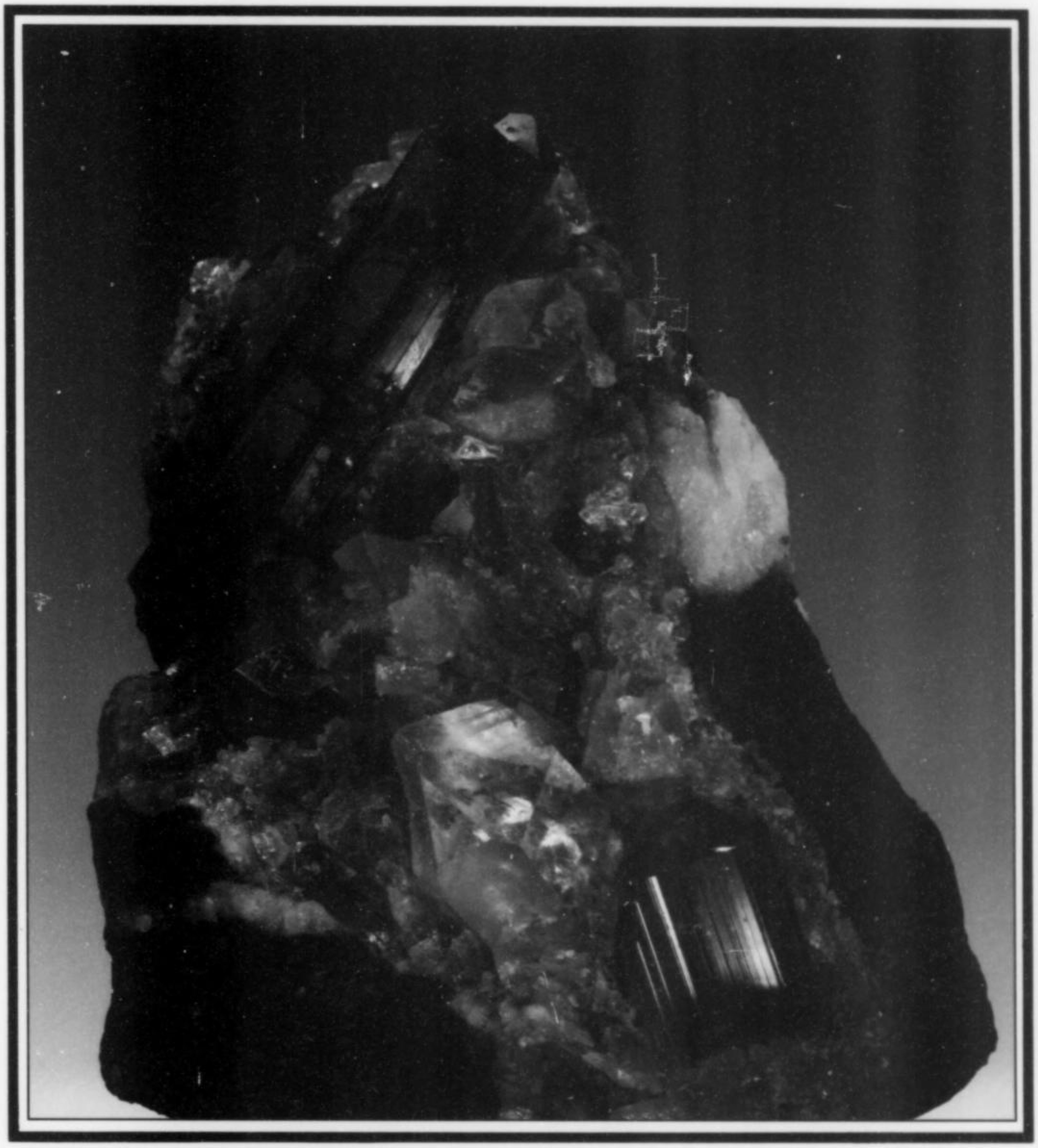
TOPAZ



MINERALOGICAL RECORD

JANUARY–FEBRUARY 1995 • VOLUME 26 NUMBER 1 • $10

Editor & Publisher
Wendell E. Wilson

Associate Editors
Pierre Bariand
Sorbonne
Paris, France
Bill Birch
Museum of Victoria
Melbourne, Australia
Michael P. Cooper
Nottingham, England
Richard C. Erd
U.S. Geological Survey
Menlo Park, CA
Steven R. Morehead
Riverside, CA
Donald R. Peacor
University of Michigan
Ann Arbor, MI
Andrew C. Roberts
Geol. Surv. of Canada
Ottawa
George W. Robinson
Natl. Museums of Canada
Ottawa, Ontario
Abraham Rosenzweig
Tampa, FL

Associate Photographers
Nelly Bariand
Sorbonne
Paris, France
Dan Behnke
Northbrook, IL
Werner Lieber
Heidelberg, W. Germany
Eric Offermann
Arlesheim, Switzerland
Jeffrey A. Scovil
Phoenix, AZ
Harold and Erica Van Pelt
Los Angeles, CA

Founder
John Sampson White

European Correspondent
Michael P. Cooper

Editing, advertising
Wendell E. Wilson
4631 Paseo Tubutama
Tucson, AZ 85715
602-299-5274
FAX: 602-299-5702

Circulation Manager
Mary Lynn Michela
(Subscriptions, back issues, reprints, book sales, shows)
P.O. Box 35565
Tucson, Arizona 85740
602-297-6709
FAX: 602-544-0815

Subscriptions
- **Individuals (U.S.):** $39 for one year; $76 for two years. (First-class mailing available; write to circulation manager for rates.)
- **Individuals (outside the U.S.):** $43 for one year, $83 for two years. (Airmail mailing available; write to circulation manager for rates.)
- **Libraries, Companies and Institutions (worldwide):** $65 for one year. (First-class or Airmail mailing available; write to circulation manager for rates.)

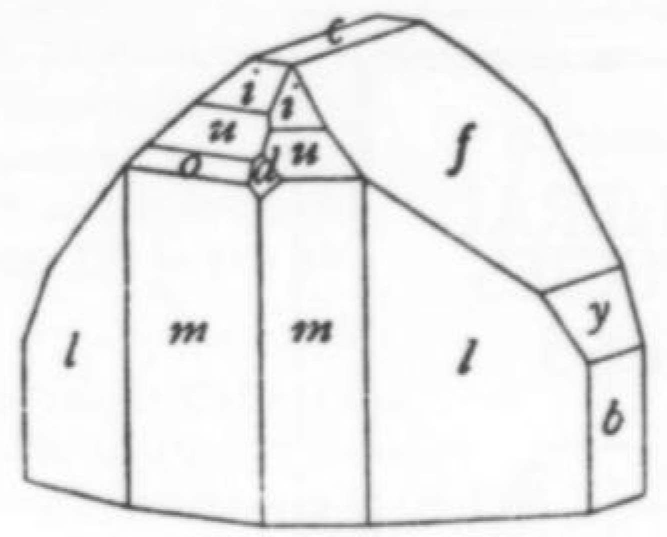
Printed in the U.S.A.

The Mineralogical Record (ISSN 0026-4628) is published bi-monthly for $39 per year (U.S.) by Mineralogical Record, Inc., a non-profit organization, 7413 N. Mowry Place, Tucson, AZ 85741. Special second-class postage paid at Tucson, Arizona and additional mailing offices. POSTMASTER: Send address changes to: The Mineralogical Record, P.O. Box 35565, Tucson, AZ 85740.

*Continued on p. 79

the Mineralogical Record®

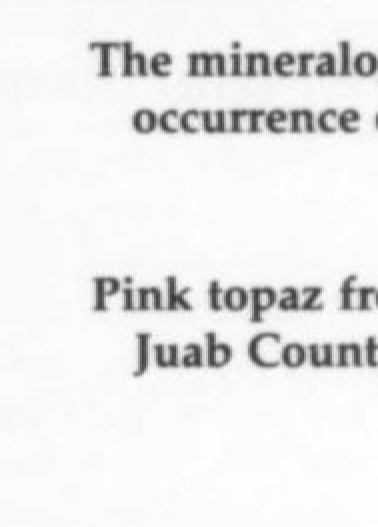
January–February 1995
Volume Twenty-six, Number One



TOPAZ!

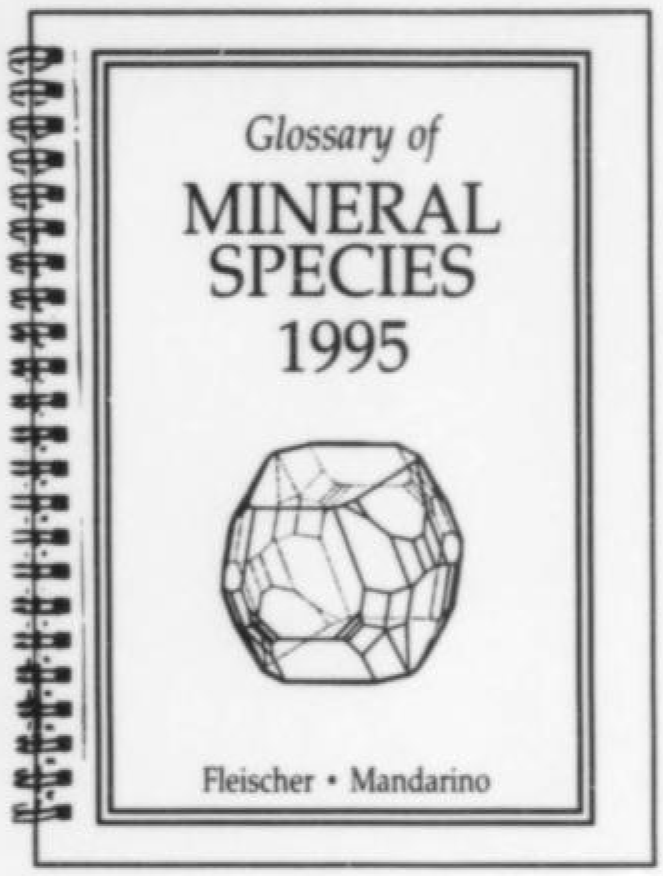
Articles

Columns



COVER: TOPAZ crystals to 4 cm, on matrix, from Ghundao Hill, Mardan district, Pakistan. F. John Barlow collection; photo by Harold and Erica Van Pelt.

notes from the EDITOR



New Glossary is Here!

The new ***Glossary of Mineral Species 1995*** is now printed and ready for delivery! This seventh edition of our long-time best-seller has been enlarged to **288 pages** of up-to-date information and references on the 3,600 known mineral species. The useful lists of species by group, at the back, now include complete formulas for each species, to facilitate comparisons. This is an essential, basic reference for all collectors, dealers and mineralogists.

Best of all, the new edition is still reasonably priced, at $18 plus $1 postage ($2 foreign).

We had originally planned to include type localities for each species in the new *Glossary.* However, the authors discovered that a tremendous amount of confusion and uncertainty surround many type localities, especially in the countries of the former Soviet Union. Researching this properly is taking more time. Consequently, we now plan to publish the type locality list, perhaps with a geographic cross-index, in a future issue of the *Mineralogical Record,* as a complement to the *Glossary.* Authors Joseph A. Mandarino and Michael Fleischer are working hard to make this list as accurate and thoroughly researched as possible.

Museum Robbed

In what must have been a well-planned and efficiently executed operation, thieves broke into the Geology Department at Mudd Hall, Carleton College in Northfield, Minnesota, and made off with no less than 626 museum-quality specimens of minerals and fossils. The burglary took place early Saturday morning, September 24. According to seismographs in the Department, the thieves broke the glass on one display case every five minutes and cleared out the case before moving on to the next; in all, about 30 minutes were required to pack up and move out the specimens. Many exceptional specimens of the common display species were taken: stibnite, malachite, rhodochrosite, silver, azurite, dioptase, beryl, copper, cerussite, etc. . . . 136 mineral specimens in all, and 490 fossils. Dealers who may have been offered such a lot of specimens in the last few months should be very suspicious. If you think you have seen these specimens being offered for sale, please contact the Carleton College Geology Department (507-663-4401).

Another Mineral Video

Mail-order shoppers who like to see what they're ordering now have a new source. Readers may recall that a company called *Video Minerals* began the trend a few years ago by producing videotapes of specimens for sale (as far as I know, they are not doing so at present). Then Stuart Wilensky began producing a fine series, and Keith Proctor put his entire (for sale) collection on video. Now Isaias Casanova of *I. C. Minerals* (P.O. Box 1376, Goldenrod, FL 32733-1376) has come out with an excellent video of specimens for sale as well, for only $6.50 postpaid. The 74 specimens themselves, many of them top competition quality, range in price mostly from $50 to $500, with a few up to $2,500. The photographic quality is among the best I've seen, and the narration is helpful and concise.

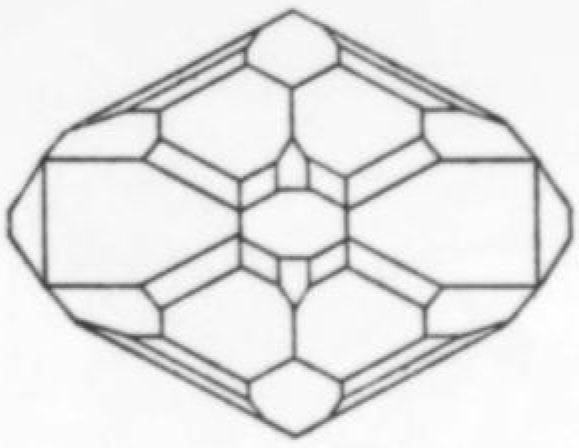
This is a very pleasant, inexpensive way to see and perhaps buy some fine minerals during those house-bound periods when you just can't get out to a show. It also serves as an ideal historical documentation of the kinds of specimens and prices available to us today, which will be evermore fascinating to look back upon in future decades. If only video had been available around the turn of the century, when dealers like A. E. Foote were sending out their dry, written lists! ("Wulfenite, Red Cloud mine, Arizona, 1-inch, 50¢; 2-inch, $2; 3-inch, $3.50" etc.) Wouldn't it be interesting to see what *those* specimens actually looked like? But even videos from ten or 20 years ago would be fun to see. In any case, I highly recommend that collectors, especially those who don't usually buy sight-unseen by mail order, check out this new way of selecting purchases.

Crystal Models

Anyone who has ever tried to study crystallography and crystal symmetry knows that the process is much easier if you have good crystal models to play with. René Just Haüy (1743–1822), the founder of mathematical crystallography, made and sold his own sets in the late 18th century, and since that time numerous other crystallographers and mineralogical supply companies have produced and sold sets. The materials used in the fabrication of the models include plaster, terra cotta, wood and colored or uncolored glass. Naturally these crystal model collections are prime collectibles today.

Among the more recent producers of crystal model sets was the German mineralogist Paul Heinrich von Groth (1843–1927), who in 1880 issued a series of 743 models. Groth, considered a founder of modern crystallography, was a Professor of Mineralogy at the Universities of Strassburg and Munich in the late 1800's. Working together with the mineral dealer Friedrich Krantz (1888–1926), he made and sold complete sets for 1,200 Marks, and later in 1887 issued a supplementary set of 213 models.

As one might expect, complete sets are very hard to find these days, and the existing sets are not identical due to periodic changes and substitutions made by Groth. Therefore, in order to sort out this confusion and make Groth's work more accessible to the modern student of crystallography, Uli Burchard has produced a book of computer-generated crystal drawings and supportive data relating to the original 743-model set. Each model diagram is fully labeled as to mineral species, space group, axes, and the Miller indices of the forms shown. These are then indexed alphabetically by species. The book is priced at $100, but for $300 you get the book plus the SHAPE program for computerized crystal drawing and a complete computer file of the Groth crystal model data. Uli will be demonstrating this system during the Tucson Show at the show office in the Executive Inn; or write to Uli c/o Martin Zinn, P.O. Box 2433, Evergreen, Colorado 80439.



The Mineralogy, Geology and Occurrence of Topaz

Michael A. Menzies
#28, 1901 Varsity Estates Drive N.W.
Calgary, Alberta, Canada, T3B 4T7

Topaz occurs in a range of fluorine-rich silicate environments, from plutonic through volcanic, and very rarely metamorphic. Gem crystals in cavities form under more limited conditions, primarily in granite-derived pegmatites, greisens and rarer hydrothermal veins, as well as in some rhyolites. Such deposits worldwide produce a variety of habits and colors of this popular mineral and gemstone.

Introduction

Topaz is an aluminum fluorosilicate with the formula $Al_2SiO_4(F,OH)_2$, in which hydroxyl (OH) can substitute up to 30% for fluorine (F). It shares a common nesosilicate structure, based on the simple silicate tetrahedron, with other aluminum silicates (kyanite, andalusite and sillimanite) and garnets. These minerals are typically hard with relatively high specific gravities and form rather equant crystals (Sinkankas, 1964). Compositionally topaz is aluminum-rich, a factor shared by the above aluminum silicates and garnets, as well as tourmaline and micas (Clarke, 1981; Černý and Hawthorne, 1982).

Topaz occurs worldwide in specimen-quality crystals and gem-grade stones. There are many descriptions of topaz in specific pegmatites and other deposits, but general literature focusing only on topaz is rather sparse. Jones (1980), Pough (1986) and Scovil (1993) have published general reviews, Deer *et al.* (1982) provide a comprehensive mineralogical description, and Ribbe (1980) describes crystallography and physical properties. Detailed crystallographic data are also provided in a much earlier text by Hintze (1897). Recent activity, however, includes two other major projects in parallel with the one reported here. Foord *et al.* have studied the environment for the crystallization of topaz (Foord *et al.*, 1990; Foord, 1991), and the book by Hoover (1992) focuses on topaz as a gemstone. Much of the earlier work on the geological environments of topaz was carried out by Russian workers including Fersman (1925, 1932, 1940), Beus (1966), Shcherba (1970), Naumov *et al.* (1977) and Ginsburg *et al.* (summarized in Černý, 1982b, c). Pegmatite investigators in the U.S., notably Jahns (Jahns and Burnham, 1969; Jahns, 1982), also made important contributions. More recently there has been a broad resurgence in interest in granites and their and mineralization, with studies in particular by Burt (1981), (Cerny (1982a, 1991a and b), Strong (1985) and London (1990), providing new insights into formation of topaz.

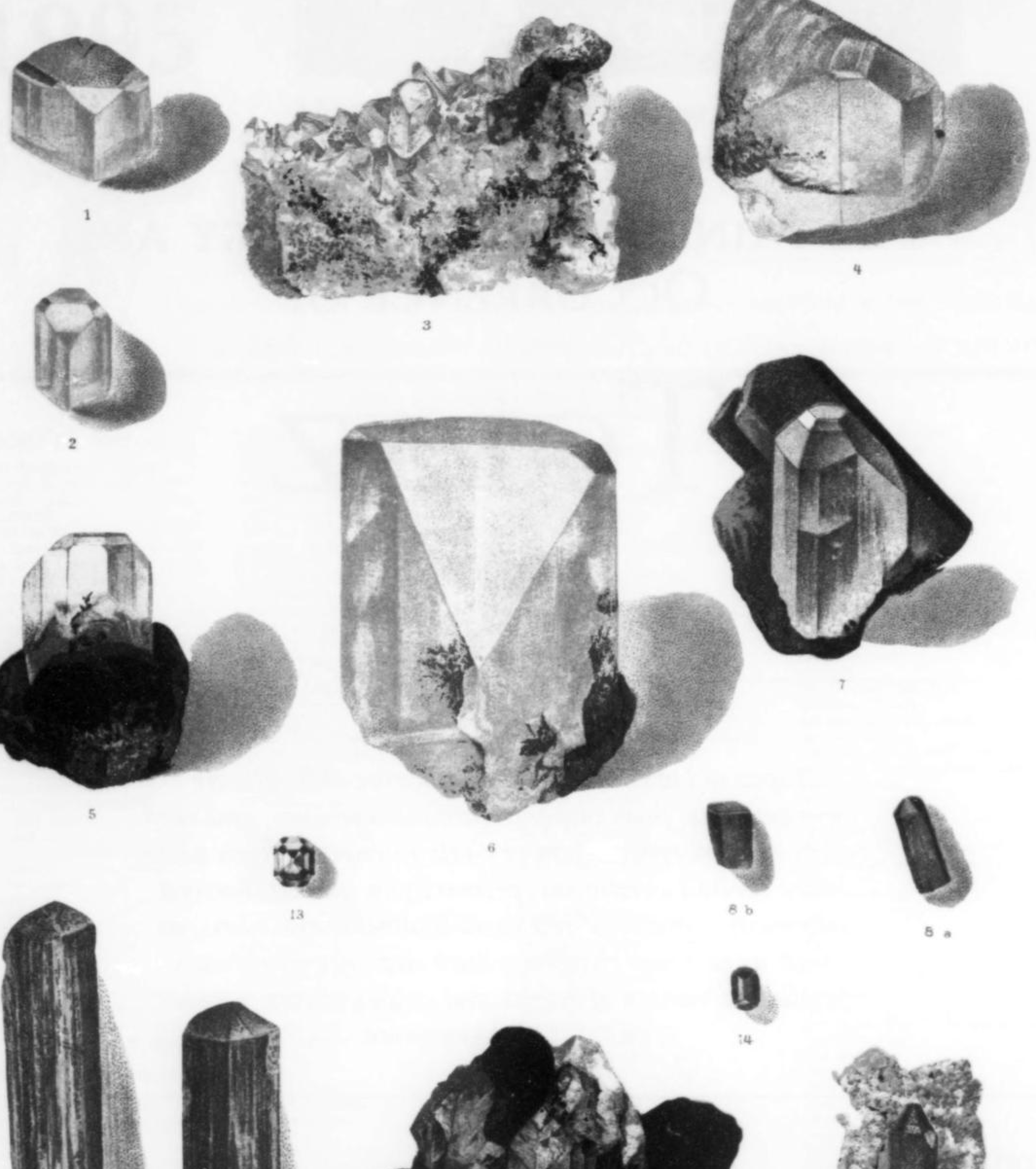


Figure 1. Topaz specimens illustrated in Reinhard Braun's *The Mineral Kingdom* (1908). 1, 2, 3 = Schneckenstein, Saxony. 4 = Urulga River, Nerchinsk district, Siberia. 5 = Mt. Makrushi, near Alabashka, Mursinka, Ural Mtns., Russia. 7 = Mursinka, Ural Mtns., Russia. 8, 14 = Sanarka River gold placers, Orenberg, Russia. 9, 10, 13 = Minas Gerais, Brazil. 11 = Adun Chilon, Nerchinsk district, Siberia. 12 = Nathrop, Colorado.

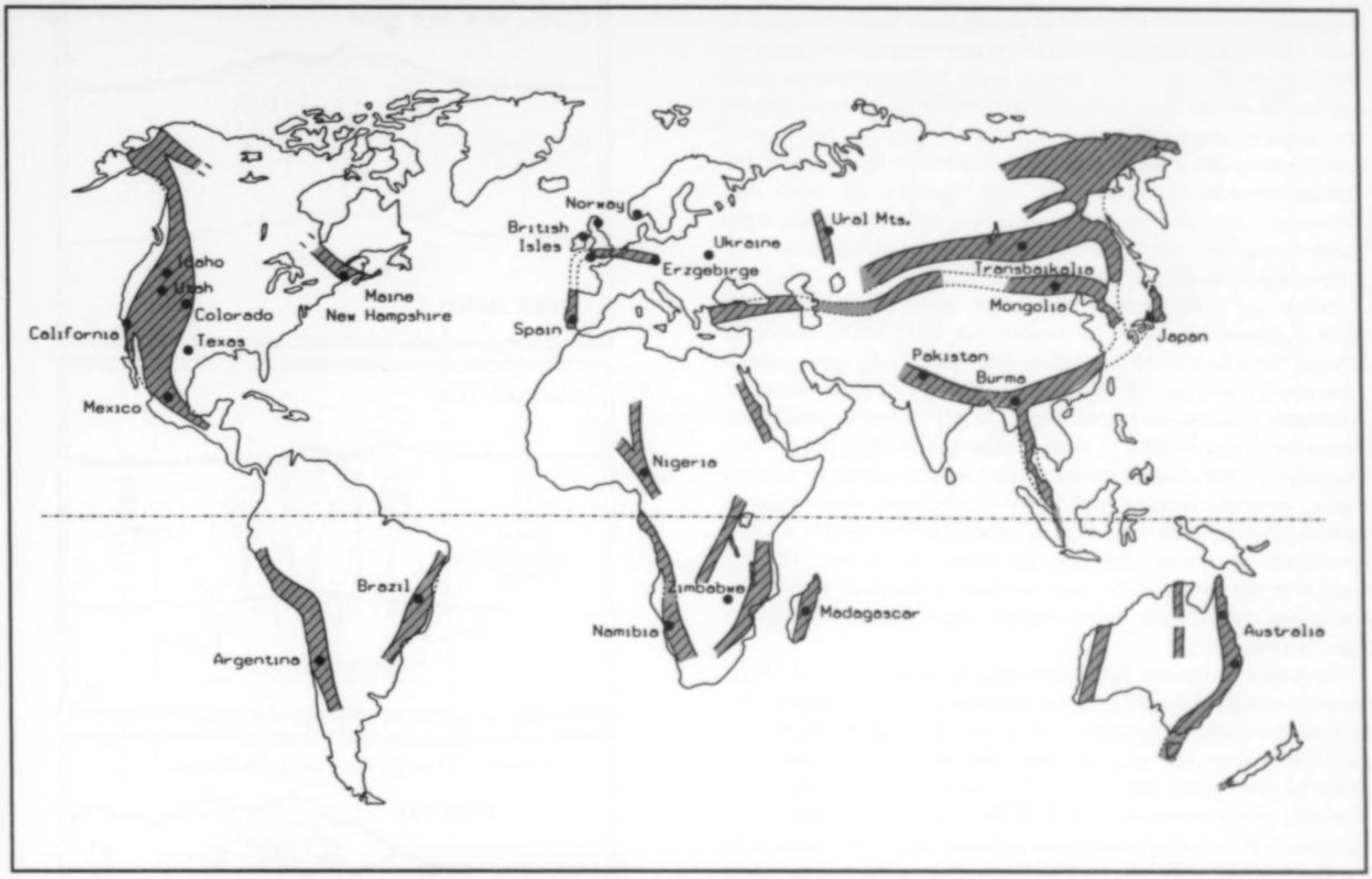


Figure 2. **Rare-metals belts and major topaz deposits (modified after Shcherba, 1970). The rare-metals belts which are shown cross-hatched, correspond well with topaz deposits marked by filled circles. Typically such belts are related to tectonic activity which gives rise to high levels of mineralization. The map shows major deposits for well-crystallized topaz, plus selected other occurrences worldwide.**

Drawing on this large body of knowledge, this article addresses questions including: how does topaz form?; what are the conditions required for good crystals?; and how does the geological environment influence topaz crystal features and associations?

Geology

Geological environments for topaz range from plutonic through volcanic, and more rarely metamorphic. It derives primarily from highly evolved granites and rhyolites that are rich in both silica and fluorine. Especially in granites, topaz formation conditions range from high-temperature magmatic conditions, through late-stage magmatic and early hydrothermal occurrence in pegmatites and greisens, to the lower temperature hydrothermal regime of vein deposits.

Most topaz is primary, but it also replaces early silicates, especially feldspars. Good crystals form in open cavities from fluorine-rich fluids that have separated from the magma. Due to this requirement for phase separation, such topaz forms at shallow depths (to a maximum of an estimated 10 kilometers).

The parent magma is created through partial melting of rocks deep within the continental crust (Clemens and Wall, 1981; Collins *et al.*, 1982) within typically long-lived, tectonically active zones. Shcherba (1970) identifies corresponding "rare-metals belts" on all continents, as in Figure 2. Such belts are typically related to rifting within mature continental crust, or to collisions primarily involving continental plates. Productive rift settings include aborted rifts as well as mantle "hot spots" or domal uplifts (Sillitoe, 1974; Mitchell and Garson, 1981; Burchfiel, 1983). Aborted rifts, if recognized, are commonly young structures that provide a conduit for rising magmas, but without the full development that typically opens new ocean basins. Both hot spots and domal uplifts tend to occur in areas of old (Precambrian) crust.

Figure 3 depicts tectonic settings for topaz deposits. Although these are common to other granitic deposits, some are particularly favorable for topaz. The parent magmas originate in two major regimes. The **orogenic** process of crustal compression has formed the world's major chains of fold-belt mountains, such as the Andes. In contrast, the **anorogenic** regime involves crustal extension, typically resulting in rifting. The two regimes may even be linked, when rifting follows the release of compression.

Anorogenic (also termed A-type) magmas solidify at shallow depths as granite, or less commonly erupt volcanically as rhyolite. These magmas have high ratios of fluorine to water, as described by Christiansen *et al.* (1986), Hess (1989) and Eby (1990). Evolution at deep crustal levels allows more time for concentration of trace elements, in particular fluorine, as the magma rises. Such igneous activity is characteristic of crustal extension during rifting or faulting, regional uplift, and deformation above hot spots. The resulting small, late-stage granite plutons are common in prominent rift zones such as in the western U.S. Anorogenic intrusions are the most common sources for topaz, typically with regionally related hydrothermal fluorite deposits, as in the western U.S. and Transbaikalia, eastern Siberia (van Alstine, 1976).

The second (orogenic) regime is typical of tectonic collision between a continental plate and either another continental plate (as in the Himalayas) or an oceanic plate (as in California). Resulting magmas are commonly created at shallower levels than for anorogenic types, with higher water contents and a broader range of compositions. They intrude as granites that form a much higher proportion of the continental surface than anorogenic granites. Orogenic topaz granites are, however, uncommon and usually form only in the late tectonic stages from highly evolved magmas that reach the shallowest levels. Continent-continent collisions are more favorable for topaz than subduction at oceanic-continental margins. In the latter case, topaz granites may form late in the tectonic sequence and inland from the primary magmatism (the "back arc" in Figure 3c).

Irrespective of the tectonic regime, the intrusive source rock for topaz is almost always a true granite, per the IUGS classification scheme (Streckeisen, 1976), rather than one of the other quartz-feldspar-rich plutonic igneous rocks. Typically it is a biotite (± hornblende or muscovite) granite that is highly evolved, light-colored (leucocratic), and intruded to shallow depths at the latest stage in any magmatic episode. Topaz granites are the youngest intrusive rocks in a region, generally forming roof zones of intrusions where volatiles such as fluorine reach their highest concentrations. Such rocks are uncommon worldwide. True granites form only around 10% by volume of the earth's crust, corresponding to less than 15% of the continental crust (Condie, 1976), and the highly evolved, fluorine-rich types are still rarer.

The main requirements for the formation of topaz, ($Al_2SiO_4(F,OH)_2$), are an excess of aluminum over that required to form feldspars, and a high concentration of fluorine. Fluorine, which is a common volatile component of granite magmas, plays the more crucial role. It is produced deep within the crust from breakdown of amphiboles and especially micas as source rocks melt to form magma (Skjerlie and Johnston, 1992). Even so, fluorine is typically only a trace element in granitic magmas, and it must be concentrated to a considerable degree in magmas or late-stage residual fluids to form topaz. Variations in source-rock fluorine content and how efficiently it is concentrated determine in large part the formation or absence of topaz. Water, the other key magmatic volatile (Whitney, 1988), is essential to many mineralizing processes, and is particularly important in the formation of topaz where its hydroxyl component can substitute for fluorine.

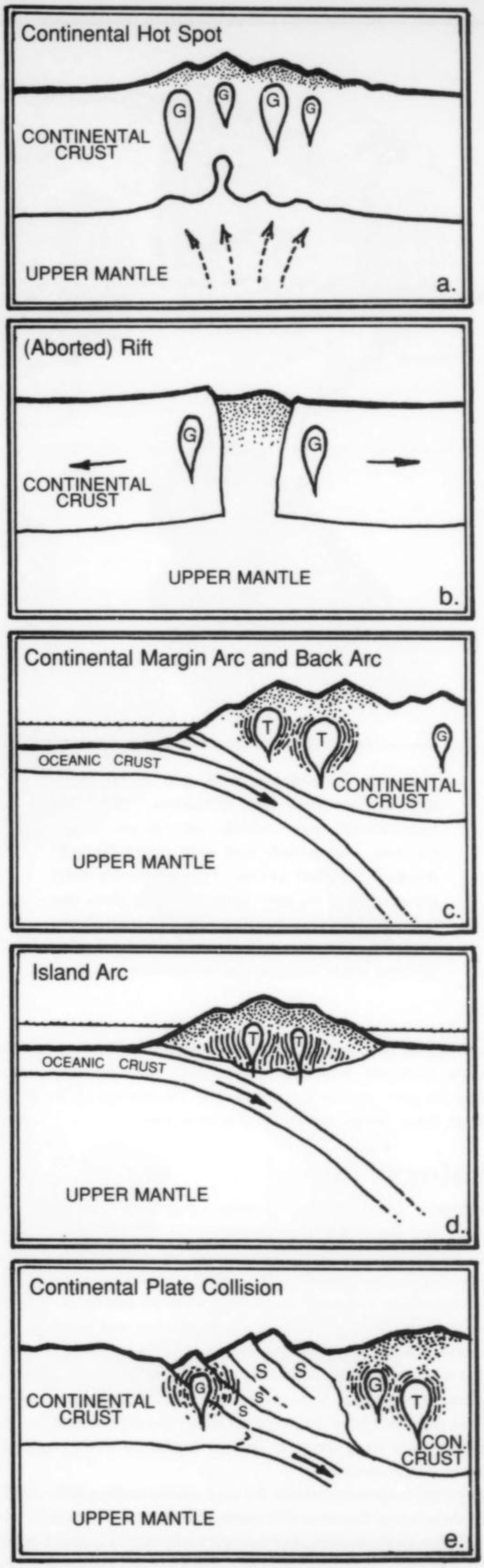


Figure 3. **Tectonic regimes for topaz granites and rhyolites (modified after Mitchell and Garson, 1976). Topaz is associated almost universally with continental crust, especially its reworking above tectonically active zones. The most important settings for topaz are (b), (e) and the back arc in (c). Island arcs are involved in a very few more complex tectonic settings. Pitcher (1982) describes these tectonic settings in more detail. Stippled = volcanic rocks; lined = metamorphic rocks; G = granite; T = tonalite-granodiorite; S = sediments.**

Examples:

(a) Continental Hot Spot: Jos Plateau, Nigeria; Transbaikalia, Siberia; Klein Spitzkopje, Namibia

(b) (Aborted) Rift Zone: Volhynia, Ukraine; Western U.S. (topaz rhyolites)

(c) Continental Margin Arc: Peninsula Ranges Batholith, California; Back Arc: Western U.S., northern Burma

(d) Island Arc: Southwest Japan

(e) Continent–Continent Collision: Northern Pakistan; Cornwall and Erzgebirge, Europe

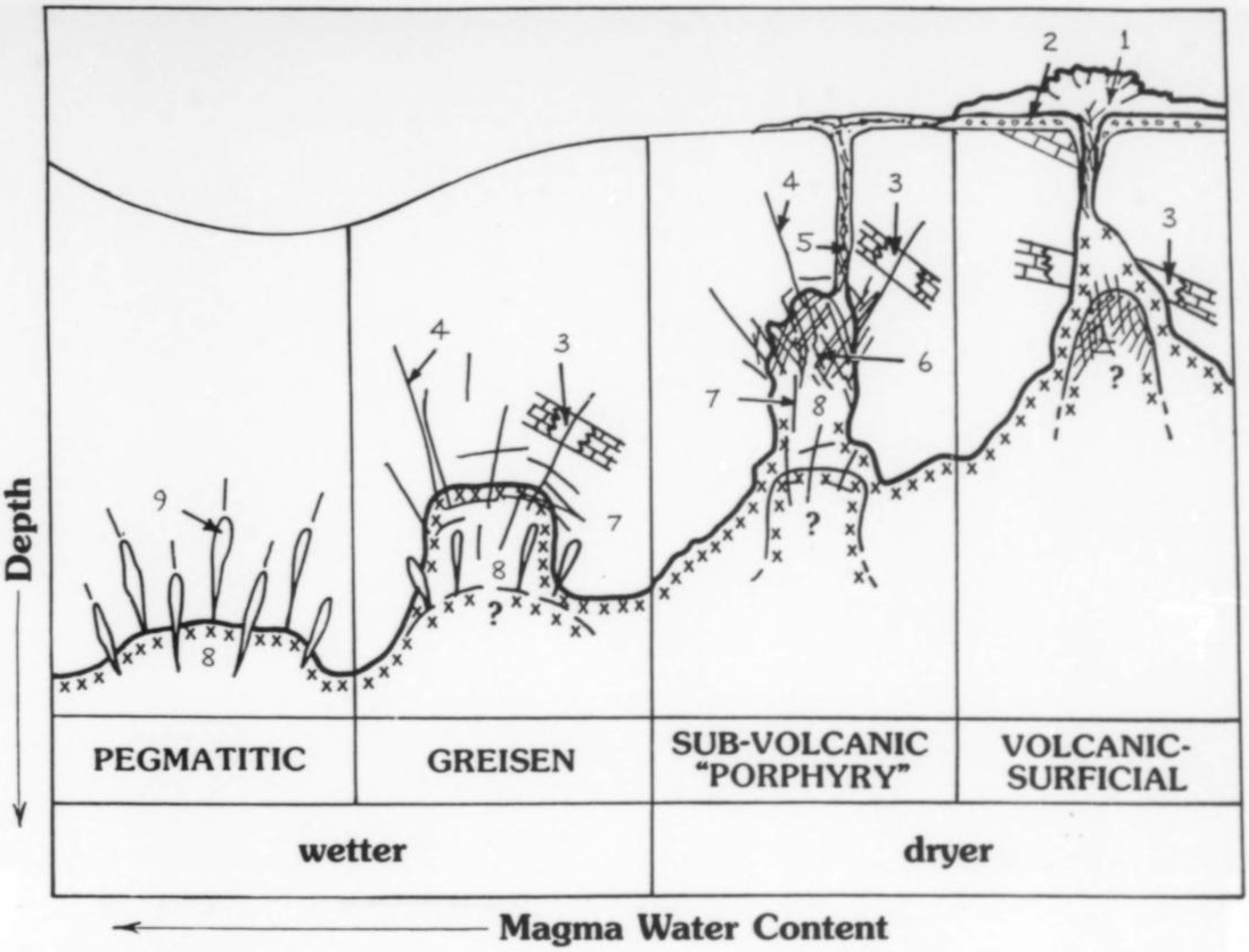


Figure 4. **Deposit types formed from fluorine-rich magmas (modified after Burt *et al.*, 1982). Deposit types are ordered by increasing depth and magma water content.**

Key:
1. **Topaz rhyolites and volcanic tin deposits**
2. **Pyroclastic (explosive volcanic) beryllium deposits**
3. **Skarns**
4. **High-temperature veins**
5. **Breccia pipes**
6. **Porphyry greisens**
7. **Greisens**
8. **Miarolitic cavities in granite**
9. **Pegmatites**

Deposit Types and Occurrence

Attempting any survey of deposits poses a challenge, due in part to overlaps and ambiguities in deposit types, as well as problems in choosing individual vs. groups of deposits vs. regional groupings. Such a survey was made, however, to show the relative importance and regional distribution of deposit types for well-crystallized topaz. Over 80 specific and regional deposits are included in over 40 countries worldwide.

About 80% of the deposits are pegmatites, about 10% are rhyolites, and the remainder are greisens, rare veins and very rare skarns. The deposit types are distributed worldwide, except for the rhyolites that all occur along the same geological trend in the western U.S. and Mexico. Within the pegmatite group, the complex, zoned intrusive type outnumber the simple miarolitic-cavity variety. More than 85% of the deposits fall within Shcherba's "rare metals belts." Close to 20% occur along the single major belt that runs from Alaska to Mexico and includes the rhyolites. The few that fall outside these belts (e.g. in central Texas, southern Norway and Zimbabwe) are generally in areas of old, stable continental crust (cratons) that have not seen igneous activity since Precambrian time.

Pegmatites (especially those in Minas Gerais, Brazil) produce the bulk of gem topaz and are also very important specimen sources. Rhyolites also provide excellent specimens. Neither greisens nor veins are generally important for either gems or specimens, but one outstanding exception may be Brazil's "imperial" topaz mines that appear to represent an unusual type of vein deposit.

Figure 4, from Burt *et al.* (1982), is a schematic diagram showing the range of deposit types, which the authors suggest may develop in a single district through successive magmatic episodes, all from a common source. These deposit types are described in more detail in Table 1.

Volcanic

RHYOLITES

In rhyolites, topaz crystallizes at high temperatures within cavities formed by the release of fluorine-rich gas directly from volcanic magmas at surface conditions.

Excellent topaz specimens occur in a unique belt of rhyolites that extends from Utah and Colorado into Mexico, along the southern section of a major rift/fault system. This system shows widespread plutonic and volcanic activity (van Alstine, 1976; Cook, 1966). Burt *et al.* (1982) and Christiansen *et al.* (1986) describe a total of 26 shallow, extrusive "topaz rhyolites" or "rare-metal rhyolites," mostly less than 30 million years old. These span both sides of the Colorado Plateau, mainly in Utah and Colorado. Typically they have extruded as small

***Figure 5.* Topaz crystal group, 8.5 cm, from rhyolite, Thomas Range, Utah. Utah Mineral and Fossil Company specimen; photo by Jeff Scovil.**

lava domes with and without banded flows, which generally overlie earlier flow breccias and other explosive volcanic deposits. Formation temperatures are estimated at between 850° and 600°C, with most toward the lower end of this range. Other features include unusually high levels of silica, fluorine and rare metals. The authors suggest formation from fractional crystallization of magmas with around 0.2% fluorine, producing up to 1% fluorine in the rhyolites.

Not all of these rhyolites produce topaz. Some of those emplaced through reactive (carbonate) rocks host only low-temperature mineralization, e.g. the Spor Mountain, Utah, beryllium (bertrandite) deposit. The topaz-bearing group forms in unreactive host rocks, with more rapid crystallization and less enrichment in rare metals. Superior specimen localities include the Thomas Range and Wah Wah Mountains of Utah, and Ruby Mountain, Nathrop, Colorado.

The best-known and most voluminous **Thomas Range** rhyolites formed as coalesced domes and banded flows. A total volume of around 50 km^3 of lava, covering an area of around 100 km^2 flowed from at least 12 separate vents between 6 and 7 million years ago. Many of these rhyolites contain cavities termed *lithophysae* (common to high-silica volcanic rocks), formed by the release of gas. Such cavities are bordered by thin, concentric shells of finely crystallized quartz and sanidine feldspar, with intervening voids. Ream (1979) describes the Thomas Range lithophysae as up to 20 cm across and flattened in the direction of lava flow. Typically they are concentrated along flow bands (alternating gray and maroon layers), and occur isolated within solid to spongy rhyolite At some localities, especially where cavities are larger, lithophysal structure may not be evident and the cavities can also show irregular shapes. Cavities may also be lined with drusy lavender-colored quartz.

Topaz is locally abundant in the lithophysal and other cavities and also occurs in open fractures and frozen in rhyolite. In cavities, topaz crystals to 4 cm or more and typically intergrown occur loose or loosely attached to the walls, making good matrix specimens uncommon. Most crystals are elongate prisms, commonly highly lustrous and gemmy to varying degrees. Sandy inclusions of microcrystalline quartz produce a range of qualities, from otherwise gemmy crystals with sandy zones corresponding to points of attachment, through completely sand-included crystals that are still lustrous, to rough-surfaced crystals with ragged terminations. These may all be present within the same cavity or to a lesser degree in the same specimen. Some doubly terminated crystals are hemimorphic, with one termination showing a more pronounced $c\{001\}$ face. Colors range locally from yellow through sherry to rose-pink. The yellow to sherry tones are readily bleached by sunlight in only a few days of exposure, leaving colorless crystals, but in other areas a pink color remains; these latter crystals are usually smaller, reaching only 2 cm. The pale to medium pink topaz from the northern part of the range appears to be colored by Mn^{3+} in an outer zone (Foord *et al.*, 1995). Associated minerals include quartz, hematite, bixbyite (uncommonly in oriented "chains"), pseudobrookite, almandine-spessartine garnet, and tabular crystals of red beryl. The attached crystals of bixbyite, garnet and other species show that rhyolitic topaz is an early to mid-stage mineral. Topaz crystals from the red beryl areas are characteristically slightly etched. Garnet is commonly highly altered to topaz and bixbyite/hematite, showing overgrowths of epitaxial, reticulated topaz and/or bixbyite crystals. Topaz may also occur as a second generation of late-stage microcrystals (E. E. Foord, personal communication, 1993). An unusual tin-bearing volcanic vent deposit produces topaz both as intergrown, colorless microcrystals and as fully terminated blades to 2 cm that appear black due to heavy inclusions of hematite (Wilson, 1986).

The well-known topaz rhyolites of central Mexico (Durango, Zacatecas, San Luis Potosi and Guanajuato) are described by Sinkankas (1959 and 1976), Burt and Sheridan (1985), and Panczner (1987). Burt

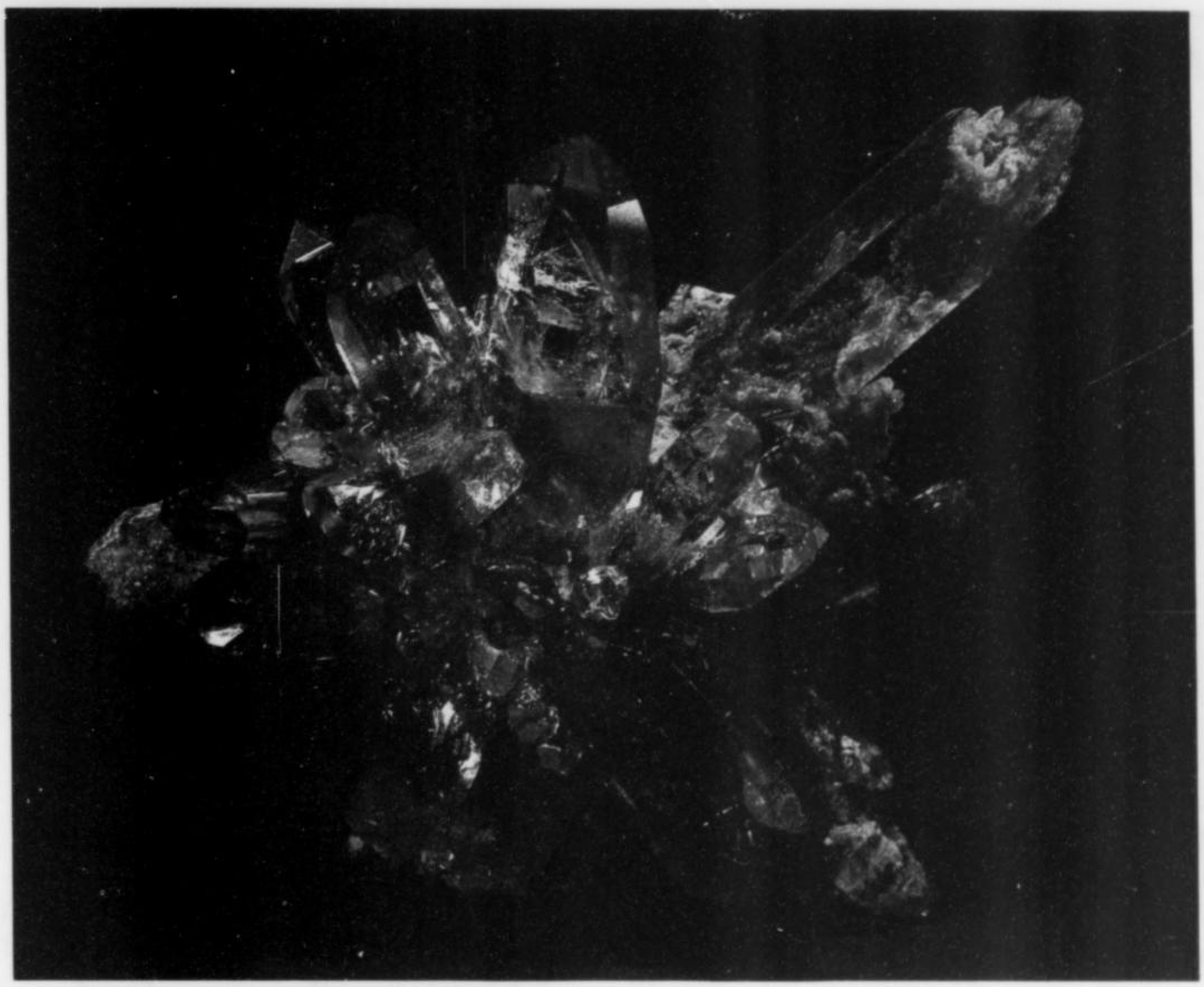


Figure 6. Topaz crystal cluster, 2.5 cm high, from rhyolite, Thomas Range, Utah. Some crystals show sandy inclusions. This specimen was collected by Ed Over. U.S. National Museum of Natural History collection; Joel Arem photo.

Figure 7. Topaz crystal, 2.3 cm high, on rhyolite, from Thomas Range, Utah. Tim Sherburn collection; Jeff Scovil photo.

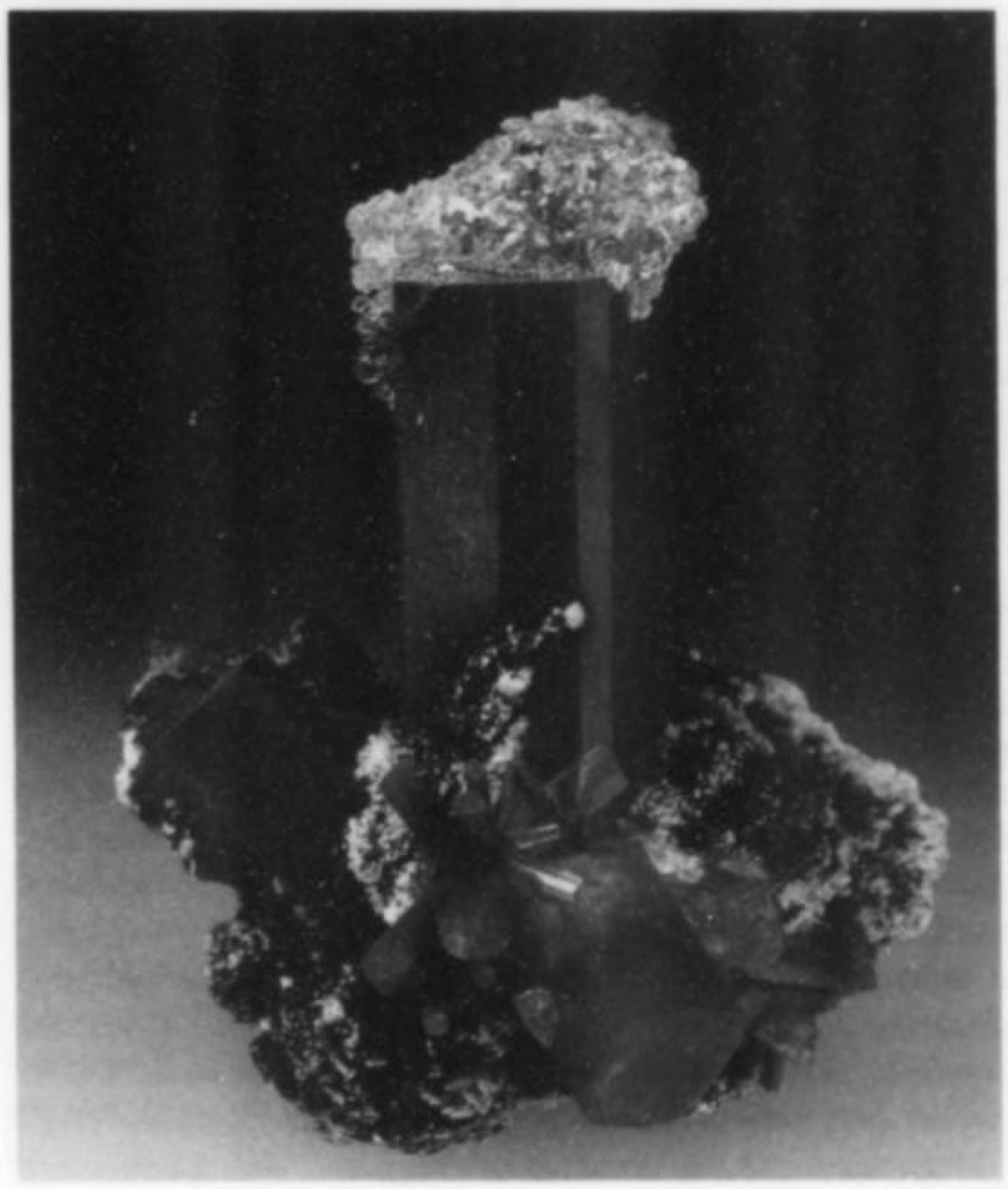


Figure 8. Topaz crystal cluster, 3.5 cm high, from rhyolite, Tepetate, San Luis Potosi, Mexico. Crystals show only the prism faces, *m*{110} and *l*{120}, and the pinacoid termination, *c*{001}. The largest crystal has hyaline opal on its termination. Dave Bunk Minerals specimen, now in author's collection; Jeff Scovil photo.

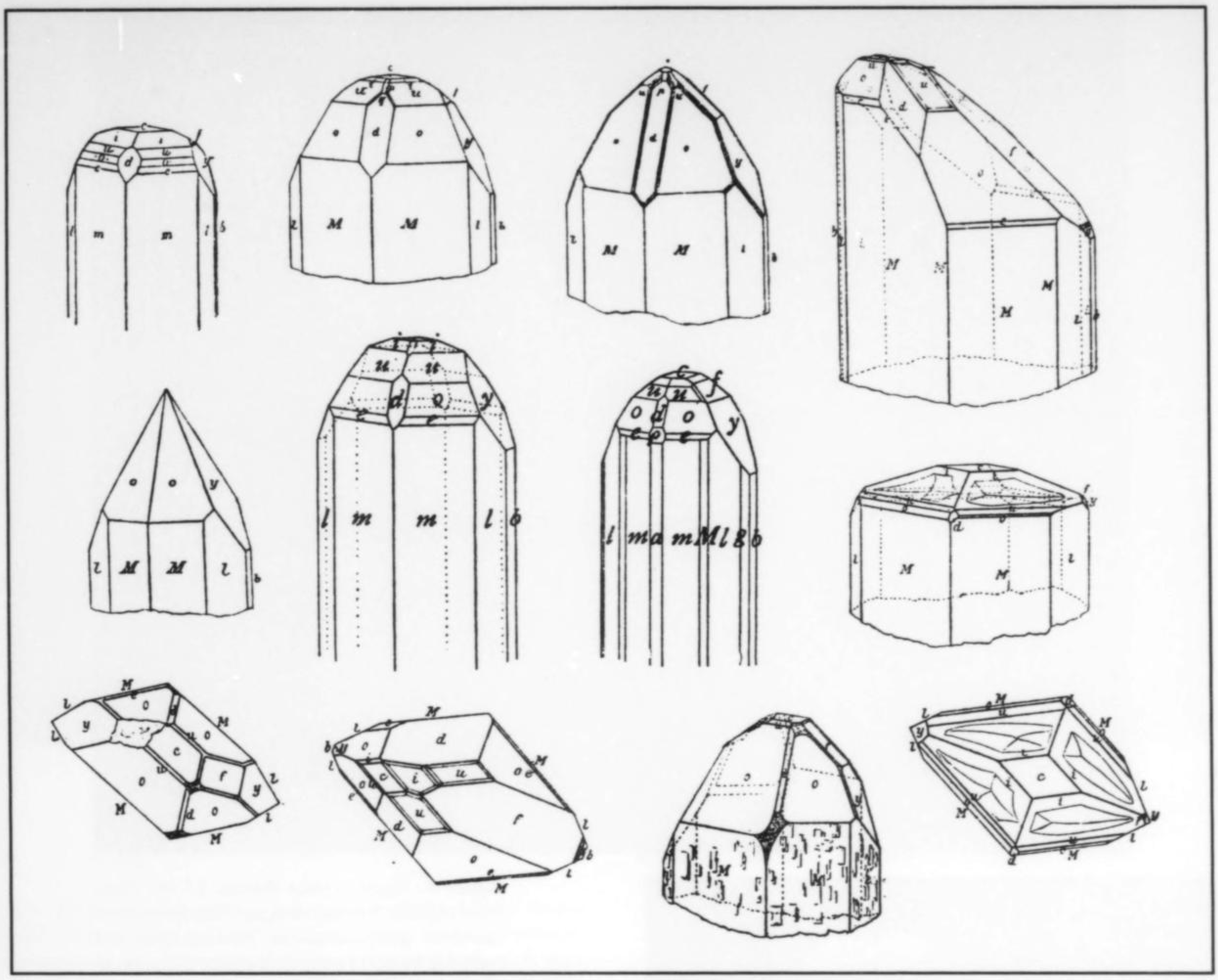


Figure 9. **Topaz crystal habits, Thomas Range, Utah (Goldschmidt, 1922).**

and Sheridan report that the Mexican deposits appear related to a common magmatic episode around 30 million years ago. In contrast to the rhyolites of the western U.S., these rhyolites lack garnet, contain tin rather than molybdenum, and are associated with boron-rich intrusions. The topaz crystals themselves are very similar to those from Utah, though some have a more pronounced reddish hue due to included hematite. Sinkankas (1959) describes the representative deposit near Tepetate, southwest of San Luis Potosi.

Magmatic

GRANITES, ONGONITES AND TOPAZITES

There is growing evidence that topaz can crystallize directly from magmas or residual melts rather than a separated aqueous fluid. Such magmatic topaz is, however, probably under-recognized since it typically forms small, subhedral crystals to anhedral grains, and is often mistaken for apatite in thin section (D. M. Burt, personal communication, 1994). It occurs as an accessory, rock-forming mineral in some particularly fluorine-rich granites (Weidner and Martin, 1987; Haapala and Rämö, 1990; Taylor, 1992; Cuney *et al.*, 1992) and topaz rhyolites (Christiansen *et al.*, 1986; Congdon and Nash, 1991). Uncommon early-stage topaz in pegmatites is also probably magmatic. Magmatic topaz also occurs in rare ongonites and topazites that are of particular interest due to their exceptionally high fluorine contents.

The **Brown Derby No. 1 pegmatite** in Gunnison County, Colorado, is described by Rosenberg (1972). In most respects it is a typical lithium-rich, epigenetic pegmatite, though it has an unusually high fluorine content. Very large topaz crystals up to 1.2 meters long apparently formed in an upper, potassium-rich zone of a water-rich residual melt. Rosenberg suggests formation from a separated aqueous phase, but there are no cavities or other evidence of such a separation, and the topaz can be considered magmatic (D. M. Burt, personal communication, 1994). The topaz crystals evidently settled under gravity in the compositionally zoned residual melt and, in spite of some alteration to muscovite, were preserved in quartz pods at the base of the core zone. Other core zone minerals include quartz, albite, lepidolite, and minor microlite.

Ongonite, rock consisting predominantly of quartz, topaz and albite with variable mica. are near-surface (sub-volcanic) equivalents of lithium-fluorine granites and topaz rhyolites that appear to represent quenched magma. They occur as dikes in Finland, Kazakhstan, Transbaikalia in eastern Siberia, Mongolia (Kovalenko and Kovalenko, 1984), and Arizona (Kortemeier and Burt, 1988). While geologically interesting, ongonites produce only micron-sized, acicular crystals of topaz frozen in host rock.

Topazites are rocks consisting predominantly of quartz and topaz

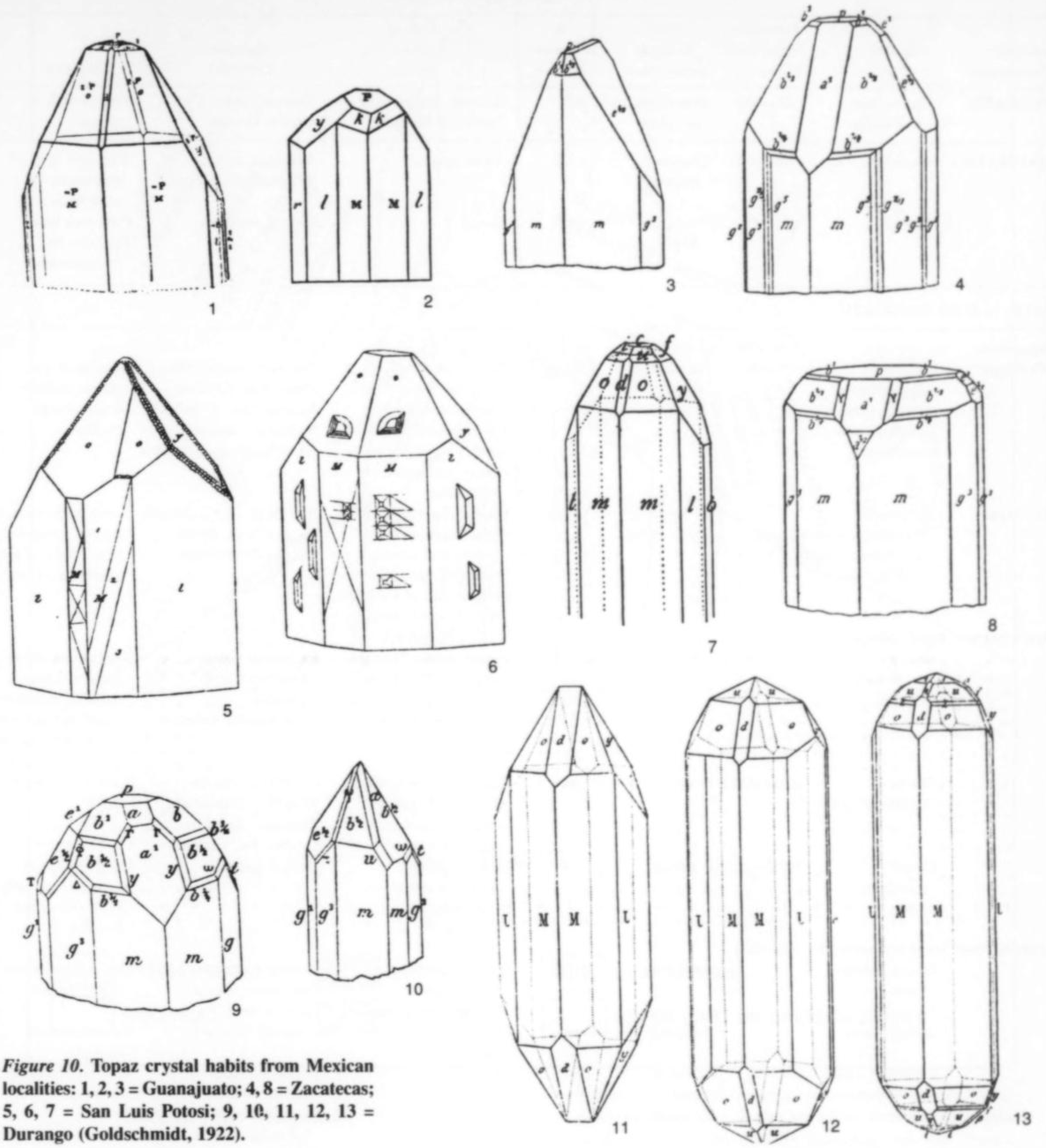


Figure 10. **Topaz crystal habits from Mexican localities: 1, 2, 3 = Guanajuato; 4, 8 = Zacatecas; 5, 6, 7 = San Luis Potosi; 9, 10, 11, 12, 13 = Durango (Goldschmidt, 1922).**

with variable mica. Such rocks are reported from three areas of eastern Australia: near Eldorado in northeastern Victoria (Birch, 1984), in the New England Batholith (Eadington and Nashar, 1978; Kleeman, 1985), and the Mount Garnet region of north Queensland (Johnston and Chappell, 1992). They also occur in Arizona (Kortemeier and Burt, 1988). In Australia they form dikes, sills or pods associated with biotite granites; in Arizona topazite dikes grade into ongonites. Topaz generally occurs only as microcrystals, reported in cavities only in Victoria and New England. The Queensland occurrence may be unique in hosting larger cavities with gem crystals, though Birch (1984) suggests that topazites may be the source of widespread alluvial topaz in Victoria.

It appears that not all topazites are magmatic. Some evidently form hydrothermally through separation of an aqueous fluid from the magma (Kortemeier and Burt, 1988), as shown by the presence of topaz in cavities in the Australian occurrences. In Arizona, there is also evidence of fluid separation following crystallization of topaz. This is apparently the cause of alteration and mineralization of rocks surrounding the topaz-bearing dikes. No cavities are reported, but there is some fracture filling by beryl.

Table 1. **Deposit types for topaz.**

Geologic Environment	*Deposit Type*	*Formation Temperature (Deg C)*	*Fluid Activity/ Replacement*	*% Fluorine in Rock*	*Typical Associated Species*	*Example Localities*	*Comments*
VOLCANIC	Gas cavities in Rhyolite	850–600	Deposition from gas phase	<1	Bixbyite, garnet, quartz hematite, Mn-beryl	Thomas Range, Utah Central Mexico	Fine crystals & groups
MAGMATIC	Ongonite	1000–600	Quenched magma	<3.5	Albite, quartz	Young, Arizona Transbaikalia, Siberia	Rare rock type—equivalent of rhyolite
	Topazite	ca. 600	Phase separation?	<6.5	Quartz	Eastern Australia	Rare rock type May also be hydrothermal
LATE- to POST-MAGMATIC							
Pegmatites:		750–<300[1]		<1			
-NYF type[2]	Syngenetic Pegmatites in granite (simple cavities, zoning uncommon)	750–450	Localized, slight	Higher	Quartz, albite, microcline (incl. amazonite), zinnwaldite, fluorite, iron species. Uncommonly beryl, phenakite, rarely spessartine, tourmaline	Sawtooth Range, Idaho Pikes Peak, Colorado Mourne Mts., N. Ireland Volhynia, Ukraine Klein Spitzkopje, Namibia	Commonly excellent crystals, many of gem quality
-LCT type[2]	Epigenetic Pegmatites, intruded into country rocks (complex, zoned)		Extensive in inner zones	Lower	Quartz, microcline, albite, lepidolite/muscovite, tourmaline, fluorite, columbite-tantalite. Other lithium and rare-element species, rarely beryl.	San Diego Co., California Minas Gerais, Brazil Pakistan/Afghanistan	Topaz uncommon. Fine crystals, commonly large, many of gem quality, in cavities
Hydrothermal: higher-temperature							
	Greisens (in or associated with granites)	550–300	Intensive to extensive	High to very high	Quartz, micas, fluorite, cassiterite. Tungsten species in some deposits. Less commonly beryl, tourmaline	Erzgebirge District, Germany/Czech Republic Transbaikalia, Siberia	Smaller crystals in cavities. Topaz typically intergrown. Significant portion of host granite may be converted to topaz.
	Skarns (in carbonate rocks)	>500–400	Extensive	Low	Calcium silicates, micas, tourmaline, fluorite, magnetite, cassiterite, sulfides	Lost River, Alaska Trumbull, Connecticut Tasmania, Australia Laacher See, Germany	Rare occurrence for topaz
	Quartz (-Feldspar) Veins	>400–<300	Intensive	Low	Quartz, feldspars, muscovite, beryl, cassiterite, molybdenite	Eastern Australia	Good crystals in cavities, especially in nearer-surface deposits
Hydrothermal: lower temperature		400–<200					
	Quartz-Feldspar Veins		Intensive	Low	Quartz, cassiterite. Also euclase, hematite, rutile (Brazil)	Eastern Australia Ouro Preto, Minas Gerais, Brazil	Fine crystals, some of gem quality
	Sulfide Veins		Extensive	Low	Quartz, sulfides, fluorite	Cornwall, England	Rare occurrence for topaz
	Carbonate Veins and Alpine Clefts	ca. 200	Extensive along fractures	Low	Calcite, quartz	Brumado, Brazil Mardan, Pakistan Untersalzbachtal, Salzburg, Austria Val Lugnez, Grisons, Switzerland	Very rare occurrence for topaz
High-grade Metamorphic Sedimentary		High	Extensive	High	Quartz, sillimanite, kyanite	Tanzania Colorado South Carolina	Massive material
	Eluvial		Decomposition of deposit		Durable minerals of original deposit	Minas Gerais, Brazil	Fine crystals
	Alluvial		Transported by water		Durable minerals of original deposit	Minas Gerais, Brazil Eastern Australia Sri Lanka	Typically water-worn crystals

[1] Pegmatite deposits listed in generally decreasing order of temperature

[2] Classification scheme per Černý (1991a)

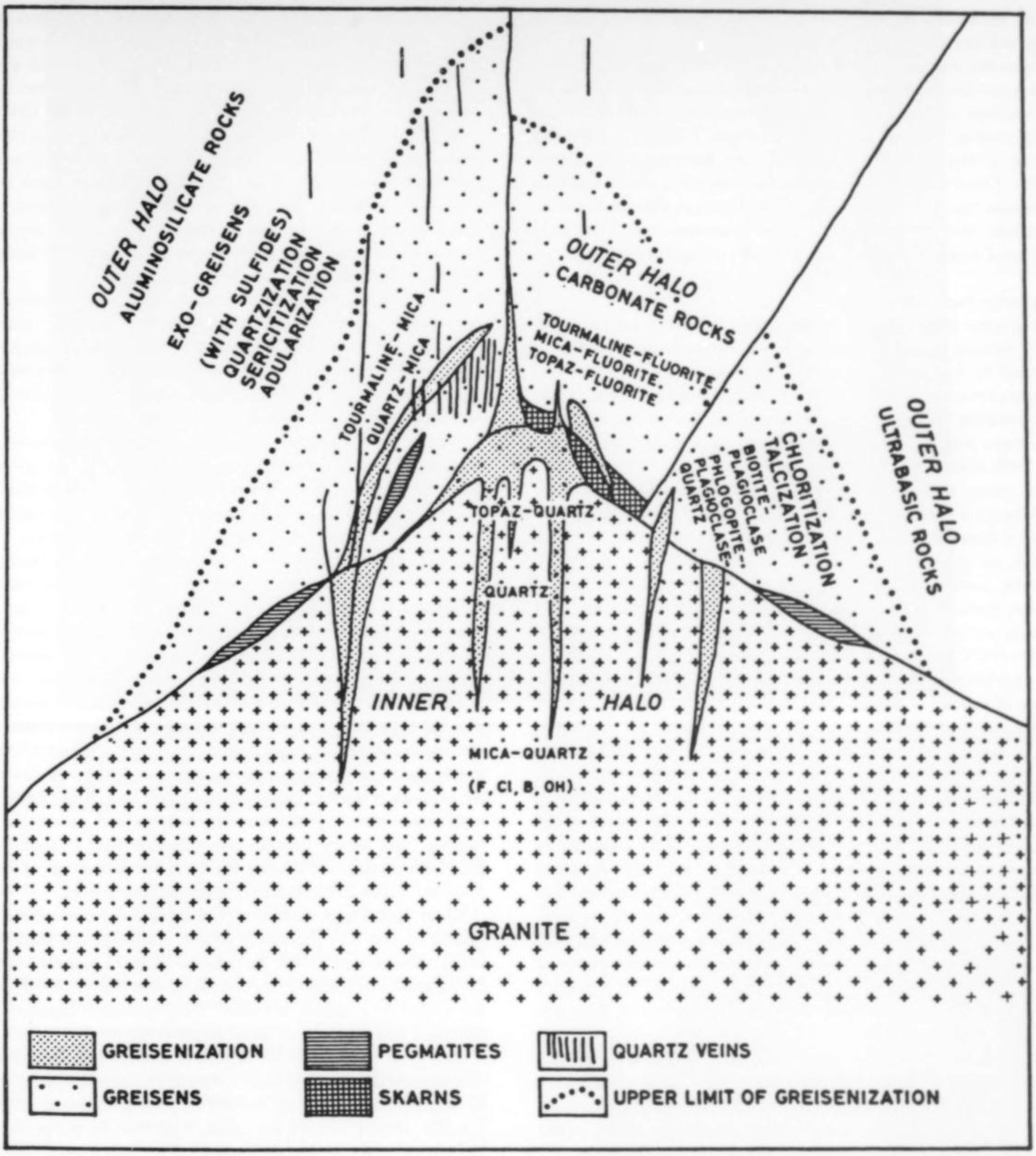


Figure 11. **Mineralization associated with granite intrusions (modified after Shcherba, 1970). Note that miarolitic cavities within the granite intrusion are not shown. Fluorine-rich residual fluids can form a range of deposit types including pegmatites, greisens, skarns and veins. The nature of deposits that form outside the source granite is determined by the type of host rock.**

Late to Post-Magmatic

PEGMATITES

Well-formed topaz crystals are most common in the central cavities of granitic pegmatites. These pegmatites derive from water-rich residual melts remaining in the final stages of crystallization of the source granites. Crystallization may start at temperatures as high as 750°C, continuing down to 300°C or even lower (Naumov *et al.*, 1977). Topaz is commonly a late-stage primary mineral.

Pegmatites are classified here primarily by mode of formation. The terminology, **syngenetic** (formed with) or **epigenetic** (formed later than), relates to crystallization timing for the pegmatites vs. the enclosing host rocks. Syngenetic pegmatites form during crystallization of and within the host granite vs. epigenetic pegmatites that are intruded into pre-existing country rocks. Syngenetic pegmatites typically have simple, compact shapes and may also be termed "pegmatite bodies" or "pegmatitic segregations." Epigenetic (also termed "intruded") pegmatites commonly show extended dike structures and more complex zoning. Both types may contain central cavities, also termed "miarolitic cavities" (small crystal-lined cavities in igneous rocks). This can lead to ambiguity, especially as smaller syngenetic pegmatites themselves, for which the cavity is typically the major feature, are commonly referred to simply as "miarolitic cavities."

Within this article, the term is used sparingly and solely with regard to syngenetic pegmatites.

Topaz-bearing pegmatites, which are typically shallow, rare-element types, also fall within two other useful classifications. The depths of formation correspond to the two shallowest categories, "rock-crystal bearing" (near-surface) and "rare-metal" (deeper), of a Russian scheme developed by Ginsburg *et al.*, and Rudenko *et al.* (Černý, 1982b). Černý's (1991a) scheme uses the magmatic source to divide pegmatites into two main families. NYF (**N**iobium-**Y**ttrium-**F**luorine) pegmatites broadly correspond to the syngenetic type. The LCT (**L**ithium-**C**esium-**T**antalum) pegmatites are typically epigenetic.

Syngenetic Pegmatites

Syngenetic pegmatites lie wholly within the parent granite, commonly forming compact, coarser-grained pegmatitic segregations, as described by Simonova *et al.* (1985). Many are cavity-bearing. These pegmatites probably fall within the Ginsburg/Rudenko shallow, "rock-crystal bearing" category. Their parent granites, predominantly anorogenic types, are emplaced at shallow depths to perhaps 5 km (Anderson, 1983; Kinnaird and Bowden, 1987).

The parent magmas are calcium-poor, and leucocratic (light-colored) due to a small proportion of mafic (dark-colored) minerals. As expected from their shallow depths, they are typically associated with volcanic rocks and breccia pipes, e.g., in the New England district of Australia. Such magmas are common and form some of the youngest granites, intruded after the latest orogenic episode. Formation temperatures are inferred to be in the upper range of those for pegmatites, i.e. 700–500°C.

Crystal-lined miarolitic cavities are created by separation from the magma of bubbles of aqueous fluid typically rich in fluorine. Smaller cavities are most common, typically to several tens of centimeters. Especially at deeper levels, these may be isolated in the host granite, generally surrounded by only a thin zone of coarser-grained granite, as in the Mourne Mountains, Northern Ireland and the Sawtooth Range, Idaho. Central cavities as large as 20 meters form within some of the more fully developed pegmatite bodies, especially at the upper levels of intrusions, as in the "chamber pegmatites" of the Volyn region of the Ukraine. These deposits commonly show significant alteration and zoning, including characteristic graphic granite surrounding the cavities. Rarely, pegmatites showing most of the compositional and structural features of the syngenetic type may occur within extended granitic dikes, as in Russia's Ural Mountains. Table 2 lists important localities for this type for topaz worldwide, and seven of these are covered in more detail below.

The **Sawtooth Batholith** is one of the largest of around 50 Tertiary granite plutons in Idaho. Although these have been regarded as anorogenic, they are more likely late- or even post-orogenic. Wernicke *et al.* (1987) describe the tectonic sequence starting with crustal thickening during the late Cordilleran orogeny of late Cretaceous age, 85–65 million years ago. The Idaho Batholith, which is partially intruded by the Sawtooth granite, was emplaced at the beginning of this period. Crustal extension followed an estimated 53 million years ago and initiated the major Challis volcanic-plutonic event; its peak around 45 million years ago corresponded with intrusion of the Sawtooth Batholith (Bennett and Knowles, 1985). Continuation or reactivation of this same regional crustal extension also produced the western U.S. rhyolites described earlier.

Extensive glaciation and predominant vertical jointing have produced excellent collecting exposures in the abundant, large talus and high ledges of the Sawtooth Range. Collecting began in the 1970s following reports of aquamarine, and subsequent geologic investigations primarily for beryllium mineralization (Reid, 1963; Pattee *et al.*, 1968; Kiilsgaard *et al.*, 1970). Ream (1989) and Menzies and Boggs (1993) describe topaz as locally abundant in miarolitic cavities that are typically 10 to 50 cm in size. Cavities usually occur isolated in pinkish to pale gray granite with little or no surrounding alteration. Topaz forms short to elongated prisms to 12 cm, typically showing greater development of *m*{110} rather than *l*{120} faces, with prominent *f*{011} face terminations. Lustrous, gemmy crystals are common, though many are etched, primarily on their terminations. Colors range from colorless to sherry and rarely pale blue. Some crystals show outer sherry zones parallel to *a*{100} surrounding a colorless central zone that is very susceptible to etching. Under shortwave and longwave ultraviolet light this central zone may also show strong yellow fluorescence. Several cavities produced very unusual crystals with opaque white zones at the terminations, in one case with overgrowths of small, yellowish spessartine trapezohedrons.

Much topaz occurs on matrix, usually albite, and commonly forms very showy specimens, with smoky quartz, microcline, zinnwaldite mica, and rarer fluorite and hematite. There is also an abundance of manganese species that include spessartine (occasionally included in topaz), helvite and masutomilite mica. Other cavities in the area also produce excellent, but typically etched aquamarine.

Despite an abundance of granites, the late Cretaceous Andean foldbelt of South America appears to host very few good topaz deposits. One of these, the **Rumi Tucu mine** is located on Mount Léon Muerto near Papachacra in the Department of Belén (70 km due north of the city of Belén) in Catamarca Province, Argentina. J. Saadi (personal communication, 1992) provided the following description of the deposit that is being exploited for specimens. The host Papachacra geological unit has an age of around 117 million years. Small pegmatite bodies of between 15 and 60 cm in size with cavities to 50 cm occur in the border zones and interior of the granite stock, especially in the south and southeast parts. The cavities, which are filled with red clay, contain well-crystallized topaz, microcline, albite growing epitaxially over microcline, smoky and citrine quartz, muscovite and florencite-Ce. Topaz crystals are typically between 1 and 5 cm in size and occur uncommonly on a matrix of feldspar or quartz. They are medium prismatic, rich in crystal forms and in rare cases doubly terminated. Most crystals are very lustrous and gemmy, in colors ranging from sherry through pale greenish blue to medium blue. Bicolored crystals show outer sherry zones parallel to *a*{100} surrounding a colorless to bluish or greenish central zone.

Klein Spitzkopje, northeast of Swakopmund in Namibia, is the smaller of two very prominent granite inselbergs (isolated, residual knobs). Martin *et al.* (1960) describe the intrusion as one of a group of Damaraland sub-volcanic ring complexes that Sillitoe (1974) suggests are related to a mantle hot spot. The Spitzkopje intrusion has an estimated late Triassic to early Jurassic age of 194 million years (Cahen *et al.*, 1984), and the deposit is inferred to have formed at a very shallow depth of less than 330 meters (Bideaux, 1981). Pegmatitic segregations containing cavities to several meters in size (more typically around 10 cm) are common around the periphery. Topaz forms up to around 2% of the granite, which shows some greisen-like alteration of the wall-rock to tourmaline, topaz and beryl. Cavities contain late-stage, usually water-clear, colorless to pale blue topaz crystals to at least 6 cm. These are mostly sharp, some showing striations, and commonly occur on iron-stained quartz. Associated minerals include excellent aquamarine and golden beryl (in several generations and commonly corroded), microcline, albite, mica, octahedral fluorite, phenakite and bertrandite (Sinkankas, 1981).

The cavity-bearing **Volhynia** pegmatites occur in the Korosten' pluton in the northwest Ukranian shield. Their estimated age of around 1,770 million years places them among the oldest known anorogenic deposits. Descriptions are provided by Beus (1966), Marakushev *et al.* (1989), and Koshil *et al.* (1991); Pavlishin (1992) also provides what is essentially an English abstract of the Koshil *et al.* article. The source granites, which form a lower horizon in the overall intrusion, are typical of a coarse-grained "rapakivi" type (containing large K-feldspar crystals with a plagioclase shell); these developed in Protero-

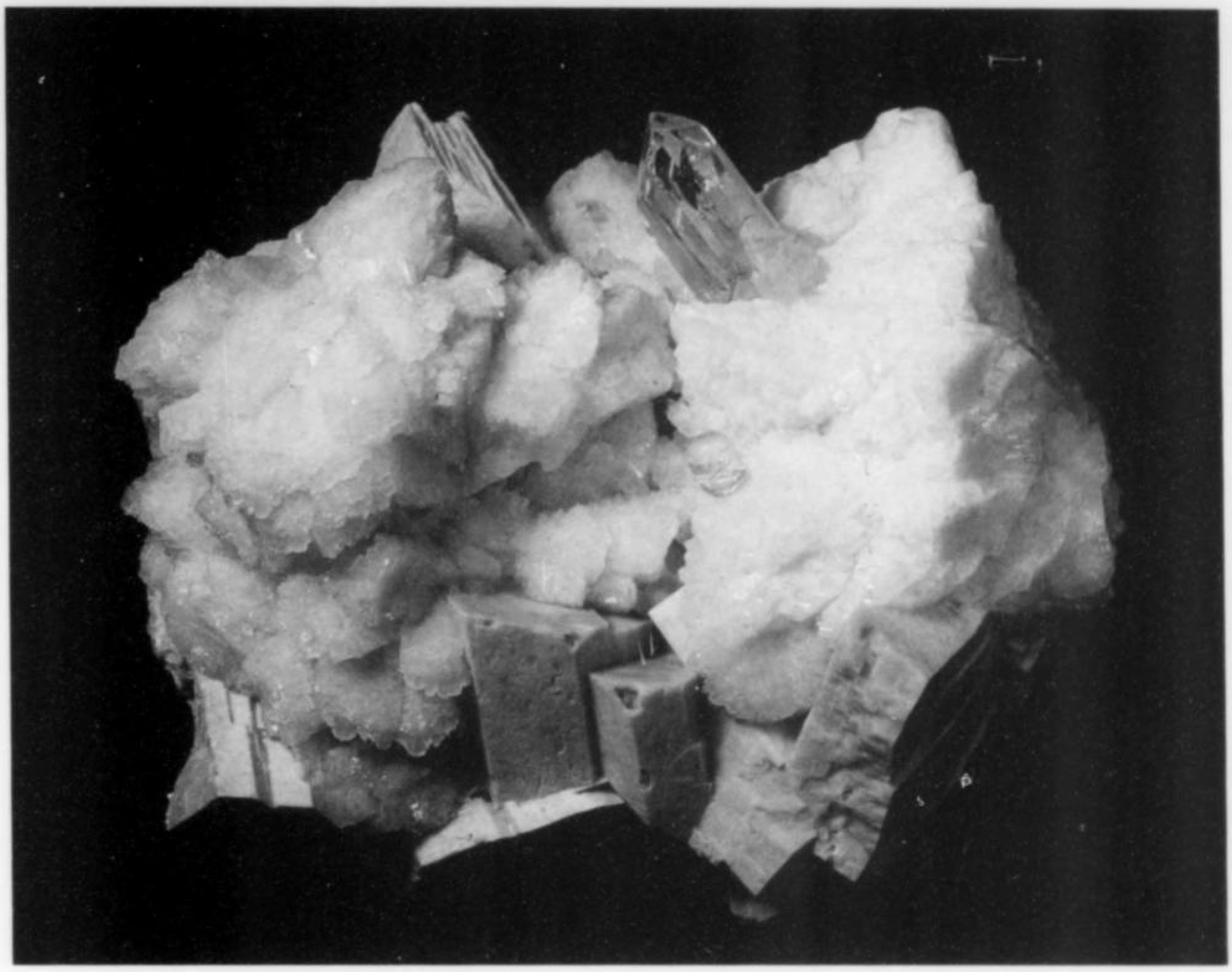


Figure 12. **Gemmy topaz crystal, 1.5 cm, on translucent albite with pink microcline, from syngenetic pegmatite, Sawtooth Range, Idaho. Author's collection and photo.**

zoic time in nearly all Precambrian shields worldwide. Pegmatites are restricted to a 0.3 to 1.5 km-wide, 22 km-long inner contact zone of the intrusion, within which they have formed in roof-zone granites. These host granites are high-fluorine, biotite-hornblende types that are unusually iron- and titanium-rich, with at least twice the iron content of most other leucocratic topaz granites. Consequently, the pegmatite bodies show a characteristic surrounding or underlying zone of darker granite enriched in ferromagnesian minerals that is apparently unique to pegmatites in the broader region of the former U.S.S.R.

This area, which is given various names including Volhynia, Wolhynien, and Wolodarsk-Wolynsky, and Woln [Ed. note: W is an artifact of initial transliteration into the German literature, but the pronunciation is V, and the names should be spelled with a V in English.], is better known for gemmy and interestingly etched, yellow-green beryls (Wilson, 1987). The pegmatites have been known for around 100 years, and mined for the last 60 years. In 1991 the large pegmatites producing the gem materials were being worked at depths of 100 to 150 meters.

Abundant pegmatitic segregations in the productive zones show varying degrees of differentiation, with only the fully differentiated type hosting crystals of topaz and other gem species. Such pegmatites are isolated within their parent granites and range in sizes from tens of centimeters to 70 meters. Their forms vary from spherical to lensoid or ellipsoid, with more complex shapes forming through coalescence of two or more bodies.

Within an enclosing graphic granite shell, pegmatite bodies are uniformly but asymmetrically zoned with feldspar enclosing the quartz core and commonly a central cavity. Cavity size is typically 1 to 2 meters but may reach 20 meters. Late-stage replacement by fluorine-

Figure 13. **Gemmy topaz crystal on smoky quartz, 4 cm high, from syngenetic pegmatite, Rumi Tucu mine, Belén, Argentina. Author's collection and photo.**

Table 2. **Gem topaz deposits worldwide. Where crystal size and quantities permit, these deposits are exploited typically only for specimen or gem material. References cover tectonic setting and geology as well as mineralogy.**

Location	*Deposit Age (my)*	*Geology*	*Literature References*
Topaz Rhyolites	mostly <30	Rift-related volcanism: lava domes and flows	Burt *et al.* (1982), Christiansen *et al.* (1986)
Thomas Range, Utah	7–6		Ream (1979)
Wah Wah Mountains, Utah	20–18		Ream (1979)
Ruby Mountain, Nathrop, Colorado	29–28		Sinkankas (1959)
Durango, Zacatecas, San Luis Potosi, and Guanajuato, central Mexico	ca. 30		Sinkankas (1959, 1976), Burt and Sheridan (1985), Panczner (1987)
Topazites			
Mount Gibson, Queensland, Australia	312	Pinnaclès Granite, Hodgkinson Foldbelt	Sillitoe (1981), Palfreyman (1984), Johnston and Chappell (1992)
Syngenetic Pegmatites			
Sawtooth Range, Idaho	45	Sawtooth Batholith, related to Challis volcanism	Reid (1963), Pattee *et al.* (1968), Kiilsgaard *et al.* (1970), Bennett and Knowles (1985), Wernicke *et al.* (1987), Ream (1989), Menzies and Boggs (1993)
Pikes Peak, Colorado	ca. 1000	Pikes Beak Batholith	Barker *et al.* (1975), Muntyan and Muntyan (1985), Michalski (1986)
Mason Co., Texas	1050	Town Mountain Granite, Llano Uplift	Sinkankas (1959), Broughton (1973), Garrison *et al.* (1979), Anderson (1983)
Carroll and Coos Cos., New Hampshire	180	Conway Granite, White Mt. Magma Series	Shaub (1955), Sinkankas (1959), Eby (1987), Holman (1987), Samuelson *et al.* (1990), Holman (1991)
Catamarca Province, Argentina	117	Andean Foldbelt granite	
Mourne Mountains, Northern Ireland	60	Mourne Granite	Greg and Lettsom (1858), Sinkankas (1959), Holland (1981)
Cairngorm Mountains, Scotland	ca. 410	Cairngorm Granite, Younger Granite Series	Greg and Lettsom (1858), Heddle (1901), Stephens and Halliday (1984)
Luumäki, southeast Finland	1700–1650	Wiborg Complex (rapakivi granites)	Simona and Mikkola (1980), Lahti and Kinnunen (1993)
Jos Plateau, Nigeria	190–145	Younger Granite Complexes	Bowden and Kinnaird (1984), Kinnaird and Bowden (1987)
Klein Spitzkopje, Namibia	180	Damaraland Sub-volcanic Complexes	Martin *et al.* (1960), Sillitoe (1974), Bideaux (1981), Sinkankas (1981), Cahen *et al.* (1984)
Voln Region, Ukraine	ca. 1770	Korosten' Pluton, Ukrainian Shield	Beus (1966), Marakushev *et al.* (1989), Koshil *et al.* (1991), Pavlishin (1992)
Alabashka, Mursinka area, central Ural Mountains, Russia	ca. 265	Permian foldbelt granites	Fersman (1925, 1932, 1940), Hamilton (1971), Sinkankas (1981), Scalisi and Cook (1983), Bancroft (1984), Fershtater and Borodina (1991), Lyckberg (1993)
Urulga River area, Transbaikal, eastern Siberia	ca. 150	East Transbaikal Mega-arch	Fersman (1925, 1932, 1940), Sillitoe (1974), Tomson and Kravtsov (1978), Scalisi and Cook (1983), Bancroft (1984)
Hentiy Province, Mongolia	ca. 150	Hentiy-Daurski Mega-arch	Tomson and Kravtsov (1978), Sinkankas (1981), Stobbe (1982)
Gifu and Shiga Prefectures, Japan	ca. 100	Naegi Granite, Younger Ryoke Plutonics	Nambu *et al.* (1970), Bateman (1978), Scalisi and Cook (1983), Wilson (1989b)
Epigenetic Pegmatites			
San Diego Co., California	ca. 100	Peninsular Ranges Batholith	Sinkankas (1959, 1976), Larson (1977), Todd and Shaw (1985), Stern *et al.* (1986), Foord *et al.* (1989), Souza *et al.* (1990)
Oxford and Sagadahoc Cos., Maine	ca. 400	New Hampshire Plutonic Series	Burbank (1934), Sinkankas (1959), Francis (1987)
Amelia Court House, Virginia	ca. 300	Raleigh Belt Granites	Sinkankas (1959), Hatcher *et al.* (1989), Kearns (1993)
Minas Gerais, Brazil (many separate localities)	ca. 500	Araçuai Foldbelt	Bauer (1968), Caplan and Wilson (1980), Almeida *et al.* (1981), Cassedane and Lowell (1982), Proctor (1984), Schobbenhaus *et al.* (1984), Wernicke (1985), Keller (1990)
Santa Teresa, Espirito Santo, Brazil	ca. 500?	Paraguai-Araguaia Foldbelt	Sinkankas (1981), Schobbenhaus *et al.* (1984), Moore (1992)
Western Spain	ca. 300	Carboniferous foldbelt granites	Sinkankas (1981)
Miami, Karoi dist., Zimbabwe	ca. 3000?	Miami Granite?	Bancroft (1984), Von Knorring and Condliffe (1987)
Alto Ligonha, Mozambique	645	Mozambique Belt granites	Von Knorring (1970), Sinkankas (1981)
Central Madagascar	ca. 500	Mozambique Belt granites	Lacroix (1922–1923), Sinkankas (1981), Wilson (1989a)
Gilgit, Pakistan	<30	Karakorum-Pamir Foldbelt	Kazmi *et al.* (1985), Searle *et al.* (1989), Zeitler *et al.* (1989), Searle and Tirrul (1991)
Mogok, Burma	ca. 200	Kabaing Granite (collisional foldbelt)	Mitchell and Garson (1981), Scalisi and Cook (1983), Keller (1990)
Northern China			Keller and Wang (1986)
Greisens			
Erzgebirge, Czech Republic and Germany	360–310	Younger Intrusive Complex	Naumov *et al.* (1977), Taylor (1979), Bancroft (1984), Russ (1989a), Štemprok (1990), Tischendorf and Förster (1990)

Sherlova Gora/Adun Chilon, Transbaikalia, eastern Siberia	ca. 150	East Transbaikal Mega-arch	Fersman (1925, 1932, 1940), Sillitoe (1974), Tomson and Kravtsov (1978), Sinkankas (1981)
Southern China	80–100	Orogenic continental crust granites	Keller and Wang Fuquan (1986), Xu Keqin and Zhu Jinchu (1986), Hervig *et al.* (1987), Yin Lin *et al.* (1993)
Skarns			
Trumbull, Connecticut	ca. 460	Related to Harrison Gneiss?Taconic orogen?	Shannon (1921), Sinkankas (1959), Hatcher *et al.* (1989)
Laacher See, Eifel district, Germany	<0.5	Volcanic district	Hentschel (1977)
Western Tasmania, Australia	ca. 400	Post-tectonic granitoids (dolomite replacement orebodies)	Taylor (1979), Einaudi and Burt (1992)
Hydrothermal Veins			
Ouro Preto, Minas Gerais, Brazil	2700–500?	Dom Bosco Syncline	Olsen (1971), Keller (1983), Cassedane (1989)
Brumado, Bahia, Brazil		Dolomite (replaced by magnesite), quartzite	Beus (1966), Cassedane and Cassedane (1978)
Cornwall, England	280	St Austell and Tregonning-Godolphin Plutons	Russell (1924), Weidner and Martin (1987), Manning and Hill (1990)
Untersalzbachtal, Salzburg, Austria	<40?	"Central Gneiss" (Carboniferous granitoid)	Meixner (1978), Russ (1989b), Merle and Cobbold (1989), Finger and Steyrer (1990)
Val Lugnez, Illanz, Grisons, Switzerland	<40?	Triassic dolomite	Bradbury and Nolen-Hoeksema (1985), Merle and Cobbold (1989), Robertson (1989), Finger and Steyrer (1990)
Sanarka River, southern Ural Mountains, Russia	ca. 265?	Permian foldbelt granites	Bauer (1968), Scalisi and Cook (1983)
Katlang, Mardan District, Pakistan	<30?	Silurian-Devonian limestone	Gubelin *et al.* (1986), Gromov and Aurang (1992)
Eastern Australia	350–250	Lachlan and New England Foldbelt granites	Myatt (1976), Chalmers (1979), Taylor (1979), Shaw and Flood (1981), Palfreyman (1984), Sillitoe (1981), Johnston and Chappell (1992)

rich (and sodium-rich) fluids has caused partial leaching of the feldspar zone and some recrystallization of the quartz core, along with caving of cavity walls. The final result is a structure that shows vertical zoning. Typically the central cavity is filled with collapse breccia, but commonly very large quartz crystals may grow from the top and sides. The immediately underlying, leached K-feldspar zone that is almost always present may contain large crystals of albite, topaz and beryl; typically corroded and/or regrown topaz and beryl crystals are found among loose mica created from disintegrating feldspar. Apparently only the larger cavities contain both topaz and beryl, which are otherwise generally mutually exclusive, with formation of one leading to dissolution of the other. Fluorite and lithian micas are also present. The large size of the cavities encourages formation of an impressive number of minerals, especially for syngenetic pegmatites. Koshil *et al.* (1991) list a total of 96 species, 95% of which by volume are silicates and aluminosilicates.

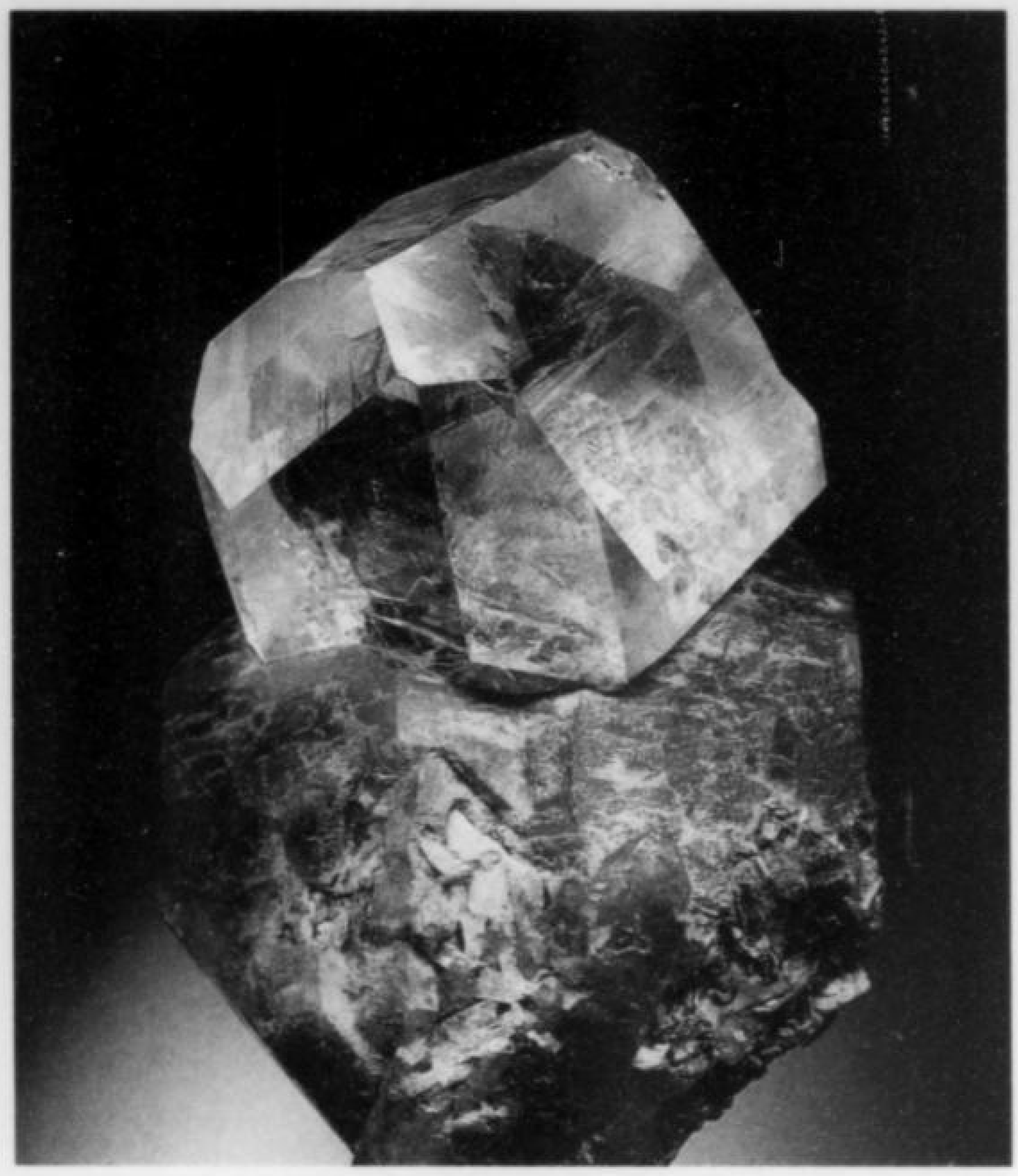
Topaz forms as excellent crystals to 117 kg, in a range of habits and colors. Most crystals show prominent *m*{110} and *l*{120} faces and terminations that typically combine *f*{011}, *k*{111} and *o*{112}, but many other forms are present. Characteristic longitudinal striations on *m*{110} and *l*{120} faces may be strong enough to obliterate face edges. Broad color variation includes white, blue to deep blue, pale pink, and honey-yellow through brownish to reddish. Crystals may also show characteristic sherry/colorless/sherry color zoning perpendicular to the *a* axis. The pink to honey-yellow colors in particular are unstable under sunlight in some crystals. Crystals are commonly sharp, though frosted, with some termination faces showing interesting etch patterns. Highly etched and gemmy but still lustrous masses are also found.

Pegmatites in the following three areas are included within the syngenetic/NYF group due to their relatively simple mineralogies and occurrence within their parent granites. In the Mursinka deposits there is also the characteristic lack of zoning around the cavities, and the geology of the Luumäki occurrence has been compared to that of Volhynia, Ukraine. In all three areas, the cavities do, however, form within dikes that are more characteristic of the epigenetic pegmatites to be described later.

Lahti and Kinnunen (1993) describe a very interesting pegmatite at **Luumäki** in the Wiborg complex, 180 km northeast of Helsinki in southeastern Finland. This deposit is of similar age and geological setting to the Volhynia pegmatites (Simoni and Mikkola, 1980). A 20-meter-wide dike discovered in 1982 and worked sporadically for gem beryl contains very large crystals of topaz, common beryl and monazite-Ce in an inner feldspar zone bordering the quartz core. The feldspar zone also contains crystal aggregates of ferrocolumbite and uranium-rich pyrochlore. Many of the crystals of common beryl are strongly altered and corroded. Cavities in both the feldspar and quartz zones contain crystals of quartz, feldspars and strongly etched, pale-green, yellow and blue beryl. Bertrandite, goethite and fluorite are also locally common. Faceting-grade pieces of blue, pale pink and colorless topaz are also reported, but it is not clear if these are from cavities.

Mursinka is north-northeast of Ekaterinberg (formerly Sverdlovsk) in the central Ural Mountains. The Carboniferous to Permian age collision of the Russian and Siberian platforms that created the Urals (Hamilton, 1970) also produced elongated, intrusive belts of granite-syenite along their east slope (Sinkankas, 1981; Fershtater and Borodina, 1991). Granodiorite and granite intrusions host topaz-bearing pegmatites within both flat and steeply dipping, long, typically 1 to 2-meter-thick dikes of coarse-grained and graphic granite. The west to east progression to younger intrusions and the faulting on the east flank where the pegmatitic deposits occur suggests a post-orogenic tectonic setting. Tectonic setting, dike structure and the presence of boron and lithium minerals suggest an LCT classification, though the lack of zoning and relatively simple mineralogy are more typical of NYF types. These classic deposits are described by Fersman (1925, 1932, 1940), Sinkankas (1981), Scalisi and Cook (1983), Bancroft (1984), Lyckberg (1993) and Evseev (1993c), with further recent information provided by P. Lyckberg and R. Triebl (personal communications, 1993).

Topaz-bearing pegmatites at Mursinka were discovered in 1738, following the initial discovery of colored stones (amethyst, smoky quartz and possibly tourmaline) as early as 1668. Gem crystals were first found at the surface directly beneath a covering of peat moss. Intensive exploitation did not take place until the late 19th century when, from 1880 to 1882, hundreds of fine topaz crystals were mined around Alabashka, a village a few kilometers north of Mursinka. These pegmatites in forested hill country were worked from hundreds of pits, mostly shallow but reaching depths of 65 meters. They were thought to have been abandoned for decades, but extensive geological mapping and mining, including underground development, has apparently continued over the last 70 years (Lyckberg, 1993). At this point,



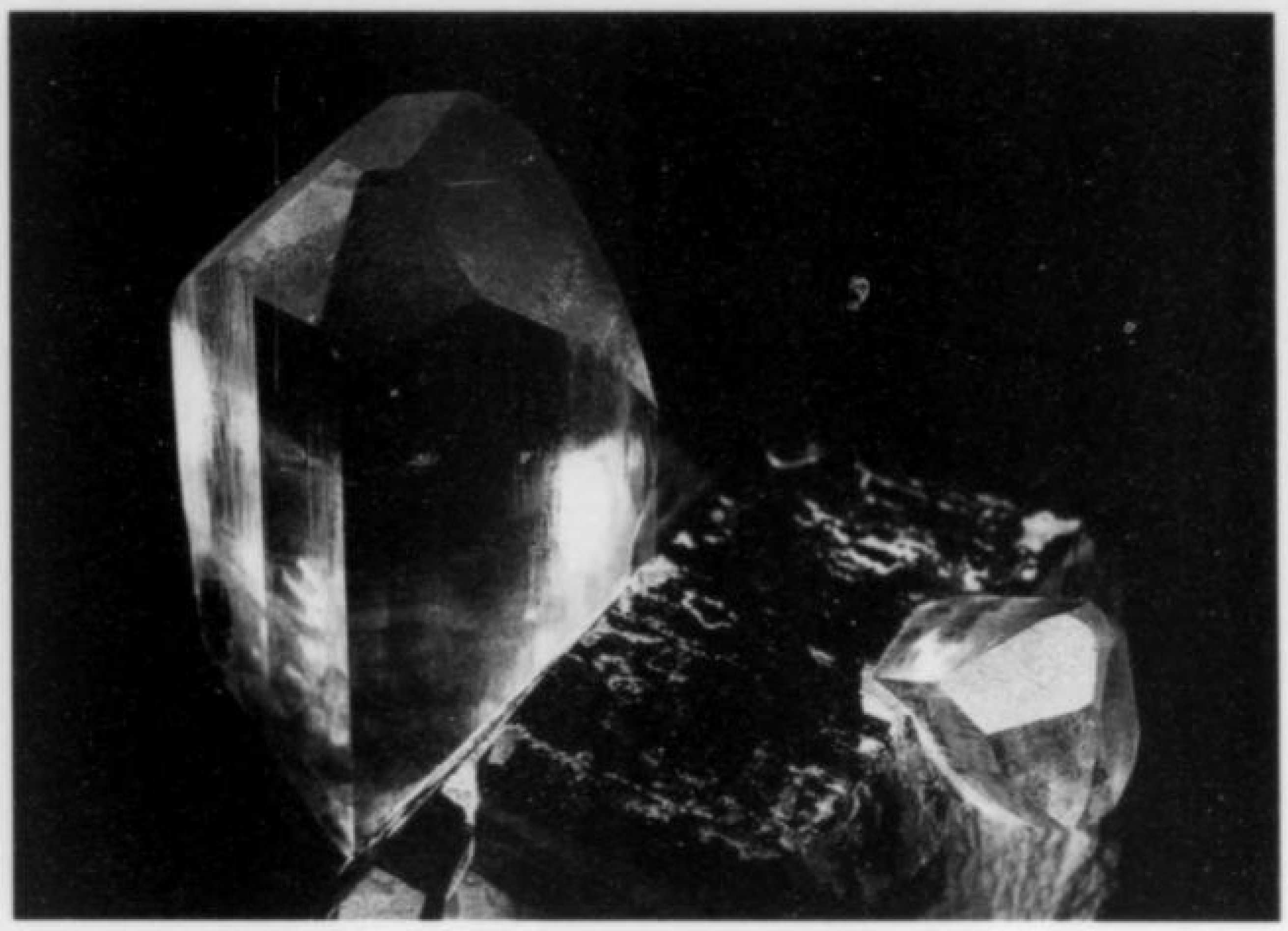
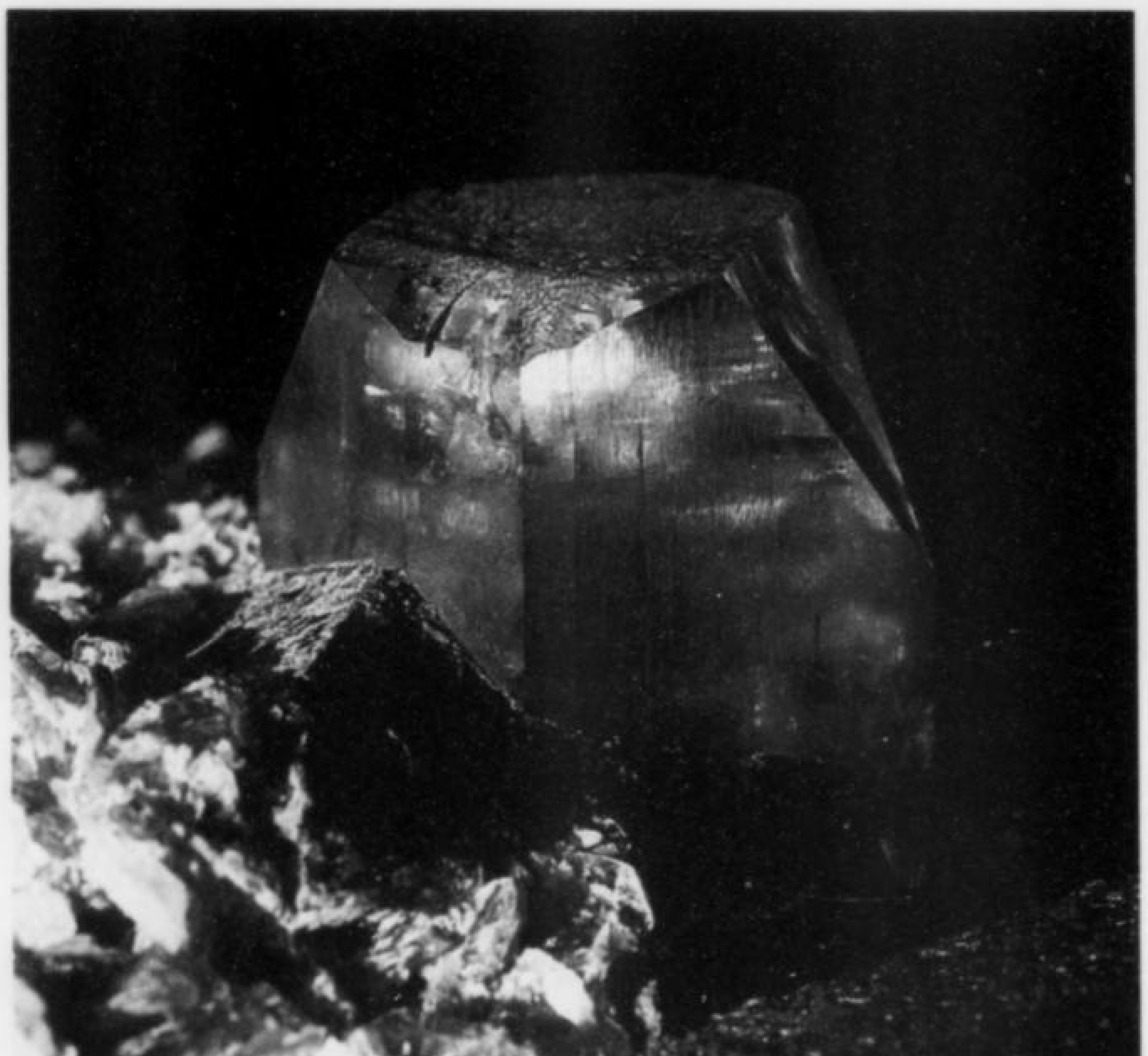


Figure 15. Gemmy topaz crystals on dark smoky quartz, 4.2 cm, collected in 19th century, from syngenetic(?) pegmatite, Mursinka, central Ural Mountains, Russia. René Triebl collection; Peter Huber photo.

Figure 14. Equant topaz crystal, 3 cm, on smoky quartz, from syngenetic (?) pegmatite, Mursinka, central Ural Mountains, Russia. Collection of the Fersman Museum, Moscow; Jeff Scovil photo.



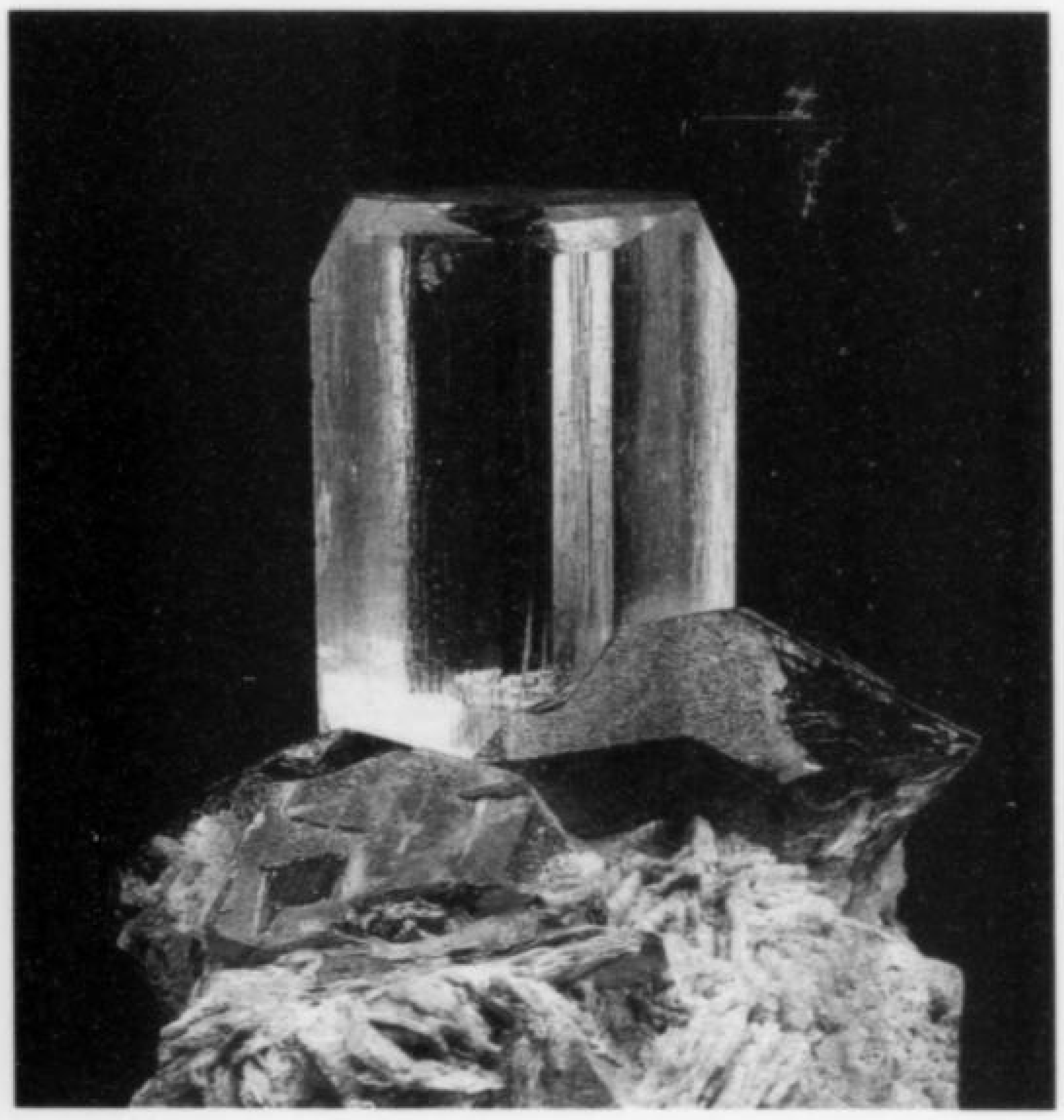


Figure 16. Topaz crystal, 4 cm, on smoky quartz from Mursinka, Ural Mountains, Russia. Collection of the Fersman Museum, Moscow; photo by Jeff Scovil.

Figure 17. Topaz crystal, 2.5 cm, on smoky quartz from Mursinka, Ural Mountains, Russia. Simone and Peter Huber collection; photo by Peter Huber.

most of the significant pegmatites are thought to have been exploited. Several mines are currently closed due to poor productivity, though some probably have remaining potential at depth.

The Mokrusha mine, the largest in the Alabashka area, is a flat-lying pegmatite that produces topaz and beryl with albite among over 50 known minerals. Hydrothermal veins containing amethyst at the north end of the mine formed around 100 million years later than the pegmatites. The largest topaz from the time of the Czars, found in 1911, is a clear, blue-green, 30-cm crystal weighing 27.8 kg that was found in several pieces. It is now reassembled in the St. Petersburg Mining Academy. Several topaz crystals, including one weighing 30 kg, were found during mining in 1976–1977. Matrix plates to 70 cm

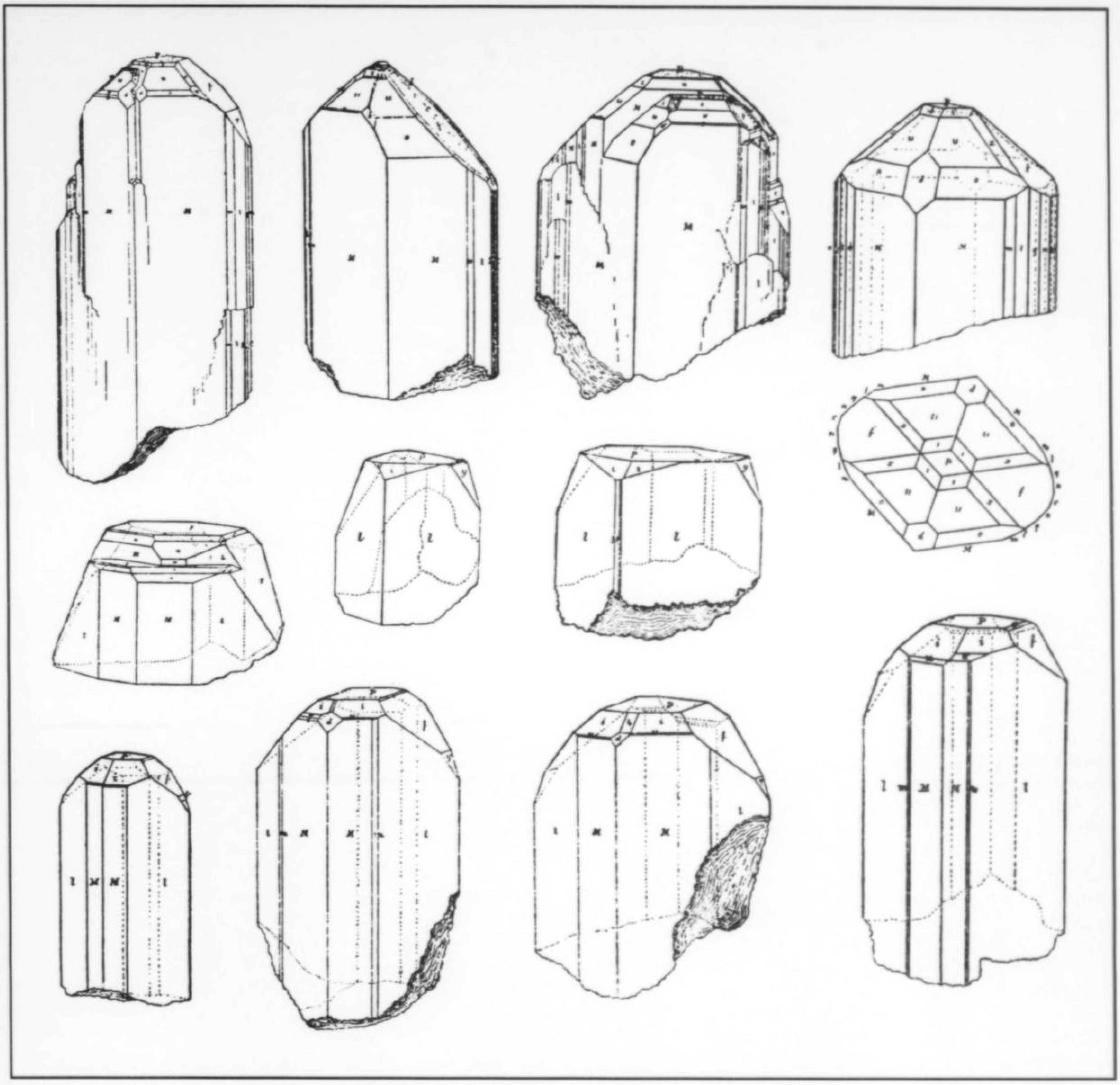


Figure 18. Topaz crystal habits from Mursinka (top and middle rows) and the Urulga River area, Russia (bottom row) (Goldschmidt, 1922).

were, found covered with albite (var. clevelandite) rosettes, and smoky quartz crystals to 25 cm (some doubly terminated). An outstanding piece, now in the Kremlin, has a dozen blue topaz crystals in the 5–8 cm range on a plate of clevelandite albite. Mining in 1985, before closure in 1986, was very successful for topaz production, which included a 44-kg crystal group on matrix with topaz crystals measuring 6 to 8 cm; unfortunately very few undamaged specimens were recovered.

The Kazjonnitsa mine has also produced excellent blue topaz. During the final day of operation, at the 30-meter level, before shutdown in June 1992, Lyckberg observed a few cavities to 200 cm^2 in size with small, pale-blue topaz crystals to 1.5 cm.

The pegmatite bodies in this area consist largely of feldspar with minor quartz and still less mica, with many crystal cavities that are accompanied by little zoning or alteration in the enclosing rock. Cavities typically reach a maximum size of 50 cm and may be clean or filled with brown clay. Topaz occurs in two generations, the first of which consists of short prismatic crystals to 30 cm, seldom on matrix, and normally of poor quality with mica inclusions. The classic, second-generation specimens comprise about only 10 to 15% of the total topaz. They occur as colorless to blue, blocky prisms to 3.5 cm with predominant *l*{120} faces and terminations typically combining prominent pinacoids, *c*{001}, and *y*{021} faces. Crystals are sharp, lustrous and gemmy but commonly internally flawed. Many are found showing a top zone parallel to *c* that is brownish, but this color subsequently disappears, leaving only blue. Crystals are commonly found on matrix showing the classic combination of topaz with lusterless smoky quartz, albite, and mica books. Associated cavity minerals include orthoclase, microcline, schorl and, less commonly, fine beryls (typically heliodor, rarely aquamarine). The topaz-bearing dikes produce only minor beryl, though topaz also occurs uncommonly in predominantly beryl-bearing dikes. The Mursinka area has also produced wine-yellow topaz, and other local mines are known for their excellent rubellite tourmaline and amethyst.

Fersman (1925, 1932, 1940), Beus (1966) and Scalisi and Cook (1983) describe the **Urulga River** area deposits in the Borschchovochnoi Mountains, south of Nerchinsk. This area of eastern Transbaikalia, close to the borders with both China and Mongolia, is geologically very complex. Arched uplifts were imposed on an earlier major orogeny (Tomson and Kravtsov, 1978). Sillitoe (1974) suggests that the Jurassic-age uplifting that resulted in granitic intrusions and regionally associated hydrothermal fluorite deposits is related to an intracontinental hot spot. These deposits produced topaz, typically associated with quartz, microcline and zinnwaldite mica, from numerous veins and pegmatites to 5 to 10 meters wide in granite. The Natural History Museum in London has several exceptional sherry-colored topaz crystals to 12 cm that are lustrous, gemmy, short prisms with combined pinacoidal, *c*{001}, and *f*{011} terminations. Individual wooden covers have been fitted over the crystals to prevent fading due to exposure to light (Bancroft, 1984).

Epigenetic Pegmatites

Epigenetic pegmatites result from the intrusion into host rocks of residual fluids produced during emplacement of parent granites. London (1990) suggests that they typically evolve from a single pulse of water-rich magma ejected from the roof zones of the parent granite. They correspond to Černý's LCT family (Černý, 1991a, b) and are more abundant than NYF types. Generally only the most highly evolved leucogranites within orogenic intrusions produce such pegmatites, though Černý (1992) suggests anorogenic origins in some cases. LCT pegmatites show a particularly high degree of differentiation from the source magma.

These pegmatites may intrude as far as several kilometers into the surrounding country rocks. The most common hosts for topaz are the lepidolite and albite subtypes that are the last to form at the greatest distances from the parent granite (Novák *et al.*, 1992). Rarely fluorine-rich beryl pegmatite subtypes may also host topaz. The resulting complex pegmatites occur in isolated clusters. Individually, they have many separate, generally concentric zones, and in some districts commonly show central cavities lined with large, well-formed crystals.

The parent magmas typically have higher contents of water and lithium, but more crucially lower levels of fluorine, that make topaz much less common than in NYF pegmatites. Formation temperatures for LCT pegmatites range from late-magmatic, around 750°C, through around 400°C for primary species, to as low 50°C (Černý, 1991a). Recent estimates of formation pressures for such cavity-bearing pegmatites (London, 1986; Černý, 1991a) suggest depths to around 10 km, which would exclude them from Ginsburg/Rudenko's "shallow, miarolitic" class.

LCT pegmatites have received more attention than their NYF counterparts owing to their greater abundance and commercial potential as sources of rare metals rather than gemstones. Thus, although more complex than their NYF counterparts, they are generally better understood.

Topaz-bearing LCT pegmatites commonly occur in the uppermost levels of intrusions, either as late-stage products of differentiation or, as suggested by Černý (1982c), separate members of larger granitic complexes. Typical geological settings are large, shallow batholiths (e.g. in the Ural Mountains, Russia) and large orogenic complexes (e.g. the Peninsula Ranges Batholith, southern California). There are many topaz localities of this type worldwide, as listed in Table 2. Of particular note are the important topaz deposits in Minas Gerais, Brazil, and the prolific pegmatites of Gilgit in northern Pakistan. Four specific areas merit further attention, as follows:

Kazmi *et al.* (1985) describe the gem pegmatites of the **Gilgit Division** of northern Pakistan in the northwest Himalayas. These are associated with granites intruded following the collision between the Asian and Indo-Pakistan continental plates that created the Himalayas. This Tertiary event, which began approximately 50 million years ago, is perhaps the most recent and most-studied major continent/continent collision. Crustal thickening followed approximately 25 million years ago and probably led to widespread melting, with rapid uplift over the last 8 million years (Zeitler *et al.*, 1989; Searle and Tirrul, 1991). The leucogranites of interest have high levels of fluorine, boron, lithium and also beryllium, and host many LCT-type pegmatites that generally intrude gneisses. Their ages are as recent as perhaps 5 million years (Searle *et al.*, 1989), making them among the youngest gem-bearing pegmatites in the world.

Topaz occurs as a principal gem species and as an associated mineral in the vicinities of Shingus, Haramosh and Stak Nala, east of Gilgit (in the Haramosh Massif within the Indo-Pakistan plate), and further east around Dusso (in the Karakoram Batholith within the Asian plate). All these localities are in the very rugged Karakoram Range and Haramosh Mountains, which span a 100-km wide area near the borders with Afghanistan and China. Variation in spelling of names and confusion between localities is common across the entire area. In particular, specimens from Dusso may also be labeled as Shigar or Skardu, towns further down river, en route out to Gilgit.

The topaz mine at Niyit Bruk, northeast of Dusso in the Skardu area, has become famous in recent years for exceptional colorless to medium-sherry topaz. Its altitude of 4,270 meters made it probably the world's highest major topaz deposit, until very recent production from Apaligun, above Nyit Bruk. The productive pegmatite at Nyit Bruk is a tabular, 40 to 70-cm thick body that has intruded into biotite gneiss. Its inner, kaolinized zone is 25 to 30 cm thick and has abundant cavities. Colorless to sherry topaz crystals are sharp, lustrous and commonly flawless. The predominant forms are *l*{120} prisms, and pinacoids, *c*{001}, which may be etched. Topaz is typically found on a matrix of or intergrown with colorless to very pale smoky quartz crystals, but also occurs with microcline and albite. Such topaz, showing predominant sherry hues along with rare pale pink or even violet, is typical of that from the general Gilgit area.

Saeed-ur Rehman and M. Rosser (personal communications, 1990) and D. Blauwet (personal communication, 1992) describe other similar topaz-bearing pegmatites nearby. These include the Boungla, Mungo and Yunau mines which, along with the Nyit Bruk and Apaligun, produce excellent-quality topaz crystals typically to 200 grams, but weighing as much as 3 kg. Mineralogies generally differ only slightly. The Mungo and Yunau mines produce some schorl, and hydroxylherderite occurs only at the Nyit Bruk mine. Recently the Mungo mines have produced topaz with overgrowing apatite in small, brown to pink, prismatic to tabular crystals. The association of topaz with quartz rather than platy albite is more common at Nyit Bruk where topaz is always colorless when associated with aquamarine. Sherry-colored crystals from Apaligun show more complex form, also with significant etching.

Other cavity-bearing pegmatites at Gone, east of Dusso, produce good specimens with similar gemmy topaz and associated crystals of aquamarine and schorl. In fact the Dusso area is probably better known for superb pale blue aquamarine, which occurs only uncommonly with topaz. In predominantly aquamarine-bearing pegmatites, topaz may crystallize on aquamarine. One very aesthetic, lustrous specimen has a colorless, 1.5-cm topaz with an unusual, pointed termination, growing on the pinacoid, *c*{001}, of a 2.5-cm, pale blue aquamarine crystal. Though labeled as from Shigar, it is likely from Dusso. Very rarely specimens show aquamarine on topaz (M. Rosser, personal communication, 1993). The area also produces uncommon green fluorite, both as grains in the matrix and as good octahedral crystals. This leads to uncommon but spectacular associations of sherry topaz, pale blue aquamarine and green, octahedral fluorite, all in large, well-formed crystals (H. Obodda, personal communication, 1990). A 1991 find of similar material at Kashmal, between Dusso and Shigar, produced several very distinctive and aesthetic matrix specimens. These combine lustrous, gemmy, yellowish sherry topaz in intergrown 1 to 2.5-cm crystals (over 60 on one 20-cm plate), with bluish green, gemmy aquamarine crystals to 8 cm. Associated minerals include blocky microcline, platy albite, unusual lustrous bronze mica, and rarer emerald-green octahedral fluorite.

The association of topaz with aquamarine and occasional fluorite is most common from the Dusso area, but topaz also occurs with other gem species at various localities in the Haramosh Massif (S. Hussain, personal communication, 1992). It is found with aquamarine in Haramosh and Stak Nala, and with fluorite and rarely both fluorite and aquamarine in Haramosh. Colorless, gemmy topaz occurs at Stak Nala with elbaite or schorl tourmaline in at least two deposits, though neither is the well-known elbaite pegmatite. Kazmi *et al.* (1985) report topaz crystals as druses on schorl and aquamarine from the Shingus area. Such topaz occurs in small, sharp crystals that are commonly water-clear, creating very showy specimens. Topaz on aquamarine also occurs in similar deposits in Kunar Province in neighboring Afghanistan. Recent finds in the Drot Balachi area south of Shingus include topaz crystals to 10 cm on platy albite and smoky quartz, and also cassiterite and rare morganite from other pegmatites (Ream, 1994).

In San Diego County, California, only a few of the many gem pegmatites have produced significant topaz. Examples include the Little Three mine, Ramona (Stern *et al.*, 1986; Foord *et al.*, 1989), and the Ware mine in the Aguanga Mountain district (Sinkankas, 1959). The regional geology is complex. It is proposed that the pegmatite-generating granitoids formed during accretion of an older island arc to the continental margin (Todd and Shaw, 1985). The parent intrusion for the **Little Three mine**, which exploits one of the more interesting dike systems in the county, is a granite of the Peninsula Ranges Batholith. Five interrelated dikes averaging 50 to 100 cm in thickness are present on the property, having intruded their mafic quartz-diorite host in Cretaceous time around 100 million years ago. The Hercules dike is famous for spessartine, and the other dikes are noted for minerals such as manganaxinite. The main Little Three dike, the prime topaz producer, shows extensive graphic granite next to the cavity zone and much schorl and spessartine frozen in pegmatite wall rock. Cavities range from small, cm-size to the major, 3.3 by 3.3-meter by 25-cm "New Spaulding" topaz find in 1976. Wet clays commonly fill cavities, many of which show evidence of crystal detachment followed by regrowth, and also abrasion from violent, late-stage cavity rupture.

Topaz occurs in two generations. Crystals from the first occur both loose and on matrix, and are sharp and translucent, weighing 450 grams and more. Colors range from pale to medium blue or sea-green, and crystals commonly have internal veils or microfractures. A second generation of much smaller (to several mm) colorless, gemmy crystals grew on other cavity minerals, most strikingly on the terminations of dark green elbaite. Terminations are either dominant pinacoids, *c*{001}, or wedges with prominent *f*{011} and *y*{021} faces. Topaz, especially from the first generation, typically fluoresces lemon-yellow under ultraviolet light. Some excellent matrix specimens were recovered with topaz (commonly of both generations), quartz, elbaite, platy albite and fluorine-rich lepidolite (Souza *et al.*, 1990). Other crystallized minerals include microcline, stibiocolumbite-stibiotantalite and microlite-uranmicrolite. In other areas the main Little Three dike also produces fluorapatite, hambergite and uncommon goshenite-morganite beryl.

Although most specimen mining occurred as recently as the mid 1970's, the **Virgem da Lapa** pegmatites in Minas Gerais, Brazil are already a classic locality. Minas Gerais has many topaz-bearing pegmatites. Some of these produce larger crystals, but most topaz is colorless and seldom on matrix and does not compete with the spectacular, natural blue specimens from Virgem da Lapa.

These pegmatites occur west of Araçuaí in the topaz-prone, low-lithium Salinas-Araçuaí pegmatite district. Keller (1990) provides a geologic overview. The district falls within the Araçuaí foldbelt created by the last major (Brasiliano) orogeny of late Proterozoic to Cambrian age. Intense reworking of earlier continental crust led to intrusion of large volumes of granitic rocks including many biotite-muscovite granites, as described by Almeida *et al.* (1981) and Schobbenhaus *et al.* (1984). Ages of 520 to 510 million years for the Virgem da Lapa host granites classify them as either late- or post-orogenic within the complex Brasiliano intrusion sequences described by Wernicke (1979). The late-orogenic group, which has significant magmatic water content, is more likely to host complex pegmatites than the generally dryer but shallower post-orogenic magmas.

At Virgem da Lapa the pegmatites intrude Precambrian mica schists. Cassedane and Lowell (1982) describe the two mines of interest for topaz, the Limoeiro and Xanda. They are in lenticular bodies between 2 and 7 meters thick containing central replacement zones rich in albite and lepidolite mica. Tortuous adits follow the zone, exploiting prolific cavities that range in size from several cm to 2 meters. Minimal weathering permitted recovery of many exceptional matrix specimens, especially colorless to medium-blue, translucent to gemmy topaz crystals. Prominent *y*{021} faces create sharp, lustrous, wedge-shaped terminations, but the *m*{110} and *l*{120} prism faces commonly show heavy etching. Crystals to 20 by 25 cm are common on matrix with lepidolite, microcline, quartz and elbaite. Lepidolite also forms very aesthetic overgrowths, creating crowns or caps on some topaz crystals.

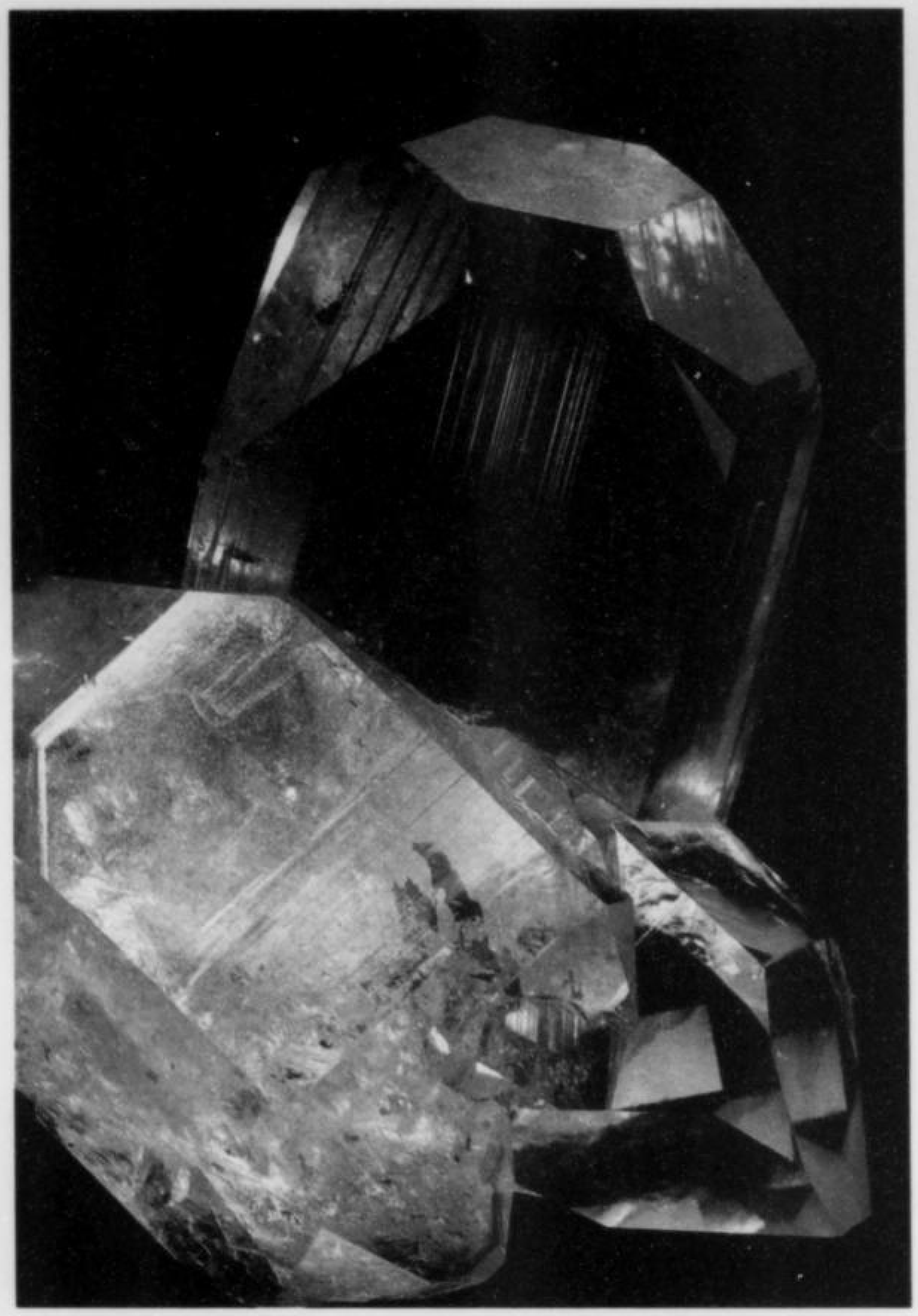
Other notable deposits in Brazil occur in Espirito Santo state. The **Mimoso do Sul mine**, Santa Teresa is of particular interest as it produces topaz from three types of cavities (E. F. de Souza, personal communications, 1992 and 1993). Cavities to 3 meters produce generally loose crystals of topaz to 1 kg that are colorless to pale blue to distinctly green. Some stubby prisms have unusual overgrowths of short, prismatic schorl crystals, and others form more elongated, distinctive, parallel-growth aggregates that may serve as the matrix for pale smoky quartz crystals. Topaz of both types is commonly intergrown (sometime intimately) with dark, lustrous to frosted smoky quartz crystals. These growth relations show topaz to be an early-stage mineral in such cavities. Other associations include prismatic, deep-blue aquamarine, and sharp to corroded microcline. Much larger cavities produce huge quartz crystals and large microclines along with topaz crystals in a range of sizes to 350 kg. Colors include shades of brown to green to blue, and at least some of the smaller crystals show color zoning from yellowish brown to pale blue back to yellowish brown across the *a* axis. Finally, minor topaz accompanies the unusual tapered crystals of aquamarine described by Moore (1992) in other cavities that also contain quartz, microcline and schorl.

Other Pegmatites

The following rarer pegmatite types also host topaz, though uncommonly in cavities.

Topaz occurs in a few cavity-poor **fluorine-lithium epigenetic pegmatites**. Western Australia has several mineralogically important, commercially mined deposits, including Wodgina (once the world's primary source of tantalite) and Londonderry (quarried for microcline and noted for gem-grade petalite). Associated minerals include quartz, feldspars, beryl, lepidolite and other lithium and rare-element species (Chalmers, 1979; Sinkankas, 1981).

Černý (1991a) classifies fluorine-iron-rich **rare-earth pegmatites** as "crossbreeds" that are principally NYF types with LCT overtones. While commercially significant for rare-earth species, typically gadolinite, they are only marginally important for well-crystallized topaz. Such pegmatites generally form larger bodies than their NYF relatives,



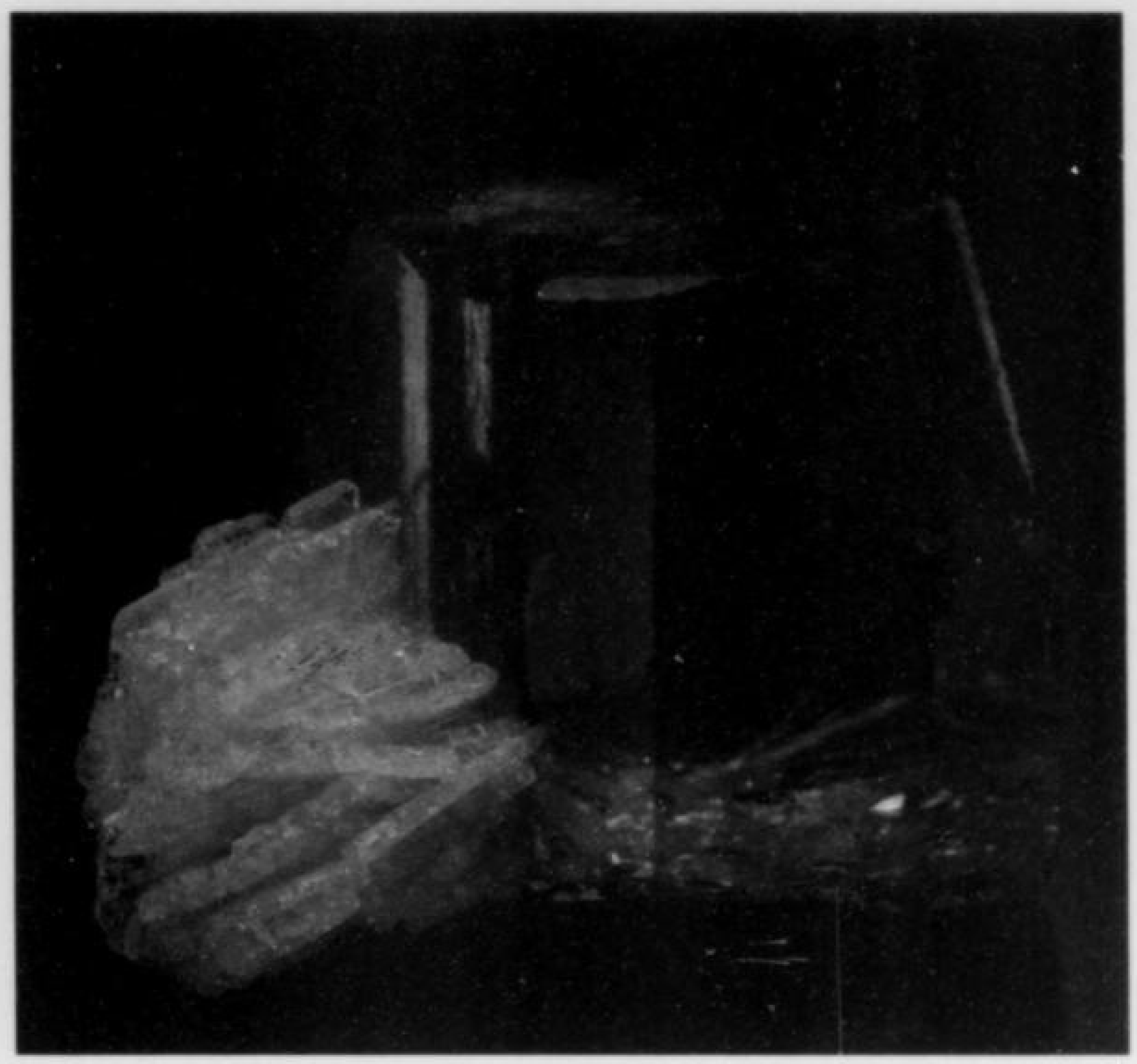


Figure 19. Topaz crystal, 1.7 cm high, on albite (var. clevelandite), from epigenetic pegmatite, Gilgit Division, Pakistan. Paula Presmyk collection; Jeff Scovil photo.

Figure 20. Topaz on doubly terminated quartz crystals, 4.5 cm high, from epigenetic pegmatite, Dusso, Skardu area, Gilgit Division, Pakistan. Werner Lieber collection and photo.

Figure 21. Topaz crystal, 5.5 cm, with smoky quartz, from epigenetic pegmatite, Dusso, Skardu area, Gilgit Division, Pakistan. Michael M. Scott collection; Harold and Erica Van Pelt photo.

Figure 22. Heavily etched topaz crystal on quartz, from epigenetic pegmatite, Dusso, Skardu area, Gilgit Division, Pakistan. Wayne Thompson collection; Wendell Wilson photo.

Figure 23. **Spectacular matrix specimen, 26 cm across, showing two blue topaz crystals with green elbaite tourmaline, albite (var. clevelandite), and smoky quartz, from an epigenetic pegmatite, the Little Three mine, Ramona, San Diego County, California. This specimen, from the major find in 1976, also shows very small, gemmy, second-generation topaz crystals on the terminations of the elbaite crystals. Collection of the Carnegie Museum of Natural History, Pittsburgh; Harold and Erica Van Pelt photo.**

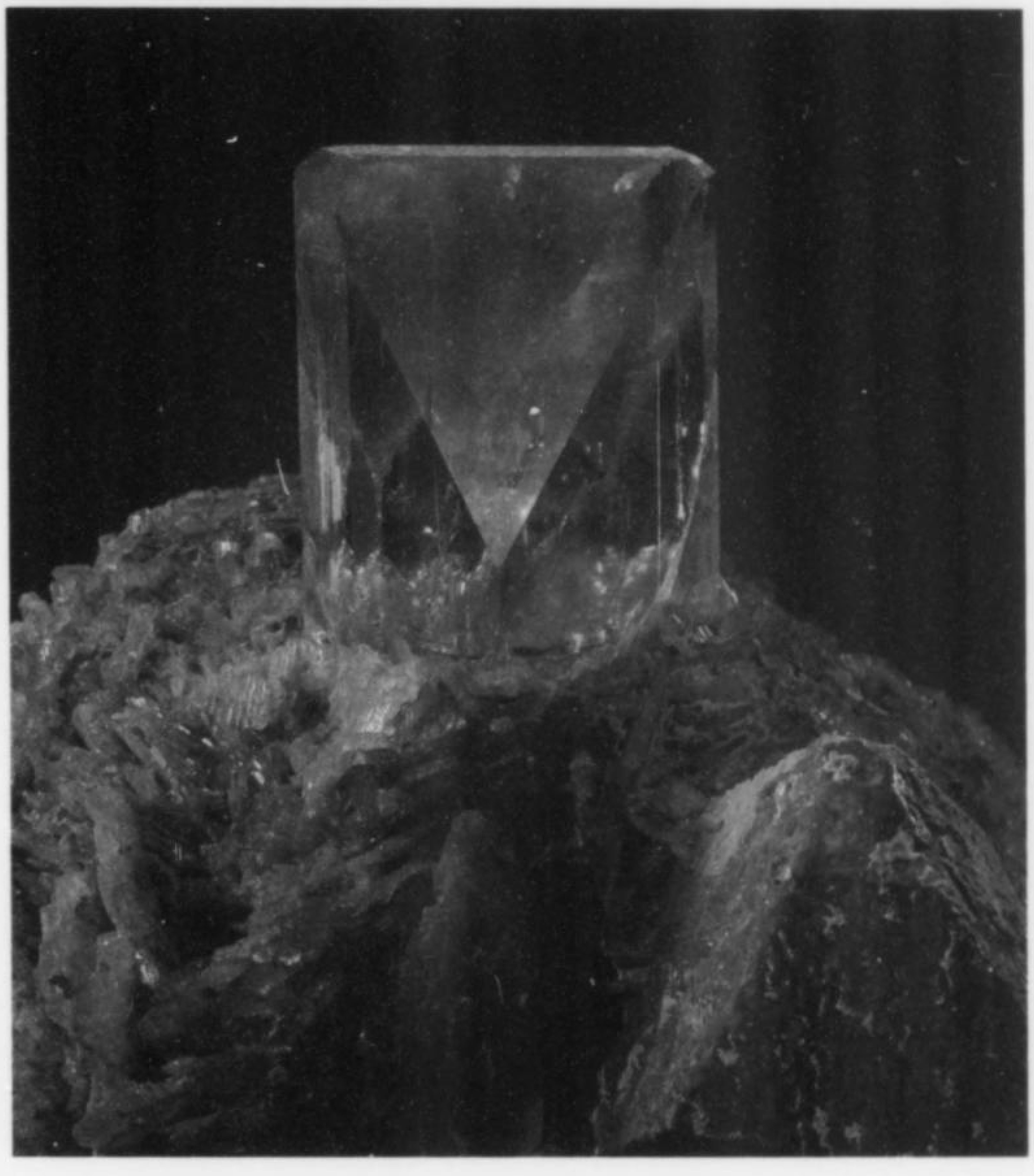


Figure 24. **Topaz crystal, 4.5 cm, on albite matrix with feldspar, from the Little Three mine epigenetic pegmatite, Ramona, San Diego County, California. Bill Larson collection; photo by Harold and Erica Van Pelt.**

Figure 25. Topaz crystal, 7.6 cm, with a "crown" or "halo" of lepidolite crystals, from the Virgem da Lapa epigenetic pegmatite, Minas Gerais, Brazil. Note the prominent *y*{021} form that produces wedge-shaped terminations on many topaz crystals from epigenetic pegmatites. Bill Larson collection; photo by Harold and Erica Van Pelt.

Figure 26. Topaz crystal with albite, lepidolite and microcline, 13 cm, from the Virgem da Lapa epigenetic pegmatite, Minas Gerais, Brazil. Bill Larson collection; photo by Harold and Erica Van Pelt.

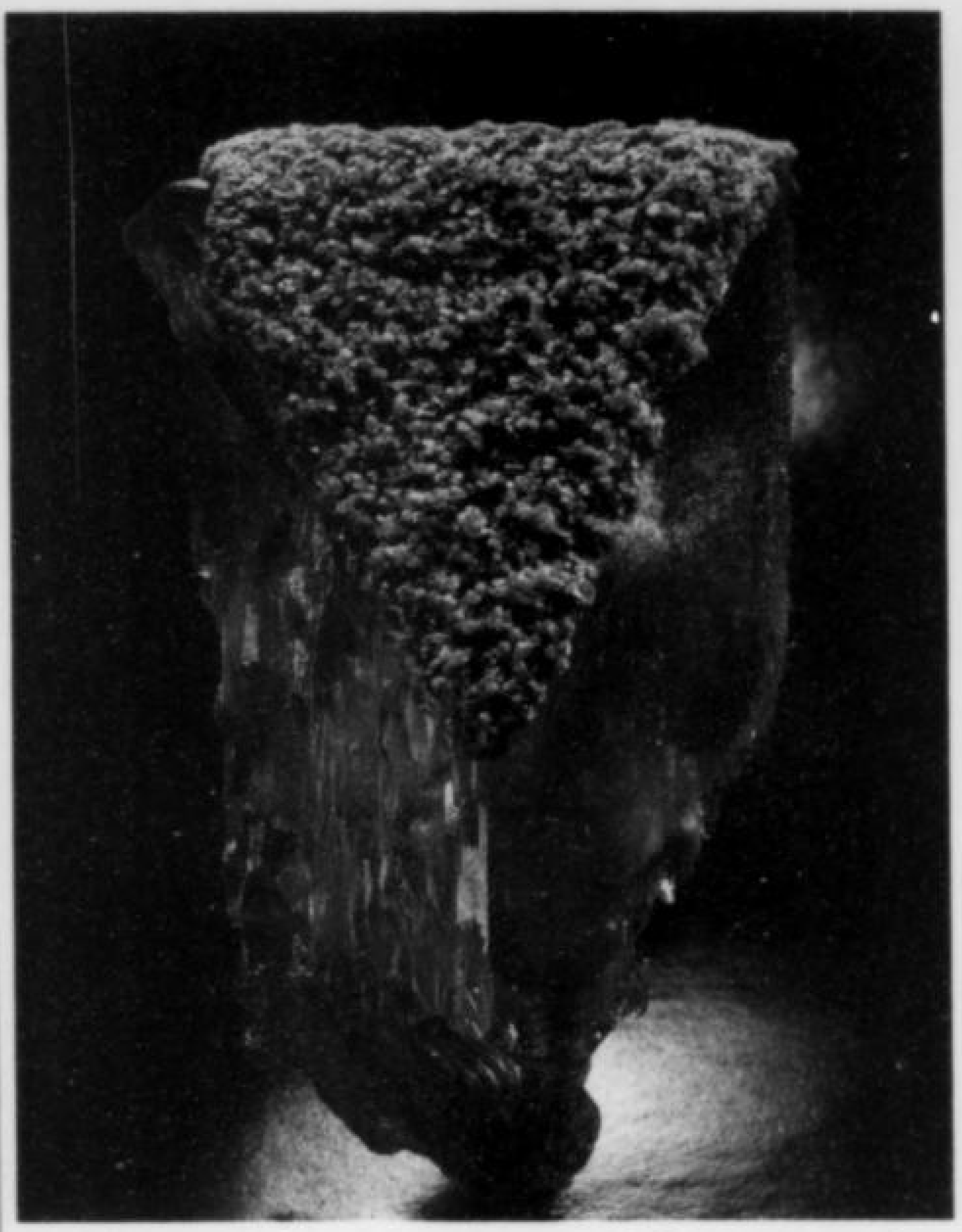


Figure 27. Large topaz crystal, 21 cm, topped with lepidolite, from the Virgem da Lapa epigenetic pegmatite, Minas Gerais, Brazil. U.S. National Museum of Natural History collection; Harold and Erica Van Pelt photo.

Figure 28. Blue topaz crystal, 18 cm, from the Xanda mine at Virgem da Lapa, Minas Gerais, Brazil. Collection of the Houston Museum of Natural Science. Photo by Harold and Erica Van Pelt.

Figure 29. Topaz crystal, 9 cm, on smoky quartz from epigenetic pegmatite near Mimosa, Espirito Santo, Brazil. Collection of the Carnegie Museum of Natural History, Pittsburgh; Joanne Schmalz photo.

Figure 30. Colorless topaz crystal, 5.1 cm, from pegmatite in granite, Llano Uplift, Mason County, Texas. This locality also produces good blue topaz. U.S. National Museum of Natural History collection; Wendell Wilson photo.

and are more complexly zoned than many LCT examples. They occur as dikes and irregular bodies within granite, gneiss and small ultrabasic intrusions, in or near the intrusive contact zone (Beus, 1966). Due to a lack of open cavities, topaz crystals are usually frozen in the core margins. Associated minerals typically include quartz, feldspars, micas, fluorite, magnetite, ilmenite, rare-earth species and, less commonly, beryl. The presence of fluorite is an indicator of higher calcium content than in most other topaz-bearing pegmatites. Localities include the Precambrian granites of both central Texas and southern Scandinavia.

In central Texas such pegmatites occur in the Llano uplift. This intrusion is of similar age (around 1,050 million years) and nature to the anorogenic Pike's Peak, Colorado granite (Anderson, 1983), though Garrison *et al*. (1979) show that it is more likely post-orogenic. Landes (1932) describes the representative Barringer Hill deposit at the northeast margin of the Llano intrusion as having open cavities containing crystallized albite and smoky quartz, and mentions fluorite but not topaz. This crossbreed pegmatite shares a common granitic parent intrusion with the well-known, **Mason County, Texas** topaz deposits. These more conventional NYF-type pegmatites occur in coarse, red granites near the northwestern margin of the Llano intrusion. Sinkankas (1959) and Broughton (1973) describe several individual in-place and alluvial deposits that produce colorless to blue, commonly gem-quality topaz in excellent crystals to 12 cm.

Topaz occurs in several rare-earth pegmatites across southern Scandinavia. Bauer (1968) describes a 60-cm, 62-kg topaz crystal from Iveland, Saetersdalen in southern Norway. P. Lyckberg (personal communication, 1993) reports topaz crystals to 40 cm from the Gundlebo mine (Skuleboda), Väne Ryr, Västergötland County near Göteborg in southwestern Sweden. These non-gemmy, dull yellowish gray-white-blue crystals are frozen in pegmatite matrix. Associated minerals include lepidolite, microcline (var. amazonite), albite, fluorite, smoky quartz, and some cassiterite along with minor other species. Other such topaz from Scandinavia includes large crystals from Fossum, near Modum west of Oslo in southern Norway (P. Lyckberg, personal communication, 1993), and germanium-bearing topaz from the Viitaniemi pegmatite, Eräjärvi, southern Finland (Sinkankas, 1981). The Viitaniemi deposit is noted for phosphates (Moore, 1973) which are rarely associated with topaz.

Topaz also occurs rarely in replacement deposits that have been termed **"desilicated pegmatites"** (Sinkankas 1981) or "pegmatites of the crossing line" (Beus, 1966). In these types of deposits, fluorine-rich pegmatitic fluids from granite intrusions transfer significant amounts of silicates to silica-poor, ultrabasic host rocks. The deposits of interest for topaz are better known for emeralds, e.g. in the Adui River district northeast of Ekaterinberg (formerly Sverdlovsk), south of Mursinka in the Ural Mountains, Russia; at Emmaville, New South Wales, Australia; and at Poona in Western Australia, all as described by Sinkankas (1981). The typical forms are lenses or veins in altered biotite or phlogopite schists. Topaz may occur in predominantly albite veins, as in the Ural Mountains (Lyckberg, personal communication, 1993). Such veins also contain lighter-colored beryl rather than emerald that is more common in the adjacent schists (Sinkankas, 1981). In this environment topaz, which is notably rarer than most other pegmatite minerals, competes for fluorine with fluorite (also apatite in the Russian deposits). Other associated minerals include quartz, feldspars, micas, common beryl, phenakite (Russia) and cassiterite (Australia). Beus (1966) notes that topaz occurs with beryl in such deposits in cavities within the contact zone of the source granites themselves.

Hydrothermal Deposits

Intrusion of a topaz granite may create a complex pattern of mineralization, especially in the roof zone, as shown in Figure 11. Residual hydrothermal fluids typically form a range of deposit types including greisens, skarns and veins, as well as the pegmatites described earlier. Any single episode of mineralization generally follows a consistent sequence with falling temperature, as illustrated in Figure 31. In practice, few intrusions develop the full range of deposit types or show each step in the sequence; even the granitic source rocks are not always evident. Some deposit types, particularly greisens and hydrothermal veins, may overlap spatially or even form at different times within the same fracture. For example, high-temperature veins commonly have greisen rims, as in the tungsten deposits of central Kazakhstan (Beus, 1966). The following description of hydrothermal deposit types highlights differences in temperature regimes and formation processes.

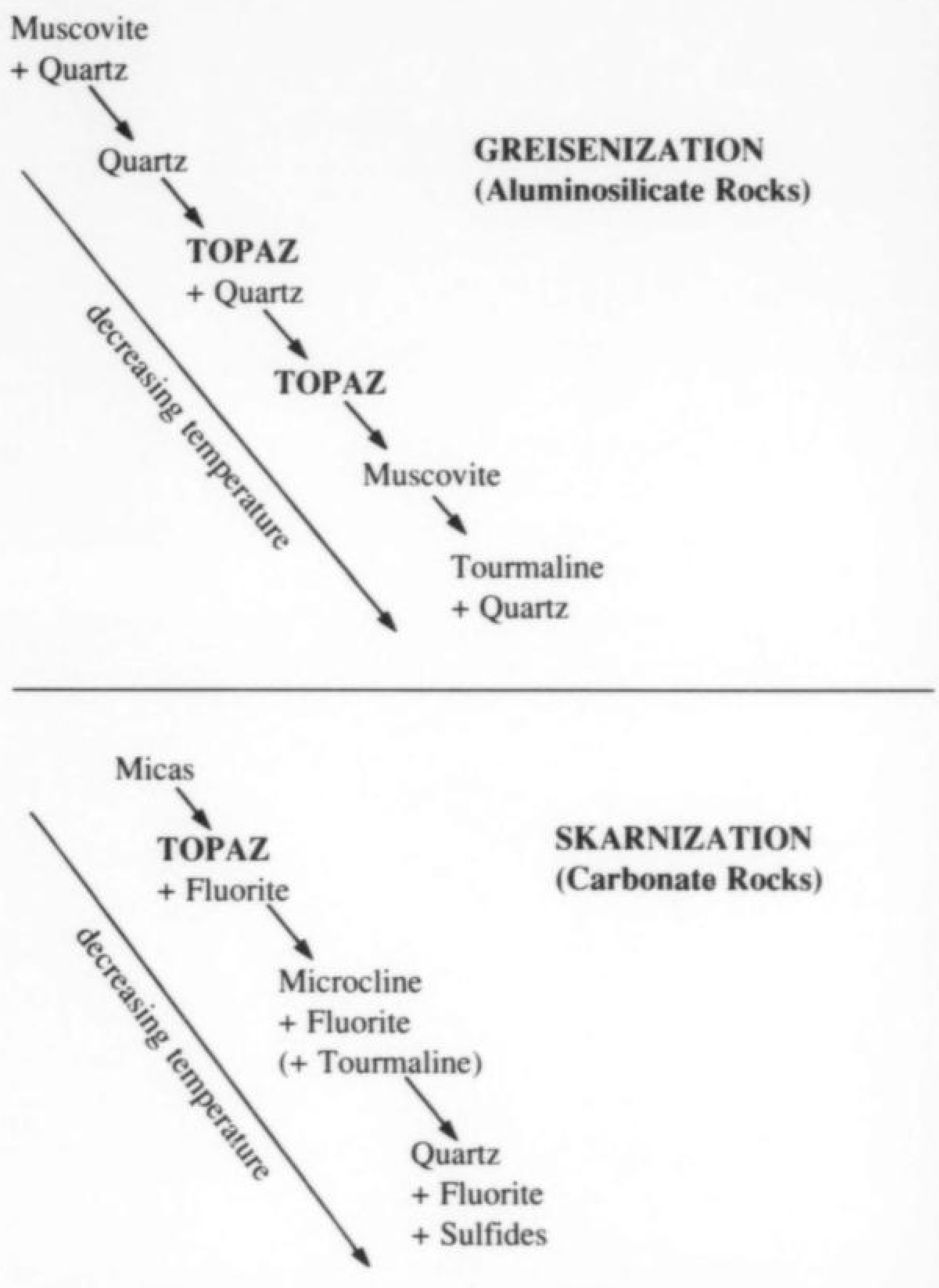


Figure 31. **Typical mineralization sequences for greisens and skarns (modified after Shcherba, 1970). Fluorine-rich acidic fluids typically deposit topaz during intermediate stages of cooling. The lower-temperature sequences, in which topaz is rare, are more typical of hydrothermal veins.**

Greisens

Greisens are aluminosilicate rocks (commonly granites) that have been transformed into granular masses consisting mostly of quartz and micas. The hot, reactive, acid fluids that are responsible typically invade along fractures. If these fluids are silica-rich and fluorine-rich, topaz forms through combination with aluminum leached out of decomposing feldspars. Estimated temperatures range from around 550°C down to as low as 300°C or even lower in massive rather than vein-type greisens (Naumov *et al.*, 1977). Shcherba (1970) and Burt

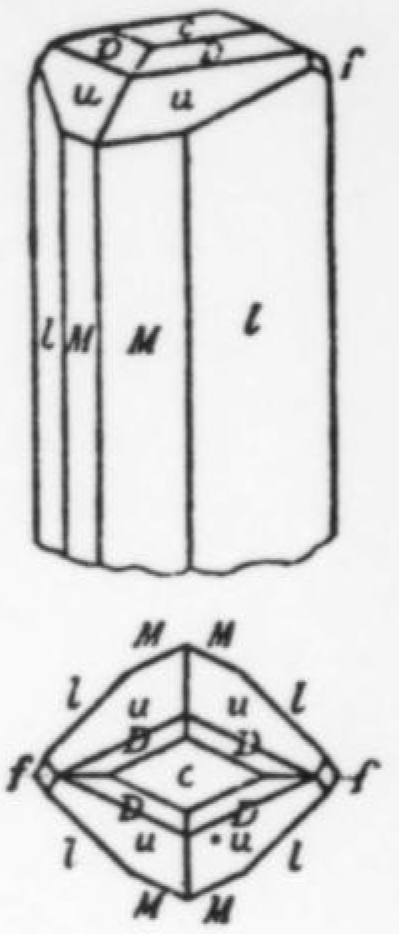


Figure 32. **Typical topaz crystal habit from Schneckenstein, Saxony (Goldschmidt, 1922).**

Figure 33. **Topaz on matrix, from the classic Schneckenstein greisen deposit, Saxony, Germany. Plate 54 from Gautier d'Agoty's *Histoire Naturelle Regne Mineral* (1781) (Richard A. Bideaux library).**

(1981) provide good descriptions of the greisenization process.

Topaz may be produced in considerable quantity, mostly in granular or massive form, but also in cavities. Greisenization typically causes net removal of rock, particularly in the early stages. This allows crystals of topaz and ore minerals to be deposited later in open cavities, commonly at points where bodies or veins widen. Unfortunately most greisen topaz specimens are unimpressive, typically with small (though sharp) intergrown crystals, on a matrix of massive vein wall, commonly with crystals of quartz and ore minerals such as cassiterite. Thus greisens are generally less important sources of specimens than might be expected.

Source granites can produce large quantities of hot residual fluids, with the potential to create extensive greisen zones. Structures include large domes, lenses or pipes, and also complex systems of fissure veins and stockworks above granite intrusions. Of particular interest are the rarer breccias or explosion breccias that are formed by rapid release of greisen fluids due to sudden opening of a fissure or chamber. This creates intense brecciation of the country rock with an increased potential for mineralized cavities.

Several areas of Europe, including the Erzgebirge in Germany and the Czech Republic, southwest England, Brittany in France, and Portugal, host important tin, tungsten and topaz-bearing granites that form greisen deposits. These granites all formed during the continental collision involving North Africa, western Europe and Britain in Devonian to late Permian time (between 370 and 230 million years ago). Intrusion timing is accepted as post-orogenic, corresponding to rifting and faulting following the major folding (Ager and Brooks, 1977).

The Erzgebirge is a classic greisen area that spans the German-Czech border. Taylor (1979) notes a total of 15–20 tin-rubidium-lithium-rich granitic intrusive complexes that have created 20–30 centers of mineralization over the 15 by 150 km area. Tischendorf and Förster (1990) describe the main ore-bearing intrusions, the post-orogenic granites of the Younger Intrusive Complex (YIC). Common characteristics include highly evolved parent magmas with high ratios of fluorine to water, and common explosion and intrusion breccias. Some granites in the eastern Erzgebirge show anorogenic characteristics, and probably represent shallow, final-stage intrusions derived from earlier orogenic granites (Štemprok, 1990). Massive greisens, usually within the granites, form the predominant orebodies, along with skarn, minor pegmatite, and sulfide deposits. Mineralization is of the tin-tungsten type with lesser molybdenum, bismuth and sulfides (Taylor, 1979).

Topaz occurs in a number of greisen (and also pegmatite) deposits. The most significant of these is in the German region of Saxony. The **Schneckenstein** deposit was exploited solely for gem topaz from around the end of the 17th century (Russ, 1989a). Its formation through explosive brecciation is uncommon for greisens, but created abundant open cavities to 30 cm across. Topaz is present in several generations (Naumov *et al.*, 1977) as both sharp individual crystals

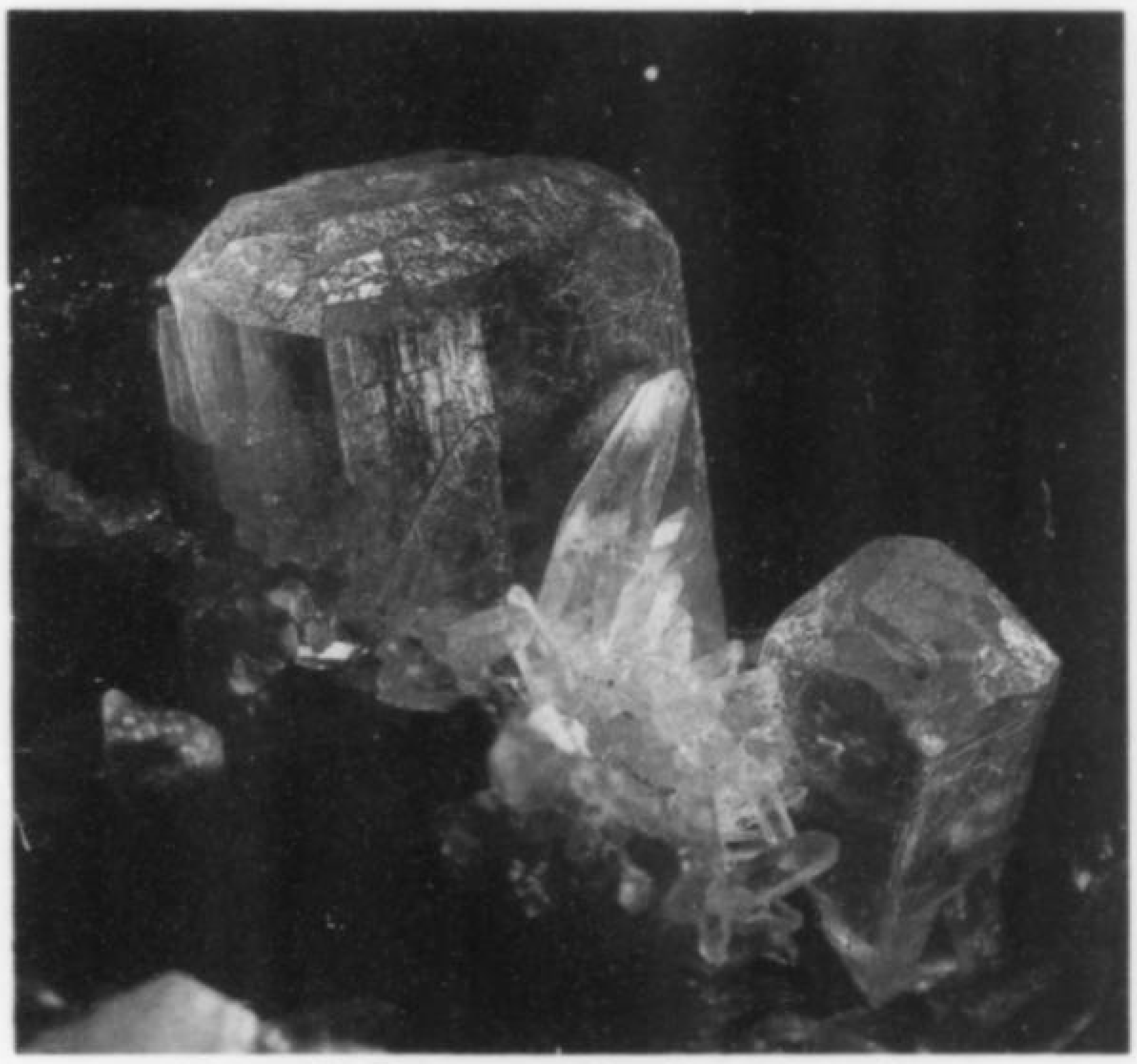


Figure 34. **Topaz crystals with quartz, 4 cm high, from greisen deposit, Schneckenstein, Saxony, Germany. Werner Lieber collection and photo.**

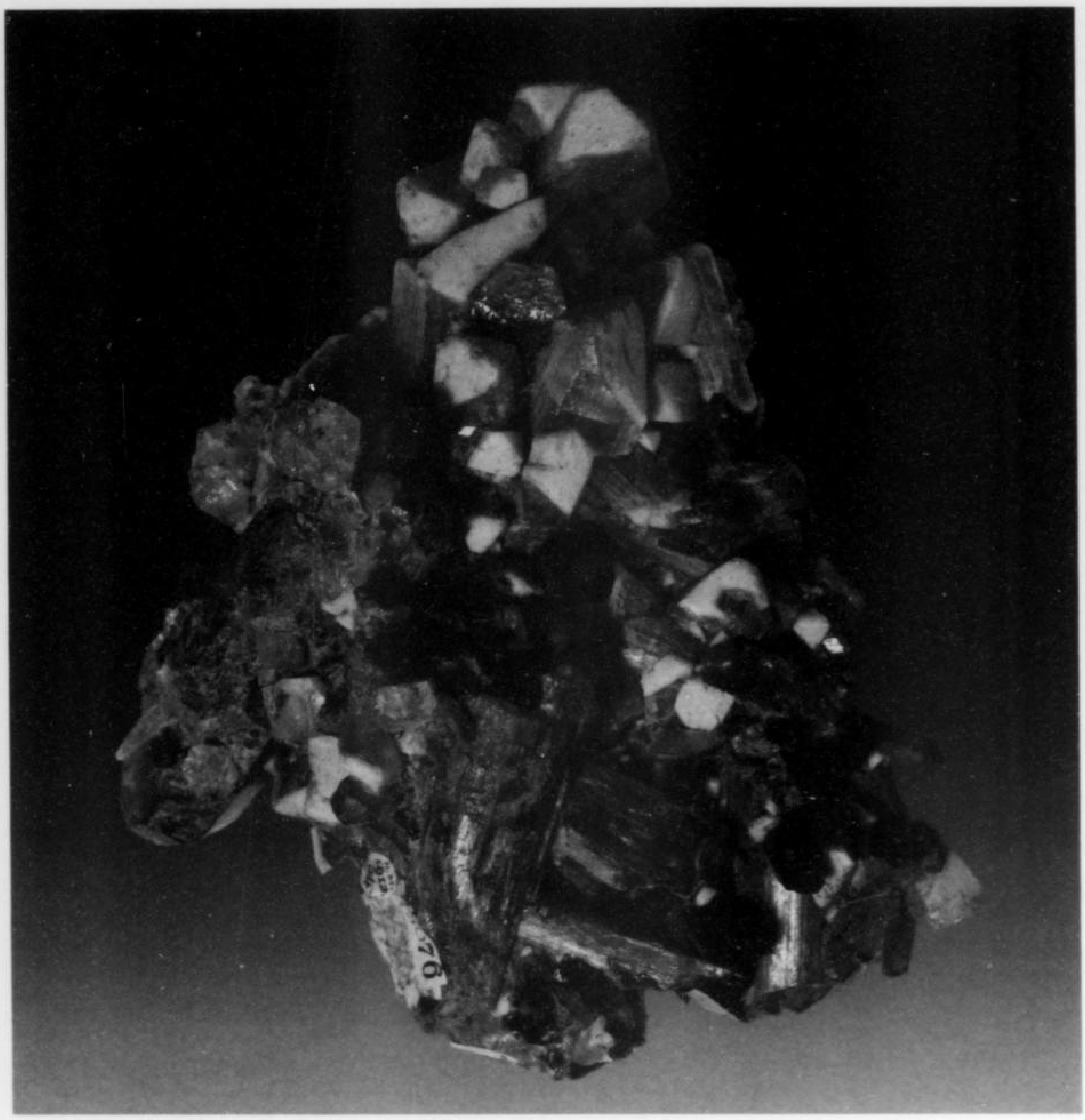


Figure 35. **Group of topaz crystals, several doubly terminated, showing unusual "white-capped" terminations, associated with beryl (var. aquamarine) and smoky quartz. The specimen measures approximately 15 by 13 cm, and is from Adun Chilon, Transbaikalia, eastern Siberia. This is a granitic deposit that may be either a syngenetic pegmatite or a greisen, or may share features of both. The Natural History Museum, London collection (BM 1912,54 originally from Henry Heuland Collection, 1833) and photo.**

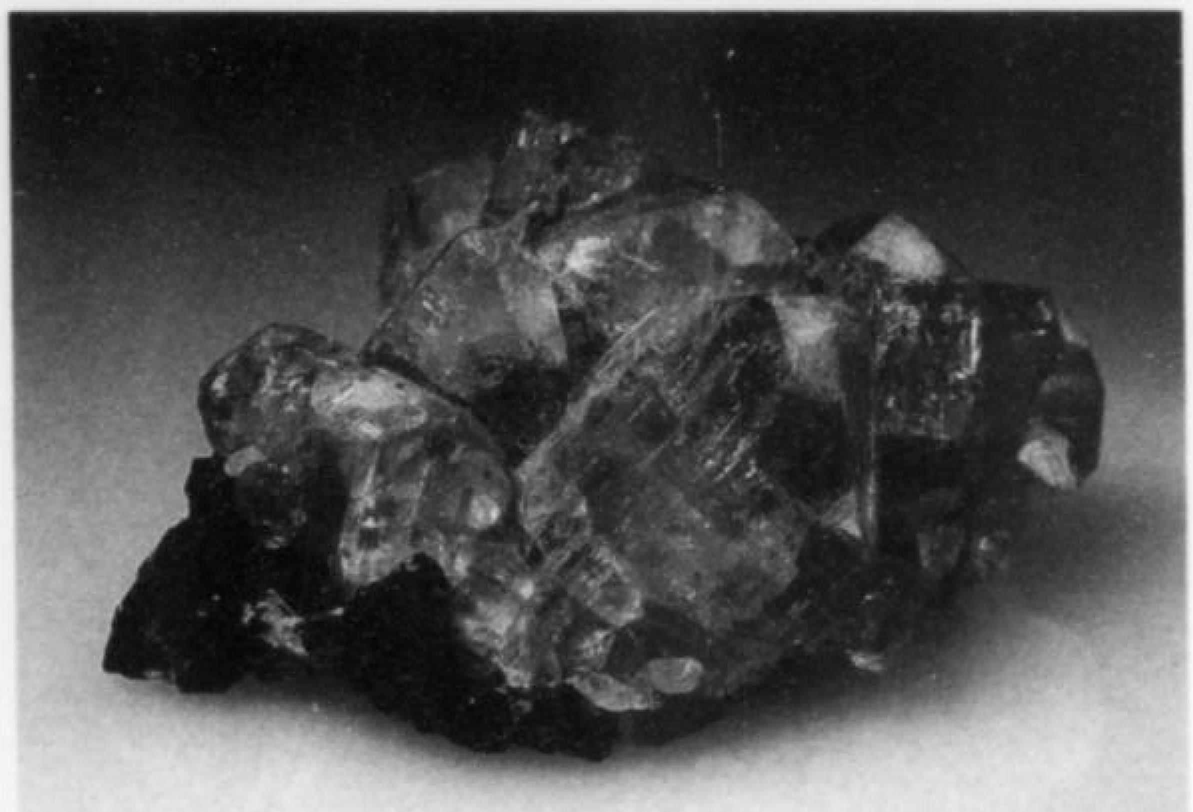


Figure 36. **Intergrown topaz crystals to 3 cm with green fluorite and minor smoky quartz from greisen deposit, Sherlova Gora, Transbaikalia, eastern Siberia. The 8-cm specimen has the typical form and associations of greisen topaz. Note the thin, opaque white zones on the *u*{112} faces of the topaz crystals. Author's collection and photo.**

and in the topaz-quartz rock which generally forms their matrix. Crystals are mostly under 1 cm, commonly gemmy, and distinctively wine-yellow. They are typically blocky in form, showing *m*{110} and especially *l*{120} faces, with strong development of the *c*{001} face on their terminations. Associated well-crystallized minerals include clear to opaque quartz crystals, green to black needles and tufts of tourmaline, apatite, fluorite, wolframite and sulfides.

Another unique and important topaz greisen deposit occurs in Transbaikalia, eastern Siberia. The regional geology has been described earlier for the Urulga River pegmatites. Gem deposits were discovered in 1723 on **Sherlova Gora** and **Adun Chilon**, two peaks on a ridge in the Onon-Borzinskaya Mountains, south of Nerchinsk. The region is best known for gem beryls (uncommon from the greisen environment), but it has produced excellent-quality topaz. Descriptions are provided by Fersman (1925), Beus (1966) and Sinkankas (1981), with recent information from R. Triebl and D. Belakovskii (personal communications, 1993). Many specimens from the general region have been labeled Adun Chilon, resulting in confusion regarding locations. Most material in collections probably dates from the 19th and early 20th centuries, but there has been some renewed mining for specimens on Sherlova Gora in the 1990's.

Fersman (1932) describes Sherlova Gora as an example of a rare lack of separation between pegmatitic and pneumatolytic (greisen) phases, resulting in a complex combination of greisenization and hydrothermal mineralization. According to Beus (1966), Sherlova

Figure 37. **Group of topaz crystals, 9 by 15 cm, from Adun Chilon, Transbaikalia, eastern Siberia. This granitic deposit may be either a syngenetic pegmatite or a greisen, or may share features of both (the intergrown form suggests a greisen environment). The Natural History Museum, London collection (BM 59545, probably from Greville Collection, 1810) and photo.**

Gora consists almost entirely of a massive greisen at the apex of a granite intrusion. Fracture systems control several different greisen zones. In order of deposition, predominant quartz-mica outer zones were followed by topaz-quartz and topaz inner zones. These formed the walls for vein fillings of quartz or quartz-beryl, and less commonly quartz-topaz. Final-stage solutions produced exceptional specimens of beryl associated with fluorite, but only after exhaustion of fluorine in the topaz stage. The less common quartz-topaz veins contain open cavities with well-formed crystals of topaz and quartz, and also rare but fine beryl crystals. Beryl occurs in two generations, with fine-quality, second-generation heliodor or aquamarine growing on the faces of topaz crystals and also on smoky quartz and first-generation beryl.

The deposits on Adun Chilon peak are shown in Fersman's map (Fersman, 1925; Sinkankas, 1981) as pegmatites. They host similar mineralization in granite but appear to show both greisen and pegmatite features. (Sinkankas (1981) indicates that the region's greisen deposits were by far the most important for gem production.)

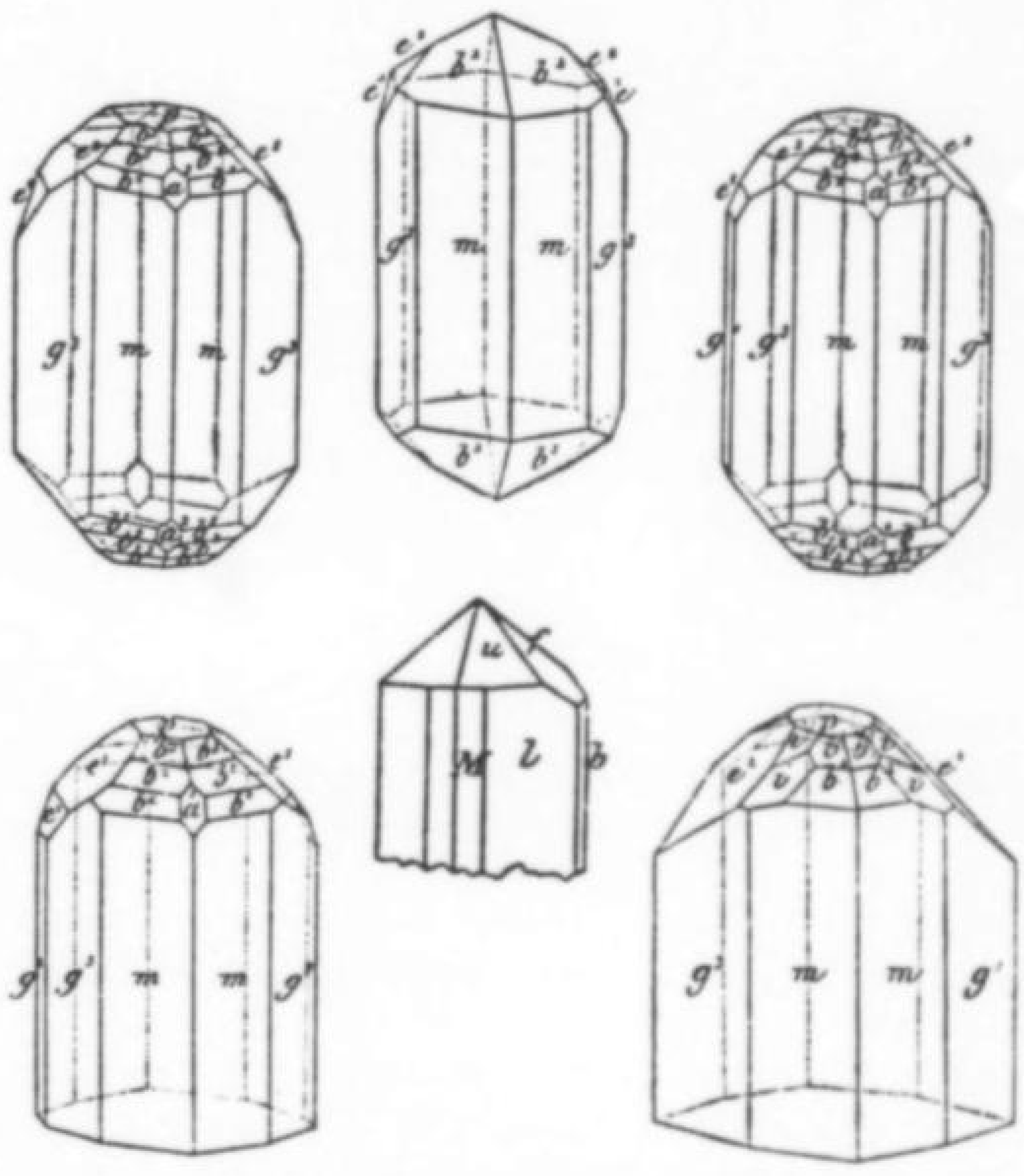


Figure 38. **Topaz crystal habits from Adun Chilon, Siberia (Goldschmidt, 1922).**

Figure 39**. Sketch of a topaz matrix specimen from Adun Chilon, Siberia, pictured in H. A. Baumhauer's *****Reich der Kristalle***** (1889).**

The region is notable for unique specimens of well-crystallized, intergrown beryl and topaz, as well as exceptional specimens of the two individual minerals. Sinkankas (1964) reports topaz in sharp, yellow, transparent crystals to 15 cm. Crystals are typically striated but unetched yellowish prisms exist which are translucent to transparent (Natural History Museum, London, personal communication, 1991). Other colors include pale blue-green and pale brown (author's collection; Cooper, 1994). The dominant crystal forms are *l*{120} prisms and *f*{011} terminations. Some topaz crystals associated with beryl have unusual opaque white zoning at their terminations. Topaz is commonly found with well-crystallized smoky quartz, and less commonly beryl and/or fluorite. Many specimens show typical greisen characteristics, with heavily intergrown smoky quartz and topaz. Other associations include very small crystals of ferberite, bismuthinite and sulfides (Beus, 1966). Sinkankas (1981) also reports feldspars, cassiterite, and additional species including zircon, rutile and brookite.

So-called "porphyry greisens," commonly associated with granites, form fluorine-rich, shallow deposits whose formation temperatures likely exceeded 500°C. Despite strong fracturing, crystallized topaz in open cavities is uncommon. Representative localities include the molybdenum mine at Climax, Colorado (White *et al.*, 1981), and the Mt. Pleasant tungsten deposit in New Brunswick, which has an uncommon rhyolite host (Parrish and Tully, 1978).

Skarns

Skarns are formed in a similar fashion to greisens by invasion of hot, reactive fluids. The difference is in the host rock, which for skarns is a carbonate that is typically altered to calc-silicate minerals (Einaudi and Burt, 1982). Fluorine-rich fluids can produce topaz, but only if there is excess fluorine over that consumed by the calcium in the host rock in forming fluorite. Skarns are not important sources of topaz, which is commonly a component of massive topaz-fluorite and mica-fluorite ores. Associated minerals typically include magnetite, fluorite and also margarite mica. Temperatures are estimated by Shcherba (1970) to be in the range 500–400°C. Taylor (1979) describes representative localities including tin deposits in northwestern Tasmania, Australia and some deposits in the Erzgebirge.

Shannon (1921a, b) and Hiller (1969) describe the **Long Hill mine** in Trumbull Township, Connecticut. This is a tungsten and limestone mine that ceased operation in 1916. Tungsten minerals formed along the lower contact of a thick bed of coarsely crystalline white limestone interbedded with hornblende schist. The age of mineralization is unknown, but it is probably related to volcanism around 450 million years ago during the Taconic orogeny (Hatcher *et al.*, 1989). The deposit is unusually fluorine-rich, with several quartz-topaz veins showing significant topaz. This occurs mostly in nodular to coarse crystalline masses with extensive alteration, apparently during the initial mineralization, to calcium-rich and fluorine-rich micas including margarite. Good topaz, including some gem-quality blue crystals, has been preserved in cavities in quartz (Sinkankas, 1959). Goldschmidt (1922) shows a medium prismatic crystal with development of *m*{110}, *l*{120} and *b*{010} forms and with a complex termination.

Hentschel (1977) describes a unique occurrence of topaz in the Bellerberg quarry in the **Laacher See** region of Germany's Eifel district. Small, transparent crystals have formed in vesicles in the contact zone between limestone and basaltic cinders. The mineralization is probably of the skarn type, due to metamorphism of the limestone by volcanics, during volcanism that started around 500,000 years ago.

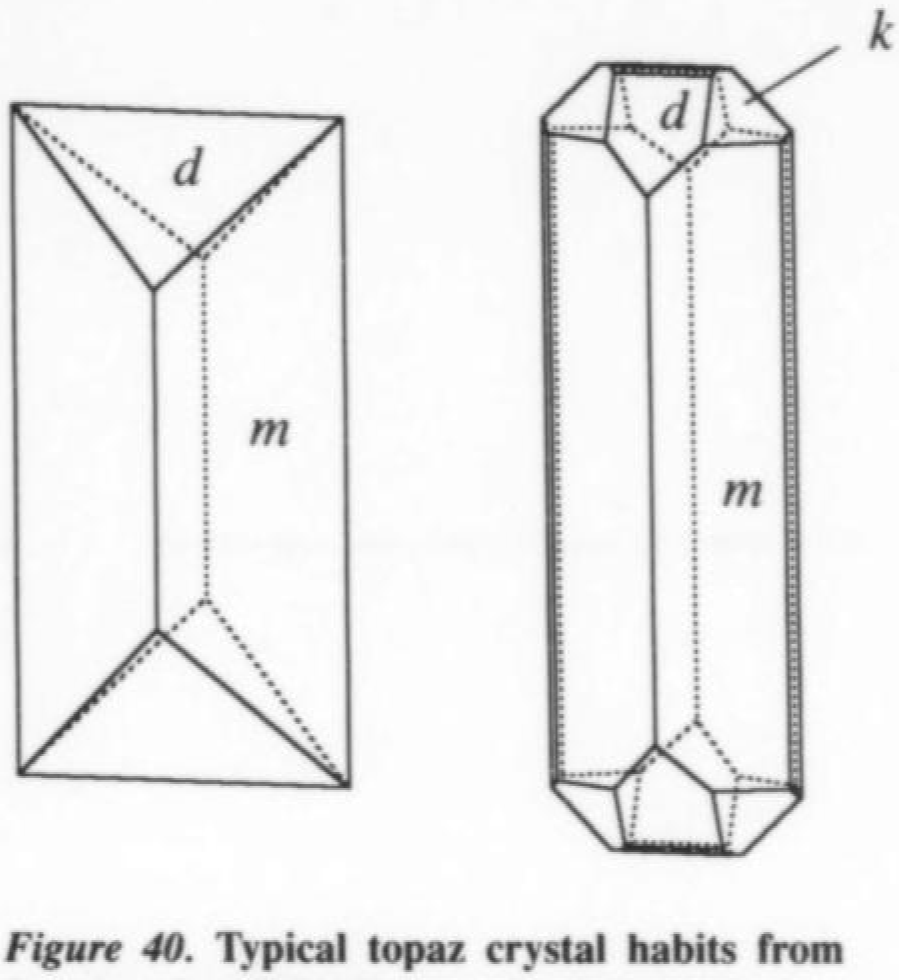


Figure 40**. Typical topaz crystal habits from Laacher See, Eifel district, Germany (courtesy of Eric Offermann).**

In basic and ultrabasic rocks, as with carbonates, fluorite generally forms in preference to topaz. Rarely, small quantities of topaz form in replacement bodies that may be termed "desilicated pegmatites," as described earlier.

Veins

The vein environment for topaz includes high-temperature tin-tungsten deposits, through lower-temperature sulfide deposits and rare low-temperature carbonate veins and alpine clefts. Mineralization occurs from the continuing action of fluids that are still hot, but are generally too fluorine-depleted to produce topaz. In many deposits, these hydrothermal veins overlap with earlier, higher-temperature greisen or other zones that are the source of the fluids. Naumov (1977) estimates temperatures in these vein systems to range from 400°C down to around 200°C.

High-temperature quartz and quartz-feldspar vein deposits are widespread in some areas, e.g. in eastern Kazakhstan (Shcherba 1970), and as described by Taylor (1979) in Cornwall, southwest England, and the New England and Heberton regions of eastern Australia. Shaw and Flood (1981) describe the orogenic parent granitoids in New England. In eastern Australia, intrusion of multiple, shallow plutons has created greisens, narrow, quartz-chlorite and

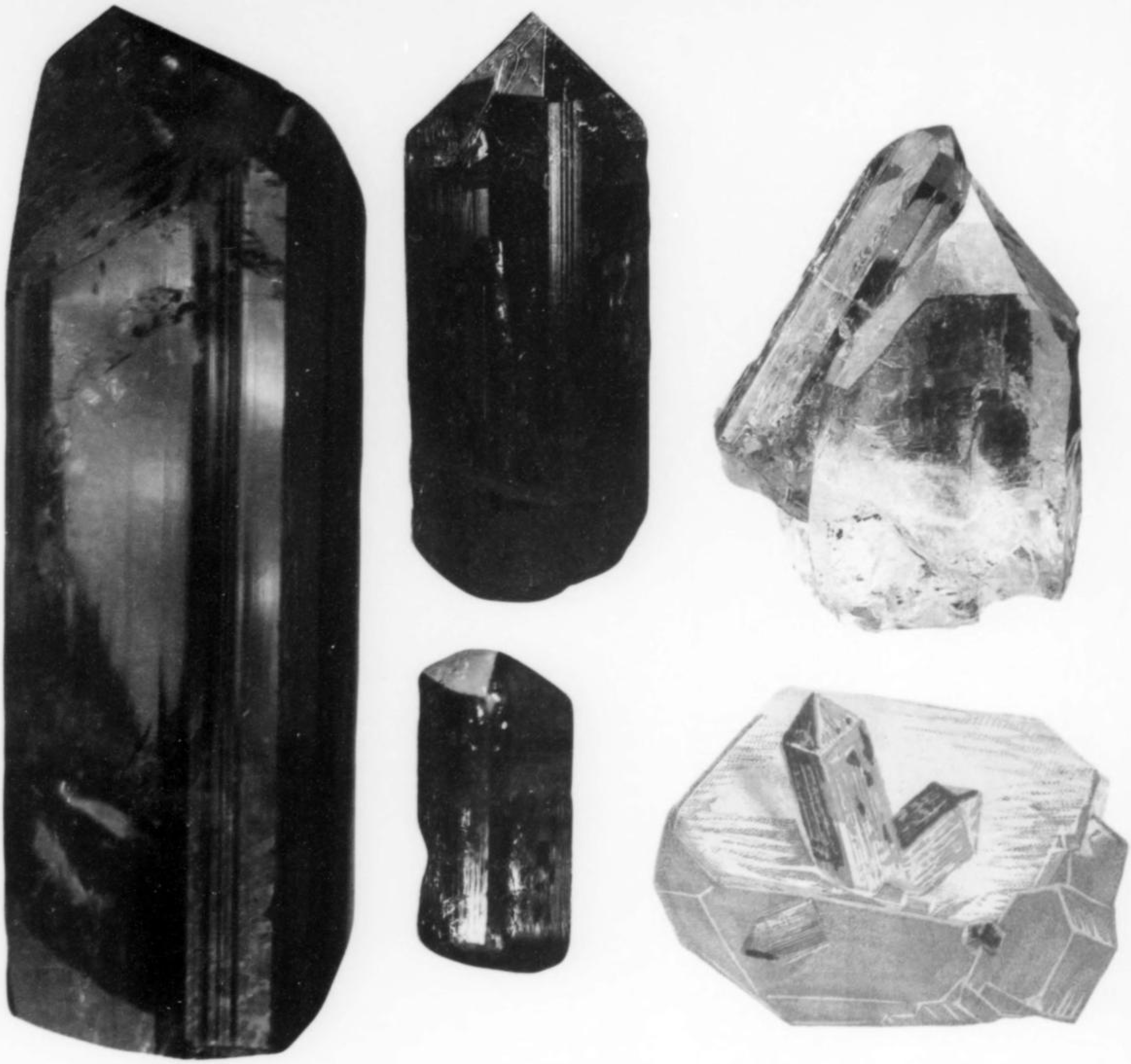


Figure 41. **Topaz crystals from the Ouro Preto area, Minas Gerais, Brazil: (left) 5.5 cm, Bill Larson collection, photo by Harold and Erica Van Pelt; (top center) 6 cm, Keith Proctor collection, photo by Wendell Wilson; (bottom center) 2-cm pink crystal, Wendell Wilson collection and photo; (top right) 2.7 cm crystal on quartz, Roland Sherman collection, photo by Jeff Scovil; (bottom right) crystals on feldspar (from Streeter, 1892).**

quartz-feldspar fissure veins, and pipes. Economic mineralization includes the tin-tungsten suite, commonly associated with bismuth, beryl and sulfides. Cavities that are locally common due to shallow deposit emplacement may contain well-crystallized topaz and cassiterite. The Cornish and eastern Kazakhstan deposits are similar but deeper, with proportionally more associated greisens and pegmatites, and apparently rarer topaz crystals in cavities.

Vein deposits generally produce only small amounts of topaz, but the unique **Ouro Preto** deposits in Minas Gerais, Brazil are an outstanding exception. They are being exploited in several commercial gem mines across a 6 by 20 km area, as described by Cassedane (1989). Highly weathered, kaolinite-quartz-K-feldspar veins that form the host structures are restricted to a narrow, horizontal fracture zone in granite-intruded, iron-rich phyllites. The geology has been the subject of considerable debate. A pegmatitic origin, e.g. as described by Keller (1983), appears most favored, but other scenarios include replacement of kaolinite by fluorine-rich fluids (Olsen, 1971) and a pneumatolytic (higher-temperature, vapor-phase) period followed by hydrothermal action (Cassedane, 1989). Although the question of origin appears unresolved, the over 25% substitution of OH for F (Barton, 1982) strongly suggests a low-temperature, hydrothermal origin. The age of mineralization is unknown, but the host rocks of the Minas Supergroup (2,500–1,800 m.y.) have undergone several tectonic and thermal events (1,350, 1,000 and 500 million years ago), including granitic intrusions (Cassedane (1989).

So-called "imperial" topaz occurs in a range of golden yellow

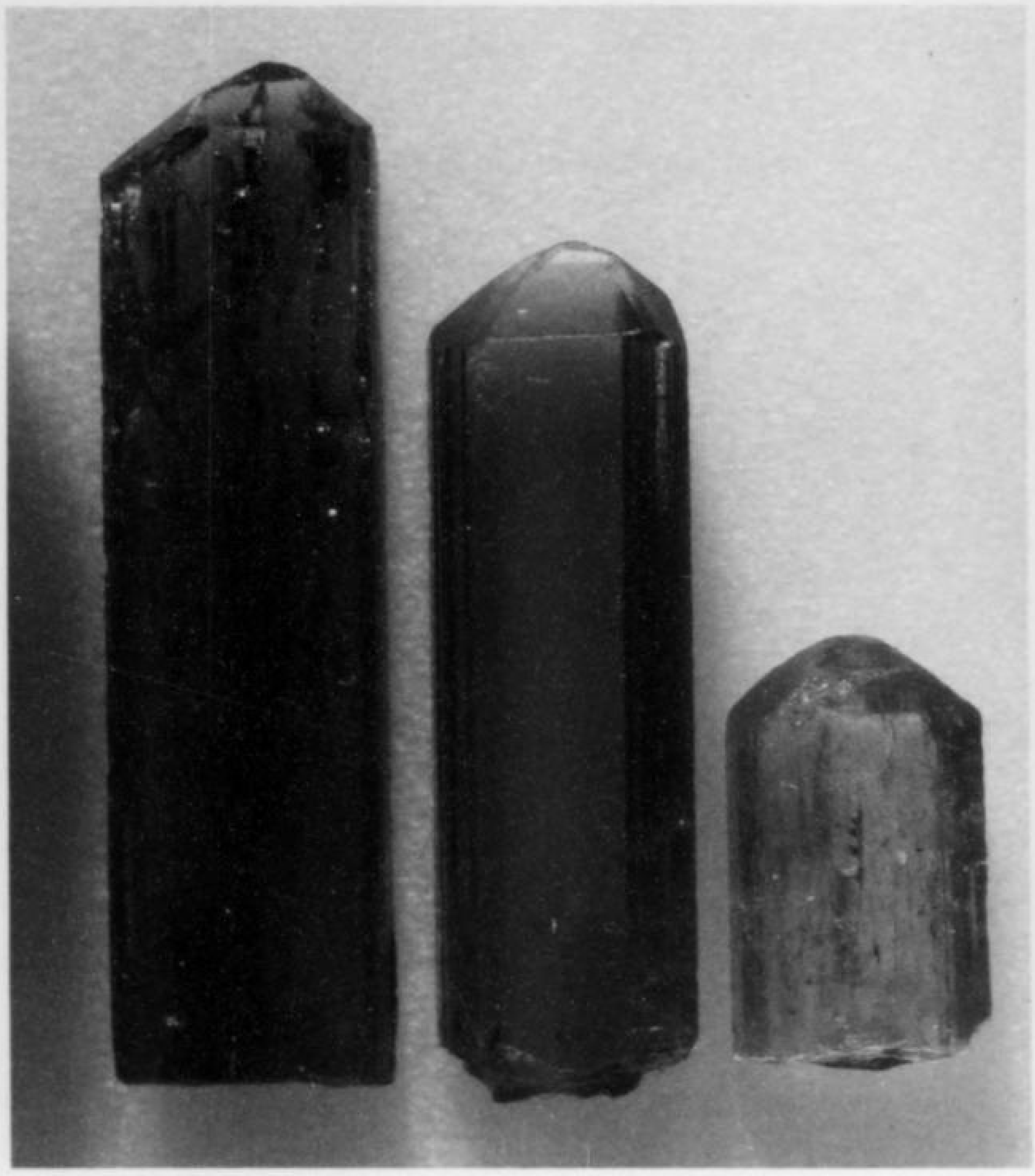


Figure 42. **Set of three topaz crystals to 1.4 by 2.2 cm, from a hydrothermal vein deposit, Sanarka River, southern Ural Mountains, Russia. These were recovered from gold washings in the 19th century. The Natural History Museum, London collection (BM 38087, from Koksharow Collection) and photo.**

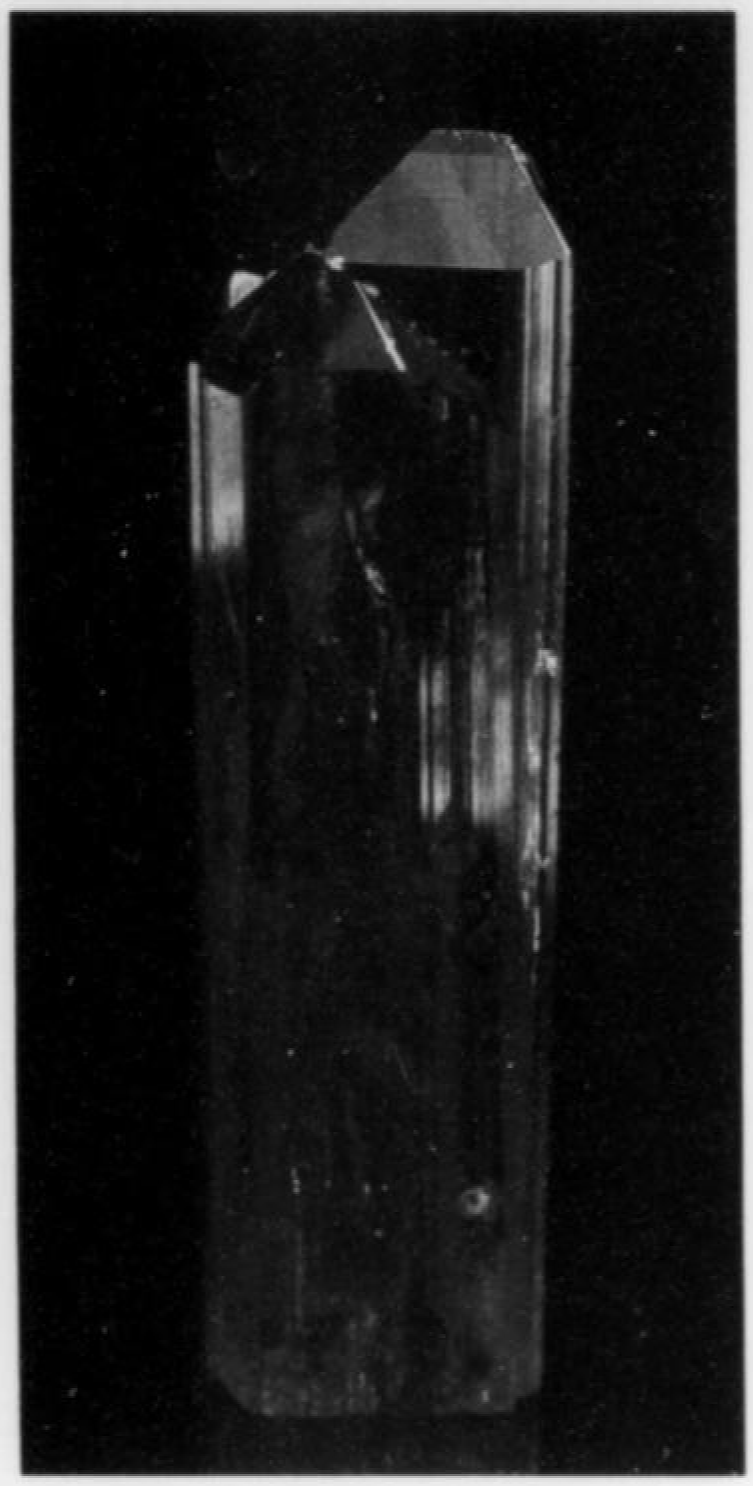


Figure 43. **Topaz crystal, 2.6 cm high, colored red by chromium, from hydrothermal vein deposit, Sanarka River, southern Ural Mountains, Russia. Collection of the Fersman Museum, Moscow; Jeff Scovil photo.**

through orange to sherry-red hues, with the reddish color component due to traces of chromium. The color spectrum also includes almost colorless, pale green, peach-pink, lilac and pale purple. Crystals, which may be gemmy, are typically elongate prisms with striated faces and prominent {342} termination faces. Doubly terminated crystals are uncommon, but can appear hemimorphic with a partially inverted, re-entrant pyramidal habit on one end. Crystals commonly reach 4 cm, but occur to 30 cm.

Very similar red topaz also occurred in historically significant but not prolific alluvial deposits along the Kamenka River and especially the **Sanarka River**, Russia (Scalisi and Cook, 1983; Evseev, 1993b). These locations are around 100 km south-southeast of Miass in the southern Ural Mountains. The regional geology is described earlier for the Mursinka pegmatites, and this deposit is likely of similar age. Colorless and yellow crystals to 6.25 cm were also found with other gem species, most importantly euclase and chrysoberyl. The *in situ* source for the topaz was later determined to be quartz veins and cavities in limestone where it occurs with chromium-bearing tourmaline and mica.

Beus (1966) notes rare topaz mineralization from low-temperature sulfide veins, e.g. at Fremont (Framont-Grandfontaine?, west of Strasbourg), France and in the tin deposits of **Cornwall**. The latter, which show combined greisen and sulfide vein mineralogy, are of similar Devonian to late Permian age and tectonic origin to the Erzgebirge deposits described earlier. Manning and Hill (1990) describe the classic topaz granites as late-stage, highly differentiated minor components of the overall intrusion. Russell (1924) reports topaz in cavities and coating vein walls from various Cornish mines.

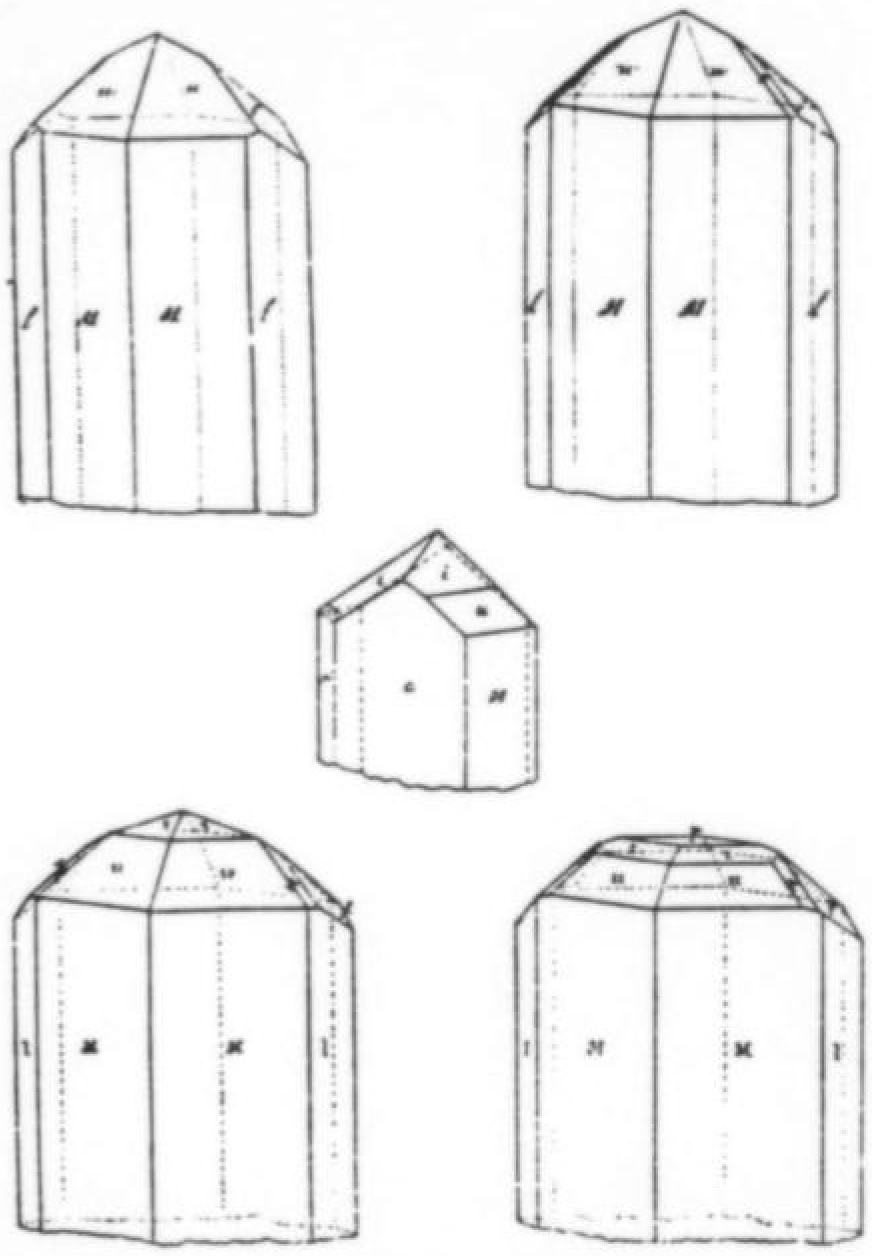


Figure 44. **Topaz crystal habits from the Sanarka River area, Russia (Goldschmidt, 1922).**

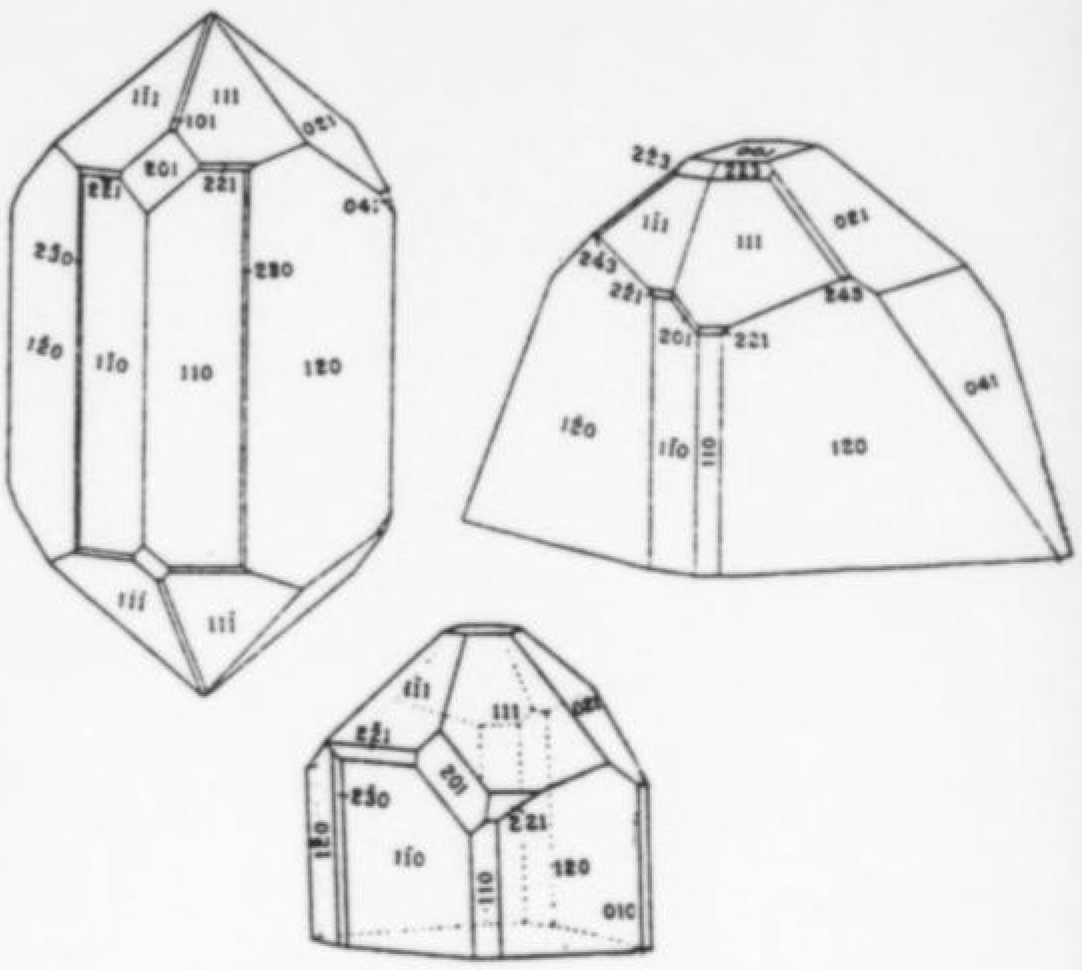


Figure 45. **Topaz crystal habits from Cornwall, England (Russell, 1924).**

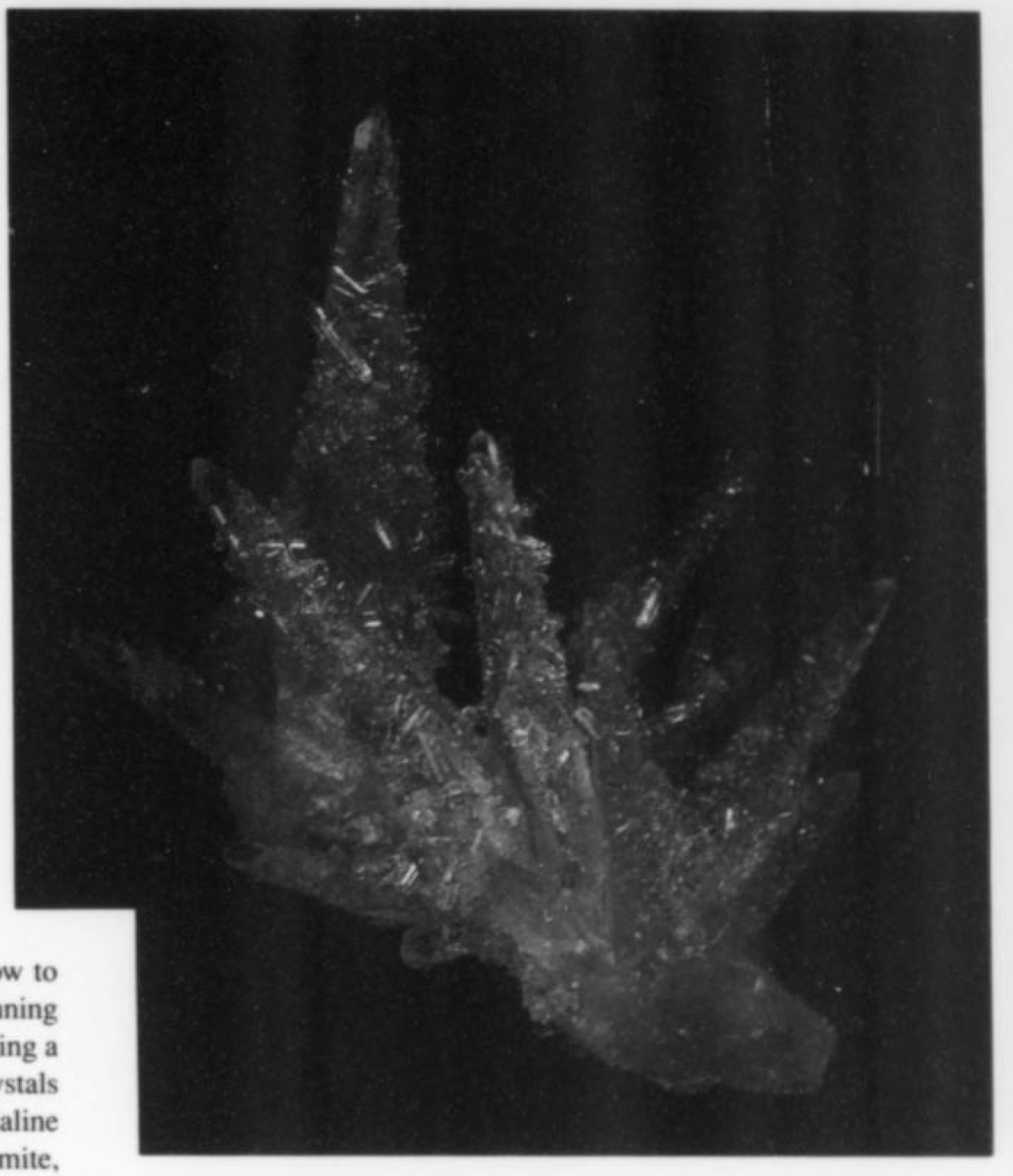


Figure 46. **Pink topaz crystals on unusual tapered quartz crystals from a hydrothermal vein, Pirajá deposit, Brumado, Bahia, Brazil. The group is about 15 cm in longest dimension. Carlos Barbosa specimen; Wendell Wilson photo.**

Crystals, which seldom exceed 1 cm, are colorless to pale yellow to pale blue with widely varied development of many forms. Manning (1981) indicates a 25% substitution of OH for F, strongly suggesting a lower-temperature origin. Topaz is commonly intergrown with crystals of quartz, zinnwaldite mica, cassiterite, and needles of tourmaline (that may form inclusions). Other associations include wolframite, sulfides and rare apatite. A unique association from the Maudlin mine, in low-grade metamorphic rocks, shows a single prism of topaz with crystals of siderite on a matrix of fluorite and pyrite.

The lowest-temperature and rarest occurrences of topaz are in carbonate veins and alpine clefts. Sinkankas (1981) reports topaz from the Bom Jesus das Meiras (now Pirajá) emerald deposit near **Brumado**, Bahia, Brazil. This deposit shows hydrothermal replacement of dolomite by magnesite, with later silica and aluminosilicate mineralization by fluids of unknown origin. The age is unknown, but magnesite deposition appears to be over 2,000 million years old, with several subsequent major tectonic events that include granitic intrusions (Schobbenhaus *et al.*, 1984). Small topaz crystals occur with calcite, quartz and tourmaline crystals in talc-calcite-quartz veins within an altered dolomitic marble. Despite similarities with the "desilicated pegmatite" type of emerald deposit, Beus (1966) suggests a hydrothermal origin. Cassedane and Cassedane (1978) also describe topaz from the magnesite deposit at Pirajá and the nearby Praca São Paulo prospect. Small crystals occur on quartz and less commonly with tourmaline, in cavities in magnesite. They also note a find of superb specimens with pink to orange topaz crystals to 1 cm on quartz, some of which is Japan-law twinned.

Gubelin *et al.* (1986) describe the unique deposit of pink, chromium-bearing topaz near **Katlang** in the Mardan district of Pakistan. The occurrence is in calcite-quartz-talc veins in limestone. Mineralizing fluids may be from a nearby granite that likely intruded during the late stages of formation of the Himalayas. Crystals are commonly embedded in calcite and highly fractured. Rare crystals in open cavities may be well-formed and of exceptional quality. Sizes rarely reach beyond 3 cm to over 7 cm. Short to medium-prismatic crystals show striated *m*{110} and *l*{120} faces and complex terminations. Some show *b*{010} faces. Colors range from colorless through pale brown to deep pink. A pneumatolytic (higher-temperature, vapor-phase) origin is proposed for the topaz, with subsequent hydrothermal deposition of calcite. High (OH) contents especially for the pink topaz, however, suggest that both minerals may have formed under lower-temperature, hydrothermal conditions. Gromov and Aurang Zeb (1992) cite the marked similarities in both morphology and composition between topaz crystals from the Katlang, Pakistan; Ouro Preto, Brazil; and the Sanarka River, Russia.

Neither of the final two vein occurrences have produced significant amounts of topaz, but they are of particular interest since both appear to be alpine cleft deposits. **Untersulzbachtal**, Salzburg, Austria, and **Val Lugnez**, Illanz, Grisons (Graubunden), Switzerland, are both located within a belt of post-orogenic granites and granitoids along the southern margin of the major Devonian to late Permian orogeny (Finger and Steyrer, 1990). The Swiss deposit is in the Leopontine Alps, part of the metamorphic core of the Alps, a structure that reemerges in the Tauern Window to host the Austrian deposit (Bradbury and Nolen-Hoeksema, 1985). Neither occurrence has an obvious source of the required fluorine-rich fluids, but mineralization may be related to remobilization of granitic rocks (in the Untersalzbachtal these are termed "central gneiss"). If so, the deposits probably formed during the latest major European orogeny that created the Alps and reached its peak in Tertiary time around 40–35 million years ago (Merle *et al.*, 1989).

At Untersulzbachtal, topaz occurs in white clay from alteration of the feldspar in quartz-feldspar veins. Colorless to pale yellow, transparent crystals reach 1 cm. Russ (1989b) and Meixner (1978) suggest "pegmatitic fluids" as the source of the mineralization. In Val Lugnez, colorless, elongate prisms of topaz to 1 cm occur with colorless quartz

Figure 47. **Topaz crystals to 1 cm with small quartz crystals from a particularly low-temperature hydrothermal vein, Val Lugnez, Grisons, Switzerland. Sketch by M. Soom.**

in Triassic dolomite (Robertson, 1989). Topaz from both occurrences contains close to the maximum 30% substitution of (OH) for F, strongly suggesting a particularly low-temperature, hydrothermal environment.

OTHER DEPOSITS

Metamorphic Deposits

Massive topaz occurs very rarely in a few high-grade metamorphic deposits with high silica contents, e.g. in Tanzania (Kemp, 1967), Colorado (Sheridan *et al.*, 1968), and South Carolina (Sykes and Moody, 1978).

Eluvial and Alluvial Deposits

In the sedimentary environment, topaz is found only as eluvial (in-place) and alluvial (water-transported) material, produced by erosion and weathering of primary deposits. Due to its high density and hardness, topaz is commonly well-preserved and may be mined from such deposits as in Minas Gerais, Brazil (Bauer, 1968), Sri Lanka (Dissanayake and Rupasinghe, 1993), and eastern Australia (Myatt, 1976).

Crystal Features

A study of topaz crystals can suggest the effects of different general geological environments on crystal features. It may also be possible to infer formation conditions and even the effects of individual variables such as temperature. This section reviews such trends and extremes of variation. Table 3 summarizes crystal characteristics, and Figure 48 shows typical crystal forms.

MORPHOLOGY

Topaz is generally accepted as an orthorhombic mineral. It may, however, also be triclinic due to degradation in crystal symmetry caused by increasing substitution of (OH) for F (Ribbe, 1980). Increasing (OH) is related to falling temperature, as described later, producing the progression from orthorhombic volcanic topaz to predominantly triclinic hydrothermal topaz.

Topaz from epigenetic pegmatites commonly shows dominant, steep *y*{021} termination faces that are rare in most other environ-

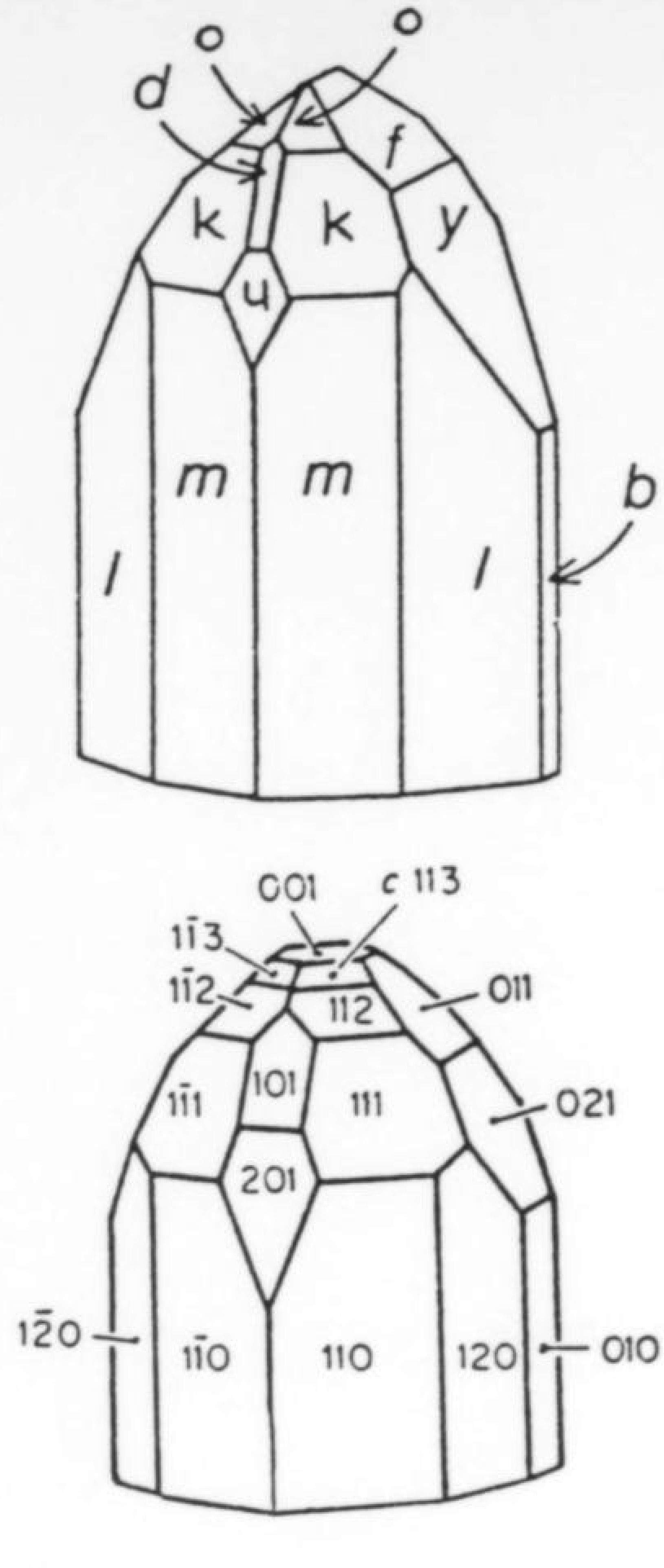


Figure 48. **Typical crystal forms for topaz. The pinacoid *c*{001} may be much more strongly developed in some crystals than in the examples shown.**

Typical crystal forms:

Pinacoids	***Prisms***	***Dipyramids***
***b*{010}**	***f*{011}**	***k*{111}**
***c*{001}**	***y*{021}**	***o*{112}**
	***d*{101}**	***s*{113}**
	***u*{210}**	
	***m*{110}**	
	***l*{120}**	

ments. The resultant wedge-shaped termination can progress almost to the exclusion of the prism forms, *m*{110} and *l*{120}. Representative localities include Virgem da Lapa, Minas Gerais, Brazil and St. Anne's mine, Karoi district, Zimbabwe. At the other extreme are the very blocky, rhombic prisms dominated by *m*{110} and *l*{120} faces, and the pinacoid, *c*{001}. When the *l* face dominates, crystals may show an almost square cross section and even an equant "cubic" appearance, e.g. those from Dusso, Gilgit, Pakistan, and also Mursinka, Ural Mountains, Russia (though these latter deposits fall more within the syngenetic classification). Syngenetic pegmatites (e.g. Sawtooth Range, Idaho; Pikes Peak, Colorado; Volyn region, Ukraine) commonly produce short prismatic crystals. These show strong development in particular of the *m*{110} as well as the *l*{120} forms, which extends

Table 3. **Topaz crystal characteristics. Note the progression from volcanic topaz which is orthorhombic, to hydrothermal topaz which is predominantly triclinic. Trace element concentration trends are from Hervig *et al.* (1987) and E. E. Foord (personal communication, 1990).**

Geologic Environment	*Composition*	*Symmetry*	*Size*	*Habit*	*Colors*	*Quality*	*Etching*	*Comments*
VOLCANIC:								
Rhyolite	Very high F High trace Li, B No CO_2, OH	Orthorhombic	Typ. to 4 cm	Medium to Long prismatic Well-developed *m* and *l* faces Dominant to absent *c* face	Yellow - sherry (u/s) Rose-pink - brown	Highly lustrous, many flawless	Slight when associated with beryl	Superb specimens
MAGMATIC:								
Topazite	Very high F		Micro to several cm		Yellow	Gemmy crystals from one locality		
LATE - to POST-MAGMATIC:								
Pegmatitic:	High F Some CO_2, OH	Orthorhombic, with triclinic domains						
-Syngenetic (in granites)			To 25 cm	Short to medium prismatic, Well-developed *m* and *l* faces, *f* and/or *y* face terminations	Colorless, blue; yellow - sherry (u/s) May be zoned perp. to *a* axis, or with irregular zoning	Commonly gemmy	May be severe	Excellent specimens, many on matrix
-Rare-earth	High F, some with high trace Ge		To 60 cm		White - blue	Opaque, frozen in rock		
-Epigenetic, Intruded (complex Li-F)	High F, some with high trace Ge		To 350 tonnes Gemmy to 270 kg	Short prismatic with extremes: Rhombic prisms (*l* + *c* faces) Wedges (*f* and esp. *y* faces)	Colorless, blue, green; sherry (u/s) Rarely zoned perp. to *c* axis	Commonly gemmy	May be severe	Some superb, large specimens, uncommonly on matrix
Greisens and and Skarns	High F, low trace Li, B		Typically small, rarely to 15 cm	Strong *l* faces with predominant *y* face terminations Acicular from one locality; *d* face terminations from one skarn locality	Colorless - yellow - light blue	May be gemmy		Excellent specimens rare
Hydrothermal Veins:	Some with high trace Cr, V Some CO_2, OH	Triclinic		Well-developed *m* and *l* faces Complex terminations, commonly without *c* face				
-Quartz-Feldspar			Typically to 5 cm, up to 30 cm	Medium to long prismatic	Yellow - sherry - red (Cr) ("Imperial")	Commonly gemmy		Includes "Imperial" topaz from Ouro Preto, Brazil
-Carbonate	High OH		To 7 cm	Short to medium prismatic, some showing *b*{010}	Colorless, pink - red (Cr)	Commonly gemmy		Excellent pink crystals from Mardan, Pakistan
-Alpine Cleft	Highest OH		To 1 cm	Short to medium prismatic Rare *b* faces from one locality	Colorless - light yellow	Transparent		Very rare environment for topaz

Crystal forms:
b{010} *c*{001}
f{011} *y*{021}
m{110} *l*{120}
d{101}

u/s = unstable to sunlight

the length of the *b* axis. Terminal faces are predominantly *f*{011} and/or *y*{021}.

Trends from other environments are less evident. Crystals from rhyolites are typically elongate prisms showing both *m*{110} and *l*{120} faces. Some Mexican specimens show only one additional form, the pinacoid, *c*{001}, producing very simple habits. In contrast, the Thomas Range, Utah produces crystals generally showing complex terminations without prominent *c*{001} faces. Similar elongate prisms with complex terminations are also common in hydrothermal deposits, e.g. from Ouro Preto, Brazil; Sanarka River, southern Ural Mountains, Russia; and some Japanese (syngenetic) pegmatites. Crystals from Ouro Preto also show apparently unique prominent {342} termination faces, and rare doubly terminated specimens may be hemimorphic. Greisens produce crystals that are typically small and intergrown with predominant *l*{120} prisms, and especially *y*{021} terminal faces that may give them a flattened appearance. Rare acicular crystals occur in a greisen/skarn at Mt. Bischoff, Tasmania, Australia. Sprays of micro crystals showing unique predominant *d*{101} terminal faces occur in an apparent skarn environment in the Laacher See region of the Eifel district of Germany. Crystals from low-temperature veins may show strong development of *b*{010} forms, as from Untersulzbachtal, Austria, and from Mardan, Pakistan.

For topaz from the range of granitic environments, Fersman (1932) suggests a trend with decreasing formation temperature from dominant *l*{120} and *c*{001} forms to increasingly prominent *m*{110} faces and more complex terminations. This is followed by a return to dominant *l*{120} forms with *y*{021} face terminations, and finally to elongate prisms. This generally parallels the observations above, but does not address wedge-shaped crystals with dominant *y* faces from epigenetic pegmatites.

Twinning in topaz is questionable. Ribbe (1980) reports on studies before 1950 that identified contact twinning and coaxial growth of topaz on *b*{010}. This, however, would only be possible for triclinic rather than orthorhombic topaz (A. Rosenzweig, personal communication, 1992). Cassedane (1989) notes "rare twinning parallel to the *c* axis" in Imperial topaz from Ouro Preto, Brazil. A specimen in the author's collection, which may be such a twin, consists of two crystals that are flattened across the *a* axis and joined parallel to the *c* axis giving a chevron-shaped cross-section. A different form of twinning may occur in crystals from the Sawtooth Range, Idaho. A single cavity produced pairs of unusual crystals that are both flattened across the *a* axis and extended along their *b* axes, well-formed but with faces that appear rather rounded. They are attached along their *b* axes, with diverging *c* axes. Twinning seems to be an area needing further investigation.

***Figure 49.* Attached pair of topaz crystals, 7 cm, from a syngenetic pegmatite, Sawtooth Range, Idaho. The crystals show an unusual rounded form and may also be twinned. Larry Piekenbrock collection; John Muntyan photo.**

COLOR

Topaz crystals occur in a range of colors, mostly pale. There are several causes of color, including color centers for blue, yellow and red (Fritsch and Rossman, 1988). Combinations produce other colors including sherry, orange and green. A different mechanism, trace-metal content, can cause pink-red hues due to chromium (Fritsch and Rossman, 1988), or in one deposit pink due to manganese (Mn^{3+}) (Foord *et al.*, 1995). This mechanism is the best understood cause of color, and the resulting shades are stable in sunlight. Natural (typically pale blue) color probably has a chemical basis, perhaps activated by natural radiation. Other mechanisms appear responsible for the strong blues produced by artificial irradiation (G. Rossman, personal communication, 1992). Most if not all sherry topaz from both the volcanic and pegmatitic environments fades in sunlight. In contrast, crystals from at least two pegmatite localities (Little Three mine, California, and Tarryall Mountains, Colorado) show blue coloration that appears or intensifies with exposure to sunlight for up to several weeks (Foord *et al.*, 1989). Iron staining, accentuated by internal reflection and refraction, may impart a false yellow hue to some colorless or even pale blue specimens.

The strongest natural blues occur in crystals from complex, epigenetic pegmatites, e.g. Virgem da Lapa, Brazil and St. Anne's mine, Zimbabwe. This environment also produces mixed blue-green colors, and rarer green crystals, e.g. from the Mimoso do Sul pegmatite, Espirito Santo, Brazil. Depth of color can vary significantly within a single cavity. For example, in both major discoveries of topaz at the Little Three mine, California, in 1976 and 1991, crystals ranged from colorless on the cavity roof through pale blue to deeper blue at the bottom (E. E. Foord and D. London, personal communications, 1992).

Other notable colors include a pronounced brownish red (rather than the more common sherry) due to hematite inclusions, in rhyolitic topaz from San Luis Potosi, Mexico. Distinctive wine-yellow crystals occur in some greisens including the one at Schneckenstein, Germany, and in many deposits in China, where the word for topaz translates as "yellow crystal" (D. M. Burt, personal communication, 1992). Strong orange-red-purple shades, with the red component due to chromium, occur in hydrothermal deposits, e.g. Ouro Preto, Brazil; Mardan, Pakistan; and Sanarka River, Ural Mountains, Russia. Sanarka River also produces spectacular, rich purple-red crystals.

Strongly color-zoned crystals are uncommon. The most striking variant, primarily from syngenetic pegmatite deposits, is sherry/colorless or pale blue/sherry zoning perpendicular to the *a* axis. Localities include the Sawtooth Range, Idaho; Volyn region, Ukraine; Gifu Prefecture, Japan, and the Rumi Tucu mine, Catamarca Province, Argentina. Crystals from the complex, epigenetic pegmatite at Mimoso do Sul, Espirito Santo, Brazil show similar combinations of yellowish brown and pale blue. Some syngenetic pegmatite topaz also shows irregularly zoned bi-colored crystals, e.g. the yellow or sherry and blue crystals from a recent find in New Hampshire (Hollman, 1987). Less commonly, pegmatitic topaz shows horizontal color banding perpendicular to the *c* axis, e.g. the sharp sherry-colored bands in some

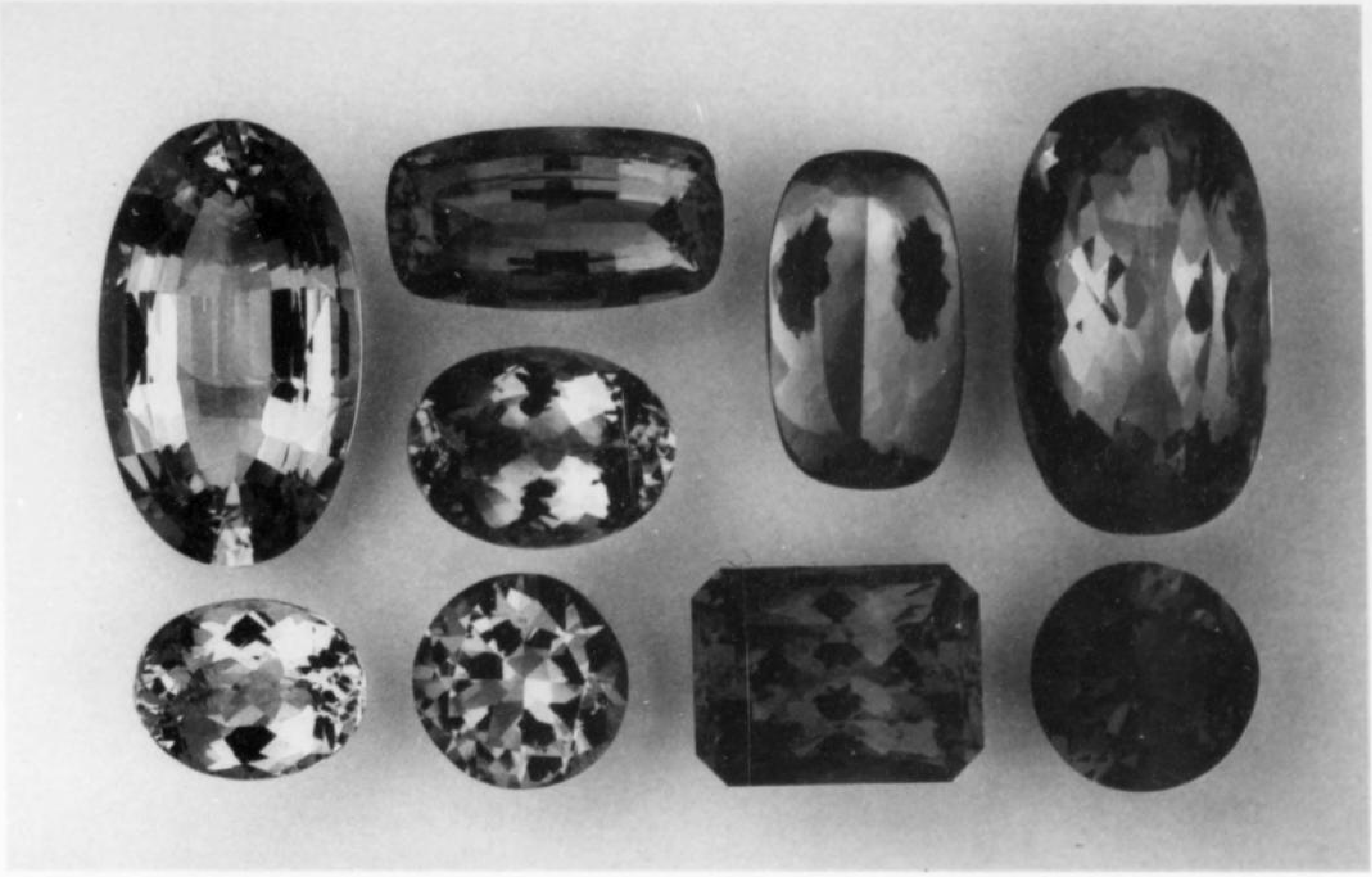


Figure 50. **Suite of faceted topaz showing range of colors. Sizes range from 4.65 to 25.25 carats. These are from: Russia (lower right and upper left may instead be old Brazilian material), Mexico (second from left at bottom), and Brazil (remaining stones). The pinkish stone (top, second from the left) and the blue stone have both been treated to enhance or change color, but all other colors are natural. Joel Arem collection and photo.**

Figure 51. **Topaz crystal, 1.5 cm, showing "white-capped" termination, with smoky quartz and pink microcline, from a syngenetic pegmatite, Sawtooth Range, Idaho. Author's collection and photo.**

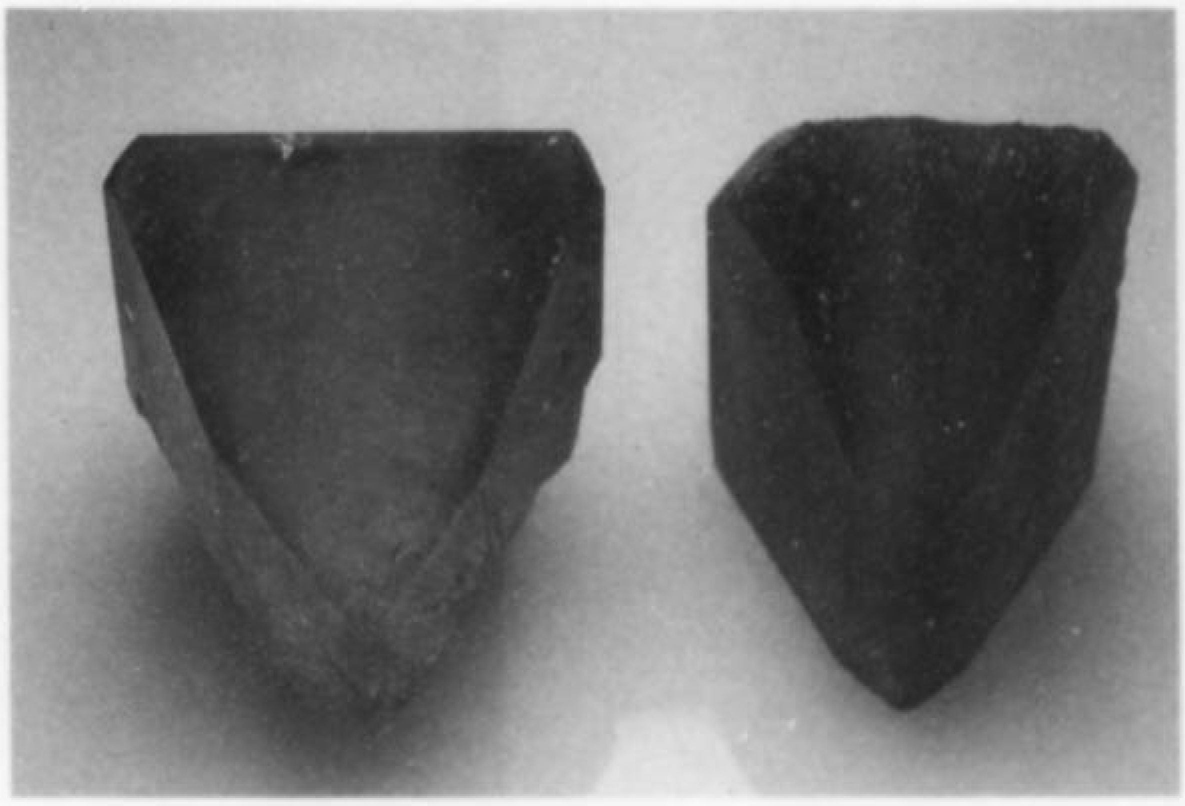


Figure 52. **Topaz crystals to 3.5 cm across, showing sherry/colorless/sherry color zoning across the *a* axis. Both crystals are from syngenetic pegmatites, from the Sawtooth Range, Idaho (left) and Volhynia, Ukraine (right). The specimen at the right shows terminal face etching that is typical, though commonly more severe, in many pegmatite specimens. Author's collection and photo.**

crystals from Dusso, Gilgit, Pakistan. Similar though less well-defined yellow to pinkish zones, either across the center or at the termination, are characteristic of blue crystals from Alabashka in the Ural Mountains, Russia (author's collection; P. Lyckberg, personal communication, 1993).

Unusual "white-capped" crystals, some with sharply defined opaque white zones at their *f*{011} terminations, occur in both the Sawtooth Range, Idaho, and Adun Chilon, eastern Siberia. This does not appear to represent replacement; rather it may be due to fluid inclusions from very rapid growth (E. E. Foord, personal communication, 1990).

Fluorescence under ultraviolet light is uncommon in topaz. Generally unknown causes produce blue-white or shades of orange through yellow to greenish-yellow (Foord *et al.* 1989, Foord, 1991) and green (Robbins, 1988). Strong fluorescence is even rarer, as in some color-zoned crystals from the Sawtooth Range, Idaho that show intense-yellow center zones, particularly under longwave ultraviolet. Zones or

Figure 53. Topaz crystal, 3.5 cm across, showing strong yellow fluorescence in the colorless central zone under longwave ultraviolet light. The crystal from the Sawtooth Range, Idaho, is the same as that shown on the left in Figure 52. Author's collection and photo.

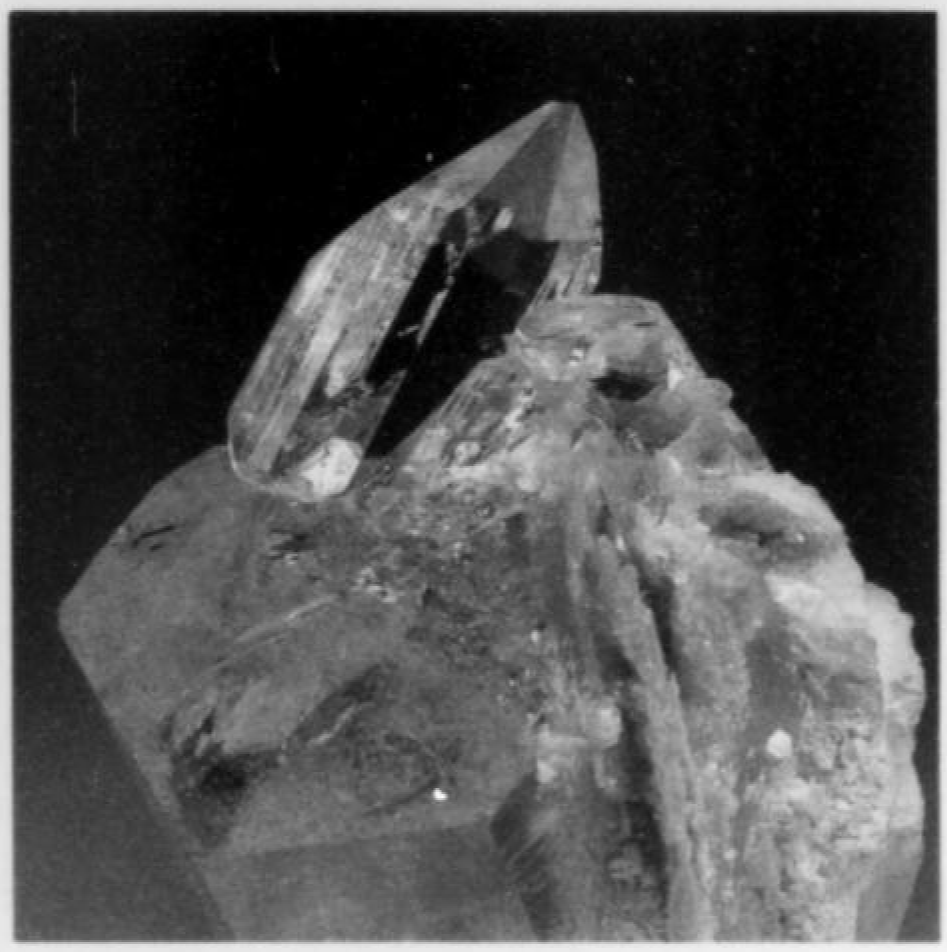


Figure 54. Topaz crystal, 1.5 cm, with an uncommon pointed termination, on pinacoid of aquamarine crystal. This unusual association is from an epigenetic pegmatite, Shigar (probably Dusso), Gilgit Division, Pakistan. Mel Bersch collection; Wendell Wilson photo.

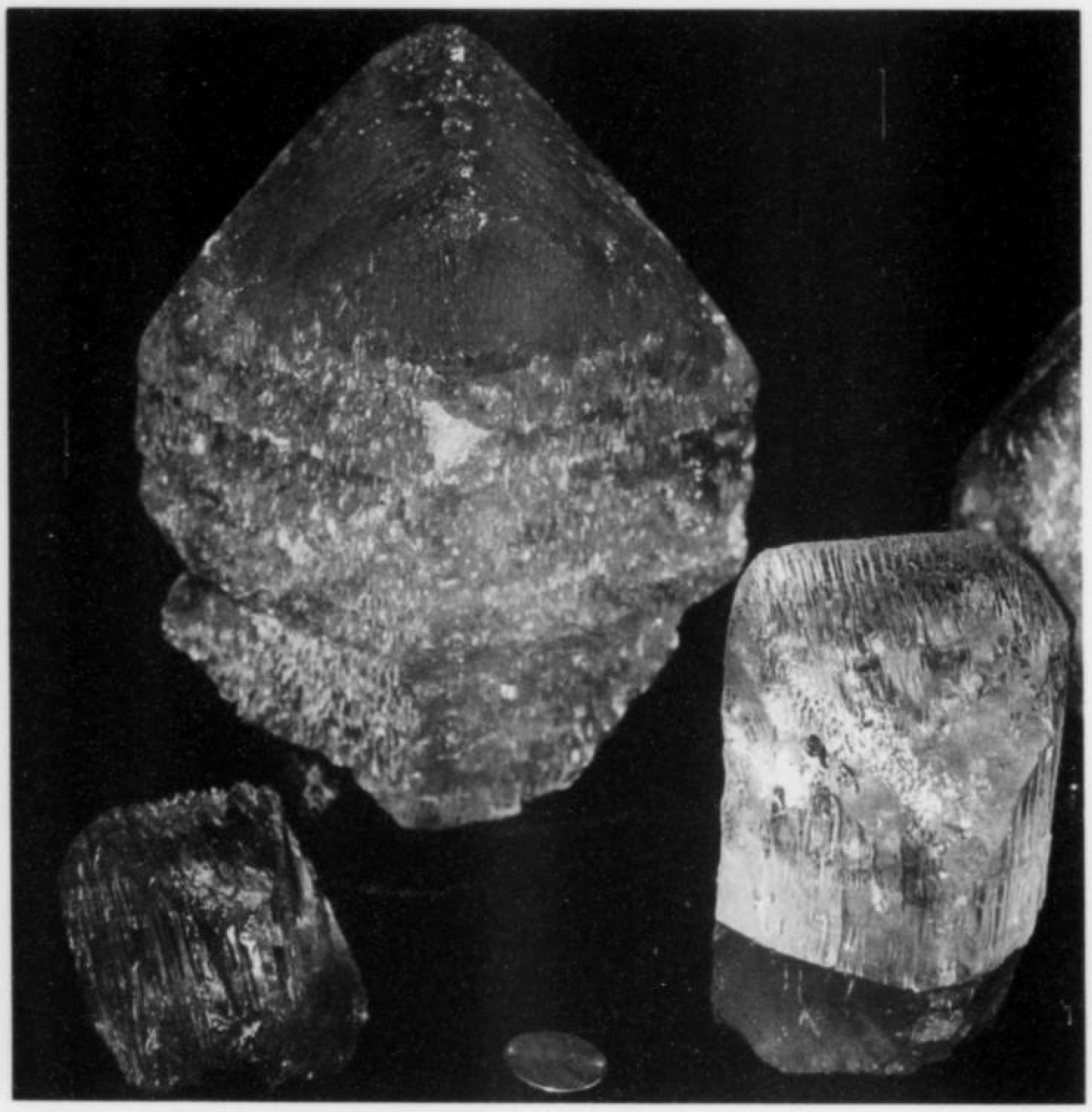


Figure 55. Heavily etched topaz crystals, to 13.5 cm across, from a large cavity in a syngenetic pegmatite, Coos County, New Hampshire. Peter Sameulson/Carlton Holt specimen; Carlton Holt photo.

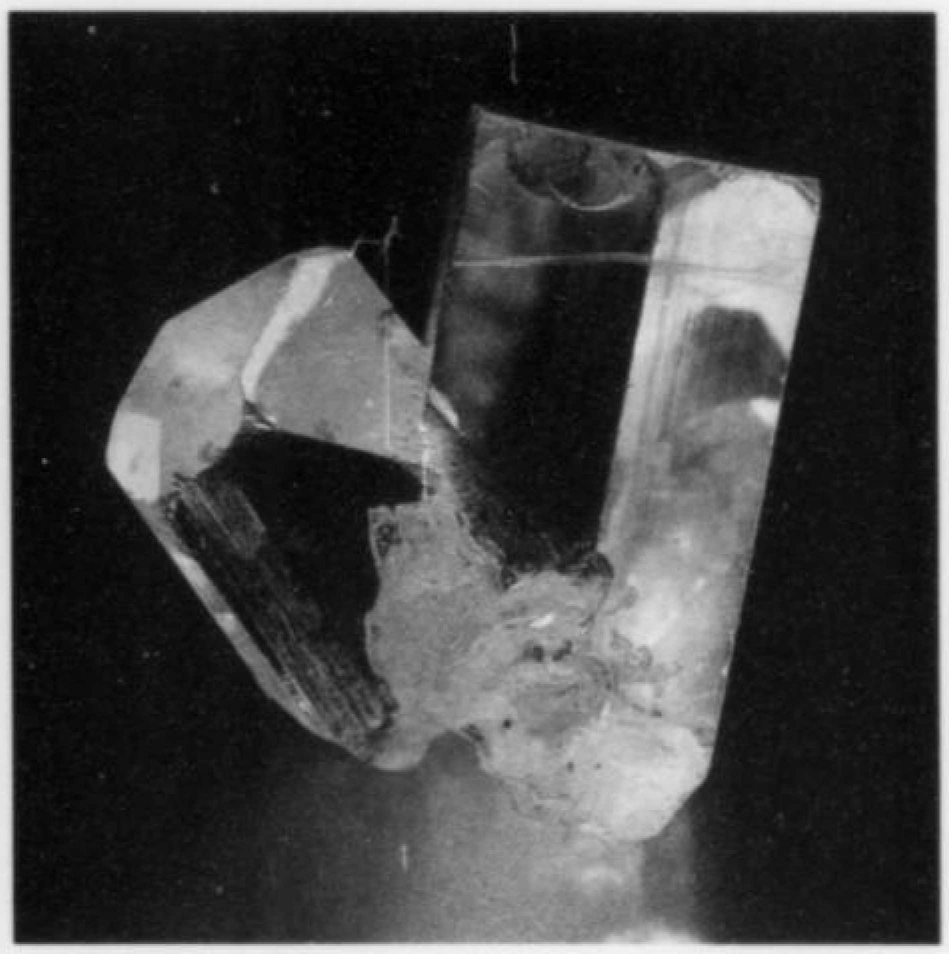


Figure 56. Topaz crystal with beryl, 1.8 cm, from Dusso, Gilgit division, Pakistan. Roland Sherman collection; photo by Jeff Scovil.

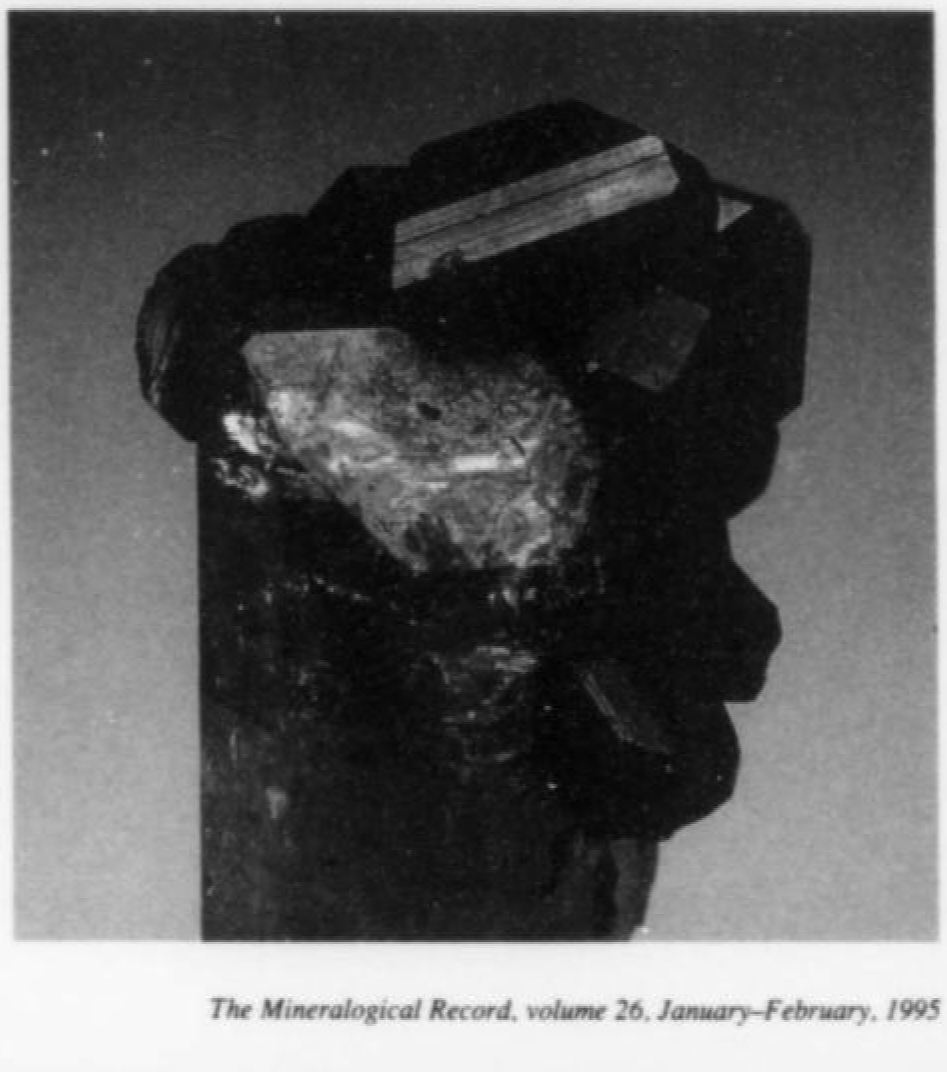


Figure 57. Schorl on topaz, from epigenetic pegmatite, Mimoso do Sul mine, Espirito Santo, Brazil. The specimen, which is 3 cm across, shows a most unusual association. Author's collection and photo.

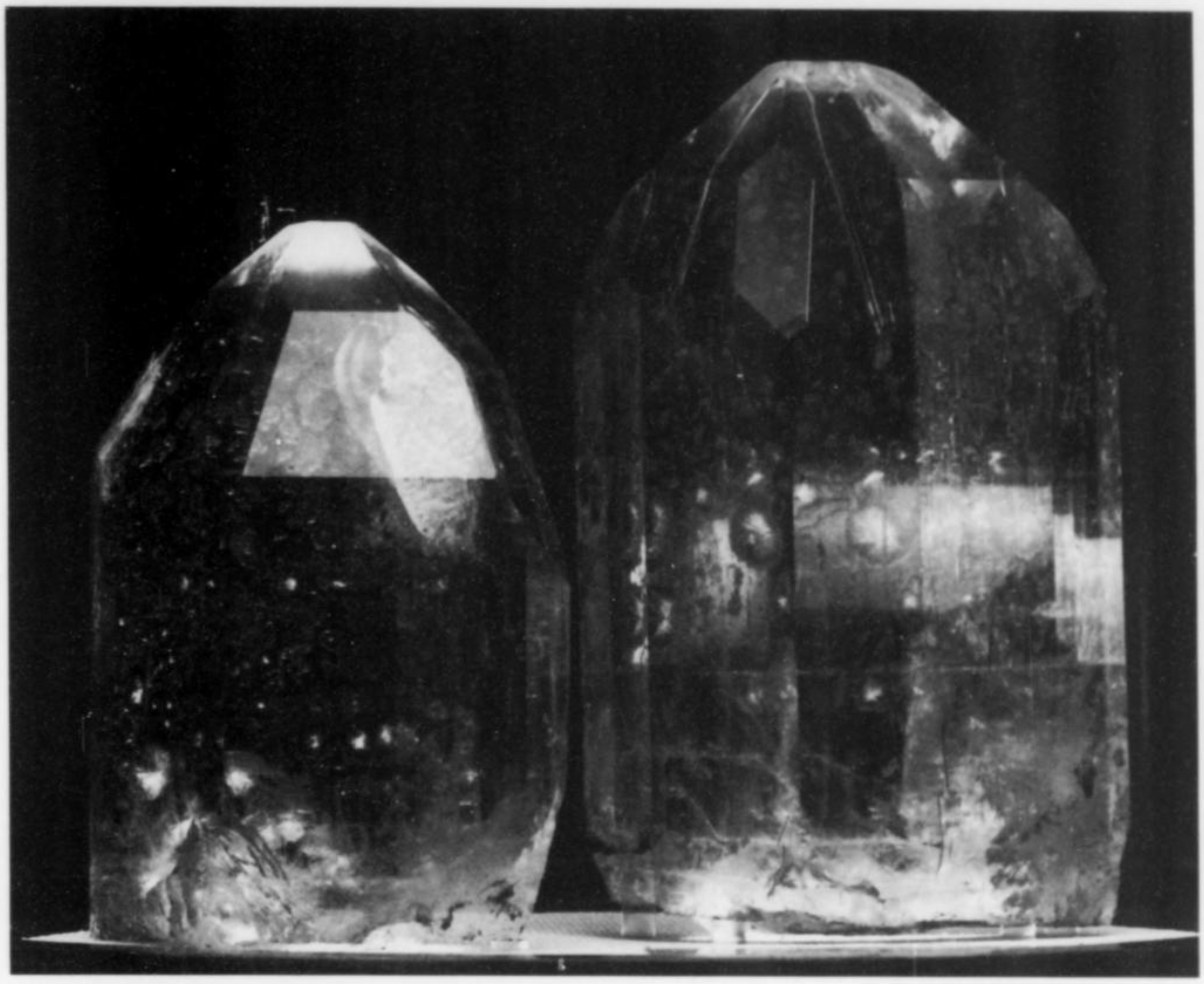


***Figure 58.* Two very large topaz crystals, from an epigenetic pegmatite, Teófilo Otoni area, Minas Gerais, Brazil. The largest crystal at the right is almost 60 cm high and weights 50 kg. U.S. National Museum of Natural History collection and photo.**

entire crystals from the Little Three mine, California also show bright-yellow fluorescence under both shortwave and longwave light. Strong blue-white fluorescence under shortwave ultraviolet occurs in portions of crystals from both Ouro Preto, Minas Gerais, Brazil, and Katlang, Pakistan.

SIZE

Complex fluorine-lithium epigenetic pegmatites, especially those in Brazil, host the largest topaz crystals, some of enormous size. Muqui in the state of Espirito Santo (the location of the Mimoso do Sul mine described earlier) produced perhaps the world's largest topaz, a 3 by 5 by 10-meter, 350 tonne crystal (Sinkankas, 1981). Sharp, gemmy crystals to 270 kg, as described by Caplan and Wilson (1980), were recovered from Santa Maria do Itabira, around 300 km south-southwest of Araçuaí in Minas Gerais. Brazilian pegmatites also produced the two light-blue 220 and 250 kg crystals, from an unnamed locality in Rio Grande do Norte state, that are in the collection of the The Natural History Museum in Paris (Peter Lyckberg, personal communication, 1993). Large size is thought to be due to suppression of nucleation (London, 1990) and/or very rapid crystal growth due to low viscosities and high diffusion rates in aqueous, residual fluids (Jahns and Burnham. 1969).

COMPOSITION

The hydroxyl (OH) component of water substitutes for fluorine (F) in topaz. The degree of substitution rises with decreasing formation temperature to reach a maximum of around 30% (Foord *et al.*, 1990). Figure 59 shows the division on this basis between the higher-temperature volcanic and pegmatite/greisen environment vs. lower-temperature hydrothermal veins.

Table 4 shows trace element concentration trends in topaz as reported by Hervig *et al.* (1987) and Foord *et al.* (1990), and further discussed by Kortemeir and Burt (1988). The major distinction is between elevated levels of boron and lithium in rhyolitic topaz and much lower concentrations of both from pegmatites and greisens. Hervig *et al.* suggest as a cause the contrast between formation in rhyolites at high temperatures and low pressure with rapid cooling rates vs. the reverse for the hydrothermal environment of pegmatites and greisens. In epigenetic pegmatites, these low levels of lithium and boron in topaz occur despite typically high bulk levels of both elements. Some pegmatitic topaz shows elevated levels of germanium, and chromium enrichment (from host schists or ultramafic rocks) occurs in some lower-temperature hydrothermal topaz.

INCLUSIONS

Inclusions in topaz, as summarized in Table 4, are particularly interesting since they may show solid, liquid and gas phases, even in the same crystal. In the granitic environment, liquid inclusions (which capture the fluid composition at the time of crystallization) are common, with microscopic inclusions of aqueous fluids typically forming veils (Gubelin *et al.*, 1986; Foord *et al.*, 1989). As described by Naumov *et al.* (1977), the trend with falling temperature, is from

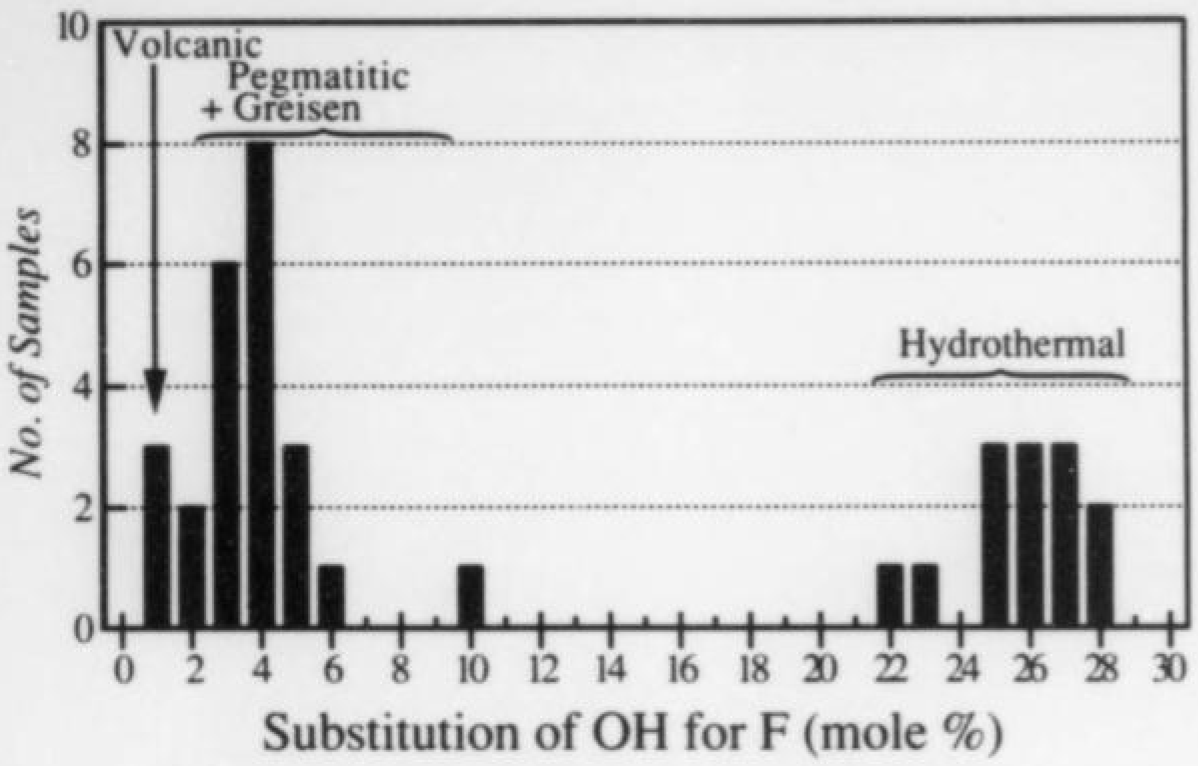


Figure 59. **Variation in (OH) substitution for F in topaz from different environments (after Foord *et al.*, 1990). The degree of substitution of (OH) for F rises with decreasing formation temperature to reach a maximum of around 30%. There is a division between the higher-temperature volcanic and pegmatite/greisen environment vs. lower-temperature hydrothermal veins. Broader deposit sampling than the 65 deposits represented would probably identify some overlap.**

Figure 60. **Topaz crystal, 4 cm high, from an epigenetic pegmatite near Conselheiro Pena, Minas Gerais, Brazil. The right side of the crystal shows a striking three-phase inclusion of complex shape. The inclusion contains a gas bubble at the center top, a viscous yellow liquid, and unidentified brown to black solids that may be iron oxides. Author's collection and photo.**

solid halides (fluorides and chlorides) to increasingly more dilute brines (solutions of fluorides and later chlorides). Liquid and gaseous carbon dioxide are also common at lower temperatures. There is considerable overlap since all of these phases are important in late- and post-magmatic mineralizing processes.

ALTERATION, REPLACEMENT, ETC.

Topaz shows a range of alteration phenomena including etching and pseudomorphism; it also occurs as granular varieties. Crystals in pegmatites are vulnerable to late-stage etching. This is typically seen on terminations but, especially in epigenetic pegmatites, topaz may be almost completely destroyed, e.g. at Topsham, Maine (Burbank, 1934). Alteration to secondary muscovite is also common, particularly at lower temperatures (Burt, 1976), via the reversal of one of the formation reactions described later. This reaction also produces quartz, and may leave a fine-grained mixture of muscovite and quartz that is commonly termed "pinite." In carbonate environments, margarite mica can replace topaz.

Topaz can also replace other minerals or be replaced to form pseudomorphs. Orthoclase occurs as pseudomorphs after topaz crystals to 3 cm at Schneckenstein, Germany (Smithsonian Institution reference collection). One syngenetic pegmatite in the Sawtooth Range, Idaho showed replacement of microcline crystals to 7 cm by a granular mixture of topaz and quartz (Menzies and Boggs, 1993). A dense covering of small, sharp, water-clear topaz crystals makes them unusually attractive pseudomorphs. Both types of pseudomorphs can be explained by the formation reaction that creates topaz and quartz from feldspar or vice versa, as described later.

Figure 61. **Group of topaz crystals, 2 cm across, with inclusions of rutile(?), from rhyolite, Cerro de los Remedios, Durango, Mexico. Eric Offermann collection and photo.**

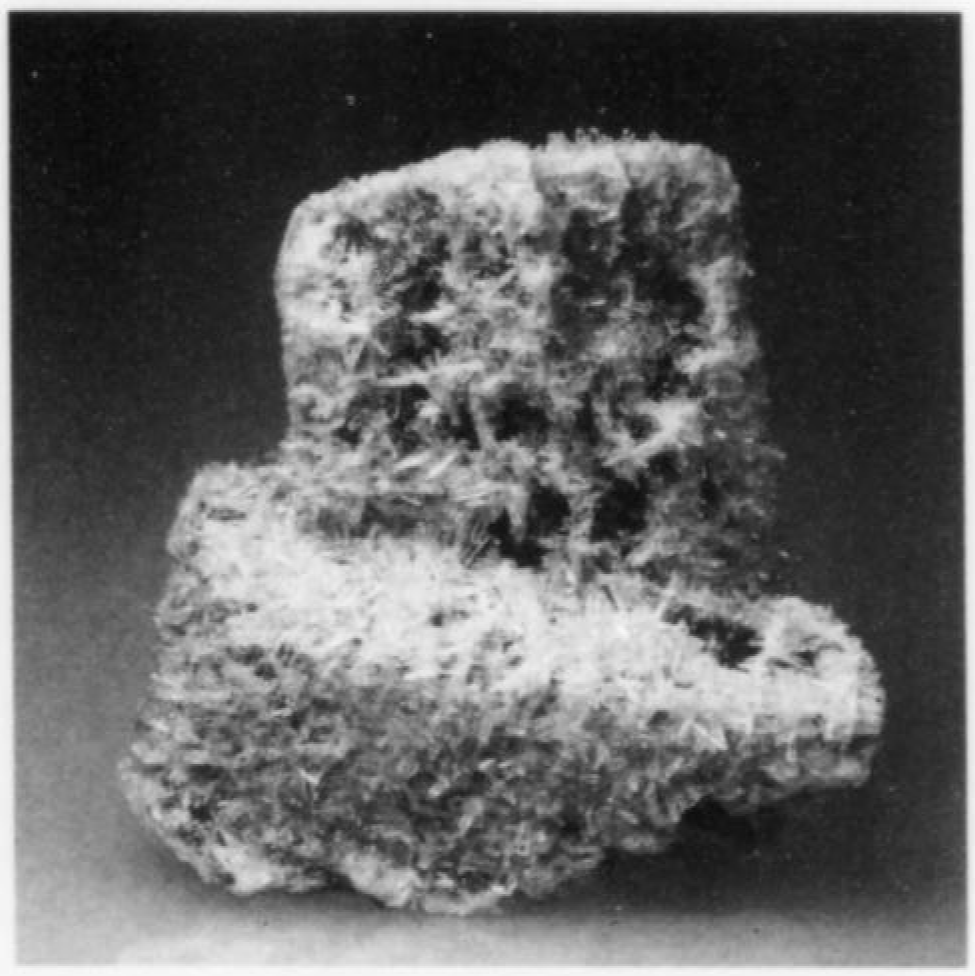


Figure 62. **Pseudomorph of granular topaz and quartz after microcline, 5.5 cm high, from a syngenetic pegmatite, Sawtooth Range, Idaho. The surface of the specimen is covered with hundreds of water-clear, colorless topaz crystals to 5 mm. Author's collection and photo.**

Table 4. **Topaz inclusions. In granitic environments, common fluid inclusions capture the fluid composition at the time of crystallization. Solid inclusions show a wide range of species, but are much rarer due to generally late-stage crystallization of topaz. In contrast, early-stage topaz crystals from rhyolites are commonly included with minerals that crystallize simultaneously with topaz.**

Geologic Environment	*Locations*	*Topaz In . . .*	*. . . In Topaz*	*Phases*	*References*
RHYOLITE					
	Utah		Quartz, pseudobrookite, hematite	S	Ream (1979)
	Central Mexico		Hematite	S	Burt and Sheridan (1985)
			Rutile?	S	Sinkankas (1959, 1976), Panczner (1987)
GRANITE:					
Syngenetic Pegmatites	General		Solid fluorides, chlorides (higher temperatures) Concentrated brines (lower temperatures)	S-L-G	
	Sawtooth Range, Idaho	Quartz	Spessartine, helvite, hematite, beryl?	S	Ream (1989), Menzies and Boggs (1993)
	Tarryall Mts., Colorado		Albite, phenakite	S	Dunn (1974)
	Voln region, Ukraine		Topaz, quartz, feldspars, micas, cryolite, fluorite, cassiterite, Na, Ca, Al fluorides, chlorides	S-L-G	Naumov *et al.* (1977), Tsaryeva *et al.* (1992)
Epigenetic Pegmatites	General		Solids, Lower-salinity brines, CO_2-rich fluids?	S-L-G?	
	Virgem da Lapa, Minas Gerais, Brazil		Elbaite, lepidolite	S	Cassedane and Lowell (1982)
Greisens	General		Concentrated brines (higher temperatures) CO_2: liquid + gas (lower temperatures)	(S)-L-G	
	Schneckenstein, Germany		Ilmenorutile	S	Russ (1989a)
			Unknown	S-L-G	Naumov *et al.* (1977)
	Adun Chilon, Transbaikalia, eastern Siberia		Unknown	S-L-G	Naumov *et al.* (1977)
HYDROTHERMAL VEINS:					
Quartz-feldspar	General		Brines + aqueous CO_2 solns. May contain solids	(S)-L-G	
	Ouro Preto, Minas Gerais, Brazil	Quartz, hematite	Mica, kaolinite	S	Cassedane (1989)
	Burnt Hill Tungsten Mine, New Brunswick, Canada		Wolframite	S	Sabina (1992)
	Svetloye deposit[1] Iul'tin, Chukotka, Siberia		Ferberite	S	Evseev (1993a)
Carbonate	Mardan, Pakistan		Low-salinity brines + gas	L-G	Gubelin *et al.* (1986)
Alpine Cleft	Untersulzbachtal, Salzburg, Austria		Copper sulfides and sulfosalts, tellurides, rare fluorides	S	Meixner (1978)
OTHER:			Actinolite, albite, brookite, calcite, cassiterite, fluorapatite, fluorite, goethite, hematite, hornblende, manganocolumbite, monazite, muscovite, phenakite, pseudobrookite, quartz, spessartine, tourmaline	S	J. Koivula (pers. comm., 1990)
			Cryolite, elpasolite, halite, manganocolumbite, muscovite, quartz, sulfur, sylvite, teepleite, villiaumite	S[2]	J. Koivula (pers. comm., 1990)

[1]Unconfirmed as vein-type deposit: topaz with aquamarine and ferberite
[2]Present in fluid inclusions. Note that five of these are fluorides.

S = Solid
L = liquid
G = gas

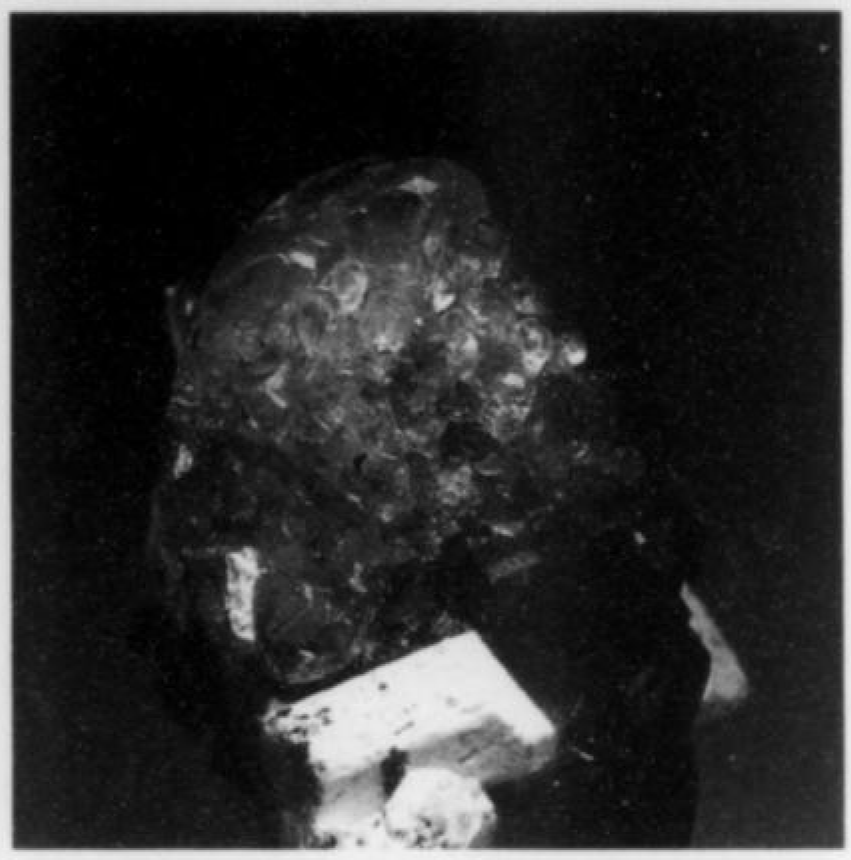


Figure 63. **Intergrowth of parallel, pale greenish topaz with smoky quartz, 4.5 cm across, from an epigenetic pegmatite, Mimoso do Sul mine, Esprito Santo, Brazil. This appears to represent uncommon early crystallization of topaz in such a pegmatite; such an intergrowth may be unique to this deposit. Author's collection and photo.**

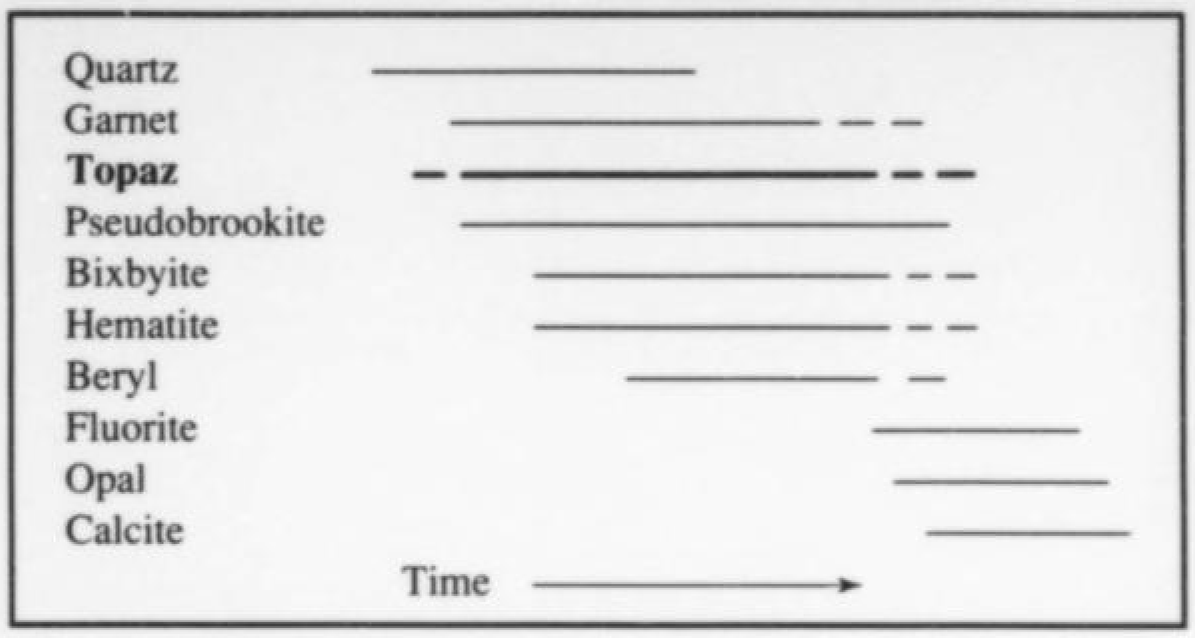


Figure 64. **Paragenetic sequence for cavity mineralization in topaz rhyolites (modified after Ream, 1979), for the Thomas Range, Utah. Precise determination of the sequences is difficult since minerals are commonly intergrown and deposited on each other. Most topaz is primary and early- to mid-stage, but a second generation of late-stage microcrystals may derive from alteration of garnet.**

Deer *et al.* (1982) describe two types of granular topaz. The most common, "pycnite," generally has a columnar form. It is typically yellowish and opaque, and is common from the Erzgebirge (particularly Altenberg, Germany), and also Kristiansand and Fossum in southern Norway (Smithsonian Institution reference collection). In "pyrophysalite" or "physalite," topaz is mostly altered to mica(s). This material, which may be reddish in color and swells on heating, occurs in aggregates in pegmatites at three localities near Falun, Dalarna, northwest of Stockholm in Sweden (Lyckberg, personal communication, 1993), and at Finbo, Sweden (Smithsonian Institution reference collection).

Paragenesis

SEQUENCES

Figure 64 shows the paragenetic sequence for cavity mineralization in rhyolites. Most topaz is primary and early to mid-stage, as shown by common attached crystals of bixbyite, garnet and other species. It may also form second-generation, late-stage, microcrystals. Further topaz may be produced by alteration of garnet, per the reaction below, with the proportions of bixbyite vs. hematite depending on the garnet's manganese vs. iron content. This explains why garnet forms good crystals in some rhyolite cavities, but when associated with topaz it is commonly highly altered and may also show overgrowths of topaz.

Garnet + HF + Oxygen <—> Topaz + Quartz +
Bixbyite/Hematite + Water

The generalized paragenetic sequence for the granitic environment in Figure 65 shows topaz crystallizing over a particularly broad range of temperature. Crystals in cavities are generally primary and mid- to late-stage. Uncommon exceptions include early-stage crystallization, especially in epigenetic pegmatites, as at Mimoso do Sul, Espirito Santo, Brazil, and late-stage formation in some hydrothermal veins, e.g. from Katlang, Pakistan. Rarely topaz forms smaller, more gemmy second-generation crystals in some pegmatites, e.g. the Little Three mine, California, and the Mursinka mines in the Ural Mountains, Russia. Less commonly, in epigenetic pegmatites, grains of topaz and lepidolite replace earlier feldspars. Topaz is also common as a replacement mineral in greisens.

Significant early-stage, commonly massive topaz that is probably magmatic is retained in a few epigenetic pegmatites, e.g. those near Amelia Court House, Virginia (Sinkankas, 1959). Large topaz crystals frozen in core margins are still rarer, though this a common occurrence for other pegmatite cavity minerals such as garnet and tourmaline. Prime locations for such topaz include the Brown Derby pegmatite in Colorado (Rosenberg, 1972), the Morefield deposit near Amelia Court House, Virginia (Kearns, 1993), as well as the uncommon rare-earth pegmatites in Scandinavia and the Luumäki pegmatite in Finland, as described earlier. The Brown Derby No. 1 pegmatite is of particular interest since it sheds light on the probable mechanism for both formation and loss of early-stage topaz. Topaz crystals evidently formed from a residual melt extremely rich in fluorine and water, and then apparently settled into quartz pods at the base of the core zone where they were mostly preserved from later alteration.

ASSOCIATIONS

Topaz from syngenetic pegmatites is found typically on quartz or feldspar. It is commonly well-crystallized and of gem quality, although it may be highly etched. Many such deposits, e.g. those in the Sawtooth Range, Idaho, provide excellent matrix specimens. The assemblage can consist of simple quartz-feldspar-mica with minor topaz, as in small cavities in the Mourne Mountains, Northern Ireland. Broader suites of minerals may result from factors including larger cavity size and high iron contents, both as in the Volyn region of the Ukraine. Fluorine concentrations can be high enough for topaz to form a significant proportion of cavity crystal contents, e.g. from the Tarryall Mountains, Colorado (Nelson, 1968). Typical associations in syngenetic pegmatites include well-crystallized smoky quartz, feldspars, zinnwaldite mica, fluorite, less commonly beryl and phenakite, and rarely spessartine and tourmaline. Other species containing essential iron may also be present. Zinnwaldite mica is typically the only major lithium-bearing species.

Topaz is less common in epigenetic pegmatites whose parent magmas commonly lack the necessary fluorine. Generally higher concentrations of lithium, boron, and in some cases phosphorus, produce more diverse cavity mineralization. Associations with topaz are, however, typically more restricted and include quartz, feldspars, lepidolite and muscovite micas, elbaite or schorl tourmaline, fluorite, columbite-tantalite, and less commonly beryl. There is a marked

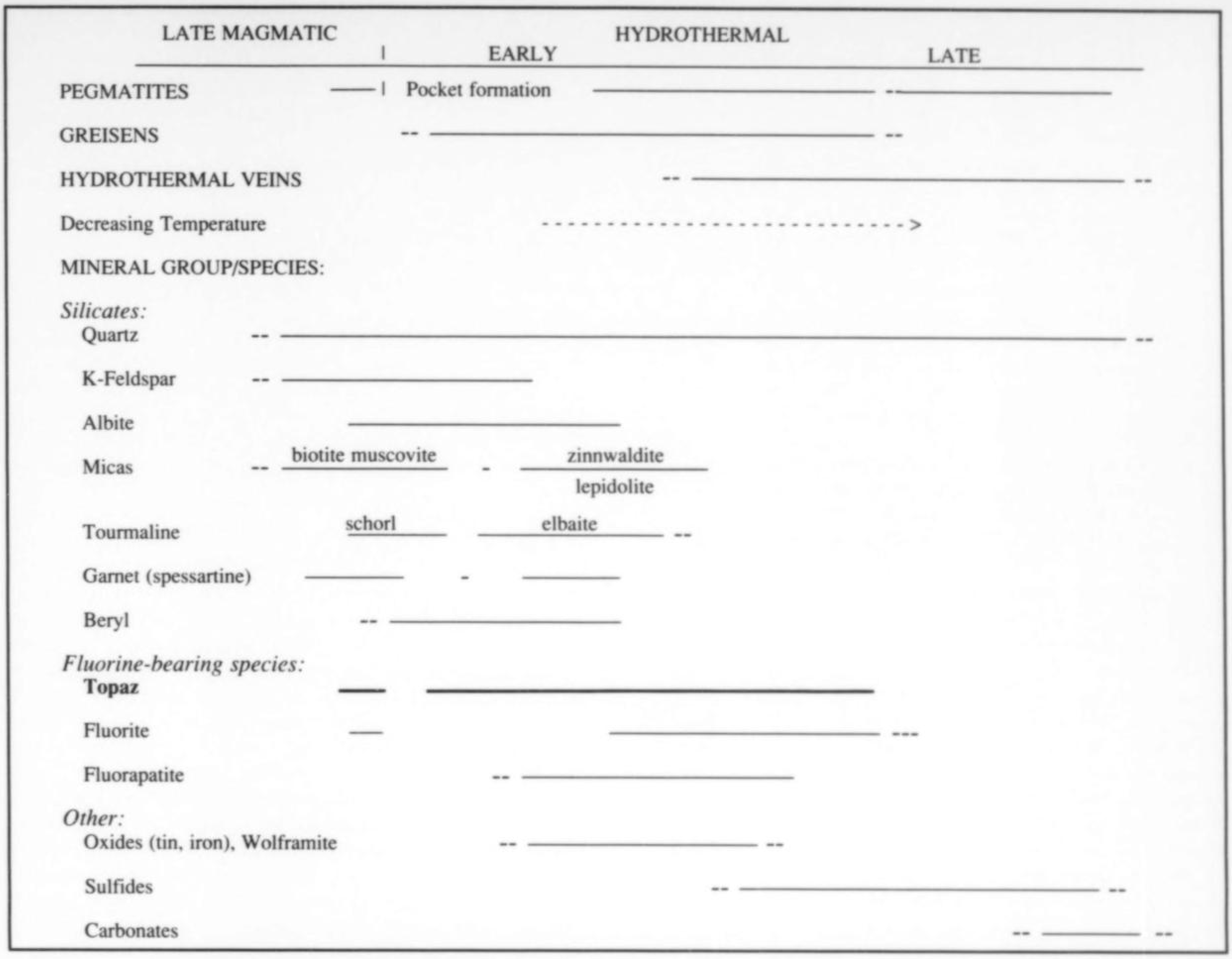


***Figure 65.* Generalized paragenetic sequence for granitic deposits. This is based on mineralization in both cavities and massive orebodies, with data from Fersman (1932), Foord (1977), Naumov et al. (1977), Neiva (1982), Strong (1985), and Menzies and Boggs (1993). Spans in crystallization timing reflect a wide range of deposit types with variations in composition of mineralizing fluids and crystallization conditions. The breaks in the bars typically represent a change in crystallization from massive material in the host rock or pegmatite core margins, to crystals in cavities. There may also be a corresponding compositional change to a different species or variety. Crystallization timing for topaz spans a particularly broad range, but topaz is rare except in central cavities of deposits.**

similarity to associations in syngenetic pegmatites, but with a shift toward lithium (rather than iron) species. Topaz crystals are commonly larger than in syngenetic pegmatites, but corrosion or weathering of the feldspar matrix plus cleaving of topaz crystals restricts recovery of matrix specimens.

In greisens, topaz is most commonly associated with quartz, micas, fluorite, cassiterite, and in some deposits tungsten species. Associations with topaz in the vein environment typically progress from quartz and feldspars with muscovite and cassiterite, through quartz, cassiterite and sulfides, and finally to calcite, as formation temperatures fall.

The association of topaz with beryl is of particular interest. Both minerals result from concentration of trace elements in granites and are common in pegmatites. Thus it is notable how few occurrences worldwide produce beryl and topaz crystals together in cavities, with still fewer showing the two in intimate association. Beryl that does form with topaz in granites is iron-bearing aquamarine or heliodor rather than the alkali-bearing morganite. In rhyolites, such beryl is the rare, water-free, manganese-bearing variety.

Several occurrences of this uncommon association in granite-related deposits have already been noted. The Gilgit, Pakistan pegmatites produce topaz with beryl and some fluorite, as well as drusy crystals of topaz on both beryl and schorl. Topaz and beryl occur in the same cavities of the Mursinka pegmatites in the Ural Mountains, Russia, although in most dikes either topaz or beryl predominate. The greisen/pegmatite deposits of Sherlova Gora and Adun Chilon, Transbaikalia, eastern Siberia produce topaz crystals intergrown with beryl, commonly aquamarine. Topaz and beryl from all these deposits commonly form sharp, unetched crystals, showing topaz crystallized along with or following beryl. In rhyolites, the association is more common, but beryl typically follows and even crystallizes on slightly etched topaz crystals.

Many syngenetic pegmatite and greisen deposits display varying degrees of incompatibility between beryl and topaz. In the pegmatites of Volyn region of the Ukraine, only the largest cavities contain both beryl and topaz, commonly as etched crystals in different zones. Beus (1966) reports both beryl and topaz from high-temperature tungsten veins with greisen rims in central Kazahkstan, but where one is found in quantity the other is either absent or forms rare, individual crystals. In the Sawtooth Range, Idaho, cavities containing topaz occur within meters of those hosting beryl (Ream, 1989; Menzies and Boggs, 1993), but the two species are not confirmed as occurring together. A similar environment on Mount Antero, Colorado produces beryl and rare topaz, but only in different cavities (Jacobson, 1993).

Several investigators suggest explanations for this rarity of beryl with topaz. Beus (1966) indicates that highly mobile, fluorine-beryllium complexes commonly transport beryllium in pegmatites. In topaz-bearing pegmatites, and probably also greisens, this may allow loss of beryllium in hydrothermal fluids while still retaining sufficient fluorine to form topaz. Supporting field evidence shows beryllium enrichment in country rocks enclosing greisens (D. M. Burt, personal communication, 1990). Similarly, rocks surrounding ongonite/topazite dikes in Arizona show late-stage fracture filling by beryl, apparently after crystallization of topaz within the dikes (Kortemeier and Burt, 1988). In the Sawtooth Range, Idaho, fracture surface "sheet pegmatites" coated with intergrown beryl crystals (Reid, 1963) suggest loss of beryllium-containing fluids during granite consolidation. Burt (1981) and Barton (1982) show that the high activities of hydrogen fluoride (HF) required to form topaz alter beryl to phenakite or bertrandite (or helvite if manganese is present: D. M. Burt, personal communication, 1994).

Syngenetic pegmatites invariably have enough fluorine to produce topaz, but either too little beryllium or too much fluorine to crystallize beryl. Their cavities do, however, conserve available beryllium by minimizing fluid outflow. Epigenetic pegmatites achieve high concentrations of beryllium, but uncommonly have sufficient fluorine to form topaz. In addition, their mode of intrusion combined with a tendency toward cavity rupture encourages loss of beryllium-rich fluids. To summarize, association of beryl with topaz appears to require a narrow, intermediate range of fluorine content, aided by restrictions on fluid loss.

Topaz granites share characteristics with granites that host economic deposits of rare metals including lithium, beryllium, tin, tantalum and niobium (in pegmatites), and molybdenum and tungsten (in high-temperature veins). Tin, and more rarely beryllium, also occur in greisens. The geology of topaz and tin are especially closely linked, so that topaz crystals and cassiterite are common in some tin placers, e.g. on the Jos Plateau in Nigeria. Tungsten ± molybdenum mineralization may also precede deposition of tin and cassiterite in greisens (Tischendorf and Förster, 1990).

GEOCHEMICAL ENVIRONMENTS

Topaz is most common in pegmatites derived from potassium-rich granites. Thus it occurs preferentially in the potassic rather than sodalithic epigenetic pegmatites of Madagascar (Lacroix, 1922–1923; Sinkankas, 1981). Crystallization of topaz, more than most other minerals, typically follows late-stage albitization (replacement of K-feldspars with Na-feldspar, especially albite) that is characteristic of many pegmatites. This is due to the generally late-stage crystallization of topaz, combined with the action of fluorine in shifting magma (feldspar) composition from K-feldspar towards albite and causing enrichment in aluminum (Kovalenko, 1977; London, 1990).

Topaz is, however, vulnerable to attack and replacement in potassium-rich systems with high water rather than fluorine contents, as in many epigenetic pegmatites. This vulnerability exists during the final magmatic stages when such fluids may be responsible for loss of early topaz, and also during the later hydrothermal stages when topaz may be deeply etched or altered (Černý and Hawthorne, 1982).

High water contents in epigenetic pegmatites typically produce micas rather than topaz (D. London, personal communication, 1990). High levels of lithium, and less commonly iron, also favor micas such as lepidolite instead of topaz (Barton, 1982). This is consistent with the scarcity of topaz in many epigenetic pegmatites, e.g. Madagascar's lithium-rich and iron-rich, sodalithic types. Topaz does occur in iron-rich, anorogenic granites (characteristically colored red by hematite), as in Pikes Peak, Colorado and Mason County, Texas, but these are commonly lithium-poor, favoring topaz over micas such as zinnwaldite.

Topaz competes for fluorine with several other minerals. Much fluorine in granites is bound up in micas, especially rock-forming biotite. The calcium content in granites must be low to avoid formation of fluorite in preference to topaz (Barton, 1982). More rarely, in some epigenetic pegmatites and greisens that contain significant calcium and phosphorus, fluorine may also be taken up by the formation of fluorapatite. Adding fluorite to Dingwell's (1985) preference order for concentrating fluorine in silicate rocks produces the sequence: fluorite, topaz, fluorapatite, biotite and finally muscovite. Within cavities, micas are more likely to be zinnwaldite or lepidolite, and there are also rarer fluorine-bearing pegmatite species such as amblygonite and herderite.

FORMATION PROCESSES

Formation of topaz requires a fluorine-rich, acidic silicate environment with an excess of aluminum over alkalis (primarily sodium and potassium). Since fluorine's average concentration in typical granites is less than 0.1% (Carmichael, 1989), this requires around a 200-fold to 300-fold concentration increase to the 15 to 21% contained in topaz. Bailey (1977) describes the behavior of fluorine in granitic systems, as depicted in Figure 66; a similar process occurs in rhyolite magmas. Loss of pressure, cooling and progressive crystallization in the rising magma releases fluorine (as hydrogen fluoride, HF). Fluorine is, however, more soluble in the magma than other volatiles such as carbon dioxide, causing it to be resorbed at higher levels. The result is a gentle degassing and concentration of fluorine in the rising magma. Particularly elevated levels are reached in shallower, roof-zone granites with their related greisens and pegmatites, where volatiles may be unable to escape. The process produces high fluorine concentrations that range from up to 1% in rhyolites, leucogranites and epigenetic pegmatites (higher in the syngenetic pegmatites), to 3 to 6% in rare ongonite dikes and topazites, to 10% or more in greisens.

An important effect of volatiles such as fluorine and water is to delay crystallization by suppressing crystallization temperatures (Kovalenko, 1977). Fluorine also increases water solubility and causes depolymerization (breaks silicate chemical bonds), markedly increasing the mobility of the magma (London, 1987). These combined effects help fluorine-rich magmas reach high levels in the crust and penetrate surrounding rocks to form typically shallow topaz deposits. Other magmatic components including lithium, and especially boron, act in a similar fashion to fluorine (London, 1987). These are more common in parent magmas for epigenetic pegmatites where higher concentrations may have an even more profound impact on water solubility. Eventual separation of an aqueous (water-rich) fluid from the magma is the key to the formation of cavities and their mineralization.

Burt (1981) describes the effects of acidity (high activity of hydrofluoric acid, HF) vs. salinity (elevated levels of sodium and potassium fluorides, NaF and KF) in fluorine-rich silicate systems. There is an equilibrium for potassium-rich fluids between topaz, quartz, and aluminosilicates including micas and K-feldspar (typically microcline). Similar equilibria exist for sodium (Na) species, involving Na-feldspar (typically albite); rarely, at very high activities of HF, cryolite may form with or instead of topaz, as in the pegmatites at Ivigtut, Greenland (Bancroft, 1984; Petersen and Secher, 1993).

Kovalenko (1973), Bailey (1977), Burt (1981), and Barton (1982) describe the following typical reactions for topaz in granitic systems.

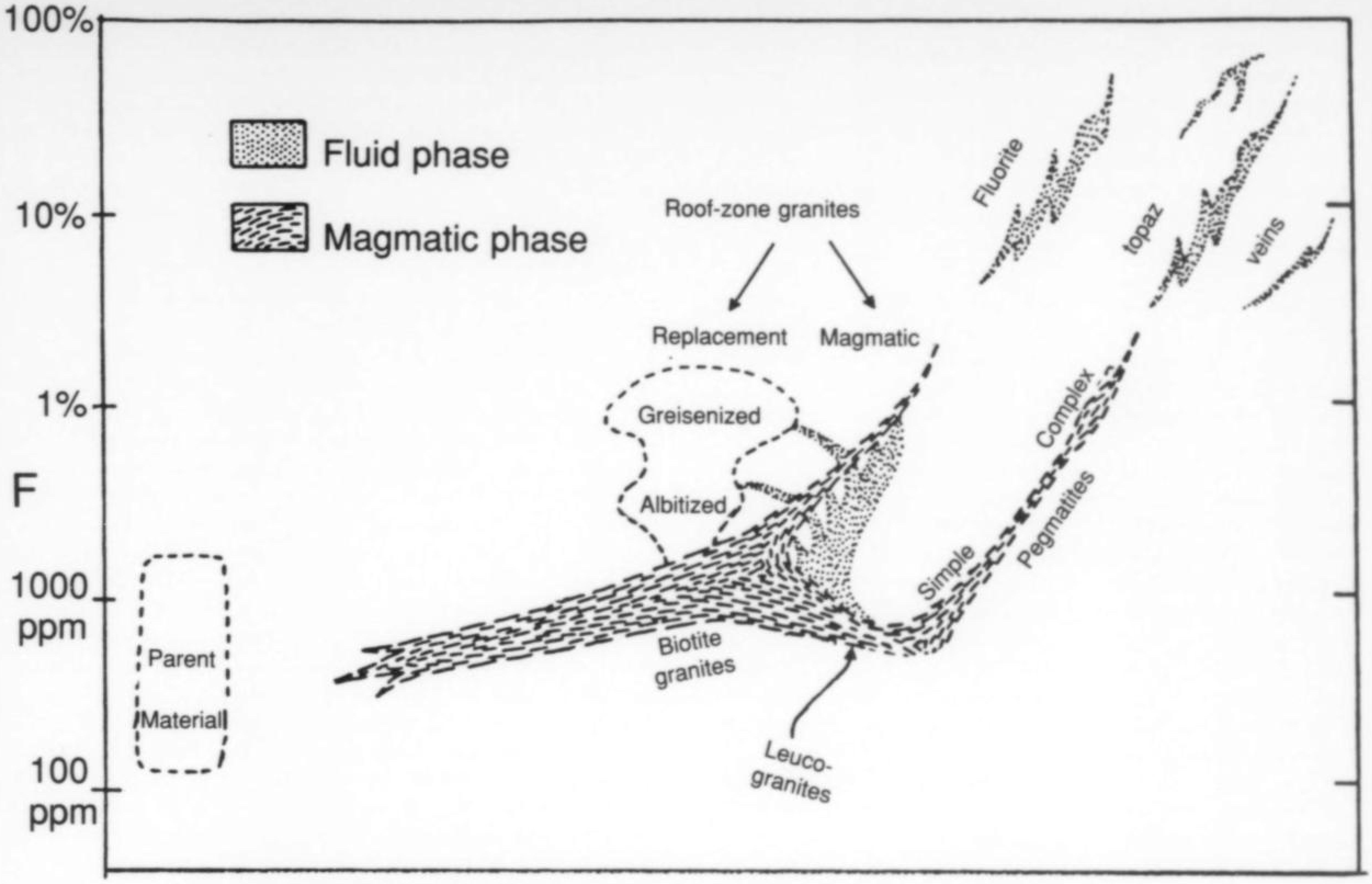


Figure 66. **Fluorine concentration in granite systems (modified after Bailey, 1977). Fluorine concentrations increase as magma rises. Still higher concentrations are reached in the water-rich residual melts that generate pegmatites, and the aqueous fluids that separate to produce greisens and veins.**

These may proceed in either direction, leading to the formation or dissolution of topaz.

Muscovite + Quartz + HF <—> Topaz + K-feldspar + Water

K-feldspar + Albite + HF <—> Topaz + Quartz + Muscovite + Na-Silicates + Water

Feldspar + HF <—> Topaz + Quartz + KF *or* NaF *or* CaF_2 + Water

A similar reaction forms primary topaz in rhyolites. In granites, if the feldspar is calcium-containing plagioclase, topaz and fluorite (CaF_2) may form simultaneously, especially in greisens or during later hydrothermal conditions.

In rhyolites, creation of lithophysal cavities by release of a fluorine-rich acid-gas provides an immediately favorable environment for early crystallization of topaz. Crystallization of topaz is also readily explained in the magmatic environment, where it forms at high temperatures under conditions where few other minerals compete for fluorine. The prime requirement is for a very high fluorine content; low contents of calcium and also magnesium and iron suppress formation of fluorite or fluorine-rich biotite respectively. Such magmas, especially those with high water contents are, however, also typically potassium-rich, making the newly formed topaz vulnerable to alteration to micas, as noted earlier.

Magmatic topaz is more common in granites or pegmatites from the most highly evolved magmas, especially those that form epigenetic pegmatites. These magmas may show a long delay in separation of an aqueous phase that extends the opportunities for concentration of fluorine and also loss of calcium, magnesium and iron. In contrast, topaz crystallizes less commonly in magmas that produce syngenetic pegmatites. Here an aqueous phase typically separates earlier, with topaz forming in cavities before it can crystallize directly from the magma.

Well-crystallized topaz forms, however, within cavities. This is a more complex situation than formation of magmatic topaz directly within the magma, and is addressed in recent experiments by London *et al.* (1988 and 1989). They show that primary topaz crystallizes only into cavities formed by the separation of an aqueous phase from the water-rich residual melt (magma). In contrast, associated primary albite-lepidolite assemblages can form directly from the melt.

The conditions necessary for formation of such topaz in granitic systems can be achieved by combinations of the following processes within the rising and cooling magma: (1) evolution of a fluorine-rich vapor, liberated by decreasing pressure, (2) increasing acidity on cooling, due to dissociation of aqueous acid complexes (Burt, 1981), and in some situations (3) loss of alkalis (primarily sodium and potassium) as dissolved salts (Kortemeir and Burt, 1988). These changes in the acid-alkali balance (along with shifts in aluminum-alkali balance) are most likely responsible for the variation in timing of topaz crystallization, including formation of second-generation crystals and loss of topaz due to etching.

London (1990) shows that fluids are typically alkaline in the early pegmatitic (late-magmatic) stage. Typically there is a progression to acidic conditions in the early hydrothermal stage and back to alkaline in the later hydrothermal stages, as described by Shcherba (1970). The acidic, early hydrothermal stage in pegmatites and greisens is the most productive for topaz. Topaz may even be an indicator of the transition from alkali to acid conditions, as suggested by Koshil *et al.* (1991).

COMPARISON of ENVIRONMENTS

Syngenetic pegmatites and greisens in granites, and lithophysal cavities in topaz rhyolites are all formed by separation of a fluorine-rich fluid. Burt (1981) underscores the similarities. The differences are mainly in the progression of mineralization and effects on the enclosing rock, reflecting the extent to which fluids are free to move in or out of the system.

Closed systems minimize opportunities for fluid escape, and are typified by pegmatites, especially the syngenetic type. Crystallization from a single batch of fluid within a cavity produces a sequence of progressively lower-temperature minerals. Crystallization of topaz is typically delayed to the mid to late stages by the need for the conditions to become sufficiently acid. Formation of earlier-stage pegmatitic topaz requires loss (leakage) of alkalis to produce this required shift to acid conditions with an excess of aluminum over alkalis. This is generally seen only in epigenetic pegmatites whose intrusive nature is more likely to allow such leakage into enclosing country rocks. D. M. Burt (personal communication, 1993) indicates that water-rich pegmatitic systems can lose alkalis as dissolved salts, but without corresponding loss of the aluminum that is required to form topaz. Černý (1982c) also notes evidence of outflow of alkalis (but not aluminum) in haloes surrounding rare-element pegmatites.

Open systems allow easy passage of the fluorine-rich acid fluids that create topaz, probably also promoting release of such fluids from the source granite. This is especially true in greisens, but may also apply to some epigenetic pegmatites. In greisens, fluids from the host granite invade the surrounding rock in one or more episodes, causing progressive alteration of the host rock and mineralization. In contrast to the closed system, this process may not be as favorable to preserving a range of well-crystallized minerals. A few greisens do, however, produce good specimens of topaz, beryl, fluorite, cassiterite and tungsten-bearing species. Not surprisingly, many deposits show both pegmatite and greisen features, e.g. the Sherlova Gora and Adun Chilon deposits in the Transbaikal region of eastern Siberia. as described earlier.

The rhyolite environment may represent a balance between open and closed conditions. Individual lithophysal cavities may represent essentially closed systems (the equivalent of miarolitic cavities in granites), but there is probably some flow of fluorine-rich vapor through the overall system. Supporting evidence includes the typical quantity of topaz in cavities and the presence of fractures and flow structures.

Conclusion

Collectors are intrigued by topaz for its beauty, diversity and crystal size. Classic localities such as Mursinka in the Ural Mountains and Schneckenstein in Germany that were discovered as early as the 17th century are now exhausted and their specimens are very highly prized. Spectacular new discoveries, in particular at Virgem da Lapa in Brazil and the pegmatites of northern Pakistan, have been made over the last two decades. Other deposits such as Ouro Preto in Brazil and the Thomas Range in Utah continue to produce superb material. The future supply and a good potential for exciting new discoveries seem assured.

Topaz has also become a much more popular gemstone, in particular with the recognition of the range of available colors and the supply of eye-catching, deep-blue treated stones in large sizes. Mineralogists are drawn by the range of the geological environments in which topaz occurs, in particular the continuing challenges of explaining the complexities of pegmatite formation, and the properties of the crystals themselves. Much light has been shed on such questions over the last few years, and further revelations can be expected in areas including pegmatite genesis, the causes of color and fluorescence, and twinning.

The number of current projects focussing on topaz, and its choice as the featured mineral for the 1995 Tucson show, are further evidence of growing fascination with this mineral and gemstone.

Acknowledgments

The author gratefully acknowledges the generous assistance of Dr. Don Burt, Dr. Gene Foord and Dr. David London, who provided much guidance with the complexities of granite and pegmatite genesis and geochemistry. Thanks also to the following people who helped in many different areas: Steve Allred, Dr. Peter Bancroft, Dimitrii Belakovskii, Rob Belcher, Richard Bideaux, Dr. Bill Birch, Dudley Blauwet, Dr. Russ Boggs, John Holfert, Don Hoover, Syed Hussain, John Koivula, Dr. Albert Levinson, Peter Lyckberg, Jimmy McNeil, Herb Obodda, Eric Offermann, Larry Piekenbrock, Keith Proctor, Lanny Ream, Saeed-ur Rehman, Dave Richerson, Mike Ridding, Dr. Abraham Rosenzweig, Martin Rosser, Dr. George Rossman, Jorge A. Saadi, Hans Schaffland, Ely F. de Souza, Rene Triebl, Dr. Wendell Wilson, and staffs of the U.S. National Museum of Natural History (Smithsonian Institution), Washington, D.C., and the Natural History Museum, London, England. Several of the above, notably Dr. Don Burt, Dr. Gene Foord, Dr. Albert Levinson, Dr. David London, Lanny Ream and Dr. Abraham Rosenzweig, have been particularly helpful in reviewing the manuscript and providing invaluable comments. Dr. Bill Birch's many constructive suggestions from two reviews of long manuscripts were especially helpful. Finally, thanks to the many photographers who submitted photographs.

References

AGER, D. V., and BROOKS, M., eds. (1977) *Europe from Crust to Core*. John Wiley and Sons, London, 202 p.

ALMEIDA, F. F. M., HASUI, Y., NEVES, B. B. B., and FUCK, R. A. (1981) Brazilian structural provinces: an introduction. *Earth Science Reviews*, **17**, 1–17.

ANDERSON, J. L. (1983) Proterozoic anorogenic granite plutonism of North America. *Geological Society of America Memoir* **161**, 133–154.

BAILEY, J. C. (1977) Fluorine in granitic rocks and melts—a review. *Chemical Geology*, **19**, 1–42.

BANCROFT, P. (1984) *Gem and Crystal Treasures*. Western Enterprises—Mineralogical Record, Fallbrook, CA, 488 p.

BARKER, F., WONES, D. R., SHARPE, W.N., and DESBOROUGH, G. A. (1975) The Pikes Peak Batholith, Colorado Front Range; a model for the origin of the gabbro-anorthosite-syenite-potassic granite suite. *Precambrian Research*, **2**, 97–160.

BARTON, M. D. (1982) The thermodynamic properties of topaz solid solutions and some petrologic applications. *American Mineralogist*, **67**, 956–974.

BATEMAN, P. C. (1978) Plutonism in Japan and Korea. *Episodes*, (1), 16–19.

BAUER, M. (1968) *Precious Stones*, Vol. 2. Transl. by L. J. Spencer, Dover Publications Inc., New York, 261–627 (originally publ. in English, 1904).

BENNETT, E. H., and KNOWLES, C. R. (1985) Tertiary plutons and related rocks in central Idaho. *U.S. Geological Survey Bulletin* **1658**, Chapter F, 81–95.

BEUS, A. A. (1966) *Geochemistry of Beryllium and Genetic types of Beryllium Deposits*. Transl. by F. Lachman. W. H. Freeman, San Francisco, 401 p.

BIDEAUX, R. A. (1981) Gem-bearing pegmatites at Klein Spitzkop, Namibia. (abs.) *In* The mineralogy of pegmatites. *4th Annual Mineralogical Society of America—Friends of Mineralogy Symposium*, Tucson, Arizona.

BIRCH, W. D. (1984) Quartz-topaz-loellingite rocks near Eldorado, Victoria. *Australian Journal of Earth Sciences*, **31**, 269–278.

BOWDEN, P., and KINNAIRD, J. A. (1984) Petrological and geochemical criteria for the identification of (potential) ore-bearing Nigerian granitoids. *27th International Geological Congress*, **7**, 85–119.

BRADBURY, H. J., and NOLEN-HOEKSEMA, R. C. (1985) The Leopontine Alps as an evolving metamorphic core complex during A-type subduction. *Tectonics*, **4** (2), 187–211.

BROUGHTON, P. L. (1973) Precious topaz deposits of the Llano Uplift area, central Texas. *Rocks and Minerals*, **48** (3), 147–156.

BURBANK, B. B. (1934) Topaz and herderite at Topsham, Maine. *Rocks and Minerals*, **9** (9), 125–131. (Republished in *Rocks and Minerals*, **62** (6), 434–438 (1987).)

BURCHFIEL, B. C. (1983) The continental crust. *Scientific American*, **249** (3), 130–142.

BURT, D. M. (1976) Generation of high HF fugacities in miarolitic pegmatites and granites: the possible role of topaz. (abs.) *Geological Society of America Abstracts with Programs*, **8**, 798.

BURT, D. M. (1981) Acidity-salinity diagrams—applications to greisen and porphyry deposits. *Economic Geology*, **76**, 832–843.

BURT, D. M., and SHERIDAN, M. F. (1985) Mineralization associated with topaz rhyolites and related rocks in Mexico. *In* Taylor, R. P., and Strong, D. F., eds., Recent advances in the geology of granite-related mineral deposits. *Canadian Institute of Mining and Metallurgy Special Volume* **39**, 303–306.

BURT, D. M., SHERIDAN, M. F., BIKUN, J. V., and CHRISTIANSEN, E. H. (1982) Topaz rhyolites—distribution, origin and significance for exploration. *Economic Geology*, **77**, 1818–1836.

CAHEN, L., SNELLING, N. J., DELHAL, J., and VAIL, J. R. (1984) *The Geochronology and Evolution of Africa*, Clarendon Press, Oxford, 512 p.

CAPLAN, A., and WILSON, W. E. (1980) Interview: Allan Caplan. *Mineralogical Record*, **11**, 351–360.

CARMICHAEL. R. S., ed. (1989) *Practical Handbook of Physical Properties of Rocks and Minerals*. CRC Press, Boca Raton, Florida, 741 p.

CASSEDANE, J. P. (1989) The Ouro Preto topaz mines. *Mineralogical Record*, **20**, 221–233.

CASSEDANE, J. P., and CASSEDANE, J. O. (1978) Famous mineral localities: the Brumado district, Bahia, Brazil. *Mineralogical Record*, **9**, 196–205.

CASSEDANE, J. P., and LOWELL, J. (1982) Famous mineral localities: the Virgem da Lapa pegmatites. *Mineralogical Record*, **13**, 19–28.

ČERNÝ, P., ed. (1982a) Short course in granitic pegmatites in science and industry. *Mineralogical Association of Canada* Short Course Handbook, **8**, 555 p.

ČERNÝ, P. (1982b) Anatomy and classification of granitic pegmatites. *In* Černý, P., ed., Short course in granitic pegmatites in science and industry. *Mineralogical Association of Canada* Short Course Handbook, **8**, 1–39.

ČERNÝ, P. (1982c) Petrogenesis of granitic pegmatites. *In* Černý, P., ed., Short course in granitic pegmatites in science and industry. *Mineralogical Association of Canada* Short Course Handbook **8**, 405–462.

ČERNÝ, P. (1991a) Rare-element pegmatites. part I: Anatomy and internal evolution of pegmatitic deposits. *Geoscience Canada*, **18** (2), 49–67.

ČERNÝ, P. (1991b) Rare-element pegmatites. part II: Relation to global environments and petrogenesis. *Geoscience Canada*, **18** (2), 68–81.

ČERNÝ, P. (1992) Geochemical and petrogenic features of mineralization in rare-element granitic pegmatites in the light of current research. *Applied Geochemistry*, **7**, 393–416.

ČERNÝ, P., and HAWTHORNE, F. C. (1982) Selected peraluminous minerals. *In* Černý, P., ed., Short course in granitic pegmatites in science and industry. *Mineralogical Association of Canada* Short Course Handbook, **8**, 163–186.

CHALMERS, R. O. (1979) *The Observer's Book of Rocks and Minerals of Australia*. Methuen of Australia, Sydney, 246 p.

CHRISTIANSEN, E. H., SHERIDAN, M. F., and BURT, D. M. (1986) The geology and geochemistry of Cenozoic topaz rhyolites from the western United States. *Geological Society of America Special Paper* **205**, 82 p.

CLARKE, D. B. (1981) The mineralogy of peraluminous granites: a review. *Canadian Mineralogist*, **19**, 3–17.

CLEMENS, J. D., and WALL, V. J. (1981) Origin and crystallization of some peraluminous (S-type) granitic magmas. *Canadian Mineralogist*, **19**, 111–131.

COLLINS, W. J., BEAMS, S. D., WHITE, A. J. R., and CHAPPELL, B. W. (1982) Nature and origin of A-type granites with particular reference to southeastern Australia. *Contributions to Mineralogy and Petrology*, **80**, 189–200.

CONDIE, K. C. (1976) *Plate Tectonics and Crustal Evolution*. Pergammon Press, New York, 288 p.

CONGDON, R. D., and NASH, W. P. (1991) Eruptive pegmatite lava: rhyolite of the Honeycomb Hills, Utah. *American Mineralogist*, **76**, 1261–1278.

COOK, K. L. (1966) Rift system in the basin and range province. *In* Irvine, T. N. (ed.), The world's rift system. *Geological Survey of Canada Paper* **66–14**.

COOPER, M. (1994) Saint-Marie-aux-Mines show. *Mineralogical Record*, **25**, 47–50.

CUNEY, M., MARIGNAC, C., and WEISBROD, A. (1992) The Beauvior topaz-lepidolite albite granite (Massif Central, France): the disseminated magmatic Sn-Li-Ta-Nb-Be mineralization. *Economic Geology*, **87**, 1766–1794.

DEER, W. A., HOWIE, R. A., and ZUSSMAN, J. (1982) *Rock-Forming Minerals*, 2nd edn., vol. 1A. Longmans-Wiley, New York, 801–815.

DINGWELL, D. B. (1985) The structure and properties of fluorine-rich magmas. *In* Taylor, R. P., and Strong, D. F., eds., Recent advances in the geology of granite-related mineral deposits. *Canadian Institute of Mining and Metallurgy Special Volume* **39**, 1–12.

DISSANAYAKE, C. B., and RUPASINGHE, M. S. (1993) A prospectors' guide map to the gem deposits of Sri Lanka. *Gems and Gemology*, **29**, 3, 173–181.

DUNN, P. J. (1974) Inclusions of albite and phenakite in gem topaz from the Tarryall Mountains, Colorado. *Gems and Gemology*, **14**, 11, 337–339.

EADINGTON, P. J., and NASHAR, B. (1978) Evidence for the magmatic origin of quartz-topaz rocks from the New England Batholith, Australia. *Contributions to Mineralogy and Petrology*, **67**, 433–438.

EBY, G. N. (1987) The Monteregian Hills and White Mountains alkaline igneous provinces, eastern North America. *In* Fitton, J. G., and Upton, B. G. J., (eds.), Alkaline igneous rocks. *Geological Society of London Special Publication No.* **30**, 433–447.

EBY, G. N. (1990) The A-type granitoids: A review of their occurrence and chemical characteristics and speculations on their petrogenesis. *Lithos*, **26**, 115–134.

EINAUDI, M. T., and BURT, D. M. (1982) Terminology, classification and composition of skarn deposits. *Economic Geology,* **77**, 745–754.

EVSEEV, A. A. (1993a) Siberia's crystals and symmetry in the distribution of occurrence of minerals. *World of Stones,* **1** (1), 11–20.

EVSEEV, A. A. (1993b) The South Urals: a brief mineralogical guide. *World of Stones*, **1** (1), 31–35.

EVSEEV, A. A. (1993c) The Urals (from Middle to Polar): a brief mineralogical guide. *World of Stones,* **2** (1), 35–41.

FERSHTATER, G. B., and BORODINA, N. S. (1991) Enclaves in the Hercynian granitoids of the Ural Mountains, U.S.S.R., *In* Didier, J., and Barbarin, B., eds., *Developments in Petrology 13, Enclaves and Granite Petrology,* Elsevier, Amsterdam, 83–94.

FERSMAN, A. E. (1925) *Dragotsennye i Tsvetnye Kamnii SSSR* (Precious and colored gemstones of Russia). Izdavaemye Kommissiy po Izucheniu Estestvennykh Proizvoditelnikh sil SSSR, Akademiya Nauk, Leningrad, Monografiya 3. vol. 2: Mestorozhdeniya. 386 p. (in Russian).

FERSMAN, A.E. (1932) *Pegmatity* (Pegmatites) Akademiya Nauk SSSR, Leningrad, 2nd. edn., 665p. (in Russian). (French transl. (1961): *Les Pegmatites*, Librairie Universitaire Uystpruyst, Louvain, Belgium, 3 vols., 738 p.)

FERSMAN, A. E. (1940) *Pegmatity* (Pegmatites) Akademiya Nauk SSSR, Leningrad, 3rd. edn., 712 p. (in Russian).

FINGER, F., and STEYRER, H. P. (1990) I-type granitoids as indicators of a late Paleozoic convergent ocean-continent margin along the southern flank of the central European Variscan orogen. *Geology*, **18**, 1207–1210. (further Comments and Replies in *Geology*, **19**, 1245–1248 (1991))

FOORD, E. E. (1977) Famous mineral localities: the Himalaya dike system, Mesa Grande District, San Diego County, California. *Mineralogical Record*, **8**, 461–474.

FOORD, E. E. (1991) Topaz, $Al_2SiO_4(F,OH)_2$, a favorite of the mineral kingdom. *Rochester Mineralogical Symposium*, Rochester, New York, April 14–16, 20–27.

FOORD, E. E., CHIRNSIDE, W., LICHTE, F. E., and BRIGGS, P. H. (1995) Pink Topaz from the Thomas Range, Juab County, Utah. *Mineralogical Record,* **26**, this issue.

FOORD, E. E., JACKSON, L. L., TAGGART, J. E., CROCK, J. G, and KING, T. V. V. (1990) Environment of crystallization of topaz as determined from crystal chemistry and infrared spectra. (abs.) *15th General Meeting of the International Mineralogical Association*, Beijing, **1**, 306–307.

FOORD, E. E., SPAULDING, L. B., MASON, R. A., and MARTIN, R. F. (1989) Mineralogy and paragenesis of the Little Three pegmatites, Ramona district, San Diego County, California. *Mineralogical Record*, **20**, 101–127.

FRANCIS, C. A. (1987) Minerals of the Topsham, Maine pegmatite district. *Rocks and Minerals,* **62**, 407–415.

FRITSCH, E., and ROSSMAN, G. R. (1988) An update on color in gems. *Gems and Gemology*, **24** (2), 88–102.

GARRISON, J. R., Jr., LONG, L. E., and RICHMANN, D. L. (1979) Rb-Sr and K-Ar geochronologic and isotopic studies, Llano Uplift, Texas. *Contributions to Mineralogy and Petrology,* **69**, 361–374.

GOLDSCHMIDT, V. (1922) *Atlas der Krystallformen*. Carl Winters Universitatsbuchhandlung, **8**, 168–195.

GREG, R. P., and LETTSOM, W. G. (1858) *Manual of the Mineralogy of Great Britain and Ireland*, John Van Voorst, London, 483 p.

GROMOV, A. V., and AURANG ZEB (1992) On the mineralogy of pink topazes from Katlang deposit (Pakistan). *Proceedings of the Russian Mineralogical Society*, No. 1, 72–79 (in Russian).

GUBELIN, E., GRAZIANI, G., and KAZMI, A. H. (1986) Pink topaz from Pakistan. *Gems and Gemology,* **22** (3), 140–151.

HAAPALA, I., and RÄMÖ, O. T. (1990) Petrogenesis of the Proterozoic rapakivi granites of Finland. *In* Stein, H. J., and Hannah, J. L., eds., Ore-bearing granite systems: petrogenesis and mineralizing processes. *Geological Society of America Special Paper* **246**, 275–286.

HAMILTON, W. (1970) The Uralides and the motion of the Russian and Siberian platforms. *Geological Society of America Bulletin* **81**, 2553–2576.

HATCHER, R. D., Jr., THOMAS, W. A., and VIELE, G. W., eds. (1989) The Geology of North America, vol. F-2: The Appalachian-Ouachita Orogen in the United States. *Geological Society of America,* 767 p.

HEDDLE, M. F. (1901) *The Mineralogy of Scotland*, 2 vols., David Douglas, Edinburgh, 148 and 247 p.

HENTSCHEL, G. (1977) Selected minerals from the volcanic district of Laacher See. Germany. *Mineralogical Record*, **8**, 313–326.

HERVIG, R. L., KORTEMEIER, W. T., and BURT, D. M. (1987) Ion-microprobe analyses of Li and B in topaz from different environments. *American Mineralogist*, **72**, 392–396.

HESS, P. C. (1989) *Origins of the Igneous Rocks*. Harvard University Press, Cambridge, Massachusetts, 336 p.

HILLER, J. Jr. (1969) The Long Hill tungsten mine, Trumbull, Connecticut. *Rocks and Minerals*, **44**, 30–31.

HINTZE, C. (1987) *Handbuch der Mineralogie*, vol. 2: Silicate und Titanate. Verlag von Veit, Leipzig, 103–127 (in German).

HOLLAND, C. H., ed. (1981) *A Geology of Ireland*. Halsted Press/ John Wiley and Sons, New York, 335 p.

HOLMAN, K. (1987) New Hampshire topaz—a remarkable discovery. *Mineral News,* **3** (8), 1–3.

HOLMAN, K. (1991) Topaz from South Percy Peak, Stratford, New Hampshire. *Mineral News*, **7** (10), 1–2.

HOOVER, D. B (1992) *Topaz*. Butterworths-Heinemann Gem Books, Oxford, England, 207 p.

JACOBSON, M. I. (1993) *Antero Aquamarines*. L. R. Ream Publishing, Coeur d'Alene, Idaho, 126 p.

JAHNS, R.H. (1982) Internal evolution of granitic pegmatites. *In* Černý, P., ed., Short course in granitic pegmatites in science and industry. *Mineralogical Association of Canada* Short Course Handbook, **8**, 293–328.

JAHNS, R. H., and BURNHAM, C. W. (1969) Experimental studies of pegmatite genesis: I. A model for derivation and crystallization of granitic pegmatites. *Economic Geology*, **64**, 843–864.

JOHNSTON, C., and CHAPPELL, B. W. (1992) Topaz-bearing rocks from Mount Gibson, North Queensland, Australia. *American Mineralogist*, **77**, 303–311.

JONES, R. W. (1980) Pegmatite minerals: topaz. *Rocks and Minerals*, **10**, 40–46 and 77–80.

KAZMI, A. H., PETERS, J. P., and OBODDA, H. P. (1985) Gem pegmatites of the Shingus-Dusso area, Gilgit, Pakistan. *Mineralogical Record,* **16**, 393–411.

KEARNS, L. E. (1993) Minerals of the Morefield pegmatite, Amelia County, Virginia. *Rocks and Minerals*, **68**, 232–242.

KELLER, P. C. (1983) The Capao topaz deposit, Ouro Preto, Minas Gerais, Brazil. *Gems and Gemology*, **19** (1), 12–20.

KELLER, P. C. (1990) *Gemstones and their Origin*. Van Nostrand Reinhold, New York, 144 p .

KELLER, P. C., and WANG FUQUAN (1986) A survey of the gemstones resources of China. *Gems and Gemology*, **22** (1), 3–13.

KLEEMAN, J. D. (1985) Origin of disseminated wolframite-bearing quartz-topaz rock at Torrington, New South Wales, Australia. *In* High heat production (HHP) granites, hydrothermal circulation and ore genesis. Conference of *The Institution of Mining and Metallurgy*, St. Austell, Cornwall, England (September 1985), 197–201.

KEMP, D. R. C. (1967) Some topaz-, sillimanite-, and kyanite-bearing rocks from Tanganyika. *Mineralogical Magazine*, **36**, 515–521.

KIILSGAARD, T. K., FREEMAN, V. L., and COFFMAN, J. S. (1970) Mineral resources of the Sawtooth Primitive Area, Idaho. *U.S. Geological Survey Bulletin* **1319-D**, 174 p.

KINNAIRD, J., and BOWDEN, P. (1987) African anorogenic alkaline magmatism—a discussion with reference to the Niger-Nigerian Province. *Geological Journal*, **22**, Tl, 297–340.

KORTEMEIER, W. T., and BURT, D. M. (1988) Ongonite and topazite dikes in the Flying W ranch area, Tonto basin, Arizona. *American Mineralogist*, **73**, 507–523.

KOSHIL, I. M., VASILISHIN, I. S., PAVLISHIN, V. I., and PANCHENKO, V. I. (1991) Woldarsk-Wolynskii geologischer Aufbau und Mineralogie der Pegmatit in Wolynien, Ukraine (Wolodarsk-Wolynskii geological structure and the mineralogy of the pegmatites in Wolhynia, Ukraine). *Lapis*, **16** (10), 28–40. (in German).

KOVALENKO, V. I. (1973) Distribution of fluorine in topaz-bearing quartz-keratophyre dike (ongonite) and the solubility of fluorine in granitic melts. *Geochemistry International*, **10**, 41–49.

KOVALENKO, V. I. (1977) The reactions between granite and aqueous hydrofluoric acid in relation to the origin of fluorine-bearing granites. *Geochemistry International*, **14**, 108–118.

KOVALENKO, V. I., and KOVALENKO, N. I. (1984) Problems of the origin, ore-bearing and evolution of rare-metal granitoids. *Physics of the Earth and Planetary Interiors*, **35**, 51–62.

LACROIX, A. (1922–1923) *Minéralogie de Madagascar*. Augustin Challamel (Paris), 3 vols., 624, 694, 450 p. (in French).

LAHTI, S. I., and KINNUNEN, K. A. (1993) A new gem beryl locality: Luumäki, Finland. *Gems and Gemology*, **29** (1), 30–37.

LANDES, K. K. (1932) The Barringer Hill, Texas pegmatite. *American Mineralogist*, **17**, 381–390.

LARSON, B. (1977) The best of San Diego County. *Mineralogical Record*, **8**, 507–515.

LONDON, D. (1986) Formation of tourmaline-rich gem pockets in miarolitic pegmatites. *American Mineralogist*, **71**, 396–405.

LONDON, D. (1987) Internal differentiation of rare-element pegmatites: effects of boron, phosphorus and fluorine. *Geochimica et Cosmochimica Acta* ., **51**, 403–420.

LONDON, D. (1990) Internal differentiation of rare-element pegmatites: a synthesis of recent research. *In* Stein, H. J., and Hannah, J. L., eds., Ore-bearing granite systems: petrogenesis and mineralizing processes. *Geological Society of America Special Paper* **246**, 35–50.

LONDON, D., HERVIG, R. L., and MORGAN, G. B., VI (1988) Melt-vapor solubilities and elemental partitioning in peraluminous granite-pegmatite systems: experimental results with Macusani glass at 200 MPa. *Contributions to Mineralogy and Petrology*, **99**, 360–373.

LONDON, D., MORGAN, G. B., VI, and HERVIG, R. L. (1989) Vapor undersaturated experiments with Macusani glass + H_2O at 200 MPa and the internal differentiation of granitic pegmatites. *Contributions to Mineralogy and Petrology*, **102**, 1–17.

LYCKBERG, P. (1993) Eine Reise zum bekannten "Mursinka-Alabaška" —Pegmatit und dem Amethyst-gebiet NNE von Jekaterinenburg in Ural. (A journey to the well-known Mursinka-Alabaska pegmatites and amethyst area NNE of Ekaterinburg in the Urals) *Mineralien Welt*, **4** (2), 51–56.

MANNING, D. A. C. (1981) The effect of fluorine on liquidus phase relationships in the system Qz-Ab-Or with excess water at 1 kb. *Contributions to Mineralogy and Petrology*, **76**, 206–215.

MANNING, D. A. C., and HILL, P. I. (1990) The petrogenic and metallogenic significance of topaz granite from the southwest England orefield. In Stein. H. J., and Hannah, J. L., eds., Ore-bearing granite systems: petrogenesis and mineralizing processes. *Geological Society of America Special Paper* **246**, 51–70.

MARAKUSHEV, A. A., GRAMENITSKIY, Y. N., and LUKASHEV, A. N. (1989) Layering of the Korosten' pluton and the occurrence of pegmatites. *International Geology Review*, **31** (6), 556–573.

MARTIN, H., MATHIAS, M., and SIMPSON, E. S. W. (1960) The Damaraland sub-volcanic ring complexes in South West Africa. *21st International Geological Congress*, Copenhagen, **13**, 156–174.

MEIXNER, H. (1978) Topaskristalle von der Stockeram, Untersalzbachtal, Salzburg. *Lapis*, **111** (1), 58–59 (in German).

MENZIES, M. A., and BOGGS, R. C. (1993) Minerals of the Sawtooth Batholith, Idaho. *Mineralogical Record*, **24**, 185–202.

MERLE, O., COBBOLD, P. R. (1989) Tertiary kinematics in the Leopontine dome. *In* Coward, M. P., Dietrich, D., and Park, R. G., eds., Alpine tectonics. *The Geological Society, London, Special Publication* **45**, 113–134.

MICHALSKI, T. C. (1986) Topaz in the Pikes Peak Batholith. *Colorado Pegmatite Symposium, Friends of Mineralogy, Colorado Chapter*, Denver, Colorado, 72–76.

MITCHELL, A. H. G., and GARSON, M. S. (1976) Mineralization at plate boundaries. *Minerals Science and Engineering*, **8**, 129–169.

MITCHELL, A. H. G., and GARSON, M. S. (1981) *Mineral Deposits and Global Tectonics*, Academic Press, London, 405 p.

MOORE, P. B. (1973) Pegmatite phosphates: descriptive mineralogy and crystal chemistry. *Mineralogical Record*, **4**, 103–130.

MOORE, T. (1992) What's new in minerals? *Mineralogical Record*, **23**, 273–281.

MUNTYAN, B. L., and MUNTYAN, J. R. (1985) Minerals of the Pikes Peak granite. *Mineralogical Record*, **16**, 217–230.

MYATT, B., ed. (1976) *How and Where to Find Gemstones in Australia and New Zealand*. Paul Hamlyn, Sydney, 511 p.

NAMBU, M. (ed.) (1970) *Introduction to Japanese Minerals*. Geological Society of Japan, 208 p.

NAUMOV, V. B., KOVALENKO, V. I., IVANOVA, G. F., and VLADYKIN, N. V. (1977) Genesis of topaz according to data on microinclusions. *Geochemistry International*, **14** (2), 1–8.

NEIVA, A. M. R. (1982) Geochemistry of muscovite and some physio-chemical conditions of the formation of some tin-tungsten deposits in Portugal. *In* Evans, A. M., ed., *Metallization Associated with Acid Magmatism*, John Wiley and Sons, Chichester, England, 243–259.

NELSON, K. E. (1968) Tarryall topaz from Colorado. *Lapidary Journal*, **48** (3), 147–56.

NOVÁK, M., ČERNÝ, P., ČECH, F., and STANĚK, J. (1992) Granitic pegmatites in the territory of the Moravian and Bohemian Moldanubicum. *In* Novak, M., and Černý, P. eds., *Lepidolite 200: Field Trip Guidebook*, Masaryk University and Moravian Museum, Brno, Czechoslovakia, 11–20.

OLSEN, D. R. (1971) The origin of topaz deposits near Ouro Preto, Minas Gerais, Brazil. *Economic Geology*, **66** (4), 627–631.

PALFREYMAN, W. D. (1984) *Guide to the Geology of Australia*. Australian Government Publishing Service, Canberra, 111 p.

PANCZNER, W. D. (1987) *Minerals of Mexico*. Van Nostrand Reinhold, New York, 459 p.

PARRISH, I. S., and TULLY, J. V. (1978) Porphyry tungsten zones at Mt. Pleasant, New Brunswick. *Canadian Institute of Mining and Metallurgy Bulletin* **71**, 794, 93–100.

PATTEE, E. C., VAN NOY, R. M., and WELDIN, R. D. (1968) Beryllium resources of Idaho, Washington, Montana and Oregon. *U.S. Bureau of Mines Report of Investigations* **7148**, 169 p.

PAVLISHIN, V. (1992) The geology and mineralogy of chambered pegmatites of Ukraine (abs.). *Lepidolite 200 Symposium,* Nové Město na Moravě, Czechoslovakia (August/September 1992), 59–60.

PEACOCK, M. A. (1935) Topaz from Devil's Head, Colorado. *American Mineralogist,* **20**, 354–363.

PETERSEN, O. V., and SECHER, K. (1993) The minerals of Greenland. *Mineralogical Record*, **24**, 31.

PITCHER. W. S. (1982) Granite type and tectonic environment. *In* Hsü, K. J., ed. *Mountain Building Processes,* Academic Press, London, 19–40.

POUGH, F. H. (1986) Gem treatment: topaz. *Lapidary Journal*, **40**, (8) 16–18.

PROCTOR, K. (1984) Gem pegmatites of Minas Gerais, Brazil: exploration, occurrence and aquamarine deposits. *Gems and Gemology,* **20** (2), 78–100.

REAM, L. R. (1979) The Thomas Range, Wah Wah Mountains, and vicinity, western Utah. *Mineralogical Record,* **10**, 261–278.

REAM, L. R. (1989) *Idaho Minerals*. L. R. Ream Publishing, Coeur d'Alene, Idaho, 329 p.

REAM, L. R. (1994) Tucson dealer news. *Mineral News*, **10** (1), 9.

REID, R. R. (1963) Reconnaissance geology of the Sawtooth Range. *Idaho Bureau of Mines and Geology, Pamphlet* **129**, 37 p.

RIBBE, P. H. (1980) Topaz. *Reviews in Mineralogy*, **5**, 215–230.

ROBBINS, M. (1988) Fluorescent forum. *Rocks and Minerals*, **63**, 487–488.

ROBERTSON, K. (1989) News from Europe. *Mineral News*, **5** (8), 1.

ROSENBERG, P. E. (1972) Paragenesis of the topaz-bearing portion of the Brown Derby No. 1 Pegmatite, Gunnison County, Colorado. *American Mineralogist*, **57**, 571–583.

RUSS, K-H. (1989a) The Schneckenstein, an old locality. *Mineral News,* **57** (4), 6–8.

RUSS, K-H, (1989b) Obersalzbach and Untersalzbach Valleys, Austria. *Mineral News,* **5** (11), 8–9.

RUSSELL, A. (1924) Topaz from Cornwall, with an account of its localities. *Mineralogical Magazine,* **20**, 221–236.

SABINA, A. P. (1992) Rocks and minerals for the collector: Estrie and Gaspésie, Quebec; and parts of New Brunswick. *Geological Survey of Canada Miscellaneous Report* **46**, p. 118.

SAMUELSON, P. B., HOLLMAN, K. H., and HOLT, C. L. (1990) Minerals of the Conway and Mount Osceola granites of New Hampshire. *Rocks and Minerals*, **65**, 288–296.

SCALISI, P., and COOK, D. (1983) *Classic Mineral Localities of the World: Asia and Australia*. Van Nostrand Reinhold Co., New York, 226 p.

SCHOBBENHAUS, C., CAMPOS, D. A., DERZE, G. R., and ASMUS, H. E., eds. (1984) *Geologia do Brasil*. Departamento Nacional da Produçao Mineral do Brasil, Brasília, 501 p. (in Portugese).

SCOVIL, J. A. (1993) Topaz, gem of legends. *Earth*, **2** (4), 64–65.

SEARLE, M. P., REX, A. J., TIRRUL, R., REX, D. C., BARNICOAT, A., and WINDLEY, B. F. (1989) Metamorphic, magmatic, and tectonic evolution of the central Karakoram in the Biafo-Baltoro-Hushe regions of northern Pakistan. *In* Malinconico, L. L., Jr., and Lillie, R. J., eds., Tectonics of the western Himalayas. *Geological Society of America Special Paper* **232**, 47–73.

SEARLE, M. P., and TIRRUL, R. (1991) Structure and thermal evolution of the Karakoram crust. *Journal of the Geological Society, London,* **148**, 65–82.

SHANNON, E. V. (1921a) The old tungsten mine in Trumbull, Connecticut. *American Mineralogist,* **6**, 126–128.

SHANNON, E. V. (1921b) Some minerals from the old tungsten mine at Long Hill in Trumbull, Connecticut. *U.S. National Museum Proceedings*, **58**, 469–482.

SHAUB, B. M. (1955) A new discovery of topaz crystals. *Rocks and Minerals,* **30**, 227–235.

SHAW, S. E., and FLOOD, R. H. (1981) The New England Batholith, eastern Australia: geochemical variations in time and space. *Journal of Geophysical Research*, **86**, B11, 10530–10544.

SHCHERBA, G. N. (1970) Greisens. *International Geology Review,* **12**, 114–151 and 239–254.

SHERIDAN, D. M., TAYLOR, R. B., and MARSH, S. P. (1968) Rutile and topaz in Precambrian gneiss, Jefferson and Clear Creek Counties, Colorado. *U.S. Geological Survey Circular* **567**, 7 p.

SILLITOE, R. H. (1974) Tin mineralization above mantle hot spots. *Nature*, **248**, 497–499.

SILLITOE, R. H. (1981) Ore deposits in Cordilleran and island-arc settings. *Arizona Geological Society Digest*, **14**, 49–70.

SIMONI, A., and MIKKOLA, A. (1980) Finland. *In* Geology of the European countries, vol. 2, *Comité National Français de Géologié*, 26th International Geological Congress, Graham and Trotman, 55–108.

SIMONOVA, L. N., OMEL'YANENKO, B. I., MAKSIMOVA, I. G., SIROTININA, N. A., and SVEZHOV, V. A. (1985) The behavior of uranium during the formation of syngenetic pegmatites. *International Geology Review*, **27** (2), 202–207.

SINKANKAS, J. (1959) *Gemstones of North America,* vol. 1. Van Nostrand Reinhold Co., New York, 675 p.

SINKANKAS, J. (1964) *Mineralogy for Amateurs*. Van Nostrand Reinhold Co., New York, 585 p.

SINKANKAS, J. (1976) *Gemstones of North America,* vol. 2. Nostrand Reinhold Co., New York, New York, 494 p.

SINKANKAS, J. (1981) *Emerald and Other Beryls*. Chilton Book Co., Radnor, Pennsylvania, 665 p.

SKJERLIE, K. J., and JOHNSTON, A. D. (1992) Vapor-absent melting of a biotite- and amphibole-bearing tonalite gneiss: implications for generation of A-type granites. *Geology*, **20**, 263–266.

SOUZA, R. A., WILSON, W. E., GANGWERE, R. J., WHITE, J. S., and KING, J. E. (1990) Minerals of the Carnegie Museum of Natural History. Special Supplement to *Mineralogical Record*, **21** [photograph, p. 24].

ŠTEMPROK, M. (1990) Intrusion sequences within ore-bearing granitoid plutons. *Geological Journal,* **25** (3 & 4), 413–417.

STEPHENS, W. E., and HALLIDAY, A. N. (1984) Geochemical contrasts between late Caledonian granitoid plutons of northern, central and southern Scotland. *Transactions of the Royal Society of Edinburgh, Earth Sciences,* **75**, 259–273.

STERN, L. A., BROWN, G. E., Jr., BIRD, D. K., JAHNS, R. H., FOORD, E. E., SHIGLEY, J. E., and SPAULDING, L. B. Jr. (1986) Mineralogy and geochemical evolution of the Little Three pegmatite-aplite layered intrusive, Ramona, California. *American Mineralogist,* **71**, 406–427.

STOBBE, J. (1982) Mongolian minerals found. Letter to *Mineralogical Record*, **13**, 179.

STRECKEISEN, A. (1976) To each plutonic rock its proper name. *Earth Science Reviews*, **12** (12), 1–33.

STRONG, D. F. (1985) A review and model of granite-related mineral deposits. *In* Taylor, R. P., and Strong, D. F., eds., Recent advances in the geology of granite-related mineral deposits. *Canadian Institute of Mining and Metallurgy Special Volume* **39**, 424–445.

SYKES. M. L., and MOODY, J. B. (1978) Pyrophyllite and metamorphism in the Carolina slate belt. *American Mineralogist*, **63**, 96–108.

TAYLOR, R. G. (1979) *Geology of Tin Deposits*. Elsevier, New York, 543 p.

TAYLOR, R. P (1992) Petrological and geochemical characteristics of the Pleasant Ridge zinnwaldite–topaz granite, southern New Brunswick, and comparison with other topaz-bearing felsic rocks. *Canadian Mineralogist, Granitic pegmatites, Special Issue* **30**, (3), 895–921.

TISCHENDORF, G., and FÖRSTER, H.-J. (1990) Acid magmatism and related metallogenesis in the Erzgebirge. *Geological Journal*, **25** (3 & 4), 443–454.

TODD, V. R., and SHAW, S. E. (1985) S-type granitoids and an I-S line in the Peninsula Ranges Batholith, southern California. *Geology*, **13**, 231–233.

TOMSON, I. N., and KRAVTSOV, V. S. (1978) Concentric metallogenic zones and their connection with arched uplifts in the east of the U.S.S.R.; problems and methods of investigation. *In* Global tectonics and metallogeny, *Laboratory of Global Tectonics and Metallogeny*, **1** (1), 42–53.

TSARYEVA, G. M., NAUMOV, V. B., KOVALENKO, V. I., TSEPIN, A. I., and ANDREEVA, I. A. (1992) Composition of pegmatite melt and its mineral crystallites (based on melt inclusion data for topaz from Voln chambered pegmatites) (abs.). *Lepidolite 200 Symposium*, Nové Město na Moravě, Czechoslovakia (August/September 1992), 73–74.

VAN ALSTINE, R. E. (1976) Continental rifts and lineaments associated with major fluorspar districts. *Economic Geology*, **71**, 977–987.

VON KNORRING, O. V. (1970) Mineralogical and geochemical aspects of pegmatites from orogenic belts of equatorial and southern Africa. *In* Clifford, T. N., and Gass, I. G., *African Magmatism and Tectonics*. Oliver and Boyd, Edinburgh, 461 p.

VON KNORRING, O., and CONDLIFFE, E. (1987) Mineralized pegmatites in Africa. *Geological Journal*, **22**, TI, 253–270.

WEIDNER, J. R., and MARTIN, R. F. (1987) Phase equilibria of a fluorine-rich leucogranite from the St. Austell pluton, Cornwall. *Geochimica et Cosmochimica Acta*, **51**, 1591–1597.

WERNICKE, B. P., CHRISTIANSEN, R. L., ENGLAND, P. C., and SONDER, L. J. (1987) Tectonomagmatic evolution of Cenozoic extension in the North American Cordillera. *In* Coward, M. P., Dewey, J. F., and Hancock, P. L., eds., Continental extensional tectonics. *Geological Society of London Special Publication* **28**, 203–222.

WERNICKE, E. (1979) O magmatismo granitoide das regioes de dobramento nordests e sudeste (Ciclo Brasiliano) do Brasil. *Transactions of the Fourth Latin American Geological Conference*, publ. in 1985, **1**, 424–439, (in Portugese, abstract in English).

WHITE, W. H., BOOKSTROM, A. A., KAMILLI, R. J., GANSTER, M. W., SMITH, R. P., RANTA, D. E., and STEININGER, R. C. (1981) Character and origin of Climax-type molybdenite deposits. *Economic Geology*, **75**th Anniv. Vol., 270–316.

WHITNEY, J. A. (1988) The origin of granite: the role and source of water in the evolution of granitic magmas. *Geological Society of America Bulletin*, **100**, 1886–1897.

WILSON, W. E. (1986) Durangite from Utah. *Mineralogical Record*, **17**, 342.

WILSON, W. E. (1987) What's new in minerals? *Mineralogical Record*, **18**, 243–244.

WILSON, W. E. (1989a) The Anjanabonoina pegmatite, Madagascar. *Mineralogical Record*, **20**, 197.

WILSON, W. E. (1989b) What's new in minerals? *Mineralogical Record*, **20**, 388, 396.

XU KEQIN and ZHU JINCHU (1986) Tin/tungsten-bearing granites in South China and their metallogenic relations. GEOSEA V Proceedings, vol. II, *Geological Society of Malaysia Bulletin* **20**, 579–599.

YIN LIN, ZHU JINCHU, and HU SHOUXI (1993) Multiple-staged granite evolution and Ta-Nb mineralization in South China. *Journal of Southeast Asian Earth Sciences*, **8**, 1–4, 321–328.

ZEITLER, P. K., SUTTER, J. F., WILLIAMS, I. S., ZARTMAN, R., and TAHIRKHELI, R. A. K. (1989) Geochronology and temperature history of the Nanga Parbat-Haramosh Massif, Pakistan. *In* Malinconico, L. L., Jr., and Lillie, R. J., eds., Tectonics of the western Himalayas. *Geological Society of America Special Paper* **232**, 1–22.

THE MUSEUM DIRECTORY

Geology and Meteorite Museums University of New Mexico
Curators:
Gary Smith (Geology)
Adrian Brearley (Meteorites)
Tel: (505) 277-4204
Dept. of Earth & Planetary Sciences
Northrop Hall
Univ. of New Mexico
Albuquerque, NM 87131
Hours: 9–4 M–F (closed on school holidays)
Specialties: Worldwide minerals and meteorites, New Mexico fossils, Harding Pegmatite Mine Collection

Museum of Geological Sciences, V.P.I.
Curator: Dr. Susan C. Eriksson
Tel: (703) 231-6029
2062 Derring Hall
Virginia Polytechnic Inst. & State University
Blacksburg, VA 24061-0420
Hours: 8–4 M–F, 10–2 Sat.
Specialty: Virginia and worldwide minerals & fossils

Montana Tech Mineral Museum
Curator: Richard Berg
Adjunct Curator:
Lester G. Zeihen
Tel: (406) 496-4414
c/o Montana Tech
Butte, MT 59701-9981
Hours: 8–5 daily June–Labor Day; M–F & Sun afternoons Labor Day–May
Specialties: Montana & Idaho minerals; systematics

Glenbow Museum
Executive Director:
Dr. Robert Janes
Tel: (403) 268-4100
Fax: (403) 265-9769
Glenbow Alberta Institute
130 Ninth Avenue S.E.
Calgary, Alberta
Canada T2G 0P3
Hours: 10–6 Tues–Sun
Specialties: W. Canadian and worldwide minerals & gems

Harvard Mineralogical Museum
Curators:
Dr. Carl A. Francis
William Metropolis
Tel: (617) 495-4758
24 Oxford Street
Cambridge, Mass. 02138
Hours: 9–4:30 M–Sat; 1–4:30 Sun
Specialties: Systematic Mineral Collection

William Weinman Mineral Museum
Curator: Kim B. Cochran
Tel: (404) 386-0576
P.O. Box 1255
Cartersville, GA 30120
Hours: 10–4:30 Tue–Sat, 2–4:30 Sun.
Specialty: Georgia & worldwide minerals & fossils

Denver Museum of Natural History
Curator of Geology:
Jack A. Murphy
Tel: (303) 370-6445
Dept. of Earth Sciences
20001 Colorado Blvd.
Denver, CO 80205
Hours: 9–5 daily
Specialties: Colorado minerals

Geology Museum Colorado School of Mines
Curator: Virginia A. Mast
Tel: (303) 273-3823
Golden, Colorado 80401
Hours: 9–4 M–Sat, 1–4 Sun. (closed on school holidays & Sundays in the summer)
Specialties: Worldwide minerals; Colorado mining & minerals

A. E. Seaman Mineralogical Museum
Curator (mineralogy):
Stanley J. Dyl II
Adjunct Curator:
Dr. John A. Jaszczak
Tel: (906) 487-2572
Michigan Technological Univ.
Houghton, Michigan 49931
Hours: 9–4:30 M–F
Specialty: Michigan minerals, copper minerals & worldwide minerals

Houston Museum of Natural Science
Curator (mineralogy):
Joel Bartsch
Tel: (713) 639-4673
Fax: (713) 523-4125
1 Hermann Circle Drive
Houston, Texas 77030
Hours: 9–6 M–Sat; 12–6 Sun
Specialty: Finest or near-finest known specimens

Grandfather Mountain Nature Museum
Curator: Jack Hanahan
Tel: (704) 825-2125
(704) 675-4879
Manager: Winston Church
Tel: (704) 733-1059
P.O. Box 129
Linville, NC 28646
Hours: 8–5 daily (winter) 8–6 daily (summer)
Specialties: No. Carolina minerals, birds, wildflowers, mushrooms, animals

Museums listed alphabetically by city

THE MUSEUM DIRECTORY

Natural History Museum of Los Angeles County
Curator (mineralogy):
Dr. Anthony R. Kampf
Tel: (213) 744-3328
900 Exposition Blvd.
Los Angeles, CA 90007
Hours: 10–4:45 Tu–Sun.
Specialties: Calif. & worldwide minerals, gold, gem crystals, colored gemstones
Support organization:
The Gem and Mineral Council

Sterling Hill Mining Museum
Curators: Robert Hauck
Richard Hauck
Tel: (201) 209-7212
30 Plant Street
Ogdensburg, NJ 07439
Hours: 10–5 M–Sun, Mar.–Dec.
Specialty: Local mining & minerals

Carnegie Museum of Natural History
Collection Manager:
Marc L. Wilson
Tel: (412) 622-3391
4400 Forbes Avenue
Pittsburgh, PA 15213
Hours: 10–5 Tues–Sat,
10–9 F, 1–5 Sun,
closed Mon. & holidays
Specialty: Worldwide minerals & gems

Musée de géologie de l'Universite Laval
Curator: André Lévesque
Tel: (418) 656-2193
Geology Dept., 4th floor
Adrien-Pouliot Building
Québec, Que., Canada G1K 7P4
Hours: 8:30–5 M–F
Specialties: Quebec and worldwide minerals and fossils; Miguasha fishes

Museum of Geology
Director: Philip R. Bjork
Tel: (605) 394-2467
South Dakota School of Mines & Technology
501 E. St. Joseph Street
Rapid City, SD 57701-3995
Hours: 8–5 M–F, 9–4 Sat., 1–4 Sun.
Specialty: Black Hills minerals, esp. pegmatites

Penn State Earth & Mineral Sciences Museum
Curator: Andrew Sicree
Tel: (814) 865-6427
Steidle Building
University Park
State College, PA 16802
Hours: 9–5 M–F & by Appt.
(closed holidays)
Specialties: Mineral properties exhibits; "velvet" malachite; old Penna. minerals; mining art

M.Y. Williams Geological Museum
Curator: Joe Nagel
Tel: (604) 822-5586
University of British Columbia
6339 Stores Road
Vancouver, B.C.,
Canada V6T 1Z4
Hours: 8:30–4:30 M–F
1:30–4:30 W (Collector Shop)
Specialty: B.C., Pacific NW, Canada; Exhibit Quality

Marshall Mint & Museum
Curator: Hugh Roy Marshall
Tel: (702) 847-0777
Fax: (702) 847-9543
P.O. Box 447 (96 N. C St.)
Virginia City, NV 89440
Hours: 9–5 seven days
Specialties: Nevada precious metals specimens

Private Museums

Hampel Mineralogical Museum
Curator: Lance T. Hampel
Tel: (414) 255-4540
P.O. Box 39
Germantown, WI 53022
Hours: by Appt.
Specialty: Midwest minerals

Museo Mineralógico M. Romero
Director: Miguel Romero
Tel: (238) 3-00-07
Fax: (238) 3-35-02
7 Norte #356
Tehuacán Puebla, México 75700
Hours: 10–12 noon M–Sat
4–6 p.m. M–F & by Appt.
Specialty: Mexican Minerals

Europe

Setesdal Mineral Park
Curator: Ole Fritjof Frigstad
Arnar Hansson
Tel: (011) 47-37-93-13-10
Fax: (011) 47-38-19-90-10
N-4670 **Hornnes, Norway**
Open May–October
Specialties: Minerals and mining equipment from Evje and Iveland; Norwegian minerals

Giazotto Mineralogical Museum
Curator: Adalberto Giazotto
Tel: 39-50-501587
Lungarno Gambacorti 39
Pisa, Italy
Hours: by Appointment
Specialty: Italian and Worldwide minerals

Additional listings welcome!
Send vital information, as shown, to the editor. There is a modest annual fee (lower than our regular advertising rates).

Colorado Dealers

David Bunk Minerals
David Bunk
9240 W. 49th Street, #317
Wheat Ridge, CO 80033
303-421-3646 (by appointment)
Colorado & Worldwide Specimens

Collector's Stope
Jim & Patti McGlasson
7387 S. Flower Street
Littleton, CO 80123
303-972-0376
Fine Minerals, Species, Micromounts

Columbine Mineral Shop
Benjy & Liz Kuehling
P.O. Box 541
633 Main Street
Ouray, CO 81427
303-325-4345, 9 a.m. to 9 p.m.
Open 7 days, May 1-Oct. 31
Off-season by Appointment
Fine Minerals for Collectors

Genesis Epoch
Mel & Pam Bersch
2417 Sandridge Court
Grand Junction, CO 81503
303-242-3134 (call for appt.)
Tsumeb Minerals, Western Colo.
Fluorite/Amethyst & Fossils

Glacier Peak Gems & Minerals
Joseph & Susan Dorris
P.O. Box 413
Manitou Springs, CO 80829-0413
719-685-4479
By appointment only.
Our mines produce choice
Colorado minerals.
Worldwide minerals.

Green Mountain Minerals
Stanley Korzeb
13812 W. Dakota Avenue
Lakewood, CO 80228
303-988-2642 (Call for Appt.)
Species, Fine Minerals, write for List

Bill Hayward Minerals
Bill & Christopher Hayward
3286 Quitman Street
Denver, CO 80212
303-455-1977 (Call for Appt.)
Colorado & Pikes Peak Minerals

COLORADO MINERAL AND FOSSIL SHOW
WED.–SUN.
SEPT. 13-17, 1995
Holiday Inn Denver North
(where I-25 meets I-70, exit 214C)
10 a.m. to 7 p.m. Daily
Be sure to attend the Museum Benefit Auction, Wed. 5 pm
Shuttle Bus to Main Show
220 Top-Quality Dealers
INFO: P.O. Box 999 • Evergreen, CO 80439

Irish Rovers
John & Gerry Shannon
7319 W. Cedar Circle
Lakewood, CO 80226
By Appt. Only: 303-232-1534
Items unique and antique for
the mining & mineral collector

Keystone Minerals
Don E. Knowles
13030 West 6th Place
Golden, CO 80401
303-233-4188
Largest Comprehensive Stock in
Colorado

L & T Creations
Lee A. McKinney
1800 Winfield Drive
Lakewood, CO 80215
By Appt. Only 303-232-6451
Colorado Amazonite

LJP—Colorado
Larry & Carmen Piekenbrock
1180 York Avenue
Cañon City, CO 81212
719-599-9420 (by Appt. only)
Colorado & Western Minerals

Mountain Minerals International
Dudley Blauwet
P.O. Box 302
Louisville, CO 80027-0302
303-665-0672, Buy/Sell/Trade
Minerals, Gems, Gem Rough

Red & Green Minerals, Inc.
Denzil Wiggins
7595 W. Florida Avenue
Lakewood, CO 80227
303-985-5559
Custom Jewelry, fine mineral
specimens, lapidary & jewelers'
tools & supplies

The Sunnywood Collection
Bill & Elsie Stone
12068 E. Amherst Place
Aurora, CO 80014
303-368-7497 (by Appt. only)
Fine Minerals & Fossils,
Mounted on Exotic Hardwoods
Custom mounting available

PINK TOPAZ

FROM THE THOMAS RANGE, JUAB COUNTY, UTAH

Eugene E. Foord
M.S. 905
U.S. Geological Survey
Box 25046, Denver Federal Center
Denver, Colorado 80225

William Chirnside
M.S. 518
U.S. Geological Survey
Box 25046 Denver Federal Center
Denver, Colorado 80225

Frederick E. Lichte
M.S. 973
U.S. Geological Survey
Box 25046 Denver Federal Center
Denver, Colorado 80225

Paul H. Briggs
M.S. 973
U.S. Geological Survey
Box 25046 Denver Federal Center
Denver, Colorado 80225

INTRODUCTION

The Thomas Range is world-famous for its production of topaz $Al_2SiO_4(F,OH)_2$, occurring in lithophysal cavities in rhyolite. Topaz Valley, at the southern end of the range, is perhaps the single most famous locality. While fine-quality, sherry-orange crystals to 5 cm or more in length occur at various localities, pale to medium pink crystals were first reported from the Thomas Range in 1934. The cause of the unusual coloration, unknown for 60 years, is now believed to be substitution of $Mn^{3+} \pm Fe^{3+}$ for Al^{3+}.

GEOLOGY and MINERALOGY

The geology, petrography and structure of the Thomas Range has been summarized by Lindsey (1982). Volcanism, faulting and mineralization in the range began about 42 million years ago. Three main stages of volcanic activity and mineralization have been identified. Topaz, both sherry and pink varieties, is associated with the youngest stage of volcanism. Alkali rhyolite volcanism deposited beryllium-rich tuff and porphyritic rhyolite members of the Spor Mountain Formation about 21 million years ago. After a period of block faulting, stratified tuff and alkali rhyolite of the Topaz Mountain Rhyolite were erupted 6–7 million years ago along faults and fault intersections. This activity was accompanied by lithophile metal mineralization that deposited F-rich minerals (e.g. topaz), beryllium and uranium. The Topaz Mountain Rhyolite consists of sequences of lithologies that are repeated several times in vertical sections; the sequence is: stratified tuff, breccia, vitrophyre, and flow-layered rhyolite (Staatz and Carr, 1964).

The mineralogy of the Thomas Range, emphasizing collectable minerals, has been summarized by Holfert (1977), Ream (1979), Henderson (1985) and Schuhbauer (1988). Table 1 lists the minerals (with their abundances), known to occur in the Topaz Mountain Rhyolite, and Figure 1 shows locations of known occurrences of topaz, pink topaz, bixbyite, pseudobrookite and durangite. Several mineral species have not been reported before, including niobian rutile and a new U-Ti-Ca-HREE hydrated oxide mineral (Foord *et al.*, 1995). The distinctive composition of the rhyolite, and the anomalous concentrations of F, Be, Li, Nb, U, Th and Y, have been noted often (Staatz and Griffitts, 1961; Shawe, 1966; Christiansen *et al.*, 1984). The mineralogical residence of these elements remains incompletely known. Mineralogical studies by Foord *et al.* (1985, 1995) have further defined the residence of the elements: i.e. uranoan thorite (U,Th), niobian rutile and pseudobrookite (Nb,Ta), and a new U-Ti-Ca-HREE hydrated oxide mineral (U, HREE).

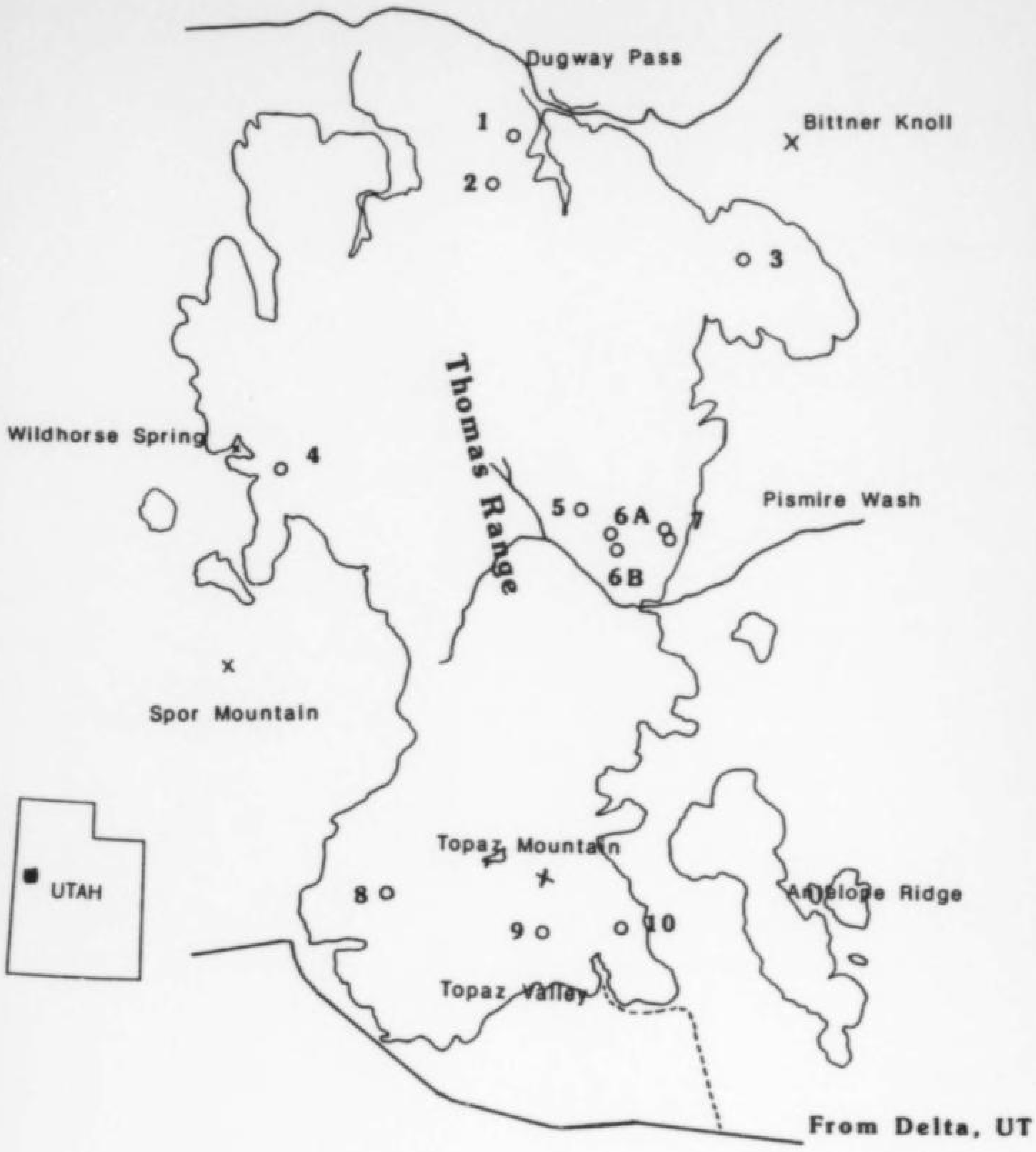


Figure 1. **Location map of known occurrences of collectable quality topaz (T), pink topaz (PT), bixbyite (B), pseudobrookite (P), red beryl (RB), and durangite (D) within the Topaz Mountain Rhyolite (outlined) in the Thomas Range, Juab County, Utah. Locality 1—B, P, T; Locality 2—Cubic Claim, B, P, PT; Locality 3—D; Locality 4—Wildhorse Spring, RB; Locality 5—RB; Locality 6A—Maynard Pit, B, P, T; Locality 6B—Bixbyite type locality, B, P, RB, T; Locality 7—Mile-Hi No. 1 claim, PT, P, B; Locality 8—RB (tabular); Locality 9—Red Beryl Pit, RB, T, P, new U-Ti mineral species; Locality 10—White and yellow needles of new mineral species (Foord *et al.*, 1995).**

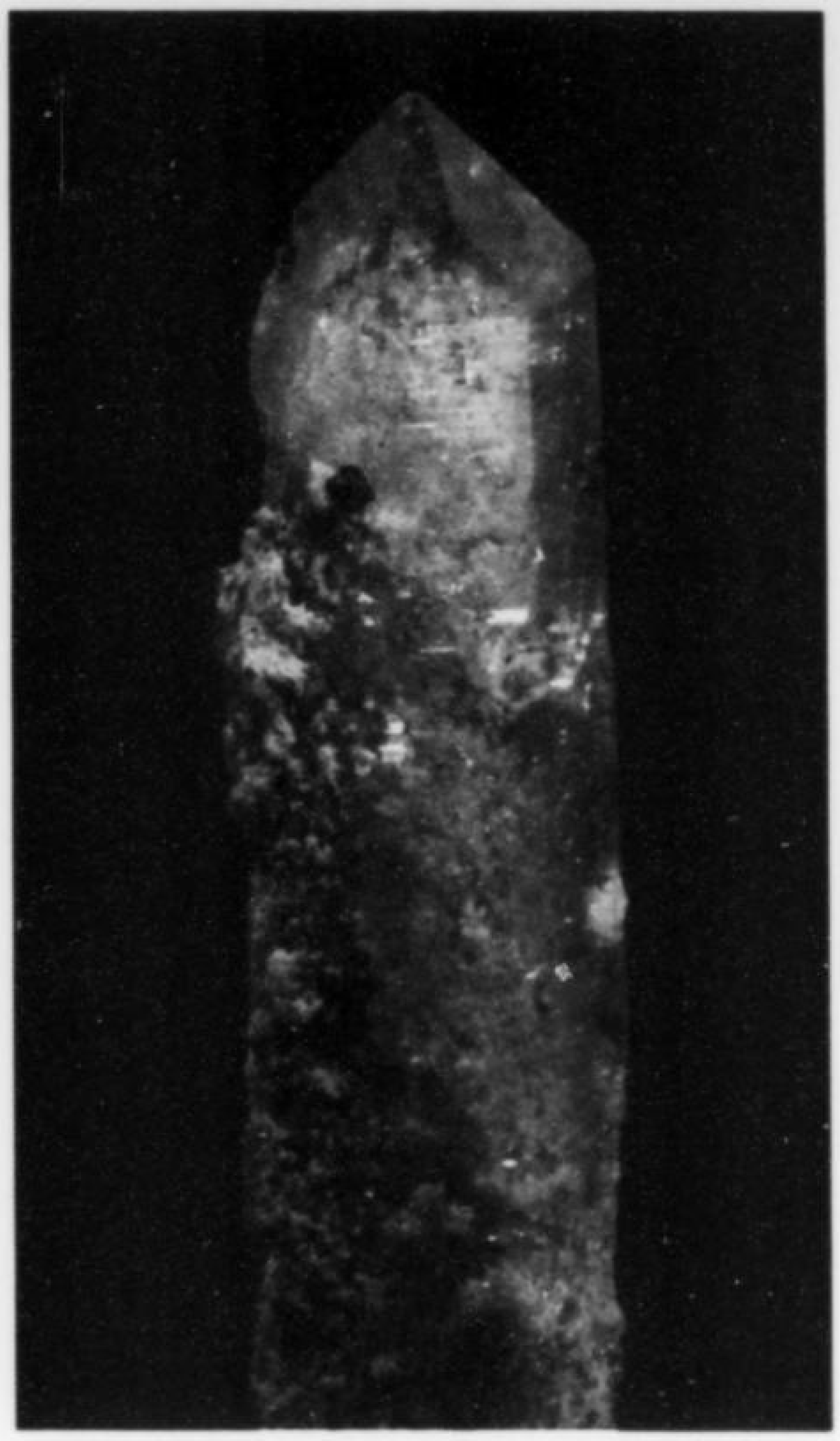


Figure 2. **A crystal of pink topaz from the Mile High Claim (location 7, Fig. 1). Length of the crystal is 2.6 cm.**

Topaz from the Thomas Range is extremely fluorine-rich, containing almost no water (<0.2 wt. % H_2O). It is also characterized by elevated levels of Li (50–80 ppm; Hervig *et al.*, 1987; Foord *et al.*, 1990, 1991) relative to topaz from other geologic environments.

The northern end of the Thomas Range is most famous for bixbyite (the type locality is near Pismire Wash; locality 6B, Fig. 1). More recently, fine crystals of durangite (Fig. 1, locality 3) and associated cassiterite have been found as well (Wilson, 1986). Pink topaz was reported from the northern end of the range (Montgomery, 1934). For approximately 40 years, the exact locality was lost to all but Arthur Montgomery. For the past 25 years or so, pale to medium pink crystals of topaz have been produced from the same general area as the durangite (Ream, 1979).

The pink topaz is found only as float crystals (and therefore has been exposed to sunlight). The occurrence is sporadic and appears to be structurally controlled by late-stage ring fractures and random fractures within the rhyolite host. As described by Montgomery (1934) and Ream (1979), the majority of the crystals (known as "sand crystals") are opaque because of quartz and feldspar inclusions, except on the edges. The crystals, as much as 4 cm in length, show a distinct pink coloration. Some crystals show a more or less uniform pink to pinkish red color, are transparent, and are of gem-quality. Such crystals are smaller and are up to 2 cm in length. Crystals of topaz contained within unopened lithophysal cavities have a yellow-orange sherry color that fades to colorless upon exposure to sunlight. Crystals typically fade to colorless in a matter of days to a week or two depending upon the air temperature, amount, and intensity of light. Heating causes the color to fade rapidly. Some crystals, however, do not completely fade to colorless but reveal an outer zone that is distinctly pink to reddish pink in color. These crystals are distinctly color-zoned and, upon close examination, are seen to have colorless cores and a distinctly medium pink to reddish pink to pinkish red zone near the outer portions (rims). Final growth was of colorless material. Figure 2 shows one of these color-zoned crystals. The pinkish red zone is masked by the initial yellow-orange sherry color. Once the sherry coloration is removed (by exposure to light and/or heat), the pink-red coloration then becomes very noticeable. The pink-red color is stable to light and heat. A transparent pink crystal, formerly amber-colored, with the termination cleaved off, remains *in situ* on the rhyolite surface exposed to direct light; and sand crystals have been found with lichens growing on them indicating many years of surface exposure. The color persists up to the decomposition temperature of topaz (>700°C).

Because the pink to reddish color is stable to a high temperature, we suspected that the color was due to the presence of a trace element(s). Montgomery (1934) believed that the color might be due to the presence of titanium because of the intimate association with pseudobrookite. Bulk chemical analysis by ICP-AES methods using gem-quality, completely colorless crystals and crystals having a distinct pink-red outer zone gave:

	Colorless	Pink
Mn	<8 ppm	20 ppm
Cr	17 ppm	11 ppm
Li	63 ppm	74 ppm
Pb	19 ppm	26 ppm
Fe	0.05%	0.08%

All other trace and minor elements were not detected at their respective limits of detection. By volume, the pink-red colored zone occupies less than 10% of the crystal, probably about 5%. If all of the Fe and Mn were concentrated in the colored zone, then, the actual values would be about 400 ppm Mn and 1.6 wt. % Fe. Cr is not believed to be a chromophore in this case because there was less Cr in the pink crystal than in the colorless crystal. Some or all of the Cr may have come from the chrome steel mortar initially used to crush the topaz crystals before final grinding. Cr is extremely low or absent in the rocks and minerals of the Thomas Range. Chemical analysis by laser-ablation ICP-MS of individual spots within a color-zoned crystal (Fig. 3), showed Mn to be clearly concentrated in the pink-red zone: MnO (0.65 wt. %) and Fe_2O_3 (0.35 wt. %). Cr, V, Co or other possible chromophores were *not* detected. Mn^{2+} is not a chromophore, but Mn^{3+} is a strong chromophore. Fe^{3+} is also a chromophore. Trivalent Mn and Fe are likely substituting for the octahedral Al in the topaz structure.

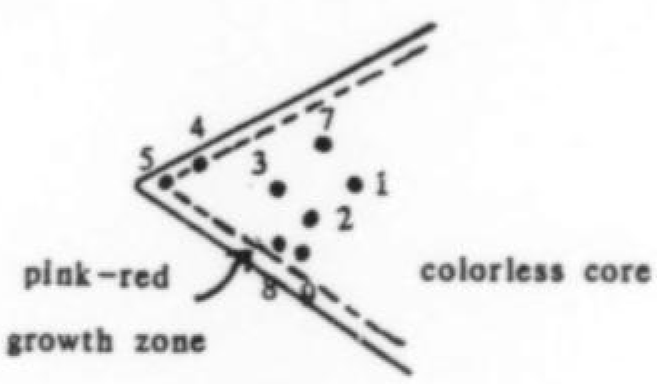


Figure 3. **Sketch of basal section of a zoned pink topaz showing location of points used for LA-ICP-MS analyses. Values for MnO (wt. %) are as follows: 1, 0.018; 2, 0.022; 3, 0.014; 4, 0.064; 5, 0.069; 7, 0.028; 8, 0.014; 9, 0.009.**

Pink-red topaz reported from other world localities (e.g. Ouro Preto, and Brumado, Minas Gerais, Brazil; southern Ural mountains (Sanarka River), Russia; and Katlang, NWFP, Pakistan) are colored by as much as 3000 ppm Cr. The Cr, as Cr^{3+}, substitutes for Al in the topaz structure. Such crystals are all from hydrothermal environments, and are associated with mafic or ultramafic Cr-bearing rocks. As far as we are aware, this report marks the first documented occurrence of pink-red topaz that is colored by Mn ± Fe.

ACKNOWLEDGMENTS

We wish to thank Daniel R. Shawe, Peter J. Modreski and Richard C. Erd of the USGS for their reviews of the manuscript.

Table 1. **Minerals identified from the Topaz Mountain Rhyolite.**

Rock-forming minerals (phenocrysts and groundmass minerals) include: sanidine, quartz, sodic plagioclase ± biotite ± Fe-rich hornblende ± titanite. Titanomagnetite is present as microphenocrysts in most samples. Magmatic accessory minerals include apatite, fluorite, zircon and allanite (Christiansen *et al.*, 1984).

Minerals occurring along fractures, in lithophysal cavities and within the groundmass of the rhyolite include:

Mineral	**Formula**	**Abundance**
Almandine-spessartine	$(Fe^{2+}Mn^{2+})_3Al_2(SiO_4)_3$	locally abundant
Beryl (pink to red)	$Be_3Al_2Si_6O_{18}$	rare
Bixbyite	$(Mn^{3+},Fe^{3+})_2O_3$	locally abundant
Calcite	$CaCO_3$	locally abundant
Cassiterite	SnO_2	locally abundant
Durangite	$NaAl(AsO_4)F$	locally abundant
Fluorite	CaF_2	locally abundant
Hematite	Fe_2O_3	common
Pseudobrookite	$(Fe^{3+},Fe^{2+})_2(Ti,Fe^{3+})O_6$	locally abundant
New U-Ti-Ca-HREE hydrated oxide (See Foord *et al.*, 1995)		rare
Quartz (incl. opal, chalcedony, agate)	SiO_2	common
Rutile (niobian) (See Foord *et al.*, 1995)	TiO_2	rare
Sanidine	$(K,Na)(Si,Al)_4O_8$	common
Thorite (U-free, yellow)	$ThSiO_4$	rare
Thorite (uranoan, green) (See Foord *et al.*, 1985)	$(Th,U)SiO_4$	rare
Topaz	$Al_2SiO_4(F,OH)_2$	locally abundant
Zircon (very pale yellow to colorless)	$ZrSiO_4$	rare

REFERENCES

CHRISTIANSEN, E. H., BIKUN, J. V., SHERIDAN, M. F., and BURT, D. M. (1984) Geochemical evolution of topaz rhyolites from the Thomas Range and Spor Mountain, Utah. *American Mineralogist*, **69**, 223–236.

FOORD, E. E., COBBAN, R. R., and BROWNFIELD, I. K. (1985) Uranoan thorite in lithophysal rhyolite—Topaz Mountain, Utah, U.S.A. *Mineralogical Magazine*, **49**, 729–731.

FOORD, E. E., JACKSON, L. L., TAGGART, J. E., CROCK, J. G., and KING, T. V. V. (1990) Environment of crystallization of topaz as inferred from crystal chemistry and infrared spectra [abs.]. *15th General meeting of the International Mineralogical Association, Beijing, PRC*, **1**, 306–307.

FOORD, E. E., JACKSON, L. L., TAGGART, J. E., FITZPATRICK, J. J., CROCK, J. G., and KING, T. V. V. (1991) Topaz: Environments of crystallization, crystal chemistry, cell data and infrared spectra [abs.]. *GACMAC joint annual meeting, Toronto, Ont., May 27–29, 1991, Program with abstracts*, p. A38.

FOORD, E. E., CHIRNSIDE, W., DAVIS, A. M., LICHTE, F. E., and ESPOSITO, K. G. (1995) A new Ti-U-Ca-HREE hydrated oxide mineral and associated niobian rutile from Topaz Valley, Juab County, Utah. *Mineralogical Record* (in press).

HENDERSON, W. A., Jr. (1985) Microminerals of the western volcanics. *Mineralogical Record*, **16**, 137–145.

HERVIG, R. L., KORTEMEIER, W. T., and BURT, D. M. (1987) Ion-microprobe analyses of Li and B in topaz from different environments. *American Mineralogist*, **72**, 392–396.

HOLFERT, J. (1977). *A Field Guide to Topaz and Associated Minerals of Topaz Mountain, Utah.* The Diamond Gallery, Provo, UT. 49 pp.

LINDSEY, D. A. (1982) Tertiary volcanic rocks and uranium in the Thomas Range and Northern Drum Mountains, Juab County, Utah.

U.S. Geological Survey Professional Paper **1221**, 71 pp.

MONTGOMERY, A. (1934) A recent find of bixbyite and associated minerals in the Thomas Range, Utah. *American Mineralogist*, **19**, 82–87.

REAM, L. R. (1979) The Thomas Range, Wah Wah Mountains, and vicinity, western Utah. *Mineralogical Record*, **10**, 261–278.

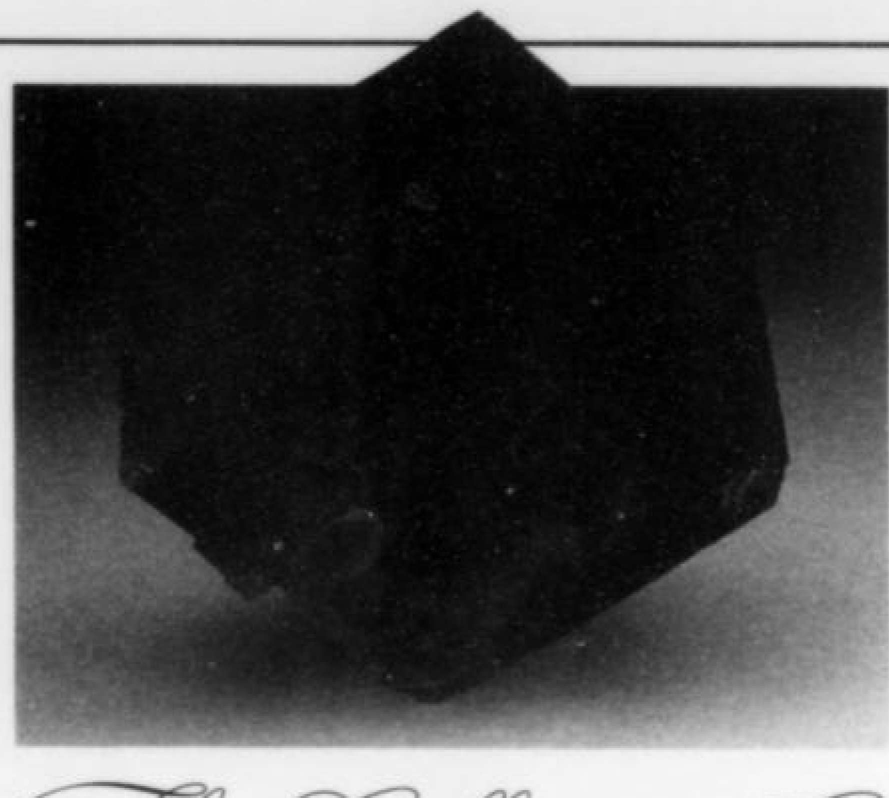
SCHUHBAUER, ERWIN (1988) Mineraliensuche in Nevada und Utah. *Lapis*, **13**, 11–27.

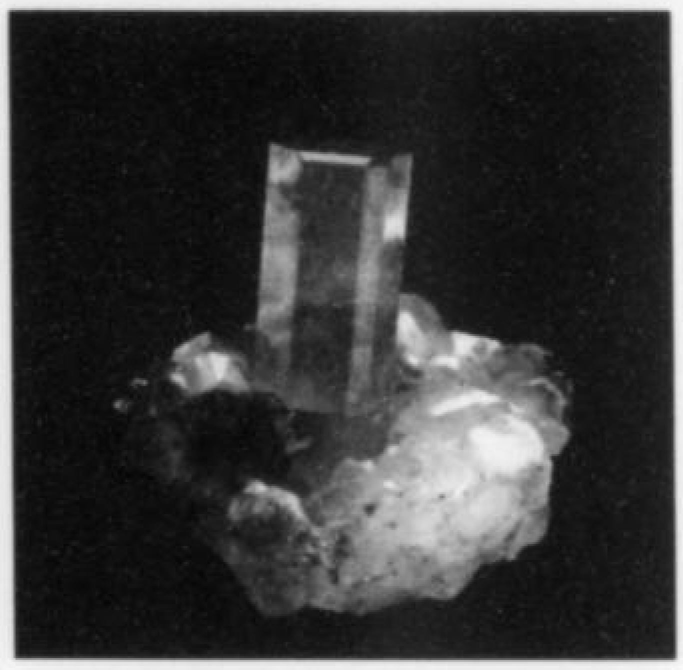
SHAWE, D. R. (1966) Arizona-New Mexico and Nevada-Utah beryllium belts, *in* Geological Survey Research, 1964: *U.S. Geological Survey Professional Paper* **550-C**, 206–213.

STAATZ, M. H., and CARR, W. J., (1964) Geology and mineral deposits of the Thomas and Dugway Ranges Juab and Tooele Counties Utah. *U.S. Geological Survey Professional Paper* **415**, 188 p.

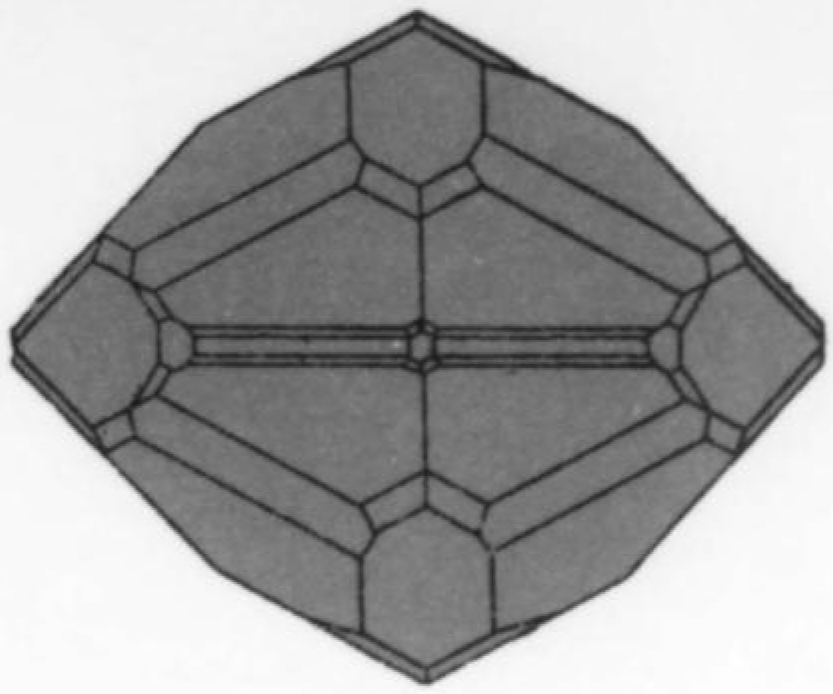
STAATZ, M. H., and GRIFFITTS, W. R. (1961) Beryllium-bearing tuff in the Thomas Range, Juab County, Utah. *Economic Geology*, **56**, 946–950.

WILSON, W. E. (1986) Durangite from Utah. *Mineralogical Record*, **17**, 342.





Topaz, Dusso, Gilgit, Pakistan



FM-TGMS-MSA
Symposium on Topaz

16TH ANNUAL MINERALOGICAL SYMPOSIUM

Sponsored by the Friends of Mineralogy, the Tucson Gem & Mineral Society, and the Mineralogical Society of America.

10:00 A.M. to 3:20 P.M.
Saturday, February 11, 1995
Tucson Convention Center

PROGRAM:

Introductory Remarks:
Beau Gordon, Symposium Co-Chairman
Robert Cook, Symposium Co-Chairman

10:00 am — The Occurrence of Topaz in Northern New England Pegmatites
Carl A. Francis and Lawrence C. Pitman

10:20 am — The Occurrence of Topaz in the Southeastern United States
Robert B. Cook

10:40 am — Colorado Topaz
Peter J. Modreski and Thomas C. Michalski

11:00 am — Notes on the Occurrence of Topaz in Idaho
Lanny R. Ream

11:20 am — Topaz from the Sawtooth Batholith, Idaho
Michael A. Menzies

11:40 am — Occurrences of Blue Topaz in the Pegmatites of the Peninsular Batholith, San Diego County, California
Jesse Fisher

12:00 - 1:00 LUNCH BREAK

1:00 pm — Pink Topaz from the Thomas Range, Juab County, Utah
E. E. Foord, W. Chirnside, F. E. Lichte, and P. H. Briggs

1:20 pm — Topaz Rhyolites in Arizona and the Southwest
Donald M. Burt

1:40 pm — Topaz and Beryl-bearing Gem Pegmatites of the Alabashka–Mursinka–Adui district, Ural Mountains, Russia
Peter Lyckberg

2:00 pm — Geology and Occurrence of Well-crystallized Topaz
Michael A. Menzies

2:20 pm — Where's the Proton? Symmetry and Structure Variations in Topaz
Paul H. Ribbe and Susan C. Eriksson

2:40 pm — Topaz: Environments of Crystallization, Crystal Chemistry, and Infrared Spectra
E. E. Foord, L. L. Jackson, J. E. Taggart, J. G. Crock, and T. V. V. King

3:00 pm — Items of North American Mineralogical and Gemological Note During 1994
Michael Gray

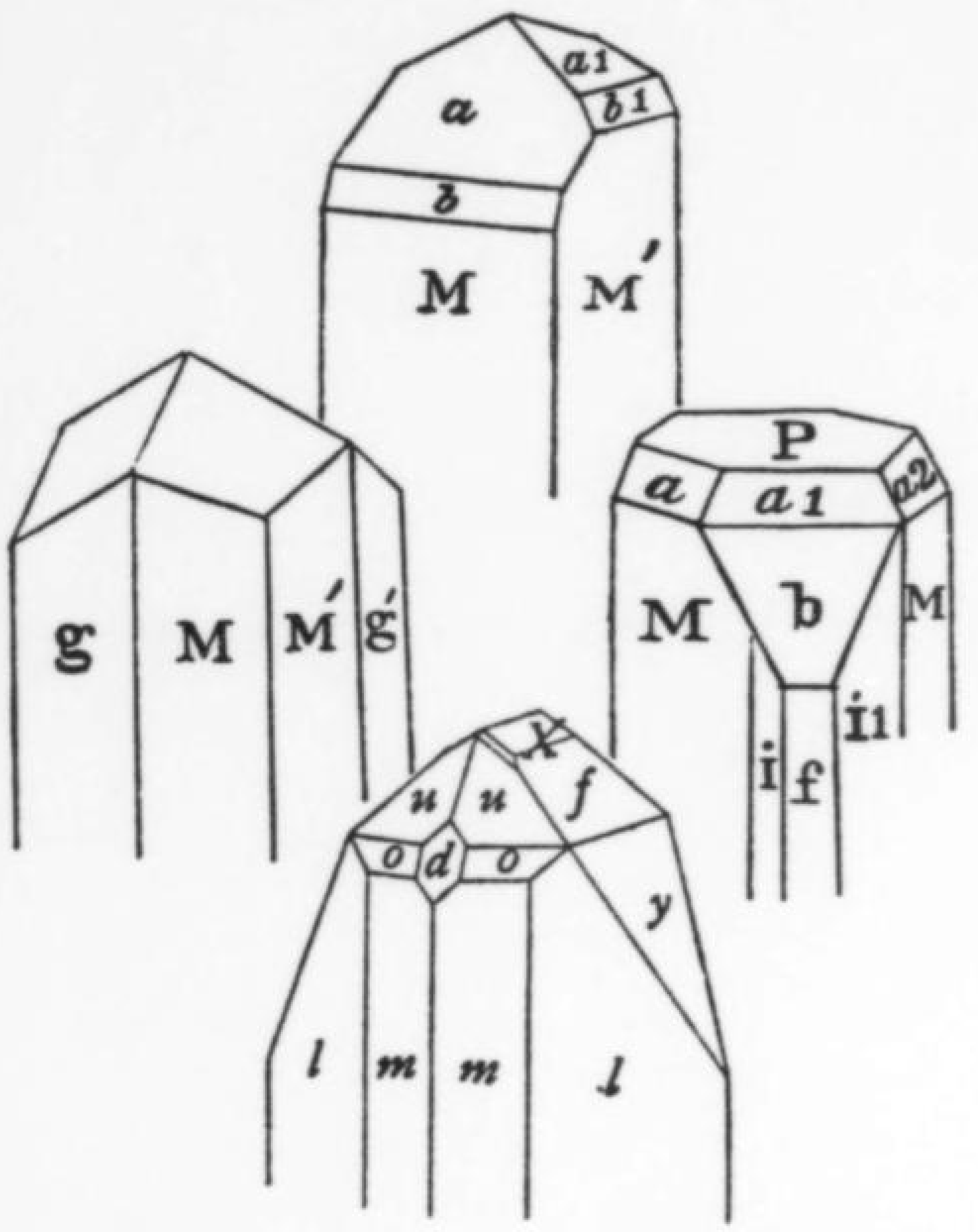
INTRODUCTION

On Saturday, February 11, 1995, the 16th annual Tucson Mineralogical Symposium will be held in conjunction with the 41st annual Tucson Gem and Mineral Show. This event is sponsored jointly by three organizations: the Friends of Mineralogy, the Tucson Gem and Mineral Society, and the Mineralogical Society of America. The featured mineral at the show this year is topaz; following tradition, topaz is also the theme of the symposium.

Topaz, an aluminum silicate, is a popular gemstone to the gemologist, an interesting accessory mineral to the mineralogist and geologist, and a widely admired aesthetically crystallized species to the mineral collector. Although not characterized by a particularly varied range of crystal habits, it has been found worldwide in pleasing shades of purple, blue, green, yellow, orange, red and brown as well as fine colorless crystals. A number of important localities today are produc-

Crystal drawings shown here (except on p. 66) are from Goldschmidt (1922).

ing thousands of crystals annually for the specimen and lapidary markets, making topaz one of the most easily acquired gem species; symposium attendees are sure to have seen many fine examples on the show floor. Through the course of this symposium, people will undoubtedly come to an even greater appreciation for, and understanding of, the scientific and aesthetic appeal of this mineral.



Trumbull, Conn. (top three), and Baldface Mtn., N.H.

The Occurrence of Topaz in Northern New England Pegmatites

Carl A. Francis and **Lawrence C. Pitman**
Harvard Mineralogical Museum
24 Oxford Street
Cambridge, MA 02138

Granitic pegmatites of both the *miarolitic* and *rare element* classes (which differ in size, depth of emplacement, and relationships to their parental granites) occur in northern New England. Both types carry topaz, but the miarolitic pegmatites of New Hampshire are particularly noted for their crystals of topaz. Sixteen intrusive complexes of Mesozoic age comprise the White Mountain igneous province. The youngest and most voluminous member of this rock suite is the Conway granite, a medium-grained, pink, two-feldspar biotite granite. Thin pegmatites near the upper contacts frequently contain primary cavities with topaz prominent among the accessory minerals. Specimens are usually loose euhedral crystals that are commonly etched. Crystals may reach 10 cm, but are typically 3 cm or less. They are commonly colorless, pale brown, or blue. The classic locality is South Baldface Mountain, a satellite stock of the White Mountain batholith. Exposures of Conway granite within the batholith on Moat Mountain and in the Government and Lovejoy gravel pits have all produced topaz. Other occurrences include Bald Mountain in the Ossipee complex, Green's Ledges in the Pilot-Pliny complex, and South Percy Peak and Victor Head in the Percy stock.

The feldspar mines in Maine are mid to late-Paleozoic rare-element pegmatites. These pegmatites are several meters thick, were intruded at deeper levels than the miarolitic pegmatites of New Hampshire, and are enclosed by high-grade metamorphic rocks rather than their parental granites. Topaz is uncommon in Maine pegmatites. The Lord Hill quarry in Stoneham, noted for large crystals, produced a 47-cm blue crystal that may be the largest fine topaz crystal from North America. This quarry lies within the White Mountain National Forest and is open to collectors. The Fisher quarry in Topsham produced 14 kg of blue crystals that are distinctive for being severely etched. Another locality is the Pulsifer pegmatite in Auburn, where topaz occurs as inconspicuous colorless to bluish anhedral crystals embedded in cleavelandite and smoky quartz and, rarely, as blue crystals in cavities.

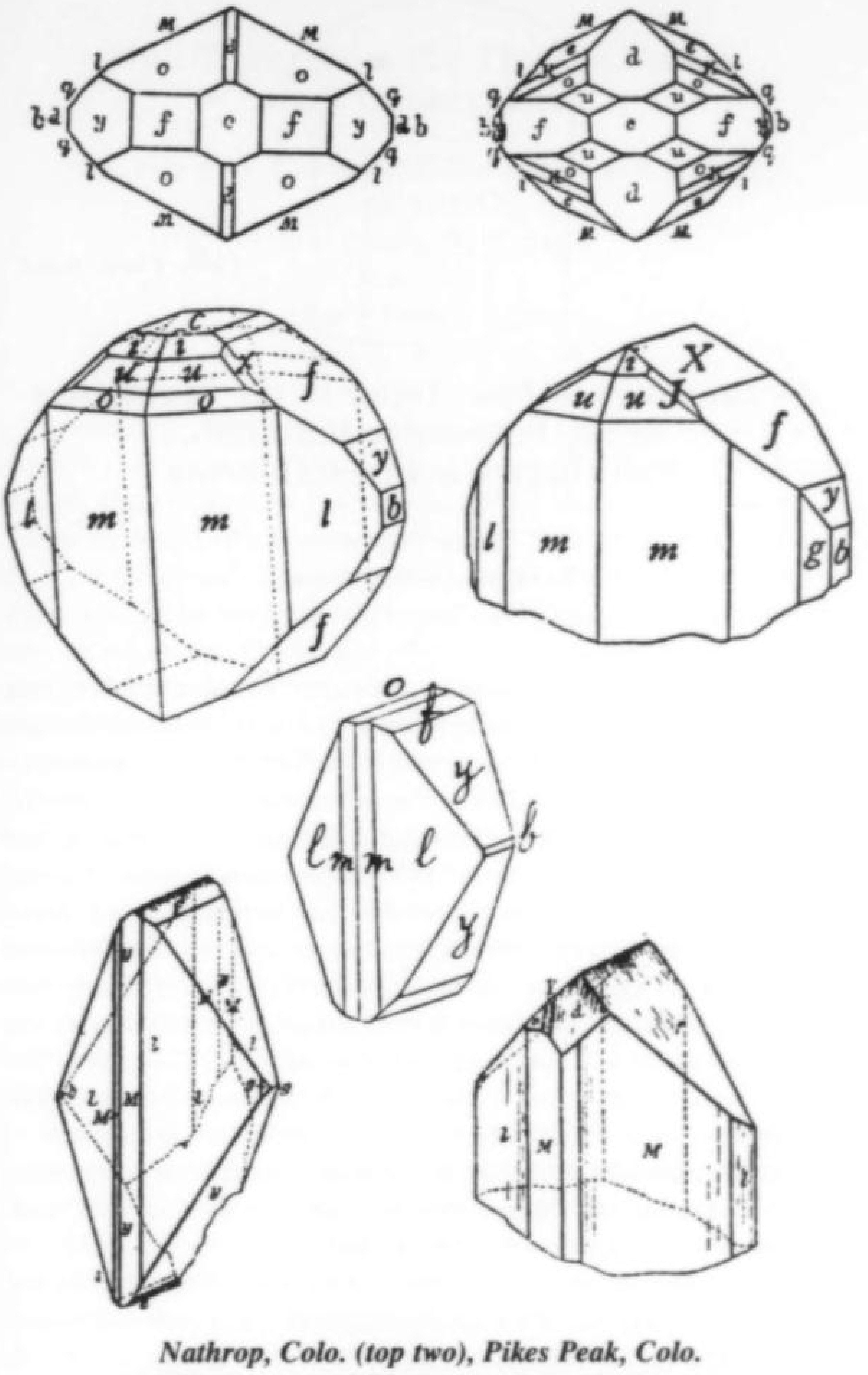
The only important chemical variation in topaz, $Al_2SiO_4(F, OH)_2$, is the substitution of OH for F. A survey of F contents calculated from the *b* unit cell parameter shows all northern New England samples tested to be F-rich. Crystals from the miarolitic pegmatites which formed at shallower depths and hence lower pressures are distinctly more F-rich than those from the rare-element pegmatites. Samples from six localities in New Hampshire range from 19.94 to 20.23 and average 20.18 weight % F, whereas five samples from the three Maine pegmatites range from 18.82 to 19.58 and average 19.19 weight % F. Massive topaz specimens from the Fisher and Lord Hill quarries have the same fluorine composition as the pocket crystals.

The Occurrence of Topaz in the Southeastern United States

Robert B. Cook
Department of Geology
Auburn University, Alabama

Topaz has been identified from 32 localities in the southeastern United States. These include five in Alabama, four in Georgia, three in South Carolina, twelve in North Carolina and eight in Virginia. Two fundamental geological environments are represented by most of these occurrences. The first is the well-known pegmatitic association, including localities in districts characterized by rare-metal-bearing zoned pegmatites such as the McAllister deposit in the Coosa County district, Alabama, and the Rutherford and Morefield mines of the Amelia district, Virginia. The second is within locally extensive aluminous alteration zones associated with currently or potentially productive gold deposits of the Carolina State belt such as the Brewer mine, South Carolina, and genetically related pyrophyllite and kyanite deposits including Graves Mountain, Georgia, Willis and Baker mountains, Virginia, and Pilot and Bowlings mountains and the Hillsborough pyrophyllite district, North Carolina. Topaz is also known in trace amounts from sulfide-bearing quartz veins in several abandoned gold prospects of the Cragford district, Alabama; as small crystals in miarolitic cavities at the Manassas trap rock quarry, Prince William County, Virginia; and as detrital grains in sediment from Virginia Beach, the Etowah River, Georgia, and streams north and east of Rockford, Alabama.

Topaz suitable for collectors or for commercial applications is uncommon in the southeastern United States. Coarsely crystalline topaz of sufficient quality for mineral specimens or lapidary rough has been reported from the Williams mica mine, Lumpkin County, Georgia; the Brewer gold mine, Chesterfield County, South Carolina; and the Morefield mine, Amelia County and the Herbb No. 2 mine, Powhatan County, Virginia. Approximately 700 tons of topaz-rich rock were produced in 1941 from the Brewer gold mine as an experimental refractory raw material, and over 200,000 tons of rock containing approximately 15% topaz were drill-indicated shortly thereafter. An enormous amount of chert-like gray and tan topaz is contained in dump material derived from the Brewer mine as a result of gold mining during the 1990's.



Nathrop, Colo. (top two), Pikes Peak, Colo. (middle three), and Florissant, Colo. (bottom two).

Colorado Topaz

Peter J. Modreski and **Thomas C. Michalski**
U.S. Geological Survey, Mail Stop 905
Box 25046, Federal Center
Denver, CO 80225

The most noteworthy Colorado topaz crystal occurrences are in granite pegmatites of the Pikes Peak batholith. Topaz-bearing pegmatites are associated with late-stage, potassic granite plutons (980–1,020 m.y. old) which intrude the main 1,020-m.y.-old batholith of the Pikes Peak Granite. Topaz crystals occur in miarolitic cavities ("pockets") in pegmatite dikes, associated with smoky quartz, microcline (some of which is amazonite), albite, fluorite, biotite, zinnwaldite, and other accessory minerals. The crystals are stout prisms with moderately complex terminations, and are colorless to pale blue or yellowish to pinkish brown; some are color-zoned. Gemmy crystals as much as 11 cm in maximum dimension are known. Notable localities are Devils Head (Douglas County), Wigwam Creek (Jefferson County), Harris Park (Park County), the Crystal Peak–Lake George area (Park and Teller Counties), the Tarryall Mountains (Park County), and several locations around Pikes Peak itself, including Glen Cove, Crystal Park (Cameron Cone), and Specimen Rock. Masses of topaz in crude crystals up to 60 cm across, white to pale blue but highly fractured and veined, occur in the cores of large, zoned pegmatites in the South Platte district of the Pikes Peak batholith.

Other Precambrian pegmatite districts in the State also contain large, crude topaz crystals which are milky white and opaque; such crystals are known from the Brown Derby pegmatite (Gunnison County) and the Chief pegmatite near Devils Hole (Fremont County). Small topaz crystals, typically less than 1 cm long, occur with spessartine garnet in Tertiary rhyolite at Ruby Mountain, Chaffee County. Topaz, though not common, occurs sporadically in the miarolitic cavities in granite on Mount Antero (Chaffee County); crystals as large as 7.5 cm are reported. Topaz is also a hydrothermal alteration mineral associated with silicic intrusive rocks in central Colorado, as at the Climax and Henderson molybdenum deposits, and it is a constituent of beryllium- and fluorine-enriched greisens, as at the Badger Flats (Boomer mine) area at the western margin of the Pikes Peak batholith, and at the California mine near Mount Antero.

Notes on the occurrence of Topaz in Idaho

Lanny R. Ream
P.O. Box 2043
Coeur d'Alene, Idaho 83816-2043

Topaz has been found in three distinctly different environments in Idaho. Best known are megascopic, often large, euhedral crystals from miarolitic cavities contained in several of the state's granitic batholiths. The most prolific in terms of quantity and quality of specimens is the Tertiary-age Sawtooth Batholith in south-central Idaho where topaz occurs with (smoky) quartz, zinnwaldite, masutomilite, beryl, spessartine and other minerals. Although topaz is sparsely scattered through much of the batholith, it is locally abundant and has been found in exposed cavities as crystals attached to cavity walls, lying on the cavity floor or packed tightly in a pocket "clay" mixture of windblown material, decomposition products of other cavity minerals and primary clays. Sawtooth topaz crystals range from less than a millimeter to as much as 12 cm in length and occur as stubby to elongate single prisms, either singly or occasionally in parallel to subparallel groups. Crystals up to 1 cm attached to matrix are common in some areas. Larger crystals attached to matrix are rare but can be very attractive. Crystal forms observed include the prisms *m* and *l*, often with prism *b*; terminations are primarily the two brachydomes *f*. Prism faces are typically sharp and brilliant while the terminations are most often lightly etched or rough. Occasionally crystals are uniformly severely etched. Colors range from colorless, to pale yellow, yellow, pale sherry-brown, medium sherry-brown and rarely pale blue. Coloring is sometimes distinctly zoned. Color fades upon exposure to sunlight, the original sherry color becoming pale yellow or colorless. Most of the topaz is somewhat milky, especially toward the centers of crystals, and small fractures are common; transparent crystals are rare. The milky central zone commonly fluoresces (yellow), while some crystals have an outer zone that fluoresces; other crystals fluoresce orange throughout. Topaz crystals have been found in sparse cavities in the Crags Batholith. The crystals occur with smoky quartz and microcline in a setting similar to that of the more abundant Sawtooth topaz.

A single occurrence of topaz in rhyolite has been reported in the China Cap rhyolite cone in Caribou County. The topaz occurs in microscopic to submicroscopic crystals; specimen-quality material has not been found at this locality.

Surprising topaz specimens have been recovered from several alluvial deposits. Colorless, yellowish or pink crystals that generally are less than 3 cm in length have been recovered recently by collectors screening gravels in and around Dismal Swamp, Elmore County.

Small (<6 mm) alluvial topaz crystals have been reported from Camas Creek, Clark County. A large fragment of a blue topaz crystal was found many years ago in a gold placer near Paddy Flat, Valley County.

Topaz from the Sawtooth Batholith, Idaho

Michael A. Menzies
#28, 1901 Varsity Estates Dr. N.W.
Calgary, Alberta, Canada T3B 4T7

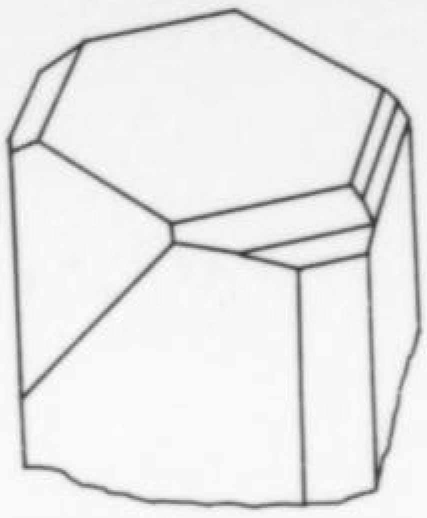
Well-crystallized topaz is locally common in cavities in granite in the Sawtooth Batholith in south-central Idaho, and is of particular interest due to the quality of the specimens and the presence of several unusual forms and associations.

The Sawtooth Batholith is one of the largest of Idaho's 50 or so Tertiary granite plutons that are termed anorogenic (emplaced through crustal extension). Predominant vertical jointing and extensive glaciation have produced spectacular scenery and excellent collecting exposures in the ledges and talus of the Sawtooth Range, within the Sawtooth National Recreation Area. Collecting began following the discovery of aquamarine, and the initiation of geologic investigations for beryllium mineralization in the late 1960's. Despite the rugged terrain, difficult access and short collecting season, there was extensive collecting from the late 1970's through the 1980's, before closure by the authorities in 1991. Many high-quality specimens were recovered.

Topaz occurs in miarolitic cavities that are typically isolated in the medium-grained, pinkish to pale gray granite. Most collectable cavities are in the 10 to 50-cm size range. Despite extraction from typically collapsed cavities, much topaz has been recovered on matrix, commonly as very showy specimens. Topaz-bearing cavities are only one of seven cavity types classified according to their major mineral assemblages; they typically also contain smoky quartz and feldspars, less commonly spessartine and zinnwaldite-masutomilite mica, and rarely hematite, fluorite and other species. Minerals containing fluorine (necessary for the formation of topaz), iron, manganese and beryllium predominate in the over 40 minerals identified to date; less than half are associated with topaz.

Topaz is a mid-stage to late-stage mineral that forms sharp, short to elongated prisms that are typically 0.5 to 2 cm in length but can reach 12 cm. Most show greater development of $m\{110\}$ rather than $l\{120\}$ faces, with prominent $f\{011\}$ face terminations. Several other forms are less common. Crystals range from translucent to gemmy, and are colorless to pale sherry or yellow (with these shades apparently unstable to light), and rarely pale blue. Many crystals are slightly to severely etched, commonly on their terminations. Some show sherry-colorless-sherry color zoning across the *a* axis. This colorless central zone is very susceptible to etching and may also show yellow fluorescence that is particularly strong under longwave ultraviolet light.

Other rare habits include topaz crystals with opaque, fibrous, white-capped terminations; topaz in one of these cavities was overgrown with small, yellowish spessartine trapezohedrons. One unique, highly altered cavity produced specimens showing a granular mixture of topaz and quartz replacing microcline crystals; overgrowths of small, sharp, water-clear topaz crystals make them unusually attractive pseudomorphs. Rare inclusions identified in topaz include spessartine, helvite and hematite. Crystals from one cavity may be twinned; these pairs of unusual crystals are attached along their *b* faces, with diverging *c* axes.



Topaz, Little Three mine

Occurrences of Blue Topaz in the Pegmatites of the Peninsular Batholith, San Diego County, California

Jesse Fisher
380 Pennsylvania Avenue
San Francisco, CA 94107

While California has few topaz occurrences of note, a number of the many gem-bearing pegmatites in San Diego County have occasionally produced crystals of blue topaz which rival those from the Russian Ural Mountains in form and color. The best known of these pegmatites is the Little Three mine, near Ramona. The Little Three property is a patented claim discovered in 1903, containing several distinct pegmatites. The main Little Three dike has produced topaz, green elbaite and occasionally morganite and aquamarine. The adjacent Hercules dike is known for excellent spessartine. Two distinct generations of topaz occur in the main dike. The earlier-formed crystals are blue to pale green and commonly weigh in excess of 100 grams. The color of some of these crystals darkens with exposure to sunlight. The later topaz crystals are usually less than 5 mm, colorless, and tend to form on the surfaces of other pocket minerals, particularly tourmaline. Topaz production has been sporadic, with significant recent finds made in 1976 and again in the fall of 1991.

Less well-known are the pegmatites of Aguanga Mountain, located in the north-central part of the county near Oak Grove. Two pegmatites discovered around 1903 have produced topaz, though neither is currently being worked. The Maple Lode mine is an unpatented claim located on the steep southern flank of the mountain at approximately 4,400 feet elevation. Surface exposure of the dike is poor due to the slope of the hill. Where visible, the pegmatite is of variable thickness, from about 1 to 5 feet, and appears brecciated. The exposed dike appears to dip gently southward. Though layered aplite, graphic granite and lepidolite occur on the dumps, internal zonation of the pegmatite is not evident in exposures. Unrecorded amounts of blue and pale green topaz, along with pencils of blue elbaite, were recovered during the most recent mining activity, between 1977 and 1982. Much of the topaz, however, was used for gem rough. Attempts at color enhancement through irradiation left the stones with a considerable residual radioactivity, possibly due to trace levels of tantalum.

The Ware mine (also known as the Emeralite #2, Mountain Lily, or Gem mine #1) is a patented claim about 0.75 mile north of the Maple Lode mine on the northeast side of the Aguanga Mountain ridge, at an elevation of 4,840 feet. Where exposed, the pegmatite dike is of variable thickness, ranging between 70 cm to 1.6 m, and dips gently southwest into the hillside. Quartz, K-feldspar, muscovite and schorl are common, along with graphic granite; lepidolite is rare. Internal zonation of the pegmatite appears poorly developed at best. Past production from the mine is difficult to estimate, but is likely to be low considering that much topaz sold as coming from the mine is now believed to be Brazilian. Mining attempts in the early 1980's produced only meager results. Besides topaz, the mine is reported to have produced blue and green elbaite, morganite and aquamarine.

Pink Topaz from the Thomas Range, Juab County, Utah

E. E. Foord, W. Chirnside, F. E. Lichte, and **P. H. Briggs**
M. S. 905
U.S. Geological Survey
Box 25046
Denver Federal Center
Denver, Colorado 80225

Extremely F-rich (>20.3 weight %) and H_2O-poor (<0.2 weight %) topaz occurs in lithophysal cavities in rhyolite throughout the Thomas Range. Pink topaz was first reported from the northern end of the Range by Arthur Montgomery in 1934. At least two distinct localities exist for pink topaz. Pink crystals are found only as float crystals, i.e. those which have been exposed to sunlight. The occurrence is sporadic and appears to be structurally controlled by late-stage ring fractures and random fractures within the rhyolite host. The majority of the crystals found are "sand crystals" and are opaque because of sandy quartz and feldspar inclusions. Crystals may be as much as 4 cm in length. Some smaller crystals (< 2 cm) are transparent and of gem-quality, and show a more or less uniform pink to pinkish red color. All crystals are a yellow-orange sherry color in unopened lithophysal cavities and typically fade to colorless in a matter of days to a week or two, depending on the air temperature, amount and intensity of light. Heating causes the color to fade rapidly. Some crystals, however, do not completely fade to colorless but reveal an outer zone that is distinctly pink to reddish pink in color. The pink-red zone is stable to light and heat.

Bulk chemical analyses by ICP-AES methods of gem-quality, completely colorless crystals and crystals having a distinct pink-red outer zone showed that the pink material contains 20 ppm Mn while the colorless material showed <8 ppm. Iron contents are also higher in the pink material (0.08% vs. 0.05%). Chemical analysis by LA-ICP-MS methods of individual spots within a color-zoned crystal showed Mn to be clearly concentrated in the pink-red zone: MnO (0.065 weight %) and Fe_2O_3 (0.035 weight %). MnO contents in colorless portions of the crystal were between 0.01 and 0.02 weight %. Cr, V, Co and other possible chromophores were not detected. Trivalent Mn and Fe are probably substituting for the octahedral Al in the topaz structure.

Topaz Rhyolites in Arizona and the Southwest

Donald M. Burt
Department of Geology
Arizona State University
Box 871404
Tempe, Arizona 85287-1404

Topaz rhyolites are fluorine-rich silicic lava flows, domes, and shallow intrusions that are characterized by the presence of gem topaz, $Al_2SiO_4F_2$, in gas cavities and along fractures, commonly associated with manganoan garnet, bixbyite, pseudobrookite, specular hematite, red beryl, quartz and other collectable minerals. In the Southwest, topaz rhyolites occur on both sides of the Colorado Plateau (in Arizona, Utah, Nevada, Colorado, and New Mexico), as well as in Idaho and Montana. They also occur in a single linear belt in north-central Mexico. Their enrichment in lithophile rare elements (lithium, rubidium, cesium, niobium, tantalum, tin, tungsten, beryllium, uranium, thorium, etc.) leads to the term rare-metal rhyolites. Similar fluorine-rich dike rocks from Mongolia and the former Soviet Union have been called ongonites. Topaz rhyolites represent a special class of the so-called bimodal or high-silica rhyolites of the Basin-and-Range province of the western United States. Geochemically, if not texturally, they resemble rare-metal pegmatites, in that rare elements have reached high concentrations as a result of fractional crystallization of parent magma.

Their extensional tectonic setting and geochemical characteristics suggest that they are the extrusive equivalents of what have been called A-type or anorogenic granites. Their formation presumably involves partial melting of Precambrian continental crust (they appear to be restricted to areas of such crust) in the presence of regional high heat flow (which tends to increase fluorine at the expense of hydroxyls in minerals and melts). Basaltic magmas ponding under the crust may provide the heat for partial melting in many cases.

Economic interest in topaz rhyolites results from their spatial and genetic associations with volcanogenic mineral deposits of beryllium, tin, uranium, and fluorine. The beryllium-fluorine deposits of Spor Mountain, Utah and the fumarolic tin deposits of the Black Range, New Mexico provide the best U.S. examples of this type of mineralization. Nevertheless, most topaz rhyolite lavas are not associated with economic metal mineralization. They are, however, excellent sites for mineral collecting. They might also serve as surface indicators of buried mineralization containing silver or fluorite (Mexican-type carbonate replacements), molybdenum (subvolcanic Climax-type porphyry deposits), tin and tungsten (greisen-type or skarn-type deposits), or even rare metals in pegmatites.

In Arizona, topaz rhyolites are known from two areas, the Burro Creek area of the southern Aquarius Range (especially an isolated garnetiferous dome called Negro Ed) northwest of Phoenix, and a poorly located site near Winkelman southeast of Phoenix. Although it is farther away, the garnetiferous topaz rhyolite dome at the northern end of East Grants Ridge, New Mexico is much more accessible than these two sites; exit Interstate Highway 40 at Grants.

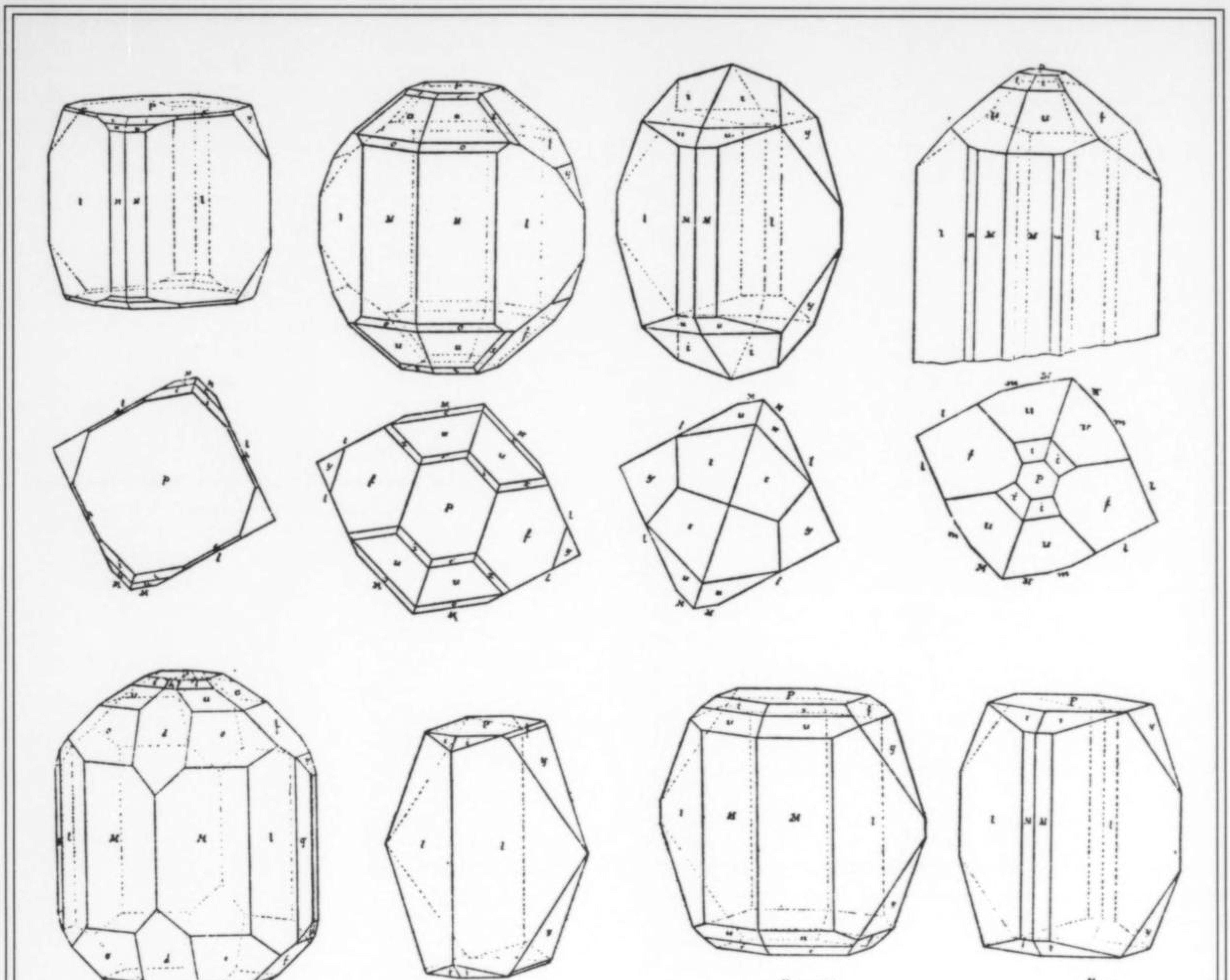
Topaz and Beryl-bearing Gem Pegmatites of the Alabashka–Mursinka–Adui district in the Ural Mountains, Russia

Peter Lyckberg
Box 25147
S-400 31 Göteborg, Sweden

The central part of the Ural Mountains 50 to 115 km north-northeast of Ekaterinburg contains more than 250 gem-bearing pegmatites, including the famous Alabashka, Mursinka, Sarapulka, Lipovka, Shaitanka and Adui districts. Some of the finest blue topaz specimens in the world have been found in the Alabashka area, mainly in the Mokrusha mine.

Pegmatites of the Alabashka area are steeply dipping veins typically 2–3 meters wide and 50 meters to over a kilometer in length. Two exceptions are the flat lying Golodnij and Mokrusha veins. Recent underground work (1976–1985) at the Mokrusha mine exploited two miarolitic pocket zones in graphic granite 3–10 meters apart vertically. The upper pocket zone produced large first-generation short prismatic topaz up to 30 kg, mostly lying loose in brown hypergene clay. Rarely, some fine, pale blue, sharp, lustrous and gemmy second-generation crystals were reportedly found growing on first-generation topaz crystals. One of the finest specimens is the Pobeda, a 44-kg albite matrix with several 6–8 cm topaz crystals. The lower pocket zone contained mainly gemmy green aquamarine and golden heliodor crystals up to 8 cm in length.

In 1993 the last working mine, the Kazjonnitsa, was closed after 2



Topaz crystal habits from Alabashka, Central Ural Mountains, Russia.

years of operation. Mining intersected the pegmatite dike at a depth of 30 meters and progressed upward to near the surface. 315 pockets up to 6 meters in maximum dimension were found. One quarter of the pockets contained either topaz or beryl and only 6 contained both. Only a few gem-quality specimens were found.

Topaz occurs as colorless to pale blue, and in one pocket pink to champagne-colored crystals. Topaz is typically associated with albite, smoky quartz, muscovite, tourmaline, garnet and beryl. Beryls range from grass-green to yellowish green to blue. The largest beryls reach 28 cm in length.

Geology and Occurrence of Well-Crystallized Topaz

Michael A. Menzies
#28, 1901 Varsity Estates Dr. N.W.
Calgary, Alberta, Canada T3B 4T7

Well-crystallized topaz occurs in cavities in some rhyolites and a range of granite-related deposits. A survey of over 80 worldwide deposits shows that about 80% are pegmatites, 10% are rhyolites, and the remainder are greisens, rare veins and still rarer skarns. Pegmatites produce most gem topaz and are also important sources of specimens; rhyolites provide excellent specimens; but neither greisens nor veins (except for the Imperial topaz deposits in Brazil) are important producers.

Topaz derives from highly evolved silicate magmas. The main requirements for formation of topaz ($Al_2SiO_4(F,OH)_2$) are an excess of aluminum over that required to form feldspars, and a high concentration of fluorine. The latter plays the more crucial role, since it must be concentrated to a considerable degree to form topaz. Crystals form in cavities from late-stage, fluorine-rich aqueous fluids that have separated from the rising magma at shallow depths. Formation requires some combination of: (1) evolution of a fluorine-rich vapor, (2) increasing acidity on cooling, and, less commonly, (3) loss of alkalis as dissolved salts.

The parent magmas form deep within the continental crust in tectonically active zones, through either aborted rifting (the anorogenic process of crustal extension), or plate collisions (the orogenic process of compression that forms major fold-belt mountains). Anorogenic magmas, typically with high fluorine content enhanced by their rise from deep levels, solidify at shallow depths as granite, or less commonly erupt as rhyolite. Orogenic magmas are commonly created at shallower levels and intrude as granites. They are more widely distributed than orogenic granites, but only the most highly evolved have sufficient fluorine to produce topaz. The intrusive source rock for topaz is typically a light-colored biotite granite that is intruded at the latest stage in a magmatic episode. Such topaz granites, which are uncommon worldwide, are generally found in the roof zones of shallow intrusions where volatiles such as fluorine reach their highest concentrations.

Most topaz in rhyolites is primary and early-stage to mid-stage. Crystals are commonly highly lustrous and gemmy and may be associated with bixbyite, almandine-spessartine garnet, quartz, hematite and red beryl.

Topaz crystallization in granites spans late-stage magmatic conditions through the broad hydrothermal regime. Crystals in cavities are generally primary and mid-stage to late-stage. Uncommon exceptions include early-stage crystallization in some epigenetic pegmatites and late-stage topaz in hydrothermal veins. Second-generation crystals may form in pegmatites (and rhyolites), and replacement topaz is also common in greisens. Since topaz competes for fluorine with other minerals, especially fluorite and micas, its formation is favored by low levels of calcium, lithium and water.

Syngenetic pegmatites (miarolitic cavities) in granite can produce significant quantities of excellent topaz crystals. Associated mineralogy ranges from simple quartz-feldspar-mica assemblages to broader suites including smoky quartz, feldspars, zinnwaldite mica, fluorite, less commonly beryl and phenakite, and rarely spessartine and tourmaline. Other species containing essential iron may also be present. Zinnwaldite is typically the only lithium-bearing species. In epigenetic, intruded pegmatites, topaz is less common but may form superb, large crystals. Associations are similar to those in syngenetic pegmatites, but with a shift towards lithium-containing species such as lepidolite and elbaite tourmaline.

In greisens, topaz occurs most commonly with quartz, micas, fluorite and cassiterite. Associations with topaz in vein deposits typically progress with falling formation temperature from quartz, feldspars, muscovite and cassiterite through quartz, cassiterite and sulfides, and finally to calcite.

Where's the Proton? Symmetry and Structure Variations in Topaz

Paul H. Ribbe and **Susan C. Eriksson**
Department of Geological Sciences
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0420

Most topaz, $Al_2(F,OH)_2[SiO_4]$, crystallizes in orthorhombic space group *Pbnm*. The structure is based on closest-packed monolayers of oxygen anions alternating with monolayers of $[F,OH]_2O_1]_\infty$ in a mixed hexagonal-closest-packed and cubic-closest-packed sequence . . . ABAC . . . . One-third of the octahedral sites are filled with Al and one-twelfth of the tetrahedral sites with Si. Oxygen anions are coordinated by 1 Si + 2 Al atoms; F and/or OH anions are coordinated by two Al atoms. Edge-sharing $AlO_4(F,OH)_2$ octahedra form crankshaft-like chains parallel to *c*. Perfect (001) cleavage results from the breaking of weak Al-F bonds.

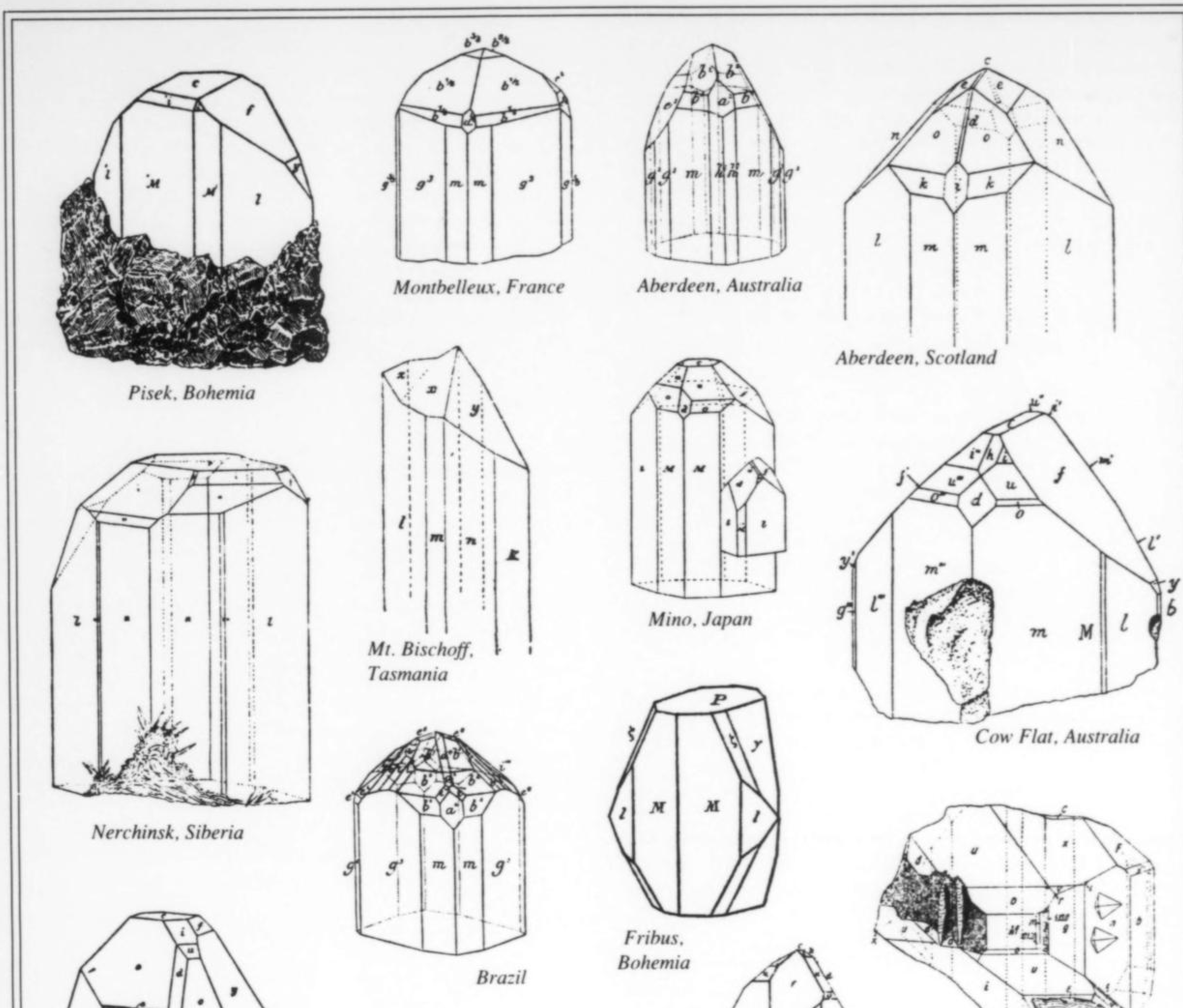
Optically "anomalous" (F,OH)-topazes have long been known, especially in sectoral textured crystals; {010} growth sectors are orthorhombic, {*hk0*} sectors monoclinic, {*hkl*} sectors triclinic (Akizuki and others, 1979). Heating at 950°C may disorder lower-symmetry sectors, restoring them to orthorhombic.

Piezoelectric and pyroelectric properties were observed by Friedel and Curie in 1885, but confirmation that non-centrosymmetric (*P*1) topaz was a result of F-OH ordering in the structure awaited the advent of neutron diffraction and the study of Parise (1980), who located the proton at only *one* of eight possible monovalent anion sites. Recently, pure OH-topaz $Al_2(OH)_2SiO_4$ was synthesized at high temperatures (1000°C) and pressures (55–100 kbar). It is orthorhombic, but may have space group *Pbn* 2_1, because there are *two non*-equivalent H (proton) positions (Northrup and others, 1994).

Topaz: Environments of Crystallization, Crystal Chemistry, and Infrared Spectra

Eugene E. Foord, Larry L. Jackson, Joseph E. Taggart, James G. Crock, and **Trude V. V. King**
M.S. 905
U.S. Geological Survey
Box 25406 Denver Federal Center
Denver, Colorado 80225

Topaz, $Al_2SiO_4(F,OH)_2$, is usually found as a vapor-phase or hydrothermal crystallization product in three principal geologic associa-



Topaz crystal from some worldwide localities.

tions; lithophysal cavities in rhyolites (R), pegmatites and greisens (P), and hydrothermal veins (H). The mineral also occurs as a liquidus phase in ongonites and some rhyolites. Compositions of 65 representative topaz samples from worldwide localities (8R, 40P, 17H) are distinctly grouped in terms of H_2O^+(>105°C), fluorine, and trace element content. The average H_2O^- content for all samples was 0.04 (±0.01) weight %. H_2O^+ contents (in weight %) for 7R topaz ranged from 0.06 to 0.11, for 40P topaz from 0.20 to 0.91, and for 17H topaz from 1.69 to 2.67; fluorine content is inversely related to water content. A maximum of about 30% of the F site is occupied by OH in H topazes. The F-OH ratio correlates with, and possibly is controlled by, the temperature of crystallization.

Trace and minor elements which vary by association include Li, Fe, Cr and Ge. The average Li content of R topaz (50 ppm) is at least five times that of P and H topaz. All samples contain trace amounts of Fe (usually less than 0.04, but as much as 0.2 weight %). Chromium, present in some samples of H topaz, is the chromophore in the pink-red and orange-red crystals from Ouro Preto and Brumado, Brazil; and Katlang, Pakistan. Mn (to 600 ppm) appears to be a chromophore is some R topaz from the Thomas Range, Utah; pink to burgundy-colored crystals from Brazil and Pakistan typically contain 400 to 500 ppm Cr. Purplish red H-type topaz from Sanarka, Orenburg district, in the former Soviet Union contains about 2,700 ppm Cr. Germanium contents are elevated in four samples of P topaz (200 ppm from Mt. Antero, CO; 500 ppm from the Little Three mine, Ramona, CA; 550 ppm from the Maple Lode mine, Aguanga Mtn., CA; and 400 ppm from Satao (Viseu), Portugal).

Other physical properties, e.g. density, ucd's, and refractive indices, vary linearly with the substitution of OH for F. Measurement of any of these properties may be used to determine the F or OH content and to predict topaz type and environment.

IR reflectance spectra of F-rich (R type) and OH-rich (H type) topaz are distinct. Three narrow, well-defined, OH absorption bands are characteristic of R topaz (3400 to 3800 cm^{-1}). P topaz shows OH absorption features from 3400 to 4200 cm^{-1}. Hydroxyl-rich topaz (H type) displays a more complex series of OH absorption bands between 3400 and 4200 cm^{-1}. Hydroxyl-rich topaz also contains CO_2 as indicated by a sharp peak at 2300 cm^{-1}. Disorder of OH-F is indicated for the OH-rich material which is consistent with its known triclinic symmetry.

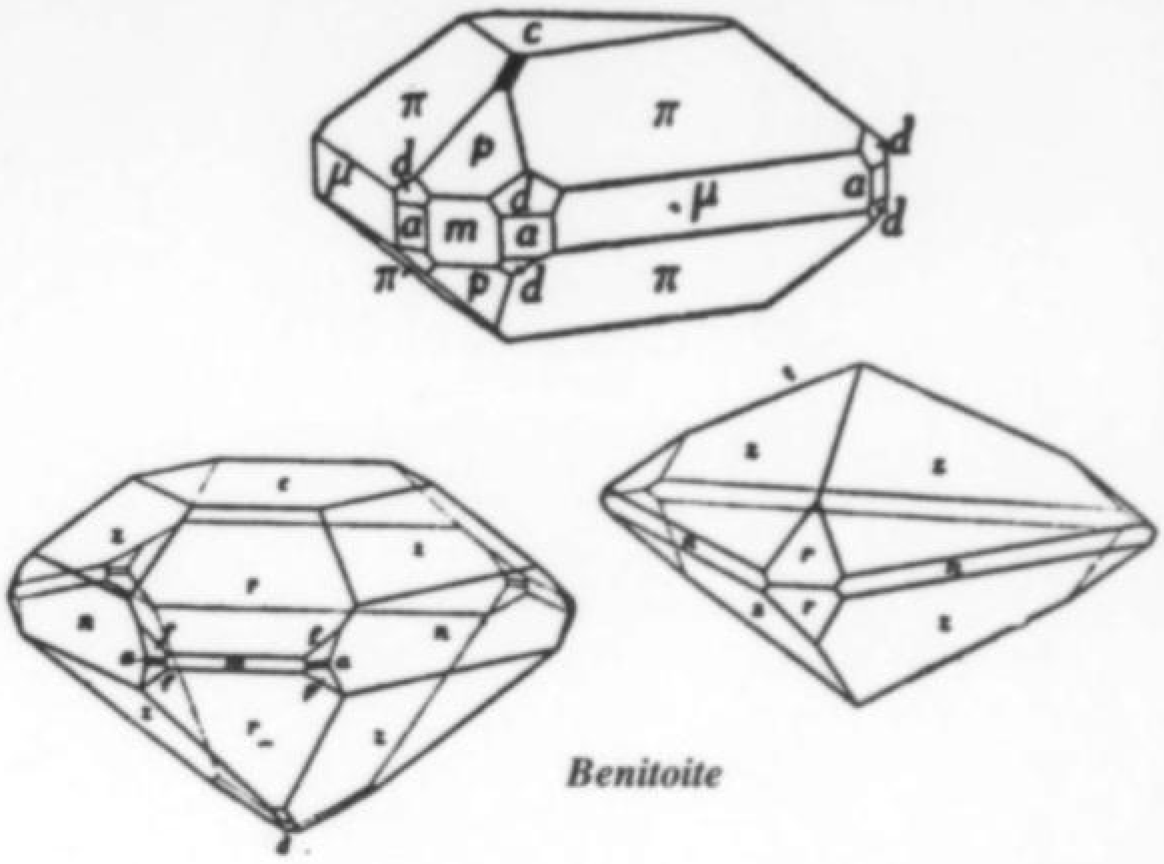
Items of North American Mineralogical and Gemological Note During 1994

Michael Gray
Post Office Box 727
Missoula, Montana 59806

Many significant developments have taken place in the previous year, in both the mineralogical and gemological fields on the North American continent. Some are technological, others are developmental.

On the technological side, a new color of **benitoite** has been attained through a heating process, and this may give a possible answer to what causes the peculiar cornflower-blue color. The new heat-treated salmon-colored benitoite has several unusual characteristics that set it apart from the normal blue color. Work is presently being done on the new color by Dr. George Rossman of the California Institute of Technology.

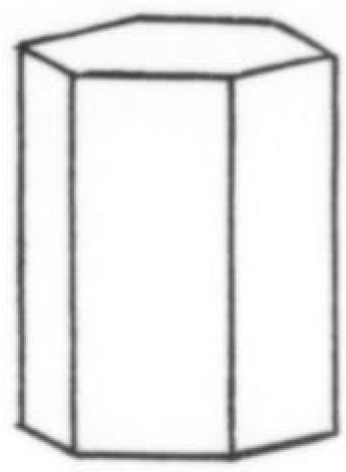
On the development side, the **diamond** pipes in Northwest Territories, Canada, are almost ready to begin production. Inside sources say



Benitoite

that mining will commence "in the near future" and that test results are favorable for large quantities of gem-quality stones. Several international corporations have invested many millions of dollars already to verify the reserves of this new area.

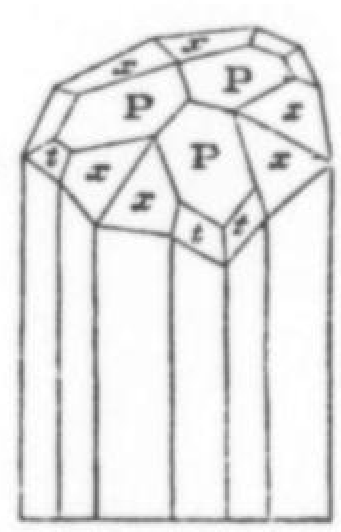
Kennecott Corporation, a wholly owned subsidiary of London-based RTZ Corporation PLC, have obtained a three-year lease, with an



Red beryl, Utah

option to buy, on the **red beryl** properties in central Utah. This is the first instance of a major mining concern leasing a gemstone and specimen property for the purpose of commercial exploitation.

A significant find of crystallized **gold** was mined in late July at the Colorado Quartz mine, Midpines, California; octahedrons, skeletal crystal and wire gold were all recovered. One large specimen reportedly contains all three habits. Some knowledgeable dealers have stated that these might be some of the finest gold specimens ever recovered from any locality.



Elbaite, Paris, Maine, 1857

Several small developments continue to produce material around the country. Mining continues, as it has for the last four years, at Mt. Mica, Paris, Maine, with a number of small, tight pockets yielding masses of small crystals of **tourmaline**, but only minor matrix specimens or gem material yet this year. Several pockets containing large Japan-law twinned **quartz** crystals were exploited at the PC mine near Basin, Montana, some with tourmaline and cerussite inclusions.

Stolen Minerals and Fossils

A burglary involving the theft of 136 museum quality mineral crystal specimens and 490 fossils, with a total value of almost $66,000, was committed early in the morning of Saturday, September 24, 1994, at the Carleton College Geology Department in Northfield, Minnesota. The mineral specimens were removed from several large display cases in the Geology Department in Mudd Hall, and most of the fossils were taken from an adjacent lab.

The stolen minerals include a large number of exceptional specimens of minerals including calcite, malachite, rhodochrosite, azurite, native copper, beryl, cerussite, stibnite, dioptase, vanadinite, tourmaline, epidote, uranium minerals, and others. Most of the specimens are several inches in size; the copper nugget is over a foot long.

The fossils include several good quality mammoth and mastodon tusks, teeth and jaw bones (of rare value because they were found in the local area in southern Minnesota), and several hundred marine shell fossils from Miocene deposits in Florida. In addition, some other fossils including shark teeth, vertebrate bones and Devonian shells were stolen.

Each of the specimens is identified with a catalog number in black pen lettering on white paint on the back or bottom side.

Anyone seeing specimens which might be from this stolen collection is urged to call the Northfield, Minnesota, police (507-645-4475) or the Carleton College Geology Department (507-663-4401, 507-663-4407).

Volunteer Coordinators
Eastern U.S.
Charles & Marcelle Weber
1172 West Lake Ave.
Guilford, CT 06437

Advertising Information
All advertising in the Mineralogical Record must be paid in advance of the closing date. Telephone orders not accepted. Write to the editor for rates.

Closing dates:

Jan.-Feb. issue	Oct. 15
March-April issue	Dec. 15
May-June issue	Feb. 15
July-Aug. issue	April 15
Sept.-Oct. issue	June 15
Nov.-Dec. issue	Aug. 15

An additional 20 days past the closing date are allowed in which advertisers may make changes (excluding size changes) in ads already paid for.

Design
Wendell E. Wilson

Graphic Production
Capitol Communications
Crofton, MD

Printing
Cadmus Journal Services,
Easton, MD

Color Separations
Hollis Phototechnics
Tucson, AZ

Circulation
P.O. Box 35565
Tucson, AZ 85740
602-297-6709

Editing, advertising
4631 Paseo Tubutama
Tucson, AZ 85715
602-299-5274

Foreign Payments
Remittance may be made in local currency, at *prevailing exchange rates*, without surcharge, to the following people:

Belgium
Paul Van Hee
Marialei 43
B-2900 Schoten

Canada
Mrs. J. W. Peat
36 Deepwood Crescent
Don Mills, Ontario M3C 1N8

Great Britain
Paul Lowe
"Endsleigh"
50 Daniell Road
Truro, Cornwall TR1 2DA

Italy
Renato & Adriana Pagano
P.O. Box 37
I-20092 Cinisello Balsamo MI

Japan
Bon Earth Sciences
Toshiro Iwamoto
42-2 Sendagi, 2 Chrome
Bunkyo, Tokyo 113

Netherlands
W. J. R. Kwak
Kabeljauwallee 23
6865 BL Doorwerth (Gld)

Norway & Sweden
Geir Wiik
N-2740 Roa
Norway

South Africa
Horst Windisch
30 Van Wouw Street
Groenkloof, Pretoria

Germany
Christian Weise Verlag
Oberanger 6
D-80331 München 2

Affiliated with the Friends of Mineralogy, an independent, non-profit organization devoted to furthering amateur and professional interests in mineralogy. For membership information contact Richard Thomssen, Treasurer, P.O. Box 1656, Carson City, NV 89702

Opinions expressed are those of the authors and do not necessarily reflect those of the Mineralogical Record Inc., its editorial staff or directors.

Advertisers Index


Topaz
Photo by
Harold and Erica
Van Pelt, Los Angeles
© 1988
Importers-Exporters of
colored gemstones & fine
minerals • Member AGTA
Pala International
912 So. Live Oak Park Road • Fallbrook, California 92028 • (619) 728-9121 • U.S. WATS 1-(800)-854-1598
CABLE: Palagems • TLX-695491 • FAX 619-728-5827