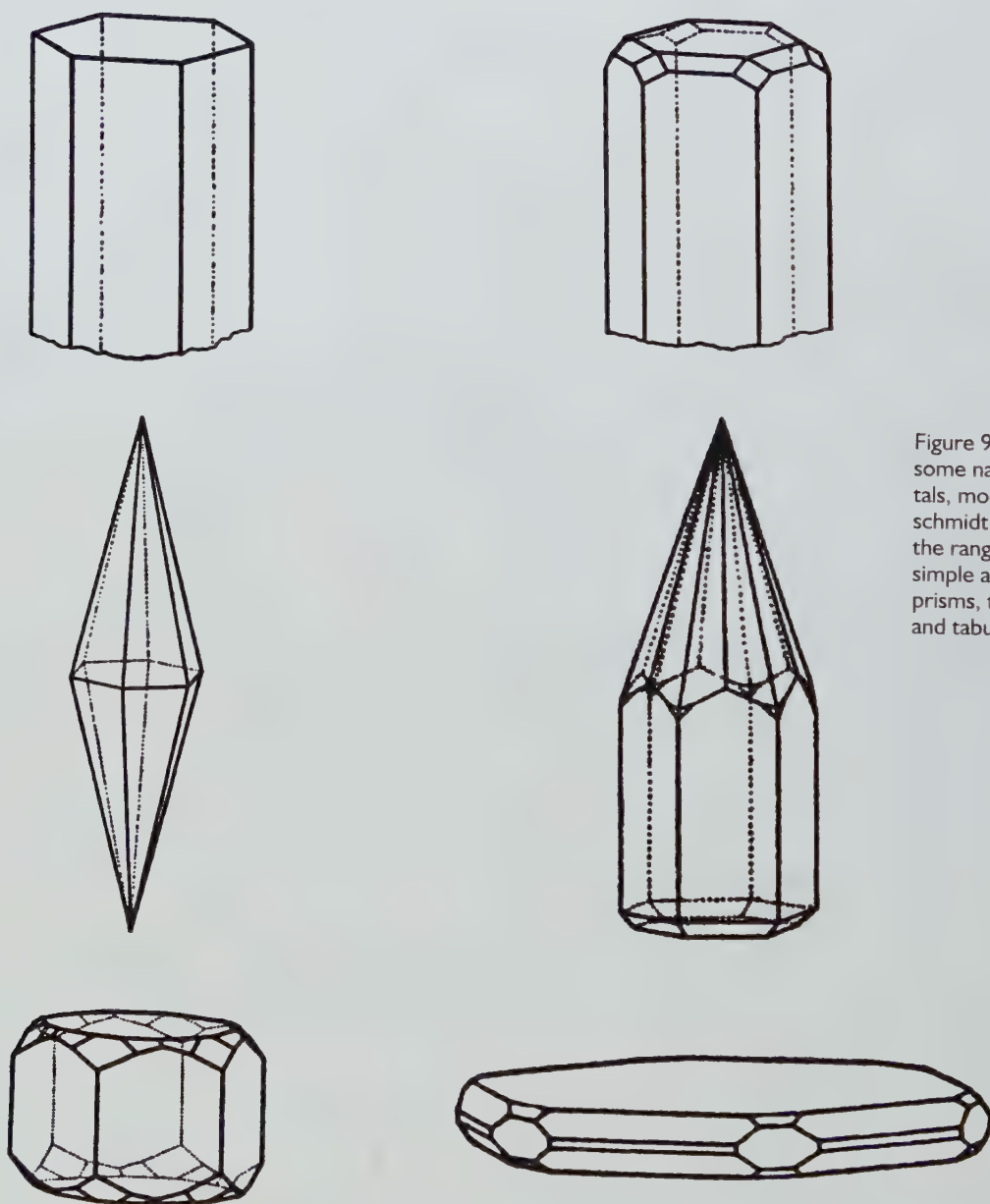


Figure 9. Drawings of some natural beryl crystals, modified from Goldschmidt (1916), showing the range of forms, from simple and modified prisms, to bipyramids and tabular crystals.

Pankrath and Langer (2002) studied the behavior of molecular water in the structural channels of alkali-free beryl. They expressed the formula in crystal-chemical terms as ${}^{\text{VI}}\text{Al}_2[{}^{\text{IV}}\text{Be}_3{}^{\text{IV}}\text{Si}_6\text{O}_{18}]_n\text{X}^{[\text{Chan}]}$, where X represents molecular and/or ionic species in the channels. From the crystal structure and the ionic radius of O^{2-} , one can calculate the interior dimensions of the channels, which Pankrath and Langer describe as “channels of interconnected ‘pumpkin-like’ cavities with maximum dimension of 5.15 Å between the rings at $z = 1/4$ and ‘bottle-necks’ with a diameter of 2.49 Å at the horizontal mirror plane of the rings.” The dimensions of the cavities allow room for one water molecule (diameter ~ 2.8 Å), which is relatively free to rotate while lodged there. By measuring H_2O content at temperatures from 600-900°C and pressures from 3.4 - 10.8 kbar, they conclude that the water content in beryl never exceeds one molecule per formula unit, or $\text{Al}_2[\text{Be}_3\text{Si}_6\text{O}_{18}]\text{H}_2\text{O}$, which corresponds to 3.24 wt.% H_2O .

The general configuration of H_2O molecules in the channels was also confirmed by Gatta et al. (2006) using a combination of experimental techniques, including neutron diffraction and polarized infrared spectroscopy.

Damon and Kulp (1958) noted that “All beryl crystals appear to contain a quantity of helium and argon in great excess over that which can be accounted for from radioactive decay. ... It seems that this excess inert gas must represent a sample of magmatic gases in the immediate environment of the forming crystal and as such can provide useful information on magmatic conditions.” If the excess argon came from some (external) source, and not just from the decay of ${}^{40}\text{K}$ originally in the beryl, then using beryl to determine the age of its host rock using K/Ar methods will be fraught with discrepancies (Deer, Howie, and Zussman 1986).

Pure beryl is naturally colorless, and most natural material is opaque in shades of white or yellow to pale green or blue. Because of its importance in the gem trade, the color of beryl has been studied in detail:



Figure 10. Simple prismatic crystal of beryl var. aquamarine, ~ 4 cm tall, in weathered pegmatite, collected ca. 1945 in Minas Gerais, Brazil. RJL2024



Figure 11. Colorless, water-clear beryl crystal with a tabular habit, about 5 X 3 X 1 cm thick, found ca. 1990 at the Chia mine, São Jose da Safira, Minas Gerais, Brazil. RJL2842

The green color of emerald can generally be attributed to chromium; natural emeralds typically contain 0.1-0.5% Cr_2O_3 , and the intensity of color varies with Cr content. Synthetic emeralds sometimes have much more chromium, from 2% in the Chatham process (Rogers and Sperisen 1942) to as much as 10% for synthetic overgrowths on colorless seed crystals. Most natural emeralds also contain traces of vanadium, and it has been shown that both Cr and V can independently produce green color in beryl (Wood and Nassau 1968). In the gem trade the term emerald was traditionally specified as “natural grass-green beryl with colour due to chromium” (Deer, Howie, and Zussman 1986). Schwartz and Schmetzer (2002), however, have proposed a more expansive definition: “Emeralds are yellowish green, green, or bluish green, natural or synthetic beryls, which reveal distinct chromium and/or vanadium absorption bands in the red and blue-violet ranges of their absorption spectra.”

The blue color of aquamarine is attributed to Fe^{2+} at concentrations of 0.1-0.3% at the so-called B site in the structural channels. Ferrous iron in the A site or replacing Al doesn't produce color. As mentioned earlier, as-mined aquamarines often have a small amount of Fe^{3+} substituting for Al; this substitution produces a yellow tint that gives the stone a greenish blue color. Heat treatment to reduce Fe^{3+} to Fe^{2+} eliminates the yellow component and thereby improves the color. Heating is done after cutting because small flaws in the raw material can grow into fractures during the heat treatment (Deer, Howie, and Zussman 1986). In blue alkali beryl of the type found at the Maxixe mine, Minas Gerais, Brazil, the color is known to fade to yellowish after exposure to heat or light. This material shows anomalous dichroism and sharp absorption bands in the region 5,000-7,000 Å (Nassau, Prescott, and Wood 1976). The color center has been attributed to CO_3^- or NO_3^- ions in the structural channels (Edgar and Vance 1977; Andersson 1979).

The color of heliodor, which can range from light greenish yellow, to golden or brownish yellow, is attributed to the substitution $\text{Fe}^{3+} \leftrightarrow \text{Al}$. Heating will destroy the yellow color by reducing Fe^{3+} to Fe^{2+} as in the case of aquamarine.



Figure 12. An interesting aquamarine crystal with a long, tapering habit, from the Mimoso do Sul mine, Espírito Santo, Brazil. RJL/498

The pink color of morganite is attributed to Mn^{2+} (Wood and Nassau 1968); assuming Mn^{2+} substitutes for octahedrally-coordinated Al^{3+} , charge compensation likely involves alkali ions in the structural channels. Manganese is

also implicated as the chromophore in red beryl (bixbite) from Utah (Nassau and Wood 1968), and in a pale rose-red Cs-rich beryl from Elba, Italy.



Figure 13. Bright green emerald, ~15 mm long, from Dabdar, western Xinjiang Province, China. RJL3740



Figure 14. Rich blue aquamarine ~4 cm tall, from Muiane, near Nampula, Alto Ligonha field, Mozambique. *RJL2384*



Figure 15. Yellowish green heliodor crystal ~6 cm tall, from Galileia, Minas Gerais, Brazil. *RJL1499*



Figure 16. Pink beryl (morganite) crystal, just over 1 cm long, with smoky quartz, feldspar, and tourmaline, from Grotta d'Oggi, Elba, Italy. RJL2251

Formation and Geochemistry

The element beryllium is relatively rare, with abundance of ~ 2 ppm in the upper continental crust. In magma, the small size of the Be^{2+} ion, along with its tendency to prefer tetrahedral coordination, limits the number of silicate minerals into which it can be incorporated. This implies that beryl should precipitate from a melt even at low Be concentrations (London 2008). Beryl is the most common mineral containing essential Be; minerals that can accommodate significant trace Be include plagioclase feldspars, some sheet silicates, and cordierite (Turner and Groat 2007).

Staatz, Griffiths, and Barnett (1965) analyzed a total of 47 beryls from a variety of environments including pegmatites, country rock adjacent to pegmatites, veins, granites, and a rhyolite. Based on compositional trends, they concluded: "The range in abundance of certain elements is different in beryls from different environments, and these differences are so large that the environment of most beryls can be determined from their composition."

A more recent treatment of the problem (Groat et al. 2007; Turner and Groat 2007) emphasizes that the complexity of many geologic environments makes it difficult to develop a single classification scheme that neatly distinguishes or differentiates all the known beryl deposits. Turner and Groat (2007) organize beryl occurrences as: pegmatitic; magmatic (\pm hydrothermal); metamorphic (\pm hydrothermal); and secondary deposits.

Beryls in igneous rocks

Common beryl, as well as aquamarine, typically occurs in cavities in granites and granite pegmatites, associated with muscovite, feldspar, quartz, topaz, spodumene, and tourmaline; less common associates include cassiterite, columbite-tantalite, samarskite, fergusonite, and amblygonite (Deer, Howie, and Zussmann 1986). London (2008) notes that beryl "is the first of the truly exotic minerals to crystallize in the evolutionary sequence of the LCT [Li-Cs-Ta] rare-element pegmatites." In many cases, it forms greenish blue prismatic crystals that start in the wall zone and grow inward toward the center of the pegmatite. It is also commonly formed at the margin between the intermediate zone (characterized by blocky microcline crystals) and the quartz core. Crystals that have grown into miarolytic cavities are especially likely to form specimens of interest to mineral and gem collectors. Giant beryl crystals, several meters long or more, are known from several pegmatites, including those of the Keystone district, South Dakota (up to 9 m long!); the Bumpus quarry, Maine; the Assunção quarry, Portugal; and several locales in Madagascar.



Figure 17. Tapered, translucent green beryl crystals (the largest is ~8 cm tall) in albite from a pegmatite in Case quarry, Portland, Connecticut. At this locality, the beryl crystals tend to taper from 4 mm at the wall zone to 150 mm or more at the core zone of the pegmatite (John Betts, personal communication). RJL4050

For the collector, excellent beryl crystals are found in many pegmatites worldwide; some locales of particular interest include the following:

Pegmatites in southern California have been important producers of gem minerals since the late 1800s. Although more famous for tourmaline, and as the original occurrence of lilac-pink spodumene (*kunzite*), the area has produced many spectacular beryls, including aquamarine and especially morganite. Fisher (2002) describes several dozen mines, in ten major districts across San Diego and Riverside counties and northern Baja, California. The pegmatites, which appear to have intruded the area about 100 My ago, are LCT-type. The abundance of tourmaline indicates that they are generally B-rich, whereas lepidolite and spodumene indicate enrichment in Li as well. Alkali beryls, morganite, and goshenite tend to be more common than aquamarine. Fine specimens of morganite have been found at: Lithia Dike; Blue Lady; Tourmaline Queen; Katerina; White Queen; Elizabeth R.; Esmeralda; and Little Three. Producers of good aquamarine crystals include: Fano; Audrey Lynn; Blue Lady; Cryo-Genie; Mack; and Pack Rat (Fisher 2002; Fisher 2005).

New England has been known for its widespread beryl occurrences since colonial times. Kunz (1892) remarked

that, "Some beautiful beryls were found at Haddam, Conn., over fifty years ago, the largest of which was 2 inches in length and 1 inch in diameter. They were remarkable for the fact that part of the crystal was of a transparent green color and free from flaws, while below a certain line of demarcation the whole was white and opaque, as if it were a flocculent precipitate." Kunz also described giant beryls (2 m long) from Grafton and Acworth, New Hampshire. Other locales mentioned by Kunz include: Stoneham, Maine; Royalston and Goshen, Massachusetts; and Portland and Haddam, Connecticut. A more modern review (Jarnot 2005) describes the pegmatites as forming a belt that runs southwest from the Paris-Rumford and Topsham districts of southern Maine, through the Grafton and Keane districts in New Hampshire, then through Massachusetts and into the Middleton district of Connecticut. Some important gem beryl locales described by Jarnot include the following: *Morganite*: Bennett quarry, Buckfield, Maine; Mount Mica, Paris, Maine; Emmons quarry, Greenwood, Maine; and the Swanson mine and Gillette quarry, both in Haddam Neck, Connecticut. *Heliodor*: Slocum quarry, East Hampton, Connecticut; and Roebling mine, New Milford, Connecticut. *Aquamarine*: Stoneham, Maine; Roebling mine, Connecticut; Rice mine, North Groton, New Hampshire; and Palermo #1 mine, Rumney, New Hampshire.



Figure 18. Opaque aquamarine crystal ~5 cm long, with feldspar and quartz, from a pegmatite in the Bumpus mine, Albany, Maine. RJL/18



Figure 19. Dull yellow heliodor crystal, ~4 cm long, in pegmatite from the Slocum quarry, East Hampton, Connecticut. R/L 3852

The Oriental pegmatite province of Brazil runs generally north to south, from southern Bahia, through northeastern and central Minas Gerais, into southern and western Espirito Santo and the northern edge of Rio de Janeiro. The pegmatites are believed to have formed between 650 and 450 My ago and are related to a large group of granitic intrusions. Menezes (2005) provides an extensive review of the aquamarine, heliodor, and emerald occurrences, which

comprise about 40 mines, most of which can be grouped into eight major districts. Menezes points out that the particular colors of beryl tend to be characteristic of different districts: aquamarine and heliodor tend to form in pegmatite bodies that are close to the parent granite, whereas goshenite and morganite tend to form, along with tourmaline, in pegmatites that are in the metamorphic rocks some distance (~200 m up to several km) from the granite.



Figure 20. Fractured beryl crystal ~11 cm long, on terminated quartz crystal, from Brumado, Bahia, Brazil. *RJL2279*

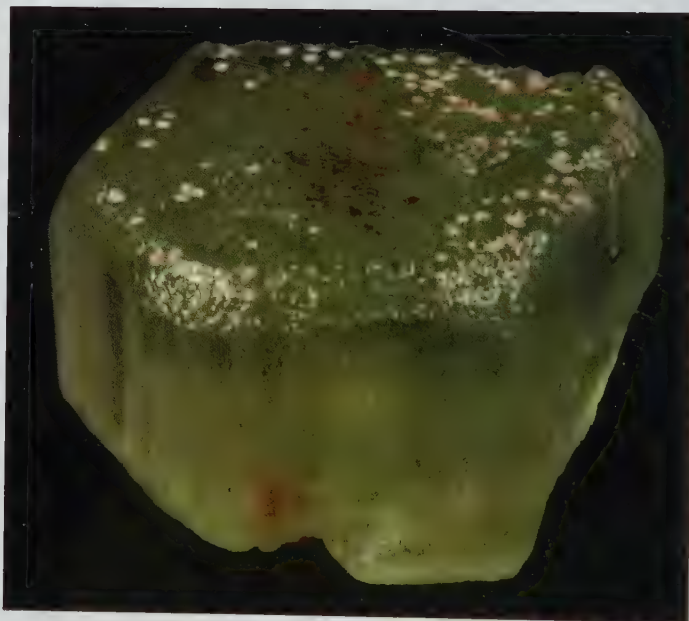


Figure 21. Greenish aquamarine crystal, ~3 X 3 X 4 cm, from Minas Gerais, Brazil. Both ends have flat pinacoid faces, with complex modifications around the edge. *RJL3733*



Figure 22. Pale yellowish green beryl crystals ~2 cm tall, on a colorless quartz crystal, from Teófilo Otoni, Minas Gerais, Brazil. *RJL3984*



Figure 23. Pale, tabular morganite crystal, ~1 cm wide, with muscovite and feldspar, from Conselheiro Pena, Minas Gerais, Brazil. *RJL1288*

A somewhat unique type of pegmatite occurs near the town of Volodarsk-Volynski, Zhitomir Oblast, Ukraine, for which the term “Volynian chamber pegmatites” was coined. This deposit was known as early as 1850 or so, and was mined for industrial quartz from 1931 to 1995. Early on, it was recognized that these pegmatites could be a promising source of beryl. Perhaps the most distinctive feature

of these pegmatite swarms is their heroic scale, in which giant quartz crystals were mined in quantities up to 100 tons from chambers that ranged up to 5,000 m³ or more! For collectors, Volodarsk-Volynski is famous for the large, highly etched, gemmy heliodor crystals that appeared on the market in 1980 (Lyckberg, Chornousenko, and Wilson 2009; Lyckberg 2005).



Figure 24. Pale yellow-green thumb-nail-sized heliodor crystal from Volodarsk-Volynski, Ukraine, showing interesting etch features. *RJ/L1300*

Pakistan is famous for gem pegmatites, which have produced huge quantities of spectacular aquamarines and smaller numbers of morganites. Major locales lie mainly in the Skardu and Gilgit districts, Northern Areas (Hammer and Muhammad 2004; Blauwet 2004; Baluwet and Muhammad 2004). Locality information provided by dealers is often confusing and/or incomplete, for a variety of reasons; Blauwet, Smith, and Smith (2004) provide an extremely useful and extensive table of the mineral localities found in the Northern Areas, including alternate spellings, precise

locations, and geographic categories, to enable an interested collector to better interpret the limited information on a specimen label. As is typical of pegmatite occurrences, the beryl is usually associated with feldspar and mica; less common associates include apatite, columbite-tantalite, cassiterite, microlite, and tourmaline. In neighboring Afghanistan, aquamarine-bearing pegmatites are found in the Nuristan region. The provinces of Laghman and Kunar lie just west of the border with Pakistan's Northwest Frontier Province.



Figure 25. Water-clear aquamarine crystal ~18 mm tall, attached to a doubly-terminated quartz crystal, from Nyet-Bruk, Braldu Valley, Skardu district, Northern Areas, Pakistan. *RJL3983*



Figure 26. Prismatic pink morganite crystal, ~2 cm wide, associated with quartz, tourmaline, and mica, from the Gilgit district, Pakistan. *RJL2489*

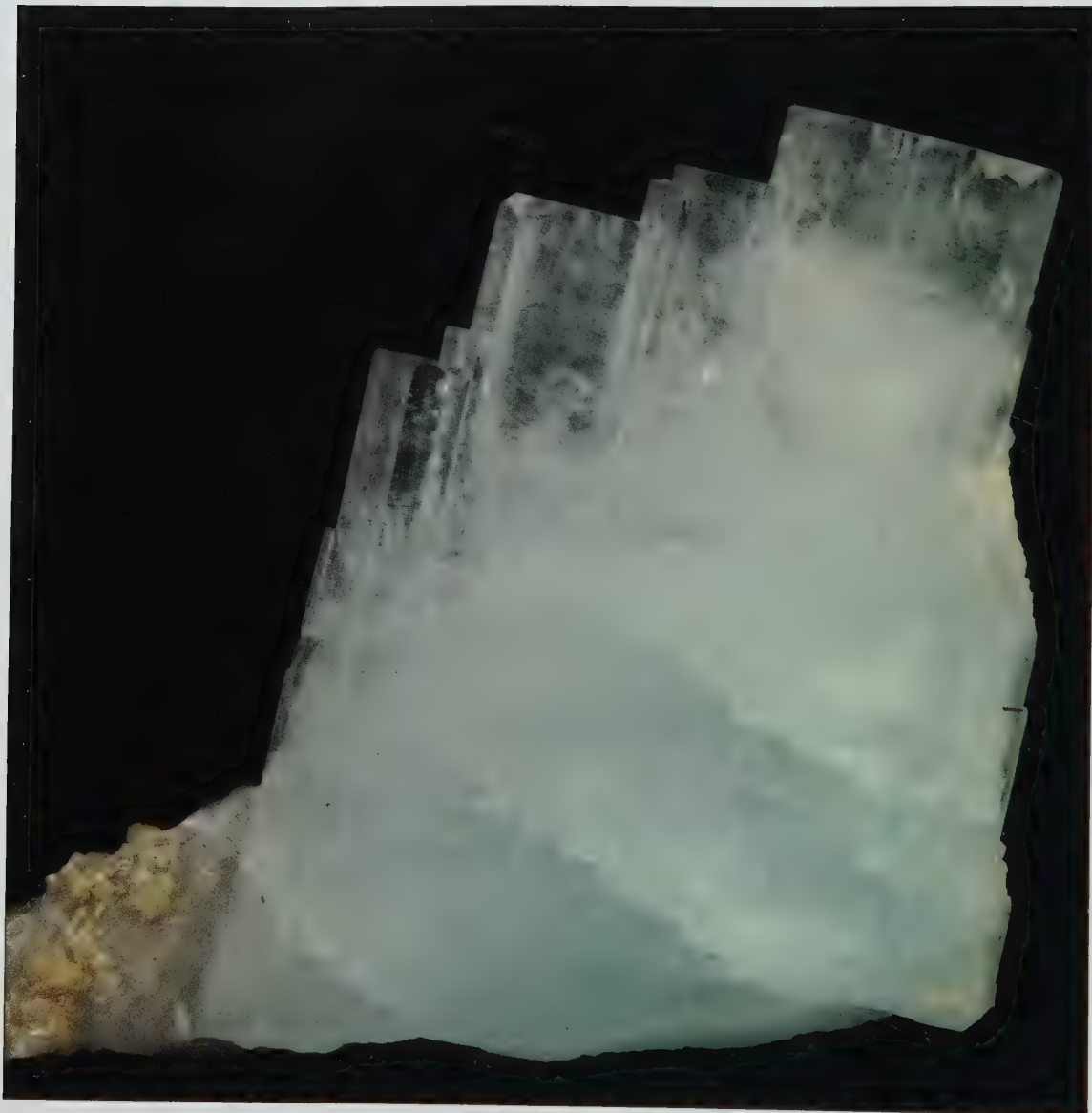


Figure 27. Tabular aquamarine crystal, $\sim 5 \times 6 \times 1$ cm, on feldspar, from the Shigar Valley, Northern Areas, Pakistan.
R/L4036



Figure 28. Aquamarine crystal ~8 cm tall, surrounded by large tabular muscovite crystals, from Laghman Province, Afghanistan. RJL/199

Emerald colored by vanadium is found in quartz and pegmatite veins cutting metamorphic rocks of Proterozoic age at Dyakou, Malipo Co., Yunnan Province, China. Some gem-grade emeralds are found in the pegmatites, but the crystals in the quartz veins are generally higher quality, as shown in the photos. The quartz and pegmatite veins have different directional trends and ages (Late Silurian and Late Cretaceous, respectively) but emerald mineralization probably took place in a single event in the late Cretaceous. CO₂-bearing saline brines (13-18% NaCl) followed the preexisting structural features, with Be and heat provided by granitic and pegmatitic intrusions. The estimated conditions (67-78 MPa, 325-372°C) are consistent with an igneous origin. Both types of veins contain similar mineral assemblages: abundant tourmaline, fluorite, and scheelite in variable amounts, along with quartz and sometimes feldspar (Zhang et al. 1999; Xue et al. 2010).



Figure 30. Slightly gemmy emerald crystal ~4 cm long, in massive quartz, from Dyakou, Yunnan, China. *RJL3739*



Figure 29. Opaque emerald crystals forming a group ~6 cm tall, in off-white feldspar, from a pegmatite vein at Dyakou, Yunnan, China. The emerald at Dyakou gets its green color from V rather than Cr. *RJL3738*

The rare mineral pezzottaite was described from the Sakavalana pegmatite, which is situated in the northern part of the Ampandramaika-Malikialina pegmatite district, a well known gem producing area in central Madagascar (Laurs et al. 2003). This pegmatite, hosted by impure marbles, is a so-called “mixed feature” granitic pegmatite, having some characteristics of both the LCT (Li-Cs-Ta) and NYF (Nb-Y-F) rare-element pegmatite families. The core zone of the pegmatite contains K-feldspar (green amazonite), zoned black/purple mica crystals, smoky quartz, and minor albite, zircon, danburite, and Nb-Ta oxides. The pezzottaite crystals were found in the core zone, in crystal-lined cavities and nearby vugs, suggesting that pezzottaite was a late-stage mineral.

Pegmatites in the Erongo Mountains, Namibia, were explored in the early 1900s and in some cases were mined economically, primarily for tin (cassiterite). Major discoveries of schorl, topaz, aquamarine, fluorite, and other minerals in the period from 1999-2000 and onward have made Erongo synonymous with spectacular crystal specimens (Cairncross and Bahmann 2006). “Classic” as-sociation pieces of well crystallized aquamarine and schorl are almost instantly recognizable and prized by collectors. Interestingly, the tin mineralizations were associated with pegmatites, whereas the best beryl and schorl tend to be found in miarolytic cavities in the Erongo Granite itself. In addition to aquamarine, green and colorless beryl is also found at Erongo, as well as beryl that is zoned and/or colored by various inclusions.



Figure 31. Bright red-orange pezzottaite crystal ~8 mm wide, from the Sakavalana pegmatite, Madagascar, showing a typical association with colorless albite and black tourmaline. *RJL3760*



Figure 32. Sharp blue aquamarine crystals to ~5 cm tall, with black schorl and white microcline, from the Erongo Mountains, Namibia. *RJL2849*



Figure 33. An interesting example of “aquador:” a cluster of beryl crystals ~2 cm tall, with pale aquamarine at the base and heliodor at the terminations, from the Erongo Mountains, Namibia. *RJL3919*

Figure 34. Colorless beryl with mud-like inclusions, associated with zoned (green to purple) fluorite crystals to ~1 cm, along with minor mica and schorl, from the Erongo Mountains, Namibia. *RJL3957*



Rhyolites are a less-common host for beryl, but deserve mention because the unusual, rich red beryl var. bixbite is found in rhyolite in the Wah Wah Mountains, Utah. Shigley, Thompson, and Keith (2003) provide an excellent review of the geology and genesis of the deposit. Topaz rhyolites, found in many places in the western United States and Mexico, are typically enriched in F and also contain such rare elements as Li, Rb, Cs, Be, U, and Th. The Thomas Range rhyolite lies near the Spore Mountain beryllium district, where the Be ore comprises disseminated fluorite and bertrandite $[\text{Be}_4\text{Si}_2\text{O}_7(\text{OH})_2]$ in water-deposited rhyolitic tuff. The presence of fluorite is important because the formation of soluble Be-F complexes aids the transport of Be in magmatic and hydrothermal systems. Volcanic activity ~23 My ago created small domes, intrusions, and lava flows, one of which is the rhyolite flow at Ruby Violet. The red beryl is typically concentrated along brown stained, clay-filled fractures in the rhyolite, and is interpreted to have formed where Be-F complexes in the hydrothermal fluids reacted with rhyolitic glass, feldspar, and bixbyite $[(\text{Mn},\text{Fe})_2\text{O}_3]$. This implies that the beryl would have formed at temperatures lower than the crystallization of rhyolite magma (650°C) but above those at which the clay alteration occurred (200–300°C).

Beryls in metamorphic rocks

Metamorphic beryl might or might not be associated with focused hydrothermal solutions that transport Be from a Be-rich source. For a purely metamorphic beryl to form without introduction of Be from outside the system, there must be preexisting Be-containing minerals such as phenakite, cordierite, feldspars, or micas that can release the Be as they break down. High F and OH^- activities will speed the diffusion of Be (Turner and Groat 2007). An example of metamorphic-hydrothermal formation is found in the emerald deposits of Zambia. There, emerald is formed in the metasomatic reaction zone where a Be-bearing pegmatite has intruded Cr-rich country rock such as metabasites. In the metasomatic zone, or “blackwall,” beryl and phlogopite are produced by fluids transporting Be, Si, and K from the pegmatite to react with the ultramafic rock, which provides Cr, Fe, and Mg. A possible example of purely metamorphic beryl is seen at the Habachtal emerald deposit in the Austrian Alps. There, beryl has presumably formed at the expense of earlier phenakite, Be_2SiO_4 (Turner and Groat 2007).

Metamorphic and metamorphic-hydrothermal deposits that have produced significant amounts of beryl include the following:



Figure 35. Red beryl crystal ~3 mm long on white altered rhyolite, from the Wah Wah Mountains, Utah. R/L216

The world-renowned emerald deposits of Columbia are an unusual case, in which the mineralization wasn't related to pegmatites or magmatic fluids, but instead is attributed to hydrothermal growth during tectonic movements. The host rocks are black shale-limestone, altered by Na-Ca metasomatism. The source of hydrothermal activity began with dissolution of evaporite (salt) beds that were interbedded with the black shale at a depth of at least 7 km and exposed to circulating water at 250°C or higher. This fluid drove the metasomatic alteration of the black shale, at the same time leaching Be, Cr, and V. Emerald precipitated in pockets, breccias, and extensional carbonate-silicate-pyrite veins. Zwaan (2006) and Groat et al. (2007) provide detailed reviews of the geochemical model, which has some interesting similarities to Mississippi Valley-type Pb-Zn deposits.



Figure 36. Thumbnail-sized specimen from the Chivor mine, Colombia, with pyrite crystals to ~8 mm on small but gemmy emerald crystals, with colorless quartz. RJL3799

The emerald deposit at Habachtal, Salzburg, Austria, has been known since ancient times and provides an interesting case study on whether or not emeralds can form via purely regional metamorphic processes, i.e., without contact metamorphism (Groat et al. 2007). The host rocks comprise metapelitic and metavolcanic rocks

containing interlayered serpentinite, near the contact with the Zentralgneiss (a Carboniferous or Permian granitoid mass that intruded Paleozoic sediments and metavolcanics). Emerald formed in metasomatic biotite schist or “blackwall” zones that developed between the host rocks during regional metamorphism. The Be concentration in the metapelites and metavolcanics, ~36 ppm, is postulated to have originated in submarine volcanic exhalations (Grundman and Morteani 1989), and their argument for regional metamorphism as the mechanism of emerald formation is based on several pieces of evidence: 1. the country rocks have “augen” textures, indicating high-grade regional metamorphism; 2. the emerald is strongly zoned with sigmoidal inclusion trails, indicating several stages of growth under deformation; 3. no evidence of contact mineralization; 4. relative abundances of certain REE suggest that nonpegmatitic fluids were abundant. The counter-argument (Zwaan 2006) notes that although no obvious pegmatitic source of Be is close by, fluids can travel great distances from a (possibly hidden) pegmatite, particularly along rocks that have undergone extensive shear. Furthermore, some pegmatite does occur in the Zentralgneiss, and the Cs content of the emerald (up to 760 ppm) suggests a pegmatitic source. Lastly, sulfide deposits associated with submarine volcanic exhalations aren't typically Be-enriched.



Figure 37. Beryl crystals to ~1 cm long, in mica schist, from Habachtal, Salzburg, Austria. In this sample, from an old German collection, most of the crystals are a muddy grayish yellow, but a few smaller crystals are more bluish. RJL3711

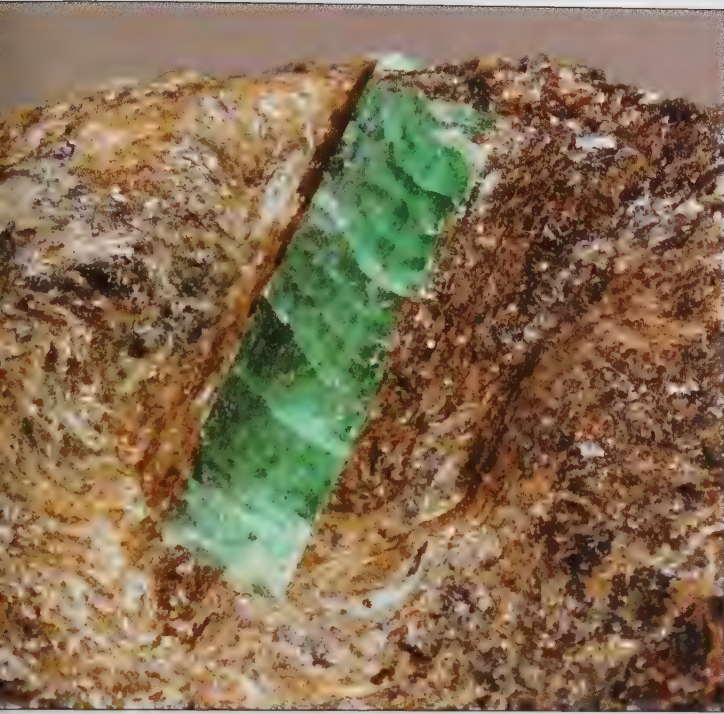


Figure 38. Emerald crystal ~15 mm long, in mica schist, from Habachtal, Salzburg, Austria. RJL3150

The Izumrudnye Kopi emerald district in the Ural Mountains, Russia, was “discovered” in 1831, although some emeralds were attributed to this general area in ancient times. After its discovery, mining in the district developed quickly so that by 1918 the Malyshevo mine was the largest emerald producer in the world. Twenty-five separate emerald deposits have been identified in the area, which covers ~50 km²; active mines include Malyshevo (also called Mariinskoe), Sverdlov, Cheremshansk, and Krasnobolotny (Groat et al. 2007; Grundman and Giuliani 2002). The geology of these deposits is extremely complex; 250 minerals have been identified, and in addition to emerald, the rare *alexandrite* variety of chrysoberyl is also found in fine, gemmy crystals. As described in great detail by Zhernakov (2009), the ore bodies at Malyshevo consist of *glimmerite* (phlogopite-rich mica schist) and emerald-bearing quartz-plagioclase veins. The glimmerite bodies are metasomatically altered units, primarily serpentinite, cut through by the quartz-plagioclase veins. Each glimmerite body consists of a vein typically 10–20 cm (but sometimes 2–3 m) thick and generally 30–50 m (but up to ~100 m) long. Within the glimmerite veins, the main minerals are phlogopite,

chlorite, actinolite, biotite, muscovite, plagioclase, beryl, and tourmaline.

Zambia is the world’s second-largest producer of emeralds. The first reports of beryl in the Kafubu area in 1928 were followed by small exploration projects over the next four decades. The district became a major producer in the 1970s and today large-scale mining is carried out by open pit methods at the Kagem, Grizzly, Chantete, and Kamakanga properties. Mining is primarily directed to the production of gem rough (Zwann et al. 2005), but the operators of the Kagem property have recently begun to devote some attention to the recovery of “specimen” materials for the mineral collector as well, and the results have been impressive (Behling and Wilson 2010; Cook 2010). The origin of the emerald deposit dates from the late stages of the Pan-African orogeny, when rare-element pegmatites and Be-rich granites intruded Cr-rich metabasalts. The Kafubu field of Be-bearing pegmatites and hydrothermal veins extends for about 20 km, overlapping the metabasalts in many places, creating a potentially large area with emerald potential. The age of the pegmatites, inferred from K-Ar dating of muscovite, is around 447–452 Ma. Emerald mineralization is attributed to metasomatic alteration of the Cr-rich country rock by Be-rich fluids from the hydrothermal veins. The emeralds are mostly found in the phlogopite reaction zones (typically 0.5–3 m wide) that lie between quartz-tourmaline veins and the metabasite (Zwaan et al. 2005).



Figure 39. Jade-green to emerald-green hexagonal emerald crystals, mostly opaque but with some transparent areas, on glimmerite from Malyshevo, Ural Mountains, Russia. RJL1594



Figure 40. Gemmy emerald crystal ~25 mm tall, in glimmerite from the Sverdlov mine, Ural Mountains, Russia.
R/L1458

Emerald deposits on the southern slope of the Mweza Range, Zimbabwe, are at least as important as those of Zambia. The Sandawana mine (originally called the Zeus mine) began as an open pit but now is worked underground in shafts and drifts as deep as 150 m, with an estimated 40 km of underground workings. The average size of cut stone from Sandawana is fairly small, but their color is highly regarded (Kanis and Schwarz 2002). The deposit is interpreted to have formed when pegmatite intruded the Mweza greenstone before or during a large deformation event. Then, a Na-rich solution that contained Li, Be, Cr, F, and P entered along shear zones, albitizing the pegmatite and forming phlogopite in the wall rock. The formation of emerald, Cr-rich ilmenorutile, fluorapatite, and holmquistite suggests that Li, Be, F, Na, P, K, Rb, Cs, Nb, and Ta were enriched in the shear zones. Emerald formation was thus likely related to K-Na metasomatism, in which such minerals as emerald, fluorapatite, albite, actinolite, and phlogopite crystallized at the expense of earlier quartz, microcline, oligoclase, and chlorite. Saline brine inclusions in some of the emerald crystals suggest that hydrothermal fluids rich in Na and F were involved. Estimated crystallization conditions are 560-650°C and 2.3-3 kbar (Zwaan 2006).

Indialite was originally found in a pyrometamorphic formation at the Bokaro coalfield, India (Miyashiro and Iiyama 1954). The matrix material, called paralava, is an interesting type of high temperature metamorphic rock formed when coal beds undergo spontaneous combustion. Because the process is going on close enough to the surface for air to get in and support combustion, the

metamorphism involves only temperature and not the application of pressure. A burning coal seam can produce very high temperatures (1000-1300°C), which are more than sufficient to fuse adjacent sedimentary rocks into a clinker or lava-like material that usually contains some glass and various high-temperature silicate phases.

Alteration and pseudomorphs

The most common alteration product of beryl is kaolinite. Kerr (1946) studied an interesting pseudomorph from Brazil, in which a large hexagonal crystal, ~15 cm long X 10 cm thick, was partially replaced by yellow to off-white kaolinite. Bulk analysis showed the pseudomorph to be 28.3% clay (mostly kaolinite) and 71.7% beryl, with traces of muscovite and small quartz grains. The crystal had been collected at a pegmatite in which the feldspar is extensively kaolinized; the alteration was attributed to weathering, but hydrothermal activity could not be conclusively ruled out.

Černý (1963) reported the replacement of beryl by chalky epididymite, $\text{NaBeSi}_3\text{O}_7(\text{OH})$, in a pegmatite near Vežná, Czech Republic. The alteration was attributed to Na-rich late hydrothermal solutions; some of the epididymite directly replaced the beryl and some crystallized in nearby cavities and fissures in the surrounding feldspar. The formation of milarite, $\text{K}_2\text{Ca}_4\text{Al}_2\text{Be}_4\text{Si}_{24}\text{O}_{60}\cdot\text{H}_2\text{O}$, represented the second product of alteration.

Beryl is also known to decompose to bertrandite, phenakite, euclase, bityite, and bavenite.

The Minerals

Bazzite

Bazzite, the scandium analog of beryl, was described by Artini (1915), based on material from miaroles of the Baveno granite, Italy; at the time it was only the second known scandium mineral. Artini provided no chemical analysis, describing the mineral simply as a “scandium silicate.” X-ray diffraction and semiquantitative spectroscopic analysis of bazzite from Graubünden, Switzerland, by Huttenlocher, Hügi, and Nowacki, published in 1954, determined that bazzite contains Be and it has the beryl structure. In reviewing these results, Fleischer (1955) commented, “Bazzite, which has never been analyzed chemically, was originally described as a scandium silicate, the beryllium content having been missed. The close correspondence of the unit cell, hardness, specific gravity, and composition makes it seem likely that bazzite is a scandian beryl.” At that time, it was still not clear whether bazzite was a scandian *variety* of beryl or the scandian *analog* of beryl. Quantitative analysis by Nowacki and Phan (1964) on Swiss material, and by Chistyakova, Moleva, and Razmanova (1966) on material from Central Kazakhstan, confirmed that bazzite is a valid species with Sc dominant at the **B** site (which is occupied by Al in beryl).

Fron del and Ito (1968) noted that the type specimen contained significant Al, equivalent to $\sim(\text{Sc}_{.67}\text{Al}_{.33})$, and conducted a series of experiments in which they were able to synthesize “pure” $\text{Be}_3\text{Sc}_2\text{Si}_6\text{O}_{18}$, as well as crystals with various dopants such as Cr^{3+} , Fe^{3+} , V^{3+} , and Mn^{3+} on the **B** site.

Bazzite is found not only in granites and granite pegmatites, but also in Alpine cleft-type deposits, and chemical differences are seen in the two parageneses. Bazzite from Alpine clefts tends to contain significant quantities of Mg, whereas bazzite from granitic pegmatites has less Mg but significant amounts of Cs (located in the structural channels). Some authors have suggested that there is some substitution of Be for Si in the silicate rings, but a rigorous structural refinement using bazzite from miarolytic granite at the type locale and bazzite from a pegmatite at Tørdal, Norway, failed to confirm any Be \leftrightarrow Si substitution (Demartin, Gramaccioli, and Pilanti 2000).

Bazzite typically forms small hexagonal prismatic crystals in various shades of blue. Commonly associated minerals include quartz, albite, orthoclase, muscovite, and laumontite in miarolytic granite; in Alpine cleft-type deposits the associates are quartz, calcite, hematite, fluorite, albite, and chlorite.

The mineral has since been recognized at about three dozen locales worldwide; it is possible that careful studies will confirm more localities, because without microanalysis, the mineral is very difficult to distinguish from ordinary blue beryl. Some reported locales include: Baveno, Piedmont, Italy (TL); Val Strem, Graubünden, Switzerland; Heiligenblut, Carinthia, Austria; Heftetjern, Tørdal, Norway; Mt. Antero, Colorado; and the Kentsk massif, Central Kazakhstan.

A Cs-rich variety of bazzite was described by Gramaccioli et al. (2000) from miarolytic cavities in the granophyre of Cuasso al Monte, Varese, Italy; examination of this material, along with re-examination of the Baveno material,

showed as much as 2.3 wt.% Cs_2O . Examination of bazzite from Heftetjern, Norway (Juve and Bergstøl 1990) indicated 2.93 wt.% Cs_2O .



Figure 41. Minute, pale blue hexagonal crystals of bazzite, with purple fluorite, from the Kentsk granitic massif, Central Kazakhstan. *RJL1292*

Beryl

Beryl has been known for several thousand years and consequently, there is no actual “type locality.” It has been found at thousands of locales worldwide, and the following sampling of beryl occurrences, organized by color, makes no attempt to be complete or comprehensive. Extensive locality listings can be found in various reference books and internet resources. As discussed in the previous chapter, excellent crystals and gems can be found in both igneous and metamorphic environments.

Common beryl, which is opaque and typically white to greenish, is found in many pegmatites. Giant crystals of common beryl have been reported from: Bob Ingersoll No. 1 mine, Keystone, South Dakota; Bumpus quarry, Maine; Assunção quarry, Portugal; and the Malakialina district, Madagascar.



Figure 42. Cluster of dark green, opaque emerald crystals ~4 cm tall, from Malyshevo, Middle Urals, Russia. *RJL3798*



Figure 43. Dull green, hexagonal, thumbnail-sized emerald from Karoi, Zimbabwe. *RJL2635*

Emerald is found in both pegmatites and metamorphic/metasomatic deposits. Some notable localities include the Chivor and Muzo mines, Colombia; the Sverdlovsk district, Middle Urals, Russia; the Sandawana district, Zimbabwe; the Kafubu district, Zambia; Mingora and elsewhere in the Swat district, Pakistan; Habachtal, Salzburg, Austria; Pizzo Marcio, Italy; in China at Dyakou, Yunnan Province, and near Dabdar, Xinjiang Province (Blauwet, Quinn, and Muhlmeister 2005); in Brazil at Brumado and Anagé, Bahia, and at Belmont and Capoeirana, Minas Gerais. The most noteworthy U. S. locale for emerald is the Rist mine and other sites near Hiddenite, North Carolina (Wise and Anderson 2006).



Figure 44. Hexagonal emerald crystal, ~2.5 cm long, from Mingora, Swat, Pakistan. *RJL2210*

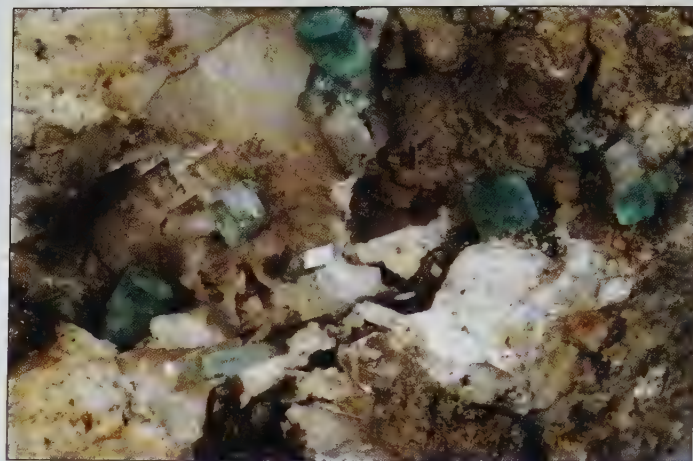


Figure 45. Gemmy emerald crystals to ~1 cm long, scattered on pegmatite from an unspecified locale in Pakistan. *RJL2403*

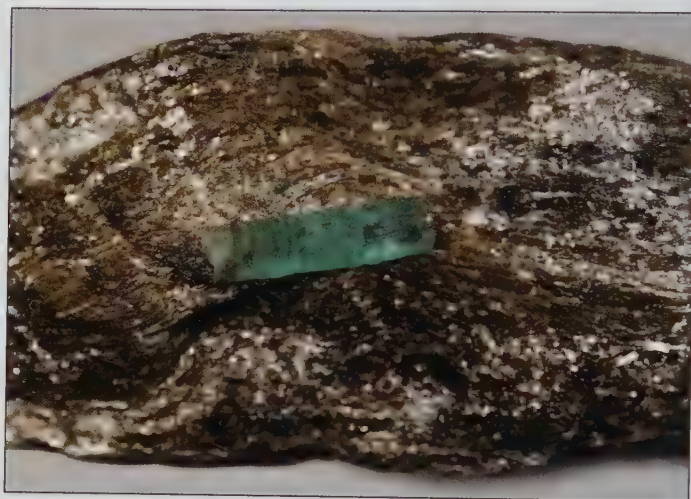


Figure 46. Small emerald in schist from the classic locale at Habachtal, Salzburg, Austria. *RJL1256*

Figure 47. Crude, translucent emerald, ~1 cm long, on a chlorite-rich matrix from Pizzo Marcio, Italy. *RJL710*

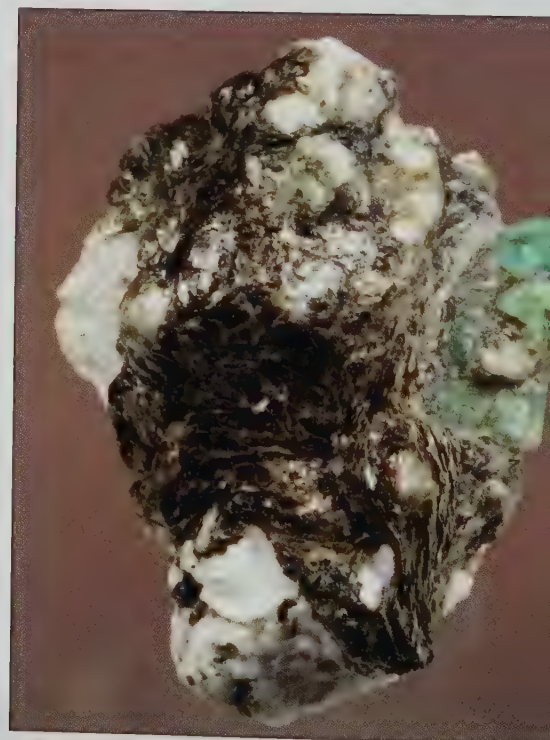




Figure 48. Opaque emerald crystal, ~2 X 4 cm, with massive gray quartz and biotite from Bahia, Brazil. RJL3913



Figure 49. Very pale blue-green, thumb-nail-sized beryl from the Adams mine, Hiddenite, North Carolina, showing some interesting etching. *RJL4045*

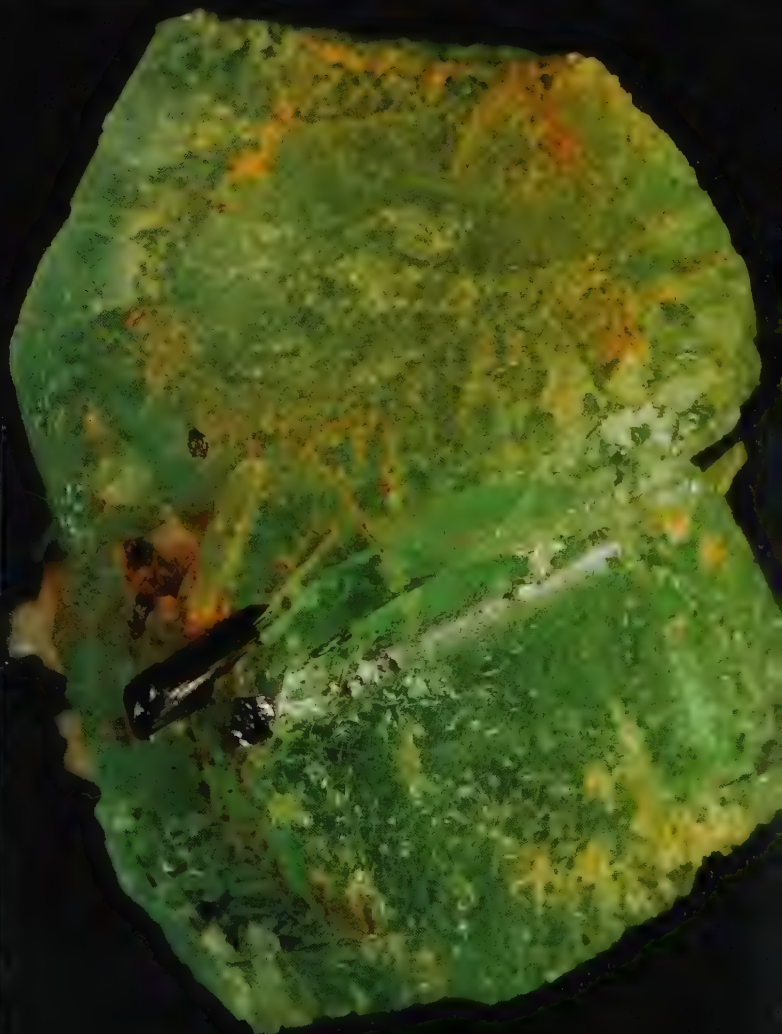


Figure 50. Small, crude emerald crystal, ~1 cm across, pierced by several thin, prismatic rutile crystals, from North American Emerald Mines, Hiddenite, North Carolina. *RJL3422*

Aquamarine is nearly always found in granitic pegmatites. Some notable occurrences include: the Erongo Mountains, Namibia; numerous pegmatites in Pakistan and in Laghman Province, Afghanistan; the Oriental pegmatite province in Brazil; and Xuebaoding Mountain, near Pingwu Co., Sichuan Province, China. Aquamarine is also found in a number of pegmatites in the northeast U. S., including: Stoneham, Maine; Songo Pond, Albany, Maine; and the Rice, Palermo, and Tripp mines, New Hampshire. The classic locale at Mount Antero, Chaffee Co., Colorado, has been known since 1885 and continues to produce fine aquamarines to the present time (Jacobson 2005).



Figure 51. Aquamarine crystal ~2 cm tall, in pegmatite from the Erongo Mountains, Namibia. The black tourmaline crystals could be schorl or foitite; the termination on the largest crystal is the type seen on some foitites. *RJL3972*

Figure 53. A cluster of very pale, 3-cm aquamarine crystals with interesting zoning of color and transparency, from Baha, Braldu Valley, Baltistan, Northern Areas, Pakistan. *RJL4034*



Figure 52. A thumbnail-sized aquamarine with equant schorl crystals, from the Erongo Mountains, Namibia. *RJL2463*

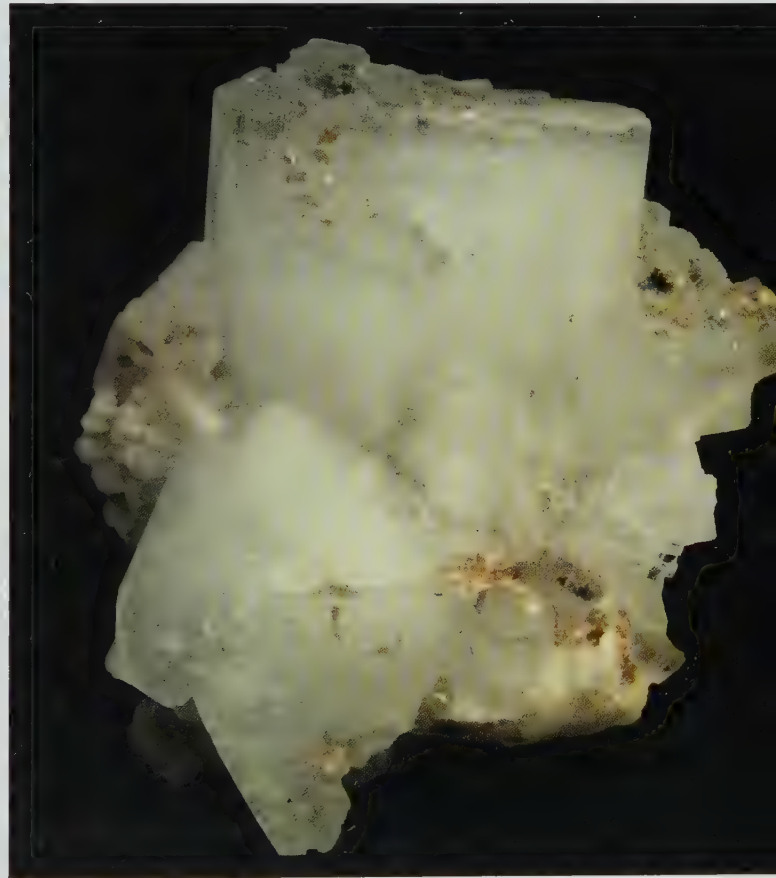




Figure 54. Aquamarine crystals to $\sim 4 \times 4$ cm, with very striking color zoning, from Raikot, Chilas, Diamer district, Northern Areas, Pakistan. RJL4035



Figure 55. Prismatic aquamarine crystal ~ 4 cm tall with a transparent, cavernous termination, associated with microcline and quartz (with schorl inclusions), from Baha, Braldu Valley, Baltistan, Northern Areas, Pakistan. RJL3794



Figure 56. Very dark blue aquamarine crystals in parallel growth, creating a complex, stepped termination, from Apaligun, Braldu Valley, Baltistan, Northern Areas, Pakistan. RJL4038



Figure 57. Prismatic aquamarine crystal ~ 3 cm long \times 7 mm thick, with interesting color zoning: mostly aquamarine, but emerald-green at the termination. Specimen is from Doko, Basha Valley, Baltistan, Northern Areas, Pakistan. RJL4039



Figure 58. Intense blue aquamarine crystal ~6 X 9 X 1 cm thick, with complex growth/etch features, from Teston, Braldu Valley, Baltistan, Northern Areas, Pakistan. RJL3953



Figure 59. Dark blue aquamarine crystal ~4 cm tall, with a habit consisting of a bundle of needles, with quartz and feldspar, from Gilgit, Pakistan. *RJL3915*



Figure 60. Pale blue to nearly colorless beryl crystals in a divergent group, from Raikot, Chilas, Diamer district, Northern Areas, Pakistan. *RJL3845*

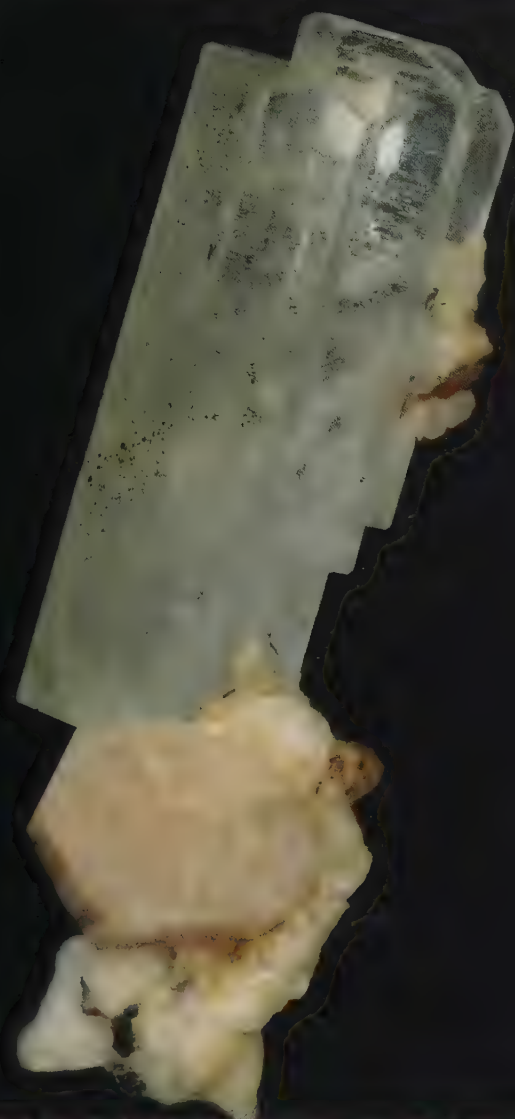


Figure 61. Pale aquamarine crystals in parallel growth, ~3.5 cm tall, with pink apatite crystal, ~1 cm across, and minor feldspar, from Shigar, Northern Areas, Pakistan. The apatite is fluorescent bright yellow in SW UV. *RJL4046*



Figure 62. Prismatic aquamarine crystal ~1 X 3 cm, associated with albite and a complex, 1-cm cassiterite crystal, from Yuno, Shigar Valley, Baltistan, Northern Areas, Pakistan. *RJL4031*



Figure 63. Transparent, very pale blue beryl crystal, with a brown manganotantalite crystal, ~5 mm tall, on its termination. Specimen is from Darrah Pech, Kunar Province, Afghanistan.
RJL4030



Figure 64. A large hexagonal aquamarine crystal, ~3 X 6 X 3 cm thick, in white pegmatitic matrix, from Pech, Laghman Province, Afghanistan. Center of crystal is colorless to very pale pink. *RJL4000*



Figure 65. Nearly opaque greenish beryl crystals with mica and feldspar, from Nuristan, Laghman Province, Afghanistan. Black tabular crystals to ~8 mm long are ~50:50 ferrocolumbite-ferrotantalite. *RJL4040*



Figure 66. Interesting prismatic beryl crystals showing variations of surface texture on the different faces, with small blue-green tourmalines and thick silvery muscovite, from Laghman Province, Afghanistan. RJL3814



Figure 67. Aquamarine crystal ~25 mm tall, with a 6-mm spessartine crystal attached, from Badakhshan, Afghanistan. *RJL3796*



Figure 68. Aquamarine crystal ~5 cm tall, from Galileia, Minas Gerais, Brazil. RJL/571



Figure 69. Tabular beryl crystal ~2 cm long, with a smaller beryl at base and an orange, 15-mm, octahedral scheelite crystal, from Pingwu, Sichuan Province, China. RJL3797



Figure 70. Sharp, pale blue tabular aquamarine crystals to ~25 mm across, on muscovite and albite, from Sichuan Province, China. *RjL2412*



Figure 71. Tabular, glassy, pale blue beryl crystals on a bit of pegmatite, from Bao Feng Wu mine, Sichuan Province, China. *RJL2269*



Figure 72. A sampling of aquamarine crystals, 1-3 cm long, ranging from blue to nearly colorless, from Mount Antero, Chaffee Co., Colorado. *RJL4029*



Figure 73. Prismatic beryl crystal, ~6 cm tall, from Songea, Tanzania.
RJL3914

Heliodor was known simply as yellow beryl for hundreds of years before the name heliodor was first applied to material from the Rössing pegmatites, near Klein Spitzkoppje, Namibia, in 1910 (Wise 2005). Fine crystals are found in the Alabashka pegmatite field, Urals, Russia, and in pegmatites at Volodarsk-Volynski, Ukraine. Other locales for gem-quality heliodor include the Slocum quarry, East Hampton, Connecticut; Luumäki, Finland; Ikalamovony, Madagascar; and Serra da Mesa, Minacu, Brazil.



Figure 75. Golden-orange, slightly corroded heliodor crystal, ~4 cm tall, from Fianarantsoa, Madagascar. RJL2464



Figure 74. Yellow beryl crystal ~2 cm tall, from the Slocum quarry, East Hampton, Connecticut. RJL3692



Figure 76. Simple prismatic beryl crystal, ~25 mm thick X 9 cm tall, from Sherlovaya Gora, Chita Oblast, Siberia, Russia. The color tends toward heliodor but is also influenced by yellowish streaks of impurities filling growth channels. RJL3693

Special mention must be made of the large “heliodor” crystals that have appeared on the market off and on since the early 1990s. They are typically purported to come from a locale in the Pamir Mountains of Tajikistan (sometimes referred to as Zelatnaya Vada, Rangkul, Tajikistan) (Belakovskiy 2005) although other examples have been attributed to Yaseen, Pakistan. It is the author’s opinion that these specimens are almost certainly not natural, but instead represent aquamarine crystals that have been irradiated and/or heat treated. Anecdotal reports include that of a

dealer who recognized a particular piece as a large aquamarine that he had sold to someone in the past, which was now returning to life as a heliodor. Other examples include pieces with certain associated minerals that clearly point to well-known aquamarine locales, such as Nagar, Pakistan; eventually, tabular “heliodor” crystals on muscovite began appearing that look suspiciously like tabular aquamarines from China. Lastly, there has never been a credible report of anyone actually seeing the purported site in Tajikistan with “heliodor” crystals *in situ*.



Figure 77. Prismatic “heliodor” crystal, ~5 cm long, with muscovite, purportedly from the Pamirs, Tajikistan. The crystal contains wispy, dark inclusions strikingly similar to those in some aquamarine crystals from the Shigar Valley, Pakistan (see Figures 89 and 91 below). RJL2250



Figure 78. A fine specimen of “heliodor” crystals to 3 cm tall, with muscovite, purportedly from Yaseen, Pakistan. Specimen is likely an aquamarine that has been treated. RJL2810

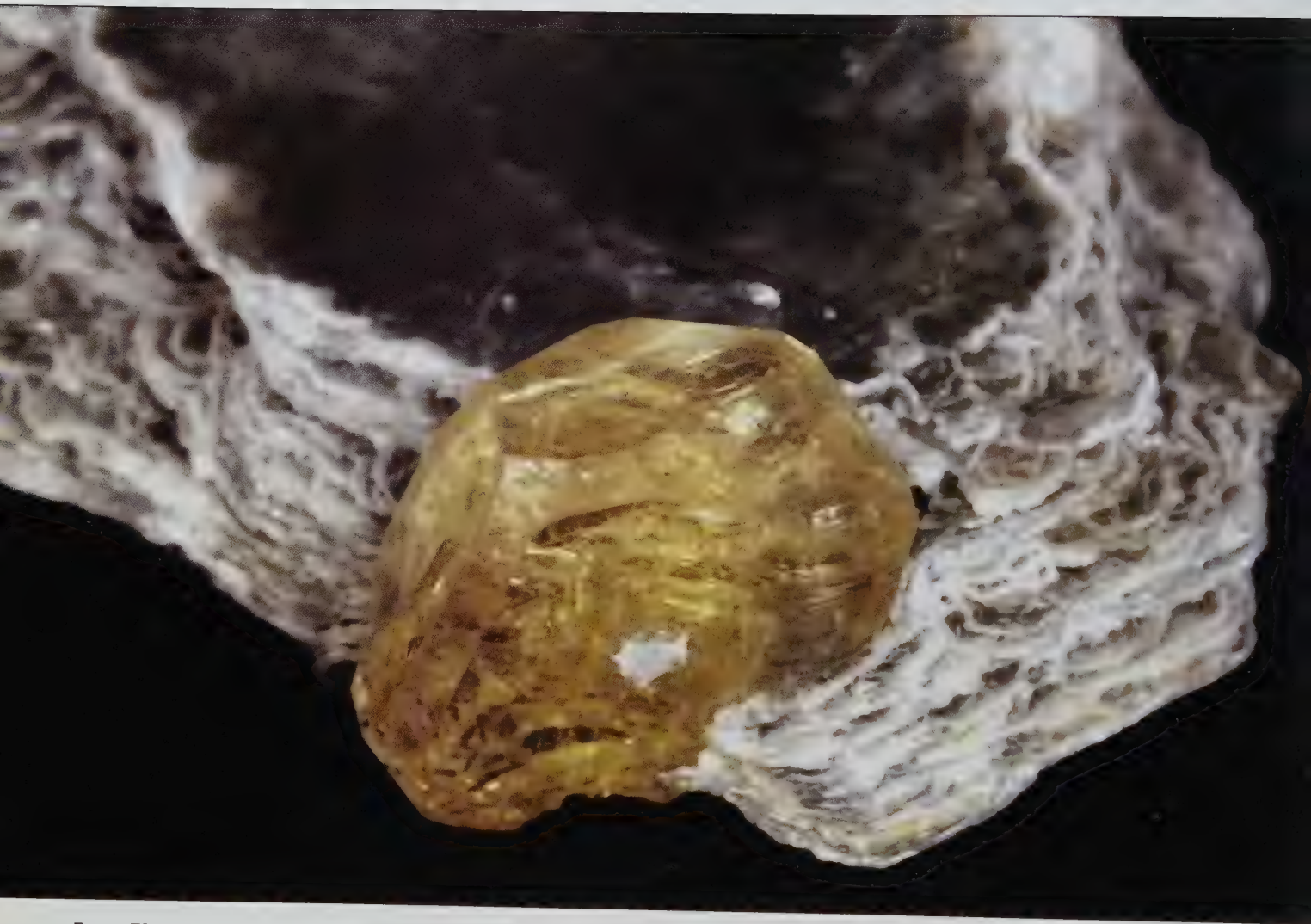


Figure 79. An even more dubious example: here, a tabular "heliodor" crystal, 2 cm wide, purportedly from Zelatnaya Vada mine, Rangul, Tajikistan, has the habit typically seen in colorless to pale aquamarine crystals from Bao Feng Wu, China (compare this crystal to that in Figure 71 above). RJL2488

Morganite, the pink variety of beryl, which often contains some Cs, is typically found in pegmatites. Some important locales are: the Bennett quarry, Maine; several pegmatites in San Diego and Riverside Counties, California; Laghman, Nuristan, Afghanistan; and Grotta d'Oggi and elsewhere on the Island of Elba, Italy.



Figure 80. A large, tabular morganite crystal, ~5 X 7 X 2 cm, from Laghman, Nuristan, Afghanistan, containing a movable bubble in a fluid-filled cavity, visible near the left edge. *RJL3793*



Figure 81. Small, translucent pink morganite crystal, ~6 X 10 mm, in pegmatite from an unspecified locale in Afghanistan. *RJL558*



Figure 82. A large beryl, $\sim 4 \times 7$ cm, from Baha, Braldu Valley, Northern Areas, Pakistan, with unusual color zoning: mostly pink but grading to aquamarine at the ends. *RJL4037*



Figure 83. A classic example of pink beryl with black tourmaline, smoky quartz, and feldspar crystals, in pegmatite from Grotta d'Oggi, Elba. This specimen came from a pre-1900 Swiss collection. Pink beryl from Elba was originally given the varietal name *rosterite*, but over time the varietal name *morganite* has come to be used generally for all pink beryl (Pezzotta 2005). RJL2251

Goshenite, or colorless beryl, was named for the occurrence at Goshen, Massachusetts (Kunz 1892). At some locales that are more commonly noted for aquamarine, such as the pegmatites of Pakistan, Namibia, and China, extremely pale to colorless beryl crystals are sometimes found as well.



Figure 84. Heavily etched, colorless beryl crystal, ~3 X 3 cm, on white feldspar, from Chhamachu, Gilgit-Skardu Road, Northern Areas, Pakistan. RJL4032



Figure 85. Colorless prismatic beryl crystals, ~15 mm long, associated with white quartz crystals, from the Erongo Mountains, Namibia. *RJL3694*



Figure 86. Somewhat tabular goshenite crystal, from Bao Feng Wu mine, Sichuan, China, so clear that it is nearly invisible against a plate of silvery muscovite crystals. *RJL1660*

Bixbite, the deep red variety, has thus far only been found at two neighboring locales in Utah: in the Thomas Range, and at the Ruby Violet mine in the Wah Wah Mountains (Nassau and Wood 1968; Shigley, Thompson, and Keith 2003).

Schaller, Stevens, and James (1962) described a bluish beryl from a pegmatite in Mohave Co., Arizona, which had an unusually high refractive index (1.610) and specific gravity (2.921). The material was significantly deficient in Si and Al, and high in Cs, Mg, and Fe^{2+} . The unusual composition presumably reflected the relatively high Mg and Fe content of the pegmatite fluid, which was attributed to partial digestion of the surrounding mafic rocks.

Fron del (1970) described a Sc-rich variety of beryl from rhyolite in the Thomas Range, Utah, which contained about 0.5 wt.% Sc_2O_3 . The bulk composition of the Thomas Range rhyolite is about 4.22 ppm Sc_2O_3 , leading Fron del to conclude that, "it is evident that some Sc was flushed out during consolidation of the rhyolite and was concentrated in crystallochemically favorable host minerals during the pneumatolytic stage. This is analogous to the well known concentration of Sc in particular host minerals, among them wolframite, cassiterite, micas, beryl, and various yttrium and zirconium minerals, in the hydrothermal veins, greisens, and pegmatites derived from deeper seated granitic intrusives."



Figure 87. Two crystals of red beryl, ~6 X 8 and 5 X 10 mm, from the Wah Wah Mountains, Utah. RJL4041, 4042

Inclusions in Beryl

Beryl crystals often contain various types of inclusions. These are of particular interest to the gemologist for three reasons: First, inclusions tend to be undesirable in transparent gems such as emerald and aquamarine. Second, inclusions may be desirable in translucent gems if they can be exploited to create attractive cat's-eye stones. Third, inclusions are extremely useful as a tool to recognize a synthetic gemstone and/or to make an educated guess as to the source of a natural stone (Rogers and Sperison 1942; Flanigen et al. 1967; Lahti and Kinnunen 1993).

Inclusions are also crucial to the work of the geochemist because they provide a snapshot of the growth conditions that existed when an inclusion became “frozen” into the crystal. Fluid inclusions are particularly useful in this respect (Zacharias et al. 2005; Gavrilenko et al. 2006; Xue et al. 2010) as they might contain water, CO_2 , traces of gases such as nitrogen or methane, dissolved salts such as NaCl or CaCl_2 , and minute crystals of halite or other minerals. Most fluid inclusions contain small bubbles, which in most cases formed on cooling; in other words, when a crystal first forms, the internal cavity is completely filled with liquid, and as the rock proceeds to cool, the liquid contracts, leaving behind a partial vacuum that looks like an air bubble. Often, the sample can be carefully re-heated while observing the bubble in a microscope. The bubble will disappear when the sample reaches the original crystallization temperature because the fluid will have expanded to fill the entire cavity. This “homogenization temperature” can also be used to study inclusions in which some or all of the liquid is actually liquid CO_2 at high pressure. Further, when the liquid contains tiny salt crystals, the temperature at which these crystals dissolve provides a measure of the salinity of the original fluid (Zacharias et al. 2005).

Solid inclusions are also of great interest because they provide more information on the conditions under which the beryl formed, and the order in which the various minerals crystallized. Zwaan (2006) provides a number of examples of mineral inclusions in emeralds from the Sandawana deposit, Zimbabwe; they include fibrous to prismatic amphiboles (actinolite and cummingtonite) tabular albite, brownish green apatite, phlogopite, and possibly zircon. The special case of inclusions in trapiche emeralds was discussed in the Introduction.



Figure 88. Transverse slice of a small Colombian trapiche emerald crystal, clearly showing the transparent central core surrounded by six radial “arms” separated by darker areas containing carbonaceous inclusions. Specimen is ~6 X 8 mm. RJL2391



Figure 89. Sharp, water-clear aquamarine crystal, ~6 cm tall, richly included by feathery brown tufts of an unknown mineral, from the Shigar Valley, Northern Areas, Pakistan. *RJL3831*



Figure 90. Another interesting example of inclusions in a beryl from Shigar Valley: here, the top half of an aquamarine crystal, ~5 cm tall, is virtually transparent; the bottom half contains tiny brown microlite crystals along with numerous fluid-filled cavities containing tiny bubbles. *RJL3795*



Figure 91. A sharp, thumbnail-sized, pale greenish beryl from Shigar Valley, containing dark tourmaline needles. *RJL3956*



Figure 92. Two equant beryl crystals from Darrah Pech, Kunar Province, Afghanistan, with an odd, dull greenish color; the crystals are somewhat murky because of finely divided inclusions of an unknown composition. *RJL3955*

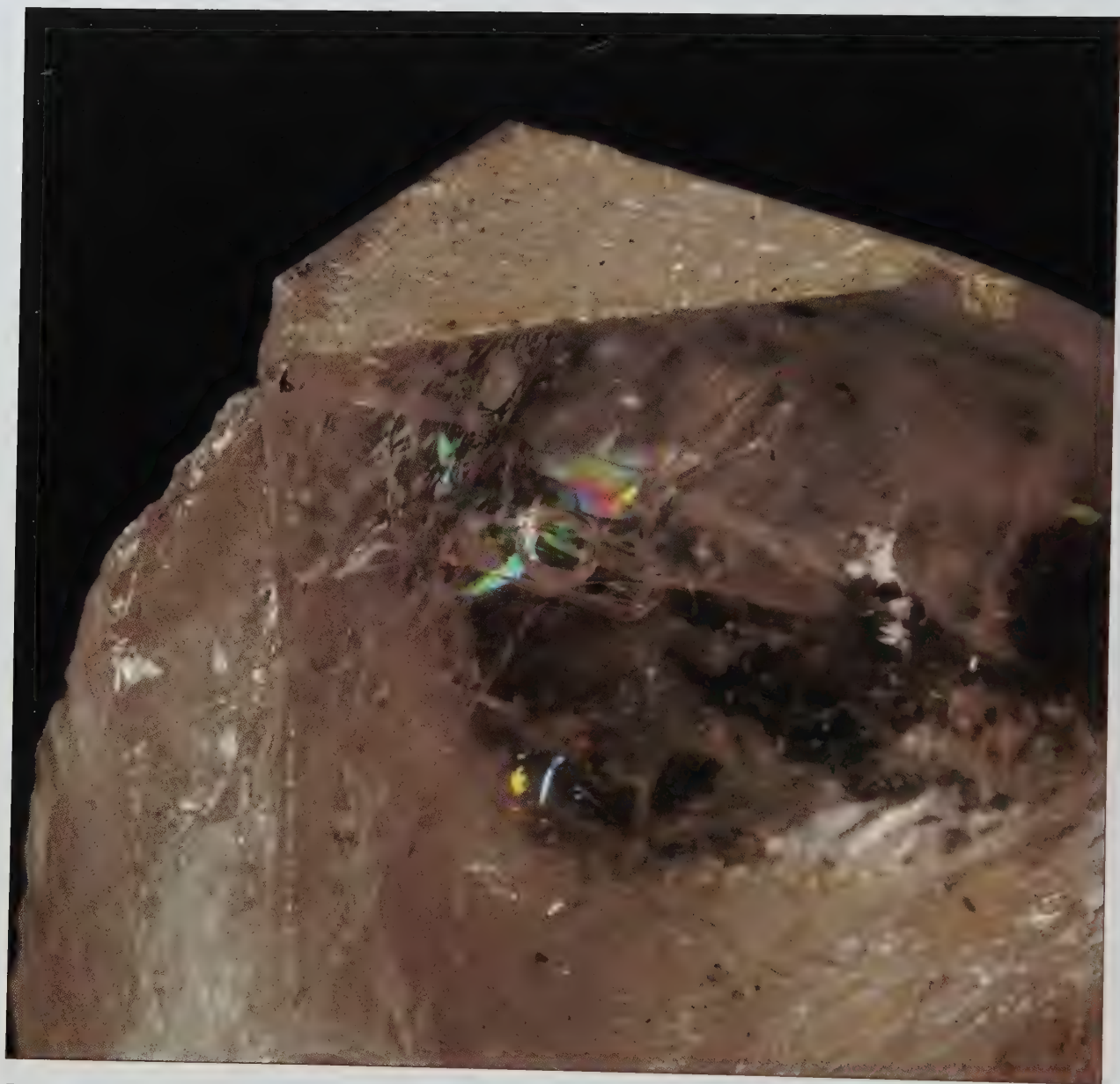


Figure 93. Detail of the morganite crystal shown in Figure 80, showing a movable bubble in a fluid-filled cavity ~5 mm long. R/JL3793

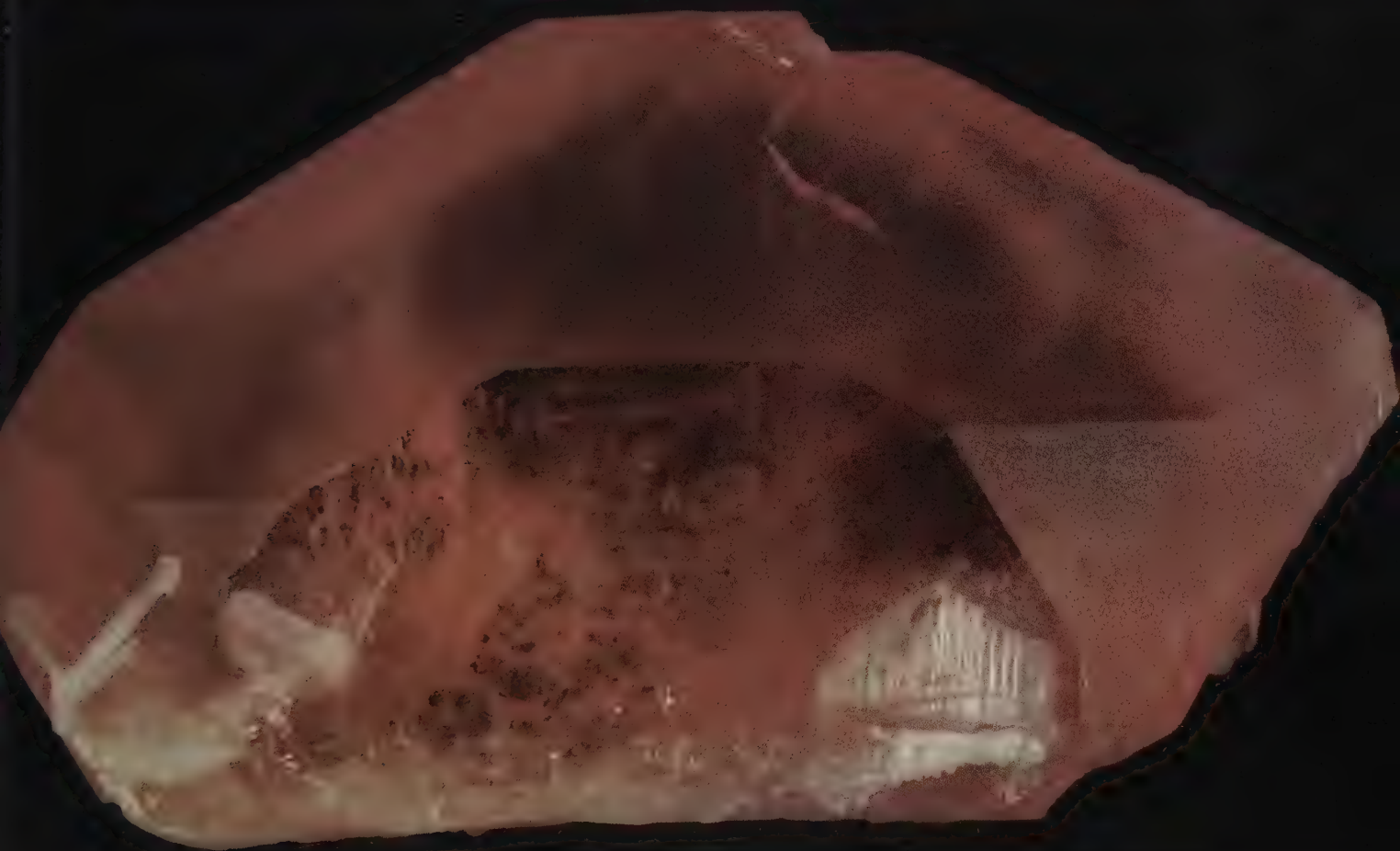


Figure 94. Transparent, tabular pink morganite crystal, $\sim 3 \times 6 \times 2$ cm, from Mawi, Laghman Province, Afghanistan. The crystal contains, as inclusions, several spodumene (var. *kunzite*) crystals, the largest of which is 1 cm across!
R/L3131

Etching and Surface Features

Beryl frequently exhibits various surface features related to crystal growth or etching processes that take place in hydrothermal systems. Sunagawa (2005) uses beryl as a representative example of crystal growth in pegmatites, and notes that, "Elemental spiral step patterns are universally observed in beryl crystals formed in pegmatite that is only slightly etched," with hexagonal patterns on {0001} and rectangular or rhombic patterns on the prism faces. He also points out that, "There are many crystals that provide evidence of the fact that etching occurs once the growth has stopped, in addition to crystals exhibiting as-grown surface microtopography." Indeed, collectors can easily find examples of beryl crystals that have been so heavily etched that the original shape of the crystal is completely obscured.

Figure 95. Thin, heavily etched, aquamarine crystal ~7 cm long X 1 cm wide, from Kollona, Uva Province, Sri Lanka. RJL3954





Figure 96. Transparent heliodor crystal, ~4.5 cm tall, from Volodarsk-Volynski, Zhitomir Oblast, Ukraine. Crystal shows the surface etching typical of samples from this locality. RJL3917



Figure 97. Nearly colorless, transparent, thumbnail-sized morganite crystal from São Geraldo do Baixo, Minas Gerais, Brazil. RJL3918



Figure 98. Sharp, bluish green beryl, ~5 cm tall, mostly transparent but with interesting etch features on the prism faces. Specimen is from Araçuaí, Minas Gerais, Brazil. RJL3966



Figure 99. Pale pink morganite crystal, ~5 cm tall, with very interesting etch features, associated with white albite. Specimen is from Saichis, near Balachi, Gilgit-Skardu Road, Northern Areas, Pakistan. *RJL3816*



Figure 100. Heavily etched aquamarine crystal, ~2.5 X 6 cm, from the Namlook mine, Dassu, Northern Areas, Pakistan. *RJL3916*



Figure 101. Several large, heavily etched, nearly colorless beryl crystals on albite, from Chhamachu, Gilgit-Skardu Road, Northern Areas, Pakistan. *RJL4033*

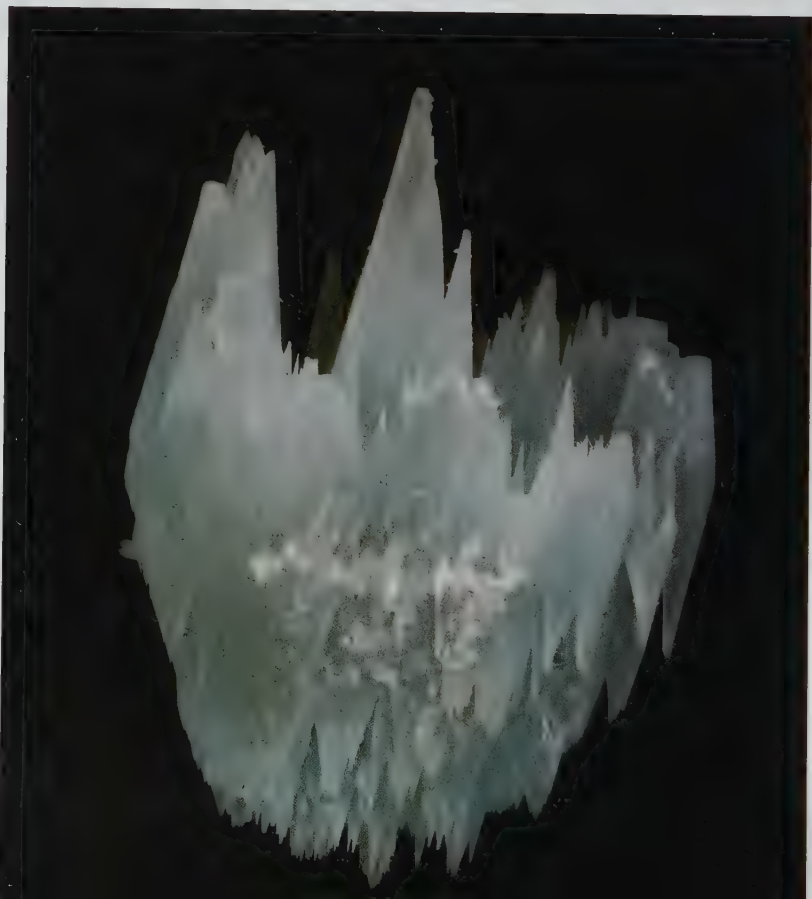


Figure 102. Heavily-etched aquamarine crystal from Balachi, Northern Areas, Pakistan; much of the original crystal has dissolved, leaving a series of conical points on both ends of the specimen. *RJL2190*



Figure 103. An interesting aquamarine crystal, ~2.5 cm tall, associated with feldspar, smoky quartz, and brownish mica. The aquamarine has surface features that suggest deep etching, but are much more likely to represent places where the crystal grew up against thin mica crystals that were later removed. *RJL3815*

Indialite

Indialite, the hexagonal polymorph of cordierite, was described from the Bokaro coalfield, India, where it had formed through the pyrometamorphic action of naturally burning coal seams on the adjoining sedimentary rocks (Miyashiro and Iiyama 1954). In the original report (Venkatesh 1952), which described the various shapes and habits of the generally microscopic crystals, they were identified as cordierite. The structure of cordierite, although closely related to that of beryl, is orthorhombic (pseudo-hexagonal) rather than hexagonal. The existence of several polymorphs of $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ had been demonstrated by Rankin and Merwin in 1918, who synthesized several forms at different temperatures. Miyashiro and Iiyama (1954) demonstrated that material synthesized by devitrifying glass of "cordierite" bulk composition, at temperatures $\sim 1200^\circ\text{C}$, was hexagonal; its powder X-ray diffraction pattern was clearly different from that of natural cordierite. Recognizing that the crystals studied by Venkatesh belonged to this hexagonal phase, they named the new mineral indialite, after the locality.

Iiyama (1955) demonstrated that a solid solution exists between a purely "magnesium indialite," $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$, and "magnesium beryl," $\text{Mg}_3\text{Al}_2\text{Si}_6\text{O}_{18}$, representing a hypotheti-

cal beryl in which all the Be is replaced by Mg. However, to date, compositions of this type have not been found in nature.

Meagher and Gibbs (1977) refined the crystal structure of indialite and discussed possible short-range ordering of Al,Si on the tetrahedral sites.

Indialite typically forms small hexagonal grains and clusters, with a white to yellowish white color and vitreous luster. Because the mineral is formed at very high temperatures, it is found in rocks of the sanidinite facies, such as buchites, paralavas, and xenoliths in volcanic rocks. Paralavas containing indialite are found at: Bokaro coalfield, India (TL); the Schoeller mine, Kladno, Czech Republic; the Powder River Basin, Wyoming; and southwestern Shannon County, South Dakota. It has been reported in xenoliths in volcanic ejecta at Somma-Vesuvius, Italy (Balassone et al. 2004); and at the Bellerberg and Herchenberg volcanoes, Eifel district, Germany. Indialite is also found in thin cordierite veins in the Unazuki schists, central Japan; its formation there is attributed to a two-stage process in which regional metamorphic rocks (staurolite-kyanite grade) were then further metamorphosed by contact with a granitic intrusion at relatively low pressure (Kitamura and Hiroi 1982).

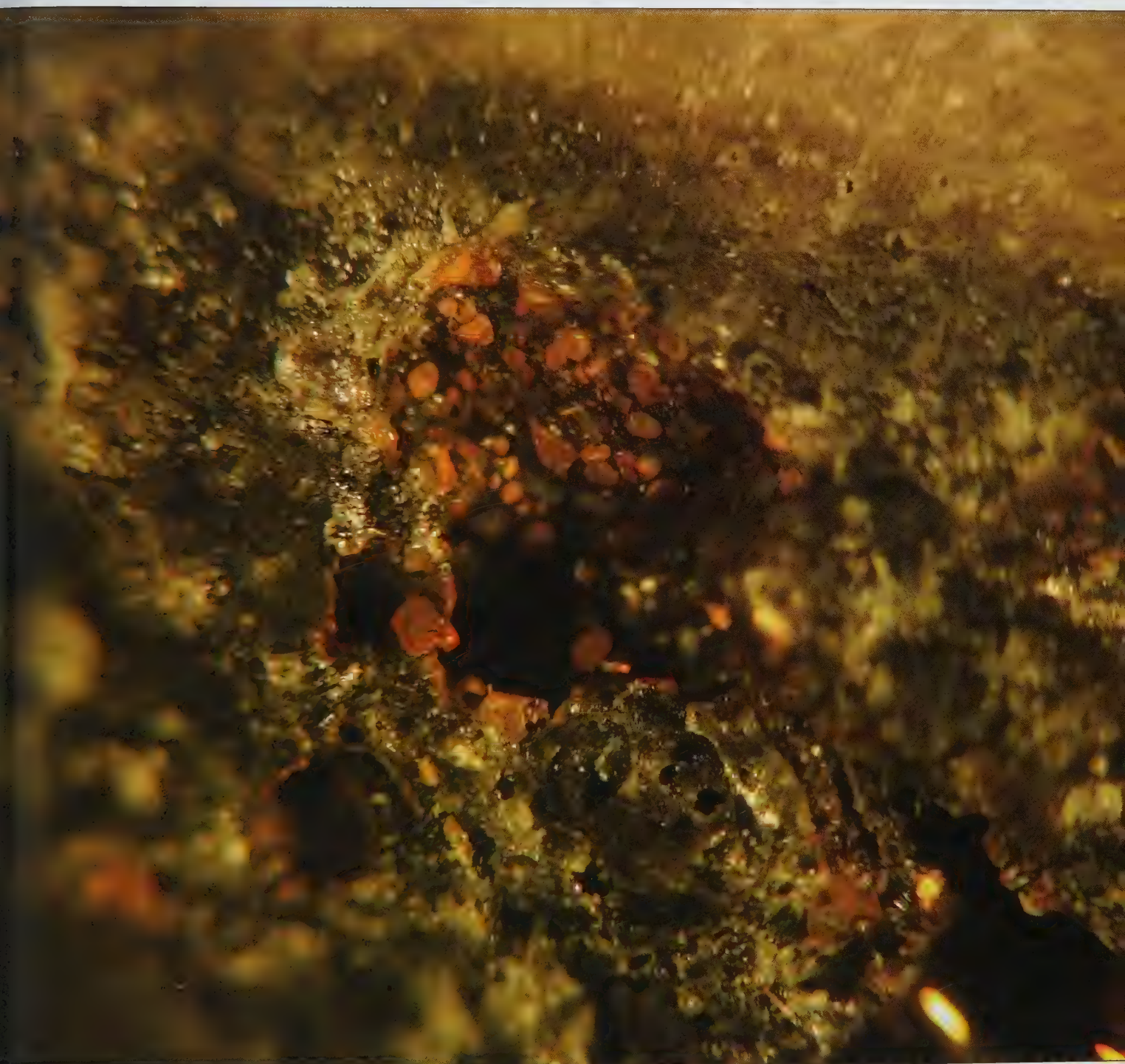


Figure 104. Microscopic, brassy, hexagonal indialite crystals in paralava formed in burning coal dumps at the historic Schoeller mine, Kladno, Czech Republic. RJL3949

Pezzottaite

Pezzottaite first appeared at the Tucson gem show in 2003, as a purplish pink to red Cs-rich “beryl,” and immediately attracted attention for its beautiful color. Careful examination of its physical properties quickly showed significant departures from those of known beryls. In particular, the Cs content (up to 15.33 wt.% Cs_2O) was higher than any previous analysis of an alkali beryl, as was the refractive index. Structure refinement showed that Cs is dominant on one of the sites in the structural channels, leading to the ideal end member composition $\text{Cs}(\text{Be}_2\text{Li})\text{Al}_2\text{Si}_2\text{O}_6$. A new mineral proposal was therefore submitted and approved (Simmons et al 2003; Laurs et al. 2003; Hawthorne et al. 2004). The type material was found in a single area in the Sakavalana pegmatite, Fianarantsoa province, central Madagascar. The crystals had formed in the pocket zone of the pegmatite in association with amazonite, smoky quartz, black tourmaline, Li-rich muscovite, and albite. Most pezzottaite crystals contain inclusions such as tiny tourmaline crystals and fine growth tubes oriented parallel to $[0001]$; when growth tubes are present in large numbers, excellent cat’s-eye stones can be cut.

The original locality, which yielded around 40 kg of crystals, appears to be largely mined out (Laurs et al. 2003).

More recently, pezzottaite has appeared, reportedly from the Deva mine, Paroon Valley, Nuristan, Afghanistan. Gems cut from this material were heavily included with stringers of particles, feathers, and smaller fractures, and both straight and angular growth lines. Compared to material from Madagascar, the Afghan pezzottaite has less Cs, less Rb, and slightly more Na, along with lower density and refractive index. One sample showed significant zoning, with Cs contents ranging from 3.58–12.95 wt. % Cs_2O , suggesting that zones of both pezzottaite and Cs-rich beryl were present in the same crystal (Laurs et al. 2005).

Stoppaniite

Stoppaniite, the Fe^{3+} -dominant analog of beryl, was described from a single piece of sanidinite in a pyroclastic flow near Capranica, Latium, Italy. It forms light blue hexagonal prisms up to 0.5 mm long in miarolytic cavities in the sanidinite (Ferraris, Prencipe, and Rossi 1998; Della Ventura et al. 2000).

Tamagnini (2005) provides further details of the circumstances surrounding the discovery, along with photos of the host rock formations. As of this writing, one 35-cm block of sanidinite from the type locale is the only confirmed occurrence, making stoppaniite an extremely rare mineral.



Figure 105. Terminated, orange hexagonal pezzottaite crystal, ~8 mm wide, on a plate of colorless albite and black tourmaline, from the Sakavalana pegmatite, Madagascar. RJL2668

References

In addition to the individual papers and reports cited below, the interested reader should be aware of several specific resources:

Emeralds of the World was published in 2002 as extraLapis English No. 2, and *Beryl and Its Color Varieties* was published in 2005 as extraLapis English No. 7; individual articles from those volumes are cited below where appropriate.

The book *Emerald and Other Beryls* by John Sinkankas, published by Geoscience Press in 1994, is occasionally available from used book sellers, as is the earlier volume *Beryl* (1986) by John Sinkankas and Peter Read.

Both *American Mineralogist* and *Mineralogical Magazine* maintain online archives of back issues; individual papers for years up to and including 1999 may be freely accessed.

Aines, R. D., and G. R. Rossman 1984. The high temperature behavior of water and carbon dioxide in cordierite and beryl. *American Mineralogist* 69:319-27.

Andersson, L. O. 1979. The difference between Maxixe beryl and Maxixe-type beryl: an electron paramagnetic resonance investigation. *Journal of Gemmology* 16:313-17.

Arem, J. E. 1977. *Color Encyclopedia of Gemstones*, New York: Van Nostrand Reinhold, 149 pp.

Artini, E. 1915. Due minerali di Baveno contenenti terre rare: weibyeite e bazzite. *Atti della Reale Accademia dei Lincei, Rendiconti della Classe di Scienze Fisiche, Matematiche e Naturali* 24:313-19.

Artioli, G., R. Rinaldi, K. Ståhl, and P. F. Zanazzi 1993. Structure refinements of beryl by single-crystal neutron and X-ray diffraction. *American Mineralogist* 78:762-8.

Aurischio, C., G. Fioravanti, O. Grubessi, and P. F. Zanazzi 1988. Reappraisal of the crystal chemistry of beryl. *American Mineralogist* 73:826-37.

Balassone, G., E. Franco, C. A. Mattia, and R. Puliti 2004. Indialite in xenolithic rocks from Somma-Vesuvius volcano (Southern Italy): Crystal chemistry and petrogenic features. *American Mineralogist* 89:1-6.

Bates, R. L. 1969. *Geology of the Industrial Rocks and Minerals*. New York: Dover Publications, 459 pp.

Bauer, M. 1904. *Precious Stones*, (1968 reprint) New York: Dover Publications, 627 pp.

Behling, S., and W. E. Wilson 2010. The Kagem emerald mine, Kafubu area, Zambia. *Mineralogical Record* 41:59-67.

Belakovskiy, D. 2005. The mysterious golden water of Tajikistan. *extraLapis English* No. 7:61-2.

- Blauwet, D. 2004. World-class localities: The Shigar, Basha, and Braldu Valleys. *extraLapis English* No. 6:36-47.
- Blauwet, D., and S. Muhammad 2004. The pegmatites at Chumar Bakhoo: Nature's treasure trove. *extraLapis English* No. 6:48-53.
- Blauwet, D., E. P. Quinn, and S. Muhlmeister 2005. New emerald deposit in Xinjiang, China. *Gems & Gemology* 41 (1):56-7.
- Blauwet, D., B. Smith, and C. Smith 2004. Table of mineral localities of the Northern Areas of Pakistan and other selected sites. *extraLapis English* No. 6:86-92.
- Cairncross, B., and U. Bahmann 2006. Famous mineral localities: The Erongo Mountains, Namibia. *Mineralogical Record* 37 (5):361-470.
- Černý, P. 1963. Epididymite and milarite – alteration products of beryl from Vežná, Czechoslovakia. *Mineralogical Magazine* 33:450-7.
- Chistyakova, N. B., V. A. Moleva, and Z. P. Razmanova 1966. The first find of bazzite in the U.S.S.R. *Dokl. Akad. Nauk SSSR* 169:1421-4 [see abstract (1967) *American Mineralogist* 52:563-4].
- Cook, R. B. 2010. Zambian emeralds: A recent find. *Rocks & Minerals* 85:74-6.
- Damon, P. E., and J. L. Kulp 1958. Excess helium and argon in beryl and other minerals. *American Mineralogist* 43:433-59.
- Deer, W. A., R. A. Howie, and J. Zussman 1986. *Rock-Forming Minerals, Volume 1B, Disilicates and Ring Silicates*, Second Edition, New York: Longman, 629 pp.
- Della Ventura, G., P. Rossi, G. C. Parodi, A. Mottana, M. Raudsepp, and M. Prencipe 2000. Stoppaniite, $(\text{Fe,Al,Mg})_4(\text{Be}_6\text{Si}_{12}\text{O}_{36})(\text{H}_2\text{O})_2(\text{Na},\square)$ a new mineral of the beryl group from Latium (Italy). *European Journal of Mineralogy* 12:121-7 [see abstract (2000) *American Mineralogist* 85:1845].
- Demartin, F., C. M. Gramaccioli, and T. Pilanti 2000. Structure refinement of bazzite from pegmatitic andmiarolitic occurrences. *Canadian Mineralogist* 38:1419-24.
- Edgar, A., and E. R. Vance 1977. Electron paramagnetic resonance, optical absorption, and magnetic circular dichroism studies of the CO_3^- molecular-ion in irradiated natural beryl. *Physics and Chemistry of Minerals* 1 (2):165-78.
- Ferraris, G., M. Prencipe, and P. Rossi 1998. Stoppaniite, a new member of the beryl group: Crystal structure and crystal-chemical implications. *European Journal of Mineralogy* 10:491-6 [see abstract (1999) *American Mineralogist* 84:1687].
- Fisher, J. 2002. Gem and rare-element pegmatites of southern California. *Mineralogical Record* 33 (5):363-407.
- Fisher, J. 2005. Beryl from the pegmatites of Southern California. *extraLapis English* No. 7:32-9.
- Flanigen, E. M., and N. R. Mumbach 1971. Hydrothermal process for growing crystals having the structure of beryl in an acid halide medium. U.S. Patent 3,567,643.
- Flanigen, E. M., and A. M. Taylor 1967. Flux-melt method for growing single crystals having the structure of beryl. U.S. Patent 3,341,302.
- Flanigen, E. M., D. W. Breck, N. R. Mumbach, and A. M. Taylor 1967. Characteristics of synthetic emeralds. *American Mineralogist* 52:744-72.
- Fleischer, M. 1955. Bazzite (= scandian beryl?). *American Mineralogist* 40:370.
- Fron del, C. 1970. Scandium-rich minerals from rhyolite in the Thomas Range, Utah. *American Mineralogist* 55:1058-60.

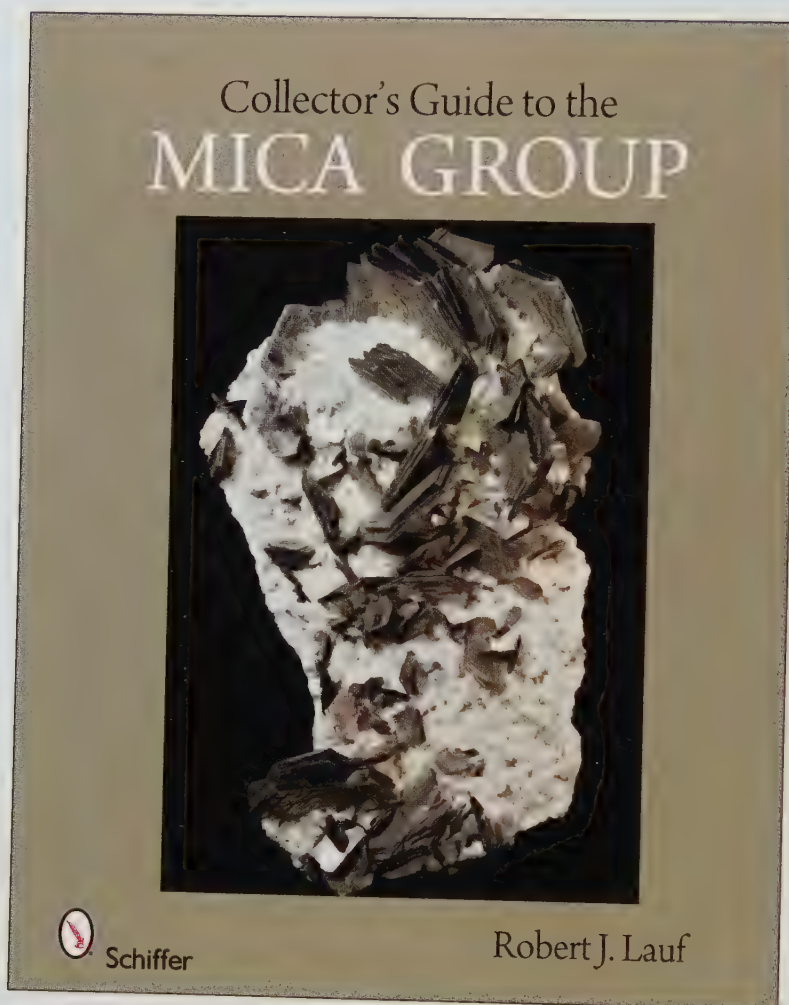
- Fron­del, C., and J. Ito 1968. Synthesis of the scandium analogue of beryl. *American Mineralogist* 53:943-53.
- Gatta, G.D., F. Nestola, G. D. Bromiley, and S. Mat­tauch 2006. The real topological configuration of the extra-framework content in alkali-poor beryl: A multi-methodological study. *American Mineralogist* 91:29-34.
- Gavrilenko, E. V., B. Calvo Perez, R. Castroviejo Bolibar, and D. Garcia del Amo 2006. Emeralds from the Delbegetey deposit (Kazakhstan): mineralogical characteristics and fluid-inclusion study. *Mineralogical Magazine* 70:159-73.
- Goldschmidt, V. 1916. *Atlas der Krystallformen* [see Facsimile Reprint in Nine Volumes (1986) by the Rochester Mineralogical Symposium].
- Gramaccioli, C. M., V. Diella, F. Demartin, P. Orlandi, and I. Campostrini 2000. Cesian bazzite and thortveitite from Cuasso Al Monte, Varese, Italy: A comparison with the material from Baveno, and inferred origin. *Canadian Mineralogist* 38:1409-18.
- Groat, L. A., G. Giuliani, D. D. Marshall, and D. Turner 2007. Emerald [in *Geology of Gem Deposits*, L. A. Groat, editor]. *Mineralogical Assoc. of Canada Short Course Series* 37:79-109.
- Grundmann, G., and G. Giuliani 2002. Emeralds of the world. *extraLapis English* No. 2:24-35.
- Grundman, G., and G. Morteani 1989. Emerald mineralization during regional metamorphism: The Habachtal (Austria) and Leydsdorp (Transvaal, South Africa) deposits. *Economic Geology* 84:1835-49.
- Hammer, V. M. F., and S. Muhammad 2004. Picking pegmatite pockets: The road from Gilgit to Skardu. *extraLapis English* No. 6:24-32.
- Hawthorne, F. C., and P. Černý 1977. The alkali-metal positions in Cs-Li beryl. *Canadian Mineralogist* 15:414-21.
- Hawthorne, F. C., M. A. Cooper, W. B. Simmons, A. U. Falster, B. M. Laurs, T. Armbruster, G. R. Rossman, A. Peretti, D. Günther, and B. Grobáty 2004. Pezzottaite, Cs(Be₂Li)Al₂Si₆O₁₈, a spectacular new beryl-group mineral from the Sakavalana pegmatite, Fianarantsoa Province, Madagascar. *Mineralogical Record* 35:369-78.
- Iiyama, T. 1955. Existence of indialite solid solutions. *Proceedings of the Japan Academy* 31 (3):166-8.
- Jacobson, M. I. 2005. Mount Antero: the peak of Colorado beryl collecting. *extraLapis English* No. 7:26-7.
- Jarnot, B. 2005. New England gem beryl. *extraLapis English* No. 7:28-31.
- Juve, G., and S. Bergstøl 1990. Caesian bazzite in granite pegmatite in Tørdal, Telemark, Norway. *Mineralogy and Petrology* 43:131-6.
- Kanis, J., and D. Schwarz 2002. Emeralds from Africa. *extraLapis English* No. 2:52-9.
- Kerr, P. F. 1946. Kaolinite after beryl from Alto do Giz, Brazil. *American Mineralogist* 31:435-42.
- Kiefert, L. 2002. Emerald treatments. *extraLapis English* No. 2:79-81.
- Kitamura, M., and Y. Hiroi 1982. Indialite from Unazuki pelitic schist, Japan, and its transition texture to cordierite. *Contributions to Mineralogy and Petrology* 80:110-16.
- Kunz, G. F. 1892. *Gems and Precious Stones of North America*, Second Edition, (1968 reprint) New York: Dover Publications, 367 pp.
- Lahti, S. I., and K. A. Kinnunen 1993. A new gem beryl locality: Luumäki, Finland. *Gems & Gemology* 29 (1):30-7.
- Laurs, B. M., W. B. Simmons, G. R. Rossman, E. P. Quinn, S. F. McClure, A. Peretti, T. Armbruster, F. C. Hawthorne, A. U. Falster, D. Günther, M. A. Cooper, and B. Grobáty 2003. Pezzottaite from

- Ambatovita, Madagascar: a new gem mineral. *Gems & Gemology* 39 (4):284-301.
- Lauris, B. M., E. P. Quinn, W. B. Simmons, and A. U. Falster 2005. A faceted pezzottaite from Afghanistan. *Gems & Gemology* 41 (1):61-2.
- London, D. 2008. Pegmatites. *Canadian Mineralogist Special Publication* 10, 347 pp.
- Lyckberg, P. 2005. Gem beryl from Russia and Ukraine. *extraLapis English* No. 7:49-57.
- Lyckberg, P., V. Chournousenko, and W. E. Wilson 2009. Famous mineral localities: Volodarsk-Volynski, Zhitomir Oblast, Ukraine. *Mineralogical Record* 40:473-506.
- Meagher, E. P., and G. V. Gibbs 1977. The polymorphism of cordierite: II. The crystal structure of indialite. *Canadian Mineralogist* 15:43-9.
- Menezes, L. 2005. Brazilian beryl. *extraLapis English* No. 7:84-96.
- Miyashiro, A., and T. Iiyama 1954. A preliminary note on a new mineral, indialite, polymorphic with cordierite. *Proceedings of the Japan Academy* 30 (8):746-51.
- Nassau, K., and D. L. Wood 1968. An examination of red beryl from Utah. *American Mineralogist* 53:801-6.
- Nassau, K., and K. A. Jackson 1970. Trapiche emeralds from Chivor and Muzo, Colombia. *American Mineralogist* 55:416-27; see also Correction, *American Mineralogist* 55:1808-9.
- Nassau, K., B. E. Prescott, and D. L. Wood 1976. The deep blue Maxixe-type color center in beryl. *American Mineralogist* 61:100-7.
- Nowacki, W., and K. D. Phan 1964. Composition quantitative de la bazzite de Val Strem (Suisse), determinee par la microsonde electronique de Castaing. *Bull. Soc. Franc. Mineral. Cristallogr.* 87:453 [see abstract (1967) *American Mineralogist* 52:563-4].
- O'Donoghue, M. 1983. *A Guide to Man-Made Gemstones*. New York: Van Nostrand Reinhold.
- Pankrath, R., and K. Langer 2002. Molecular water in beryl, ${}^{\text{VI}}\text{Al}_2[\text{Be}_3\text{Si}_6\text{O}_{18}]\cdot n\text{H}_2\text{O}$, as a function of pressure and temperature: An experimental study. *American Mineralogist* 87:238-44.
- Pezzotta, F. 2005. The Monte Capanne pegmatites. *extraLapis English* No. 8:20-7.
- Rogers, A. F., and F. J. Sperisen 1942. American synthetic emerald. *American Mineralogist* 27:762-8.
- Schaller, W. T., R. E. Stevens, and R. H. James 1962. An unusual beryl from Arizona. *American Mineralogist* 47:672-99.
- Schmetzer, K. 2002. Laboratory emeralds. *extraLapis English* No. 2:84-92.
- Schwarz, D., and K. Schmetzer 2002. The definition of emerald. *extraLapis English* No. 2:74-8.
- Shigley, J. E., T. J. Thompson, and J. D. Keith 2003. Red beryl from Utah: a review and update. *Gems & Gemology* 39 (4):302-13.
- Simmons, W. B., A. U. Falster, S. F. McClure, E. P. Quinn, G. R. Rossman, and F. C. Hawthorne 2003. A new saturated purplish pink Cs-"beryl" from Madagascar: Preliminary analysis. *Gems & Gemology* 39 (1):50-4.
- Sinkankas, J. 1981. *Emerald and Other Beryls*. New York: Van Nostrand.
- Staat, M. H., W. R. Griffiths, and P. R. Barnett 1965. Differences in the minor element composition of beryl in various environments. *American Mineralogist* 50:1783-95.
- Sunagawa, I. 2005. *Crystals: Growth, Morphology, and Perfection*. Cambridge: Cambridge University Press, 295 pp.

- Tamagnini, F. 2005. Discovery stoppaniite. *extraLapis English* No. 7:20-1.
- Turner, D., and L. A. Groat 2007. Non-emerald gem beryl [in *Geology of Gem Deposits*, L. A. Groat, editor]. *Mineralogical Assoc. of Canada Short Course Series* 37:111-143.
- Venkatesh, V. 1952. Development and growth of cordierite in paralavas. *American Mineralogist* 37:831-48.
- Wise, M. 2005. Mellow yellow: heliodor and golden beryl. *extraLapis English* No. 7:58-60.
- Wise, M. A., and A. J. Anderson 2006. The emerald- and spodumene-bearing quartz veins of the Rist emerald mine, Hiddenite, North Carolina. *Canadian Mineralogist* 44:1520-41.
- Wood, D. L., and K. Nassau 1968. The characterization of beryl and emerald by visible and infrared absorption spectroscopy. *American Mineralogist* 53:777-800.
- Xue, G., D. Marshall, S. Zhang, T.D. Ullrich, T. Bishop, L. A. Groat, D. J. Thorkelson, G. Giuliani, and A. E. Fallick 2010. Conditions for Early Cretaceous emerald formation at Dyakou, China: fluid inclusion, Ar-Ar, and stable isotope studies. *Economic Geology* 105:339-49.
- Yancey, P. J. 1973. Hydrothermal process for growing crystals having the structure of beryl in highly acid chloride medium. U.S. Patent 3,723,337.
- Yaverbaum, L. H. 1980. *Synthetic Gems Production Techniques*. Park Ridge, NJ: Noyes Data Corp.
- Zachariáš, J., V. Žáček, M. Pudilová, and V. Machovič 2005. Fluid inclusions and stable isotope study of quartz-tourmaline veins associated with beryl and emerald mineralization, Kafubu area, Zambia. *Chemical Geology* 223:136-52.
- Zhang, S., M. Feng, H. Wang, and W. Lu 1999. Geological features and genesis of emerald deposit in Malipo County, Yunnan, China. *Geological Science and Technology Information* 18:50-4 [in Chinese; see summary in Groat et al. (2007)].
- Zhernakov, V. I. 2009. Ural emerald mines (Izumrudnye Kopi): Notes on mineralogy. *Mineralogical Almanac* 14(2).
- Zwaan, J. C. 2006. Gemmology, geology and origin of the Sandawana emerald deposits, Zimbabwe. *Scripta Geologica* 131:1-121.
- Zwaan, J. C., A. V. Seifert, S. Vrana, B. M. Laurs, B. Ankar, W. B. Simmons, A. U. Falster, W. J. Lustenhouwer, S. Muhlmeister, J. I. Koivula, and H. Garcia-Guillermín 2005. Emeralds from the Kafubu area, Zambia. *Gems and Gemology* 41:116-48.

MORE SCHIFFER EARTH SCIENCE MONOGRAPH TITLES

www.schifferbooks.com



Collector's Guide to the Mica Group. Robert J. Lauf. Mica is a broad term encompassing about forty minerals, ranging from the common to the rare, many at times forming excellent crystals jewelers use. This book features examples recently described among the 115 striking color photos and electron micrographs that illustrate the text. A detailed entry for each type includes information on where each is found, associations of micas with other minerals, pseudomorphs (minerals that masquerade as mica), and micas that fluoresce under UV light. This fascinating guide is for those interested in minerals.

Size: 8 1/2" x 11"

ISBN: 978-0-7643-3047-6

115 color photos
soft cover

96pp.
\$19.99

Collector's Guide to the EPIDOTE GROUP



Schiffer

Robert J. Lauf

Collector's Guide to the Epidote Group. Robert J. Lauf. Over 90 striking color photos display minerals of the epidote group, well known to mineral collectors for their rich colors and the many interesting minerals with which they occur. Lapidary artists also value epidote, particularly in the form of unakite, and precious or semiprecious varieties of the related mineral zoisite, including thulite and tanzanite, some which have inclusions that allow them to be cut into popular catseyes. This informative book provides all presently known species, detailed entries for each of the eighteen minerals, and extensive locality information. This book will be of interest to those interested in developing a better understanding of silicate minerals.

Size: 8 1/2" x 11"

ISBN: 978-0-7643-3048-3

92 color photos
soft cover

96pp.
\$19.99

OTHER SCHIFFER TITLES

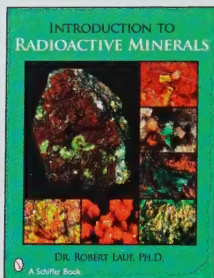
www.schifferbooks.com



Introduction to Radioactive Minerals.

Robert J. Lauf. Collectors have long admired uranium and thorium minerals for their brilliant colors, intense ultraviolet fluorescence, and rich variety of habits and associates. Radioactive minerals are also critically important as our source of nuclear energy. Understanding them is crucial to the safe disposal of radioactive waste. This book provides a systematic overview of the mineralogy of uranium and thorium, generously illustrated with nearly 200 color photos and electron micrographs of representative specimens. Includes an historical discussion of the discovery of radioactive elements and the development of uranium and thorium ore deposits, a discussion of the geochemical conditions that produce significant deposits, and a description of important localities, their geological setting and history. Major occurrences of interest to mineral collectors are arranged geographically. The minerals are arranged systematically, to emphasize how they fit into chemical groups, and for each group a few minerals are selected to illustrate their formation and general characteristics. With the resurgence of interest in nuclear power, this book is an invaluable guide for mineral collectors as well as nuclear scientists and engineers interested in radioactive deposits.

Size: 8 1/2" x 11" 196 color & b/w photos 144pp.
ISBN: 978-0-7643-2912-8 soft cover \$29.95



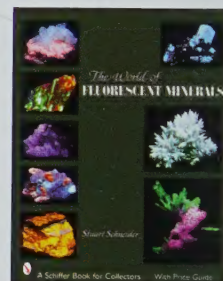
Picropharmacolite, Quartz, Spinel, Smithsonite, plus many more. But don't let the hard-to-pronounce names keep you away. Over 800 beautiful color photographs illustrate how fluorescent minerals look under the UV light and in daylight, making this an invaluable field guide. Included are values, a comprehensive resources section, plus helpful advice on caring for, collecting, and displaying minerals. The field of collecting fluorescent minerals is relatively new and this is one of the most complete references available.

Size: 8 1/2" x 11" 846 color photos 192pp.
ISBN: 0-7643-2091-2 soft cover \$29.95

The World of Fluorescent Minerals.

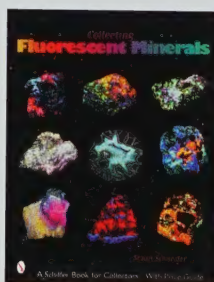
Stuart Schneider. The rich and diverse world of fluorescent minerals is explored in this sweeping survey. Breathtakingly pure colors, with their ethereal glow, immediately capture your attention. Did you know that color television is a result of the study of fluorescing minerals? Fresh finds of fluorescent minerals are showing up regularly around the globe, and their collection is an entertaining and popular pastime. To help the collector, over 825 photos display the minerals both as they might be found in daylight and in under the effects of ultraviolet light. Written for the collector and the merely curious, this pictorial reference will enrich your collecting experience with its informative text. It is an essential source for enjoying and identifying fluorescent minerals.

Size: 8 1/2" x 11" 825 color photos 176pp.
ISBN: 0-7643-2544-2 soft cover \$29.95



Collecting Fluorescent Minerals.

Stuart Schneider. Seeing fluorescent minerals up close for the first time is an exciting experience. The colors are so pure and the glow is so seemingly unnatural, that it is hard to believe they are natural rocks. Hundreds of glowing minerals are shown, including Aragonite, Celestine, Feldspar, Microcline,



Schiffer books may be ordered from your local bookstore, or they may be ordered directly from the publisher by writing to:

Schiffer Publishing, Ltd.
4880 Lower Valley Rd.
Atglen, PA 19310

(610) 593-1777; Fax (610) 593-2002

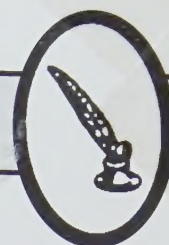
E-mail: Info@schifferbooks.com

Please visit our web site catalog at www.schifferbooks.com or write for a free catalog. Please include \$5.00 for shipping and handling for the first two books and \$2.00 for each additional book. Full-price orders over \$150 are shipped free in the U.S.

Printed in China

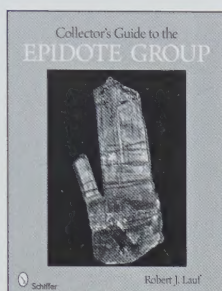
MORE SCHIFFER TITLES

www.schifferbooks.com



Collector's Guide to the Epidote Group. Robert J. Lauf. Over 90 striking color photos display minerals of the epidote group, well known to mineral collectors for their rich colors and the many interesting minerals with which they occur. Lapidary artists also value epidote, particularly in the form of unakite, and precious or semiprecious varieties of the related mineral zoisite, including thulite and tanzanite, some which have inclusions that allow them to be cut into popular catseyes. This informative book provides all presently known species, detailed entries for each of the eighteen minerals, and extensive locality information. This book will be of interest to those interested in developing a better understanding of silicate minerals.

Size: 8 1/2" x 11" 92 color photos 96pp.
ISBN: 978-0-7643-3048-3 soft cover \$19.99

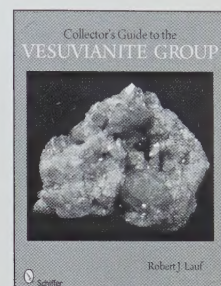


originate, are found, and what they signified in ancient times.

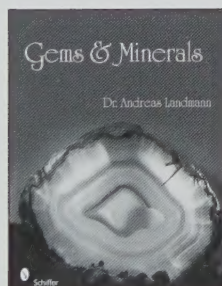
Size: 8 1/2" x 11" 166 color photos 180pp.
ISBN: 978-0-7643-3066-7 hard cover \$24.99

Collector's Guide to the Vesuvianite Group. Robert Lauf. Over 90 full-color photos of vesuvianite show what good specimens look like and what minerals one might expect to find associated with vesuvianites. Detailed text explains the chemistry and taxonomy, discusses ongoing research into problems such as color, structure, and optically anomalous crystals, and important localities.

8 1/2" x 11" 97 color photos, 4 illus. 96pp.
ISBN: 978-0-7643-3215-9 soft cover \$19.99

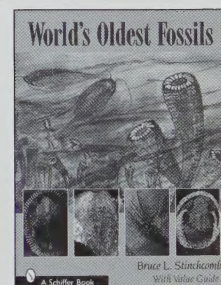


Gems & Minerals. Dr. Andreas Landmann. In recent years, minerals and gems have enjoyed growing renown and popularity. At this time there are some 3,800 different minerals known from all parts of the world that have been deep in the earth for millions of years and grew there over thousands of years. Learn to identify the most important groups of minerals, including quartz, feldspar, beryl, tourmaline, corundum, diamond, garnet, spinel, fluoroite, precious metals, and more. More than 150 photos with descriptions relate how minerals



World's Oldest Fossils. Bruce L. Stinchcomb. Covers the earliest fossil record of life from strata called Precambrian and Cambrian by geologists. Illustrated and discussed are structures formed by very primitive photosynthetic life forms, Cambrian trilobites, problematic fossil-like objects, and fascinating paleontological "puzzles." Includes collector information, glossary, value ranges.

Size: 8 1/2" x 11" 509 color photos 160pp.
Price Guide
ISBN: 978-0-7643-2697-4 soft cover \$29.95



Schiffer books may be ordered from your local bookstore, or they may be ordered directly from the publisher by writing to:

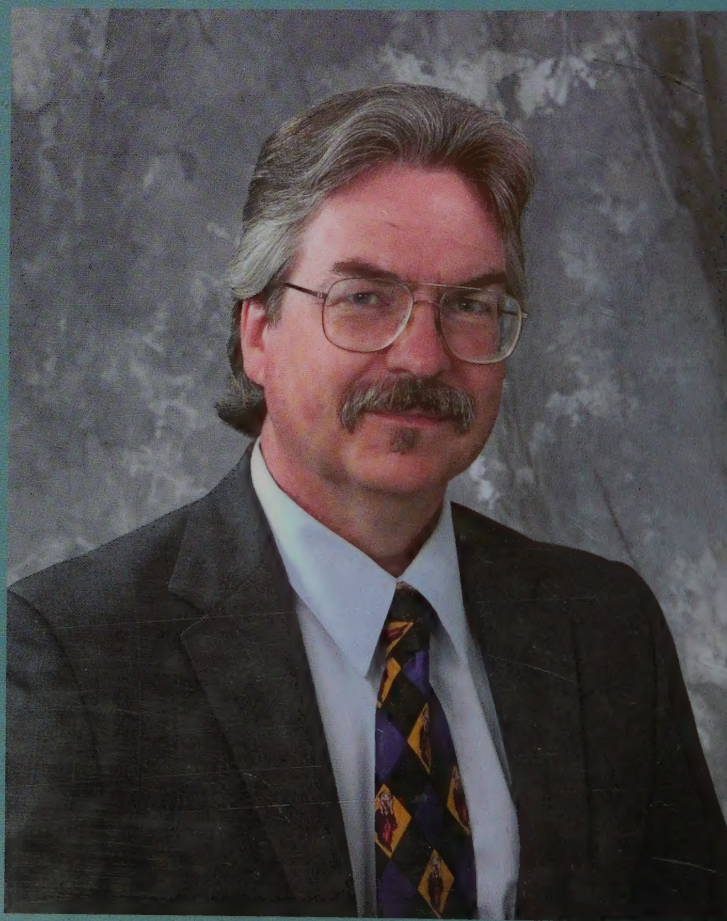
Schiffer Publishing, Ltd.
4880 Lower Valley Rd.
Atglen, PA 19310
(610) 593-1777; Fax (610) 593-2002
E-mail: Info@schifferbooks.com

Please visit our web site catalog at www.schifferbooks.com or write for a free catalog. Please include \$5.00 for shipping and handling for the first two books and \$2.00 for each additional book. Full-price orders over \$150 are shipped free in the U.S.

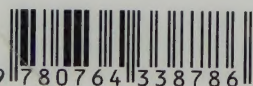
Printed in China

WITHDRAWN
PROPERTY OF
DAVID O. MCKAY LIBRARY
BYU-IDAHO
REXBURG ID 83460-0405

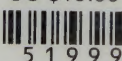
Beryl in its many color varieties is a favorite of both mineral collectors and gemologists. Superb examples are found at many locales worldwide in pegmatites and schists. Other members of the group are prized by mineral collectors and micromount enthusiasts. This book explains how beryl is formed and the unique conditions that create fine aquamarines and emeralds. After a brief introduction, the general treatment begins with an explanation of the chemistry and taxonomy of the group. A section on their formation and geochemistry explains the kinds of environments where beryls are formed. Detailed entries for each mineral provide locality information and full-color photos so that collectors can see what good specimens look like and which minerals one might expect to find in association with them. An extensive bibliography is provided for further study. Over 100 photographs of these beautiful minerals show each species in its geological context.



Robert J. Lauf



US \$19.99



ISBN: 978-0-7643-3878-6