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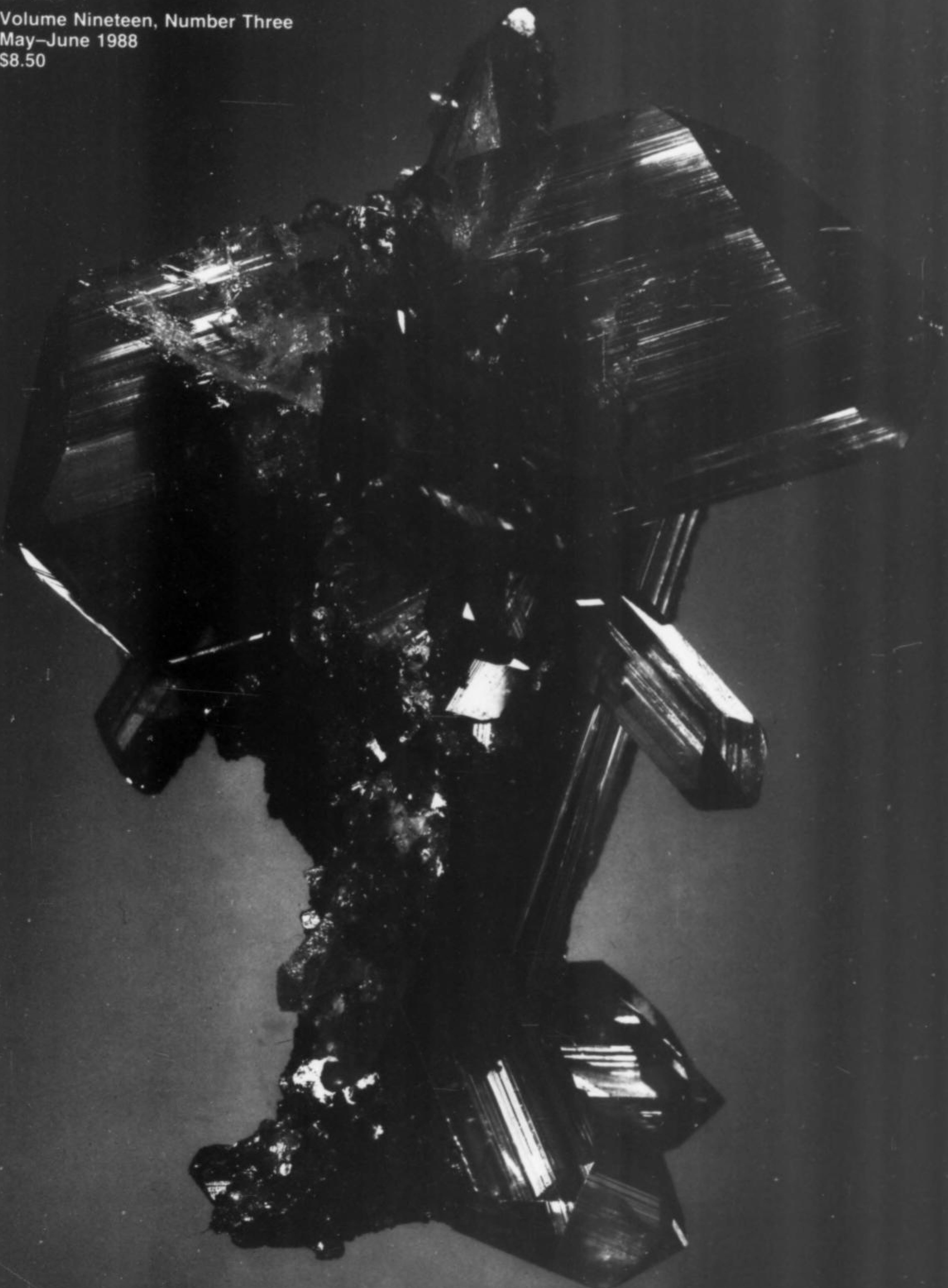


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*Continued on p. 223

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Articles

Departments

COVER: ANGLESITE from the Touissit mine, Morocco. The large crystal measures 4.5 cm. This is one of the specimens stolen from Victor Yount during the Tucson Show this year; see "What's New in Minerals?" Photo by Harold and Erica Van Pelt.

notes from the EDITOR

MINERALS OF CORNWALL

It is an honor indeed for the Mineralogical Record to be involved in co-publishing a book with the British Museum: Peter Embrey and Robert Symes' *Minerals of Cornwall and Devon*. We received our first complete copies by air freight just prior to the Tucson Show this year, and sold most of them during the course of the week.

The idea for such a book arose several years ago. Peter Embrey, curator of minerals at the British Museum, had long been planning to compile a comprehensive, technical review of the mineralogy of Cornwall and Devon. The original concept was similar to that of Greg and Lettsom's monumental *Mineralogy of Great Britain and Ireland* (1958). However, it eventually became clear that such a thorough compilation would necessarily run to several volumes and require far more man-years than Peter had remaining before retirement. Following discussions with the museum's Publications Department it was concluded that a less technically ambitious but more popular treatment was both attainable and desirable.

Robert Cross, then the museum's head of publications, corresponded with the Mineralogical Record to see if we would be interested in taking part in the project. We were; and through the course of several meetings and much correspondence we developed for them an outline for the book which we thought would appeal to our market of mineral collectors worldwide.

In many respects our recommendations followed the guidelines we later published for authors assembling locality articles for the *Mineralogical Record*. It should have a thorough review of the history, including many antique mining photos and engravings, and many detailed maps showing the locations of all the important mines. The geology should be covered briefly but intelligibly. Information on early mineral collectors and dealers should be gathered, and of course there should be a maximum amount of high-quality mineral photography accompanied by informative, detailed figure captions. Finally, a lengthy and thorough bibliography would be good to have.

Embrey set to work, Cross marshalled the museum's staff of photographers to begin taking large-format transparencies of the best specimens in the British Museum collection, and Robert Symes was brought in to help with the history and geology sections. After several years of labor and much mailing of photo proofs and manuscript pages back and forth across the Atlantic, the job was completed late last year and went to press. Although the copies which the museum planned to sell through its own bookstore were all scheduled to be bound softcover, we requested that all of ours be hardbound in recognition of the high quality and lasting value which the contents would have (the extra cost turned out to be very small).

When we finally saw the finished product, we were impressed with how beautifully and expertly the British Museum publishing staff had done their job; it is better than we had dared to hope, a first-class production in every way, from the paper stock and color reproduction quality to the layout and design.

It should come as no surprise, then, that we recommend this book highly. It has been custom-tailored by the most authoritative and competent authors, photographers and publishing staff to precisely comprise all the things that *Mineralogical Record* readers enjoy most, with the exception of hardcore technical mineralogy.

In addition, the price is right; $28 for a large-size book of 154 pages with color photography on practically every page, and hardbound as well, is extremely reasonable.

We want to thank the authors and photographers, and everyone else involved at the British Museum (including Clive Reynard who took over for Robert Cross) for their excellent and highly professional work on this project.

Copies of *Minerals of Cornwall and Devon* may be ordered for $28 plus $4 shipping and packaging ($5 outside the U.S.) from the Mineralogical Record Bookstore, 1601 Fairview, Suite C, Carson City, Nevada 89701. Satisfaction is guaranteed.

CALL FOR PAPERS

The tenth Symposium sponsored jointly by Friends of Mineralogy, the Tucson Gem and Mineral Society, and the Mineralogical Society of America will be held in Tucson, on February 12, 1989. The topic of the Symposium will be **Galena,** the featured mineral of the 35th Tucson Gem and Mineral Show. Papers are invited on topics in any way related to galena, including its descriptive mineralogy, associations or paragenesis, classic localities, etc. An audience of knowledgeable amateurs as well as professional geologists and mineralogists is expected. The atmosphere of the meetings is informal.

If you feel you would like to present a paper please write immediately to Henry Truebe, Chairman (Dallhold Resources, 2002 North Forbes Blvd., Tucson, AZ 85745), with your topic, a few sentences describing the paper, and an address or phone number at which you may be contacted. Presentations will be 15 to 20 minutes in length followed by a period for questions. Upon acceptance of topics all authors will be required to submit a 200-word abstract by September 30, 1988. A camera-ready copy of the paper, 5 to 10 doubled-spaced pages in length including illustrations, will be due on December 31, 1988.

Papers by students are encouraged and will be considered for the "Best Student Paper" award from Friends of Mineralogy. The award is intended to cover all or part of the expenses incurred by the student while traveling to the symposium.

NEWS FROM JAPAN

The first *Tokyo International Mineral Fair* will be held June 2–8, 1988, at the Shinjuku Dai-Ichi Life Insurance Building in Tokyo. Approximately 180 dealers are expected to take part, at a fee of 40,000 yen per booth. The sponsor is the Tokyo International Mineral Fair Executivé Committee, Yoneo Suzucki, Chairman (*Planey Company Ltd.*) and H. Hori, Secretary (*Hori Mineralogy*). For more information contact Hori Mineralogy, P.O. Box 50, Nerima, Tokyo-176, Japan—phone Tokyo (03)-993-1418.

A society known as the Friends of Mineral, Tokyo, is issuing a new publication entitled *Quartz*, mostly in Japanese but with some English translations of titles and captions. They sound interesting . . . "More originality! At the starting of our society and journal" (by Hidemichi Hori), "Past and today of famous Ichinokawa mine" (by Shirō Nagasaka), "Realgar and orpiment from the Suzukura mine" (by Hiroyuki Ii), "Szaibelyite recently found at the Chichibu mine" (by Kuniaki Kato and Hidemichi Hori), "Collecting report: Hikagezawa gold mine, Shizuoka Pref." (by Hiroyuki Ii), "Some episodes around amateur mineralogy" (by Kin-ichi Sakurai), and one that piqued my interested in particular: "The relationship between sake and radioactive minerals in brewing." We wish the new society and journal the best of luck! To arrange a subscription write to *Friends of Mineral, Tokyo*, 4—13, Toyotamanaka, Nerima, Tokyo 176.

COMPUTER MINERAL FILE

William B. Simmons, Jr., Professor of Mineralogy at the University of New Orleans, is marketing a new PC-compatible computer program

(continued on page 207)

THE
Tonopah-Belmont Mine
MARICOPA COUNTY, ARIZONA

George B. Allen
Route 6, Box 32
Golden, Colorado 80403

William Hunt
10350 Andover Avenue
Sun City, Arizona 85351

The Tonopah-Belmont mine is a micromounter's paradise. An uncommon suite of base-metal oxides, carbonates, silicates, phosphates, arsenates, vanadates, sulfates, molybdates and chromates can be found at the mine. The abundance of species makes it an ideal introduction to the many mineral occurrences of the Big Horn Mountains.

INTRODUCTION

The Tonopah-Belmont mine is the second largest producer of metals in the aerially extensive Osborn Ag-Au district of Maricopa County in west-central Arizona. The primary property in the district is the U.S. mine, where a 1.4-million-ton orebody is now under production (Kerr, Dawson and associates, 1984). Mineralogically significant properties in the Osborn district include the Pack Rat, Moon Anchor and the Potter Cramer claims. The Pack Rat is the co-type locality for hemihedrite (Williams and Anthony, 1968), and the Potter Cramer claim is the type locality for wickenburgite. The Tonopah-Belmont mine is located in the southwest quarter of section 36, T4N, R7W, at the boundary between the Big Horn and Belmont Mountains of west-central Arizona. The mine is approximately 40 km south of Wickenburg. To get there drive south out of Wickenburg on the Vulture Mine road until the Tonopah-Aguila Road is encountered. From there continue south along a poorly maintained dirt road until Belmont Mountain, the host for the Tonopah-Belmont mine is in view. Then follow the obvious spurs toward the lone peak.

HISTORY

There are two conflicting accounts of the discovery of mineralization at Belmont Mountain. Ramsing (1957) reports the occurrence was discovered in 1904 and subsequently named the Belmont McNeal. Wilson (1967) reports that the discovery was made by George Dillar in 1907. In any event, the claims were sold in 1926 to the Tonopah-Belmont Company of Nevada which renamed the claims the Tonopah-Belmont mine. The Tonopah-Belmont company sank a 155-meter shaft and built a 50-ton bulk flotation plant (Ramsing, 1957). The mine was operated from that time until the Depression, at which time low metal prices forced closure. During the closure, some time between 1937 and 1939, a mine fire erupted. The rising hot gases from the fire traveled to the main adit level and along it to the old shaft which acted as a chimney. During the fire the roof of the tunnel melted to slag and some of the minerals were altered to a depth of 8 cm.

From 1941 until 1947 Ernest Dickie owned the mine. He extracted the high-grade pillars and reachable ore on each side of the shaft. Consequently the stopes caved up to the adit level and the shaft timbers collapsed.

The Arizona Bureau of Geology and Mineral Technology files report total historic production of 450,000 kg of copper, 4250 kg of silver and 240 kg of gold. Present mine workings consist of two steep inclines on the north side of Belmont Mountain, a 20-meter shaft on the south side which connects to a haulage adit, and numerous cuts and trenches which circumscribe Belmont Mountain.

GEOLOGY

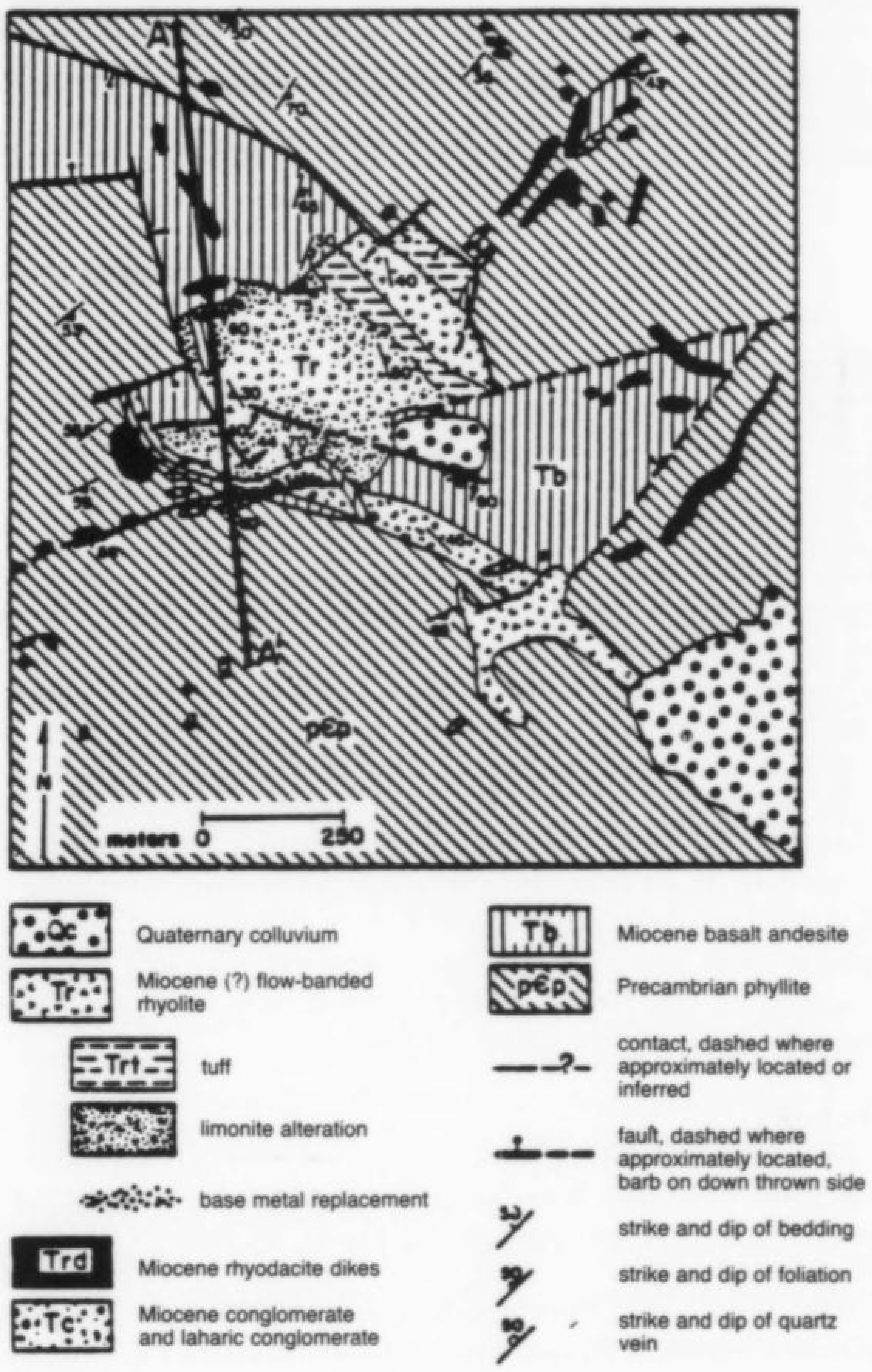
West-central Arizona is a region of varied, highly deformed Proterozoic, Mesozoic and Tertiary crystalline and (rare) sedimentary rocks. Our understanding of the geologic framework for this region is a product of a renaissance of regional and detailed geologic studies of the past seven years (Reynolds, 1980; Rehrig and Reynolds, 1980;

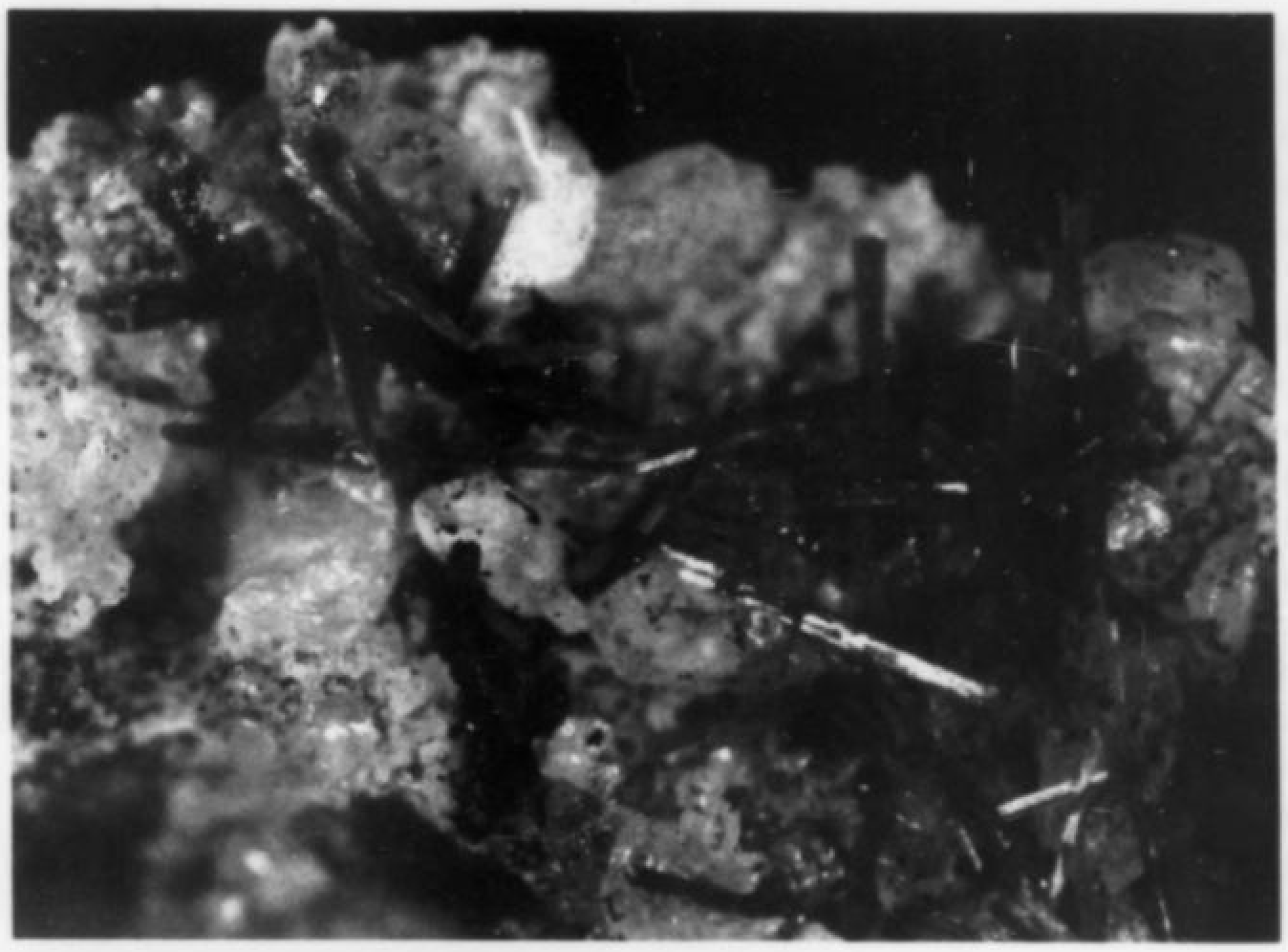
Figure 1. **Belmont Mountain; mine dumps at center.**

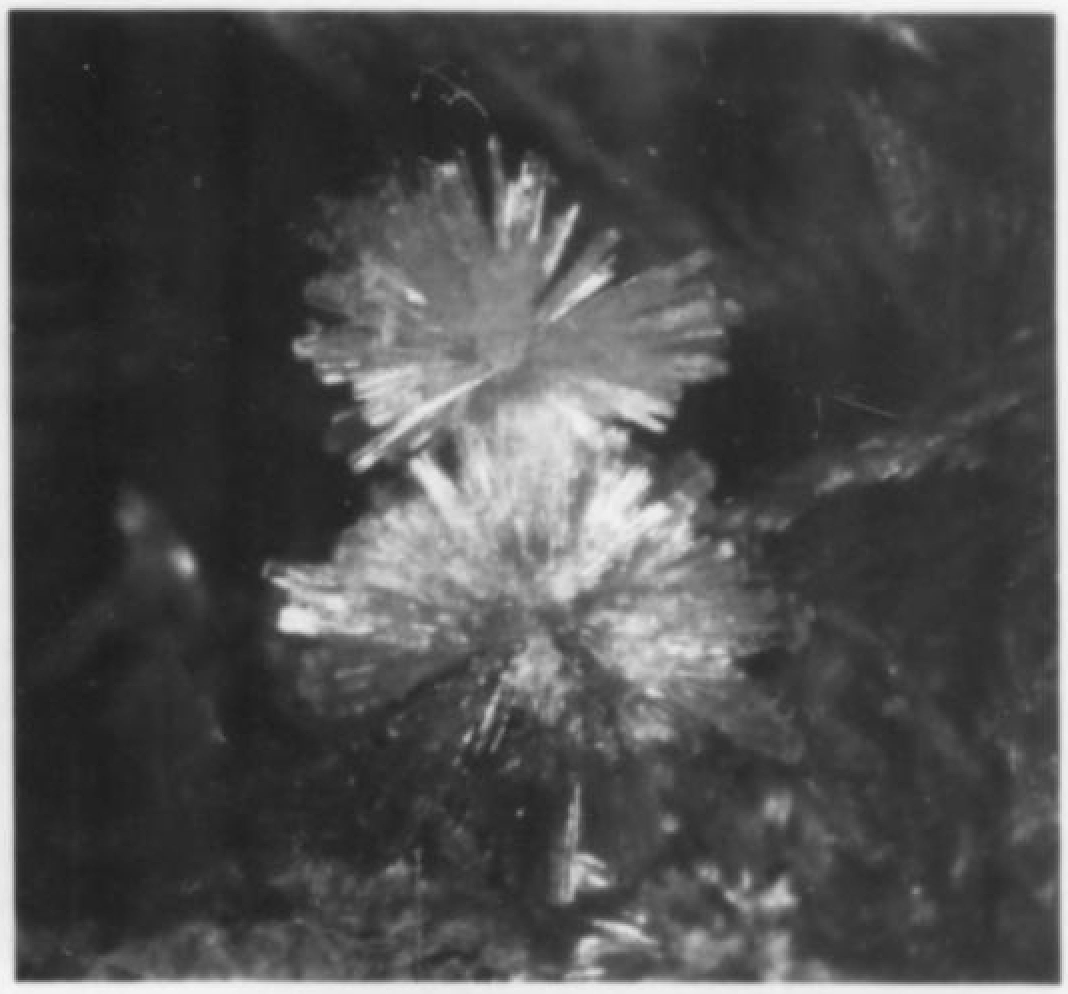
Rehrig *et al.*, 1980; Reynolds and Spencer, 1985; Hardey, 1984; Capps *et al.*, 1985a and 1985b). These works have established that the Harquahala Mountains to the west of the Big Horn Mountains and the White Tank Mountains to the southeast of the Belmont Mountains are metamorphic core complexes, raised segments of the middle crust which are bounded by low-angle normal faults. These faults are major structural discontinuities and are termed detachment faults. A detachment fault probably underlies the Big Horn and Belmont Mountains. Movement along the detachment fault and related faults in the upper plate is probably the cause of widespread tilting of the Tertiary rocks throughout the region.

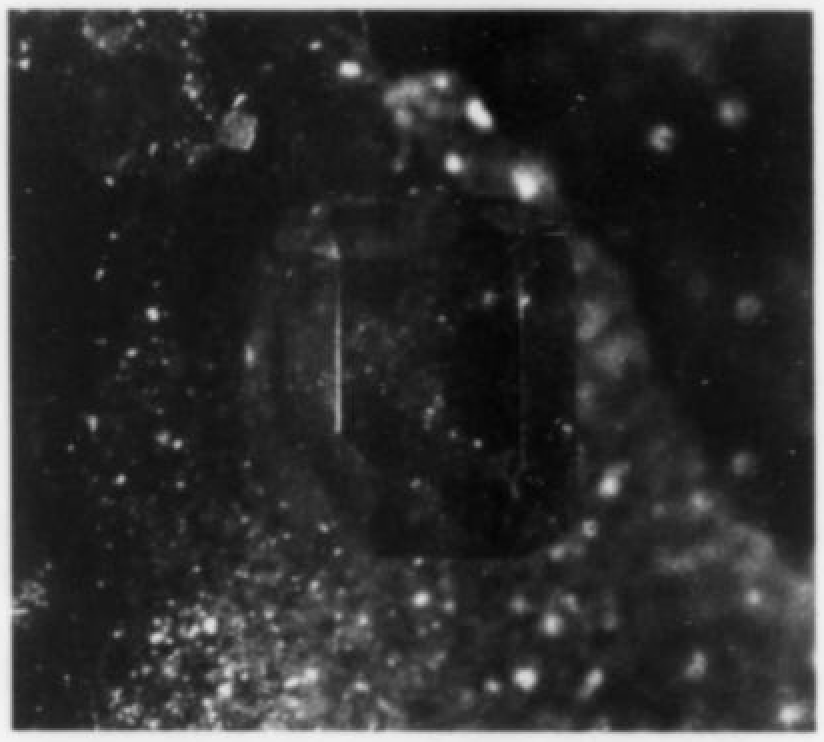
Three major lithologic terrains crop out in the Big Horn and Belmont Mountains: (1) Proterozoic amphibolite, phyllite, shist, gneiss and granite, (2) Mesozoic monzonite to diorite intrusives, and (3) Cenozoic mafic and silicic volcanic rocks and rare clastic sedimentary rocks. The entire Big Horn-Belmont Mountains area is cut by and tilted along north to northwest-trending low to moderate-angle normal faults that in places are cut by east to northeast-trending strike-slip faults. Four mineral districts occur in the Big Horn-Belmont ranges: the Tiger Wash barite-fluorite district, the Big Horn gold district, the Aguila manganese district, and the Osborne silver-gold-base metal district. The Big Horn district is thought to be Laramide (early Tertiary) in age (Allen 1985). The other three districts are likely to be mid-Tertiary in age and of an interrelated genesis (Allen 1985).

The geologic setting of the Tonopah-Belmont mine is moderately complex. The mine is hosted in a structurally isolated block of Miocene rocks that are surrounded by Proterozoic phyllite on all sides except to the southeast where the Miocene block is in fault contact with mid-Tertiary Belmont granite (Capps *et al.*, 1985a). The oldest rocks in the mine are Proterozoic phyllites, which are laminated steel-gray when fresh and brown to tan when weathered. Typically the phyllite is fine-grained and consists of 10% quartz and 90% muscovite. The phyllite generally strikes northeast with highly varied dips that are generally steep. Unconformably overlying the phyllite is a 26 to 40-meter sequence of mid-Tertiary volcanic and volcaniclastic rocks.

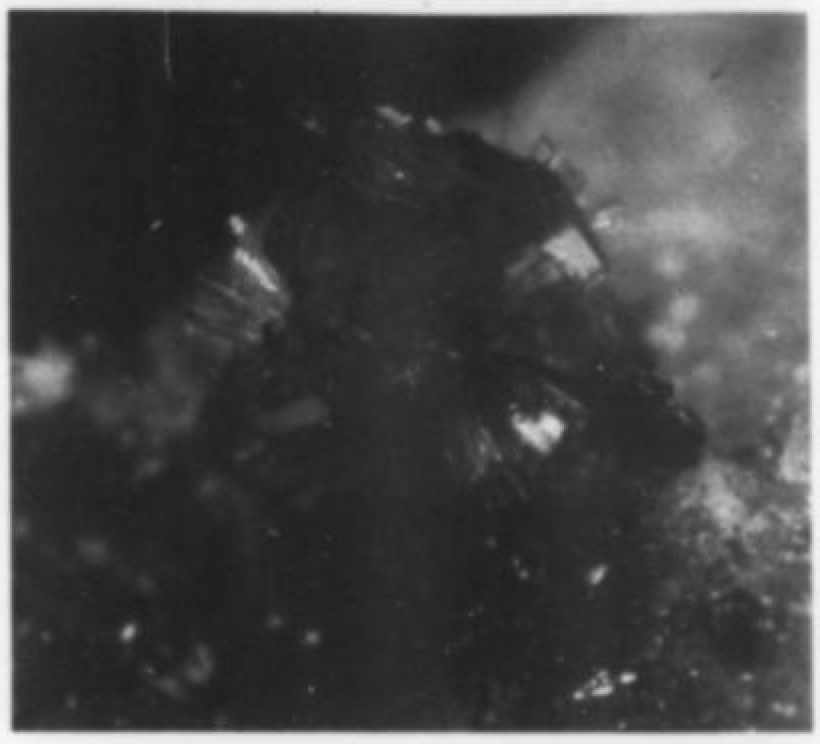


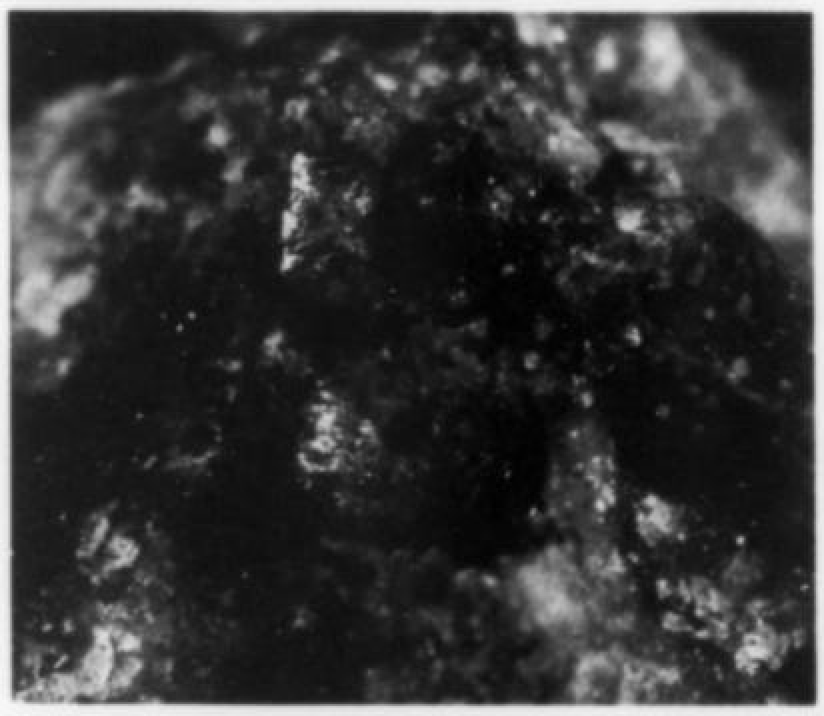






Clockwise from left:
Figure 2. **Wulfenite crystal, 3 mm.**
Figure 3. **Brochantite crystals to 2.6 mm.**
Figure 4. **Willemite sprays, 1.3 mm, on brochantite.**
Figure 5. **Caledonite crystals, 0.6 mm.**
Figure 6. **Linarite crystals, 1 mm.**
Figure 7. **Vanadinite crystal group, 3.5 mm, with descloizite.**
Figure 8. **Rosasite sphere, 3.5 mm.**
Figure 9. **Molybdofornacite crystals, 1 mm.**
All photos by William Hunt.





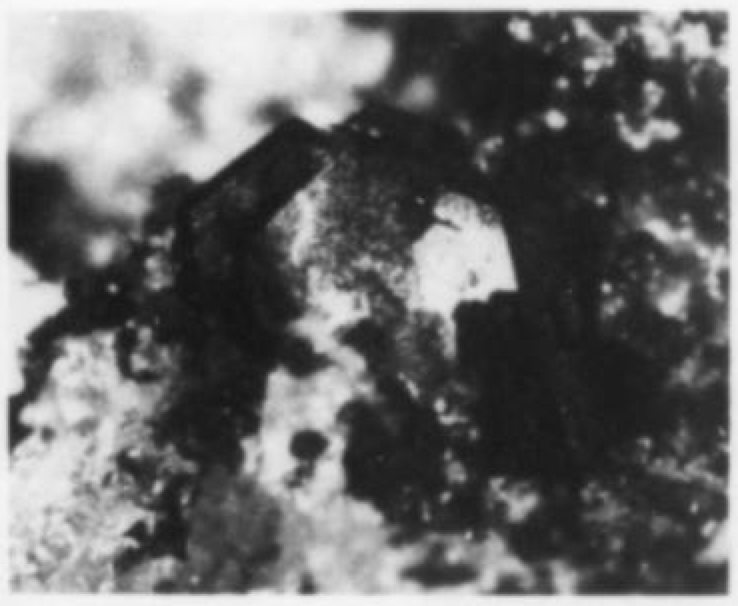
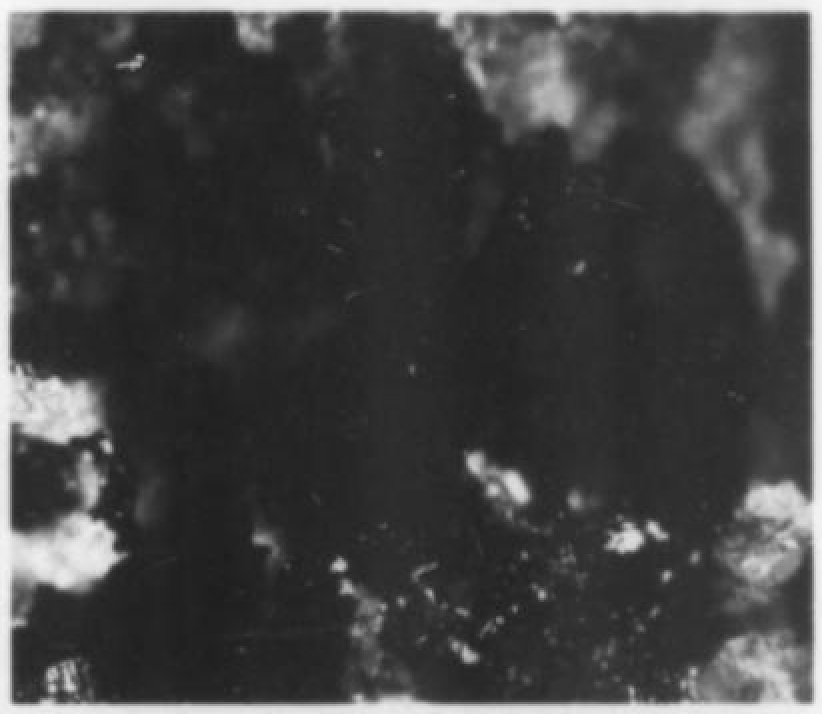
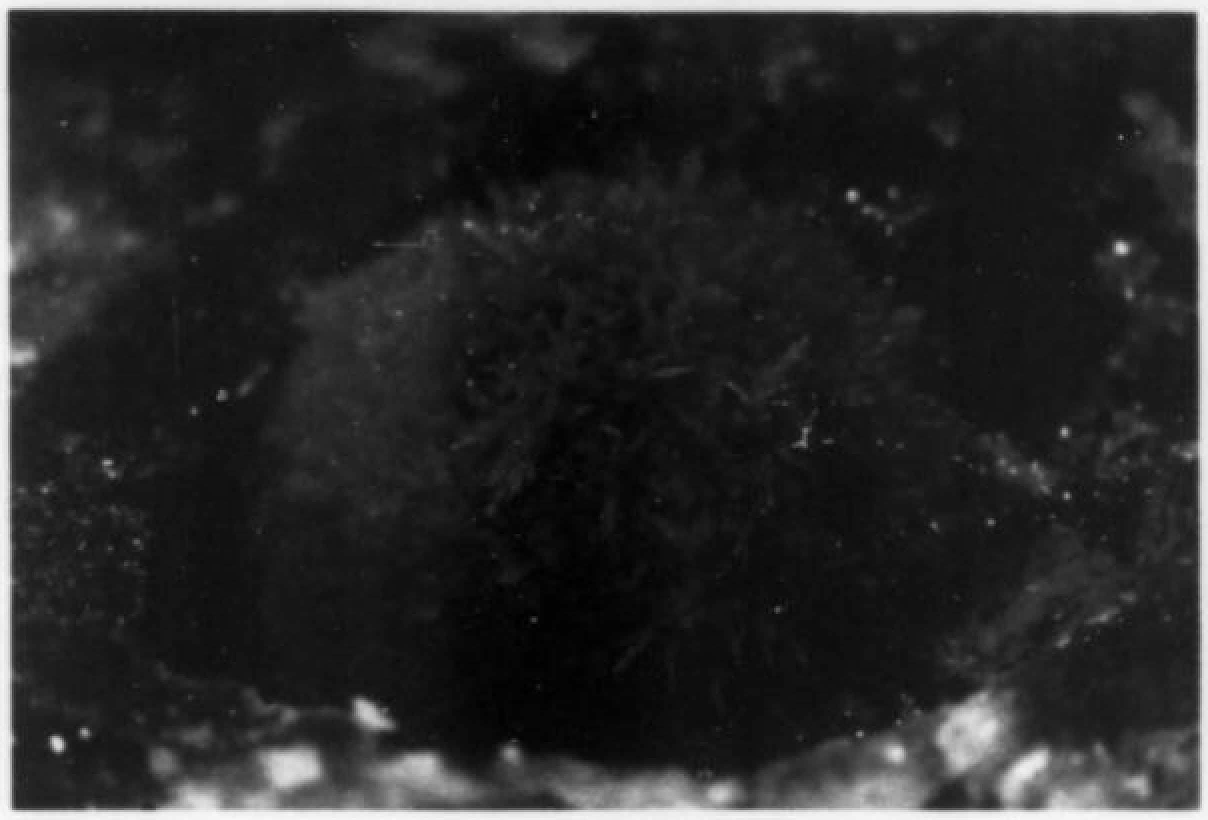
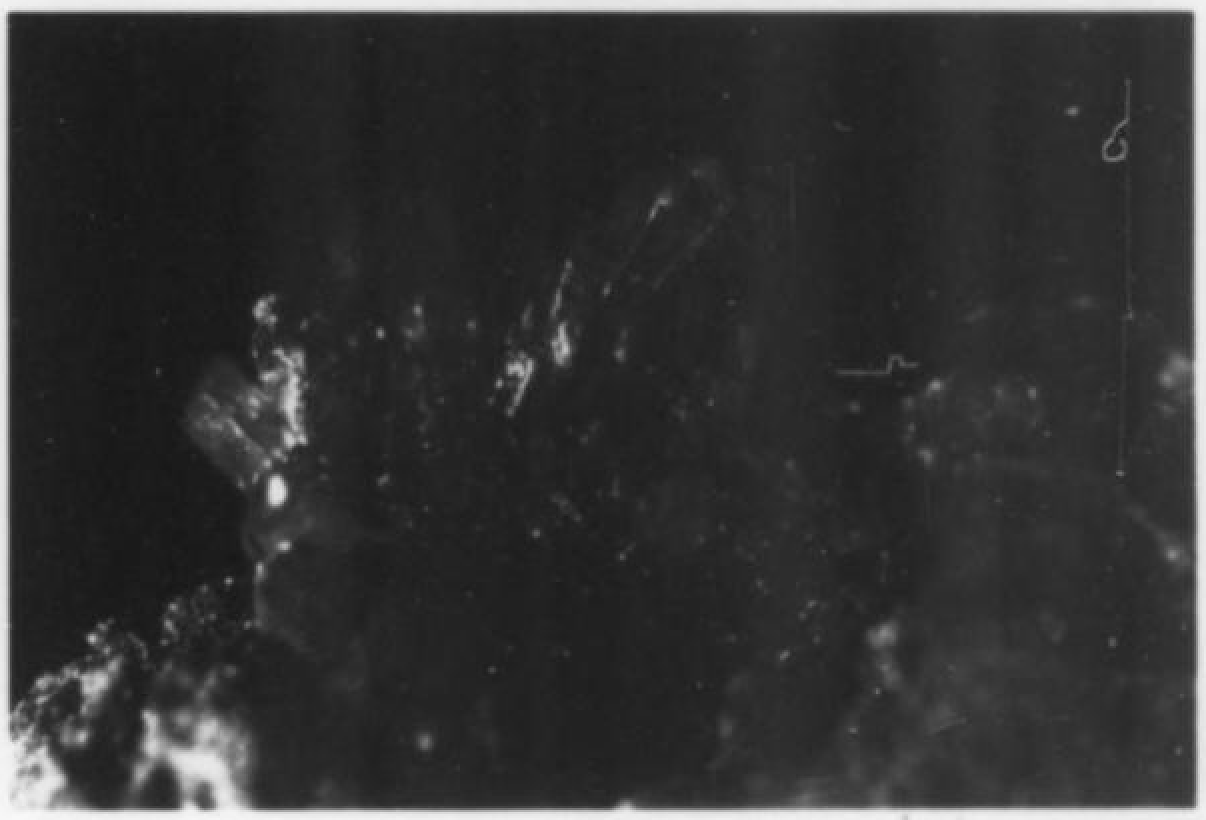


Figure 10. (above) **Plumbojarosite, 1 mm.**







From bottom to top the sequence is, (1) 10 to 13-meter basalt flow, (2) 12 to 18 meters of dark gray to green laharic sedimentary rock that has abundant phyllite clasts, (3) a thin flow of basalt, (4) 31 meters of rhyolite and tuff along with a flow-foliated rhyolite intrusive named the Morning Star Rhyolite, and (5) rhyodacite dikes which intrude each of the units in the section.

The major structure of the area is a N40°W-striking, southwest-dipping, low-angle fault that drops out from 500 meters northwest of Belmont Mountain for 2 km to the southeast where the fault changes to a north strike and a west dip (Capps *et al.*, 1985a). The low-angle fault juxtaposes moderately northeast-dipping rocks in the hanging wall against the Proterozoic phyllite. This major fault is offset by east-northeast-striking cross faults that are loci of mineralization. The N75°E to N65°E-striking, southeast-dipping normal faults are the localizing structures of the south and north Tonopah-Belmont veins. A N20°W-striking, northeast-dipping normal fault cuts off both veins on the west end of Belmont Mountain. On the east end of Belmont Mountain the northern vein appears to die out whereas the southern vein is offset by a N70°W-striking, southwest-dipping normal fault. The structural relationships suggest that mineralization occurred during low-angle faulting, but did not continue after tectonism. The fact that the veins were cut off by a fault at the 130-meter level (AZBGMT Files) supports a syntectonism age of mineralization.

The north vein trends N70°E and dips 60°SW. It is exposed along strike for 120 meters, and ranges in thickness from 1 to 12 meters. The vein is mostly banded milky quartz with lesser copper carbonates as fracture fillings in a fault zone. The encompassing fault zone is at the contact between the basal Morning Star rhyolite flow or intrusion and a basalt flow. Whether the Morning Star unit is an intrusion or a flow determines the exact nature of the localizing contact. The character of this contact is obscured by the highly varied vertical flow foliations in the rhyolite, the absence of demonstrable offset on the north and south sides of the outcrop, and the unclear nature of the contact between the Belmont Mountain massif and the Morning Star tuff to the northeast.

The south vein trends N75°E, dips 80°NW, extends for 150 meters and varies from 2 to 10 meters in thickness. The south vein is localized at the contact of the basal laharic unit with the lowermost basalt, both of which are in the hanging wall of the steeply dipping normal fault of small displacement. This vein consists mostly of milky quartz breccia and replacement textures in contrast to the banded fracture-filling appearance of the northern vein.

Fluid inclusion studies were initiated with specimens from the Tonopah-Belmont veins, but a paucity of suitable calcite or quartz prevented acquisition of thermometric or compositional data. Studies on specimens from the geologically similar U.S. mine, however, were successful. Homogenization temperatures and freezing point depressions, which indicate the temperature and salinity of ore forming fluids, suggest temperatures and salinities ranging from 190° to 225° C and 8 to 14% total salt (Allen 1985).

MINERALS

Even though 46 minerals have been found at the Tonopah-Belmont mine, the micromount collecting potential has only begun to be probed. The fact that most of the underground workings are inaccessible in no way detracts from the collecting possibilities. Each of the identified species has come from the dump samples and all but three are found in euhedral microcrystals.

The large dump below the adit contains much barren rock but, with some searching, mineralized material can be found. Fortunately the small dump above the adit mostly consists of mineralized rock.

Outcrops peripheral to the old workings include 5 to 50-cm mineral veins that were ignored by the early miners. These small seams afford good specimens for those willing to break bedrock.

Table 1 lists and describes minerals found to date and their asso-

***Table 1.* Minerals found at the Tonopah-Belmont mine**

Species/Composition	Habit and Associations	Location
Anglesite $PbSO_4$	Mainly as a gray rind surrounding relict galena which is, in turn, surrounded by cerussite. There is a second generation of white, poorly crystallized material associated with linarite, brochantite, caledonite and leadhillite.	1, 2, 3
Aurichalcite $(Zn,Cu)_5(CO_3)_2(OH)_6$	Found sparingly as pearly blue-green blades with malachite and rosasite.	1, 2
Azurite $Cu_3(CO_3)_2(OH)_2$	Represented by malachite pseudomorphs after azurite to 6 mm.	8
Barite $BaSO_4$	Mainly as opaque white laths in quartz; also as brilliant, transparent, euhedral microcrystals to 1.5 mm, with descloizite.	1, 2
Brochantite $Cu_4(SO_4)(OH)_6$	Bright green microcrystals, acicular to prismatic, with linarite, caledonite, leadhillite and anglesite.	1, 2, 3
Calcite $CaCO_3$	Rare, opaque white rhombohedrons on willemite with hydrozincite.	1
Caledonite $Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$	Pale blue crystals to 2 mm with linarite, brochantite, leadhillite and anglesite	1, 2, 3
Cerussite $PbCO_3$	White crystalline crusts on anglesite rinds surrounding galena cores, also transparent euhedral crystals to 5 mm with brochantite.	1, 2
Chalcophanite $(Zn,Fe,Mn)Mn_3O_7{\cdot}3H_2O$	Found only in peripheral quartz veins outside the orebody, as striated rhombohedrons (with a brilliant *c* face) to 1.5 mm, with cryptomelane.	3
Chalcopyrite $CuFeS_2$	Weathered remnants, sometimes covered by covellite.	1, 2, 3
Chlorargyrite AgCl	Seen in a fragment of high grade ore with gold and willemite.	4
Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4{\cdot}nH_2O$	Cavity fillings and pseudomorphs after an acicular mineral.	1, 2, 3, 5
Coronadite $Pb(Mn^{+4},Mn^{+2})_8O_{16}$	Pitch-like botryoidal incrustations with radial structure.	4

Covellite CuS	Iridescent purple coatings on chalcopyrite and sphalerite.	1, 2
Creaseyite $Pb_2Cu_2Fe_2Si_5O_{17}\cdot 6H_2O$	Pale green acicular crystals to 0.8 mm with plumbojarosite.	5
Cryptomelane $K(Mn^{+4},Mn^{+2})_8O_{16}$	Acicular crystals with chalcophanite, in peripheral quartz veins.	3
Descloizite $PbZn(VO_4)(OH)$	Sparingly as pale to dark brown crystals to 1.4 mm on barite and vanadite.	1, 2, 7
Epidote $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$	Pale green microcrystals in basalt.	7
Galena PbS	Corroded cores mainly, but also in one small cavity as 0.1-mm cubes.	2
Goethite $FeO(OH)$	Thin iridescent to yellow velvety coatings.	1, 2, 3, 5
Gold Au	In high grade ore with gypsum.	4
Gypsum $CaSO_4\cdot 2H_2O$	"Ram's horn" habit.	4
Hematite Fe_2O_3	Bright red scales and botryoidal masses.	1, 8
Hemimorphite $Zn_4Si_2O_7(OH)_2\cdot H_2O$	Locally abundant as rosettes of 5-mm crystals with most of the secondary minerals.	1, 2, 3
Hydrozincite $Zn_5(CO_3)_2(OH)_6$	Pearly, matted crystals on one specimen with calcite and willemite.	1
Jarosite $KFe_3(SO_4)_2(OH)_6$	Pale to dark brown tabular crystals to 2 mm.	2, 5
Leadhillite $Pb_4(SO_4)(CO_3)_2(OH)_2$	Subhedral crystal crusts and also surface alteration coatings on cerussite, intimately associated with caledonite and linarite.	2, 3
Linarite $PbCu(SO_4)(OH)_2$	Subhedral crystal groups; occasional euhedral transparent blue crystals to 1.5 mm with brochantite, caledonite, anglesite and leadhillite.	1, 2, 3
Malachite $Cu_2(CO_3)(OH)_2$	Sprays of acicular crystals with rosasite; less abundant than brochantite.	2, 8
Mimetite $Pb_5(AsO_4)_3Cl$	Sparingly as opaque, yellow 0.5-mm pyramidal crystals with wulfenite, fornacite and willemite.	2, 3, 7
Minium Pb_3O_4	Bright red pseudomorphs after cerussite on willemite.	
Molybdofornacite $Pb_2Cu[(As,P)O_4]$ $[(Mo,Cr)O_4](OH)$	Pale to dark green euhedral crystals to 1.2 mm, and rosettes of subhedral microcrystals with willemite, wulfenite and pyromorphite.	2, 3, 6
Murdochite $PbCu_6O_{8-x}(Cl,Br)_{2x}$	Brilliant cuboctahedrons in a single willemite pocket.	1
Plattnerite PbO_2	Tufts of brilliant black acicular crystals in oxide ore.	1
Plumbojarosite $PbFe_6(SO_4)_4(OH)_{12}$	Pale to dark brown hexagonal scales, some coated by creaseyite, at one location.	5
Pyrite FeS	Represented only by pseudomorphs.	8
Pyromorphite $Pb_5(PO_4)_3Cl$	Colorless to pale green prismatic crystals, some tapered, to 2.5 mm with fornacite, vauquelinite and wulfenite.	2, 3, 4, 6
Quartz SiO_2	Mainly a gangue mineral but also as druses on secondary minerals.	1, 2, 3, 5, 6
Rosasite $(Cu,Zn)_2(CO_3)(OH)_2$	Balls of acicular crystals to 4 mm; blue to green.	1, 2, 3
Sphalerite ZnS	Only as remnants in weathered ore, sometimes coated with covellite	1
Sulfur S	On one specimen with gypsum and gold.	5
Vanadinite $Pb_5(VO_4)_3Cl$	Orange to red prisms to 5 mm, some with full or partial pyramidal terminations. Scarce on the south side of the mountain but plentiful on the north.	3, 6, 7
Vauquelinite $Pb_2Cu(CrO_4)(PO_4)(OH)$	Greenish brown to brown crystals to 2 mm in groups with willemite, wulfenite and pyromorphite. Much rarer than fornacite.	2, 3, 6
Willemite Zn_2SiO_4	Very plentiful as transparent, prismatic crystals to 3 mm, some tapered. Also as sprays of white acicular crystals.	1, 2, 3
Wulfenite $PbMoO_4$	Pale to dark orange tabular crystals to 8 mm with pyromorphite, mimetite, willemite, fornacite and vauquelinite.	2, 3
Zircon $ZrSiO_4$	Dark brown crystals, less than 0.05 mm, in andesite.	1

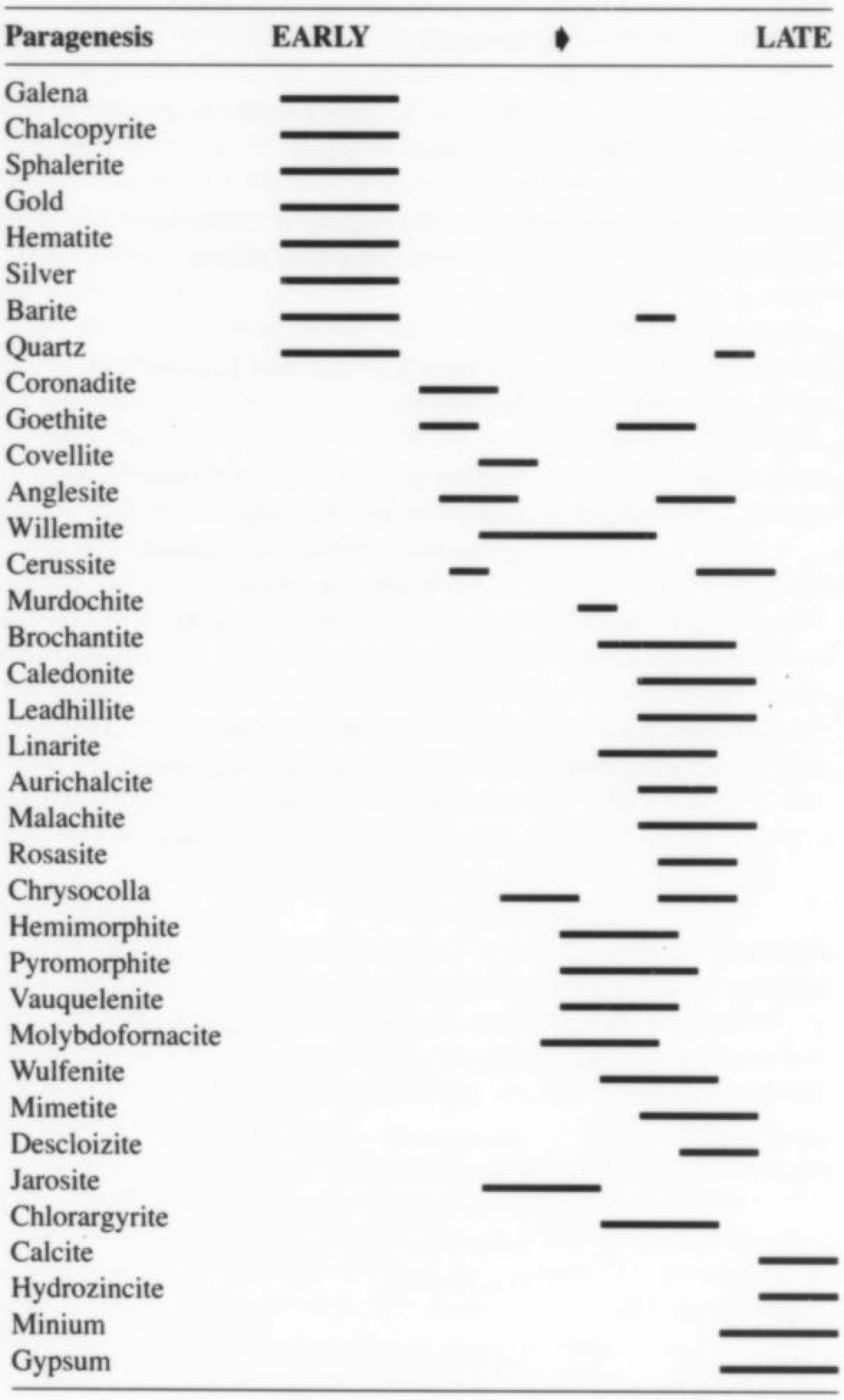
ciations. The numbers at the right-hand column are keyed to the list directly below and indicate where the minerals are found.

1—Large dump below the adit
2—Old dump above the adit
3—Outcrops above the old workings
4—Underground on the adit level
5—Dump on the north side of the mountain
6—Outcrops on the north side of the mountain
7—Prospects on the north side of the mountain
8—Prospects on the east side of the mountain

PARAGENESIS

The sequence of crystallization of the major phases, from early to late, is: sphalerite-pyrite-chalcopyrite-galena as primary sulfides plus gold; quartz as primary gangue. Aurichalcite, smithsonite, azurite, malachite and jarosite are secondary minerals. A detailed paragenitic study based on microcrystals indicates early pyrite-galena-chalcopyrite-sphalerite-gold-hematite-native silver-barite and quartz. A second generation of minerals include coronadite, goethite, covellite, anglesite, cerussite, brochantite, caledonite, leadhillite, linarite, aurichalcite, malachite, rosasite, chrysocolla, hemimorphite, pyromorphite, vauquelenite, molybdofornacite, wulfenite, mimetite, descloizite, jarosite and chlorargyrite. The final generation includes minor calcite and hydrozincite along with more abundant minium and gypsum.

The chemistry of the paragenesis suggests some overall patterns: primary introduction of metals and sulfur resulting in an early sulfur-native element stability phase with barite-quartz gangue; a diverse episode of oxide, sulfate, carbonate and lesser silicate stability; an episode introducing the heavy elements phosphorus, arsenic, molybdenum and vanadium; and a final episode with oxide-sulfate and lesser carbonate stability.



As stated previously, complex variations in the water table and limited accessibility of the lower workings have prevented determination of a definitive paragenesis. The paragenetic chart below was worked out using only specimens from locations 1, 2 and 4. These locations are all on the same zone of mineralization.

DISCUSSION

The stratigraphic, structural and geochronological framework established by Capps *et al*. (1985 a and b), combined with the district-wide fluid inclusion data of Allen (1985) and the paragenetic data presented here, suggests an integrated geologic history for the Tonopah-Belmont mine mineral occurrence.

Mineralization at Belmont Mountain occurred between 21 and 16 million years ago during a period of widespread volcanism and block tilting. The lower age is constrained by radiometric determinations on biotite from the Morning Star Rhyolite host rock. The upper age is constrained by the age of the fault that cuts the Tonopah-Belmont vein at its eastern end. This fault is of a generation that regionally cuts 16 m.y. basalt. The mineralizing fluids that formed the Tonopah-Belmont deposit were probably dilute brines, having temperatures of 170° to 230° C. The range-wide similarity of fluid inclusions and widespread occurrence of potassium-metasomatized rocks (Allen 1985) suggests that these fluids were regional in distribution and manifest themselves only where local structures connect to deeper seated conduits. The mineralization at the Tonopah-Belmont mine may be a consequence of fluids rising along the conduits of the rhyolite vent at Belmont Mountain, and subsequent cooling and dilution as meteoric waters mixed with the hydrothermal fluids (Allen, 1985). The fluid inclusion data from the U.S. mine permits cooling and dilution as a mechanism of mineral precipitation.

The paragenetic sequence outlined combined with the historic record of a mine fire suggest five mineral-forming episodes: (1) an early base-metal sulfide, native precious metal, quartz, barite hypogene episode which was caused by dilution and cooling of hydrothermal waters by meteoric waters; (2) a series of oxide-silicate-hydroxide-carbonate-forming episodes as a consequence of fluctuating watertable levels; (3) a possible second phase of epithermally introduced elements expressed by the appearance of phosphates, arsenates, molybdates and vanadates; (4) a final dropping of the watertable and seasonal formation of calcite, hydrozincite, minium and gypsum as a result of descending perennial waters; and (5) an episode of high-temperature low-pressure mineral stability resulting from the late 1930's mine fire.

ACKNOWLEDGMENTS

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(continued on page 207)

James Bowdoin and Parker Cleaveland

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In the years immediately following 1800, the study of mineralogy and geology in America was off to a good start. This was inspired by the increased formal study of these sciences in Europe, the increasing need for industrial metals and minerals by the colonists, and the gradual relaxation of religious prejudice against the teaching of these subjects. Bowdoin[2] College is acknowledged as one of the leading centers of activity in the geological sciences during this time (Frondel, 1970). Professor Parker Cleaveland, teaching these sciences at Bowdoin, was the motivating force and he had a very complete and valuable collection to work with, the James Bowdoin mineral collection.

JAMES BOWDOIN

James Bowdoin III, son of Governor Bowdoin of Massachusetts, being very well educated and scientifically inclined, was much interested in the study of mineralogy and geology. He purchased nearly everything in print on the subjects, including the works of Rene Haüy, Professor and Curator of minerals at the School of Mines, in Paris, France, whose famous five volumes were published in 1801. Haüy's work so impressed Bowdoin that he negotiated for the purchase of a mineral collection from him. In 1806, the collection was assembled and catalogued by a Mr. Lucas. According to the catalog it consisted of 449 specimens and 58 crystal models done in clay. Actually there were 480 mineral specimens because Mr. Lucas had a propensity for duplication of numbers. Bowdoin was apparently so impressed with the ceramic crystal models that shortly afterward he purchased a more complete set of some 300 pieces.

About 1806 Bowdoin obtained from William Maclure 119 specimens of rocks and minerals, mostly European, with a few from New England. Maclure travelled extensively in Europe, visiting most of the famous early localities. For his later extensive work in America he became known as the father of American geology.

To this fine collection Bowdoin added considerable scientific apparatus: an electrometer, a goniometer, a specific gravity balance, chemicals and blow-pipes; so that at this early date he had a very fine and complete collection composed primarily of early European specimens and instruments.

Bowdoin's health was rather poor and later, in 1810, it became quite serious, so much so that Benjamin Vaughn, M.D., a friend of both Bowdoin and Parker Cleaveland, addressed a letter (Cleaveland papers, Bowdoin College Library) in which he discussed Bowdoin's rapidly failing health and said among other things ". . . you will at the same time have his collection of minerals . . ." Just over a year later, Oct. 11, 1811, James Bowdoin III died at age 59. His will bequeathed the mineral collection, scientific apparatus and his extensive library (James Bowdoin III Library, Bowdoin College Library) to Bowdoin College. On Dec. 3, 1811, John Abbot received the material on behalf of the college and recorded (Bowdoin College Records, Bowdoin College Library) that it consisted of 623 mineral specimens, 385 crystal models, scientific apparatus and an extensive library. Mr. Abbot placed a value of $400.00 on the mineral collection and $200.00 on the crystal models. There is no record to indicate whether or not this price had any relation to what Bowdoin may have paid Haüy.

In May, 1812, just a few months after arrival of the collection, Parker Cleaveland made a report (College Records, 1812, Bowdoin College Library) to the board of overseers of the college which stated "The James Bowdoin Collection is very valuable both in regard to variety and quality of specimens. In addition to the minerals there is

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[1] This article is published posthumously, and has been edited by A. M. Hussey, II, Chairman, Department of Geology, Bowdoin College.

[2] Pronounced "Bōd'n."

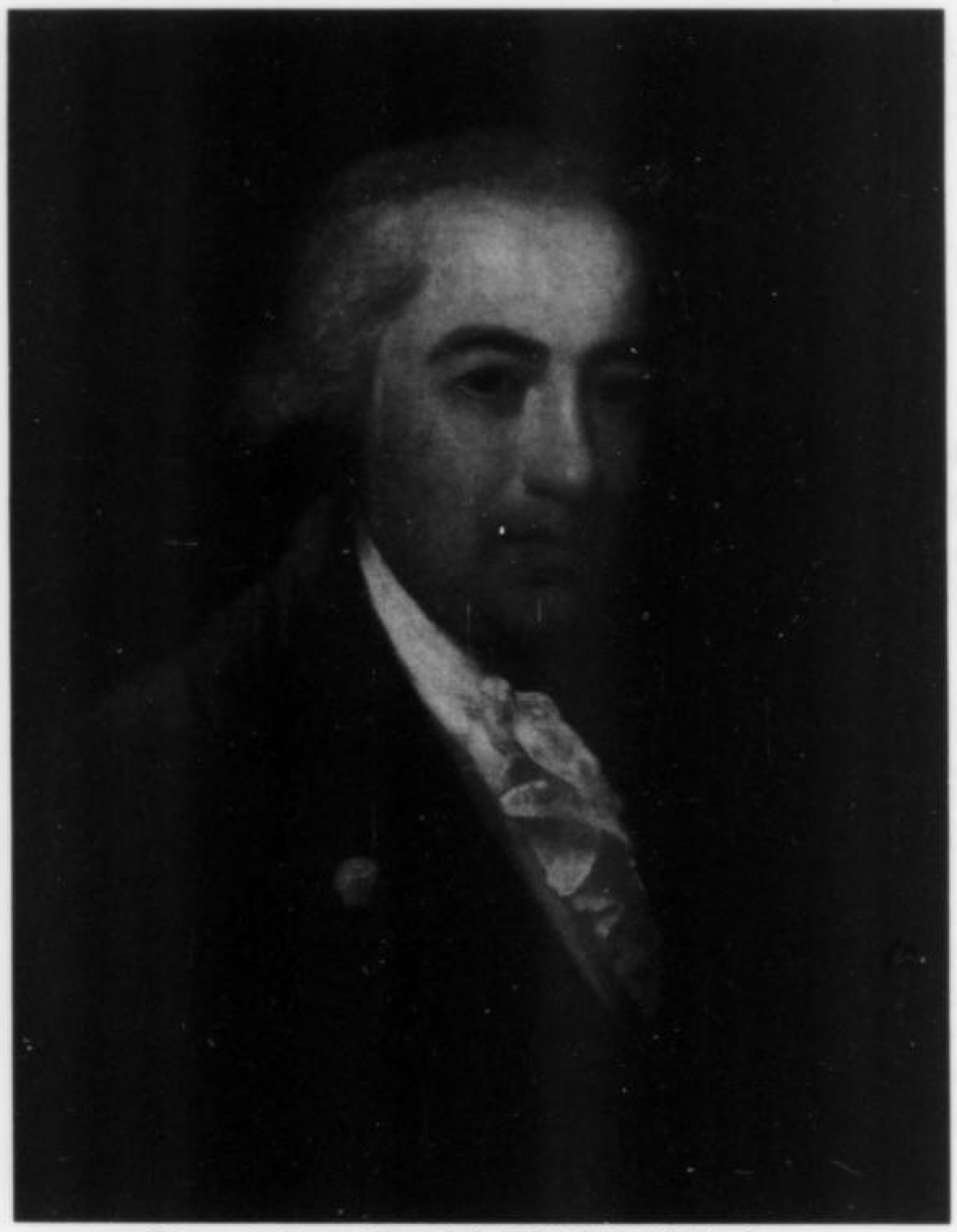


Figure 1. **James Bowdoin III (1752–1811), from a painting by Gilbert Stuart in the Bowdoin College Museum of Art.**

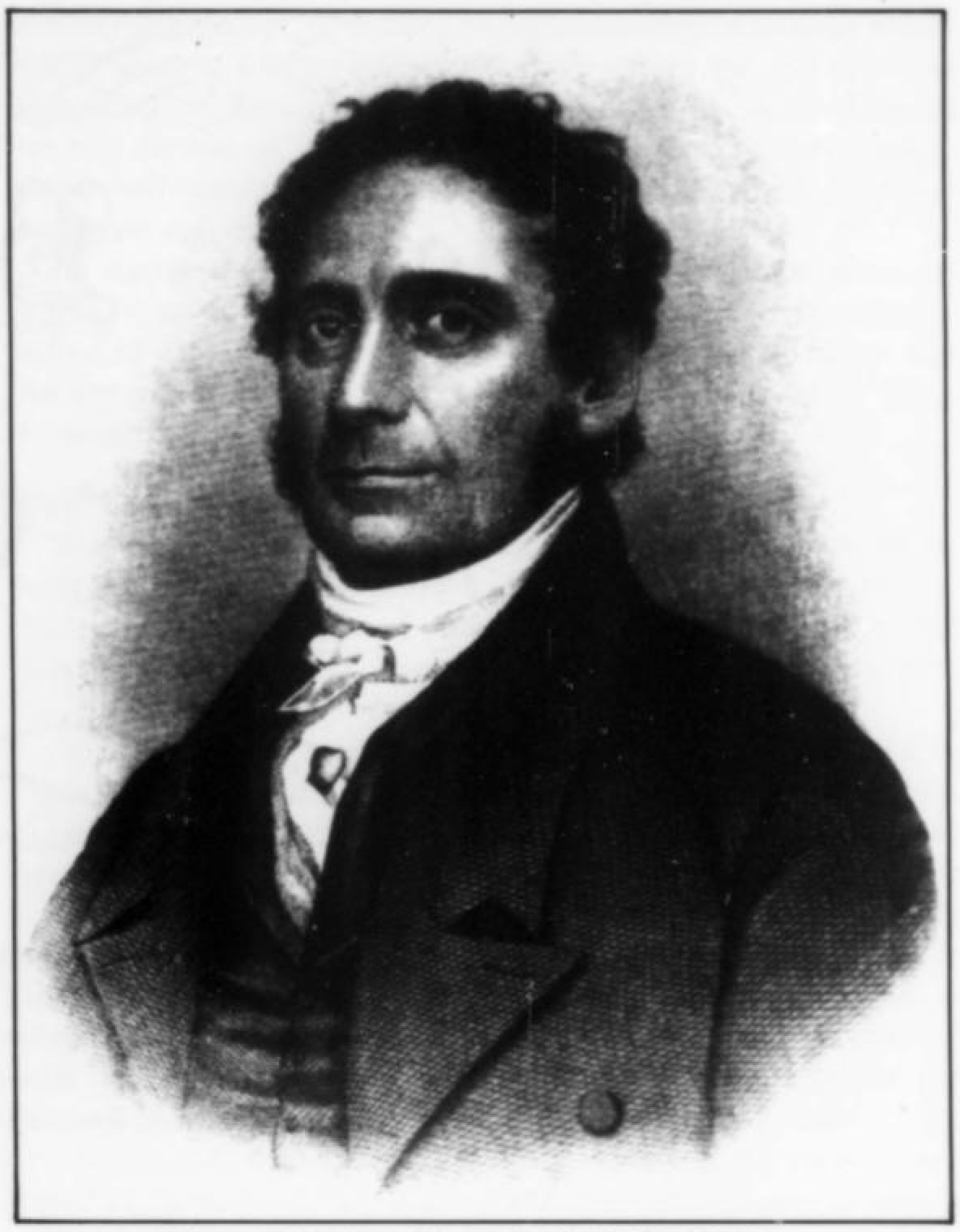


Figure 2. **Parker Cleaveland (1780–1858).**

also a very fine collection of crystallography consisting of 385 models. This collection is composed of two parts: one containing 56 models of crystals in porcelain clay designed to illustrate Haüy's very beautiful theory of the formation of crystals. The other part consists of 329 models of crystals in painted clay, designed to exhibit the various primary and secondary forms natural crystals assume." Cleaveland made a new catalog for the collection (which included the Maclure specimens and all the crystal models as well as the original Haüy specimens), written for the most part in French script.

It was most opportune for Cleaveland that this collection arrived when it did, because he was already working on the manuscript for his text, *An Elementary Treatise on Mineralogy and Geology*, the first in America, which was published in Boston in 1816. The James Bowdoin Collection is therefore unique historically for it ties together the work of Rene Haüy, father of crystallography; William Maclure, father of American geology and Parker Cleaveland, father of American mineralogy. It is doubtful if any other early American collection can claim a similar distinction.

In 1872 Peleg W. Chandler, son-in-law of Cleaveland, decided to establish a memorial to his famous father-in-law; Chandler financed the rebuilding of the top of Massachusetts Hall on the Bowdoin College Campus so that it became a fairly large museum. At the dedication in 1873, Parker's nephew, Nehemiah Cleaveland, named it "The Cleaveland Cabinet." The Cabinet contained the James Bowdoin Collection in two large showcases on the north wall; in other cases around the room were Cleaveland's private collection and the large college collection he had assembled. In the center of the floor was the Shattuck Shell Collection in glass-topped cases. For many years following, the James Bowdoin Collection was often referred to as the Haüy Collection. The Cleaveland Cabinet was quite an attraction into the early 1900's. I remember seeing it many times as a small boy.

The college was expanding quite rapidly and therefore space for classrooms and offices became a problem. It first resulted in selling the Shattuck Shell Collection to clear the main floor, and next moving some minerals and display cabinets to the Searles Science Building where classes in mineralogy were being held. When more space was required, during the teens and early twenties, it was decided to cull the remaining specimens in Massachusetts Hall, eliminating what appeared to be the least spectacular material. Well over a thousand specimens were destined for the dump, including a considerable portion of the James Bowdoin Collection. Samuel Furbish, then treasurer of the college, asked for and was given the entire lot of culls which he placed in storage in a shed back of his brother's hardware store in Brunswick, where it remained well into the 1930's. In the spring of 1938 the brother, Benjamin Furbish, contacted me, knowing my interest in minerals, and offered the entire lot because he needed the space it occupied. Again space problems were hounding the Cleaveland Cabinet of Minerals. Needless to say the boxes and barrels of specimens were accepted and placed in dry storage for examination at leisure. What may have appeared dull and uninteresting to those doing the culling, was often historically valuable. The years in the shed back of the hardware store resulted in many labels falling off, rotting or otherwise becoming lost so that tracing back to the original collection is very difficult, involving much detective work and ingenuity. However, some of the specimens have been identified and returned to the collection at the college.

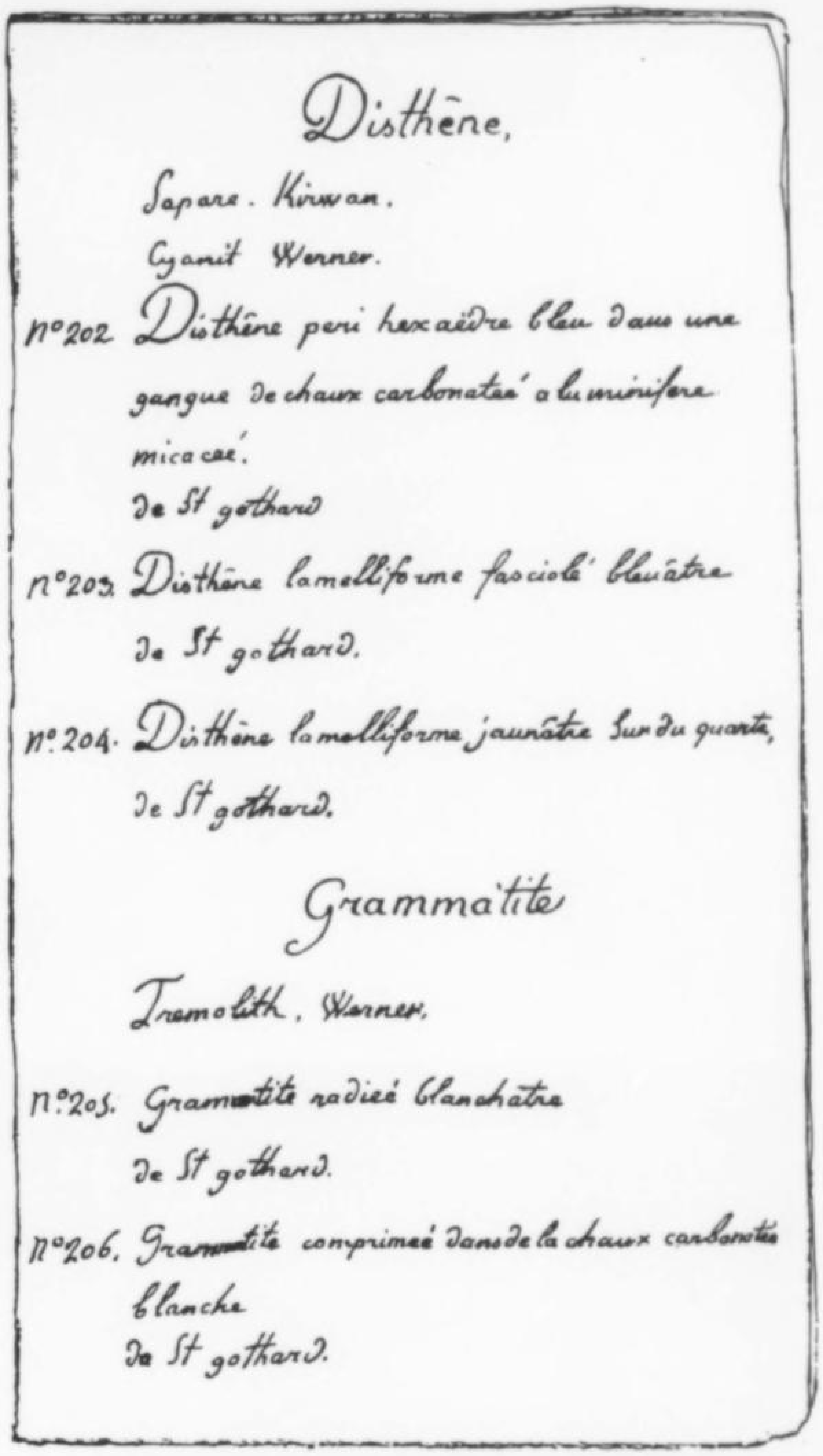
Even after the Cleaveland Cabinet had been rigorously culled it occupied too much space and finally it was boxed and placed in the basement of the college chapel, a humid and often wet place where labels molded, fell off and rotted. Some specimens were stolen. This condition existed until 1956.

Bowdoin College had dropped mineralogy and geology from its curriculum following Professor Meserve's death in 1941 and did not reinstate the course until 1956 when Professor M. W. Bodine was appointed. The intervening fourteen years were particularly hard on the collections, as almost no interest in the specimens existed. Professor Bodine, realizing the historic value of this mass of specimens, immediately began attempts to salvage it. Because of so many labels being lost he started a new general catalog, listing specimens by an assigned number and species name. Some twenty to thirty percent of the specimens had enough of the original labels to identify them positively to belong in a definite collection. The others were listed only by number and species name. The work was not completed when Professor Bodine went on to another college and Dr. Arthur M. Hussey II came to take over the department. Dr. Hussey continued the work as time permitted, and much labor with ingenuity, as well as detective work, resulted in some 4500 specimens being tentatively cataloged. Of these over a hundred specimens were of the James Bowdoin Collection. I have continued the work, as a volunteer curator, and today there are just over 170 of the James Bowdoin specimens accounted for. The remainder of the original 599 specimens which included Haüy and Maclure material will probably never be positively identified because of the loss of their original labels. The Haüy crystal models, on the other hand, have been much easier to properly identify, and now 254 out of a possible 385 have been located.

The idealized geometric forms that minerals assume when crystallized constitute the bulk of Haüy's models. (Originally each model had a small paper label cemented to it giving a number, name and crystalline form. Unfortunately, most of these labels have become illegible or detached and lost. With Haüy's atlas of crystal model drawings in volume 5 of his *Traité de Mineralogie*, it is nevertheless not difficult to assign to each the number, name and form originally designated on the labels. Some of the models show the effect of age, wear and actual abuse. Corners are knocked off and occasionally fractures of considerable consequence exist.

The whole collection is being recataloged, minerals and crystal models, using a card index in such a manner that the original catalog applies, and Haüy's system of classification is preserved for historical reasons. Haüy had four classes for minerals as follows: Substances Acidiferes, Substances Terreuses, Substances Combustibles, Substances Metallique. He used a numbering system for specimens that ran consecutively through all four classes. A cross reference is being set up listing mineral and petrology specimens by present-day names and classification. It is divided into three parts; mineralogy, petrology and curios. At the time when Haüy made up the collection for James Bowdoin it was common practice to include rocks under the general heading of minerals and to add a few curiosities and man-made substances as one's fancy dictated. This is true of the James Bowdoin collection, which lists under minerals quite a few rocks and curios such as a calcified bird's nest, an asphalt-saturated piece of linen from an Egyptian mummy, cast pieces of tin, lead, bismuth, antimony and chemicals made in the laboratory, such as salammoniac and blue vitriol. The number of these curiosities is not great, being well under five percent. One amusing example is specimen No. 249, classed under "substances metallique." It is a lump of melted and oxidized lead, the result of a bolt of lightning striking a lunatic asylum in Paris, France. The following is a translation of the French under specimen No. 249 in the original catalog.

> Lead melted and oxidized by the fluide electric, coming from the ball of the dome of the Salpetriere,[3] when it was thunderstruck by the thunder. From Paris.



Disthène,

Sapare. Kirwan.

Cyanit Werner.

n°202 Disthène peri hexaèdre bleu dans une gangue de chaux carbonatée aluminifère micacée.

de St gothard

n°203. Disthène lamelliforme fasciolé bleuâtre

de St gothard.

n°204. Disthène lamelliforme jaunâtre sur du quartz,

de St gothard.

Grammatite

Tremolith. Werner.

n°205. Grammatite radiée blanchâtre

de St gothard.

n°206. Grammatite comprimée dans de la chaux carbonatée blanche

de St gothard.

***Figure 3*. A typical page from the original Haüy catalog.**

The James Bowdoin Collection is predominantly European with the exception of a very few New England specimens obtained from William Maclure. Of the 119 Maclure specimens, the most part are European because he travelled extensively in Europe, collecting from many famous early localities before settling down to his famous early geological work in America. The Bowdoin Collection represents a broad overall coverage including some original localities from which minerals received their names and other localities long since exhausted. There are beautiful small crystals of cobaltite from Tunaberg, Sweden, and splendid crystals of malachite and azurite from the Baron Demidoff mine, Nizhne Tagilsk, Siberia.

A careful study of the specimens in the Bowdoin Collection should reveal minerals other than Haüy's listing, as it is evident in many cases that there are associated minerals on specimens named only for the major constituent. One example is Haüy's specimen No. 193 which he designated as "Cocolithe ou pyroxene, granular." Examination reveals it to be clinochlore, grossular and diopside quite definitely from Ala Valley, Piemonte, Italy, although Haüy gave no locality.

Mineral names have changed since Haüy's time, and a copy of a typical page of his catalog (Fig. 3) illustrates this; "disthene" is the old name for kynaite and "grammatite" that for tremolite. The catalog generally uses the nomenclature of Kirwan and Werner.

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[3] Salpetriere = Alms House and Lunatic Asylum.

Figure 4. **Specimens from the Bowdoin Collection: (left to right) amethyst (7 cm) from Hungary, agate from Russia, and quartz with chlorite from Switzerland (?).**

Figure 5. **Calcite crystal group (15 cm) from St. Andreasberg, Harz Mountains, Germany. Cleaveland Collection.**

PARKER CLEAVELAND

The first recorded Cleaveland in America was Moses Cleaveland, who settled in Woburn, Massachusetts, in 1635. Parker Cleaveland is descended from him. Parker's grandfather was Rev. John Cleaveland, and his father was Parker Cleaveland, M.D., a doctor at Byfield, Massachusetts. Parker Cleaveland, the mineralogist, was therefore really Parker Cleaveland II, although he seems never to have used the designation. He was born at Byfield, January 15, 1780, during the worst blizzard of a rugged New England winter. He attended the usual elementary school of the time and early transferred to Dummer Academy, 4 km from his home, the distance he walked both ways each day. At sixteen he entered Harvard and graduated in 1799 with an A.B. Degree, attaining the highest honors of his class. College education fitted him for any of three things: the ministry, law or teaching. Almost no emphasis was placed on natural sciences at this time, so upon graduation he had absolutely no contact with or knowledge of mineralogy and geology. Parker tried schoolteaching; first at Haverhill, Massachusetts, and then at York, Maine. At both places he was highly successful and most popular. While at York, being undecided between the ministry and law as a profession, he served as a part-time assistant to Mr. Daniel Sewall, Clerk of Courts, to see what the law profession was like.

When later he returned to Harvard as a tutor, many said they would rather lose their minister than their schoolteacher. It was November 23, 1803, that he became tutor of mathematics and natural philosophy at Harvard. As late as 1804 he leaned strongly toward the ministry. In the spring of 1805 he definitely gave up ideas of the ministry and

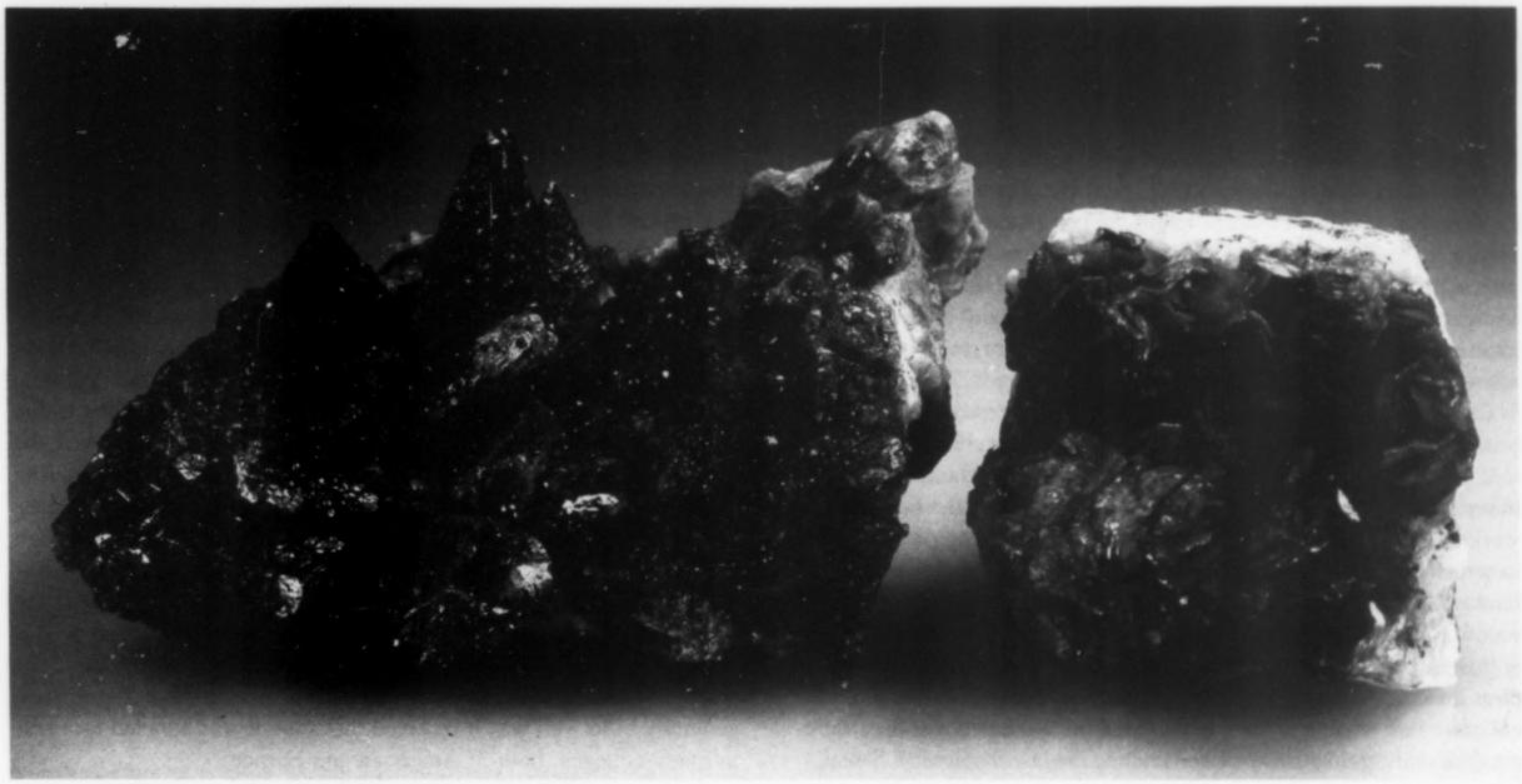
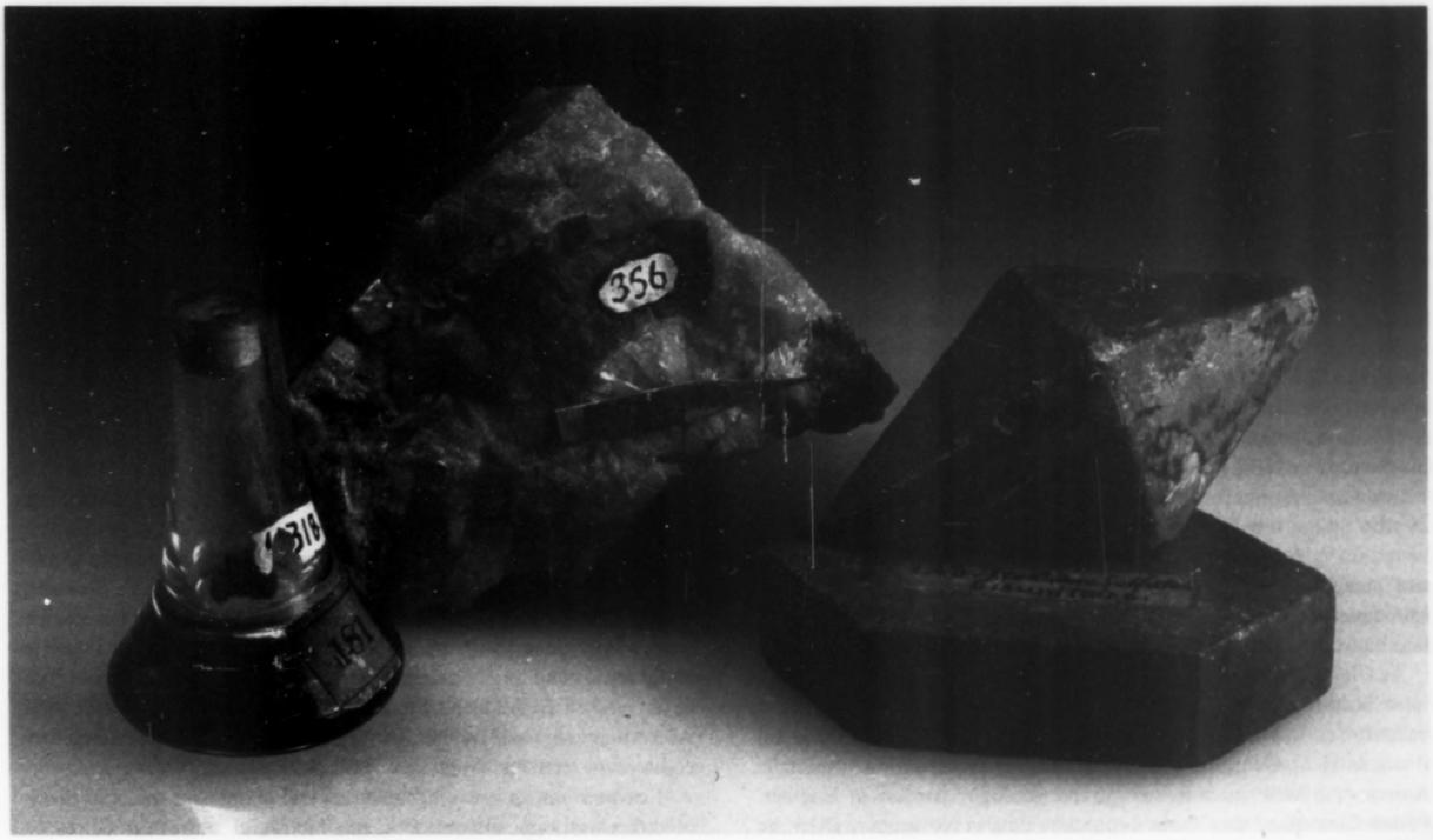


Figure 6. Chalcopyrite with calcite, 11 cm, from the Ecton mines, Ecton, England (left; Parker Cleaveland collection); siderite crystal group, 5.7 cm, from Cumberland, England (right; Bowdoin collection).

Figure 7. Cobaltite crystals in glass vial (left) from Tunaberg, Sweden, a gift to Parker Cleaveland from Alexandre Brongniart. "Ytterocite," probably yttrocerite (center) from Fahlun, Sweden, a gift to Parker Cleaveland from J. J. Berzelius. Clay crystal models (right) purchased from R. J. Haüy by James Bowdoin around 1806.

law, because Professor John Abbott of the three-year-old Bowdoin College in Brunswick, Maine, strongly persuaded him to accept the position of professor of mathematics and natural philosophy at Bowdoin. To reach the town of Brunswick, Maine, required a journey of some 240 km by stagecoach. He disliked travelling very much, especially by water, and dreaded crossing large bridges, so his trip was a rather terrible experience, requiring five days, one of which was the Sabbath spent at Portsmouth, New Hampshire, for rest religious observance. He was publicly inducted into the position at Bowdoin on October 23, 1805. There was no mention whatever regarding any duties required of him to teach or lecture on the subjects of chemistry, mineralogy or geology. Some writers have said or implied that Parker



Cleaveland was professor or lecturer on these subjects beginning with his appointment to the faculty in 1805; this is not so. It was not until the spring of 1808 that he voluntarily started a series of lectures on chemistry and mineralogy.

During his first year at Bowdoin he built a large house on Federal Street, a short walk from the college. The next year he married Martha Bush and became well established in the community. They had eight children, two eventually graduating from Bowdoin. Not long after his arrival in Brunswick, there occurred a series of bad fires. Parker instigated the formation of a volunteer fire company and was made chief. He was present at all fires day or night for years thereafter, taking his place at the front line of activity.

Cleaveland's interest in mineralogy was not awakened until two years after being appointed to the faculty of Bowdoin. He later jokingly told his classes that when he graduated from Harvard he assumed that there was only one kind of rock in the world. Later in the fall of 1807 workmen blasting ledges at the falls of the Androscoggin River between Brunswick and Topsham, Maine, to construct a sluice-way for lumber, exposed some interesting minerals. They imagined they had found diamonds, gold and silver, so they hastened to the new professor at Bowdoin, whom they assumed knew everything. The minerals were clear quartz crystals, pyrite and molybdenite. Parker Cleaveland was not quite sure what they were but assured the workmen that they were not diamonds, gold or silver. Even reading the last chapter in Chaptal's Chemistry left him uncertain about the specimens so he packed them and sent them to Professor Dexter of the chemistry department at Harvard for confirmation of his tentative identification. A prompt reply came stating that Cleaveland's identification was correct and the Professor Dexter was forwarding a box of named minerals for study. A cousin, Nehemiah Cleaveland, was living with Parker at the time and later said, "I accompanied him on his first visit to the falls and helped him bring home the first basket of stones he ever collected." The basket contained much more than the quartz, pyrite and molybdenite the workmen had earlier brought to him. He became completely fascinated with what he had found and began an intensive study of minerals. Books were hard to come by on the subject in America at that time, however his friend Benjamin Vaughn, M.D., of Hallowell, Maine, a mineral collector, passed on to him a first edition of Robert Jameson's *System of Mineralogy* (1804–1808) and a French copy of Werner's monograph on the external characteristics of minerals (published in 1795). These, with the help of Professor Dexter at Harvard, made it possible for Cleaveland to rapidly become quite versed on the subject by the spring of 1808, when voluntarily he started a series of lectures on mineralogy. The first lectures were held in the college president's laundry for lack of other space. So much interest in the lectures was expressed that by September, 1808, the College Board voted to increase his salary by $200 for the extra effort. From this time on, in addition to being professor of mathematics and natural philosophy, he was listed as lecturer of chemistry and mineralogy. Later, in 1828, he became full professor of these subjects. Cleaveland was not quite the first professional lecturer on mineralogy in America; Benjamin Silliman at Yale had preceded him by four years, starting his lectures in 1804.

From his first interest in mineralogy he read practically everything in print on the subject. He made summaries and balanced one theory or system against another, compiled much data about mineral localities and gathered the information into manuscript form. In his correspondence with Professor Silliman, he was urged to put this into a text that could be used in mineralogy classes.

As Cleaveland worked on his manuscript, mineralogy and geology were becoming more popular subjects of study. Several large and beautiful collections were being made, such as those of Archibald Bruce and Col. George Gibbs. There was a great need for a systematic American treatise on mineralogy and geology, written in English. Parker Cleaveland was about to produce this; in November, 1815, he advised Professor Silliman that the manuscript was in the hands of the printer, Hilliard and Metcalf at the University Press, Cambridge, England, and that it would be published by Cummings and Hilliard of No. 1, Cornhill, Boston, Massachusetts. The book, *An Elementary Treatise on Mineralogy and Geology*, was published in 1816. It was bound in a gray paper cover. Most libraries and private collectors have full or half bound leather copies which were custom-bound after the original purchase.

During February, 1817, Professor Silliman advised Cleaveland that he had his copy stitched over with blank sheets interleaved, for notes, and was using it regularly in his classes at Yale. In Europe Professor Clarke, of Cambridge University, used no other with his lectures. Mineral collectors began to arrange their specimens according to the new book. At exactly the right time Cleaveland had furnished the needed work. Earlier or later it might not have met with such a flattering reception. Its appearance placed him in the front rank of mineralogists of the world. The book was immediately given notice in terms of high commendation by literary and scientific journals in America and Europe. *Silliman's Journal of Science and Arts* sums up quite well the reception of the book: "In our opinion this work does honor to our country, and will greatly promote the knowledge of mineralogy, besides aiding in the great work of disseminating a taste for science generally." So well was it received that soon it was adopted as a text in many colleges, both in American and Europe.

At the time of the appearance of Cleaveland's text there were two principal schools of thought regarding mineral classification. One maintained the classification should be determined by external characteristics (Werner's system), and the other based insofar as possible on the chemical composition (Haüy's system). Brongniart had made an attempt to combine the two, as Cleaveland gives him credit in the preface of his book. Cleaveland followed Brongniart's lead but executed it in a manner entirely his own. Cleaveland placed the work of great European mineralogists as well as his own ideas before the public in an accessible and attractive form, adding new species and new localities, all done in simple clear English.

A second edition, enlarged to two volumes, was published in 1822. Even this was soon exhausted, so great was the demand. The text by then had become the standard college textbook on the subject in America and was used in many European colleges and universities. A third edition was in demand and Cleaveland, although overloaded with work in connection with the new Maine Medical School, somehow found time to prepare an extensive manuscript, complete even to an index. This manuscript gave crystal structure and interfacial angles for most minerals and used for the first time a numbering system somewhat like that later introduced by Dana. The species numbers in this manuscript range from 1 to 1228. For some reason it was never published and today it is in the Special Collections Section of the Bowdoin College Library.

In honor of Cleaveland's remarkable work. H. J. Brooke of London, England, having determined the angles of a platy variety of albite feldspar supplied to him, proposed the name of "cleavelandite" in 1822. This name was accepted and is still in common use today. Cleaveland's name was also given to a compartment of Mammoth Cave in Kentucky. It is reached by a passage through Silliman Avenue, and contains beautiful forms of gypsum.

Cleaveland rarely found time away from his college duties to visit his folks at Byfield and do a little prospecting for minerals. For such a trip he had to hire a chaise from William Alexander of Brunswick, one of only three in the whole town. After a long journey inland to avoid ferries and large bridges over the principal rivers along the coast he arrived in Byfield and found time for quite fruitful prospecting. According to his half brother, Reverand John Cleaveland, related forty eight years after the event:

> I helped him in breaking open several composite rocks in the street wall opposite our door, that he might get fresh fractures.

> I well remember the forenoon of a warm day in the first week in June, 1811, when he made his first trip to the "Devil's Den" in Newbury. This was a small cavity on the right of the old road from Dummer Academy to Newburyport, four miles from the house where the professor was born. It had been visited once before by a professor from Harvard, and once by some professor from foreign parts; but it's riches were reserved for my brother's eye. He returned to my father's house with one or two candle boxes filled, and my mother's kitchen was at once turned into a laboratory, and the floor strewed with fragments of every variety which the den had yielded. Serpentine, greenstone, pure hornblende, simple feldspar, asbestos, quartz and black tourmaline were a part of the day's spoils. No miser ever worshipped his money as he did these specimens. Many of them which I helped him pack up on that day, have long had a place in French, German and Russian cabinets. (Cleaveland Papers, Bowdoin College Library).

Parker Cleaveland was somewhat timid by nature in regard to certain things, such as crossing bridges, as before mentioned. He also considered stagecoaches a most dangerous means of travel, and when steam trains appeared he regarded them even more so. Summer thunder showers with their lightening he feared most of all. If it were at all possible he would head for home at the approach of a shower, to lie in the center of a large feather bed well away from the walls of the room. After lightening rods came into being he had them installed on his buildings and became more tranquil.

In his college work he was punctual to the extent that year in and year out he entered the lecture hall at the exact appointed hour, fair weather or foul, often suffering from some illness. Seven minutes after the scheduled hour of his lecture, usually two o'clock in the afternoon, he had the door closed and demanded silence. He instilled and kept strict discipline in his classes, however his stern features lit up with a glow of enthusiasm, forgetful of himself, as he launched into his subject and every student became fascinated; listlessness and inattention were nonexistent. He mixed a little wit and humor with his discourse, much to the pleasure of the students.

His ability as a lecturer became known beyond the college and people in nearby towns desired to hear him. One amusing lecture he gave before the Brunswick, Topsham and Harpswell Temperance Society, on April 27, 1814, is worth quoting from. In days when preaching "hell-fire and damnation" was popular he fell in line and gave them a lurid if somewhat imaginative picture of the dangers of being an alcoholic. Regarding the consumption of beverages high in alcoholic content he warned:

> . . . and the whole body thus gradually becomes impregnated with an alcoholic substance which is highly combustible. It is an undoubted truth that in a number of instances the bodies of intemperate persons, on approaching a lighted candle or some other burning substance have actually taken fire and been entirely consumed in a very short time. This has been communicated to the Medical Journal. (Cleaveland Papers Bowdoin College Library).

In 1818 Cleaveland gave a few public lectures on chemistry and mineralogy in Hallowell, and Portland, Maine, and in Portsmouth, New Hampshire. All specimens for his demonstrations during each lecture had to be transported by ox team. Because of the pressure of the college work and the time consumed in travelling to the place of lecture he soon realized that he could not continue lecturing in public.

From the first contact with minerals in the fall of 1807, he started a private collection which rapidly grew. He cataloged them in numerical order, applying small square paper tags bearing red numbers on white paper. The name, locality and donor, if any, were written only in the catalog. No attempt was made to group specimens according to any system other then numerical. There were specimens donated by nearly one hundred early collectors both in America and Europe, some of them outstanding scientists and mineralogists, such as J. J. Berzelius, the Swedish chemist of renown, Alexander Bronginart of Paris, France, Col. George Gibbs, of America, and others. The specimens accumulated during his life amounted to nearly 3,000 in his private collection.

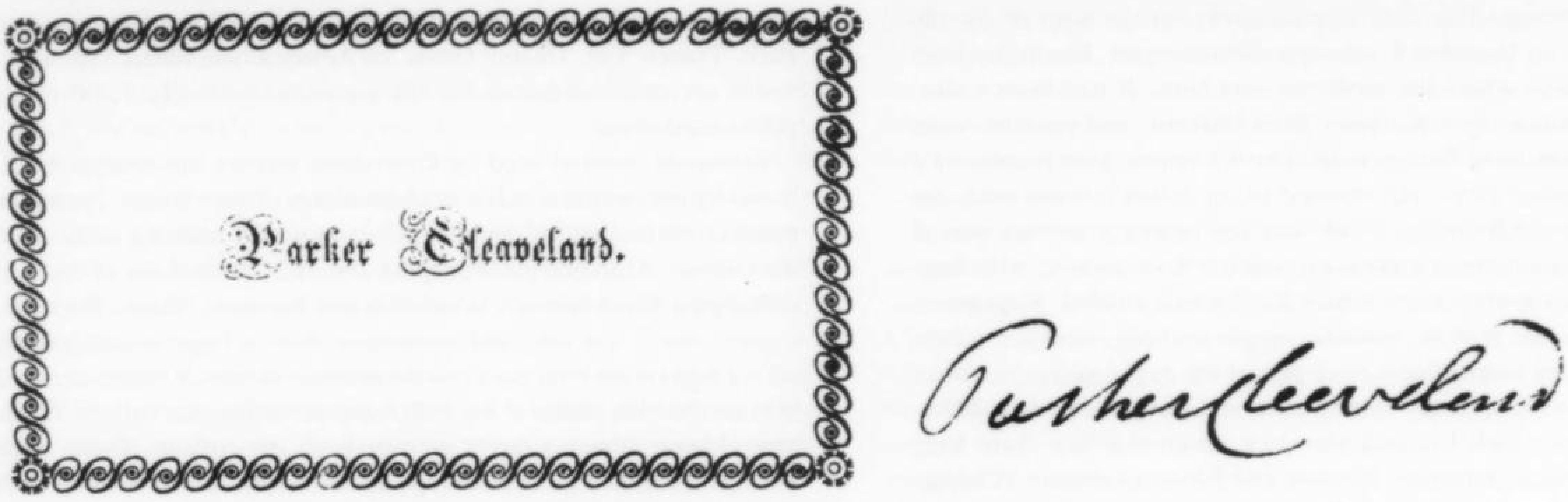
Exchange material used by Cleaveland was for the most part collected by him within a radius of about 40 km of the college. Pegmatite minerals were plentiful and handy, even within walking distance of the college. Molybdenite was quite abundant at the falls of the Androsgoggin River between Brunswick and Topsham, Maine. Fuchsite, a green mica, was obtained in quantity from a large erratic boulder sitting high on the river bank, on the Brunswick side. Kyanite occurred in beautiful blue blades along with staurolite at Dundee Falls in Windham, Maine, about a day's journey from the college. These three minerals he traded all over Europe and America, which built up both his private collection and one for the college.

The college collection was distinguished by the use of small square paper labels with black numbers on white. When, as often happened, a fairly large collection of minerals was donated to the college, such as the James Bowdoin collection, he kept the original labels and catalogs as they were. To this day the James Bowdoin collection has the small oval, yellow labels bearing black numbers and is accompanied by a catalog done in French as supplied by Haüy when he sent the collection from Paris to Bowdoin, then living in Boston, Massachusetts. Cleaveland was a pioneer in listing the localities of minerals in his textbook, but often omitted the locality and even donor in the catalogs he prepared for his private collection and that for the college.

He tells of one collecting trip to nearby Bowdoinham, Maine, where over a bushel of "emeralds" (beryl crystals) were taken from the soil at the foot of a large ledge containing more. Some of these he sent to Professor Silliman at Yale and on June 28, 1811, Silliman wrote him saying among other things, "I was especially gratified with the emeralds (beryls), feldspar, graphic granite, molybdena, magnetite crystals, mica and garnets." (Cleaveland Papers, Bowdoin College Library). This is typical of his generosity, whenever he found something of interest in any quantity he passed some of it on to those he knew would be interested.

Some early American and European collectors made trips to Brunswick to see Cleaveland personally; the following are just a few examples: William Maclure, Col. George Gibbs, and Charles Cramer. There is an abundance of correspondence from collectors in Europe and America, now on file with the Cleaveland Papers in the Special Collections Section of the Bowdoin College Library. For example, the following are just a very few of the early correspondents (before 1858), giving the number of their letters on file; Professor Benjamin Silliman, (20), Charles Cramer, St. Petersberg, Russia (8), Col. George Gibbs, Newport, Rhode Island (5), Mr. Gilmor, Baltimore, Maryland (4), Dr. H. H. Hayden, Baltimore, Maryland (2), James Pierce, New York City (6) and Professor John W. Webster of Harvard University (41). The number of correspondents is about a hundred. One interesting letter from Dr. David Hunt, Northampton, Massachusetts, dated August 12, 1812, is quoted as follows; "Our friend Col. Gibbs and myself at last blasted the interesting tourmaline rock at Chesterfield, Hampshire County, Massachusetts, and have obtained the red, green and blue in large quantities. I transmitted 1057 pounds of the Goshen and Chesterfield rocks to Boston for him." Hunt concludes by asking Cleaveland if he would like some of the specimens. As a result of this, a few good specimens from this first significant working were placed in Cleaveland's collection.

In 1820 the Medical School of Maine was established at Bowdoin College, occupying the third floor of Massachusetts Hall on the college campus. At the same time Cleaveland was appointed professor of chemistry and *materia medica* with the additional duties of secretary to the faculty of the new school, all of which greatly reduced the time



Parker Cleaveland.

Parker Cleaveland

Figure 8. **Parker Cleaveland's personal book plate and signature, from his copy of Jameson's *System of Mineralogy* (1816).**

he could devote to his beloved minerals. It is rather interesting to note that he was professor of *materia medica* in the new school in 1820, three years before he had an M.D. degree, which was awarded by Dartmouth College as an honorary degree in 1823.

In the face of all this extra work he never lost interest in minerals, continuing to teach and write on the subject with great interest. To within a few weeks of his death on October 1, 1858, he was almost as active as at any time during his life of 78 years. When, at last, too weak to walk to his classes, he conceded to be conveyed by chaise. The day before he died was the only day he ever missed a class. His obituary in the *American Journal of Science* was written by Silliman. During his life he received the following degrees: A.B. from Harvard, 1799; M.A. from Harvard, 1802; Honorary M.D. from Dartmouth, 1823; and an honorary LLD from Bowdoin, 1824. He was a member of some sixteen scientific societies including the principal ones in Europe.

CONCLUSION

With the number of Cleaveland, Bowdoin and Haüy specimens already identified, cataloged and in part displayed in well-lighted cabinets, plus the material preserved in the Cleaveland Papers in the Bowdoin College Library which consists of a vast amount of correspondence, manuscripts, sketches, books and other material, this may be one of the most historically important collections in America.

ACKNOWLEDGMENTS

Mary Huges of the Special Collections Section, Bowdoin College Library, has been of the utmost help in finding information that has made this article possible.

Theresa Doucette has given much valuable help with the translation of Haüy's French. Mrs. Doucette is Secretary to the Chief Librarian, Bowdoin college Library.

Neal Yedlin gave valuable help in identifying mineral specimens when visiting at Bowdoin College, June 30, 1975.

EDITOR'S NOTE:

Parker Cleaveland's personal library remained more or less intact in the Cleaveland home until the early 1950's. Mrs. Slater Quinn, Cleaveland's great-granddaughter, finally liquidated the family antiques, books and papers through some private sales and an auction around 1951. Portland book dealer Francis O'Brien attended the auction and purchased over 1,000 books from Cleaveland's library, not to mention hundreds of pounds of correspondence and paperwork of all sorts. Of course the library contained not only mineralogical works but also volumes on travel, natural history subjects and religion. At least a dozen of the more important mineralogical works are now in the library of Herbert Obodda. The Cleaveland home has been restored and is today still a great house. (My thanks to Francis O'Brien for much of the above information.)

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ZEOLITES AND RELATED MINERALS FROM THE TABLE MOUNTAIN LAVA FLOWS

near Golden, Colorado

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Zeolites and related minerals have been found in the Table Mountain lava flows near Golden, Colorado, for more than 100 years; specimens are present in many major museum collections. Fourteen zeolite species, as well as fluorapophyllite, calcite and other associated minerals, are known to occur at this Dana locality. The Table Mountains are a significant North American occurrence of zeolites, noteworthy for the exquisite beauty and morphological variations of thomsonite.

INTRODUCTION

The excellence and abundance of the zeolites occurring at the Table Mountain locality have been well documented. However, these deposits have received little attention of late because of an absence of recent comprehensive work relating either to the geology of the locality or to the descriptive mineralogy of the zeolite species, and because of the relative unavailability of older literature. This neglect has resulted in some of the more significant minerals being misidentified in private and museum collections. The geology and mineralogy of this area are reviewed here with an emphasis on those species occurring in specimens of significant size and quality.

LOCATION

The Table Mountains are situated immediately east of Golden, Colorado, which is about 21 kilometers (13 miles) west of Denver (Fig. 1). Golden has an elevation of approximately 1,729 meters, and is the home of the Colorado School of Mines. The Table Mountain locality is actually composed of two mesas, designated as North and South Table Mountains. These are typical mesas, formed by a resistant capping-layer of Tertiary lava protecting softer underlying sedimentary rocks from erosion. The lava was originally a continuous sheet that was subsequently divided by Clear Creek to form the two mesas present today (Fig. 2). The tops of these mesas are relatively flat, with the lava flows forming prominent vertical cliffs overlying steep-sided slopes. North Table Mountain, rising 244 to 305 meters above Clear Creek, has a maximum elevation of approximately 2,003 meters, while the maximum elevation for South Table Mountain is 1,927 meters. The combined area of North and South Table Mountain is about 10 to 12 square kilometers (4 to 5 square miles).

Ralston dike, located about 3.2 kilometers north of North Table Mountain, is a body of intrusive monzonite, and probably represents the vent from which the Table Mountain lava originated (Emmons and others, 1896; Waldschmidt, 1939; Van Horn, 1976). This dike consists of two ridges, separated by a dammed valley occupied by Long Lake. The western ridge is the most prominent, rising 202 meters above the surrounding terrain. Green Mountain is situated about 3.2 kilometers south of South Table Mountain and rises about 305 meters above the surrounding terrain. This mountain is composed primarily of Tertiary sediments, and is capped by a coarse conglomerate. A small rock outcrop on a knoll located near the northern flank of Green Mountain is presumed to be a remnant of a lava sheet that represents the southernmost limit of the Table Mountain lava flows (Van Tuyl and others, 1938; Waldschmidt, 1939; Reichert, 1954; Scott, 1972). The topography immediately west of the Table Mountains is characterized by steep hogbacks formed by resistant upturned Triassic, Jurassic and Cretaceous sedimentary rocks; these hogbacks are absent in the vicinity of Golden due to reverse faulting. West of the hogbacks are abruptly rising foothills composed of Precambrian schists and gneisses, and the region east of the Table Mountains is part of the Great Plains physiographic province.

The climate in this area is semiarid and mild, with an annual average precipitation of about 38 cm (15 inches), most of which falls in April, May and August. The collecting areas are entirely on private property and, although access in some areas has been unrestricted, permission must be obtained when entering fenced or posted areas.

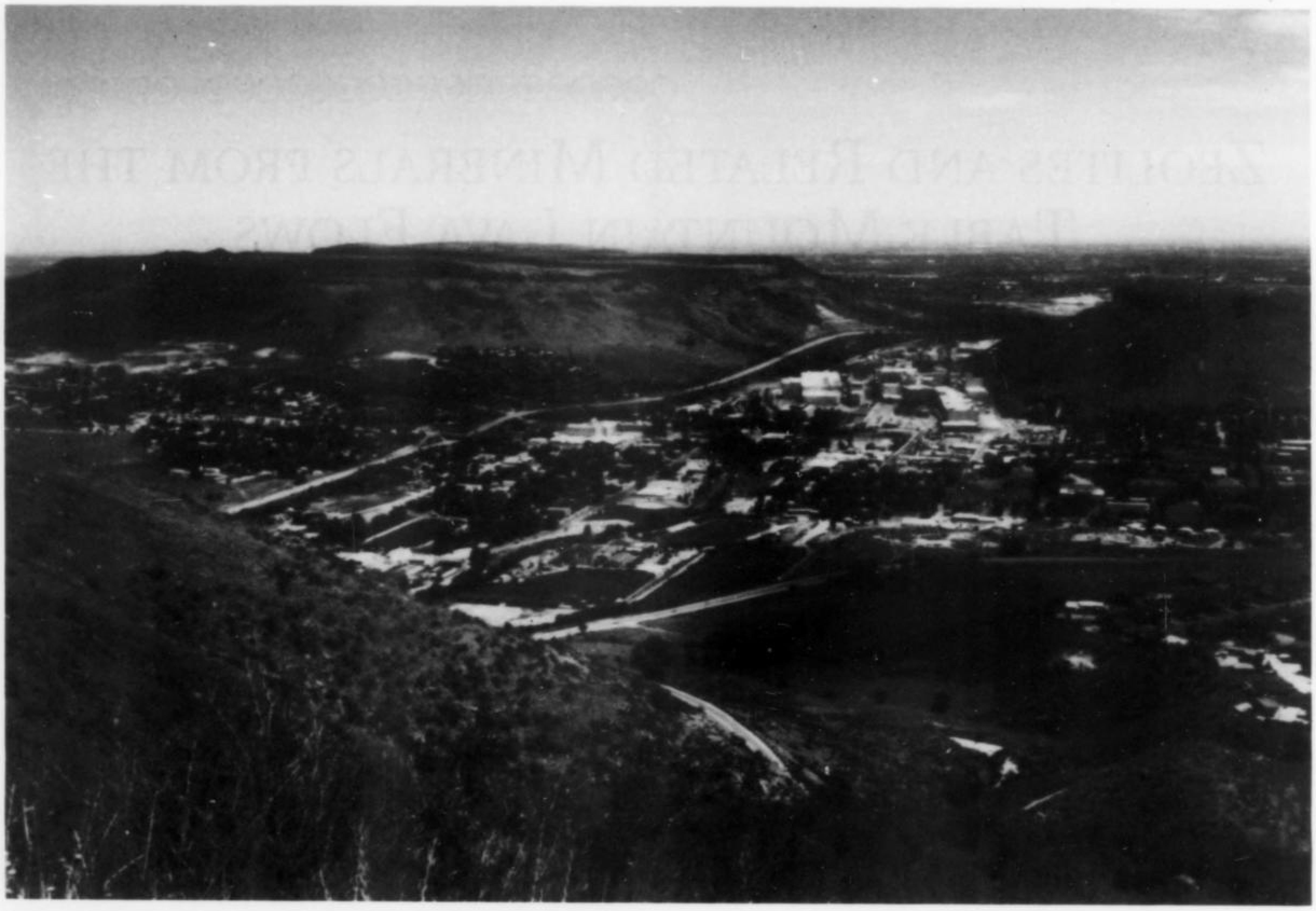


Figure 2. **North and South Table Mountains, as viewed toward the northeast from Lookout Mountain. The city of Golden lies at the western base of the mesas; buildings at right center are part of the Colorado School of Mines. All photographs by the authors unless otherwise noted.**

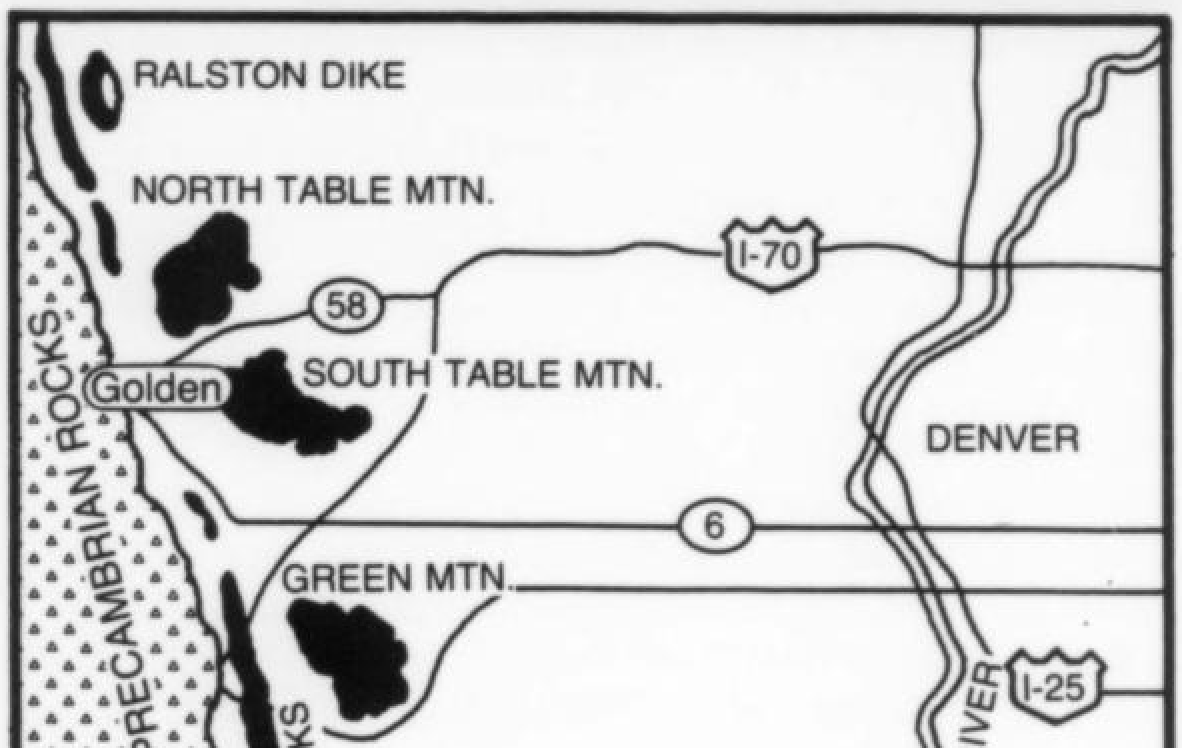


Figure 1. **Location map of the Table Mountain locality (adapted from Modreski *et al.*, 1984, and Trimble and Machette, 1979).**

HISTORY

Geologic observations of this region were reported as early as 1869 by the Hayden Survey (Hayden, 1869), and a preliminary review of the area mineralogy was recorded by Endlich (1878). Cross and Hillebrand (1882a, 1882b, 1885) subsequently provided the first detailed account of the minerals occurring at the Table Mountains, and the classic monograph on the geology of the Denver Basin in Colorado by Emmons and others (1896) was published shortly thereafter. This comprehensive monograph summarized the geology and mineralogy of the Table Mountain locality known to that time, and has served as the foundation for subsequent studies of the area. An excellent mineralogical study was written by Horace Patton (1900), who at that time was the curator of the Geology Museum at the Colorado School of Mines. There has been little comprehensive work published regarding the minerals of this locality since then, except for brief reviews by Johnson and Waldschmidt (1925) and Waldschmidt (1939), and a short article by Ellermeier (1947). Literature published since the early 1900's concerning the geology and stratigraphy of the area is considerably more prolific, and includes a series of Colorado School of Mines publications (Johnson, 1930, 1934; Van Tuyl and others, 1938; Waldschmidt, 1939; LeRoy, 1946; Reichert, 1954) as well as other works (Brown, 1943; Van Horn, 1957 and 1976; Ahmad, 1971).

Collecting and mining activity dates back to the nineteenth century, with the recovery of mineral specimens from the south side of North Table Mountain having been documented prior to 1882 (Cross and Hillebrand, 1882a). Much of the material used for later mineralogical studies was acquired prior to 1900 from various localities on North Table Mountain by students from the Colorado School of Mines. The specimens used by Patton (1900) in his study of Table Mountain minerals originated from an area located on the east side of North Table Mountain; other mineral-producing quarries were subsequently operated during the early to mid-1900's by the Colorado School of Mines at sites located on the eastern and western sides of North Table Mountain. However, most of the early activity here was of a more practical nature, with numerous mining companies quarrying the caprock lava that was useful for a wide variety of applications because of its durability and weather resistance. Quarries, maintained during the early to mid-1900's on North and South Table Mountains by the City of Denver and others, produced paving blocks for street surfacing, as well as crushed rock for concrete aggregate and railroad ballast. Later operations provided large tonnages for damsite fill and ballast. The Wunderlich quarry, with a production of 900 to 1,000 tons per day, was located on South Table Mountain and provided the fill for Cherry Creek Dam (near southeast Denver) during 1948 and 1949, while a large quarry and crushing plant located on North Table Mountain, operated by the Indianapolis-based Rogers Company, produced up to 3,500 tons per day of fill from 1949 to 1951; this material was used at the Harlan County Dam in Nebraska (Argall, 1949; Reichert, 1954). Many of these quarries used aerial tramways to transport the rock to crushing plants located at the base of the mesas. Other applications for this lava included ornamental and monument stone, and building and landscaping stone. However, many of these uses (such as paving blocks and building-facing stone) have become outmoded in the past 20 to 30 years, and thus the quarries are now inactive or abandoned, providing collectors with productive areas from which to obtain zeolite minerals.

GEOLOGY

The geologic history of the area is characterized by a series of regional uplifts followed by successive erosion and sedimentation cycles. These mountain building episodes produced the Front Range of the Rocky Mountains west of Golden, which, in this vicinity, is composed largely of Precambrian schist and gneiss (1.7 to 1.8 b.y. and older) formerly known as the Idaho Springs Formation. The sedimentary rocks derived from these erosion cycles overlie the Precambrian formations; the sequence of deposition in the Golden area is shown in Figure 3. Some of these sedimentary rocks (with gently southeastward-dipping strata) compose the base of the Table Mountains and form other prominent topographic features in the area. An intense uplift of the Front Range, known as the Laramide orogeny, that began at middle Pierre time (in the Cretaceous Period, about 80 m.y. ago) and continued until early Tertiary time (about 40 m.y. ago) resulted in the eastward tilting and faulting of flat-lying Paleozoic and Mesozoic rocks. Differential weathering of these upturned strata formed the prominent hogbacks located northwest and southeast of Golden; significant movement along the Golden fault during the late stages of the Laramide orogeny accounts for the absence of these hogbacks in the immediate vicinity of Golden. Regional orogenic activity and associated volcanism commencing near the end of the Cretaceous Period resulted in the extrusion of the Table Mountain lavas in Tertiary (early Paleocene) time; this sheet of lava covered the sediments of the Denver Formation that form the base of North and South Table Mountains (Figs. 4 and 5). During the Quaternary Period alluvial gravels were deposited on top of the older sedimentary rocks; these are locally preserved on Green Mountain and elsewhere in the area.

The Denver Formation is of Late Cretaceous to Tertiary age, and the Table Mountain lava flows (which are considered to be a separate formation) occur within the upper part. In the Golden area, the part of the Denver Formation that originally covered the Table Mountain lava flows has been removed by erosion. This formation is characterized by poorly consolidated, nearly flat-lying sandstones, claystones, siltstones and conglomerates that are composed primarily of altered andesitic debris containing locally abundant fossilized leaves

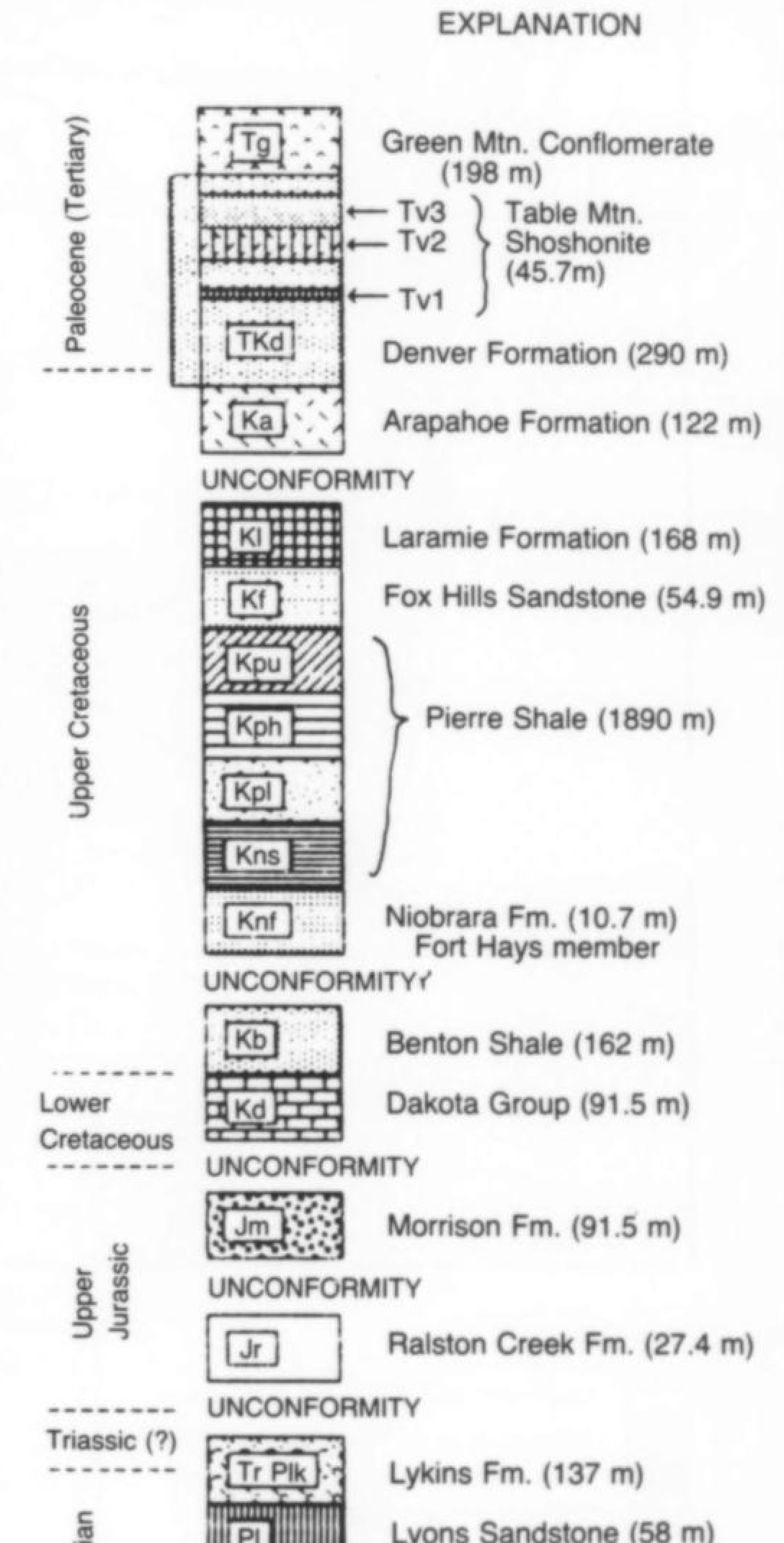


***Figure 3*. Stratigraphy in the Golden area. Formation thickness given in meters (adapted from Scott, 1972, and Van Horn, 1976).**

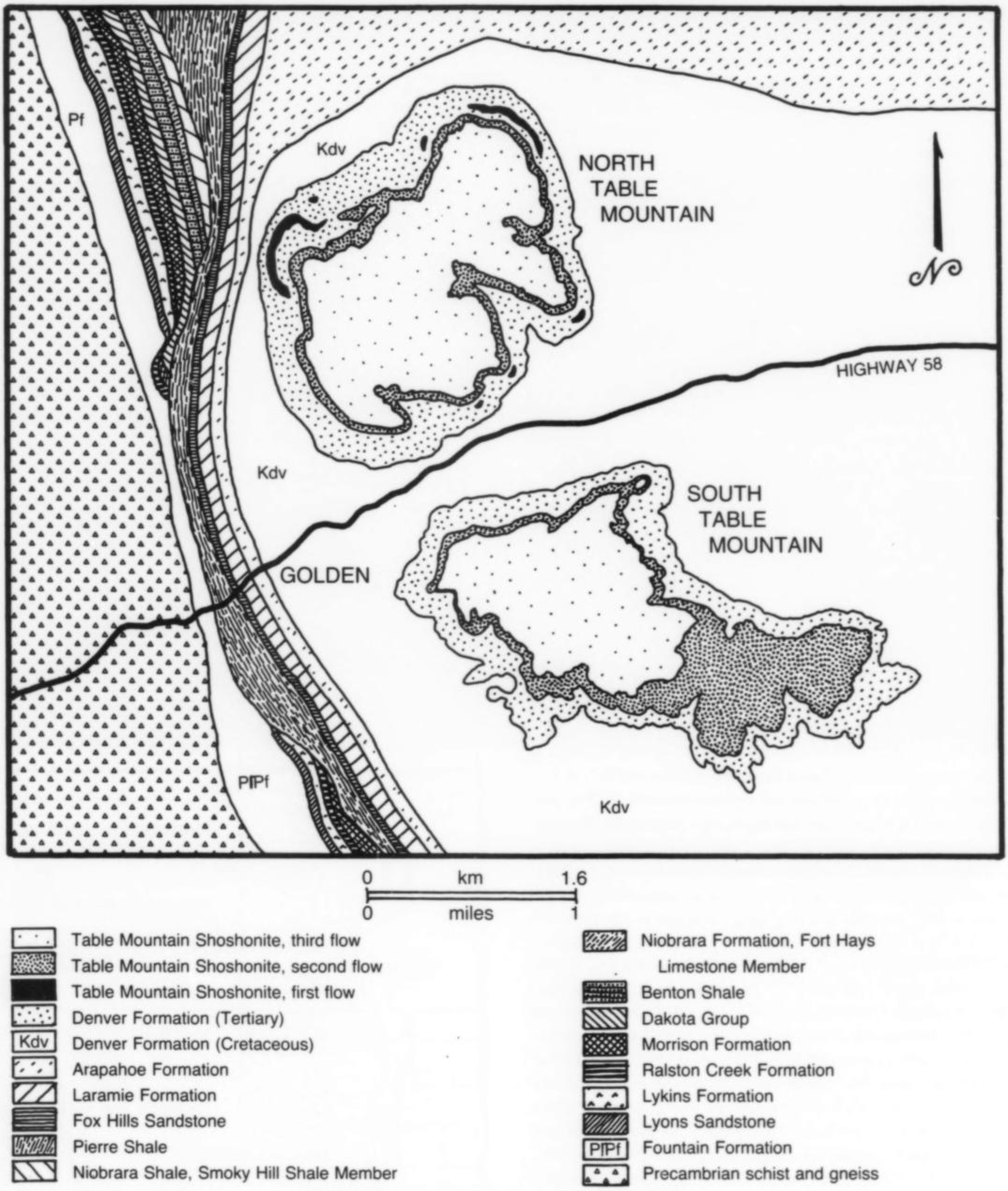


***Figure 4.* Areal geology of the Table Mountain locality (adapted from Van Horn, 1957 and 1972, Scott, 1972, and Smith, 1964).**

and twigs. These plant remains, representing about 225 species, are particularly abundant on the south side of South Table Mountain (Emmons and others, 1896; Knowlton, 1930). Dinosaur remains (Triceratops) have been noted from the slopes of South Table Mountain in the lower (Cretaceous) part of the Denver Formation (Johnson, 1931; Brown, 1943, 1962), and poorly silicified petrified wood, in stumps as large as 60 cm in diameter, is locally abundant on the lower slopes of North Table Mountain. Sediments of the Denver Formation were derived from eastward-flowing streams carrying volcanic material that originated from an area west and northwest of Golden (Van Horn, 1976). These clastic sediments were deposited as alluvial fans that spread over the plains east of Golden 60 to 80 million years ago, during Late Cretaceous and early Paleocene time (LeRoy, 1946; Reichert, 1954; Van Horn, 1976). Although the Denver Formation has been reported to vary from 213 to 457 meters in thickness in the Denver area, the thickness remaining in the vicinify of Golden is less than

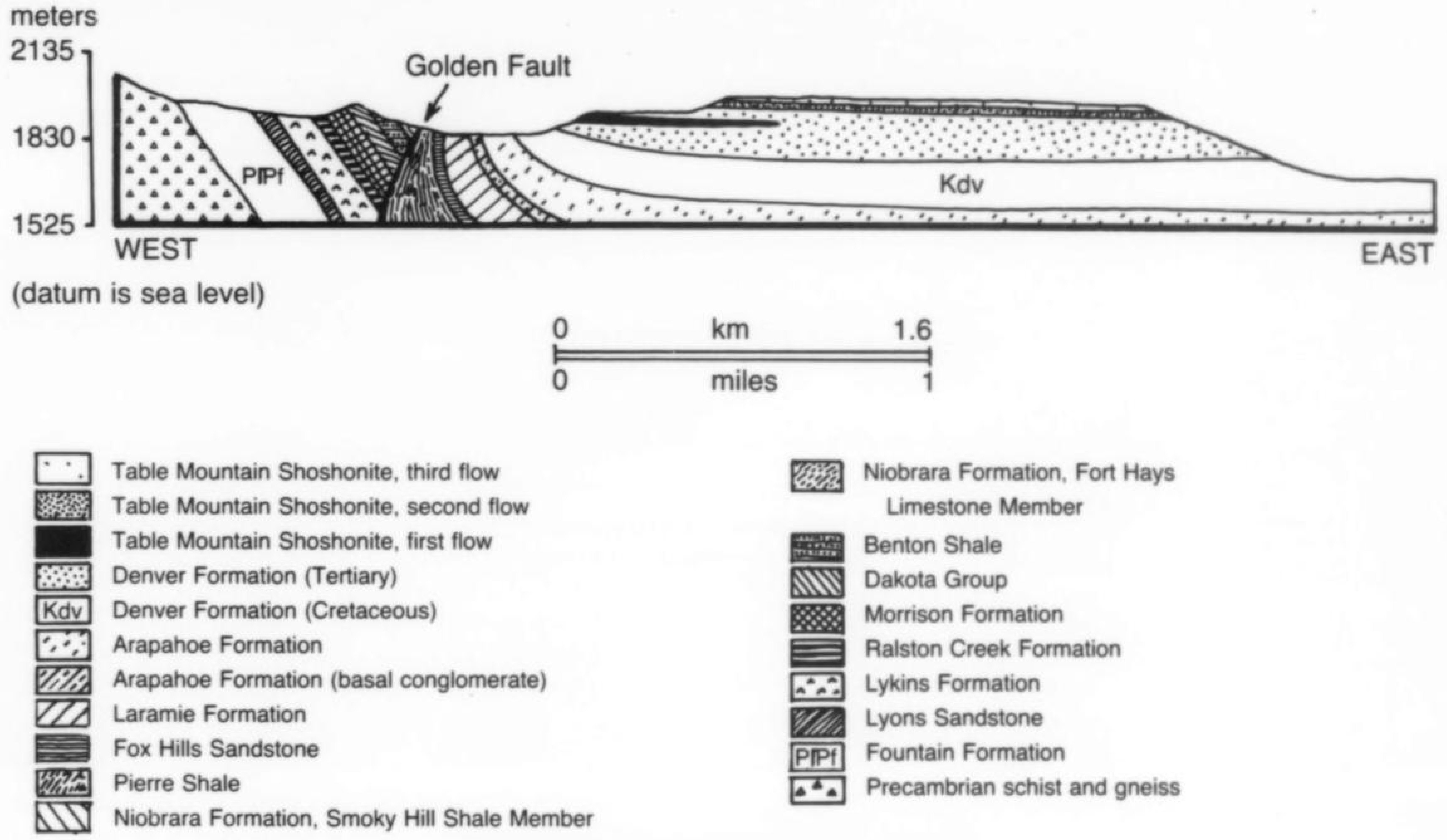


***Figure 5.* Geologic section of the North Table Mountain area (adapted from Van Horn, 1957).**

244 meters (Van Horn, 1976), with an estimated 40 meters having been eroded from the top of the lava flows (LeRoy, 1946; Reichert, 1954).

Because of the relatively poor exposures of sedimentary rocks in the area, and an apparent intermingling of Late Cretaceous vertebrates with Tertiary (Paleocene) flora, an intense controversy has continued over the past 90 years concerning the exact placement of the Cretaceous-Tertiary age boundary, as well as the nomenclature and boundaries for the Laramie, Arapahoe and Denver Formations. Recent studies (Van Horn, 1972, 1976; Scott, 1972) have concluded that the original distinction between the Denver and Arapahoe Formations, in which the first appearance of andesitic material defines the base of the Denver Formation (Emmons and others, 1896), was essentially correct, as was Brown's (1943) placement of the Cretaceous-Tertiary boundary at the 1,768 meter elevation near the southeast side of South Table Mountain. This age boundary was based on paleontological evidence; recent work by Newman (1979), based on palynological (pollen) studies, indicated this boundary to be located approximately 14 meters below Brown's boundary on South Table Mountain. As projected onto the south side of North Table Mountain, the Cretaceous-Tertiary boundary would be located approximately 61 meters below the outcrop of the first lava flow (Tv1), which is at a point about halfway between this outcrop and the road (Highway 58) at the base of North Table Mountain (Fig. 6). Based on these age and formational boundaries, the Table Mountain lavas are considered to have been extruded in the upper part of the Denver Formation during early Paleocene time. Scott (1972) recently computed the age of the middle (second) lava flow, based on a radiometric determination, to be 63 to 64 m.y.

Three distinct flows occur on North Table Mountain, each representing a successive period of extrusion (Figs. 7 and 8); two form the protective cap, and one less prominent earlier flow (which does not appear on South Table Mountain) occurs farther down the slopes of North Table Mountain (Figs. 9 and 10). One investigator (Ahmad,

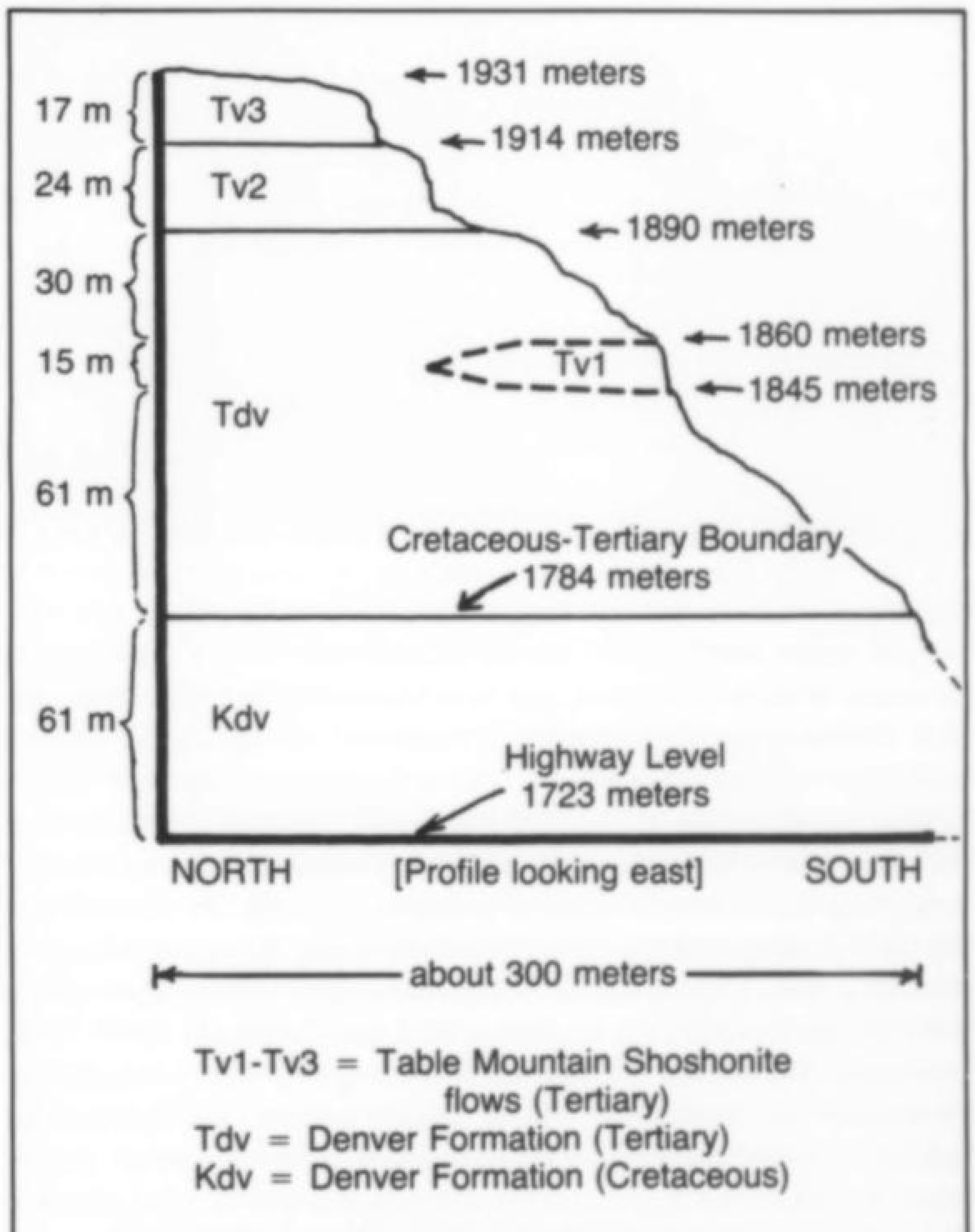


***Figure 6.* Generalized stratigraphy at the south side of North Table Mountain. Vertical exaggeration approximately 1.5:1.**

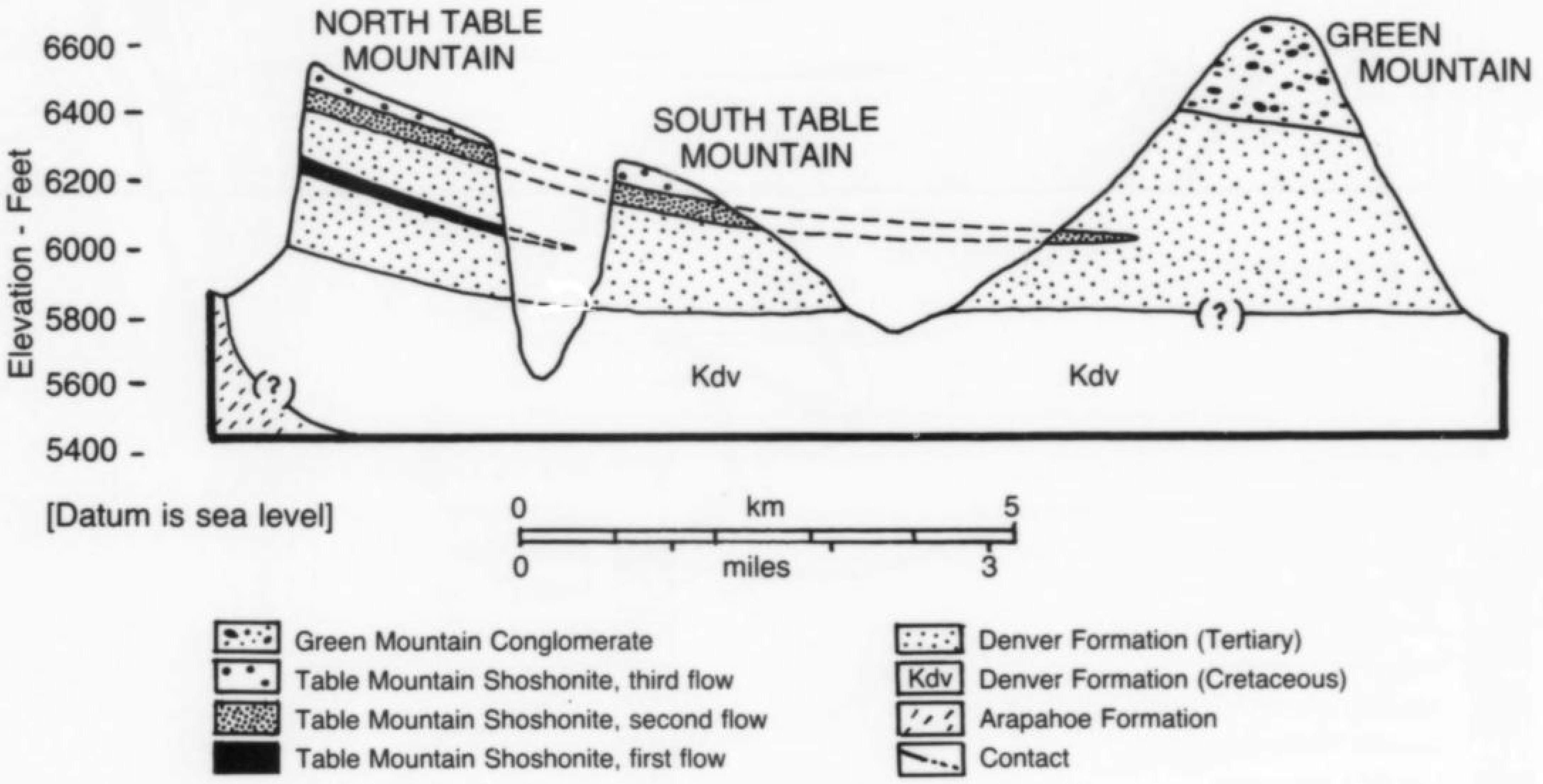


***Figure 7.* Geologic section of the Golden area. Section NNW to SSE-SE, through the approximate centers of North and South Table Mountains. Vertical exaggeration approximately 12:1 (based on Van Horn, 1957, and Scott, 1972).**

1971) suggested that the uppermost capping flow was actually composed of two flows, thereby creating a total of four distinct flows at the Table Mountains; this conclusion, however, has not been widely accepted inasmuch as all other authors have defined only three flows. Cross first named and described this dark gray lava as the "Table Mountain Basalt" (Emmons and others, 1896). Van Horn (1957, 1972, 1976) subsequently considered it to be a latite, but others (Scott, 1972; Trimble and Machette, 1979) have more recently classified it as a shoshonite, which is a basaltic rock rich in potassium feldspar. Thus, these flows are formally known as the Table Mountain Shoshonite (Scott, 1972). This shoshonite is coarsely crystalline in the lower to middle portions of the two capping flows, whereas in the more vesicular upper parts of the flows the groundmass is finer grained. The essential minerals include augite and plagioclase (andesite-labradorite), which compose part of the groundmass and also occur as well defined 4 to 5-mm phenocrysts, and olivine, which has been mostly altered to serpentine and is noted as small, irregular, yellow-brown to green phenocrysts. Small (4 to 8 mm) euhedral black crystals of augite are particularly evident at an exposure along the road leading up the west side of North Table Mountain, where they have weathered out of a poorly consolidated, sandy-textured sediment layer at the base of the second (Tv2) lava flow. Accessory minerals in the Table Mountain Shoshonite include minor amounts of either sanidine or orthoclase (as small, clear, poorly defined grains), apatite (as small grains or stubby crystals), magnetite (abundant as uniformly distributed, irregular black grains) and biotite (uncommon, as small anhedral brown grains). Alteration of the iron-bearing minerals leaves a locally conspicuous limonite coloring on the rock. Although Johnson (1930, 1934) and Ahmad (1971) postulated that the Table Mountain lava was extruded from a point located near the northwestern corner of North Table Mountain, most writers (Emmons and others, 1896; Waldschmidt, 1939; Van Horn, 1976) have suggested an origin at or near Ralston dike because of the similar petrography and age of these two occurrences. The age of Ralston dike has been given as 63 ± 2.5 m.y. (Scott, 1972). This dike, which intruded the Cretaceous Pierre Shale, has been classified as a mafic monzonite, and is a dark, coarse-grained rock showing poor columnar jointing (Van Horn, 1976).

The two capping flows are much more extensive than the first flow, and overlie most of North and South Table Mountains with a combined thickness of up to 76 meters. The thickness of these flows is greatest on North Table Mountain, decreasing to the east and south (presumably due to thinning as the lava spread southward) until in places at the southern end of South Table Mountain only about 3 meters of the flows remain. Waldschmidt (1939) estimated the original extent of the Table Mountain flows to be up to 16 kilometers in length, measured from the center of Ralston dike to the north slope of Green Mountain. Although a jagged and cinder-like surface between the two capping flows, showing no evident erosion, indicates a short time interval between their deposition, an exposure of conglomerate that lies in a small stream channel between these flows (which is located in a roadcut on the west side of North Table Mountain) suggests that a more substantial period of time may have elapsed between the emplacement of the capping flows.

Of the three lava flows, the first (Tv1) is the earliest, and with a southern limit not much farther than the southernmost edge of North Table Mountain (Waldschmidt, 1939), it is also the least extensive. This flow, seen only on North Table Mountain, is exposed sporadically in at least six places around the perimeter. These small outcrops form irregular benches about two-thirds of the way up the slopes, and have a maximum thickness of 15 to 18 meters at a site on the northeast side of the mesa (Fig. 9). They were apparently deposited as small "tongues" or lava streams, occupying stream channels or shallow

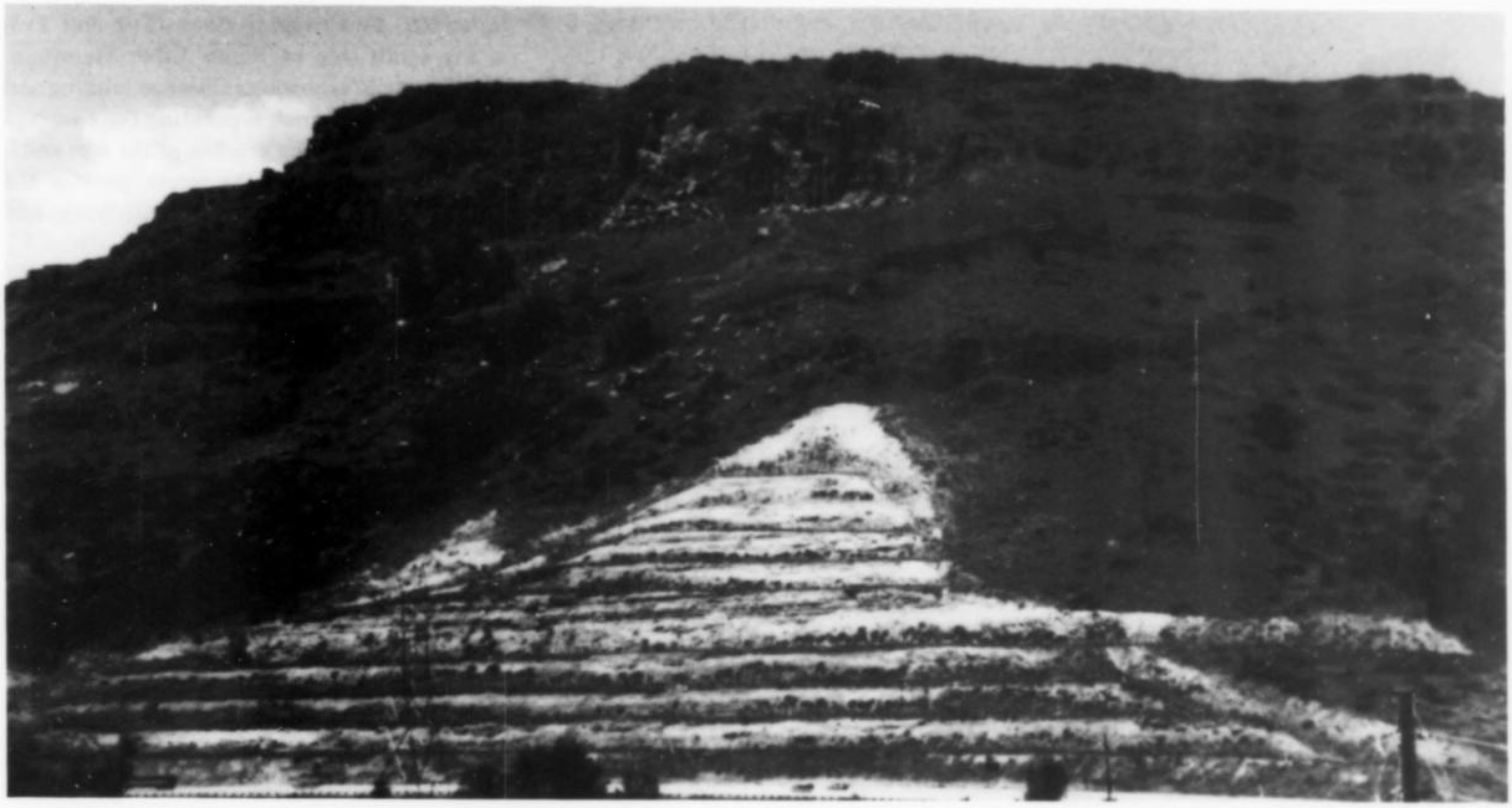


Figure 8. **South side of North Table Mountain, with highway 58 at base (refer to Fig. 6). Two capping flows (Tv2 and Tv3) are distinguishable at the top, and an abandoned quarry can be seen in the lowermost capping flow, near the middle of the photograph. A conspicuous bench between the two capping flows is visible at the upper left. Small outcrops of the earliest (Tv1) lava flow can be seen just above the apex of the terraces cut into the side of the mesa, which have exposed the Denver Formation.**

Figure 9. **Northeast side of North Table Mountain showing a prominent outcrop of the earliest (Tv1) flow, and the two capping flows (Tv2 and Tv3), which are distinguishable by a conspicuous bench between them.**

depressions in the original landscape that now constitutes part of the Denver Formation. This flow has a structure similar to that of the capping sheets described below, with a dense, compact central core and a more vesicular zone at the outer margins. Augite is more abundant here than in the two capping flows; zeolites are practically nonexistent, with calcite typically being the only prominent cavity-filling mineral observed. This earliest flow (Tv1) occurs 31 to 46 meters below the base of the second flow (Tv2), and is overlain by sedimentary rocks of the Denver Formation, indicating that a substantial period of time elapsed prior to the extrusion of the capping sheets.

The second and lowermost capping flow (Tv2) varies in thickness from 23 to 35 meters on North Table Mountain, and from 12 to 23 meters on South Table Mountain. This was the most extensive of the three flows, with a remnant being found on the northern slope of Green Mountain (Emmons and others, 1896; Waldschmidt, 1939). The base of this flow rests directly on the Denver Formation, with what appears to have been charred vegetation evident along some places of the contact. This second flow is particularly well exposed at the head of the large southeast-facing gully on North Table Mountain, where the uppermost capping flow (Tv3) has eroded back from the top of the lower flow. The bottom 30 to 60 centimeters of the lower flow are characterized by a very porous zone, while the next 20 meters, or middle part of the flow, consists of a more massive and dense zone that shows prominent cliff-forming columnar jointing (with column diameters ranging from 1 to 6 meters) and locally conspicuous spheroidal weathering. The upper third of the second flow (12 to 15 meters) is highly vesicular and contains numerous oval to elliptical cavities that are partly or completely filled with zeolite minerals (Fig. 11). Areas toward the bottom part of this upper zone (which also exhibits columnar jointing) contain cavities of modest size, averaging 5 to 8 cm but which can be as much as 31 cm in length, whereas areas in the uppermost part of this zone (forming the top 8 meters of the second flow) are much more porous and vesicular, and may contain much larger cavities. The larger cavities in this portion of the flow can be quite substantial in linear dimension, being up to 1.8 meters in length and 90 cm across, but smaller cavities in this zone may have an overall length of only 2.5 to 5 cm. These larger cavities are horizontally elongated (possibly in the direction of flow), and generally are not as symmetrical or oval in shape as are the smaller cavities located farther down. Shoshonite nearest the contact with the overlying

Figure 10. **Two capping flows (Tv2 and Tv3) on the south side of North Table Mountain. Prominent cliffs showing columnar jointing and the conspicuous bench separating the two capping flows (caused by erosion of the less resistant vesicular zone of the upper part of the second flow) are readily distinguishable features.**

(Tv3) flow is scoriaceous, containing small, irregular cavities. The uppermost vesicular and scoriaceous zone of the second flow is less weather-resistant and has eroded back to form a conspicuous bench that serves as a distinct boundary distinguishing this flow from the one directly above (Figs. 8, 9 and 10). A lighter color is evident in this upper zone, indicating some degree of alteration.

The third, or last flow (Tv3) is similar in structure to the lower parts of the second flow, being characterized by prominent cliffs showing columnar jointing. Approximately 52 meters of this flow remain on the west side of North Table Mountain, but it is generally only 15 to 27 meters thick elsewhere, thinning to the southeast and presently covering only the western two-thirds of South Table Mountain, where it attains a maximum thickness of 15 to 18 meters. A comparison of the type and distribution of vesicles in the second and third flows has led some authors to conclude that the third flow may originally have been as much as 61 meters thick (Emmons and others, 1896). A considerable part of this flow has apparently been eroded, and the upper and middle-level vesicular zone is now absent. The cavities present tend to be similar to those in the lower parts of the second flow, being rather small and containing few minerals. Although the third flow is not generally noted as a source of mineral specimens, a small area located in a roadcut on the west side of North Table Mountain contains euhedral crystals of pale salmon-colored chabazite. These crystals occur in a brecciated zone at the base of the third flow, near the contact with the underlying Tv2 flow, where they formed within angular spaces between fragments of breccia.

MINERALOGY

The minerals from the Table Mountain locality, particularly thomsonite, are noteworthy for their beauty as well as for their unique habits and associations. However, in recent years a great deal of confusion has persisted concerning the identity of these minerals. Much of this is the result of a relative unavailability of earlier publications describing these species, and also to an absence of recent comprehensive literature relating to the locality.

The descriptive mineralogy that follows is compiled from earlier literature and from more recent studies by the authors and others. Most of the reported descriptions are based on material collected from North Table Mountain. Although in most cases the individual species description and occurrence does not differ significantly between localities on North and South Table Mountain, minor locality-dependent variations have been observed. For example, natrolite is generally restricted to South Table Mountain, whereas the crystal habits of chabazite and thomsonite are noted to vary between several localities on North Table Mountain. Analogous regional variations in zeolite distribution have been noted in Iceland (Walker, 1960a), Ireland (Walker, 1960b), the Faeroe Islands (Betz, 1981), India (Sukheswala and others, 1974), and Brazil (Murata and others, 1987), while a regional variation in the crystal habit of chabazite was noted at a locality in Ireland (Walker, 1951). Such variations in species distribution and crystal habit are presumably the result of slight differences in environmental conditions, such as temperature and solution composition, during crystallization. Unfortunately, a lack of complete locality information for many specimens from the Table Mountains has made a comprehensive evaluation of regional variations at this locality somewhat uncertain. The relative abundance of the principally occurring minerals at the Table Mountains can also vary considerably from one area to another, but in general, thomsonite, analcime, chabazite, mesolite and calcite are relatively common, while fluorapophyllite, levyne, garronite, and cowlesite occur less frequently, and natrolite, gonnardite and euhedral laumontite and stilbite crystals are uncommon.

Most of the described minerals occur within amygdaloidal or vesicular cavities in the upper part of the lower capping flow (Tv2), but several species are found within fractures in the shoshonite. The minerals within the cavities can be divided into two groups which appear to be controlled partly by cavity size. The first group of minerals, consisting of the dominant species at the Table Mountains, are found primarily in the medium to larger-size cavities (those greater than about 2.5 cm), but can be noted in smaller cavities as well. The second group consists of fewer mineral species; these are relatively uncommon and mostly restricted to the smaller cavities (generally those less than 2 cm), and they have few associated minerals. A comprehensive list of the confirmed minerals in these two groups is presented in Table 1. Minerals within a given group are seldom associated with species in the other group. The random distribution of the various sizes of cavities within a given area of the Tv2 lava flow does not indicate a complete vertical size segregation; the smallest

Table 1. **Alphabetical list of mineral species occurring at the Table Mountain locality**

Analcime	Levyne (*)
Aragonite	Limonite (pseudomorph)
Calcite	Mesolite
Chabazite	Natrolite
Chlorite [group] (*)	Nontronite (‡)
Chrysocolla (†)	Offretite (*)
Cowlesite (*)	Opal
Fluorapophyllite	Phillipsite (*)
Garronite (*)	Phlogopite
Gonnardite (*)	Smectite [group]
Heulandite (*)	Stilbite
Laumontite	Thomsonite

(*) = species occurs primarily in small cavities
(†) = species occurs as fracture filling
(‡) = species occurs in shoshonite as an alteration product of phenocryst minerals

Table 2. **Summary of published analytical data**

Mineral	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	F	H_2O	Reference
Large-cavity minerals										
Analcime	55.78	22.64	—	—	—	—	13.13	—	8.33	2,3
Chabazite	47.52	19.49	—	9.74	—	0.36	0.52	—	22.11	2
Fluorapophyllite	51.89	1.54	0.13	24.51	—	3.81	0.59	1.70	16.52	2
"Albine"	67.96	8.48	1.04	5.47	0.53	1.23	0.74	—	14.55	2
Laumontite	51.44	20.96	1.04	11.75	—	0.33	0.33	—	14.42	2, 4
Laumontite—stratified layers:										
yellow crystals	51.12	20.79	1.56	12.01	0.01	0.29	0.25	—	14.34	2, 4
white crystals	52.07	21.30	—	11.24	—	0.42	0.48	—	14.58	2
Mesolite	45.88	26.03	—	8.85	—	—	6.92	—	12.42	2, 5
Natrolite	43.66	24.89	—	4.87	—	—	14.66	—	8.09	2
Stilbite (euhedral)	54.67	16.78	—	7.98	—	—	1.47	—	19.16	2
Stilbite (stratified)	55.09	17.60	0.77	8.47	—	0.12	1.47	—	16.66	1
Thomsonite-I	39.53	29.15	1.34	12.28	0.02	0.22	4.34	—	13.41	1, 4
Thomsonite-II	40.77	29.85	—	11.99	—	—	4.61	—	12.77	2, 4
Thomsonite-III	41.40	29.49	—	11.16	—	—	5.27	—	12.72	2,5,6,7
Small-cavity minerals										
Cowlesite	43.52	23.74	0.00	10.84	—	0.04	0.62	—	NR	8
Levyne	46.76	21.91	—	11.12	—	0.21	1.34	—	18.65	2
Garronite (?)†	46.97	23.39	—	10.85	—	1.17	0.79	—	18.03	2
Scolecite*	46.03	25.28	0.27	12.77	—	0.13	1.04	—	14.48	2

* = Designated as scolecite by Cross and Hillebrand (1885); their analysis (no. 20) probably represents cowlesite (see text).

† = Described by Cross and Hillebrand (1885) as an unnamed fibrous mineral (analysis no. 22; see text).

NR = not reported

References

1. Cross and Hillebrand, 1882b
2. Cross and Hillebrand, 1885
3. Clarke and Steiger, 1900
4. Henderson and Glass, 1933
5. Patton, 1900
6. Hey, 1932
7. Clarke and Steiger, 1902
8. Wise and Tschernich, 1975

cavities, with their unique set of minerals, can be situated immediately adjacent to large cavities containing a completely different set of minerals.

A summary of the early analytical data on Table Mountain zeolites was provided by Clarke (1903) and Waldschmidt (1939). These data (shown as composite averages where multiple analyses were done), as well as more recently published analyses, are presented in Table 2; designation of a specific generation was inferred from the original descriptions provided. Microprobe analyses by the authors are given in Tables 3 through 7; most analyses in these tables are averages of three analytical points. Electron microprobe analyses of the zeolite minerals were made on an ARL-SEMQ microprobe. Decomposition of these highly water-bearing minerals was minimized by using low voltage and current operating conditions (10 kV accelerating potential, 5 nanoamp sample current), and analysis of most mineral grains was made with a beam defocused to a 20 micron diameter spot. Counting times were 40 seconds on element peaks and 10 seconds on high and low background positions. As a check on analytical accuracy, most minerals were analyzed with two independent matrix correction programs and sets of standards: (1) MAGIC-IV, using as standards albite (Na, Al, Si), orthoclase (K), diopside (Ca, Mg), spessartine (Mn), hematite (Fe), $SrTiO_3$ (Sr, Ti), and BaF_2 (Ba); and (2) Bence-Albee, using as standards plagioclase (Na, Ca, Al, Si), orthoclase (K), and olivine (Mg, Fe). The two methods usually agreed to within ±2% for major oxide components; Tables 3 through 7 include analyses obtained by both methods.

A detailed review of the structure, chemistry and historical background of the zeolite species described here is provided by Gottardi and Galli (1985). Although the formulae shown following the species designations were taken from Fleischer (1987), the atomic proportions for some of the minerals in Tables 3 through 7 were calculated based on the ideal formulae given by Gottardi and Galli (1985). This was done for garronite, phillipsite and offretite to permit a direct comparison of the composition of related minerals; in the case of stilbite the analytical data more closely matched the ideal formula given by Gottardi and Galli (1985).

Many of the minerals described below crystallize in more than one generation of growth. This is particularly noted for analcime, thomsonite and calcite, each of which show four generations of deposition. The physical descriptions given below are based on distinctive morphological characteristics of a given generation; these generations are shown in Tables 8 and 9. A complete discussion of these tables is provided in the Paragenesis section.

Confirmed Mineral Species

Analcime $NaAlSi_2O_6 \cdot H_2O$

Endlich (1878) reported leucite from the Table Mountains, but this was later determined to be an erroneous identification of analcime. Cross and Hillebrand (1882a) first described analcime from this locality and provided analytical data; Clarke and Steiger (1900) gave additional analytical data, and Clarke (1903) subsequently compiled the analyses known to that point. Analcime is one of the more abundant minerals occurring here, with fine examples commonly noted. This species can occur as large, euhedral crystals in the larger cavities, or as minute, transparent microcrystals, 1 to 2 mm in size, lining the walls of small (less than 1 cm) cavities, where they are typically the only mineral

Table 3. **Electron microprobe analyses of Table Mountain zeolites**

	Analcime (third generation)	Chabazite	Cowlesite	Garronite (#1)	Garronite (#2)	Gonnardite
Na_2O	12.81	0.24	0.66	0.43	0.81	6.39
K_2O	0.02	0.19	0.11	0.30	0.63	0.00
MgO	0.00	0.00	0.09	0.02	0.00	0.00
CaO	0.04	10.24	13.21	12.66	10.94	8.51
SrO	0.00	0.66	0.00	0.00	0.00	0.00
BaO	0.14	0.09	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.01	0.01	0.02	0.05	0.08	0.05
Al_2O_3	21.64	20.94	23.86	22.10	23.27	26.33
SiO_2	53.28	51.59	42.46	46.53	45.57	42.94
TiO_2	0.00	0.02	0.02	0.04	0.02	0.00
Total	87.94	83.98	80.43	82.14	81.32	84.22
H_2O (c)	12.06	16.02	19.57	17.86	18.68	15.78
H_2O (theor)	8.18	21.34	24.22	18.41	18.41	15.60
Cation Proportions per Formula Unit:						
Na	0.947	0.073	0.090	0.183	0.346	1.677
K	0.001	0.038	0.010	0.084	0.177	—
Mg	—	—	0.009	0.006	—	—
Ca	0.002	1.733	0.996	2.802	2.582	1.234
Sr	—	0.060	—	—	—	—
Ba	0.002	0.006	—	0.001	—	—
Mn	—	—	—	—	—	—
Fe	—	0.001	0.001	0.009	0.015	0.006
Al	0.947	3.897	1.978	5.724	6.041	4.200
Si	2.032	8.147	2.987	10.225	10.037	5.811
Ti	—	0.002	0.001	0.006	0.003	—
Σ_{ox}	6.000	24.000	10.000	32.000	32.000	20.000

Σ_{ox} = number of oxygen atoms in assumed stoichiometric formula

Note: Data in weight-percent oxides. Total Fe expressed as FeO. Total = total of metal oxide components. H_2O (c) = estimated H_2O content, calculated by difference of analytical total from 100%; H_2O (theor) = theoretical H_2O content, based on the ideal formula of the mineral species.

present. The crystals have sharp trapezohedral faces that often have a glassy luster, and when unweathered they can be quite transparent (Figs. 12, 13 and 14). Analcime varies from milk-white in the larger crystals to transparent in the smaller crystals. Analcime crystals at this locality can range up to 5 cm in size, but they seldom exceed 2.5 cm. Large plates of intergrown analcime crystals up to 36 cm across have been documented by Reese (1936).

Crystallization of this species within the larger cavities occurred in four generations of growth. The first two generations appear to have commenced earlier than was previously reported. First-generation crystals are rarely noted as minute (less than 1 mm) orange-colored trapezohedrons associated with the stratified layers of laumontite and stilbite, discussed below. The second-generation crystals are typically quite small (less than 2 mm) and are noted as thin layers of intergrown crystals lining cavity walls; they are usually overgrown by second-generation thomsonite. The most prominent deposition of analcime occurred in the third generation; these crystals become progressively larger, and can occur either as intergrown crystals lining cavity walls or as individual crystals isolated on other minerals, such as thomsonite or smaller analcime crystals. Although the apparently continuous formation of this generation throughout most of the second and third generations of thomsonite (discussed below) indicates a prolonged period of crystallization, growth seems to have temporarily diminished during the deposition of thomsonite. A fourth generation within the larger cavities is represented by nearly perfect microcrystals (approx-

Figure 11. **In-place cavities in the upper part of the lowermost capping flow (Tv2); prominent cavity on left is approximately 8 cm across and contains third (IIIa) generation thomsonite.**

Table 4. **Electron microprobe analyses of Table Mountain zeolites**

	Heulandite	Laumontite	Levyne (#1)	Levyne (#2)*	Levyne (#3)†	Mesolite
Na_2O	0.27	0.19	1.90	0.59	0.43	4.98
K_2O	1.72	0.53	0.18	0.10	0.10	0.03
MgO	0.39	0.04	0.00	0.01	0.00	0.00
CaO	4.60	12.25	8.17	10.32	10.68	8.76
SrO	0.53	0.03	0.00	0.01	0.14	0.04
BaO	0.63	0.01	0.00	0.00	0.14	0.00
MnO	0.00	0.00	0.00	0.00	0.01	0.00
FeO	0.04	0.60	0.00	0.00	0.00	0.04
Al_2O_3	14.64	21.33	19.49	22.38	20.45	24.69
SiO_2	57.53	51.63	45.01	47.56	48.59	42.64
TiO_2	0.03	0.14	0.02	0.00	0.00	0.00
Total	80.38	86.75	74.77	80.97	80.54	81.18
H_2O (c)	19.62	13.25	25.23	19.03	19.46	18.82
H_2O (theor)	15.71	15.32	21.30	21.30	21.30	12.37
Cation Proportions per Formula Unit:						
Na	0.125	0.028	0.981	0.281	0.206	2.023
K	0.526	0.052	0.061	0.031	0.032	0.008
Mg	0.139	0.005	—	0.004	—	—
Ca	1.181	1.013	2.331	2.719	2.832	1.966
Sr	0.074	0.001	—	0.001	0.020	0.005
Ba	0.059	—	—	—	0.014	—
Mn	—	—	—	—	0.002	—
Fe	0.008	0.039	—	—	0.019	0.007
Al	4.422	1.941	6.116	6.486	5.964	6.095
Si	13.785	3.987	11.983	11.695	12.024	8.932
Ti	0.005	0.008	0.004	—	—	—
Σ_{ox}	36.000	12.000	36.000	36.000	36.000	30.000

Σ_{ox} = number of oxygen atoms in assumed stoichiometric formula

Note: Data in weight-percent oxides. Total Fe expressed as FeO. Total = total of metal oxide components. H_2O (c) = estimated H_2O content, calculated by difference of analytical total from 100%; H_2O (theor) = theoretical H_2O content, based on the ideal formula of the mineral species.

* = coarse-bladed, euhedral crystals

† = thin "boxwork-like" plates with offretite

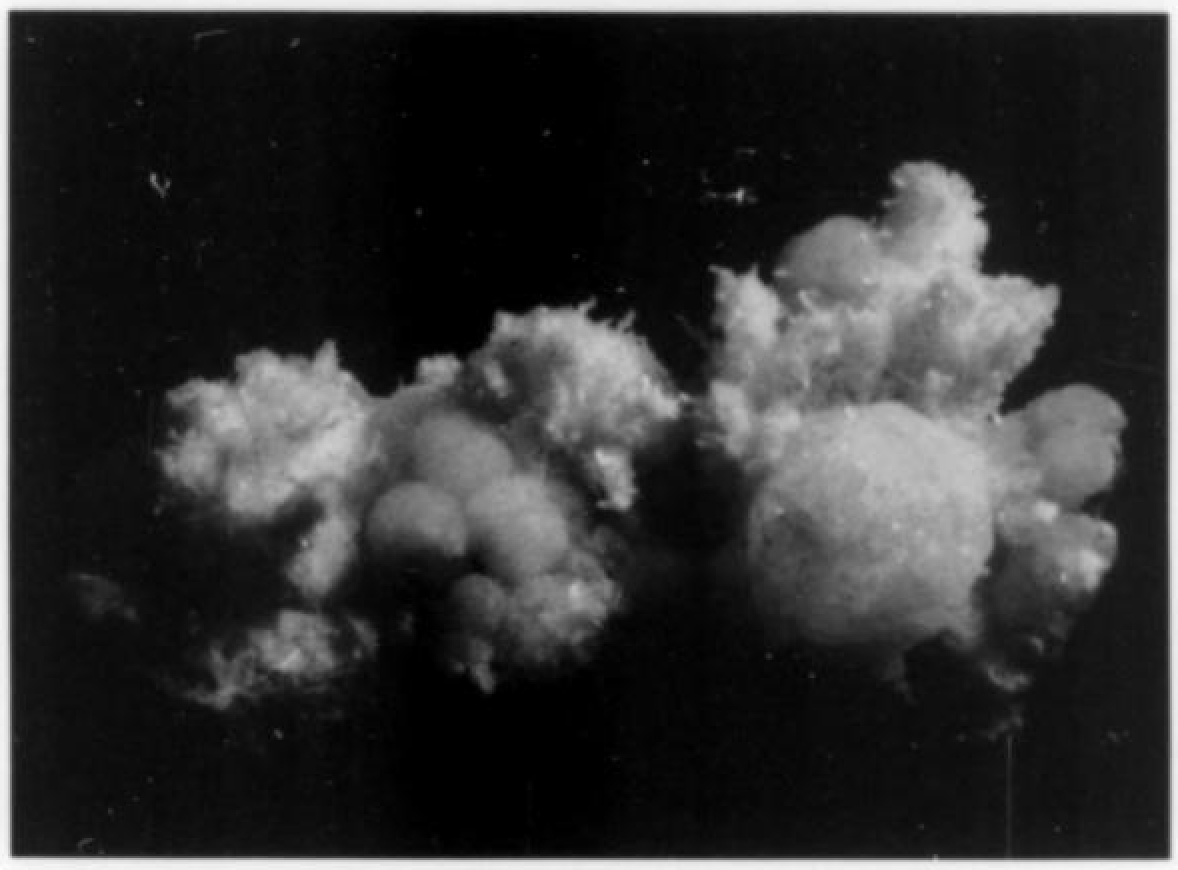


Figure 12. **Analcime trapezohedron with second and third (IIIb) generation thomsonite. Analcime is 2 cm across; overall length of the specimen is 6.5 cm. All specimens shown are from the south side of North Table Mountain and are in the authors' collections unless otherwise noted.**

imately 1 mm in size), which are often found as "floater" crystals (showing no point of attachment) within aggregates of delicate mesolite fibers, or situated on earlier-formed generations of minerals (Figs. 15 and 16).

Aragonite $CaCO_3$

Aragonite was first reported from the Table Mountain locality by Endlich (1878), and later described by Cross and Hillebrand (1882b); the authors have confirmed this species by X-ray diffraction (XRD). This is a late-stage secondary mineral that is observed as a thin botryoidal crust which resembles a caliche-type deposit with little visible crystal structure; optical and XRD examination shows that most aragonite is also intergrown with opal and calcite. Aragonite can be either white or stained orange to yellow by iron minerals. A white fluorescence under shortwave ultraviolet light is a distinctive characteristic of this mineral.

Calcite $CaCO_3$

Endlich (1878) first noted calcite from the Table Mountains, and Cross and Hillebrand (1882b) subsequently provided a detailed description. Calcite is found as well formed crystals within the larger cavities at this locality, often in attractive associations with other minerals. Four periods of deposition are noted. The earliest generation is characterized by small (less than 1.3 cm) orange-yellow scalenohedral crystals that have terminations modified by the rhombohedron.

Table 5. **Electron microprobe analyses of Table Mountain zeolites**

	Natrolite	Offretite	Phillipsite	Stilbite (second generation)
Na_2O	15.27	0.19	0.54	0.70
K_2O	0.00	2.11	4.32	0.20
MgO	0.01	0.23	0.00	0.00
CaO	0.02	8.44	8.10	8.16
SrO	0.01	0.05	0.00	0.00
BaO	0.00	0.00	0.26	0.05
MnO	0.01	0.02	0.06	0.00
FeO	0.00	0.07	0.00	0.04
Al_2O_3	26.60	19.38	21.82	17.09
SiO_2	45.36	51.90	45.81	58.76
TiO_2	0.00	0.04	0.05	0.00
Total	87.28	82.43	80.96	85.00
H_2O (c)	12.72	17.57	19.04	15.00
H_2O (theor)	9.48	18.28	16.19	17.62
Cation Proportions per Formula Unit:				
Na	1.940	0.089	0.235	0.621
K	—	0.650	1.239	0.117
Mg	0.001	0.083	—	—
Ca	0.001	2.183	1.951	4.001
Sr	—	0.007	—	—
Ba	—	—	0.023	0.009
Mn	0.001	0.004	0.011	—
Fe	—	0.014	—	0.015
Al	2.054	5.513	5.780	9.217
Si	2.973	12.528	10.296	26.890
Ti	—	0.007	0.008	—
Σ_{ox}	10.000	36.000	32.000	72.000

Σ_{ox} = number of oxygen atoms in assumed stoichiometric formula

Notes: (1) Data in weight-percent oxides. Total Fe expressed as FeO. Total = total of metal oxide components. H_2O (c) = estimated H_2O content, calculated by difference of analytical total from 100%; H_2O (theor) = theoretical H_2O content, based on the ideal formula of the mineral species.

(2) K_2O data for offretite is lower than expected; it is probable that the material analyzed was a mixture of offretite intergrown with levyne.

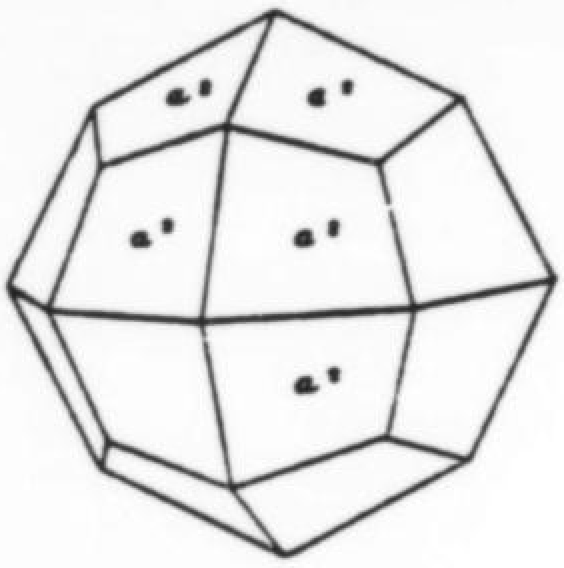


Figure 14. **Analcime crystal drawing showing trapezohedron form present at the Table Mountains (from Goldschmidt, 1913).**

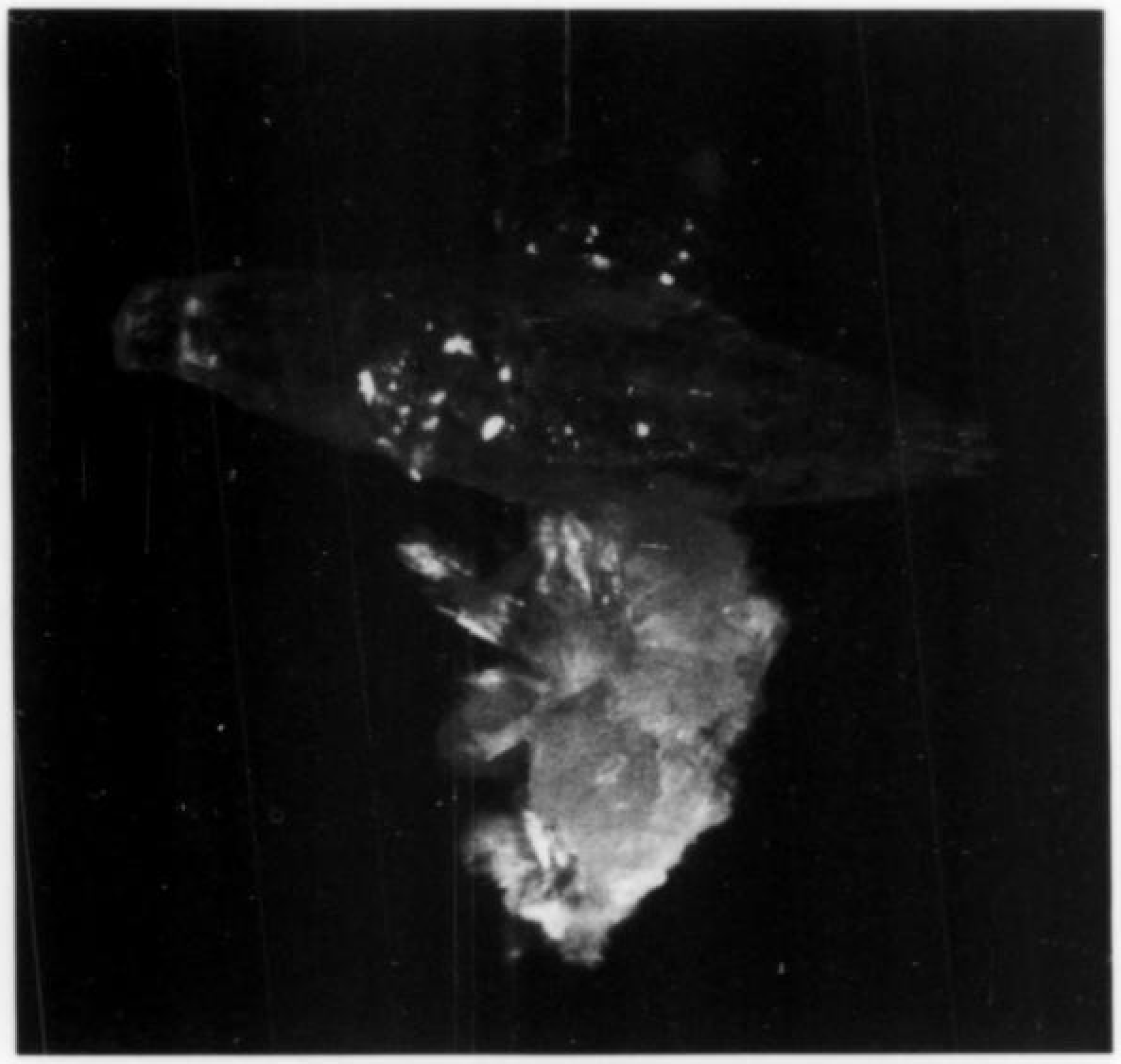


Figure 15. **Fourth-generation microcrystal of analcime on third-generation calcite and thomsonite. Overall specimen length is 6 mm.**

Figure 13. **Amygdaloidal cavity showing analcime (white trapezohedrons), second-generation thomsonite (isolated hemisphere), and calcite. Calcite is seen here as a pale yellow, second-generation scalenohedron and as orange, first-generation crystals located on several areas of the cavity wall and covered by later-formed minerals; cavity is approximately 6 cm across.**

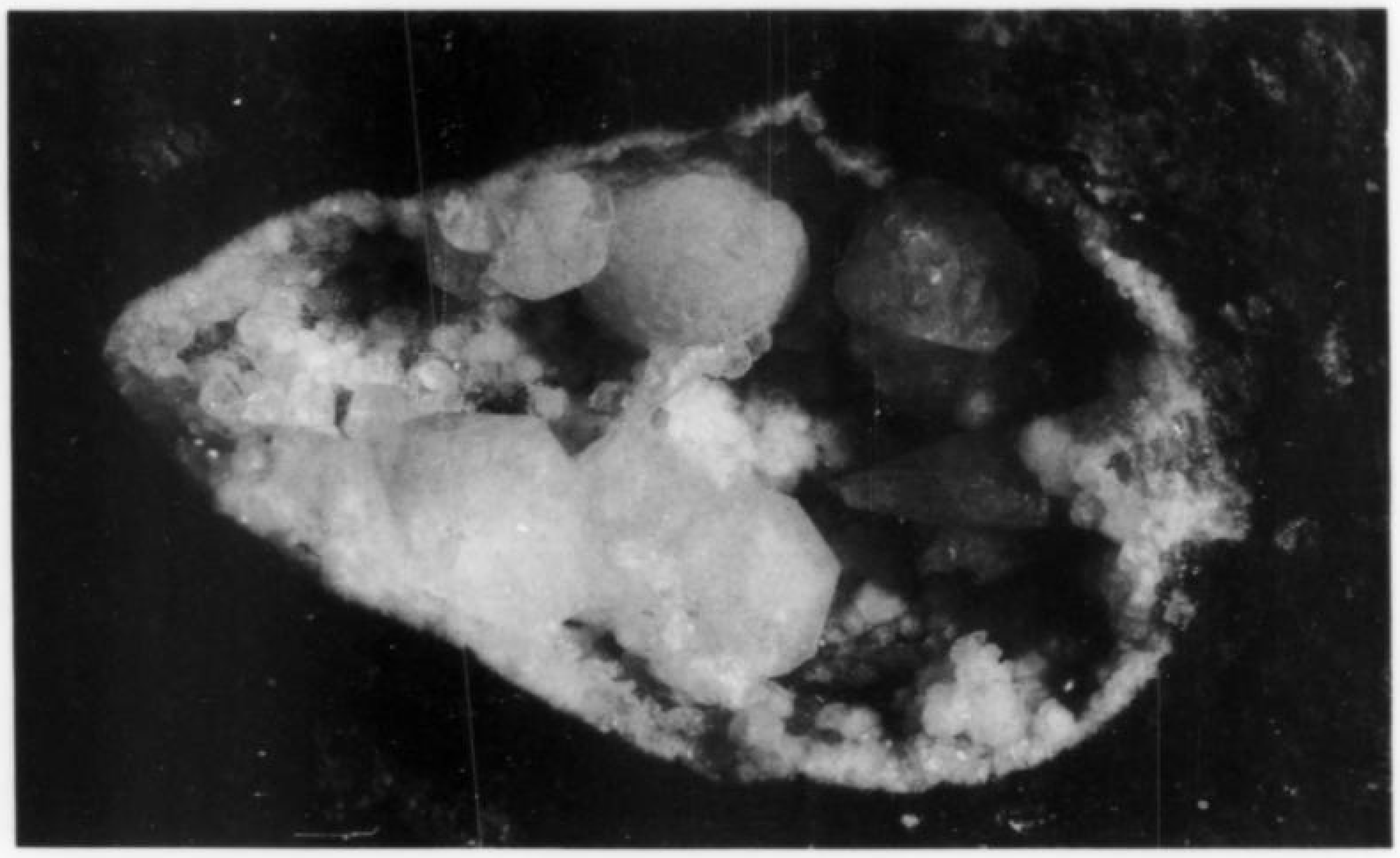


Table 6. **Electron microprobe analyses of Table Mountain zeolites**

Large-cavity thomsonite

	first generation				**second generation**				**third generation**					**fourth generation**
					#1		**#2**							
	#1*	**#2****	**#3****	**#4†**	**base**	**tip**	**base**	**tip**	**III††**	**III‡**	**IIIa**	**IIIb**	**IIIb**	**IV**
Na_2O	4.15	3.73	3.46	3.95	3.91	5.12	4.23	5.18	5.35	4.65	5.18	5.27	5.53	5.31
K_2O	0.03	0.03	0.23	0.07	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.00	0.03
MgO	0.67	0.43	0.38	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02
CaO	10.82	12.54	11.91	11.80	12.01	10.77	12.03	10.85	10.30	11.49	10.89	10.16	11.18	10.64
SrO	0.20	0.00	0.11	0.14	0.08	0.18	0.10	0.11	0.06	0.05	0.08	0.29	0.21	0.16
BaO	0.06	0.07	0.04	0.00	0.00	0.22	0.00	0.01	0.00	0.01	0.00	0.18	0.00	0.06
MnO	0.06	0.11	0.02	0.03	0.00	0.11	0.00	0.02	0.01	0.08	0.00	0.00	0.00	0.00
FeO	1.06	0.31	1.15	0.50	0.09	0.00	0.09	0.00	0.05	0.00	0.00	0.02	0.01	0.04
Al_2O_3	28.77	27.69	27.65	28.68	29.46	29.55	29.86	29.65	28.00	29.79	30.17	28.14	28.14	29.80
SiO_2	37.55	39.38	37.68	38.19	38.26	40.36	38.51	39.96	39.08	40.62	40.83	39.14	38.35	41.64
TiO_2	0.00	0.03	0.11	0.00	0.02	0.00	0.00	0.00	0.03	0.12	0.04	0.01	0.00	0.00
Total	83.37	84.32	82.74	83.37	83.85	86.33	84.83	85.79	82.89	86.81	87.19	83.24	83.42	87.70
H_2O (c)	16.63	15.68	17.26	16.63	16.15	13.67	15.17	14.21	17.11	13.19	12.81	16.76	16.58	12.30
H_2O (theor)	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40	13.40
Cation Proportions per Formula Unit:														
Na	1.134	0.992	0.943	1.063	1.042	1.326	1.116	1.347	1.440	1.193	1.323	1.416	1.490	1.348
K	0.005	0.005	0.041	0.012	0.004	—	—	0.002	0.002	—	—	0.004	—	0.005
Mg	0.141	0.088	0.080	0.002	—	0.004	0.002	—	—	—	—	0.002	—	0.004
Ca	1.633	1.842	1.793	1.754	1.770	1.541	1.754	1.560	1.532	1.630	1.537	1.508	1.665	1.493
Sr	0.016	—	0.009	0.011	0.006	0.014	0.008	0.009	0.005	0.004	0.006	0.023	0.017	0.012
Ba	0.003	0.004	0.002	—	—	0.012	—	0.001	—	0.001	—	0.010	—	0.003
Mn	0.007	0.013	0.002	0.004	—	0.012	—	0.002	0.001	0.009	—	—	—	—
Fe	0.125	0.035	0.135	0.058	0.010	—	0.010	—	0.006	—	—	0.002	0.001	0.004
Al	4.591	4.475	4.580	4.690	4.755	4.650	4.790	4.688	4.582	4.647	4.684	4.596	4.609	4.600
Si	5.309	5.400	5.296	5.299	5.261	5.389	5.241	5.361	5.426	5.377	5.379	5.424	5.330	5.454
Ti	—	0.003	0.012	—	0.002	—	—	—	0.003	0.012	0.004	0.001	—	—
Σ_{ox}	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000

Σ_{ox} = number of oxygen atoms in assumed stoichiometric formula

Note: Data in weight-percent oxides. Total Fe expressed as FeO. Total = total of metal oxide components. H_2O (c) = estimated H_2O content, calculated by difference of analytical total from 100%; H_2O (theor) = theoretical H_2O content, based on the ideal formula of the mineral species.

* = boxwork-like layers

** = brown spherules

† = tan microspherules within stratified layers of laumontite and stilbite

†† = small group of radiating "pincushion" crystals

‡ = base of large (2 cm diameter) radiating third-generation hemisphere

These crystals precede the second generation of thomsonite, and are almost invariably covered by succeeding generations of minerals (Fig. 13). Although the authors have not observed this form of calcite to be associated with chabazite, such an association was previously reported by Cross and Hillebrand (1882b, 1885). Second-generation calcite represents the major deposition of the species; crystals typically form sharp scalenohedrons, and can be either pale yellow or colorless (Figs. 17, 18 and 19). Terminated crystals have been observed up to 6 cm in length, but they seldom exceed 4 centimeters. Inclusions which impart a brown color to the crystals are occasionally noted. These inclusions are composed of a manganese oxide, and have a botryoidal form that is evident under scanning electron microscopy (SEM); the mineral species has not as yet been determined. Second-generation calcite succeeds the third generation of analcime and is contemporary with late third-generation thomsonite. Later-formed, third-generation transparent microcrystals of calcite have also been noted; these crystals were deposited concurrently with mesolite and the last generations of chabazite, analcime, fluorapophyllite and thomsonite. A final, fourth-generation deposition (confirmed by XRD) is noted as thin layers coating earlier-formed minerals such as chabazite; this generation may be concurrent with aragonite, and has a distinct bluish fluorescence.

Fluorescence of calcite from this locality (which is strongest under shortwave ultraviolet light) is related to the content of MnO. Microprobe analysis shows 0.05 weight % MnO in first-generation calcite, which exhibits a patchy white fluorescence, while second-generation calcite, containing 0.21 to 0.41 weight % MnO, has a weak to moderate red fluorescence. Fourth-generation calcite intergrown with aragonite and opal contains 0.00 weight % MnO, and up to 6.38 weight % MgO (first and second-generation calcite contains 0.00 and 0.27

Table 7. **Electron microprobe analyses of Table Mountain zeolites**

	Small-cavity thomsonite				
	early generation			late generation	
	#1	#2	#3	#1	#2
Na_2O	4.39	4.36	4.40	5.36	4.84
K_2O	0.02	0.01	0.01	0.07	0.01
MgO	0.01	0.02	0.00	0.01	0.01
CaO	13.27	13.07	11.99	10.38	11.01
SrO	0.07	0.11	0.14	0.05	0.10
BaO	0.06	0.01	0.05	0.00	0.00
MnO	0.03	0.04	0.01	0.03	0.01
FeO	0.04	0.03	0.00	0.00	0.00
Al_2O_3	28.24	28.86	28.53	28.55	29.48
SiO_2	39.60	40.10	38.25	40.32	40.36
TiO_2	0.00	0.00	0.02	0.00	0.03
Total	85.73	86.61	83.40	84.77	85.85
H_2O (c)	14.27	13.39	16.60	15.23	14.15
H_2O (theor)	13.40	13.40	13.40	13.40	13.40
Cation Proportions per Formula Unit:					
Na	1.152	1.130	1.183	1.404	1.256
K	0.004	0.002	0.002	0.012	0.002
Mg	0.002	0.004	—	0.002	0.002
Ca	1.925	1.872	1.782	1.502	1.578
Sr	0.006	0.008	0.011	0.004	0.008
Ba	0.003	0.001	0.003	—	—
Mn	0.003	0.005	0.001	0.003	0.001
Fe	0.004	0.003	—	—	—
Al	4.505	4.547	4.664	4.594	4.649
Si	5.360	5.360	5.305	5.445	5.400
Ti	—	—	0.002	—	0.003
Σ_{ox}	20.000	20.000	20.000	20.000	20.000

Σ_{ox} = number of oxygen atoms in assumed stoichiometric formula

Note: Data in weight-percent oxides. Total Fe expressed as FeO. Total = total of metal oxide components. H_2O (c) = estimated H_2O content, calculated by difference of analytical total from 100%; H_2O (theor) = theoretical H_2O content, based on the ideal formula of the mineral species.

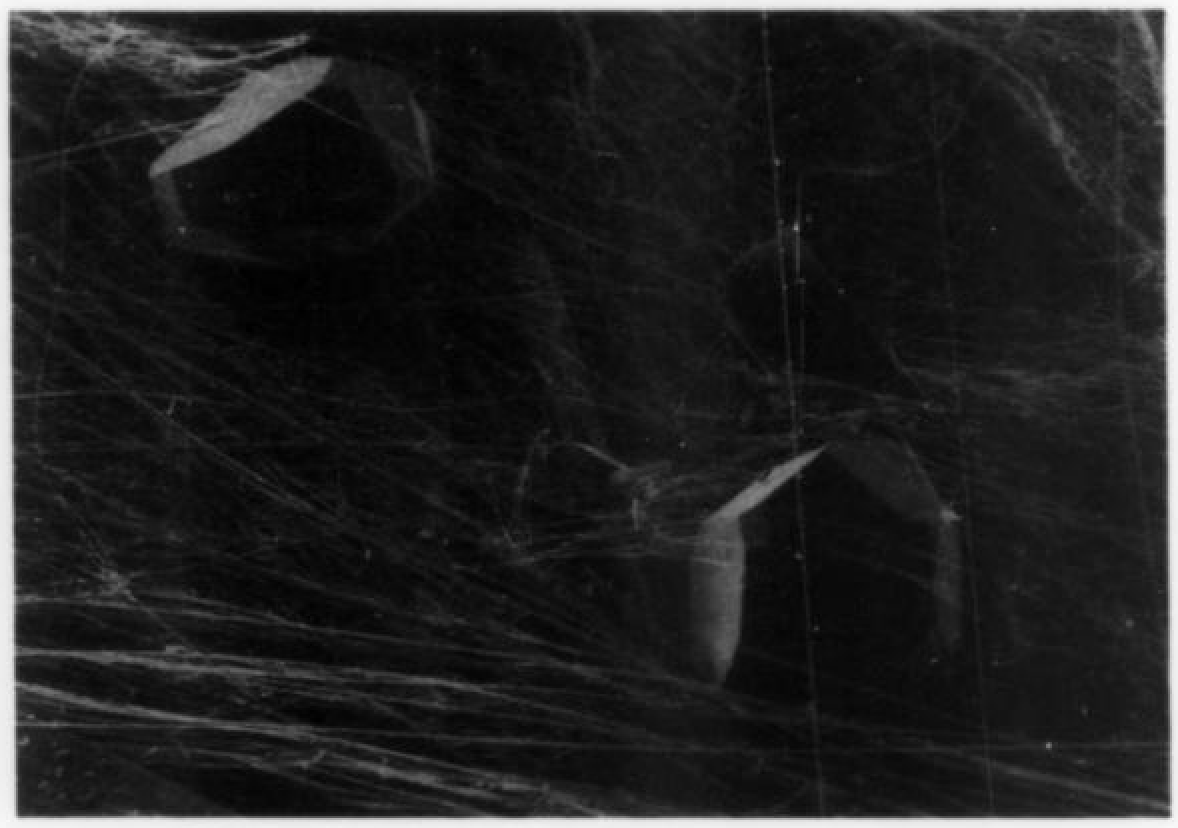


***Figure 16.* SEM photograph showing the contemporary deposition of fourth-generation analcime, fourth-generation thomsonite, and mesolite. Scale: 780X.**

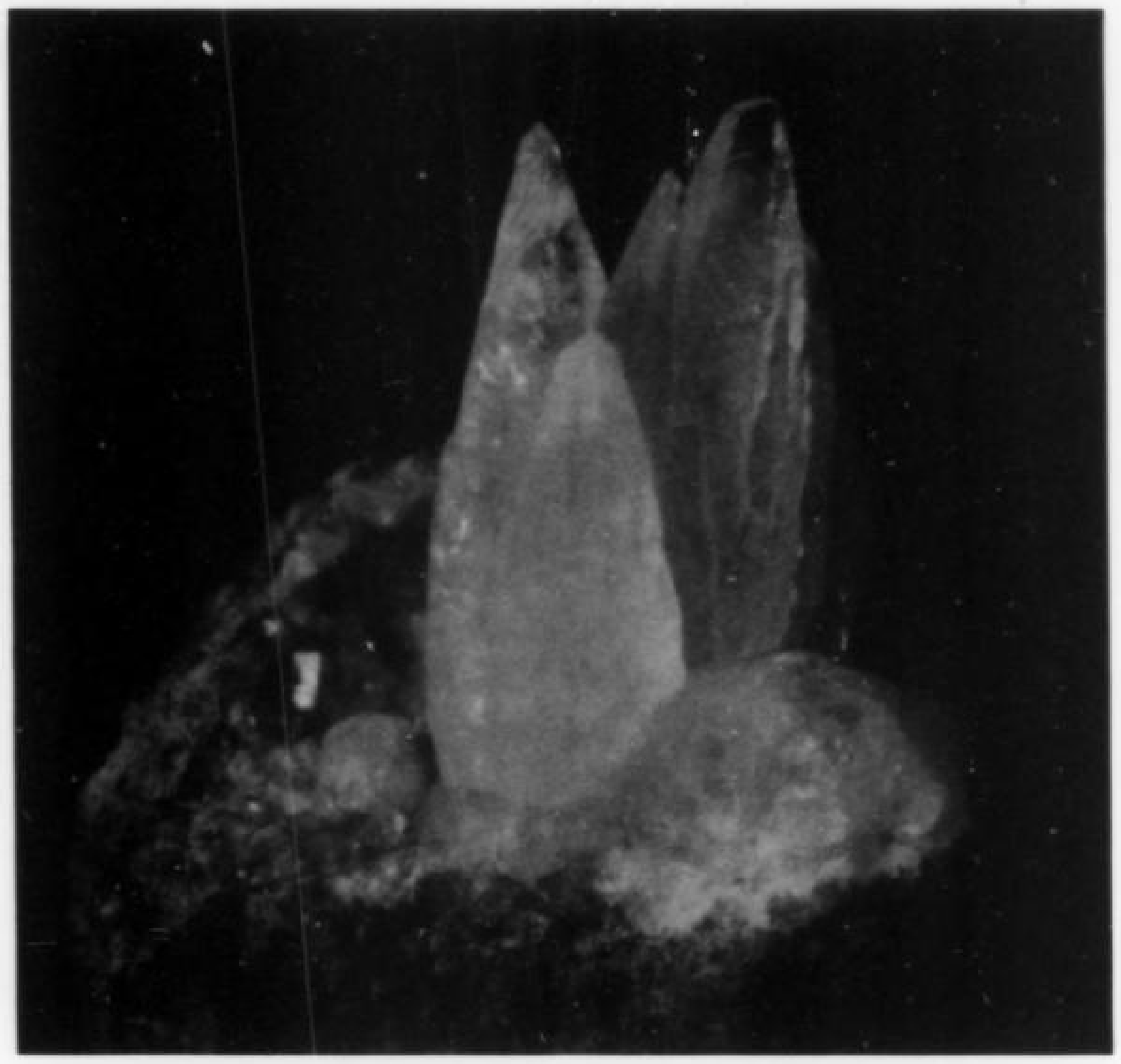


***Figure 17.* Translucent, second-generation calcite scalenohedrons, up to 3 cm in length, on analcime.**

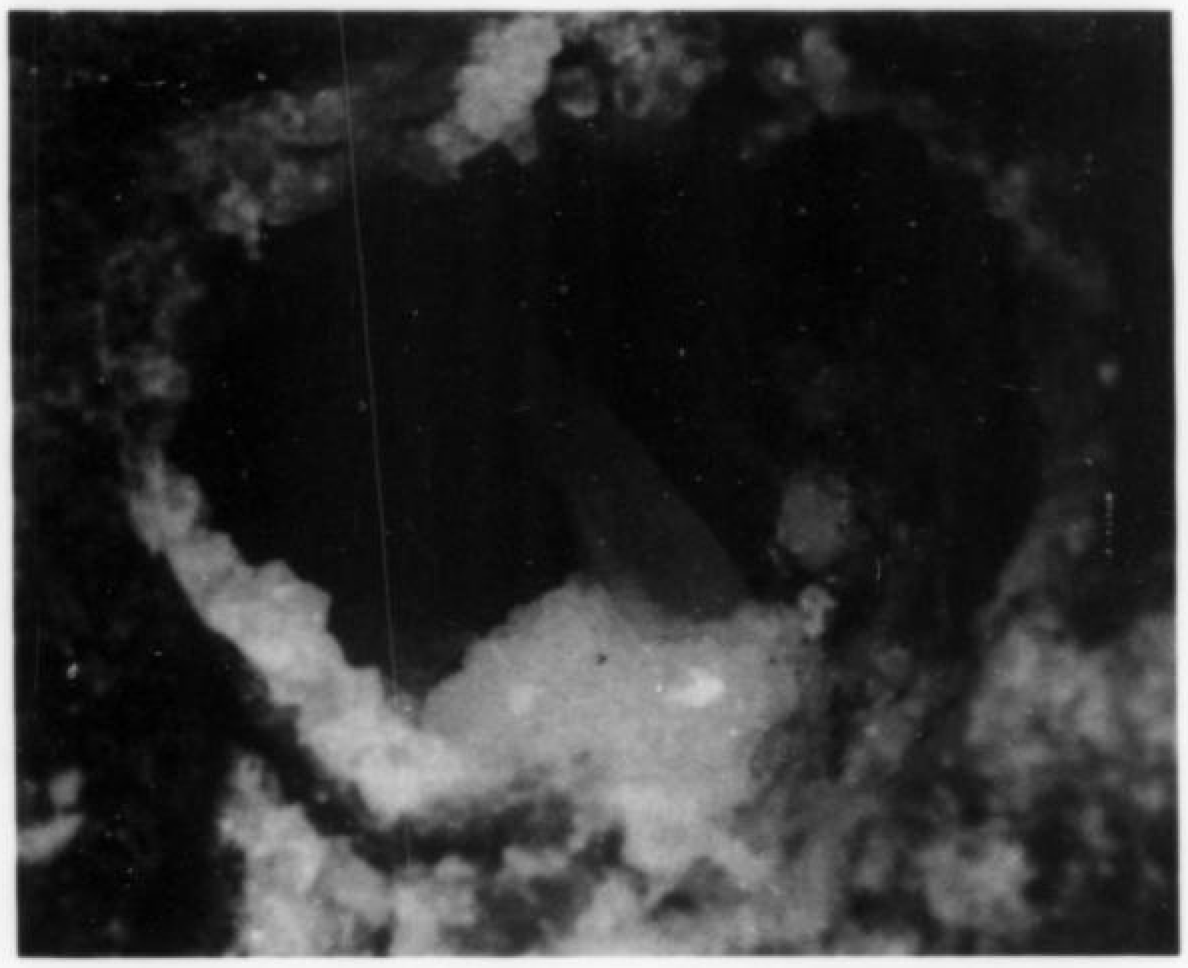


***Figure 18.* In-place amygdaloidal cavity with sharp scalenohedral second-generation calcite on analcime; cavity size approximately 6 cm.**

weight % MgO, respectively). Euhedral second-generation crystals also display a pronounced phosphorescence. Seaman (1936) described a yellow-green to yellow fluorescence from "brown" calcite from North Table Mountain, and observed no fluorescence from the colorless calcite.

Chabazite $CaAl_2Si_4O_{12}\cdot 6H_2O$

Chabazite was first documented from the Table Mountain locality by Endlich (1878). Cross and Hillebrand subsequently provided a description (1882a) and an analysis (1885), and Gude and Sheppard (1966) more recently gave X-ray powder diffraction and optical data. This mineral is most commonly found within the larger cavities, where it is generally the first zeolite species that formed euhedral crystals; it is also noted within small cavities as microcrystals lining the cavity walls. Crystals occurring in the large cavities are usually less than 6 mm on edge, but they can range up to 12 mm. Although chabazite

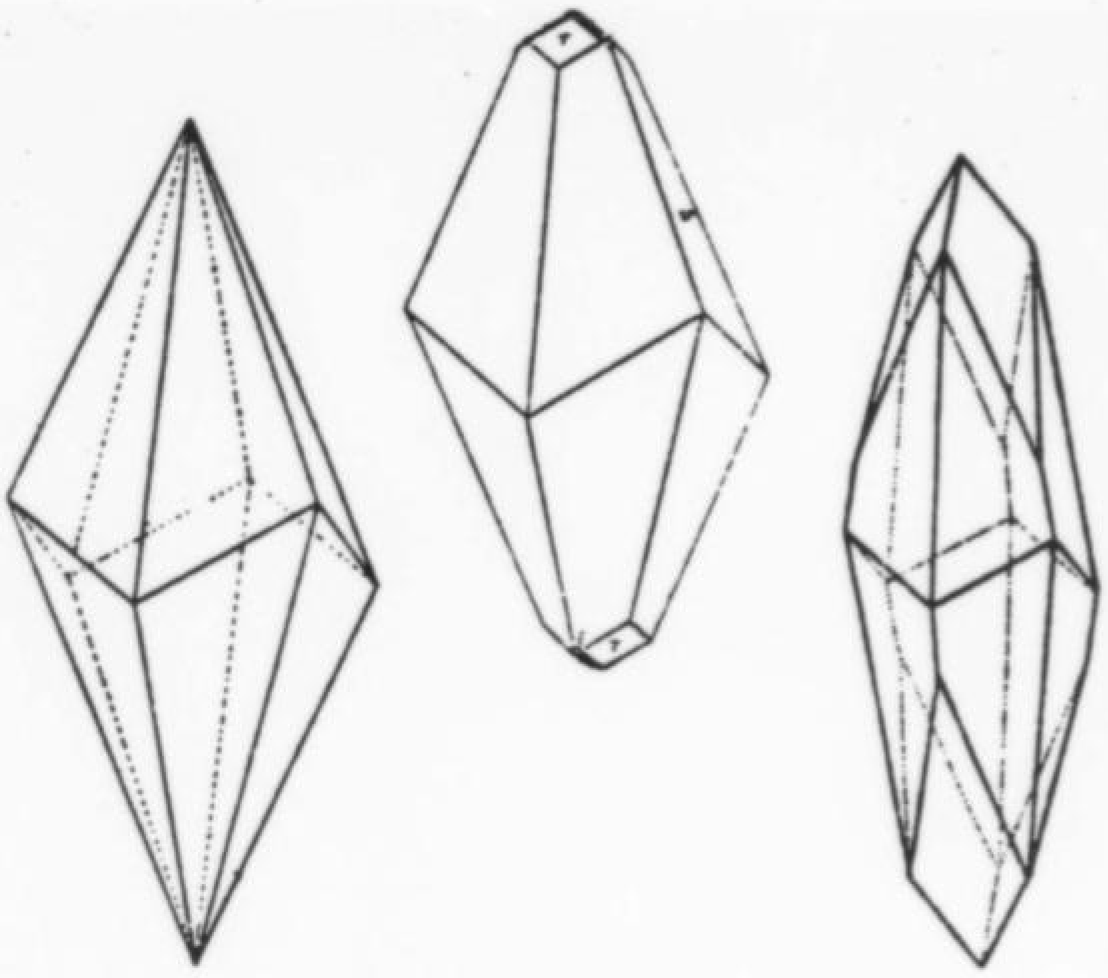


Figure 19. **Calcite crystal drawings showing scalenohedral forms present at the Table Mountain locality (from Goldschmidt, 1913).**

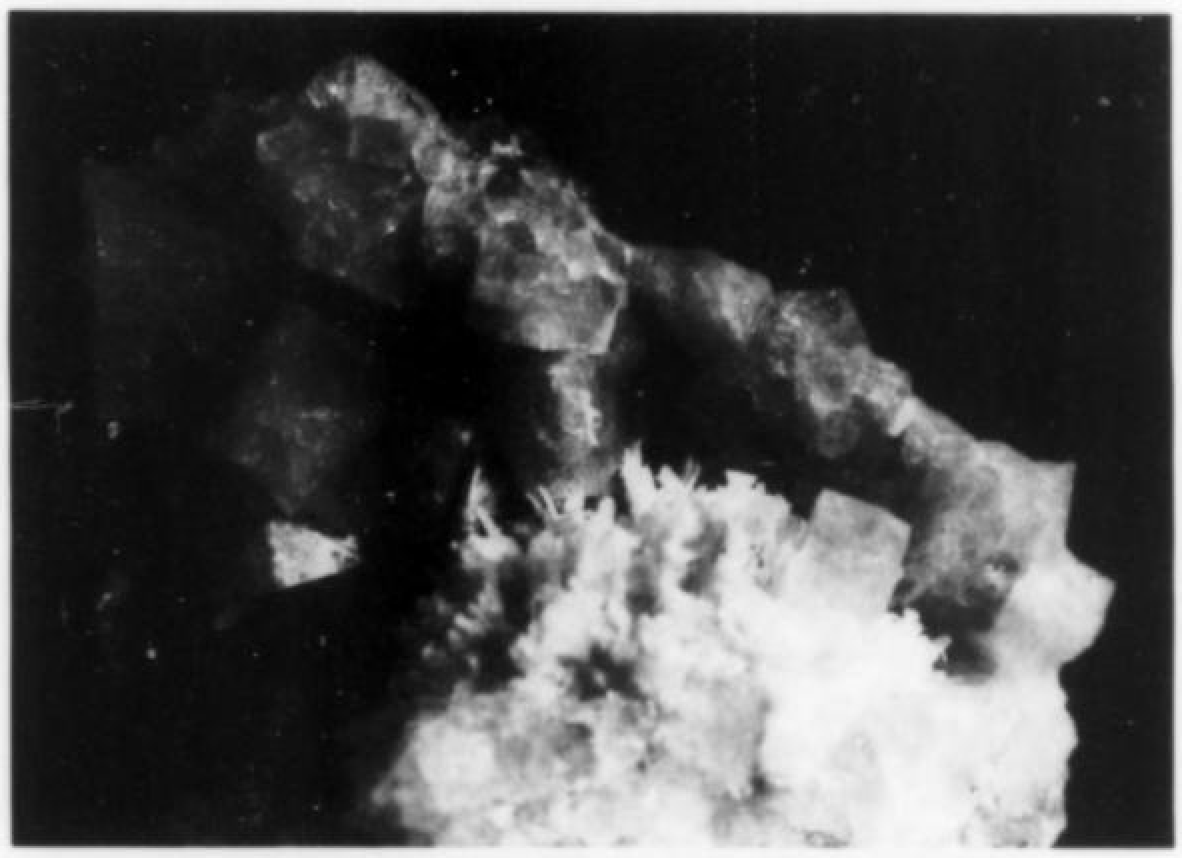


Figure 20. **Rhombohedral chabazite, associated with third (IIIb) generation thomsonite. Chabazite crystals are gray in color and range in size to 8 mm on edge.**

at this locality typically occurs in well defined simple rhombohedral crystals or as penetrating twins (Figs. 20, 21 and 22), more complex forms have been noted from a locality on the east side of North Table Mountain (Patton, 1900), and recently from an area on the south side of North Table Mountain, where the crystals exhibit modified corners (Fig. 22). A later (second) generation of transparent microcrystals is evident in some cavities. Chabazite typically has a gray to white color, but it also occurs with a tan to pink coloration in an exposure of brecciated lava at the base of the uppermost capping flow (Tv3) located along a roadcut on the west side of North Table Mountain. Crystals from this last locality have been found up to 9 mm in size.

Chlorite

A mineral presumed to be in the chlorite group is noted as a gray to greenish gray coating which lines vesicle walls, and sometimes forms a thin coating on phlogopite or other early-formed minerals (Fig. 23). Analysis by SEM shows it to be an Fe-Mg-Ca-K-Al-silicate; the exact identity of the species within the chlorite group has not been determined.

Figure 21. **Transparent microcrystals of chabazite surrounding an acicular limonite nucleus, within a cavity containing thomsonite; cavity size approximately 5.5 mm.**

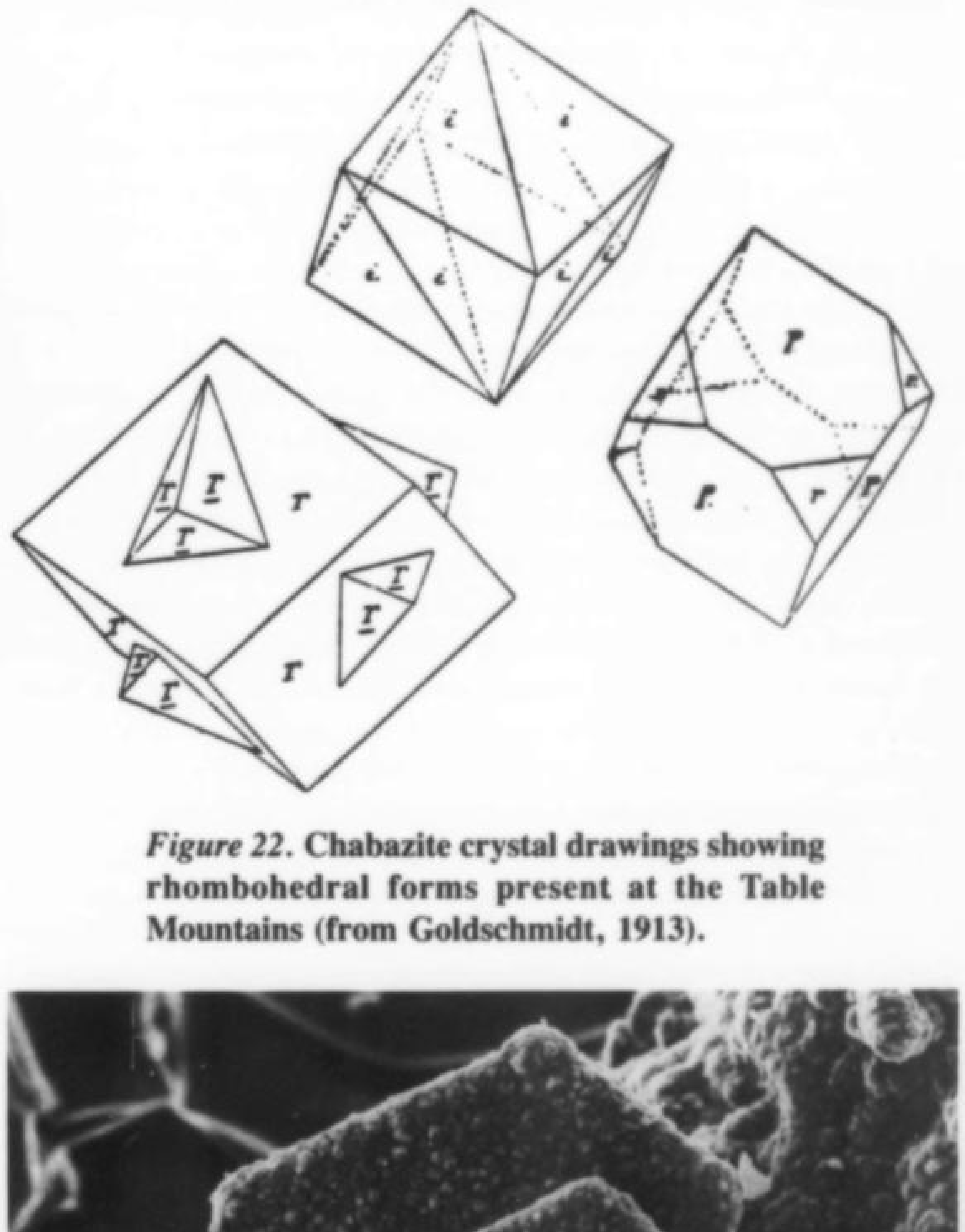


Figure 22. **Chabazite crystal drawings showing rhombohedral forms present at the Table Mountains (from Goldschmidt, 1913).**

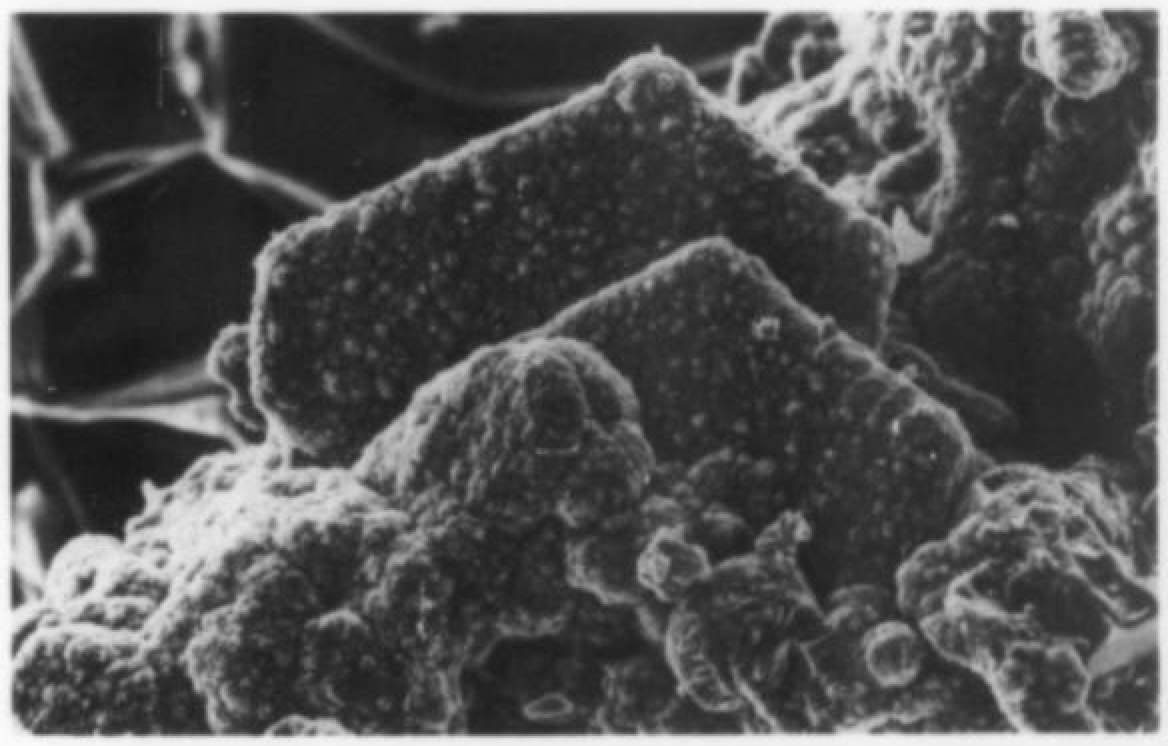


Figure 23. **SEM photograph showing a layer of a chlorite group mineral on phlogopite. Scale: 178X.**

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$

Chrysocolla, noted earlier by Robert Cobban (personal communication, 1986) and also represented by a Colorado School of Mines specimen that was collected in the late 1940's (no. TM 9500), appears as thin bluish green layers coating fracture surfaces in shoshonite (Tv3) at the southern end of a large quarry which is located on the southwest side of North Table Mountain. The authors have confirmed this species by SEM.

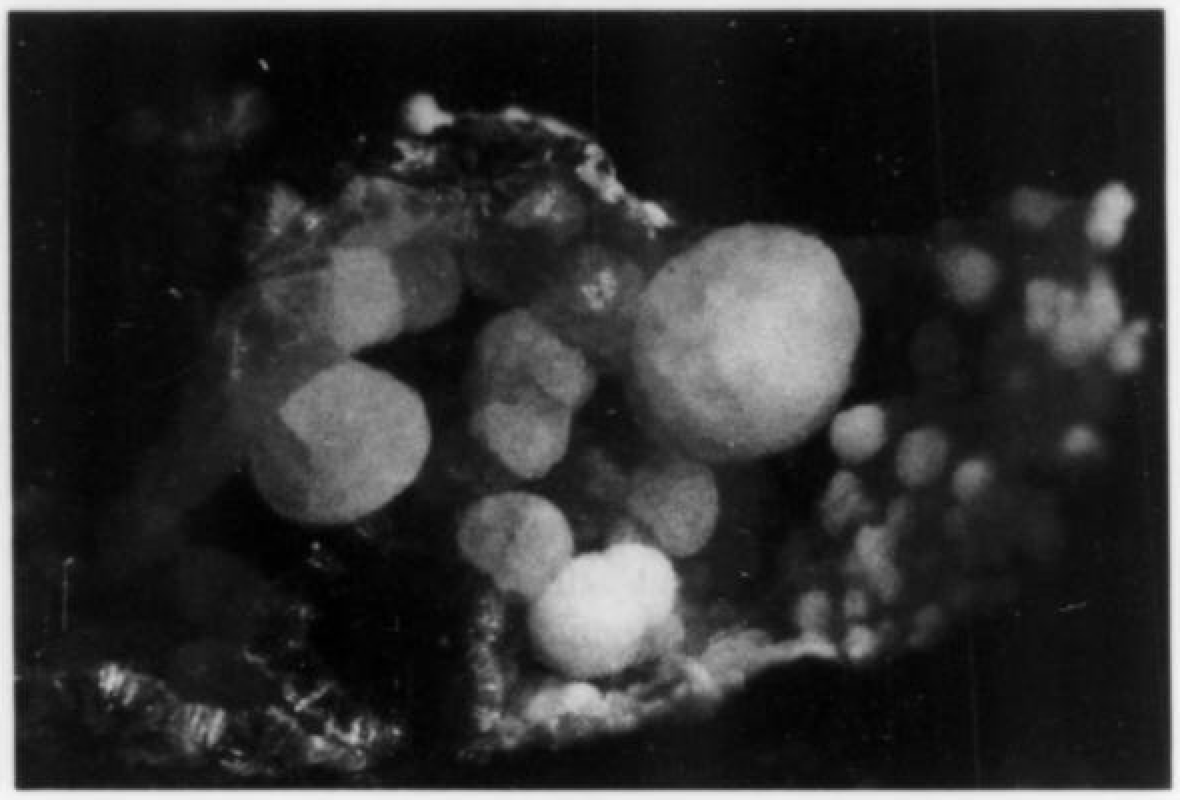


Figure 24. **Cowlesite, in typical cream-white spherules (largest spherule approximately 2 mm in diameter) within a small vesicle.**

Cowlesite $CaAl_2Si_3O_{10}\cdot 5\text{–}6H_2O$

This mineral was probably misidentified as scolecite by Cross and Hillebrand (1885); their analysis XX was interpreted by them to be scolecite, but the data nearly fit cowlesite, which was not known as a mineral species at that time (the compositions of these two minerals differ only in their water content). Specimens matching Cross and Hillebrand's original description of scolecite (1885) have been confirmed by the authors (using XRD) as cowlesite; additionally, "scolecite" specimens in the U.S. National Museum (USNM) that were collected by Whitman Cross were identified, by XRD, as cowlesite by Pete J. Dunn (personal communication, Paul W. Pohwat, USNM, 1987).

This species was first identified as cowlesite from the Table Mountain locality by Wise and Tschernich (1975), who described it as minute, white, lath-shaped crystals (to 1.5 mm) occurring in small rosettes with an appearance similar to thomsonite; analytical and optical data were also given by these authors. Cowlesite more typically occurs here either as small (0.5 to 1 mm) intergrown spherules with a white-to-gray satin luster (Fig. 24), or as slightly larger (2 to 3 mm) spherules that have a pale yellow color and a radiating fibrous habit with a vitreous luster. These two habits can be found within the same cavity, and may in fact indicate two generations for this mineral. The spherules occasionally have a green spot in the center, which may be chlorite. Cowlesite also commonly occurs as radiating fibers that completely fill minute (less than 8 mm) cavities. This mineral is generally restricted to small cavities that are less than 2 cm in diameter; although it is usually the only species within the cavity, it has been observed associated with biotite, levyne and the early generation of small-cavity thomsonite, as well as either gonnardite or garronite. Cowlesite can closely resemble small thomsonite spherules, but its much lower hardness (about 2, compared to 5 for thomsonite) can be used to distinguish it.

Fluorapophyllite $KCa_4Si_8O_{20}(F,OH)\cdot 8H_2O$

This species (which is not a zeolite) was first described from the Table Mountain locality as apophyllite by Cross and Hillebrand

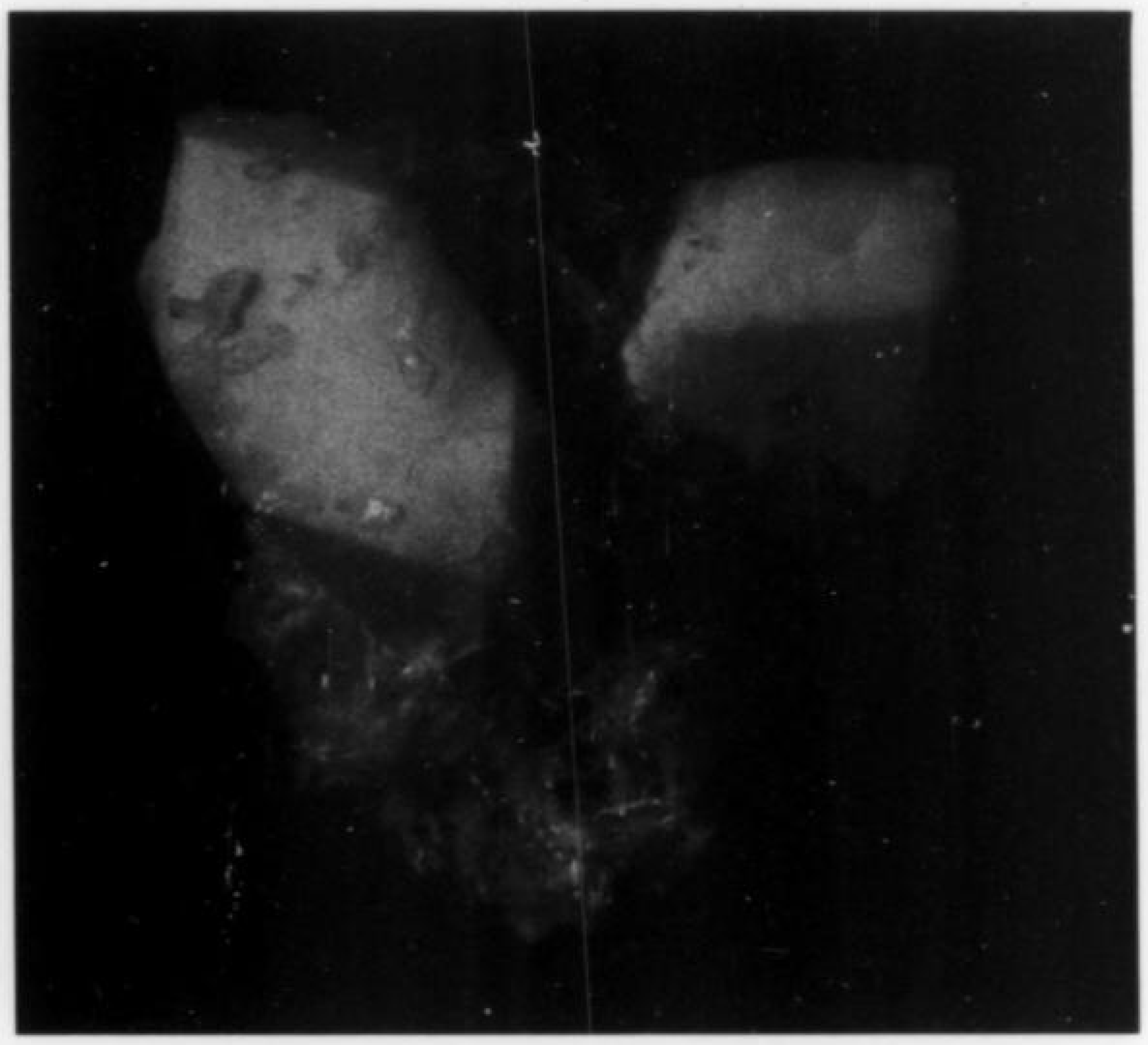


Figure 25. **White fluorapophyllite crystals showing prominent first-order prism and second-order pyramid faces, associated with third (IIIb) generation thomsonite; specimen is 3 cm across.**

Figure 26. **White prismatic fluorapophyllite crystals associated with second and third (IIIb) generation thomsonite; specimen is 10 cm in length.**

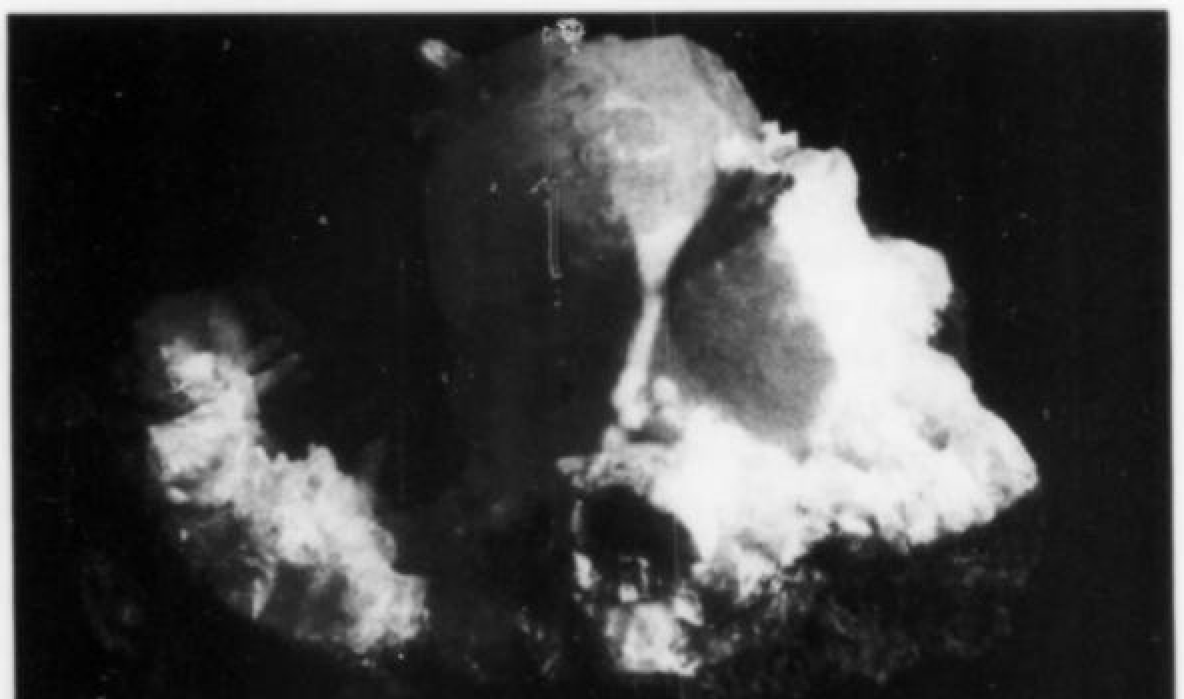


Figure 27. **Prismatic, white fluorapophyllite crystal associated with trapezohedral analcime; specimen size is 4.7 cm across.**

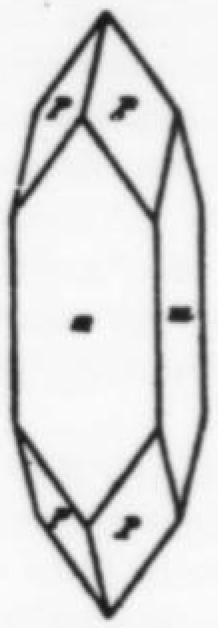


Figure 28. **Apophyllite crystal drawing showing the characteristic first-order prism and second-order pyramid form present at the Table Mountain locality (from Goldschmidt, 1913).**

(1882b, 1885), who included analytical data with their description. The reported content of fluorine in their analysis, however, (1.7% by weight, which equals 0.80 F atoms per formula unit), warrants a species designation of fluorapophyllite. This mineral, which is one of the less common species at the Table Mountains, appears to have crystallized in three generations. The earliest (first generation) deposition occurs as anhedral interstitial grains within the yellow-orange horizontally stratified laumontite and stilbite layers (described below) that are found in some cavities located in the upper part of the lower (Tv2) capping flow. Second-generation fluorapophyllite represents the most prominent crystallization of this species; crystals typically occur in the large cavities as first-order prisms that are terminated with steeply inclined, multiple second-order pyramids (Figs. 25 through 28). The larger crystals are opaque and snow-white, and rarely exceed 19 mm in length. Smaller crystals are more prismatic and translucent; they are occasionally pale green and are seldom longer than 6 mm. Because of the extreme brittleness and perfect basal cleavage of this mineral, the recovery of intact specimens on matrix is difficult, and good examples are scarce. Second-generation fluorapophyllite precedes the third generation of analcime, and appears to have started crystallizing as early as the later stages of second-generation thomsonite. The final (third generation) deposition of fluorapophyllite is characterized by transparent microcrystals that are often found on terminations of earlier-generation crystals, or associated with mesolite.

A pearly white, finely foliated alteration product of fluorapophyllite, appearing in fissures parallel to the basal cleavage plane of that mineral, was analyzed and described by Cross and Hillebrand (1882b, 1885), who noted a resemblance to a material previously designated as "albine." Although they determined it to be an alteration product rich in silica and alumina, and depleted in fluorine, alkalies and calcium, they concluded that the altered material was not albine. A recent petrographic examination of several specimens of snow-white fluorapophyllite indicated only the presence of fluorapophyllite containing numerous inclusions of unknown composition; XRD patterns of these specimens show only apophyllite. More work will be required to clearly establish the identity of the alteration product described by Cross and Hillebrand, as well as to characterize the inclusions within the fluorapophyllite.

Garronite $Na_2Ca_5Al_{12}Si_{20}O_{64}\cdot 27H_2O$

Garronite was reported to occur at the Table Mountains by Wise and Tschernich (1975), who based their identification on external morphology (William Wise, personal communication, 1987). Garronite at this locality has been confirmed by the authors by XRD and microprobe. This species may actually have been described, but not identified, by Cross and Hillebrand (1885), who noted "a fibrous mineral, dull white in color and never showing any crystal faces . . . associated with the levynite in some cavities or appearing independently in adjoining ones." Their analysis (no. XXII) of this mineral is very close to our analysis of garronite in composition and atomic proportions, and their description suggests garronite. Garronite is typically an inconspicuous white mineral that occurs only in the smaller cavities (generally those less than 2 cm), often completely filling them with solidly intergrown and compact radiating fibers (Fig. 29). Although this species can closely resemble thomsonite, it can be distinguished by concentric fractures that are perpendicular to the fibers; these distinctive fractures and an absence of the satin luster that is typical of thomsonite differentiates these two minerals. Garronite is apparently an early-formed mineral in the small cavities; although it is seldom associated with other species, it has been noted to form concurrently with the early generation of small-cavity thomsonite, and to precede chabazite, analcime and the later generation of small-cavity thomsonite. X-ray diffraction shows that much of the Table Mountain garronite is intergrown with phillipsite (described below), which is apparently an alteration product. It is difficult to visually determine the degree of intergrowth of the two minerals but, in general, pure garronite is somewhat transparent, whereas garronite altered to phillipsite has more of a white, chalky and porcelaneous appearance, and its fibrous character is less evident.

Figure 29. **Garronite, at the bottom of an amygdaloidal cavity, showing characteristic concentric fractures; it is overgrown by subhedral chabazite. Specimen is approximately 4 cm high.**

Gonnardite $Na_2CaAl_4Si_6O_{20}\cdot 7H_2O$

Gonnardite was identified from the Table Mountain locality by XRD (Robert R. Cobban, personal communication, 1986) and confirmed by XRD and microprobe analyses by the authors. This is an inconspicuous white mineral that occurs only in small (less than 2 cm) cavities, filling them completely with compact radiating fibers. Gonnardite typically has a silky, bluish white, almost opalescent luster, and it may exhibit a faint concentric banding. It resembles garronite, but lacks the pronounced concentric fracturing of that species. Gonnardite is quite uncommon in the small cavities. Although seldom associated with other minerals, it has been observed to occur with cowlesite, and with both the early and late generation of small-cavity thomsonite (Robert R. Cobban, personal communication, 1986).

Heulandite $(Na,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$

Heulandite was reported by Pearl (1972) as being present at the Table Mountains, but it has not been confirmed from either North or South Table Mountain. The authors have recently confirmed heulandite (by XRD and microprobe analyses) in cobbles of vesicular lava found below the outcrop of Table Mountain Shoshonite that is located on a small knoll on the northeast side of Green Mountain; there is some doubt, however, as to whether or not these cobbles are part of the Table Mountain lava flows. Heulandite at this locality occurs within small cavities as transparent 1 to 2 mm crystals, and has not been observed associated with other minerals. Microprobe analysis (Table 4) shows that the heulandite plots within the field of "heulandite type 1," as defined by Alietti (1972), distinguishing it from "heulandite type 2" and the closely related mineral, clinoptilolite. Recent construction activity at this knoll has obliterated much of the exposure; further work could render the area inaccessible, or even completely remove the remaining shoshonite. Heulandite has also been noted as euhedral crystals within fossil plant material in sediments of the Denver Formation at several sites within a few kilometers of Green Mountain (Modreski and others, 1984), and within cobbles of lava in Quaternary gravels on Green Mountain.

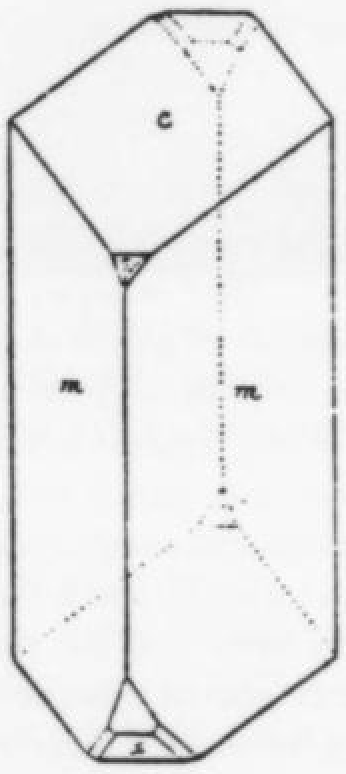


***Figure 30.* Laumontite crystal drawing showing characteristic prismatic form present at the Table Mountains (from Goldschmidt, 1918).**

Laumontite $CaAl_2Si_4O_{12}{\cdot}4H_2O$

Cross and Hillebrand (1882b, 1885) provided the earliest description and analytical data for laumontite from the Table Mountain locality, and additional analytical and optical data were given by Henderson and Glass (1933). Laumontite is an early-formed mineral that most commonly appears as transparent, microscopic, subhedral to euhedral grains which are usually intergrown with microscopic grains of stilbite, forming yellow-orange, horizontally bedded and stratified layers that have the texture of friable sandstone. These layers are generally found in irregular cavities in the uppermost part of the second (Tv2) flow. The ratio of laumontite to stilbite in these layers appears to be variable, with the composition varying depending on the "stratigraphic" position within the layer. An analysis of one sample by XRD indicated approximately 95% stilbite and about 5% laumontite; another sample was found to contain mostly laumontite and minor fluorapophyllite. The orange color of the laumontite appears to be due to the presence of iron (0.6% by weight as FeO, or 0.67% as Fe_2O_3, according to microprobe analysis).

A second generation of laumontite is noted as euhedral, prismatic microcrystals that range from 2 to 10 mm in length; these crystals may be opaque and white or transparent and colorless (Fig. 30). Patton (1900) observed crystals of this generation situated on an early (second?) generation of thomsonite, and a Colorado School of Mines specimen shows euhedral laumontite crystals resting directly on top of the stratified laumontite-stilbite layers (Fig. 31). Although the crystallization of second-generation laumontite appears to follow that of chabazite and the second generation of stilbite, it is too infrequently observed in association with other minerals to allow a precise assignment in the paragenetic sequence. "Leonhardite," a partially dehydrated variety of laumontite, is probably present at the Table Mountain locality but has not been confirmed; the accuracy of the totals in the the microprobe analyses (the observed range of water content, estimated by difference, is 14 ±2 weight % in six analyses) is insufficient to discriminate between laumontite and its partially dehydrated equivalent. It is likely that clear crystals are unaltered laumontite, and opaque white crystals are somewhat dehydrated.

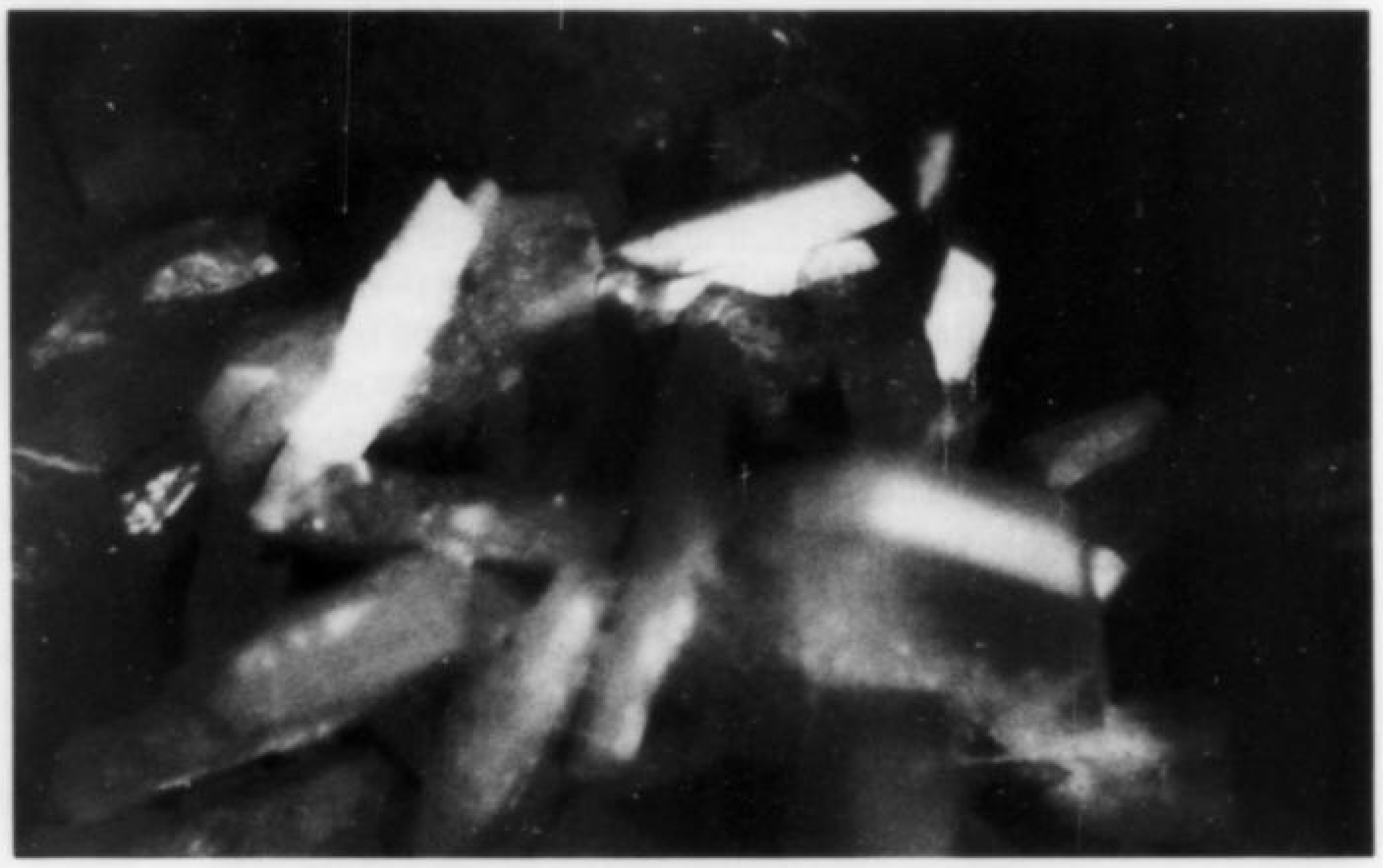


***Figure 31.* White laumontite prisms showing a characteristic monoclinic habit and associated with stilbite; crystal size is approximately 3 mm. Colorado School of Mines specimen no. TM 5579; specific locality unknown.**

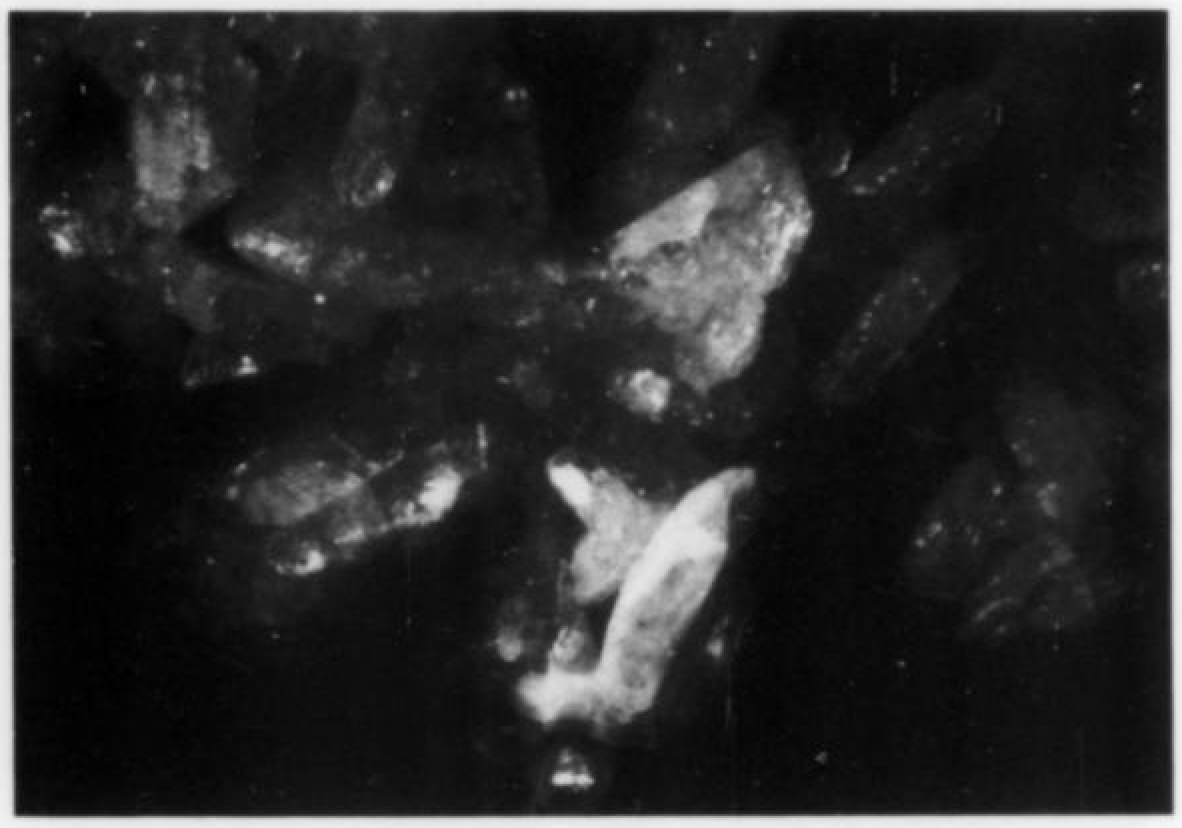


***Figure 32.* Intergrown, white, translucent, hexagonal plates of levyne standing on edge; crystals are approximately 3 mm across.**

Levyne $(Ca,Na_2,K_2)_3Al_6Si_{12}O_{36}{\cdot}18H_2O$

The earliest report of this species (formerly called levynite) from the Table Mountains was given by Cross and Hillebrand (1885), who also provided analytical data. Levyne is one of the less frequently noted minerals from this locality, and has been confirmed by XRD, SEM, and microprobe analyses. This mineral is characterized by translucent, colorless to white hexagonal plates standing on edge within the smaller cavities; the crystals are generally less than 5 mm in diameter (Fig. 32 and 33), and are typically intergrown into friable groups. Levyne also occurs as thin plates that are tightly intergrown

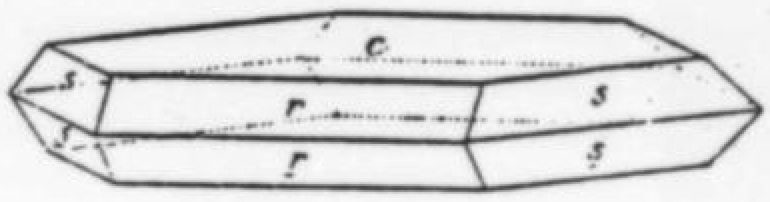


***Figure 33*. Levyne crystal drawing showing characteristic hexagonal form at the Table Mountains (from Goldschmidt, 1918).**

in a boxwork-like arrangement. Crystals showing this latter habit are found within much smaller cavities (generally those less than 2 cm); they are never completely formed, and are invariably coated or intergrown with a thin layer of offretite, imparting a "sandwich-like" appearance. Although levyne has been observed overgrown with calcite and preceded by analcime, cowlesite and possibly chabazite, it is usually the only mineral within the cavity.

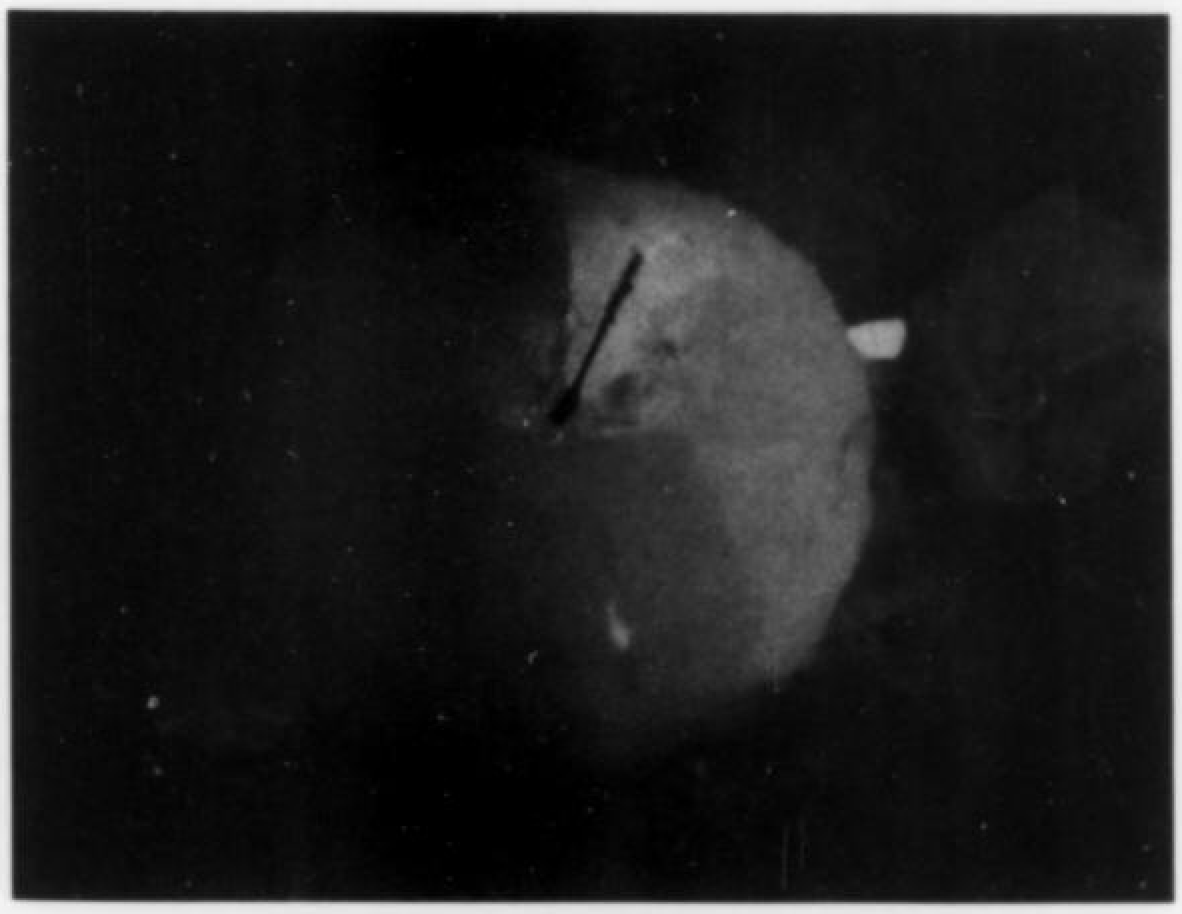


***Figure 34*. Acicular limonite surrounded by a second generation thomsonite spherule; spherule is approximately 8 mm in diameter.**

"Limonite"

Small, brown acicular needles occasionally noted within vesicles or amygdaloidal cavities are, for lack of positive identification, referred to as limonite. These early-formed needles (observed up to about 5 mm in length) often serve as nuclei for the stalactitic growth of other minerals, usually thomsonite, analcime or chabazite (Fig. 34). Semi-quantitative analyses (SEM/energy-dispersive X-ray) of several specimens has indicated the range of constituents, on a weight % basis, to be Fe_2O_3 = 32–96%, SiO_2 = 2–44%, Al_2O_3 = 0.5–11%, CaO = 0.3–6%, MgO = 0–7%, MnO = 0–0.7%, TiO_2 = 0–0.1%, and K_2O = 0–0.1%. This material may be a pseudomorph replacing or coating an earlier mineral.

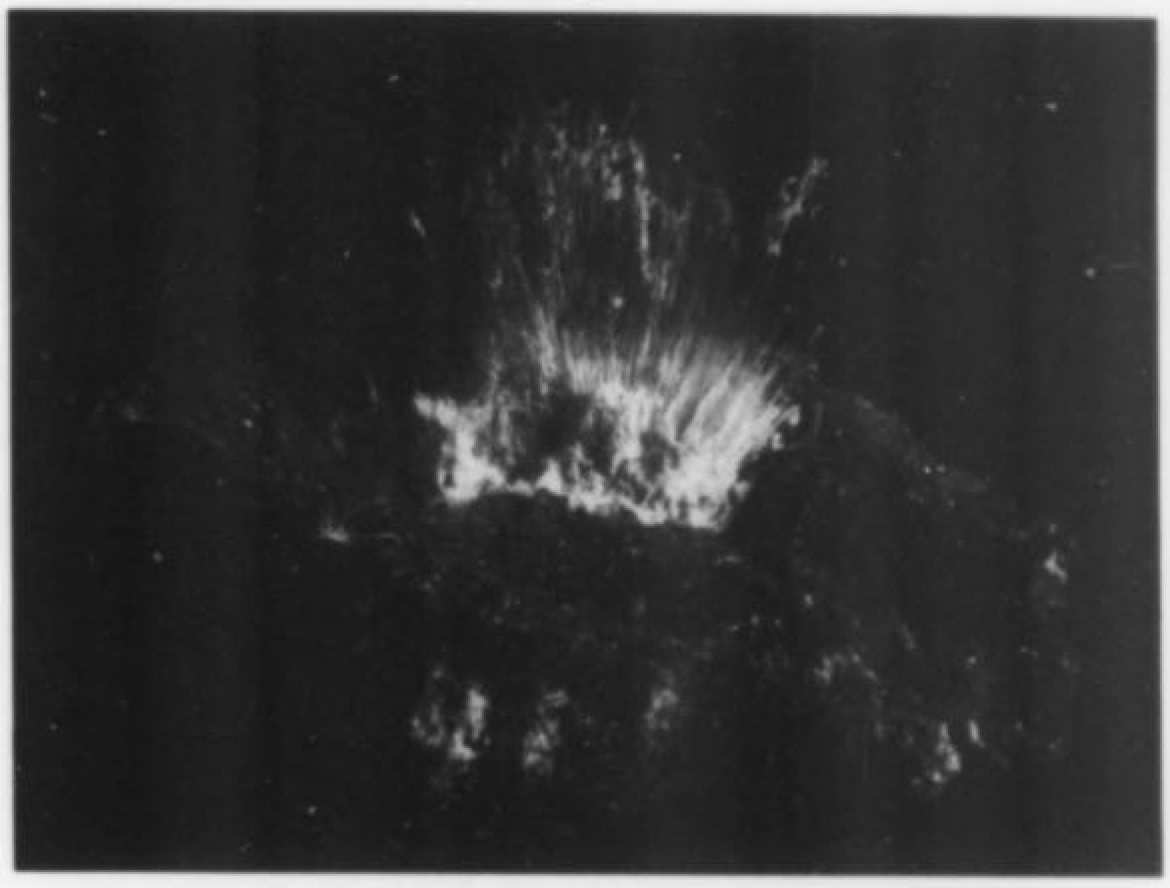


***Figure 35*. Acicular mesolite crystals, approximately 2.5 cm in length, radiating from a base of intergrown thomsonite (third-generation) and mesolite. Specimen is 9 cm across.**

***Figure 36*. Delicate white mesolite "cobweb," approximately 3 cm high, extending from late third-generation thomsonite that is resting on a bed of second-generation thomsonite.**

Mesolite $Na_2Ca_2Al_6Si_9O_{30}\cdot 8H_2O$

Mesolite was first reported from South Table Mountain by Endlich (1878), and later described and analyzed by Cross and Hillebrand (1882b, 1885). Additional data and a detailed description for mesolite from the Table Mountains was provided by Patton (1900). This distinctive mineral usually occurs within the larger cavities as flexible, slender microscopic crystals arranged either into delicate, colorless to white hairlike fibers (Fig. 35), or into loosely felted masses with a cobweb or gauze-like appearance (Figs. 16 and 36). Mesolite appears to represent one of the later stages of cavity mineralization, having been found on all other major species except aragonite. This mineral is typically associated with third and fourth-generation thomsonite, where it forms some of the more attractive specimens at the Table Mountain locality.

Natrolite $Na_2Al_2Si_3O_{10}\cdot 2H_2O$

Natrolite was noted at this locality by Endlich (1878), and specimens collected from South Table Mountain were later described by Cross and Hillebrand (1885), who also included analytical data with their report. This mineral typically occurs as transparent, white to colorless slender radiating needles, or as stubby bristle-like prisms (Fig. 37). The macroscopic appearance of natrolite from the Table Mountains can be similar to that of third-generation thomsonite (which has often been mislabeled as natrolite), however its microscopic appearance as elongated prisms with nearly square, pseudotetragonal cross sections

Figure 37. **Acicular, colorless natrolite crystals showing a characteristic radiating habit. Specimen is approximately 11 cm high. Colorado School of Mines specimen no. TM 12213-1-2; specific locality unknown.**

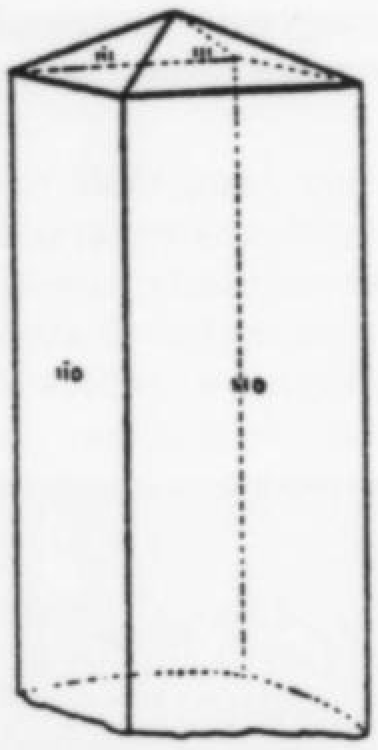


Figure 39. **Natrolite crystal drawing showing orthorhombic (pseudotetragonal), prismatic form present at the Table Mountain locality (from Goldschmidt, 1920).**

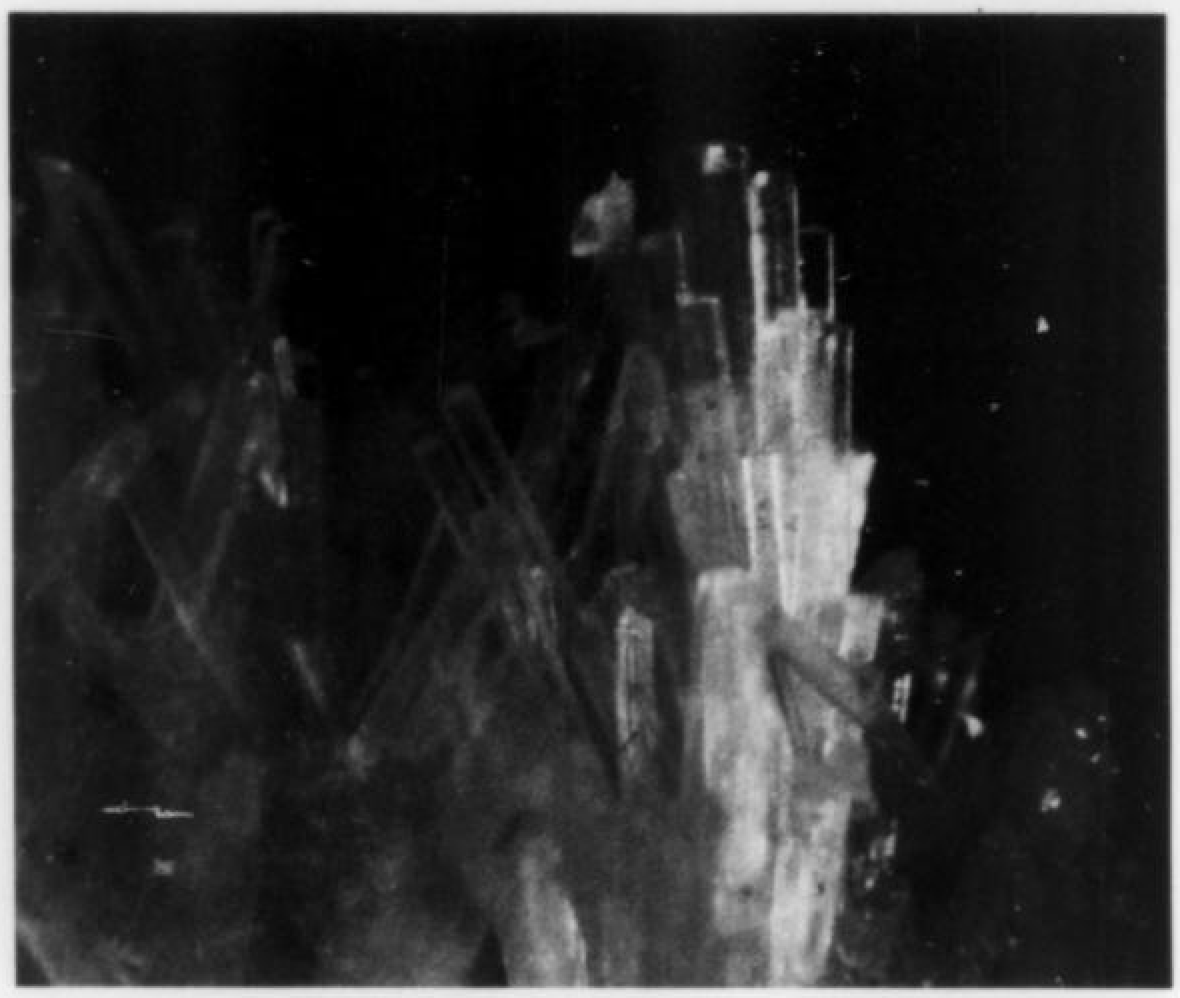


Figure 38. **Transparent, acicular natrolite crystals, approximately 4 to 5 mm in length, showing a typical nearly square (orthorhombic) cross section. Colorado School of Mines specimen no. TM 12213-1-2; specific locality unknown.**

its identity (Figs. 38 and 39). Natrolite is an uncommon mineral at this locality; it is most prevalent on South Table Mountain, and is seldom observed on North Table Mountain. Although this species has been noted to crystallize earlier than calcite, its uncommon occurrence and infrequent association with other minerals makes assigning an exact place in a paragenetic sequence uncertain.

Nontronite $Na_{0.33}Fe_2^{+3}(Si,Al)_4O_{10}(OH)_2 \cdot nH_2O$

Nontronite has been reported as occurring on basalt (shoshonite) from South Table Mountain, where it is noted as an alteration of phenocryst minerals (Schlocker, 1947); it is not found within amygdaloidal or vesicular cavities. This mineral is an iron-bearing member of the smectite clay group. All clay minerals thus far examined by the authors have been found to be in the smectite group; they are moderately iron-rich (0.4 to 3 weight % Fe_2O_3) but do not contain sufficient iron to warrant designation as nontronite, which has an ideal Fe_2O_3 content of about 36 weight %.

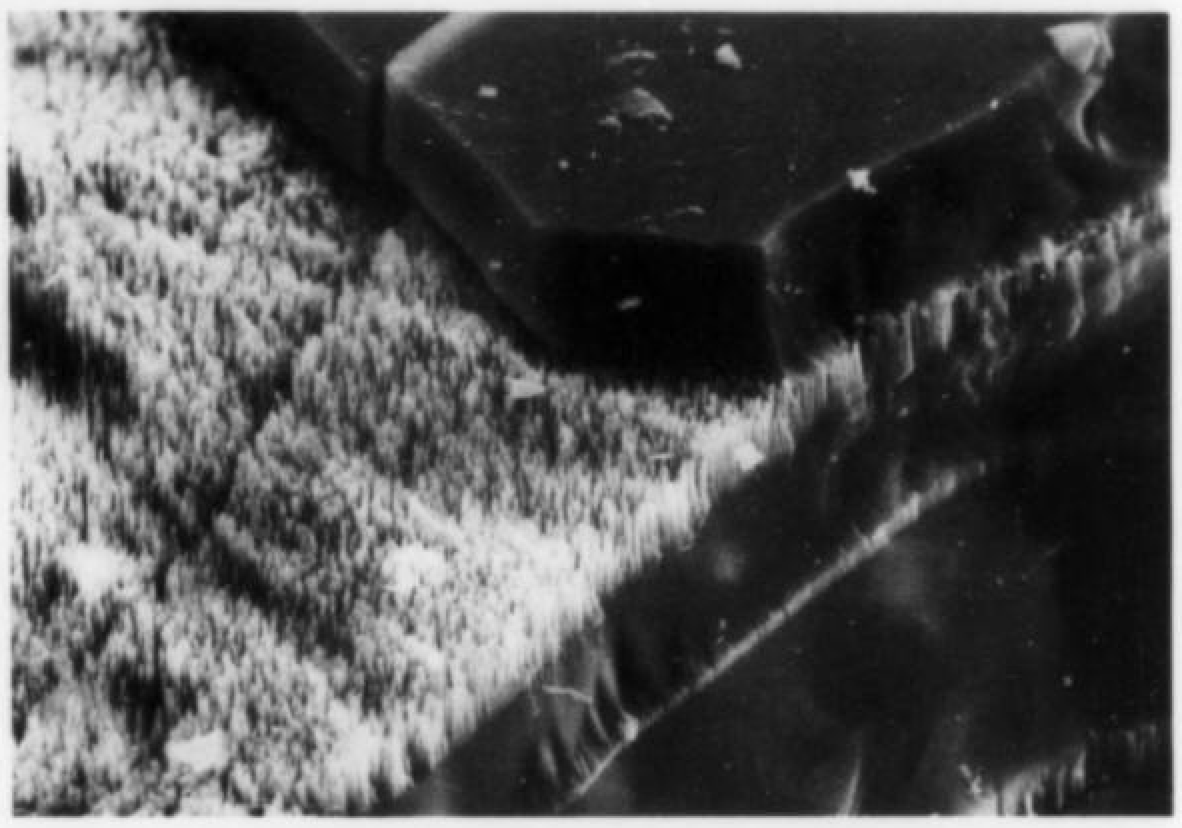


Figure 40. **SEM photograph showing the characteristic fibrous habit of offretite, situated perpendicular to {0001} of levyne; scle: 850X.**

Offretite $(K_2,Ca)_5Al_{10}Si_{26}O_{72} \cdot 30H_2O$

Cross and Hillebrand, in their report on the Table Mountain minerals (1885), gave a brief description and analysis of an unidentified fibrous zeolite that was associated with levyne; Sheppard and others (1974) subsequently presumed this unidentified mineral to represent an occurrence of offretite analogous to a Grant County, Oregon, locality (the offretite from Grant County was later identified by Bennett and Grose, 1978, as erionite, a closely related zeolite). However, the composition reported by Cross and Hillebrand (1885) closely matches that of garronite, which was not known as a mineral species at that time. Garronite has been confirmed to occur in cavities at the Table Mountain locality, and could thus correspond to the rather general physical description given by Cross and Hillebrand.

The description of the Oregon offretite given by Sheppard and others (1974) indicates a thin, white, fibrous "sandwich coating" on levyne, with the fibers having an orientation perpendicular to the levyne *c* face. A recent examination of material (by SEM and microprobe analyses) from North Table Mountain showing a similar association and fibrous habit (Fig. 40) confirms its identity as offretite, although XRD results have been inconclusive because of the large amount of intergrown levyne. The fibers are optically length-fast (negative elongation), which differentiates it from erionite. Microprobe analyses of offretite given in Table 5 are of the purest layer of offretite that could be found, but it may, in fact, be intergrown with some levyne.

Opal $SiO_2{\cdot}nH_2O$

A thin, translucent, colorless, and glassy secondary coating noted on other mineral species or interlayered with aragonite has been confirmed by optical and SEM analyses as opal. This mineral has an intense yellow-green fluorescence under shortwave ultraviolet light, which is due to the presence of the uranyl ion.

Phillipsite $(K,Na,Ca)_{1-2}(Si,Al)_8O_{16}{\cdot}6H_2O$

Phillipsite has been identified by XRD and microprobe analyses as an apparent alteration product of garronite within the small cavities. Much of the garronite found at North Table Mountain shows some degree of alteration to phillipsite when examined by XRD; the external appearance of this phillipsite closely resembles the garronite it has replaced, but the phillipsite is more opaque and chalky white, and it has a porcelaneous luster. Although XRD indicates essentially pure phillipsite, there is no evident development of crystal faces, even under SEM. The absence of euhedral crystals of phillipsite suggests that the alteration occurred after the cavities were filled by the late generation of small-cavity thomsonite. This appears to be the first report of this type of alteration (or pseudomorphism). Natural phillipsite can exhibit a considerable range in composition; the Table Mountain phillipsite is relatively high in Ca and low in Na. Its formation by alteration of garronite requires an addition of K and a slight loss of Ca.

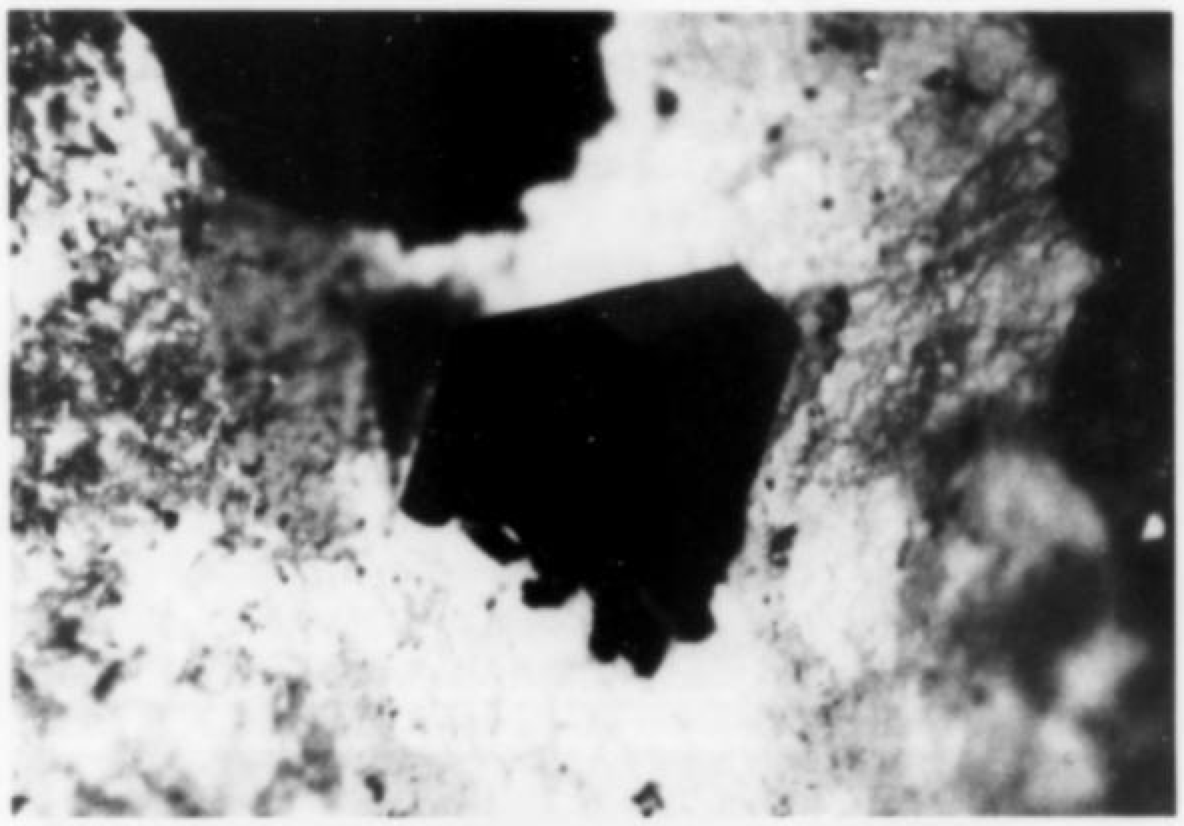


Figure 41. **Transparent light brown phlogopite crystal, showing characteristic hexagonal form; crystal is approximately 1 mm across.**

Phlogopite $K(Mg,Fe^{+2})_3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$

This mineral was first described by Emmons and others (1896), who referred to it as biotite. However, it has recently been identified by the authors as phlogopite, which, on the basis of optical measurements (β = 1.586, and γ = 1.588), has a composition intermediate between biotite and phlogopite, but closer to that of phlogopite. Semiquantitative analysis by SEM/energy-dispersive X-ray analysis confirms it as an iron and titanium-bearing phlogopite; electron microprobe analysis showed one crystal to contain about 1% by weight FeO and 2% by weight TiO_2. This species is occasionally noted as isolated, pale brown, transparent crystals on the walls of larger cavities where it is invariably overgrown by later-formed zeolite minerals. It also appears as free-standing, thin hexagonal plates (to 2 mm) situated on edge within small cavities (Figs. 23 and 41); these delicate crystals are usually coated by a chlorite group mineral.

Smectite

Light to dark brown clays are commonly noted in cavities containing the earliest (first) generation of thomsonite. The exact species have not been determined, but XRD shows them to be impure smectite clays; semiquantitative microprobe analysis (on unpolished samples) shows, on a weight % basis, about 0.4% Na_2O, 8–10% MgO, 3–4% CaO, 0.2 to 3% Fe_2O_3, 20% Al_2O_3, and 50% SiO_2.

Stilbite $NaCa_2Al_5Si_{13}O_{36}{\cdot}14H_2O$

Cross and Hillebrand (1882b, 1885) provided the earliest description and analysis of stilbite from the Table Mountain locality. This mineral most commonly occurs as transparent, microscopic, subhedral grains associated with laumontite in the early-formed, stratified yellow-orange layers; these layers are seen in the bottom of some of the irregular cavities that are located in the upper part of the lower (Tv2) capping flow. Stilbite also occurs in a later generation of growth as larger, euhedral crystals that are translucent and colorless. A Colorado School of Mines specimen (TM 5580) shows these crystals situated directly on top of the stratified sandy layer of laumontite and stilbite; they range from 2 to 10 mm in length and have the typical habit of this species (Fig. 42). Stilbite can also occur in a more densely intergrown habit, characterized by sheaves of euhedral white crystals that display a pearly luster and lamellar structure. This last habit was noted from a locality on the east side of North Table Mountain, with the crystals being approximately 13 mm in length.

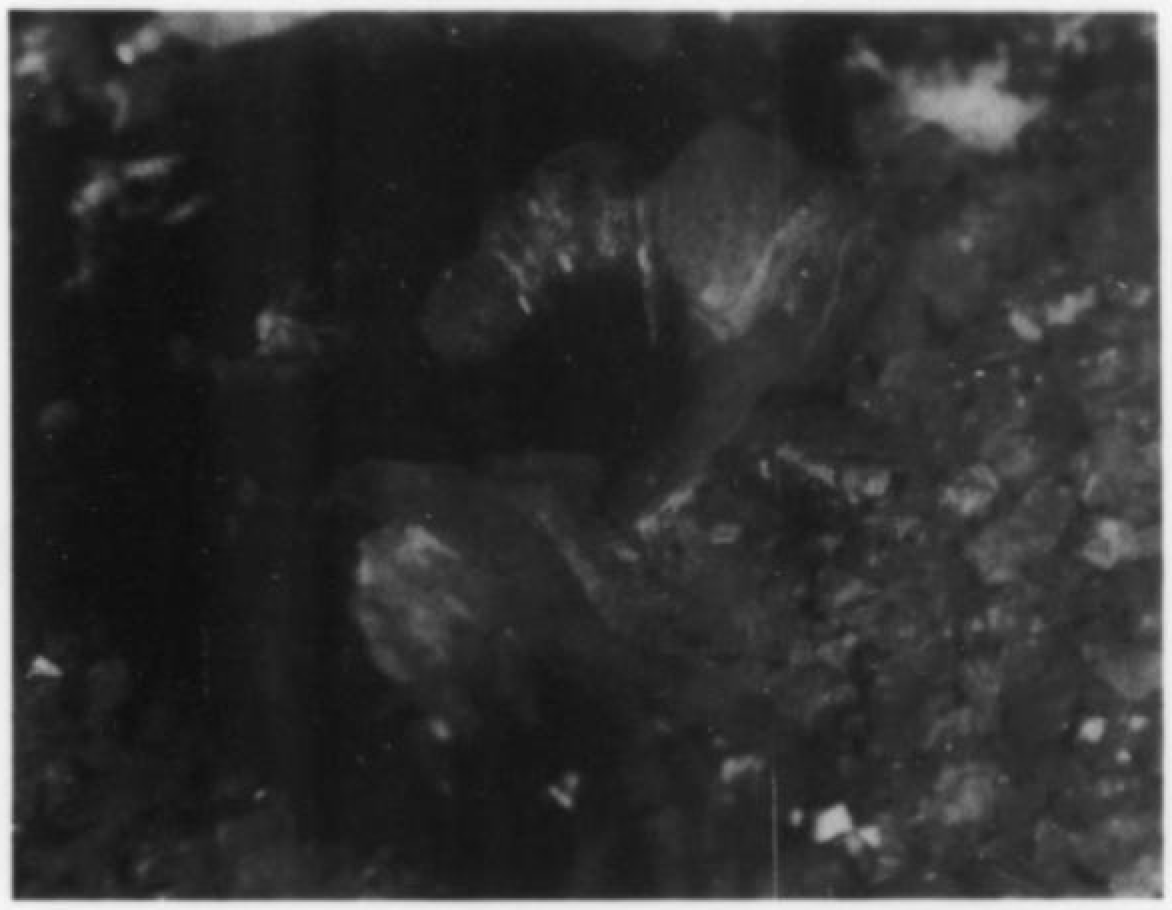


Figure 42. **Stilbite, associated with chabazite and situated on top of a stratified layer of laumontite and stilbite. The crystals are approximately 6 mm in length. Colorado School of Mines specimen no. TM 5580; specific locality unknown.**

Thomsonite $NaCa_2Al_5Si_5O_{20}{\cdot}6H_2O$

Cross and Hillebrand (1882a, 1882b, 1885) gave the earliest description and analytical data for thomsonite from the Table Mountain locality. Additional data were provided by Patton (1900), and Clarke and Steiger (1902), while Clarke (1903) summarized the analytical data for thomsonite known to that point. Subsequent analytical and optical data were given by Hey (1932), and by Henderson and Glass (1933).

Thomsonite from the Table Mountains may be present within either large or small cavities. In the large cavities it shows an extreme variation in morphology, with each variant likely being a manifestation of a changing environment throughout successive periods of crystallization. The unique and varied habits of this species, as well as the beautiful associations with other minerals found here, qualify the Table

Mountains as one of North America's most noteworthy zeolite occurrences. However, this diversity in form has also led to the frequent misidentification of the species.

Patton (1900) suggested three morphological types for Table Mountain thomsonite, based on the presumed sequence of deposition. Two of these types were further divided into subtypes, creating a total of five categories of thomsonite habits. Patton's original categories are here redefined into four generations of thomsonite occurring within the larger cavities, and two generations occurring within the smaller cavities. Small-cavity thomsonite appears to be paragenetically unrelated to the minerals occurring within the larger cavities. For the large-cavity thomsonite, a newly defined first generation is added, Patton's types I, II, and IIa are reorganized into a second and third generation (with the third generation including several variants), and a fourth generation is identified. Thomsonite occurring within the small cavities includes an early-formed generation, and a later-formed generation which incorporates Patton's earlier-described types III and IIIa thomsonite. These redefined generations appear to better account for the multiplicity of forms noted within the large and small cavities, and they more closely fit the observed mineral associations as well as the sequence of mineral deposition and concomitant morphological changes noted at different locations on North and South Table Mountains. The descriptions of the various habits of thomsonite presented below are divided into two sections based on cavity size. A drawing depicting the idealized morphology of the successive generations of large-cavity thomsonite is shown in Figure 43.

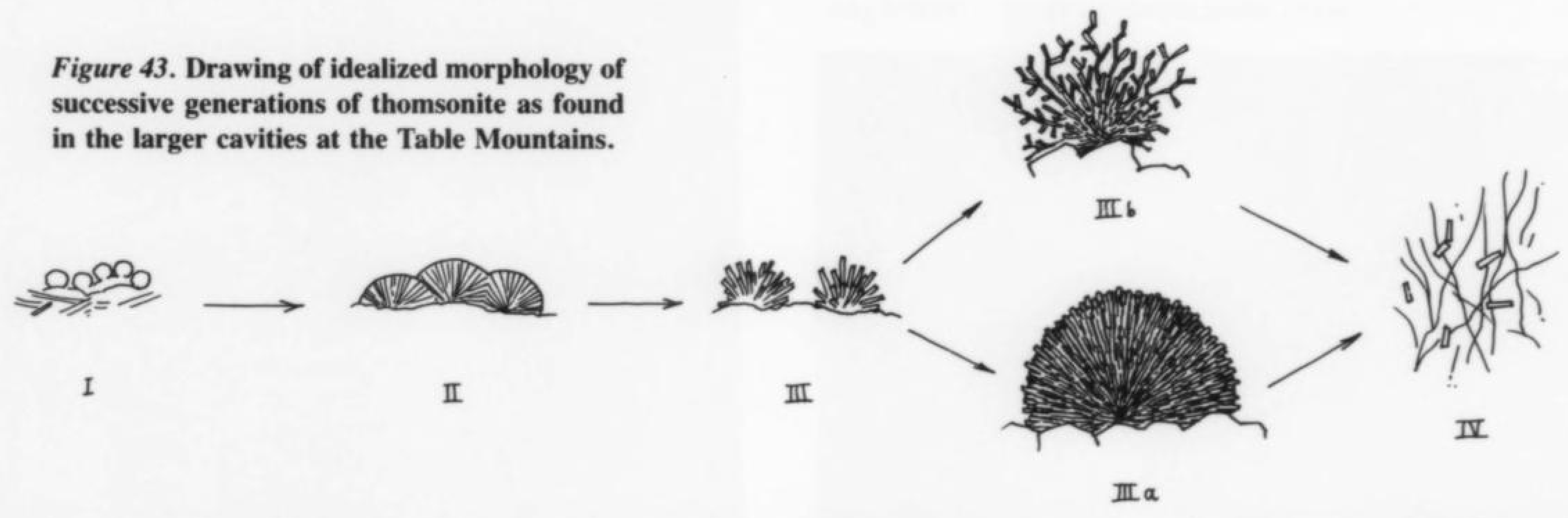


Figure 43. **Drawing of idealized morphology of successive generations of thomsonite as found in the larger cavities at the Table Mountains.**

Thomsonite Occurring in Large Cavities

The first generation of large-cavity thomsonite is characterized either by small, dense spherules that have a waxy-appearing reddish brown interior and an off-white to tan exterior, or by a massive form that has a translucent, reddish brown vitreous luster. This massive form often appears as thin layers (that are an off-white color on external surfaces) which have a boxwork-like structure. The spherules, which may show an indistinct radial structure, range from 2 to 5 mm in diameter (Fig. 44) and are generally found in irregular cavities within the uppermost parts of the second (Tv2) shoshonite flow, where they are usually situated on a massive form of thomsonite of the same generation. This generation of thomsonite is seldom associated with other zeolite minerals; it often occurs in cavities that are partly filled with a smectite clay mineral. A slightly later-formed variation of this early generation may be found as minute white spheres (approximately 1 mm in diameter) intergrown with laumontite and stilbite within the stratified layers. It is uncertain whether this habit and the larger spherules described above represent two different generations, but based on chemical composition and an apparently continuous gradation of form, it appears that these two habits were deposited at approximately the same period of time. Cross and Hillebrand (1882b, 1885) and Henderson and Glass (1933) provided analytical data on the composition of first-generation thomsonite (Table 2), and new data by the authors is included in Table 6; this data shows that first-generation thomsonite has a higher content of iron and magnesium relative to the later generations.

Several interesting variations of early-formed thomsonite are worth noting. One such variation is exemplified by a specimen from South Table Mountain, in which a massive form of thomsonite with an opaque, light tan color and porcelaneous texture nearly fills a small (approximately 5 cm) irregular cavity. This thomsonite exhibits distinctly stratified layers, and the uppermost surface is overgrown by a later (second) generation of thomsonite, and analcime. Another unusual variation of early (first-generation) thomsonite can be found at a small outcrop on the northeast side of South Table Mountain, where the shoshonite appears as a scoriaceous, coarse flow breccia composed of angular and slightly rounded fragments. The thomsonite at this and other similar but less prominent exposure on North and South Table Mountain does not occur within cavities, but is instead found as thin layers that form a boxwork-like network partly filling interstitial areas of the breccia. These layers have an off-white color on external surfaces, and a reddish brown color and vitreous luster on broken surfaces. Emmons and others (1896) speculated that the occurrence of brecciated shoshonite was caused when the uppermost (Tv3) flow encountered uneven terrain as it flowed over the underlying (Tv2) surface, resulting in a broken and jumbled lava.

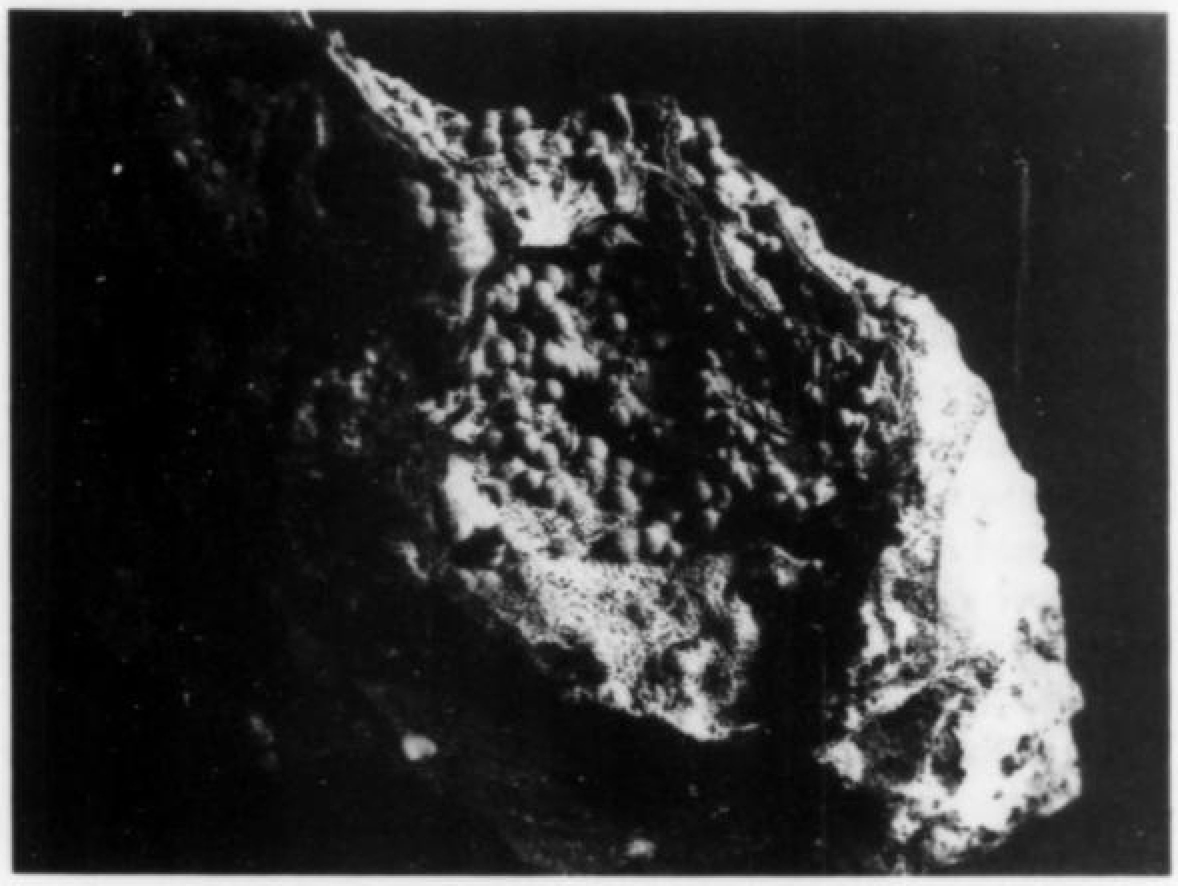


Figure 44. **First-generation thomsonite, as spherules (1 to 2 mm in diameter) situated on top of a layer of reddish brown massive thomsonite. Specimen in 8 cm wide.**

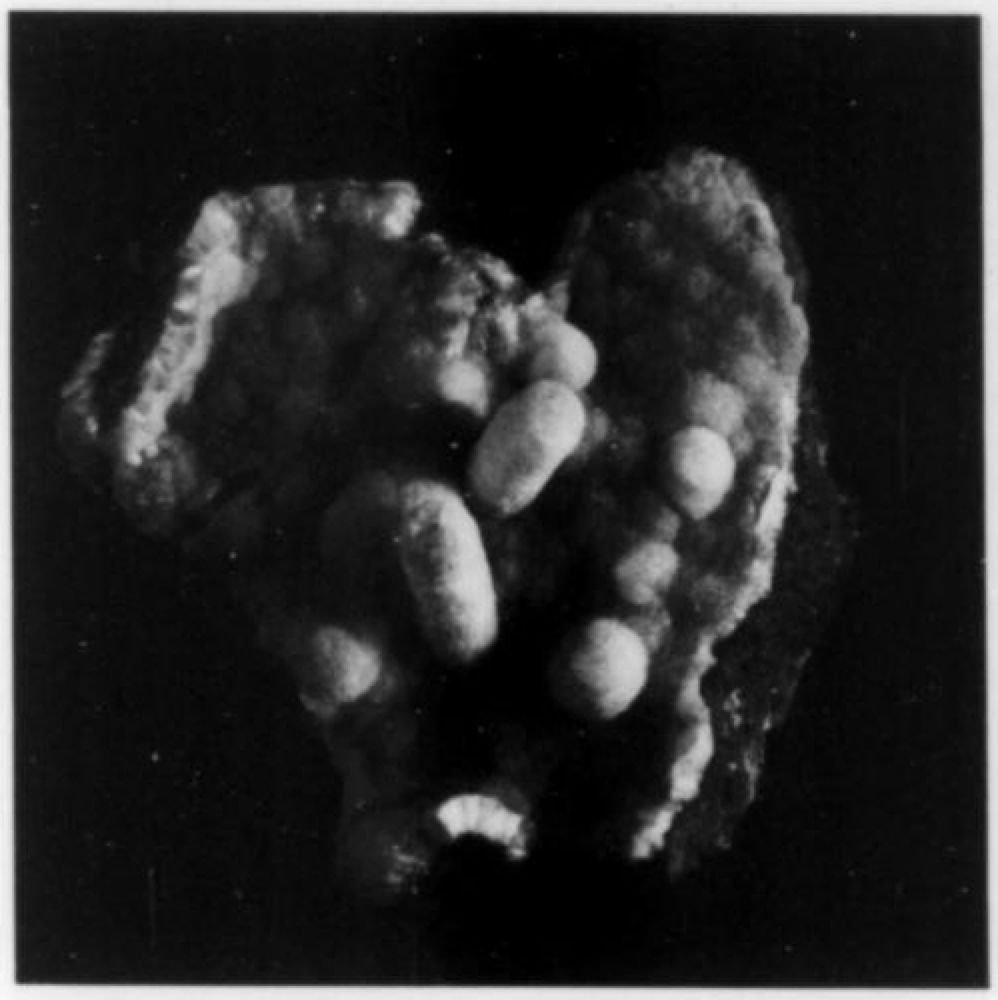


***Figure 45*. Second-generation ivory-colored thomsonite showing a prominent stalactitic form; stalactites surround a limonite nucleus. Specimen size approximately 8 cm across.**

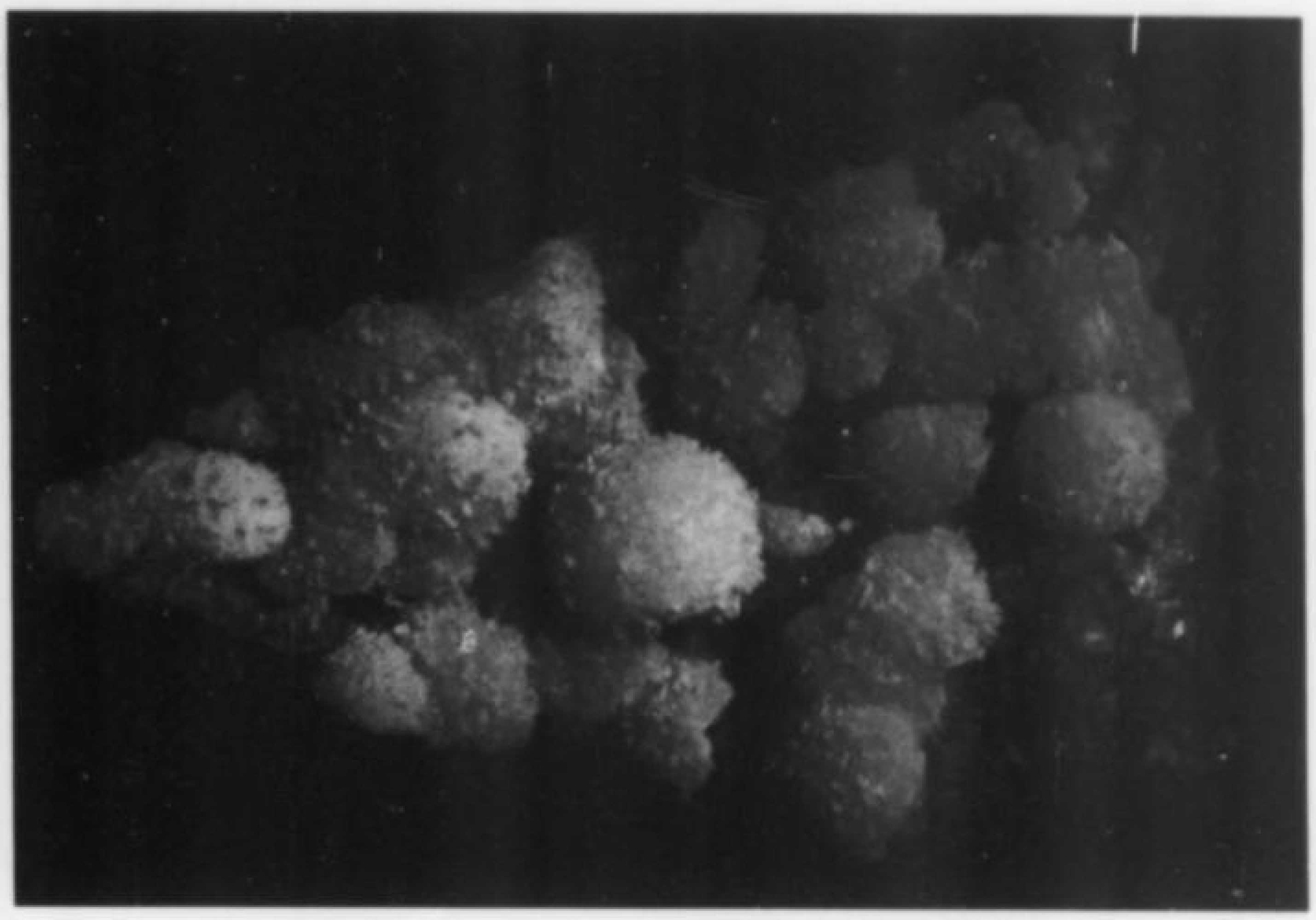


***Figure 46*. Second-generation ivory-colored hemispherical thomsonite showing an extended growth; specimen is 6.5 cm across.**

The second generation of large-cavity thomsonite is represented by larger hemispheres that are composed of minute subparallel rectangular blades radiating from a central point. These crystals are sufficiently compact to impart a satin luster to unweathered hemispheres. Thomsonite in this generation can be seen in a stalactitic form, as crusts of intergrown hemispheres that line cavity walls and exhibit an undulating surface, or as isolated hemispheres that are often situated on top of an earlier generation of analcime (Figs. 13, 34 and 45). The hemispheres range from approximately 3 to 16 mm in diameter, and their color varies from off-white to shades of gray or tan. Isolated hemispheres can make attractive specimens because of their contrast in color and form with other minerals. They may be "extended" by a continuation of growth consisting of a slightly later stage of thomsonite, which appears as a thin, white "mealy" crust composed of densely intergrown and poorly defined crystals (Fig. 46). The morphology of the second generation may be controlled by previous mineralization in the cavity, as evidenced by the observation that thomsonite deposited in vesicles without prior mineralization tends to form a continuous layer of undulating hemispheres, whereas thomsonite deposited in vesicles with prior analcime crystallization typically forms isolated hemispheres.

The third generation of thomsonite is characterized by more isolated, rectangular and tabular crystals (Fig. 47). These crystals vary from 1 to 2 mm in length, and can be organized into a variety of extended or diverging forms. This generation appears to have had a prolonged period of deposition, which both preceded and followed the major crystallization (third generation) of analcime; there appears to have been an interval of diminished growth of thomsonite during the deposition of analcime. Thomsonite crystallizing before and after the deposition of analcime has not been designated as separate generations since the change in morphology throughout the period of crystallization appears to have been gradual. Early third-generation thomsonite (hereafter designated as III) is generally organized into relatively small hemispherical aggregates which terminate as individual extended crystals. These forms have compact interiors and a radiating structure similar to that of second-generation thomsonite; their textures, however, differ in that the third-generation thomsonite does not possess the compactness and satin luster that is characteristic of the second generation. Thomsonite which formed early in the third generation (III) is differentiated from that formed later in the third generation in that the hemispherical forms are relatively smaller, and they precede the major deposition (third generation) of analcime. The later third-generation thomsonite (succeeding the major deposition of analcime) appears to have followed two independent lines of crystallization, as manifested by two different habits (which may infrequently show intermediate forms) that have a similar paragenetic position relative to analcime and mesolite. These two habits, hereafter designated as IIIa and IIIb, appear to be contemporary (a point that is substantiated by their similar chemical compositions), but since they have not been observed to occur together, it is not possible to assign a sequential paragenetic position. The occurrence of these variants appears to be locality-dependent, suggesting that environmental factors controlled the morphology. It is these late third-generation forms of thomsonite that, because of their size and unique associations with contrasting minerals, provide some of the most outstanding specimens from the Table Mountain locality.

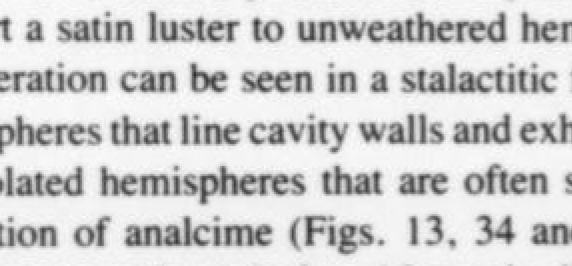


***Figure 47*. Crystal drawing of thomsonite showing tabular (orthorhombic) and prismatic form present at the Table Mountain locality (from Goldschmidt, 1922).**

The first habit of this late third-generation thomsonite (IIIa) is characterized by compact radiating hemispheres, which appear to be an extended growth of the earlier-formed third (III) generation thomsonite. These hemispheres may range in size from 1 cm to over 3 cm in diameter, and are terminated by tapering bundles of parallel rectangular crystals, giving the hemispheres a "pincushion" appearance (Figs. 48, 49 and 50). Such aggregates often grade imperceptibly into delicate mesolite fibers. This habit seems to be prevalent at a locality on the east side of North Table Mountain, and at an area west of the quarry on the south side of North Table Mountain.

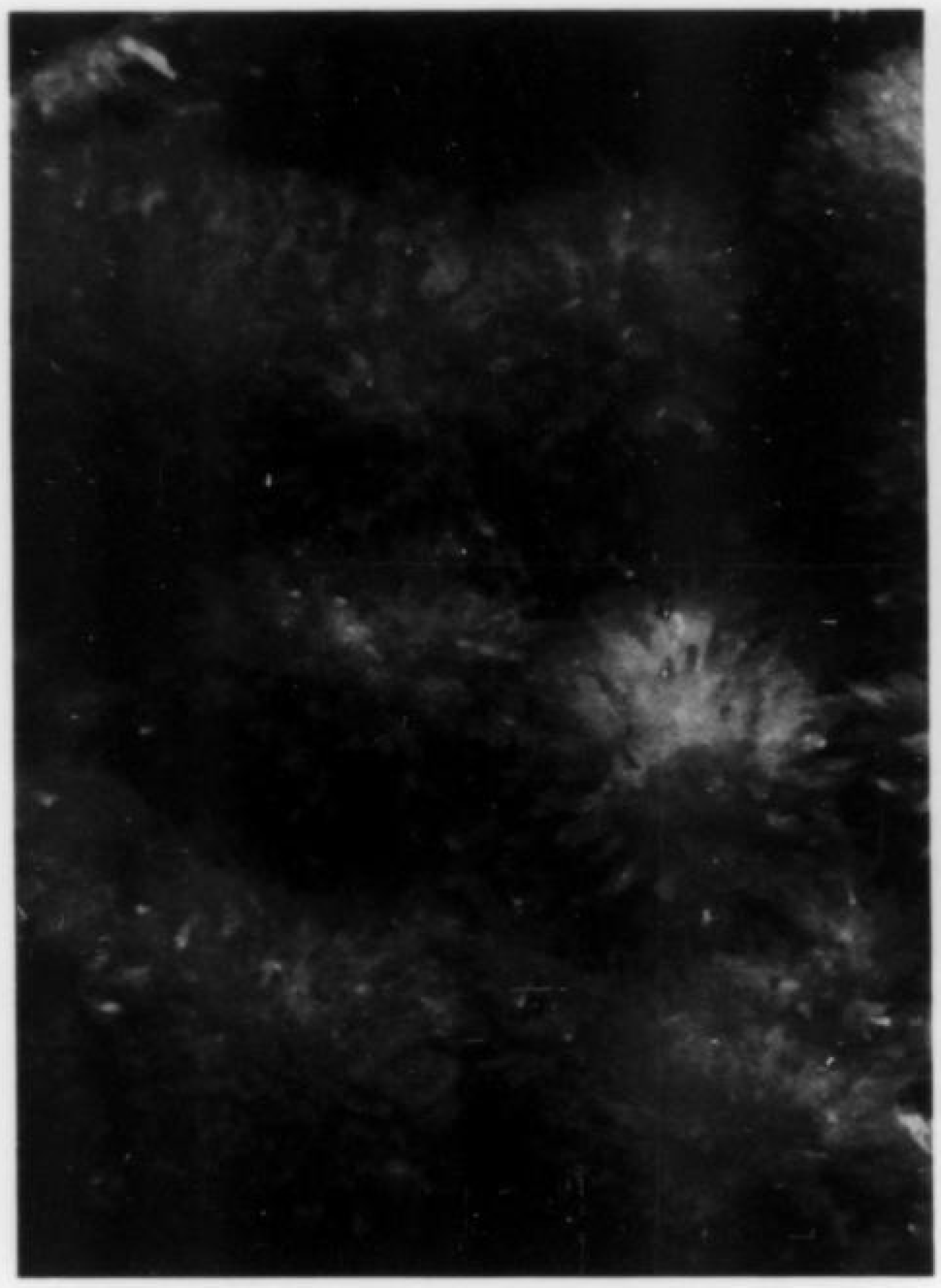


Figure 48. **Third (IIIa) generation tan-colored thomsonite, showing extended bundles of parallel tabular crystals in a form characteristically found at a site on the eastern side of North Table Mountain. Colorado School of Mines specimen no. 456:1:3; field width of photograph is approximately 6 cm.**

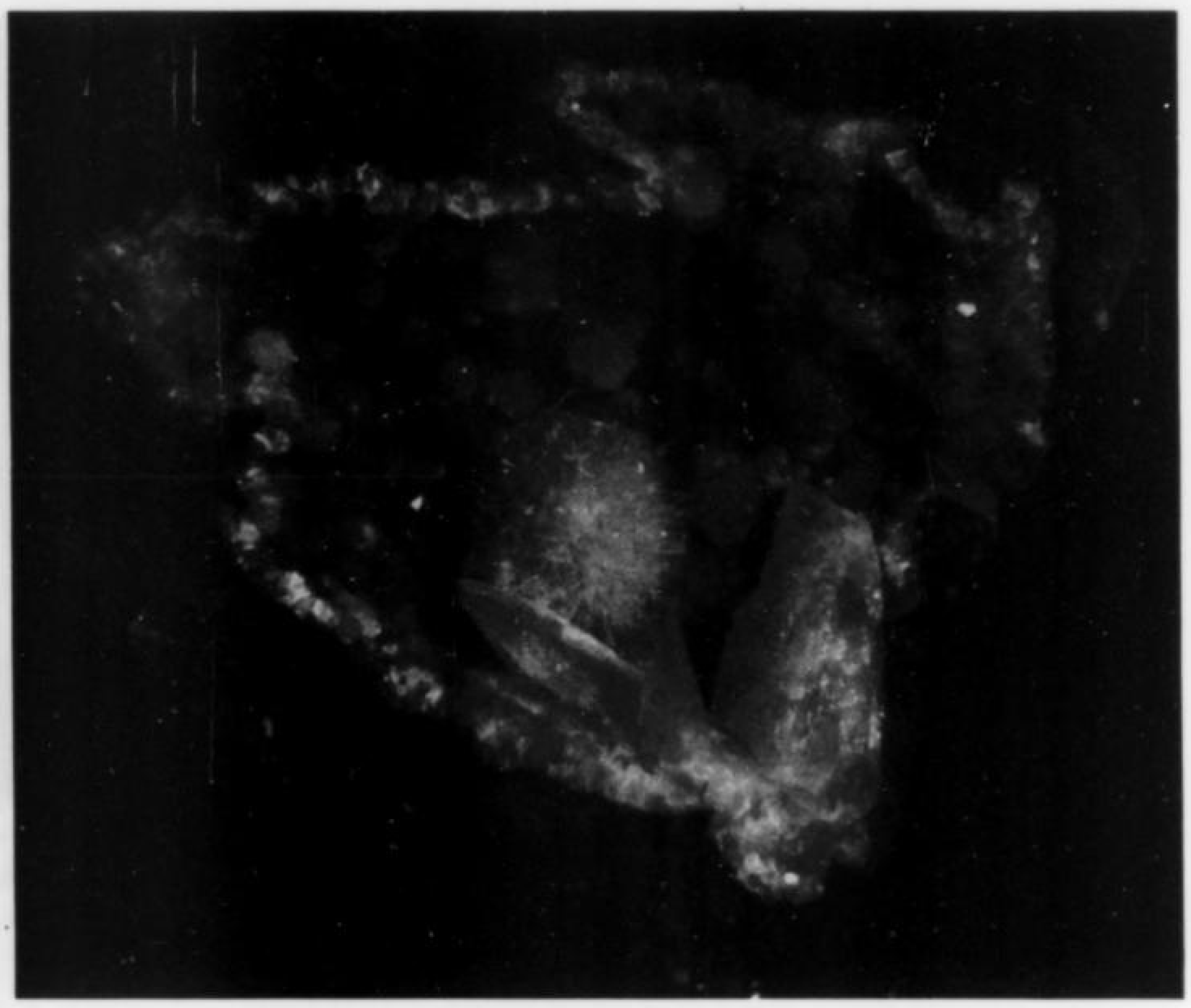


Figure 50. **Hemispherical, cream-colored thomsonite showing elongated, rectangular crystals characteristic of the later stages of the third (IIIa) generation. Associated with second-generation thomsonite and calcite; specimen size approximately 13 cm wide.**

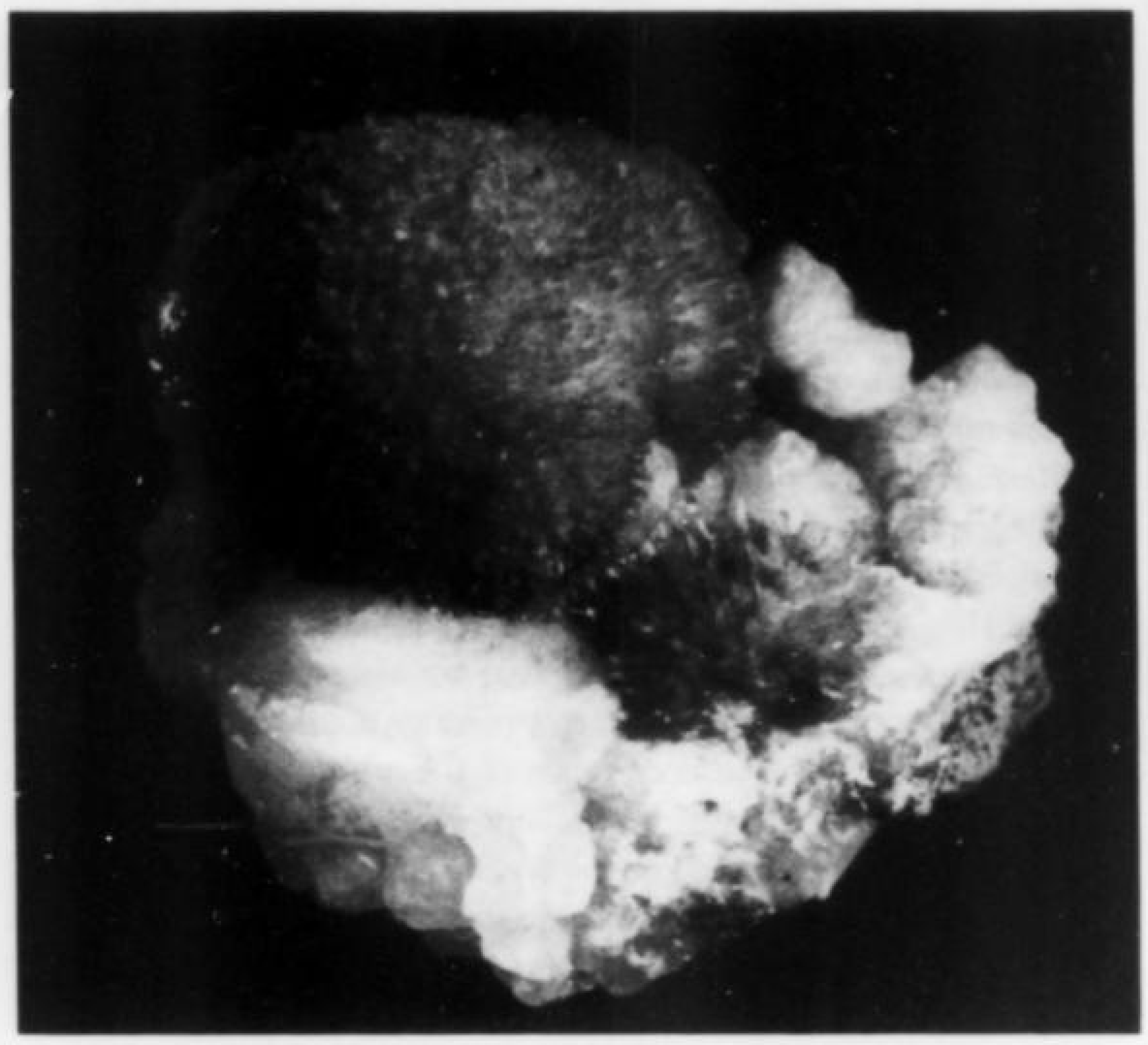


Figure 49. **Third (IIIa) generation tan-colored thomsonite in prominent hemispherical form, on analcime. Hemisphere is 2.5 cm in diameter.**

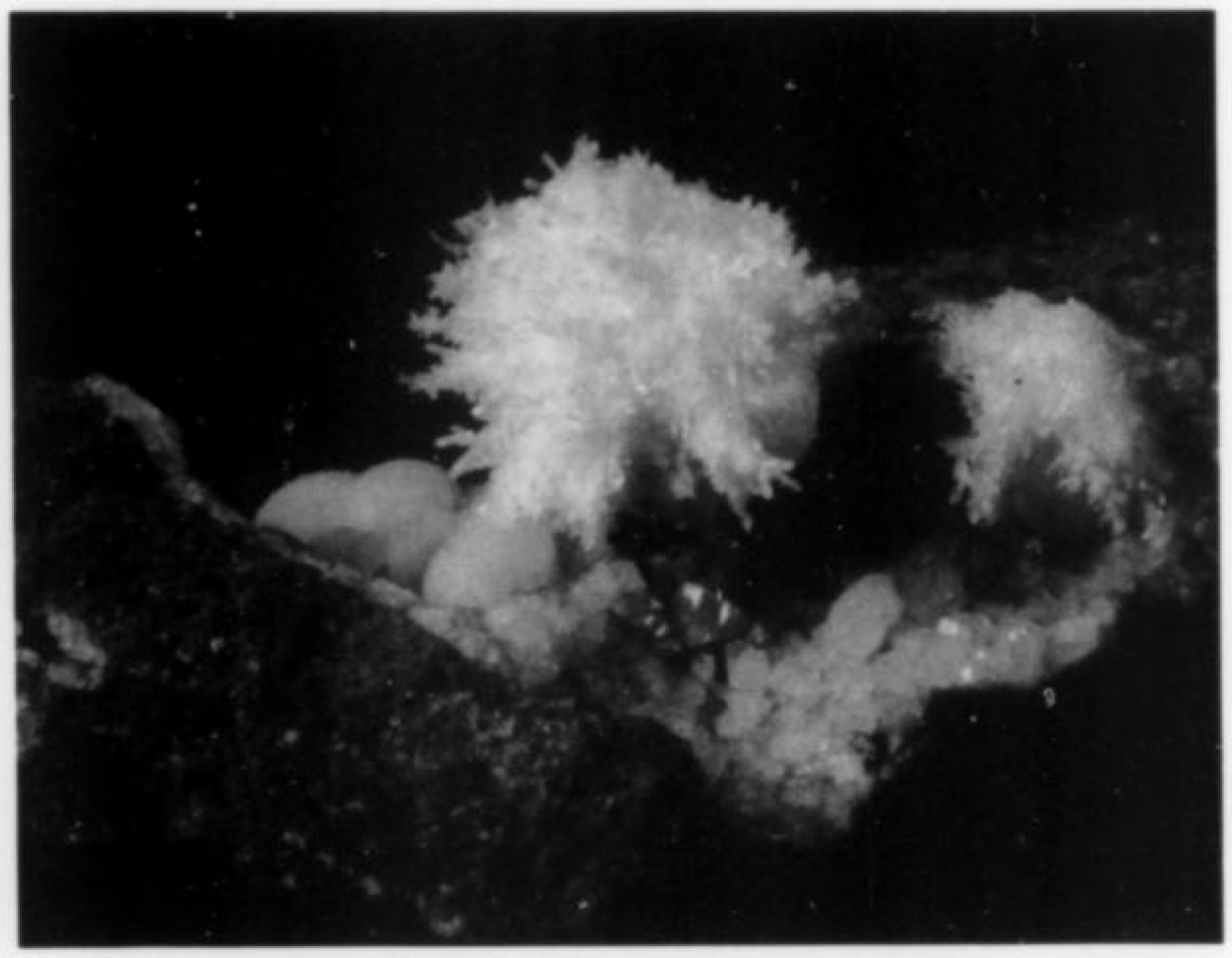


Figure 51. **Arborescent, radiating form of third (IIIb) generation thomsonite (2.5 cm in diameter), on second-generation thomsonite, and associated with chabazite; specimen width is 9.3 cm.**

The second late third-generation morphology (IIIb) is characterized by a more arborescent habit that is composed of individual rectangular crystals. These crystal aggregates, which are often extended from the more compact, earlier third (III) generation thomsonite, form delicate, radiating arborescent patterns or hemispherical branching structures that can range in size to over 2.5 cm in diameter. They are snow-white in color and constitute exquisite specimens when associated with contrasting minerals (Fig. 51). Smaller and more isolated crystal sheaves or fans are commonly noted; they are often situated on other, earlier-formed minerals, and may closely resemble stilbite (Fig. 52). The arborescent habit of thomsonite deposited later in the third generation shows a transition from stout, diverging crystal bundles to a progressively more extended and elongate morphology composed of more isolated crystals that exhibit less of a branching structure. This progression culminates in a habit characterized by a loosely interwoven

Figure 52. **Microcrystals of third (IIIb) generation thomsonite organized into delicate radiating sheaves; specimen size approximately 4.5 mm across.**

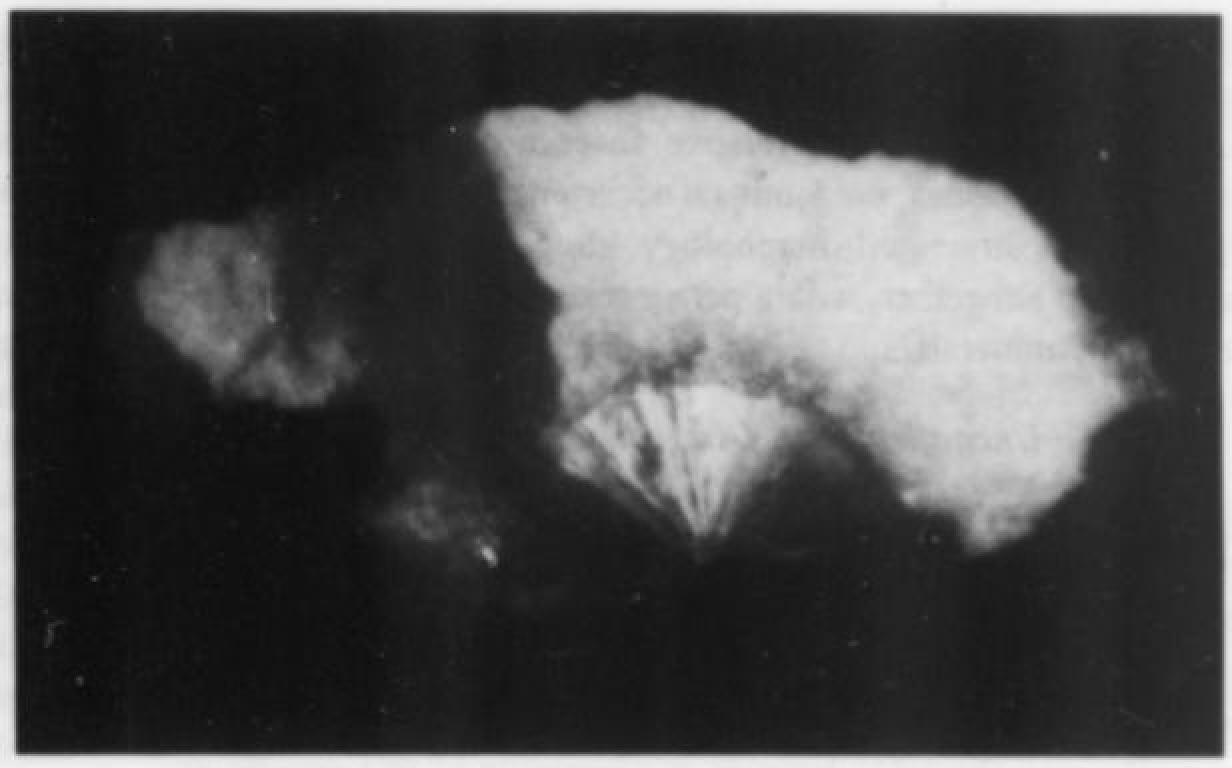


Figure 53. **Single bluish gray hemisphere of early-formed small-cavity thomsonite, showing characteristic satin luster; it is overgrown by massive, late-formed small-cavity thomsonite which had completely filled the cavity. Specimen width approximately 3 cm.**

network of randomly interlocking microcrystals that often completely fill a cavity, and which are almost invariably associated with mesolite; such aggregates may also constitute a more consolidated mass that has a porous texture. The late third-generation crystals possess a distinct tabular habit and rectangular (orthorhombic) cross section (Fig. 47). Extended and branching forms of thomsonite are frequently mislabelled as natrolite because of the elongate nature of the crystal aggregates. However, these two species can be microscopically differentiated by comparing the nearly square cross section of the pseudotetragonal natrolite to the more rectangular cross section of thomsonite. Third (IIIb) generation thomsonite showing a pronounced arborescent morphology is predominant in an inactive quarry located on the south side of North Table Mountain.

A fourth generation of thomsonite is characterized by isolated, elongated rectangular microcrystals that typically occur intertwined with mesolite fibers (Fig. 16). These crystals were formed concurrently with microcrystals of analcime, chabazite, fluorapophyllite and calcite. Thomsonite crystals in the fourth generation differ from those of the late third (IIIa or IIIb) generation in that they are more delicate and transparent, and have a greater degree of elongation with almost no branching structure.

Thomsonite showing an unusually high silica content has often been referred to in earlier literature as "faroelite." The first reference to "faroelite" from the Table Mountain locality was given by Cross and Hillebrand (1882a and 1885), who referred to it by its former name of "mesole." Their analyses of thomsonite approximated that of the earlier-described "faroelite" (Dana, 1884); they presumed the high silica content to be a result of contamination by mesolite fibers, but were unable to completely resolve this discrepancy. Although "faroelite" was classified as a variety of thomsonite by Dana (1892), Wherry (1923, 1925) attempted to define it as a distinct mineral species, whereas Winchell (1925, 1926) considered it a silica-rich end member of an isomorphous thomsonite series. "Faroelite" was later discredited as a species (Hey, 1932): use of this term as a variety of thomsonite is for the most part obsolete, but it is used here to maintain continuity with earlier descriptions.

The brief physical description of "faroelite" given by Dana (1884, 1892) suggests an early generation of hemispherical thomsonite (either the second generation in large cavities or the early small-cavity generation, discussed below). However, some of the analytical data reported by Cross and Hillebrand (analyses no. XI and XII, 1885) were derived from samples whose physical descriptions most closely matched a later (third) generation of large-cavity thomsonite, and subsequent optical data provided by Wherry (1923, 1925) were obtained from the same third-generation sample (no. XI) used by Cross and Hillebrand (1885). It therefore appears that some of the above studies were based on samples from the Table Mountain locality that did not correspond to the description of "faroelite" as originally given by Dana (1892). Our study of spherules having the physical characteristics attributed to "faroelite" confirms (by XRD) that they are thomsonite, but microprobe analyses do not show a significantly higher silica content in this material compared to later-formed thomsonite in either large or small cavities (Tables 6–7). In light of these data, the varietal designation seen in earlier literature for this habit of thomsonite does not seem useful with respect to thomsonite occurring at the Table Mountain locality.

Thomsonite Occurring in Small Cavities

The early-formed generation of thomsonite in the small cavities has a distinctive appearance, being characterized by bluish gray spherules up to 1 cm in diameter, which are invariably overgrown by later-formed minerals (Fig. 53). These spherules have a waxy luster and radiating habit, and are composed of indistinct, tightly intergrown crystals. Early-formed small-cavity spherules are similar in appearance to second-generation thomsonite in the larger cavities, but they can be distinguished by their bluish color, and by the fact that they occur within relatively small cavities as single, isolated hemispheres (never as intergrown hemispheres lining cavity walls) that are often associated with minerals such as garronite, which are not typically found in large cavities. This early generation of thomsonite has been noted to form concurrently with garronite (and possibly analcime), and to precede gonnardite, analcime, chabazite and the later generation of thomsonite. The composition of early-formed small-cavity thomsonite is very comparable to that of second-generation thomsonite found in larger cavities (Tables 6 and 7).

The later generation of thomsonite in the small cavities can be characterized by either a chalky white massive material without any visible external structure (Fig. 53), or by a compact, intergrown, radiating form that typically nearly fills an entire cavity, but which develops a rough hemispherical surface when the cavity is not completely filled. This habit of thomsonite is seldom seen associated with the more common large-cavity-filling mineral species; it is usually observed in smaller cavities, succeeding the earlier generation of small-cavity thomsonite (described above), garronite or chabazite. Patton (1900) considered this form as a later generation of thomsonite (types III and IIIa, by his definition) that represented a paragenetic continuation of the minerals filling the larger cavities. However, although this compact habit of thomsonite is very similar in composition to the third-generation thomsonite in the larger cavities, and can occasionally be found in larger cavities, its relative absence of association with the more common species, predominant occurrence in smaller cavities, and atypical, less structured morphology, suggests that it represents a separate group altogether, with a paragenesis that is independent of the large-cavity minerals.

Unconfirmed or Discredited Species

Halloysite $Al_2Si_2O_5(OH)_4$

Halloysite was first described as "bole" by Cross and Hillebrand (1885); they included an analysis with their description, but did not further identify the species. Although Eckel (1961), based on the description given by Dana (1892), subsequently designated this material as halloysite, there has been no confirmation of this species at the Table Mountain locality. None of the clay samples thus far analyzed by the authors have an aluminum content that is sufficiently rich to approach the composition of halloysite. Cross and Hillebrand (1885) described this material as a light to dark brown clay mineral occurring principally on the north side of South Table Mountain, where it completely fills some of the cavities in the scoriaceous crust of the lower (Tv2) capping flow.

Leucite $KAlSi_2O_6$

Leucite was reported by Endlich (1878), and discredited by Cross and Hillebrand (1882a), who identified it as analcime.

Mordenite $(Ca,Na_2,K_2)Al_2Si_{10}O_{24}\cdot 7H_2O$

Mordenite, referred to as "ptilolite" in earlier literature, was reported as occurring at the Table Mountains by Pearl (1972); this is probably an erroneous description referring to an occurrence of mordenite ("ptilolite") on Green Mountain that was noted by Cross and Eakins (1886, 1892). Mordenite has recently been confirmed by the authors (by XRD) from sedimentary rocks of the Denver Formation in an area near the northeast side of Green Mountain, where it occurs as delicate white acicular fibers lining walls of irregular cavities that are bordered by a layer of anhedral gray heulandite. The mordenite is associated with a hemispherical habit of pale yellow calcite and cubic pyrite.

Scolecite $CaAl_2Si_3O_{10}\cdot 3H_2O$

The material described as scolecite by Cross and Hillebrand (1885) was probably cowlesite; the chemical compositions of scolecite and cowlesite differ only in the water content, and except for that constituent the data provided by Cross and Hillebrand (1885) closely match the ideal composition for cowlesite. Material matching the description of scolecite as given by Cross and Hillebrand (1885) has been identified as cowlesite by XRD; additionally, the original specimens collected by Whitman Cross, which were provided to the authors by the National Museum of Natural History (NMNH numbers 80462, 83272, and 83274), proved to be cowlesite.

Wavellite $Al_3(PO_4)_2(OH,F)_3\cdot 5H_2O$

Wavellite was reported by Endlich (1878) and never confirmed by subsequent studies; it was probably erroneously identified thomsonite.

PARAGENESIS

The Table Mountain locality is a unique area in which to study zeolite paragenesis and crystal growth because of the many diverse habits of a given species (particularly thomsonite) that may be found within a single cavity. Several comprehensive studies have been published since the early 1880's which listed a sequence of mineral deposition (Cross and Hillebrand, 1885; Patton, 1900). The most extensive of these was written by Patton (1900), who indicated 15 separate periods of deposition in a linear sequence of paragenesis. This may in fact be an accurate representation of the total number of mineral species and varieties that occur here, but it nevertheless gives the impression that the periods of crystal growth occurred at discrete intervals. Although in some cases this is true, most minerals appear to be intergown with other species, indicating more or less continuous crystallization over a period of time. For example, although the first and second generations of thomsonite appear to have formed at discrete intervals, the third generation seems to have had an extended period of concomitant deposition with other mineral species. Thus, establishing a sequence of mineral deposition at this locality is difficult because of the overlapping and concurrent growth of the various mineral species. Another problem results from the possible occurrence of divergent or independent lines of paragenesis within the larger-size cavities; this is evidenced by certain mineral associations being commonly noted, whereas others are rarely seen at all. As an example, the first generation of calcite seems to occur only with analcime, and seldom or never with chabazite. Finally, the relative scarcity of specimens showing certain mineral associations often renders a definitive interpretation of some segments of the paragenetic sequence uncertain. Extensive work will be required to resolve these problems, with the lack of accurately labeled material in older collections being a primary obstacle.

Although cavity size appears to be the dominant factor controlling mineralogy and paragenesis, other variables such as temperature and fluid composition may also be important. This is suggested by differences in mineralogy and crystal habit noted between various localities on North and South Table Mountain (this locality dependence can in itself lead to apparent contradictions in interpreting the order of deposition). In fact, the paragenetic sequence and mineralogy within individual cavities may even be controlled by the vertical position (height) of the cavity within the flow at a particular location. Several studies at other localities have reported distinct vertical zones of zeolite species within lava flows. Walker (1960a) described three such zones in the basalts of eastern Iceland, with mesolite and scolecite being the dominant zeolites in the lowest zone, followed by an analcime zone, and then an uppermost zone rich in chabazite and thomsonite. A similar vertical zoning, but with different mineral assemblages, was also noted in the zeolites of the Faeroe Islands (Betz, 1981). Such variations are presumably the result of slight differences in environmental conditions during crystallization. Temperature is one likely factor controlling such vertical zoning, with rock buried at increasing depths having been subjected to correspondingly higher temperatures. Kristmannsdóttir and Tómasson (1978), in a study of zeolite deposition in an Iceland geothermal area, found a correlation between zeolite zones and the temperature at which they formed, with the first zone (lowest-temperature) minerals dominated by chabazite, followed, in order of increasing temperature, by a mesolite/scolecite zone, a stilbite zone, and finally a laumontite zone. Temperature-controlled regional zoning has also been documented in zeolite occurrences in Ireland (Walker, 1960b), India (Sukheswala and others, 1974), and Brazil (Murata and others, 1987). Heat may have been derived from regional heat flow from depth, or from emplacement of subsequent dikes or flows.

In contrast to the above studies that show a temperature-controlled vertical zonation of zeolite minerals, Keith and Staples (1985) found no regional pattern of zoning in the Siletz River Volcanics, Oregon. They presumed that the completely different mineral assemblages within cavities in close proximity to one another were accounted for by the high degree of sensitivity of zeolite minerals to slight changes in physical and chemical conditions, including fluid composition, pH, temperature and cavity size. A preliminary evaluation of the mineral distribution at the Table Mountains does not indicate any clearly defined vertical zoning of the large-cavity minerals, although, as stated earlier, differences in mineralogy and crystal habit (such as seen in chabazite and thomsonite) are noted between widely spaced localities on North and South Table Mountain; this lateral zonation is undoubtedly a result of variations in environmental conditions such as have been noted by other authors. Furthermore, there does not appear to be any vertical zonation of the small-cavity minerals. The apparent absence of vertical zoning in either large or small-cavity minerals at the Table Mountain locality may be due, in part, to the relatively thin deposit of lava, which would not permit a significant temperature gradient. Further study will be necessary to clearly establish the presence or absence of such vertical zoning at the Table Mountains, as well as to facilitate a better understanding of regional (lateral) variations in mineralogy and crystal habit.

Temperature may have been an important factor controlling not only the mineralogy, but also the paragenetic sequence within an individual cavity. This was pointed out by Kleck (1972), who, in a study of zeolite localities in the southern Willamette Valley, Oregon, suggested that the sequence of minerals was controlled by decreasing temperature, as indicated by the progressively increasing water content of the zeolite species throughout the period of cavity mineralization. A similar relation of water content and paragenetic sequence was also noted in an area of western India by Sukheswala and others (1974). An evaluation of mineral paragenesis at the Table Mountains does not show any consistent trend in water content. Nevertheless, temperature appears to have controlled the order of deposition to a limited extent. Although the observed mineral assemblages allow no specific conclusions about the temperature of deposition at any time during the sequence of crystallization, it is likely, and consistent with known data, that the first generation of thomsonite and the associated early laumontite and stilbite formed at relatively higher temperatures than did the later-formed cavity minerals which are presumed to have been deposited at or near normal groundwater temperatures. A higher temperature of deposition for the early minerals is evidenced by the higher content of iron and magnesium in the first-generation thomsonite, and of iron in the laumontite (Tables 2, 4, and 6). This supposition is in agreement with the study by Kristmannsdóttir and Tómasson (1978), who found relatively higher temperatures of formation for laumontite and stilbite relative to that of chabazite and mesolite. Murata and others (1987), using fluid inclusion studies of calcite from the southeastern Parana Basin in Brazil, confirmed the higher temperatures of formation for laumontite and stilbite. These data are consistent with the observed paragenetic sequence at the Table Mountain locality. Based on the above information, it is probable that the minerals in the vesicular cavities were derived from an alteration of the surrounding shoshonite by low temperature meteoric or hydrothermal water (this point is substantiated by the presence of a zone of lighter-colored shoshonite surrounding some of the cavities), and that temperature controlled, to some extent, the early paragenetic sequence and possibly also regional variations in crystal morphology as noted earlier.

The minerals found at North and South Table Mountain comprise a suite of generally low-silica zeolites, reflecting their occurrence in a host rock which contains no free quartz. The shoshonite contains slightly more silica (the average of published analyses is about 52 weight % SiO_2) than average basalt, but the high content of alkalies, especially potassium, in the shoshonite (about 4 weight % K_2O and 3 weight % Na_2O) results in a low activity of silica in the rock and consequently an absence of quartz. Zeolites commonly found coexisting with quartz, such as erionite, epistilbite, stilbite and heulandite (Coombs and others, 1959), are uncommon or absent at the Table Mountains. The data presented in Tables 2 through 7 suggest no general paragenetic trends among the Table Mountain zeolites with respect to change in the content of silica, water or other oxides during the course of crystallization, although some individual minerals may show such trends. Thomsonite, for example, shows an increase in the Na:Ca and Si:Al ratios throughout its deposition (Fig. 54 and 55).

An apparent relation between cavity size and mineralogy has resulted in two distinct groups of minerals (large and small cavity), and consequently two independent lines of paragenesis. The paragenetic sequence of the Table Mountain minerals is therefore divided into two groups of species that predominately occur in either large or small cavities. These groups are not completely exclusive, inasmuch as some minerals that typically occur in large cavities (such as analcime, chabazite and thomsonite) may in fact occur in small cavities as well; the major crystallization of each species, however, is within one or the other cavity size.

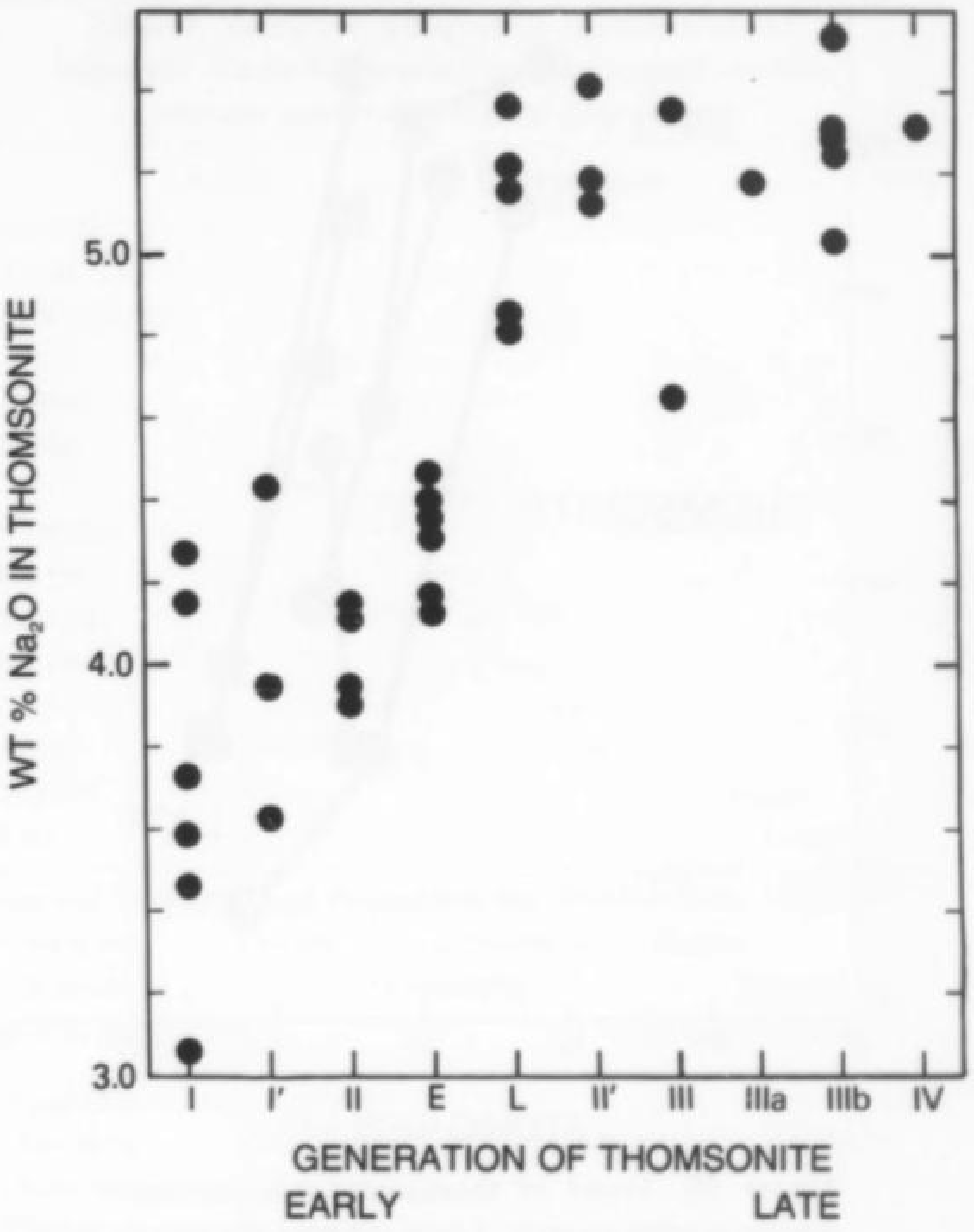


***Figure 54.* Na_2O content of thomsonite vs. morphological generation. Each point represents a microprobe analysis of one specimen. Designation of generations I, II, III, IIIa, IIIb, and IV follows text description. I' = spherules within stratified laumontite layer, II' = tips of second-generation hemispheres; E and L = early and late small-cavity thomsonite, respectively.**

The sequence of mineral deposition presented here is the result of extensive field studies at a number of localities on North Table Mountain, preliminary work on South Table Mountain, and an examination of private and museum collections of specimens originating from both North and South Table Mountain.

Minerals Occurring Primarily in Larger Cavities

The chronology of mineralization within larger cavities can be divided into five periods of deposition, which are defined by the similar characteristics of the species within each period. It is important to note the distinction made between the term "generation," which relates to morphological differences within a given species, and the term "period," which relates to comparable characteristics between different species that formed at approximately the same time. The first and highest temperature period consists of phlogopite and limonite (the latter possibly being a pseudomorph of a silicate). The second period is represented by the earliest generations of thomsonite, laumontite and stilbite. Thomsonite was the earliest of these minerals, appearing as massive, vitreous, reddish brown layers or spherules;

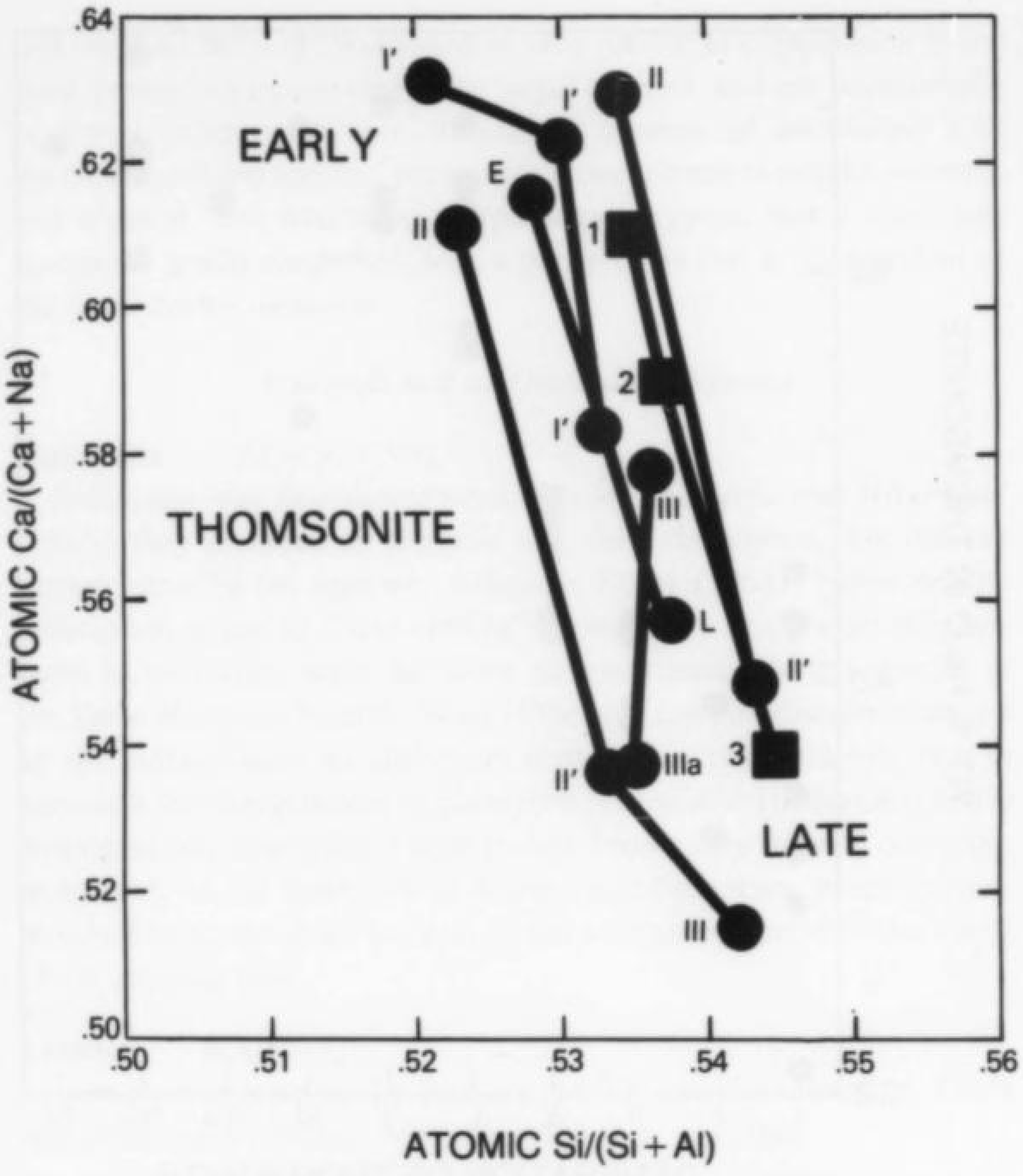
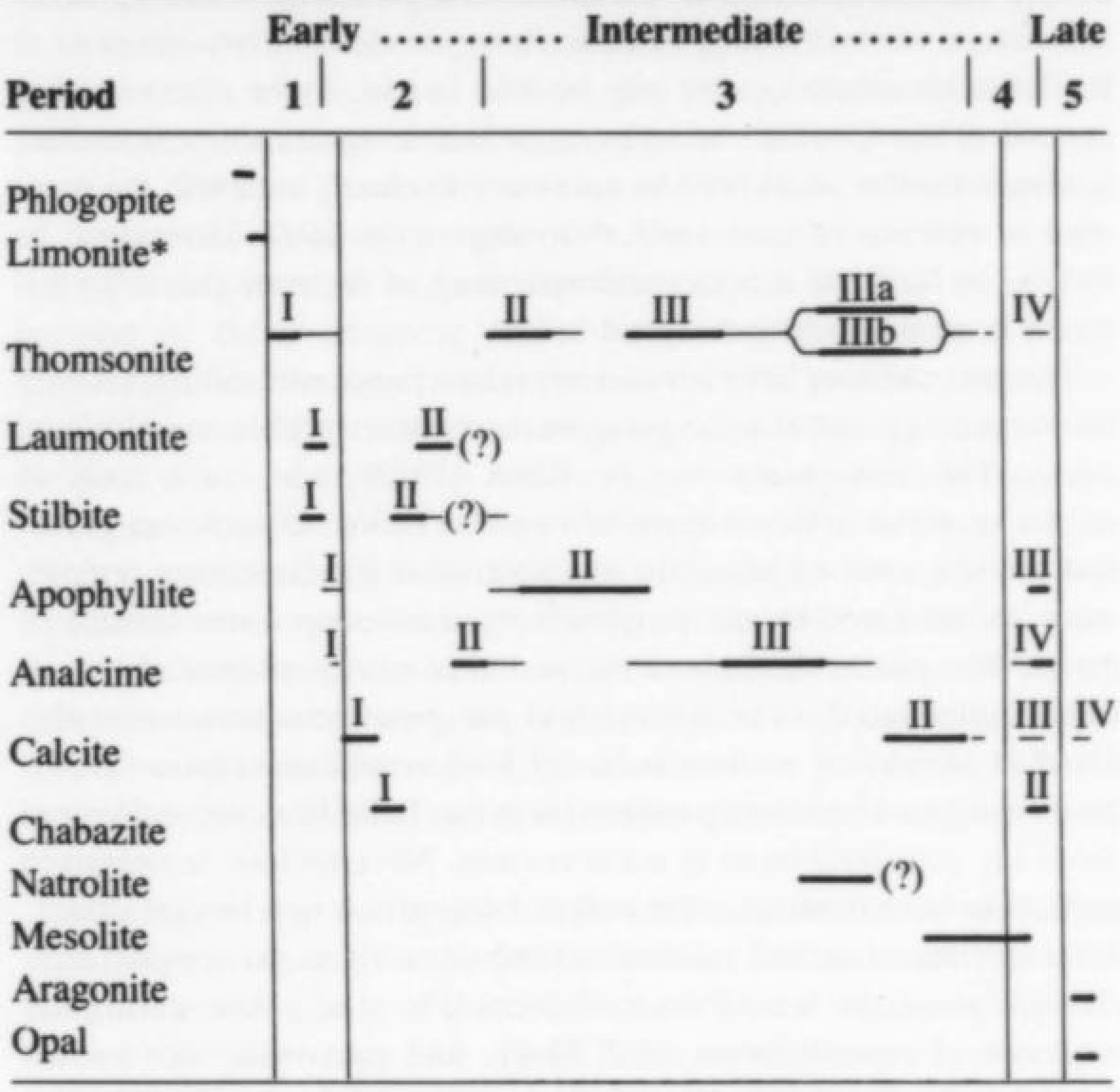


Figure 55. **Trend of thomsonite composition during crystal growth. Lines connect the compositions of successive stages of thomsonite found within individual cavities or hemispheres. Thomsonite generations are numbered as in Figure 54. Data (expressed as atomic ratios) from microprobe analyses, except line 1-2-3, which is derived from previously published analyses (Table 2).**

this deposition was immediately followed by the formation of orange-yellow stratified layers composed primarily of interlocking microcrystals of laumontite and stilbite. These layers often contain microspherules of thomsonite, and more rarely microcrystals of analcime or interstitial, anhedral fluorapophyllite. The higher Fe and Mg content and Ca/Na ratio in the second-period thomsonite compared to that of later generations of the same species indicate a distinctly different set of environmental conditions in which the second-period minerals were formed. For example, the temperature was probably somewhat higher during this period, as suggested by the presence of laumontite and stilbite, which have been shown to crystallize predominately at elevated temperatures. Emmons and others (1896) presumed that the stratified layers were deposited by water percolating through open fractures in the upper zones of the lava, which would have resulted in the formation of subhedral crystals as a consequence of a rapid rate of growth.

The second-period minerals were followed by the prominent crystallization of colorless to white, euhedral mineral species in the third period. The formation of euhedral minerals in those cavities containing the earlier-deposited stratified layers presumably commenced either when fissures leading into the cavities became sealed, or when cavity permeability was reduced by cumulative mineral deposits, permitting a slower rate of crystal growth. The fourth period is characterized by microcrystals signifying the final generation of many of the earlier-formed mineral species. These minerals represent the culmination of a general trend that shows a transition to progressively smaller and more isolated crystals throughout the later periods of deposition. This tendency is possibly a manifestation of a gradual depletion of dissolved components in the fluids from which the crystals formed. The last, or fifth period consists of anhedral minerals, which are aragonite, calcite and opal. It is important to recognize that these five periods are not separate or isolated events, but are best considered as a continuum, or a progressive change in crystal form and size, as controlled by a gradually changing environment during crystallization.

Table 8. **Paragenetic sequence of the minerals occurring primarily within large cavities (roman numerals indicate generation)**



* = probably a pseudomorph after an earlier, higher-temperature mineral

The gradual transition in crystal habit at the Table Mountain locality suggests a declining rate of growth throughout periods one through four. Thus, the fastest growth presumably occurred during the deposition of the massive, vitreous thomsonite (and the stratified layers composed of laumontite and stilbite microcrystals) and likely gradually declined throughout periods two and three, where larger crystals and crystal aggregates are predominant. The transition toward smaller and more isolated crystals in the fourth period suggests a depletion in the mineral-forming elements of the cavity fluids as discussed above, and possibly a continuing reduction in the rate of growth; it is unlikely that the formation of these microcrystals was a result of a resumption of a faster rate of growth. Slight changes in temperature, solution composition and rate of water movement are examples of variables that could have controlled the mineralogy and crystal habit within the cavities. These environmental changes also appear to have controlled the composition of individual mineral species. For example, an evaluation of the compositional data from earlier literature for the three generations of thomsonite (Table 2) indicates a progressive decrease in calcium and increase in sodium content throughout the period of deposition. A parallel trend is evident in the change in silica content, which ranges from approximately 39% in the earliest generation to 41% in the later generations. These trends were confirmed by recent analyses by the authors (Tables 3 through 7, and Figs. 54 and 55), which show a compositional progression toward increased ratios of Na:Ca and Si:Al during crystallization. This tendency toward decreasing calcium would be expected considering the observed transition in cavity mineralogy from predominately thomsonite to that of mesolite (which has a lower calcium content) in the final stages of zeolite deposition.

Wise and Tschernich (1978) correlated the silica content of thomsonite to habit, and found that crystals composing the botryoidal or spherical forms had a higher silica content than did larger crystals that were more isolated and bladed. They in turn related this compositional change to the rate of growth, with a faster rate resulting in crystals having a higher silica content. The correlation of a rapid rate of growth with a botryoidal form is in agreement with that which has been observed for thomsonite habits at the Table Mountains. However, the relation of a high silica content to a more bladed, isolated crystal habit is opposite to what is noted at this locality. The later generations of thomsonite at the Table Mountains, showing progressively more complex forms composed of tabular and isolated crystals, have a slightly higher silica content relative to that of earlier generations consisting of more compact, spherical forms. This apparent contradiction may be due, in part, to the fact that the samples studied by Wise and Tschernich (1978) were obtained from a number of different localities, whereas varying habits of thomsonite used in this study originated from a single locality (and in some cases, from within a single cavity). Thus, with respect to thomsonite at the Table Mountains, the transition toward an arborescent crystal habit appears to have resulted from compositional changes in the cavity fluids as well as a concomitant decreasing rate of growth; the silica content is apparently not dependent on the rate of crystallization.

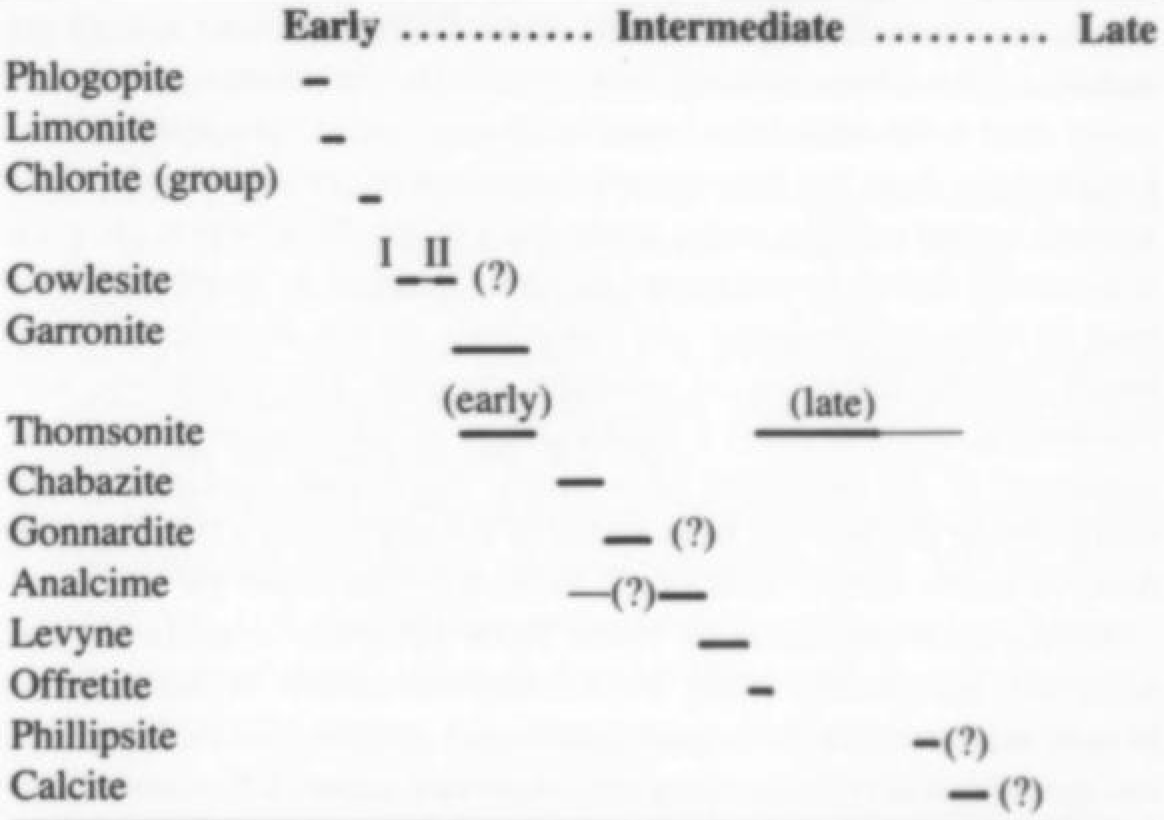
The minerals occurring within the larger cavities are listed in the left column of Table 8, and the five periods of deposition are indicated by vertical lines. The bar diagram shows the deposition of each mineral as a continuous process, with the extent of overlap accounting for observed intergrowths of different species. These bars indicate the approximate duration of major crystallization, while the thin lines reflect a diminished rate of crystal growth. Only a single generation is given for a species when there is a gradual transition in crystal form. Those species or generations having an uncertain position in this table are indicated by a question mark.

Minerals Occurring Primarily in Smaller Cavities

The unique set of minerals found within the smaller cavities indicates a high degree of sensitivity of zeolite crystallization to subtle environmental changes. A determination of the paragenetic sequence for these minerals is difficult since they are seldom associated with other species within the same group, and are rarely associated with the dominant mineral species occupying the larger cavities. The preliminary sequence of small cavity mineral deposition shown in Table 9 is therefore tentative because of the limited number of specimens that show associations. Additional material will need to be collected and studied in order to more completely characterize the paragenetic relations of minerals occurring within the small cavities.

An evaluation of compositional data for the small-cavity minerals (Tables 3, 4, 5 and 7) leads to several conclusions regarding their paragenesis and geochemistry. For example, evidence of a geochemical trend is seen in several sequences of these species, where an increase in SiO_2 and K_2O and a decrease in CaO is exhibited by the sequences cowlesite-levyne-offretite, and garronite-phillipsite. Furthermore, the similar composition of the early-formed small-cavity thomsonite and the second-generation thomsonite in the large cavities, and of the later-formed small-cavity thomsonite and the third-generation thomsonite in the large cavities, suggests that environmental conditions in the large and small cavities (such as temperature and fluid composition) were similar during crystallization at a given period of time. This correlation may imply that crystallization of the early and late-formed thomsonite within the small cavities was concurrent with their counterparts in the larger cavities. Given an assumption that certain small-cavity minerals common to large cavities (such as chabazite, analcime and calcite) formed at the same time in both sizes of cavities, a correlation can be made between the relative time of deposition of the large and small-cavity minerals throughout the entire sequence of mineralization. It thus appears that the formation of small-cavity minerals was concurrent with mineral deposition in the larger cavities, and it can therefore be concluded that cavity size was not a controlling factor of the relative time of deposition.

***Table 9.* Tentative paragenetic sequence of the minerals occurring primarily within small cavities (roman numerals indicate generation)**



Observed Sequences of Deposition for Small-Cavity Minerals:

1. Cowlesite — — Levyne — — Offretite — — Calcite
2. Thomsonite — — — — — Gonnardite — — — — — Thomsonite
   (early generation) (late generation)
3. Analcime — — — Levyne
4. Garronite — — Thomsonite (early generation) — — Chabazite
5. Garronite — — — Analcime
6. Chabazite — — — Levyne
7. Thomsonite (early generation) — — — Levyne
8. Thomsonite (early generation) — — — Garronite
9. Thomsonite (early generation) — — — Analcime

COLLECTING

The documented record of collecting at the Table Mountain locality dates back to the activities of students from the Colorado School of Mines prior to the 1880's. Although many of the specimens on display in local museums were more readily collected in years past when fresh material was continually being exposed during active quarry operations, a fair amount of exertion can still produce excellent examples of zeolites and other minerals, as shown by a number of fine specimens that have been recovered in recent years by local collectors. Most of this collecting activity occurs in early spring, before high summertime temperatures make working next to a cliff or in a quarry too uncomfortable.

Many excellent specimens have been collected from quarries located on the southern and eastern sides of North Table Mountain (Patton, 1900; Ellermeier, 1947). However, several quarries on South Table Mountain have also been a source of exceptional zeolites that are comparable to those on North Table Mountain (Waldschmidt, 1939; Ellermeier, 1947). Exploration elsewhere on North Table Mountain has also produced excellent specimen material. For example, a site west of the southern quarry on North Table Mountain has yielded fine fluorapophyllite, mesolite and stilbite crystals (Eckel, 1961), and well-crystallized tan to salmon-colored chabazite has been found in a road-cut on the west side of North Table Mountain. Almost any area in the upper third of the lowermost capping flow (Tv2) can be expected to provide good to excellent zeolites. The location of this upper part of the second capping flow can be readily determined by the conspicuous bench between the second and third flows. In some areas on

North Table Mountain, a narrow band of shoshonite is visible in this bench area, midway between the cliff faces of the two flows. This zone is the uppermost scoriaceous part of the second (Tv2) flow, near its contact with the overlying (Tv3) flow; the amygdaloidal cavities are located immediately below this zone. Cavities located toward the middle of the lower capping flow, where the shoshonite is a darker color, tend to be smaller and more uniformly oval in shape than those higher in the flow, but the minerals within these cavities are often less altered. Larger cavities in the upper parts of this flow, where the rock is generally lighter in color, may be up to 2 meters in length, but they tend to be quite elongated and sometimes do not provide adequate height for the formation of complete crystals. The shoshonite surrounding a cavity is often a lighter color, which may be an external indication of the proximity of a cavity. Significant specimen-grade zeolite minerals have not been found in the uppermost (Tv3) capping flow, or in the earliest flow (Tv1) located farther down the slope.

Access to several areas of North Table Mountain is generally unrestricted, particularly along the southern boundary. However, collectors are reminded to respect residential property located nearby, and not to seek access through yards or private drives. Other collecting areas or access roads leading to the top of North and South Table Mountains may be fenced or posted and will require permission from the owner prior to entry. Collecting at this locality usually entails a strenuous climb of as much as 150 meters to reach the capping lava flows, followed by a prodigious effort that is required to break the rock; the collector will soon find out why this durable material was so useful for road surfacing! Unfortunately, this seemingly inordinate exertion is necessary because exposed zeolites weather very rapidly to dull and opaque specimens; good material can be found only in freshly opened cavities. Therefore, a variety of heavy tools will be required for collecting here, each of which must be laboriously transported up (and down) the hill. A heavy, 4 to 6-pound hammer and a set of sturdy chisels (with a cutting edge no wider than 2.5 cm) are required to split the larger rocks that show evidence of cavities. A direct assault on the lava with a heavy (8 to 10-pound) sledge hammer is not as efficient in splitting the rock as is a heavy chisel and a 4-pound hammer. This latter technique is more effective for working apart existing fractures in the rock, and it is also less likely to shatter the minerals within the cavities. Smaller chisels (about 1 cm blade width) are used for trimming or carefully exposing a cavity. An effort should be made to collect the crystals intact on the cavity wall, rather than disintegrating a large specimen into small individual pieces; this requires patiently working around the cavity with smaller tools until the specimen can be removed in one piece. Even so, minerals with a well-developed cleavage (calcite and fluorapophyllite) often detach from the matrix, and the brittle zeolites may shatter regardless of the precautions taken, causing extreme mental anxieties and hostile fantasies to compound the already present physical agony.

Earlier literature (Ellermeier, 1947; Pearl, 1972) indicates that blasting was particularly effective for collecting here. This method, however, is not only unnecessary for collecting good specimens, but it is also likely to create an abundance of animosity from nearby homeowners as well as an unpleasant encounter with the local law-enforcement agency due to the proximity of residential areas. The use of a portable gas drill with feathers and wedges can be effective for splitting larger rocks, but an extraordinary effort may be required to transport this heavy equipment to many areas.

Caution is advised when working in an abandoned quarry or near a cliff face; numerous documented landslides and rockfalls attest to the hazards present in these quarries and in the surrounding area (Van Horn, 1976). It is a good idea to carry a supply of bandages or other first aid items (including safety glasses), because lacerations, abrasions and severe contusions become a way of life to dedicated collectors at this locality. Rattlesnakes are present in the area, and appropriate care must be taken, particularly in the late spring and summer months.

Specimen trimming is best accomplished with a mechanical breaker, which can more effectively control the direction of splitting. This requires carrying some rather large, untrimmed specimens down the hill along with all the paraphernalia that was carried up; the results, however, generally make the effort worthwhile. Good specimens need to be carefully protected and transported; even a moderate breeze is sufficient to destroy a delicate tuft of mesolite. Cleaning can be done only with water, as acids immediately decompose or alter the luster of zeolite minerals. A solution of sodium hypochlorite (bleach) can occasionally be effective in removing organic stains from weathered zeolites, and an ultrasonic cleaner may be helpful for dislodging dirt from some of the more durable mineral species. The very delicate species (particularly mesolite and some thomsonite) cannot be cleaned in water at all; they must therefore be carefully protected from dirt during collecting and transporting.

CONCLUSIONS

The Table Mountain lava flows near Golden, Colorado, continue to be a noteworthy source of zeolites and other minerals. Thomsonite and mesolite are particularly striking in view of their considerable variation in morphology and contrasting associations with other species. The mineral associations and forms within these cavities afford an excellent opportunity for the study of mineral growth, paragenesis and geochemical evolution. However, much work remains to be done on the mineralogy at this locality, including a more detailed study of the composition of fluorapophyllite, as well as an investigation of the clay minerals, chlorite and other poorly characterized species occurring here. A more comprehensive study of the variations in species distribution, paragenesis and crystal habit as affected by cavity size and position (both vertical and lateral) within the lava flows would also be of interest, as would an investigation of the change in silica composition of analcime and chabazite throughout the paragenetic sequence.

Zeolites from this locality are not as commonly seen on the mineral market as material from other worldwide occurrences due to the inactive status of the quarries, and also because of the effort required to collect here. Nevertheless, these deposits contain a nearly inexhaustible supply of mineral-bearing cavities, and a steady but limited quantity of specimens is likely to be available into the forseeable future.

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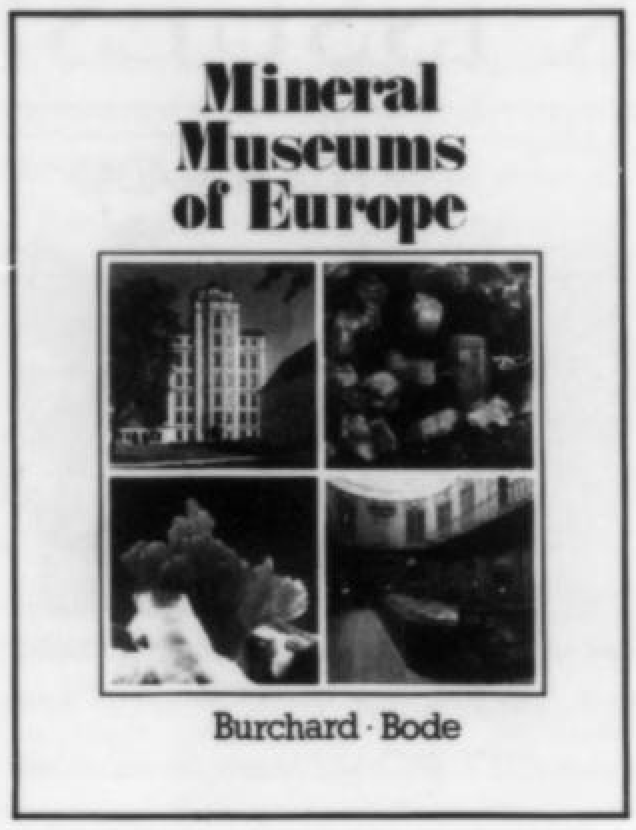

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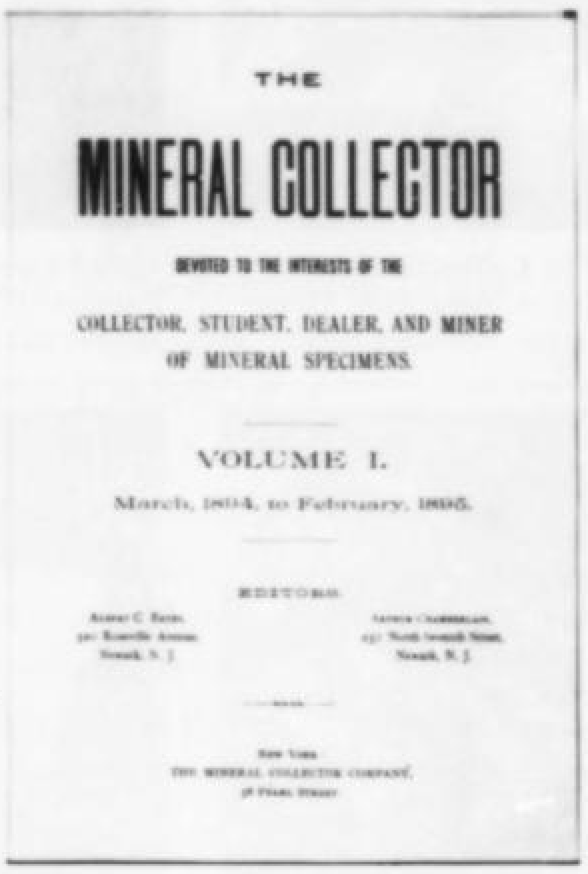

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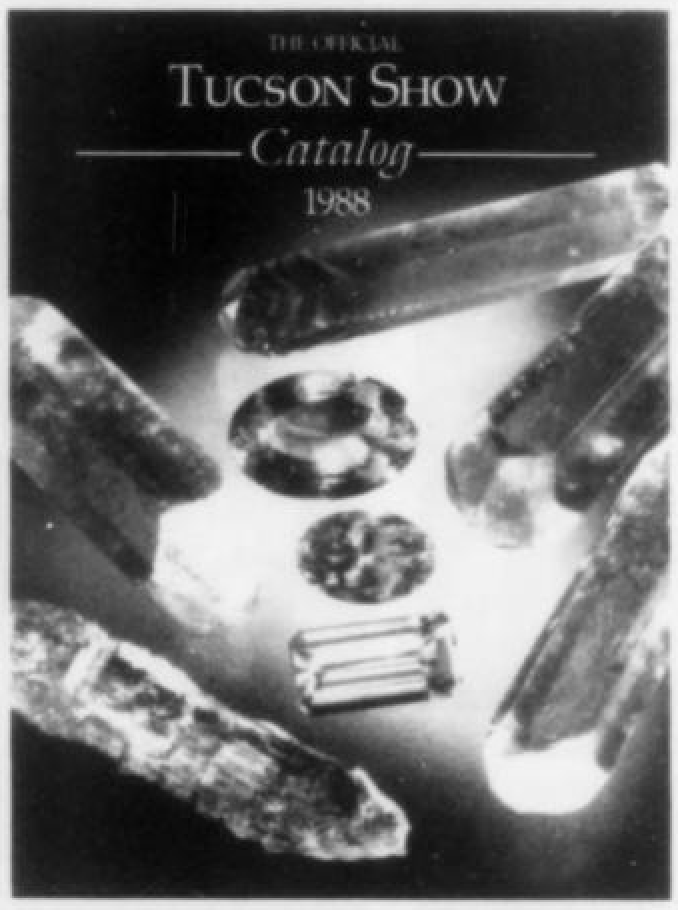

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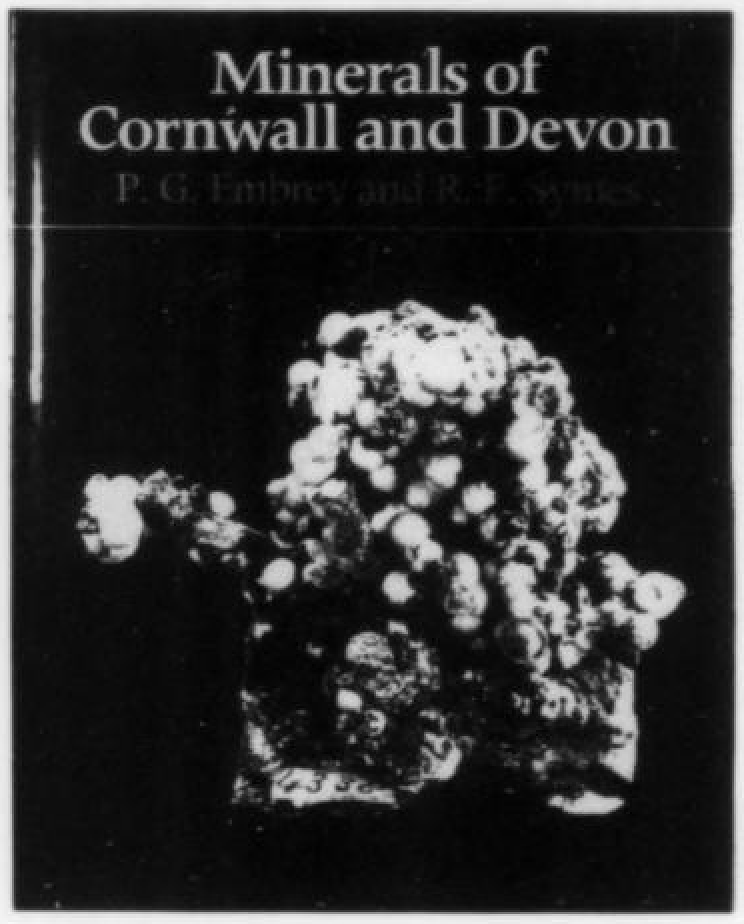

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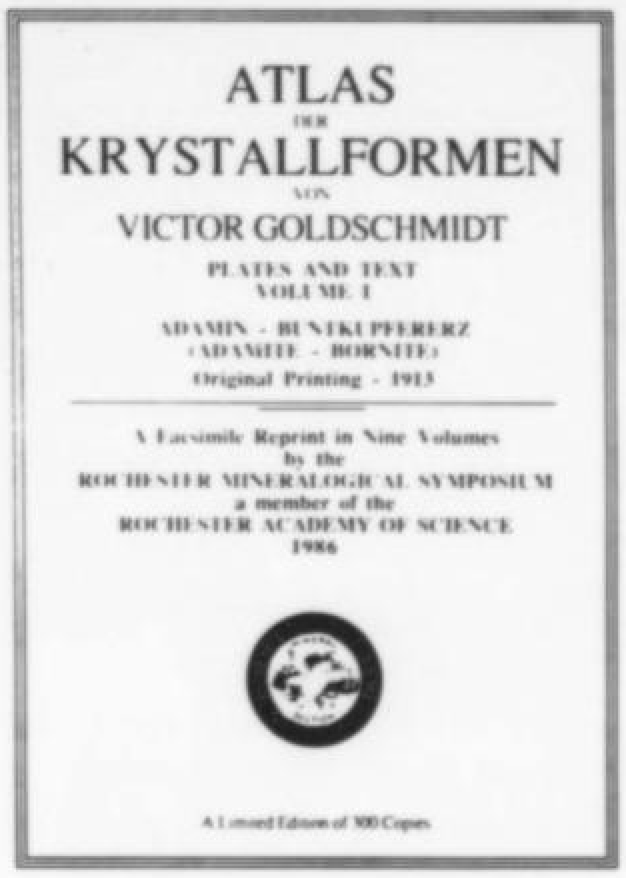

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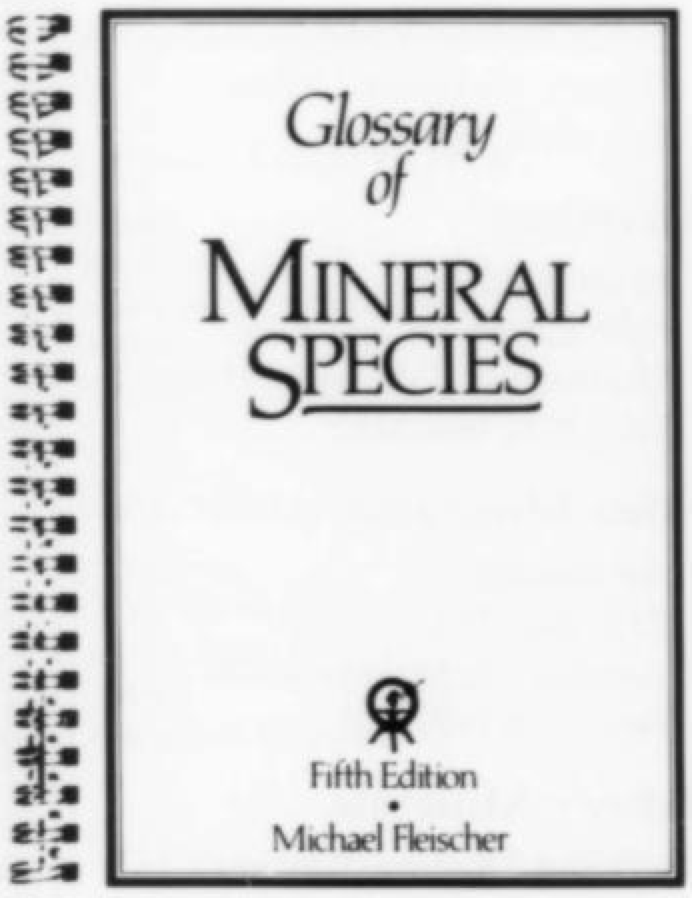

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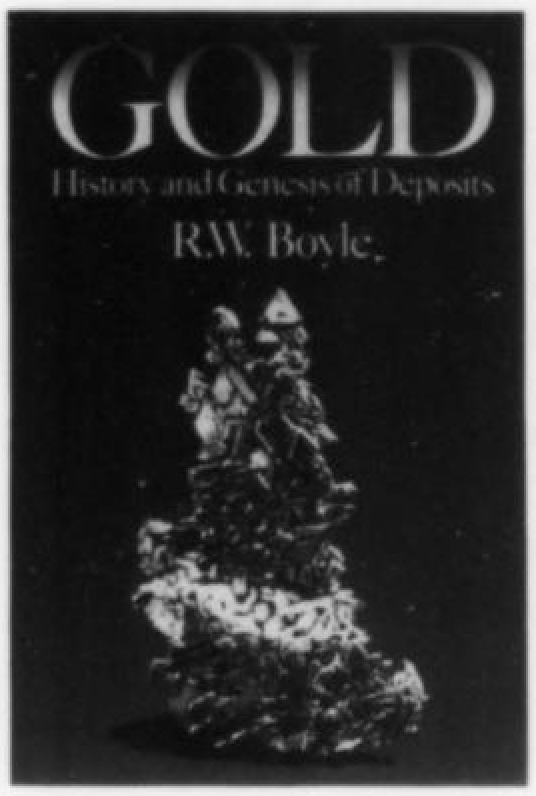

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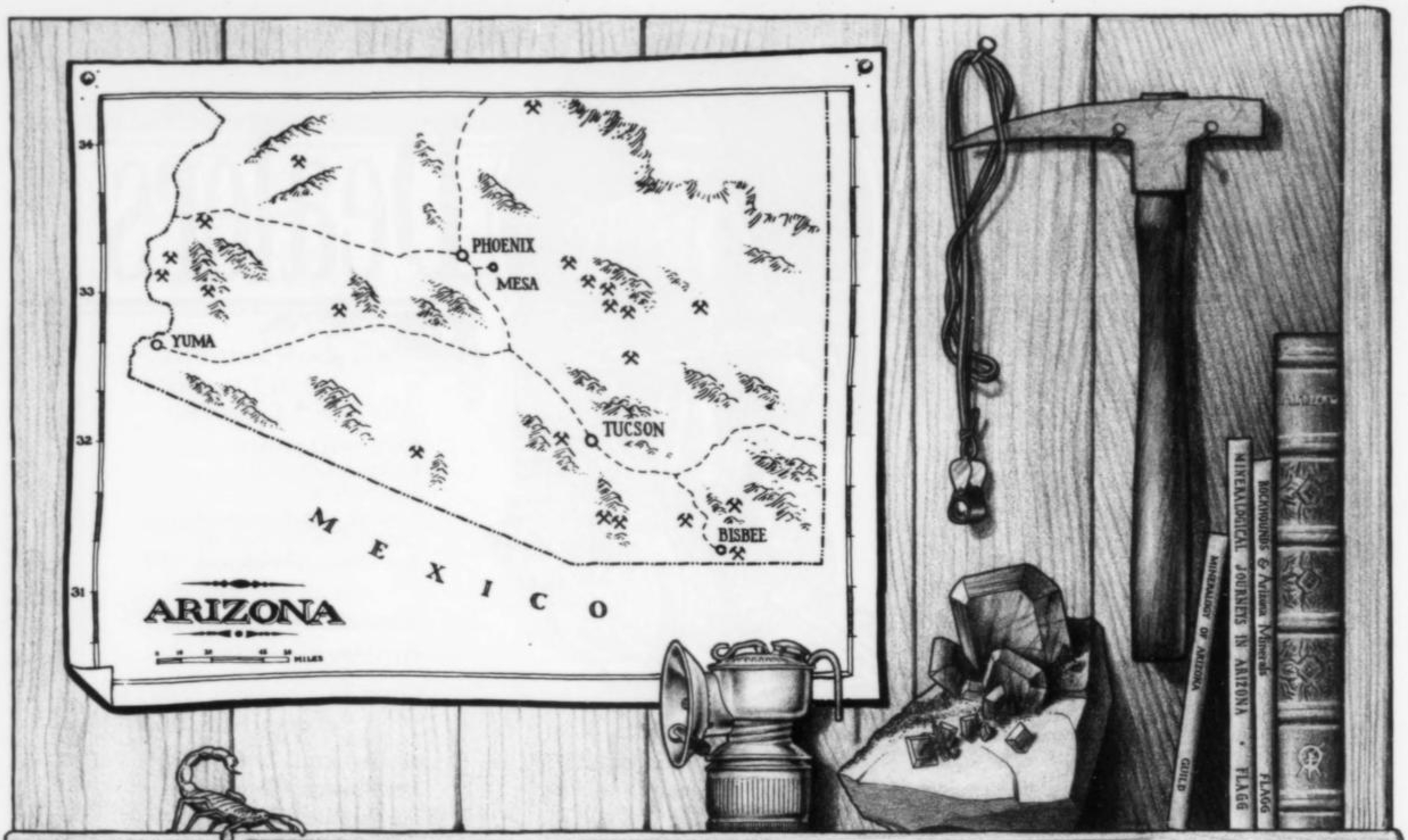
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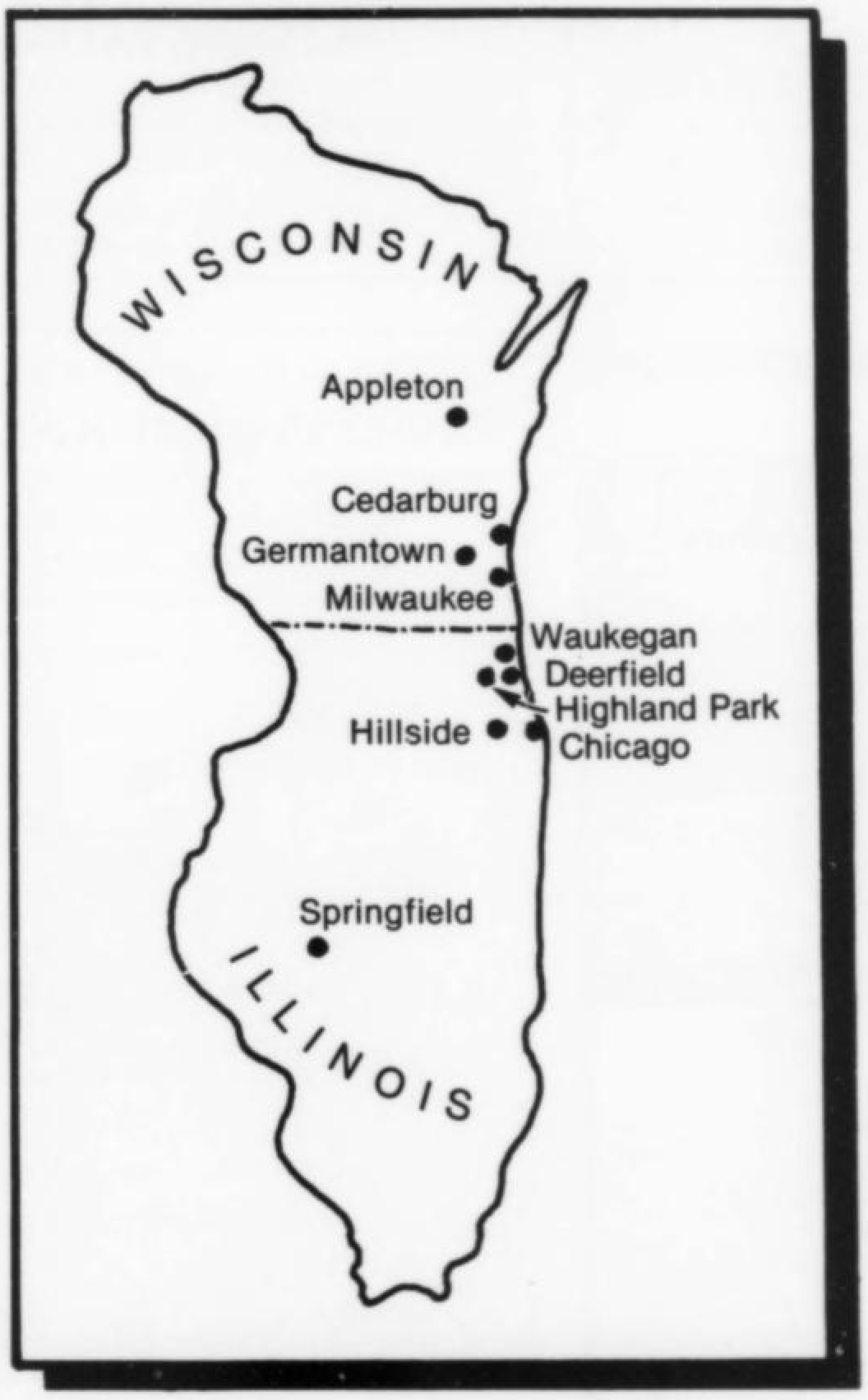
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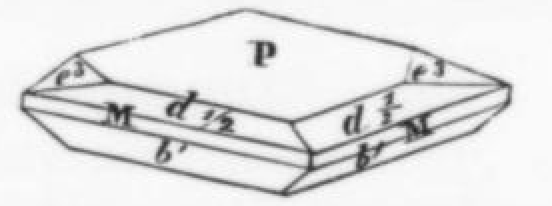
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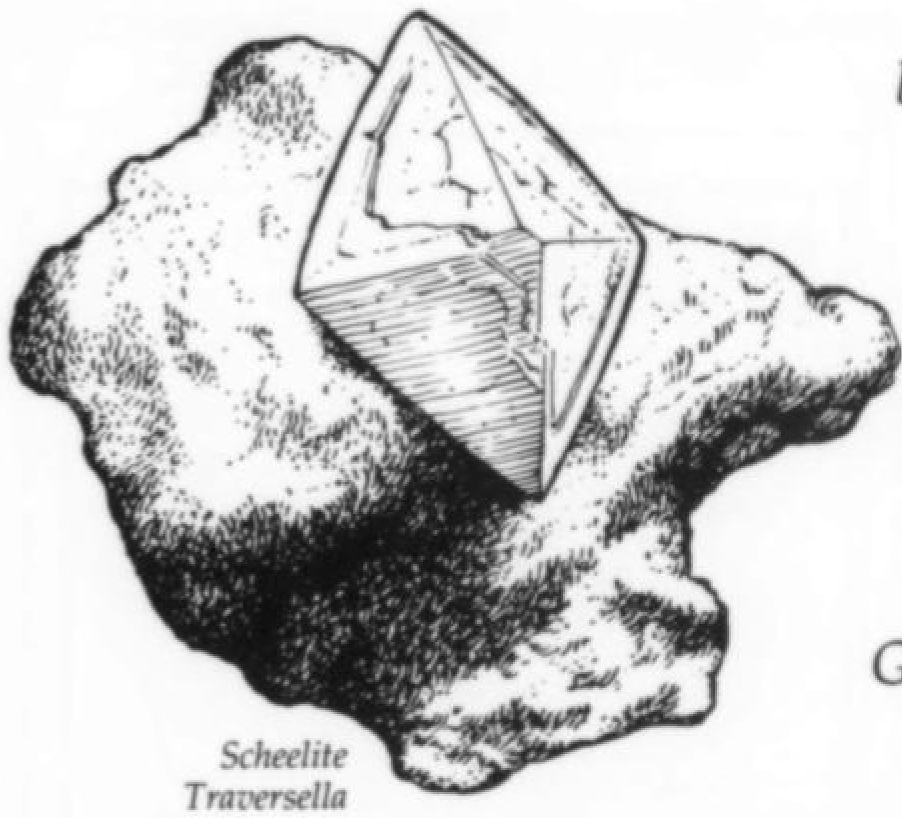

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Microminerals

Bill Henderson

When one approaches 10,000 micromounts, each one entombed in its own little plastic mausoleum, labeled and filed away, perhaps never again to see the light of day, one tends to become jaded. One tends to turn up his nose at the commoner species, and this is a mistake, as witness the specimens I received from Allen and Barbara Lundgren. They offered to send quartz, goethite, manganite and siderite, all common species, from the iron mines of Minnesota, all species I had coming out of my ears. But wait and look! Some of the quartz (Fig. 1) is in beautiful, transparent crystals perched on individual needles of goethite and decorated with still finer goethite, the latter of a bright orange-brown color. I hadn't seen them before. Nor had I ever seen such brilliant, jet-black, well formed manganite crystals as those they sent from the Robert mine, Cuyuna, Crow Wing County, Minnesota. Their high reflectivity (Figs. 2 and 3) makes them very difficult to photograph. The siderite they sent (Fig. 4) is interesting for its habit—stacks of little pie-shape crystals with a light orange color on dark brown goethite. The Lundgrens are swappers (their address: Mr. and Mrs. Allen Lundgren, 765 Redwood Lane, New Brighton, Minnesota 55112).

Ray DeMark (6509 Dodd Place, N.E., Albuquerque, New Mexico 87110) deserves credit for improving the breed with the honey-yellow scheelite he collected, shown in Figure 5. These crystals are nicely striated, thus revealing their tetragonal symmetry, and are from the Ortiz gold mine, Santa Fe County, New Mexico. Of equally nice quality is the bright orange scheelite on pyrrhotite from the Morro Velho mine, Nova Lima, Minas Gerais, Brazil, shown in Figure 6. This was sent to me along with other fine material by Richard Thomssen of Carson City, Nevada. Already in my collection are scheelites from six other localities, but the only ones which approach the attractiveness of the crystals shown here are colorless to white ones from Schlaggenwald, Bohemia, and cream-colored scheelites included in quartz from near Dragoon, Cochise County, Arizona.

Frank W. Robinson (51 Sixth Street, Parkdale, Victoria 3194, Australia) sent some calcite crystals perched on an unknown acicular mineral (Figs. 7 and 8). The equant calcites are oriented perpendicular to the stems, the calcite being colorless to white and the stems a dull orange. As it turns out, both the caps and stems are calcite, and the caps, then, are a second generation of calcite growing on an earlier generation of unusually elongated habit. These are in basalt from the Jindevick quarry, near Warregul, Victoria, Australia. Frank has very nice zeolites from Australian localities, and many of these micro zeolites are equal to or superior to the same species from other localities.

Pyrite is another species which every micro collector has in abundance. Still, it was only recently that the three shown next came down

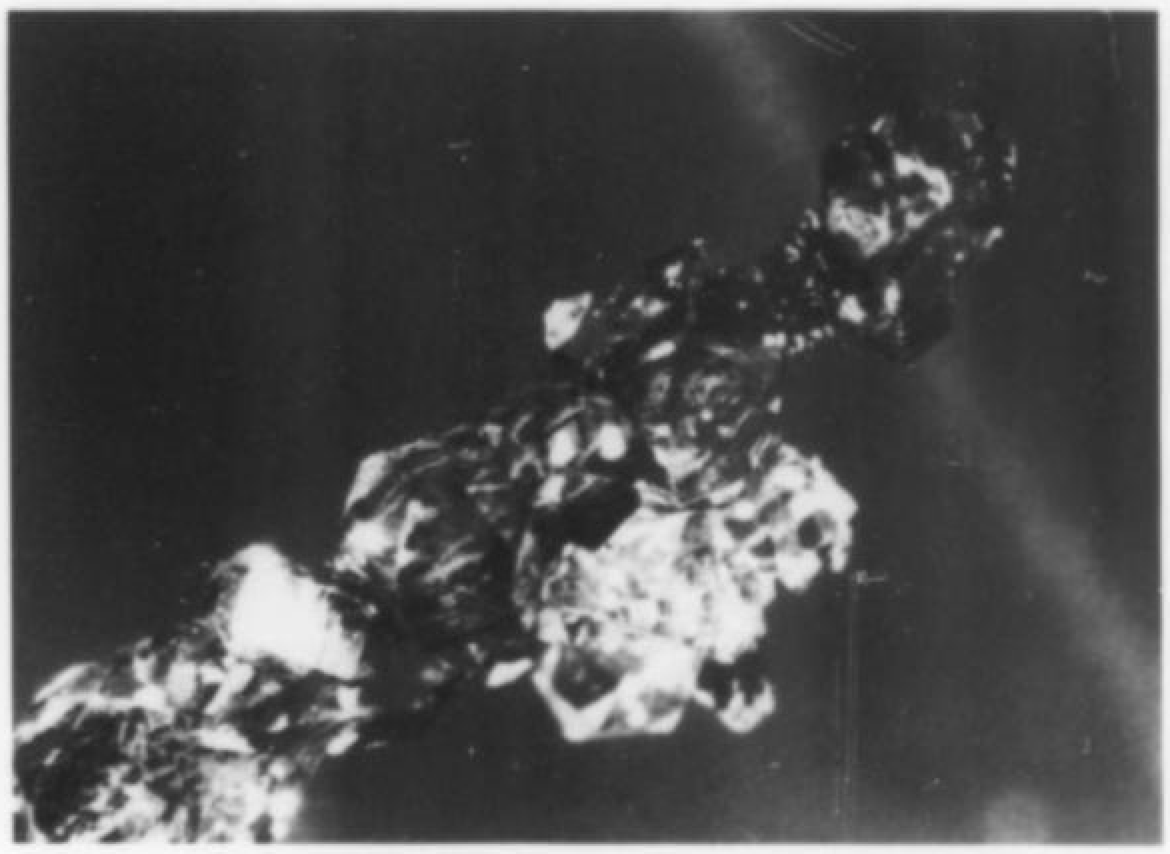

Figure 1. **Colorless quartz crystals on rust-colored goethite needle with secondary goethite, from the Portmouth mine, Crosby, Crow Wing County, Minnesota. Length of group, 7 mm.**

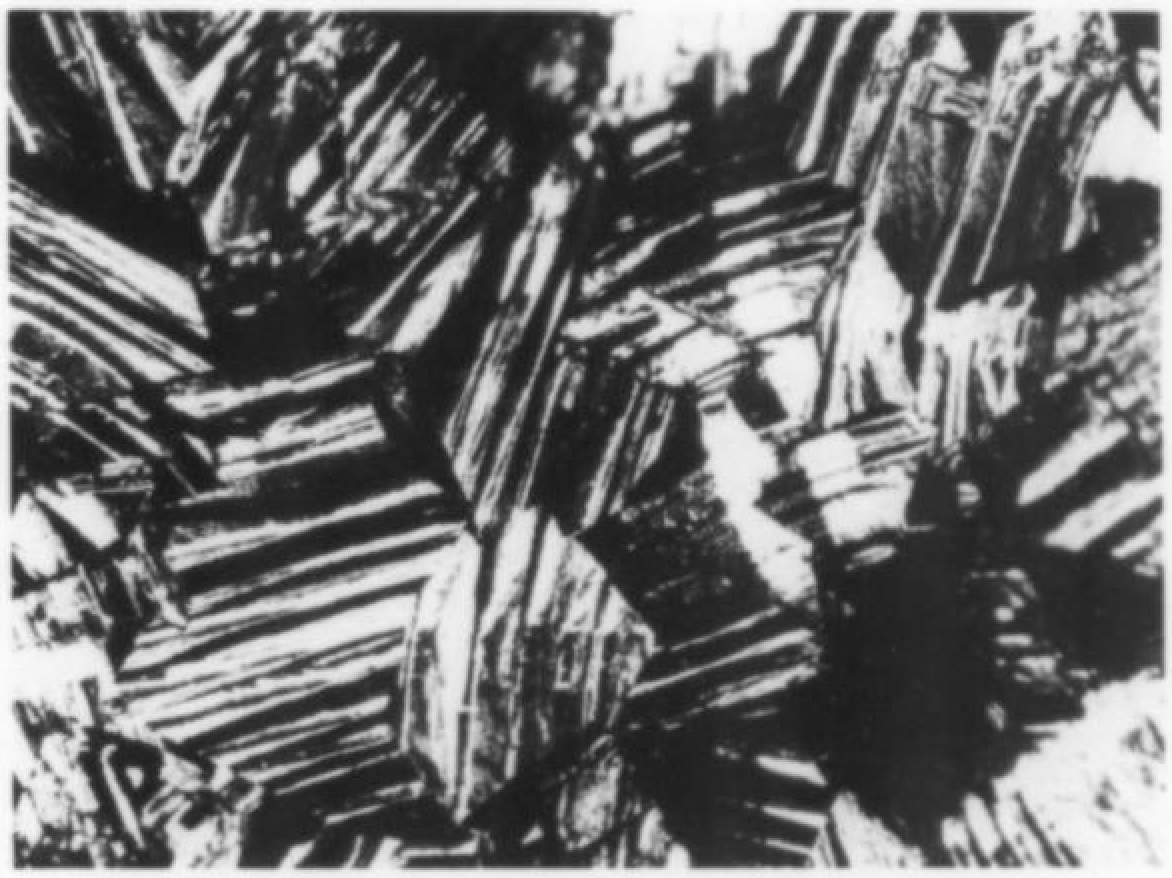

Figure 2. **A druse of jet-black manganite crystals; field of view 15 mm. From the Robert mine, Cuyuna, Crow Wing County, Minnesota.**

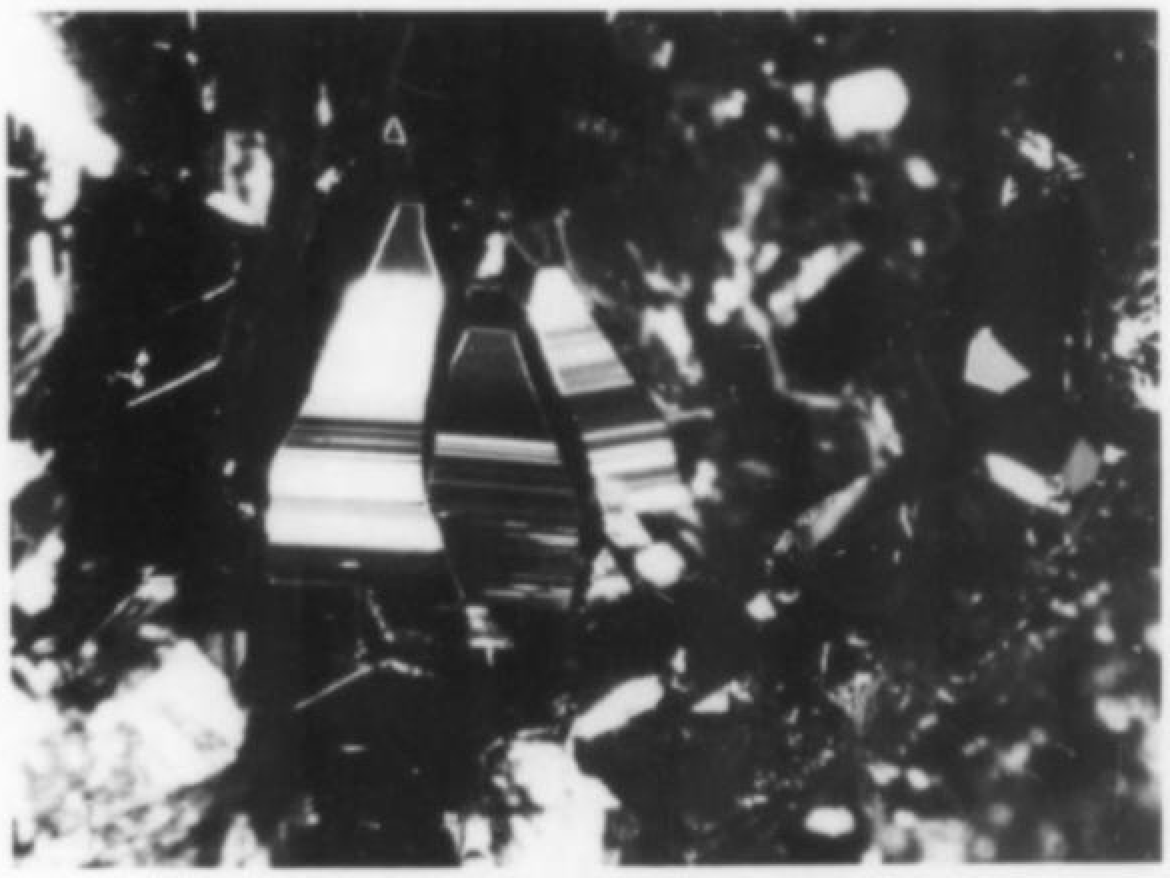

Figure 3. **Brilliant, black manganite crystals to 1.5 mm in length, from the Robert mine, Cuyuna, Crow Wing County, Minnesota.**

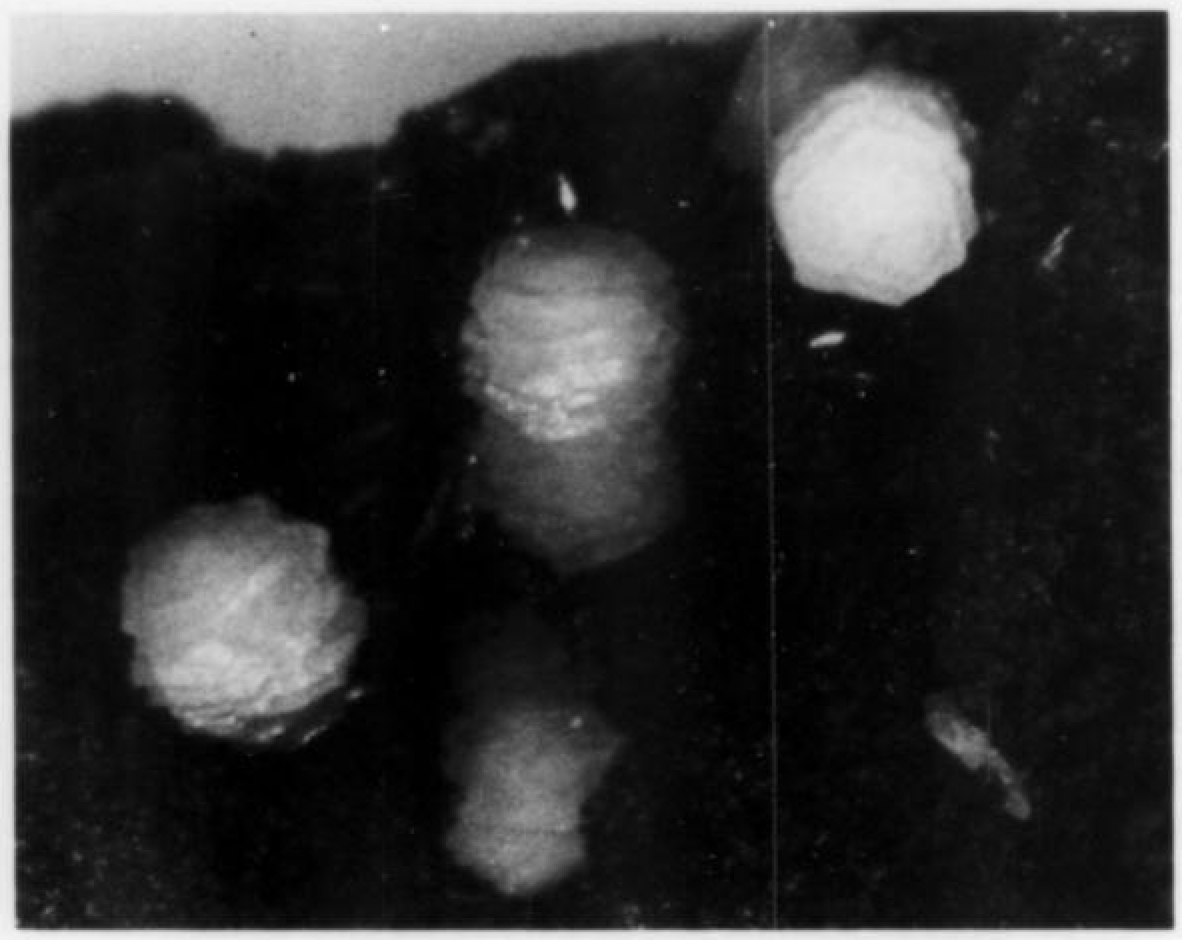

Figure 4. **Light tan, stacked up, pie-shape siderite crystals on dark brown goethite. Crystals are about 0.5 mm across, and are from the Huntington mine, Ironton, Crow Wing County, Minnesota.**

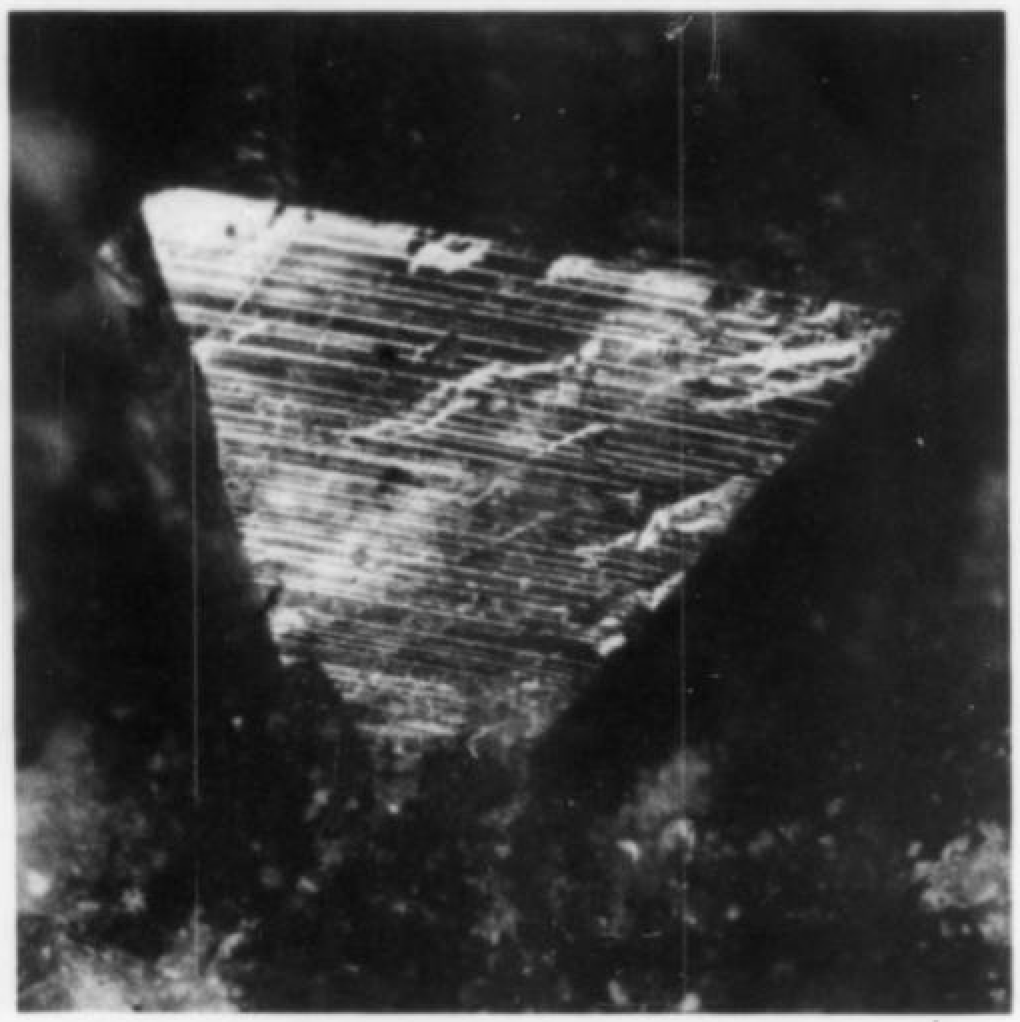

Figure 5. **A 2.5-mm, light yellow, striated crystal of scheelite with pyrite on quartz, from the Ortiz Gold mine, Santa Fe County, New Mexico.**

the pike, and they are completely different from any of the fifty or more already in my collection. Dan Behnke sent the photos shown in Figures 9 and 10. These show pyrite in remarkable spherical aggregates, possibly made up of radiating, distorted cubes. It's also interesting that these spheres from Gray's quarry, Hamilton, Hancock County, Illinois, are associated with or even growing on normal pyrite cubes. Figure 11 shows pyrite from the Eagle mine, Gilman, Eagle County, Colorado, with almost equal development of the pyritohedron and octahedron. A diagram of just such a crystal is shown in *Dana's Textbook of Mineralogy,* Fourth Edition, page 81. As a consequence of equal development of the two forms, the crystal shows a spurious five-fold symmetry. The highly reflective pyrites shown in Figure 12 are from the Bethlehem Steel quarry in Cornwall, Lebanon County, Pennsylvania, and are growing on apophyllite. They show what at first appear to be cube and octahedron faces, the latter being deeply pitted. However, close inspection shows that the "cube" faces are

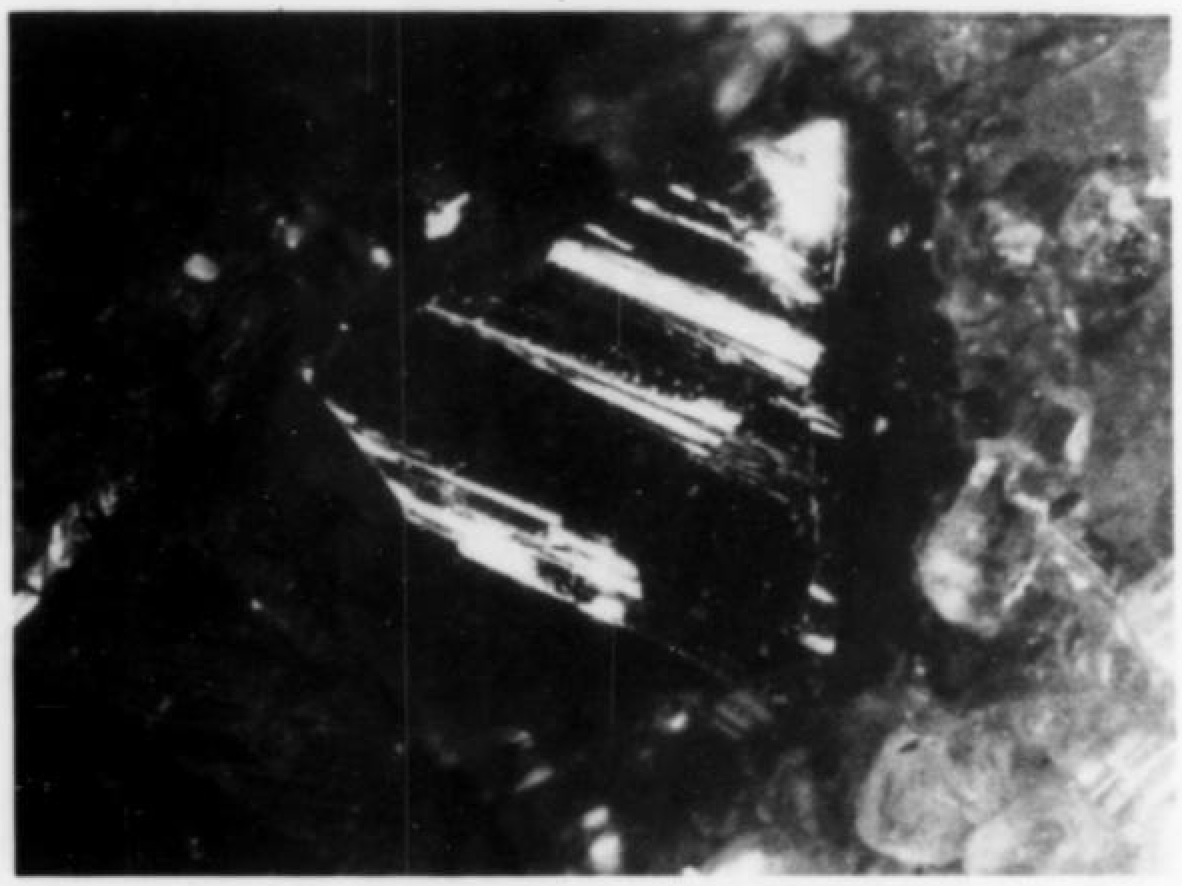

Figure 6. **A deep orange, 1.5 mm crystal of scheelite with pyrrhotite on calcite. From the Morro Velho mine, Nova Lima, Minas Gerais, Brazil.**

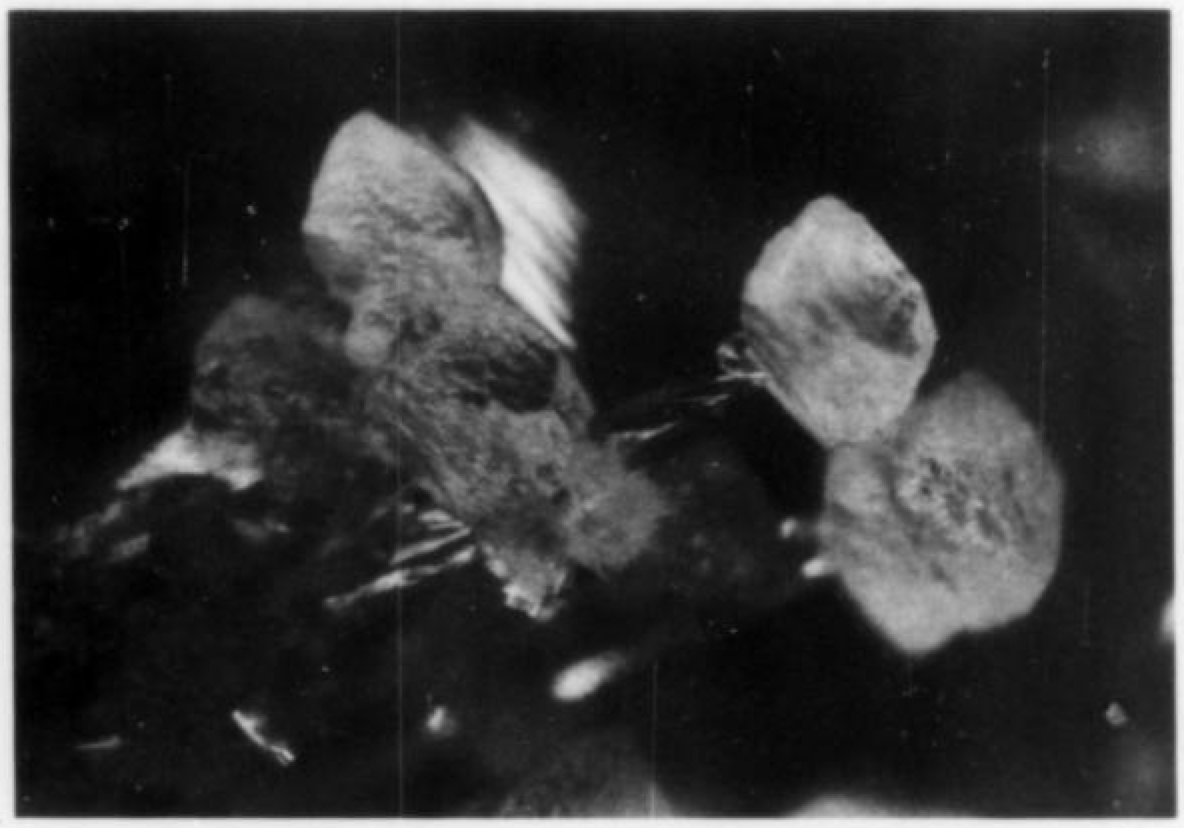

Figure 7. **Colorless, equant calcite crystals oriented on the terminations of orange, acicular calcite crystals; field of view 2.5 mm. The specimen is from the Jindevick quarry, Victoria, Australia.**

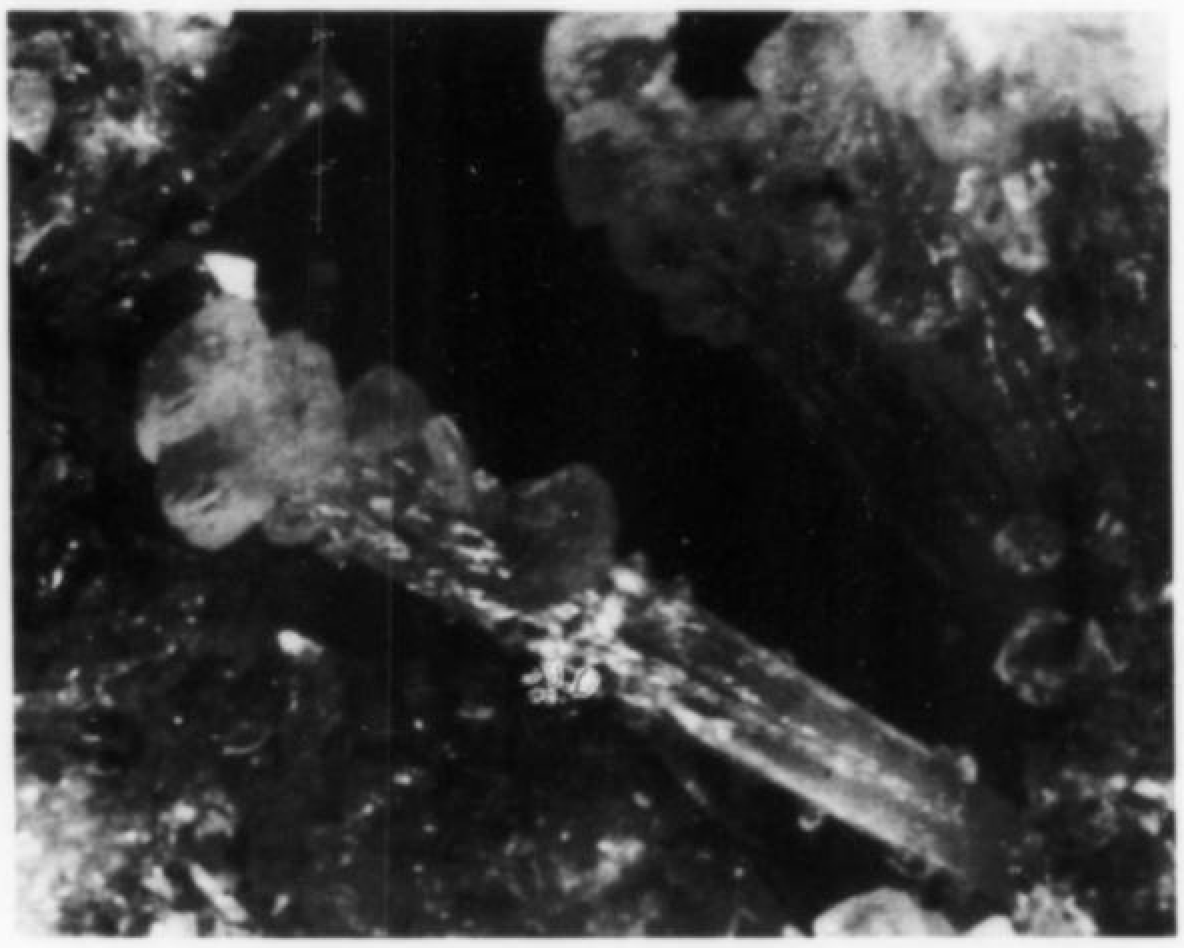

Figure 8. **Calcite oriented on calcite as in Figure 7.**

Figure 9. **A sphere of radiating pyrite crystals on pyrite from Gray's quarry, Hamilton, Hancock County, Illinois. Size of sphere, 0.16 mm. Dan Behnke photograph.**

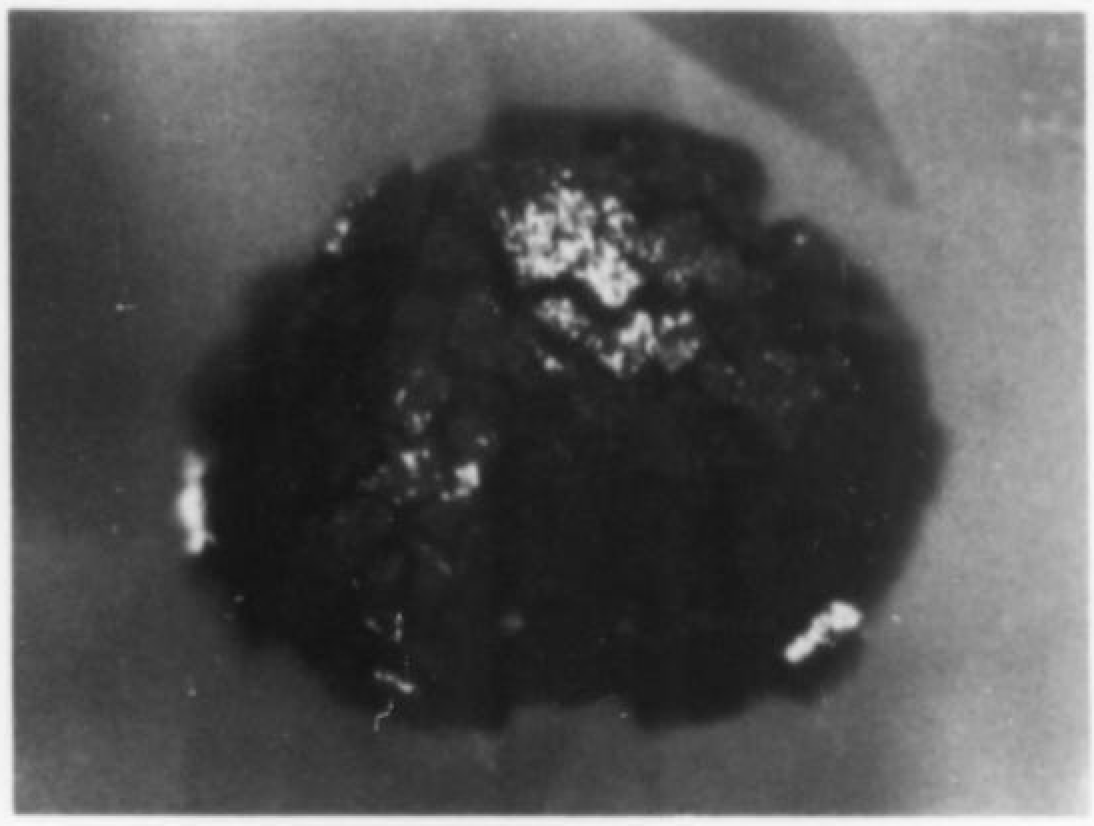

Figure 10. **A 0.47-mm sphere of radiating pyrite from Hamilton, Hancock County, Illinois. Photo by Dan Behnke.**

Figure 11. **A brass-yellow pyrite showing equal development of the octahedron and pyritohedron; hence, a pseudo five-fold symmetry. The crystal, 2.2 mm across, is from the Eagle mine, Gilman, Eagle County, Colorado.**

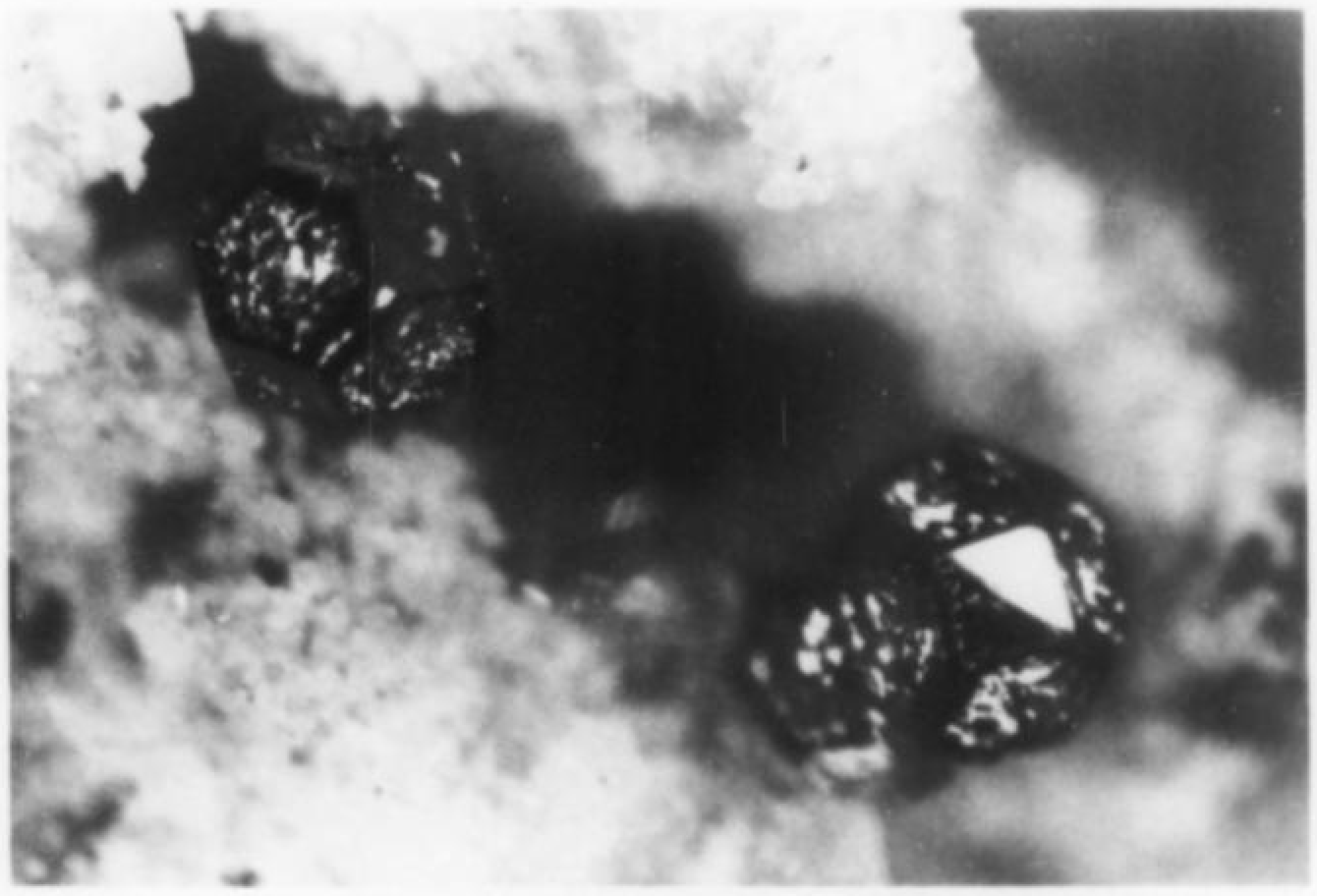

Figure 12. **Two 0.5-mm, brilliant crystals of pyrite with deeply pitted octahedron faces, from the Bethlehem Steel quarry, Cornwall, Lebanon County, Pennsylvania.**

made up of two or three faces (note diagonal line in Fig. 12). It appears that these are actually pairs of shallow pyritohedron faces, sometimes divided by a very minor cube face along the diagonal.

Within the last few months, I have obtained several fine African minerals, most of them using the silver pick. The first of these was a 7.5-cm piece of calcite matrix covered with over a hundred single crystals, twins and trillings of brilliant, black hausmannite from Wessels mine, Kuruman, South Africa. One such trilling is shown in Figure 13. The specimen was obtained at the last show sponsored by the New Jersey Earth Science Association in Wayne, New Jersey. This is a fine, medium-size show with excellent dealers and exhibits. Not the least of the dealers is Dick Gaines, from whom this specimen was obtained. He can always be counted on to have rare, old or unusual specimens at very reasonable prices, and I never manage to get away from his booth without picking up several choice items.

Also from South Africa are the specimens shown in Figures 14 and 15. The first of these is a jet-black crystal of gaudefroyite, a hexagonal, manganese borate-carbonate, with a colorless crystal of what is probably calcite growing from its side. The second is a distinctly columnar,

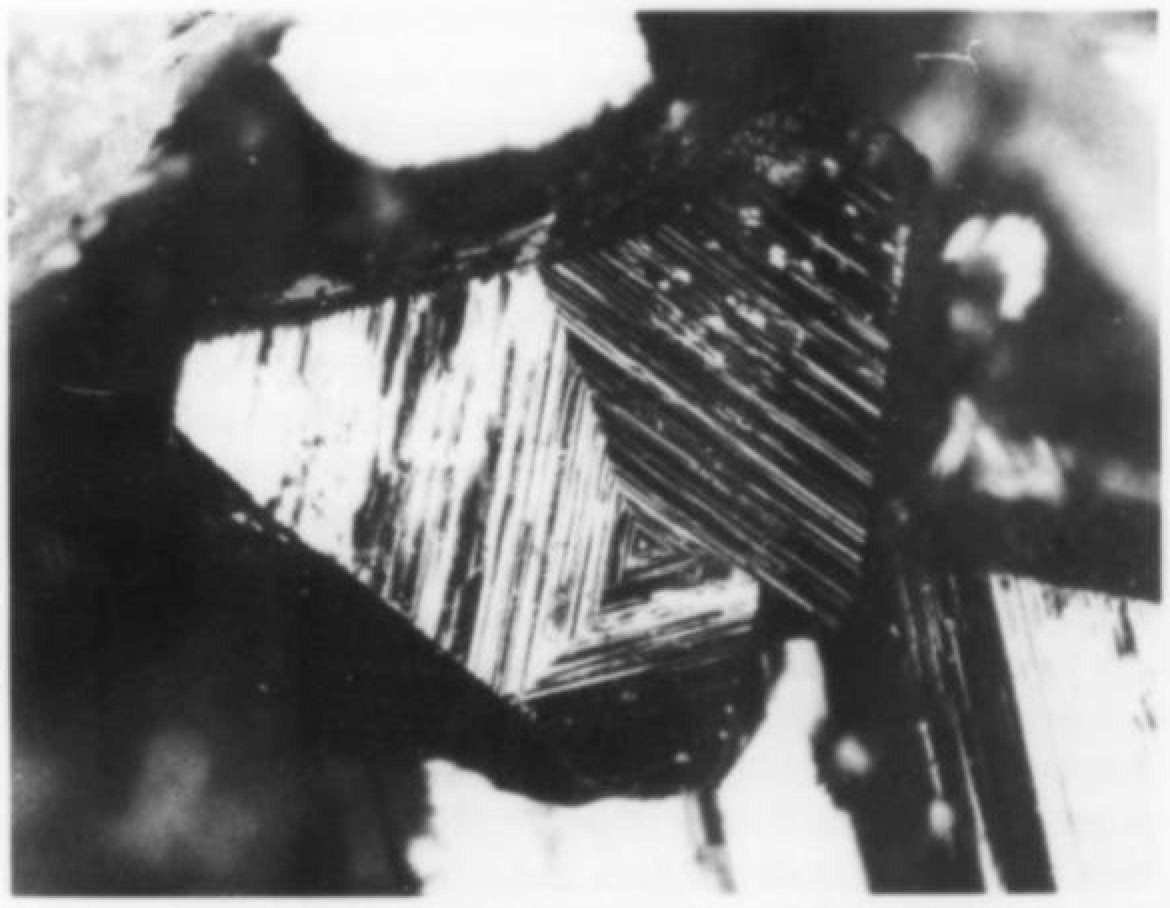

Figure 13. **A trilling of brilliant, black hausmannite crystals on calcite. The specimen, 1.6 mm across, is from the Wessels mine, Kalahari Manganese Field near Kuruman, South Africa.**

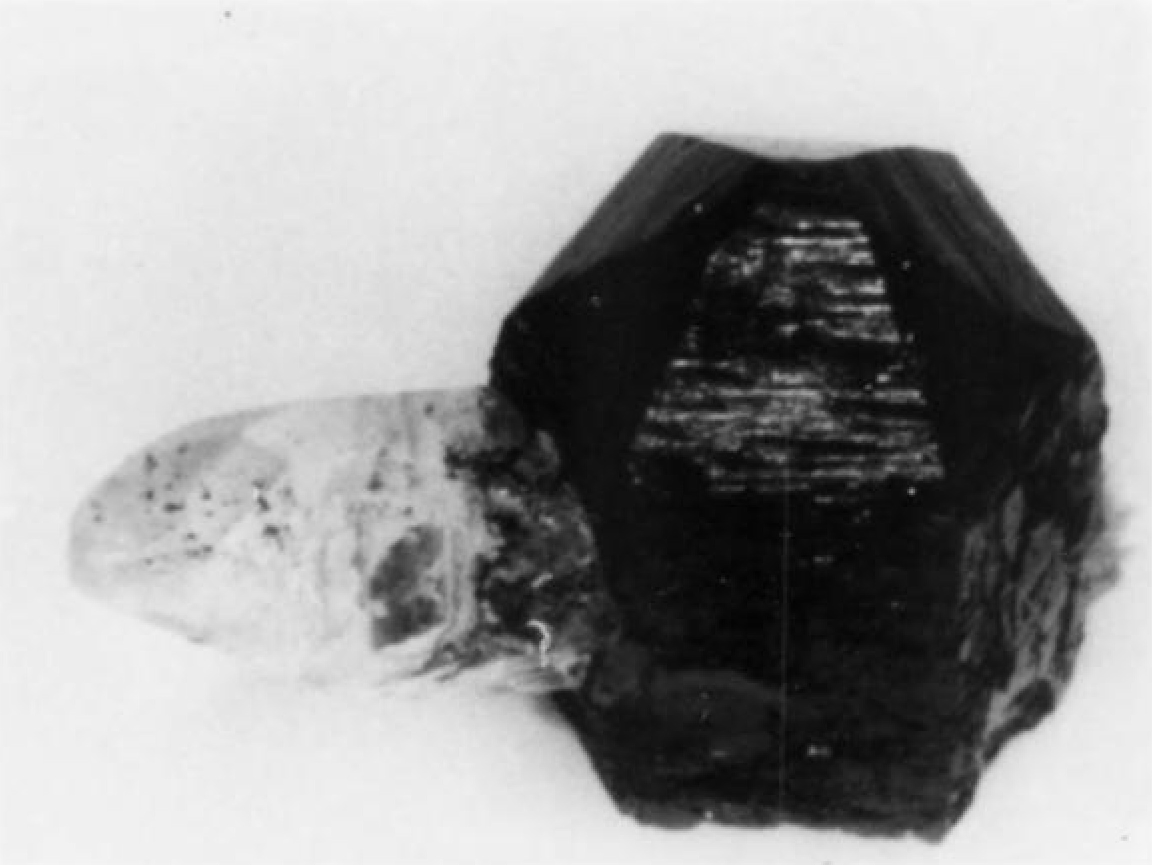

Figure 14. **A black, 6.5-mm gaudefroyite crystal, hexagonal, with an adhering calcite (?) crystal, from the N'Chwaning mine, Kalahari Manganese Field, Cape Province, South Africa.**

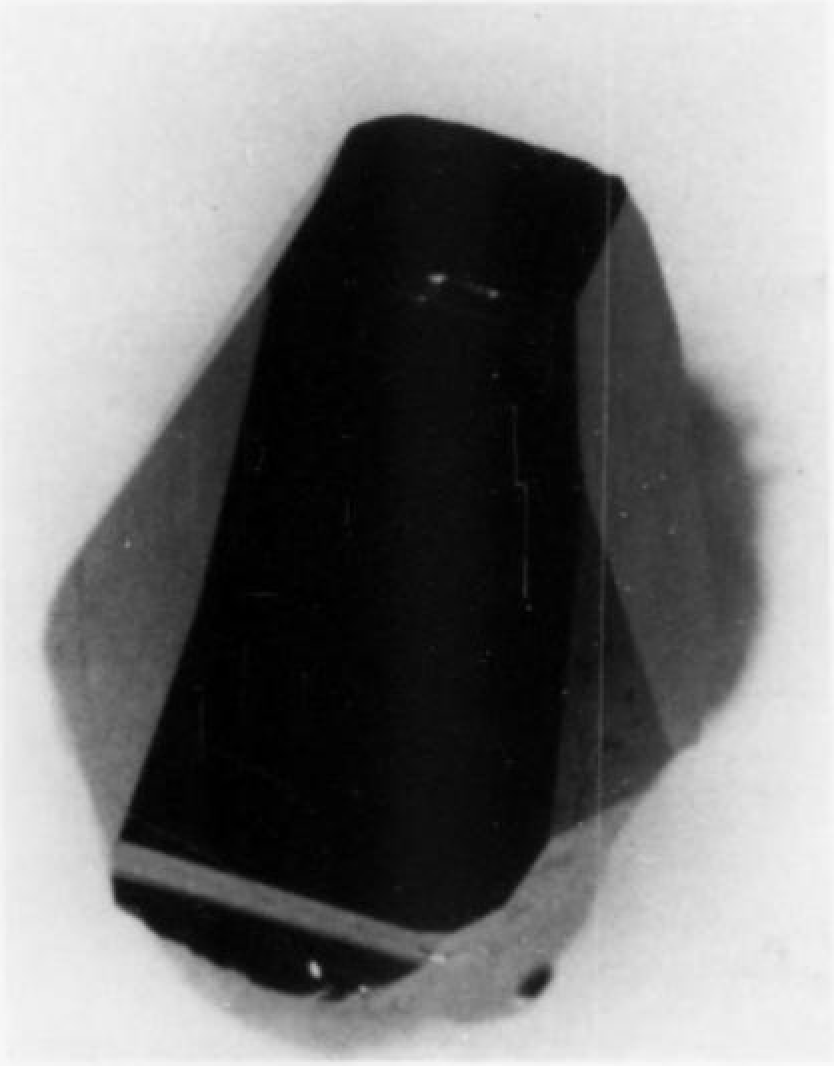

Figure 15. **A columnar, 9-mm black hematite crystal with metallic luster, from the N'Chwaning mine, Kalahari Manganese Field, Cape Province, South Africa.**

Figure 16. **Brilliant, black gaudefroyite crystal, 1.5 mm high, from the N'Chwaning mine, Kalahari Manganese Field, Cape Province, South Africa.**

Figure 17. **Colorless, columnar calcite crystals showing prominent prism faces, from the Rössing Uranium mine, Rössing, Namibia. The largest crystal is 4.5 mm long.**

brilliant, black crystal of hematite. Both are from the N'Chwaning or Black Rock mine in the Kalahari Manganese Field, Cape Province, South Africa. These were obtained at the Eastern Federation Show in Warwick, Rhode Island, from Mike Haritos (STD Mineral Company, 22 Spring Hill Road, Hyde Park, Massachusetts 02136). Mike and his partners had these and other nice species such as purple *crystals* of sugilite and todorokite in gypsum from Africa at reasonable prices, and locally collected species such as babingtonite from several Massachusetts localities at ridiculously low prices.

Recently, we had the pleasure of entertaining John Gliddon, Mine Superintendent of the Palabora Open Pit, South Africa. It's the largest open pit operation in all of Africa, and exploits a number of valuable ore minerals occurring in carbonatite, an igneous carbonate rock. The locality has several minerals in common with the Jacupiranga mine, another carbonatite operation in São Paulo, Brazil. From John, we received a large number of attractive and well crystallized micro-

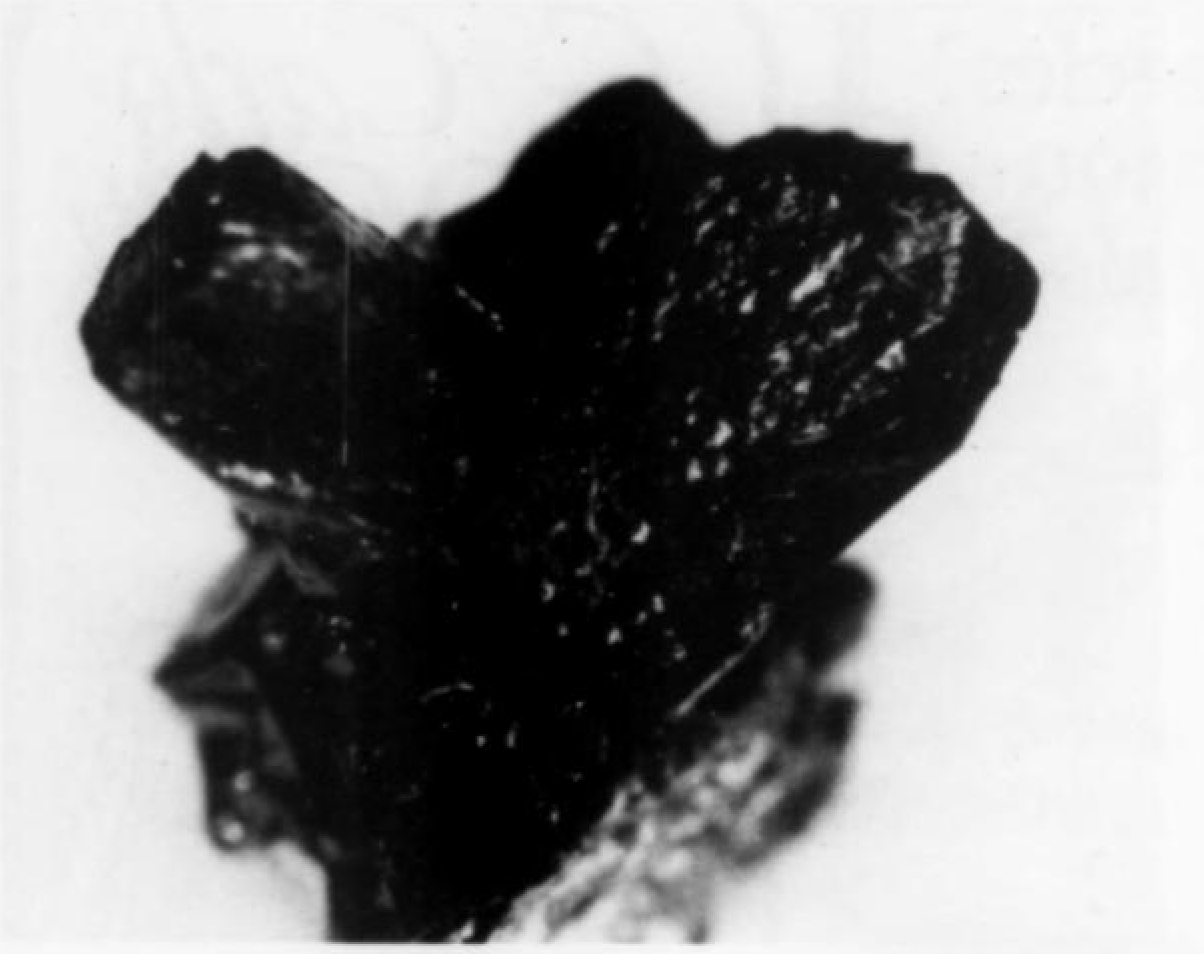

Figure 18. **A 6.0-mm group of jet-black baddeleyite crystals from the Palabora Open Pit, Phalaborwa, Transvaal, South Africa.**

Figure 19. **Colorless to white mesolite crystals, 2.4 mm long, from the Palabora Open Pit.**

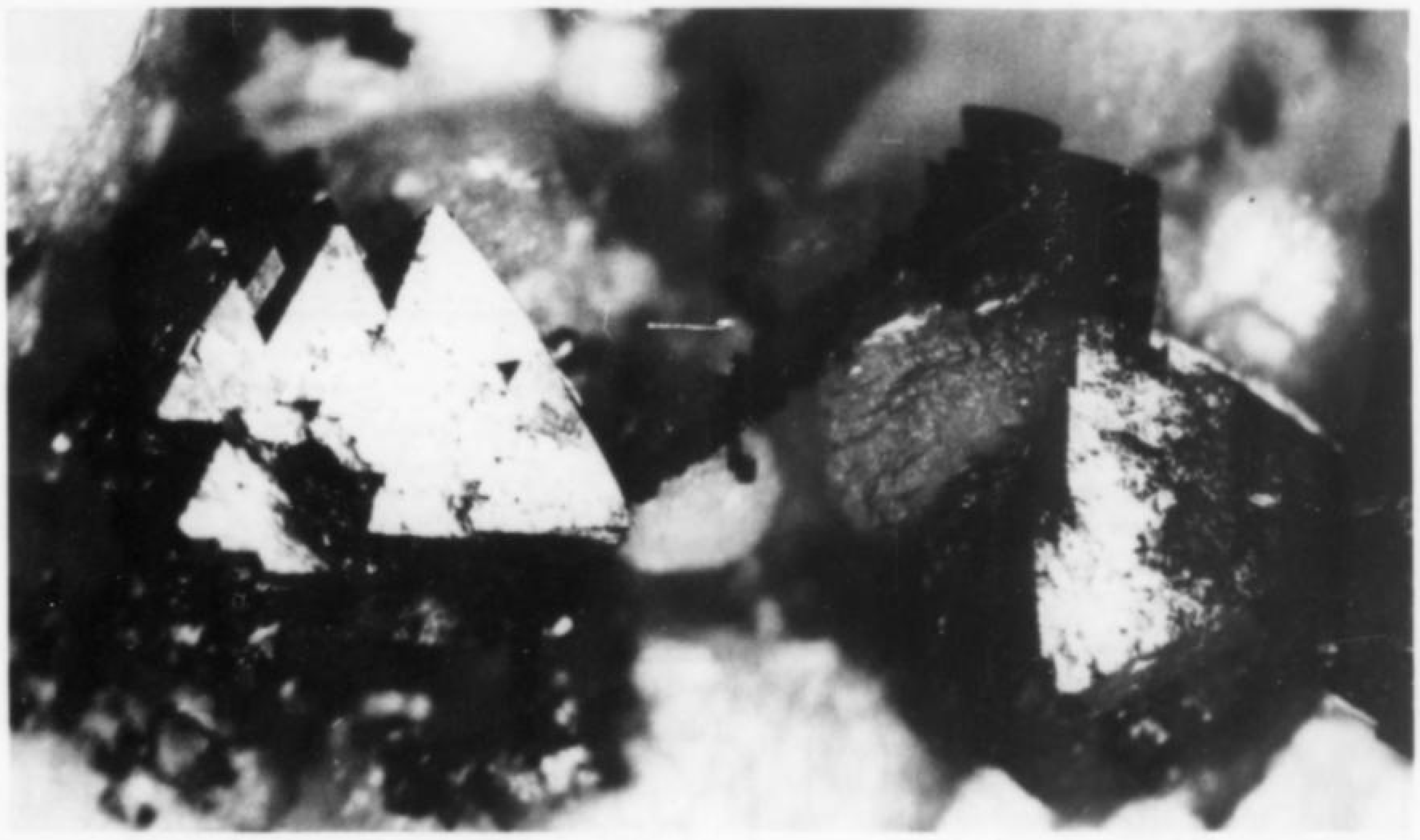

Figure 20. **Brilliant, black octahedrons of magnetite with an interesting parallel growth of smaller magnetite crystals at center of photo; field of view 1.5 cm. From the Palabora Open Pit.**

specimens. The first of these was another gaudefroyite (Fig. 16), but of an entirely different habit from the one shown earlier. Indeed, John's specimen shows at least one other crystal habit much simpler than the one shown in Figure 16. A much commoner species but one showing unusual crystal form is the calcite from the Rössing Uranium mine shown in Figure 17. The extent of elongation and the predominant prism faces are rarely seen in calcite. The terminations, although rounded, appear to be made up of a major scalenohedron and one or more minor rhombohedra.

From the Palabora open pit, John sent us the baddeleyite in Figure 18. Baddeleyite, ZrO_2, is extremely rare and is one of the minerals common to the Palabora pit and the Jacupirange mine. Interestingly, there is enough of the mineral at Palabora that it is an economically important constituent of the ore. Although not an ore mineral, the mesolite crystals shown in Figure 19 are remarkable for their thick, columnar habit and well developed terminations, the latter being made up of a multitude of parallel, acicular segments. The last species shown from the Palabora open pit is the magnetite in Figure 20. Magnetite is a substantial component of the carbonatite but, curiously, it cannot now be economically used and must be stockpiled because of its high titanium content. Besides the sharp, octahedral crystals shown, the magnetite from Palabora also shows curious, parallel growths made up of smaller octahedrons such as that in the center of Figure 20. Other Palabora species obtained from John are fluoborite as white, acicular crystals with magnetite; brucite in two completely different habits; and extremely beautiful, deep orange, well formed crystals of chondrodite. Although John is not quite a dealer, he does have the above and many other attractive and well formed micros for sale. (His address is P.O. Box 1414, Phalaborwa, Transvaal, South Africa.)

These and other minerals such as the new finds of sturmanite show that there is an abundance of fine species to be obtained from southern Africa these days. And speaking of those sturmanites, micromounters would do well to watch for associated white and black minerals in micro crystals. These promise to be very interesting.

Have any of you readers detected a certain amount of improvement in the photos in this column? In the past, I took photos using a 25-year-old Unitron microscope, hanging thereon a broken Pentax camera body using a $35.00 adapter. Exposure and focus were by guess and by golly. Of late, though I have been using an expensive Olympus scope with dedicated camera, automatic film advance, side viewing telescope, computer controlled exposure, automatic reciprocity failure correction, and a diaphragm at the objective lens to control depth of field. I give thanks for all the technological advances in this world. They certainly make writing these columns easier.

Happy hunting!

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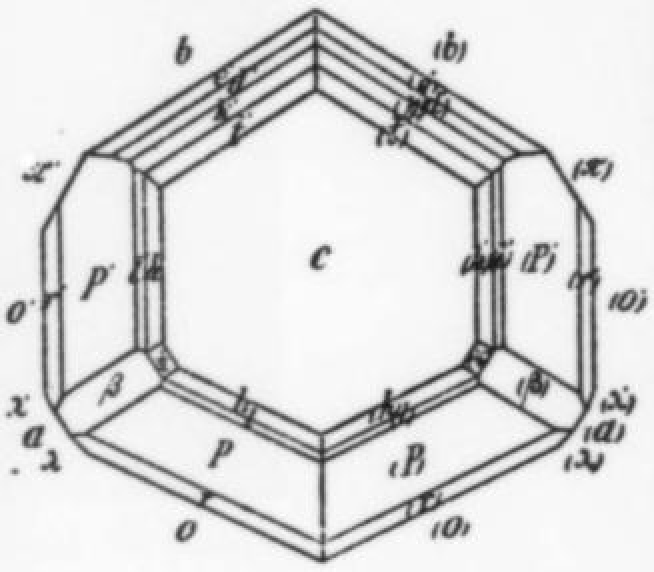
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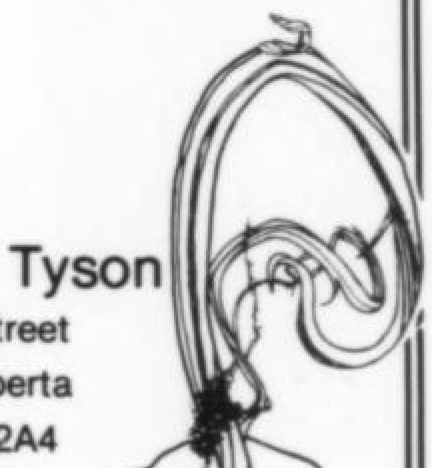
Tetrahedrite
Carrara




SHOWS

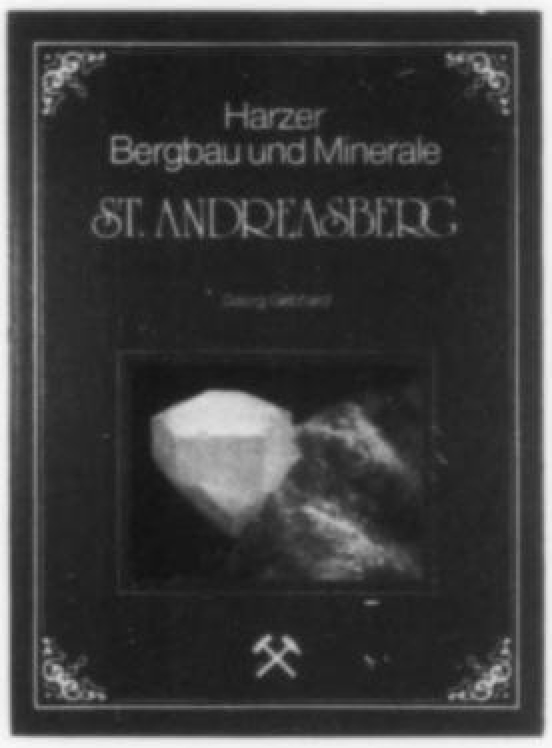
Book Reviews

The World of Minerals Through Postage Stamps

by Jean-Michel Autissier, preface by Pierre Bariand (1987), published by Atelier JMA, Saint-Amand-Montrond, France; distributed in the United States by the Mineralogical Record Book Department, P.O. Box 1656, Carson City, NV 89702. Softcover, $6^{1}/_{2} \times 9^{1}/_{2}$ inches, 121 pages, 44 color plates showing postage stamps and mineral specimens, $25 postpaid ($26 foreign).

If you have been tantalized by the pictures of mineral stamps shown periodically in the *Mineralogical Record*'s letters column, and want to see more, this colorful book is just the thing. Nearly 300 postage stamps depicting gems and minerals from around the world are reproduced in full color. They are grouped into 44 plates, more or less by mineral species, and have a brief and basic accompanying text discussing the minerals. The text, in side-by-side French and English, is so short and simple that only people who know practically nothing about minerals will get much out of it. But considering that the book is aimed at stamp collectors and not mineralogists, the coverage is satisfactory and makes a nice introduction for young collectors and potential collectors. And despite its brevity, we still learn a few interesting things here and there; for example, that the largest known tetrahedrite crystal (15 cm) was found at the Irazein mine in the French Pyrenees and is on exhibit at the Sorbonne in Paris.

Tables listing in detail all known mineral stamps that have been issued to date, by country and by species, are included to make the book a useful collector's reference as well as a pretty picture book. This is an interesting book to browse through, one of the rare references on mineral art of any kind, and will also make a nice gift for beginning stamp and mineral collectors.



Harzer Bergbau und Minerale: St. Andreasberg

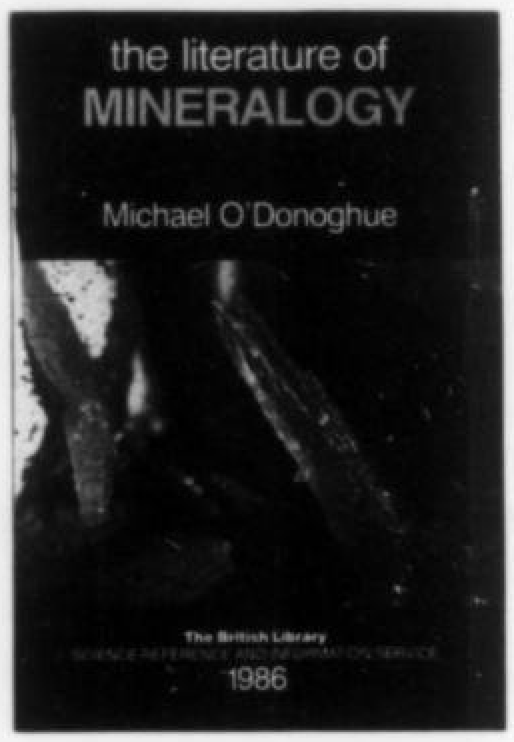
by Georg Gephard, in collaboration with Klaus Stedingk, with mineral photography by Olaf Medenbach and Rainer Bode. Published by Verlag Christel Gebhard-Giesen, available through Mineralogical Record Bookstore, P.O. Box 1656, Carson City, NV 89702. Hardcover, $8^{1}/_{2} \times 11^{1}/_{4}$, 167 pages, with many maps, diagrams and engravings, and 66 full-color mineral photographs (most of them half-page or larger) $43 postpaid (foreign orders add $1). In German.

Several major articles and reviews of the mineralogy of St. Andreasberg have appeared in the German literature during the last few years; this is by far the best and most beautifully illustrated. It is also the first to be published in a full-size, hardcover format.

St. Andreasberg is the most famous mining and mineral locality in the West German half of the Harz Mountains. Known at least since 1487, the mines have yielded vast quantities of silver and silver minerals, right up until the closing of the last mine in 1931. Gebhard's excellent monograph recounts the rich history in detail, with many fine old period illustrations, then launches into an equally detailed review of the geology and the underground workings. The mineralogy section describes all species known from St. Andreasberg, beginning with a discussion of the "classic" occurrences and then proceeding in Dana order through all of the minerals. At the end is a listing of recently found species that are new to the St. Andreasberg list, followed by an interesting chapter on prominent early collectors and collections specializing in St. Andreasberg minerals, and concluding with a bibliography, a species checklist and a glossary of early German mining terminology.

The book is liberally illustrated with fine color photographs by German masters Olaf Medenbach and Rainer Bode. The beautiful proustites, pyrargyrites and fluorites are supplemented by many old crystal drawings and reproductions of antique labels and period illustrations of specimens from early mineral books.

Despite the language barrier, this is a very satisfying book to leaf through. It is so well illustrated that the reader obtains a thorough introduction to St. Andreasberg even without reference to the text which, at least for technical information on the species, is understandable with only a little work. Collectors and mineralogists as well as mineral historians with any interest in European localities should consider this book an essential reference.



The Literature of Mineralogy

by Michael O'Donoghue (1986). Published by the British Library, Science Reference and Information Service, 25 Southampton Buildings, Chancery Lane, London WC2A 1AW. Softcover, $6^{1}/_{2}$ x 9 inches, saddle stitched, 94 pages; price £12. (ISBN 0-7123-0737)

The literature of mineralogy is vast and widely dispersed, both geographically and temporally. So a title like *The Literature of Mineralogy* suggests a grand bibliographical compendium. Michael O'Donoghue's booklet is instead a modest effort designed to hit only the high spots, and concentrating mostly on very recent books and journals. The selection is adequate as far as it goes, and most entries are given some annotation. Omissions, however, are massive in such a short work; consequently the listings should be considered as only an introduction to the more recent literature.

The booklet has an attractive color cover showing a green mineral (unfortunately not identified inside). Nine pages at the back are devoted to crystal drawings, apparently lifted (unreferenced) from Goldschmidt's *Atlas der Krystallformen* and having nothing to do with the rest of the booklet. The type is unfortunately typewriter-style rather than a conventional book typeface which would have been easier to read and more space-efficient.

The booklet includes a lot of blank space (at least 22 page's worth), and an 11-page index, suggesting that the manuscript has been stretched to make it appear closer to book-length. (The text is actually about equal in length to a moderately long article in the *Mineralogical Record.*) This padding need not be considered an objection in itself provided that the price remains reasonable; however, £12 does not seem reasonable. Mineral collectors looking for a brief introduction to recent mineralogical literature will probably find this booklet useful if they don't object to the price. With a deceptive title like *The Literature of Mineralogy*, however, some readers will unfortunately be misled into thinking this is all there is to mineralogical literature.

Glossary of the Minerals of the Lake District and Adjoining Areas

by B. Young (1987), published by the British Geological Survey; available through the Mineralogical Record Bookstore, P.O. Box 1656, Carson City, NV 89702. Softcover, $8^{1}/_{4}$ x $11^{1}/_{2}$ inches, 104 pages, \$23 postpaid in the U.S., foreign orders add \$1.

England's Lake District, in Cumbria near the border with Scotland, is an area of remarkably varied geology and mineralogy. A number of famous mineral localities occur within its borders, particularly Caldbeck Fells where the Roughtongill mine has produced England's finest specimens of pyromorphite.

As the author points out in his introduction, topographical mineralogy has been a rather neglected field in England since Greg and Lettsom's compendious *Manual of the Mineralogy of Great Britain and Ireland* (1858) and Heddle's *Mineralogy of Scotland* (1910). The updating of Greg and Lettsom to make a modern, comprehensive British mineralogy was the unfulfilled ambition of several eminent but now-deceased mineralogists. The task has now become so enormous that it will most likely have to be done as a series of separate regional studies, and Young's *Glossary of the Minerals of the Lake District* is an admirable and thorough beginning.

The length (104 pages) is deceptively short; there are no illustrations, save for one map, a fine color photo of a sphalerite specimen from the Force Crag mine on the front cover, and four color specimen photos on the back cover. The pages are somewhat oversized, and the type is very small (8-point condensed). Consequently the book is dense enough to have filled twice that number of standard-size pages in standard 10-point type with a moderate selection of photos. The lack of specimen photos is a definite deficiency, but the hard mineralogical data is all there in meticulous detail. Species are listed alphabetically, and under each the various occurrences are listed alphabetically with descriptions. All previous literature has been culled, and a significant number of unpublished occurrences are noted based on specimens in the British Museum (Natural History), the Geological Museum, and the National Museum of Wales, all carefully referenced. A bibliography of 279 titles is included.

This is clearly a professionally prepared, basic reference on British mineralogy which deserves a place in every mineralogical library.

Mineral Economics of Africa

by N. de Kun (1987), published by Elsevier Science Publishing Co., Inc., P.O. Box 1663, Grand Central Station, New York, NY 10163. Hardcover, $6^{3}/_{4}$ x $9^{3}/_{4}$ inches, 345 p., \$86.75 (postage free with prepaid orders).

Professor de Kun's latest work, coming 23 years after his larger and more detailed compilation, *Mineral Resources of Africa* (Elsevier), is very broad in scope. It covers the development of petroleum, hydroelectric power, fertilizers, water, building materials and ore processing as well as minerals in all of the African nations. Consequently the amount of space that can be devoted to any one commodity per country is comparatively small in a book of only 345 pages. The situation is made worse by the use of typewriter type rather than formal typesetting, an abominable practice that publishers should learn is offensive to readers.

The format, given these restrictions, is compact and fact-filled. Maps show the locations of important deposits, and mining companies are regularly identified by letter codes keyed to a listing at the back of the book. Key words in the text are underlined for easy scanning.

Unfortunately, text references to other literature are entirely lacking. In place of a bibliography is given a perfunctory listing (called "Further Reading") consisting mostly of journal titles and a handful of specific articles and books, 63 entries total, which is virtually useless to the reader seeking further data on specific countries or deposits.

Despite its shortcomings, this book does provide much basic information not easily available on the mineral deposits of Africa, a virtue uncompromised by our desire for more.

WEW

Notes from the Editor
(Continued from page 138)

with which the user may call up mineral formulas by name, or a list of minerals and formulas containing specified elements. It was being demonstrated in February at the Tucson Show and everyone who saw it was satisfactorily impressed. The program is called MINCAT; it consists of two diskettes and a manual, available for $99.99 from PC Geological Software Systems (Dept. of Earth Sciences, UNO, Lakefront, New Orleans 70148, Tel: (504) 286-6791).

Tonopah-Belmont mine
(Continued from page 144)

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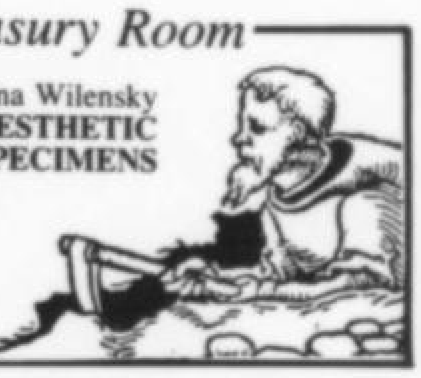

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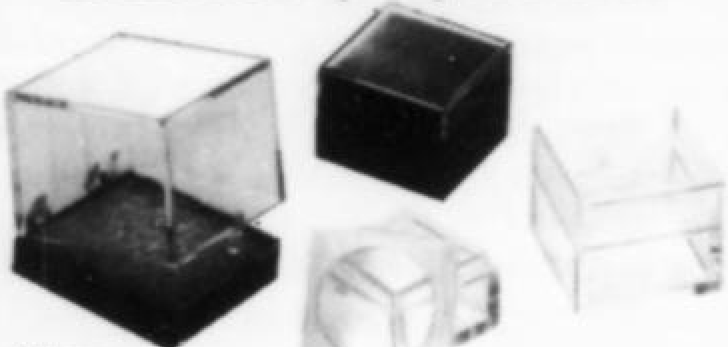

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What's New in Minerals?

by Wendell E. Wilson

Tucson Show 1988

This year the phenomenon known collectively as the Tucson Show set more records for attendance and sales, as it seems to do almost every year. Roughly 27,000 people passed through the gates at the Tucson Community Center, where the Tucson Gem and Mineral Society puts on the finest mineral show in the world. The many motel shows around town also reported heavy attendance and heavy sales. Many motel dealers began arriving around February 1 and 2, and by the scheduled opening dates of the motel shows (typically February 4-6) some dealers had already sold more material than they had during the entire 1987 show!

A large proportion of sales this year went to new customers, especially the metaphysical and "crystal consciousness" market which continues to grow and grow. The new buyers range from the deeply committed to the merely curious, but they seem very interested in learning more about minerals. It was heartening to see mineral dealers like Wayne Thompson (in the Community Center wholesale section) drilling customers on chemical composition ("Calcite is calcium *carbonate* and gypsum is calcium *sulfate* . . ."), and see the people respond seriously, trying to memorize the information. Dealers are best positioned to help educate this market, and those who are working at it deserve our praise. By this time, no one can fail to see that, as traditional rockhounding wanes, the next generation of mineral collectors may well have their first exposure to minerals through the "crystal power" movement.

But let's get down to minerals.

Some interesting new discoveries have been made recently at the famous Mont St-Hilaire quarries in Quebec. Gilles Haineault found a large (over 1 meter) pod of massive **carletonite** which proved to contain a small open pocket with rare free-growing carletonite crystals to more than 2 cm. The crystals are simple equant to slightly elongated tetragonal prisms with a transparent and colorless outer zone surrounding a beautiful, deep blue inner zone. Most crystals are riddled with internal fractures, but a few have actually yielded some fine faceted stones. The best quality crystals are in the 7 to 10 mm range and usually lack matrix. About 50 good crystals were recovered along with a substantial poundage (kilogrammage?) of cleaved massive material. These were for sale through *Tyson's Minerals* in the Travelodge; the faceted stone I saw was cut by Art Grant.

Tyson's also had some other nice Mont St-Hilaire material, including serandite and well-formed leucophenite crystals of grayish tabular habit to 2.5 cm.

The Brumado mine in Bahia, Brazil, has been a significant specimen-producer for many decades (see the article in vol. 9, no. 3). It has continued to yield new and interesting material over the last few years, including red **uvites** to 2 cm or so, as singles and groups with quartz and magnesite. The habit consists mostly of rhombohedral terminations with very little of the prism separating them, resulting

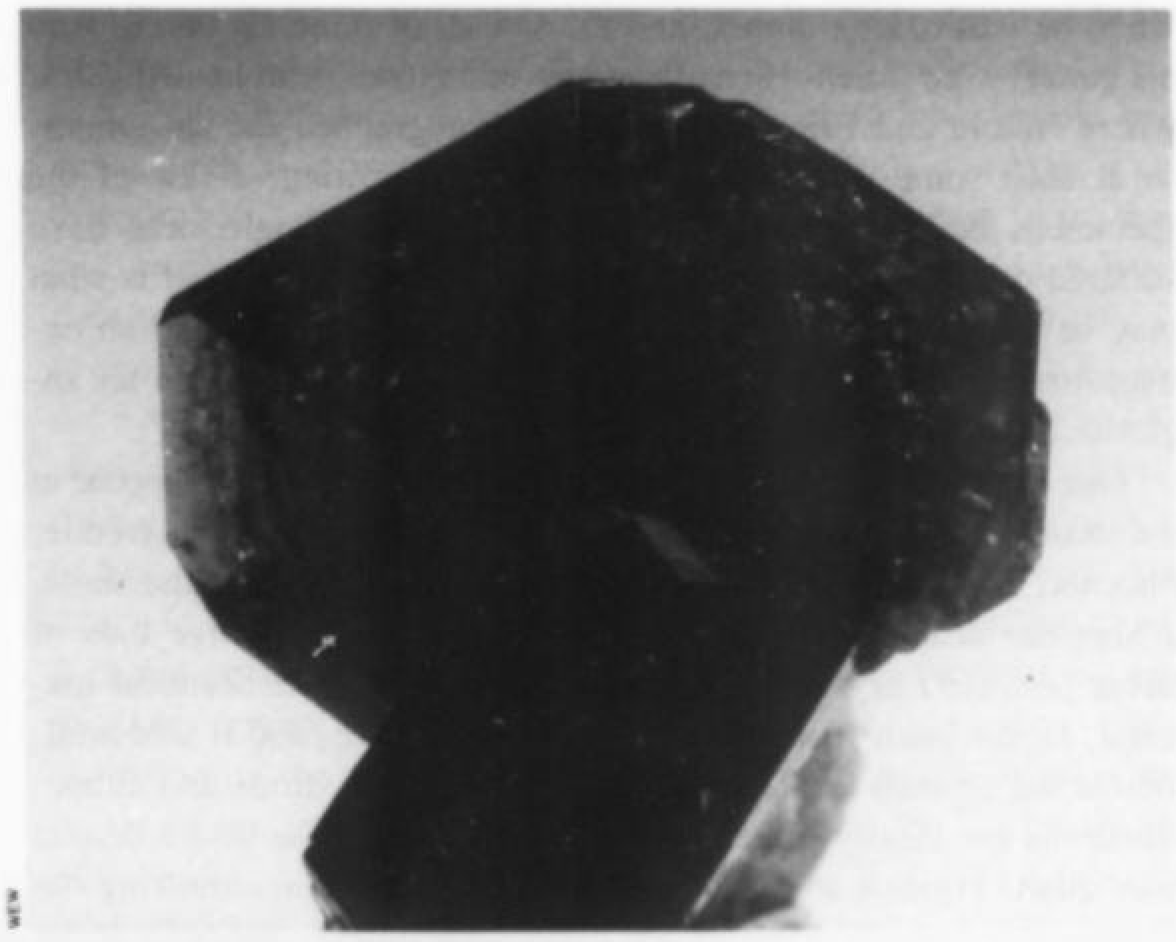

Figure 1. Uvite crystal, 1.9 cm, from the Brumado mine, Bahia, Brazil. Carlos Barbosa specimen.

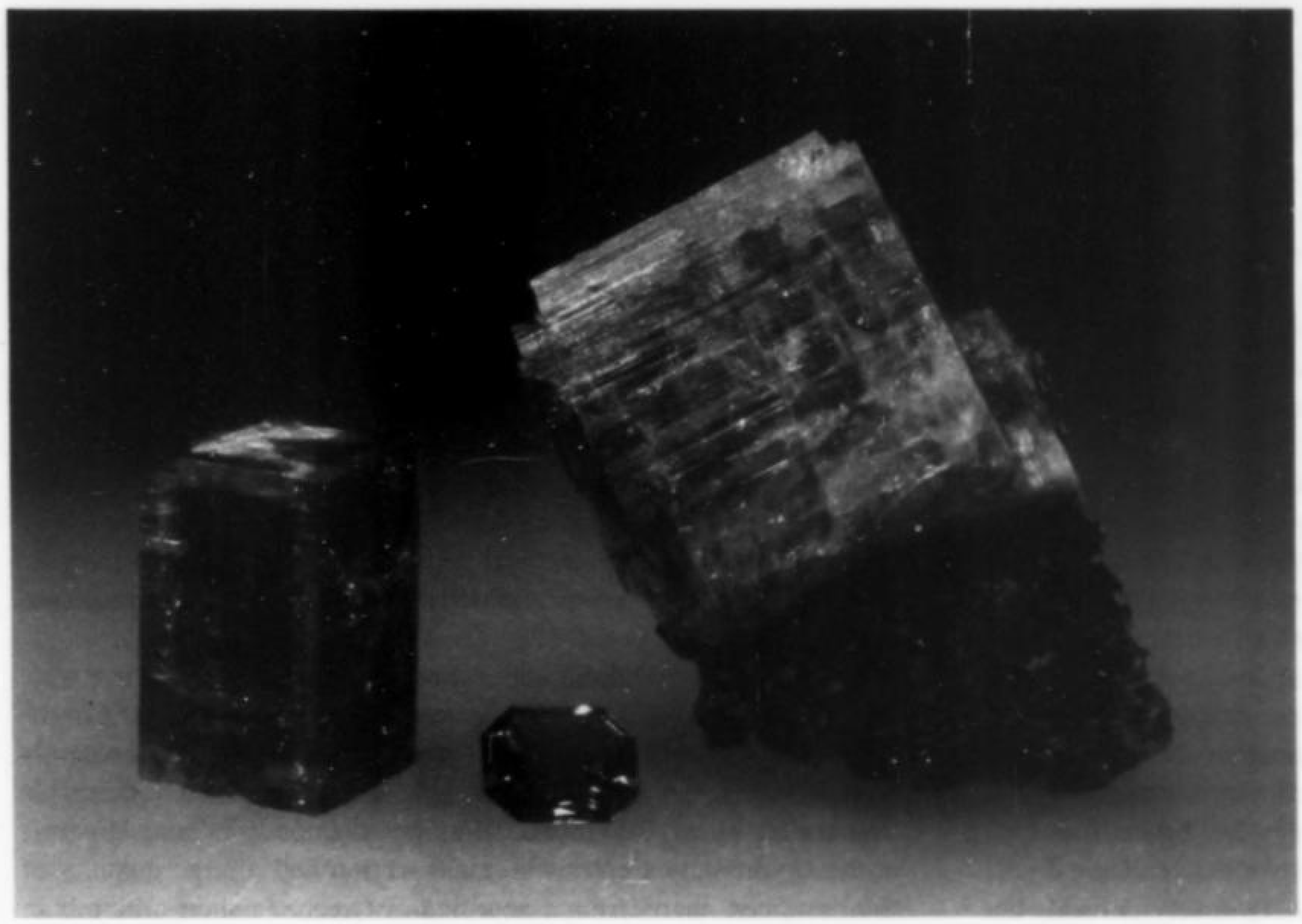

Figure 2. Carletonite crystals to 1.6 cm and small faceted carletonite, from Mont St-Hilaire, Quebec. *Tyson's Minerals* and Art Grant specimens respectively.

in rather flattened hexagonal crystals. Color ranges from a deep green to greenish brown. A few showed up at the Denver Show in September, most of which were purchased by Benjy Kuehling of *Columbine Mineral Shop*, who made them available in his booth at the Tucson Community Center. The lot consisted predominantly of two flats of thumbnails. Ken Roberts (also at the Community Center) had a superb cabinet piece consisting of a terminated, clear quartz crystal about 8 cm long, studded with four large, dark green uvite crystals to nearly 2 cm each, and plenty of sparkly colorless magnesite crystals. Carlos Barbosa in the Desert Inn had many fine thumbnails and even some miniatures. Taken together, several hundred pieces were available.

One of the most admired items was not a mineral at all but an antique boxed set of 50 German-made colored-glass **crystal models** which David Crawford had in his room at the Travelodge. Each model, perfectly cut and polished, measures about 3 cm and accurately depicts the habit *and color* of a particular mineral species. Each has its own labeled recess in the custom-fitted flat case; and when the padding is peeled back, newspaper fragments glued to the inside of the wooden box show a date of 1890.

The sad story of the year was from Victor Yount, who had very recently obtained what are or were probably the world's finest **anglesite** crystals from the Touissit mine, Morocco. His van was broken into while he was having dinner, and the satchel of minerals (along with his guitar) were stolen. He had just arrived in town from Los Angeles, where Harold and Erica Van Pelt had photographed the specimens, so at least some photos survive. As of this writing, a few of the specimens have been recovered by the police, though some have suffered damage. Among the other specimens returned intact is what may be the finest known specimen of **nadorite** ($PbSbO_2Cl$), an extraordinary 2.7-cm rosette of brown-red crystals perched on an anglesite crystal, also from Touissit.

One of the few really new and interesting discoveries to appear at the show was in the room of *Myer's Lapidary* (5820 N. 35th Avenue, Phoenix, AZ 85017) at the La Quinta Motor Inn. Prior to the show, a Mexican dealer had appeared on their doorstep with five flats of **silver** on quartz crystals from Taxco, Mexico. This is beautiful material, in specimens from thumbnail to cabinet size, and it sold well. Where the crystals are large enough to see, octahedrons and cuboctahedrons are clearly discernible. And the thick druse layers draped over quartz crystals are clean and sparkling, sometimes showing the hexagonal-pyramidal habit of the underlying quartz. Analysis at the University of Arizona indicates that silver is actually present only as a thin layer on a pyrite crystal druse.

Mike Ridding (*Silverhorn*) and Robert Belcher (*Aesthetics Underground*, Box 2143, Banff, Alberta T0L 0C0) displayed the results of a recent trip to Pakistan in their room at the Desert Inn. Some interesting **titanite** crystals, very flat and an opaque green, show that the pegmatite region still has some surprises left. The titanites are diamond-shaped and twinned, measuring up to about 4 cm. Mike and Bob also had some extraordinary **epidotes** from the Haramosh Valley, Pakistan (still no firm locality name for these though). About 30 fine, gemmy thumbnails, three large cabinet pieces of exquisite museum quality, a few superb small cabinet pieces, and many lesser-quality specimens (about 300 pieces total) comprised the lot. These are generally very transparent except in the largest crystals, with flattened development accentuating the color and clarity of individual crystals. Form and sharpness are excellent, and at least one large piece actually shows a herringbone habit like Knappenwand (Austria) epidotes.

Larry Conklin, in his room at the Desert Inn, was showing off some fine specimens of Elmwood, Tennessee, **calcite,** among other things, and also the "type specimens" of **kunzite**, the lilac-colored variety of spodumene (see his interesting write-up on the history of kunzite in vol. 18, no. 5). Of course, there can be no real type specimens for individual varieties since mineralogists generally do not recognize varietal names as being useful or rigorously defined, but Larry had the original specimens first sent to George F. Kunz for identification.

Some large and unusual crystals of **rhodochrosite**, up to about 8 cm in length, have recently come from Santa Eulalia, Chihuahua, Mexico. Consie Prince (*Collector's Choice*) had a few of these, which are the first I've actually seen of the elongated habit. The surface irregularities indicate that these are cigar-shaped bundles of semi-parallel crystals, sometimes with multiple terminations, and associated quartz and fluorite.

Edward Tripp (Route 1, Box 161, Blue Ridge, TX 75004) once again had some fine Chinese material at his booth in the lobby of the Desert Inn. The centerpiece was a superb cabinet group of brilliant yellow **orpiment** crystals with white scalenohedral calcite. Tripp also had some small (nearly 1 cm) crystals of Chinese scheelite.

Ken Roberts at the Community Center had some remarkable green **quartz** crystals and groups from Naica, Chihuahua, Mexico. The crystal habit is nothing unusual, but the color and internal quality closely resemble a frozen green oil, and the luster is so bright and perfect as to be almost adamantine. The coloring agent is supposedly chlorite, but it must be extremely finely divided to produce that optical effect.

A new batch of **cubanite** has come forth from Chibougamau, Quebec (see the article in vol. 14, no. 3). Frank Melanson (*Hawthorneden*) at the Community Center had most of these but some other dealers including Bernard Bordaus (1698 Duchesne, Val d'Or, Quebec) at the Desert Inn also had specimens. The crystals are of typical twinned sixling habit, sometimes V-twins and singles as well, up to 2 cm or more.

Frank Melanson also had a large, fine batch of old (1952–1954) **babingtonite** and prehnite specimens from the classic locality near Westfield, Massachusetts, the Lane Quarry. These were taken from an old collection Frank salvaged, numbering about 70 miniatures and cabinets and 70 thumbnails of babingtonite, with crystals to about 1.5 cm, on quartz. The rounded growths of prehnite have a particularly strong and pleasant lime-green color.

With dealer space at such a premium in the downtown area, establishments other than motels have been renting out space to dealers during the show. One such is Boatner's Car Wash, just south of the Travelodge, where I counted no less than *60 dealers* set up on the surrounding grounds and in the repair bay. There were many nice things to be found there in the open sunshine, a selection which would be the envy of many small shows around the country. Frank Valenzuela (215 B. Avenue, San Manuel, AZ 85631), for example, had the finest array of recently collected Arizona **wulfenites** of any dealer in town. Particularly abundant were fine miniatures and cabinet pieces from the Rowley mine, Maricopa County.

Bob Lane (P.O. Box 39343, Phoenix, AZ 85069), an active Arizona field collector, was set up at the La Quinta with some very attractive **rosasite** and **aurichalcite** from the Isle Royale mine, Helvetia, Arizona. It was a big strike, literally hundreds of flats, with many cabinet pieces recovered.

Hilde Sklar (*Oceanside Gem Imports*) in the Community Center wholesale section had her usual fine array of Brazilian specimens, including some very interesting **muscovite** crystals from Mantena, Minas Gerais. The individual crystals measure up to 8 cm, and have beautifully developed pinacoidal surfaces with thousands of sub-parallel steps rising up rosette-fashion. The two I saw were museum-quality.

Quartz is a popular mineral, especially these days, and there were several new discoveries to choose from. Tom Palmer (*Crystal Cavern Minerals*) and Reo Pickens at the Travelodge had hundreds of recently collected Mexican quartz crystals that are almost indistinguishable from the Herkimer, New York, "Herkimer diamonds." *Galas Minerals* in the Community Center wholesale section had a large quantity of chlorite-green quartz from a new find in Greece (a short article is in

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***Figure 3.* Rock Currier of *Jewel Tunnel Imports* holding a large Japan-law quartz twin from Minas Gerais, Brazil.**

preparation). John Medici was selling the results of a very productive mining venture at the aforesaid Herkimer, New York, locality which yielded thousands of crystals including some extraordinary groups; Don Olson was selling some of this lot as well. Wayne Thompson in the Community Center wholesale section had the cream of the New Mexico smoky quartz crop discovered by Bob Thompson (1723 E. Winter Drive, Phoenix, AZ 85020). Gary Nagin in the Travelodge had more quartz from his Santander, Colombia, claim. Scott Bowlden and John Rember (Box 503, Hailey, OH 83333) at the Sheraton poolside tent had a fine lot of lustrous, blocky smoky quartz from a recent find in Idaho. Howard Minerals at the Desert Inn (now under the late Howard's father, Mel Belsky) had a large batch of fine smoky quartz from Switzerland. Jack Lowell in the Desert Inn had some interesting amethyst molds after aragonite from Artigas, Uruguay. The list could go on . . . quartz was everywhere.

Bill Larson (*Pala Properties*) had the first sizeable lot of Ukrainian **heliodor** (yellow beryl) *thumbnails* to be seen, at his booth in the Community Center. Some of these are very fine and would fit well in the best thumbnail collections, even though the color appears a bit pale in such small crystals. *The Rocksmiths* also had some excellent specimens.

Several dealers including *Weber's Minerals* at the Community Center and *Brera Minerales* (San Romualdo, 26, Madrid 28037, Spain) at the Desert Inn carried bright yellow-green pyromorphite groups from the San Andres mine, Villaviciosa de Cordoba, Spain. Most of the specimens are thumbnail to miniature size with crystals to 4 or 5 mm in matrix-free groups.

Some nice Afghanistan **lazurite** crystals were brought back recently by Dudley Blauet (*Mountain Minerals International*), including several groups containing individual crystals to 3 cm. The crystals appear to have grown along veins or fractures in the lapis lazuli rock; only a single specimen per ton, on the average, contains such crystals, and Dudley has trained the miners to save these for him. The precise locality is the Kokcha River, Farmggu, Badakshan Province. Slabs to 12 or 14 cm across have been recovered, along with good thumbnails and miniatures.

Ems Gems (Tucson, AZ), who were set up in the Community Center Arena, had some large and attractive morganite (pink beryl) crystals to 10 cm, with quartz and feldspar matrix to about 40 cm across, from Afghanistan, and other fine morganite crystals to 8 cm from the White Queen mine, Pala, California.

Mineral Kingdom, in their booth at the Community Center, had a recently collected pocket of tennantite crystals from Tsumeb, Namibia. The crystals are rather large, roughly 2 to 7 cm on edge, dull gray in color, and judging by the cracking and shrinkage appear to have been heavily corroded by natural solutions. The pocket consisted of eight or ten significant pieces.

Readers will recall that this editor sees nothing wrong in the occasional slabbed and polished mineral specimen (e.g. variscite or liddicoatite) in a mineral collector's cabinet. With appropriate specimens, polishing best shows off their most important or interesting features. Similarly, the occasional faceted collector stone can also lend variety and beauty to a display, especially in the "rough and cut" type of collection. This year a new choice was available: polished fluorite octahedrons, cuboctahedrons, cubes, marbles, plates and other odd shapes. Cleavage octahedrons have for years been a mainstay of rock shops across the country, but only recently have people been polishing these, primarily for sale to the crystal-healing market. (Practitioners insist that a polished fluorite octahedron pressed to the forehead can relieve headaches.) Headache or not, these little polished fluorites are infectiously attractive. The limpid interiors, often with complex and colorful zoning, are exhibited beautifully and will tempt the eye of almost any mineral collector. Joe Kielbaso (*Gemini Minerals*, P.O. Box 52, Tipp City, OH 45371) sold thousands of these through his room at the Desert Inn, and donated a fine yellow octahedron-dodecahedron combination to the Mineralogical Record Auction. He is investigating the possibility of preparing mathematically accurate crystal models, cut from fluorite using a faceting machine to assure correct interfacial angles.

While on the subject of fabricated items, I should mention that lovers of the art of stained glass have a friend in Pat Carlon (*Maple Hill Studio*, 1110 E. Emerson, Bloomington, IL 61701), who has been making large stained glass windows depicting actual mineral specimens. To see a Colorado amazonite and smoky quartz specimen rendered in stained glass well over a meter on edge would be a thrill anywhere, but especially in the den or exhibit room of a mineral collector. Pat has some windows in stock and also does custom work.

Exhibits

Exhibits at the Convention Center are among the prime attractions at this great show, which none of the satellite shows even attempt to match. Most of the major mineral museums in the United States participate, and because beryl was the featured species this year the institutional showcases abounded with emeralds, aquamarines, heliodors, morganites, and everything in between (especially the Smithsonian case).

The exhibit shown by the delegation from the People's Republic of China contained some fascinating items including a 7.5-cm vesuvianite (Hebei Province), fine aquamarine crystals to 15 cm, cinnabars (from Guizhou Province), topaz crystals (Yanan) and extremely fine stibnite crystals from Hunan Province that are comparable in quality to the smaller of the Japanese crystals.

Curator Werner Quellmalz of State Museum of Mineralogy and Geology in Dresden, East Germany, brought a beautiful selection of classic minerals (pyrargyrite, argentite, silver, purple fluorapatite, etc.) from localities in the Saxon Erzgebirge such as Freiberg, Zinnwald, Schneeberg, Ehrenfriedersdorf and Johanngeorgenstadt. It was a rare

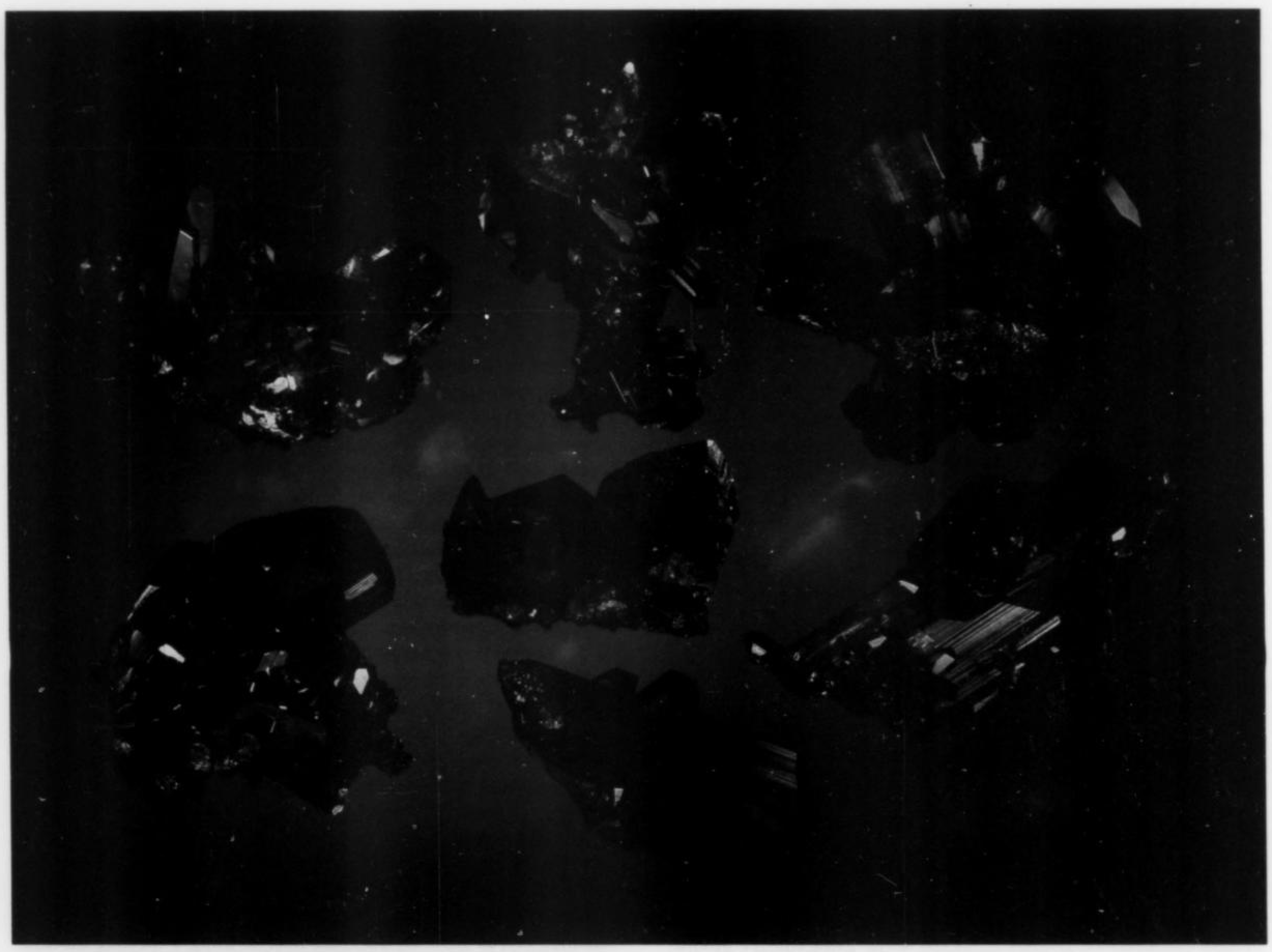

Figure 4. **Some of the new anglesites from the Touissit mine, Morocco, which were stolen from Victor Yount during the Tucson Show. Upper right specimen measures 7 cm. Photo by Harold and Erica Van Pelt.**

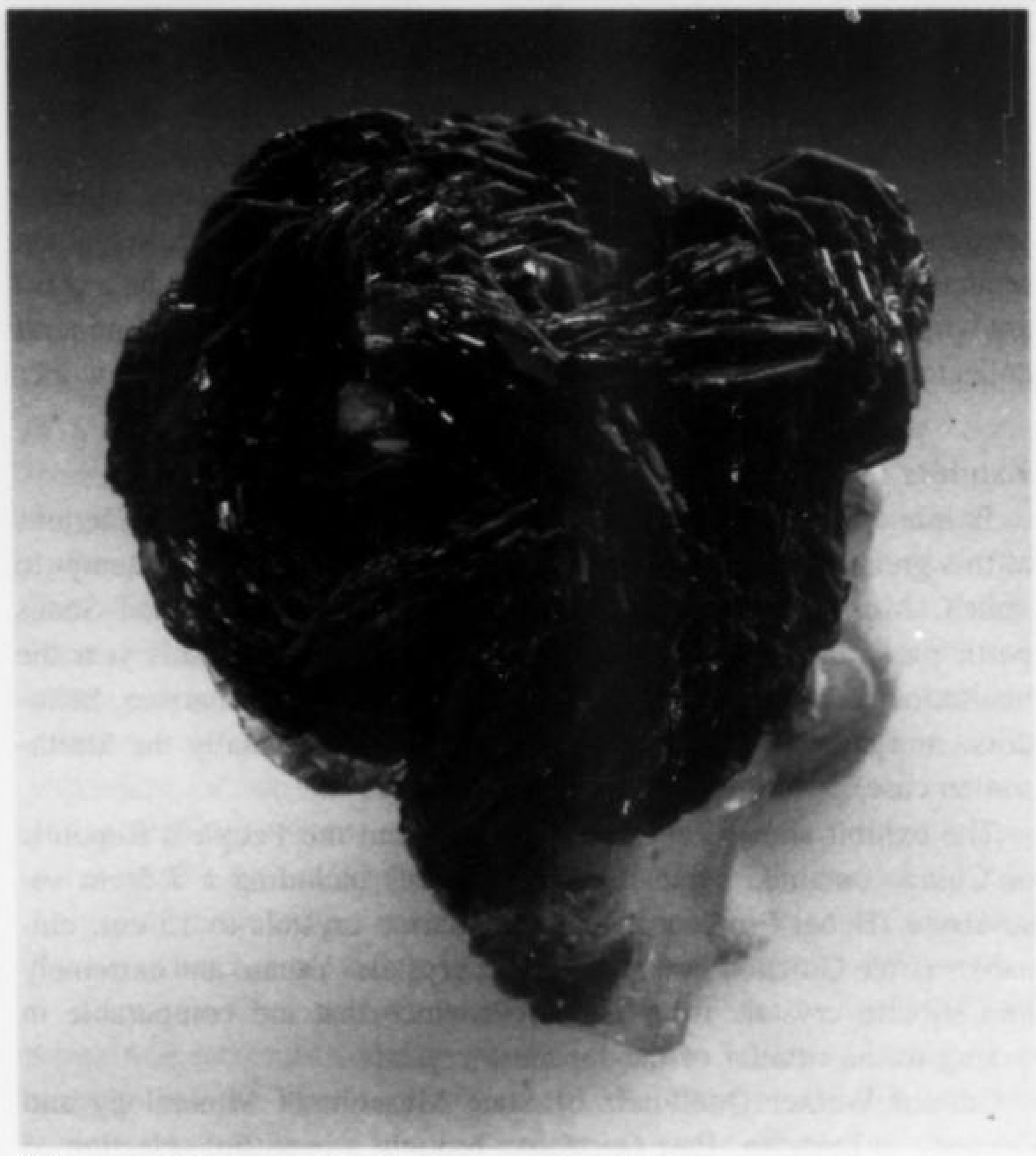

Figure 5. **Nadorite rosette, 2.7 cm across, on anglesite from Puit IX, Touissit, Morocco. Victor Yount specimen.**

Figure 6. **Cubanite crystal, 1.6 cm, on calcite matrix from Chibougamau, Quebec. Bernard Bordaus specimen.**

Figure 7. **Green quartz group 5 cm across from Naica, Chihuahua, Mexico. Carolyn Manchester collection, from Ken Roberts.**

Figure 8. **Silver druse on quartz crystal group 8 cm across, from Taxco, Mexico.** ***Ikon Mining & Exploration*** **specimen.**

Figure 9. **Rhodochrosite composite crystals to 7.6 cm, from Santa Eulalia, Chihuahua, Mexico.** ***Collector's Choice*** **specimens.**

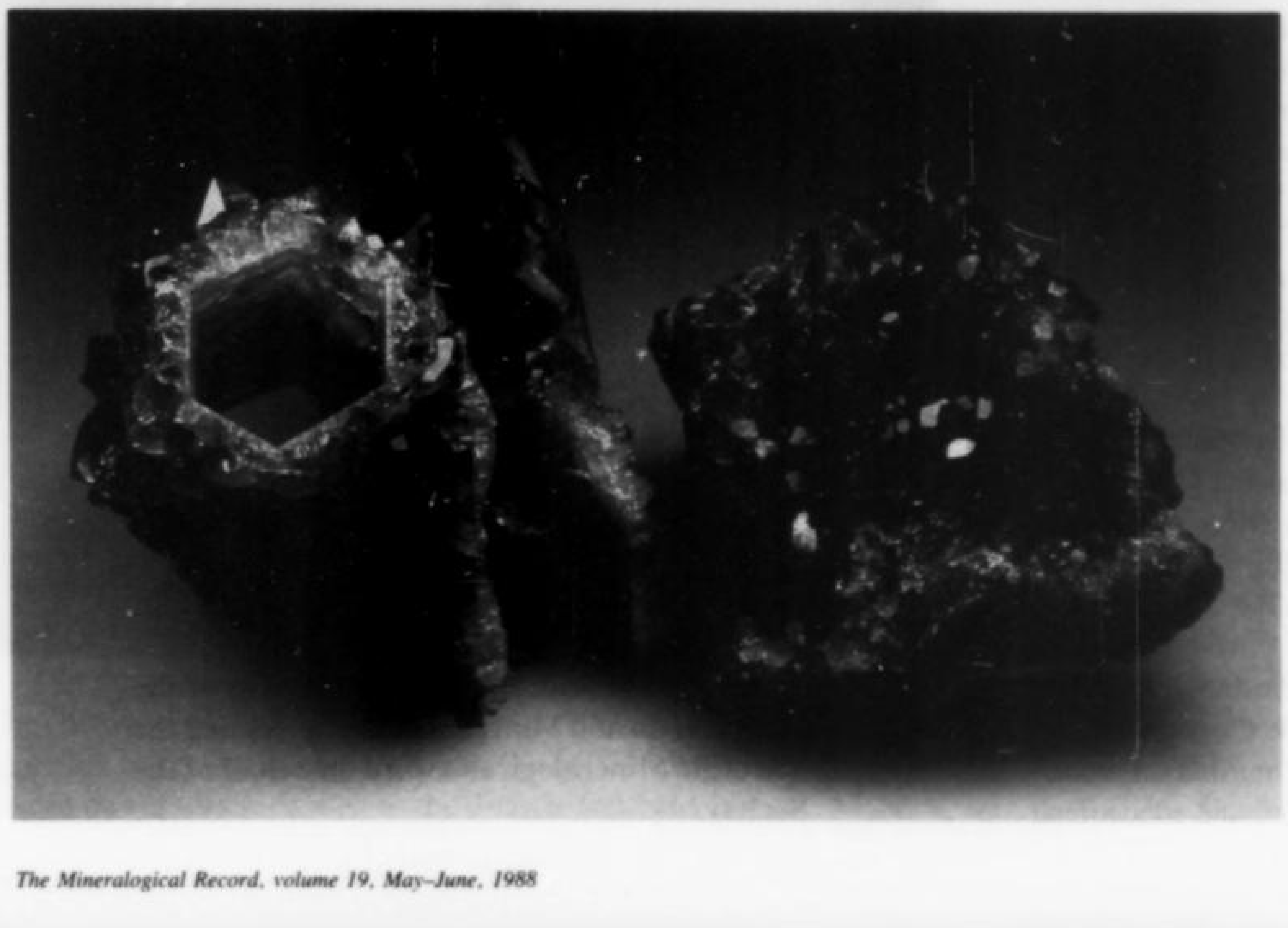

Figure 10. **Amethyst molds after a hexagonal prismatic mineral, probably aragonite, from Artigas, Uruguay. Jack Lowell specimens; the left mold measures 5 cm across.**

privilege to see these remarkable specimens, and quite a coincidence since his museum was featured in the January-February issue along with a photo of Dr. Quellmalz himself.

Levon Nercessian had a single glass case containing but a single specimen, one of the giant red elbaites on albite matrix from the Jonas mine, Itatiaia, Minas Gerais, Brazil. This one has not been seen before in the U.S., as far as I know. The crystal measures about 16 or 18 cm across the termination, and is in splendid undamaged condition.

One of my personal favorites, and one which drew a lot of chuckles and groans and longing looks, was the case entitled "A good day at the Red Cloud," by Arizona collectors George Godas, Dick Morris and Mark Hay. It was a sort of simulation, with genuine Red Cloud mine rubble thickly covering the bottom of the case, mining tools lain about, a well-used dust-mask tossed in a corner, and two beer flats packed open-face with two or three dozen superb Red Cloud mine wulfenites, looking as if they had just been removed from a pocket moments before.

An exhibit I was particularly pleased to see contained some fine Bisbee copper minerals shown by Phelps Dodge Corporation, the mining company that operates the mines at Bisbee. Too many mining companies are totally oblivious or even hostile to the aesthetic, scientific and cultural value of the mineral specimens their properties produce; not Phelps Dodge! Through enlightened and intelligent management, Phelps Dodge has regularly endeavored to preserve specimens, to be hospitable to visiting mineral clubs, to open the famous Copper Queen mine to public tours, to support the Bisbee historical museum, and to maintain staff mineralogists to study the unique mineralogy of their deposit. Rare indeed is the mining company that contributes to the public good on so many levels.

There were many other cases worthy of mention, only a few of which can be listed here: Tom Rosemeyer's case of minerals from the Camp Bird mine in Colorado, the selenides and tellurides exhibit shown jointly by William Pinch and the National Museum of Canada, Herb Obodda's case of Pribram (Czechoslovakia) memorabilia and minerals, Harvard's incredible gold specimens from the Burrage collection, Bill Larson's huge and spectacular beryl collection, Steve and Clara Smale's fine collection including a St. Andreasberg pyrargyrite illustrated in Sowerby's *Exotic Mineralogy* (1811, plate 33), the Kile-Muntyan-Piekenbrock case of Colorado fluorites, and many more.

Winners

The Lidstrom trophy for best single specimen entered in competition went to Evan Jones for his cabinet-size Kongsberg wire silver. The McDole award for best minerals in the show was won by Jim Bleess for his absolutely superb case of thumbnails and "toenails" (specimens just a little too large to be thumbnails). This particular size seems to offer a unique potential for highly refined and elegant aesthetics which larger and smaller sizes lack. Jim's collection truly stands out from all the other thumbnail collections I've seen. Perhaps we'll feature a selection of his specimens in the pages of a future issue.

Each year the Friends of Mineralogy presents an award for the most outstanding article to appear in the *Mineralogical Record*. There are no exact guidelines for the selection, and it is up to each judge to decide what is "outstanding." Nevertheless, the article should contain a significant amount of original work or observation by the author(s). This year, for the first time, the selection made by the five judges was unanimous: "Minerals of the Carrara Marble," by Marco Franzini, Paolo Orlandi, Giovanni Bracci and Domenico Dalena. Coming in a solid second with nearly all the judges was Bill Birch's "Gold in Australia" from the recent Gold Issue. The winning authors receive a certificate, and FM makes a $200 donation to the *Mineralogical Record* in their name.

The Carnegie Museum of Natural History in Pittsburgh this year established a new annual award in mineralogy: The Carnegie Mineralogical Award. The purpose is to recognize major contributions which promote and improve the preservation, conservation, and educational

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***Figure 11*. Dr. Carl Francis, curator of the Harvard Mineralogical Museum, installing an exhibit of gold specimens.**

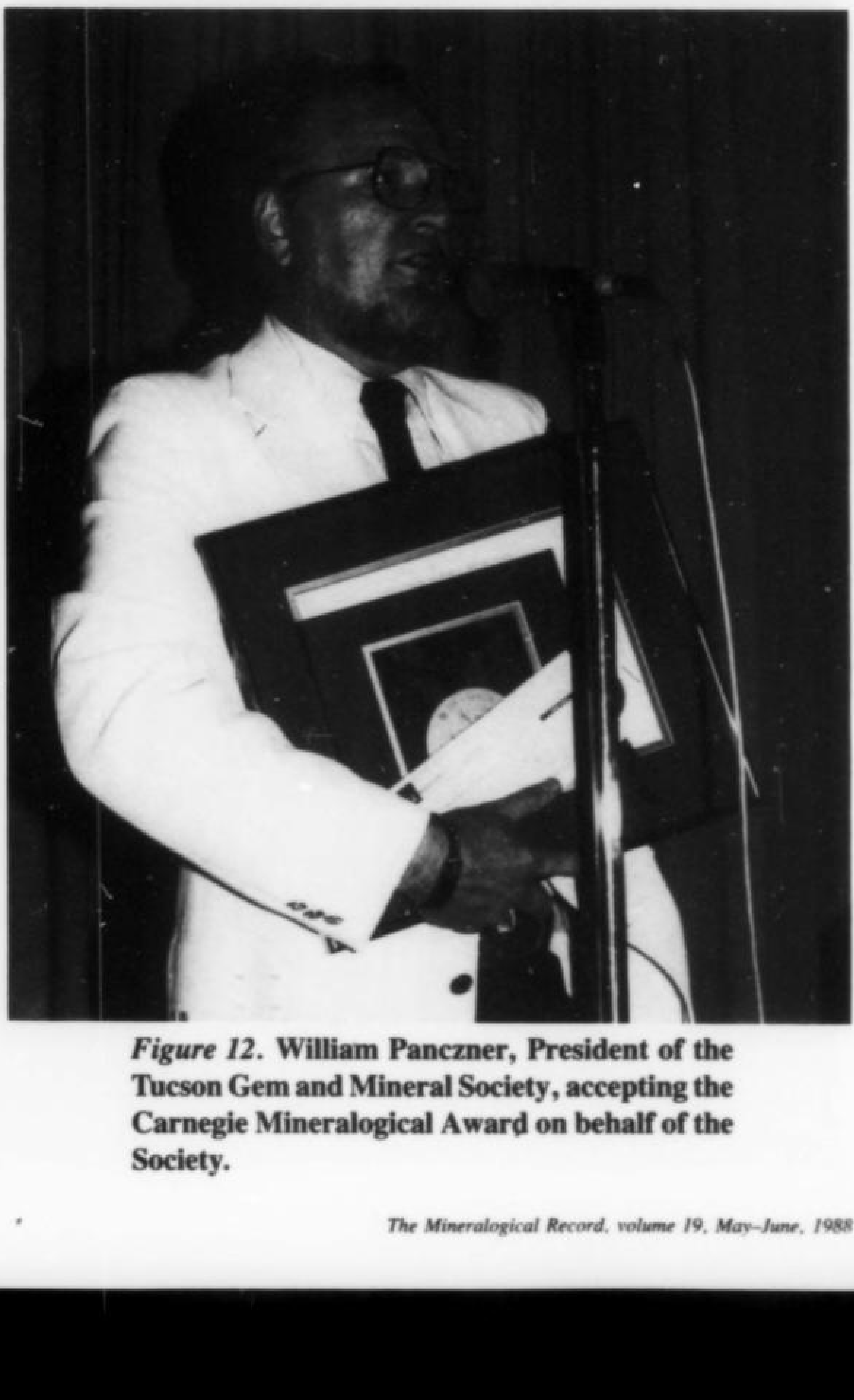

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***Figure 12*. William Panczner, President of the Tucson Gem and Mineral Society, accepting the Carnegie Mineralogical Award on behalf of the Society.**

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Figure 13. **Evan Jones, winner of the Lidstrom Award.**

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Figure 14. **Jim and Von Ceil Bleess, winners of the McDole Trophy.**

use of minerals and mineral collecting. The award consists of a cast bronze medallion, a certificate of recognition, and a $1500 cash prize underwritten by the Hillman Foundation. Eligible recipients will include collectors, curators, mineralogical societies, museums and universities, and others as well. Administration of the award will be the responsibility of the Mineral Museums Advisory Council.

The Carnegie Mineralogical Award will be presented each year at the Tucson Gem and Mineral Show, as part of the Saturday night program hosted by the *Mineralogical Record*. This year the first Carnegie award was presented to the Tucson Gem and Mineral Society.

Nominations for the 1988 award may be sent to the MMAC, c/o Ron Bentley, 6 Claremont Street, Enfield, CT 06082.

DISCOVERIES IN COLORADO AND IDAHO

[The following report was provided by Barbara L. Muntyan.]

Fine specimen minerals just seem to keep coming from Colorado. As reported in this column earlier, 1987 saw an important find of scheelite from the Camp Bird mine, gahnite from near Canon City, fluorite crystals from the Ransom mine near Eureka, and a considerable quantity of amethyst groups from the Red Feather Lakes locality. Now two of the state's well-known field collectors, Daniel and Dianne Kile of Aurora, have made an important find of clear barite from the southeast quadrant of Colorado, as well as a major pocket of amazonite and smoky quartz from the Crystal Peak area.

Concretions containing calcite and barite are found in the Upper Cretaceous shales in El Paso, Otero, and Las Animas counties on Colorado's eastern plains. The material somewhat resembles the better-known clear barite specimens from the Book Cliffs near Grand Junction at the western end of the state. However, the barite from eastern Colorado can be much more transparent, unflawed, and attractively emplaced on coffee-brown calcite rhombs. An exceptional and absolutely flawless barite crystal measuring 6 cm was collected early in 1987 from this locale by the Kiles. The specimen won both Best-in-Show and Best Field-Collected Specimen at the Denver Gem and Mineral Show in September.

Other specimen material from this area includes attractive white calcite in an extremely flattened rhombohedral form (looking like little round discs), up to about 5 cm in size, found on earlier-generation brown calcite. Several different habits of distorted and elongated pale tan to medium brown calcite can also be found at this locality. Barite is rare, compared to calcite from this area, especially as well terminated crystals. Those that are found are generally stubby, but some are elongated and clear with complex terminations. The color ranges from absolutely colorless to palest blue to faint lavender. The largest barite crystal I have seen from this locality measures approximately 9 cm in length and has a large "ball" of cream-colored intergrown calcite rhombs next to it. The specimen which was honored at the Denver Show is certainly the best ever found from this area and may be the finest barite from anywhere in Colorado.

These same field collectors also made an exceptional find of amazonite and smoky quartz in the Crystal Peak area in mid-October (as if one major find per year wasn't enough!). The overall measurement of the irregular pocket was 1 x 1.5 x 1.5 meters. The pocket yielded about 20 flats of specimen material. The color of the amazonite is a pleasing robin's-egg blue; the smoky quartz is gemmy and very dark in color. Three major pieces measuring up to 25 cm were found, one an exceptional Manebach twin of amazonite with a large smoky quartz crystal growing straight up the back of the twin. In addition, there were another eight or ten hand specimens composed of amazonite clusters associated with albite or smoky quartz. One large lavender-colored fluorite crystal approximately 9 cm on edge and perched on amazonite was also recovered from this pocket. A considerable number of large, doubly terminated smoky quartz crystals were also removed, some measuring 15 cm in length.

What makes this particular find of note is the unusually large size and quality of the individual amazonite crystals. Typically, amazonite from Crystal Peak forms crystals less than 5 cm in size. The largest crystals from this pocket are better than 12 cm on edge. A small selection of the finer pieces from this pocket was on display in the 1988 Tucson Gem and Mineral Show.

Three Colorado field collectors made a significant find of topaz in Boise County, Idaho, in August of last year. Larry, Carmen and Tom Piekenbrock of Louisville walked many miles into the Sawtooth Mountains wilderness area and uncovered a large pocket containing topaz, microcline, zinnwaldite and smoky quartz.

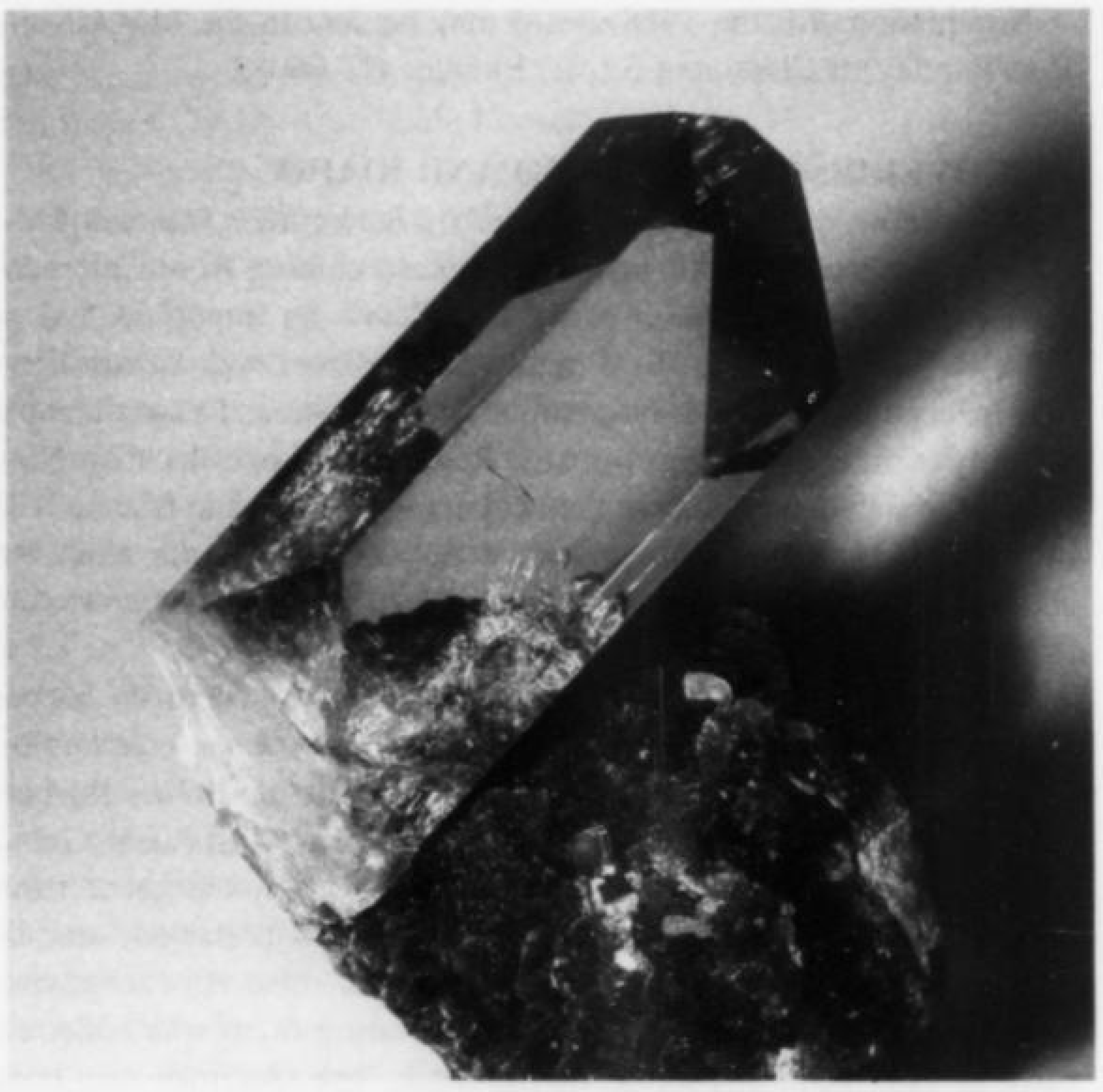


Figure 15. **Very pale purple barite crystal, 6 cm, from eastern Colorado. Dan Kile collection; photo by Barbara Muntyan.**

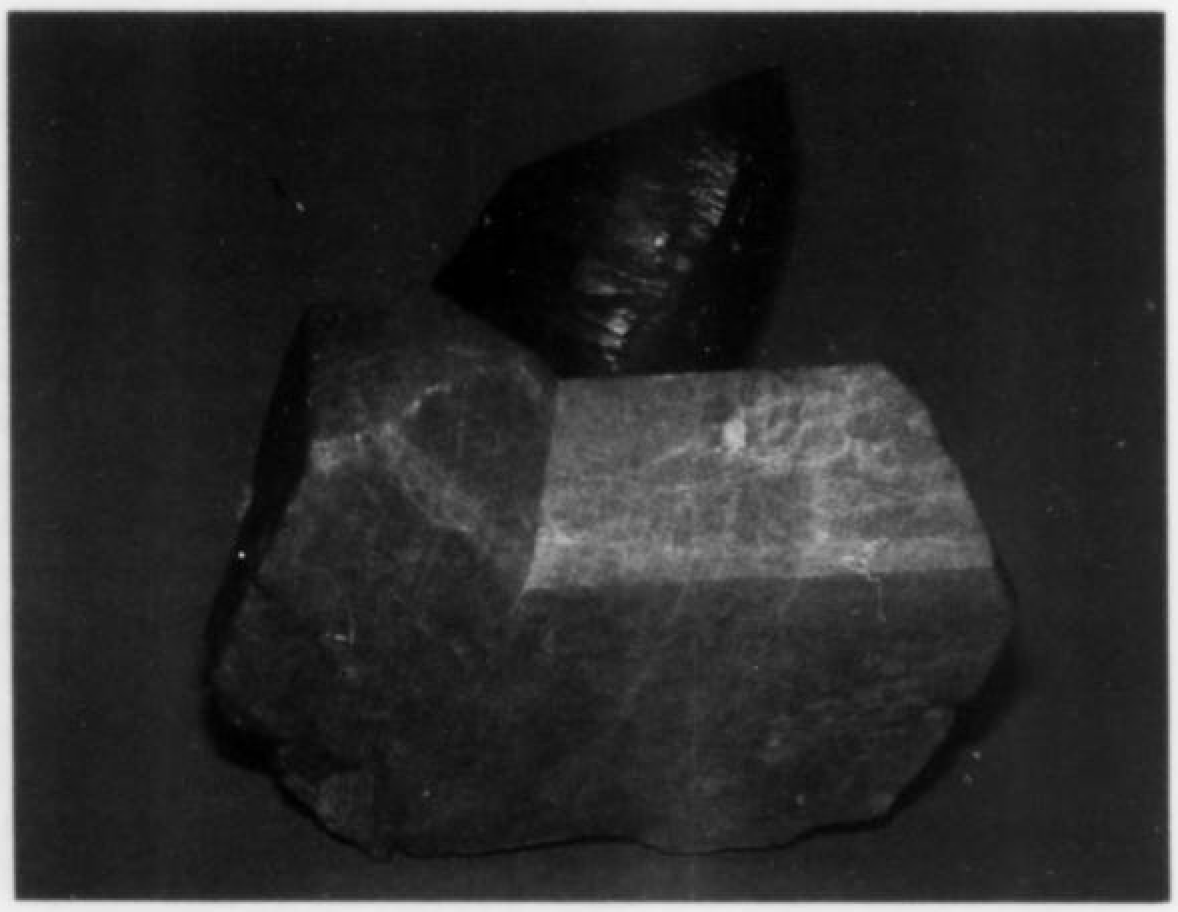


Figure 16. **Smoky quartz and amazonite groups, the large twin measuring 25 cm, from Crystal Peak, Colorado. Dan Kile collection, Barbara Muntyan photo.**

The pocket was lenticular in shape, measuring approximately 50 x 100 cm and dipped steeply at approximately a 70° angle to the south. The occurrence is a barren outcrop of gray granite in open pine forest; topaz float led to the pocket.

One hundred and ten topaz crystals were removed, many on matrix, as well as 135 smoky quartz crystals. The topaz is a pleasing sherry color, with a satin surface to the crystals, especially along the prism faces. The smokies are very dark and many are doubly terminated. Approximately one dozen large matrix pieces were recovered, consisting of groups of white microcline and smoky quartz crystals, and topaz perched on the smokies.

The find was nicknamed the "Bubblegum Pocket" because it had an unusual bright pink clay filling. According to Larry Piekenbrock, the worst thing about finding this exceptional pocket was that it was discovered on the way into the wilderness area, and the specimens recovered had to be carried around for the rest of the trip!

Some of the better pieces from this find were also on display at the Tucson Show.

Special Exhibit

Minerals from East Germany

Readers have written suggesting that we show some of the fine specimens that were on exhibit at the Tucson Show. This year for the first time, the State Museum for Mineralogy and Geology in Dresden, G.D.R., sent an exhibit of East German minerals in the care of curator Werner Quellmalz. Immediately following the show, Dr. Quellmalz travelled to Los Angeles where Harold and Erica Van Pelt were kind enough to photograph several of the specimens from the exhibit so that we could show them here. As Peter Bancroft demonstrated in the January-February issue, there are a great many superb specimens in Eastern European museums, and only a rare opportunity allows us in the West to see some of them. Our thanks to Dr. Quellmalz, the administrators of the Dresden Museum, and the East German government for allowing us this glimpse of some of their treasures.

Figure 17. **Pyrargyrite crystal group, about 9 cm across, from Johanngeorgenstadt, East Germany. Collection of the SMMG, Dresden. Photo by Harold and Eriça Van Pelt.**

Figure 18. **Purple fluorapatite group with crystals to 1.4 cm, from Ehrenfriedersdorf, East Germany. Collection of the State Museum of Mineralogy and Geology, Dresden (SMMG); photo by Harold and Erica Van Pelt.**

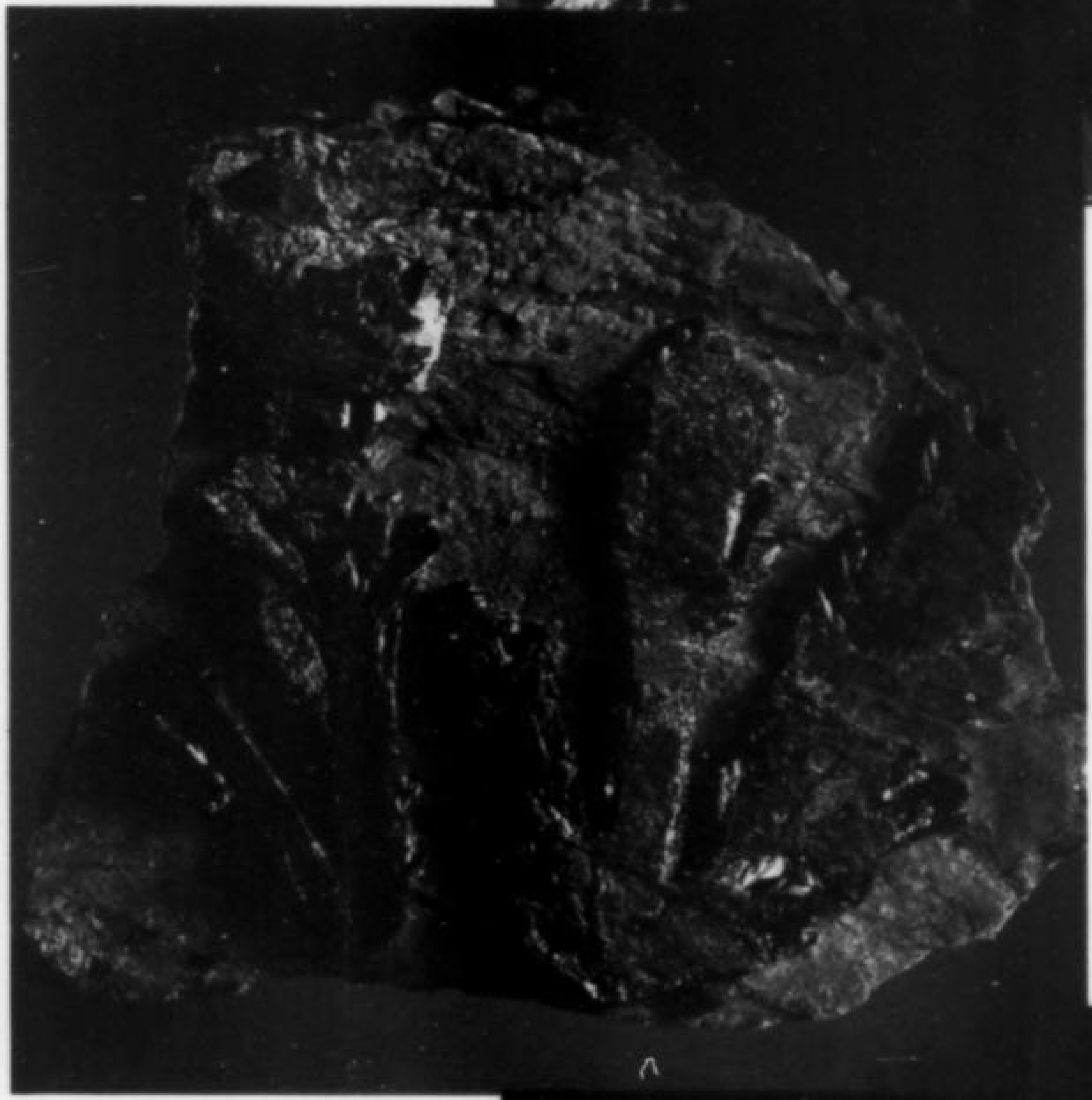
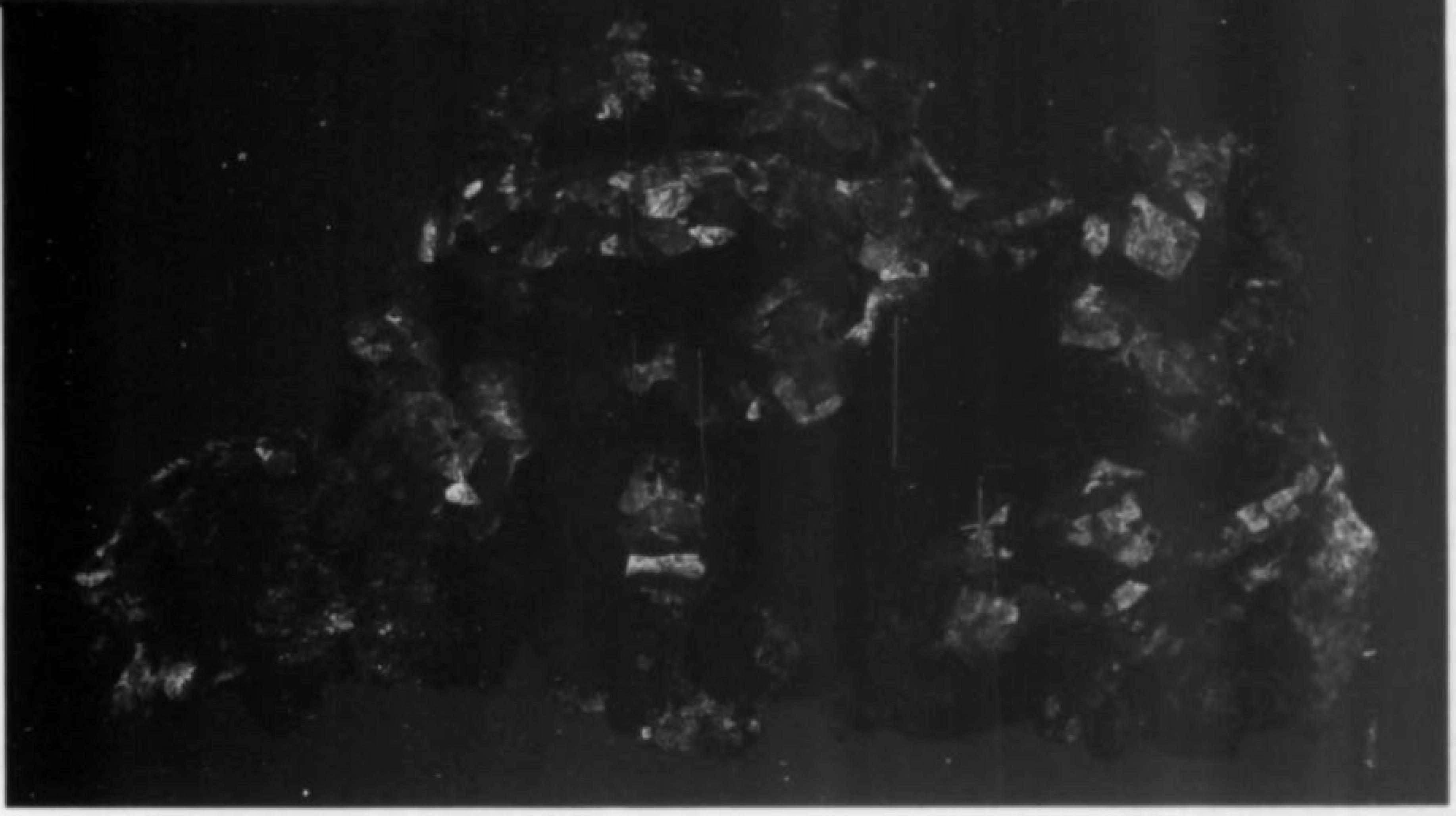


Figure 19. **Pyrargyrite crystal group, about 13 cm across, from Kleinvoigtsberg, East Germany. Collection of the SMMG, Dresden. Photo by Harold and Erica Van Pelt.**

Figure 20. **Argentite from Freiberg, East Germany, about 18 cm across. Collection of the SMMG, Dresden; photo by Harold and Erica Van Pelt.**



For more information on East German mining districts see Lieber and Leyerzapf (1986) "German silver; an historical perspective on silver mining in Germany." *Mineralogical Record*, **17**, 3–18.

THANKS

Once again we want to thank all of the volunteers who helped us at mineral shows this year, and the sponsoring organizations which kindly provided us with booth space.

Our annual fund-raising auction was very successful, thanks to our volunteer staff of 74 people (considerably larger than the staff which puts on many mineral shows), and of course the many generous donors who graciously gave us the materials to sell. Auction Manager Wendell Wilson Sr. kept everything well organized and running smoothly, with the help of team captains Bill Basbagill (silent auction), Sandy Ludlum (processing), Tom Gressman (collecting), Don Olson (Saturday night auction), and Gary Hansen (auctioneer).

In particular we would like to thank TGMS Show Chairman Terry Wallace and the rest of the Tucson Gem and Mineral Society for their continued cooperation over the years; we are proud to be associated with this most prestigious of all mineral shows.

M.R.

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Mineralogical Record
Show Schedule

Dates subject to change and error. Confirm before travelling.

June 9-11	Elko Mining Expo, NV
July 14-17	(MWFMS) Macomb, IL
July 30-31	Elko Quarry, NV
Aug. 11-14	Shreveport, LA
Aug. 12-14	Springfield, MA
Aug. 26-28	(CFMS) Costa Mesa, CA
Sept. 16-18	Denver, CO
Sept. 24-25	The Hague, Neth.
Sept.	Houston, TX
Oct. 9	Brend, Neth.
Oct.	Franklin, NJ
Oct. 7-9	Torino, Italy
Oct. 8-9	Pasadena, CA
Oct. 14-16	Detroit, MI
Oct. 14-16	Munich
Oct. 31-	GSA – Denver
Nov. 3	TBA
Nov. 5	Zwijndrecht, Neth.
Dec. 4	Amsterdam, Neth.
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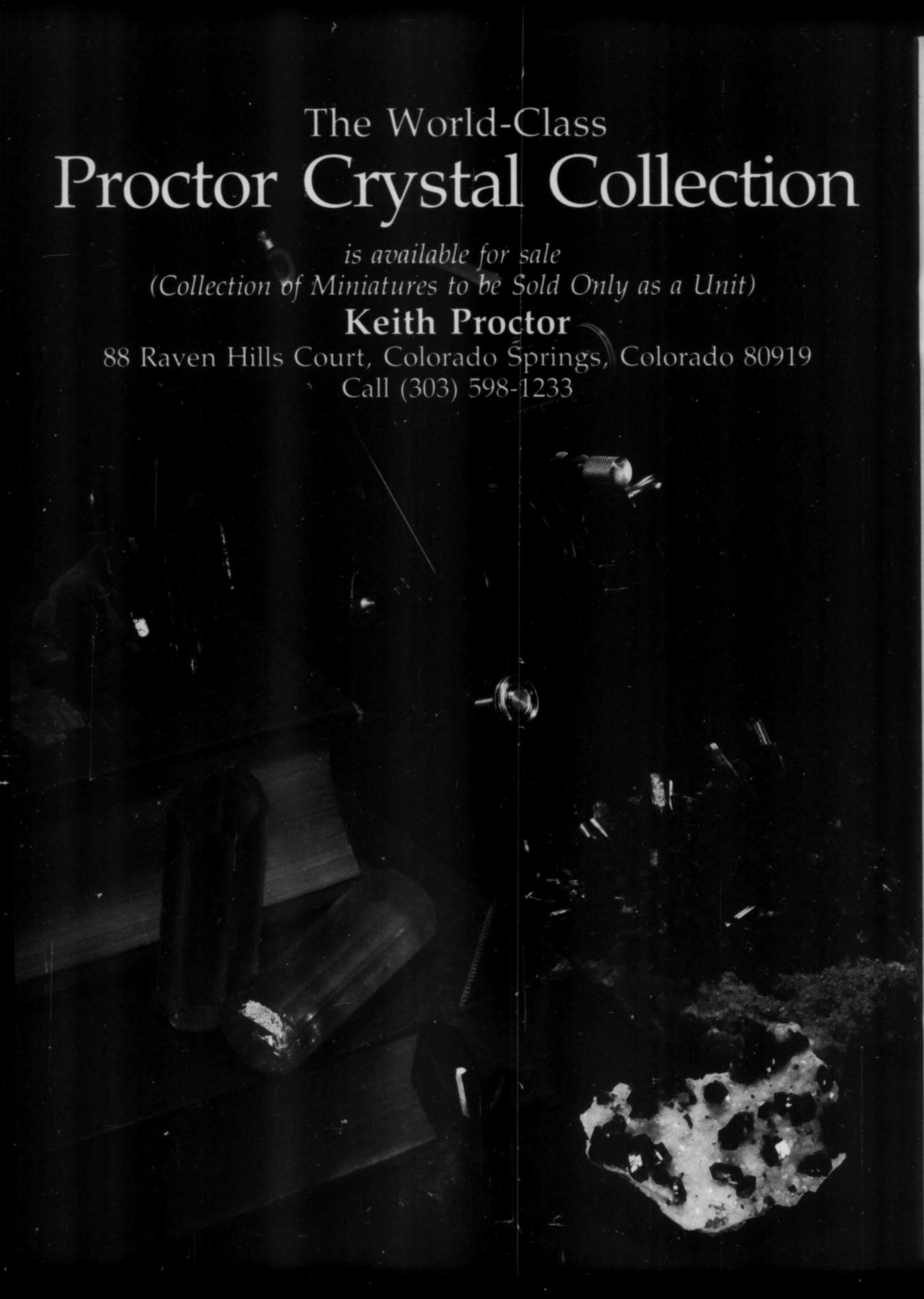

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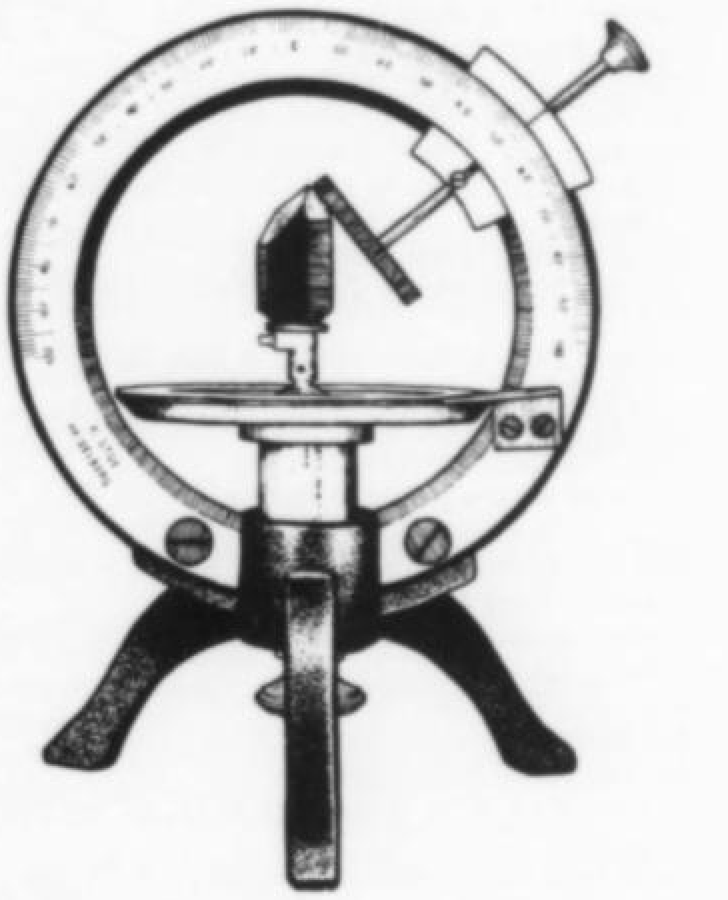

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