# PEGMATITE
## ISSUE #1

The Mineralogical Record

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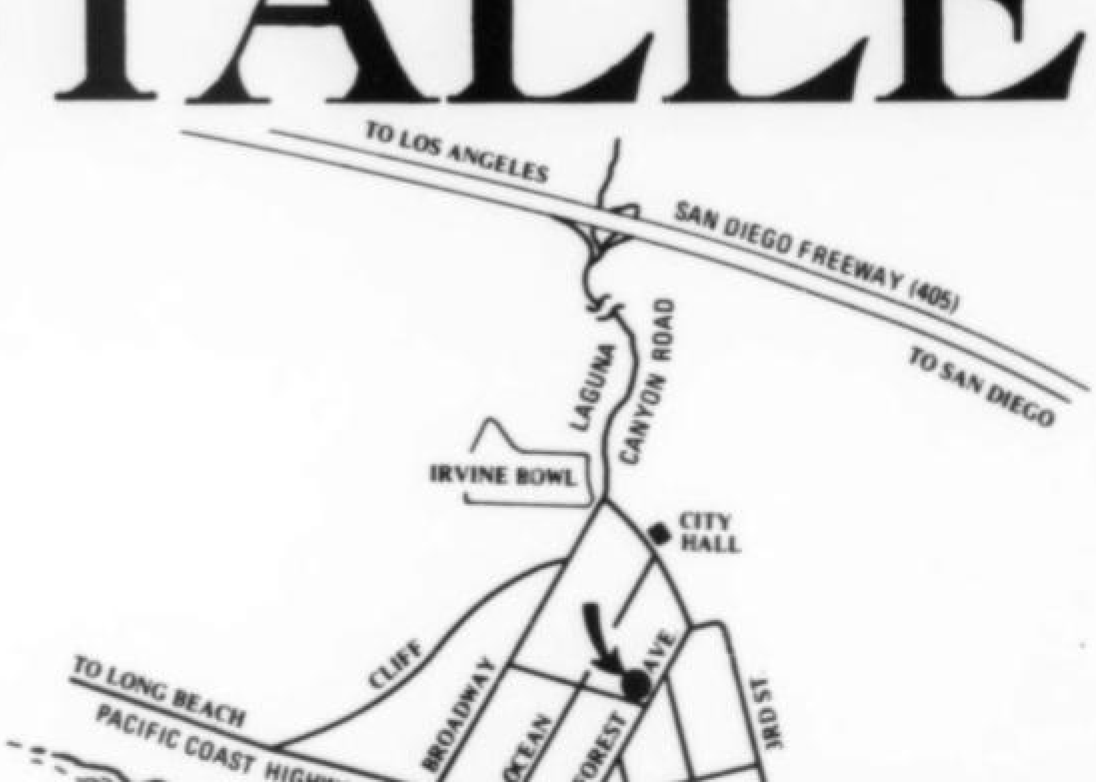
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CITY HALL
TO LONG BEACH
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the Mineralogical Record

Volume Eight/Number Two
MARCH – APRIL 1977

# PEGMATITE ISSUE #1

## feature articles

## departments

COVER: THE ROEBLING APATITE (actually fluorapatite), from the Pulsifer quarry near Auburn, Maine; 3 x 3.8 x 4.3 cm, on display in the Gem Hall of the Smithsonian Institution. Photo by Wendell E. Wilson.

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# GUEST EDITORIAL

by Marie Huizing*

[*Ed. note:* *The Cincinnati Mineral Society is one of the country's most enthusiastic and active groups devoted primarily to mineralogy rather than lapidary. Marie Huizing edits and writes in their newsletter,* ***the Quarry****. Some club newsletters are, frankly, boring but* ***the Quarry*** *is alive and interesting, much to the credit of its editor. The following essay appeared in the November, 1976, issue of* ***the Quarry****, and I asked to reprint it for* ***Record*** *readers. Hopefully it will be an inspiration to* ***get involved****! Some may lament that their local area does not offer all of the opportunities generated by the Cincinnati Mineral Society. In that case this editorial may serve as a guide to the kind of activities you or your local organization could work to create. Plenty active yourself now? Then pass this editorial on to a younger or newer collector. Perhaps a fledgling Dana is in your midst, in need only of a little inspiration and guidance!*

## I AM CURIOUS (and) GREEN

“Every mineral club has its giants, those seasoned individuals who appear all-knowing about all aspects of mineralogy, those persons who, were it told, probably came into this world clutching a hammer in one hand and a chisel in the other. To the neophyte just peeking in at the door, such a thorough acquaintance with a subject can seem awesome, even intimidating.

More often than not the newcomer has no formal training in mineralogy or geology, and probably no background in physics or chemistry either. Of one thing he is sure, though...here is a subject he wants to know more about. But where to begin, where to get that first toe-hold? Working within the framework of the Cincinnati Mineral Society you, as a novice, could:

- Read one hobby-related book a year, beginning with *The Golden Book of Rocks and Minerals* if that's where you're at.
- Subscribe to one periodical that suits your needs and read it faithfully.
- Take an adult evening course in geology.
- Visit one show per year in addition to the local show; while you're there, attend one talk, study two cases in depth, learn the names of three new minerals, browse through the swapping area, and study dealer material for mineral names, locales and prices.
- Volunteer to clerk at a show and eavesdrop on judges' evaluations of specimens.
- Make a point to see the University of Cincinnati collection and the collection at the Cincinnati Natural History Museum. Learn the names of a couple of new minerals while you're there.
- Go on one field trip per year and when you get home look up information on the minerals you found.
- Display at our show. Go non-competitive if you'd just as soon not hear what the judges have to say about your material.
- Give a talk to a scout group or elementary school class on collecting. It gives you a reason to gather information, and a deadline for having it together. (How technical would you have to be for children?)
- Attend as many CMS meetings as you can and really listen to what the speakers have to say. Take notes, jot down words to look up. Preferably, do some background reading before coming in. If you don't have mineral reference books, visit a library or turn to your encyclopedia.
- *Listen* as old-timers reminisce about the old collecting days, as active collectors discuss current sites, as judges rehash why cases were scored like they were, and as collectors talk "shop" about which collections are really worth seeing, which books are worth reading, etc.
- Write a *Mineral of the Month* article for *the Quarry* and really get to know a mineral.
- Put together a display for your suburban library to help publicize our annual show.
- Help the Specimens for Children Chairman sort, bag and label donated minerals to be given out free at the show.
- Visit local shops and study their wares.
- Keep a mental (or written) list of collections you'd like to see, minerals you'd like to buy, shops you'd like to visit, places you'd like to collect — all "someday" things you'd eventually like to do. Never cross off something on the list without replacing it with a new goal. (If you've been to the Detroit Show, replace it with a Regional Federation or National Show; after seeing those, shoot for the Tucson Show. After that, go all the way and set your sights on the Zürich Show.)
- Read dealer ads in magazines and where it says "write for free list," write. Then study the list with an eye to what specimens are currently available, their sizes, colors, associations, locales and prices.
- Take the *Lapiday Journal* Buyer's Guide or the *Midwest Federation Directory* on vacations with you. Look up meetings, swaps, shows, shops and collectors to visit as you travel.
- Pick up exchange bulletins from the literature table and skim them for items of interest...field trip notices, good articles, book reviews, synopses of speakers' talks, etc.
- Note each month's *Mineral of the Month* in *the Quarry*, read up on that mineral, then carefully examine the specimens set out at the monthly meeting.
- Go to one swap. (If you're choosing just one, recommended is the Bedford, Indiana, swap.) Take a few specimens to barter as an ice breaker.
- Spend evenings at the library thumbing through books on minerals, just getting a feel for your new field of interest.
- Go to club business meetings if only to see the host's collection.
- Write to State Geological Surveys for their lists of free and inexpensive literature. Send for what appeals to you most and read it.
- Go to the Saturday movies at the Natural History Museum when the subject has to do with some aspect of geology.
- Volunteer to help someone catalog their collection. (Who could refuse such an offer?) There is nothing like a couple of hours of concentrated work with minerals on a regular basis, handling, cleaning, labeling and grouping them. You learn almost in spite of yourself.
- Get up early some Sunday and go on one of the City or County Park Board's geology hikes led by a park ranger.

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***5431 Thrasher Drive, Cincinnati, Ohio 45239**

- Choose a weekend workshop, seminar or symposium; fill your car with like-minded friends; you can split the expenses while doubling your fun and also probably doubling what you know. (These sessions take place all across the nation from Rochester, New York's Spring symposium to the Los Angeles Micromounter's Conference held the weekend before the Tucson Show.)
- Call up a CMS member who's been around awhile and ask to see his/her collection.
- Take the Mineral Identification Course offered by the Natural History Museum.
- Examine the classified ads in hobby magazines and follow up on the swap-by-mail offers that sound interesting.
- Come to our annual auction early enough to study the specimens at leisure; ask yourself why certain specimens command the bids they get.
- Try Dr. Grover's* Crystallography Series given just prior to our meetings starting in January. Afraid you won't understand everything? You can always go home and fill in the gaps with reading.
- Allow yourself plenty of time at our show's "See 'n' Touch Booth." Follow the instructional signs and learn about the physical properties of minerals—how they feel, heft, smell, taste and streak. Test them for hardness; peel some mica; cleave some calcite; test the magnetism of the lodestone and the double refraction of calcite.
- Bring your unknowns to the show's Mineral Identification Booth and have them identified by experts. Ask the expert what clues told him the mineral's identity. Watch and listen as the experts identify specimens for other collectors.
- If your ego can take it, try one of Dr. Grover's mineral identification quizzes after our meetings. Then use your corrected paper as an individualized study sheet showing where you need the most work.
- Offer to help a dealer at a show. You're not making a gracious gesture...he'll be doing *you* the favor! The booth provides a unique opportunity to meet new collectors and see what new mineral material has come out on the market.

And so it builds, bits of information gathered here and there, gained almost effortlessly, enjoyably, steadily, until after a period of time you're no longer on the outside looking in. You begin joining the conversations, you mention collections seen, books read, collecting sites visited. You go out of your way to juggle time and schedule for a special speaker or event. In short you find that a little learning has created an appetite for more, the kind of learning that isn't just rote memorization, but rather an enjoyable assimilation of facts and experiences.

Did you notice the first word of each suggestion? Go, attend, help, write, offer, choose, volunteer, visit, display, speak, work, sign up. What those words suggest is learning through involvement. You can be a "closet mineralogist" and learn a great deal by yourself, but you multiply your opportunities for learning by becoming an involved, participating, contributing mineralogist. ”

# NOTES FROM THE EDITOR

Here it is: our first Pegmatite Issue! Actually this accumulation is a happy accident; while going through our file of articles I realized we had enough pegmatite-related papers to fill an issue. One advantage of such a grouping is that after reading through the issue one obtains a more well-rounded understanding of pegmatites in general... the whole is more educational than the sum of its parts, in a way. In addition, such topical issues are an aid when attempting to recall which past issue contained a certain article. The article on the Harding pegmatite, for instance, may not cause **"Vol. 8, no. 2!"** to leap immediately into your mind in future years, but you will certainly recall that it was in the *pegmatite* issue.

Someone is sure to notice that the tourmaline mineral **uvite**, described here in detail for the first time, does not actually occur in pegmatites! This is true, but the tourmaline *family*, at least, is commonly represented in pegmatites and, in addition, the article is an important contribution; these facts were sufficient incentive for us to slip the paper, as well as the accompanying dravite paper, into the pegmatite issue anyway.

This issue also provided an appropriate place for the personality sketch of Gunnar Bjareby. Bjareby was one of the East Coast's premier collectors for several decades and "one of the most outstanding of 20th century amateur mineralogists." Much of his collecting centered on the New England pegmatites, several of which are mentioned in this issue.

Some readers may notice that this issue contains several articles of a higher technical level than seen in other recent issues. This is to be expected from time to time, and pegmatites seem to generate more than their share of finely detailed studies. Although we endeavor to keep the level of articles understandable to most collectors, we do feel that the publication of new mineral descriptions (e.g. **perloffite** in this issue) is of sufficient importance to justify the technical level. In particular we are soliciting descriptions of new minerals from Minas Gerais, Brazil, for a future *double-issue* on that incredible state. Articles on localities within Minas Gerais are also needed; although publication is more than a year away, authors should contact us regarding their intentions so that we may make appropriate preparations.

Who can forget the superb photography in the recent Colorado issue of *M. R.*? No one, certainly, but *we* forgot to indicate that, except where noted, the photos were all taken by Richard A. Kosnar, one of the authors. Our simultaneous congratulations and apologies, Rich.

To make certain that no one slides back from the edge of their chair, let me remind readers that the next issue is on Tsumeb! It may be a little late getting mailed, for reasons that will be obvious when you finally see it.

W.E.W.

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*John E. Grover, Professor of Mineralogy at the University of Cincinnati.

# FAMOUS MINERAL LOCALITIES:
# THE PULSIFER QUARRY

by Wendell E. Wilson
P.O. Box 783
Bowie, Maryland 20715

## INTRODUCTION

The photos on the cover and in this article are enough to demonstrate why purple apatite* from the Pulsifer quarry near Auburn, Maine, is *the* standard against which all other apatite specimens from anywhere in the world have been compared... and found wanting. Such stature is the mark of a true "classic" locality. The "Royal Purple" color (due to $Mn^{+2}$ according to Moore, 1973), the clarity and richness in forms have dazzled collectors for decades. The locality has only recently become extinct, after having produced for nearly 70 years. Other quarries on Mt. Apatite, where the Pulsifer quarry is located, have produced similar apatite but usually in lesser quantity and quality. This gives hope to collectors for the future; still, the past of the Pulsifer quarry, presented here, will always be remembered in connection with the world's most beautiful apatite.

## LOCATION

The Pulsifer quarry is located about 1 mile from Route 121, between Minot and Auburn, Maine, in Androscoggin County. The Pulsifer quarry, along with the Keith and Wade quarries, is on the west side of Hatch Road, which branches northward from Route 121 about 2.2 miles east of Minot.

## HISTORY

Gem tourmaline was first reported from Mt. Apatite in 1839 when the Maine State Geologist added three specimens to the state collection of minerals. In 1883 a pocket containing 1500 tourmaline crystals was discovered on the Hatch farm and, from that time on, Mt. Apatite was prospected and mined with enthusiasm.

In 1901 Pitt P. Pulsifer discovered a gem pocket in a pegmatite on his farm. Wolff and Palache (1902) commented that the find was "noteworthy for the unusually rich purple color of the [apatite] crystals"; Palache acquired most of the specimens for Harvard University. About 2000 crystals of purple apatite were recovered from this one pocket. The Pulsifer quarry leaped into the public eye in grand style.

During Pulsifer's early work, he discovered several pockets containing gem tourmaline valued at about $10,000 in terms of today's dollars. His method of mining was slow and deliberate: after each haying season he spent exactly $100 developing his quarry as a hobby and, although his first pocket turned out to be his biggest, he apparently made regular discoveries of new gem tourmaline and purple apatite (Stevens, 1972).

Around 1945, Stanley Perham and Hillard Nevin leased the area including the Pulsifer quarry and opened a large pocket containing tourmaline as well as apatite. A second pocket was discovered in an unfortunate way: the contents were blown out into the woods by a charge of dynamite and never found!

During the summer of 1963, the quarry was leased by Kenneth Grover of Danville Junction, Maine, although he worked only the dump.

During 1964 and 1965, the quarry was leased by Mr. and Mrs. Irving Groves, who also discovered a pocket of fine gem tourmaline and purple apatite.

In 1966 and 1967, the Pulsifer quarry was leased by Terry Szenics. He held the lease from May of 1966 to December of 1967. With the help of Frank Perham several extremely fine pockets were opened and over 100 specimens of fine purple apatite were recovered, as well as a large amount of tourmaline. During this time the productive zone of the pegmatite that remained was completely removed, and the locality may now be considered extinct.

Since 1972 the quarry, stripped of all its treasures, has again come into the hands of the Groves. Florian Couture, the owner, died in 1967; his wife and sons inherited the property. She later traded the property to the Groves, who own it today.

## THE ROEBLING APATITE

The finest apatite ever recovered from the Pulsifer quarry has fortunately been preserved. It measures 3 by 3.8 by 4.3 cm,

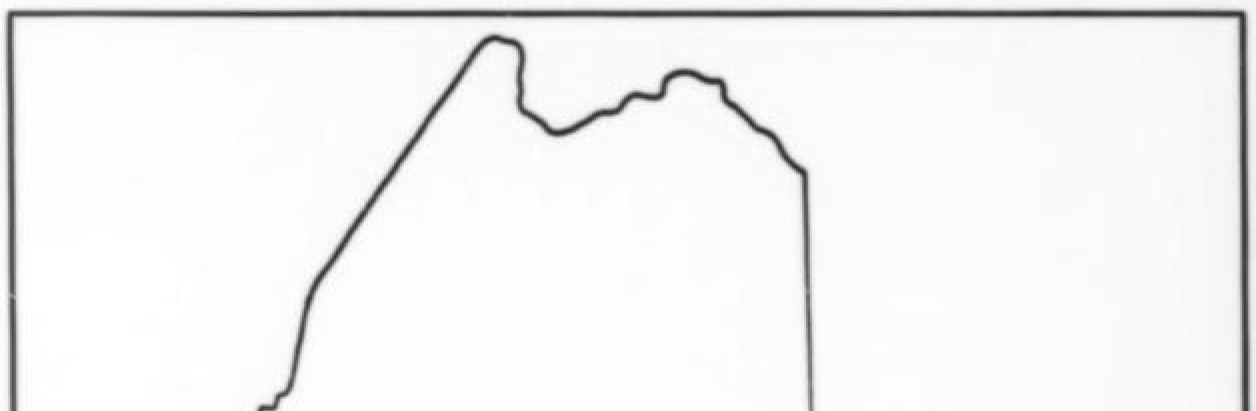

*Figure 1.* **Oxford and Androscoggin Counties produce the bulk of the pegmatite minerals found in Maine. The six quarries shown comprise the Auburn-Poland Area; the Berry-Haven property is at Poland and the other five are considered part of Mt. Apatite.**

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*Fluorapatite, specifically (See Dunn, p. 81, this issue).

*Figure 2.* **Photo by J.G. Manchester, taken in June of 1916 (from Manchester and Bather, 1918). Pitt Pulsifer is at center, showing visitors around the Pulsifer quarry.**

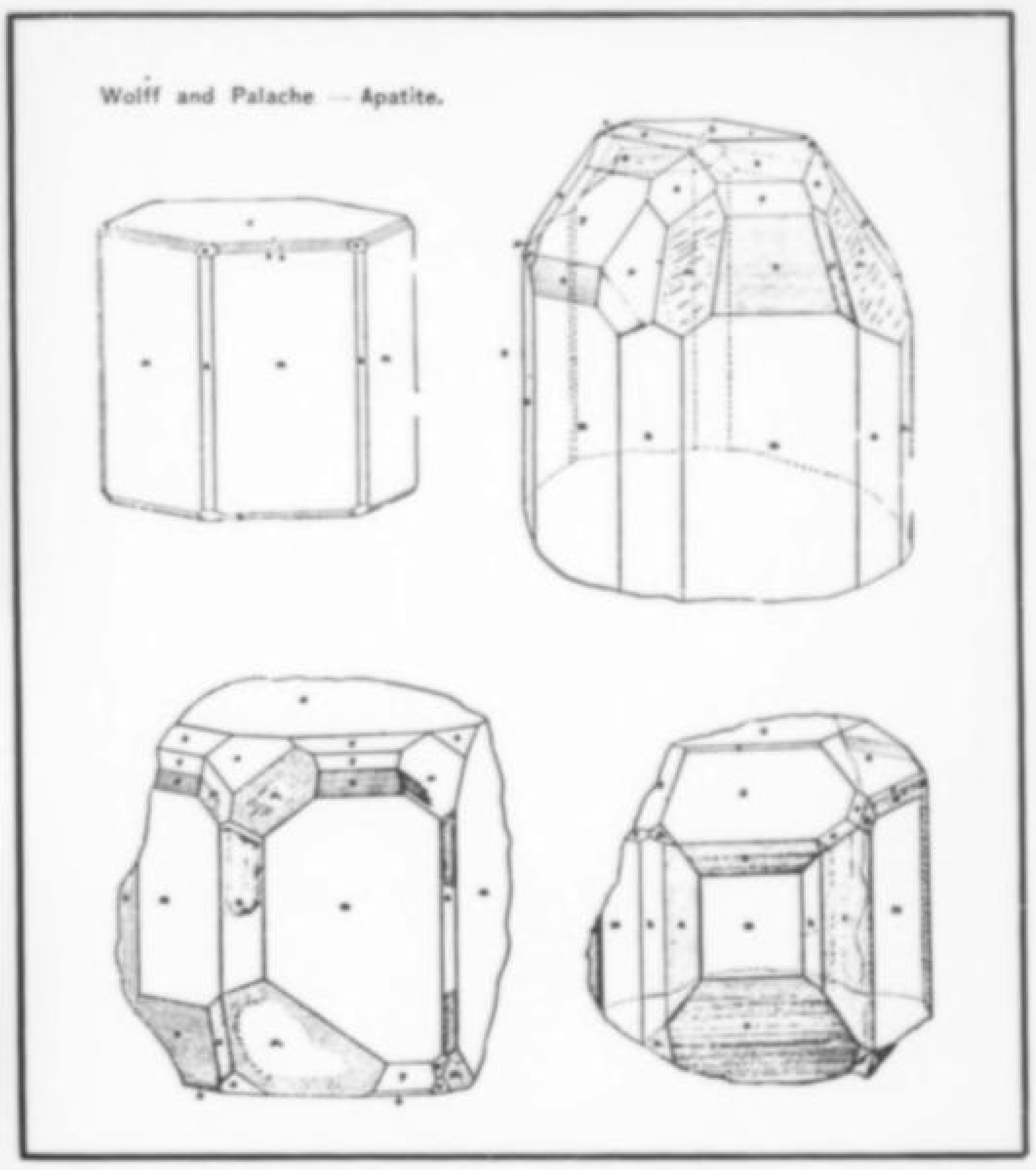


*Figure 3.* **Crystal drawings of Pulsifer quarry apatite from Wolff and Palache (1902).**

and is shown on the cover of this issue; many people (the author included) feel this specimen is without question the world's finest apatite. It was first mentioned by Manchester and Bather (1918) as being in the possession of Pitt Pulsifer in June of 1916. The crystal was described in detail by W.E. Ford in 1917 (see inset and Fig. 4.), at which time it was in the possession of A.H. Petereit (a dealer) of New York City. By 1918 it had been acquired by Washington A. Roebling, a famous collector of the time and also the architect of the Brooklyn Bridge in New York City. Mrs. Roebling purchased it for $250 and presented it to Colonel Roebling for his birthday (Manchester, 1940). After Roebling's death, his collection passed to the Smithsonian Institution through his son, and today the "Roebling apatite" can be seen (in unflattering fluorescent light) on public display in the Gem Hall. Although no one cares in the slightest, the specimen is actually repaired; the small lower crystal and matrix are glued to the large crystal.

## GEOLOGY

Around the turn of the century the pegmatite "sheet" of southwestern Maine produced fine gem minerals at many separate quarries, and thereby became world-famous. The sheet extends roughly from Boothbay Harbor to the Rangeley Lakes, and covers portions of Sagadahoc, Androscoggin and Oxford Counties (Perham, 1972).

Szenics (1967,1968) described Pulsifer quarry geology in detail; most of this section is abstracted from his work.

The gem-producing zone at the Pulsifer quarry was a layer of pegmatite, a pegmatite "ledge," oriented nearly horizontally (dipping at about 10°) for the most part. Practically the whole top of Mt. Apatite is composed of pegmatite, but only small areas are gem producers. Diabase dikes cross through the pegmatite and are considered a good general indicator for gem zones. Rock types intruded by the pegmatites include various schists and gneisses, at least some of which are of sedimentary origin. The contacts between pegmatite and the intruded rocks are generally sharp, and the regional metamorphism which produced the schists and gneisses is not thought to be related to pegmatite emplacement (Bastin, 1911). The pegmatite zones are usually oriented parallel to bedding planes in the host rocks. The pegmatite in the area of the Pulsifer quarry is generally flat-lying and lenticular in shape (Szenics, 1967). Bastin believed the pegmatites were emplaced roughly 400 million years ago.

The pegmatite area at the Pulsifer quarry consisted largely of quartz and feldspar in a graphic intergrowth; the texture became coarser lower in the layer near the core zone, and it is the more coarsely textured areas that contained gem material. The pegmatite zones below the gem pocket zone were, first, a zone rich in schorl and, below that, a layer rich in garnet which terminated the zone of complex mineralization. Below this was graphic textured simple pegmatite again and then schistose country rock. Guide minerals to the location of gem pockets at the Pulsifer quarry were blue albite first, then lepidolite, blue cleavelandite, smoky quartz and imbedded green tourmaline... an assemblage known to miners as "lithium blossom." Indicators, however, were often of little help at the Pulsifer quarry because they only occurred in very close proximity to the gem pockets; rock even 30 cm away from a pocket often showed no indications at all.

The thickness of the gem layer varied from over a metre to about 45 cm; the pegmatite overburden was often 3 to 5 metres thick, and was thicker still over the downward-plunging end of the pegmatite layer.

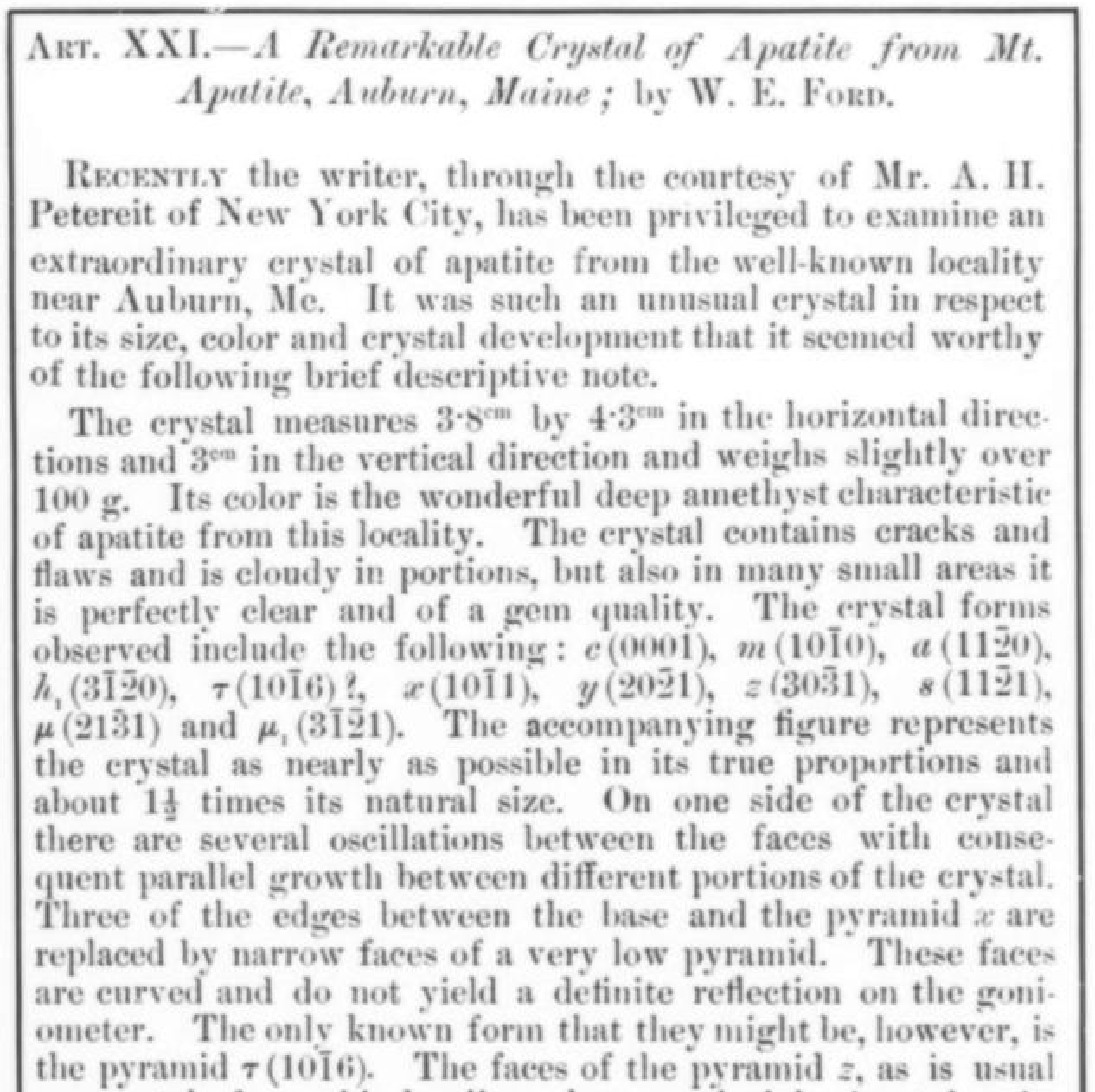
Pockets within the gem-producing layer were commonly around 5 cm in diameter but occasionally were over a metre in size, and several centimetres in thickness. They were most commonly filled with a sticky black mud but rare pockets were filled with kaolinite.

## POCKET MINERALOGY

Rather than present a listing of species with each entry accompanied by descriptions of the many variations found for that species, it may be more instructive to present a listing of the recorded pockets found, with a description of their contents. Pocket contents at the Pulsifer quarry were consistently unpredictable with regard to the species that might be expected, the habits, colors and sizes of those species, and even the amount, if any, of gem species present in the pockets. Most pockets contained a suite of minerals unique from the suites in other pockets in one way or another, and even pocket size bore no discernable relationship to contents. So, in order to include information on the various pocket assemblages as well as the varying characteristics of the pocket species, the minerals are described below by pocket rather than by species.

*Pitt Pulsifer's first pocket (1901)*
(Described by Wolff and Palache, 1902)

The pocket contained: about 2000 crystals of purple apatite with a total weight of about 1 kilogram (2 pounds). Included were about a dozen large groups on matrix, and about 300 loose crystals having *at least* one perfect termination; 500 crystals were slightly less perfect and the remaining 1200 crystals were imperfect or fragmentary. The pocket consisted of a single cavity lined with crystals of quartz, orthoclase and lepidolite, accompanied by small amounts of albite, muscovite and cookeite. The quartz crystals ranged up to 15 cm (6 inches), and consisted of a smoky quartz core covered by a 1-3 mm skin of milky quartz. The apatite crystals penetrated the milky quartz but never the smoky quartz. Some of the lepidolite was in the form of distinct hexagonal prismatic crystals with slightly rounded terminations. The crystals are purple lepidolite throughout the interior but have an epitaxial coating of greenish muscovite 1 mm thick, separated by a sharp boundary. Orthoclase, albite and cookeite form in typically unspectacular habits. The apatite and milky quartz appeared to have formed nearly simultaneously late in the sequence after the smoky quartz, lepidolite, orthoclase and albite (the common constituents of the granite pegmatite). Minor cookeite and quartz formed after the apatite. The bulk of the apatite from this pocket was sold to Harvard University.



Art. XXI.—*A Remarkable Crystal of Apatite from Mt. Apatite, Auburn, Maine*; by W. E. Ford.

Recently the writer, through the courtesy of Mr. A. H. Petereit of New York City, has been privileged to examine an extraordinary crystal of apatite from the well-known locality near Auburn, Me. It was such an unusual crystal in respect to its size, color and crystal development that it seemed worthy of the following brief descriptive note.

The crystal measures $3{\cdot}8^{cm}$ by $4{\cdot}3^{cm}$ in the horizontal directions and $3^{cm}$ in the vertical direction and weighs slightly over 100 g. Its color is the wonderful deep amethyst characteristic of apatite from this locality. The crystal contains cracks and flaws and is cloudy in portions, but also in many small areas it is perfectly clear and of a gem quality. The crystal forms observed include the following: $c(0001)$, $m(10\bar{1}0)$, $a(11\bar{2}0)$, $h_1(3\bar{1}\bar{2}0)$, $\tau(10\bar{1}6)$?, $x(10\bar{1}1)$, $y(20\bar{2}1)$, $z(30\bar{3}1)$, $s(11\bar{2}1)$, $\mu(21\bar{3}1)$ and $\mu_1(3\bar{1}\bar{2}1)$. The accompanying figure represents the crystal as nearly as possible in its true proportions and about $1\frac{1}{2}$ times its natural size. On one side of the crystal there are several oscillations between the faces with consequent parallel growth between different portions of the crystal. Three of the edges between the base and the pyramid $x$ are replaced by narrow faces of a very low pyramid. These faces are curved and do not yield a definite reflection on the goniometer. The only known form that they might be, however, is the pyramid $\tau(10\bar{1}6)$. The faces of the pyramid $z$, as is usual on crystals from this locality, show marked horizontal striations and the prisms $a$ and $h_1$ commonly show faint vertical striations. All of the other faces are plane with no distinctive markings. Both the right and left forms of the third order pyramid, $\mu$ and $\mu_1$, are present, with no apparent distinction to be made between them in regard to their luster, etc. While the figure shows the majority of the faces occurring upon the crystal, several very small and narrow faces of the second and third order pyramids had to be omitted from the drawing.

A small crystal showing the same forms is attached at one side to the lower part of the large crystal but is not represented in the figure. A small amount of cookeite is attached to the crystal.

Mineralogical Laboratory of the
Sheffield Scientific School of Yale University,
New Haven, Conn., June 15, 1917.

***Inset:* Ford's 1917 description of the Roebling Apatite in the *American Journal of Science.***

*Later Pitt Pulsifer pockets*
(Described by Manchester and Turner, 1918, and Perham, 1972)

Pulsifer reportedly encountered a number of tourmaline and apatite pockets after his initial discovery. Most of the apatite he found was of a deep "royal" purple, although some were shades of pink or blue. It is uncertain whether the Roebling apatite came from the first find in 1901 or from a second find later, but it was first reported as being in Pulsifer's possession in 1916. The tourmaline pockets found by Pulsifer in the early days contained both pink and green tourmaline in relatively small crystals (6-8 carat cut stones were the maximum), valued, in those days, at about $2000.

*Stanley Perham and Nevin pocket (around 1945)*
(Described in Perham, 1972)

The area surrounding the pocket consisted primarily of bluish cleavelandite with masses of zoned lepidolite and large crystals of garnet. About 500 carats of tourmaline of a peculiar salmon brown color were removed from the pocket. A pink crystal from the pocket weighed 40 carats. Also found were some fine crystals of blue apatite.

*Groves pocket (1964-1965)*
(Described in Perham, 1972)

Most of the tourmaline from this pocket was a rich, deep green; other tourmaline crystals were colored light pink, salmon-pink, light blue or gray. A number of fine specimens of purple apatite were also produced, including a gemmy crystal 2 x 2½ cm. One specimen consisted of a coating of quartz and purple apatite crystals attached to a green tourmaline crystal 5 cm long.

*Szenics and Frank Perham pocket #1 (1966)*
(Described in Szenics, 1967)

The pocket was about 20 cm in diameter and was packed with black mud. Also contained were many poorly formed quartz crystals 1 to 2 cm long, a 13 mm green tourmaline crystal, and a 1 cm purple apatite crystal.

*Szenics and Perham pocket #2 (1966)*
(Described in Szenics, 1967)

This was actually a series of interconnected pockets, all filled with black mud, and about 10 to 15 cm each in size. The first small pocket contained a total of 35 purple apatite crystals generally ranging in size from a 7 mm single crystal to a crystal cluster 4 cm across with an average crystal size of 13 to 17 mm. The finest single crystal was 2.5 cm wide and 1.3 cm thick; it has an unusual yellow core. Matrix pieces of fine purple apatite on white amblygonite were also found; they averaged about 8 x 8 cm with purple apatite crystals to 1.7 cm. This particular pocket zone, when fully excavated, was seen to be 15 x 30 x 60 cm (½ x 1 x 2 feet). The zone yielded a total of 136 superb purple apatite crystals and crystal groups, and 12 matrix specimens of the finest museum quality. Hundreds of tiny crystals and fragments to 1.3 cm were also recovered. The pocket contained much green, pink and blue tourmaline, but all crystals were securely attached to large sections of matrix and shattered as the pocket was opened; two lunch pails were filled with tourmaline, but none proved to be gem grade. Other minerals found included lithiophilite, triphylite, beryl, columbite, and montmorillonite.

*Szenics and Perham pocket #3 (June, 1967)*
(Described in Szenics, 1968)

As with pocket #2 above, this was actually a series of interconnected pockets in a very localized zone of the pegmatite. The largest pocket in this small pocket zone was about 30 cm square and contained black mud, as usual. Suspended in the mud and clinging to the pocket walls were several dozen purple

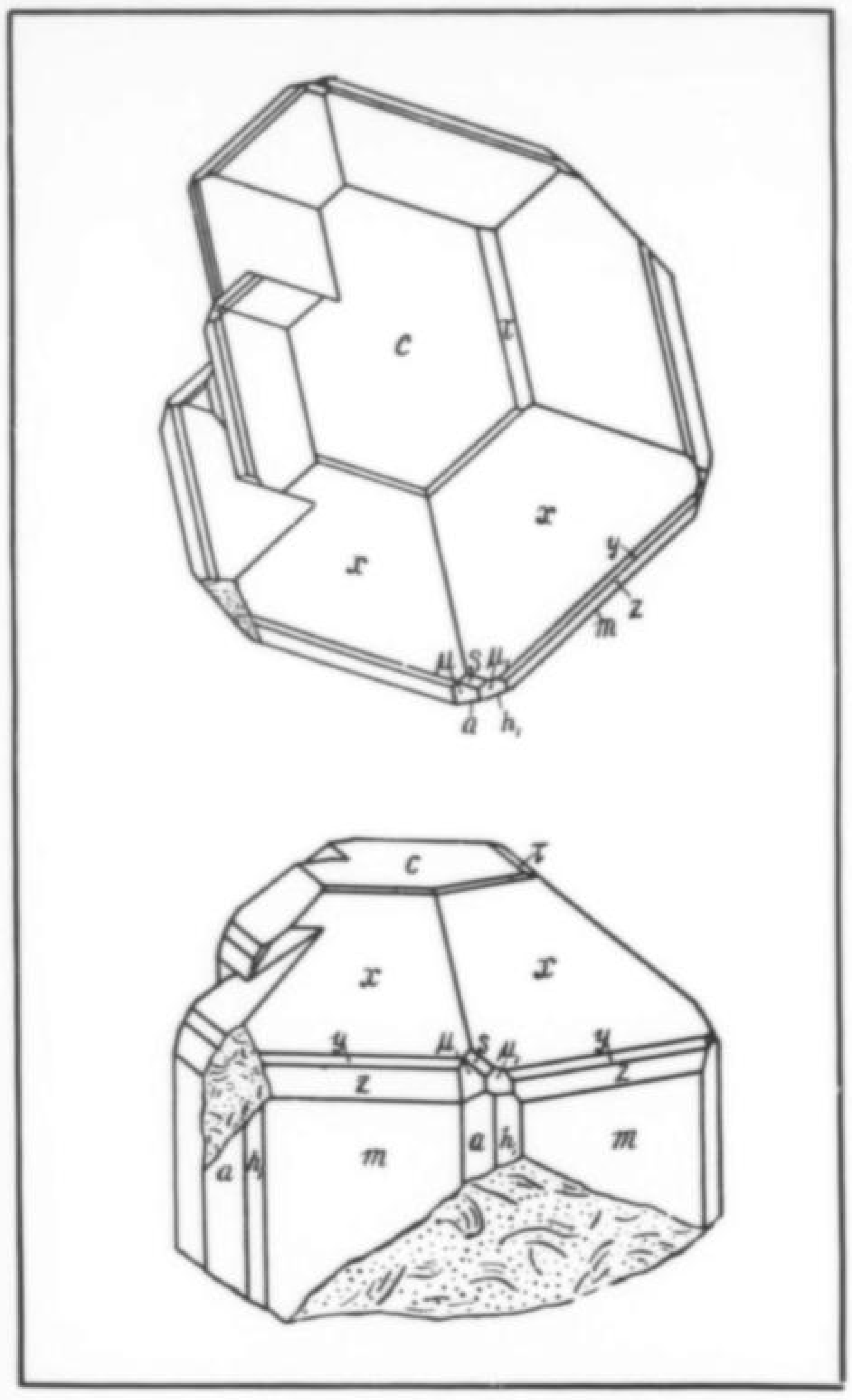


*Figure 4. (left)* **Crystal drawings of the Roebling Apatite from Ford (1917) (see inset).**

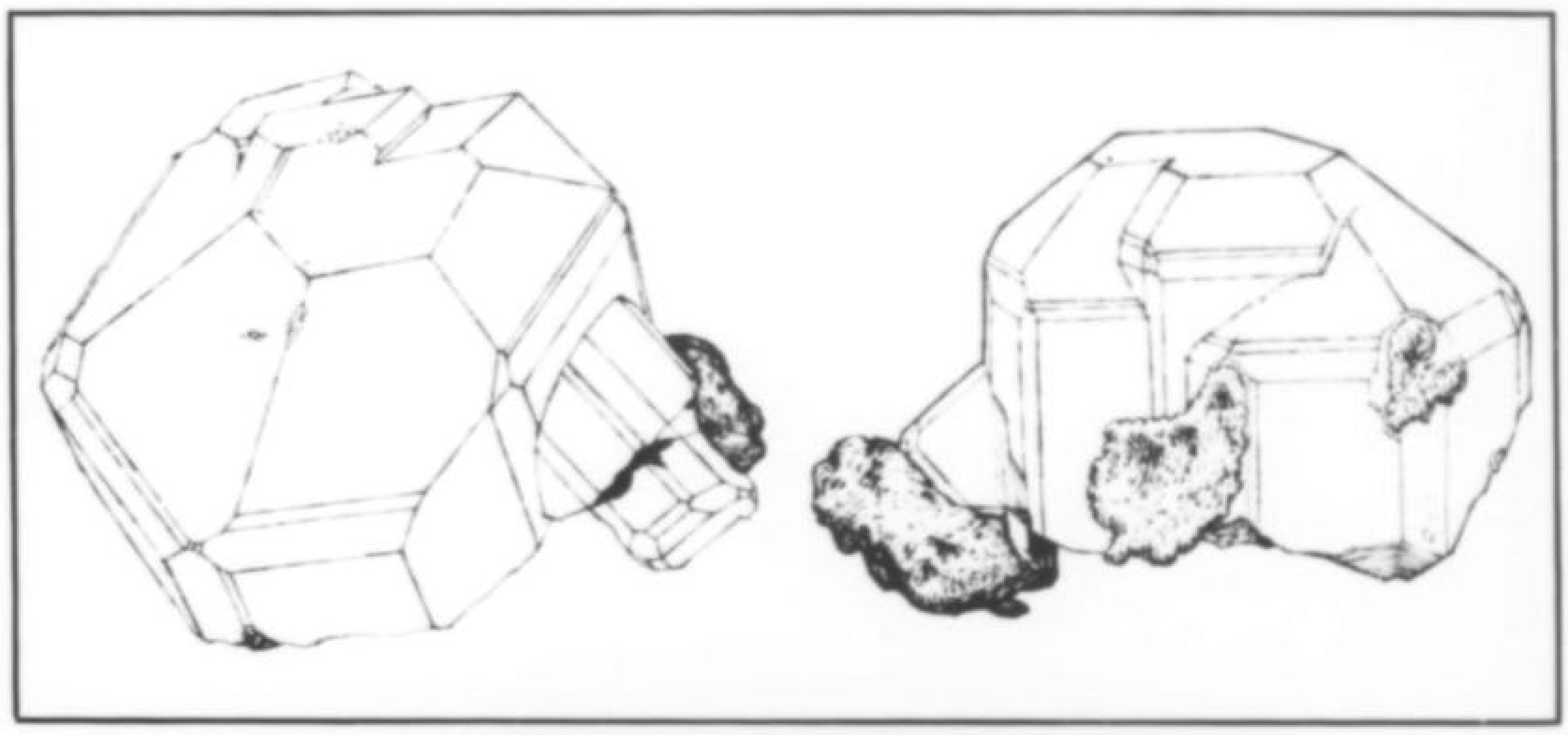
*Figure 5. (top right)* **Recent sketches of the Roebling Apatite.**

*Figure 6. (middle left)* **Tilt-bucket bulldozer clearing away overburden during the mining by Szenics and Perham in 1967. (Photo by T. Szenics)**

*Figure 7. (bottom left)* **A pale blue apatite crystal only 3 mm long, showing perfect development of a hexagonal dipyramid. Smithsonian specimen B13199.**

*Figure 8. (middle right)* **Lepidolite crystal rimmed by epitaxial muscovite, with apatite. The specimen is 5 cm tall. Smithsonian specimen B13195.**

*Figure 9. (bottom right)* **Rich purple apatite in 1.5 cm crystals on white quartz. Smithsonian specimen R17256.**



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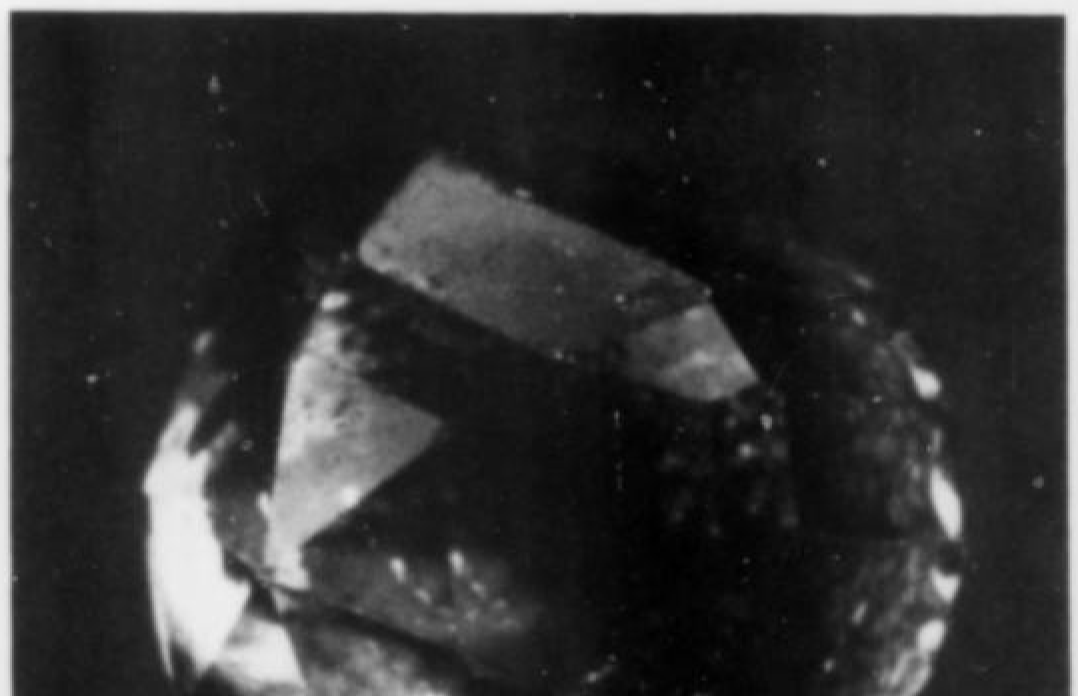

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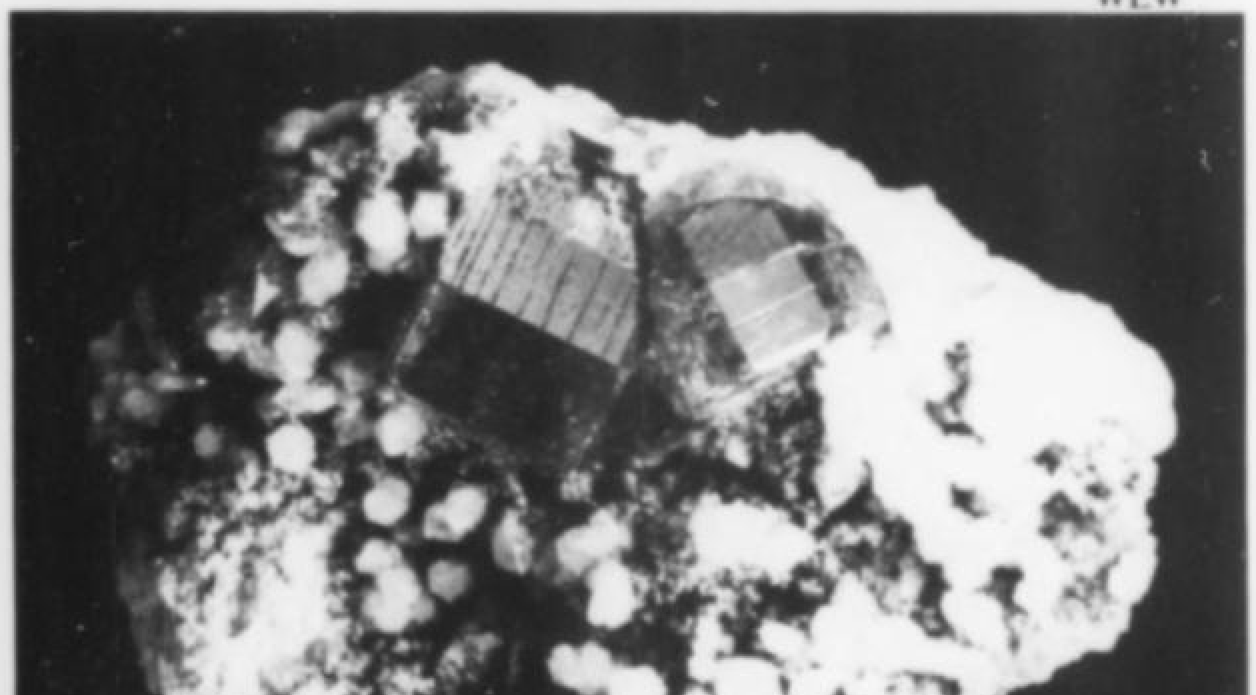

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apatite crystals; the best single crystal was a tabular prism 3 x 4.5 cm, and of the finest color, with minor cookeite attached at the base. Some specimens consisted of 1.3 cm milky quartz crystals with 1.3 cm purple apatite crystals attached. There was no trace of tourmaline in the pocket, and Szenics notes that at the Pulsifer quarry the best apatite is found associated with gem-green tourmaline; apatite unassociated with tourmaline is somewhat poorer in quality; apatite associated with "cinnamon-pink" tourmaline is the poorest. Lower quality apatite is characterized by opacity and poor luster.

*Szenics and Perham pocket #4 (June, 1967)*
(Described in Szenics, 1968)

This pocket, over a metre in circumference and associated with nearly a ton of purple lepidolite, was filled with kaolin and contained only two choice thumbnail apatite crystals.

*Szenics and Perham pocket #5 (June, 1967)*
(Described in Szenics, 1968)

The pocket contained masses of unusual yellow-green cookeite and rare wine-red lepidolite. White apatite crystals, showing only the pinacoid and prism forms, were found accompanied by later purple apatite crystals of complex morphology.

*Szenics and Perham pocket #6 (October, 1967)*
(Described by Szenics, 1968)

The pocket contained pink tourmaline and purple apatite of very good quality.

*Szenics and Perham pocket #7 (October, 1967)*
(Described by Szenics, 1968)

The pocket was spherical in shape and lined with quartz, tourmaline and lepidolite. The pocket contents were segregated; purple apatite crystals were found in one corner and pink tourmaline crystals were found in the opposite corner. The best of the pink tourmaline crystals was a 1.3 x 6.4 cm transparent prism.

*Szenics and Perham pocket #8 (October, 1967)*
(Described in Szenics, 1968)

The pocket was about 30 cm in size and was lined with fine lepidolite crystals; it contained about 90% green tourmaline and 10% purple apatite. Some specimens consisted of purple apatite within empty molds that had been left after the dissolution of tourmaline crystals; in some cases a small amount of corroded green tourmaline remained, and in one instance a pseudomorph of purple apatite after tourmaline was found. At least 85% of the green tourmaline from this pocket was of gem quality; the usual percentage is around 10%. About 1700 carats of choice gem rough were eventually separated. The best tourmaline crystal was about 15 cm long (in three sections) and 2 cm wide, with perfect emerald-green color and fine transparency. The purple apatite was of excellent color, platy habit, and implanted on "spongy" feldspar. Nearly all the tourmaline crystals were broken and lying like jack-straws on the bottom of the pocket, embedded in white cookeite. Szenics observed that, in general, tourmaline-apatite pockets are characterized by tourmaline lying in a pile at the bottom of the pocket, and the apatite crystals lining the upper surfaces of the pocket although this was not the case with a few of the pockets.

Szenics described finding Pulsifer tourmaline of a deep blue color, tourmaline "bicolored" pink and green, tourmaline with more than two distinct color zones, and tourmaline of the "watermelon" type, having a pink center and a green rim. None of these were assigned to specific pockets anywhere in his writings.

## CONCLUSIONS

Pulsifer purple apatite is extremely rare on the market today; collectors possessing specimens tend to retain them above all else. Fine purple apatite has appeared from Panasqueira, Portugal, (see Dunn, p. 78, this issue) and from South Dakota, among other places, but the quality has never matched the finest of Pulsifer. With the locality extinct and specimens hoarded so jealously, it would be nearly impossible to even see specimens were it not for those in the Smithsonian, American Museum and Harvard University collections. All readers are urged to view these specimens and to be alert for the occasional privately-owned pieces put up for sale.

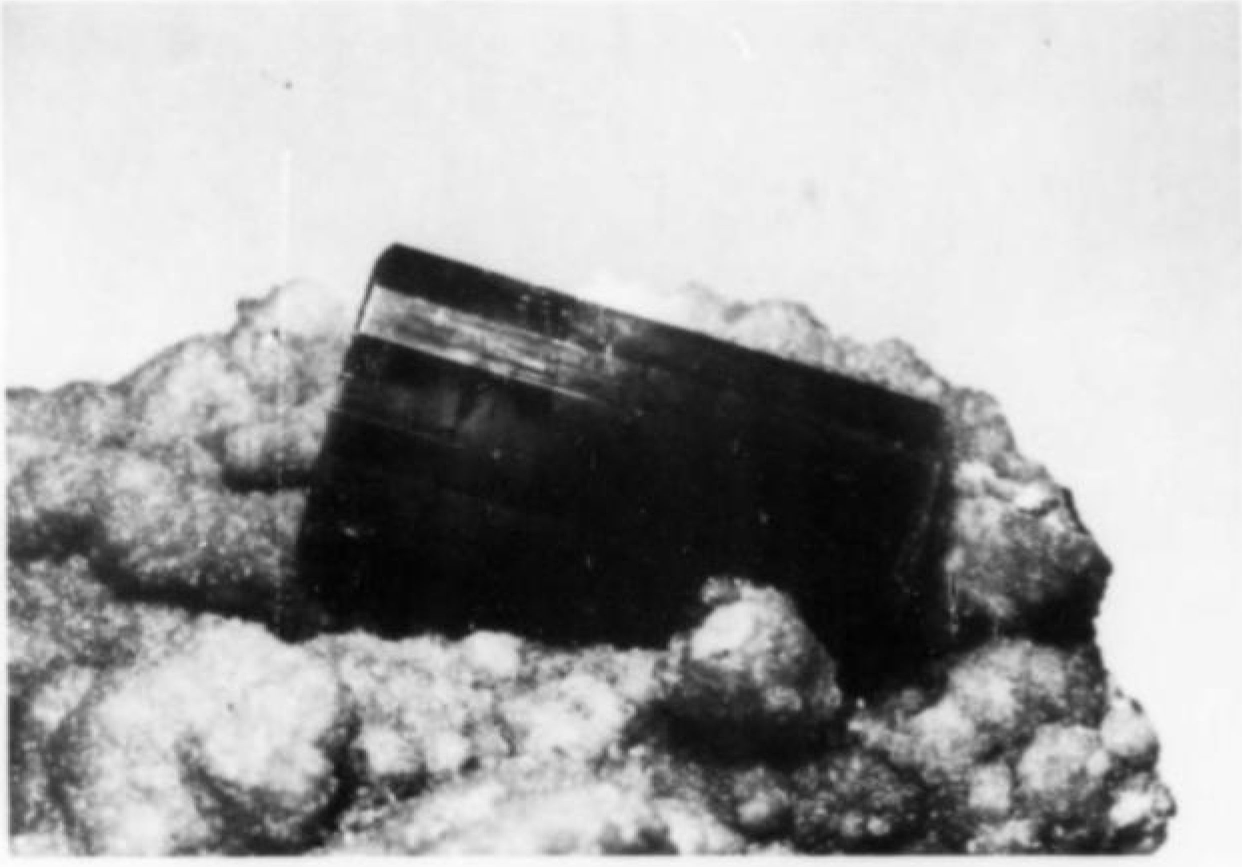

*Figure 10. (top)* **Doubly terminated 3.2 cm crystal of deepest purple, on cookite matrix. Specimen and photo: R. A. Kosnar.**

*Figure 11.* **Elbaite crystal (pink) with cookite and purple apatite. The elbaite crystal is 1.5 cm wide. Specimen and photo: R. A. Kosnar.**

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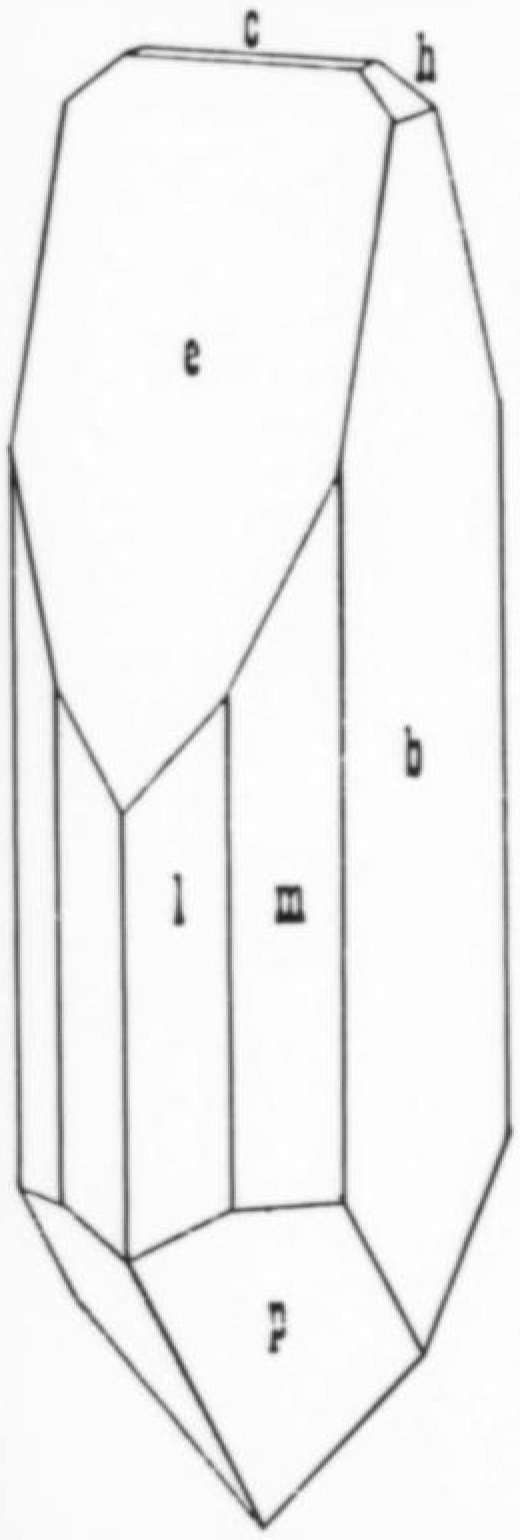

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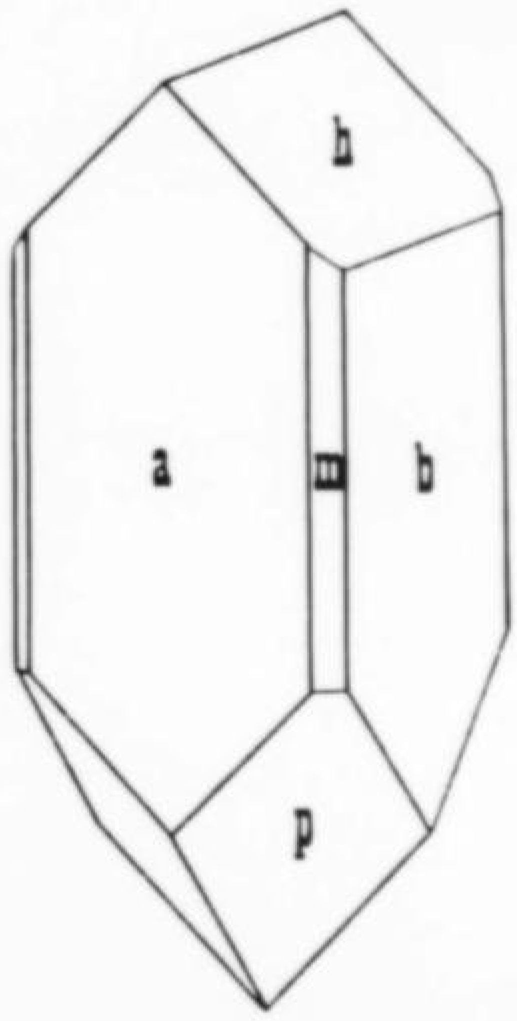

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# APATITE

## A GUIDE TO SPECIES NOMENCLATURE

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APATITE is a generic name for a group of mineral species whose composition can be expressed by the general formula $Ca_5(XO_4)_3(F,Cl,OH)$. The $(XO_4)$ position is predominantly filled by the phosphate radical $(PO_4)$ with minor substitution of the carbonate radical $(CO_3)$ in small amounts in the minerals carbonate-fluorapatite, $Ca_5(PO_4,CO_3)_3\,F$, and carbonate-hydroxlapatite, $Ca_5(PO_4,CO_3)_3(OH)$. Arsenic, vanadium, and silicon can also substitute for phosphorus, in minor amounts.

The main species designations for the apatite group are made on the basis of the predominant anion among Cl, F, and (OH). The three most common apatites are:

| | |
|---|---|
| fluorapatite | $Ca_5(PO_4)_3\mathbf{F}$ |
| hydroxlapatite | $Ca_5(PO_4)_3\mathbf{(OH)}$ |
| chlorapatite | $Ca_5(PO_4)_3\mathbf{Cl}$ |

Inasmuch as few collectors are aware of the proper species designations for the well-crystallized apatites favored by collectors, the following chart (Table I) was constructed as an aid to labelling species of the apatite group. Analyses from the literature are given on table 1, with references. The few specimen apatites not yet described were analyzed with an electron microprobe using an operating voltage of 15 kV and a beam current of 0.15 uA. The data obtained were computer-corrected using Bence-Albee correction factors. The results of these analyses are presented as Table II.

One occurrence of fluorapatite deserves special mention, inasmuch as it has attained special status in the collectors' prestige pecking order.

*FLUORAPATITE*, Panasqueira, Portugal

Originally described briefly by Bloot and DeWolf (1953), these beautiful specimens have become the dominant apatite on the specimen market in recent years. They are recovered in sufficient quantity to satiate the demand (except in the case of extremely high quality specimens) and to permit their proliferation far and wide. The crystals occur in two basic colors: green, and a violet to colorless combination. They are frequently associated with ferberite and arsenopyrite. A notable attribute of Panasqueira fluorapatite is the moderate-to-high degree of transparency when compared with apatites from many other localities. (See Gaines and Thadeu, 1971, for a description of the Panasqueira deposit.)

The green crystals, figure 8, usually have simple morphology and are composed of the hexagonal prisms $\{10\bar{1}0\}$ and $\{1120\}$, capped with the pinacoid $\{0001\}$. Pyramidal modifications are occasionally seen, but not abundant. The crystal faces are usually quite flat and highly lustrous, affording exquisite specimens. Concentric zoning, parallel to $\{10\bar{1}0\}$ is obvious in many crystals, which have dark green centers overlain by light green material. Green Panasqueira fluorapatite exhibits a moderate response to ultraviolet radiation of both long and short wave lengths. The fluorescence is of a mustard-yellow color with no phosphorescence. Bloot *et al.* (1953) examined fluorescent and non-fluorescent sectors of one crystal and attribute the fluorescence to a manganese/antimony activation.

Also known from Panasqueira are violet-to-colorless crystals (Figure 7), but they are far less abundant than the green material. The two museum specimens available for study had only quartz present as an associated mineral; the other associations, if any, of the violet fluorapatite specimens are unknown. Aside from their color, the violet crystals also exhibit several other noteworthy characteristics; they do not respond to ultraviolet radiation, and they have a notable morphology. Unlike the green crystals, these violet-colored specimens have multi-striated prisms, and are quite similar to elbaite upon casual examination.

*Figure 1.* **Fluorapatite (blue) from Pisek, Czechoslovakia. The specimen is 3 cm wide (Smithsonian #123374).**

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*Figure 2.* **Fluorapatite (colorless) from Llallagua, Bolivia. The crystal is 1.7 cm wide (Smithsonian #114176).**

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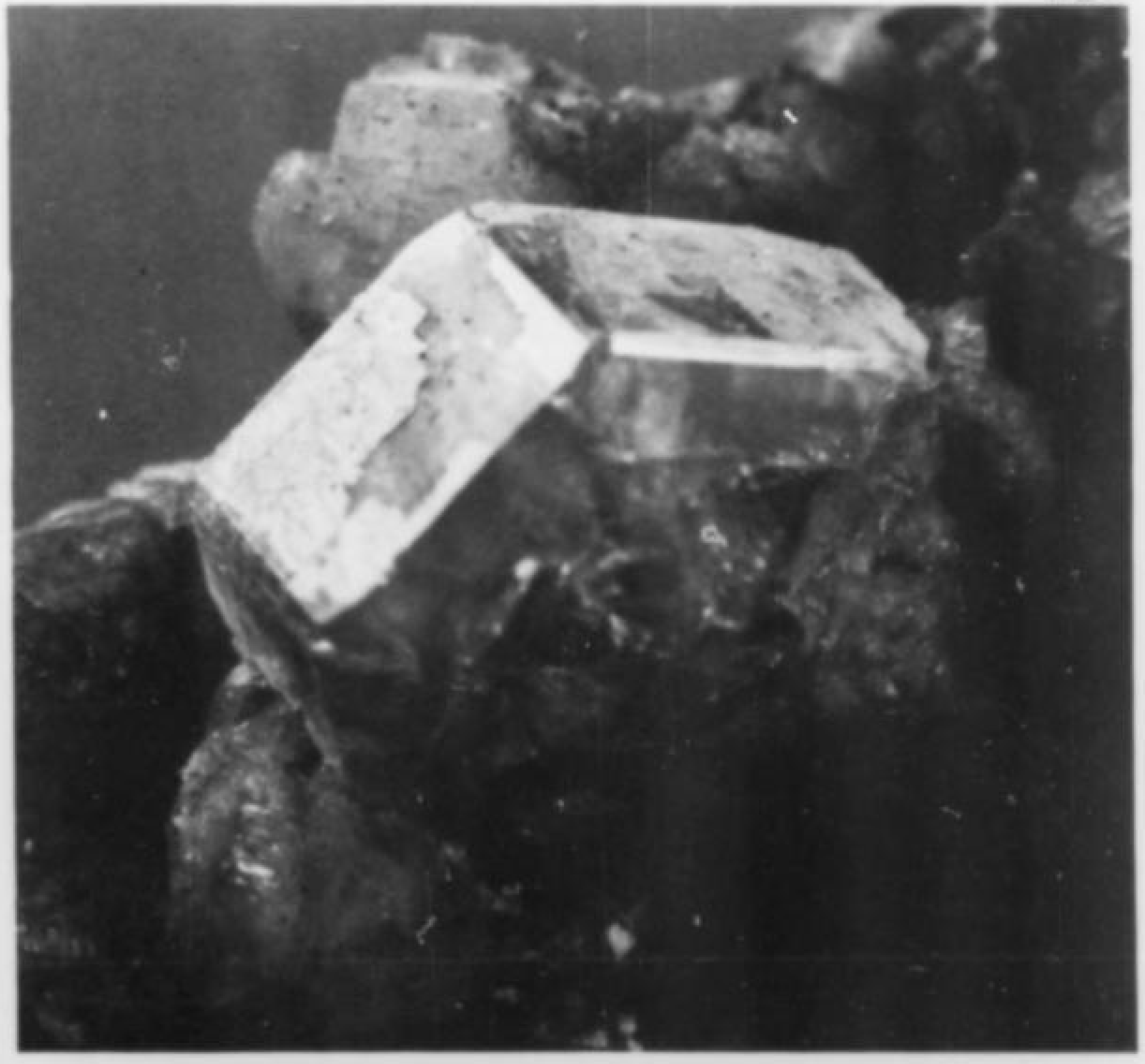
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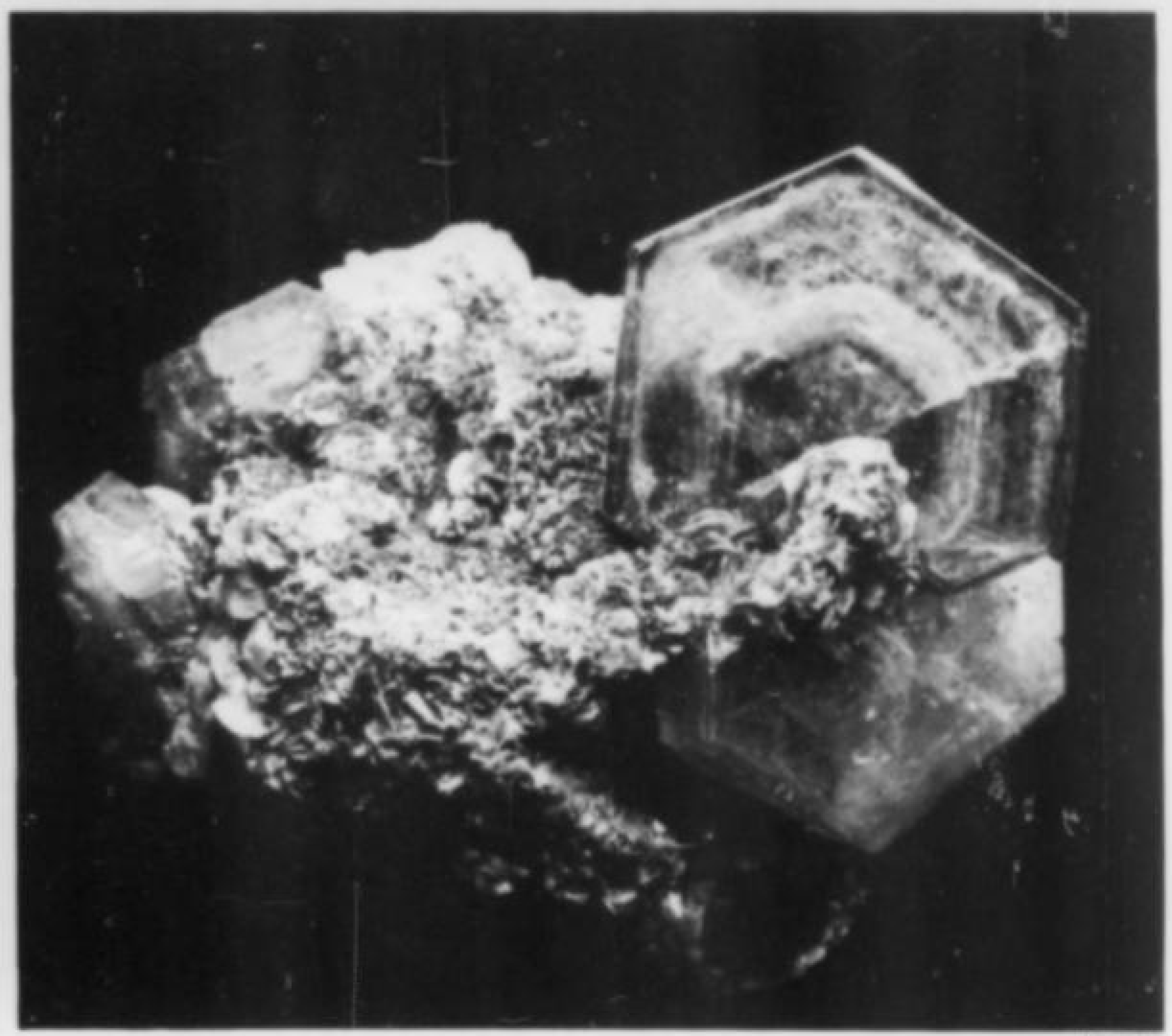
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***Figure 3. (above)* Fluorapatite (pale purple) from Llallagua, Bolivia. The crystal is 2 cm tall (Smithsonian #114340).**

***Figure 4. (above right)* Fluorapatite (blue) from the Pulsifer quarry, Auburn, Maine. The crystal is 7 mm wide (Smithsonian #B13172).**

***Figure 5. (bottom left)* Fluorapatite (colorless) from Knappenwand, Untersulzbachtal, Tyrol, Austria. The crystal is 3.9 cm tall (Smithsonian #123532).**

***Figure 6. (bottom right)* Fluorapatite (green with purple edges) from Panasqueira, Portugal. The crystal is 2 cm (Smithsonian #128055).**

The morphology is still simple, as with the green crystals, and the above-mentioned prisms and pinacoid are the dominant forms. The purple crystals tend to be more prismatic in habit whereas the green crystals tend to be flattened on {0001}; equant crystals occur in both colors.

It is hoped that the above correct species designations for well-crystallized apatite from specific localities will be of assistance to collectors and curators alike. It is neither possible nor desirable however, to examine specimens of apatite for collectors to ascertain species designations. *Most* well-crystallized apatite is fluorapatite.

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## TABLE 1.
## APATITE SPECIES FROM THE LITERATURE

| Locality | Color | Species | Reference |
|---|---|---|---|
| Knappenwand, Untersulzbachtal, Tyrol, Austria | colorless | fluorapatite | Carnot (1896)* |
| Zillertal, Tyrol, Austria | colorless to white | fluorapatite | Hoskins-Abrahall (1889)* |
| Grant mine, Buckingham, Quebec, Canada | greenish gray | fluorapatite | Hoffmann (1879)* |
| Ritchie mine, Portland, Ontario, Canada | light green | fluorapatite | Hoffmann (1879)* |
| Wilberforce, Ontario, Canada | green | fluorapatite | Bhatnagar (1968) |
| Faraday Township, Ontario, Canada | green | fluorapatite | Dadson (1935) |
| Templeton, Quebec, Canada | light greenish white | fluorapatite | Hoffmann (1879)* |
| Burgess, Ontario, Canada | red | fluorapatite | Hoffmann (1879)* |
| Renfrew County, Ontario, Canada | green | fluorapatite | Jannasch (1910)* |
| Branchville, Connecticut | white | fluorapatite | Penfield (1880)* |
| Pisek, Bohemia, Czechoslovakia | green | fluorapatite | Kovar (1889)* |
| Wheal Franco, Devonshire, England | gray to green | carbonate-fluorapatite | Sandell *et al* (1935) |
| Luxullian, Cornwall, England | yellow | fluorapatite | Walter (1907)* |
| Ehrenfriedersdorf, Saxony, Germany | violet | fluorapatite | Hoskins-Abrahall (1889)* |
| Minot, Maine | dark violet | fluorapatite | Wolfe (1902)* |
| Cerro de Mercado, Durango, Mexico | yellow | fluorapatite | Young *et al* (1969) |
| Franklin, New Jersey | green to bluish-green | fluorapatite | Penfield (1880)* |
| Ødegården, Bamle, Norway | white | chlorapatite | Carnot (1896)* |
| Snarum, Norway | white | chlorapatite | Weber (1851)* |
| Jumilla, Spain | green | fluorapatite | Hoskins-Abrahall (1889)* |
| St. Gotthard, Switzerland | colorless | fluorapatite | Rose (1827)* |

*Analyses and original references are found in Hintze (1933) *Handbuch der Mineralogie*, 1, **4**, 487-582.

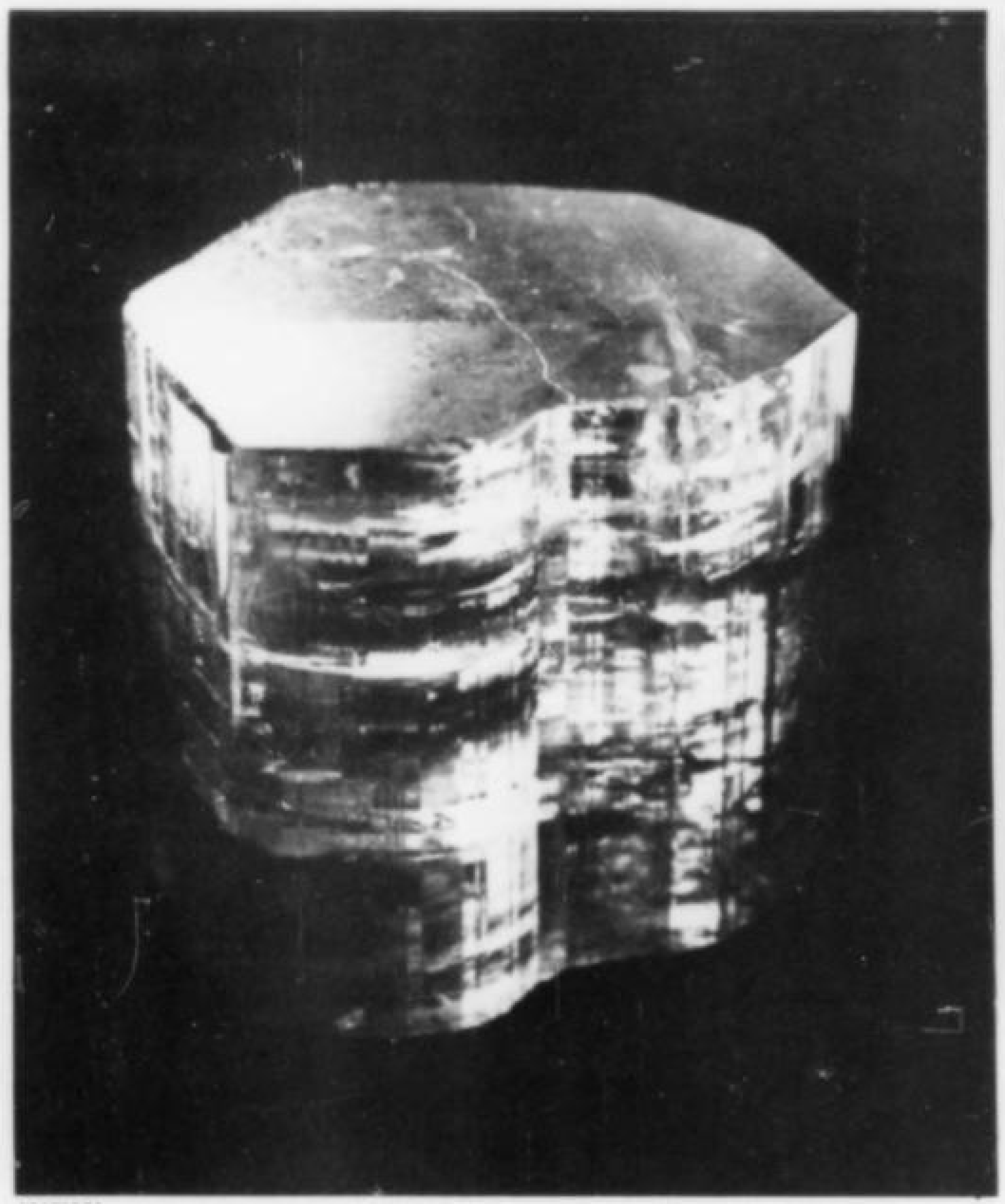
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***Figure 7. (above)*** **Fluorapatite (pale yellow-green core in lower half, rimmed by blue and purple zones; upper half of crystal is completely colorless) from Panasqueira, Portugal. The crystal is 2.5 by 2.5 cm (Smithsonian #128086).**

***Figure 8. (top right)*** **Fluorapatite (deep yellowish green) from Panasqueira, Portugal. The crystal is 3 cm wide (Smithsonian #127321).**

***Figure 9. (bottom right)*** **Fluorapatite (pale blue-green) from Ehrenfriedersdorf, Saxony, East Germany. The crystal is 1.4 cm wide and is accompanied by fluorite cubes (Smithsonian #B12998).**

*Figure 10. (top left)* **Chlorapatite (white) from Snarum, Norway. The crystal is 2.2 cm wide (Smithsonian #R5226).**

*Figure 12. (bottom left)* **Fluorapatite (pale purple) from the Harvard quarry, south of Greenwood, Oxford County, Maine. The specimen is 6.9 cm long (Smithsonian #R12760).**

*Figure 11. (top right)* **Fluorapatite (colorless) from Branchville, Connecticut. The crystal is 2.4 cm wide (Smithsonian #C4064).**

*Figure 13. (bottom right)* **Fluorapatite (greenish sulfur-yellow) from Cerro Mercado, Durango, Mexico. The crystal is 7.5 cm (3 inches) long (Smithsonian #R16466).**


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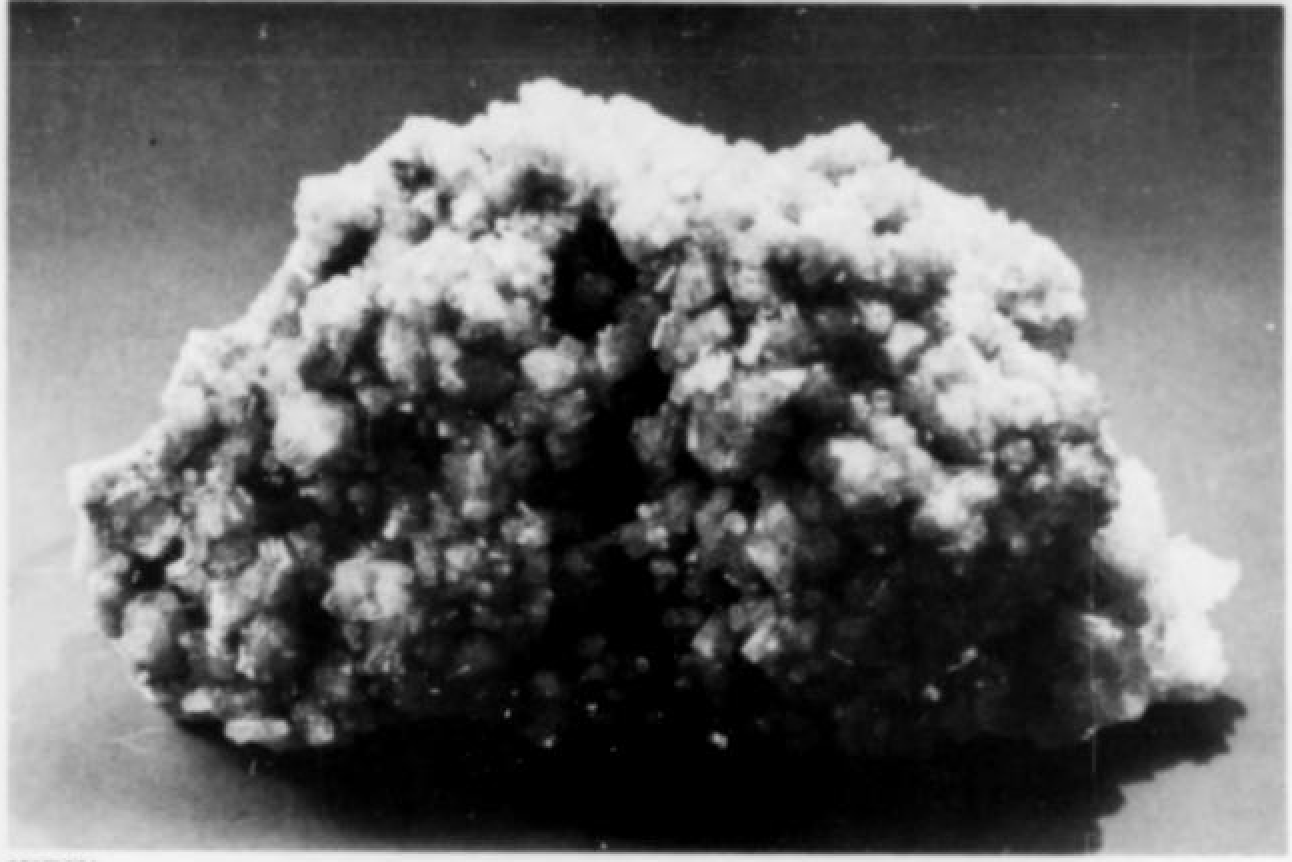
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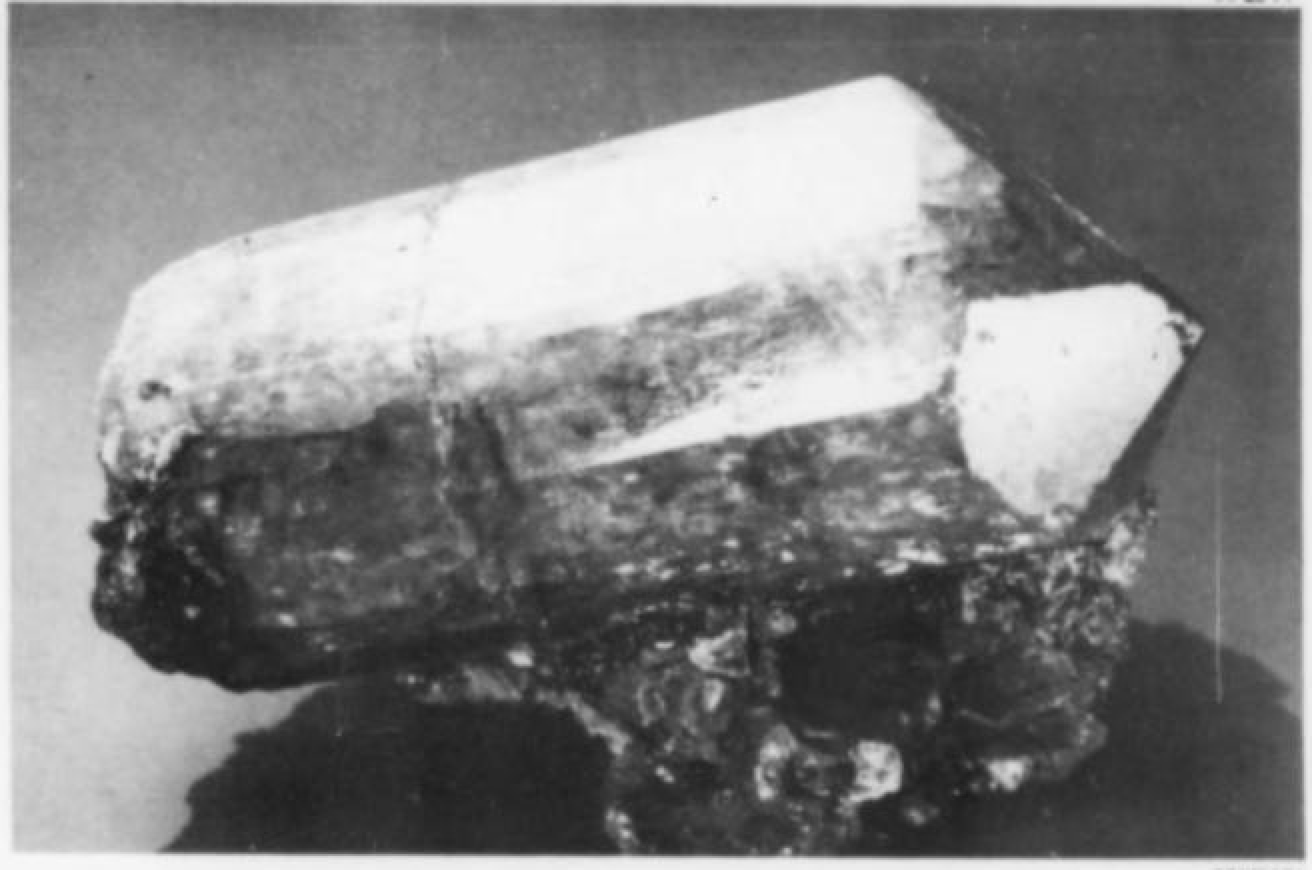
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**Table 2. New Analyses of Fluorapatites**

| Locality | Color | CaO | $P_2O_5$ | F | Cl | Total | NMNH # |
|---|---|---|---|---|---|---|---|
| Llallagua, Bolivia | colorless | 55.10 | 41.97 | 3.82 | 0.00 | 100.89 | 114175 |
| Llallagua, Bolivia | violet | 55.96 | 42.43 | 3.38 | 0.00 | 101.77 | 114464 |
| Pala, California* | violet | 55.14 | 42.09 | 2.82 | 0.00 | 100.05 | 126617 |
| Pontiac Co., Quebec, Canada** | green | 53.25 | 41.74 | 3.65 | 0.00 | 98.64 | 121303 |
| Haddam, Connecticut | colorless | 55.33 | 42.00 | 3.49 | 0.00 | 100.82 | B13201 |
| Schwarzenstein, Austria | white | 55.58 | 42.13 | 3.04 | 0.00 | 100.75 | 82049 |
| Harvard quarry, Greenwood, Maine | violet | 52.46 | 41.14 | 4.06 | 0.40 | 98.06 | R12760 |
| Pulsifer quarry, Auburn, Maine | violet | 55.29 | 42.22 | 3.55 | 0.00 | 101.06 | 123471 |
| Santa Cruz, Sonora, Mexico | greenish white | 55.50 | 42.19 | 2.54 | 0.55 | 100.78 | R12256 |
| Hammond, New York | green | 54.48 | 41.34 | 2.97 | 0.26 | 99.05 | 116695 |
| Rossie, New York | bluish green | 55.59 | 40.93 | 3.63 | 0.00 | 100.15 | R5224 |
| Macomb, New York | light green | 55.42 | 40.88 | 3.75 | 0.00 | 100.05 | 48275 |
| Panasqueira, Portugal | green | 55.30 | 42.28 | 3.52 | 0.00 | 101.10 | 121136 |
| Panasqueira, Portugal | violet | 54.65 | 41.68 | 4.00 | 0.00 | 100.33 | 128086 |

Accuracy of data ±2% relative.

*Richard Robert claim, Stewart Hill
**Yates uranium mine
note: low summations may be due to undetermined manganese.


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*Figure 14. (left)* **Fluorapatite (white) from Santa Cruz, Sonora, Mexico. The crystal is 8 cm tall (Smithsonian #R15503).**

*Figure 15. (above)* **Fluorapatite (greenish yellow with reddish brown stains in the cracks) from Renfrew, Ontario. The crystal is 10.5 cm long (Smithsonian #C4060).**

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**errata**

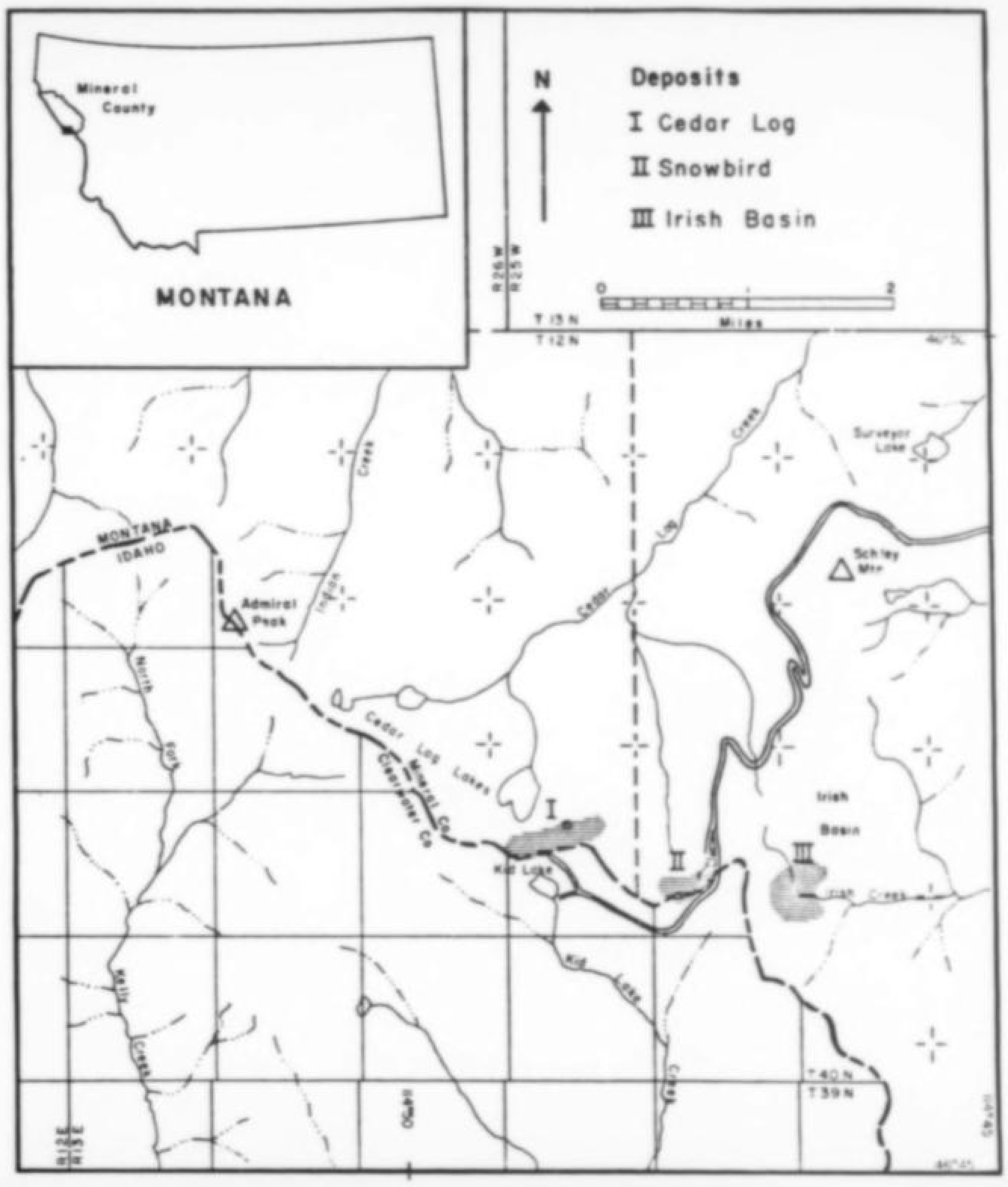
**P. 321 of the Colorado Issue** (v. 7, n. 6) column 3, middle of lower paragraph; the sentence in Paul Patchick's letter should read:

> "I myself felt somehow that it was *less* valuable and
> desirable with that old horse glue underneath;"

The word "less" was erroneously omitted. W.E.W.

**P. 56 of v. 8, n. 1,** under "CONCULSION" it should have said:

> "*Although inadequate detailed* genetic data
> for most Bolivian tin occurrences are available..." R.B.C.



# THE SNOWBIRD MINE

## Montana's Parisite Locality

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### INTRODUCTION

Through the years, parisite crystals from Montana have been occasionally seen in collections. Frequently, the precise location did not appear with the specimen as the distributors attempted to keep the localities confidential. The excellence of the crystals coupled with their unusual pegmatite environment make Montana's parisite unique. It is fairly certain that prior to 1955, parisite crystals found their way into collections from the White Cloud mine (Pyrites) area of Ravalli County, Montana. After 1955, parisite generally originated from the Snowbird mine, Mineral County. This report concerns only the more recent Snowbird mine location; it is the source of all recently collected parisite specimens from Montana.

### LOCATION

The Snowbird mine is located in unsurveyed Section 19, T.12N., R.25W., southwest Mineral County, Montana. The property is at an elevation of 2018 metres (6560 feet) in the Bitterroot Mountain Range. It can be reached from Interstate 90 by taking the Fish Creek Exit between the towns of Alberton to the east and Tarkio to the west. From the highway one should drive 20.0 miles up Fish Creek (S. Fork) and then turn right up the Schley Saddle Road to reach the map area shown (Fig. 1,2). A second, somewhat easier way to reach the property is to turn right earlier on Surveyor Creek Road #7734. One must bear left 1.7 miles after leaving the South Fork of Fish Creek on Road #7734. It should be remembered that snow restricts access, and only from June through September can a field vehicle be driven to the property.

### HISTORY

At the property, mining was begun during 1956 by F & S (Finlen and Sheridan) Mining Company of Butte, Montana. The claims, Snowbird 1 through 19, were owned by Everett Lord and Mort Bacon, and collectively were known as the Snowbird mine. During that period, the late Robert Applegate* recognized parisite at the mine and was probably responsible for making specimens from this locality available to collectors. During the two year of operation (1956-1957), the F & S Mining Company shipped 6,500 tons of metallurgical-grade fluorite, nearly exhausting the deposit. During 1967 the property was restaked as the Snowshoe claims—they are presently being explored by Glen E. Bunker, 155 N. Center, Delta, Utah. The property is posted against trespassers.

### GEOLOGY

The Snowbird deposit is a rare-earth-rich, carbonate-fluorite-quartz pegmatite, intruding carbonaceous argillite of the Wallace formation (Belt Supergroup), Precambrian in age. The pegmatite body has an exposed length of 275 metres, is cone-shaped in cross section, and extends to a depth of 125 metres. There has been some debate regarding whether or not the Snowbird deposit is a carbonatite body. Considering that quartz is a major constituent

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*R. Applegate met death during a mountain-climbing accident in South America.

of the deposit, the term "rare earth pegmatite" is more appropriate and will be used throughout this paper.

The pegmatite exhibits features that clearly demonstrate the process of mineralization stoping. The process is characterized by the removal of rock by rising solutions during early-stage activity, collapse and brecciation of the rock thus left unsupported, and deposition of minerals in the brecciated mass. Within the lower portion of the deposit, large collapse breccia fragments of the Wallace formation are in evidence. The roof of the deposit exhibits "crackle breccia" – smaller fragments showing some rotation, but not transported any distance from their original position.

The Snowbird deposit has been dated at 74 ± 1 million years old using thorium and lead isotopes in parisite. This date corresponds to that of the large Idaho batholith situated to the west and suggests a common origin. Regionally, the Wallace formation along the east margin of the batholith has been altered with the development of scapolite (marialite) metacrysts. Superimposed upon this regional alteration are other changes; the rocks surrounding the pegmatite have been bleached, locally sericitized, with some addition of feldspar and ankerite. Small veinlets of biotite, muscovite, and ankerite with magnetite and allanite surround the deposit.

Cutting through the pegmatite, and into the country rock, are late-stage breccia dikes. The interstitial filling in these late dikes has the same composition as the older pegmatite body.

## MINERALOGY

Michael C. Metz (1971) has thoroughly presented the details of the Snowbird deposit in a Master's thesis. He demonstrated that the pegmatite has concentric mineral zoning with quartz on the periphery and carbonates+fluorite in the core. In detail, along the outer contacts there is a thin layer of ankerite representing a reaction rind between the mineralizing solutions and the country rock. Next follows a quartz-rich zone with some calcite, fluorite, and ankerite. The quartz is generally in the form of giant crystals, up to 6 metres long, projecting toward the center of the pegmatite. Parisite crystals are found partially included in the quartz crystals and extending into adjoining calcite, ankerite, and, locally, into fluorite. Isolated crystals of parisite and masses of gersdorffite occur suspended in a carbonate matrix between the quartz crystals. The core of the pegmatite consists of very coarsely crystalline, massive calcite and ankerite.

Fifteen different minerals have been identified by Metz at the Snowbird mine. Additional work might uncover other unusual oxidation minerals not yet described. A detailed description, in alphabetical order, follows.

### ALLANITE $[(Ce,Ca,)_2(Fe,Al)_3(SiO_4)_3(OH)]$

The mineral was identified by Metz using X-ray diffraction. It is found as slender black prismatic crystals 2 mm to 3 cm in length, projecting toward the centers of quartz-biotite veins that surround the pegmatite.

### ANKERITE $[Ca(Fe,Mg,Mn)(CO_3)_2]$

Ankerite is one of the abundant minerals at the Snowbird mine. It occurs along outer contacts and as disseminated grains and coarse masses throughout the calcite matrix. X-ray diffraction and atomic absorption analysis show that 20 percent of the magnesium positions are taken by iron, thus defining the

*Figure 2.* – **Geologic map of Snowbird fluorspar deposit, Mineral County, Montana.**

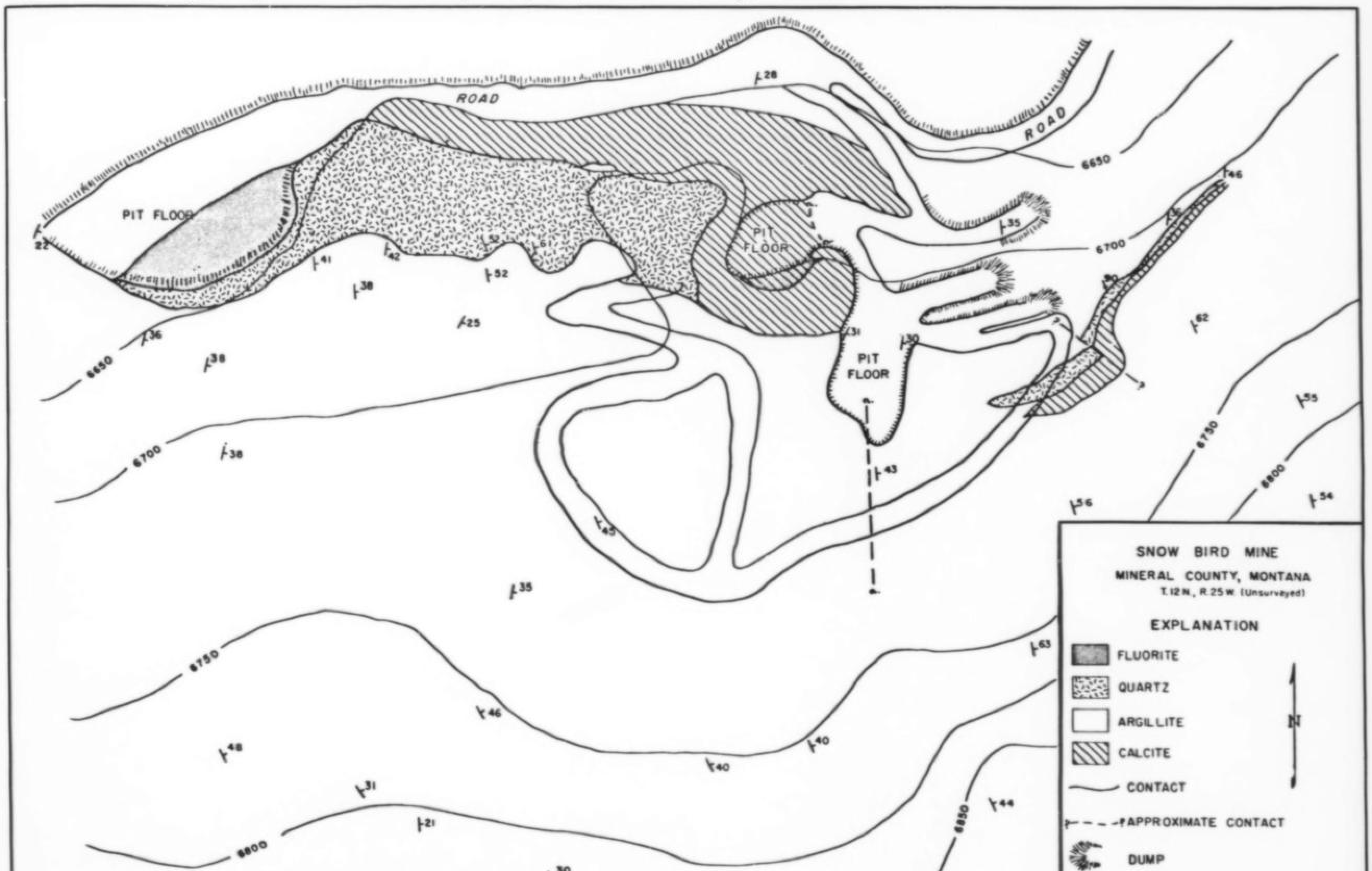


*Figure 3.* **The Snowbird mine.**

mineral as ankerite. Free-growing crystals of ankerite have not been observed.

**ANNABERGITE** [$Ni_3(AsO_4)_2 \cdot 8H_2O$]

This green supergene mineral is found as stains along calcite cleavages in the immediate vicinity of partially-to-completely oxidized sulfide grains. Nodules of annabergite up to 2 cm long have been observed.

**CALCITE** [$CaCO_3$]

Calcite is the most abundant mineral at the property; it occurs as cleavages 1 cm to 1.1 metres long. The calcite is generally white and forms the matrix on which all other minerals at the property are found. Due to the rarity of primary cavities, no free-growing crystals have been seen.

**FLUORITE** [$CaF_2$]

Fluorite is found as lenses up to 65 cm in diameter in contact with quartz crystals. The quartz has been generally corroded in these areas and shows casts after fluorite cubes. Fluorite formed contemporaneously with calcite. Colors range from clear to pale green, blue-green, purple and nearly black. Fluorite is coarsely crystalline but, due to subsequent tectonic activity, is shattered throughout the deposit. The Snowbird pegmatite was exploited solely for its fluorite content. At one time a 30-metre-long massive lens was present at the west end of the pit.

**FLUOCERITE** [$(Ce,La)F_3$]

This uncommon mineral was identified (Metz, 1971) by X-ray diffraction of residual material remaining after parisite was dissolved in hydrochloric acid. Fluocerite occurs as very tiny grains disseminated in parisite.

**GERSDORFFITE** [NiAsS]

Gersdorffite is found intimately associated with parisite in large, crude single crystals (from 1 to 10 cm) totally enclosed by calcite and ankerite. It occurs partially or completely oxidized to annabergite.

**GOETHITE** [FeO(OH)]

Goethite is found throughout the deposit in pseudomorphs after pyrite crystals and ankerite. Locally ground waters have dissolved the ankerite, filling the resulting void with limonite and clays.

**MAGNETITE** [$Fe_3O_4$]

Magnetite is found in trace amounts throughout the deposit. Veins above the deposit contain magnetite octohedrons up to 5 mm in size.

**MILLERITE** [NiS]

Millerite is rare, found only as small, anhedral 2 mm to 5 mm inclusions in pyrite and gersdorffite.

**PARISITE** [$(Ce,La)_2Ca(CO_3)_3F_2$]

Parisite is the most abundant cerium group rare-earth mineral at the Snowbird mine. It occurs as euhedral, elongated, sometimes distorted crystals from 0.5 to 24 cm in length. The color ranges from a medium brown to a medium yellow-brown. Parisite is soluble in dilute hyrochloric acid.

A spectrochemical analysis by Metz (1971) revealed the presence of cerium, lanthanum, neodymium, praseodymium and yttrium in Snowbird mine parisite; spectrographic analysis also indicated 17,000 ppm thorium and 57.4 ppm uranium.

From a collector's viewpoint, parisite is moderately abundant at the property, but is nearly always imbedded in compact calcite. Dissolving the calcite in acid would destroy the parisite as well. The best crystal groups were found free in a clay matrix filling old water courses along the contacts of giant quartz crystals. Upon removal of the clay, parisite crystals could also be seen projecting from the carbonate walls, but they were difficult to remove.

**PYRITE** [$FeS_2$]

Pyrite is the most abundant sulfide at the deposit. It is found as cube-pyritohedron crystals coating breccia fragments and as disseminations in the wall rock adjacent to the pegmatite. Single pyrite crystals were also observed coating corroded quartz crystals. The pyrite is partially to totally oxidized to goethite. A tiny fresh pyrite crystal totally enclosed in clear quartz was collected.

**RUTILE** [$TiO_2$]

Very tiny acicular crystals (less than 1 mm) were collected by Metz from the cross-cutting breccia dikes. The rutile is generally found along the breccia fragment boundaries or as inclusion in quartz. The X-ray powder pattern suggests that the rutile is niobium-rich.

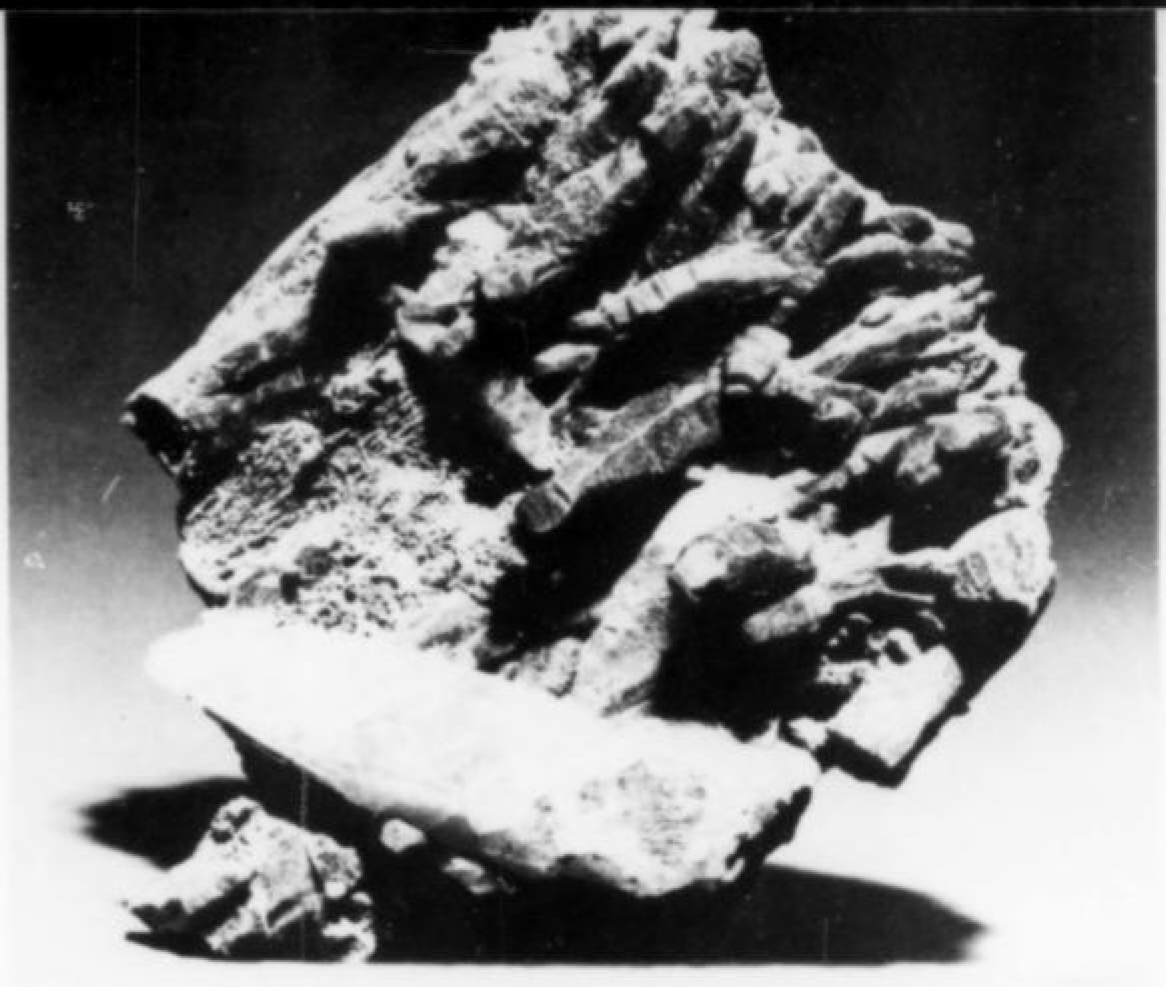
**XENOTIME** [$YPO_4$]

This is the sole phosphate and yttrium group rare-earth mineral identified from the deposit. It is found as disseminated euhedral to anhedral crystals in calcite. The crystals are generally less than 1 mm in size and are estimated to constitute 0.15 percent of the calcite samples by weight. The samples were concentrated by leaching the calcite in 10 percent acetic acid; identification by X-ray powder diffraction was then performed on the residue.

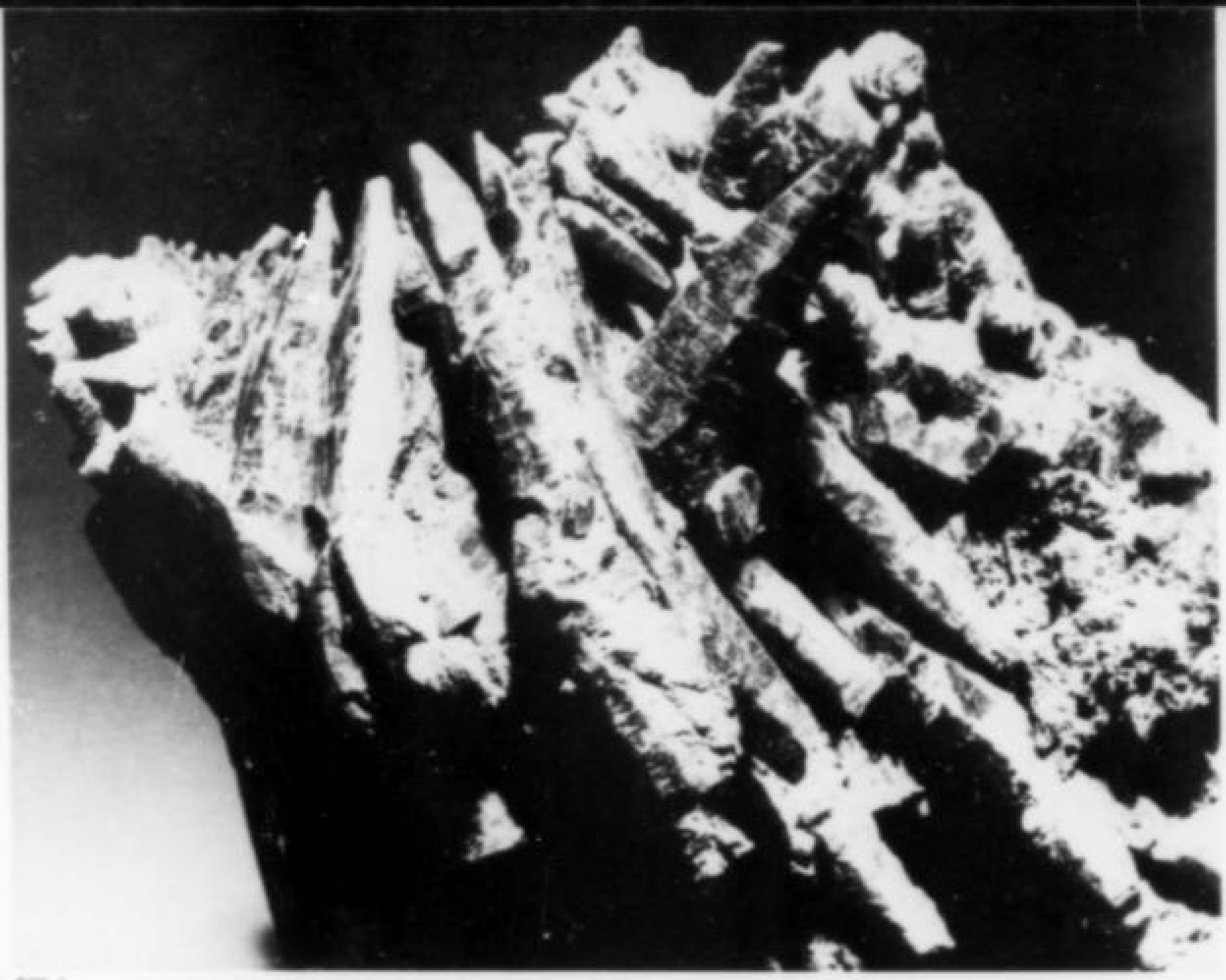
## OTHER PARISITE LOCALITIES

In the Snowbird mine vicinity there are two other deposits having the characteristics of breccia dikes. One mile west of the Snowbird mine is located the Cedar Log prospect, containing parisite, quartz, ankerite and fluorite. The Irish Basin property

*Figure 4.* **The Snowbird mine.**



JEA
*Figure 5.* **Parisite crystals on matrix (Smithsonian specimen).**



JEA
*Figure 6.* **Parisite crystals on matrix (Smithsonian Specimen).**

is located three quarters of a mile east of the Snowbird mine. It also contains quartz, ankerite and fluorite.

The Snowbird deposit actually is at the north end of a 175-mile-long regional belt of rare-earth occurrences. The belt correlates with the eastern edge of the Idaho batholith and roughly follows the Idaho-Montana boundary. From north to south the other localities are: Pyrites, east of Florence (see below); Stevensville; Victor; north and south of Conner; Blue Nose Mountain west of Gibbonsville, Idaho; west of Wisdom; Lemhi Pass west of Grant; southwest of Red Rock.

Previous references refer to parisite crystals found at Pyrites, Montana. The occurrence was described by Penfield and Warren in 1899. Pyrites is a small settlement associated with the White Cloud gold mine along Eightmile Creek, 8 miles east of Florence, Ravalli County, Montana. The following description has been condensed from Penfield and Warren:

> "The matrix is a fine-grained loosely coherent white material which can be readily crushed with the fingernail. It consists essentially of silica, alumina, calcium, and a little alkali and has the appearance of a decomposed rhyolite or trachyte, but its exact nature has not been more definitely determined. Throughout this white material, crystals of pyrite and parisite are scattered, generally isolated, but at times the parisite has grown over and partly or completely surrounded the pyrite crystals. The pyrite is crystallized in pyritohedrons modified by small faces of the cube and octohedron, and ranges in size from microscopic to 3 mm in diameter. The average size of the parisite crystals, which are quite numerous, is about 1 mm in diameter and 10 mm in length. The habit is horizontally striated hexagonal shafts made up of steep pyramids in oscillatory combination, terminated at the end by enlarged pyramids. The color is nearly uniform yellowish-brown."

## EDITOR'S NOTE

R. Lasmanis has duplicate specimens of parisite which, upon request, will be donated to geology departments of universities.

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FLUORITE, Plumosa Mtn Az., green cubic xls on matrix, 3in 1.75
METEORITE, Canyon Diablo Az., iron-nickel type 1in 5.00
COPIAPITE, Jerome Az., aggregates of micro xls 2in .90
BARITE, Hartsell Co., single blue xls 2in 1.00, 1in .40
VOLTAITE, Magma Mi Az., sharp xls in matrix, 1in 1.00
VANADINITE, Princess Mi Az., deep red xls on matrix 2in .85
NATROLITE, Horseshoe Dam Az., clear xls in basalt vugs 2in .85
AZURITE, Copper Basin Az., micro xls in tuffs on matrix, 2in .80
WULFENITE, Red Cloud Mi., 10-15mm single xls .75 to 1.50 each
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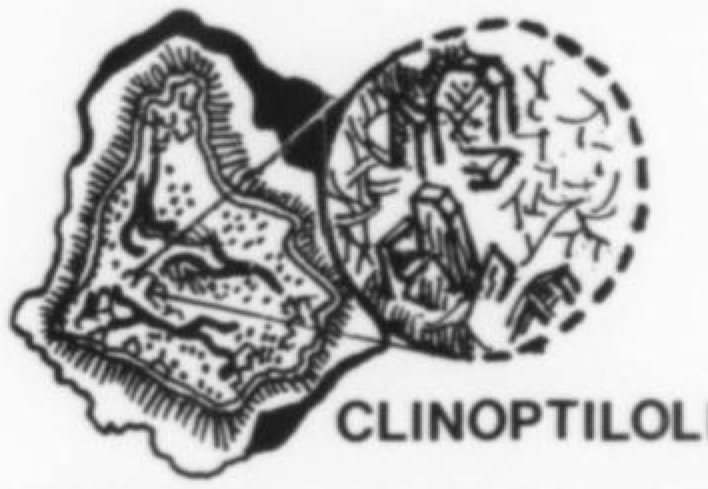

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# THE CLEAR CREEK PEGMATITE: A RARE EARTH PEGMATITE IN BURNET COUNTY, TEXAS

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## ABSTRACT

The author inspected in detail a 3-square-mile area east of Lake Buchanan, Burnet County, Texas, to study the geologic aspects of a concentrically zoned rare-earth-bearing pegmatite. The deposit has been mentioned only briefly in previous literature and never before named; the body is here referred to as the Clear Creek pegmatite, named for the small creek which runs immediately south of the area. The pegmatite occurs within the Valley Springs gneiss near the eastern margin of the Lone Grove granite pluton. The pegmatite body is pod-shaped with a quartz core surrounded by concentric but often discontinuous zones. These zones are: (1) wall zone of graphic granite, varying to gneissic in texture, (2) outer intermediate zone of biotite, zircon (cyrtolite), and perthitic microcline, (3) middle intermediate zone of larger perthite crystals, and (4) inner intermediate zone of quartz and microcline with uraninite, gadolinite, fergusonite, allanite, and other rare earth minerals. Crystallization is believed to have occurred inward from the pegmatite walls following the system of Bowen's reaction series.

Replacement is not evident at the Clear Creek pegmatite. However, extreme stages of alteration, especially of the rare earth minerals, are apparent. Allanite has weathered to bastnaesite, gadolinite to rowlandite, yttrialite, and behoite, and fergusonite to another form of bastnaesite. Several specimens of the mineral yttrocrasite were found, making the Clear Creek pegmatite the third known locality in the world for this rare mineral.

Pegmatite emplacement is believed to have taken place during the late pulses of the magmatic body which produced the Lone Grove pluton and the famous Baringer Hill rare earth deposit. The simultaneous emplacement theory is based on the comparative mineralogy of the two bodies. The rare earth deposits of this pegmatite are too small and varied to warrant any economical investigation other than that of the amateur weekend mineral collector.

## GEOLOGIC SETTING

Two rock types predominate in the area of the Clear Creek pegmatite: a Precambrian gneiss and schist and a younger Precambrian granite. A third Precambrian unit, the Packsaddle schist, occurs throughout the region but not locally at the pegmatite. Quartz-biotite-feldspar gneiss, granite gneiss, biotite schist, and impure metamorphosed limestone constitute the Valley Springs formation. The granite is part of the Lone Grove pluton complex and is known as the Town Mountain formation. The granite is conformable to the regional foliation of the metamorphic rocks and displays flow structures along the contacts. This consists of partial alignment of microcline crystals parallel to the contact. The most common set of joints is perpendicular to the contact. A contact zone of highly enriched alkali feldspar exists for approximately 460 metres from the western contact of the granite. The gneiss is partially granitized and constitutes a zone of major structural weakness. This zone has been subjected to minor east-west stresses and has been repeatedly folded and faulted, although almost entirely on a local scale. Quartz dikes are common, often filling fault-controlled fissures.

*Figure 1.* **Location of the Clear Creek pegmatite, Burnet County, Texas.**

## PEGMATITE STRUCTURE

The Clear Creek pegmatite is an irregularly shaped, internally zoned body approximately 250 m in length and 100 m in width. It is a relatively large complex and is closely similar to those described by Heinrich (1958). Quartz cores commonly represent the highest topographic feature though weathering of the entire body is evenly distributed. Areal plan diagrams are roughly elliptical and the body is thought to be ovoid in three dimensions. Miarolytic cavities are common in places in the pegmatite and contain euhedral crystals of smoky quartz and amethyst. Pegmatite feldspar is reddened, especially near the presence of radioactive minerals, and often is covered with a hematite or limonitic surface stain. No flow structure alignment is evident within the pegmatite. The pegmatite transects local quartz veins.

The zoning of the Clear Creek pegmatite is very irregular, though a concentric arrangment is still discernible. On the north and west sides of the body the pegmatite is essentially a mixture of large quartz and perthitic microcline crystals. Zones are best exposed on the eastern side, around the quartz core. Contact of the pegmatite with the country rock is sharp, though outer margins have often been enriched in quartz to form a margin 15 to 50 cm in width.

**The wall zone** is composed of graphic granite with some biotite laths, though these are small and not uniformly present. The graphic granite becomes coarser in texture toward the interior, with the quartz cuneiform figures being over 1.3 cm in length near the outer intermediate zone. Rare earth mineralization in this zone is confined to a few small crystals of zircon (cyrtolite).

The termination of the graphic granite marks the beginning of **the outer intermediate zone.** This is composed of small biotite flakes, perthitic microcline, and zircon (cyrtolite). Cyrtolite is the most common radioactive mineral present and is easily identified by three characteristics of the adjacent host rock alteration: (1) intense smokiness of quartz, (2) intense reddening of perthite, and (3) stepped compromise growth lines against the quartz crystals. Biotite is confined to small plates, unlike the large aggregate books described by Haynes (1965) in the South Platte, Colorado, region. Additional rare earth mineralization is confined to small euhedral crystals of fergusonite. These are found as small, slender prisms next to the biotite flakes.

**The middle intermediate zone** consists entirely of large perthite crystals. Quartz is less smoky in this zone than in any other part of the pegmatite. Small miarolytic cavities occur, lined with minute smoky quartz crystals. One piece of deep purple fluorite was found in one such cavity. The middle intermediate zone does not continue on the western side of the core and grades into the outer intermediate and graphic granite zones on this side.

**The inner intermediate zone**, unlike the complex zoned counterparts found in Colorado (Haynes, 1965), is composed basically of two minerals. These are perthitic microcline and quartz with the latter increasing in abundance near the core zone. Interspersed with the quartz and microcline are numerous rare earth minerals which often form inside cavities. The most abundant is the mineral allanite, which is always surrounded by heavily fractured smoky quartz. Without exception, the fractures tend to radiate outward from a central body of allanite. Both fresh and heavily weathered specimens were collected. Those exposed to weathering displayed a surrounding zone of bastnaesite. Fergusonite, gadolinite, yttrocrasite, zircon (cyrtolite), samarskite, and uraninite were also found. Many of the specimens represent isolated pockets often with euhedrally formed crystals. Along with the alteration of the rare earth minerals, heavy stains of both limonite and hematite were common inside the cavities. Fluorite and yttrian fluorite occur within this zone, but only as minor constituents and always near the outer margins toward the middle intermediate zone. Ilmenite and magnetite, minor constituents of the other zones, occur in increasing abundance near the rare earth minerals. Radiating fan-like structures of ilmenite over 2 cm in length were observed. As is the case in other rare earth localities of the region, the sudden abundance of one or both of these oxides is an excellent indicator for the presence of some type of radioactive or rare earth mineral. The inner intermediate zone is continuously concentric about the innermost core.

**The core zone** is without exception monomineralic, being composed solely of quartz. The quartz is mostly milky in color though both some smoky quartz and amethyst are present near the margins of the inner intermediate zone.

Replacement was not evident at the Clear Creek pegmatite, however, *in situ* alteration was quite common especially among the rare earth minerals. Wherever these minerals had been exposed to surface weathering conditions, zones of alteration had formed. Uraninite found on the surface always had a bright yellow-orange coating of "gummite" on it; much of the gadolinite had thin coatings of yttrialite, rowlandite, tengerite, and/or behoite; fergusonite had rims of bastnaesite; allanite also had coatings of well-formed bastnaesite. Often very little of the original allanite was left after alteration. The specimens of yttrocrasite found also had thin alteration rims of a metamict mineral but the altered state has yet to be identified. Among the rare earth species, only the minerals samarskite and zircon (cyrtolite) remained unaltered. The cyrtolite however, was observed to have altered internally by gradually losing its structural stability.

In addition to the rare earth alteration, hematite and limonite were found to impregnate cavities throughout the pegmatite and to replace biotite. Chlorite was also found near some of the hematite staining on the extreme margins of the pegmatite.

Once emplaced, the pegmatitic "magma" is believed to have crystallized inward following the reaction trend of Bowen due to the gradual removal of heat from the system. Zonal distinctions are based both upon textural and compositional differences. Compositional changes are probably due to fractional crystallization whereas the textural differences may be due to several factors, among which are temperature, water content, viscosity, and nucleation rates. The Clear Creek pegmatite is believed to be of late development in the magmatic history of the Lone Grove complex. Structure and mineralogy are identical to those of the famous Baringer Hill pegmatite, which lies some 3 miles to the east. Though more concrete evidence is required, it seems probable that the Clear Creek pegmatite was emplaced at approximately the same time as the Baringer Hill pegmatite. The development of zones and giant perthitic microcline crystals are a direct response to the post-emplacement fall in temperature.

## PEGMATITE MINERALIZATION

Twenty-eight minerals have been identified at the Clear Creek pegmatite. Fifteen of these have been classified as rare earth or radioactive species, and are thus of primary interest. A brief description of each follows:

**Quartz** is the most abundant mineral in the pegmatite and occurs in all zones, though it is most prominent in the core and inner intermediate zones. It is generally milky in color but is intensely smoky when near rare earth minerals. Small crystals of amethyst are also present.

**Microcline** is the dominant feldspar in the pegmatite. It is most evident in the intermediate zones as perthite—the result of an unmixing of albite with potassium feldspar due to decreasing solubility between the two as the temperature within the pegmatite was lowered. It is generally pink in color except when in contact with radioactive minerals which turn the microcline brilliant red.

**Albite** is not abundant by itself but is present wherever the perthite has formed.

**Biotite** occurs as small flakes and is most common in the exterior zones of the pegmatite. A small quantity has been replaced by hematite.

**Magnetite** is present throughout the pegmatite but becomes locally abundant as the percentage of rare earth minerals increases. It is widespread in the inner intermediate zone as black anhedral masses often reaching 1.5 cm in length.

**Ilmenite:** the occurrence is identical to that of magnetite. Ilmenite forms fan-like structures, many over 2 cm in length. Both magnetite and ilmenite weather easily and have formed considerable unconsolidated deposits on the surface of the inner intermediate zone.

**Hematite** occurs throughout the pegmatite, most commonly as a surface alteration stain. It replaces biotite in graphic granite zones, and stains cavities filled with rare earth minerals.

**Limonite:** the occurrence of limonite is similar to that of hematite: a surface gossan stain.

**Chlorite** occurs on the extreme margins of the pegmatite, presumably as an alteration of biotite.

**Fluorite:** small crystals of deep purple fluorite were found near the outer margin of the middle intermediate zone. No relationship to the rare earth occurrence could be detected. The lack of large masses of fluorite is the primary difference between the Clear Creek site and the large rare earth pegmatites of the South Platte region, Colorado.

Several very small pieces of purple yttrian fluorite were found within the pegmatite. These are usually not in any particular association and are a very minor constituent of the rare earth assemblage.

**Pyrolusite:** this mineral occurs as small dendritic stains on the surface of the outer margins of the pegmatite.

**Pyrite** can be found as small crystals of ½ mm size in the graphic granite zone of the pegmatite.

**Spessartine:** two small, euhedral trapezohedrons were found in the exterior margin of the graphic granite. The garnet composition was confirmed by optical analysis.

**Allanite** occurs in quartz inside the inner intermediate zone; it causes radiating fractures in the surrounding quartz. Both crystals and large black masses up to 200 grams in weight were found. Allanite is common near the surface of the pegmatite, where it has been severely altered by surface exposure.

**Bastnaesite** occurs as alteration coatings on both allanite and fergusonite. Many of these coatings have completely replaced the original crystals.

**Zircon** *(cyrtolite):* both structurally undeformed zircon and cyrtolite were found in the pegmatite, the former in the graphic granite zone and the latter in all three intermediate zones, often in large red-brown crystal masses. These crystals all had the characteristic curved faces of radioactively damaged zircon.

**Gadolinite:** next to allanite, gadolinite is the most abundant rare earth mineral in the pegmatite. It is associated with large feldspar masses and occurs as both large, black shiny masses and as crude crystals. One of these was over 15 cm in length and displayed the complete crystal form of gadolinite.

**Tengerite** occurs as a thin white alteration rim on some of the pieces of gadolinite exposed on the surface of the pegmatite.

**Yttrialite, Rowlandite:** both of these minerals have formed as alterations of gadolinite, occurring as thin fillings within internal fractures of large anhedral masses.

**Behoite** occurs as the most common alteration rim mineral on the masses of gadolinite.

**Uraninite** found in the Clear Creek pegmatite is extremely rich in rare earths and lead, and somewhat depleted in uranium (this variety was called *nivenite* by Hidden, 1889). It is a minor constituent of the pegmatite but occurs in euhedral cubes up to 1 cm on a side.

**Gummite** is the collective term given to the yellow-orange alteration stains that form around the small crystals of uraninite. Several undetermined species are present.

**Samarskite** occurs as very small masses, often associated directly with gadolinite and fergusonite. These are always very minor but amazingly free of alteration.

**Fergusonite** occurs in combination with cyrtolite, gadolinite, and uraninite. Large masses are uncommon, but small, slender, prismatic crystals do occur near biotite plates. External alteration is common, forming a buff-colored material which has been identified as a variety of bastnaesite.

**Yttrocrasite**, associated with allanite, gadolinite, and fergusonite, occurs as a minor rare earth constituent of the inner intermediate zone. Two small crystals were found which have been the subject of a previous paper (Crook, 1976). Both specimens found had an alteration coating similar to that on fergusonite, but whether or not this is a new species is not certain at this time.

## ECONOMIC ASPECTS

The Clear Creek pegmatite, though probably the largest remaining source of rare earths in the region, is still too small and varied in content to warrant any economic interest. Though high radiation counts may be obtained, they are local in nature and do not represent a sizable quantity of ore (for example, gadolinite masses weighing over 90 kg and allanite masses of 130 kg were found at Baringer Hill whereas no piece over 0.2 kg was recovered from the Clear Creek pegmatite). Therefore interest in the Clear Creek pegmatite must be confined to geologic study and the enjoyment of the amateur mineral collector.

## CONCLUSION

The rare-earth-bearing pegmatites of the Llano-Burnet region developed in the late magmatic history of the eastern margins of the Lone Grove pluton. Though further investigational evidence is required, it is believed that the Clear Creek pegmatite was emplaced at a time similar to that of the Baringer Hill locality. Primary zonation and the development of large crystals are believed to be the product of fractional crystallization in response to the drop in temperature and continual enrichment of residual magmatic fluids.

Other rare earth locations in the region consist only of minor deposits, with the one exception of the Rode Ranch pegmatite, a similar Baringer Hill-type deposit (Ehlmann, 1964). Present field relations at the Rode Ranch, when compared to early reports on the Baringer Hill locality, suggest that there is a higher content of mineralization of rare earth elements near the margin of the Lone Grove pluton. However, personal confirmation is now impossible since Baringer Hill has been flooded by the construction of Lake Buchanan. Rare earth mineralogy of the Clear Creek pegmatite is identical with that of Baringer Hill, with the notable exception of the presence of the mineral yttrocrasite. Considering that yttrocrasite is known to occur at only two other localities in the world, its presence at the Clear Creek pegmatite is significant.

The interpretation of the magmatic history of the region suggested here is at best speculative. Detailed work on the Lone Grove pluton and its relationship to the pegmatites is needed. Perhaps then the age of pegmatite emplacements can be conclusively determined, and will allow a more complete understanding of this singularly important pegmatite province.

## ACKNOWLEDGEMENTS

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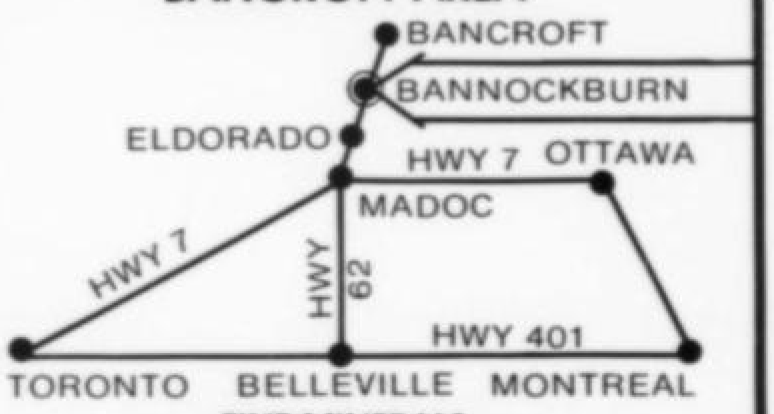

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# THE HELVITE GROUP*

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**Department of Mineral Sciences**
**Smithsonian Institution**
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## *INTRODUCTION*

The helvite group consists of three isomorphous species; helvite $Mn_4Be_3(SiO_4)_3S$, danalite $Fe_4Be_3(SiO_4)_3S$, and genthelvite $Zn_4Be_3(SiO_4)_3S$. Manganese, iron, and zinc substitute mutually in the structure, and most samples are mixtures of the three end-members in varying proportions.

They are an uncommon group of minerals, usually occurring in tactites and scarns (helvite and danalite) and coarse-grained granites and syenites (danalite and genthelvite).

## *MORPHOLOGY AND DISTINGUISHING CHARACTERISTICS*

Crystals of the species in the helvite group are usually euhedral and frequently occur in rather sharp, well-defined isometric habits. The predominant habit is tetrahedral (Figure 1). The crystals are usually in random intergrowth, but the tetrahedral habit is easily observed. The positive tetrahedron $\{111\}$ is usually modified by the negative tetrahedron $\{1\bar{1}1\}$; the combination giving the appearance of an octahedron (Figures 2 & 3). Any confusion is easily cleared up as the luster on the two tetrahedra are distinctly different, whereas on an octahedron they would be identical. Other common modifying forms are the dodecahedron and cube, also exhibiting different lusters.

Less well-crystallized members of the helvite group resemble garnets. Although the above morphological observations suffice to determine the nature of well-crystallized specimens, it is, at first glance, very difficult to characterize anhedral grains. Refractive index determinations are of limited use since the refractive indices of iron-bearing members overlap those of garnets in the pyrope-almandine series and both the garnet and helvite groups are isotropic. Color is of little use; danalite is always brownish-red and helvite and genthelvite with more than a third of the danalite component are also reddish in color. The purest known natural genthelvite is light green to yellowish-green, and pure helvite is yellow. The most obvious characteristic of the helvite-group minerals one can test for is the moderately strong sulfur odor which is released when they are powdered. X-ray data for pure helvite and genthelvite have been published (Dunn, 1976) and x-ray powder patterns can sometimes be used to characterize an unknown member of the group. Samples with a cell-edge less than 8.14Å are usually zinc-rich (genthelvite), and samples with a cell-edge greater than 8.23Å are usually manganese rich (helvite). Samples with cell-edge between 8.14Å and 8.23Å are usually iron rich but need other supporting data for responsible characterization.

## *CHEMISTRY*

The miscibility between danalite and helvite was well-established by Glass *et al* (1944), but the miscibility between these two members and the zinc member, genthelvite, was not established. This study (Dunn, 1976) was initiated to determine the miscibility between the three end-members. Seventy-five samples in the U.S. National Museum of Natural History and the Harvard Geological Museum were partially analyzed with an ARL SEMQ electron microprobe. A plot of these analyses and those from the literature is presented in Figure 4 and demonstrates complete miscibility between helvite and danalite and between danalite and genthelvite. The absence of manganese-zinc mixtures is still unexplained, and may be due to a structure incompatibility.

## *END-MEMBERS*

During the course of this study, two heretofore unknown "pure" end-members of the group were discovered.

***Figure 1.* Helvite, Saxony, Germany (photo by Ben Chromy).**

***Figure 2.* Genthelvite from Cookstove Mountain. El Paso County, Colorado (NMNH #113108) (26 x 9 mm).**

---

*A synopsis of a paper entitled "Genthelvite and the Helvine Group" published in *Mineralogical Magazine* **41** (in press) (1976)

A brief description of their occurrence is warranted. Two new occurrences for genthelvite, the rarest member of the group are described.

### GENTHELVITE

Pure crystals of this mineral, the zinc-rich end-member of the group, were found in 1970 in the De-Mix quarry, Mt. St. Hilaire, Quebec, Canada, by Quintin Wight, a noted Canadian micromounter. The crystals occurred as colorless, rounded, tristetrahedra (1.0 mm) implanted on microcrystals of wurtzite. This association, although unique, is quite appropriate in the "comfortable chemistry" point-of-view inasmuch as both minerals contain zinc and sulfur. Several years later, additional samples of abundant genthelvite were collected by John Stewart of Boston University in the De-Mix quarry. They occurred as light green and buff-colored sharp, euhedral, crystals (up to 3 mm) associated with acmite, serandite, natrolite in the "usual" Mt. St. Hilaire assemblage. Both the initial and subsequent occurrences are very pure, with less than 1.00% MnO and FeO combined. It is both notable and interesting that Mt. St. Hilaire, unlike other localities where helvite group minerals have occurred, has, to date, generated only relatively pure end-members of the group, and not the isomorphous mixture found at other localities. A helvite from Mt. St. Hilaire, bright yellow in color, contained only 1.51% FeO and ZnO combined.

### HELVITE

A relatively pure helvite occurs in rhodonite from the East Moulton mine, Butte, Montana, and also at the Lexington mine at the same locality. The crystals are very small (less than 1.0 mm) and occur as anhedral blebs in massive rhodonite in both mines. The material is the purest to date, having only 0.73% FeO and ZnO combined. This helvite has no visual appeal and is quite rare at the locality.

### DANALITE

No pure end-members were found, but a crystal from the Iron mine in Barlett, New Hampshire, did contain 86% of the iron component.

### NOTES ON OTHER OCCURRENCES

#### Rhode Island

During the mid-1960's large rough crystals of "danalite" were recovered from the granites in Cumberland, Rhode Island. Some of this material was collected by Gilbert George, an expert on Rhode Island mineralogy. Analysis of many Cumberland specimens indicates that they are almost all zinc-rich and thus genthelvite! Several large crystals (5-6 cm) have been found here, but the quality of the material is lower than the superb Colorado crystals.

#### Colorado

The finest genthelvites found to date are the splendid crystals (Figure 2) originally described by Scott (1957) and the crystal which was described by Glass and Adams (1953). Neither of these excellent display-quality crystals had been analyzed before this study. Both have now been analyzed; they were found to be zinc-rich and thus genthelvite. It is indeed ironic that the crystal described by Glass and Adams (which was the largest genthelvite crystal known until the Rhode Island occurrence) has zinc just barely predominant over iron and so just barely missed being termed a danalite!

In summary, genthelvite and danalite are completely miscible, as are danalite and helvite. Relatively pure genthelvite is known from Mt. St. Hilaire and relatively pure helvite from Butte, Montana. Although not common in collections, specimens of these minerals are occasionally available when old collections are broken up and redistributed via the marketplace.

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***Figure 3.* Line drawing of the crystal in figure 2 from Scott, 1957).**

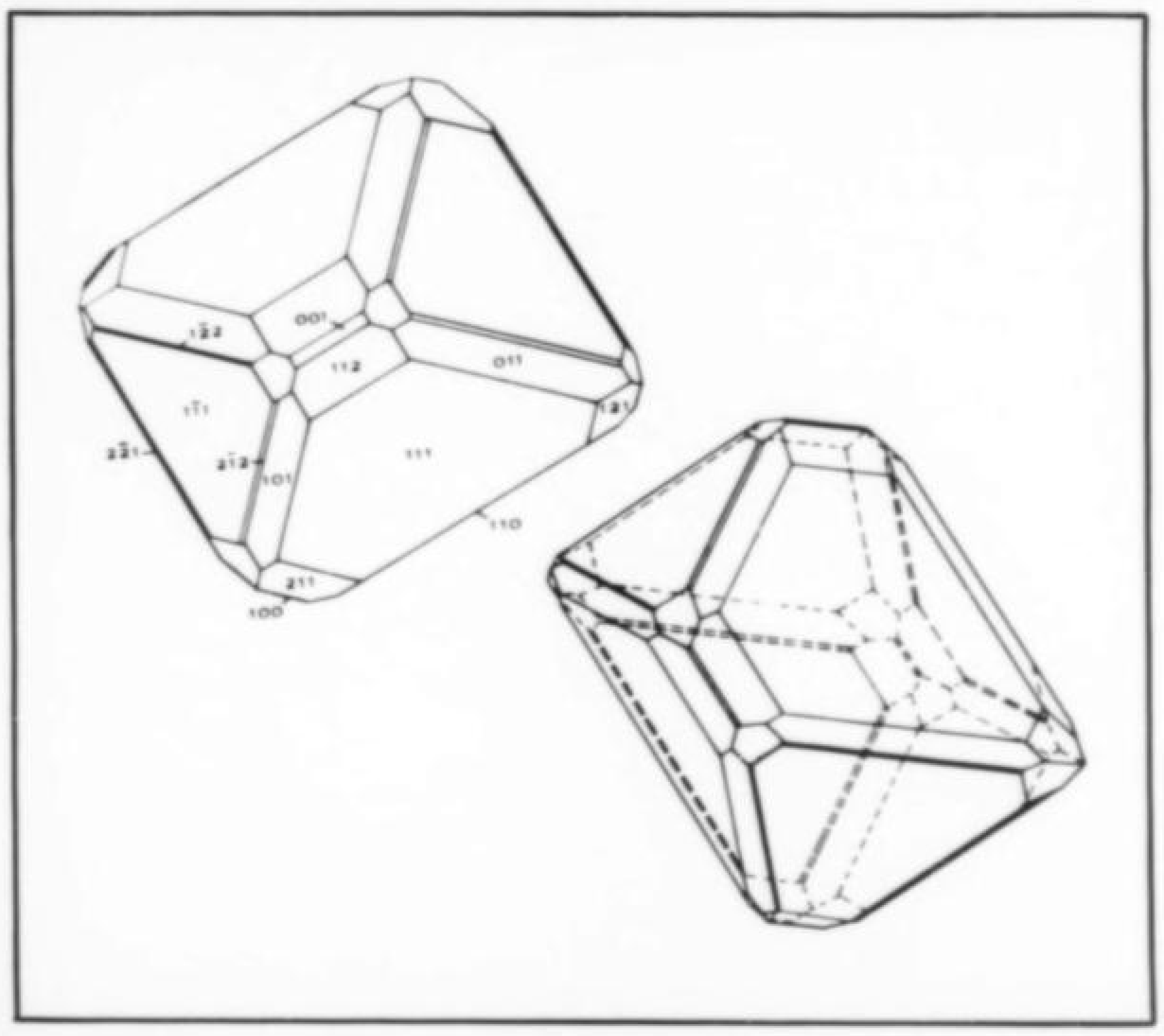
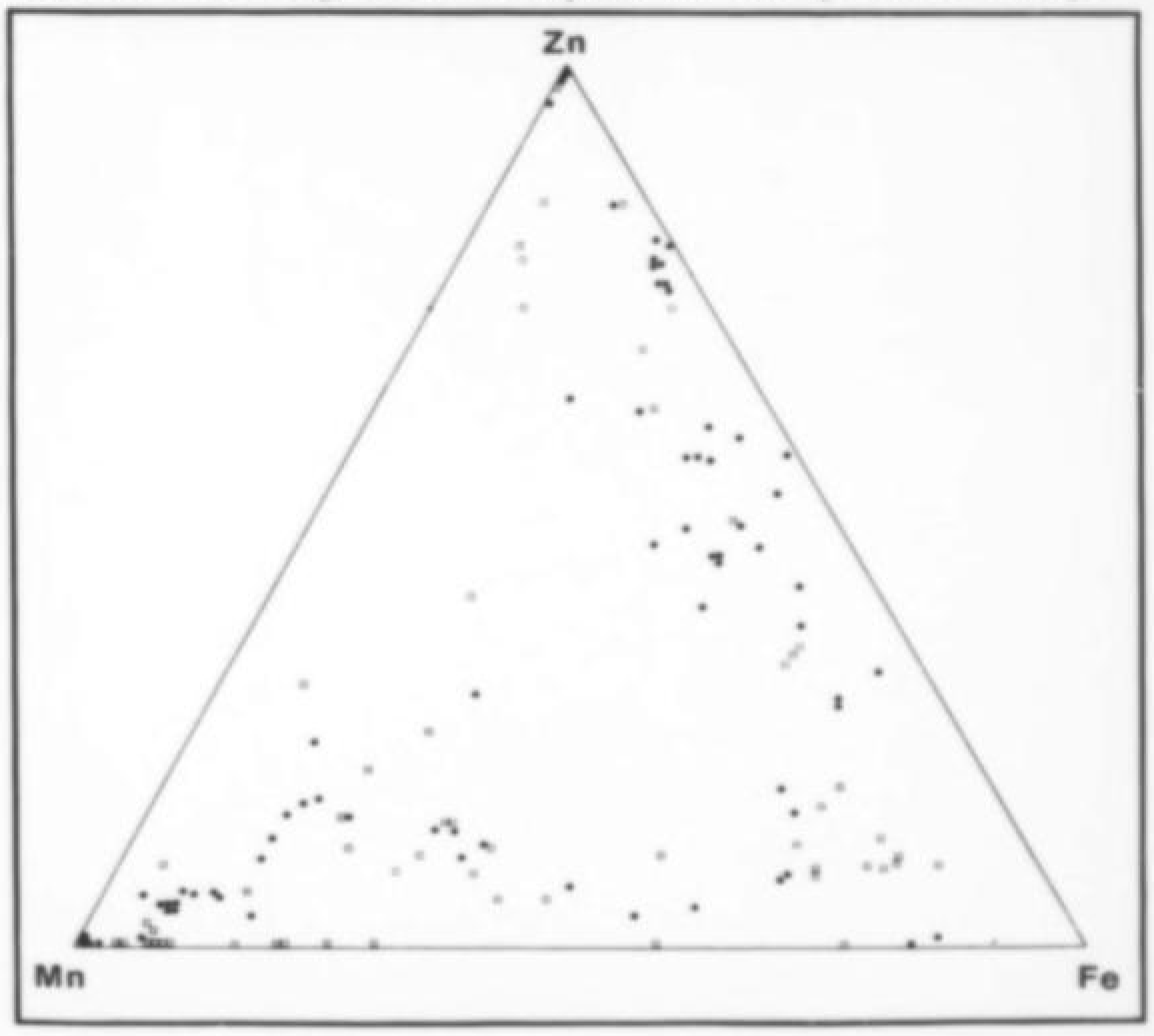


***Figure 4.* Plot of analyses of helvite group minerals. Square dots represent analyses from the literature and round dots represent analyses of the present study.**



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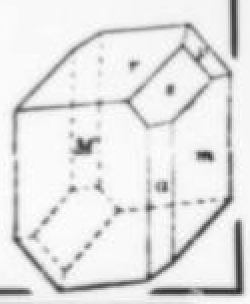

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# LITHIOPHILITE CRYSTALS FROM THE FOOTE MINE

by
R.W. Thomssen
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## INTRODUCTION

Lithiophilite, formerly known only as primary crystals intergrown with feldspars and quartz in pegmatites, occurs as free-standing, euhedral crystals in fissures cutting pegmatites at the Foote Spodumene mine, near Kings Mountain, Cleveland County, North Carolina. These clear crystals, which are of a striking sherry color, were found in 1966 by the late Kent C. Brannock and identified by John S. White, Jr., in 1967. The mineral was characterized at that time as being a relatively iron-free end member of the lithiophilite-triphylite isomorphous series, on the basis of refractive indices determined by Peter B. Leavens. Subsequently, additional material was collected by one of us (RWT) and Jack Eaker of Kings Mountain. Eaker found several V-shaped crystal pairs which proved upon measurement to be twins. This is the first twin law reported for the species.

An electron microprobe study of a number of minerals from Kings Mountain, made in 1969, showed the lithiophilite to be essentially iron-free $LiMnPO_4$. This paper presents the results of further examination of this unique find.

## PREVIOUS WORK

Lithiophilite was first described from Branchville, Connecticut, by George J. Brush and Edward S. Dana (1878). The original material occurred as irregular rounded masses of a light salmon color, 1 to 3 inches across, enclosed in albite, and coated by a black oxidized crust. Some of these masses resembled single crystals, although the authors did not identify crystallographic forms.

Numerous additional occurrences of lithiophilite, all as a primary mineral in granite pegmatites, have been described since the initial work by Brush and Dana. In all cases lithiophilite (Mn >Fe) and the isostructural mineral triphylite (Fe >Mn), which form a complete substitutional series, have been found so intergrown with feldspar and quartz that recognizable crystal forms are seldom observed. The species is commonly altered surficially, as was the Branchville material, so that only crude evidence of crystal forms is preserved.

## OCCURRENCE

An open pit mine in a pegmatite swarm near Kings Mountain is operated by the Foote Mineral Company, primarily for spodumene. The mining operation and the local geology have been described by Kesler (1961). The pegmatites, as much as 2000 feet long and 200 feet thick, trending slightly east of north and dipping steeply and irregularly both east and west, were intruded into thin-layered amphibolite and fine-grained mica schist. Core drilling results indicate that although the dikes are roughly tabular many are complexly connected at depth.

The pegmatites show almost no zoning and are remarkably uniform in mineralogy and texture. Spodumene was the earliest mineral to form with muscovite, microcline, and albite plus quartz, following in that order. The earlier-formed minerals are broken and veined by a fine-grained equigranular intergrowth of albite and quartz. Spodumene crystals approach euhedral form only where they are included in randomly distributed small bodies of massive quartz. These relationships suggest that the pegmatites were intruded and completed crystallization during a period of active regional deformation which prevented the retention of concentrically zoned internal structure typical of lithia-rich pegmatites.

After the spodumene pegmatites had crystallized, the pegmatites and the adjacent wall rocks were both cut by subparallel fractures. These fractures, which are mostly extensional or dilational in character, are essentially perpendicular to the N15°W strike of the pegmatites and dip steeply to the southwest.

A common derivation appears probable for these transverse fractures and the fractures containing northwesterly-trending dikes within the southwestern segment of the Appalachian region, as described by Philip B. King of the U.S. Geological Survey (1961). King concludes that these dikes "probably reflect the deep-seated tensile stresses that existed during Late Triassic time." This event fixes a maximum age on the minerals which have crystallized within the fractures and suggests a lapse of 200 million years between the formation of the pegmatites in the Devonian and the transverse fractures in the Late Triassic.

Lithiophilite and a number of alkali-bearing phosphates and silicates, including the new species, switzerite, brannockite, and eakerite, line cavities within the transverse fractures. Several carbonates and sulfates, as well as the new hydroxide species tetrawickmanite, formed late and are perched on the earlier species. Albite and quartz, which formed first on the walls of the fractures, together make up more than 90 percent of the vein material. A vividly dichroic, pinkish brown apatite is the most common phosphate present and is a constant associate of lithiophilite.

*Figure 1.* **Plot illustrating the variation of indices of refraction with iron and manganese content of some minerals in the lithiophilite triphylite series.**

Crystals of lithiophilite appear to have formed in only a small number of pockets in one, or possibly two, closely associated, sub-parallel veins exposed on bench 11. A little was also found on bench 10 and, possibly, on bench 12, suggesting a known vertical range of about 40 feet. The coordinates of the find, taken from the mine map, are 10,000N and 10,315E. The occurrence falls on section 10N in the center of the pit (Kesler, 1961).

It is of interest to speculate on the origin of the chemical components comprising the minerals, such as lithiophilite, which are now found within the transverse fractures. The original pegmatite minerals, including spodumene, apatite, and the alkali feldspars albite and microcline, contain all the components required to produce the later fracture minerals except for water, carbonate, and sulfur. If it is assumed that after consolidation these pegmatites and their wallrocks were saturated with an interstitial aqueous solution containing some dissolved carbonate and sulfur, this fluid might also have been the agent to dissolve and transport components of the primary pegmatite minerals. This solution could migrate interstitially into and through the open fractures in the pegmatites. Dissolution of the primary pegmatite minerals might occur under the influence of the modified physical conditions. Crystallization of new species would be initiated in the transverse fracture cavities as a result of the complex interplay of continually varying pressure, temperature, and solution concentration as the entire system approached equilibrium. This process may have been analogous to the formation of Alpine veins within the crystalline massifs of the Swiss Alps, as described by Robert L. Parker (1960).

**TABLE 1.**

Physical Properties of Kings Mountain Lithiophilite

| Optics: | Refractive indices (white light) |
|---|---|
| Opt. sign (+) | $\alpha$ =1.665 ±0.002 |
| 2V =70° | $\beta$ =1.667 ±0.002 |
| Dispersion r<v strong | $\gamma$ =1.674 ±0.002 |
| Orientation X = *c* | |
| Y = *a* | |
| Z = *b* | |
| Specific Gravity: | |
| (Meas.) 3.445 ±0.006 at 22°C. | |
| (Calc.) 3.433 g/cm$^3$ | |
| Unit Cell Dimensions: | |
| $a_0$ = 6.094 ±0.005 Å | |
| $b_0$ =10.427 ±0.005 Å | |
| c° = 4.743 ±0.001 Å | |
| a:b:c = .5844 : 1 : .4549 | |

That conditions within the transverse fracture cavities did not readily attain a general stability is reflected in the dissolution and redeposition of some lithiophilite to yield delicate crystal clusters. This secondary lithiophilite partly fills cavities under and within apatite from which the early or primary lithiophilite has been leached. It differs from the early generation of crystals only in being more slender and having a simpler habit.

## OPTICAL PROPERTIES, SPECIFIC GRAVITY, AND UNIT CELL DIMENSIONS

The optical properties of Kings Mountain lithiophilite were measured using the spindle stage. The results, which confirm the initial findings of Peter Leavens, are reported in Table 1. In Figure 1 these refractive indices and the indices of some other members of the lithiophilite-triphylite series (Palache et al., 1951) are plotted against their iron and manganese contents. The essentially linear dependency of refractive indices on cation content is apparent.

The specific gravity (3.445 ± 0.006) was measured by the sink-float method in diluted Clerici solution monitored by a Westphal balance. This result is 0.1 higher than the value found by Zambonini and Malozzi (1931) on artificial material. However, these authors noted black inclusions in crystals obtained by both fusion and pneumatolytic methods of synthesis, and their value is probably inferior to that obtained in the present study. The unit cell parameters, derived from least-squares refinement of measurements from Weissenberg X-ray photographs, lead to the calculated density of 3.433 g/cm$^3$, in good agreement with the measured specific gravity.

## CRYSTALLOGRAPHY

The largest of the Kings Mountain lithiophilite crystals are euhedral, about 0.08 inch (2 mm) in length, and elongated along the *a* crystallographic axis. The principal faces in the striated [0kl] zone are {021}, {011}, and {010}. Characteristically, the best developed and most perfect of the forms at the extremities of the elongated crystals is {111} which, interestingly enough, had not been reported previously. Terminal forms also noted are {100}, {110}, {130}, and {140}. Many crystal fragments show the excellent front pinacoidal cleavage {100}. The secondary lithiophilite crystals mentioned previously differ from these earlier formed crystals in being less bulky and in characteristically showing a greater ratio of length to breadth. These secondary crystals are also elongated on the *a* axis but typically display only the forms {021}, {111}, and {100}.

Handsome, well-formed simple contact-twinned crystals are joined on {130}, as illustrated in Figure 2. This is the first twin law reported for either lithiophilite or triphylite. An unusual aspect of the twinned crystals is that no measurable goniometrical signals were observed which correspond to the slope of the large, habit-controlling terminal forms of the kind {hk0} seen on all the twinned crystals (Figure 2). Close examination of these surfaces reveals that they are of inferior quality and are striated by alternating tiny faces of the forms {100} and, probably, {140}. Together, these forms make up a "pseudo-form" whose slope corresponds to {110}.

## COMPOSITION

The results of corrected electron microprobe analyses of the two types of lithiophilite from Kings Mountain are shown in Table 2. Initial uncorrected microprobe analyses on this material indicated that the FeO content was less than 0.2 percent and, together with the early optical work of Peter Leavens,

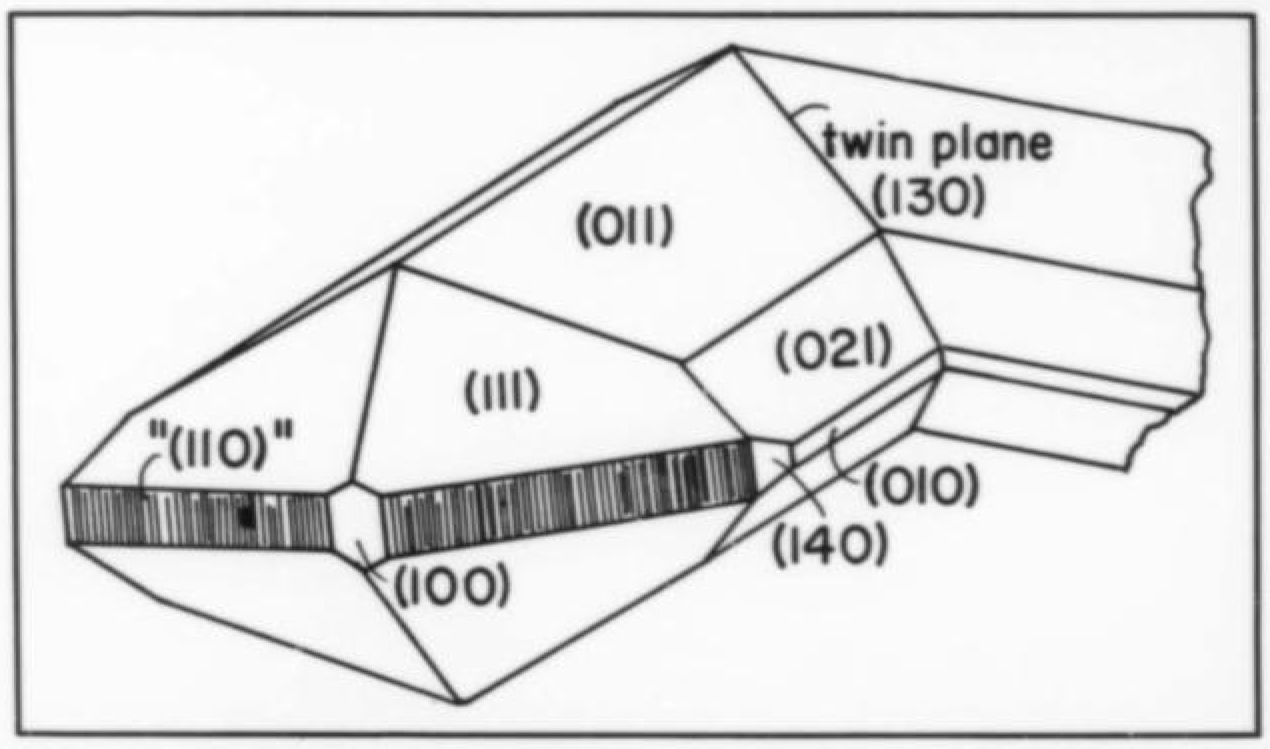

***Figure 2.* Modified axonometric projection of a portion of a twinned lithiophilite crystal. (The projection makes the angle between the twinned individuals seem larger than the 60 degree value.)**

established the Foote mine lithiophilite as being essentially the manganese end member of the lithiophilite-triphylite series.

A search for non-stoichiometric impurities disclosed the remarkable, notably low, iron content of the Foote mine lithiophilite. Associated dark burgundy apatite on specimen USNM 126995 was found to contain FeO - 0.06, MnO - 0.81, SrO - 1.26, F - 0.14, with alkalis other than CaO all well under 0.1 percent. As noted by J. S. White, Jr. (personal communication, 1975), this MnO content is low for much of the Foote mine apatite. A distinct partition of manganese and strontium is evident between apatite and lithiophilite within the transverse veins.

## ACKNOWLEDGMENTS

Peter B. Leavens carried out the initial optical investigation of the lithiophilite crystals. Joseph Nelen (Smithsonian Institution) performed the microprobe analyses. Mrs. Peter Galli translated the pertinent section on specific gravity determination in the Zambonnini and Malozzi article. Jack W. Eaker, Kings Mountain, North Carolina, lent us the twin crystals for study and supplied detailed data concerning the occurrence of lithiophilite within the Foote mine open pit. Their assistance is gratefully acknowledged. Discussion and editorial assistance from John S. White, Jr. contributed significantly to the completion of this study.

*Figure 3*. **Lithiophilite twin viewed along the *c* axis.** Julius Weber

**TABLE 2**

Microprobe Analysis of Lithiophilite, Kings Mountain, North Carolina

CONDITIONS: 15KV; 0.15 UA; SMALL BEAM

STANDARDS: Manganite Mn-value 62.4%
Durango Apatite P-value 18.6%

APPLIED CORRECTIONS: Background and Bence/Albee (Anal. Chem. *42*, pp. 1408-1414)

SAMPLES: (1) Lithiophilite NMNH 126995)-prismatic, early crystals
(2) Lithiophilite-needle-like, secondary crystals

ANALYST: J. Nelen, National Museum, of Natural History, Washington, D.C.

| | (1) | (2) |
|---|---|---|
| $Li_2O$ | — | — |
| MnO | 46.1 | 46.4 |
| FeO | 0.18 | 0.16 |
| $P_2O_5$ | 46.3 | 44.5 |
| $SiO_2$ | 0.06 | 0.09 |
| $Al_2O_3$ | 0.03 | 0.07 |
| TOTAL | 92.7 | 91.2 |

Average of analyses on ten spots. $Li_2O$ not detectable by microprobe. Other components sought and found to be generally below detection limits: MgO, CaO, SrO, $K_2O$, and $Na_2O$. $SiO_2$ and $Al_2O_3$ should be considered $< 0.1\%$.

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# Uvite,

## a New (Old) Common Member of the Tourmaline Group and Its Implications for Collectors

by
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**Department of Mineral Sciences**
**Smithsonian Institution**
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## INTRODUCTION

Tourmaline is a name applied to a group of mineral species consisting of elbaite, dravite, schorl, buergerite and uvite. Although these species all have very similar crystal structures and appearance, they comprise a broad range of chemical compositions. Tourmalines are found in many different environments. They repose in most mineral collections and are popular with collectors because they occur in a variety of colors and because they frequently form euhedral crystals.

The chemistry of the tourmaline group was a cause of much bewilderment to early chemists and mineralogists. This early confusion led Ruskin (1891) to mention in discussing tourmaline, that "on the whole, the chemistry of it is more like a medieval doctor's prescription, than the making of a respectable mineral."

The tourmaline group, until recently, has usually been said to consist of only four species: elbaite, schorl, buergerite and dravite. These conform to the general formula for the tourmaline group: $Na(R)_3Al_6B_3Si_6O_{27}(OH,F)_4$. The above species designations have been made on the basis of the dominant element in the *R* position of the formula, which may be either lithium/alumium (elbaite), ferrous iron (schorl), ferric iron (buergerite), or magnesium (dravite).

Inasmuch as there is broad and extensive substitution of elements in the tourmaline group, few tourmaline specimens have been found to be pure end-members. Most tourmaline crystals are, in fact, mixtures of two or more species. Iron can exist in either the ferrous or ferric state and is frequently found in both oxidation states within the same crystal. Both simple and coupled substitution mechanisms can also be present simultaneously.

Those tourmalines in which calcium occupies the site usually filled with sodium have been largely ignored.

Dravite crystals with a significant calcium content were reported as early as 1888 (Riggs) but chemists and mineralogists had not yet agreed on a satisfactory formula for tourmaline. High-calcium dravites were ignored in the quest for an ideal formula to encompass the majority of tourmaline analyses. The excellent analyses of Riggs (1888) and his insights into the chemistry of this complex group, coupled with the definitive work of Kunitz (1929), shed much light on tourmaline chemistry and gave us many of the species designations in use today.

In preliminary work, microprobe chemical analyses of many gem quality brown tourmalines showed that they were almost all calcium-rich, and many had little or no sodium. Considering that much dravite is formed in metamorphosed limestones where calcium is abundant, it seemed likely that other dravites might also be calcium-rich. A detailed examination of dravite appeared necessary so the present study was initiated.

Kunitz (1929) proposed a theoretical end-member, $H_8Ca_2Mg_8Al_{10}Si_{12}B_6O_{62}$, which may be rewritten as $\mathbf{CaMg_3(MgAl_5)B_3Si_6O_{27}(OH)_4}$ to conform to the general formula cited previously. Kunitz proposed this molecule to explain the existence of analyses of three calcium-rich magnesium tourmalines from Ceylon, Gouverneur, New York, and DeKalb, New York. He named this proposed theoretical end-member "uvite" for the province of Uva of Ceylon (Sri Lanka).

We have demonstrated that uvite does exist in nature and that is is a valid end-member in the tourmaline group. We have shown that there is complete miscibility between dravite and uvite and that uvite is the exact calcium analog of dravite.

Uvite was submitted to the IMA Commission on New Minerals and New Mineral Names for approval. It was the judgment of the Chairman of the Commission that the term "uvite" was already well-established in the literature, and thus was out of the jurisdiction of the Commisson.

## PREVIOUS WORK

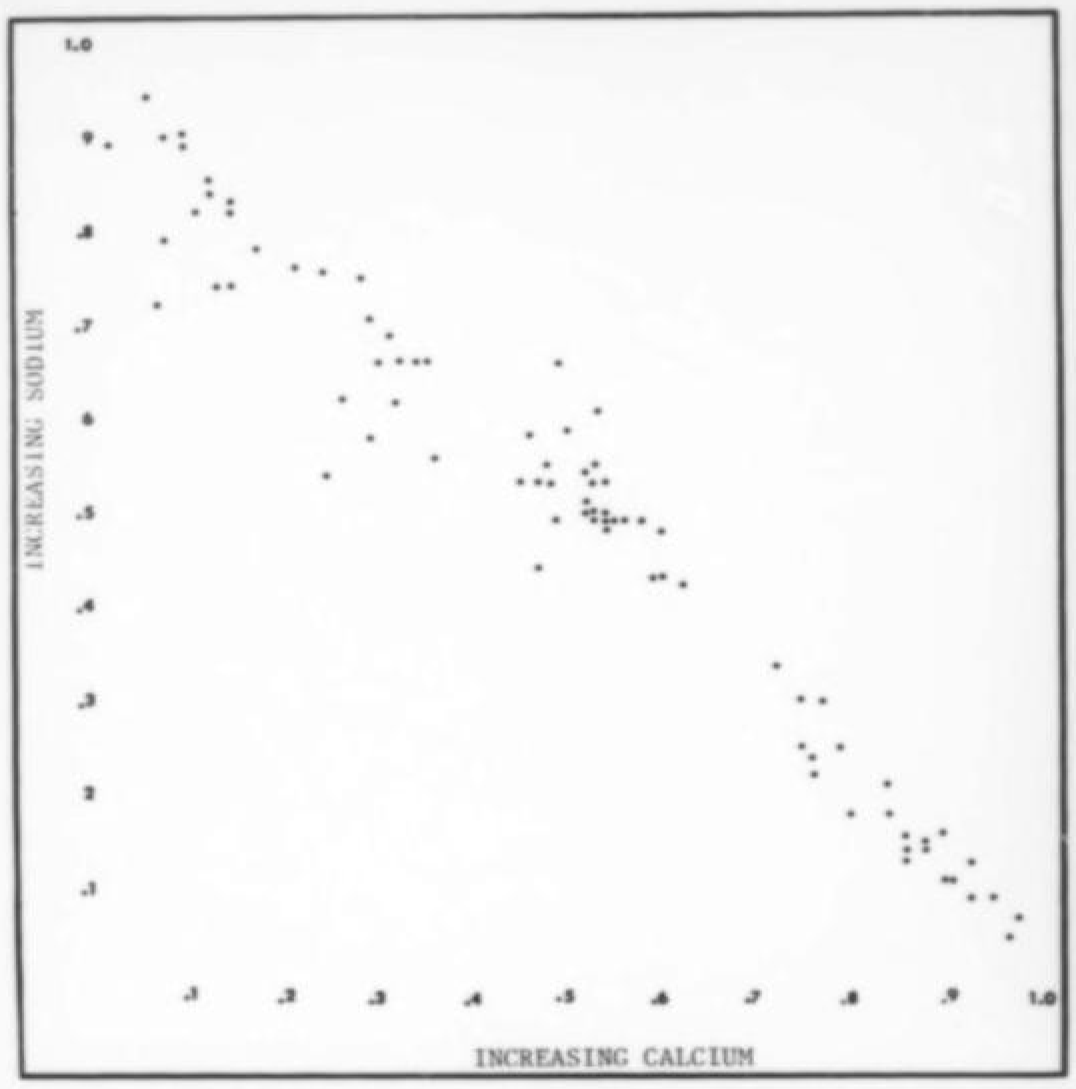
Various investigators have reported calcium-rich magnesium tourmalines. A tabulation of these is presented as Table 1. The analyses are arranged in order of decreasing calcium content. The analysis of Sargent (1901) is anomalous in view of its reported high sodium *and* calcium content.

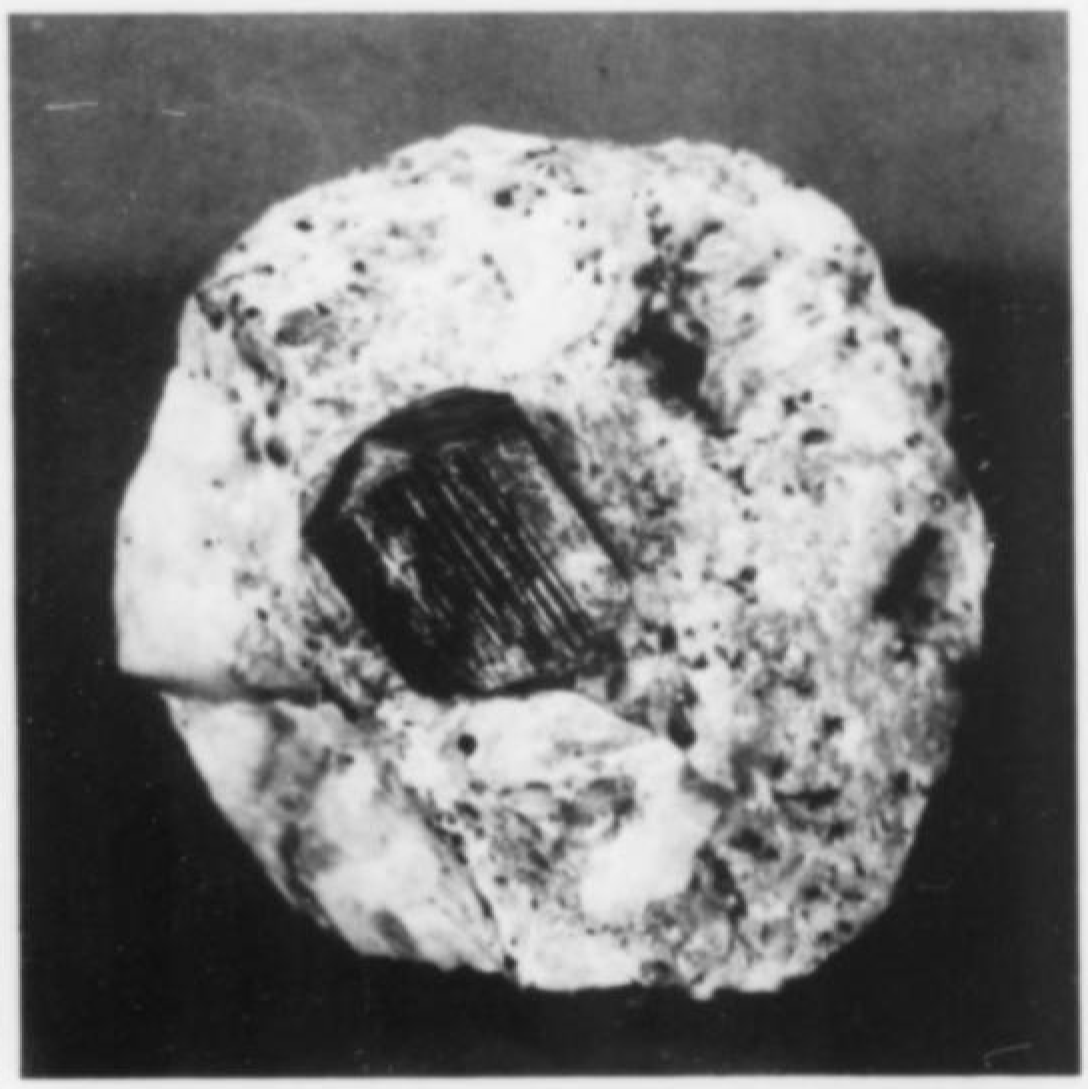
## MORPHOLOGY

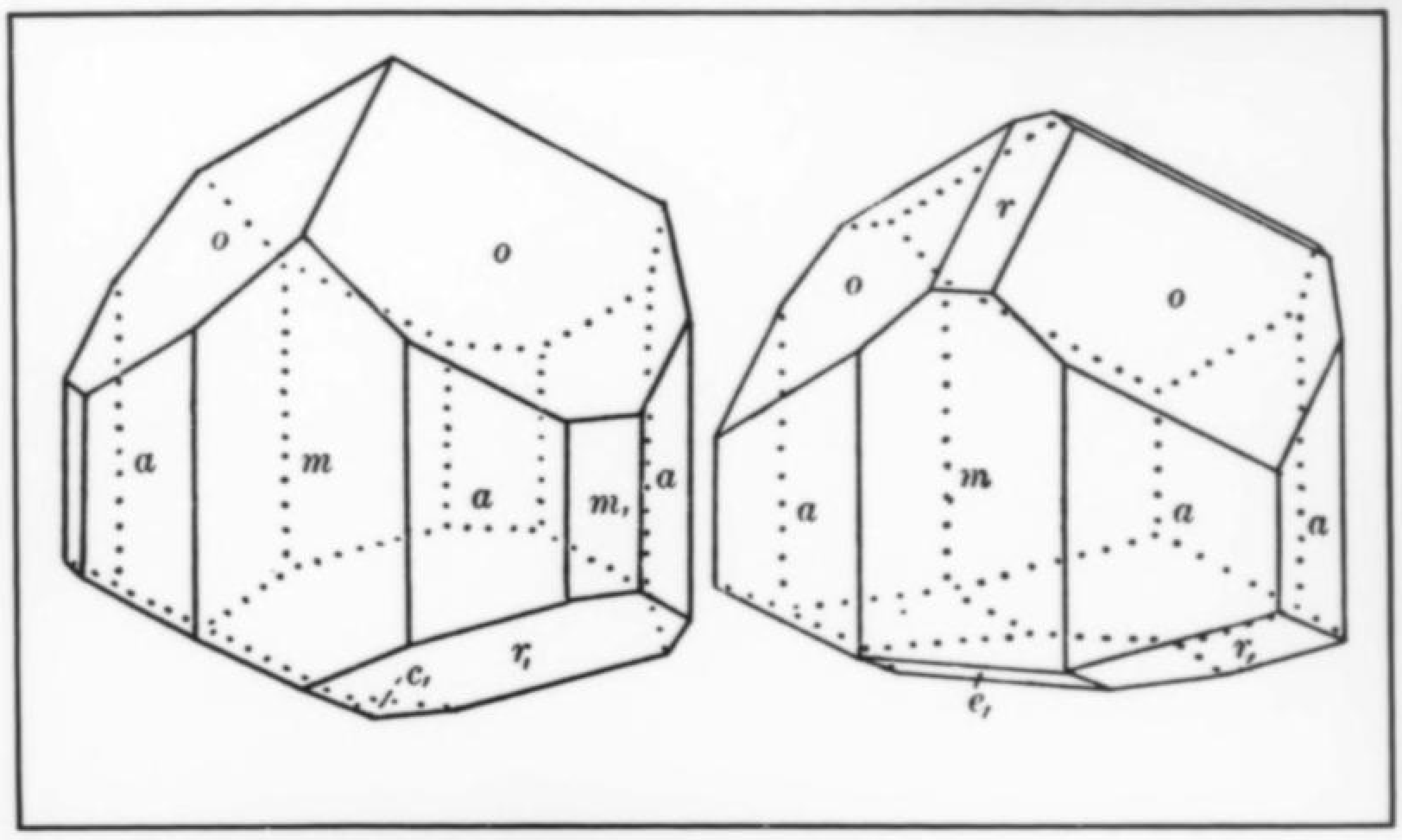
*Crystals of uvite do not exhibit any peculiar or diagnostic morphology which might aid in their identification.* Forms present, and their relative dominance, are not diagnostic for the species. Uvite crystals of both prismatic and pyramidal habit are found. Ceylon uvite crystals which are quite gemmy are, for the most part, tabular on {0001}, but uvite from Gouverneur, New York, is frequently elongate and pyramidal in habit. Franklin uvite is usually somewhat equant. The Ceylon uvites examined in this study were mostly stream pebbles of gem quality. Fine crystals of brown tourmaline from Ceylon were described by Worobieff (1900) as being very rich in forms, with one crystal having 59 different forms. Additional morphologic observations on magnesium tourmaline were made by Pfaffl and Niggemann (1967) who noted the predominance of the prism $\{11\bar{2}0\}$ over the prism, $\{\bar{1}010\}$ in 70 magnesium tourmalines from Bayrischer Wald, Bavaria, and a reverse relationship in iron-rich tourmalines from Drachselsrieder mine near Arnbruck.

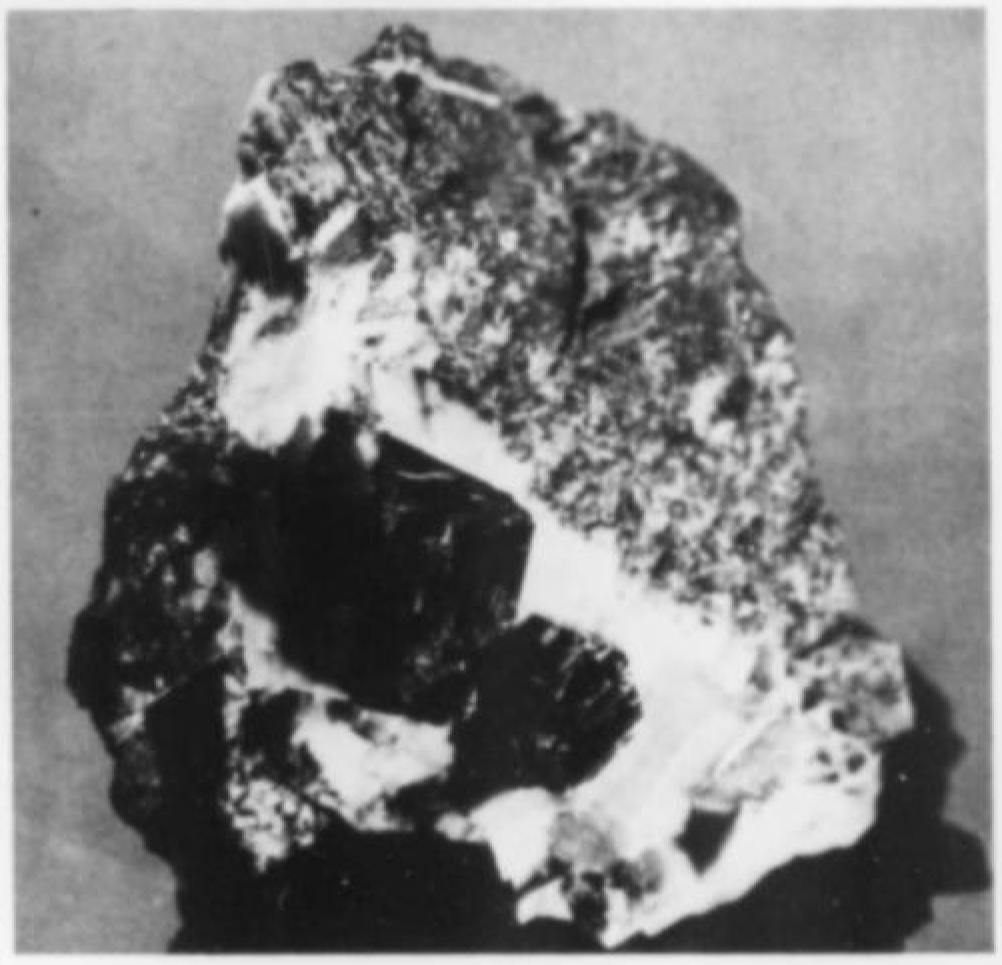
## PHYSICAL AND OPTICAL PROPERTIES

Uvite has a Mohs' hardness comparable to that of dravite (~7½). The density of the purest (most calcium-rich) uvite ranges unsystematically from 2.96 to 3.06. The range is the same for pure (most sodium-rich) dravite. Although calcium is nearly twice as heavy as sodium and one might expect an increase in the density with increasing calcium content (inasmuch as the cell volumes of end-member uvite and end-member dravite are very









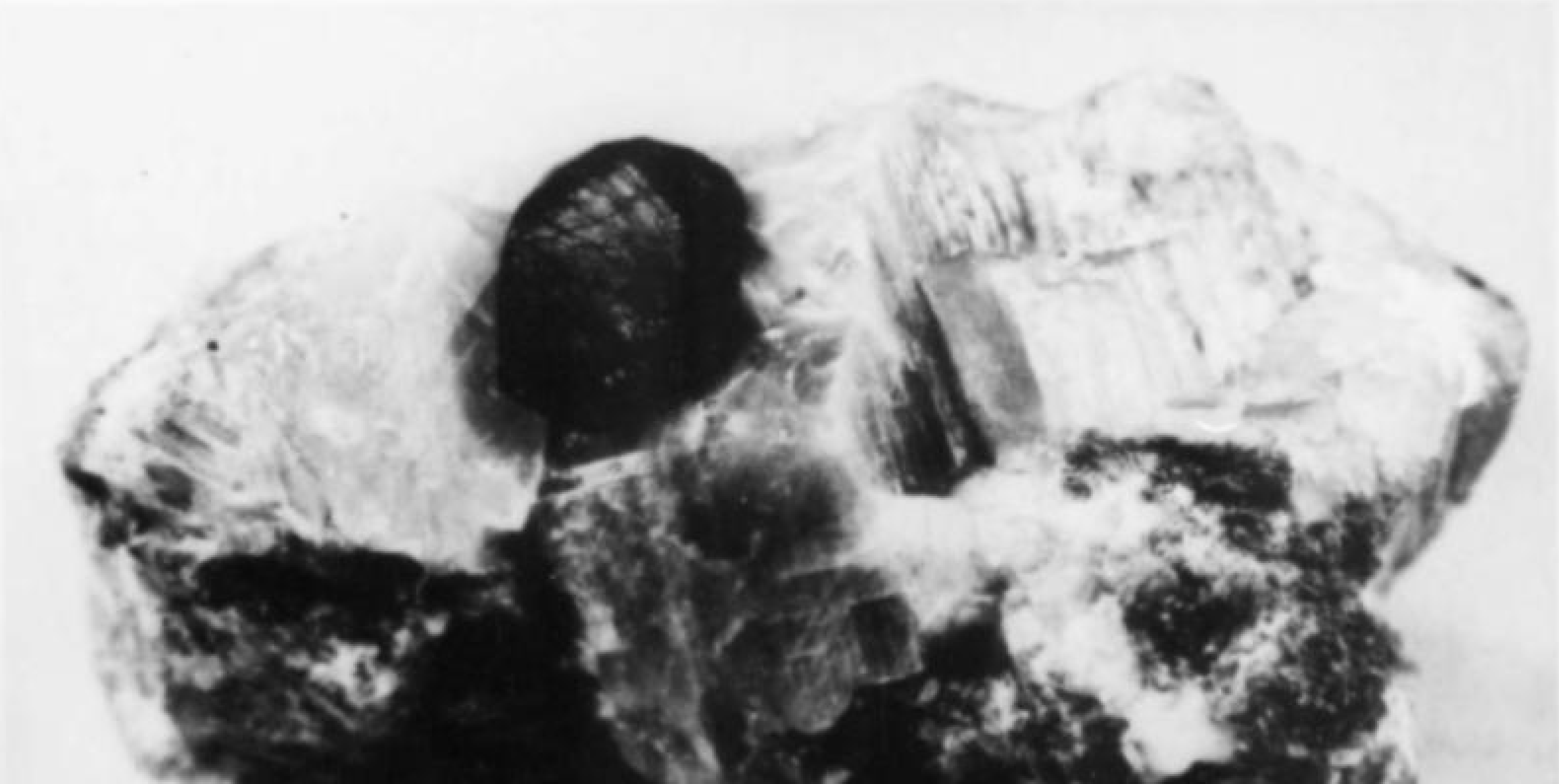


***Figure 1.*** ***(top left)*** **Graph of calcium/sodium in atom percent from microprobe analyses.**

***Figure 2.*** ***(top right)*** **Light green uvite from Franklin, New Jersey. The crystal is 20 mm in its maximum dimension (NMNH #C3283).**

***Figure 3.*** ***(middle left)*** **Line drawings of Franklin uvites [from Palache, (1935)** ***The minerals of Franklin and Sterling Hill, Sussex County, New Jersey.*** **]**

***Figure 4.*** ***(middle right)*** **Dravite from Franklin, New Jersey. This crystal has an uncommon habit for Franklin tourmaline, and is the only known dravite from Franklin. The largest crystal is ~ 25 mm (NMNH #R18133).**

***Figure 5.*** ***(bottom left)*** **Dravite from Yinniethara, Western Australia (NMNH #R17274).**

***Figure 6.*** ***(bottom right)*** **Uvite in calcite from Gouverneur, New York. The crystal is 14 mm in maximum dimension.**

## TABLE 1. PREVIOUS ANALYSES OF UVITE

|  |  | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $B_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | MnO | $K_2O$ | $Na_2O$ | $H_2O$ | F | Total | Less O≡F | Total | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| McAfee, New Jersey |  | 33.72 |  | 25.88 | 10.00 | 1.82 | 3.23 | 14.07 | 6.92 |  | 0.20 | 2.52 | 1.80 |  | 100.16 |  |  | Sargent (1901) |
| Renfrew, Ontario |  | 35.29 | 0.025 | 28.93 | 10.56 | 2.35 | 0.70 | 14.53 | 5.49 |  | 0.22 | 1.72 | 0.70 | 0.84 | 101.35 | 0.355 | 101.00 | Bruce (1917) |
| Dnieper Basin, U.S.S.R. |  | 34.54 | 0.77 | 29.05 | 9.70 | 4.45 | 1.0 | 10.42 | 5.36 |  | 0.12 | 0.40 | 4.26 |  | 100.07 |  |  | Dadko (1969) |
| U.S.S.R. | *u* | 36.20 | 0.34 | 25.25 | 10.12 | 5.32 | 4.66 | 10.01 | 5.33 | 0.01 | 0.18 | 0.36 | 1.99 | 0.23 | 100.00 | 0.09 | 99.91 | Kornetova (1975) |
| Ceylon (Sri Lanka) |  | 35.46 |  | 29.58 | 11.36 |  | 0.45 | 14.04 | 5.13 |  | 0.20 | 0.23 | 3.55 |  | 100.00 |  |  | Wulfing *et al* (1913) |
| Hamburg, New Jersey |  | 35.25 | 0.65 | 28.49 | 10.45 |  | 0.86 | 14.58 | 5.09 |  | 0.18 | 0.94 | 3.10 | 0.78 | 100.37 | 0.33 | 100.04 | Riggs (1888) |
| Hnusta, Czechoslovakia | *a,u* | 40.20 | 0.50 | 25.62 | 9.65 |  | 2.03 | 12.34 | 4.85 | 0.03 | 0.02 | 1.47 | 2.20 | 0.95 | 99.89 | 0.40 | 99.49 | Bouska *et al* (1973) |
| New Zealand |  | 36.3 | 2.2 | 23.1 | 9.6 |  | 12.3 | 7.8 | 4.5 |  |  | 1.0 |  |  | 96.8 |  |  | Black (1971) |
| Uzbekistan, U.S.S.R. | *b* | 37.70 | 0.15 | 34.40 | 10.78 | 0.71 | 0.89 | 10.67 | 3.60 |  |  | 0.23 | 0.60 |  | 99.89 |  |  | Dzhamletdinov (1973) |
| Ceylon (Sri Lanka) | *f,u* | 36.51 |  | 30.00 | 10.57 |  | 0.74 | 12.84 | 3.91 |  | 0.54 | 0.72 | 4.17 |  | 100.00 |  |  | Wulfing *et al* (1913) |
| Gouverneur, New York | *c* | 35.94 | 0.79 | 28.92 | 10.94 | 0.43 |  | 14.43 | 3.82 | 0.01 | 0.06 | 1.09 | 3.07 | 1.15 | 100.65 | 0.48 | 100.17 | Rath (1959) |
| Uzbekistan, U.S.S.R. | *d* | 38.55 | 0.12 | 33.28 | 10.44 | 0.68 | 0.92 | 10.53 | 4.20 |  |  | 0.40 | 0.64 |  | 99.86 |  |  | Dzhamaletdinov (1973) |
| DeKalb, New York |  | 36.88 | 0.12 | 28.87 | 10.58 |  | 0.52 | 14.53 | 3.70 |  | 0.18 | 1.39 | 3.56 | 0.50 | 100.83 |  |  | Riggs (1888) |
| DeKalb, New York | *e,u* | 36.72 | 0.05 | 29.68 | 10.81 |  | 0.22 | 14.92 | 3.49 |  | 0.05 | 1.26 | 2.98 | 0.93 | 101.11 | 0.39 | 100.72 | Penfield *et al* (1899) |
| Pierrepont, New York |  | 35.61 | 0.55 | 25.29 | 10.15 | 0.44 | 8.19 | 11.07 | 3.31 | tr | 0.20 | 1.51 | 3.34 | 0.27 | 99.93 |  |  | Riggs (1888) |
| Pierrepont, New York |  | 35.86 | 0.70 | 22.91 | 11.46 | 2.56 | 6.08 | 11.06 | 3.04 |  | 0.20 | 1.19 | 2.99 | 0.72 | 98.77 |  |  | Dittrich *et al* (1913) |
| Macomb, New York |  | 37.05 | 0.56 | 28.61 | 10.28 | 0.44 | 1.31 | 13.66 | 2.97 |  | 0.31 | 1.45 | 3.05 | 1.20 | 100.89 |  |  | Wulfing *et al* (1913) |
| Pierrepont, New York |  | 36.64 |  | 27.18 | 9.55 |  | 9.08 | 10.13 | 2.91 |  | tr | 1.50 | 3.01 |  | 100.00 |  |  | Dana (1892) |
| Gouverneur, New York | *u,f* | 35.96 | 0.14 | 30.85 | 10.73 |  | 0.76 | 13.67 | 2.41 |  | 0.09 | 1.63 | 4.16 |  | 100.40 |  |  | Kunitz (1929) |
| India |  | 36.01 | 0.77 | 32.70 | 10.66 |  | 2.59 | 10.99 | 2.28 | 0.03 | 0.06 | 1.09 | 2.72 | 0.41 | 100.31 | 0.17 | 100.14 | Jacob (1938) |

*a*-Contains 0.031 $P_2O_5$
*b*-Contains 0.10 $V_2O_5$ and trace of $Li_2O$
*c*-Contains trace of $Li_2O$
*d*-Contains 0.01 $V_2O_5$ and trace of $Li_2O$
*e*-Average of two analyses
*f*-Given in mole percent, recalculated here as weight percent
*u*-Reported as uvite

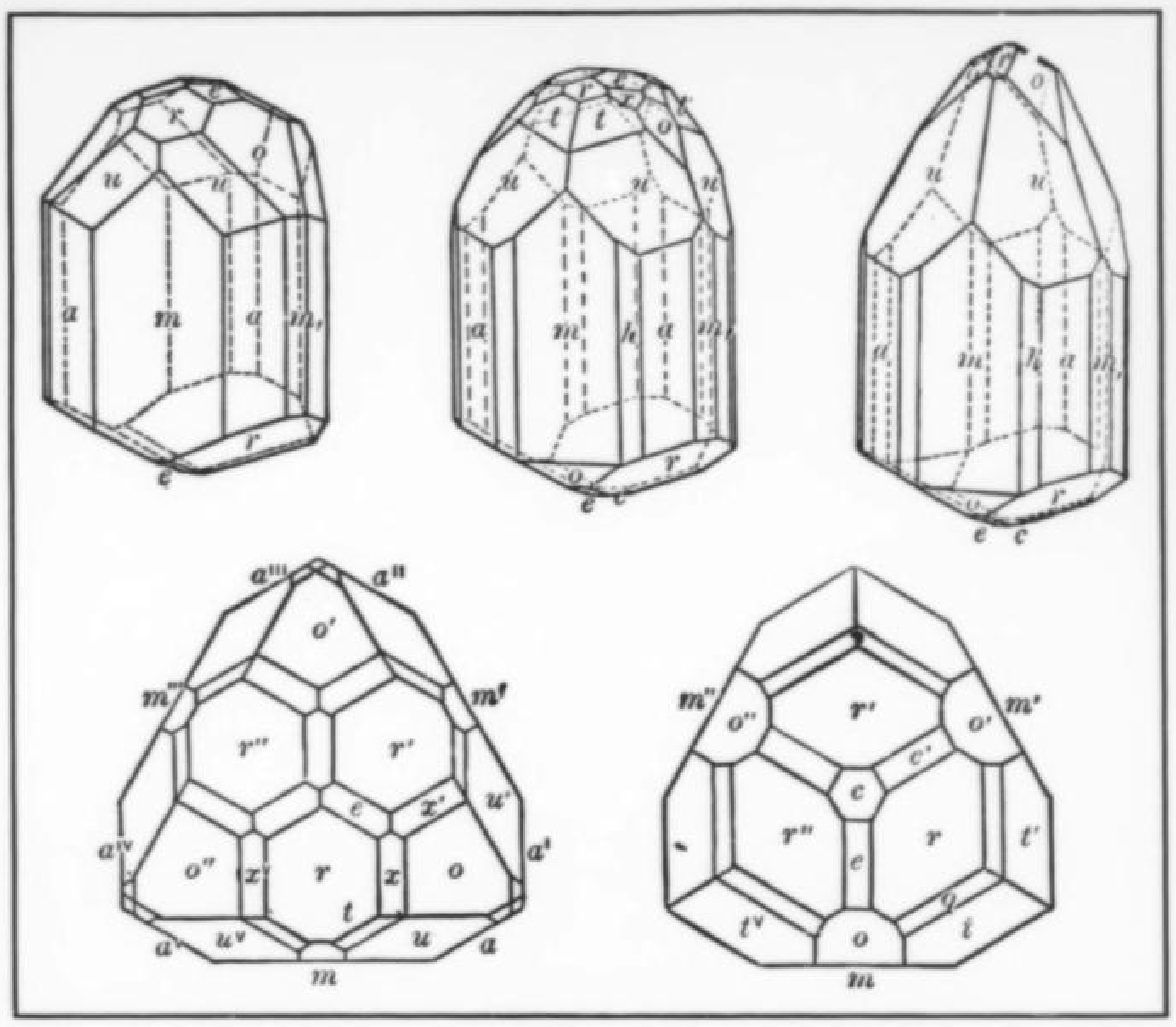


*Figure 7.* **Line drawings of uvites from Gouverneur, New York [from Dana, (1892) *The System of Mineralogy*, p. 552].**

*Figure 8.* **White tremolite with brown uvite, Gouverneur, New York. The tremolite crystal is 8.5 cm long. The uvite is 4 cm in its maximum dimension (NMNH #C3287).**

similar), the concomitant substitution of magnesium for aluminum balances this. The net result is that *specific gravity is of no use in the determinative process.* The calculated value for uvite, NMNH C5212, is 3.01 compared with the observed value of 2.97.

The color of uvite is variable. Most uvite, like dravite, is brown. Notable exceptions to this are the colorless DeKalb, New York, material and the light green crystals from Franklin, New Jersey, both of which have very low iron content. In general, brown uvites demonstrate a correlation between color and iron content, the color darkening with increasing iron to near opacity when the iron content exceeds 0.8%. The same relationship exists in dravite, supporting the observations of Slikvo (1957), who suggested that the chromophore causing brown color in tourmaline was $Fe^{+3}$.

Uvite is uniaxial negative, absorption $\omega > \epsilon$. The streak is variable; light green, light brown, or white. The refractive indices of uvite do not differ from those of dravite and are thus of no use in determining the species. Although Kunitz (1929) did present a graph of variation of refractive indices with increasing calcium/sodium ratio, his observations have not been supported by the present study and his observed range in values may have been influenced by iron substituting for magnesium or aluminum in his samples. Since the refractive indices of tourmalines increase with increasing iron and manganese content (Deer *et al.*, 1962), samples were chosen for optical examination which had a very low iron content ($<$0.41%FeO) and which varied from 95% to 51% of the uvite end-member. Dravites with comparable low-iron contents were not found. The refractive indices of these uvites are presented in Table 2.

Both uvite and dravite, when low in iron content, fluoresce a weak mustard yellow color under short-wave ultraviolet radiation. There is no response in long-wave ultraviolet, and no phosphorescence in either wavelength.

Uvite and dravite, therefore, are indistinguishable on the basis of their physical and optical properties.

## CHEMISTRY

### *General*

Uvite, $CaMg_3(Al_5Mg)B_3Si_6O_{27}(OH,F)_4$, is the calcium analog of dravite, $NaMg_3Al_6B_3Si_6O_{27}(OH,F)_4$, and is thus an end-member in the tourmaline group.

The substitution of divalent calcium ($Ca^{+2}$) for monovalent sodium ($Na^{+1}$) in magnesium tourmaline requires a coupled substitution. There is a concomitant increase in divalent magnesium ($Mg^{+2}$) substituting for trivalent aluminum ($Al^{+3}$) to provide electrostatic charge balance. Magnesium tourmalines with Ca $>$ Na are thus uvite and those with Na $>$ Ca are dravite.

Eighty magnesium tourmalines in the mineral collection of the National Museum of Natural History (Smithsonian Institution) were partially analyzed with an ARL-SEMQ electron microprobe utilizing an operating voltage of 15 kV and a sample current of 0.15 μA and NMNH microprobe standards of high reliability. Of the 80 samples analyzed, 43 were uvite and 37 were dravite. This ratio is not necessarily indicative of the natural abundance of these species as the samples were chosen in a search for the calcium-rich member. These are partial analyses. The boron, water and fluorine contents were not determined. All iron is calculated as FeO since it was determined as total iron. The analyses are presented as Table 3, in order of decreasing calcium content. Three samples were subjected to complete wet-chemical analysis and the results of these analyses are presented as Table 4. These compare closely with the theoretical values given in Table 5 for end-member uvite. Following the suggestion of Barton (1969) the "excess" boron over 3.0 atoms per formula unit is assumed to be substituting for Si in the tetrahedral six-membered rings; the total of silicon plus excess boron should be 6.0 atoms per formula unit in the ideal structure. The numbers of atoms per formula unit (Table 4) have been computed directly from the analyses, including OH and F, on the basis of 31 (O, OH, F) per formula unit. However, the errors in the $H_2O$ and F determinations are probably sufficient to allow for enough adjustment of the O:(OH, F) ratios to achieve complete charge balance.

### *Wet Analytical Procedures*

Reduction of sample size was done first in an iron percussion mortar to -40 mesh, followed by further grinding in a tungsten carbide mill to -160 mesh.

Moisture, $SiO_2$, $Al_2O_3$, FeO, CaO and MgO were determined on 0.5 g portions by classical chemical methods. (Peck, 1964), Prior to filtration of silica, boron was volatilized by repeated dehydration with a HCl-methanol mixture (Hillebrand *et al*, 1953). Iron in the $R_2O_3$ portion was determined using O-phenanthroline, titanium as the tiron complex; aluminum was precipitated with 8-hydroxyquinoline (Jarosewich, 1966).

For total water the Penfield method (Peck, 1964) was used, the $H_2O^+$ being the difference between total water and moisture.

For fluorine 0.2 g samples were fused with $ZnO$-$Na_2CO_3$ flux and filtered (Grimaldi *et al*, 1955). The fluorine in the filtrate was distilled using a constant temperature distilling apparatus (Huckabay *et al*, 1947) and titrated with thorium nitrate.

Alkali content was determined flame photometrically after sample decomposition with $HF$-$H_2SO_4$.

Boron was titrated with NaOH and mannitol after removal of interfering substances and neutralization. Precision of the method was ± 0.2% $B_2O_3$ on NBS 93 (a 12.76% borosilicate glass).

### *Miscibility*

Within the tourmaline group there is miscibility between schorl and elbaite and between schorl and dravite (Epprecht, 1953). Little evidence exists for miscibility between dravite and elbaite. The dravite analyses of this study support earlier evidence of miscibility between schorl and dravite. The analyses of Tables 3 and 4 clearly demonstrate that there is complete miscibility between uvite and dravite. The CaO content varies smoothly from 5.86% to 0.03% (1.00 to 0.05 calcium in atom percent) while the $Na_2O$ content sympathetically varies from 0.08% to 2.92% (0.02 to 0.94 sodium in atom percent). The concomitant adjustment in aluminum and magnesium, although not as gradual, is also clearly demonstrated. The less-smooth variation in the aluminum-magnesium ratios is likely due to the fact that available iron can substitute in either the divalent or trivalent site. Figure 1 is a graph of calcium vs. sodium (in atom percent) for the uvite and dravite analyses of this study. This graph demonstrates complete miscibility between the end-members, with no gaps in the solid solution series.

**TABLE 2**
**OPTICAL DATA FOR SELECTED LOW-IRON UVITES**

| NMNH # | Locality | $\epsilon$ | $\omega$ | % Uvite |
|---|---|---|---|---|
| C5212 | Ceylon (Sri Lanka) | 1.619 | 1.638 | 98 |
| B14707 | DeKalb, New York | 1.620 | 1.638 | 90 |
| C3290 | DeKalb, New York | 1.620 | 1.634 | 72 |
| B14698 | DeKalb, New York | 1.620 | 1.634 | 54 |
| R3958 | DeKalb, New York | 1.620 | 1.636 | 53 |

All observations in sodium light ( ±0.003). Samples arranged in order of decreasing calcium content. All samples have less than 0.41 % FeO.

## CRYSTALLOGRAPHY

Uvite fragments from sample C5212 were studied by single-crystal x-ray diffraction techniques. Long-exposure zero-level, upper-level and cone-axis precession photographs showed no deviation from space group *R3m*, the usual tourmaline symmetry. Cell dimensions were determined from single-crystal measurements to be: $a$ = 15.88 Å, $c$ = 7.17 Å. These parameters were adjusted by least-squares indexing and refinement of powder-diffraction data. Using the program of Appleman *et al*, (1973). The refined parameters are $a$ = 15.981 ± 0.002 Å, $c$ = 7.207 ± 0.001 Å (Si standard). These values fall precisely on the schorl-dravite series cell-dimension plots (Epprecht, 1953). Uvite cannot, therefore, be distinguished readily from dravite by x-ray diffraction methods, short of a complete structure determination. Indexed X-ray powder diffraction data for uvite (#C5212) has been deposited with the *Joint Committee on Powder Diffraction Standards* (JCPDS).

## NEOTYPE UVITE

The uvite examined by Kunitz, if he did indeed examine a specific specimen, has long been lost. Therefore, one of the samples in this study has been designated as neotype uvite. The neotype material is a gem fragment from Ceylon (C5212) and is half of a gemstone originally weighing 20.05 carats. This specimen is one of the three which have been wet-chemically analyzed. It was chosen because it is from Ceylon, whence uvite was named, because its composition is similar to the analysis (Wulfing, 1913) cited by Kunitz, and because it is a single crystal, ideally suited to further mineralogical and crystallographic studies. Fragments of neotype uvite will be distributed to the British Museum (Natural History) and the major part will be deposited in the National Museum of Natural History, Smithsonian Institution, Washington, D.C., under catalog number C5212.

## NOTES FOR COLLECTORS AND CURATORS ON SPECIFIC LOCALITIES

### *FRANKLIN, NEW JERSEY*

Fine specimens of both brown and light green magnesium tourmaline have been found at this locality for many years, and are in most major mineral collections today. Although the tourmalines are not found in the zinc orebody, they are common in the white calcite marble of the Franklin area, and especially at the Fowler quarry (Palache, 1935). They are notable for their size, development of forms (Figures 2 and 3), and the lovely specimens resulting from the contrast with the white marble in which they repose.

Fifteen specimens from Franklin were examined in this study, and were chosen to represent the various colors and habits of the Franklin material. Fourteen of the fifteen specimens are uvite and contain 75 to 100% of the uvite end-member. The light brown, dark brown, light green, and rich green crystals are all calcium-rich, but no one color more so than the others. The light green Franklin uvites have a much lower iron content than the brown crystals, but the cause of the green color is unexplained.

The only sodium-rich crystal (dravite) from Franklin is a rather unique specimen on exhibit in the Hall of Minerals at the Smithsonian (R18133). This crystal (Figure 4) has a very dark brownish-green color and notable morphology; the crystal is comprised of a trigonal prism $\{10\bar{1}0\}$ and pedion $\{0001\}$ with only slight pyramidal modifications. This crystal is quite unlike the common Franklin uvites which are highly modified and frequently equant in habit.

Inasmuch as zinc is found in most Franklin minerals, it was sought for in the analyses of this study. Zinc impurities were negligible and did not exceed 0.05% in any of the specimens. This is not too surprising as the uvites are not found in the zinc orebody but in the marbles of the area.

### *HAMBURG, NEW JERSEY*

This uvite locality was known as Rudeville in the older literature and crystals from here are referred to by Palache (1935). Here, as at Gouverneur, New York, the uvites are associated with tremolite crystals, in calcite. Crystals from Hamburg were described by Eakle (1894). Six specimens from this locality were analyzed and all have calcium greater than sodium and are thus uvite.

### *YINNIETHARA, WESTERN AUSTRALIA*

Sizable brown crystals, up to 15 cm, of equant to prismatic habit from this locality, have been on the specimen market for many years now. (Figure 5). The 3 analyses of this study demonstrate that these brown crystals have Na >Ca and are thus dra-

## TABLE 3. PARTIAL MICROPROBE ANALYSES OF UVITE AND DRAVITE

|  | NMNH# | $SiO_2$ | $Al_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $TiO_2$ | TOTAL % | UVITE | COLOR | LOCALITY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uvite | C5212 | 36.08 | 27.02 | 0.54 | 15.39 | 5.50 | 0.23 | 0.58 | 85.34 | 98 | Brown | Sri Lanka (Ceylon) |
| Uvite | B14687 | 35.28 | 27.48 | 0.21 | 15.63 | 5.46 | 0.14 | 0.28 | 84.48 | 97 | Green | Franklin, New Jersey |
| Uvite | C6735 | 36.16 | 25.33 | 0.52 | 15.71 | 5.30 | 0.28 | 0.59 | 83.89 | 95 | Brown | Franklin, New Jersey |
| Uvite | R18132 | 35.39 | 27.30 | 0.44 | 15.34 | 5.21 | 0.41 | 0.49 | 84.58 | 93 | Brown | Franklin, New Jersey |
| Uvite | 82273 | 35.80 | 26.52 | 0.11 | 15.61 | 5.19 | 0.28 | 0.09 | 83.60 | 93 | Green | Franklin, New Jersey |
| Uvite | C6726 | 35.25 | 27.05 | 0.21 | 15.28 | 5.08 | 0.33 | 0.19 | 83.55* | 91 | Green | Franklin, New Jersey |
| Uvite | B14707 | 36.27 | 27.18 | 0.33 | 15.54 | 5.06 | 0.49 | 0.19 | 85.06 | 90 | Brown | De Kalb, New York |
| Uvite | B14682 | 35.12 | 28.09 | 0.29 | 15.00 | 5.04 | 0.35 | 0.35 | 84.24 | 90 | Brown | Franklin, New Jersey |
| Uvite | B14688 | 35.76 | 26.74 | 0.80 | 15.50 | 4.96 | 0.46 | 0.29 | 84.51 | 88 | Brown | Hamburg, New Jersey |
| Uvite | R18134 | 35.62 | 28.23 | 1.23 | 14.31 | 4.93 | 0.47 | 0.36 | 85.15 | 88 | Brown | Hamburg, New Jersey |
| Uvite | 106906 | 35.98 | 27.21 | 0.79 | 14.64 | 4.84 | 0.43 | 0.22 | 84.27* | 86 | Brown | Horicon, New York |
| Uvite | 134441 | 35.45 | 26.28 | 0.81 | 14.72 | 4.82 | 0.40 | 0.20 | 82.84* | 86 | Brown | Franklin, New Jersey |
| Uvite | C6728 | 34.81 | 28.83 | 0.48 | 14.47 | 4.80 | 0.51 | 0.17 | 84.07 | 86 | Brown | Gouverneur, New York |
| Uvite | 118110 | 34.97 | 27.51 | 0.41 | 14.76 | 4.71 | 0.56 | 0.16 | 83.08 | 84 | Brown | Horicon, New York |
| Uvite | B14684 | 35.81 | 28.42 | 0.28 | 14.40 | 4.54 | 0.65 | 0.28 | 84.38 | 81 | Green | Franklin, New Jersey |
| Uvite | B14691 | 35.42 | 26.92 | 0.33 | 15.38 | 4.50 | 0.56 | 0.19 | 83.30 | 80 | Brown | Franklin, New Jersey |
| Uvite | C6729 | 35.49 | 27.62 | 0.90 | 14.51 | 4.42 | 0.77 | 0.20 | 83.17* | 79 | Brown | Hamburg, New Jersey |
| Uvite | 118651 | 35.77 | 27.54 | 0.22 | 14.51 | 4.32 | 0.92 | 0.21 | 85.49 | 77 | Green | Franklin, New Jersey |
| Uvite | C6730 | 34.63 | 29.85 | 1.00 | 13.42 | 4.25 | 0.74 | 0.46 | 84.51* | 76 | Brown | Hamburg, New Jersey |
| Uvite | C6727 | 34.86 | 28.95 | 0.19 | 14.09 | 4.24 | 0.69 | 0.28 | 83.30 | 76 | Green | Franklin, New Jersey |
| Uvite | C6731 | 33.74 | 30.27 | 1.06 | 13.18 | 4.22 | 0.77 | 0.40 | 83.6 | 75 | Brown | Hamburg, New Jersey |
| Uvite | B14686 | 36.20 | 27.10 | 2.34 | 13.13 | 4.18 | 0.92 | 0.56 | 84.43 | 75 | Brown | Franklin, New Jersey |
| Uvite | C3290 | 36.51 | 27.81 | 0.21 | 15.12 | 4.06 | 1.05 | 0.15 | 84.91 | 72 | White | De Kalb, New York |
| Uvite | B14700 | 35.90 | 28.96 | 0.42 | 13.86 | 3.40 | 1.31 | 0.18 | 84.03 | 61 | Brown | Macomb, New York |
| Uvite | 134439 | 36.28 | 28.33 | 0.33 | 14.27 | 3.35 | 1.48 | 0.72 | 84.76 | 60 | Brown | Gouverneur, New York |
| Uvite | 104379 | 36.08 | 27.65 | 0.30 | 14.59 | 3.34 | 1.33 | 0.59 | 83.88 | 60 | Brown | Gouverneur, New York |
| Uvite | R18135 | 36.02 | 27.73 | 0.40 | 14.14 | 3.31 | 1.35 | 0.69 | 83.64 | 59 | Brown | Hamburg, New Jersey |
| Uvite | R18116 | 35.75 | 29.35 | 0.22 | 13.77 | 3.25 | 1.53 | 0.09 | 83.96 | 58 | White | De Kalb, New York |
| Uvite | B14694 | 36.05 | 30.32 | 0.20 | 13.81 | 3.15 | 1.54 | 0.09 | 85.16 | 56 | White | De Kalb, New York |
| Uvite | B14696 | 36.07 | 29.15 | 0.24 | 13.78 | 3.12 | 1.49 | 0.10 | 83.95 | 56 | White | De Kalb, New York |
| Uvite | R18136 | 36.54 | 27.76 | 0.35 | 14.45 | 3.07 | 1.54 | 0.97 | 84.68 | 55 | Brown | Gouverneur, New York |
| Uvite | R14705 | 36.12 | 30.46 | 0.22 | 13.45 | 3.03 | 1.54 | 0.09 | 84.91 | 54 | White | De Kalb, New York |
| Uvite | R3453 | 35.93 | 28.78 | 7.83 | 10.39 | 3.01 | 1.58 | 0.33 | 87.85 | 54 | Black | Pierrepont, New York |
| Uvite | B14698 | 35.85 | 30.13 | 0.23 | 13.25 | 3.00 | .156 | 0.09 | 84.11 | 54 | White | De Kalb, New York |
| Uvite | 134440 | 35.67 | 27.26 | 1.69 | 13.07 | 2.99 | 1.71 | 0.64 | 83.13 | 53 | Brown | Macomb, New York |
| Uvite | R3958 | 35.69 | 29.72 | 0.19 | 13.66 | 2.97 | 1.54 | 0.10 | 83.87 | 53 | White | De Kalb, New York |
| Uvite | C3290-2 | 36.55 | 30.12 | 0.21 | 13.34 | 2.96 | 1.51 | 0.09 | 84.78 | 53 | White | De Kalb, New York |
| Uvite | 82279 | 35.98 | 28.60 | 0.36 | 13.91 | 2.95 | 1.58 | 1.08 | 84.46 | 53 | Brown | Gouverneur, New York |
| Uvite | B16254 | 34.00 | 23.42 | 12.16 | 7.93 | 2.95 | 1.89 | 0.98 | 83.33 | 53 | Black | Santa Cruz., Sonora, Mexico |
| Uvite | 116996 | 34.79 | 24.14 | 8.84 | 9.71 | 2.93 | 1.55 | 0.66 | 82.62 | 52 | Black | Pierrepont, New York |
| Uvite | C6733 | 35.71 | 25.95 | 7.58 | 10.35 | 2.91 | 1.56 | 0.34 | 84.40 | 52 | Black | Pierrepont, New York |
| Uvite | B14680 | 36.46 | 27.54 | 0.36 | 13.83 | 2.89 | 1.67 | 1.21 | 83.96 | 52 | Brown | Gouverneur, New York |
| Uvite | 116454 | 36.82 | 28.32 | 0.58 | 14.15 | 2.83 | 1.83 | 0.31 | 84.84 | 50 | Brown | Canton, New York |
| Dravite | 80879 | 36.15 | 28.12 | 0.32 | 14.21 | 2.74 | 1.74 | 1.21 | 84.49 | 49 | Brown | Gouverneur, New York |
| Dravite | 78719 | 36.25 | 27.26 | 0.37 | 13.95 | 2.73 | 1.53 | 1.21 | 83.30 | 49 | Brown | Gouverneur, New York |
| Dravite | B14681 | 35.97 | 28.87 | 0.49 | 13.69 | 2.70 | 1.65 | 1.48 | 84.85 | 48 | Brown | Gouverneur, New York |
| Dravite | 48280 | 36.58 | 28.36 | 1.66 | 12.87 | 2.67 | 1.71 | 0.74 | 84.59 | 48 | Brown | Macomb, New York |
| Dravite | 48279 | 35.39 | 25.70 | 7.70 | 10.41 | 2.66 | 1.66 | 0.46 | 83.98 | 47 | Black | Pierrepont, New York |
| Dravite | 48283 | 36.82 | 28.61 | 0.85 | 13.87 | 2.54 | 1.81 | 0.39 | 84.89 | 46 | Brown | De Kalb, New York |
| Dravite | C6733 | 35.13 | 25.88 | 7.29 | 10.31 | 2.53 | 1.67 | 0.32 | 83.13 | 45 | Black | Pierrepont, New York |
| Dravite | 103488 | 36.06 | 31.89 | 0.31 | 11.49 | 2.48 | 1.45 | 0.65 | 84.48** | 44 | Brown | Texas, Maryland |
| Dravite | R3959 | 36.28 | 31.99 | 0.64 | 11.73 | 2.04 | 1.73 | 0.49 | 84.90 | 36 | Brown | Kingsbridge, New York |
| Dravite | R7084 | 34.74 | 21.71 | 13.43 | 7.95 | 1.98 | 2.05 | 1.29 | 82.65 | 35 | Black | Snarum, Norway |
| Dravite | R18118 | 34.85 | 21.14 | 13.05 | 8.01 | 1.90 | 2.04 | 1.36 | 82.35 | 34 | Black | Snarum, Norway |
| Dravite | R17268 | 35.14 | 30.13 | 4.24 | 9.65 | 1.86 | 1.91 | 0.11 | 83.04 | 33 | Black | Yinniethara, Australia |
| Dravite | R16248 | 35.44 | 26.72 | 9.62 | 8.41 | 1.79 | 2.06 | 0.63 | 84.67 | 32 | Black | Santa Cruz, Sonora, Mexico |
| Dravite | R18117 | 35.20 | 26.08 | 11.25 | 7.26 | 1.73 | 2.13 | 0.63 | 84.28 | 31 | Black | Kjenlid, Arundel, Norway |
| Dravite | R17267 | 33.92 | 26.93 | 10.52 | 6.60 | 1.70 | 2.05 | 1.01 | 85.73 | 30 | Black | Yinniethara, Australia |
| Dravite | R18133 | 35.86 | 30.73 | 0.91 | 11.88 | 1.63 | 1.81 | 0.20 | 84.18* | 29 | Green | Franklin, New Jersey |
| Dravite | R7083 | 35.92 | 23.58 | 13.03 | 8.10 | 1.61 | 2.21 | 1.18 | 85.63 | 29 | Black | Fredriksvarn, Norway |
| Dravite | 4025 | 34.50 | 26.48 | 9.20 | 8.23 | 1.56 | 2.32 | 0.92 | 83.21 | 28 | Green | Lambertville, New Jersey |
| Dravite | B20711 | 35.65 | 31.72 | 1.95 | 10.65 | 1.44 | 1.90 | 0.30 | 83.61 | 26 | Brown | Sri Lanka (Ceylon) |
| Dravite | 80575 | 35.38 | 32.32 | 2.66 | 9.88 | 1.36 | 2.36 | 0.78 | 84.74 | 24 | Brown | Colfax, California |
| Dravite | B14539 | 34.10 | 31.94 | 7.91 | 5.62 | 1.32 | 1.69 | 1.03 | 83.77* | 24 | Black | Cyrilov, Moravia, Czechoslovakia |
| Dravite | 44572 | 35.54 | 32.41 | 1.68 | 9.95 | 1.16 | 2.35 | 0.47 | 83.56 | 21 | Brown | Orford, New Hampshire |
| Dravite | B14566 | 34.69 | 27.03 | 9.95 | 7.06 | 0.96 | 2.42 | 0.83 | 83.04 | 17 | Black | Simplon Tunnel, Switzerland |
| Dravite | 133607 | 35.57 | 28.66 | 5.89 | 9.42 | 0.81 | 2.57 | 0.51 | 83.63 | 14 | Black | Bjordam, Bamble, Norway |
| Dravite | 96761 | 35.97 | 32.73 | 4.81 | 8.20 | 0.79 | 2.29 | 0.30 | 85.09 | 14 | Gray | Alabama |
| Dravite | 103791 | 36.12 | 33.26 | 0.23 | 11.59 | 0.76 | 2.53 | 0.27 | 84.76 | 14 | Brown | Dobrawa, Carinthia, Austria |
| Dravite | C3282 | 35.20 | 31.06 | 5.34 | 8.35 | 0.72 | 2.30 | 0.42 | 83.39 | 13 | Black | Warren, New Hampshire |
| Dravite | 122399 | 35.86 | 30.89 | 2.77 | 10.08 | 0.70 | 2.61 | 0.85 | 83.76 | 12 | Brown | Baltimore County, Maryland |
| Dravite | B14541 | 36.55 | 33.25 | 0.30 | 11.08 | 0.69 | 2.63 | 0.27 | 84.77 | 12 | Brown | Prevali, Carinthia, Austria |
| Dravite | B14708 | 36.68 | 32.95 | 0.20 | 11.20 | 0.56 | 2.62 | 0.23 | 84.44 | 10 | Brown | Dobrawa, Carinthia, Austria |
| Dravite | B14542 | 36.76 | 33.17 | 0.28 | 11.22 | 0.52 | 2.69 | 0.30 | 84.94 | 9 | Brown | Prevali, Carinthia, Austria |
| Dravite | R17272 | 35.44 | 31.29 | 0.61 | 11.28 | 0.52 | 2.69 | 0.79 | 82.62 | 9 | Brown | Yinniethara, Australia |
| Dravite | 92824 | 35.69 | 32.96 | 3.52 | 8.60 | 0.42 | 2.46 | 0.21 | 83.86 | 7 | Brown | Carinthia, Austria |
| Dravite | R17274 | 36.24 | 32.36 | 0.46 | 11.05 | 0.38 | 2.80 | 0.81 | 84.10 | 7 | Brown | Yinniethara, Australia |
| Dravite | R10375 | 34.96 | 32.02 | 9.98 | 4.86 | 0.34 | 2.24 | 0.28 | 84.68 | 6 | Black | Plumas County, California |
| Dravite | R17273 | 36.85 | 32.57 | 0.38 | 11.45 | 0.28 | 2.92 | 0.77 | 85.22 | 5 | Brown | Yinniethara, Australia |
| Dravite | 126030 | 36.47 | 31.75 | 4.17 | 9.27 | 0.03 | 2.77 | 0.25 | 84.71 | 1 | Red | Narok District, Kenya |

Unless otherwise noted, all analyses contain less than 0.05 ZnO or MnO and less than 0.10$K_2O$ or $Cr_2O_3$.

*Contains-0.10 to 0.18 $Cr_2O_3$.

**Contains-0.15% $K_2O$.

Analyst: Pete J. Dunn

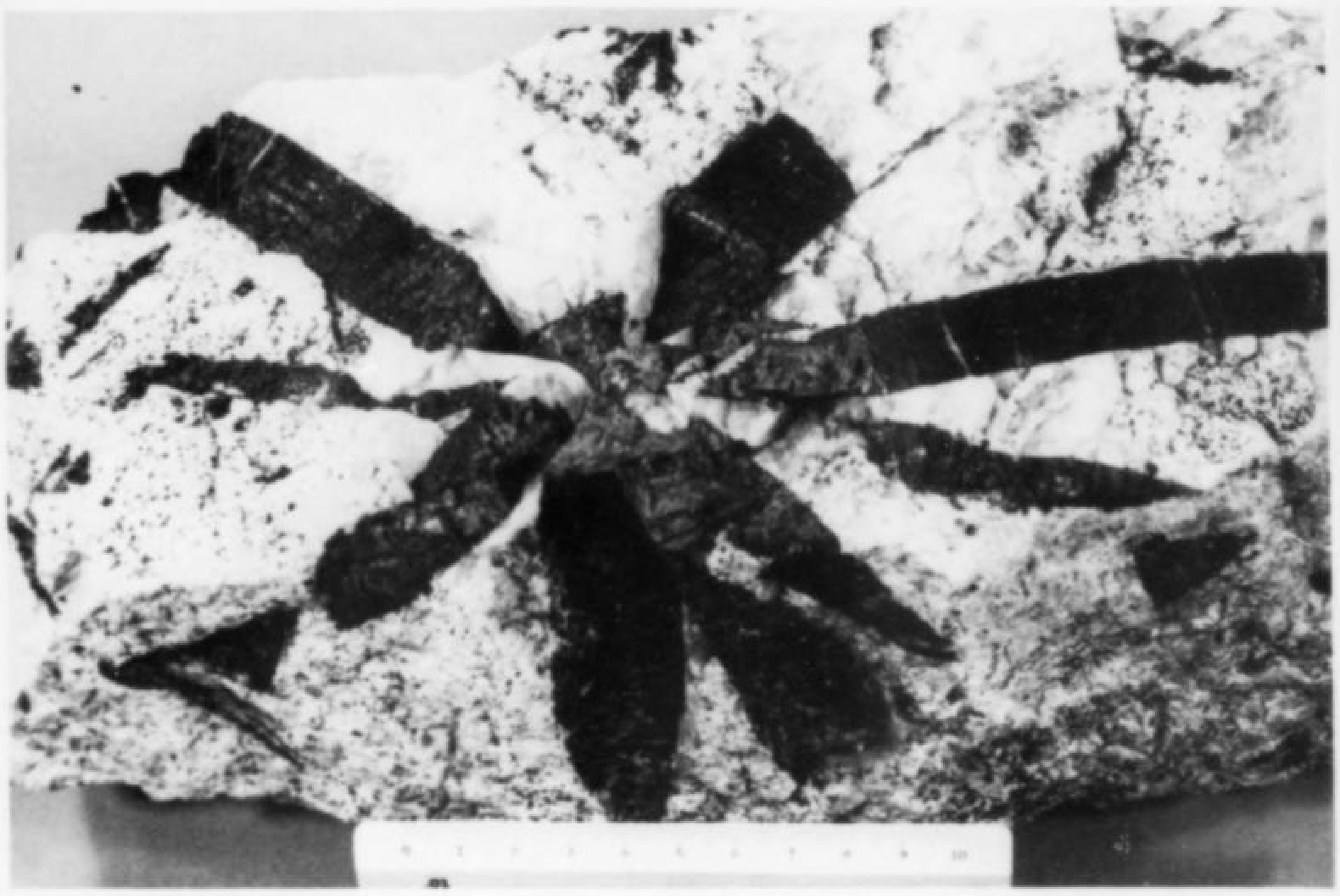


***Figure 9.* Radiating dravite from near DeKalb, New York. The scale is in centimetres. The crystal is 7.5 cm long (NMNH #48283).**

***Figure 10.* Uvite from Pierrepont, New York. The crystal is 28 mm in its maximum dimension. (NMNH #C6733).**

vite, and that the composition varies only slightly from crystal to crystal.

### *GOUVERNEUR, NEW YORK*

Next to Franklin, the locality that has produced the most prodigious amount of excellent uvite specimens is Gouverneur, New York. The locality is an old one and was noted by Beck (1842). The uvite crystals, (Figures 6,7 and 8) are found associated with tremolite, apatite, and scapolite in calcite and attain sizes in excess of 10 cm. The tremolite is noteworthy as the crystals are of simple morphology and range from microscopic to lengths exceeding 8 cm (Figure 8). Nine specimens of brown tourmaline from this locality were examined. Six of the nine examined are uvite, as are the two previously reported analyses in the literature (Table I). The remaining three, although they have sodium greater than calcium, are near the midpoint in the series, containing between 48% and 49% of the uvite end-member.

### *DEKALB, NEW YORK*

Long noted for the colorless to light brown tourmaline that is found here, DeKalb has also the added distinction of producing the most iron-free uvites known. Nine specimens of the colorless to white tourmaline were analyzed and all have $Ca > Na$. The samples contain from 53% to 90% of the uvite end-member. The two previous analyses from the literature (Table I) are also of calcium-rich members.

One sample, #48283, reported to be from DeKalb, is quite unlike the common DeKalb colorless uvites. This specimen consists of radiating sunbursts of 10-15 cm brown crystals in limestone (Figure 9). This material is dravite.

### *HORICON, NEW YORK*

Located at the northwest end of Branch Lake, this locality has produced some exquisite specimens of uvite in calcite. The rich dark brown crystals are stout, prismatic and average about 1 x 10 cm. Two samples from the U.S. National Collection were analyzed and have 86% of the uvite end-member.

## NOTES ON BLACK TOURMALINE FROM SPECIFIC LOCALITIES

Black tourmaline from several classic localities, known for calcium minerals, was examined in search of a possible calcium-rich iron tourmaline. None was found, but purported schorl from some localities is magnesium-rich and thus dravite or uvite. Comments on some of these localities follow. "Schorls" from albitic pegmatites were not analyzed in the study as they should be sodium-rich.

### *PIERREPONT, NEW YORK*

Exquisite, sharp, and well-formed crystals of black tourmaline (Figures 10 and 11) have been found here since the original description of 3 inch black crystals by Finch (1830). The crystals are quite lustrous, frequently tabular on {0001}, and have a morphology complex enough to have warranted a description by Solly (1884). Five crystals from the Smithsonian collection were analyzed. The magnesium content is greater than the iron content and thus Pierrepont black tourmalines are not schorl. The three analyses from the literature, and three of the five analyses of this study have $Ca > Na$. The preponderance of analyzed Pierrepont black tourmalines are uvites and, for consistency, it is recommended that all Pierrepont black tourmaline be labelled uvite.

The oxidation state of the iron in Pierrepont uvite is not definitively resolved as the microprobe cannot distinguish between $Fe^{+2}$ and $Fe^{+3}$. However, the analyses of Dittrich *et al.* (see Table 1) and Kalb (see Doelter *2*, 2, page 751, Anal. 11) of Pierrepont uvite contain 2.56% and 3.90% $Fe_2O_3$ respectively, plus appreciable ferrous iron. An assumption that the iron content of Pierrepont uvite is partially ferric is also supported by the relatively low aluminum content of the analyses of this study. This low aluminum content strongly suggests that part of the iron is held in the trivalent position in substitution for aluminum.

### *SNARUM, NORWAY*

Four crystals from two specimens of black tourmaline associated with calcite were analyzed. The specimens have $Na > Ca$ and are magnesium-rich. They are dravite. As in the Pierrepont uvite, the aluminum content is very low, suggesting that part of the iron is ferric.

### *YINNIETHARA, WESTERN AUSTRALIA, AUSTRIALIA*

Fine black euhedrons imbedded in mica have come from this classic Australian locality in recent years. Although less abundant on the specimen market than the more common brown dravites, they are available in adequate supply. Two crystals from the Smithsonian collections were analyzed and both are magnesium-rich and thus are ferroan dravites. The iron content of these crystals varies considerably but the calcium:sodium ratio is about the same. These black dravites have a higher calcium content than the brown dravites from the same locality. A representative crystal is shown in Figure 12.

## SUMMARY

In summation, uvite is a rather common mineral. It is abundant at various localities and fine specimens already grace most major, and many minor, mineral collections. In general, brown tourmalines from metamorphosed limestones are usually uvite.

Although the above statements might sit somewhat uncomfortably with collectors long since used to the convention wherein all black tourmalines are schorl, and all brown tourmaline is dravite, mineral names represent chemical compositions, and the correct nomenclature is as follows:

Dravite - magnesium tourmaline with sodium greater than calcium.
Uvite - magnesium tourmaline with calcium greater than sodium.

In terms of attractive mineral specimens, dravite is considerably less abundant than uvite. Most of the famous American localities for magnesium tourmaline contain uvite and not dravite as was formerly understood.

**Table 4. Wet Chemical Analyses of Uvite**

| | Franklin, N.J.<br>B14687 | Ceylon<br>C5212 | Franklin, N.J.<br>C3285 |
|---|---|---|---|
| $SiO_2$ | 35.45 | 35.96 | 36.52 |
| $Al_2O_3$ | 27.30 | 26.80 | 26.76 |
| FeO | 0.07 | 0.41 | 0.38 |
| MgO | 15.16 | 15.20 | 15.29 |
| CaO | 5.86 | 5.50 | 5.18 |
| $Na_2O$ | 0.08 | 0.13 | 0.17 |
| $K_2O$ | 0.00 | 0.00 | 0.00 |
| $H_2O^+$ | 2.53 | 2.70 | 2.68 |
| $H_2O^-$ | 0.02 | 0.04 | 0.02 |
| $TiO_2$ | 0.30 | 0.62 | 0.32 |
| $Li_2O$ | 0.00 | 0.00 | 0.00 |
| $B_2O_3$ | 11.39 | 11.49 | 11.34 |
| F | 2.10 | 1.49 | 1.79 |
| Total | 100.26 | 100.34 | 100.45 |
| Less O = $F_2$ | 0.88 | 0.63 | 0.75 |
| | 99.38 | 99.71 | 99.70 |

**Number of Atoms on the Basis of 31 (O, OH, F)**

| | | | | | | |
|---|---|---|---|---|---|---|
| Si | 5.688 | | 5.784 | | 5.847 | |
| B | 3.155 | | 3.190 | | 3.134 | |
| Al | 5.163 | 8.834 | 5.081 | 8.856 | 5.050 | 8.789 |
| Fe | 0.009 | | 0.055 | | 0.051 | |
| Mg | 3.626 | | 3.645 | | 3.649 | |
| Ti | 0.036 | | 0.075 | | 0.039 | |
| Ca | 1.007 | 1.032 | 0.948 | 0.989 | 0.889 | 0.942 |
| Na | 0.025 | | 0.041 | | 0.053 | |
| H | 2.707 | 3.773 | 2.896 | 3.654 | 2.862 | 3.768 |
| F | 1.066 | | 0.758 | | 0.906 | |
| Si+(B-3.00) | 5.84 | | 5.97 | | 5.98 | |

Analysts: J. Nelen
J. Norberg

### TABLE 5.
### THEORETICAL COMPOSITIONS OF UVITE AND DRAVITE

| | Uvite | Dravite |
|---|---|---|
| $SiO_2$ | 37.07 | 37.62 |
| $Al_2O_3$ | 26.19 | 31.90 |
| $B_2O_3$ | 10.72 | 10.88 |
| MgO | 16.56 | 12.62 |
| CaO | 5.76 | |
| $Na_2O$ | | 3.23 |
| $H_2O$ | 3.70 | 3.75 |
| TOTAL | 100.00 | 100.00 |

It is hoped that the above correct species designations for magnesium tourmalines from specific localities will be of assistance to collectors and curators alike. It is neither possible nor desirable, however, to examine specimens of magnesium tourmalines for collectors to ascertain correct species designations for obscure localities. In general, *most* brown tourmaline associated with calcium minerals is uvite, and *most* brown tourmaline associated with schist and non-pegmatite micas, is dravite.

The authors are indebted to great mineral collectors. Without the Canfield, Roebling, and Bosch mineral collections of the Smithsonian Institution, this study might have taken many years of specimen gathering, instead of one week. Of the 89 specimens analyzed in this study, 59 came from the above mentioned collections. Their contributions were invaluable. The authors are also indebted to Akira Kato for calling their attention to the work of Bouska *et al*, Dadko, and Dzhamaletdinov, and to John S. White, Jr., for a critical reading of the manuscript. Thanks are also due Michael Fleischer for a translation of Kornetova's work, and Clifford Frondel for helpful suggestions.

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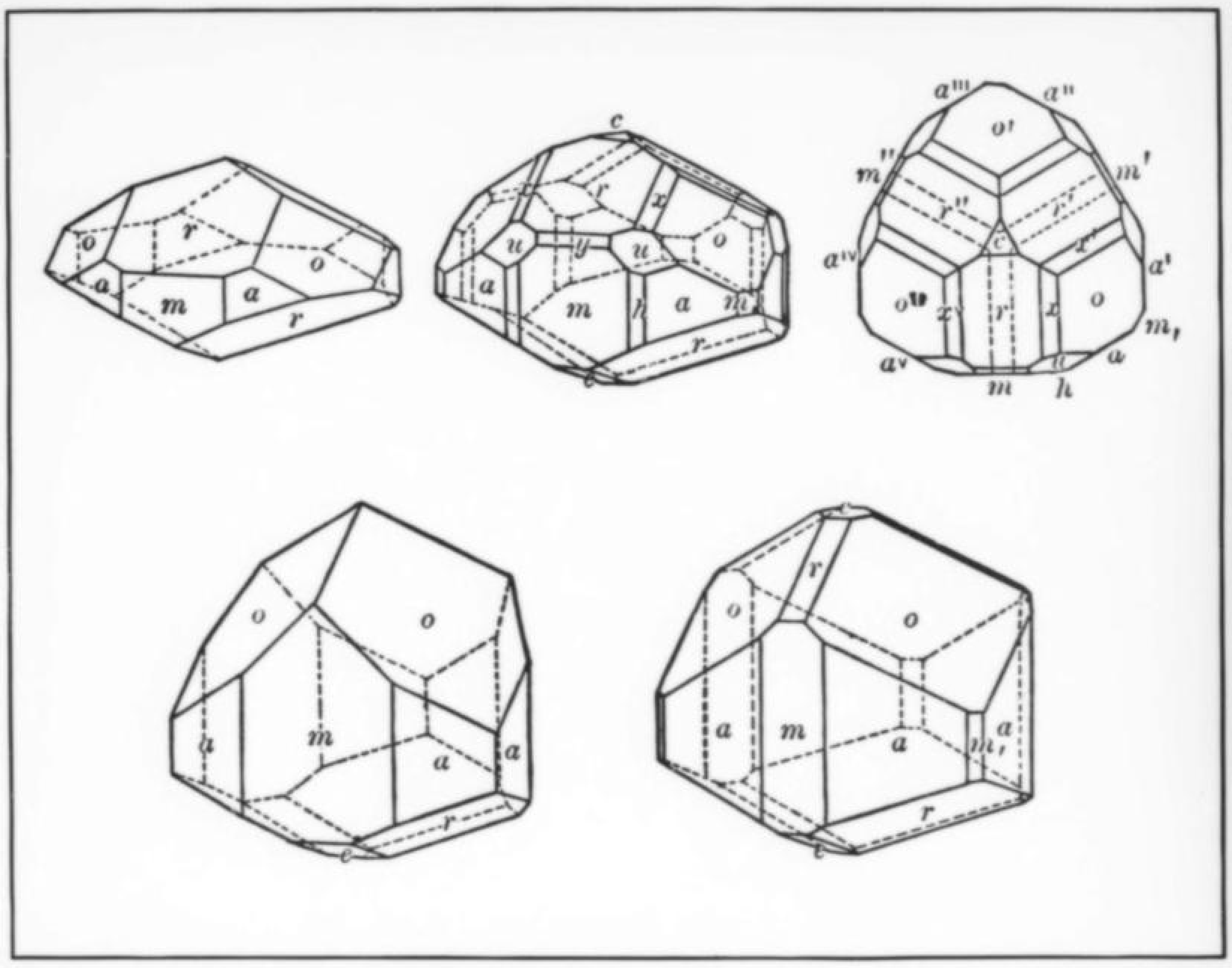

*Figure 11.* **Line drawings of Pierrepont, New York uvite [from Dana, (1892), *The System of Mineralogy*, p. 551].**

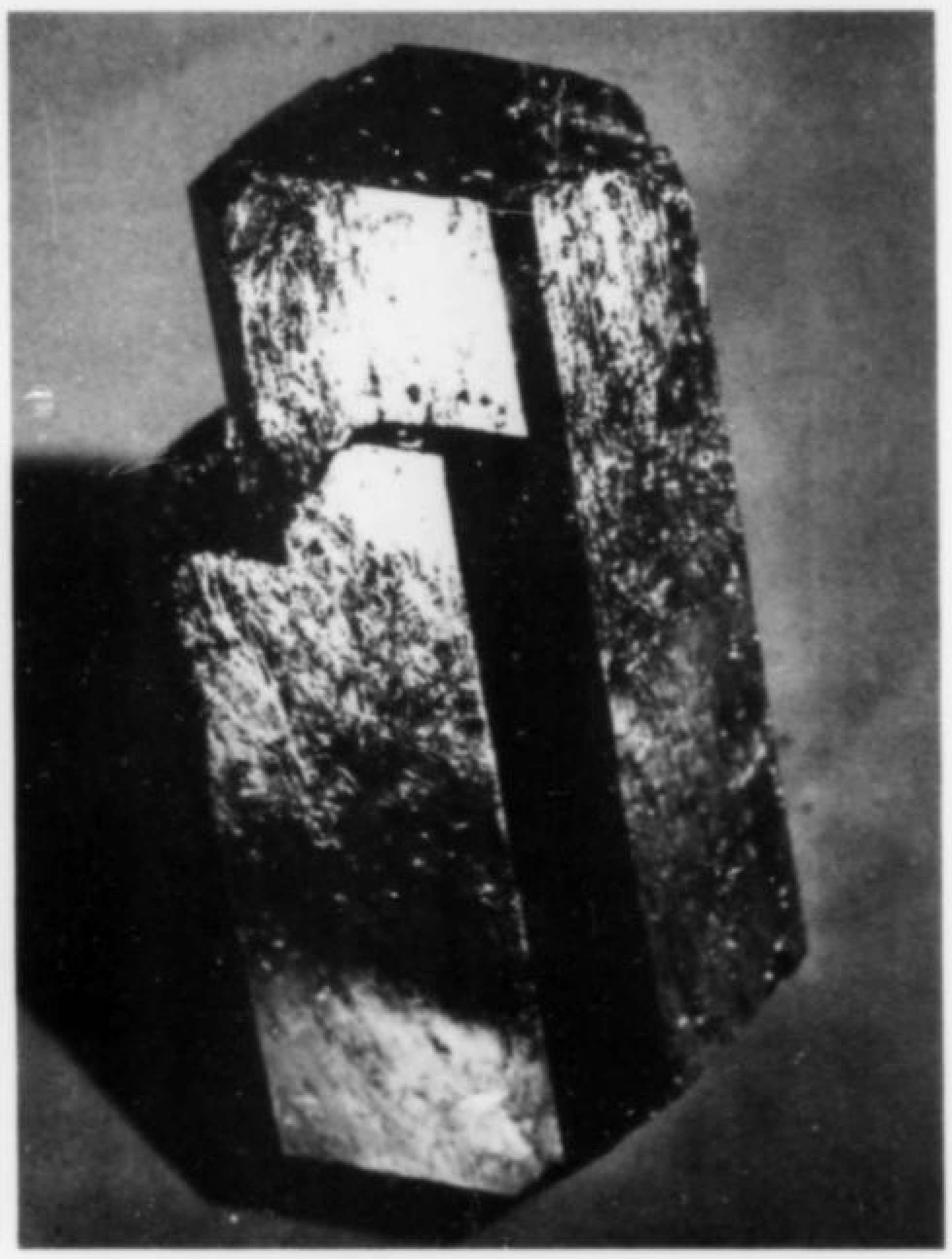

*Figure 12.* **Black dravite from Yinniethara, Western Australia, Australia. The crystal is 9 cm long (NMNH #R17267).**

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# THE DRAVITE CRYSTAL BONANZA OF YINNIETHARRA, WESTERN AUSTRALIA

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**The spectacular dravites from Western Australia which burst upon the mineral specimen market several years ago are among the finest dravite specimens ever found. The deposit, which had been known for many years, was exploited solely for the dravite by Soklich Trading Company and yielded approximately 12 tons of crystals. The open cut mine, picturesquely described by Soklich (1970), is on Mineral Claim 82, 8 km north of Yinnietharra Station Homestead, (24° 39′ S., 116° 9′ E.), 800 km north of Perth.**

## EARLY DISCOVERY

Yinnietharra dravite crystals were first collected by H. G. Stokes in 1918, from the road between Morrissey Hill and Bangemall, (Simpson, 1951). In 1952, W. Poland submitted to the Government Chemical Laboratories a 1 kg crystal showing parallel growth which probably came from the outcrop of the mined deposit. Since that time, dravite crystals have been reported from several other localities in the vicinity of Yinnietharra, but none appear to approach the quality of the Soklich deposit. In 1964, W. H. Cleverley of the Kalgoorlie School of Mines collected from the outcrop which was well known to the station people and local prospectors.

A. Soklich claimed the area in 1968 and mining took place between January, 1969, and January, 1971; since then it has not been worked. The total production of dravite crystals was around 12 tons, about ¾ of which were first grade, doubly-terminated crystals with a value of $16,000 Aust. (from $3.30 to $1.65/kg). The majority of these were bought by H. Sering of Indiana, U.S.A., for retail sale. Excellent and comprehensive photographs of the crystals and deposit have been published by Soklich (1970).

The Yinnietharra district has long been renowned among Australian collectors for the large pegmatites that produced beryl during and after World War II. Many minerals are recorded from the area, including uraninite, gummite, weeksite, tanteuxenite and other rare Ta/Nb minerals, fluorite, quartz (amethyst), bismuth minerals, chrysoberyl, corundum, rare phosphates, apatite, staurolite, variscite, gem beryl (aquamarine), gem garnet and gem diopside. One of the authors (PJB) visited the mine in August, 1971, while examining the pegmatites of the district. Specimens of cordierite and clinobisvanite collected on this trip have been the subjects of papers by Pryce (1973) and Bridge and Pryce (1974).

## REGIONAL SETTING

Yinnietharra is near the center of a major structural unit, the Gascoyne Province (Daniels and Horwitz, 1969) of the extensive Precambrian shield of Western Australia. In direct contrast to its present stable condition, the Gascoyne Province was a highly unstable area of the earth's crust in Proterozoic times (Daniels, 1975). The province now consists of migmatites representing reworked Archean rocks, unconformably overlain by argillaceous Lower Proterozoic Wyloo Group rocks which were strongly metamorphosed and intruded by copious amounts of granitic rock. Middle Proterozoic sedimentary rocks were subsequently deposited unconformably on the older sequence. The metamorphic grade decreases gradually from the fringes of the belt; the most intense activity included vigorous hydrothermal alteration which took place in the Yinnietharra area. The final phase solutions were emplaced as the pegmatites of the region.

## ASSOCIATION

The dravite is enclosed in a phlogopite-plagioclase schist which ranges from massive knotted phlogopite to plagioclase veins, all enclosing dravite crystals. The plagioclase is a calcic oligoclase, approximately $An_{29}$, some of which occurs in the dravites as poikilitically aligned, flattened laths, sub-parallel to the dravite "*c*" axis; the feldspar comprises as much as half the volume of some dravite crystals (though absent in the smallest crystals of dravite).

Minor phlogopite, subhedral rutile, apatite, zircon and fluorite are also included in the crystals, with the rutile ubiquitous in the dravite and phlogopite. Green apatite in lumps up to 10 cm in diameter, rarely as small crystals, and minor monazite are also found in the phlogopite. Minor chlorite occurs in the plagioclase veins. Secondary opal and carbonates resulting from weathering have cemented the upper part of the deposit, encrusting some crystals. The phlogopite is similar in optical properties to that from the nearby cordierite occurrence described by Pryce (1973) but has a different composition.

## TABLE I.

### CHEMICAL, PHYSICAL, OPTICAL & CRYSTAL DATA OF BROWN DRAVITE AND PHLOGOPITE MATRIX FROM YINNIETHARRA, W.A.

| | 1 | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 36.61 | 42.24 | Si | 5.774 | 8.00 | 5.855 | |
| $B_2O_3$ | 10.35 | | B | | | 2.858 | |
| $Al_2O_3$ | 32.62 | 14.54 | Al | 2.226 | | 6.000 | |
| | | | Al | 0.116 | 5.65 | 0.148 | 3.988 |
| $TiO_2$ | 0.90 | 0.75 | Ti | 0.077 | | 0.109 | |
| $P_2O_5$ | 0.44 | 0.03 | P | 0.003 | | 0.060 | |
| $Fe_2O_3$ | 0.41 | 1.10 | $Fe'''$ | 0.113 | | 0.050 | |
| FeO | 0.09 | 0.28 | $Fe''$ | 0.032 | | 0.012 | |
| MgO | 11.29 | 26.05 | Mg | 5.309 | | 2.692 | |
| CaO | 1.10 | 0.13 | Ca | 0.019 | 1.72 | 0.188 | |
| $Na_2O$ | 2.34 | 0.31 | Na | 0.082 | | 0.727 | |
| $K_2O$ | 0.01 | 8.18 | K | 1.427 | | 0.002 | |
| $Li_2O$ | — | 0.35 | Li | 0.192 | | | |
| $H_2O^-$ | 0.01 | 0.27 | | | | | |
| $H_2O^+$ | 3.90 | 5.27 | OH | 4.796 | 5.11 | 4.149 | 4.245 |
| F | 0.17 | 0.72 | F | 0.310 | | 0.086 | |
| Σ | 100.24 | 100.22 | | | | | |
| $O \equiv F_2$ | 0.07 | 0.30 | | | | | |

| | 1 | 2 | 5 | 6 |
|---|---|---|---|---|
| Σ | 100.17 | 99.92 | | |
| $V_2O_5$ | 100 ppm | 90 ppm | a(Å) = 15.939(1) | — |
| $Cr_2O_3$ | 25 ppm | 25 ppm | c(Å) = 7.199(1) | — |
| MnO | 100 ppm | 150 ppm | c/a = 0.4517 | — |
| $Li_2O$ | 90 ppm | | V(Å³) = 1584 | — |
| Sr | 12 ppm | | D =3.03 | 2.80 |
| Rb | <1 ppm | | $\epsilon$ =1.617 | $\alpha$ =1.558 |
| Ga | 20 ppm | | $\omega$ =1.638 | $\beta$ =1.585 |
| $CO_2$ | n.d. | n.d. | $\omega$(capucine | $\gamma$ =1.590 |
| S | n.d. | n.d. | yellow 15b) > $\epsilon$ | $2V\alpha$5-20° |

1. Dravite analysis (P.E. Hewson)
2. Phlogopite analysis (P.W. Hewson)
3. Phlogopite atomic ratios based on 24 (O, OH, F)
4. Dravite atomic ratios based on 31 (O, OH, F)
5. Crystal and Optical Date (Na D line) of dravite
6. Crystal and Optical Data (Na D line) of phlogopite.

n.d. = not detected.
Analysis indicates minor apatite and rutile impurity.

Analyses by well-known gravimetric, volumetric & spectrophotometric methods.

*Figure 1.* **"Dodecahedral" dravite crystal from Yinnietharra.**

## DRAVITE CRYSTALS

The surfaces of many of the dravite crystals are idented and pockmarked by phlogopite and plagioclase. The almost equidimensional dravite crystals are so similar to dodecahedral garnets that they initially confused collectors. An example is shown in figure 1. The narrow prism face reflecting light in the photograph indicates that the crystal is not isometric.

The maximum weight of a single crystal was around 11.5 kg and numerous crystals around 15 cm long were found; the smallest were less than 1 cm long. Crystal forms present are the hexagonal prism (*a*) with a trigonal prism (*m*) and terminated by the rhombohedron (*r*). Numerous parallel groups of crystals were found. The dravite color is close to *Ridgway Bister 15" m*, with glints of golden brown, a subvitreous lustre and a *Ridgway Pale Ochraceous - Buff 15' f* streak (Ridgway, 1912, standardized colors).

## BLACK DRAVITE

A black schist composed of phlogopite (which expands up to four times its original volume on heating) from between granite and a rose-quartz vein one mile north of the main dravite deposit on M.C. 346 contains black dravite mistakenly called schorl (White, 1970). The crystals are well-formed, many doubly terminated with internal zoning visible in thin section and with an *MgO* content of 9.85%. Production of these black dravites was around 1.3 tons with a maximum size of about 60 by 23 cm for a specimen showing parallel growth.

## ANALYSES

The physical, chemical and optical properties (Table 1) are those of a typical brown dravite and phlogopite, and are of interest due to the wide distribution of material among museums and collections.

## X-RAY STUDY

The X-ray unit cell of a dravite crystal from Yinnietharra was determined by the method of Pryce (1970) as $a$ = 15.939 (1*), $c$ = 7.199 (1) Å. A crystal from the nearby black dravite deposit had $a$ = 15.938 (2), $c$ = 7.191 (1) Å. Both the determined unit cells are close to the cell of the dravite end-member of Epprecht (1953).

## ACKNOWLEDGEMENTS

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*Numbers in parentheses give estimated standard deviations of the digit in last place.

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## A NEW MINERAL:

# PERLOFFITE,

## THE $Fe^{3+}$ ANALOGUE OF BJAREBYITE

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### Introduction

The similarity in the roles played by $Al^{3+}$ and $Fe^{3+}$ in crystals formed at moderate and low temperature is well established. This realization moved Moore *et al.* (1973), when describing the new mineral bjarebyite, $Ba(Mn, Fe)(Al_2(OH)_3(PO_4)_3$, to suggest the possible existence of the ($Fe^{3+} > Al^{3+}$) analogue of this species. In 1974, Vandall King of Bristol, Maine, collected a specimen of vuggy ludlamite at the Big Chief pegmatite, Glendale, South Dakota. In one vug, he observed lustrous, black, spear-shaped crystals which he was unable to identify. Subsequently, he provided this specimen for identification. Detailed study has shown these crystals to represent a new mineral species, which is, in fact, the $Fe^{3+}$ analogue of bjarebyite.

### Occurrence and Paragenesis

The new species, here named perloffite, is as yet known only from the Big Chief pegmatite. Careful examination of the type specimen, provided by King, and of several specimens provided by W.L. Roberts of the South Dakota School of Mines and Technology, revealed the complex mineralogy of the perloffite assemblage. Single crystals and sprays of perloffite crystals occur perched on earlier-formed crystals of ludlamite, hureaulite and siderite in vugs in ludlamite derived from the hydration of parent triphylite. Later-formed phosphate species include vivianite, messelite, beraunite, rockbridgeite, whitmoreite, jahnsite, mitridatite and carbonate apatite. Conspicuously absent are the aluminum-bearing phosphates which typify the bjarebyite association at the Palermo No. 1 pegmatite, North Groton, New Hamphire.

### Physical Properties

Perloffite is dark brown to greenish-brown in small crystals (0.1 mm); however, larger crystals have a black appearance. The streak and powder are greenish-yellow. The luster is vitreous to subadamantine. It has a hardness of approximately 5 on Mohs' scale and a perfect {100} cleavage. Crystals are slowly soluble in cold 1:1 HCl. The amount of material available was insufficient for a reliable measurement of the specific gravity using the Berman microbalance or similar methods. Crystals sink rapidly in pure methylene iodide (s.g. 3.32), thus precluding the use of this sink-float method for density determination.

### Morphology

Although small crystals of perloffite often possess rounded and indistinct faces, larger crystals, which range up to 1 mm in greatest dimension, generally possess sharp, easily descernible faces (Fig. 1). The crystal class is monoclinic holosymmetric (2/m) and crystals commonly exhibit a simple development consisting of only 4 forms: $c\{001\}$, $g\{\bar{1}01\}$, $t\{021\}$ and $x\{\bar{1}31\}$. This contrasts with the complex development of bjarebyite crystals on the type specimen. Only the forms $c\{001\}$ and $t\{021\}$ are common to both species. No twinning was observed in perloffite, but semi-parallel growth appears common. A plan and clinographic projection of a typical perloffite crystal are shown in figure 2.

### X-ray Crystallography

Single-crystal precession photographs provided the unit cell geometry and extinction criteria. The cell constants were refined by a least-squares fit of 22 indexed powder reflections. The similarity in the cell parameters of perloffite and bjarebyite (Table 1) suggests that these minerals are isostructural. The larger cell constants of perloffite are consistent with the replacement of $Al^{3+}$ in the bjarebyite structure by the larger $Fe^{3+}$ cation.

Calculated and observed powder data for perloffite appear in Table 2. The calculated intensities were obtained from a structure factor computation utilizing the atomic coordinates determined by Moore and Araki (1974) for bjarebyite and substituting $Fe^{3+}$ for $Al^{3+}$. The close agreement between the observed and calculated powder intensities is further evidence that perloffite possesses the bjarebyite structure.

### Chemical Composition

Electron microprobe analyses were performed by Anthony J. Irving, utilizing barite and arrojadite standards. Averaging eleven sample points over three crystals yielded **Ba** 17.6, **Ca** 1.1, **Mg** 0.39, **Mn** 11.1, **Fe** 18.7, **Al** 0.15 and **P** 13.3. Owing to the small amount of material available, water content could not be determined. The **(OH)**$^-$ anion and the valence states and structural sites of the cations were assigned by analogy to bjarebyite.

The proposed formula based upon P = 3 is $(Ba_{0{\cdot}89}Ca_{0{\cdot}09})(Mn_{1{\cdot}41}Fe_{0{\cdot}37}Mg_{0{\cdot}11}Ca_{0{\cdot}11})^{2+}(Fe_{1{\cdot}96}Al_{0{\cdot}04})^{3+}(OH)_3(PO_4)_3$. The density of perloffite calculated using this formula and the aforemen-

**TABLE 1. PERLOFFITE AND BJAREBYITE. CELL PARAMETERS**

| | Perloffite | Bjarebyite* |
|---|---|---|
| *a*(Å) | 9.223(5) | 8.930(14) |
| *b*(Å) | 12.422(8) | 12.073(24) |
| *c*(Å) | 4.995(2) | 4.917(9) |
| $\beta$ | 100.39(4)° | 100.15(13)° |
| V(Å$^3$) | 562.9(5) | 521.8(1.5) |
| space group | $P2_1/m$ | $P2_1/m$ |
| formula | $Ba(Mn,Fe)_2^{2+}Fe_2^{3+}(OH)_3(PO_4)_3$ | $Ba(Mn,Fe)_2^{2+}Al_2(OH)_3(PO_4)_3$ |
| Z | 2 | 2 |

*Moore *et al.* (1973).

**TABLE 2. PERLOFFITE. CALCULATED AND OBSERVED POWDER DATA**

| Calculated |  |  | Observed* |  |
|---|---|---|---|---|
| I/Io | d | hk*l* | I/Io | d |
| 13 | 9.072 | 100 | 2 | 9.06 |
| 32 | 5.125 | 120 | 3 | 5.12 |
| 9 | 4.193 | 001 |  |  |
| 38 | 4.689 | $\bar{1}01$ | 3 | 4.69 |
| 39 | 4.569 | 011 | 3 | 4.56 |
| 20 | 3.663 | 220 | 1 | 3.651 |
| 10 | 3.528 | $2\bar{1}1$ |  |  |
| 7 | 3.379 | 121 |  |  |
| 64 | 3.166 | 031 | .10 | 3.166 |
| 36 | 3.166 | $\bar{2}21$ |  |  |
| 53 | 3.104 | $\bar{1}31$ | 4 | 3.105 |
| 35 | 3.058 | 230 |  |  |
| 60 | 2.979 | 211 | 5 | 2.982 |
| 31 | 2.938 | 310 | 4 | 2.939 |
| 19 | 2.938 | 140 |  |  |
| 40 | 2.887 | 131 | 3 | 2.887 |
| 24 | 2.751 | 221 | 8 | 2.73 (broad) |
| 43 | 2.742 | $\bar{3}11$ |  |  |
| 31 | 2.719 | 320 |  |  |
| 10 | 2.589 | $\bar{1}41$ |  |  |
| 25 | 2.487 | $\bar{1}02$ | 2 | 2.490 |
| 19 | 2.457 | 002 | 2 | 2.457 |
| 7 | 2.373 | $\bar{2}41$ |  |  |
| 9 | 2.231 | 410 | <1 | 2.229 |
| 22 | 2.195 | $\bar{1}51$ | 2 | 2.195 |
| 7 | 2.167 | 340 |  |  |
| 11 | 2.132 | 122 | <1 | 2.130 |
| 9 | 2.088 | $\bar{4}21$ |  |  |
| 25 | 2.070 | 060 | 4 | 2.070 |
| 9 | 2.040 | $\bar{2}32$ |  |  |
| 11 | 1.991 | 132 | 1 | 1.990 |
| 7 | 1.954 | $\bar{4}31$ |  |  |
| 6 | 1.915 | 222 |  |  |
| 6 | 1.894 | $\bar{1}61$ |  |  |
| 6 | 1.871 | $\bar{2}42$ |  |  |
| 6 | 1.833 | 142 | <1 | 1.837 |
| 8 | 1.820 | $\bar{4}12$ | 1 | 1.815 |
| 7 | 1.814 | 500 |  |  |
| 6 | 1.804 | $\bar{4}41$ |  |  |
| 6 | 1.722 | 351 |  |  |
| 10 | 1.640 | 441 | <1 | 1.637 |
| 9 | 1.610 | 501 | <1 | 1.610 |
| 7 | 1.591 | $\bar{1}62$ |  |  |
| 6 | 1.565 | 541 | <1 | 1.565 |
| 10 | 1.536 | 271 |  | 1.53 (broad) |
| 11 | 1.530 | 370 |  |  |
| 11 | 1.523 | 033 |  |  |
| 8 | 1.501 | $\bar{3}71$ | 2 | 1.498 |
| 10 | 1.496 | $\bar{5}32$ |  |  |

*114.6 mm camera diameter, Mn filtered Fe radiation.

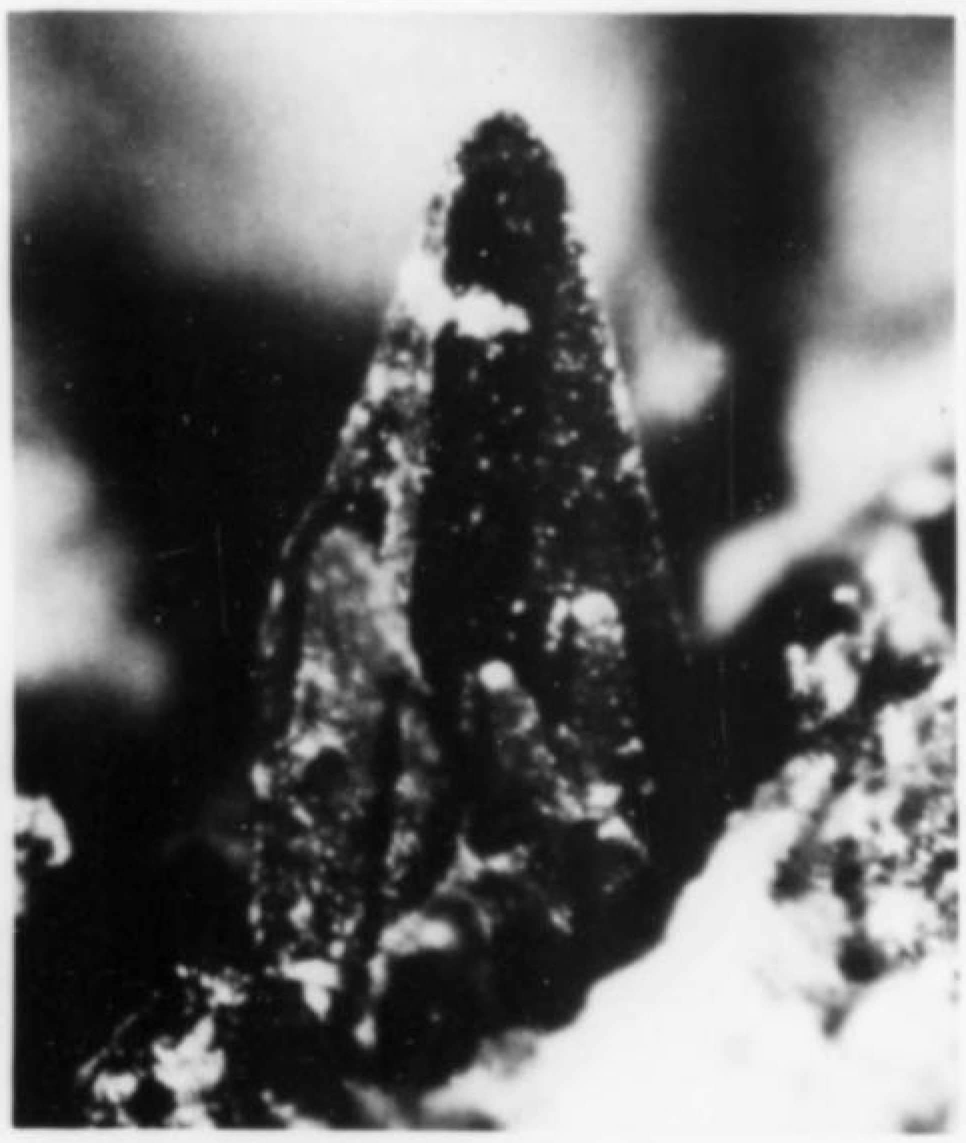

***Figure 1 (right).*** **Perloffite crystals on the type specimen. The large crystal is about 1 mm long (photomicrograph by Julius Weber).**

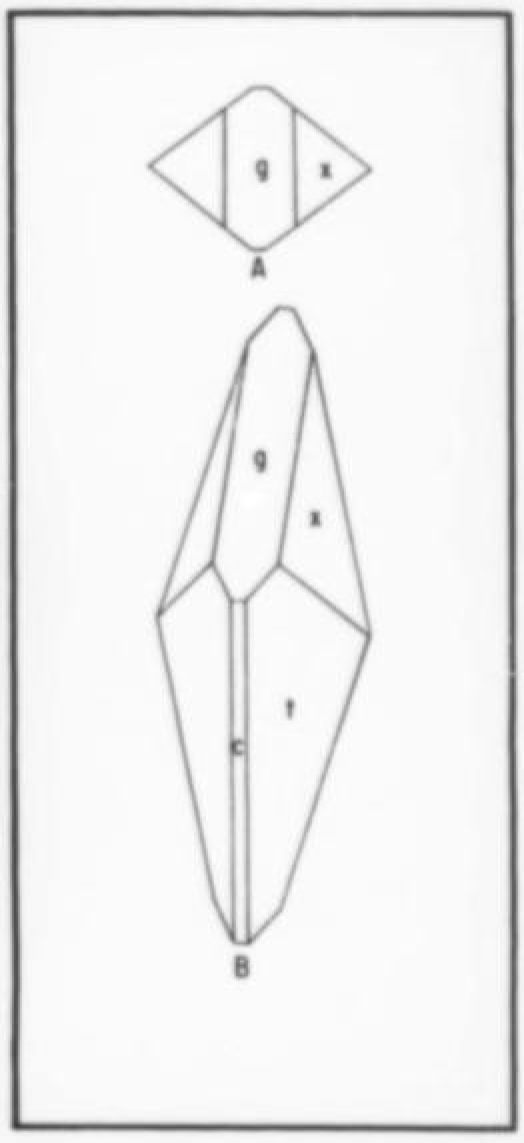

***Figure 2 (far right).*** **Crystal drawing of perloffite showing the forms *c*{001}, *g*{$\bar{1}$01}, *t*{021} and *x*{$\bar{1}$31}. A. Plan. B. Clinographic projection.**

tioned cell parameters is 3.996 gm/cm$^3$. The formula may be idealized as **Ba(Mn,Fe)$_2^{2+}$Fe$_2^{3+}$(OH)$_3$(PO$_4$)$_3$**.

## Optical Properties

The optical properties of perloffite are summarized in table 3. Perloffite exhibits much more pronounced absorption and pleochroism effects than does bjarebyite. The strong absorption in the **X** optical direction is attributable to electron transfer along the Fe$^{3+}$ octahedral chains which parallel the *b*-axis; the strong absorption in the **Z** direction is attributed to Fe$^{2+}$ – Fe$^{3+}$ charge transfer between the M(1) and M(2) cation sites (see Moore and Araki, 1974).

## Name

It is a pleasure to name this new mineral after Louis Perloff of Tryon, North Carolina. His keen eye, unceasing curiosity, and years of experience with minerals rank him as one of the most outstanding amateur mineralogists in our country. His remarkable ability as a mineral photographer and his penchant for delightfully dry witticisms have captivated many an audience.

The species and name were approved by the International Commission on New Minerals and New Mineral Names (IMA). The type specimen is preserved in the collection of the U.S. National Museum of Natural History (Smithsonian Institution).

**TABLE 3. PERLOFFITE. OPTICAL DATA**

| | |
|---|---|
| $\alpha$ | 1.793(5) |
| $\beta$ | 1.803(5) |
| $\gamma$ | 1.808(5) |
| 2V | 70° - 80° |
| sign | (-) |
| absorption | $X,Z > Y$ |
| pleochroism | X,Z dark greenish-brown<br>Y light greenish-brown |
| dispersion | $r \ll v$ |
| orientation | $x \parallel b$, $Y \wedge c$ -42° |

## Acknowledgements

Vandall King brought the original specimen to my attention and sacrificed it for study. Willard L. Roberts provided additional specimens. The photomicrograph of perloffite was prepared by Julius Weber. Paul B. Moore offered many helpful comments.

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# THE HARDING MINE

## Taos County, New Mexico

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## INTRODUCTION

The Harding mine, in the western part of the Picuris Range about 20 miles southwest of Taos (Fig. 1), has yielded substantial amounts of commercial beryl, lepidolite, spodumene, and tantalum-niobium minerals over a period of half a century. It also has become widely known as a source of handsome mineral specimens, as a provocative locality for scientific studies, and as an attraction for those who appreciate spectacular exposures of pegmatite. It lies 4 miles southeast of the Rio Grande Canyon at an altitude of 7400 feet, and it is readily accessible from a nearby point on State Highway 75 about 6 miles east of Dixon and 9 miles east of Embudo.

The mine property has been leased by the owner, Arthur Montgomery, to the University of New Mexico for preservation as one of the state's unusual natural assets. The university is planning not only to provide for such preservation, but also to make this locality continuingly available for public inspection, study, and mineral collecting on a modest scale. Anyone with an interest in visiting the property should contact the Chairman, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131. A splendid collection of representative Harding mine minerals, donated by Montgomery, can be viewed in the university's Geology Museum.

The published record of the Harding mine consists of early general descriptions (Roos, 1926; Just, 1937) and mineralogical notes (e.g., Schaller and Henderson, 1926; Hirschi, 1928, 1931; Hess, 1933), summaries of extensive exploratory work by the U.S. Bureau of Mines in 1943 and 1948 (Soulé, 1946; Berliner, 1949), descriptions of milling operations for tantalum minerals (Wood, 1946) and mining operations for beryl (Montgomery, 1951), and various discussions of mineralogical and structural relationships in the pegmatite bodies (e.g., Cameron and others, 1949; Montgomery, 1950; Page, 1950; Jahns, 1951, 1953a,b; Mrose, 1952; Rimal, 1962). The purpose of the present paper is to describe the geology, mineralogy, and mining history of the Harding locality, in part as an aid to those who visit the property or who view some of its characteristic minerals in Albuquerque at the Geology Museum. The treatment is based on detailed field studies that began in 1942 under the aegis of the U.S. Geological Survey and continued intermittently for more than two decades, and on mineralogical investigations in several laboratories.

## HISTORY

Mining at the Harding property has been varied in purpose and style, unique in part, and successful in general. The most successful operations were those of J. L. Danziger during the 1920's and Arthur Montgomery during the 1940's and 50's. The colorful mining history of the Harding mine can be divided into three periods based primarily on the minerals mined.

### *The Lepidolite Period (1919-1930)*

Scattered large blocks and low outcrops of pegmatite quartz attracted prospectors to the Harding locality before the turn of the century, but it was not until 1918 that Joseph J. Peyer of Taos recognized significant lithium mineralization in the form of large masses of lilac-colored lepidolite. Beginning in 1919 Peyer and two partners, Frank Gallup of Taos and Arthur H. Gossett of Embudo, mined the lepidolite by blasting loose boulders and working the open cut on the north-facing hillside. They hand-sorted the broken ore and hauled it by wagon over an improvised road to Dixon, from whence it was shipped by rail to Wheeling, West Virginia, for grinding and sale to the ceramic industry. At that time lepidolite was used mainly in the manufacture of opaque white glass for jar tops and lighting fixtures because of its properties as a flux, opacifier and toughener.

Late in 1920 the operation was taken over by Mineral Mining and Milling Corporation of New York. An adit was driven southward into the hillside to permit expansion of the open cut by glory-hole methods, and a second cut adjacent on the east was

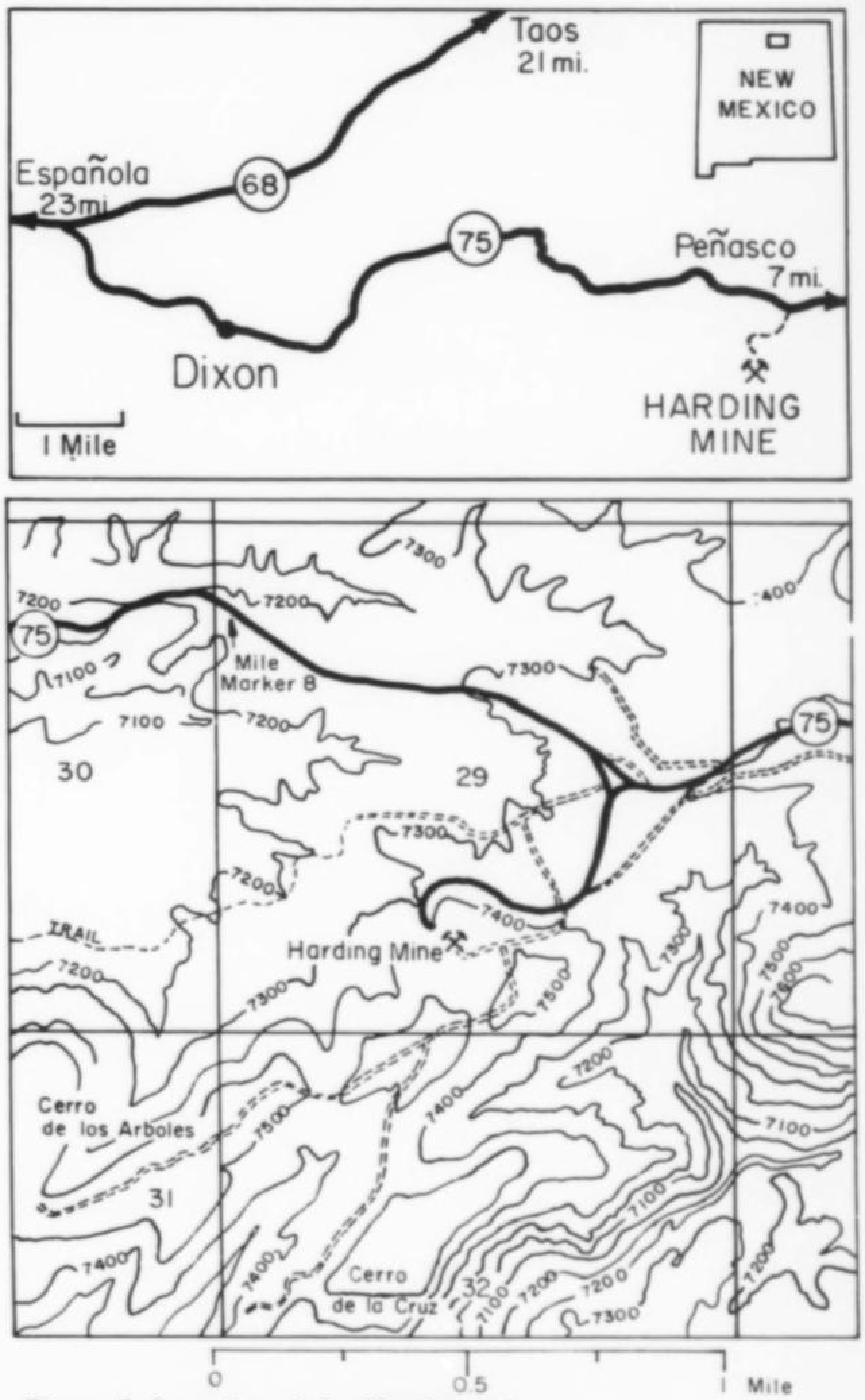


*Figure 1.* **Location of the Harding mine.**

(Maps from J.E. Taggart, New Mexico Bureau of Mines 1976 Annual Report) opened (northeast entry, Fig. 2). By 1923 production had risen to 800 tons per year, but the venture proved unprofitable and mining ceased in 1924. During that year, two shipments of apparently excellent lepidolite caused grave difficulties when used for making glass; this material may well have contained a significant amount of the tantalum mineral microlite.

In 1924 the Embudo Milling Company, under the direction of J. L. Danziger of Los Angeles, began construction of a mill near the railroad depot at Embudo and in 1927, upon completion of the facility, the company reopened the Harding mine. The main pit was much enlarged and merged with the east cut. A second adit was driven in from the west and, along with the first adit, was subsequently daylighted; they are now the main and west entries to the quarry (Fig. 2, 4). The hand-sorted ore was trucked to the Embudo mill for crushing, purifying and sacking for shipment to glass factories.

The demand for lepidolite was high and production soon far exceeded levels of previous years. Quality was maintained at a high level but the operation was barely profitable; in 1928 production of $58,858 in ore yielded only $619.42 in profit. By 1929 the large, pod-like body of rich lepidolite had been mined out and efforts turned to the more expensive extraction of irregular projections and shoots. Several undercuts were made in the south face of the quarry (Fig. 9) and finally a large, room-like opening, still accessible for inspection, was developed opposite the main quarry entry (Fig. 7). The mine shut down in 1930 and was transferred back to the original owners in 1931.

Although this first period of mining was, in general, unprofitable, workings were developed which provide some of the world's finest exposures of complex pegmatite.

### *The Microlite Period (1942-1947)*

The Harding mine was reborn in 1942; the United States' wartime need for tantalum was acute, and microlite, a relatively rare calcium tantalate, had been reported from the main quarry (e.g. Hirschi, 1931). Small amounts of tantalite-columbite had been recovered from placer deposits in the area, but it was Arthur Montgomery (incidentally, the principal early benefactor of the *Mineralogical Record*) who first identified the Harding property as a potentially economic source of tantalum. Acting on Montgomery's appraisal, the U.S. Geological Survey sampled the dump and mapped the mine area in detail; favorable results led Montgomery to enter into a lease-purchase agreement for the property in 1942.

***Figure 2.*** **Southwestward view of Harding quarry from North Knob, showing the sharp, irregular hanging wall of the main pegmatite body as exposed by open-cut mining prior to 1943. The body dips gently away from the observer, and its footwall is exposed near portal of main entry in right foreground. Active workings for microlite ore are at left in quarry, beyond the northeast entry. Temporary structure of U.S. Bureau of Mines camp appears on the wooded slope in center distance.**

The microlite ore, incredibly rich, was hand-mined without explosives so that none would be lost through blasting. The resulting yield (6137 pounds of concentrate containing 71% $Ta_2O_5$ and 6% $Nb_2O_5$) in 1943 was by far the largest single unit of domestic tantalum production ever recorded. In that same year a carload of high-grade spodumene was also produced.

Smaller shipments of microlite were made in 1944 and 1945, and in 1946 more lepidolite was mined and shipped along with microlite. By the time tantalum production ceased in 1947 the eastern parts of the main quarry face had been considerably reshaped, and a labyrinthine network of tunnels and small rooms had been developed south of this face (Fig. 7). Most of these underground workings have since become inaccessible or unsafe for entry.

During 1943 and 1948 the U.S. Bureau of Mines explored the area adjoining the quarry on the south; 46 diamond-drill holes aggregating to 5770 feet were sunk and the cores analyzed. A considerable tonnage of spodumene and Ta-Nb ore was discovered; thus the Harding became the first domestic pegmatite mine with blocked out reserves, reserves that remain in place today.

The Microlite Period at the Harding mine saw production of 41 tons of spodumene, 558 tons of lepidolite ore, nearly 500 pounds of tantalite-columbite and over 22,000 pounds of microlite concentrate averaging 68% $Ta_2O_5$ and 7% $Nb_2O_5$. Profit from the operation was sufficient to permit purchase of the property by Montgomery.

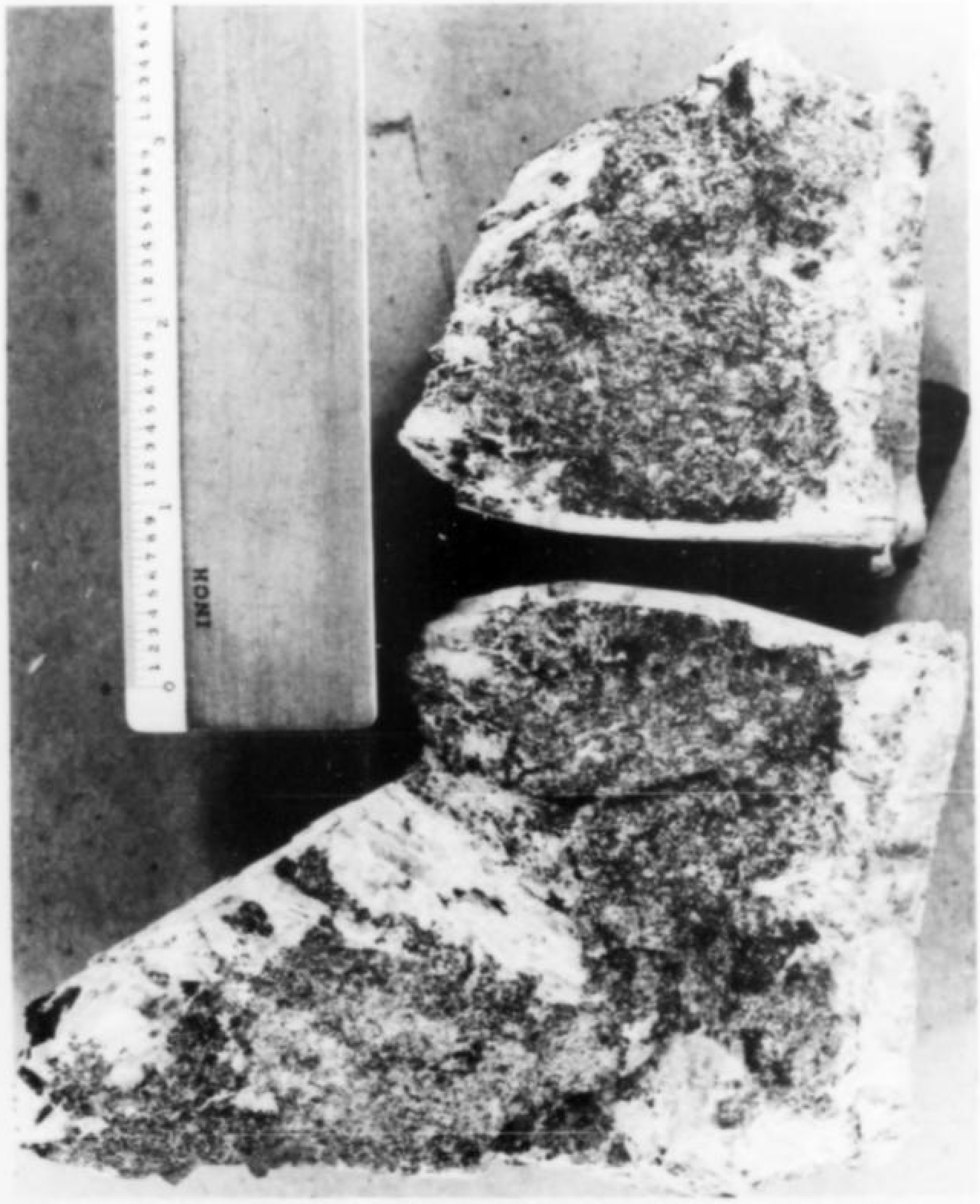


*Figure 3.* **Tantalum ore of exceptionally high grade, obtained from eastern part of main quarry in 1943. Large but thin blades of spodumene, some of them with highly corroded edges, enclose a finer-grained aggregate of microlite, tantalite-columbite (dark), muscovite, lepidolite, albite, and spodumene. The abundant microlite appears mainly as light gray sports, 0.03 to 0.05 inch in diameter, that are crowded within a darker matrix of scaly micas.**

### *The Beryl Period (1950-1958)*

Beryl was identified at the Harding locality during the early years of mining there (e.g. Just, 1937, p. 26) but was regarded as no more than a rare accessory mineral in the pegmatite until the U.S.G.S. survey late in 1942 showed it to be widespread and locally abundant.

In 1944 Montgomery found many loose chunks of beryl, one weighing nearly 100 pounds, on an old dump. Subsequent work high in the quarry near the west entry revealed a thick, elongate lens of nearly pure beryl lying at the upper surface of the pegmatite "much like a thick dab of frosting on the top of a cake." The 23-ton shipment from this occurrence contained nearly 11% BeO (pure beryl would yield ≈ 13%). More beryl was subsequently located by the U.S. Bureau of Mines in 1943; several drill holes penetrated beryl in various parts of the pegmatite body and one of them (No. 22, Fig. 7) penetrated 5 feet of nearly pure beryl at the top of the pegmatite. Mapping and trenching further documented the presence of beryl in many parts of the hanging wall zone.

Montgomery and Flaudio Griego of Dixon mined beryl from 1949 until Griego's death in 1958. By early 1950 the working face was solid beryl for days at a time (Fig. 6). Production ranged from 500 to 2000 pounds per day, all by four men or less and a mule named Beryl. During this time the distribution of minerals in the pegmatite was seen to be irregular but clearly systematic (e.g. Cameron and others, 1949).

### *The Dormant Period (1959-present)*

After 1958 the Harding property was leased to several companies. Actual production was limited to clean-up work on already broken rock and to the driving of a few short tunnels.

Now the mine and its remaining ores are to be preserved for the enjoyment and educational benefit of the public; Montgomery has elected to conserve the property "both as a historical landmark in New Mexico mining and as a treasure-house of rare and exotic minerals."

## GEOLOGIC SETTING

The Harding pegmatites lie within a complex terrane of Precambrian rocks that have been mapped, described, and variously interpreted by Just (1937), Montgomery (1953), and Long (1974). This terrane features a thick section of arenaceous and pelitic metasedimentary rocks with interlayered metavolcanic rocks of basaltic to rhyolitic composition, and also large intrusive bodies of younger igneous rocks that have been collectively referred to as the Dixon granite or Embudo granite. Both Just and Montgomery recognized important textural and compositional differences among the exposed granitic rocks, and more recently Long has shown that they probably represent at least four distinct episodes of magmatism occurring at progressively increasing depth over a considerable span of Precambrian time.

The east-west outcrop belt of pegmatite bodies at the Harding locality corresponds in general position with a complicated boundary between quartz-muscovite schists on the north and amphibolitic rocks on the south. The well-defined planar structure in these rocks trends northeast to east-northeast and dips steeply southeastward (Fig. 2), and the boundary between them has a similar general attitude in both directions beyond the pegmatite area. No granitic rocks are exposed in the immediate vicinity of the mine, but less than a mile to the east the prominent Cerro Alto consists of intrusive metadacite, and in the area west of the mine porphyritic quartz monzonite underlies Cerro de los Arboles and Cerro Puntiagudo. To the south, in the canyon area traversed by the Rio de Peñasco (Rio Pueblo), are many exposures of biotite quartz monzonite and granodiorite that represent a large pluton of considerable complexity (Long, 1974).

Bodies of pegmatite, youngest among the Precambrian rock units, are widespread in the region and are especially abundant in the belt of metamorphic rocks traversed by State Highway 75. Many are long thin dikes, with northeasterly trend and steep dip, that consist of quartz, alkali feldspars, muscovite, garnet, and sparse yellowish green to green beryl in well-formed prisms. Most of these dikes are internally zoned, with prominent core segments of massive quartz. Other zoned bodies, in general smaller and more pod-like, consist almost wholly of quartz, albite, and muscovite. Bodies of a third kind, characterized by greater thickness, prevailingly gentle dip, and unusual abundances of Be, Li, and Ta-Nb minerals, are known only in the mine area and at an unnamed locality about half a mile to the northwest.

Marked differences in composition, structure, and host-rock relationships suggest that the several kinds of pegmatite in the region may well be of different ages, but a sequence cannot be firmly established and dated from radiometric information now available. Aldrich and others (1958) reported K-Ar and Rb-Sr

***Figure 4.* A 1943 southwestward view of west entry, some of the dumps from main quarry, and old platform for lepidolite ore. The parallel trenches on the hillslope were excavated by U.S. Bureau of Mines to expose the beryl-bearing upper part of the pegmatite body. The gently dipping contact between pegmatite (light) and overlying amphilbolite (dark) appears high on the entry wall at upper left. The old dump in immediate foreground at left yielded the first microlite ore to be commercially recovered from the property (see Fig. 9).**

ages of 1260 million years for four Harding muscovites and 1350 m.y. for a Harding lepidolite; Gresens (1975) reported a K-Ar age of 1335 m.y. for muscovite from an unnamed pegmatite in the Picuris Range. Neither these ages nor that suggested by Fullagar and Shiver (1973) for granitic rocks in the region can be unequivocally translated into a dated episode or sequence of plutonism, but Long (1974) has pointed out that the Harding pegmatites may be as much as 100 million years younger than the youngest of the granitic plutonites. An age difference of such magnitude is consistent with field and petrographic evidence suggesting that these pegmatites may not be genetically related to any of the granitic intrusives now exposed in the Picuris Range.

## THE PEGMATITE BODIES

### *General Features*

The Harding pegmatites, in the south half of Section 29, T23N, R11E, crop out in a well-defined belt about 2500 feet long and 150 to 500 feet wide. Most of the bodies are pinching-and-swelling dikes that in general are 5 to 20 feet or more in thickness, trend west to west-northwest, and dip southward at low to moderate angles. Several thinner, steeply dipping branches and connections trend north to northwest. The main body, at the western end of the belt, is well exposed in outcrop and mine workings along the southwestern side of a shallow canyon (Fig. 2), and an extensive up-dip erosional remnant lies opposite on the flank of North Knob. The ridge extending east-southeastward from this knob is marked by the outcrops of several thinner dikes, most of which have been opened by means of pits, cuts, and short tunnels. The easternmost of these bodies can be traced across a steep-walled canyon that drains southward into the Rio de Peñasco.

All the dikes are granitic in bulk composition and consist chiefly of quartz, potash feldspar, and albite. Muscovite is widespread, along with lesser amounts of accessory apatite, beryl, garnet, magnetite, microlite, and tantalite-columbite. Some of the bodies are grossly homogeneous or contain no more than pods of quartz and other local expressions of internal zoning, but those in the central and western parts of the belt contain extensive and well-defined internal units of markedly contrasting lithology. It is in these distinctly zoned bodies that nearly all major concentrations of beryl, lepidolite, spodumene, microlite, and tantalite-columbite are found.

Some of the Harding dikes are enclosed by amphibolitic rocks, chiefly hornblende-plagioclase schist with layers and pods of epidosite (a rock consisting mainly of epidote and quartz) and dark, impure quartzite, and others extend northward into the terrane of quartz-muscovite schists. The main dike is overlain at the present outcrop level by the amphibolitic sequence (Fig. 2) and underlain by schists with numerous thick layers and septa of amphibolite. Alkali metasomatism of the wall rocks adjacent to pegmatite is indicated by extensive conversion of hornblende to biotite and by abundant metacrysts of potash feldspar, muscovite, and albite. Some quartzite and quartz-rich schist on North Knob are heavily impregnated with lithium-bearing micas.

### *The Main Dike*

#### General Relationships

The main Harding dike is highly irregular in surface plan, with an exposed length of about 1100 feet and breadth ranging from a few feet to as much as 250 feet in the quarry area (Fig. 1); maximum breadth is considerably greater if the pegmatite on North Knob is included. The principal quarry face (Fig. 2), trending west-northwest approximately parallel to the original outcrop, provides more of a cross section than a longitudinal section, because in three dimensions the body has the general shape of a wide and nearly flat, southwestward-extending tongue with tapering, sharply downturned lateral margins and a central region 50 to 80 feet thick. The gently undulatory major axis of the tongue has an average plunge of about 10 degrees and an explored length of nearly 1600 feet. The original length is not known, as up-plunge parts of the body have been removed by erosion beyond North Knob.

Upper and lower surfaces of the tongue are broadly wavy (Fig. 2), and in places they also are marked by sharp, somewhat irregular corrugations with amplitudes of a few inches to at least 15 feet. Nearly all these rolls plunge at low angles, and in

*Figure 5.* **Portal of main beryl tunnel in hanging-wall pegmatite at west end of main quarry, June 1950. The stockpile in foreground represents four months of mining and hand sorting by three men.**

general their trend is parallel to the strike of foliation in the adjacent country rocks. Parallel to this foliation in both strike and dip is a well-defined set of numerous fractures that transect the pegmatite. A fault with like attitude and vertical separation of 5 to 8 feet also cuts the pegmatite exposed near the inner end of the west entry and the outer end of the main entry (Fig. 7).

### Internal Zoning

The tongue-like main dike contains a remarkable segregation of constituent minerals into contrasting zones whose general shape and distribution reflect the upper and lower surfaces of the body (Fig. 8). Most of the zones thus appear as wide subhorizontal stripes on the main quarry face (Figs. 2, 9) and in areas of extensive outcrop, although their surface distribution on North Knob is complicated by the geometry of dip-slope exposure. For present purposes, a brief description of zones in the thickest portion of the main dike, well-known in three dimensions from surface exposures and exploratory drilling, will suffice to illustrate the major aspects of segregation.

The upper contact with country rocks is marked by a white border rind, ½ inch to 1 inch thick, of fine-grained quartz-albite-muscovite pegmatite (Fig. 9). Beneath this rind is a continuous layer, typically 1 to 5 feet and locally as much as 10 to 14 feet thick, that also is rich in quartz, albite, and muscovite but is in large part very coarse grained. Potash feldspar is locally abundant, and apatite, beryl, and tantalite-columbite are widespread accessory constituents. Spectacular concentrations of coarse to very coarse beryl have also been found, especially beneath the crests of major rolls that are most abundant in lateral parts of the tongue (Fig. 6). An analogous layer, characterized by the same accessory minerals but in general with less beryl, is present along the lower surface of the tongue. It is rich in coarse quartz, but in many places its prevailing texture is more aplitic than pegmatitic and is distinctively sugary in appearance because of abundant fine-grained albite.

Beneath the upper beryl-bearing zone is a continuous layer of massive quartz, 2 to 8 feet thick, that is well exposed in the main quarry (Figs. 2, 9) and on the low knob immediately to the east. In some down-plunge parts of the dike it reaches subsurface thicknesses of 20 to 35 feet. Muscovite, microcline, and albite of the cleavelandite variety are present locally, and both cleavelandite and muscovite are widespread and abundant constituents of an analogous massive-quartz unit in the footwall half of the dike (Fig. 8).

The upper massive-quartz zone is underlain by a spectacular quartz-lath spodumene zone (Fig. 9). This widespread unit is 6 to 20 feet thick in surface exposures and reaches subsurface thicknesses of 20 to 40 feet at places where it fills the entire interior of the dike. The spodumene characteristically occurs as long, thin, blade-like crystals of moderate to great size with a tendency toward arrangement in jackstraw fashion. As displayed in the eastern half of the main quarry, the crystals are oriented somewhat more regularly to form a crudely comb-like pattern (Figs. 2, 9). Beryl, apatite, white to green microcline, and Ta-Nb minerals are present locally in the lower part of this zone. Some portions of the quartz-lath spodumene rock have been pseudomorphously replaced, the spodumene selectively by rose muscovite and the quartz by cleavelandite. Similar replacement rock is present in footwall parts of the dike (Fig. 8).

The core of the dike is distinguished by varieties of lithium- and tantalum-bearing pegmatite that in general are less coarse grained than rocks of the overlying zones. The dominant variety, known as "spotted rock," is a relatively even-grained aggregate of spodumene, microcline, and quartz, with various combinations of accompanying finer-grained albite, lithium-bearing muscovite, lepidolite, microlite, and tantalite-columbite. Much of the spodumene and potash feldspar occurs as rounded masses about an inch in average diameter, and with surfaces that are ragged in detail (Fig. 10). Both minerals have been extensively corroded and replaced by micas in aggregates of tiny flakes.

The "spotted rock" contains an average of 12 to 15% spoumene and about 0.15% Ta-Nb minerals, and hence might be viewed as low-grade ore. The principal body of this rock has the general form of a loaf of French bread, with one prominent constriction and an equally prominent vertical bulge (Figs. 7, 8). It is 20 to 55 feet in maximum thickness and 50 to 175 feet wide (Fig. 7), with a long, or downplunge extent of nearly 700 feet southwestward beyond the main quarry face. Its position is reflected in some places by a broad bulge in the hanging wall of the pegmatite body, and in others by a sag in the footwall (Fig. 8).

Typical "spotted rock" grades into lepidolite ore containing rounded masses of spodumene but relatively little potash feldspar; with decreasing spodumene content the "spotted rock" grades into bodies of nearly pure lepidolite. Several of these bodies were encountered long ago in the main quarry, but little of the material remains in place today. Another core variant, common in the eastern part of the quarry and also found locally in the western part, is distinguished by platy or lath-like individuals of spodumene 2 to 30 inches long. These occur either as isolated units (Fig. 10) or as jackstraw aggregates (Fig. 11) with finer-grained matrices of spodumene, lepidolite, Li-muscovite, albite, quartz, and Ta-Nb minerals. Veinlets and small, irregular masses of dark smoky quartz are present locally. This rock has been the host for most of the high-grade tantalum ore thus far encountered, and it has been referred to as the largest known body of microlite in the world (Baker, 1945).

### Bulk Composition

The main pegmatite body, as exposed in the quarry and penetrated by drill holes, has been extensively sampled. Analysis of a weighted composite obtained from these samples indicates that the pegmatite is typically granitic in terms of major constituents, with a high $Na_2O/K_2O$ ratio that in part is reflected by an abundance of albite in footwall parts of the body that are not well exposed. It is low in iron and strikingly deficient in calcium and magnesium. Remarkable for any large mass of granitic rock are its high contents of lithium (mainly in spodumene and micas), cesium and rubidium (mainly in micas, potash feldspar, and beryl), and fluorine (mainly in micas, apatite, and Ta-Nb minerals). It also contains about 0.03% Be and 0.08% Ta+Nb.

The composition of the border rind along the hanging wall is distinctly different from that of the pegmatite body as a whole, hence the rind cannot be readily viewed as a conventional chilled margin. It is relatively rich in $Na_2O$ and poor in $K_2O$ and $SiO_2$, and it may well be compositionally complementary to added constituents in the zone of potash and silica metasomatism in adjoining country rocks.

The $SiO_2$ content of "spotted rock" corresponds to a relatively low percentage of quartz, the high $K_2O/Na_2O$ ratio to an abundance of potash feldspar and micas, and the high $Li_2O$ content to an abundance of spodumene and lithium-bearing micas.

## MINERALOGY

The following brief summary of Harding minerals and their occurrence is based chiefly on our own studies of the pegmatites and materials collected from them. Its purpose is to provide notes on the most abundant or important species at this locality and to list the remainder as additional search targets for the diligent collector. Reports by other investigators are referenced for special features or for species we have not personally seen and confirmed. For many useful details not included here the reader should refer to *Minerals of New Mexico* (Northrop, 1959).

### *Major Minerals*

**Quartz** [$SiO_2$] is by far the most widespread pegmatite mineral. It occurs prominently as thick layers and pod-like masses of milky white to smoky gray anhedral crystals 0.5 inch to 3 feet in diameter, some with rude rhombohedral cleavage, and as very coarse aggregates interstitial to large crystals of spodumene (Fig. 11). Quartz also forms extensive fine-grained, sugary-appearing aggregates with albite and microcline. It is common elsewhere as a fine- to medium-grained interstitial or groundmass mineral. Light to very dark smoky quartz forms scattered irregular veinlets and small pods, in places containing well-faced crystals of beryl, spodumene, uranian microlite-pyrochlore, and tantalite-columbite, as well as rare allanite, thorite, and zircon.

**Albite** [$NaAlSi_3O_8$] occurs as fine-grained aggregates, especially with quartz and muscovite in outer parts of dikes, and also as the variety *cleavelandite* in lustrous curving plates and blades 0.2 to 2.5 inches long. It is common as coarse fracture-filling and replacement aggregates in quartz, and is generally white, but also commonly light gray and very pale green. Composition ranges from $Ab_{91}$ to $Ab_{99}$, with the remainder mainly or entirely Or; most coarse material is nearly pure Ab.

**Microcline** [$KAlSi_3O_8$] is widespread as extensive aggregates of coarsely perthitic subhedral crystals 1 inch to 4 feet in diameter, and as large, roughly euhedral individuals in massive quartz. Typically it is cream-colored, gray, and pale pinkish tan. It is also abundant with quartz and muscovite in fine-grained aggregates. Locally interstitial to large laths of spodumene, the crystals are white to light green (amazonstone), reaching 1 to 3 inches in diameter. Microcline is a major constituent of "spotted rock" as ½- to 4-inch individuals with rounded and corroded margins; non-perthitic and in general almost soda-free, the microcline ranges from white to lilac according to the degree of impregnation by extremely fine-grained lepidolite and Li-muscovite. Some pale pink masses may have been mistaken for amblygonite by early observers (e.g., Hirschi, 1931).

**Muscovite** [$KAl_2(AlSi_3)O_{10}(OH)_2$] is abundant in smaller dikes and in outer parts of the main dike as pale yellow-green to green flakes and thick plates 0.1 to 1.5 inches in diameter, typically containing 0.3 to 0.8% $Li_2O$. It occurs in the inner parts of several dikes as aggregates of tiny lilac, lavender, violet, pink, or gray flakes and plates forming large irregular pods or smaller masses interstitial to crystals of spodumene, cleavelandite, and other minerals. Such aggregates, somewhat translucent and waxy in appearance, generally contain 1.0 to 3.4% $Li_2O$. Muscovite also occurs as columnar crystals 0.2 to 2.5 inches long (parallel to c-axis), typically in radiating aggregates with cleavelandite and quartz. A widespread rose variety, in bright, pink flakes 0.1 to 0.8 inches in diameter and generally with less than 0.3% $Li_2O$, occurs variously as fracture fillings and replacement masses in "spotted rock" and adjacent pegmatite, as overgrowths on crystals and crystalline aggregates of lepidolite, as pseudomorphs after spodumene, microcline, and topaz, and as complex intergrowths with cleavelandite. Gray to faintly lavender-gray Li-muscovite also impregnates quartzose wall rocks in several places along the main dike.

For more data on composition see Roos (1926), Schaller and Henderson (1926), Heinrich and Levinson (1953), and Rimal (1962).

**Lepidolite** [$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$] is most abundant in "spotted rock" and other interior zones of the main dike as finely crystalline to extremely fine-grained translucent, waxy-appearing masses 0.2 inch to tens of feet in maximum dimension. The color is bluish gray, wine-red, lilac, lavender, and pale to deep purple, with a general range of 3.5 to 4.6% contained $Li_2O$. Lepidolite also forms fracture fillings, embayments, and replacement masses in microcline, and less commonly in spodumene. It occurs with quartz and albite in several dikes and in the outer parts of the main dike as individual thick crystals and as aggregates of lilac to pale purple flakes and plates 0.1 to 0.3 inch in diameter. Some larger plates, 0.2 to 0.7 inch across, consist of several smaller crystals, each elongated parallel to its *c*-axis and rotated about this axis relative to its neighbor, giving the three-dimensional appearance of single tapering crystals or narrow sprays of slender prisms.

Distinguishing lepidolite from the muscovites is often difficult as many of the properties and associations are similar, but in general the lepidolites are slightly more bluish and are readily fusible on thin edges exposed to a hot flame. Firm identification ordinarily requires chemical analysis, optical studies under the microscope, or X-ray determination of crystal structure. See also Levinson (1953) and Rimal (1962).

**Spodumene** [$LiAlSi_2O_6$] is typically white to very light gray, but faintly greenish or yellowish on many freshly broken surfaces. It is abundant in massive quartz as thin, slightly tapering, lath-shaped crystals and crystal fragments a few inches to several feet long, arranged in various parallel, radiating, and criss-crossing patterns (Figs. 2, 9). The largest observed individual is 14 feet long, 4 to 11 inches wide, and 0.5 to 0.9 inch thick. Most crystals are broken along cross-fractures with fissure fillings of quartz (Fig. 9) and rarely microcline. It is also abundant in "spotted rock" as discoidal crystal fragments, 0.5 to 3 inches in diameter, with irregular but grossly rounded margins, and in adjacent lithium-rich parts of the main dike as jackstraw aggregates of laths 2 to 30 inches long (Fig. 11). Spodumene also occurs in a few pods and veins of dark smoky quartz as small, pale gray-green euhedral crystals. Most crystals in the interior parts of dikes are corroded, veined, and partly replaced by various aggregates of lepidolite, Li-muscovite, rose muscovite, albite, and quartz. Some are also partly altered to very fine-grained eucryptite, micas, and albite. The $Li_2O$ content of relatively fresh crystals ranges from 6.0% to nearly 7.2%, with an average of about 6.8%.

**Figure 6.** ***(above)*** **Flaudio Griego at rich working face of a beryl tunnel, June 23, 1950. Small rolls in the pegmatite hanging wall are shown here in cross-section, with a thin, downward-projecting septum of country rock at left. At right the pegmatite body drops off abruptly on the flank of a large, asymmetric roll.**

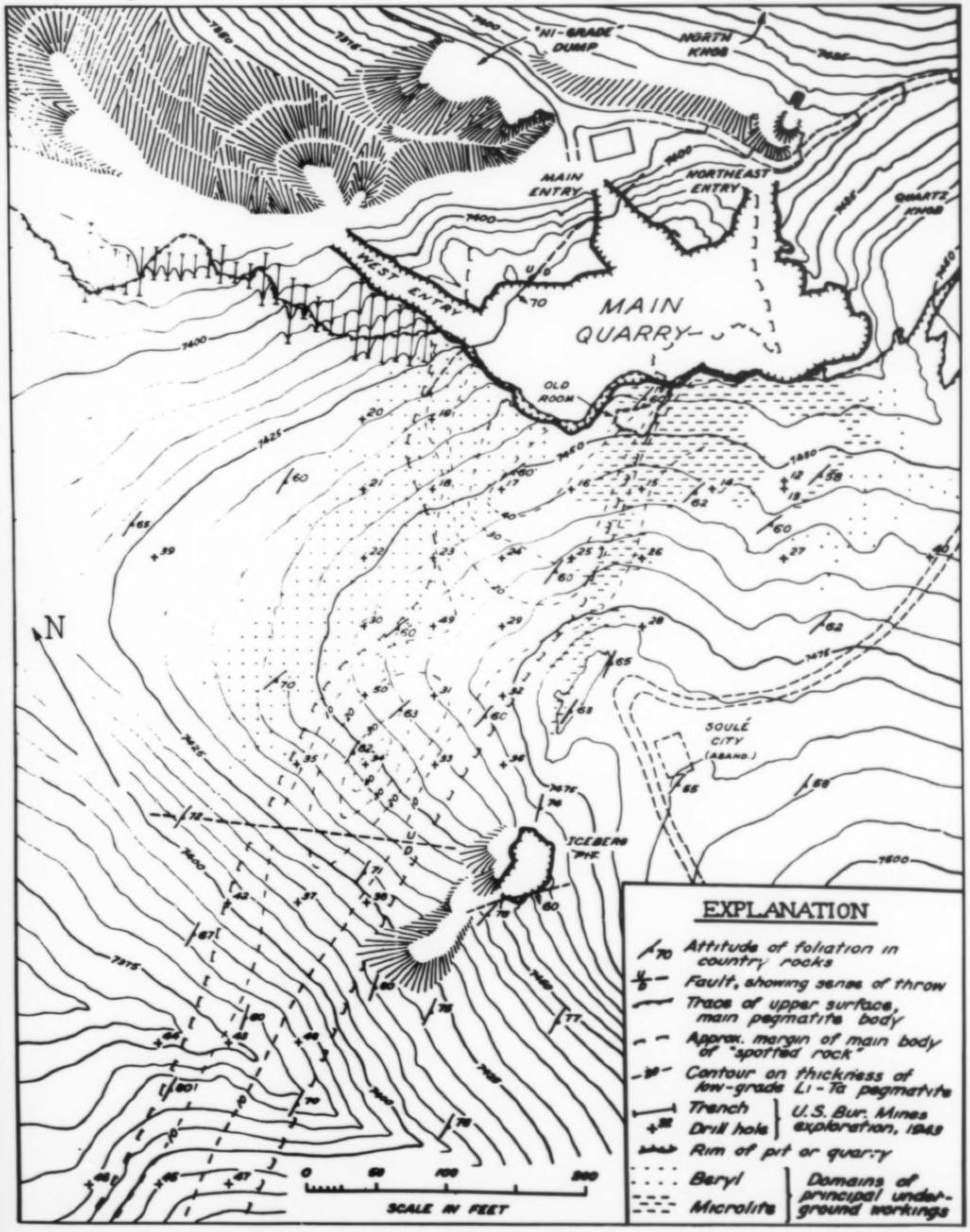


**Figure 7.** ***(left)*** **Map of a part of the Harding area showing general distribution of mine workings, exploratory trenches and drill holes, and principal concentrations of Be, Li, and Ta-Nb minerals.**

### *Principal Accessory Minerals*

**Apatite** [$Ca_5(PO_4)_3(F,OH,Cl)$] occurs as irregular anhedral masses and stubby, rough-faced crystals 0.2 to 5 inches in maximum dimension. The color is dark greenish blue to very deep blue and is strongly fluorescent yellow-gray under ultraviolet light. Some crystals are markedly color zoned, having blue interiors and gray, non-fluorescent rinds. Apatite occurs mainly near walls of dikes, and locally in a quartz-lath/spodumene pegmatite.

**Beryl** [$Be_3Al_2Si_6O_{18}$] is widespread in nearly all dikes, but is by far most abundant along and near walls of the main dike as equant anhedral to subhedral crystals 0.5 inch to 5 feet across, in places forming coarse lens- and layer-like aggregates of considerable tonnage. Rude basal cleavage is locally prominent. Some large crystals displayed rough basal, prism, and pyramidal faces, and a few noted by Arthur Montgomery enclosed prismatic phantoms 3 to 4 inches long and 0.2 to 0.5 inch in diameter. The crystals are milky white, gray, and faintly pinkish, greenish, or yellow-greenish, typically with a resinous or greasy luster. Interior parts of some crystals are pale rose and transparent, with vitreous luster and conchoidal fracture. Beryl also occurs in interior parts of the quartz-lath/spodumene zone as white to pink equant crystals 0.3 to 4 inches in diameter; crystals are anhedral to subhedral and in part transparent. Locally beryl is abundant as small, white to pale pink and yellowish gray tablets with hexagonal outline in light to dark smoky quartz of the pegmatite core, especially in eastern parts of the main dike. It is present sparingly in at least three other dikes as pale yellowish green stubby prismatic crystals 0.5 to 2 inches long. It is found locally in adjacent country rocks as blue to greenish blue prisms and anhedral crystals within small cleft-like cavities, where it is associated with crystals of quartz, schorl, epidote, garnet, and magnetite.

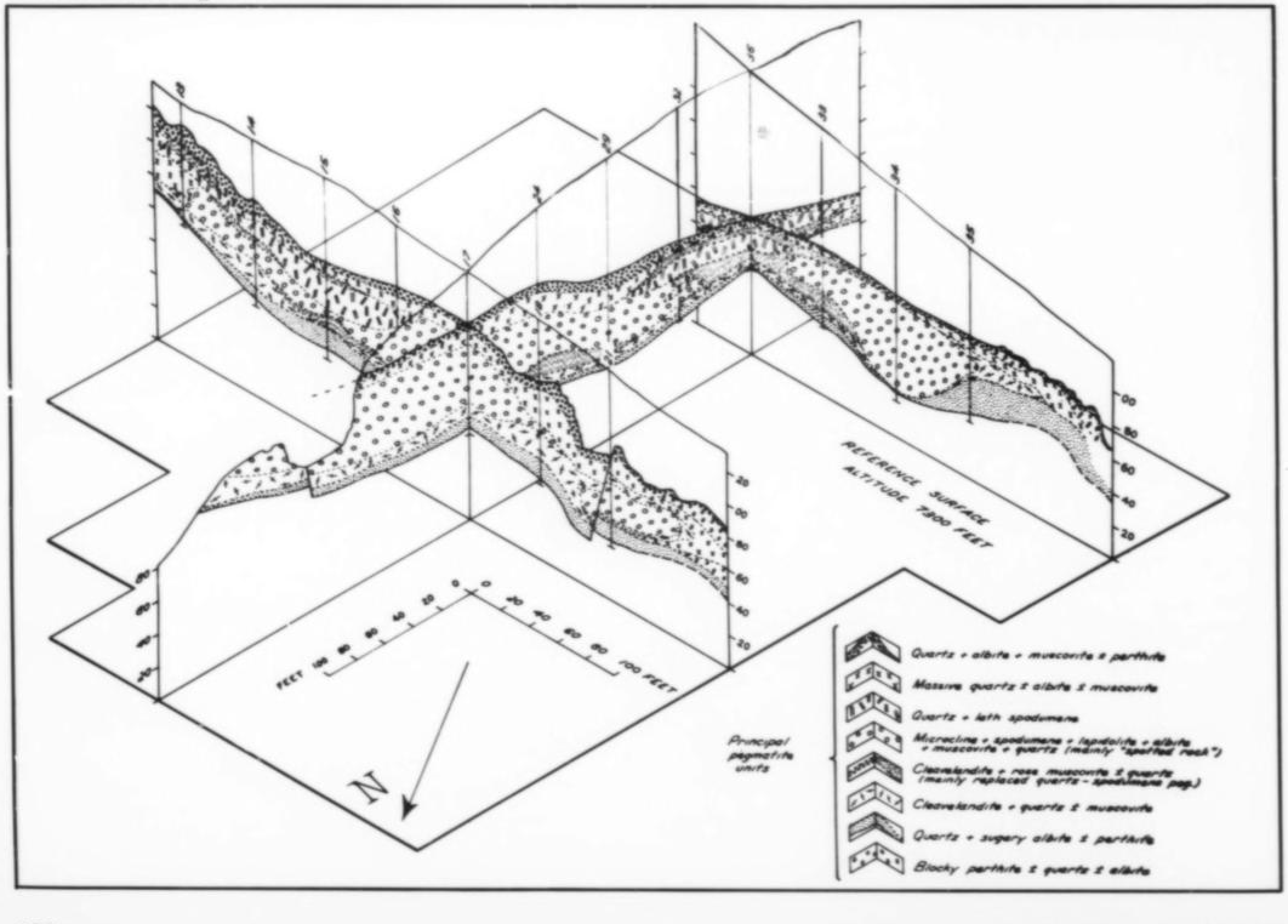
Corresponding to occurrence from the walls inward to the core of the main dike are shifts in crystal habit from prismatic to equant to tabular, a general increase in ω index of refraction (from 1.582 to 1.594), a general decrease in BeO content (from 12.77 to 11.2), and general increases in contents of $Li_2O$, $Na_2O$, and $Cs_2O$. Common low-alkali beryl apparently occurs only in thin dikes with no conspicuous lithium mineralization. The blue beryl from small cavities in the country rocks is unusual in its high content of both BeO (13.11 - 13.23) and alkalies, and it may be Li-poor and Fe-rich like the variety reported from Arizona by Schaller and others (1962).

**Garnets** [$(Mn,Fe)_3Al_2(SiO_4)_3$]. Wine-red almandine occurs as small, widely scattered crystals. It is locally abundant in fine-grained footwall rocks of the main dike. Pale salmon-pink to orange-red spessartine is sparse to abundant in interior parts of lithium-bearing dikes and common in albite-rich pegmatite of the main dike as rough dodecahedral crystals 0.05 to 1.2 inches in diameter. Larger crystals are much fractured, and some are heavily stained by manganese oxides.

**Microlite** [$(Na,Ca,U)_2(Ta,Nb)_2O_6(O,OH,F)$] occurs as small grains and crystals with octahedral or dodecahedral form and many modifying faces, larger subhedral and roughly euhedral crystals 0.2 to 0.8 inch across, and rare crystals reportedly as large as 3 inches. It occurs chiefly as dispersed individuals in "spotted rock," in aggregates of lepidolite and Li-muscovite, and along margins of spodumene crystals; it is also found as local dense concentrations (Fig. 4). The color ranges from white to pale yellow, honey-yellow, yellowish to bronzy brown, dark maroon, and dark reddish brown to nearly black, with dull to vitreous luster. Many crystals are color-zoned, generally with lighter cores and darker rims. The darkest material is metamict or nearly so.

With reference to the general formula $\mathbf{A_2B_2O_6X}$, **A** in these materials is chiefly Ca, Na, and U with very minor K, Mn, Fe, and Th. **B** is Ta and Nb with a little Ti, and **X** includes both OH and F. The range from light to dark colors can be correlated with progressive decreases in Ta+Nb oxides content

***Figure 8.*** **Fence diagram showing two vertical sections through the pegmatite body and its constituent lithologic zones in ground southwest of main quarry. Locations of numbered diamond-drill holes are indicated in Figure 9.**



and Ta/Nb ratio (from 75.58% $Ta_2O_5$ and 5.8% $Nb_2O_5$ to 59.05% $Ta_2O_5$ and 9.32% $Nb_2O_5$), and with progressive increases in the OH/F ratio and U, Ti, and Mn content. The weight ratio of $Ta_2O_5$ to $Ta_2O_5+Nb_2O_5$ is typically 0.86 to 0.89 for the darkest material, averages about 0.92 for the brownish yellow, and is 0.93 to 0.95 for the palest yellow to off-white material. Of the 45 Harding specimens and bulk concentrates that have been analyzed, all have proven to be tantalum-rich, and hence to be microlite rather than pyrochlore. Harding uranian microlite, with a known maximum content of about 10% $UO_2+UO_3$, commonly has been referred to the variety *hatchettolite*, even though it is not in the pyrochlore range.

**Tantalite-columbite** [$(Fe,Mn)(Ta,Nb)_2O_6$] occurs in outer parts of dikes as blade-like to thickly tabular black crystals with dull to very bright luster. Most crystals are 0.2 to 1.3 inches in maximum dimension, but a few 3- to 4-inch waterworn chunks have been found in nearby placer deposits. It also occurs scattered through "spotted rock" and other internal units as thick blades, plates, and equant crystals 0.05 to 0.8 inch in maximum dimension, generally in association with microlite. It is sometimes roughly cleavable. Rare mahogany-brown manganotantalite, associated with albite in interior parts of the main dike, forms 0.3- to 1.5-inch tablets with distinct cleavage and bright, slightly resinous luster. Some crystals are zoned, having thick rims of black tantalite. Very rare bismutotantalite occurs as small, irregular residua in masses of earthy yellow bismutite found locally in coarse-grained quartz.

The 18 samples of Harding tantalite-columbite thus far analyzed have ranged from Ta-rich columbite to nearly pure tantalite having weight ratios of $Ta_2O_5$ to $Ta_2O_5+Nb_2O_5$ ranging from 0.45 to 0.94. The ratios for most crystals in the hanging-wall zone of the main dike probably are near 0.6, and those for crystals in the "spotted rock" near 0.8.

### *Other Minerals*

#### Silicates

**Allanite** [$(Ca,Ce,Y)_2(Al,Fe)_3Si_3O_{12}(OH)$]. Very dark brown slender prisms in massive quartz. Rare.

**Amphibole** [$(Na,Ca,K)_2(Mg,Fe,Ti,Al,Li,Mn)_5(Si,Al)_8O_{22}(OH,F)_2$]. Abundant coarse, greenish black hornblende in amphibolitic country rocks. Tiny needles of *holmquistite* (Li-, K-, F-bearing) locally along pegmatite contacts.

**Andalusite** [$Al_2SiO_5$]. Small gray masses as residua in country-rock metacrysts (Montgomery, 1953).

**Bertrandite** ($Be_4Si_2O_7(OH)_2$]. Thin, finely scaly to earthy white alteration crusts on beryl.

**Biotite** [$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$]. Dark scales from alteration of hornblende, and small euhedral plates in country-rock cavities near pegmatite contacts.

**Chloritoid** [$(Fe,Mn)_2Al_4Si_2O_{10}(OH)_4$]. Thin, broad plates in country-rock schist (Montgomery, 1953).

**Chrysocolla** [$(Cu,Al)_2H_2Si_2O_5(OH)_4.nH_2O$]. Pale green coatings on fractures, chiefly in massive quartz.

**Cordierite** [$Mg_2Al_4Si_5O_{18}$]. Gray metacrysts in country-rock schist (Montgomery, 1953).

**Epidote** [$Ca_2(Al,Fe)_3Si_3O_{12}(OH)$]. Abundant in amphibolitic country rocks. Also small green euhedral crystals in cavities near pegmatite contacts.

**Eucryptite** [$LiAlSiO_4$]. With spodumene as earthy white fracture fillings and alteration crusts. Fluoresces red in ultraviolet light. See also Mrose (1952).

**Illite** [$(K,H_3O)(Al,Mg,Fe)_2(Al,Si)_4O_{10}(OH)_2,H_2O$]. Extremely fine-grained micaceous aggregates in main dike. Light gray to white. Noted as hydromuscovite by Soulé (1946).

**Kaolinite** [$Al_2Si_2O_5(OH)_4$]. Widespread clay, mainly from alteration of feldspars. White, but commonly iron-stained.

**Montmorillonite** [$(Na,Ca)_{1/3}(Al,Mg)_2Si_4O_{10}(OH)_2\cdot nH_2O$]. Widespread clay, mainly from alteration of spodumene and feldspars. Creamy white to very pale pink.

**Pyrophyllite** [$Al_2Si_4O_{10}(OH)_2$]. In country rocks, "partly altered to kaolin" (Just, 1937, p. 28).

**Thorite** [$ThSiO_4$]. Dark reddish brown to black masses and thick prismatic crystals with dull to vitreous luster. Mainly in smoky quartz. Probably identical with the "thorium mineral" described by Hirschi (1928).

***Figure 9.*** **An easterly part of main quarry face as well exposed in December 1942. Beneath the sharply convoluted contact between pegmatite and overlying amphibolitic country rock near top of view are five distinctive pegmatite units: (1) 1/2-inch border rind (white) of fine-grained quartz-albite-muscovite pegmatite, (2) 2- to 3-foot layer (gray) of coarse-grained quartz-albite-microcline-muscovite pegmatite with locally abundant apatite and beryl, (3) 2- to 5-foot layer (darker gray) of coarse-grained massive quartz, (4) 10- to 15-foot layer of coarse-grained quartz (dark) with large, lath-like crystals of spodumene (light) and local coarse microcline, apatite, and beryl, and (5) epidolite-spodumene-microcline pegmatite with some albite and scattered small crystals of microlite (removed from undercut as lepidolite ore).**

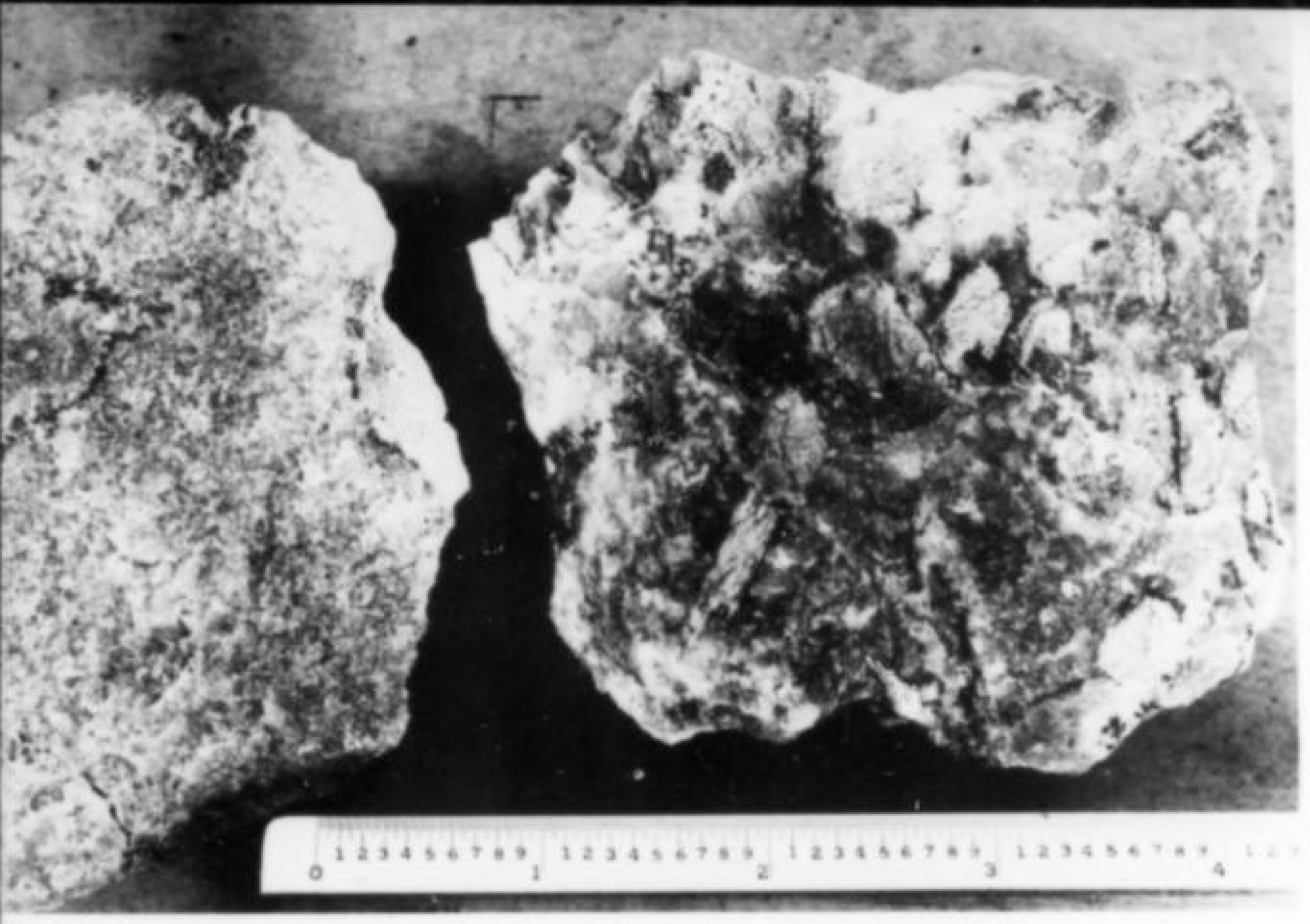


*Figure 10.* **Specimens of lithium-tantalum ore from main quarry. At left is a variety of "spotted rock" in which patches of coarse microcline are outlined by small, dark-colored crystals of lepidolite, tantalite-columbite, and uranian microlite-pyrochlore. The microcline is partly replaced by minute scales of lepidolite, which also are abundant in remainder of the rock. At right is an aggregate of spodumene laths and plates, most of them much corroded, in a matrix of purple lepidolite (dark), albite, and quartz with scattered small crystals of tantalum-niobium minerals.**

**Topaz** [$Al_2SiO_4(F,OH)_2$]. Thick prismatic crystals 0.3 to about 5 inches long, in core of main dike. Sparse, and largely or wholly altered to rose muscovite and clay minerals. Small, fresh, white to golden yellow grains moderately abundant in "spotted rock."

**Schorl** [$Na(Fe,Mg)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$]. Deep blue-black aggregates of radiating or criss-crossing fibers and prisms in amphibolitic country rocks near pegmatite contacts. Also as sharply striated thin prisms in country-rock cavities.

**Zircon** [$ZrSiO_4$]. Small, dark yellowish to greenish brown prisms in quartz-albite-muscovite pegmatite of dike interiors. Not abundant.

Oxides

**Bismite** [$Bi_2O_3$]. Grayish green, powdery to earthy. With bismutite in massive quartz.

**Cassiterite** [$SnO_2$]. Tentatively identified by Hirschi (1931) from the Harding mine, but not reported in other references.

**Gahnite** [$ZnAl_2O_4$]. Very small, dark greenish gray grains and 0.02- to 0.1-inch octahedral crystals in massive quartz.

**Ilmenite** [$FeTiO_3$]. Thin plates and roughly faced thick tablets 0.2 to 1.5 inches in diameter. Black and slightly magnetic. Mainly in pods and stringers of quartz in country rocks. sparingly in quartz-rich apophyses from pegmatite dikes.

**Limonite** [Hydrous iron oxides]. Widespread as light to dark brown stains and films, chiefly on outcrop and fracture surfaces.

**Magnetite** [$Fe_3O_4$]. Minor constituent of "spotted rock," and very sparsely scattered through other pegmatite zones. Typically forms grains and equant, roughly faced crystals less than 0.2 inch in diameter.

**Pyrolusite** [$MnO_2$]. Widespread as thin black films and dendritic stains.

**Rutile** [$TiO_2$]. Tiny needles, very dark reddish brown to black, in some quartz of dike borders. Also forms small grains and prismatic crystals in adjacent country rocks.

**Titanite** [$CaTiSiO_5$]. Small, thin, tabular and wedge-like yellowish brown crystals in country rocks near pegmatite contacts. Partly altered to very light gray leucoxene.

**Tenorite** [$CuO$]. Rare black non-dendritic stains and earthy coatings, mainly on quartz. Also reported by Kelley (1940) from Iceberg pit (see section on calcite, farther on).

Carbonates

**Azurite** [$Cu_3(CO_3)_2(OH_2)$]. Rare bright blue stains on quartz and feldspars near small masses of chalcocite.

**Beyerite** [$(Ca,Pb)Bi_2(CO_3)_2O_2$]. Rare tiny plates, yellow to greenish yellow, associated with bismutite and bismutotantalite.

**Bismutite** [$Bi_2(CO_3)O_2$]. Bright yellow to pale green earthy, scaly, and fibrous masses in quartz, generally 0.3 to 2.5 inches in maximum dimension. In part pseudomorphous after native bismuth or, rarely, bismuthinite and bismutotantalite. See also Heinrich (1947).

**Malachite** [$Cu_2(CO_3)(OH)_2$]. Green stains on quartz and feldspars, and thin alteration crusts on small masses of chalcocite.

Phosphates

**Amblygonite** [$(Li,Na)Al(PO_4)(F,OH)$]. Reported by Hirschi (1931) and others, but never confirmed. Observed material may have been microcline, with or without finely disseminated pink micas.

**Lithiophilite** [$LiMnPO_4$]. Rare cleavable pale cinnamon-brown masses, 2 inches in maximum dimension, with microcline near base of quartz-lath/spodumene zone in main quarry. Much stained by manganese oxides.

**Monazite** [$(Ce,La,Nd,Th)PO_4$]. Sparse, small, sharply faced tablets in smoky quartz, interior of main dike.

**Wavellite** [$Al_3(PO)_4)_2(OH)_3\cdot 5H_2O$]. Informally reported but never confirmed.

Sulfides and Arsenides

**Bismuthinite** [$Bi_2S_3$]. Fibrous gray residual masses in bismutite. Rare.

**Chalcocite** [$Cu_2S$]. Rounded pod-like masses 0.5 inch in maximum diameter, generally in coarse-grained quartz. Dull gray and distinctly sectile. Rare.

**Chalcopyrite** [$CuFeS_2$]. Very rare tiny grains in quartz of "spotted rock." Also reported by Kelley (1940) from Iceberg pit (see section on calcite further on).

**Loellingite** [$FeAs_2$]. Silvery grains and masses 0.1 to 0.8 inch in diameter, chiefly in quartz of "spotted rock" and quartz lath/spodumene pegmatite.

**Pyrite** [$FeS_2$]. Rare tiny grains in massive quartz and in quartz of "spotted rock."

Miscellanae

**Bismuth** [Bi]. Small, dull-white residual masses in bismutite. See also Heinrich (1947).

**Fluorite** [$CaF_2$]. A minor constituent of "spotted rock" as small yellowish to purplish grains, generally with etched surfaces. Fluoresces faintly bluish under ultraviolet light.

**Calcite** [$CaCO_3$] is present in the Harding pegmatites only as crusts and veinlets of rather nondescript supergene caliche, but it is worthy of special note here because a small but extraordinary deposit of "Iceland spar" (Johnson, 1940; Kelly, 1940) was found as an isolated occurrence in country rocks only 300 feet south-southwest of the main quarry (Fig. 7). This deposit, known as the Iceberg, was recognized in 1931, opened up for production in 1939, and completely mined out within about a year. The calcite formed a pipe-like mass, about 30 feet long and

9½ feet in maximum thickness, that was approximately conformable with the planar structure of the enclosing highly altered amphibole schist. The outer parts of the mass consisted of calcite crystals as much as 1½ feet across, some of them extending outward as projections into the country rock. Most were transparent or nearly so, and they yielded substantial quantities of optical-grade material. The core of the mass consisted of two gigantic anhedral crystals, one about 7 x 8 x 11 feet and the other about 8 x 9 x 10 feet in size (Kelley, 1940). Large parts of these crystals also were clear and relatively unflawed.

Approximately 850 pounds of cleaved, optical-grade calcite were shipped in 1939, and the largest single piece of this flawless material weighed 5 pounds, 8 ounces. According to Kelley, three types of calcite were present: (1) white, somewhat milky material, the most abundant type (2) clear, colorless optical spar, and (3) banded pinkish material. Most of the calcite was readily cleavable, but some exhibited almost perfect conchoidal fracture.

The Iceberg deposit appears to have been formed along an intersection between country-rock foliation and a fault that trends west-northwest and offsets the underlying main pegmatite body (Fig. 7). Concentration of the calcite less than a hundred feet above the pegmatite may well have been fortuitous rather than an expression of genetic relationship, and the difference in age between pegmatite and calcite could be very great. Moreover, veins and pods of very coarse calcite are known from other parts of the Picuris Range in areas where there is little or no pegmatite. The largest of these, the Calspar deposit about 2 miles north of the Harding property, was a nearly vertical bean-shaped mass in quartzose metamorphic rocks. It consisted of anhedral crystals of milky to almost clear calcite 2 inches to 5 feet across, along with one enormous crystal about 18 feet in maximum dimension.

## PEGMATITE GENESIS

The Harding pegmatite bodies are most readily explained as products of highly differentiated rest-liquid derived from granitic magma and injected into already deformed and regionally metamorphosed host rocks at considerable depth. An igneous origin, rather than metasomatic or metamorphic derivation from the host terrane, is indicated by several features of the occurrence. The bodies are distinctly discordant in most places, for example, and they are sharply bounded from the country rocks. Local severe deformation of these rocks adjacent to margins of the bodies, clearly superimposed upon the results of earlier regional deformation, bespeaks forceful injection of pegmatite "magma." Internal zoning of the dikes reveals a consistent paragenetic sequence of major minerals, and the gross geometry of these zones reflects the shapes of the containing bodies rather than features of the enclosing metamorphic rocks. The dikes themselves show no significant compositional variations that could be correlated with lithologically contrasting parts of the adjacent metamorphic terrane. Furthermore, the pegmatites contain suites of Be, Li, Nb, Ta, U, and other trace elements at high concentration levels that are more compatible with an igneous than with a directly metamorphic derivation.

The pegmatites are not obviously related, in either spatial or compositional senses, to any of the exposed granitic plutons in the region. They are not systematically distributed with respect to the plutons, nor do they reflect the regional metamorphism that left its stamp on most of the other rocks. And if the remarkable abundances of rare elements in the Harding pegmatites are attributed to extreme magmatic differentiation, the compositions of known granitic plutons of the region do not identify them as attractive candidates for a cogenetic relationship. The quartz monzonites in areas south and east of the Harding occurrences, for example, are very low-Ta, high-Ti rocks whereas the pegmatites are very rich in Ta and poor in Ti. The dissimilarities among these and other minor constituents are difficult to reconcile with any simple model of genetic association. Perhaps more important, the pegmatites may well be much younger than the youngest of the exposed granitic rocks (Long, 1974), and they may also represent a deeper level of emplacement.

Like the pegmatites of the Petaca District west of the Rio Grande (Jahns, 1974), those in the Harding area probably were emplaced at depths of 7 miles or more and were slowly cooled under high confining pressure in the presence of a halide-rich aqueous fluid. Emplacement was accomplished in a terrane of pervasively deformed rocks with relatively high metamorphic rank, and it occurred long after dacite and other igneous rocks were formed at relatively shallow depths. Many of the pegmatite bodies are fringed by zones of metasomatic reaction with the wall rocks. None of the bodies contains crystal-lined pockets or primary cavities, and they are not associated with aplitic rocks of the kind formed by sudden relief of confining pressure. The potent fluxing effect of volatile constituents held in magmatic solution under high pressure is attested to by subsolvus crystallization of alkali feldspars in the pegmatite bodies and especially by primary formation of nearly pure K and Na phases in their central parts.

Further discussion of the nature, gross segregation, and observed paragenetic relationships of the pegmatite minerals cannot be offered here, but in sum these features are compatible with the genetic model for pegmatite crystallization outlined by Jahns and Burnham (1969) on the basis of field, petrographic, and experimental investigations. Most of the crystallization probably occurred in the presence of both silicate melt and dense aqueous vapor rich in F and Cl, and nearly all the remainder in the presence of the vapor. Existence of this vapor can be inferred on several grounds and is more directly attested to by numerous fluid inclusions in the pegmatite quartz and beryl. Its influences as a catalyst and as a medium for material transfer are implicit in the metasomatic interactions between dikes and country rocks, in the nearly complete unmixing of early-formed alkali feldspars to yield coarse perthite, in the leaching of calcium from the feldspars for fixing in microlite and late-stage apatite, and in widespread mineral recrystallization and replacement under both hypersolidus and subsolidus conditions. The most extensive of the replacement reactions led to formation of albite at the expense of quartz and microcline, and micas at the expense of microcline and spodumene.

## ACKNOWLEDGMENTS

We are indebted to John W. Adams and William P. Irwin of the Geological Survey and to Lauren A. Wright of the Pennsylvania State University for important contributions during the early periods of field work, and to Arthur Montgomery of Lafayette College and Lincoln R. Page and the late Waldemar T. Schaller of the Geological Survey for numerous penetrating discussions of the Harding mineral associations. We wish also to acknowledge the valued aid of Stuart A. Northrop of the University of New Mexico in compiling an authoritative list of minerals found in the Harding pegmatites. It is a special pleasure to recall, in connection with the field investigations, the hospitality and many courtesies received from Arthur Montgomery, John H. Soulé of the U.S. Bureau of Mines, Eliseo Griego, the late Flaudio Griego, and Lydia and "Doc" Zellers of Dixon, New Mexico.

C.O. Ingamells, F.S. Grimaldi, E.K. Oslund and Petr Černý contributed chemical analyses for this study, and have our sincere thanks.

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*Figure 11.* **A typical museum specimen of Harding pegmatite. Large laths of spodumene, locally seamed and bordered by scaly aggregates of rose muscovite, form a jackstraw-like framework enclosing lustrous white blades of cleavelandite and spodumene, irregular pods of muscovite, and scattered small crystals of tantalum-niobium minerals. Parts of the specimen are traversed by veinlets of gray smoky quartz.**

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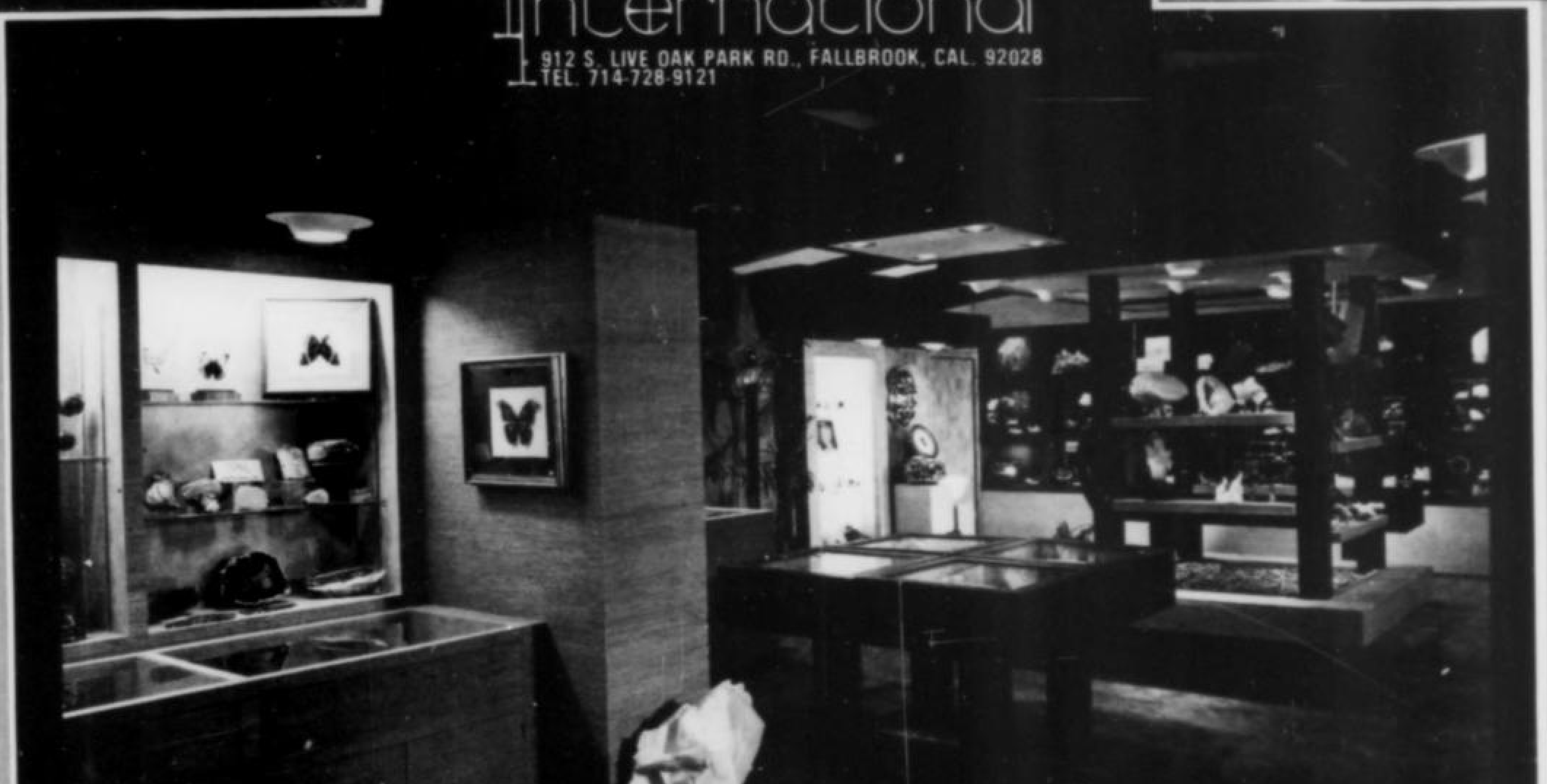
**Note added in proof:**

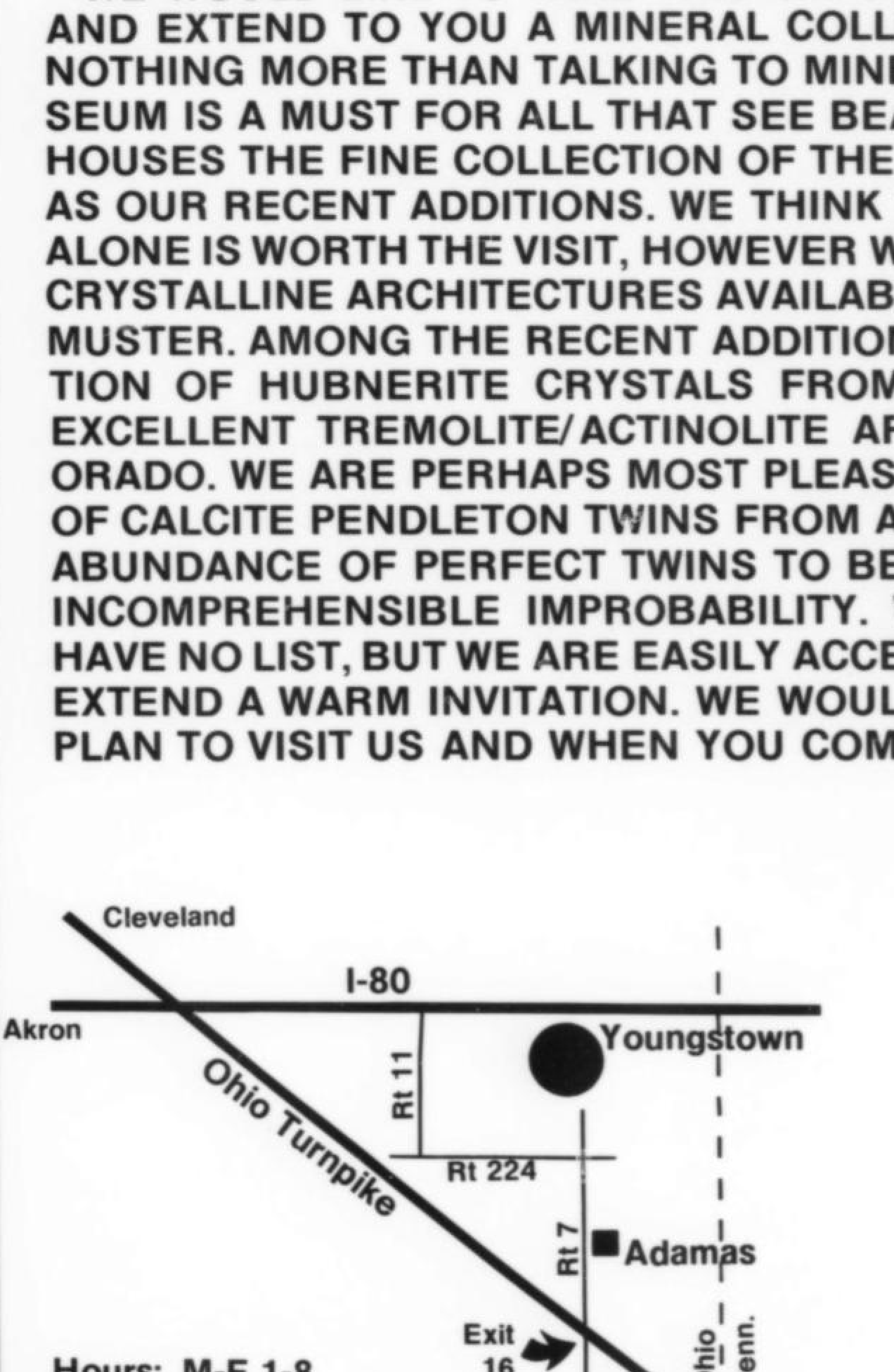
A similar version of this article has appeared in the *New Mexico Geological Society Guidebook* No. 27, 1976. Ed.

**Tourmaline**
Himalaya mine
Mesa Grande, Calif.

**Topaz**
Virgem da Lapa
Brazil

SHOWN
BELOW!

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# PERSONALITY SKETCH:

## GUNNAR BJAREBY 1899-1967

**by Stephen and Janet Cares**
**18 Singletary Lane Sudbury, Mass. 01776**

Alfred Gunnar Bjareby was born in a small town in southern Sweden. He first started collecting minerals at the age of ten, after viewing the collection of a boy two years his senior. "In those early years," Gunnar wrote, "I collected birds' eggs, insects, plants, coins, stamps, and Swedish Stone and Bronze Age implements." Minerals became most important, however, and in his early youth his bicycle provided transportation to the few accessible quarries as well as brooks, where he and his friend patiently panned for non-existent gold. When the time came to learn his trade and to study art, time became more limited and collecting could be done only sporadically.

In 1923 Gunnar came to the United States. After settling in Boston he spent much of his spare time at the Harvard University Mineralogical Museum and at the now defunct New England Museum of Natural History studying their mineral collections and noting nearby localities which could be reached by bus or streetcar. By also covering many miles on foot he was able to collect at many localities which are now closed to collecting.

In 1937 he joined the newly-formed Boston Mineral Club, which at that time made organized trips to localities such as Gillette, Strickland, Newry, Mt. Mica, Palermo, and the Lane quarry while they were producing magnificent specimens. This also gave him the opportunity to associate with the great mineralogists of Harvard such as Palache, Berman, LaForge, Hurlbut, and Frondel while they were actively collecting. He was at one time president and later was made an honorary member in recognition of his contributions. For many years as Chairman of the Locations Committee he spent many hours working on the club's collection of Geological Survey maps of New England, marking mines and prospects and noting their mineral assemblages. His thatch of white hair and intense blue eyes were a familiar sight on club field trips and when he was not busy digging or working out a prize specimen he was in demand to identify the finds of other collectors. He was active to the end, having made a collecting trip to Nova Scotia, one of his favorite areas, less than a month before his death.

Over the years Gunnar accumulated perhaps the finest private collection in New England. He acquired many specimens through trading with collectors all over the world, and his ability to read and write in several languages undoubtedly served him well in this enterprise. A sizable part of his collection he obtained himself through vigorous use of sledge hammer, chisel, and shovel. He looked for quality, not quantity, and often returned from a field trip with only a small pack of material to be broken down for micromounts.

As he often pointed out to other collectors, about half of the known mineral species occur only in crystals too small to be readily discernible to the unaided eye. For this reason he became an avid micromounter and was a charter member of the Micromounters of New England, formed in 1966. His micros were mounted in small cardboard boxes of his own construction. Duplicates were cemented to handwritten labels and stored in cigar boxes. These boxes were circulated among local micromounters who were thus able to add new species, habits, or localities to their collections. Many collectors tried to return the favor, but this was difficult, as his collection contained over a thousand species.

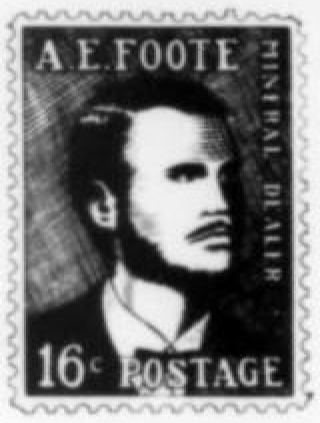
In a series of eight articles published in *Rocks and Minerals*, Gunnar recounted "Fifty Years of Mineral Collecting." Here he related experiences of his travels in the United States and Europe, and described some of the famous mineral localities and collectors he had known. His experience and acute observations enabled him to identify minerals with amazing accuracy even in the field. In a number of instances he was the first to report the occurrence of a mineral at a new locality. He was always ready to help the novice, and gave encouragement to students hoping to make a career of mineralogy. There is no doubt that he would have been an enthusiastic supporter of *The Mineralogical Record.*

He was also an accomplished artist and received a number of awards at various exhibits. Many of his paintings are displayed on the walls of the Ipswich, Massachusetts, home of his widow, Kaarina, and son, Thiman. In his profession he painted murals, both in private homes and commercial establishments.

The bulk of his mineral collection was purchased by a private collector in Chicago, but his micromount collection went to the University of Chicago. At U.C. researchers discovered a specimen collected by Gunnar in 1947, but which he indicated to be of questionable identity. Analysis showed this material to be a new species and, in 1973, Gunnar received long-overdue recognition with the publication of a paper by Moore, Lund, and Keester in *The Mineralogical Record* describing "Bjarebyite... a New Species." The new species was appropriately in micro crystals from the Palermo mine, North Groton, New Hampshire, one of Gunnar's favorite localities. (The mineral name is properly pronounced *bee-yar´-ah-bee-ite.*) Good specimens are rare today and much sought after.

No finer tribute could have been paid than that by the authors of the bjarebyite description who said, "The beauty of the crystals, the location and the source of the specimen provide us with the honor of naming the new species **Bjarebyite** after the late Gunnar Bjareby of Boston, a talented artist and naturalist, who had assembled a magnificent collection of hand specimens and micromounts, particularly of New England pegmatites. He amassed a micromount collection of over 1000 exquisite Palermo specimens and was a phosphate mineral student with extraordinary insight and knowledge. The care and detail of his investigations, unfortunately never published, place Mr. Bjareby among the most outstanding of 20th century amateur mineralogists."

# Letters



## CLIMAX MEMO

*Dear Readers,*

*We have received a copy of the following memo.*

*Ed.*

November 24, 1976

TO: All AMAX Suppliers (Climax and Henderson Properties)

SUBJECT: Appointments - Sales Personnel Calling at our Climax Mine and Henderson Mine and Mill

Gentlemen:

In continuation of our efforts to control visitations to our Climax mine and Henderson mine and mill properties, eliminating unwarranted waste of time, our existing appointment procedures are revised and updated as follows. This revised procedure shall become effective December 1, 1976.

Except in cases of emergency or at the specific request of AMAX personnel, requests for appointments at the various mine and mill sites must be made five days in advance of the appointment date desired.

All requests for appointments are to be made through the Golden Purchasing Department, (303) 234-9020, ext. 277. You are to advise your name and those accompanying you, company you represent, your phone number, person or persons you wish to make an appointment with, and date and hour appointment is desired. If you do not hear to the contrary, you can assume your appointment is confirmed.

All visitors must secure gate passes at the main gate prior to entering the property.

Very truly yours,
H. G. Durkop
Assistant Director of Materials
Climax Molybdenum Company
A Division of AMAX Inc.
13949 West Colfax Avenue
Golden, Colorado 80401

## COMPETITION LOSES

Dear sir,

I was very interested in the opinions on competition at shows (in Vol. 7, no. 5). Thirteen New Jersey clubs have joined together to form the New Jersey Earth Science Association; Association shows are strictly non-competitive. Many people had become dissatisfied with (competitive) Federation shows. This year (August, 1976) was the fourth annual show and the best ever. Clubs and individual club members exhibit; the quality of minerals is high, the same as though people were trying for First Prizes. There was an absence of dissatisfaction.

Naomi McGregor
Oceanpoint, New Jersey

*My congratulations to the N.J.E.S.A. on their successful show, and I am glad that no one was dissatisfied. However the main thrust of the "Forum on Competition" was to find ways to make competition more agreeable to people so that it would* ***not*** *have to be totally eliminated, as your show has done. Whereas I am pleased by the success of your show, I hope that other shows attempt to adjust and refine their competition procedures so that competition will survive. Rules set down by the Tucson Show seem to be the most progressive in this respect; other shows should consider obtaining a copy of Tucson Show rules as a possible guide.*

*Ed.*

## FAN MAIL

Dear sir,

As you will have observed, an increasing number of professional and amateur mineralogists in Australia are now subscribing to your excellent journal. This, in part, is due to the interest generated by the recently formed Mineralogical Societies of New South Wales and Victoria. As Vice President of the Victorian Society, I have been pleased to do what I can to commend your publication to our members.

Howard K. Worner
North Balwyn, Victoria, Australia

*Our birthday congratulations to the two new Mineralogical Societies.*

*Ed.*

Dear sir,

Congratulations on the Mibladen issue (Vol. 7, no. 5); it was superb. I showed it to some friends of mine and they are going to subscribe, even though they speak little English!

I'm here now looking for oil, working on a basis of 28 days on and 28 days off. As you can suppose, I have plenty of free time on the drillship; reading old issues of the *Record* makes good relaxation. Keep on the line you've adopted. You're the best.

Tomas Piera
Phillips Petroleum Company
Abidjan, Ivory Coast

## EXCHANGES

Dear sir:

I'm a young man from Sweden who would like to establish contacts in the USA and worldwide for exchanging minerals. As a reader of your excellent magazine, I know that if this is published, there will be no problem establishing contacts both in the USA and abroad.

I can offer many species, rare things like trolleite, attacolite, berlinite, svanbergite, pollucite, väyrynenite, Mn-tantalite, thortveitite, zeophyllite, cerite, pyrophyllite and several others.

I look forward to hearing from anyone.

AKE TRUEDSSON
S-380 65 DEGERHAMN
SWEDEN

## SELLING AT SHOWS

Dear sir,

I have a comment regarding your editorial in Vol. 7 no. 6 of the *Record* relating to sales of mineral specimens by collectors.

I have for several years sold personally collected specimens to dealers at the Seattle Regional Gem and Mineral Show without renting space. It turns out that the show sponsors have at some time in the past adopted a rule prohibiting any person who is not a space renting dealer from "attempting to solicit business." The rule is sufficiently vague as to seemingly even prevent persons who meet at the show from trading. What actually happens is that many dealers ignore the rule and risk expulsion from the show by purchasing material from private parties.

I have been led to believe that many shows have similar rules; if so, then collectors and dealers are being cut off from opportunities to mutually benefit each other by the arbitrary action of show sponsors. This is particularly the case for dealers who travel a considerable distance and who appreciate the opportunity to examine and purchase material that is of otherwise local distribution.

Jack Zektzer
Seattle, Washington

*I agree. My complaint (in last issue's What's New in Minerals?) regarding the rigidity of Show Committes toward selling* ***outside*** *of the shows by* ***dealers*** *parallels your complaint about selling* ***inside*** *of shows by* ***non-dealers.*** *Presumably the intent of the show committees is to protect the welfare of the show in the following ways: **(1)** by not allowing sales outside of* *the show, so that all buyers would have to come to the show itself to spend all of their money, thereby maximizing gate receipts and receipts of dealers who paid for show space (and who will buy space next year if successful this year),* **(2)** *by not allowing non-dealer sales inside the show so that all money spent would add to the receipts of dealers with paid space (thereby making them more successful and more liable to buy space again next year). Certainly almost everyone who comes to town for a show will pay at the gate and go in even if he or she has visited the motel sales. So the Show Committes are really only trying to protect the show by keeping the paying dealers happy, as far as I can see. Clearly such restrictions are not in the best interests of show-goers. But are such restrictions really in the best interests of the show or of paying show dealers, and are such dealers really in favor of the restrictions? We will print any replies we receive from dealers on this topic (or other topics);* ***names will be withheld upon request****, so feel free to express your feelings and opinions. We also invite any members of show committees to respond. Let's hear from you.*

*Ed.*

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# FM friends of mineralogy

## A CODE FOR GEOLOGICAL FIELD WORK

**Issued by the Geologists' Association of London, 1975.**

A GEOLOGICAL 'CODE OF CONDUCT' has become essential if opportunities for field work in the future are to be preserved. The rapid increase in field studies in recent years has tended to concentrate attention upon a limited number of localities, so that sheer collecting pressure is destroying the scientific value of irreplaceable sites. At the same time the volume of field work is causing concern to many site owners. Geologists must be seen to use the countryside with responsibility; **to achieve this, the following general points should be observed.**

1. Obey the Country Code, and observe local bylaws. Remember to shut gates and leave no litter.
2. Always seek prior permission before entering private land.
3. Don't interfere with machinery.
4. Don't litter fields or roads with rock fragments which might cause injury to livestock, or be a hazard to pedestrians or vehicles.
5. Avoid undue disturbance to wildlife. Plants and animals may inadvertently be displaced or destroyed by careless actions.
6. On coastal sections, be sure you know the local tide conditions.
7. When working in mountainous or remote areas, follow the advice given in the pamphlet 'Mountain Safety', issued by the Central Council for Physical Education, and, in particular, inform someone of your intended route.
8. When exploring underground, be sure you **have the proper equipment,** and the necessary experience. **Never go alone.** Report to someone your departure, location, estimated time underground, and your actual return.
9. Don't take risks on insecure cliffs or rock faces. Take care not to dislodge rock, since other people may be below.
10. Be considerate. By your actions in collecting, do not render an exposure untidy or dangerous for those who follow you.

### Visiting Quarries

1. An individual, or the leader of a party, should have obtained **prior** permission to visit.
2. The leader of a party should have made himself familiar with the **current state** of the quarry. He should have consulted with the Manager as to where visitors may go, and what local hazards should be avoided.
3. On each visit, both arrival and departure must be reported.
4. In the quarry, the wearing of safety hats and stout boots is recommended.
5. Keep clear of vehicles and machinery.
6. Be sure that blast warning procedures are understood.
7. **Beware of rock falls.** Quarry faces may be highly dangerous and liable to collapse without warning.
8. Beware of sludge lagoons.

### Research Workers

1. No research worker has the special right to 'dig out' any site.
2. Excavations should be back-filled where necessary to avoid hazard to men and animals.
3. Don't disfigure rock surfaces with numbers or symbols in brightly colored paint.
4. Ensure that your research material and notebooks eventually become available for others by depositing them with an appropriate institution.

### Societies, Schools and Universities

1. Foster an interest in geological sites and their wise conservation. Remember that much may be done by collective effort to help clean up overgrown sites (with permission of the owner, and in consultation with the Nature Conservancy Council).
2. Create working groups for those amateurs who wish to do field work and collect, providing leadership to direct their studies.
3. Make contact with your local County Naturalists' Trust, Field Studies Centre, or Natural History Society, to ensure that there is coordination in attempts to conserve geological sites and retain access to them.

It is hoped that the widest possible publicity will be given to this Code, and that authors and teachers will quote it whenever possible.

This Code, initiated by the Geologists' Association, has the support of the following organizations:

The Geological Society of London
The Edinburgh Geological Society
The Geological Society of Glasgow
The Manchester Geological Association
The Liverpool Geological Society
The Yorkshire Geological Society
The East Midlands Geological Society
The Geological Society of Norfolk
The Palaeontological Association
The Geographical Association
The British Geomorphological Research Group
The National Museum of Wales, Cardiff
The Nature Conservancy Council.

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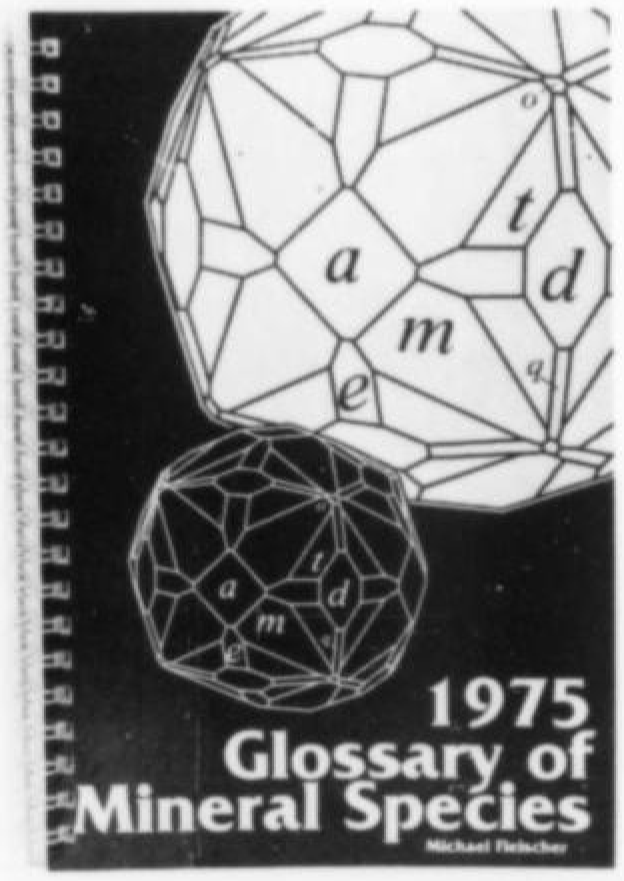

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