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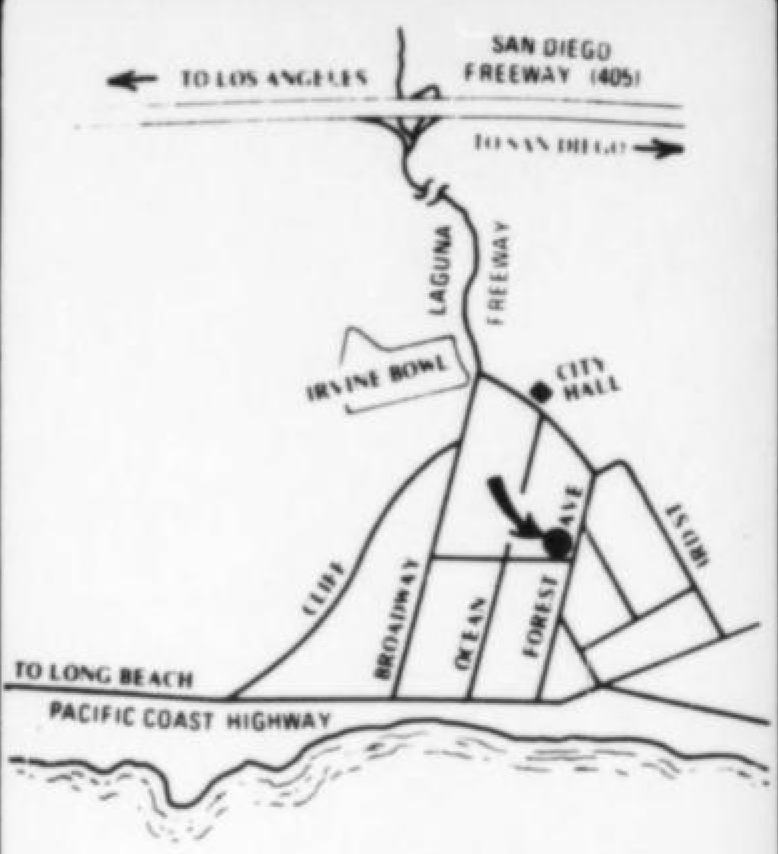


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COVER: RHODOCHROSITE from the Huallapon mine, Pasto Bueno, Peru. The large crystal measures about 3 cm. Roberts Minerals specimen, now in the Smithsonian collection. Photo by Harold and Erica Van Pelt, Los Angeles.

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GUEST EDITORIAL

ELUSIVE MINERALS—A RESPONSE

I would like to add some perspective to the editorial on "elusive minerals" by Hal Steacy and colleagues (vol. 11, page 66). First, let me concede that I am in accord with many of their comments. Errors do happen, and we can all stand improvement.

However, I feel the criticism was overly harsh. Despite the final paragraph disclaimer, the editorial was critical of mineral dealers. Those who buy rare minerals should remember that such species are often elusive *by nature,* and this is no fault of the dealer. If the mineral is there, no matter how elusive, the dealer has fulfilled his responsibility. I don't think it is asking too much for institutions with mineralogists, staffs of technicians, and sophisticated equipment to locate a species on a small sample if it is present. The dealer has performed a feat in simply supplying them with a specimen containing, somewhere, that elusive species. Unfortunately, technicians attempting to verify purchased species may not be skilled at visual identification, and may repeatedly X-ray the wrong portions of the specimen. This also is no fault of the dealer (and he certainly should not be charged for it!). It is a burden on the dealer to have specimens returned; to provide an independent analysis proving the mineral is really present in order to make a sale is impractical.

Despite the lack of sophisticated facilities, most mineral dealers are remarkably accurate. For example, of the thousands of specimens of rare species I've distributed to retail dealers in the last three years, only two have turned out to be misidentified, and those two were caught by the retailers before any were sold to the public. (Of course I may have made some as-yet undiscovered errors.) On the other hand, at least 13 specimens which originated with me have been returned to the retailer by buyers who could not locate species that were nevertheless present. In other words, far more specimens are erroneously returned than are erroneously identified at the time of sale.

Specimens are sold with the clear stipulation that each one has *not* been individually X-rayed. Individual analyses would increase the cost of rare species by a factor of ten or more, which no one would want. The occasional misidentification is the unavoidable companion to reasonable prices on the whole. (And even if individual analyses were provided, errors would still occur. Perfection is impossible.) Considering that specimens are not priced and sold as individually analyzed, one could make a case for dealers charging buyers for a confirming analysis in response to a complaint. Dealers do guarantee their product by offering refunds on erroneously identified specimens. But buyers, it seems, are not required to guarantee the accuracy of their complaints.

A factor contributing to the confusion is the purchasing policy of some institutions. With limited funds, they prefer to spend more money per specimen on display pieces, and less on rare species. Naturally, it should be expected that if they buy the lowest priced specimens in a given lot of a rare mineral, the mineral will be sparsest and most difficult to find on those specimens.

I agree that we should take more care to offer better descriptions of what to look for, and attach arrows to some specimens. But arrows come off easily, especially in ultrasonic cleaners, and one cannot be expected to attach arrows to microscopic patches, or to grains which are intergrown, totally imbedded, or otherwise impossible to pinpoint. We'll do our best to improve. But perfection should not be expected at any price. And the buyer must accept a share of the responsibility for uncertainty unless he is willing to pay the dealer for individually analyzed specimens.

F. Cureton II
Cureton Mineral Company

As a species collector it has been my experience that no one is above error in specimen identification. For example, rare minerals from "old" collections, no matter how famous, are often misidentified. Over the years I have had misidentified specimens from Roebling medalists, mineralogists of great fame in the last century, respected amateurs, *et al.*

Though anyone can make an error, it is still important to know *who* made an identification, rather than just that "it was identified at the University." In the first X-ray course I ever took, I can remember my friend Ted shouting, "Eureka! Unknown No. 4 is akrochordite!" I couldn't convice him that (a) he hadn't been careful enough, (b) he didn't have a good enough match for his data, and (c) no specimens of akrochordite were yet available to anyone. (They are now though.) The unknown proved to be montebrasite. This anecdote helps to illustrate that, if a student or careless technician does the job and makes a mistake, the resulting misidentification can be worse than making no test at all.

Regarding a dealer's responsibility, I feel we must provide material in which we have confidence. A reasonable effort should be made to assure label accuracy. Of course, what the customer then does with the specimen, as far as trimming or analyses, is out of our control and we therefore cannot be held liable for difficulties he might have. The discovery of a misidentified specimen should be brought to our attention within a year of purchase, and a prompt refund will be made (except, of course, in cases of switched-specimen fraud, severely altered specimens, etc.). If a specimen is sold via mail order lists and later found to be misidentified, the dealer should attempt to contact every buyer and offer a refund. We at Ward's try to follow this policy.

Vandall T. King
Ward's Natural Science Establishment

notes from the EDITOR

FLASH—DATELINE DETROIT:

There's been a major change in the motel-selling situation at the time of the coming Detroit Gem and Mineral Show. The group of lapidary dealers at the Holiday Inn has expanded to fill five floors instead of their previous two or three. The mineral dealers (now known as the *Detroit Satellite Mineral Show*) have moved to the Flying Dutchman Motor Inn on Eight Mile Road, about 3 miles east of the Armory. The *Satellite* show is headed by Ron Bentley, who is now in charge of *all* show-time reservations at the motel . . . dealers' rooms and "civilian" sleeping rooms too. Reservations must be made through Ron, not the motel. He doesn't charge any commission on sleeping rooms though . . . the arrangement is simply to prevent double-booking. Preparations have been made for a free shuttle-bus to run hourly between the Flying Dutchman and the Armory . . . for people tired of trying to hitch a ride back and forth, this will be a welcome convenience. And to top it off, the rooms at the Flying Dutchman are just as nice as at the Holiday Inn but are considerably less expensive. If you wish to stay there during the show, call Ron immediately to make your reservation: 602-298-3758.

NEW MAGAZINE OUT

It's always a pleasure to see a new mineral magazine emerge at a high level of quality. Such is the case with *Emser Hefte* ("Hefte" means periodical or paperback book, and "Ems" is, of course, a region in Germany). Three issues have appeared thus far, covering Bad Ems (#1), Grube Georg (#2), and Grube Wolf (#3). Each is superbly done with fine color mineral photography, interesting antique photos of mining scenes, and detailed information on the minerals and history of each locality. The Bad Ems issue, for example, contains a marvelous group of twelve color photographs showing Bad Ems pyromorphite in various habits and colors. Perhaps the most remarkable photo in that group is a shot by Olaf Medenbach of what is called "blaubleierz" ("blue lead ore") . . . bluish pseudomorphs of galena after hexagonal pyromorphite, with partial overgrowths of second-generation yellow-green pyromorphite . . . a strikingly beautiful specimen. Well, as you can see, I've already overdone it with the superlatives, and I haven't even described the rhodochrosites from Grube Wolf yet! Suffice to say, the magazines are worth the price even if you don't read German. *Emser Hefte* measures 6 x 8¼ inches and is issued twice a year. The cost per year is DM 17.00 for Americans (DM 14.00 for Europeans). A check in Deutsch Marks can be easily obtained at most large banks. Send your subscription to *Emser Hefte*, Rainer Bode, Hohe Eiche 26, D–4630 Bochum 7, West Germany.

NEW MINER'S LAMP BOOK OUT

Up until recently, the number of good books dealing exclusively with the collecting of antique miners' lamps could be counted on the thumb of one hand (Henry Pohs' *Early Underground Mine Lamps*, 1974, Arizona Historical Society Museum Monograph #6). Now there is another, unfortunately in German, which admirably covers open-flame miners' lamps, with an emphasis on those from Germany. There simply is no other reference on many lamp types other than this book, at least in any comprehensive form. The many styles of "frog" lamps illustrated are truly enlightening. The title is *Des Bergmanns offenes Geleucht* ("the miners' open-flame lamp"), by Karsten Porezag. To illustrate the critical need filled by this book, of a press run of 5000 copies, 2500 were sold *before* publication! I would otherwise have waited to mention this book until the next installment of the *Record Bookshelf* is published in a future issue, but time may be critical in getting a copy before it sells out. The price is DM 36 (plus an extra DM 6 or DM 8 for airmail postage if desired). Order from: Verlag Glückauf GmbH, Verkaufsabteilung, Postfach 10 39 45, D–4300 Essen 1, West Germany. The book is hardcover, 103 pages, and very well illustrated.

WHICH *MIN. RECORD?*

Well, *we* all know what we're talking about when we say "the *Min. Record*," or "the *Record*," or even just "the *M.R.*" But please don't use those shortened forms when writing for publication. It happens that there is a weekly mining publication entitled *The Mining Record*. And you can see that all three of the above shortenings could apply just as well to that title. People finding a bibliographical reference to *"Min. Record"* in future years will face an ambiguity. If the urge to abbreviate cannot be overcome, *"Mineral. Record"* is still unambiguous as far as I know. But imagine how much more precise it would look spelled out completely.

The Mining Record, incidentally, is devoted to mining events, technology and legislation of interest to those involved in hard rock mining and coal. A one-year subscription is $14 (311 Steele Street, Denver, Colorado 80206). *The Mining Record* has been published continuously for the last 91 years . . . just a little longer than the *Mineralogical Record*.

ARIZONA ISSUES

As I write this at the last minute before publication (July 25), Mary Lynn White reports that sales of extra copies of *Arizona-I* and *Arizona-II* are extremely brisk. Orders for more than 1000 extra copies of each have already come in, though it's been only about a month since *Arizona-I* was received by readers (and *Arizona-II* has not even been received by readers yet). We had less than 3000 extra copies to begin with, so I would advise anyone wanting extra copies to write for them *immediately* before they are sold out. The price to *Record* subscribers and bona fide dealers is $2.00 per copy, and we pay postage. At the time you place your order you may also reserve for yourself an equal number of copies of *Arizona-III*, which we hope to put out sometime next year. But don't include payment for *Arizona-III* yet . . . we'll invoice you for it when it's ready.

WHAT-ELSE-COULD-POSSIBLY-GO-WRONG DEPARTMENT

Just when you think you've experienced every possible kind of error or problem, and have confidently built in safeguards against them, something new turns up. We've just begun receiving calls from some surprised subscribers (only those on our first class/airmail mailing list). They opened their envelope expecting to see *Arizona-II* in all its glory, and found instead . . . a biology magazine. Despite a lot of checking, we still haven't determined how this happened, but we will naturally send out replacements as needed (tear off the cover of the biology magazine and include it with your replacement request). In the meantime, why not take the opportunity to bone up on your biology?

MILESTONES

Leonard Thiel, of Ann Arbor, Michigan, passed away on April 25, 1980, as a result of a stroke. He was an avid mineral collector, and the owner of Eastern Mineral Supplies. Len donated many specimens to the collections of Wayne State University (Detroit), Michigan State University, the Cranbrook Institute (Detroit), and the University of Michigan. In addition to the donation of museum-quality specimens, he furnished many classroom specimens for use at Wayne State University and the University of Michigan.

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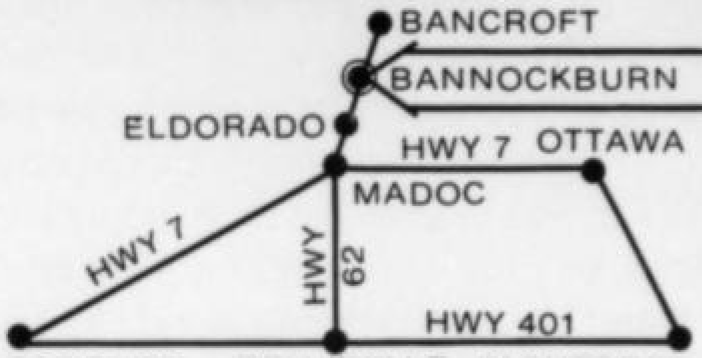

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Los Lamentos

Chihuahua, Mexico

by **Wendell E. Wilson**
The *Mineralogical Record*
P. O. Box 35565
Tucson, Arizona 85740

For decades the Erupcion and Ahumada lead mines in the Los Lamentos Range, northeastern Chihuahua, have been famous among collectors for a single species: wulfenite. Periodic discoveries, the most recent made in January of 1980, have yielded an interesting variety of distinctive crystal habits.

LOCATION

The mines of the Los Lamentos district are located in the Sierra de Los Lamentos (Los Lamentos Range), about 65 km (40 miles) east of Villa Ahumada, which is itself about 187 km (115 miles) south of El Paso, Texas, on highway 45. The range is within the *municipio* of Villa Ahumada; some early specimen labels give Villa Ahumada as the locality for what is actually Los Lamentos wulfenite. The two principal mines, the Erupcion mine and the Ahumada mine, connect underground and occupy portions of a single deposit.

HISTORY

The Los Lamentos district derives its name from the mountain range in which it is located, not because of any sorrowful lamentations of disappointed mineral collectors, but because of the peculiar sound made by wind passing through the limestone caverns.

The deposit was discovered by an unknown Mexican in 1907. A 7-meter-deep prospect shaft was dug, which encountered high-grade cerussite ore. The original claim was won by David Fenchler in a raffle; but the new owner did nothing to develop the workings further.

In 1905, two years preceding the actual discovery, Jose Maria de la Peña had suggested to David Bruce Smith, then in charge of the San Pedro de Corralitos mine in Chihuahua, that he should visit the Los Lamentos area. Smith finally made the trip in 1909, and examined the workings on the Erupcion claim. In 1916 Smith returned again and purchased an option on the claim from Fenchler for $50,000.

Smith had two chief difficulties: not enough water and too many bandits. During the first two years he hauled water to the camp from a spring 26 km away. With the aid of a telescope he could see bandits coming from a considerable distance across the flat, dusty plains, and was generally able to be out when they called. Unfortunately he was finally captured by bandits (revolutionaries) under Francisco "Pancho" Villa in 1918, along with E. F. Knotts, presi-

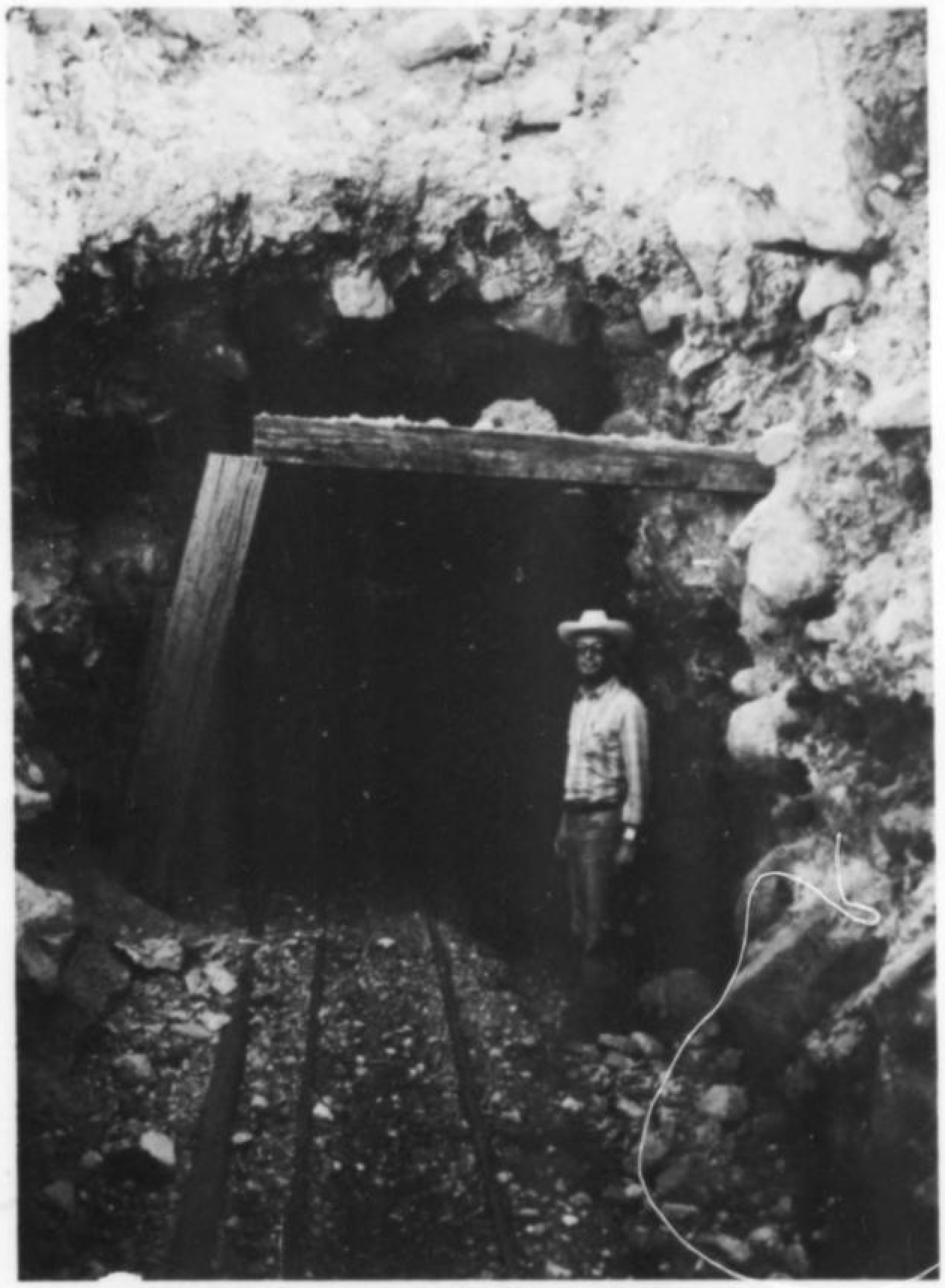


***Figure 1.* Entrance to the Frente de Guia tunnel of the Ahumada mine today. Miguel Romero photo.**

dent of the Erupcion Mining Company, who had the misfortune to be visiting the property at the time. After 12 days of captivity Smith was released so that he could obtain $20,000 ransom for Knotts. After an additional 13 days of waiting, Knotts was released upon payment of the $20,000 by C. L. Baker of the American Smelting and Refining Company; the ransom money was provided as an advance on ore receipts from the Erupcion mine.

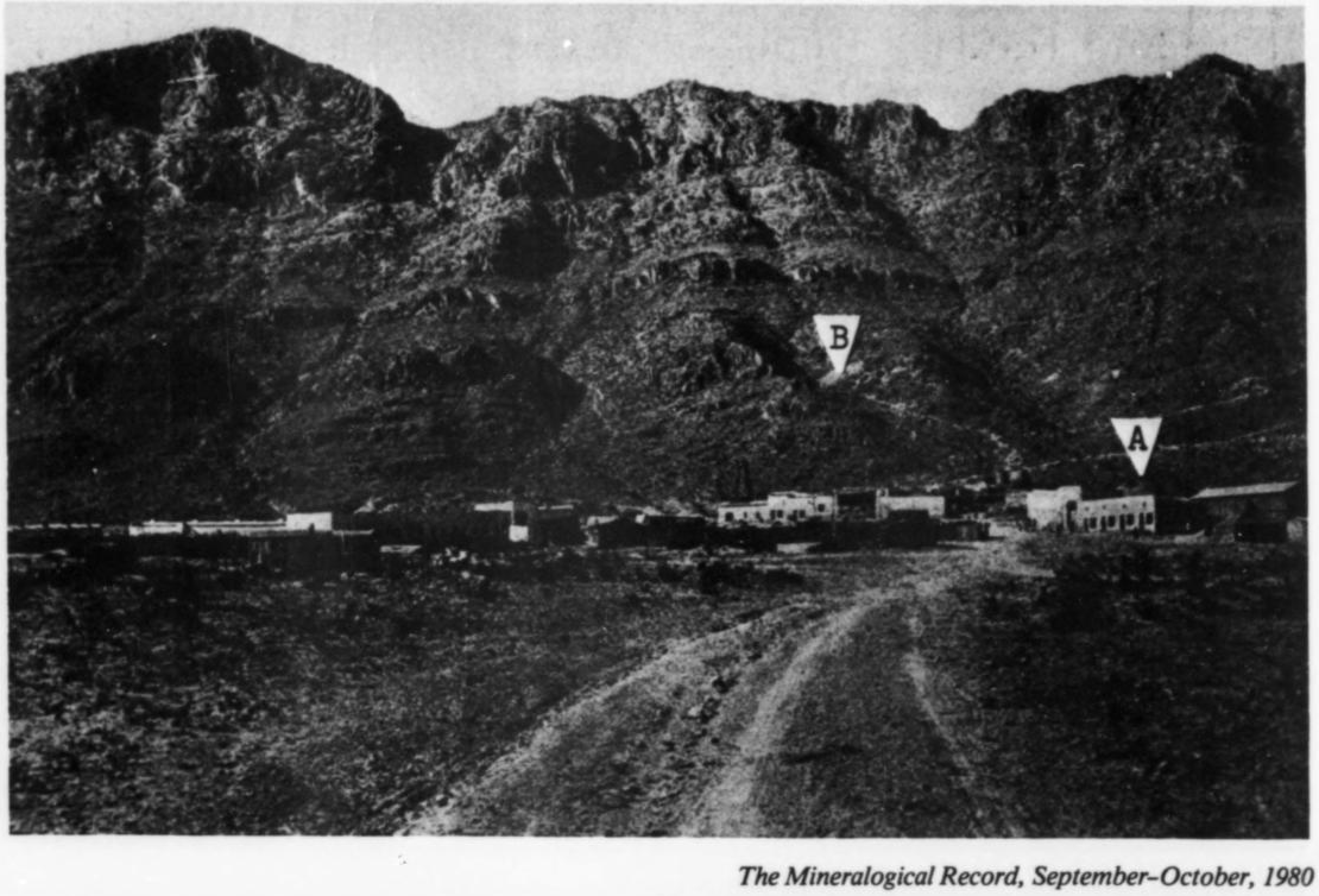
Figure 2. **The revolutionist Francisco "Pancho" Villa abducted Erupcion mine director Smith and mining company president Knotts in 1918, extorting $20,000 in ransom. Photo courtesy of the Arizona Historical Society.**

The episode with Villa brought an end to such difficulties. Villa had promised to protect the mine from further raids if the ransom was paid, and he was true to his word. The Erupcion mine shipped 8000 tons of anglesite lead ore averaging 42.5 percent lead (that is, about 62 percent anglesite) to Villa Ahumada during 1917 and 1918. From there the ore was sent by rail to the city of Chihuahua.

Nevertheless, the operation suffered from a lack of capital until 1919, when Henry C. Dudley, a mining engineer from Duluth, Louis D. Ricketts and John C. Greenway agreed to buy the remaining stock in the company, stipulating that the money be used for further development. Dudley and associates took over management of the mine, incorporating as the Ahumada Lead Company; they eventually took over controlling interest in the operation. Workings opened from this time forward were given a new name, the Ahumada mine, despite the fact that they were only a natural extension of the Erupcion mine. Exploratory work revealed promising signs of dolomitized limestone accompanied by a broad fracture zone extending a considerable distance on the surface. Adjacent properties were acquired until, by 1924, the mining property covered 1600 hectares (4000 acres).

T. A. Rickard visited the property in the early 1920's and subsequently described the history of the mine and the extent of its workings in 1924. W. F. Foshag of the Smithsonian Institution visited the locality in the early 1930's, and briefly described the species occurring there in 1934. Most of the information presented here has been drawn from these two articles, though neither author described the wulfenite beyond a brief mention. Unfortunately, most of the species mentioned by Foshag have not been present on mineral specimens reaching the market in recent decades.

Figure 3. **The Los Lamentos Range, with the locations of the Marjorie tunnel (A) and Berrenda workings (B) indicated. (From Rickard, 1924.)**



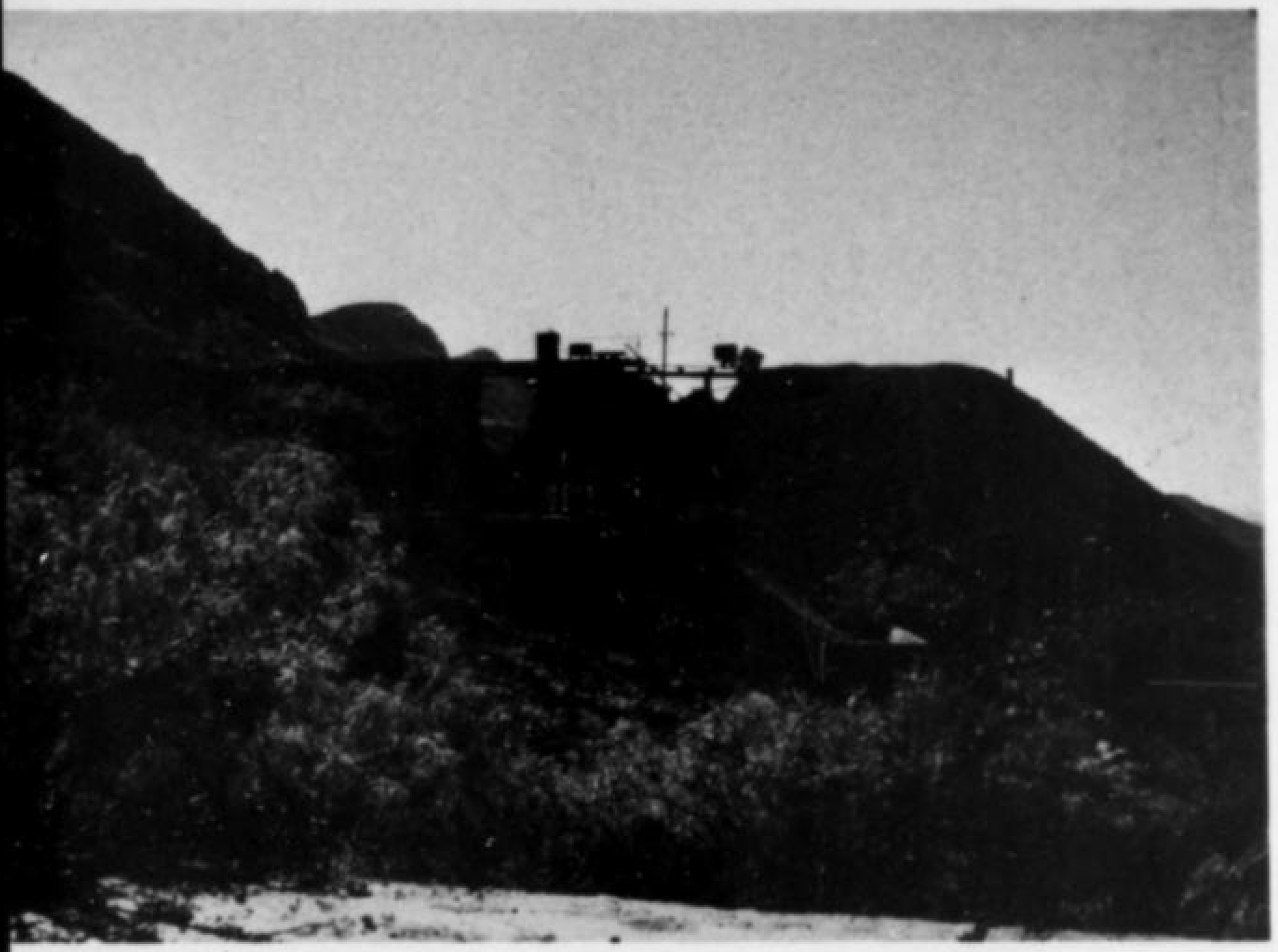


Figure 4. **Dump of the Frente de Guia tunnel today. Miguel Romero photo.**

According to Foshag (1934) the property was being operated by the Compania Minera de Plomo, S.A., at the time of his visit. Since that time the Los Lamentos mines have been worked periodically, reportedly by a miners' cooperative in the 1960's, resulting in some occasional production of lead ore and wulfenite specimens. The local miners have been aware of the value of mineral specimens and there has rarely been any restriction on collecting by the miners, while under the cooperative. Private parties from the United States have also attempted to work the property for wulfenite.

MINE WORKINGS

The mine is entered by an adit known as the Marjorie tunnel, which proceeds horizontally for about 320 m, then downward from the horizontal at a 14° angle for 450 m, and from there downward at a 22° angle for another 160 m. At least this was the extent of the tunnel as of Rickard's 1924 report . . . additional drifting and stoping has undoubtedly been undertaken since, but a revised underground map could not be obtained.

Miguel Romero (personal communication) visited the mines in June of 1980 and reports as follows: "I found that there are now four tunnels, all on the west side of the mountain. *El Cuervo* is the current name of the original tunnel (the Marjorie tunnel). About 50 m below El Cuervo is another tunnel named *Frente de Guia;* it is presently the longest, 1400 m, and is in partial operation. Above these and to the left (not in the main deposit) are two other tunnels, *Santa Cruz* and *Berrendo* or *Berrenda,* currently being worked for lead ore by a few miners. I checked with the miner in charge at the Frente de Guia tunnel, and saw the little shrine to the Holy Cross about 80 m inside from the entrance. You can still see the remains of a small cross monument. I was told the patron saint of the mine is "San Nicolas," and there is a chapel nearby, in ruins."

Even the extreme lower end of the workings required no artificial ventilation. Natural fractures in the limestone provide excellent natural circulation in all portions of the mine. In fact, miners would light cigarettes and note the flow of air by the smoke, then mine in the direction of greatest flow on the assumption they would find ore-lined caverns.

The upper portion of the mine, to a distance of about 700 m from the portal, is the Erupcion mine, and further workings are the Ahumada mine. Near the adit entrance a chamber was cut for a shrine holding a simple cross draped with flowers. Primitive methods of mining were still in use in the 1902's; timbers weighing up to 77 kg (170 pounds) were carried through the mine on the backs of miners, who secured them with a strap which passed across the forehead. Ore was carried out in a similar way, in a rawhide bag holding 70 or 80 kg of ore, attached to a strap across the brow.

GEOLOGY

The Los Lamentos Range is a limestone block generally trending east-west and rising steeply on its southern face to an altitude 600 m above the surrounding plain. The general structure is that of an

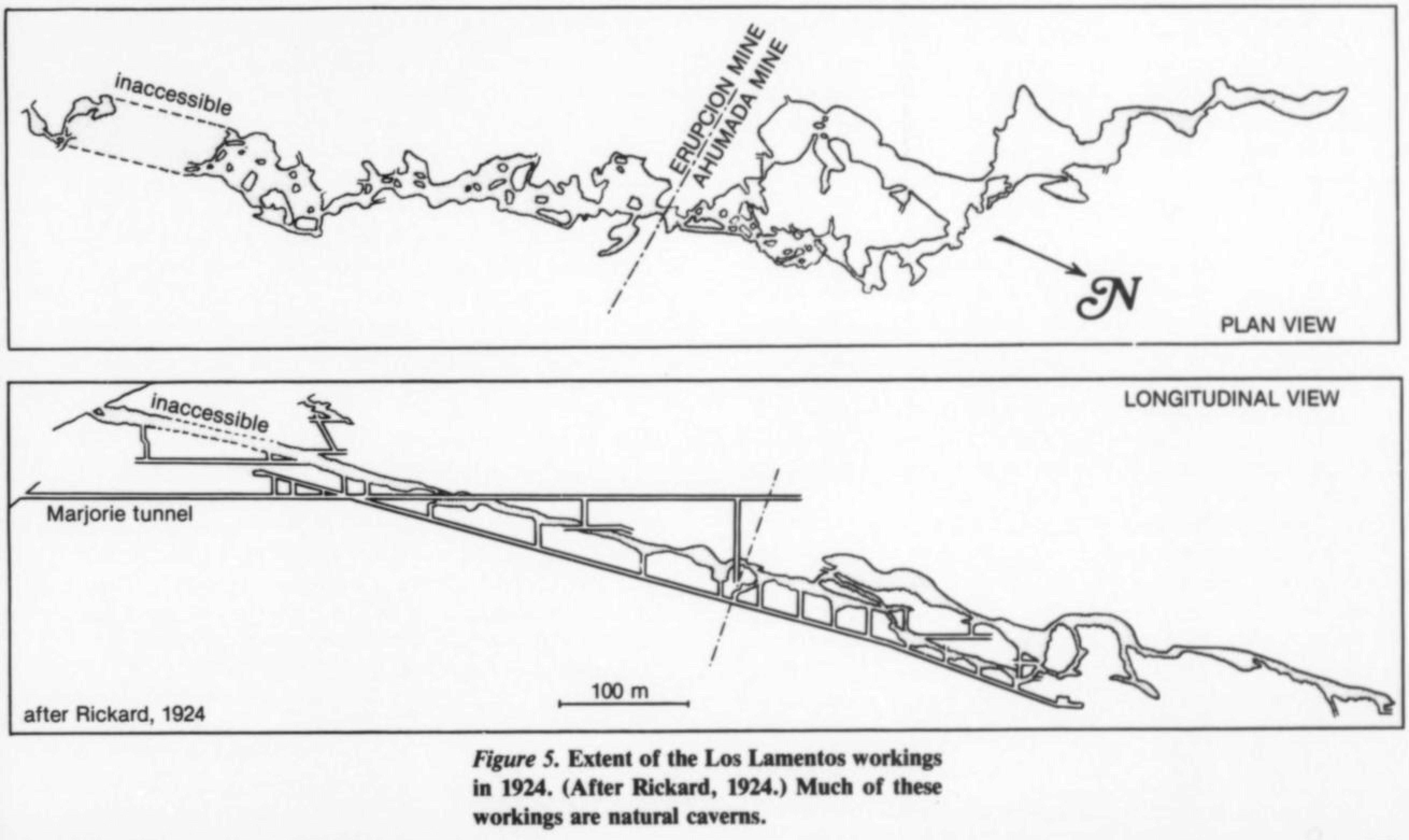


Figure 5. **Extent of the Los Lamentos workings in 1924. (After Rickard, 1924.) Much of these workings are natural caverns.**

Figure 6. **Miners working an ore cavern. (From Rickard, 1924.)**

arched fault block in which the beds dip gently to the north and are cut off by a fault scarp which forms the steep southern face. Four limestone formations are exposed on the scarp: the Bufa, San Vincente, Los Lamentos, and Angela limestones, from top to bottom. The manto-type ore body is located in the Los Lamentos limestone along its lower contact. These rocks are part of the Comanche series of Cretaceous age.

Manto-type deposits of Mexico have a number of features in common. They take the form of huge chimneys cutting across limestone beds, or mantos ("blanket" or "mantle" in Spanish) paralleling the beds. Intrusive rocks are not evident, though anticlinally folded ranges are common and may be the result of intrusions at depth. Ore minerals contain lead, zinc, iron, and often silver, though copper mineralization is typically almost totally absent. Dolomitization of the limestone surrounding ore bodies is typical as well. Such Mexican deposits, notably Mapimi and Santa Eulalia, have yielded many millions of dollars in lead, zinc and silver. The Los Lamentos deposit is among the simplest examples, consisting of a single manto developed along a favorable zone for its entire length. Whether this manto is an off-shoot of an as-yet undiscovered chimney is unknown.

Ore in the Los Lamentos district is associated with dolomitization of limestone, the dolomite forming aureoles averaging 15 m in thickness which surround ore. In some places the dolomite aureole is considerably thicker, but in other places the ore is in direct contact with unaltered limestone. Several large areas of dolomite appear to be unassociated with ore mineralization. The dolomite is medium grained, ranges in color from gray to reddish brown and white, and is vuggy in places.

The upper portion of the ore pipe (the Erupcion mine area) is fairly regular, averaging about 10 m in thickness and 50 m in width. The lower portion (the Ahumada mine area) is characterized by irregular ore concentrations. The manto passes under a series of limestone caverns and is commonly covered by masses of limestone which have spalled off the cavern ceilings. Much ore has been found in the walls and floor of these caverns.

The ores change character with depth. All are oxidized, and carry the occasional residual lump of galena as the only remaining primary sulfide. Anglesite was the chief ore mineral in the upper levels, occurring as pure, compact masses and fine to coarse sand. Gypsum and sulfur were abundant, commonly coated with small crystals of anglesite. Also found in the upper levels were large bodies of plumbojarosite containing about 19 percent lead.

In the lower levels the ore was an iron-stained cerussite, commonly associated with hematite, averaging 30 percent lead. At the 5th level, in the Ahumada portion of the workings, wulfenite, vanadinite and descloizite began to appear in abundance, and these minerals formed a significant portion of the ore on the 7th level (just above the water table). Several stopes were worked almost entirely in loose, spongy masses of dark brown vanadinite (*endlichite*) needles averaging 65 percent lead and 12 percent vanadium oxide. Below the 7th level the ore consisted of a mixture of cerussite, wulfenite, vanadinite and descloizite crystals. Scattered pipes and nests of wulfenite were found in other stopes as well.

The controlling factor which resulted in the Los Lamentos limestone being a favorable bed for deposition of ore is apparently unrelated to chemical composition; that of the underlying Angela limestone is very similar (Foshag, 1934). Instead, it appears that the Los Lamentos limestone was favorable because of some physical property, most likely its heterogeneous texture and brecciated and

Figure 7. **Brilliant yellow wulfenite crystals, the largest about 15 mm, from Los Lamentos.** ***Western Minerals*** **specimen.**

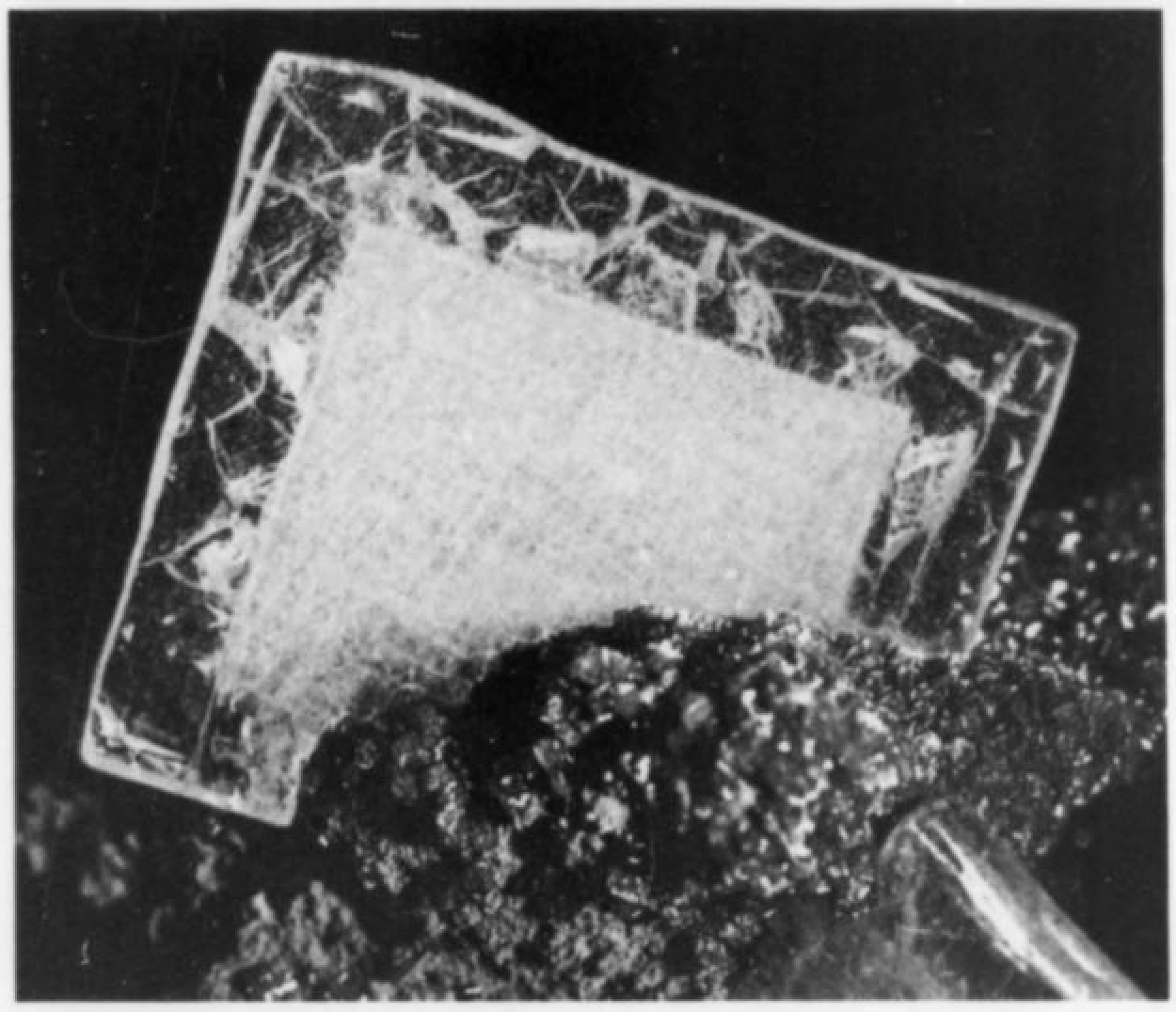


Figure 8. **An orange crystal of wulfenite from Los Lamentos, showing a transparent zone surrounding a translucent zone, and measuring 15 x 18 mm. Olaf Medenbach photo.**

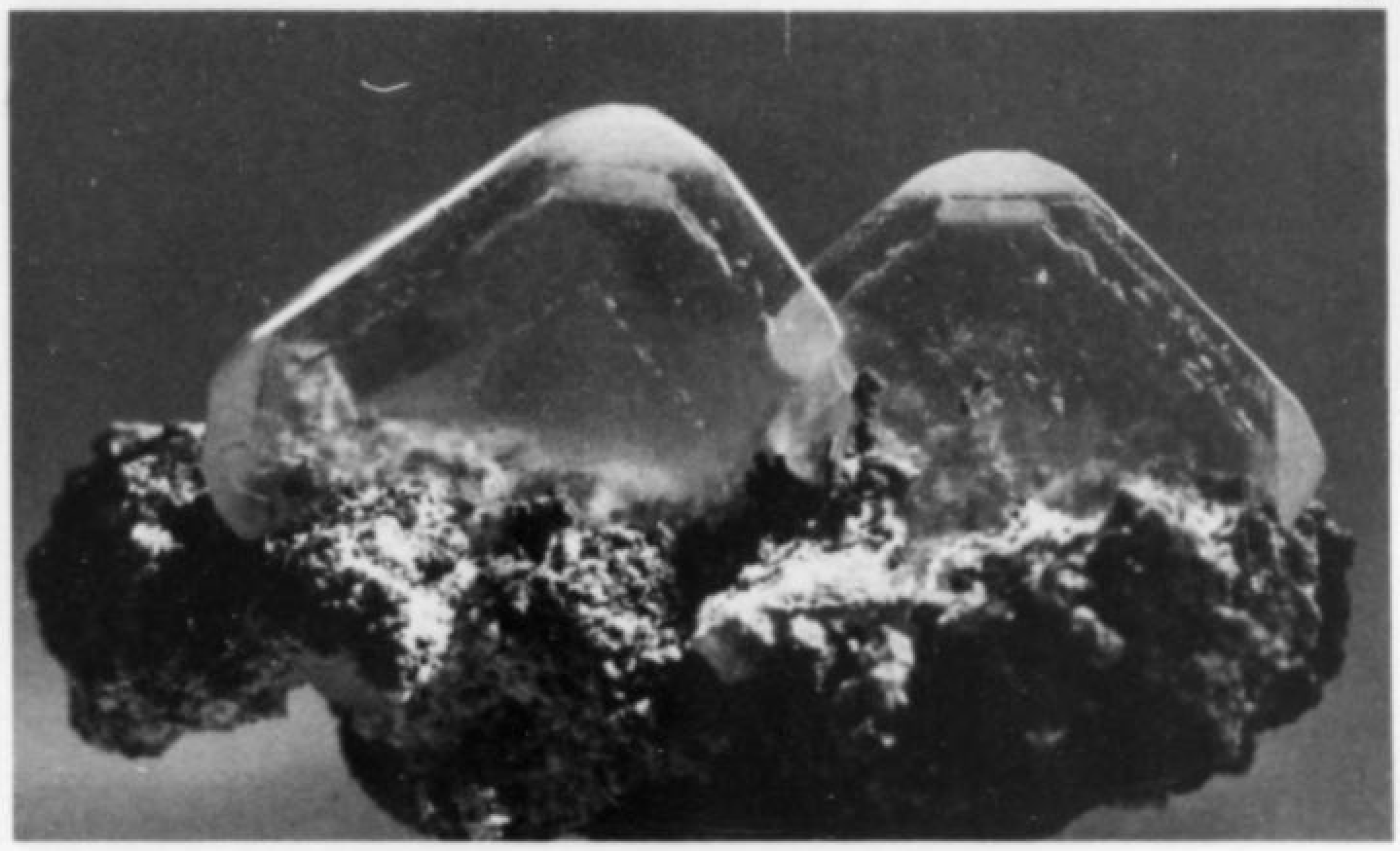


Figure 9. **Two transparent yellow crystals of wulfenite from Los Lamentos. The matrix measures 4.7 cm across.** ***Western Minerals*** **specimen.**

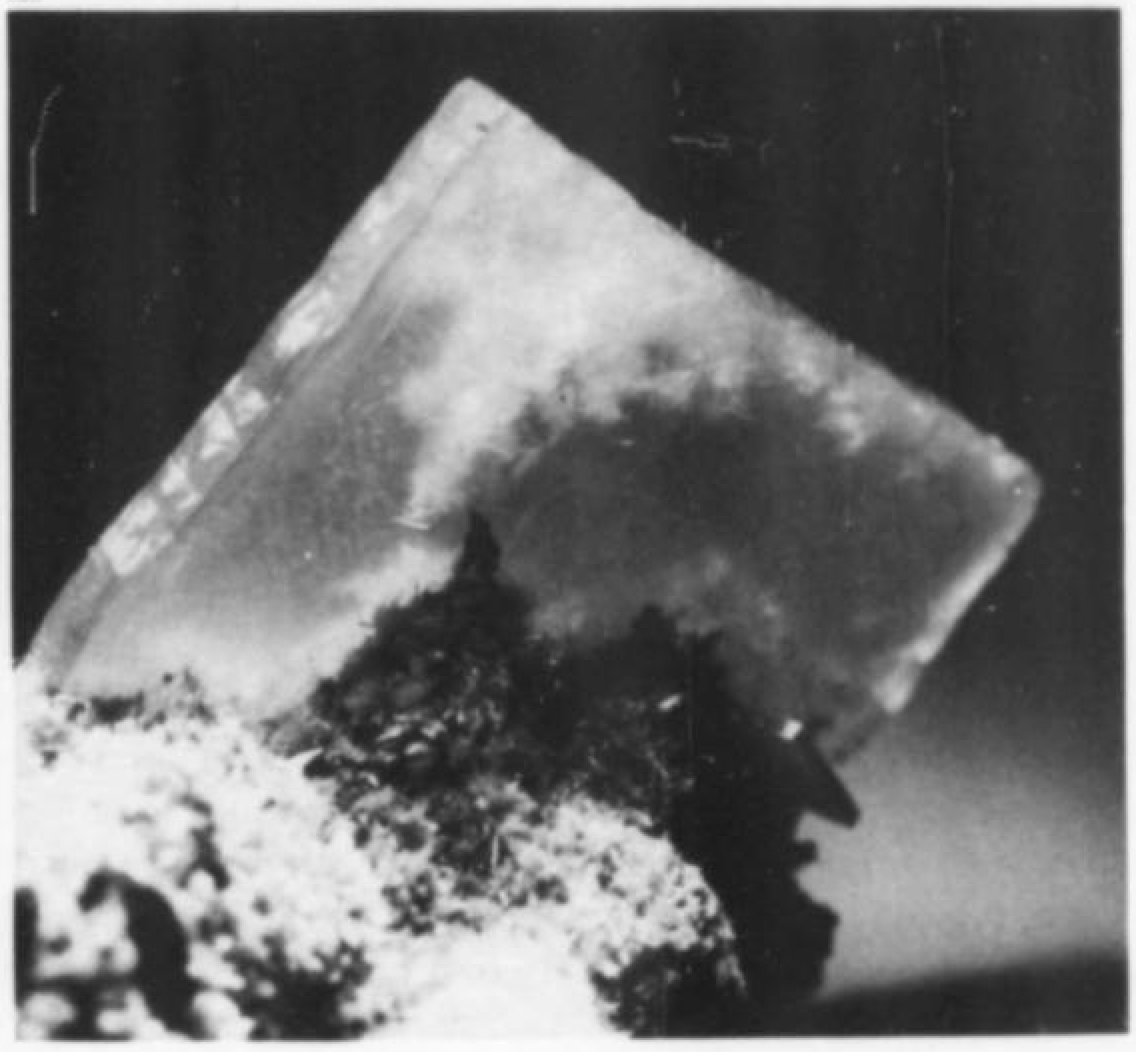


Figure 10. **An orange crystal of wulfenite about 2 cm across, from Los Lamentos. Collection of the author.**

Figure 11. **An extremely large, orange crystal of wulfenite measuring 5.9 cm (2¼ inches) diagonally, from Los Lamentos. Steven Morehead collection.**

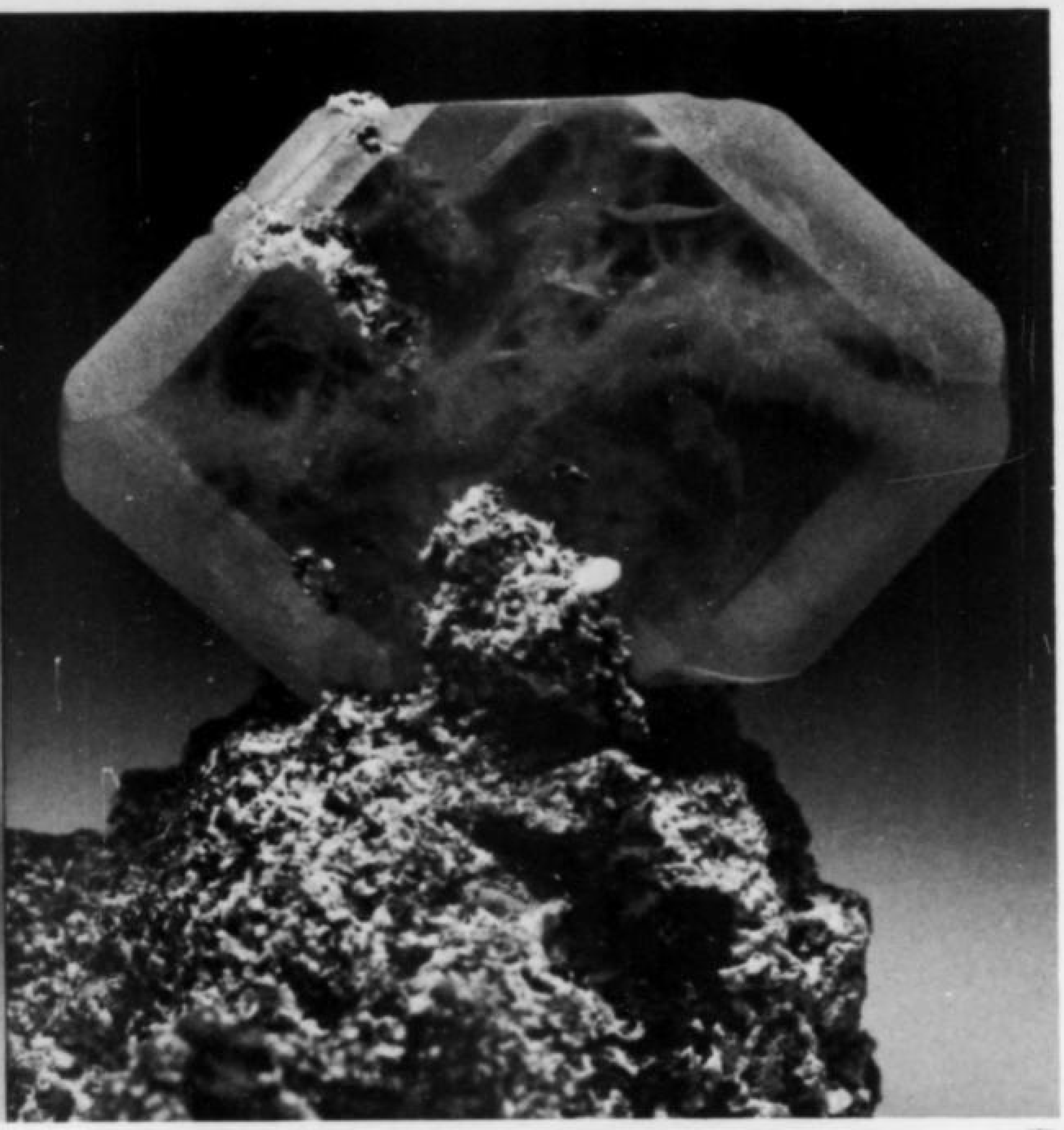


Figure 12. **An orange wulfenite crystal about 3 cm across from Los Lamentos, found in 1978 or 1979. Arizona-Sonora Desert Museum specimen.**

fractured character which provided abundant channels for ore-forming solutions.

Early investigators presumed that the molybdenum concentrated at depth near the water table, in the form of wulfenite, was the result of secondary enrichment. Considering that no appreciable amount of unaltered ore was found for examination, it remains possible that primary molybdenum minerals in the upper portions of the manto yielded the molybdenum which formed wulfenite. Nevertheless, no molybdenite has been found in the rare patches of unaltered ore, a situation which is typical of many major deposits of wulfenite in the American Southwest. A recent study (Wilson, in preparation) has shown a rough correlation between lead deposits carrying large amounts of wulfenite, and the occurrence within a few kilometers of large copper-molybdenum porphyry bodies. The implication is that molybdenum put into solution in groundwater and surface water by the weathering of the porphyry traveled until being precipitated as wulfenite in areas of altering lead deposits, the lead being far less mobile in solution than molybdenum. If a copper-molybdenum porphyry body exists within 10 or 20 km of Los Lamentos it may well be the source of the molybdenum.

MINERALOGY

Wulfenite

The mineral of principal interest to collectors at Los Lamentos is wulfenite, which occurs in crystals to more than 6 cm, primarily in the Ahumada mine. Crystals range in habit from thin tabular to blocky and pseudocubic, and to steeply bipyramidal, with many minor variations along the way. In general, specimens have emerged on the mineral market in batches. Each batch seems to be distinctive in habit, suggesting a single, localized occurrence within the mine for each batch. Collectors at the locality have reported either feast or famine . . . wulfenite is difficult to locate but, when found, is locally abundant. If sufficient data could be gathered, one could probably date the discovery of a particular specimen on the basis of its habit.

Pseudocubic crystals have been found in the Erupcion mine (Sinkankas, 1964) but wulfenite there is rare. Most wulfenite has come from the Ahumada mine, and it is generally safe to label specimens that way in the absence of any information to the contrary. In the few Erupcion mine specimens I have examined there was no particular feature which might serve to distinguish them on a general basis.

The color ranges from a clean, pale yellow (see the photo in Wilson, 1980) through various shades of orange to an iron-stained purplish black. Crystals are commonly color-zoned perpendicular to the *c* axis, looking like sandwiches. The various zones range from translucent to transparent. Prism and pyramid faces tend to be rounded irregularly, making goniometry impossible; a rather bubbly appearing surface composed of intergrown hillocks is typical. The *c* face, where present, is usually lustrous and well formed, though it may be incised with numerous pits and lines sometimes on a square pattern rotated approximately 11° from the square perimeter of the face. In extreme cases the *c* face disappears entirely in favor of irregularly intergrown pyramids or tightly packed acicular terminations. Such crystals, though interesting and regular, may lack a single measureable form.

Associations are limited to calcite (which covers the matrix as a fine grained white blanket to 1 or 2 cm thick on some specimens), vanadinite, descloizite, willemite and hydrozincite. A dusting of minute, green, poorly formed crystals on the calcite matrix of some specimens has been identified as pyromorphite (Romero, personal communication). Some wulfenite occurs on spongy black hematite.

The following minerals, except for pyromorphite, were described by Foshag (1934).

Anglesite

Anglesite formed the major ore mineral in the Erupcion mine and also occurred to a lesser extent in the Ahumada mine. Pure masses of fine grained gray anglesite were found in the Erupcion mine, as well as coarse anglesite sand and gravel consisting of rough crystals up to 1 cm in size. Banded nodules with a core of galena

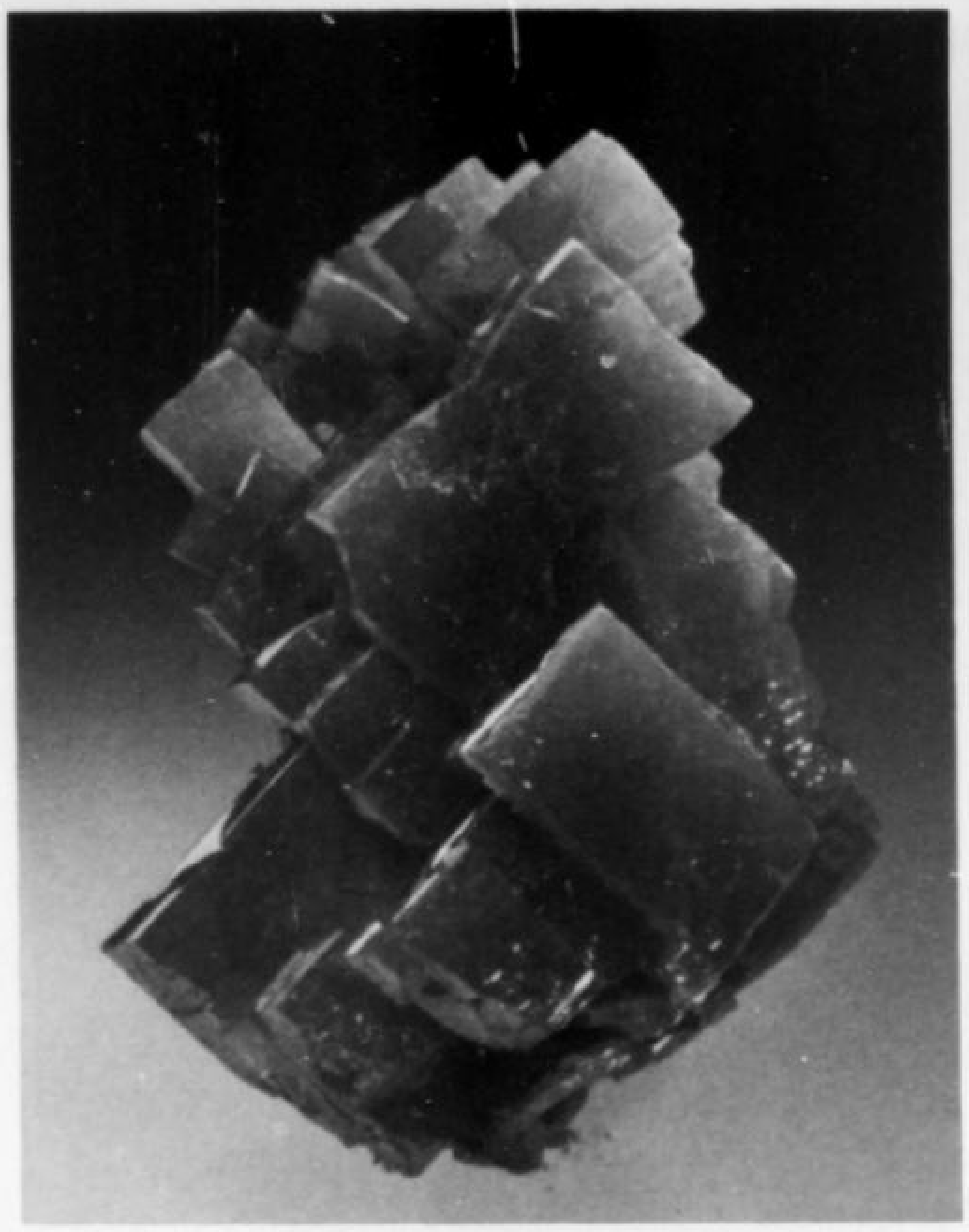


Figure 13. **Orange wulfenite crystals from Los Lamentos in a parallel growth 3.7 cm tall. *Western Minerals* specimen.**

Figure 14. **Orange wulfenite crystals showing a rounded habit, from Los Lamentos. The matrix is 4.5 cm across. *Western Minerals* specimen.**

Figure 15. **Pale, milky orange Los Lamentos wulfenite crystals showing a habit which is, in a way, the reverse of that shown in Figure 14. The prism faces are concave or re-entrant rather than rounded outward. The matrix is 5.8 cm across. *Western Minerals* specimen.**

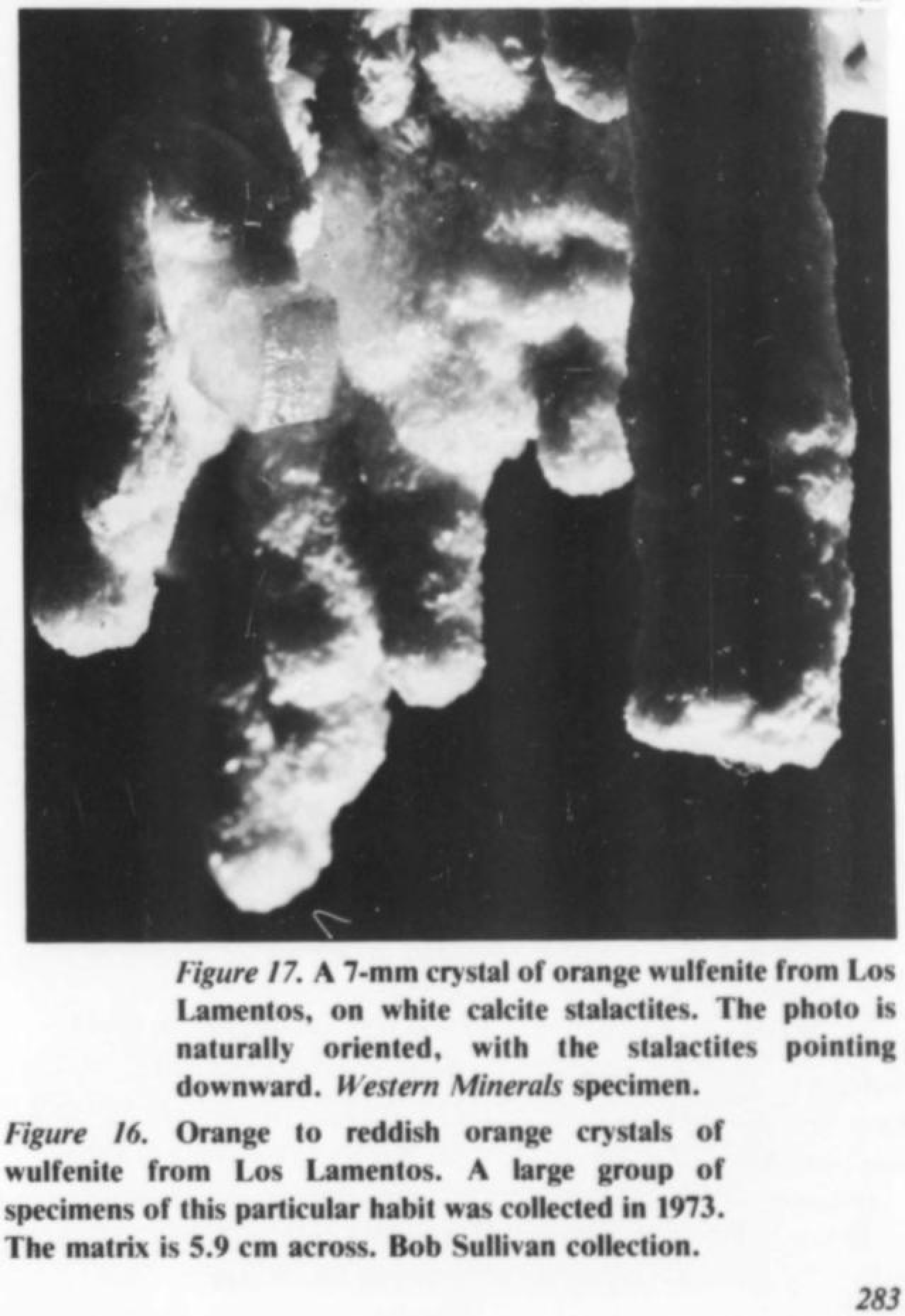


Figure 17. **A 7-mm crystal of orange wulfenite from Los Lamentos, on white calcite stalactites. The photo is naturally oriented, with the stalactites pointing downward. *Western Minerals* specimen.**

Figure 16. **Orange to reddish orange crystals of wulfenite from Los Lamentos. A large group of specimens of this particular habit was collected in 1973. The matrix is 5.9 cm across. Bob Sullivan collection.**

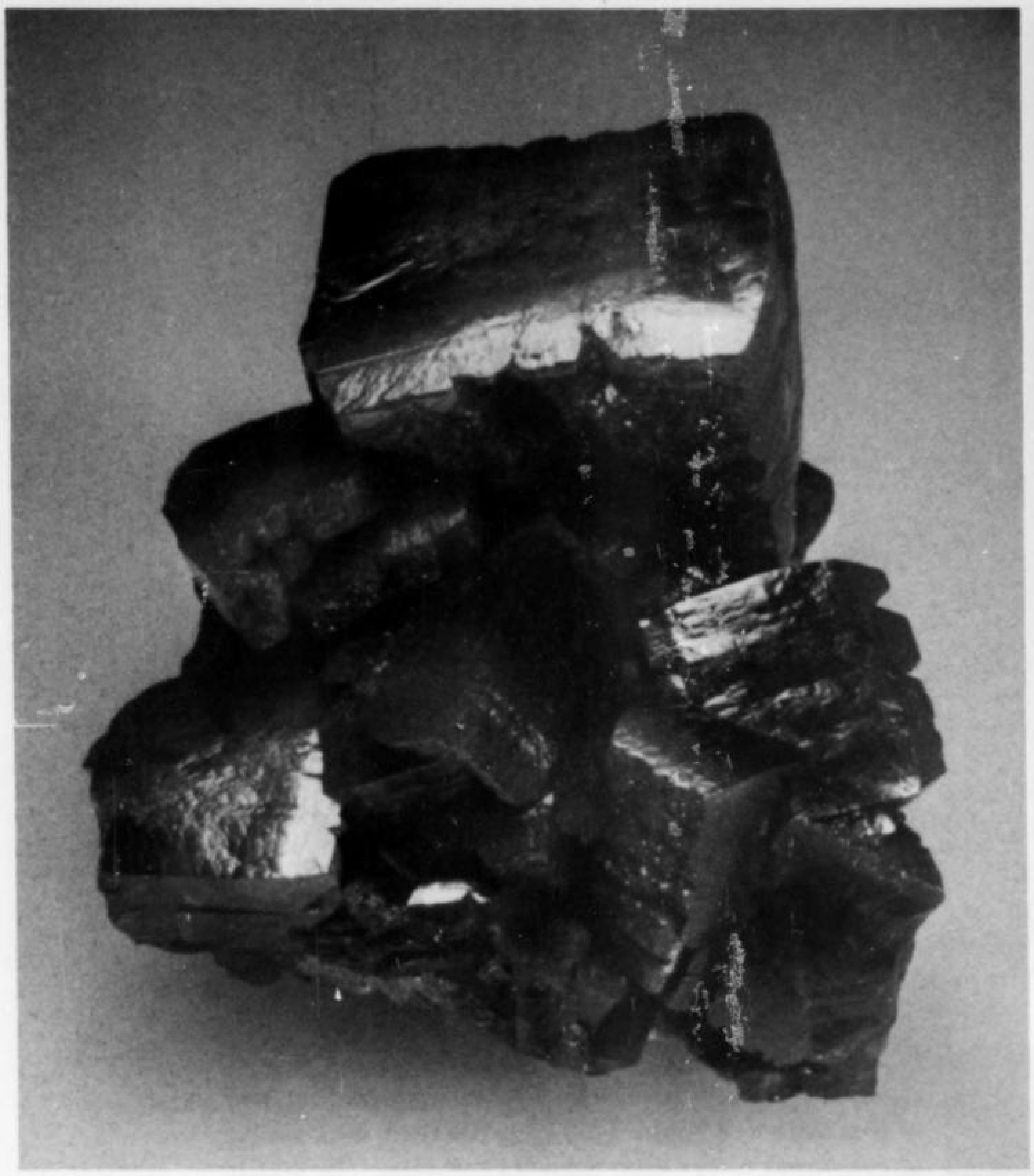


Figure 18. **A group of exceptionally large, blocky crystals of deep orange wulfenite, the largest measuring 2.4 cm across, from Los Lamentos. Collection of the author.**

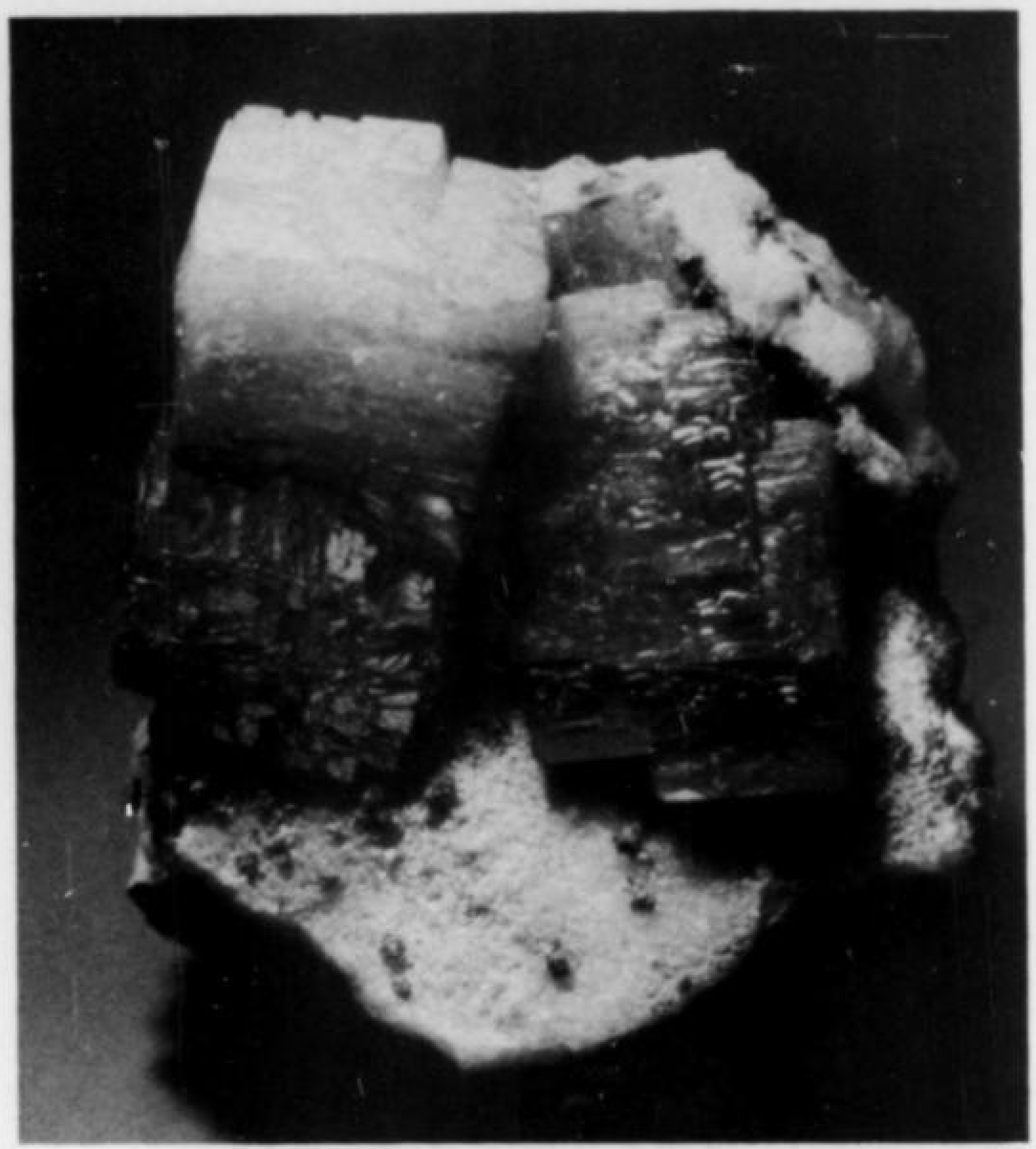


Figure 19. **Two wulfenite crystals, about 1.5 cm each, showing color zoning (yellows and browns) parallel to the *c* faces, and an elongation along the *c* axis. Collection of the author.**

Figure 20. **Red-orange crystals of Los Lamentos wulfenite, the largest about 1.5 cm, showing the steep bipyramidal habit. Marshall Sussman collection.**

were abundant at one time. Perfectly formed but etched crystals to more than 6 cm in size were frequently found imbedded in gypsum or sulfur. In the lower levels anglesite usually occurred as porous iron-stained masses. The anglesite ore occurred on the floor and in the walls of the limestone caverns.

Brochantite

Foshag (1934) reports seeing one small specimen of brochantite and gypsum from Los Lamentos. Copper minerals are almost entirely absent at the deposit.

Calcite

Calcite is abundant as secondary crystals and coatings associated with the ore minerals. It commonly covers limestone to form the matrix for wulfenite crystals. Simple, transparent rhombs occur in small cavities in massive calcite, and in association with wulfenite.

Cerussite

Cerussite was the main ore mineral at the Ahumada mine, though wulfenite and vanadinite were significant components. For the most part it was present as cerussite sand. Spongy masses stained by hematite, and a few poor crystals were also found.

Descloizite

Descloizite was typically found in close association with vanadinite and wulfenite, and more rarely with calcite and willemite near the borders of the pipe. Spongy masses of lustrous crystals, and irregular nodular masses were common. At least one pocket of wulfenite contained crystals coated with descloizite that seemed to have been formed at the expense of the underlying wulfenite, which was corroded.

Dolomite

Dolomite has been reported as the principal gangue mineral. It was formed by the alteration of limestone and has not been found as crystals. It ranges from gray to white and reddish. Chemical tests on a large number of specimens in the Smithsonian collection failed to show any dolomite; all dolomite-like material tested, both matrix and overgrowths, proved to be calcite (John S. White, personal communication).

Galena

A few remnant cores of unaltered galena have been found associated with anglesite and cerussite in the lower levels. Some cleavages contain crystals of sulfur.

Goethite

Thin, lustrous crusts of goethite were found lining cavities in

Figure 21. **Brown, cavernous crystals of vanadinite (variety *endlichite*) from Los Lamentos. The crystals reach a maximum of 1 cm. *Western Minerals* specimen.**

Figure 22. **Large, lustrous crystals of brown vanadinite (variety *endlichite*) from Los Lamentos. The group is 4 cm tall. *Western Minerals* specimen.**

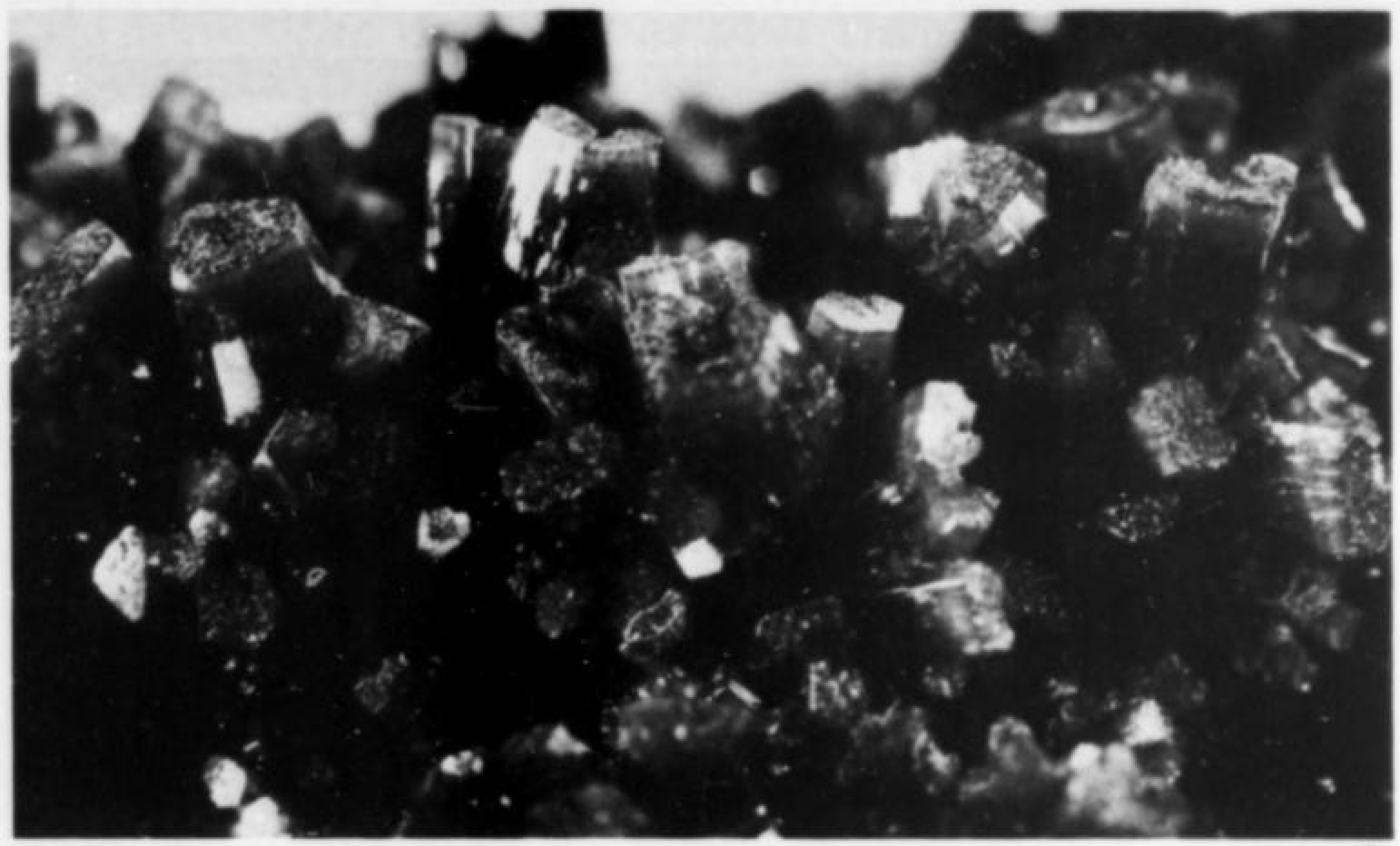
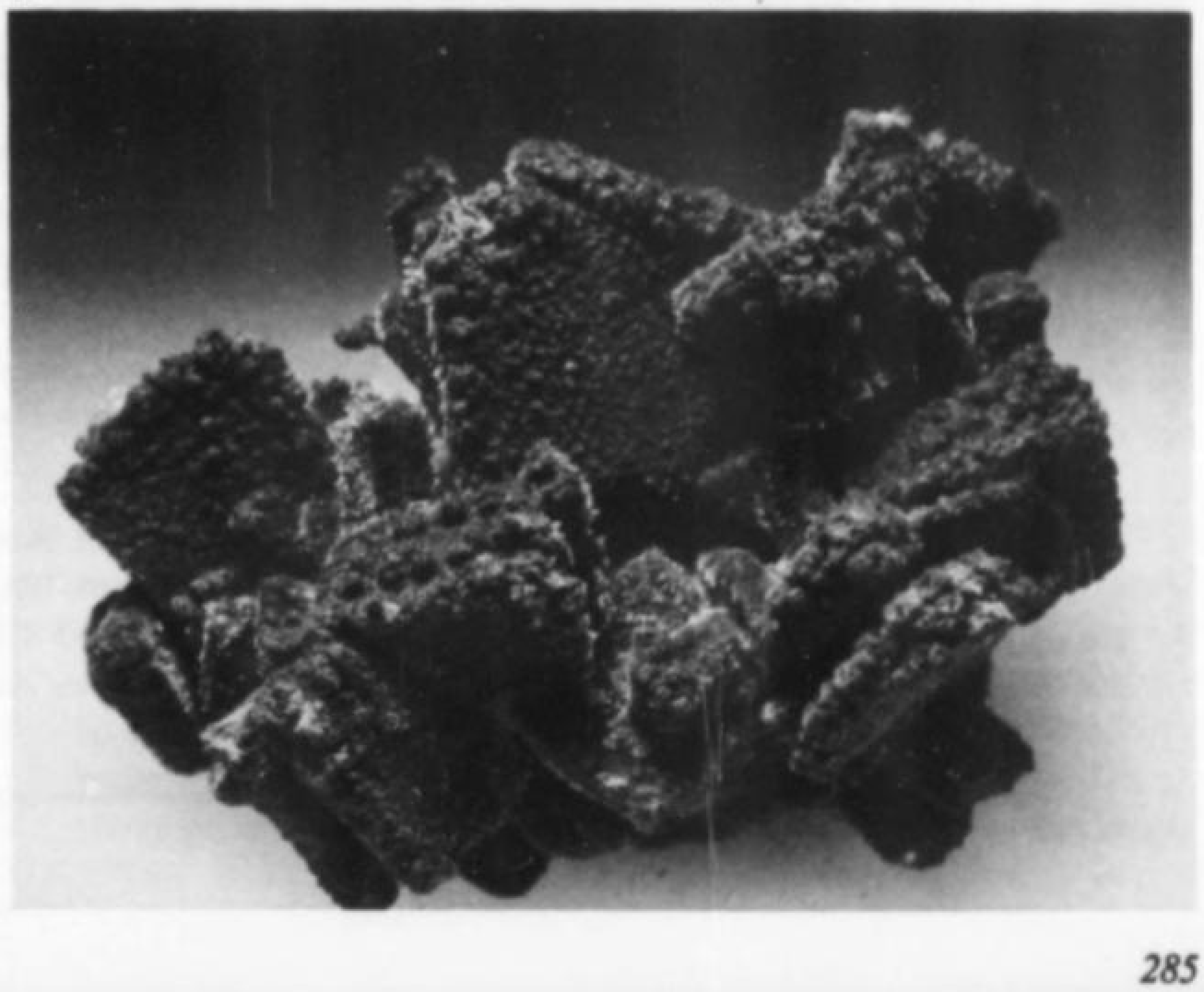


Figure 23. **Brownish red crystals of vanadinite (variety *endlichite*) from Los Lamentos. The largest crystals are about 4 mm. *Western Minerals* specimen.**

Figure 24. **Large, tabular crystals of orange wulfenite coated by a crust of brown vanadinite (variety *endlichite*). Though most of the vanadinite crystals are dull and brown, those deep in the valleys between crystals are transparent, perfectly formed, and a brilliant sherry-red color. The specimen is 6.5 cm across. *Western Minerals* specimen.**



limonite near the surface; elsewhere it is rare.

Gypsum

Gypsum was found as zones of flaky material within the ore and as efflorescences in the caverns. In one cave, long iron-stained filaments of gypsum hung from the ceiling and waved beautifully with every movement of air. Elsewhere it formed colloform masses covering the floor.

Hematite

Hematite is abundant in earthy to fine grained masses, especially at the outcrop which is stained red. Scaly to silky masses occur throughout the mine, becoming black in the lower levels.

Hydrozincite

White, chalky masses and streaked or banded zones occur with earthy red hematite.

Plumbojarosite

Pure masses of plumbojarosite suitable for ore were found in the Erupcion mine. The ocherous brown material possessed a silky sheen.

Pyrite and Sphalerite

A small pocket of unaltered pyrite and sphalerite was discovered on the tunnel level.

Pyromorphite

Minute, poorly formed crystals of green pyromorphite associated with wulfenite have been identified by X-ray and chemical analyses (Miguel Romero, pers. comm.).

Quartz

Clusters of small, light gray to colorless crystals occur with hematite on the surface of calcite crusts.

Sulfur

Small crystals of sulfur were abundant in vugs in anglesite. Otherwise it occurred massive, in pods and zones as large as 4.6 by 2.8 by 2.5 meters (15 by 9 by 8 feet).

Vanadinite (variety *endlichite*)

Vanadinite was once abundant in the lower levels, especially near the water table, in places forming crystalline masses of high purity which were mined as ore. It occurred in fine, large crystals of a raisin-brown to medium brown color. The smaller crystals were well formed, the larger ones cavernous. The larger masses contained vugs lined with brilliant crystals. Vanadinite has replaced wulfenite in some areas, and in other places it forms crusts over wulfenite crystals.

Willemite

Willemite was found as spongy aggregates of small, hexagonal crystals colored chocolate-brown by iron oxides. White tufts and acicular crystals were occasionally found in red hematite masses, and are still found in association with wulfenite (recent X-ray identification reported by Miguel Romero, pers. comm.).

ACKNOWLEDGMENTS

I wish to thank Richard A. Bideaux for several interesting discussions regarding wulfenite localities, in particular for his suggestion about the possible correlation of wulfenite-lead deposits with copper-molybdenum porphyries. Thanks are also due Eugene Schlepp of *Western Minerals,* Tucson, for permitting me to draw on his large stock of fine specimens for examples to photograph, Miguel Romero for information and for making a special trip to the time to take photos, and William Panczner of the Arizona-Sonora Desert Museum for making specimens available.

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Brown's Deposit

Northern Territory, Australia

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Fine specimens of cerussite, malachite and pyromorphite have been recovered from Brown's deposit (also known as Rum Jungle) in Australia's Northern Territory. In addition to specimens, the deposit has also yielded a rare opportunity for mineralogists to study a complete ore deposit of secondary minerals in which large portions have not been removed by previous mining.

INTRODUCTION

Brown's deposit is an unworked copper-lead-zinc orebody located approximately 1 km west of the former Rum Jungle uranium mine, which is 70 km south of Darwin in the Northern Territory of Australia (Lat. 12°59'S, Long. 131°0'E). It is an area of low to moderate relief and has a tropical climate with high monsoonal rainfall in the period from December to March. The deposit is of probable syngenetic origin with some later tectonic and metamorphic remobilization of the sulfides. It lies fairly concordantly within upper Precambrian graphitic slates and limestones belonging to the Batchelor group. These rocks are gently folded and domed around a core formed by the Archaean Rum Jungle granitic complex, and both groups are cut by the massive Giants Reef fault, which, even if it is not genetically related to the metal deposits, may at least be responsible for some of the minor tectonic effects.

The deposit has been known since the beginning of this century but was first surveyed geologically and geophysically by the Bureau of Mineral Resources (Ward, 1953) (Allen, 1951). The current leaseholder, Conzinc Riotinto Australia Ltd., has in recent years extensively drilled the deposit and put down a trial shaft to investigate the extent and nature of the primary ore. It proved to be very fine grained and difficult to treat by standard mineral dressing procedures, which has raised doubts about the economic viability of mining operations. The presence of minor but appreciable cobalt and nickel within the lode has been established.

The principal area of mineralogical interest has been a small oval-shaped pod of oxidized ore along the easterly strike of one of the thinner lodes. It was exposed a few centimeters below the surface by trenches bulldozed to expose the outcrop. Loose blocks of gossanous limonite nearby have been known for many years to contain pyromorphite, and fragments of malachite and cerussite are plentiful in topsoil gravels. Within this zone the orebody is enclosed between the upper surface of the Coomalie dolomite, a coarsely crystallized magnesian limestone, and overlying pyritic and carbonaceous quartzitic siltstones of the Masson formation, which are its principal host.

EXCAVATIONS

Interest in the oxidized mineral content of the deposit was aroused about ten years ago by amateur collectors and mineral dealers, who obtained specimens of massive crystallized malachite and cerussite from shallow depths not exceeding 2 m. Since then, on two occasions in 1973 and 1977, the leaseholders have granted permission for the museum section of the Bureau of Mineral Resources to make mechanized excavations on the site, and have in many ways actively assisted the project. Cooperation was also received from other State Museums, the C.S.I.R.O. and the Northern Territory Geological Survey. The objective each time was to observe the character of the massive secondary mineralization exposed and to preserve collections of representative specimens for research and posterity.

The 1973 excavation exposed the southern margin of a solid mass of cerussite, malachite and pyromorphite 20 m long, 5 m wide and 2 m deep within a pit 4 m deep. No indication was obtained of the depth or thickness of this material or how far it might extend along strike in either direction. The total depth penetrated was only a little more than 4 m and although many fine specimens were collected, the deposit was still little understood.

The 1977 excavation was undertaken jointly by the Bureau of

Figure 1. **The 1977 excavations at Brown's prospect, showing trenches cut down to the water level.**

Figure 2. **Excavations being made at Brown's prospect in 1973.**

Mineral Resources and National Museum of Victoria. It was much larger than the 1973 pit and was designed to expose the full width of the mineralized zone in those sections formerly left covered. The arrangement of the two pits in relation to the orebody is shown in Figure 3. The 1977 excavation was the more successful as it revealed the zone of well-crystallized minerals to be about 55 m long and 20 m wide. The more exceptional specimens were collected at a depth of about 5 m and continued below the groundwater level—5.5 m at the time of excavation. This district of northern Australia receives an annual average rainfall of 150 cm, which in 1977 extended into the dry season causing the groundwater to stand higher than usual for July, and preventing deeper observations, especially the transition into primary ore minerals.

MINERALIZATION

Malachite is the most spectacular mineral collected at the Brown's excavations. It shows classic botryoidal forms, developing sheets and horizontal void fillings up to 8 cm thick. Growth surfaces commonly display a dark green felted matt texture of minute projecting fibers. This initial stage of malachite deposition passes into the more familiar densely packed mass of radial acicular crys-

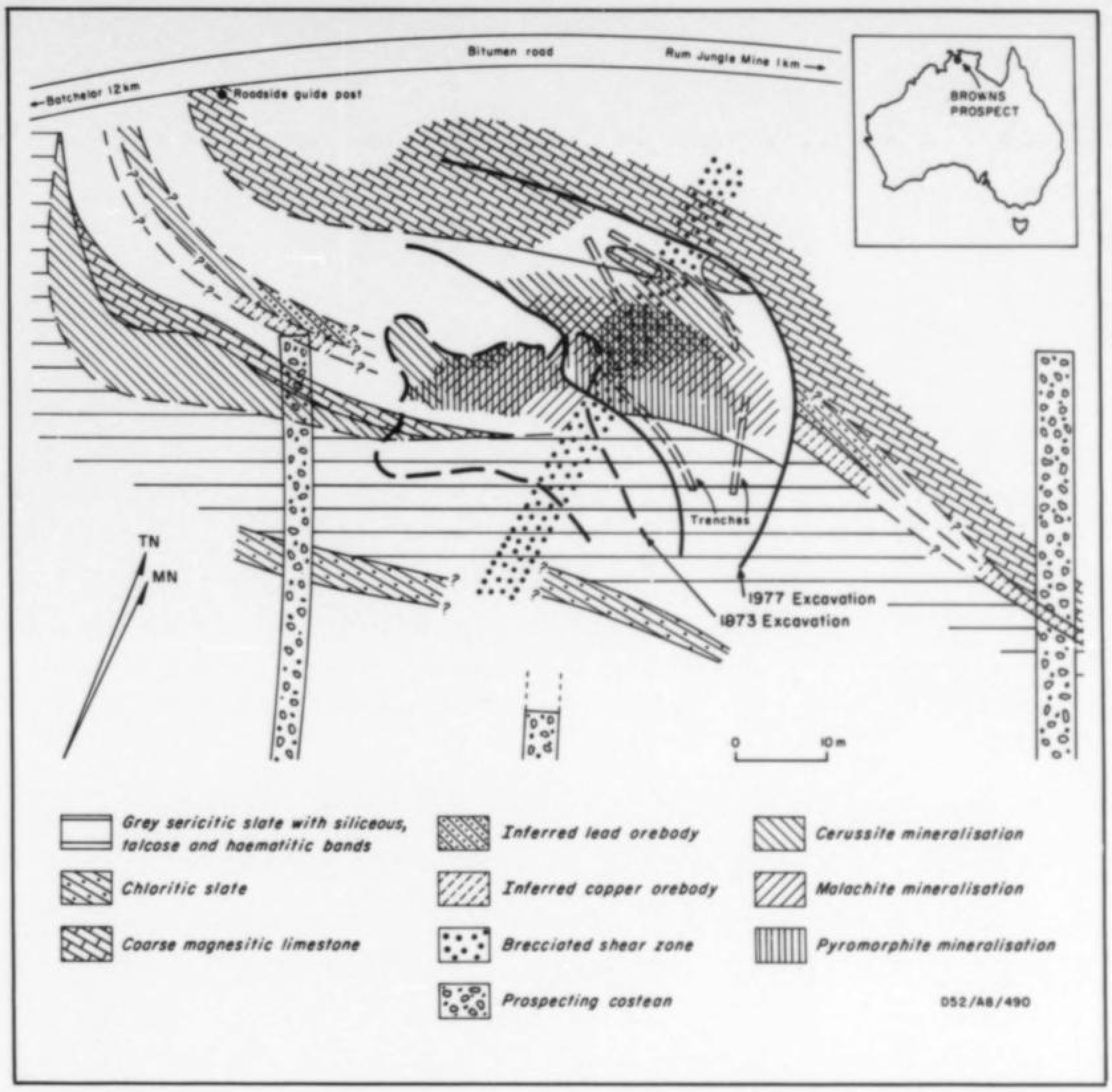

Figure 3. **Geological plan of Brown's prospect showing the locations of the 1973 and 1977 excavations.**

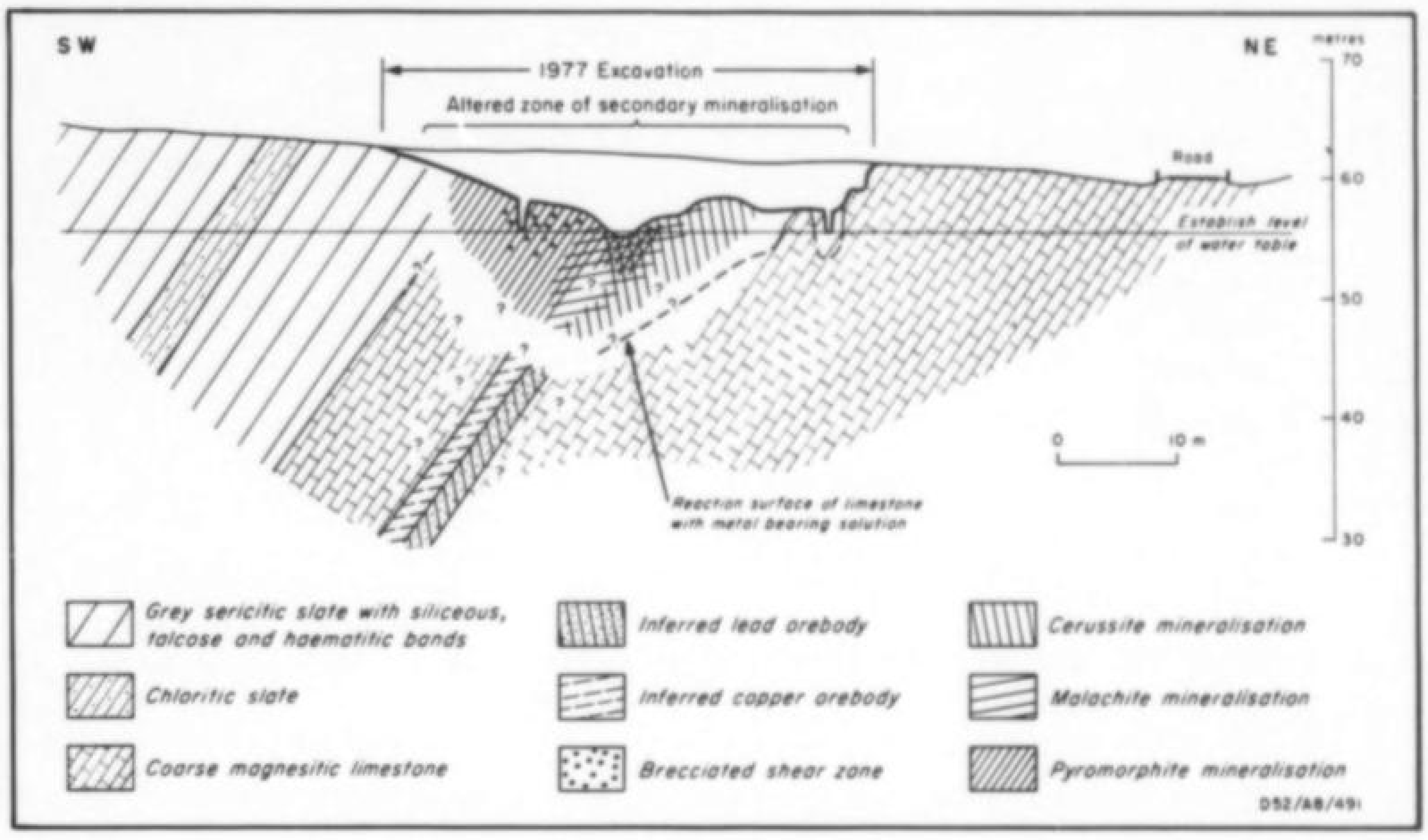

Figure 4. **Diagrammatic cross section showing secondary copper-lead mineralization.**

tals transgressing concentric light and dark green banding.

Some drusy crusts of very dark green, unusually coarse, malachite crystals were found lining brecciation cavities in talcose argillite near the center of the excavation. Various unusual shapes which are typically derived by deposition from water solution were also recovered (e.g. stalactites). Most of the massive malachite is rather coarsely crystallized for lapidary purposes, but is capable of being polished (Fig. 5), and has been used in gems.

Cerussite is present throughout the deposit but is most prevalent on the northern and western sides. Vitreous transparent crystals were common, with short terminated prisms and abundant twinning on (110) producing short stellate structures (Fig. 7), but with only a slight tendency to reticulation. The predominance of short, thick, terminated crystals over the elongate reticulated habit was very obvious. Some quite large masses of cerussite were found in the western end of the 1973 pit. These were up to 0.5 m in diameter and consisted of interlocked masses of coarse vitreous crystals, but were too heavy and friable to stand transportation.

Pyromorphite is concentrated on the southern side of the occurrence and tends to diminish markedly towards the center. Around the northern edge carbonate minerals are predominant in the vicinity of the limestone. Much of the pyromorphite has the form of thin crusts over malachite or cerussite, but within the southern portion of the brecciated zone larger crystals have formed. The color varies from brown, through sulfur-yellow to greenish, and crystals are commonly simple hexagonal prisms. In some instances the crystals show a tendency to a barrel shape, which more rarely takes on the extreme curvature of the *campylite* variety. Analysis of these specimens, however, showed negligible arsenate, so that the species is still correctly called pyromorphite.

Minor species identified were flat tabular crystals of wulfenite up to 3 mm diameter (Fig. 9) which were found very near the ground surface with malachite-cerussite vugs, and pale blue encrustations of chrysocolla coating malachite and cerussite.

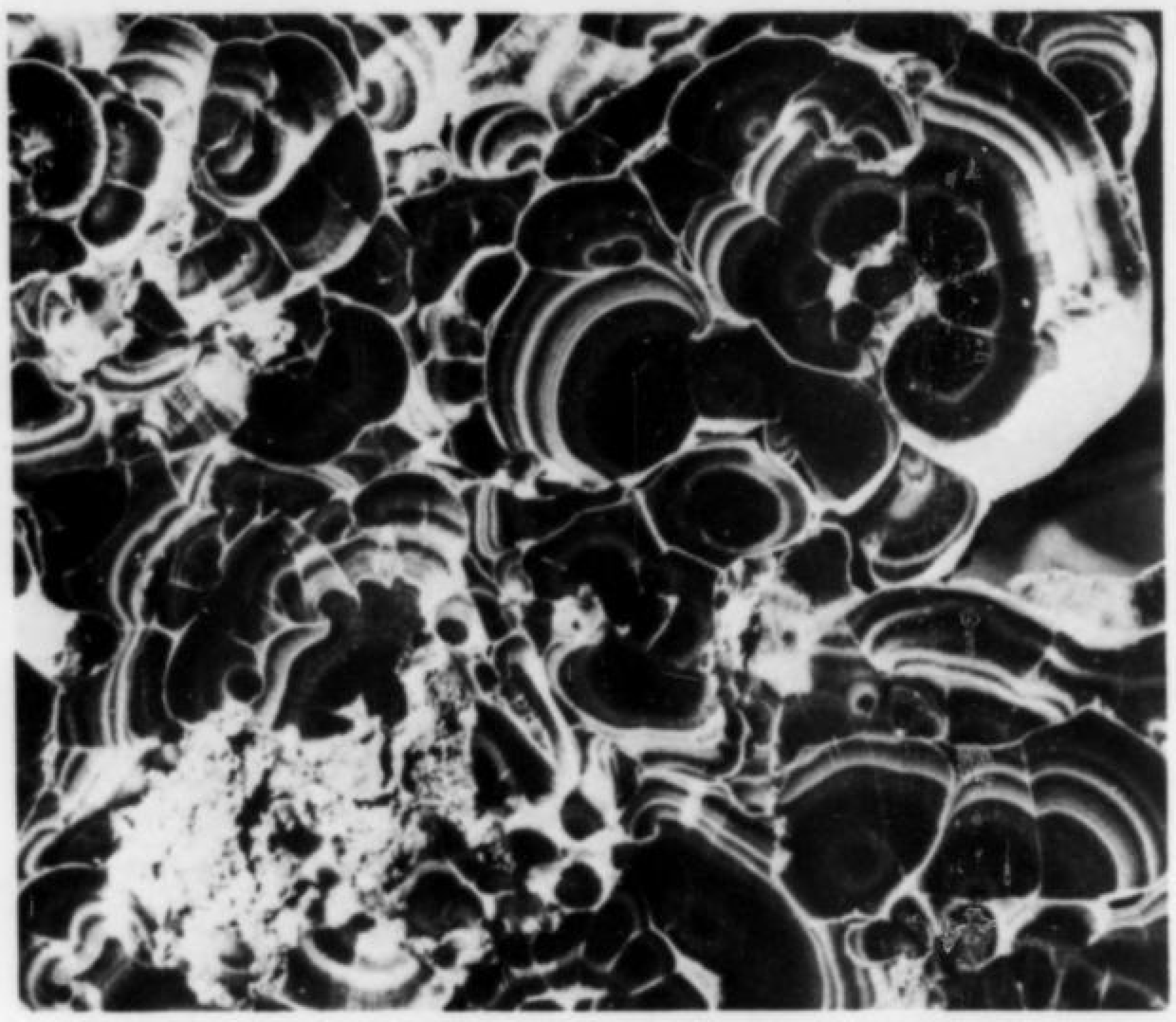

Figure 5. **Sawn and polished botryoidal malachite from Brown's prospect.**

Specimens from Brown's deposit reached the American mineral market at the 1977 Detroit Show (Wilson, 1978).

MINERAL GENESIS

Two principal factors are believed to have influenced the formation of this restricted but exceptionally rich pod of secondary minerals. Firstly, crystallization has virtually been enforced by the localized envelopment of the lode within the carbonate part of the host rock, which does not occur anywhere else in the deposit. Secondly, the transverse zone of brecciation provides a permeable zone allowing percolation of surface water, which in this region of high rainfall creates an environment favorable for the mobility of metal ions and their consequent reaction with the carbonate.

The formation of malachite to the total exclusion of azurite is a striking feature of Brown's deposit which does not occur at either copper occurrences in the district. The relationship between these two minerals can be expressed by the following equation:

$$\underset{\text{Malachite}}{3Cu_2(CO_3)(OH)_2} + CO_3^{2-} \rightleftharpoons \underset{\text{Azurite}}{2Cu_3(CO_3)_2(OH)_2} + 2OH^-$$

Consequently the development of malachite is favored in the presence of a wet alkaline environment which would be maintained by the high rainfall and dolomitic limestone host. This evidently suppresses the contrary effect of the high local activity of carbonate.

The malachite is being formed very rapidly and continuously at Brown's deposit and small tufts of fibers were found in the 1977 ex-

Figure 6. **A colorless cerussite crystal on lustrous, dark green malachite from Brown's prospect.**

Figure 7. **Colorless cerussite twin on yellow pyromorphite from Brown's prospect.**

Figure 8. **Colorless cerussite and yellow pyromorphite on dark green malachite from Brown's prospect.**

Figure 9. **Yellow-orange wulfenite crystal on cerussite from Brown's prospect.**

cavation, growing on fragments of cardboard buried in the 1973 excavation.

The form of the cerussite crystals is also quite rare, being peculiar to formation of the mineral in areas of high carbonate activity. The Tsumeb mine, Southwest Africa, material is of similar habit and is formed within a similarly carbonate-rich host rock, while by contrast the finer elongated and reticulated cerussites typical of Broken Hill, Australia, and Tiger, Arizona, come from lithologies which are carbonate-poor by comparison. Consequently it appears the development of cerussite crystals along the [100] axis (the length of the prism) is favored by high lead to carbonate ratios, but the converse condition favors growth along the other axes and formation of the {110} prism faces which terminate the length.

The absence of secondary zinc minerals, or those of nickel and cobalt, is attributed to their greater solubility in the intensely leaching conditions. The strong north-south zoning of the pyromorphite is an indication of the source rocks contributing the carbonate and phosphate which lie on opposite sides of the lode.

One remaining question which was not answered by the excavations concerns the possibility that a zone of secondary sulfide enrichment might be very slight or even nonexistent between the oxidized ores and the primary sulfides recovered from drillholes. It seems possible that in this environment of permanently shallow groundwater and rapid precipitation of metal carbonates, only the oxidized near-surface accumulation may exist. The metal ions would be fixed as carbonates very quickly and may not have had opportunity for the upward and downward transportations and oxidation-reduction reactions which normally produce secondary enrichments.

CONCLUSION

Brown's deposit has provided a unique opportunity to unearth an extremely rich pod of oxidized copper-lead mineralization in what was virtually undisturbed condition. All too often such deposits were destroyed by mining operations during the last century, giving no opportunity for modern mineralogists to study them *in situ*, or to see the central richest portion of the lode where chemical deposition was most active. This has been the first occasion when Australian mineralogists have been able to participate in the excavation of a metalliferous orebody solely for research and museum purposes, and it is pleasing that it should have produced such striking crystallized specimens.

ACKNOWLEDGMENTS

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People at Batchelor Township gave much hospitality to visitors who came for the excavation, and of these special thanks are due to Harry and Gwen de Sachau.

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Rare Chromates

from Seh-Changi, Iran

by **Pierre Bariand** and **J. F. Poullen**
Laboratoire de Mineralogie et Cristallographie
Universite Pierre et Marie Curie, tour 16–26
4, place Jussieu, 75230 Paris, France

Phoenicochroite, fornacite, iranite and hemihedrite, all rare chromates of lead, zinc and copper, occur in association with cerussite, phosgenite, wulfenite, mimetite, diaboleite, willemite, hemimorphite, hydrocerussite, beta-duftite, massicot and chrysocolla in the Seh-Changi lead-zinc-copper deposit in eastern Iran.

LOCATION

The Seh-Changi deposit is situated in one of the least-known regions of Iran, the southern part of Khorassan near the far eastern border with Afghanistan. The region is completely desert with very moderate relief (the Lut Desert). The area is reached by desert tracks 207 km southeast of Tabas, near the settlements of Nayband and Dehuk, which lie at 55 and 90 km respectively from the mine workings.

DESCRIPTION OF THE MINERALIZED REGION

The mineralized formations near Darmian, Qolleha and Shurab to the east of Birjand are associated with essentially clastic sediments of Mesozoic age having little economic importance, but the metalliferous deposits worked in the district of Seh-Changi and Hauz-e-Rais to the west are in a thick, Eocene, volcanosedimentary series of economic interest.

This series, which is as much as 3000 m thick, has been studied in detail by Stöcklin *et al.* (1965) in the eastern part of the Shotori mountain range. It is representative of the formation generally recognized in the Lut Block, consisting of a succession of basaltic, andesitic, and dacitic tuffs (with fragments of quartz, biotite, plagioclase and iron oxides) between which are interstratified some red sandstones considered to be continental by Stöcklin. The beds are horizontal or subhorizontal, a characteristic that distinguishes this region from those in other parts of eastern Iran where the same Eocene volcanosedimentary facies are present. This whole succession follows innumerable mafic volcanic flows (complex ophiolites with radiolarite) of the Cretaceous "colored melange" in which the Iranian chromium deposits occur.

The formation containing the primary sulfide mineralization seems associated with post-volcanic activity and is controlled by the northwest-southeast fractures, along which are aligned most of the exploitation pits of the mine. According to Stöcklin, the tectonic movements have continued during the deposition of the sulfides, as evidenced by fragments of sulfides which can be seen rolled in the mineralized volcanic breccia at the contact of the principal fault. This breccia is the principal element of the major subvertical vein which cuts the series; it has a thickness varying from 0.2 to 5 m (Burnol, 1968). The mineralization cements fragments of the enclosing rock, which is brecciated and bleached by hydrothermal alteration. These veins were the object of important workings in the past which have been deepened in pits that reach the watertable (at a depth of 40 m). Workings have more recently been reopened on the principal vein and later on others. The ores consist mainly of galena and sphalerite, in veins and crystallized seams, but also of chalcopyrite, bornite, pyrite and minerals of the tennantite-tetrahedrite series.

However, it is noted that the abundance of copper varies widely from one pit to another. Pyrite, chalcopyrite and tetrahedrite-tennantite (rare) are dispersed as inclusions in the other sulfides. Bornite and chalcocite are associated with crystals of chalcopyrite; sulfides become progressively more important below the 40-m level (Burnol); the gangue is composed of late quartz and calcite. According to Burnol, the emplacement of the hypogene mineralization corresponds to a single phase of deposition with a normal order of succession.

The oxidation zone in a desert regime, which especially interests us here, is developed above 40 m. It includes many secondary minerals. All the crystals are small, their dimensions rarely exceeding 2 mm. Besides the chromates (iranite-hemihedrite, fornacite, phoenicochroite) are found cerussite, phosgenite in small transparent crystals, hydrocerussite in the form of yellow powder, wulfenite and mimetite in colors varying from yellow to bright red, diaboleite in blue plates 1 to 2 mm long, and willemite in doubly terminated transparent prisms. The crystals of hemimorphite and descloizite from this deposit are also of small size. Coatings of beta-duftite, massicot and chrysocolla are fairly common.

In an arid climate it is commonly accepted that the direction of

Figure 1. **The Seh-Changi mine in 1969.**

Figure 2. **Locations of the principal Iranian chromate deposits.**

the percolating solutions, which determines the formation of the oxides at the expense of the primary sulfides, is from the bottom up; that is to say from the top of the watertable up to the topographic surface in connection with the intense evaporation in these regions. The repercussions of this are important to the environment of formation and its evolution, and also to the movement of diverse elements.

MINERALS OF THE OXIDATION ZONE

The chromates of lead are the most remarkable minerals of the Seh-Changi deposit, although the first Iranian chromates (iranite, phoenicochroite, fornacite) were discovered in 1960 on the dumps of the small abandoned mine of Sebarz, situated in the Anarak region. They are associated with cerussite, atacamite, diaboleite, chrysocolla and dioptase. In 1970, hemihedrite, another chromate of lead discovered in Arizona, was described by S. A. Williams and J. W. Anthony. In 1972, Adib, Ottemann and Nubar published on two other chromates of the Anarak region (Chah-Khuni mine): "khuniite" and "chrominium." "Chrominium" was very soon realized to be identical to phoenicochroite, and an examination of the original specimens of iranite and of "khuniite" later revealed that these two names designated the same species. We had earlier (1963) discovered another occurrence of iranite at the Seh-Changi mine (region of Nayband). On the other hand, several visits to the Sebarz mine in 1961 and 1963 did not permit us to find in place the chromates found in 1960 on the dumps. More recently, in 1973, we rediscovered in the underground workings of the Chah-Khuni mine the chromates described by Adib *et al.* (1972). In comparing these specimens to those from Sebarz, we have come to the conclusion that the specimens of iranite and phoenicochroite discovered in Sebarz came from Chah-Khuni. It is well known that many ores originating from other mines were treated and stocked at Sebarz about 50 years ago. Long discussions with old miners in the region have confirmed that this was frequently the case. It was the same at Bagherog, where the ores of Talmessi were smelted before the installation of the foundry there.

***Figure 3.* Iranite crystals, dark brown in color, measuring about 0.1 mm in size, from the Seh-Changi mine.**

Iranite-hemihedrite series chromates are exceptionally abundant at Seh-Changi and are, in general, associated with wulfenite, mimetite and fornacite, with which they form very attractive specimens. The small crystals (rarely over a millimeter) occur in two rather different forms: (1) simple prisms terminated by several faces, and (2) more isometric crystals often doubly terminated, where the extension of various faces from one specimen to another renders the orientation difficult.

The color goes from brown to orange, the powder is saffron-yellow. The mineral crystallizes in the hemihedral class of the triclinic system; in using the orientation proposed by S. A. Williams for hemihedrite, we obtain the following parameters: $a = 9.57$ Å, $b = 11.42$ Å, $c = 10.84$ Å, $\alpha = 120^\circ 23'$, $\beta = 92^\circ 27'$, $\gamma = 56^\circ 06'$, very close to those found by that author for crystals from the Florence mine, which are: $a = 9.50$ Å, $b = 11.44$ Å, $c = 10.84$ Å, $\alpha = 120^\circ 30'$, $\beta = 92^\circ 06'$, $\gamma = 55^\circ 50'$. Bariand and Herpin (1963)

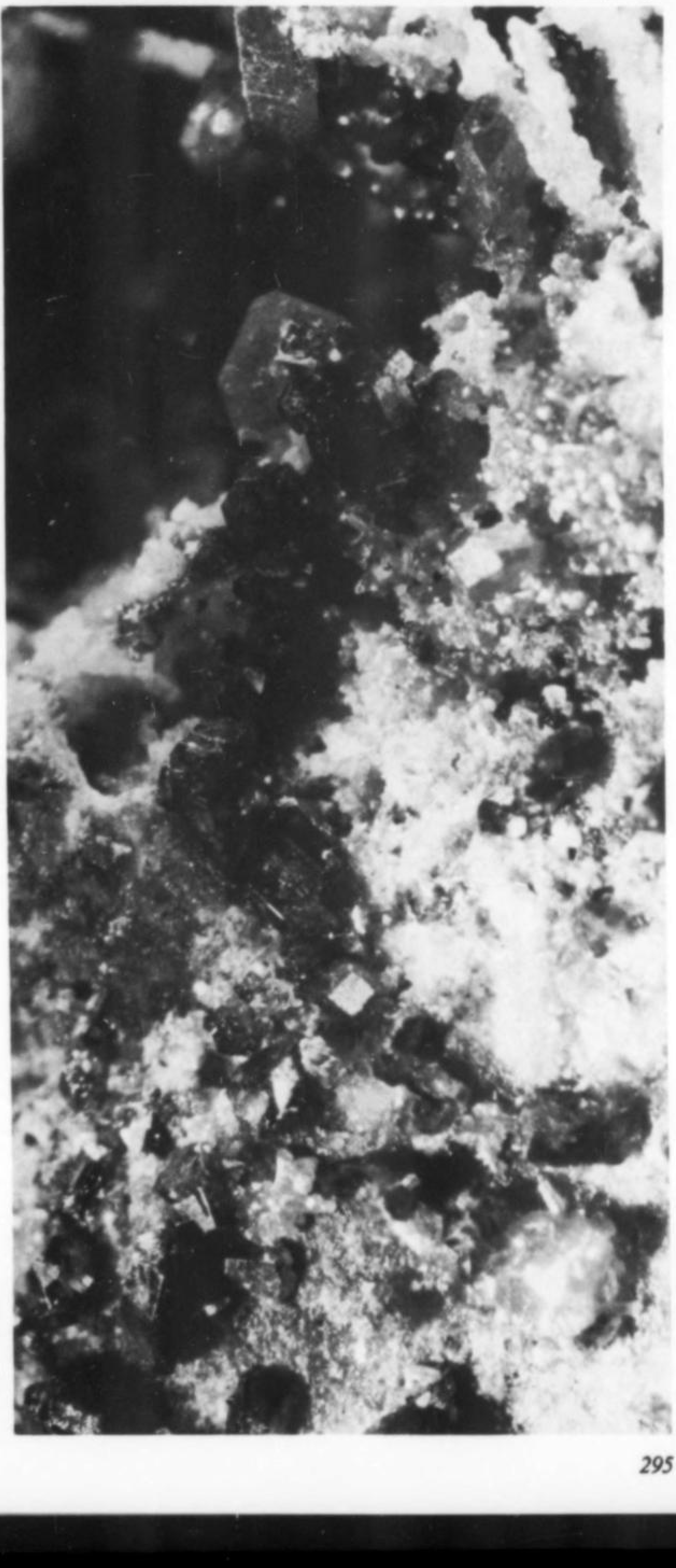

***Figure 4.* Dark iranite crystals to 0.1 mm, with larger red wulfenite crystals and extremely small, yellow mimetite crystals on matrix, from the Seh-Changi mine. (Photos by Nelly Bariand.)**

have proposed a different orientation for iranite from Chah-Khuni, difficult to use since the axes chosen by these authors to define the morphological cell are different from those used to define the X-ray orientation, and the change to the Williams cell gives differences of several degrees, especially in the α angle. In reality, the variations of parameters between hemihedrite and iranite are very small. These two species have the general formula:

$$(Zn,Cu)Pb_{10}(CrO_4)_6(SiO_4)_2(OH,F)_2$$

Hemihedrite and iranite form a continuous series varying in the ratio Zn:Cu; type hemihedrite from the Florence mine corresponds to the simplified formula: $ZnPb_{10}(CrO_4)_6(SiO_4)_2(OH,F)_2$, and type iranite from Chah-Khuni to: $CuPb_{10}(CrO_4)_6(SiO_4)_2(OH,F)_2$. Study of the relative content in CuO and ZnO in the crystals from Seh-Changi leads to the conclusion that these crystals are, in reality, hemihedrite or iranite:

	iranite (theor.)	**SC 1**	**SC 2**	**SC 3**	**SC 4**	**hemihedrite** (theor.)
CuO	2.65	1.85	1.52	1.31	0.55	—
ZnO	—	0.58	0.85	1.27	1.35	2.66

These crystals are frequently twinned on $(12\bar{1})$ (Williams indexing). Willians, McLean and Anthony (1970) have shown the structural analogy between hemihedrite and a series of isostructural monoclinic minerals: tsumebite, brackebuschite and fornacite. It is concluded that the $(12\bar{1})$ plane of the triclinic cell is transformed to the (010) plane of the monoclinic lattice, which is a plane of pseudosymmetry and hence a twinning plane for hemihedrite and iranite.

Fornacite, $Pb_2Cu(AsO_4)(CrO_4)OH$, is also common at Seh-Changi, and forms small sprays of olive-green crystals sometimes arranged directly on cupriferous hemihedrite. The faces are corroded and do not permit measurement on the goniometer. The parameters that we have observed on the diffraction photos are identical to those obtained by previous authors on fornacite from other deposits. The structure is very close to that of hemihedrite, but is monoclinic and hence the twin (010) does not appear.

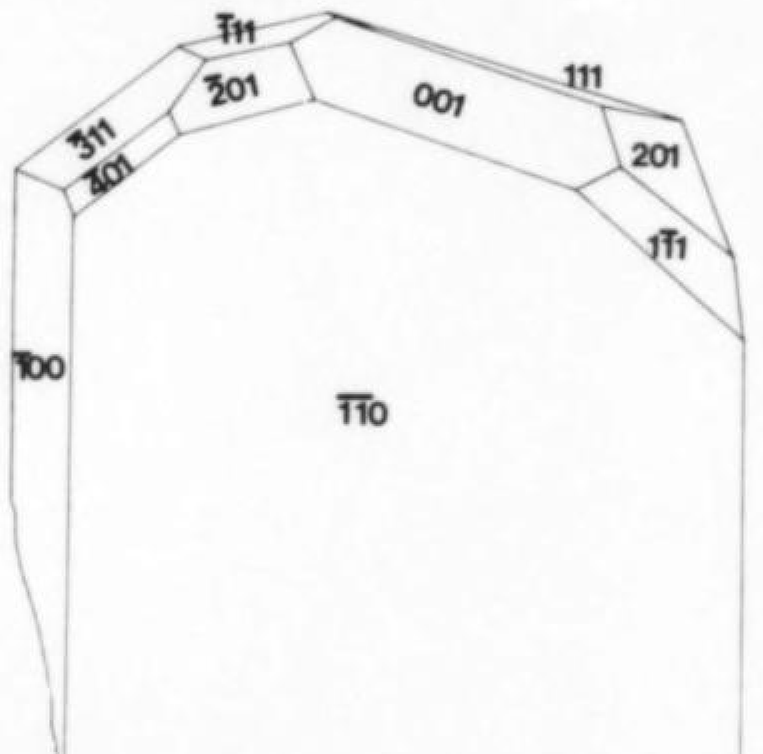

Figure 5. **Morphology of phoenicochroite from the Seh-Changi mine.**

Phoenicochroite, $Pb_2O(CrO_4)$, is the rarest chromate at the deposit. The crystals, isolated and very small, are of bright red color with the yellow streak characteristic of chromates. These are, in general, prisms elongated on [001] and flattened on {110}. Electron microprobe analyses have shown that part of the chromium was replaced by sulfur. Phoenicochroite has therefore the same structure as lanarkite, $Pb_2O(SO_4)$, but the large difference of ionic radius between sulfur and chromium makes it difficult to fit the sulfur into tetrahedral positions in the structure of phoenicochroite: there is only about 1 percent SO_3 in phoenicochroite from Seh-Changi.

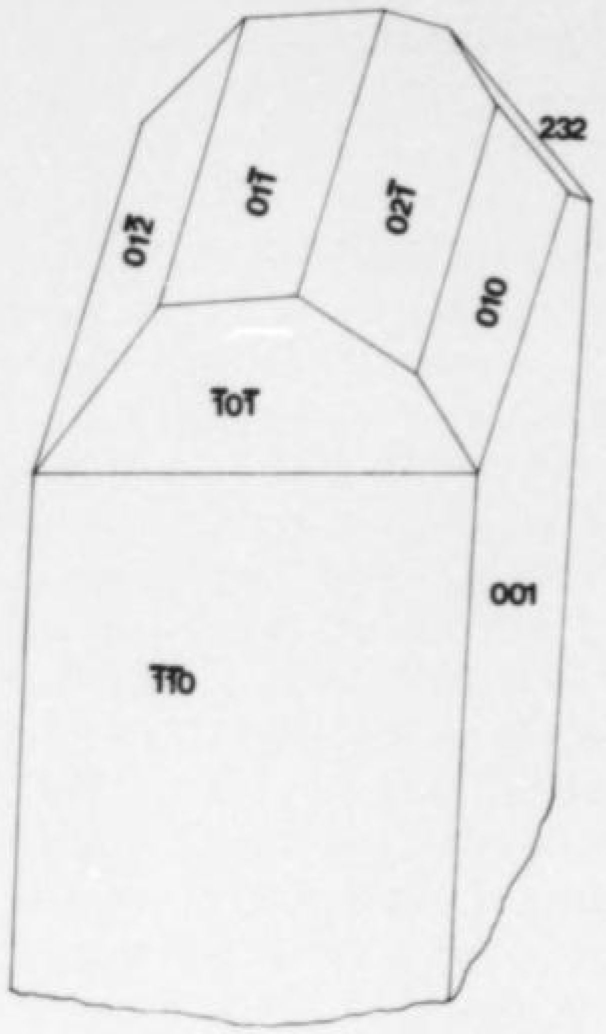

Figure 6. **Morphology of cupriferous hemihedrite (X-ray oriented) from the Seh-Changi mine.**

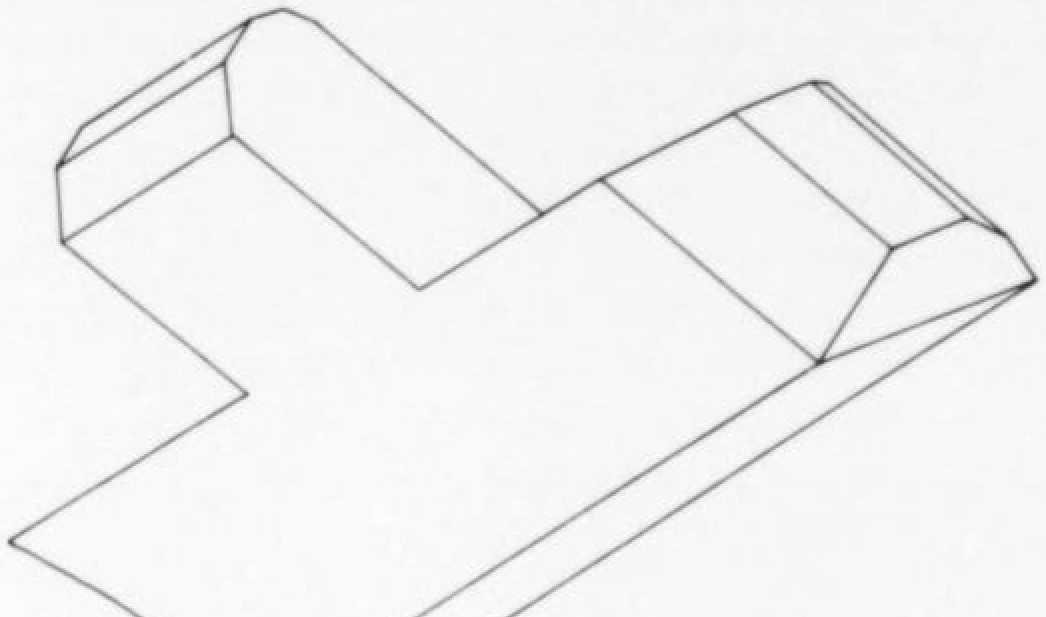

Figure 7. **Morphology of a twinned crystal of cupriferous hemihedrite from the Seh-Changi mine.**

GENESIS OF THE CHROMATES OF SEH-CHANGI

The succession of the chromates in time, deduced from observation of specimens, seems to be: phoenicochroite → cupriferous hemihedrite → fornacite. Phoenicochroite is practically never associated directly with the other two chromates. It is probable that the rather low Eh and the neutral to slightly basic pH have favored the precipitation of hemihedrite and fornacite, but the almost constant presence of wulfenite crystals with acute bipyramids {111} next to the phoenicochroite suggests that the phoenicochroite had a very different environment of growth (following the reasoning of Williams, 1966). This chromate usually forms under basic pH, but its limits of stability, in relation to other chromates of the deposit, depend mainly on the concentration of copper and zinc with respect to lead in the solutions.

The morphology of wulfenite crystals depends more on the content of other substituted elements than on the physicochemical conditions. Thus, the first wulfenite that formed, before or contemporaneous with the chromates, is orange, with very flat form due to the extension of the {001} faces, and contains very little chromium in substitution for molybdenum. With the increase in the content of

CrO_3 incorporated in the lattice, the {001} form tends to disappear and to be replaced with bipyramids. This phenomenon is also observed in synthetic wulfenite with increasing concentrations of chromium. The content of substituted chromium can exceed 10 percent CrO_3. It is interesting to note that the bipyramidal red wulfenite which is richer in chromium has crystallized after the chromates: these maximum values correspond without doubt to the time when the chromium was still abundant in the solutions, but not in quantities sufficient to favor the precipitation of independent chromates.

It is quite unusual to have free chromium during oxidation and also to find it in independent mineral phases (i.e. chromates) or in substitution in other minerals (e.g. wulfenite, mimetite), since the change of chromium from the trivalent to the hexavalent state happens only under well defined conditions. But it must also be present in the rock which is undergoing oxidation. This element can come either from small amounts in the hypogene sulfides or from the surrounding rock.

Williams and Anthony (1970) found 0.14 percent CrO_3, measured by X-ray fluorescence, in a specimen of altered diabase from the Florence mine. But no ultrabasic rocks were noted at Seh-Changi, and the primary sulfides don't have chromium. The origin of the element must then be sought in the volcanic breccias or in the interstratified sandstones. The presence of chromium in such sediments would not be surprising since deposition followed the Cretaceous which, in Iran, was a period when important chromium deposits were formed.

ACCESS

The mine, difficult of access, has been abandoned since 1973. The possibility of lodging there is nonexistent. Because of the chaotic political situation in Iran and Afghanistan it would prove a great optimism to hope to do collecting or research in these regions.

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MINERALS
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Nealite
a new mineral from Laurion, Greece

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ABSTRACT

Nealite, $Pb_4Fe(AsO_4)_2Cl_4$, is a new mineral found in the slags of Laurion, Attike, Greece. It forms prismatic or bladed crystals in radial or parallel growth and is associated with aragonite, annabergite and georgiadesite on the two known specimens. Nealite is triclinic, space group $P1$ or $P\bar{1}$, with $a = 6.537(7)$, $b = 10.239(7)$, $c = 5.582(5)$ Å; $\alpha = 96.20(5)°$, $\beta = 89.39(10)°$, $\gamma = 97.74(7)°$, $V = 368.1(5)$ Å^3 and $Z = 1$. The strongest lines in the X-ray powder diffraction pattern are: 3.542 (10) 021, $1\bar{2}1$; 6.480 (8) 100; 4.237 (7) $\bar{1}20$, $\bar{1}01$, 101; 10.09 (6) 010; 3.247 (6) $\bar{1}21$, 200; 2.783 (6) 201, 002. Electron microprobe analysis yielded FeO = 4.8, ZnO = 0.6, PbO = 68.8, Cl = 10.3, As_2O_5 = 17.3, less O = Cl = 2.3, sum = 99.5 percent. Nealite is bright orange with a light orange streak, has adamantine luster, no cleavage and is very brittle. The calculated density is 5.88 g/cm^3. Refractive indices all exceed 2.00. The name is in honor of the late Leo Neal Yedlin.

INTRODUCTION

About five years ago, the late Neal Yedlin of New Haven, Connecticut, brought to the attention of the senior author a bright orange mineral from Laurion, Attike, Greece. There was but one crystal, which Mr. Yedlin willingly sacrificed so that he might know what he *had* rather than keep an unknown mineral in his micromount collection. The unknown was found to possess a unique but unidentifiable powder diffraction pattern, but the crystal was inadvertently lost during preparation for other investigative procedures. It was this unfortunate incident which prompted Mr. Yedlin to comment about what he jokingly referred to as a horrible situation, to wit: "To consume your only specimen and *not* know what you *had*," (Yedlin, 1974). Subsequent to this incident, Mr. Yedlin found one more specimen of the orange unknown and, notwithstanding his prior experience, he brought it to the Smithsonian for further study. Within months, yet another specimen was obtained from Curt Segeler, of New York City, and the present study was initiated.

This unknown orange mineral from Laurion, Greece, is now a valid new mineral species, a triclinic lead iron arsenate chloride. We take great pleasure in naming this new species *nealite* in honor of Leo Neal Yedlin (1908–1977). His contributions to mineralogy were truly broad in scope and impact; he would gladly sacrifice part or all of any specimen which was needed for scientific study. The breadth of Yedlin's contributions and perspectives on his personality have been presented by Bentley *et al.* (1979) and need not be repeated here. We are pleased to name for Neal Yedlin a species he discovered and it is also interesting to note that the other species which bears his name, yedlinite (McLean *et al.*, 1974), was also found by him.

The new species and the name were approved by the I.M.A. Commission on New Minerals and Mineral Names, prior to publication. Type material is preserved in the Smithsonian Institution under catalog #137115. The name is pronounced nēl•īt.

DESCRIPTION

Nealite crystals are prismatic to bladed in habit and occur in clusters, which are either radially divergent or exhibit parallel growth. The crystals are too small for goniometric measurement or precise assignment of Miller indices to all of the forms. On the type specimen, nealite crystals occur in a radial group (Fig. 1) of bladed crystals which are tabular on {010}, and elongated and striated parallel to [001]. On the specimen obtained from Mr. Segeler, nealite occurs as stout to elongated prismatic crystals, both isolated and in parallel growth (Figs. 2 and 3). The associated minerals are aragonite, annabergite, georgiadesite, goethite and some lead oxychlorides of unknown identity.

The extreme paucity of nealite and the very small crystal size precluded the determination of some optical and physical properties. Nealite is bright orange in color with a light orange streak, and an adamantine luster. No cleavage was observed. The hardness could not be measured due to the extremely small crystal size. The mineral is very brittle. The observed density is greater than 4.27 g/cm^3; the calculated density is 5.88 g/cm^3. Optically, nealite has refractive indices greater than 2.00, is non-pleochroic, and is length-slow parallel to the long dimension of the crystals. The orientation of the indicatrix could not be determined. Nealite does not respond to ultraviolet radiation.

CHEMISTRY

Nealite was chemically analyzed using an ARL-SEMQ electron microprobe, utilizing an operating voltage of 15 kV and a beam current of 0.15 μA. The standards used for analysis were PbO for lead, synthetic ZnO for zinc, synthetic olivenite for arsenic, NaCl for chlorine, and hornblende for iron. The data were corrected using a modified version of the *MAGIC-4* computer program. A wavelength-dispersive microprobe scan indicated the absence of any elements with atomic number greater than nine, except those reported herein. The paucity of material precluded a spectrographic analysis, but no light elements are common in the geochemical environment of nealite.

Our initial attempts at analysis were frustrated by the presence of other, as yet unidentified, lead oxy-chloride compounds in intimate intergrowth with nealite. Hence, to ensure reliability of the data, we analyzed the very crystal used for the single-crystal studies. It was analyzed unpolished, on a flat face, and the resultant analysis is presented as Table 1, together with the theoretical composition.

Figure 1. **Scanning electron micrograph of a sub-parallel group of bladed nealite crystals from the type specimen. Small spherules on the face of the crystals are glue inadvertently spilled on the crystals during mounting. NMNH 137115 (280x).**

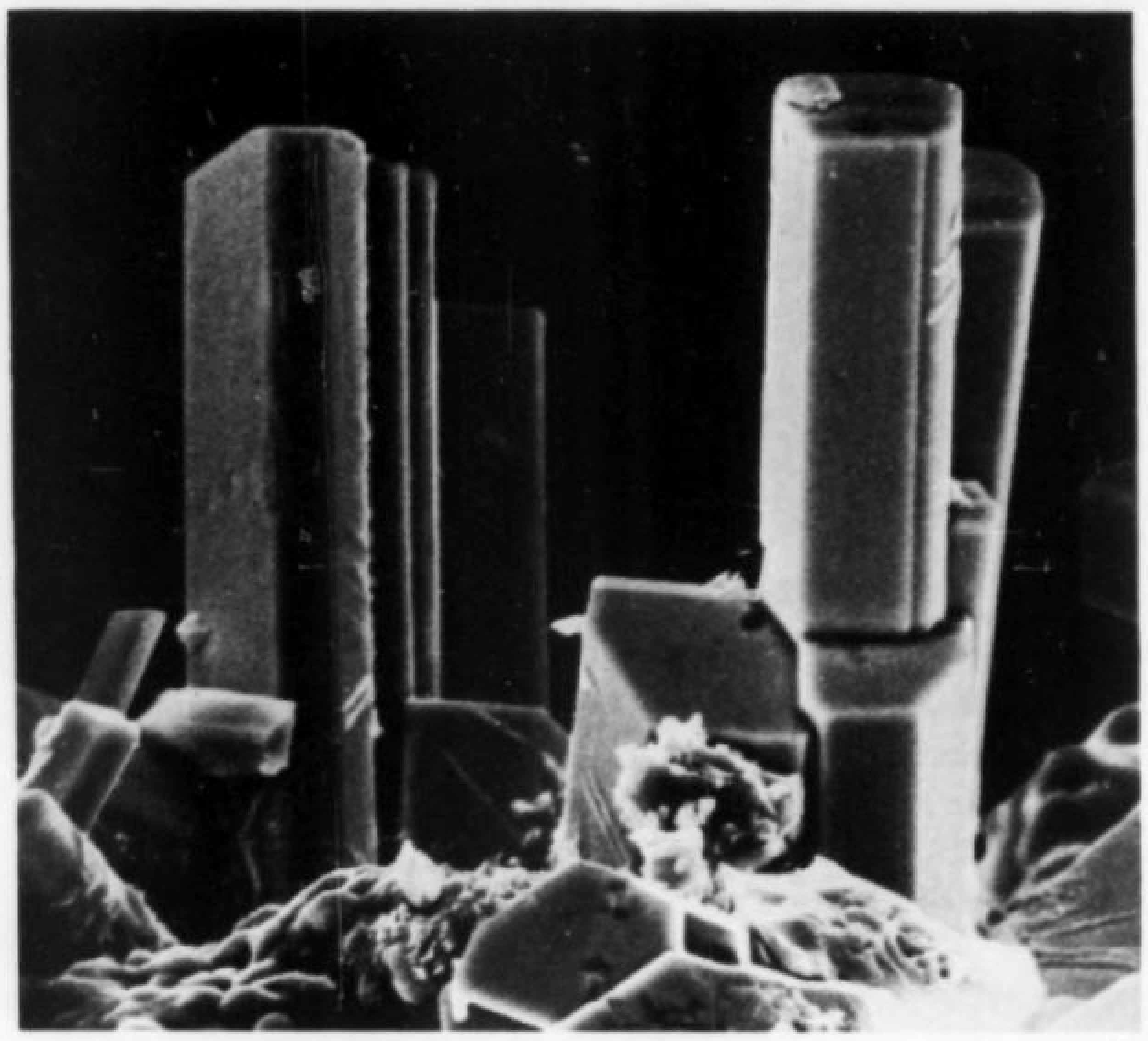

Figure 2. **Scanning electron micrograph of crystals of nealite from the Segeler specimen (1190x).**

Iron was determined as ferrous by microchemical test. Assuming two arsenic atoms per unit cell, the analysis yields the formula $Pb_{4.10}(Fe^{2+}_{0.89}Zn_{0.10})_{\Sigma 0.99}As_2O_{8.16}Cl_{3.86}$, in excellent agreement with the proposed formula, $Pb_4Fe(AsO_4)_2Cl_4$ with Z = 1. Nealite is slowly soluble in cold 1:1 hydrochloric acid.

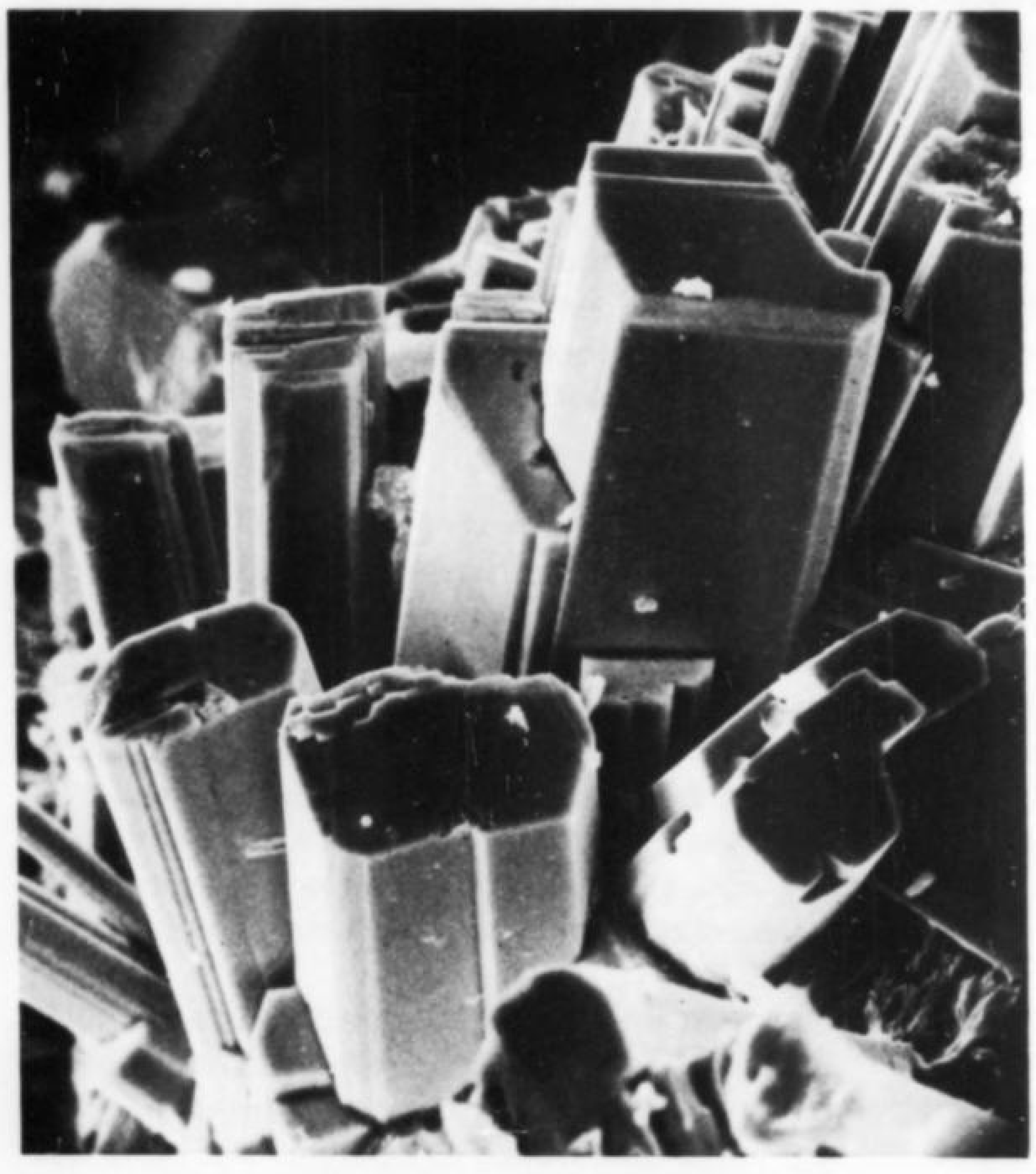

Figure 3. **Divergent spray of nealite crystals similar to those shown in Figure 2. (980x).**

Table 1. **Microprobe analysis of nealite.**

	$FePb_4(AsO_4)_2Cl_4$	NEALITE
FeO*	5.51	4.8
ZnO	----	0.6
PbO	68.45	68.8
Cl	10.87	10.3
As_2O_5	17.62	17.3
Total	102.45	101.8
O = Cl	2.45	2.3
Total	100.00	99.5

Accuracy of data: 4 percent of the amount present.

* Iron determined as total iron and calculated as ferrous on the basis of microchemical test.

CRYSTALLOGRAPHY

Only one crystal of nealite was of sufficient size and quality to be utilized for single-crystal X-ray study. This crystal was examined by the precession, Weissenberg, and rotating crystal methods and found to be triclinic, $P1$ or $P\bar{1}$, with $a = 6.537(7)$, $b = 10.239(7)$, $c = 5.582(5)$ Å, $\alpha = 96.20(5)°$, $\beta = 89.39(10)°$, and $\gamma = 97.74(7)°$. The unit cell has a volume of 368.1(5) Å^3 and contains one formula weight. The crystal was twinned by two-fold rotation around [001]. Cell parameters were refined by least-squares using thirteen reflections from a Gandolfi photograph. The latter was obtained using a powdered sample, CuKα radiation, and an NBS silicon (a = 5.43008 Å) internal standard. Indexing was accomplished with the aid of single-crystal photographs. Powder diffraction data for nealite are presented in Table 2.

OCCURRENCE

Nealite is found as microscopic crystals lining cavities in slags from Laurion, Attike, Greece. The Laurion mines were worked as early as 600 B.C. by the Athenians and later by a French zinc-mining company. The extraction of lead and silver by the smelting processes of the early Greeks was not efficient and some of these metals remained in the slag, which was dumped into the sea. The sea water reacted with the slags to produce the rare and exotic minerals for which Laurion is now justly famous. Included in this suite of unusual minerals are laurionite, paralaurionite, penfieldite, fiedlerite, diaboleite, boleite, pseudoboleite, cumengeite, georgiadesite and others. For the reader interested in learning more about the Laurion minerals and a discussion of the arguments for these

Table 2. **X-ray powder diffraction data for nealite.**

I_{obs}	d_{obs}	d_{cal}	hkl
6	10.09	10.09	010
8	6.480	6.477	100
1	5.823	5.817	$\bar{1}10$
«1	5.078	5.145	110
«1	4.661	4.655	011
7b	4.237	4.267	$\bar{1}20$
		4.223	$\bar{1}01$
		4.206	101
5b	3.919	3.950	$0\bar{2}1$
		3.887	$\bar{1}\bar{1}1$
2	3.668	3.668	111
10	3.542	3.547	021
		3.537	$1\bar{2}1$
3	3.358	3.362	030
6	3.247	3.247	$\bar{1}21$
		3.239	200
1	3.028	3.023	$0\bar{3}1$
5	2.971	2.970	210
«1	2.908	2.909	$\bar{2}20$
5	2.874	2.873	$1\bar{3}1$
5	2.833	2.833	130
6	2.783	2.792	201
		2.775	002
5b	2.765	2.752	$0\bar{1}2$
		2.744	$\bar{2}11$
5b	2.643	2.658	$\bar{2}\bar{1}1$
		2.638	$\bar{1}31$
		2.623	$\bar{1}\bar{3}1$
2	2.581	2.581	211
1	2.558	2.554	$\bar{1}02$
		2.547	102
1	2.460	2.465	$\bar{1}40$
		2.449	$\bar{1}12$
1	2.427	2.434	131
		2.426	$1\bar{2}2$
2	2.262	2.263	$0\bar{3}2$
3	2.086	2.090	$\bar{2}\bar{3}1$
		2.089	$\bar{3}20$
		2.081	$\bar{1}\bar{3}2$
2	2.058	2.064	$\bar{2}\bar{1}2$
		2.056	310
		2.053	$2\bar{4}1$
1	2.038	2.036	$3\bar{1}1$
		2.035	032
2	2.006	2.009	301,$\bar{3}11$
		2.004	$\bar{1}50$
1	1.980	1.988	231
		1.982	$3\bar{2}1$
«1	1.951		
«1	1.932		
2	1.890		
3b	1.825		
3	1.711		
1b	1.670		
«1	1.644		
2	1.600		

114.6 mm Gandolfi camera, NBS silicon internal standard, CuKα radiation, visually estimated intensities, b = broad line.

compounds being considered legitimate mineral species, we recommend the recent paper by Kohlberger (1976).

Nealite has been found on only two very small specimens of the Laurion slags. On the type specimen, nealite occurs as a single isolated cluster of crystals («0.1 mm) in a cavity about 4 mm in diameter. The only other mineral in the cavity is a colorless crystals of aragonite. An adjacent cavity on the same specimen is lined with a druze of georgiadesite crystals, thus making the type nealite specimen the second known specimen of georgiadesite.

On the second nealite specimen, provided by Curt Segeler, the bright orange nealite crystals line fractures in the slag, and are more abundant. The specimen is severely oxidized and friable. In addition to abundant cellular goethite, nealite is associated with dull green annabergite.

ACKNOWLEDGEMENTS

The authors are indebted to Mary Jacque Mann of the Smithsonian SEM laboratory for assistance with the photomicrography. Curt Segeler provided additional specimens. Robert Jaxel provided many references to the mineralogy of Laurion, Attike, Greece, for which we are most thankful. Richard Johnson and Frank Walkup painstakingly prepared polished sections of minute nealite crystals, and Charles Obermeyer provided technical assistance with the microprobe. To all of these we express our gratitude.

To a very great degree, we are indebted to the late Neal Yedlin, who initiated not only this study, but many others, and provided the inspiration and impetus for a large number of mineralogical research efforts. His influence will be long remembered.

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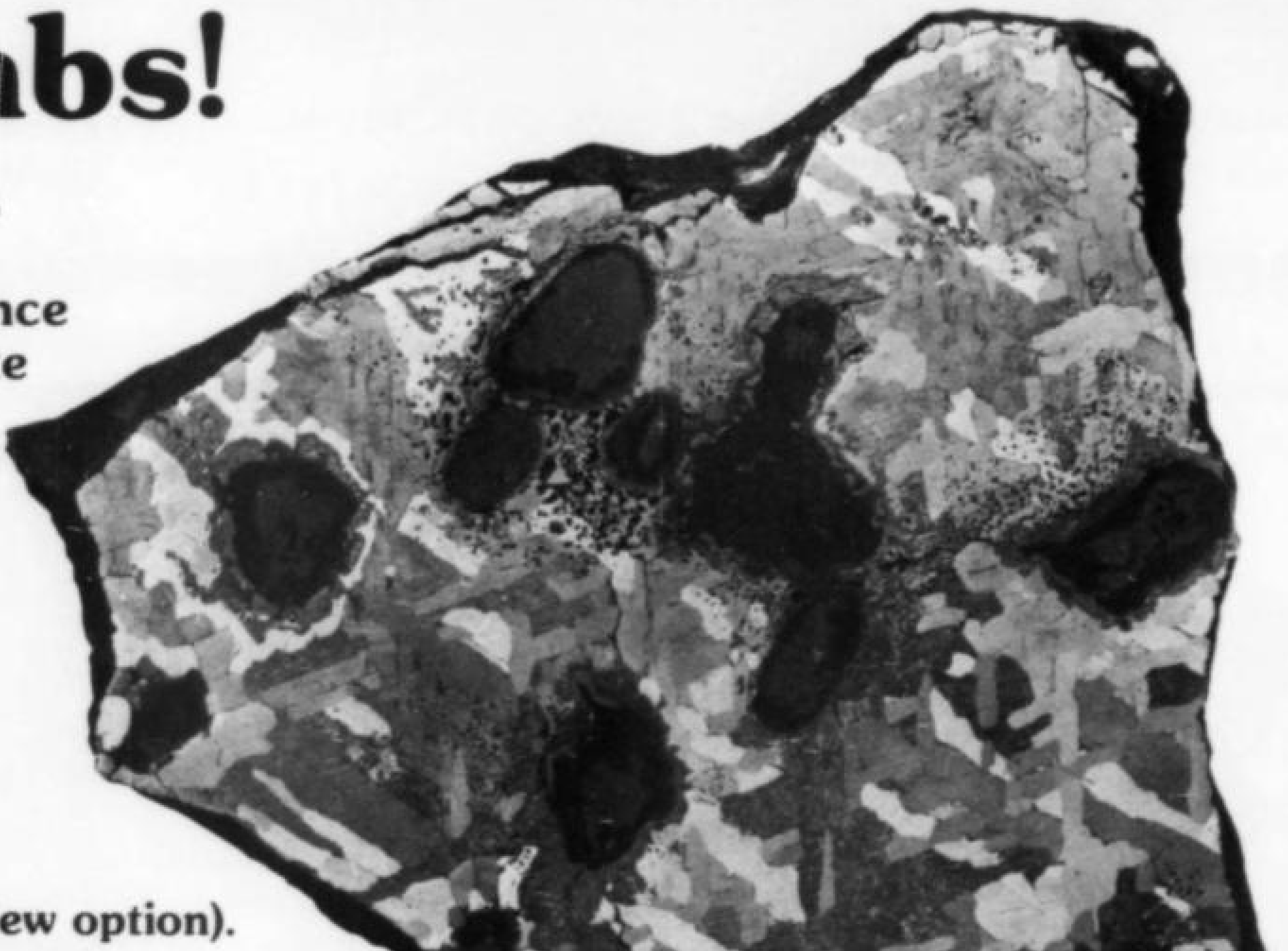

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INTRODUCTION

The granulite belt of northern Finnish Lapland forms an arc which extends from the Norwegian border in a north-south direction and intersects the Russian border in an east-west direction (Fig. 1). The most recent general survey of the geology and petrology of this rock complex has been published by Meriläinen (1976).

For the past 90 years, placer gold has been recovered in river beds which cut the hilly to low mountainous country in the southwestern parts of the granulite complex. Though never really remarkable, some washings are still operated during the summer by a few individuals, probably more for pleasure than for economic gain. The origin of the gold remains a puzzle. The country is covered by a thin carpet of glacial drift which is fairly local, not transported from long distances. The gold must originate from the rocks of the granulite belt itself. A number of veins are known from the area. They consist of siderite-magnesite, quartz, pyrite, hematite and limonite and, in some instances, contain traces of gold. These veins might represent the source of the placer gold, but such a conclusion needs verification.

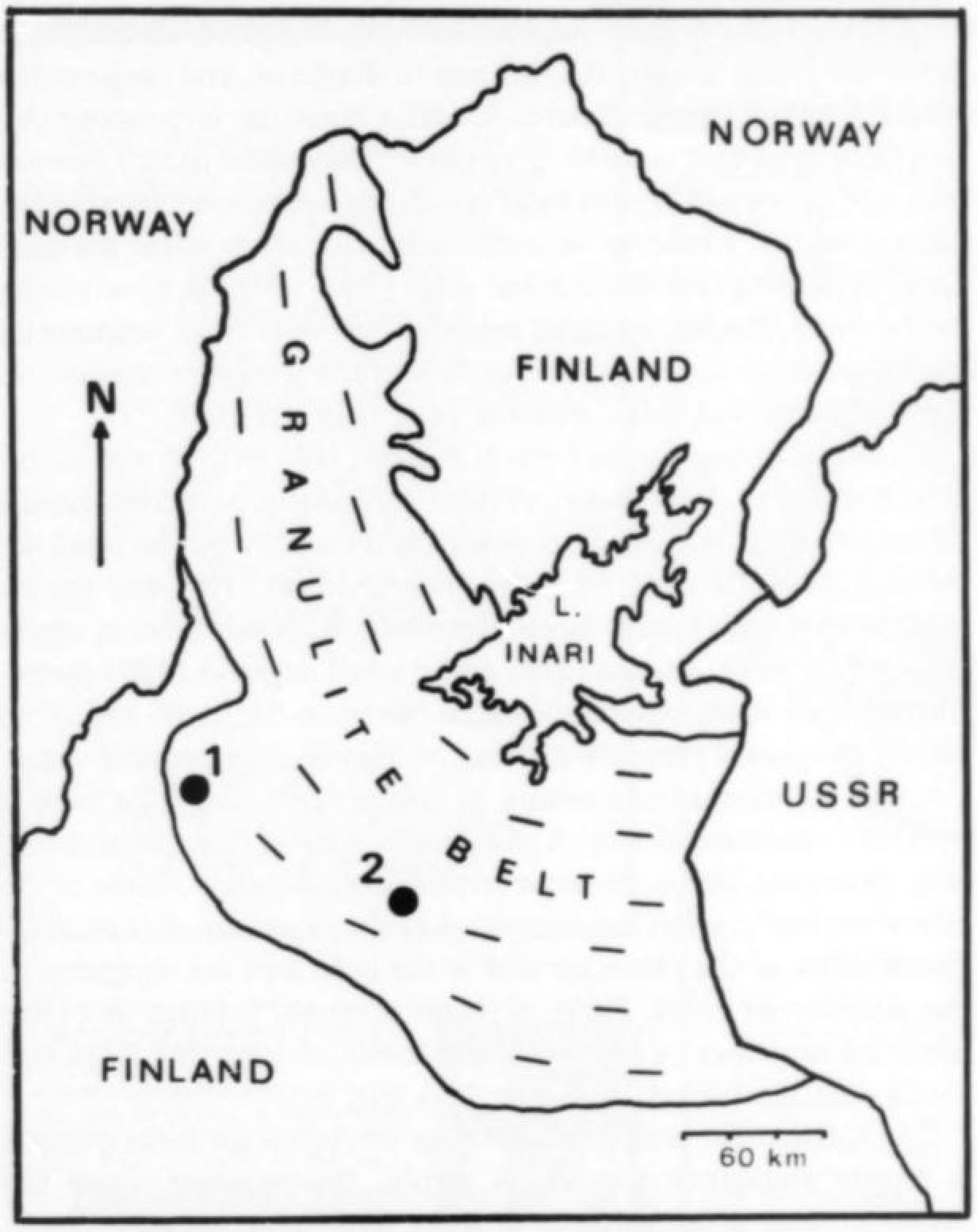

Figure 1. **Sketch map of the granulite belt in northern Finnish Lapland. 1: Miessi River. 2: Sota River.**

The gold concentrates were known to contain minor amounts of platinum. About ten years ago well developed sperrylite crystals were also detected and identified. However, no data were published. Independently of the previous work, one of us (H.K.) made some washings at the beds of two small rivers, the Miessi River and the Sota River. These localities are indicated in Figure 1. The concentrates of the washings contained the following heavy minerals (heavier than garnet): ilmenite, magnetite, faintly brownish yellow monazite, almost colorless zircon, deep red rutile, gold and traces of metallic platinum. No sulfide minerals were detected. In addition, minute amounts of euhedral sperrylite crystals were found and picked up by hand under a binocular microscope.

The joint occurrence of sperrylite with platinum and gold in Finnish Lapland suggests a common origin of these minerals. Sperrylite is fairly widespread as a minute accessory in nickel-copper sulfide deposits, but such deposits are not known near the localities where sperrylite was found. In addition, no extended intrusions of basic or ultrabasic massifs are known in the strongly metamorphic granulites of these localities. On the other hand, it is known that platinum is more mobile than previously understood (*e.g.*, Stumpfl, 1974). Could it enter the solutions of the carbonate-bearing quartz veins and crystallize there as $PtAs_2$?

Because of the rather unusual occurrence and the well developed euhedral form, the sperrylite crystals of the Miessi River were subjected to a laboratory study. The mineralogy and geochemistry of the platinum group metals was at a stage of rapid development. Therefore, it was thought that the data for the Miessi River mineral might interest some professional and amateur mineralogists. The sperrylite crystals from both localities in Figure 1 are identical in appearance.

Figure 2. **Simple sperrylite cube {100}. Crystal size 0.4 mm. Scanning electron micrograph.**

Figure 3. **Sperrylite crystal, a combination of a cube {100} and an octahedron {111} with traces of some dodecahedron {110} faces. Crystal size 0.3 mm. Scanning electron micrograph.**

Figure 4. **Sperrylite crystal, platy parallel to an octahedron face. Crystal size 0.5 mm. Scanning electron micrograph.**

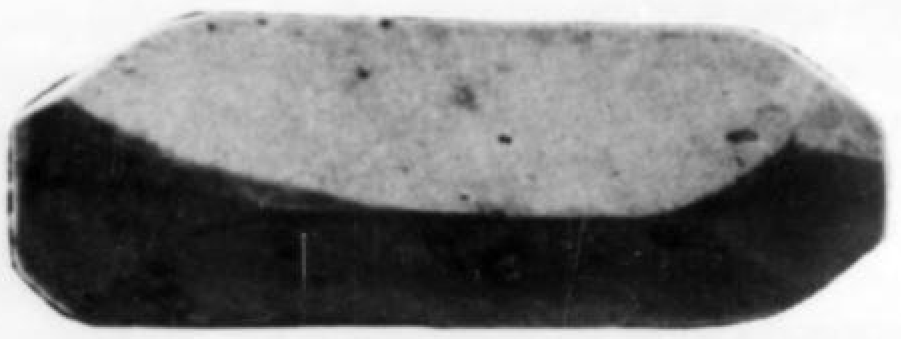

Figure 5. **Cuboctahedral sperrylite crystal, elongated parallel to [110]. Crystal size 0.3 mm. Scanning electron micrograph.**

Figure 6. **Octahedral sperrylite twinned on (011). Crystal size 0.4 mm. Scanning electron micrograph.**

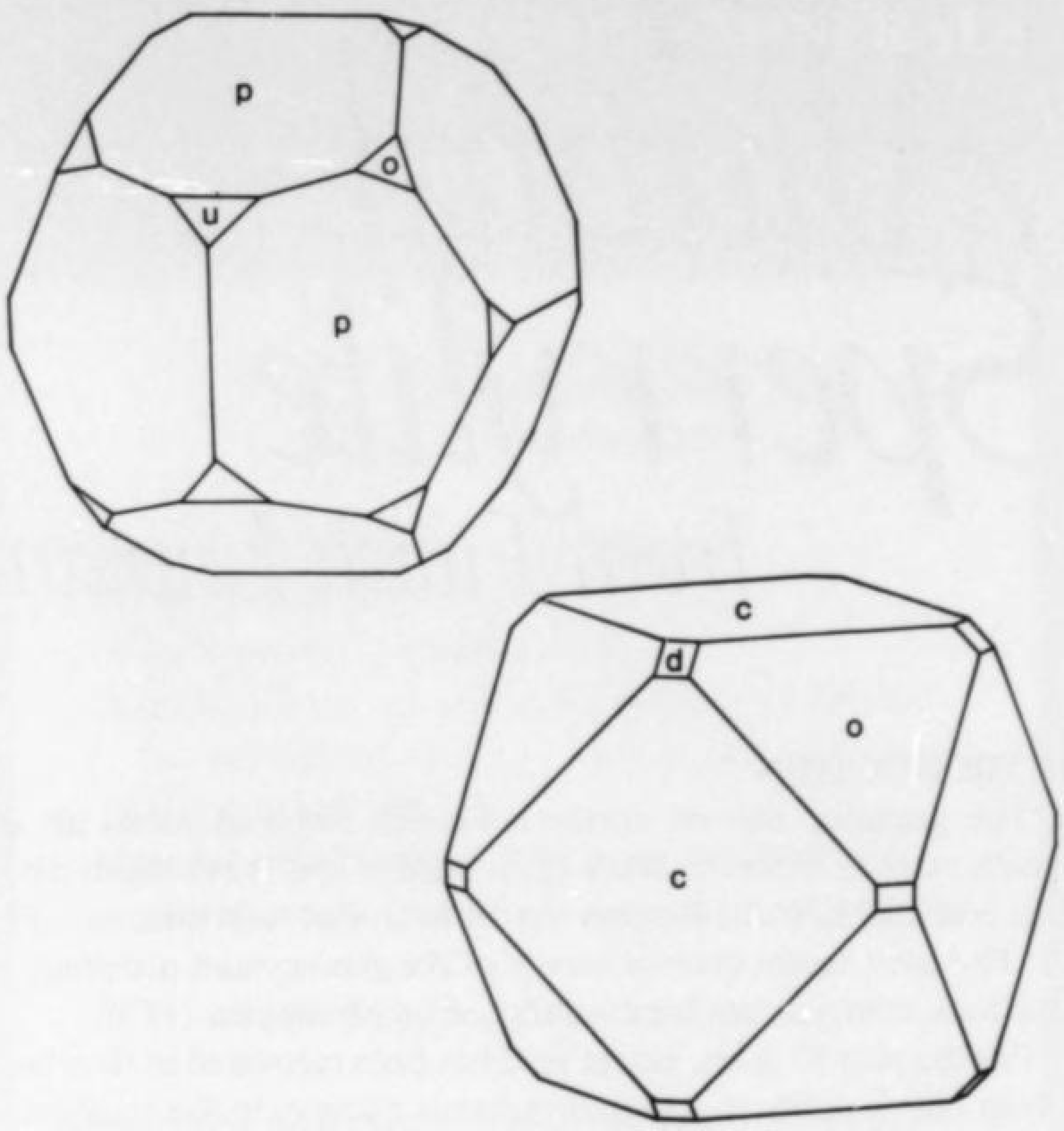

Figure 7. **Two main crystal habits of sperrylite from the Miessi River. A: cuboctahedral, small trisoctahedral faces not shown. B: pyritohedral.** ***c*** **= cube.** ***d*** **= dodecahedron.** ***p*** **= positive pyritohedron.** ***u*** **= negative pyritohedron.**

MORPHOLOGY

The sperrylite crystals washed out from the gravel of the Miessi River are small, usually 0.1–0.2 mm in diameter, and range exceptionally up to half a millimeter. Under a binocular microscope they display a steel-blue to silver-gray color. They show mostly more or less well developed crystal faces which are sometimes characteristically rounded. However, smooth faces with sharp edges are common, indicating that the original source rock of the mineral cannot be far away. Empty, rounded negatives left over from neighboring grains are often visible on the surfaces of the sperrylite crystals. No double grains with other minerals have been detected.

The dominating crystal form is a cube {100} (Fig. 2) and an octahedron {111} either alone or, more commonly, as a combination of the two (Fig. 3). Such crystals almost invariably exhibit small additional faces. Of these faces the dodecahedron {110} and the trisoctahedron {221} have been identified. Another form is represented by a large positive {210} and a small negative {120} pyritohedron with small octahedral faces. Because the small and often poorly developed faces are difficult to identify, the possible occurrence of additional faces cannot be entirely excluded. The habit is generally equidimensional. A platy habit parallel to an octahedron (Fig. 4) or cube face is, however, remarkably common. Some of the cuboctahedral crystals are elongated in the direction of [110] (Fig. 5) and a few of the plates parallel to the cube face are elongated in the direction of [100]. Figure 6 shows a crystal twinned on (110). Idealized drawings of the two main habits of sperrylite from this locality are reproduced in Figure 7, A and B.

The variation in crystal morphology of the Miessi River mineral is largely analogous to that of pyrite, for example, from the hematite mine of Elba Island in Italy. The habit reported here is well known for the mineral sperrylite, the most recent study of which was presented by Razin and Yakovlevskaya (1968) on the alluvial sperrylite from the southern Yakutia (U.S.S.R.).

X-RAY CRYSTALLOGRAPHY

A series of single crystal X-ray precession photographs indicate the unique space group *Pa3*. An X-ray powder pattern (Philips wide angle goniometer, internal silicon standard) yielded a = 5.967 ± 0.001 Å. This value agrees reasonably with the precision value presented by Szymański (1979), *viz.*, a = 5.9681 ± 0.0001 Å.

CHEMISTRY

The Miessi River sperrylite was analyzed by microprobe using as standards: stoichiometric arsenopyrite for As and metallic platinum for Pt. The analytical data reduction was performed with the EMPADR VII program by J. Rucklidge and E. L. Gasparrini. Four analyses were made of three crystals (two analyses of crystal No. 1, one analysis of Nos. 2 and 3, respectively). The microprobe work was carried out by Mrs. K. Hämäläinen, of the Exploration Department, Outokumpu Mining Company, Espoo, Finland. The following results were obtained: **As** 43.3%, 43.3%, 43.2%, 43.4%, average 43.3%; **Pt** 56.8%, 56.1%, 57.1%, 56.6%, average 56.7%. These values indicate a strictly stoichiometric composition $PtAs_2$. Scanning electron microscopy with an energy-dispersive display revealed an absence of other elements. A microprobe test for sulfur was negative. If elements other than Pt and As are present, they must exist only in trace amounts, below the limit of detection. The absence of the other platinum group metals is worth noting.

On the basis of the composition and the unit cell volume the density was calculated as 10.74 g/cm^3.

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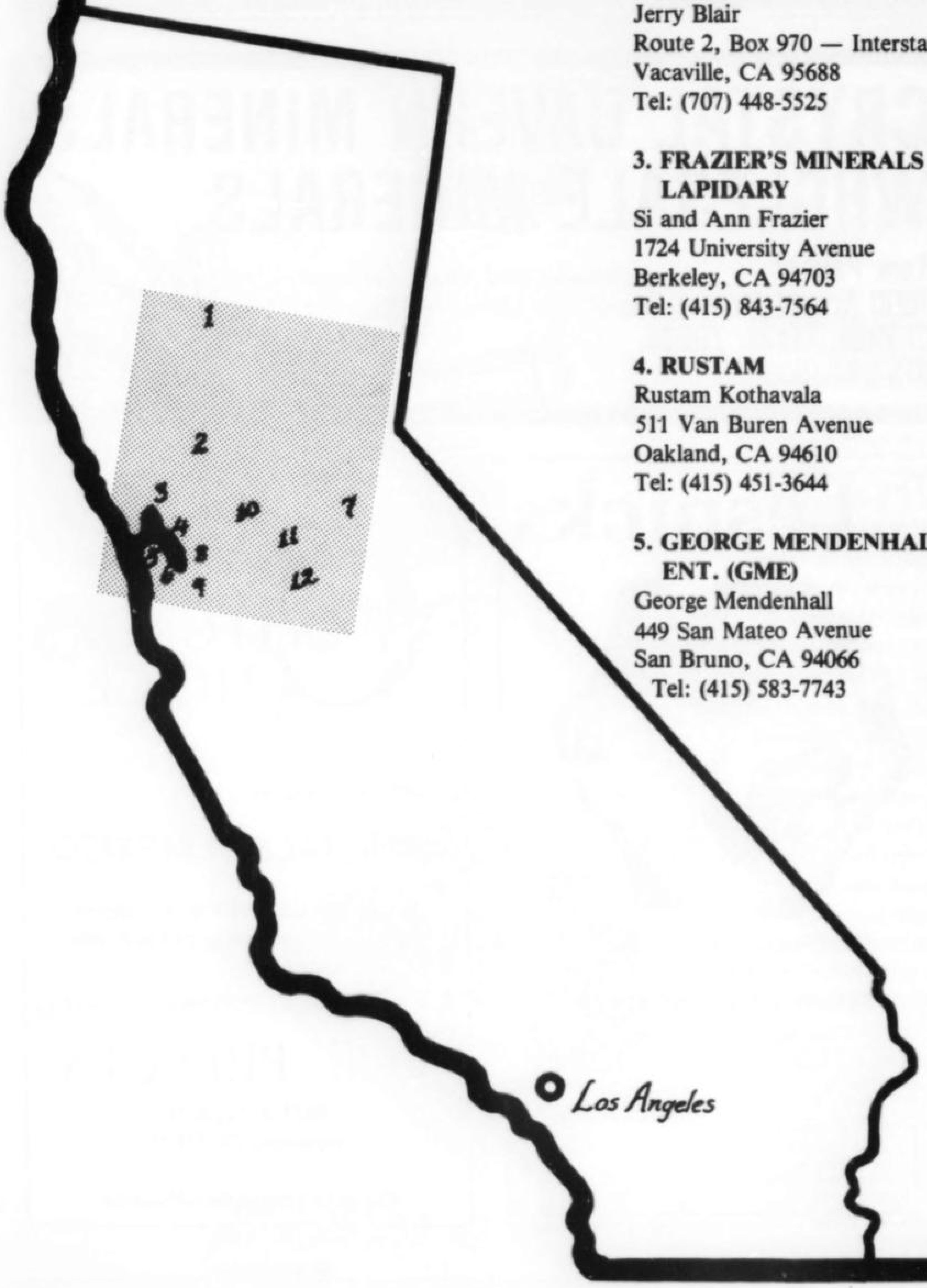

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Mullica Hill, New Jersey

by **Wm. A. Henderson, Jr.**
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Introduction

In 1977 my family and I, in company with Charlie and Marcelle Weber of Fairfield, Connecticut, and Vince and Marge Matula of Allentown, Pennsylvania, spent a weekend collecting at three East Coast localities. The three, Mullica Hill (New Jersey) and Moores Mill and Hellertown (Pennsylvania), are noted for their extremely colorful and well crystallized micro phosphate minerals. In addition, Mullica Hill phosphates show a very interesting paragenesis. In this article, I will describe the minerals from these three localities, concentrating primarily on those from Mullica Hill.

Mullica Hill, New Jersey

The minerals at Mullica Hill are exposed in the steep banks of a brook in poorly cemented Cretaceous sandstones called greensands. While most of the sandstone is colored light brown to greenish brown by the iron oxide cement, in some areas it is colored blue-green by uniformly distributed, finely divided vivianite. In other outcrops the vivianite is localized, and is found in casts after fossil belemnite "pens" (probably *Belemnitella americana*) and after clam shells. These pens are chambered like the shells of nautiloids, but are the internal shells of belemnites, an extinct family of squid-like animals. Both the pens and the clam shells were originally composed of calcium carbonate.

At the most interesting outcrop and the one where most of our collecting was done, not only vivianite but also a number of other micro phosphate minerals are to be found in the casts. Here, specimen bearing material is easily removed in large chunks using long chisels and medium weight hammers. The sandstone around the casts is much more thoroughly cemented, so a few blows with the hammer breaks away most of the matrix to leave irregular pieces the size of small potatoes, each containing one or more casts.

At home, these are easily trimmed using a rock splitter. At first, only the remains of the loose outer shell breaks away, but the last judicious application of the splitter will break open the belemnite cast lengthwise, hopefully revealing numbers of micro crystals. Most often the cast is a dud, filled with loose sand or with massive vivianite or poorly crystallized material, but perhaps one cast in ten is a real winner. The process of opening the casts is very much like shelling peanuts. One says, "Just one more," but it is very hard to stop. Several times, I have sat down to open just one or two specimens, only to arise hours later with my benchtop covered with opened cavities.

Vivianite, $Fe_3^{2+}(PO_4)_2 \cdot 8H_2O$, is the most common phosphate in the casts. It commonly fills the belemnite casts solidly, crystallizing in a radial fashion. In other cases the vivianite is partially redissolved to leave groups of poorly formed crystals in roughly parallel orientation. On further dissolution, only a boxwork of thin plates of vivianite remains. Only rarely are good crystals found, so the most interesting cavities are those where a thin shell of vivianite is left, covered on the inside with other phosphate minerals.

In freshly opened cavities the vivianite varies in color from almost colorless through very pale shades of green to dark blue. Interestingly, a year or so later I can find in my collecting only the blue to dark blue material. This change in color of vivianite on exposure to air has been noted many times, and is ascribed to partial oxidation of ferrous to ferric iron in the mineral.

Kertschenite, $Fe_3^{3+}(OH)_3(PO_4)_2 \cdot 5H_2O$, is a problematical species formed by further oxidation of vivianite, and has been most actively studied in Russia. The mineral is amorphous to X-rays (P. B. Moore, personal communication). At Mullica Hill it is found as rusty brown, dull-lustered material forming a rind or rim on the *outside* of the vivianite. The kertschenite shows the same crude

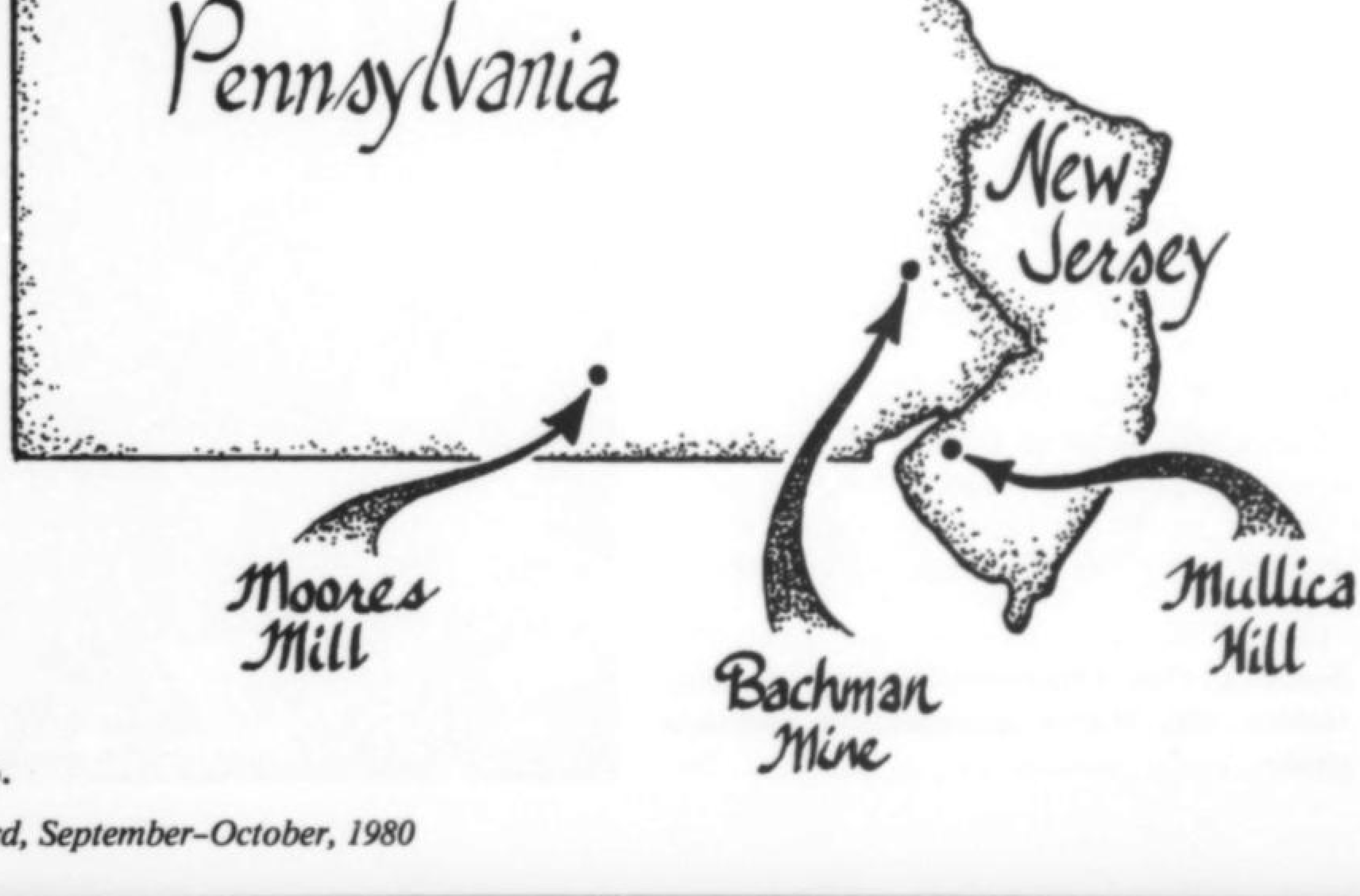


Figure 1. **Location map.**

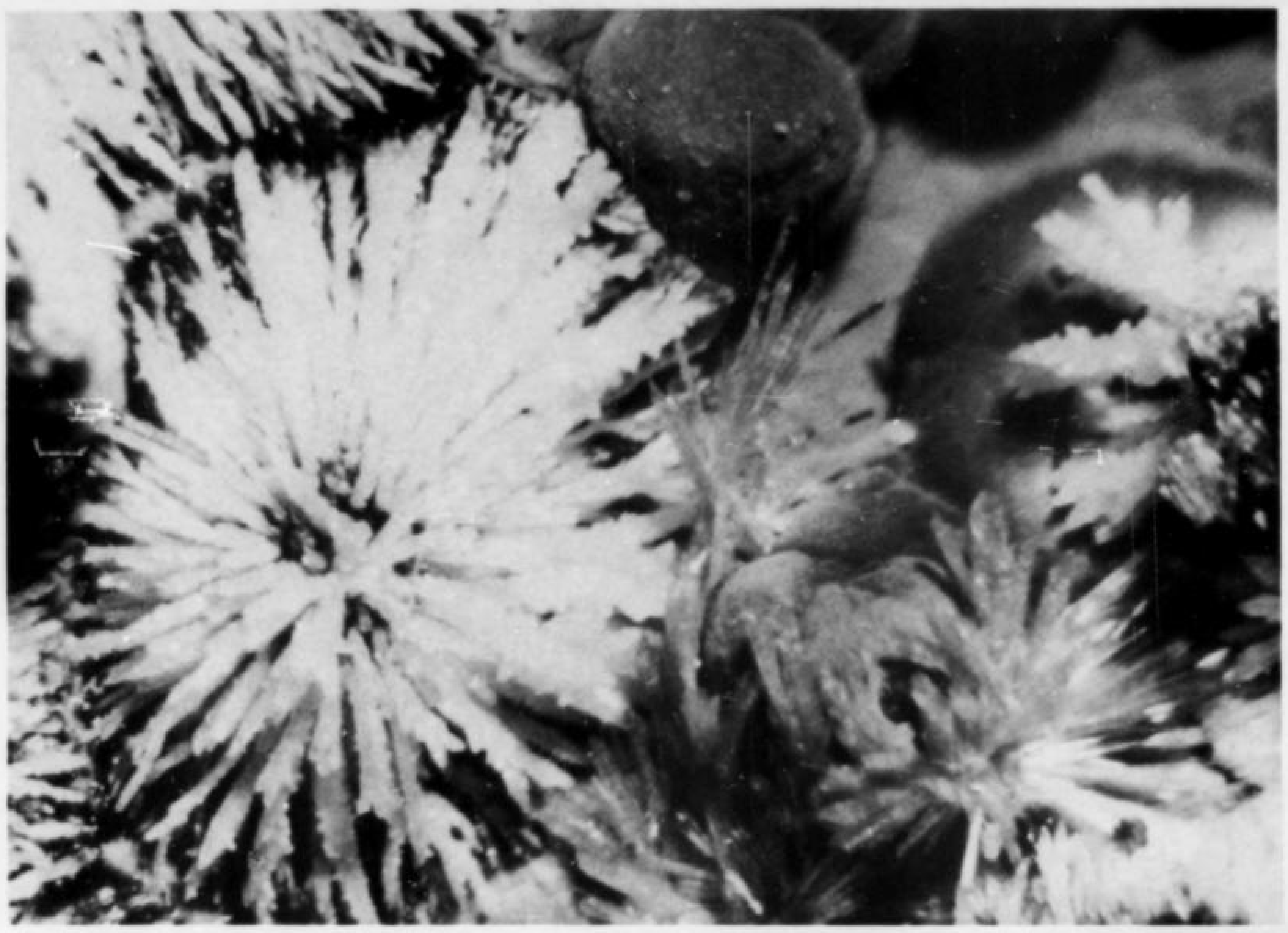
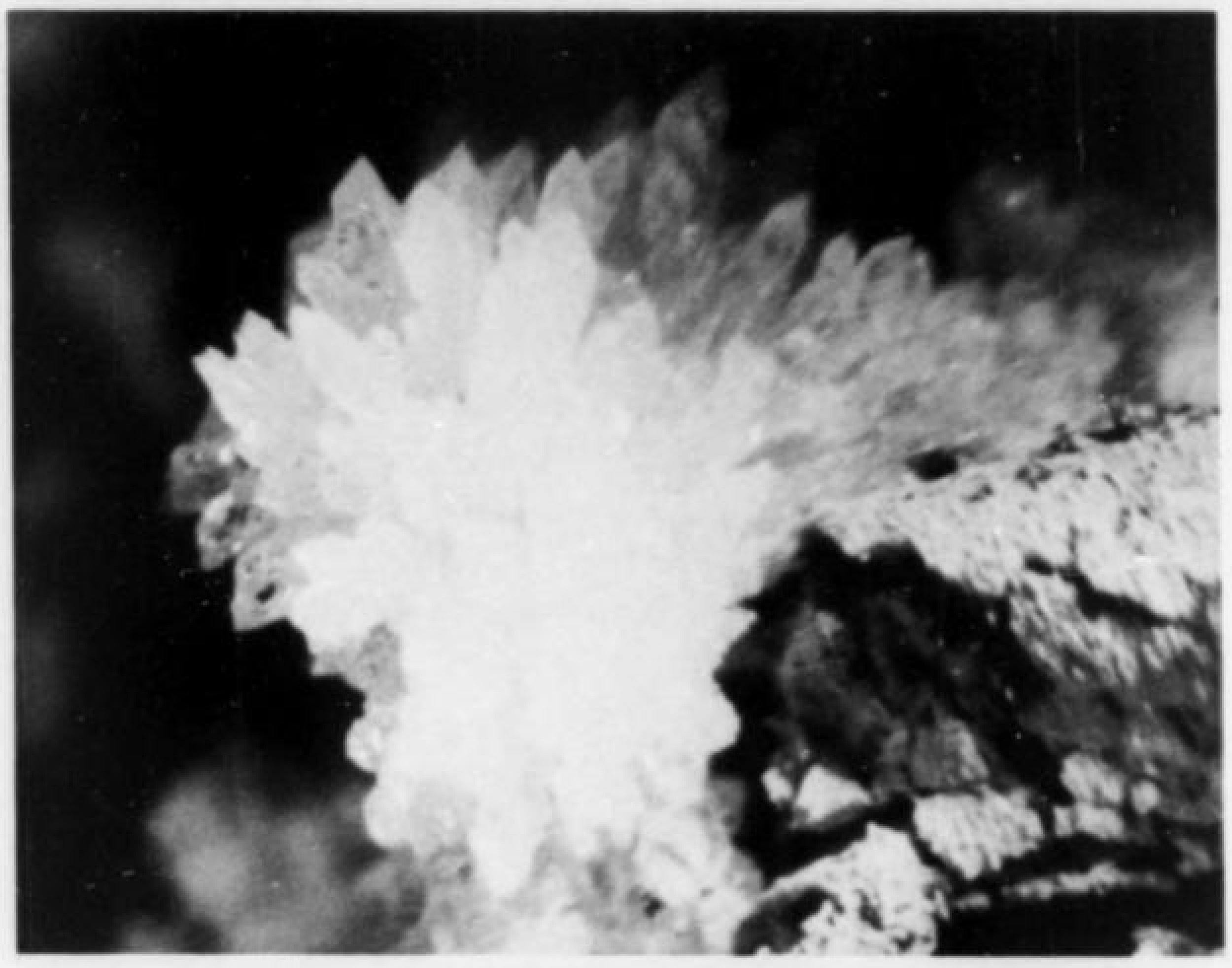


Figure 2. **A pink strengite rosette with radiating, acicular, orange strunzite from Mullica Hill. Weber specimen; photo by Vi Anderson.**

Figure 3. **A radiating group of pink strengite crystals from Mullica Hill. Weber specimen; photo by Vi Anderson.**



crystal forms as the vivianite and, as at other localities, it is pseudomorphous after that mineral as a result of complete oxidation of the iron.

Rockbridgeite, $(Fe^{2+},Mn^{2+})Fe^{3+}_4(OH)_5(PO_4)_3$, is the most commonly found phosphate, after the two above-described minerals. It is most often found as druses of minute, black to dark green crystals lying on vivianite and between the vivianite rind and the hollow core of the cast. The finest rockbridgeite crystals, however, appear to be a second generation of the mineral, most often forming on pink strengite. These are euhedral, square, tabular crystals with a brilliant luster and jet black color, and occur singly or in sparse clusters. The color contrast and the perfection of the forms make these crystals extremely fine micro material.

At first I thought the black and green material might be two species, especially as the X-ray powder pattern of the black material fits rockbridgeite best, while the X-ray pattern of the green material is a better fit for frondelite. Since Moore (Moore, P. B. (1973) Pegmatite phosphates: descriptive mineralogy and crystal chemistry. *Mineralogical Record,* **4**, 103.) has warned that chemical analysis is needed to distinguish the two, I had microprobe analyses done for iron, manganese and phosphate. The results showed that both minerals contain less than 0.01 percent manganese, thus demonstrating that the green mineral is not frondelite, $(Mn^{2+},Fe^{2+})Fe^{3+}_4(OH)_5(PO_4)_3$. However, the green material showed significantly less iron and more phosphate than the black material, suggesting that it is a slightly oxidized rockbridgeite or possibly beraunite. Moore reports that rockbridgeite varies from black when completely reduced to shades of green or brown on oxidation.

Strengite, $Fe^{3+}(PO_4)\cdot 2H_2O$, is found as extremely beautiful, colorless to bright pink rosettes or flower-like aggregates of lath-shaped crystals. Scattered on rockbridgeite and often associated with other phosphates, the strengite groups make striking micromounts indeed.

Phosphosiderite, a polymorph of strengite with the same formula, is quite rare at Mullica Hill. It forms tabular, rectangular crystals, often in stacked up aggregates and frequently lying flat on rockbridgeite. As can be seen in the accompanying figure, the crystals show two pinacoids and a prism. The angle between the

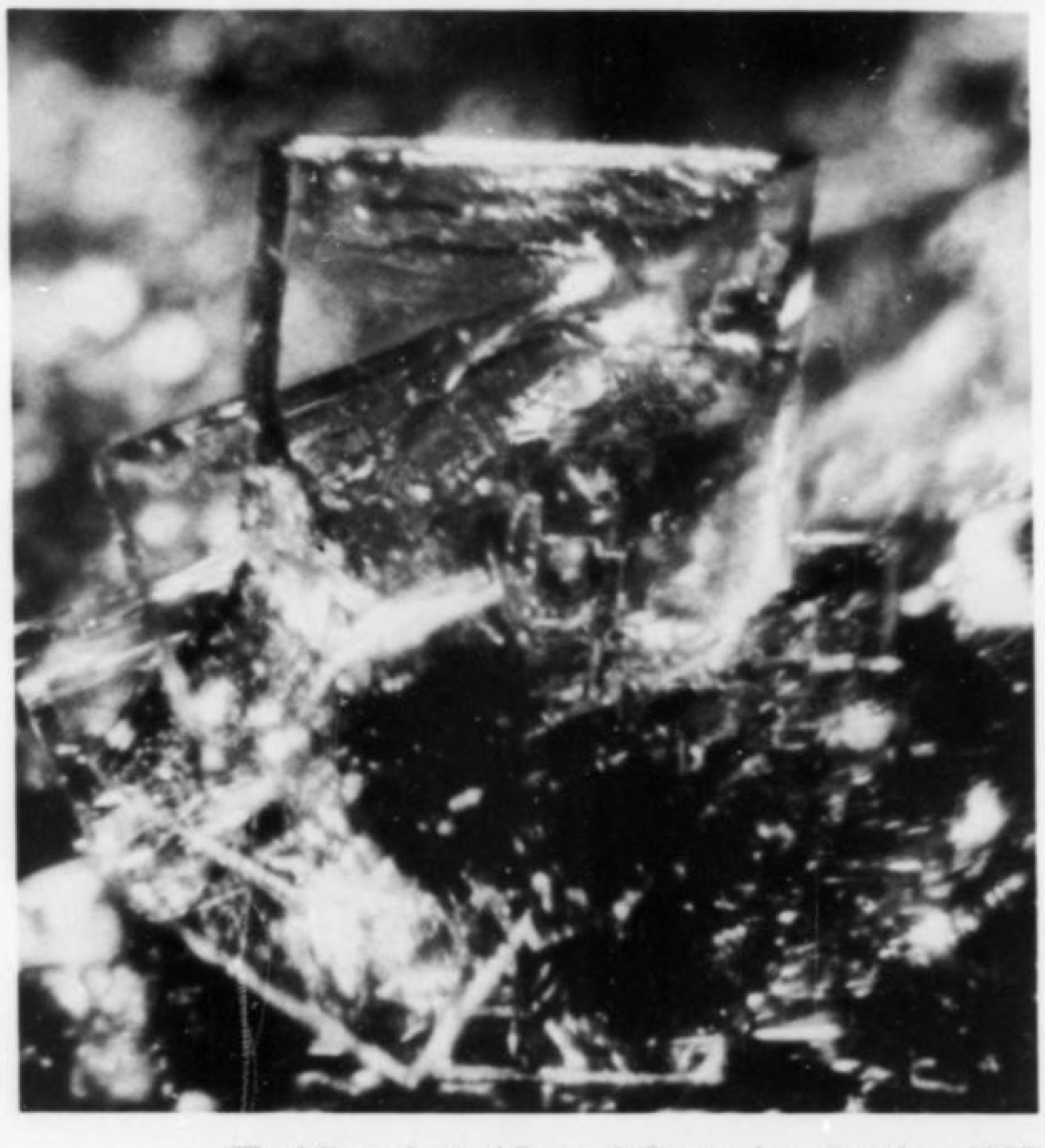


Figure 4. **Pink phosphosiderite crystals from Mullica Hill. Weber specimen, Vi Anderson photo.**

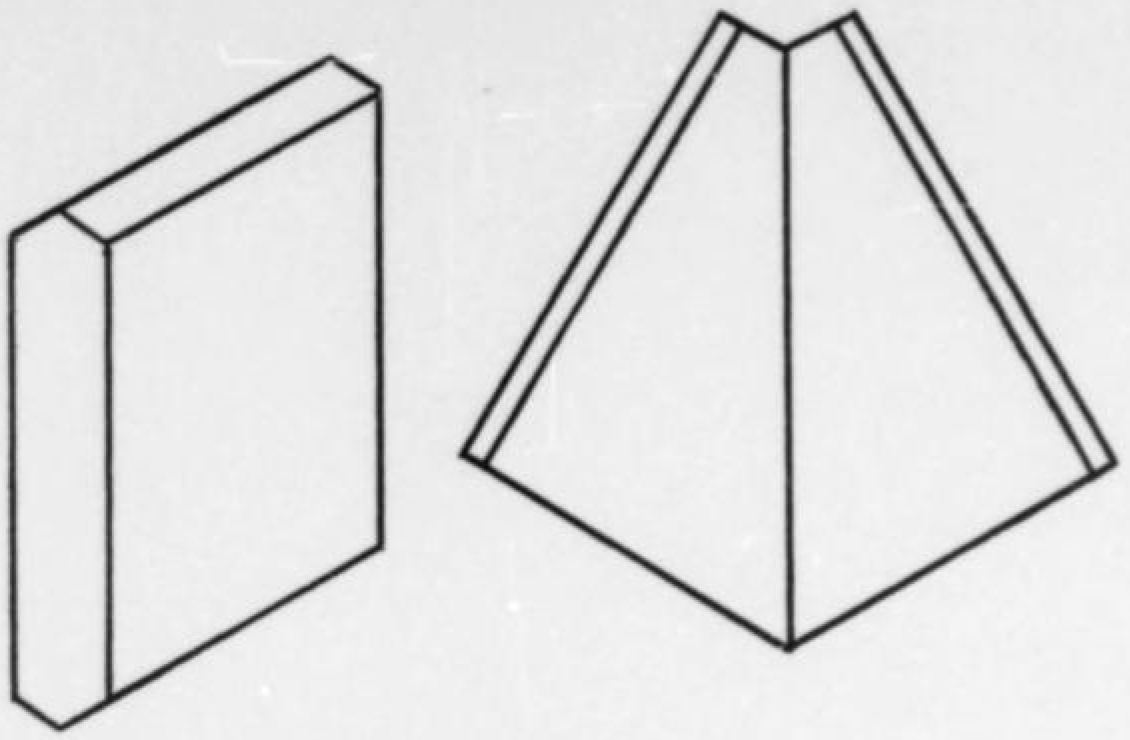


Figure 5. **Sketches of a single phosphosiderite crystal and a twin from Mullica Hill.**

normals to the larger pinacoid face and the prism is 61°. A very small number of contact twins of phosphosiderite have been found. The contact plane of the two individuals making up the twin is seen as a sharp line across the twin, and a very definite re-entrant angle is present. The angle subtended by the longer sides of the twin (those modified by the prism) is 65°. Interestingly, these twins are virtually identical in form to the isotypic metavariscite twins found at Lucin, Utah, although the metavariscite twins are apple-green in color and show a second prism face. This similarity is not surprising since metavariscite, $Al^{3+}(PO_4)\cdot 2H_2O$, has the same crystal structure as phosphosiderite and differs from it only in that it contains Al^{3+} rather than Fe^{3+}.

Most of the phosphosiderite crystals are transparent and colorless, and are thus quite inconspicuous. Occasional larger crystals are light pink to purple in color, and more attractive. The identities of both the strengite and phosphosiderite were confirmed optically.

Beraunite, $Fe^{2+},Fe_5^{3+}(OH)_5(PO_4)_4\cdot 6H_2O$, is found as bright orange to orange-red crystals, usually quite small, in tufts of radiating individuals and on rockbridgeite. A few larger, more equant crystals are to be found and some of the green material on which beraunite crystals grow may be less oxidized beraunite rather than rockbridgeite. The crystals of beraunite were too small to test optically, but the little that could be learned was consistent with the properties of beraunite.

Cacoxenite, $Fe_9^{3+}(OH)_{15}(PO_4)_4\cdot 18H_2O$, is found at Mullica Hill in radiating groups of bright yellow crystals, some of them surprisingly large for this mineral. The most beautiful combination is that of the bright yellow cacoxenite on deep blue vivianite. Optically, cacoxenite is unixial positive, with quite low indices for an iron phosphate mineral. The Mullica Hill cacoxenite was found to have these properties.

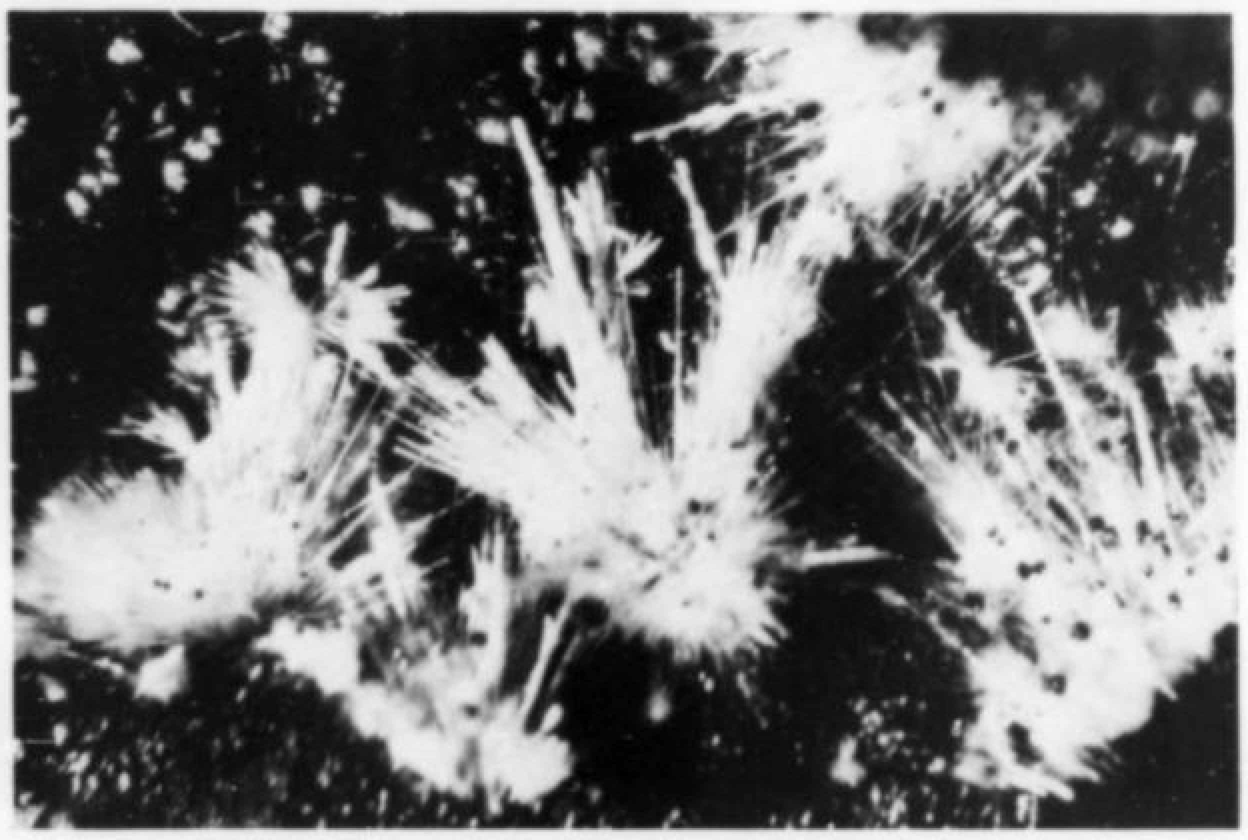


Figure 6. **Yellow strunzite needles on black rockbridgeite from Mullica Hill. Henderson specimen and photo.**

Strunzite, $Mn^{2+}Fe_2^{3+}(OH)_2(PO_4)_2\cdot 6H_2O$, is the rarest of the phosphates found at Mullica Hill. Most of the acicular crystals found are much larger than the cacoxenite crystals, and occur as isolated individuals rather than as spheres. They are dull in luster and show substantial alteration under the microscope. Only very occasionally are brilliant, unaltered crystals found. The color varies from straw yellow to light yellow-brown or orange-brown. The mineral was identified by its X-ray powder diffraction pattern.

The paragenetic sequence observed at Mullica Hill raises some interesting questions. By way of background, the first formed mineral, vivianite, contains only reduced or ferrous iron, Fe^{2+}. The other phosphate minerals are formed after vivianite, most frequently in the sequence shown in the accompanying figure. Exceptions to this sequence are found. It should be noted that the iron in all the species that formed after vivianite has been partially or wholly oxidized to ferric iron, Fe^{3+}. Only the manganese iron phosphate strunzite contains a cation other than iron.

Spatially, as mentioned before, kertschenite forms a rind on the outside of the vivianite. The other phosphates form layers or patches inside the vivianite extending toward the hollow center of the cast, as many as six minerals being found in a single cavity.

The minerals are not uniformly distributed throughout the deposit. Productive layers appear to extend roughly horizontally, with empty casts or ones filled with sand or massive vivianite occurring above and below the richer layers. In addition, the minerals are zoned somewhat in a horizontal direction. Most of the phosphosiderite is to be found in one section of the exposure, while in another most of the cacoxenite was found in its striking color combination with vivianite.

The questions to be answered, then, are as follows. Why did the vivianite form in the belemnite and clam casts and not elsewhere? What caused the formation of the vivianite and the other phosphate minerals? How does this paragenesis relate to others found in different environments?

From the known history of the Atlantic coastal plain deposits and the types of fossils found at the Mullica Hill location, it can be inferred that the sandy sediments laid down there were deposited in shallow offshore seas. It might be speculated that the fossil organisms themselves were the source of the phosphate needed to form the minerals described, but it seems very unlikely that they were the sole or main source. Animal tissue does indeed contain phosphate, but only in very small amounts relative to the quantities needed to completely fill these casts with vivianite. It is much more likely that the phosphate ion and iron required were carried into the casts in circulating interstitial water percolating through the sediments.,

The precipitation of vivianite in such sediments is currently going on, for example, in sediments in Chesapeake Bay (O. P. Bricker, private communication). This process has been described by Bray, Bricker and Troup (Bray, J. T., Bricker, O. P., and Troup, B. N. (1973) Phosphate in interstitial waters of anoxic sediments; oxidation effects during sampling procedure. *Science,* **180**, 1362.) who showed that while the bottom waters in the bay are oxidizing and acidic in nature, conditions change drastically in the sediments below. Only a few centimeters below the surface of the sediments, Eh has dropped from +100 to -300 and pH has risen from 7 to 9, i.e., conditions are reducing and less acidic in nature. Iron phosphates are soluble in acid and less soluble under basic conditions. In addition, Fe^{3+} is the stable iron ion under oxidizing conditions, while Fe^{2+} is formed under reducing conditions. Further, as pH rises and the hydrogen ion concentration drops, other phosphate ions ($H_2PO_4^{1-}$ and HPO_4^{2-}) dissociate to give PO_4^{3-}, thus increasing its concentration. With the increase in concentration of Fe^{2+} and PO_4^{3-} in the sediments, the solubility product of vivianite is

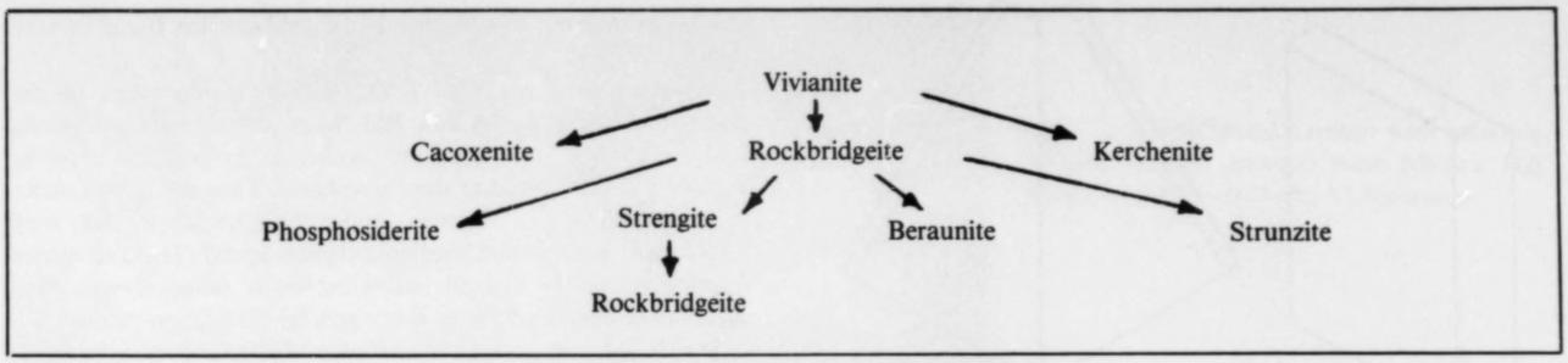


***Figure 7.* The most typical paragenetic sequence at Mullica Hill.**

exceeded, and the mineral forms.

Similar processes may be widespread in occurrence, and need not be restricted to bay waters. Conditions in offshore sediments might well be similar, and the widespread occurrence of sedimentary deposits of apatite, vivianite, wavellite and variscite in the Atlantic coastal plain deposits suggests that this is the case. Vivianite is also formed in fresh water lakes and bogs where similar reducing but acidic conditions are present.

There are at least two possible roles of the organic remains of the belemnites and clams in localizing the precipitation of vivianite. First, the decaying organic matter of the remains would locally greatly deplete the interstitial water of oxygen, and would make the immediate area more strongly reducing in nature. Second, the dissolving calcium carbonate of the animal shells would sharply increase the pH in the immediate area. Either of these effects, or both in concert, would decrease the solubility of the constituents of vivianite and encourage its precipitation.

If the activity of calcium ions in the area is too high, however, the stable ferrous iron species would be siderite and not vivianite. It is conceivable that the calcium in the animal tissues was first precipitated as siderite, which was in turn replaced by vivianite. The much stronger cementation of the sandstone immediately around the clam and belemnite casts suggests a higher local concentration of iron, present now as iron oxides but perhaps present earlier as siderite.

Because the other phosphate species found are all ones in which Fe^{2+} has been partially or wholly oxidized to Fe^{3+}, it is obvious that the first formed vivianite has been subsequently subjected to oxidizing conditions. The process of oxidation probably began when, through uplift and erosion, the Mullica Hill sediments were exposed to oxygen-rich ground waters. Indeed, the oxidation is quite probably going on today.

Obviously, these "secondary" phosphates are more stable than the "primary" vivianite under the oxidizing conditions of the day. However, with continuing exposure of the deposit to oxidizing conditions and flowing groundwater, these minerals too will suffer dissolution when their solubility products are no longer exceeded. Thus, the long term prognosis of the deposit is not good!

It is very instructive to look at the similarities and differences between this paragenesis and that in phosphate pegmatites. In the pegmatites, initial temperatures are far higher. Under these conditions, hydrates are not stable, and the primary phosphate species are anhydrous minerals such as triphylite, lithiophilite, graftonite, etc. (Moore, 1973). This is to be compared to Mullica Hill's primary vivianite, which is a hydrate and forms at much lower temperatures. However, like vivianite, the primary phosphates in pegmatites are also formed under reducing conditions and contain only iron in the ferrous (Fe^{2+}) state. As temperatures drop below about 250° and more oxidizing conditions obtain, a host of secondary phosphates are formed in pegmatites. These are formed by leaching, oxidation and hydration of the now unstable primary phosphates. The Mullica Hill secondary minerals form under similar conditions. According to Moore, all of the secondary phosphates common to Mullica Hill and to phosphate pegmatites are late hydrothermal minerals. Moore's paragenetic scheme suggests that rockbridgeite, while late, precedes strengite, beraunite, strunzite and cacoxenite, which form in that order. This is essentially the same sequence as is seen at Mullica Hill. Interestingly, Moore's paragenetic diagram even shows two generations of rockbridgeite, as seen at Mullica Hill. In contrast to the paragenetic sequence at Mullica Hill, he describes vivianite in pegmatites as being very late! Of course, at Mullica Hill temperatures were probably consistently around 25°C, whereas by the time a pegmatite has cooled below 100°C or so, any minerals subsequently formed will be considered "late." A final point of difference is that while cacoxenite is rare in phosphate pegmatites, it is common at Mullica Hill and other non-

***Figure 8.* Colorless single crystals of wavellite from Moores Mill. Matula specimen, Vi Anderson photo.**

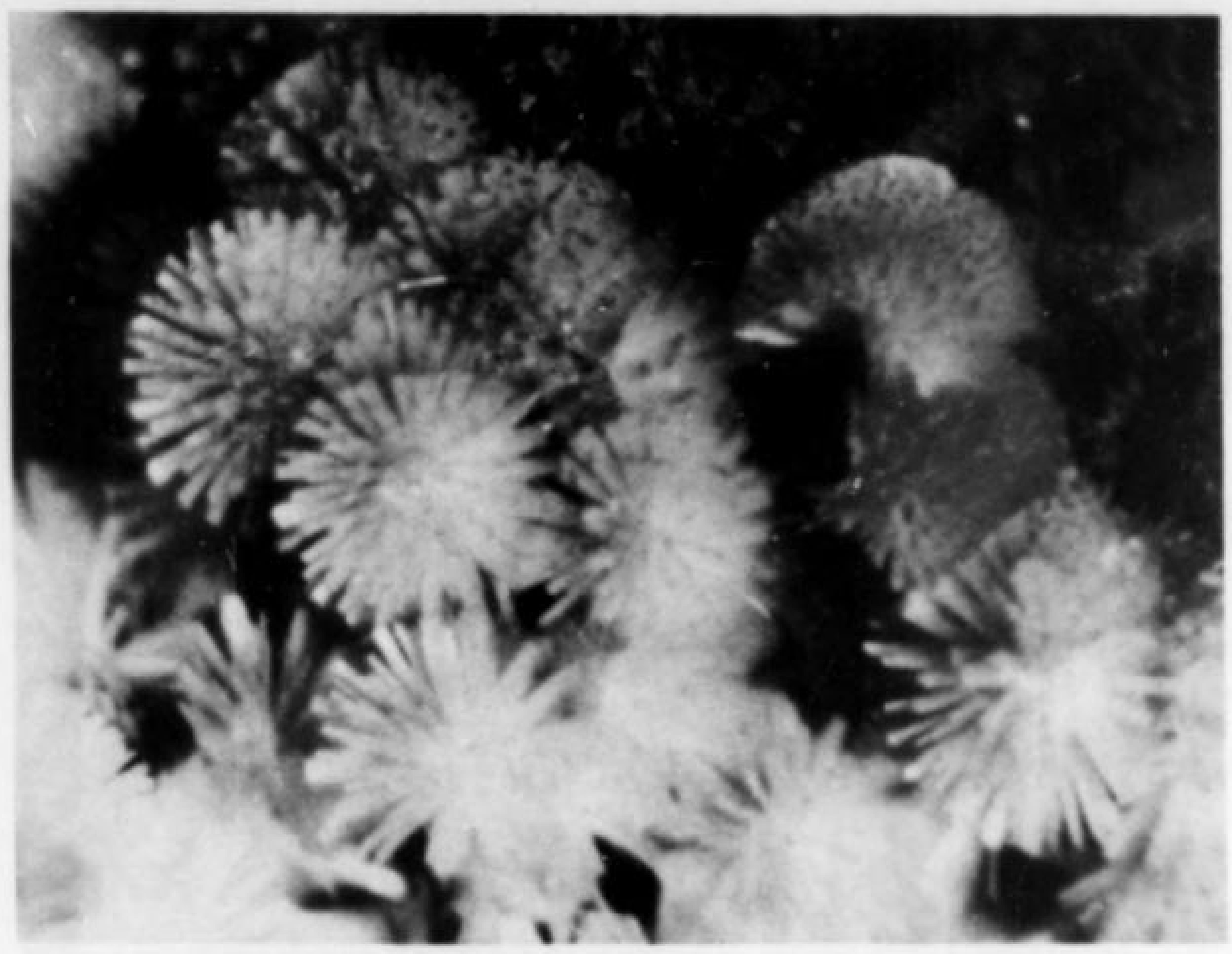


Figure 9. **Radiating yellow cacoxenite from Moores Mill. Henderson specimen, Vi Anderson photo.**

pegmatite localities. The differences between the two types of deposits can be ascribed to the different temperatures of formation and the resultant restrictions as to the stability of the various primary phases.

Moores Mill, Pennsylvania

Moores Mill, about 4 miles west of Mount Holly Springs, Pennsylvania, is an entirely different type of deposit. The principal ore mineral, wavellite, was mined as a source of elemental phosphorus. The mine operated around the turn of the century, and the phosphorus produced was used in the production of matches. The main pit was about 100 feet in diameter and 25 feet deep, and there were numerous smaller trenches besides. Phosphorus minerals can now be found in the extensive dumps.

Wavellite is found largely as white nodules of massive material in clay. Broken open, some of the nodules contain radiating wavellite crystals, colorless to bluish white in color and with a silky luster and fibrous structure. The best crystals, from a micromineral collector's point of view, are columnar to acicular, striated lengthwise and well terminated.

Very pretty yellow cacoxenite is also found. It varies in habit from smooth-surfaced, mammillary groups to well-formed, radiating, acicular crystals. The solid spheres have a surprisingly deep color and, where broken open, often have a radially banded appearance. The single crystals are usually lighter in color than the botryoidal material. Deep red to brownish red beraunite is found in radiating columnar crystals and also in tabular, almost equant individuals. The most attractive material is that where the bright yellow cacoxenite occurs on or close to the red beraunite. Other minerals found at Moores Mill are cryptomelane, goethite, strengite and turquoise.

Hellertown, Pennsylvania

The last locality visited, the Bachman mine in Hellertown, Pennsylvania, was operated for iron ore in the late 19th century. Some 15,000 tons of ore were mined. The ore was found in a brecciated and mineralized Cambrian quartzite. The phosphate minerals are found in cavities and cracks in the quartzite and in goethite.

Figure 10. **Acicular, red beraunite crystals from the Bachman mine. Henderson specimen, Vi Anderson photo.**

By far the finest mineral found at this locality is matulaite, $CaAl_{18}(PO_4)_{12}(OH)_{20}\cdot 28H_2O$, named for Marge Matula. Since she was one of our guides on this trip, I can think of no more reliable way to collect! This new species has recently been described by P. B. Moore (*Der Aufschuss,* **31**, 55). Most commonly, matulaite occurs as druses of platy, white to bluish-white, tabular crystals in radiating groups. The best crystals appear to be single ones (although they are not), and have a slightly rounded, tabular, rectangular appearance. Matulaite was at that time to be found in surprisingly large quantities.

In addition to matulaite, one finds beraunite, cacoxenite and wavellite in colors and habits not much different from those at Mount Holly Springs. Other species found at the Bachman mine are rockbridgeite, cryptomelane, goethite and turquoise. Again, the most attractive material shows colorful combinations of the above minerals; cacoxenite spheres with matulaite clusters, matulaite on wavellite, wavellite on matulaite, or cacoxenite on beraunite.

The minerals from these three low temperature phosphate occurrences make attractive and interesting additions to any micromount collection. Should you wish to exchange for some of these species, you might try writing to the author or either of the following:

Mrs. C. H. Weber, Jr.
39 Benson Place
Fairfield, Conn. 06430

Mrs. V. J. Matula
Route 4
Allentown, Penn. 18103

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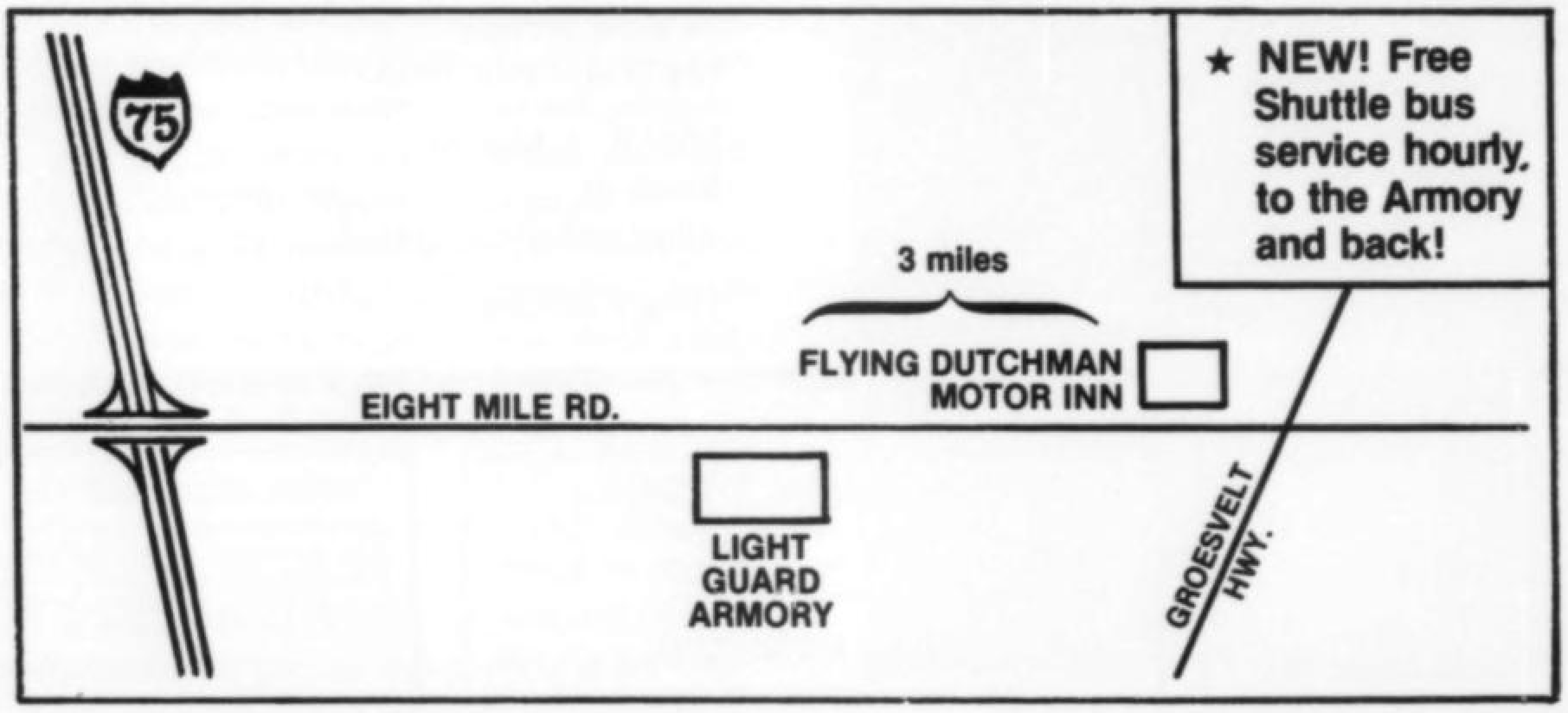


NEWS FROM THE AMNH

by **Joseph J. Peters** and **George E. Harlow**
Department of Mineral Sciences
American Museum of Natural History
New York, New York 10024

AMNH Acquires Columbia University Collection

Our introductory column (*Record,* **11**, 40) served to acquaint the readers of the *Record* with the new faces and facilities here at the American Museum. Most mineral collectors would love to go on a "behind the scenes" tour of their favorite museum. Alas, if we were to offer this service on a full-time basis, we would have time for little else. We hope this column will serve as your "vehicle" for contact with the mineral collections of the AMNH. So, let's unlock a few of the cabinets and see what we find.

We are delighted to announce the recent acquisition of the Columbia University systematic mineral collection. Columbia has been a part of the New York scene since 1754 when King George II granted a charter for the establishment of an institution of higher learning. In the 1850's, the purchase of the collection of James Renwick, the first professor in geology, marked the beginning of the Columbia collection. With the opening of the School of Mines and Metallurgy in 1864, Thomas Egleston, as chairman, made the collection grow in significance and size. Ultimately, the Columbia collection became one of the finest mineral collections ever assembled in the U.S. and today contains approximately 40,000 specimens. Its purchase represents the largest acquisition of minerals ever made by the AMNH. We are indebted to the administration and trustees of the museum who had the foresight to recognize the immense value of the Columbia collection and were able to raise the funds necessary for the purchase.

The decision to sell the collection was made after considerable deliberation at Columbia. The cost of maintaining a full-time curatorial staff is often a burden that a university is not in a position to handle. With AMNH virtually next door, there was no cultural demand for a museum display at Columbia. The past decade also witnessed a shift in the research emphasis of the Department of Geological Sciences away from classical geology and towards the specialized areas of geophysics, geochemistry and oceanography. Consequently, there were no longer direct research needs of the mineral collection, which, in any case, can now be supplied by AMNH. Columbia will use the purchase funds for the endowing of a professorship, while it is retaining a teaching collection of between 5,000 and 10,000 specimens. An extraordinary 30-ounce platinum nugget obtained by Professor Egleston in trade from Czar Nicholas II of Russia in 1869 is also being retained by the University. Other specimens obtained in that historical exchange *were* acquired by the AMNH.

The bulk of the collection will be temporarily stored in 24 of the original oak cabinets used to house and display the collection when it was exhibited in Columbia's Schermerhorn Hall; these have been double-stacked to conserve space (see photo). Larger specimens and overflow from the oak cabinets will be stored on steel shelves. We estimate it will take from 3 to 5 years to unpack, inventory, catalog and integrate Columbia specimens into the current AMNH mineral collection. As soon as the specimens have been unpacked and temporarily stored, they will be available for study by the scientific community (by the time this is published).

Most of the world's great mineral collections were built around the fabulous private collections assembled during the middle to late 19th century. The heart of our collection is the Clarence S. Bement collection acquired in 1901. Similarly, one can name the Roebling and Canfield collections (Smithsonian), the William S. Vaux collection (Philadelphia Academy of Science), the A. F. Holden collection (Harvard Mineralogical Museum)—and the list goes on. All of these collections were assembled with the idea of obtaining the finest crystallized examples of minerals then available. Consequently, localities which were producing specimens in those early days are heavily represented in these collections.

One of the great values of the Columbia collection lies in its diversity and scope. Representing the combined efforts of several generations of Columbia geologists, this remarkable collection was assembled more from a scientific than an esthetic viewpoint. Specimens were collected from mineralogically interesting localities, regardless of whether they produced finely crystallized minerals. Equally important, the Columbia geologists who visited classic Dana localities collected massive examples or even gangue associations, as well as the more esthetically pleasing crystallized varieties. For example, we had never seen a plain massive chunk of chalcocite from Bristol, Connecticut, until we encountered several in the Columbia collection. This is important because a massive piece can be extensively sampled for research while an esthetic crystal cannot, or at least should not. Virtually all of the Bristol chalcocites in the AMNH mineral collection are valuable crystallized specimens and sampling them for research would be difficult if not totally inadvisable. Ever seen any of the gangue minerals from Kongsberg, Norway? Columbia has them! Another strongpoint of the Columbia collection is its incredible European locality representation. Obscure localities in Germany, France, and particularly the U.S.S.R., are present in abundance. It would almost appear that Columbia's geologists sampled every quarry and building site in Europe during the latter half of the 19th century.

The quality of the 2,000 to 3,000 display specimens varies as you might imagine, though we've really only seen the "tip of the iceberg" so far. However, what we have seen is very exciting. An impressive suite of crystallized sulfides and sulfosalts from Sonora, Mexico, stands out in particular. Choice acanthite, pyrargyrite, polybasite and stephanite specimens are abundant. The stephanite is perhaps the most interesting. One specimen consists of an enormous crystal over 5 cm across with another 2.5 cm crystal attached to it.

Superb examples of the above species from Freiberg, East Germany, and Andreasberg, Harz, West Germany, were found. One especially impressive specimen from Freiberg consists of a compact mass of thick wire silver partially altered to acanthite and studded with equant acanthite crystals averaging 1 cm across. This specimen measures 10 x 7.5 cm. We opened a box labeled "pyrargyrite—Andreasberg, Harz" and found no less than six competition-quality thumbnails. Similar materials have also been uncovered "sleeping" in the study part of the collection; we expect to find a fair percentage of "sleepers" before we're through cataloging.

We could go on and on listing the incredible display material we've discovered so far. However, we will describe some of the other mineral specimens we've recently acquired (an in-depth article on the fascinating history of the Columbia collection as well as a detailed photo-documentation of its more important exhibit specimens is now in preparation). We've just acquired another "world beater" from David Wilber: a stupendous wire silver from Kongsberg, Norway. Some of you may recall seeing it at last year's Detroit Show, displayed next to Dave's remarkable crystallized gold specimen. Previously owned by Keith Proctor and Peter Bancroft, this specimen certainly ranks as one of the finest silver specimens to have escaped the Kongsberg smelters (see photo).

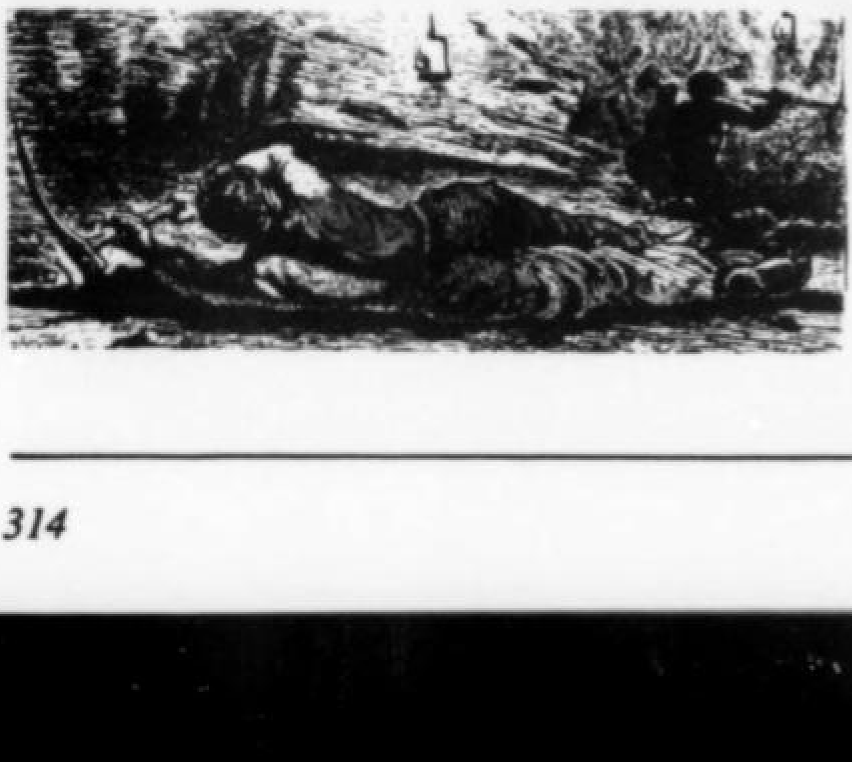
A number of superb specimens were acquired at the recently concluded Tucson Show. An exciting collection of beryl crystals was obtained from *Pala Properties International.* A tapered, pastel-green aquamarine 14 cm long, from Minas Gerais, Brazil, was especially outstanding as was a golden-yellow 13-cm-long Brazilian helidor crystal. Both crystals came from the collection of Gilbert Gauthier of Paris. A suite of fine, transparent, green aquamarine crystals from Afghanistan was also acquired. The best crystal is a perfectly formed prism 7.5 cm long. Also from *Pala Properties* were a translucent spray of azurite crystals reminiscent of the Zacatecas material, a superlative crystallized andorite group from Bolivia with individual crystals averaging 1.5 cm across, a fine Congo dioptase miniature and last, but not least, a doubly-terminated corundum (sapphire) crystal from Sri Lanka measuring 8.75 cm from tip to tip. This fine crystal was previously owned by Hermann Bank of Idar-Oberstein and David Wilber.

A suite of transparent spodumene (kunzite) crystals from Afghanistan was obtained from Herb Obodda. Through Herb we have assembled a most comprehensive collection of specimens from the gem pegmatites of Afghanistan. The collection contains scores of superb kunzites, aquamarines, morganites, tourmalines, as well as some of the less common species like cassiterite, samarskite and väyrynenite. An excellent suite of Afghan minerals donated by Dr. and Mrs. Julian Reasenberg of New York City further strengthens this collection.

An interesting suite of beryl (morganite) crystals from Haddam Neck, Connecticut, was obtained from Lawrence Conklin. A number of superb specimens were obtained from Larry in past months. Among the most notable is an azurite crystal group from Chessy, France, measuring 15.0 by 10.0 cm with individual crystals averaging 5.0 cm across. Another standout is a crystallized sphaerocobaltite from Shaba, Zaire. This species rarely forms crystals.

The museum has been receiving a number of outstanding minerals and gems via donation in recent years. Space doesn't permit us to relate them all, so we'll limit our comments to one collection of special merit, donated by Allan Caplan of New York City. It contains a number of very fine pegmatite and gem crystals. A super, doubly-terminated corundum (sapphire) crystal of good blue color from Sri Lanka will make a fine companion piece to our other newly-acquired crystal. An exquisite group of gem-quality emerald crystals averaging 2 cm across in matrix from Muzo, Colombia, was also impressive as was a tantalite crystal 12.5 cm long from Minas Gerais and a columbite crystal 7.5 cm across from Beecher Lode, South Dakota.

If you'd like to see some of the specimens described in this column, we suggest you pay a visit to the American Museum's Mineral and Gem Hall. These specimens, along with many others not described, will be displayed in our newly installed "Recent Acquisitions" and "Special Exhibition" cases.



BOB SULLIVAN'S

LETTER from EUROPE

As a result of the present situation in Afghanistan, the supply of minerals from this country has just about ceased including the famous rich blue lazurite (lapis lazuli) from Firgamu, Badakschan. Prices on the lapis have risen sharply and stocks of the pegmatite minerals which had been coming principally from Pech, Nuristan, have rapidly dwindled. However, "where there is a will, there is a way," and early this spring an excellent small lot of aquamarine specimens was brought out of Afghanistan, reportedly over the Khyber pass and on down to Karachi, Pakistan. A few of them were subsequently available in France but the bulk of the collection, consisting of about 100 major pieces, was offered at the Intergem show in Denver, Colorado, in late April.

The location was stated to be near the town of Kunar in the province of Kunar in northeast Afghanistan. To my knowledge this is the first time this locality for aquamarines has been reported, but the mine has apparently been worked for some time as the recent specimens were actually taken out of this mine more than a year and a half prior to their appearance in Europe and America. The small town of Kunar lies in a deep valley cut by the Kunar river, about 8 miles from the major town of Narang on the opposite side of the river, and is about 10 miles as the crow flies from the northern border of Pakistan. In between, however, is an extensive, high mountain range with peaks ranging from 15–16,000 feet topped by 25,230-foot Tirich Mountain, about 100 miles north of Kunar. Kunar lies in a strategic valley about 175 miles from Kabul and about 80 road miles via Jalalabad to the Khyber pass. As I write this in May, there is very heavy fighting going on in the general area of Kunar and reportedly the mine is inactive.

There are several things that characterize these aquamarine specimens as quite special, one of which is their extreme gemminess. Many of the crystals are completely gemmy "tip to toes" and most contain at least 60–70 percent facet rough which also accounts for their rather high price. Crystals range generally in size from 1 to 2¾ inches in length, with a few reaching 4 to 5 inches. Generally speaking, the crystals are long and slender, and one nearly 5-inch long single aquamarine crystal has a ¾-inch pink morganite crystal attached at the base of it. Truly attractive! Another specimen contains a movable water bubble, something rather frequently seen in quartz crystals but rarely in aquamarine.

The sharpness of the crystals is especially notable, some having razor-like edges, and on most of them the terminations are highly modified. The typical flat termination of aquamarine is really conspicuous by its absence and in the accompanying photo the two larger crystals have 12 and 13 faces respectively at the terminated end. Several of the specimens contain one or two very fine gemmy crystals attractively protruding from a typical biotite-albite matrix. The largest of these was a 4 x 5 x 8-inch beauty containing two very gemmy aquamarine crystals, one about 5 inches and the other about 4 inches long with the asking price in the 8 kilobuck region. If there is any drawback to the specimens, it is the paleness of the blue color which to me perhaps reduced their value as gem material but detracted little from them as really fine examples of the beryl family. (See *What's New in Minerals?* in this issue for more information on Afghan minerals.)

Thanks to Wendell Wilson who took all of the accompanying photos, I am able to catch up a bit on some of the mineral finds mentioned in recent columns. It is hoped that in the future more photographic examples can be provided which in turn may ease the task of reading some of those long descriptions I have had to use in the past.

Figure 2 shows a group of those Arizona hematite "iron roses" found in the Quartzsite area in 1974 and mentioned in my last two columns. They are from our personal collection and range in size from 0.6 to 0.8 inches in diameter. Mike Sprunger, who found the pocket, points out a couple of corrections on this find as it was originally reported by me (vol. 11, no. 1, p. 30) and the *Record* previously (vol. 10, no. 3, p. 189). First, the very large, 2½-inch diameter, gorgeous hematite from near what is now known as the Veta Grande claim is not an iron rose and by the time you read this a photograph of it should have appeared in the *Record* (Arizona-II issue). Also it was found about 20 miles from where the iron roses came from, all of which adds up to the fact that the biggest iron rose was about 1 inch and not 2½ as originally mentioned in my columns. No one has yet disputed the suggestion that they are perhaps America's first iron roses, and the world's first double-sided-floater iron roses, but I am still waiting to hear any challenge to these claims.

You may recall the "prominent Swiss collector" who said I could not quote him when he commented that the Arizona iron roses could not be from Arizona as they were bet-

Figure 1. **Water-clean, pale blue beryl crystals from Kunar, Afghanistan. The largest crystal is about 1¼ inches.**

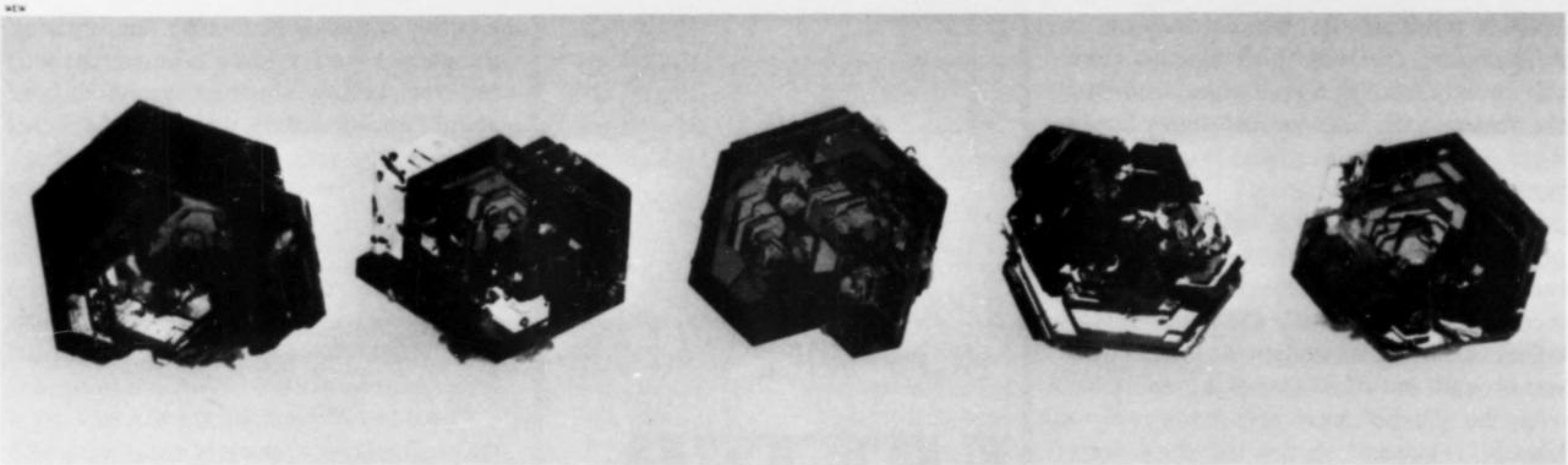


Figure 2. **Double-sided hematite "iron roses" from near Quartzsite, Arizona. The largest rose is a little over ½ inch.**

ter than the Swiss ones (this in my vol. 11, no. 1 column). Well, a recent letter from him says I can now quote him and you may be surprised to learn it was Eric Offerman, a staff photographer for the *Record* and a friend for quite a few years. Eric writes "although I am a Swiss my national pride goes not so far as to avoid admitting that there are better iron roses than the Swiss ones." Eric does point out correctly, however, that some of the Swiss ones are bigger, "but what does size mean to me?" Thanks for coming out of the bushes Eric!

Figures 3 and 4 illustrate the really fine gold-coated native copper from the Andacollo mine near Coquimbo, Chile, mentioned in my last two columns. You may recall that these unusual copper specimens were found in a mine in Chile in 1968 but remained in storage in Germany for 10 years and did not appear on the mineral scene until the spring of 1979.

Morocco has done it again, this time harking back to the famous locality of Mibladen for a late spring surprise of super vanadanite specimens. The mines at Mibladen, which have been closed since January of 1976, for many years produced the world's finest vanadanite plus an assortment of other fine minerals including cerussite, barite, anglesite, galena and, less frequently, wulfenite. The most highly prized specimens were those of rich gemmy vanadanite on a matrix of pure white, bladed barite, but since the barite zone of the mine had been passed through in mid-1974, they have until now remained a thing of the past.

Most of Mibladen's original 150 miners have moved away and the small village which was totally dependent on the mine's operation is virtually deserted. Some of those who remained continue to pick away at various areas of the mines, searching for minerals, and they are occasionally joined by other former residents now living in Midelt or Aouli, each about 10 miles (16 km) in opposite directions from Mibladen. For obvious reasons most of this "work" is done at night and occasionally there is a "hit" but it has been quite a few years since anything of real significance has been found.

Not so this past April, for a pocket which was hit in the old barite zone was both sizable and prolific. It produced about 75 major pieces of vanadanite on barite ranging in size from 2 to 8 inches in diameter; about 90 percent of these ended up in the hands of an on-the-ball French dealer. It has generally been true in the past that the vanadanite crystals found on white barite have been exceptionally gemmy but smaller in size, seldom reaching ⅖ inch in diameter. Also the color has been more brown than red. The very large, deep red crystals which really made Mibladen famous have always been found in other sections of the mine and on the more common soft rhyolite matrix. Many of the very gemmy crystals in the latest pocket, however, exceed ⅗ inch and the color ranges from a rich brownish red in the larger crystals to a bright orange in some specimens on which a secondary deposit of microcrystals of vanadanite has occurred. According to several veteran collectors, these specimens are considered to be among the best, if not *the* best to have ever occurred in the combination of vanadanite on white barite. Prices range from $100 up to several thousand with the asking price on the 8-inch beauty being $5,000. A really fine cabinet specimen approximately 3 by 4 inches could be had for $650–750 which I thought a pretty fair price for a super specimen of this rare combination. It is unlikely that many of these pieces will reach the States but if so, prices will be at least doubled. Meanwhile, quite a few French collectors in particular were delighted by the new find, and once again the month of April came through as a "hit month." *(FLASH—Victor Yount just acquired an excellent lot of these. Ed.)*

Congratulations to Michael O'Donoghue of Sevenoaks, Kent, England, on his first-of-the-year appointment as editor of the British lapidary and mineral magazine *Gems.* Michael, who has been a frequent correspondent, carries a flock of letters after his name, eight to be exact, and is not only one of England's top gem experts but also has a very keen interest in minerals. I have always enjoyed *Gems,* now in its 12th year, and have especially liked their locality articles covering all of the United Kingdom and Ireland. Best of all I have enjoyed reading an overseas mineral magazine in my own language!

According to Michael the mineral collecting side of the hobby is beginning to grow more rapidly in England and he intends to place more emphasis on the subject as well as the more serious side of gemmology and mineralogy in future issues of *Gems.* England has been very strongly oriented towards lapidary and jewelry making and if you have ever attended a British show, this fact is most obvious.

Gems is published six times a year by The Randall Press Ltd., 9 Kennet Road, Crayford, Kent, England, and costs £3.50 (about $7.50) surface mail, £6.00 (about $13.00/yr.) airmail.

It has always amazed me how certain minerals show up in England that are seldom seen or imported into America or continental Europe. Certainly the minerals of the ex-colonies are very well represented but this is to be expected. Russian minerals also appear rather frequently and England seems to have an exclusive on the direct import of diamonds on matrix from the Mir Pipe, Yakutia, Siberia, Russia.

But there are many others and, as a result of correspondence with Michael O'Donoghue, perusal of various dealers' lists and discussions with several visiting English dealers, I can present here a few of the more interesting offerings I have seen in the last six to eight months. (The British are sticklers for correct locality information, a fact which may be worth noting on some of these.) They include alexandrite sixlings from Campo Formoso, near the Carniaba Emerald mine, Bahia, Brazil; also single small crystals from Espirito Santo, Brazil; alexandrite, including sixlings, from Fort Victoria, Rhodesia and also "from Russia;" anglesite crystals on galena from the Antelope mine, Zaire; celestite and selenite crystal groups from Turkistan, Russia; gold on quartz from Rhodesia; pyromorphite

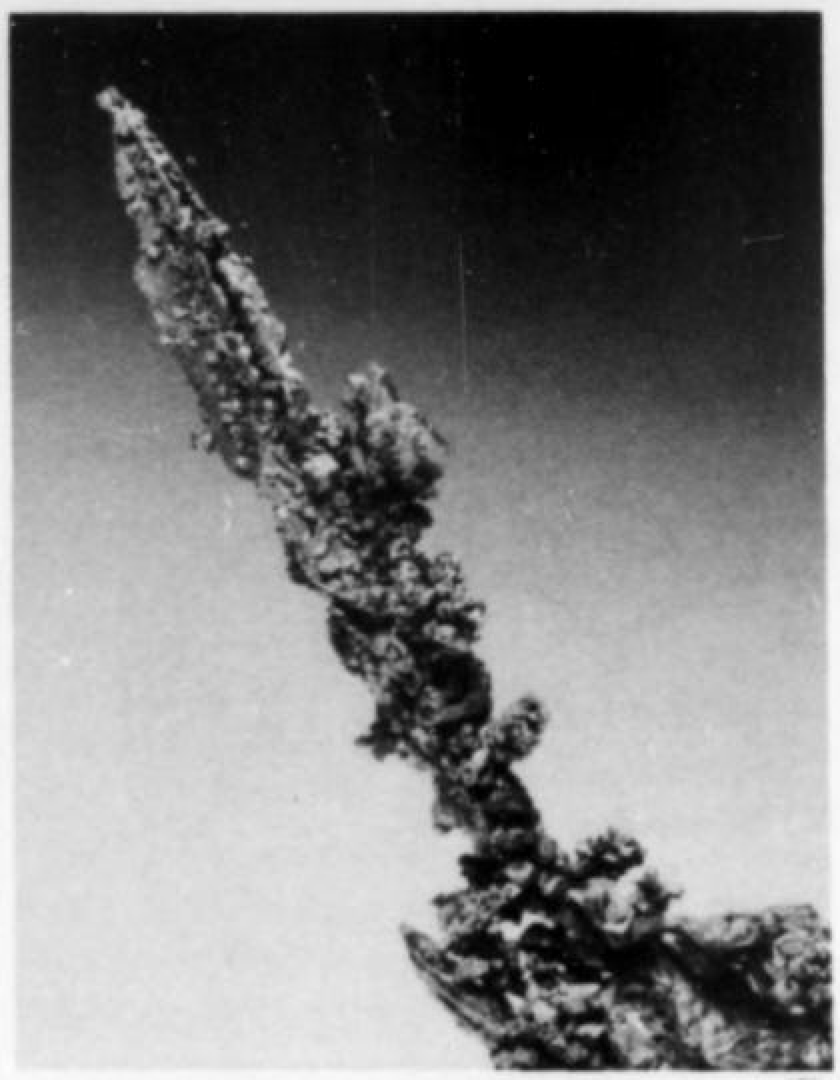


Figure 3. **Gold-coated copper crystals from the Andacollo mine near Coquimbo, Chile. The spear is about 2 inches long.**

crystals with crocoite from Russia; twinned amblygonite crystals from Linopolis, Minas Gerais, Brazil; colemanite groups from Eskisehir, Turkey; phenakite crystals and groups from San Miguel de Piracicaba, Minas Gerais, Brazil, and others. Being an axinite admirer, my eye was caught by one notation in particular: "large axinite crystals, some with tourmaline" from Santa Rosa, Bahia, Brazil. They are up to 3 inches long and are most unusual in that, as Michael describes them, "a decided orange-red in one of the directions with much less of the purple component than I'm used to seeing in most axinite." Here are a few more: golden beryl crystals with smoky quartz and orthoclase from Tokojawa, Urals, Russia; (this one sounded most intriguing) dioptase crystal groups from Katanga, Zaire; terminated, transparent topaz crystals in white and pale shades of blue and green from Nigeria; vivianite crystals on matrix from Czechoslovakia, also wulfenite crystals groups from the same locality; crystallized native copper groups plus rhodonite crystals on galena from Mufulira, Zambia; and finally, some unusual locations for emeralds including Zambia, India, the Ural Mountains of Russia, Red Sea, Egypt, and Habachtal near Salzburg, Austria. So much for England.

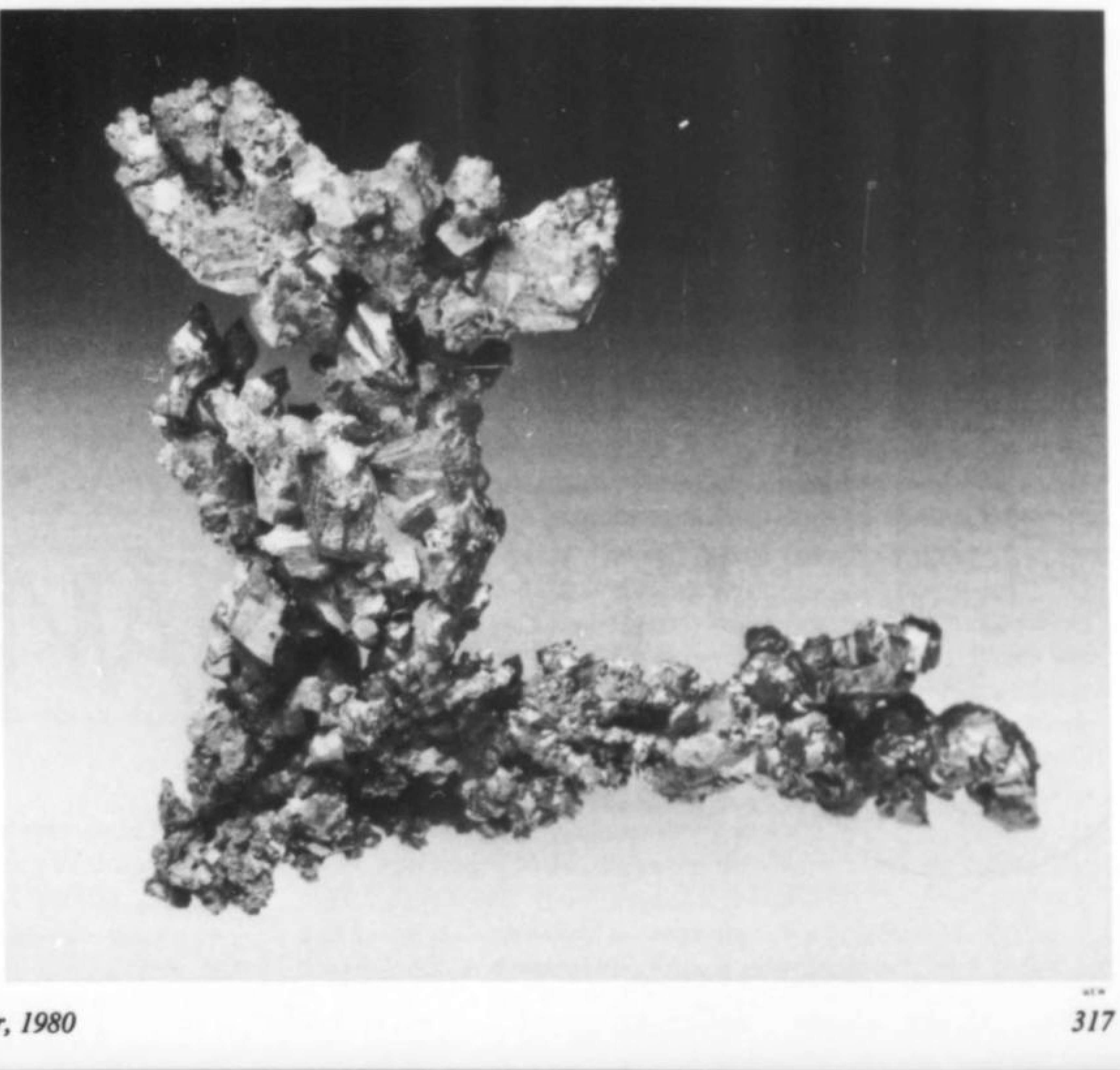
Here is the latest rundown on some of the 1980 fall and winter European bourses as listed by the German mineral and gemstone magazine *Lapis.* Altdorf, Switzerland, Sept. 6–7; Brussels, Belgium, Sept. 13–14; Cologne, Germany, Sept. 20–21; Hannover, Germany, Oct. 4–5; Paris, France, Oct. 4–5; Torino, Italy, Oct. 10–12; Munich, Germany, Oct. 17–19; Zurich, Switzerland, Nov. 8–9; Stuttgart, Germany, Nov. 8–9; Basel, Switzerland, probably Dec. 6–7; Paris, France, Dec. 6–7. Before making any plans with respect to these bourses, be sure to check out the dates as a few of them are subject to changes.

Speaking of *Lapis,* in the January 1980 issue they really stole the show with a featured article in color about the sensational "cranberry" tourmaline find of April, 1978. The article by Simone and Peter Huber of Wiener Neustadt, Austria, was beautifully illustrated with three large color photos taken by them and I must say the "cranberry" color reproduction was just perfect. The authors pointed out that in America this particular color of rubellite is known as "cranberry tourmaline," with the cranberry being akin to the European "preisel" berry. To them the color does not resemble the "preisel" berry but is closer to that of a ripe raspberry. Being an old New Englander who has lived in Europe for more than fifteen years I can only comment that the much smaller woodland "preisel" berry is quite a different colored berry than a true cranberry and I will go along with "cranberry" tourmaline as being the most appropriate description. It should be noted however that "cranberry" tourmaline does have many minor variations in color and this can readily be seen when one examines a tray of faceted gemstones cut from these crystals.

The Hubers visited the mine site and surrounding area taking detailed notes on all aspects of the find. In their article they pointed out that the site of the mine was 3 miles (ca. 4.8 km) southeast of Conselheiro Pena whereas in previous reports it had been placed both "3 miles east," Lallemant (*Record,* vol. 9, no. 5) and "5 km west," (Keller, *Record,* vol. 10, no. 1). The authors also visited Jonah Lima's home in Governador Valadares and, by paying him 200 cruzeiros each (then approximately $8.00), they were able to view the 4 major pieces in their individual glass cases, including the famous 42½-inch "rocket" rubellite crystal on matrix. Each piece was described in great detail and it was easy to imagine their individual beauty. The real surprise, however, was a beautiful colored sketch the Hubers had made of the most beautiful specimen. This consists of two very large rubellite crystals 10 x 20 inches and 10 x 12 inches attractively growing out of a 3-foot diameter matrix composed of large white albite aggregates and two intergrown, lightly smoky quartz crystals 18 and 8 inches long. Quite a piece, and the Hubers are to be congratulated for bringing the world this fine sketch. Someday, though, I hope Jonah may allow the pieces to be photographed!

While dashing up the stairs of the Desert Inn at the time of the Tucson show I was flagged down by a young fellow from Rome and quickly hauled into the coffee shop to hear his story. Seems like he was an avid reader of the *Record* and was well aware of the sensational blue anatase find from Norway covered in the Europe issue (vol. 8, no.

Figure 4. **Gold-coated copper crystals from the Andacollo mine near Coquimbo, Chile. The group is about 1¾ inches in size.**



4). What he wanted me to know was that just a few months before, at Val Veny on the Italian side of France's Mont Blanc (called Monta Bianco by the Italians), several pockets of rich blue anatase, also on quartz crystals had been discovered. The quartz crystals were small, seldom exceeding ⅖ inch and from most of the pockets the anatase averaged 0.1 to 0.2 inch in length. From one super pocket, however, the beautiful blue anatase crystals ran up to 0.6 inch in length and averaged about 0.3 inch, large by any standard. He was very enthusiastic about the find, said it was still being exploited and he had high hopes for some really super specimens in the near future. Unfortunately I didn't even get his name, but I thank him for the information anyway (and I hope he'll write me).

Incidentally, I have seen no mention of it anywhere, but to me one of the finest minerals to show up at Tucson was one of the rare ones, the world's best skutterudite from the cobalt mine at Bou Azzer, Morocco. It was offered by several dealers including one from France. The silvery crystals run to quite large size, some exceeding an inch and are especially sharp and very brilliant. Normally skutterudite from this locality occurs mostly in rather flat, uninteresting, crystallized plates but not so these beauties, whose variously sized crystals are attractively stacked up in many esthetic forms. They are available from thumbnail to fist size, and on many of the specimens there has been a partial secondary dusting of fine, extra bright skutterudite which adds even more to their attractiveness. Thumbnail and miniature specimens were eagerly snapped up by competitive collectors who seem to feel they represent a fine balance between rarity and beauty. They were somewhat expensive, with a top miniature being in the $150-plus range. The cobalt mine at Bou Azzer lies from 170 miles southeast of the major Moroccan city of Marrakech and is equally famous for its superbly crystallized erythrite and roselite, both of which also rank among the world's best. Unfortunately the portion of the mine which produced these latter two minerals has been closed for quite a few years, but the mine dumps do occasionally yield some good examples which usually command top prices when they reach today's market.

Incidentally, what with the rash of fine minerals appearing from Morocco these days, you might want to go back and review the literature on this fascinating country. You don't have to go very far as the September–October 1976 issue of the *Record* (vol. 7, no. 5) contains two very fine articles on Morocco and its minerals, complete with many excellent colored photos. That's it for now and special thanks go to my good friend C. Gobin of France for information on the recent Moroccan vanadanite and to Linda Kubler of Switzerland for helpful information on the European mineral scene.

Cheers,

Bob Sullivan

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Tucson, Arizona 85705
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THE HISTORICAL RECORD

by Ron Bentley
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Tucson, Arizona 85710

Yes, I've now moved to Tucson as well, I'm happy to say. (*Bentley's Minerals* is not fully operative at present, but visits and correspondence from customers and friends are still welcome.) Tucson seems to be enjoying renewed activity as a mineral center these days. Aside from the world-famous annual show, Tucson boasts a growing number of mineral dealers. *Bideaux Minerals,* now under Dick Bideaux, Gene Schlepp's *Western Minerals* and Suzie Davis' *Davis Minerals Inc.* are among the long-time resident dealers (the phone book lists seven more). Not long ago Bob Sullivan, dealer and *Record* columnist, moved in; a California dealer (who wishes to remain anonymous for the moment) just recently bought Tucson property with the intention of relocating here in a couple of years; Beth and Stan Lesnick (*The Lesnicks*) already own a house in Tucson and are planning to move in permanently. Just a stone's throw away in Bisbee, Dave Garske is getting settled after his recent move, and Jack Lowell's *Colorado Gem and Mineral Company* is just a couple of hours to the north. With the huge number of California dealers a day's drive to the west, and the wholesale center of El Paso even closer to the east, Tucson seems ideally located. Figure in the climate, the beautiful scenery, and the field collecting possibilities, and there remains no doubt that Tucson is an excellent place to be! I wouldn't be surprised if future years see the resettlement of even more dealers in Tucson.

Enough of the present and the future; let's get back to the past. Earl Pemberton recently passed along to me some interesting diary entries written by George Burnham, long-time California mineral dealer (*Burminco*). George wrote these while on a collecting trip in Africa in 1951, nearly 30 years ago, and they still make enjoyable reading for envious collectors.

Tuesday, March 27, 1951: Broken Hill (Zambia)

I arrived at Broken Hill at 8:45 this evening . . . another gosh-awful hotel without plumbing.

March 28

At the Broken Hill mine this morning I met Mr. Gleeson, the manager, who told me that no fine crystals are now coming from the mine. The mine is now working below the oxide zone where crystallized minerals had usually occurred. However, he said that I might find some specimens on the dump. . . . We hadn't been on the dump 5 minutes before I was finding excellent specimens of tarbuttite crystals, also hopeite, parahopeite, and a few specimens of beautiful green pyromorphite crystals. A rough count at dusk established a figure of about 200 specimens of the various minerals in all sizes.

March 29

I've collected a large number of fine tarbuttite specimens today. Their method of occurrence reminds me very much of the adamite from Mexico. The crystals occur in a box-work of limonite, and are about the size of Mexican adamite crystals. I found also today a little more hopeite and parahopeite.

April 4

Six more days of collecting on the dump, each producing about the same number and quality of specimens, mostly tarbuttite. Tonight finds 1000 specimens of selected tarbuttite collected and I shall consider this enough. I sorted these out from about 1500 specimens collected altogether, and threw away those which were second-rate. There are only 5 or 6 specimens of hopeite and about 100 specimens of parahopeite. I'm disappointed in being unable to find more hopeite.

April 7

This has been a banner day. I finished packing all the specimens collected at about 10:30 this morning, but the last box was not quite full. I had seen a band of white smithsonite in the wall of the old abandoned open pit workings nearby, so I decided to finish filling the last box with some of these. I had dug at the smithsonite only a few seconds when my chisel broke through a thin wall into a cavity lined with gorgeous crystals of hopeite. It was one of the most beautiful sights I've ever seen. These crystals are translucent and orange in color—about the color of wulfenite from Los Lamentos, Mexico, but much more brilliant. Tongues of smithsonite and limonite in wierd shapes protrude into the cavity and these were covered with crystals of hopeite up to ¾ inch long, glistening like diamonds. In some places I dug out fragile, solid groups of crystals in dendritic masses. I found tonight that I had an even 100 specimens ranging from 1 x 2 inches to about 8 x 10 inches and at least that many more smaller ones.

April 9

All the hopeite specimens were packed by noon today and I began to hope that I would get away from here tomorrow. However, when I went back up to the diggings to bring down my tools, I couldn't resist poking around once more in the cavity before leaving it. Tapping on the back wall of the vug produced a suspiciously hollow sound, so I attacked it vigorously with hammer and chisel and a long bar I had found. The wall soon broke through to reveal *another* cavity behind, lined with more of the beautiful hopeite crystals. I had to lie on my back in the hole with only my feet and legs from the knees down protruding. It required all afternoon, but I dug out another 75 or so excellent specimens.

April 12

Fortunately there was a passenger train from Broken Hill today. I was scheduled to leave at 12:40 but was just under 2 hours late. With wonderful relief I left Broken Hill, which would not be at all a bad place were it not for having to stay at that hotel.

Monday, April 23, 1951: Brazzaville, Congo.

At 7 o'clock this morning Mr. Rebout, government geologist, and Mr. Briot, government mining engineer, picked me up at the hotel and we were off to the dioptase locality at Reneville. We did not reach Reneville today. By the time we had extricated ourselves from being stuck in the sand several times, and had visited Mayama, it was too late to go on to Reneville this afternoon. We established camp in a native village on the bank of the Ojoue River. It was impossible to cross the river in our trucks, so we will have to cross it in native dugout canoes tomorrow and go the balance of the way, some 7 or 8 miles, on foot.

The route up here is picturesque. The road winds among rolling hills, the crests and sides of which are covered by green grasses and a few bushes. The canyons and valleys between the hills are thickly overgrown with jungle vines and rich, glossy-leaved trees among which are palms, bananas and tangerines. Nearly all the canyons contain streams and marshy ground. The steamy heat is stifling but the swarming insects seem to thrive in it.

We were courteously received in the village where we camped tonight by the chief, who brought us chairs, water in which to wash, and a large welcome bowl of tangerines. We bought a chicken from the villagers, and one of the boys is now cooking it over an open fire. We just sit around and let the native servants do most of the work of setting up camp, cooking, washing dishes, etc. Life is easy for the whites in this country. However, the place is infested with mosquitos. We'll sleep under netting tonight.

April 24

Our breakfast finished, we set off on foot for Reneville at sunup this morning. The trail over the hills led much of the way through coarse elephant grass which is quite thick and up to 12 feet tall. When the sun rises a little and beats down into this thick, steaming maze the heat and humidity are terrific. We walked rapidly for 2½ hours without rest in order to reach Reneville. The native bearers carried our lunch, water, tools and other equipment in baskets on their heads.

Reneville is a cluster of native huts near some copper prospects which had been explored some 20 years ago, but without becoming much of a success as a producing copper mine. However, the prospect pits reveal an amazing occurrence of magnificent dioptase crystals—emerald-green, some transparent and some up to an inch long. They are associated with azurite, quartz crystals, plancheite, cerussite and another botryoidal mineral which may be mimetite, descloizite or mottramite (I suspect the latter). Whoever mined here very thoughtfully piled all the dioptase in one place. In about 2 hours I had gone through the pile and sorted out about 750 crystallized specimens of dioptase ranging in size from about 1 x 1 inch up to 5 x 6 inches, averaging about 2 x 3 inches. By 3 o'clock we were back at camp, packed up and ready to return to Brazzaville.

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What's New in Minerals?

Peruvian rhodochrosite

Interesting specimens of rhodochrosite have been coming out of the Huallapon mine near Pasto Bueno, Peru, for a number of years (see for example, *Record,* vol. 9, no. 1, p. 36–37). Gary Hansen, Gary Nagin, and others have been working to bring them out. Ken Roberts visited Peru in March, and met up with the former physician of the Huallapon mine, now working at a hospital in Lima. During the year and a half in which the physician worked at the mine, he had accumulated a sizeable hoard of rhodochrosite specimens via the miners. These Ken was able to buy, 113 specimens including 54 thumbnails, several excellent miniatures and several superb cabinet specimens (one on the cover of this issue). The specimens are priced as low as $35, though the dozen or so top pieces are considerably higher. The best pieces all consist of rhodochrosite crystals on quartz matrix, the matrix in the form of "floaters" which have thin, colorless quartz crystals projecting from all sides. These floater specimens are so similar in habit that they probably all came from the same pocket. The rhodochrosite crystals themselves are interesting in that they are zoned, the cores lighter and less transparent than the outer zones. The crystals range in size up to at least 2 inches. The specimen shown in the Wright's Rock Shop ad (vol. 11, no. 3, p. 186), though obtained earlier, is of very similar habit. According to the physician, the miners saved the specimens he had acquired over a period of three or four years (though the best may still have been found all at one time). Prospects seem good for more rhodochrosite in the future, and several different dealers continue to obtain it on a semi-regular basis, although the level of quality will always be unpredictable.

***Chinese* azurite?**

Yes, Cal Graeber of *Pala Properties* even loaned a sample to be photographed for "What's New." The locality is Guong Dong province, and at least 100 specimens have come out thus far. The azurite crystals form single and double rosettes resembling Bisbee (Arizona) and Chessy (France) rosettes in habit. The prices are "relatively" inexpensive as fine azurite rosettes go . . . $500 to $1500. The Lesnicks have also received an excellent lot of these roses 1½ to 5 inches in size.

"New" garnet

Also new at *Pala* is a "new" garnet, chemically between rhodolite and spessartine but with distinctive refractive indices. The name it has been given is *malaya,* and it may turn out to be a new garnet species, but then again perhaps only a new variety; Vincent Manson at the Gemmological Institute of America in California is working on it. The new garnet is from Tanzania near the Kenya border—a more exact locality designation is unavailable—and ranges from a golden honey color to a peachy orange, cinnamon, and less attractive brownish shades. It makes fine gemstones, but unfortunately for collectors of mineral specimens it does not occur in well formed crystals. The material was actually discovered over 11 years ago, but was erroneously sold as spessartine in Europe. It currently is receiving wide recognition as a new gemstone (regardless of whether it turns out to be a new species).

More Euclase

Cal also reports that several more superb blue euclase crystals, doubly terminated and reaching 1¾ inches, have lately come from Rhodesia. And a new strike of lustrous azurite crystals and also mimetite crystals occurred at Tsumeb, Southwest Africa, a few months ago.

Pakistani pegmatite discovered

The indefatigable Herb Obodda has been getting some remarkable pegmatite minerals lately from a newly discovered deposit in Pakistan near the Afghan border. The pegmatite was apparently discovered by the Chinese while cutting a road through in order to supply the Afghan rebels in their battle against the Soviet Union. "Free lance" miners were able to work the deposit long enough to extract some superb specimens before the Chinese put it off limits.

Herb's associates have gone to the locality, and report that it is in the Haramosh Valley, between Gilgit and Skardu in Asad Kashmir province.

The lot acquired by Herb was shown at the Rochester Symposium. Many flawless, water-clear, pale blue crystals, some on matrix and reaching 3½ inches in length, were in that lot. Probably the best pieces were acquired by David Wilber. One consists of two long, pale blue beryl crystals on a matrix of mica books and beautiful pink apatite crystals to an inch or so. Other minerals in the lot include excellent pale brown topaz crystals in habit similar to Ural Mountains topaz and reaching 2 x 2 inches, although Herb has seen crystals that reach 4 x 4 inches. Also from the same deposit are

Figure 1. **Azurite rose 2⅛ inches across from Guong Dong province, mainland China.** ***Pala Properties*** **specimen. The crystal shows an attractive amount of blue color rather than being almost totally black like its Bisbee counterparts.**

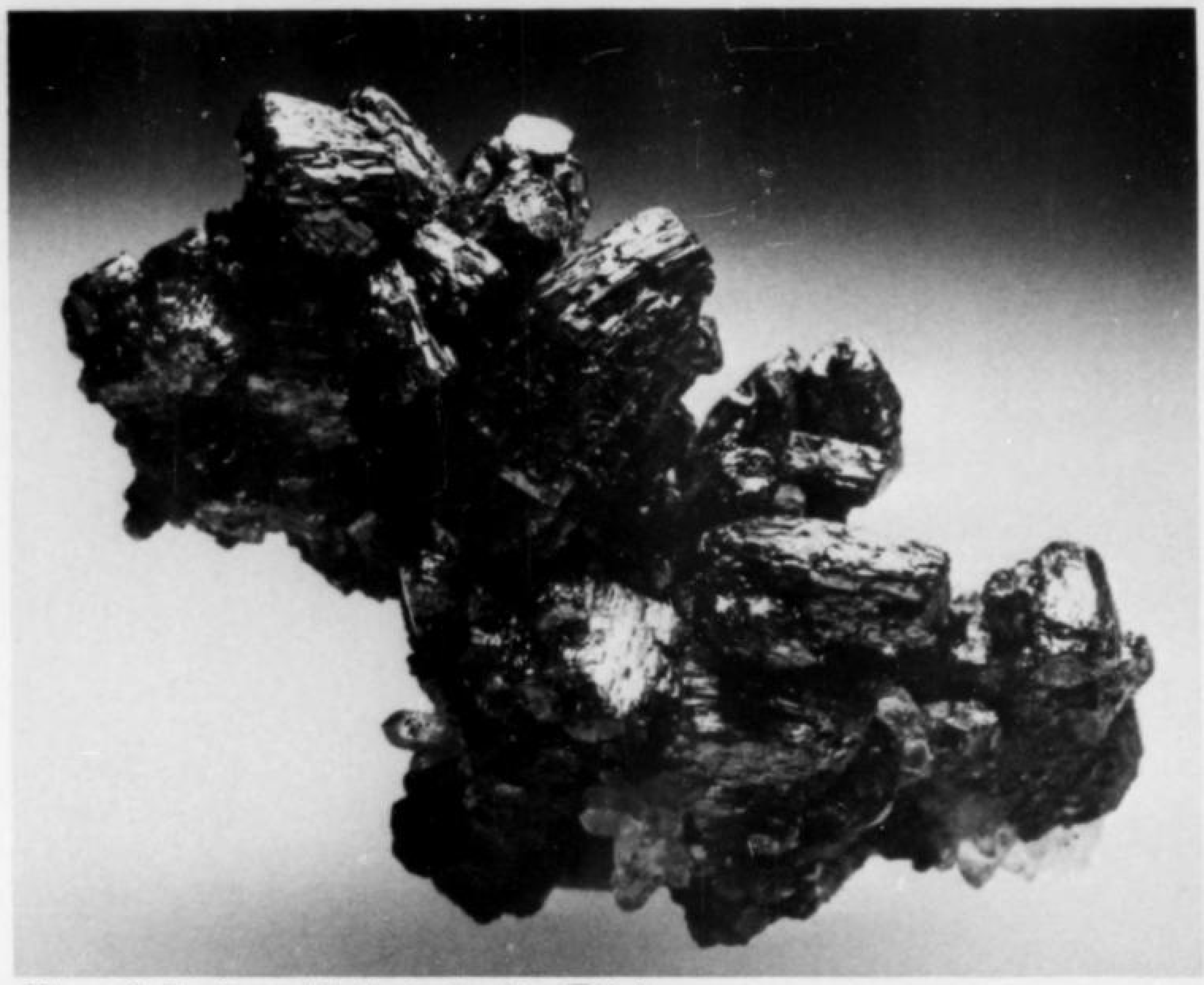

Figure 2. **Lustrous black stephanite crystals on quartz matrix 2 inches across from La Veta Grande mine, Zacatecas, Mexico.** ***Western Minerals*** **specimen.**

fine spessartine crystals to a half inch or more on white albite and, in some cases, on aquamarine. Herb reports seeing one specimen consisting of a spessartine crystal perched on a pink apatite crystal, which itself was perched on a pale blue aquamarine crystal!

The Afghanistan pegmatites near Mawi in Laghman province continue to yield material as well, and Herb has acquired some excellent kunzite (spodumeme) crystals to 3 inches *on matrix,* the matrix consisting of white albite, stilbite, and green tourmaline. These are probably the finest, and perhaps I should dare to say virtually the *only,* matrix spodumenes of any significance. Not on matrix but equally impressive is a lot of yellow spodumene crystals, blocky in habit and flawless, over 3 pounds in weight for the largest crystals.

Bob Sullivan reports on another Afghan aquamarine discovery (elsewhere in this issue) which sounds very similar to the above-mentioned Pakistani find. Both Bob and Herb have reliable sources for information, so both discoveries are reported in this issue as separate finds.

Mexican stephanite

Gene Schlepp of *Western Minerals* recently received a fine selection of large, black, semi-metallic-lustered stephanite from La Veta Grande mine in Zacatecas, Mexico. About a dozen pieces comprised the lot, with "crystals" to ½ inch. The crystals are crudely barrel-shaped and appear to be multiple crystals in parallel growth which approximate the outlines of large single crystals. They occur grouped esthetically on quartz matrix, making them some of the finest stephanites known.

More Bolivian cassiterite

Richard Bideaux of *Bideaux Minerals* has obtained a rather large lot of fine Bolivian cassiterite from Viloco. The crystals reach more than an inch in length, though most are somewhat smaller. They range in color from black to a transparent brown-green, and form blocky, equant crystals of typical form which are commonly twinned. Many occur on a matrix of small quartz crystals.

Chinese cinnabar!

The dream of many collectors is to own one of those well-known but highly scarce specimens of beautifully twinned cinnabar on matrix from mainland China. Recently Russell Behnke (Meriden, CT) succeeded in obtaining access through the Chinese, and has obtained not only fine cinnabar, but also the Chinese azurite mentioned above. Stanley and Beth Lesnick carried most of these cinnabars at the Washington, D.C., show early this summer and report that sales were brisk despite comparatively high prices. Thus far the Lesnicks have received 11 specimens of cinnabar crystals ⅛ to ½ inch in size on quartz matrix. There are from two to 12 crystals per specimen, with sharp edges and classic twinning. Charles Key received some of the Behnke specimens as well.

Record publisher John White attended last year's Munich and Torino Shows. His report follows; it should be of interest to people thinking about attending these shows this year.

W.E.W.

MUNICH AND TORINO—1979

The Munich Show (Mineralientage München) is probably in a class all its own. The 1979 version, the 16th in succession, was held on September 28, 29 and 30, dates which caused it to coincide with Oktoberfest in Munich. Due to its physical proximity to the show, Oktoberfest was both a blessing and a curse: a blessing to those mineral people who wanted to partake of the world's greatest beer-bust but it did, I feel, adversely affect the attendance at the show. The immense crush of people at the "fest" put a heavy strain on all facilities including hotels and parking. There was, however, no shortage of beer.

The show is held in a facility that is so large one must see it in order to believe it. The "Messegelände" covers many square miles with huge airplane-hanger-like exhibition halls; the Mineral Show is always in Messehalle 16. The full name of the show, for the curious, is *Internationale Fachmesse und Verkaufsausstellung für Mineralien, Edelstein, Fossilien und Zubehör.* (Deliciously German isn't it?) The last word, I believe, means "findings."

The Messehalle is certainly more than double the size of the floor space of the Tucson Show, probably closer to three or four times

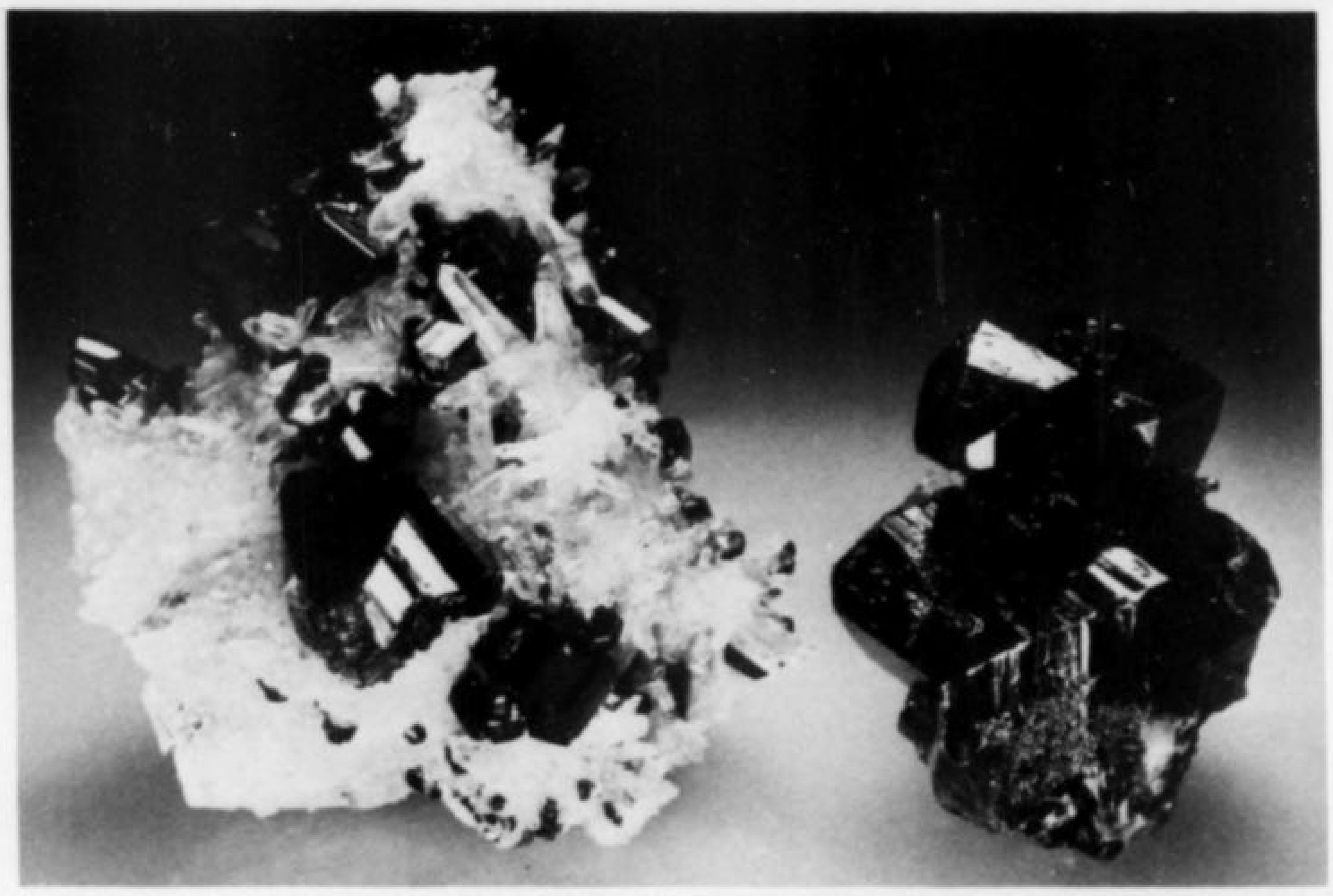

Figure 3. **Lustrous dark brown cassiterite crystals, one with quartz matrix, from Viloco, Bolivia.** ***Bideaux Minerals*** **specimens. The group on the left is 2⅓ inches tall.**

Figure 4. **Munich Show, 1979. The special exhibit consisted of individual specimens in competition. Photo by John White.**

Figure 5. **The** ***Gäste aus Übersee*** **(Guests from Overseas) section was devoted to American, Australian and other non-European dealers. Photo by John White.**

the size. The sponsors boast nearly 300 dealers, which comprise, of course, the heart of the show. This is an unabashedly commercial show and no pretenses of it being anything else are offered. As such it is phenomenally successful. Still, special exhibits are provided and they are always stunning. In '79 it was a selection of extraordinary specimens from the David P. Wilber (of Fallbrook, California) collection, including the world's largest phosphophyllite crystals (a twin) on matrix from Bolivia, magnificent wire silver and crystallized gold, and the "postage stamp tourmaline." An outstanding exhibit of old mining lamps was on view, made even more interesting by the use of two life-sized mannikins dressed in mining costumes.

The *finest of the dealers* is a feature unique (in my experience) to the Munich Show. A large rectangular enclosure is created by side-by-side stacking of glass display cubes to a height of about 2 meters. The cubes open to the inside of the enclosure only. All who care to may enter his or her favorite specimen, which is placed within one of the cubes, each with a label, of course. A panel of experts judges these entries. First, second and third place winners are selected in both a beauty and a rarity category.

The beauty winners for 1979 were (1st) an azurite crystal group from Touissit, Morocco, about 18 cm high, (2nd) a large, flaring, single elbaite crystal from Afghanistan, and (3rd) a wonderful group of lovely blue, radiating, needle-like wavellite crystals from Llallagua, Bolivia. Rarity had, for its winners, (1st) one of the strange, etched, fluorite crystals from the Elmwood mine, Tennessee, (2nd) a 5-cm Korean scheelite crystal on matrix and, (3rd) an immense specimen of deep red realgar on black matrix, etched out of calcite, from the Getchell mine, Nevada.

Bob Sullivan has commented on some of the material available at the show (*Record,* **11,** 113–116) so I will not. While a large contingent of North Americans was on hand last year, the prospects are less bright for a heavy American attendance in 1980 due to the unfortunate fact that Munich and Detroit are having their shows only a few days apart. The dates for Munich: October 17–19.

Fortunately, the scheduling of the Munich Show and that of the Torino (Italy) Show were such that I could attend both in one trip to Europe. The latter (October 13 and 14) was even larger than the former, but could not match Munich in most of the most important categories, such as high quality and great variety of minerals, and fame and excellence of dealers. Nonetheless Torino was well worth the effort and I hope to return very soon. In order to provide a measure of size, I can report an estimated one kilometer of dealers' tables and a two-day attendance of more than 50,000 people.

There was, of course, an abundance of Italian material, especially Piemonte, Sardinia and Sicily minerals. From the Piemonte were numerous specimens of grossular, vesuvianite, perovskite, epidote and schorl. Of the many Sicilian and Sardinian minerals sulfur, aragonite and barite were most abundant, with Elba pyrite and hematite also well-represented. There were, of course, many other things to see, enjoy and buy, such as Romanian stibnite, Moroccan azurite, Tasmanian crocoite, Saharan gypsum (roses) and Spanish fluorite.

Perhaps the most satisfying aspect of the show, however, was the cordiality and the warmth of the sponsors. In spite of continual rain and unbelieveable crowds they were always courteous and friendly. One left with the feeling of warmth that comes from sharing a common interest with enthusiastic collectors who pursue the mineral hobby for the love and sheer joy of it. I heartily endorse Torino. As if the minerals weren't enough, the countryside abounds with truffles and some of the best wild mushrooms that can be found anywhere.

John Sampson White

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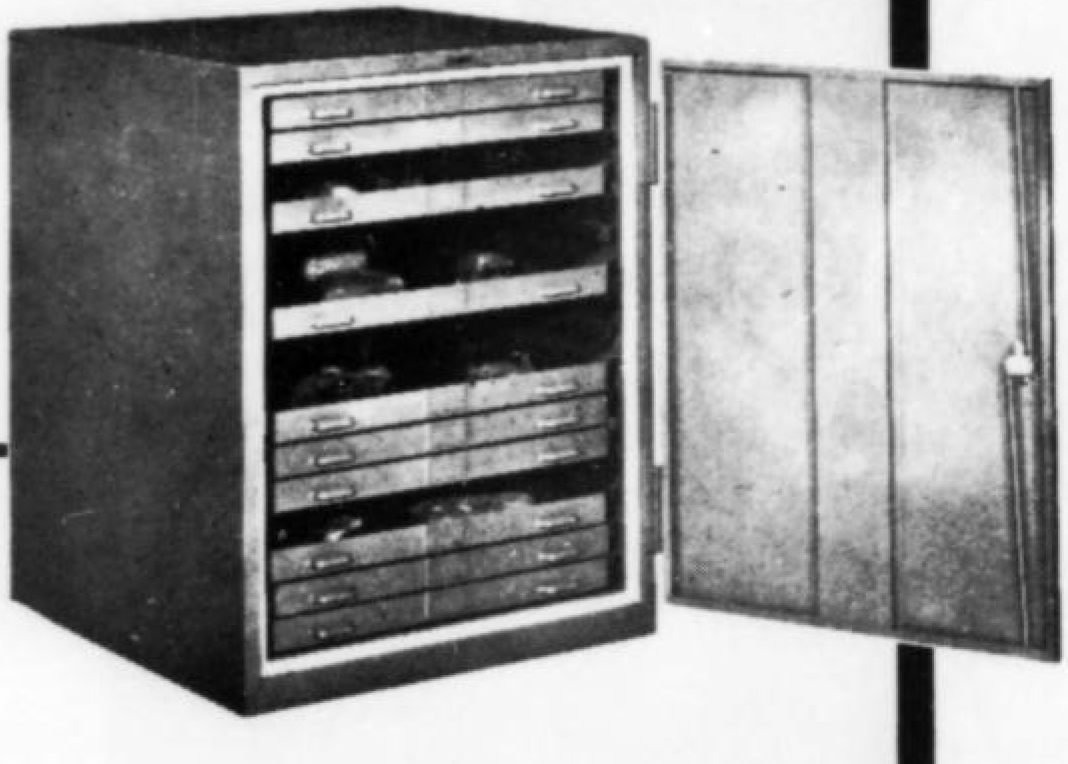

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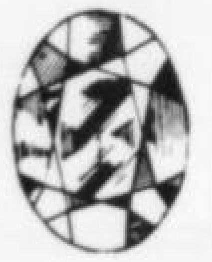

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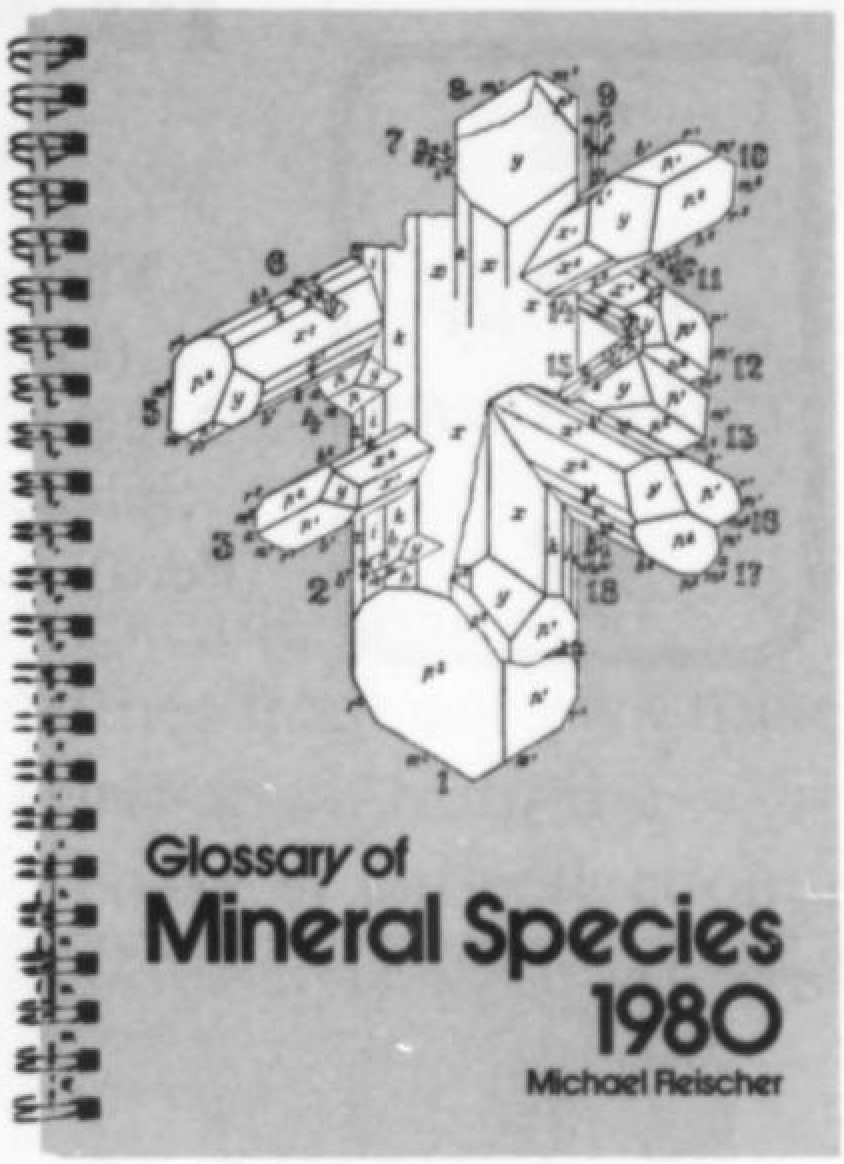

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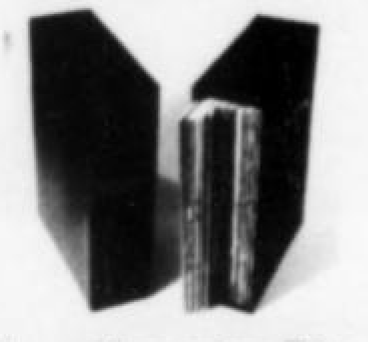

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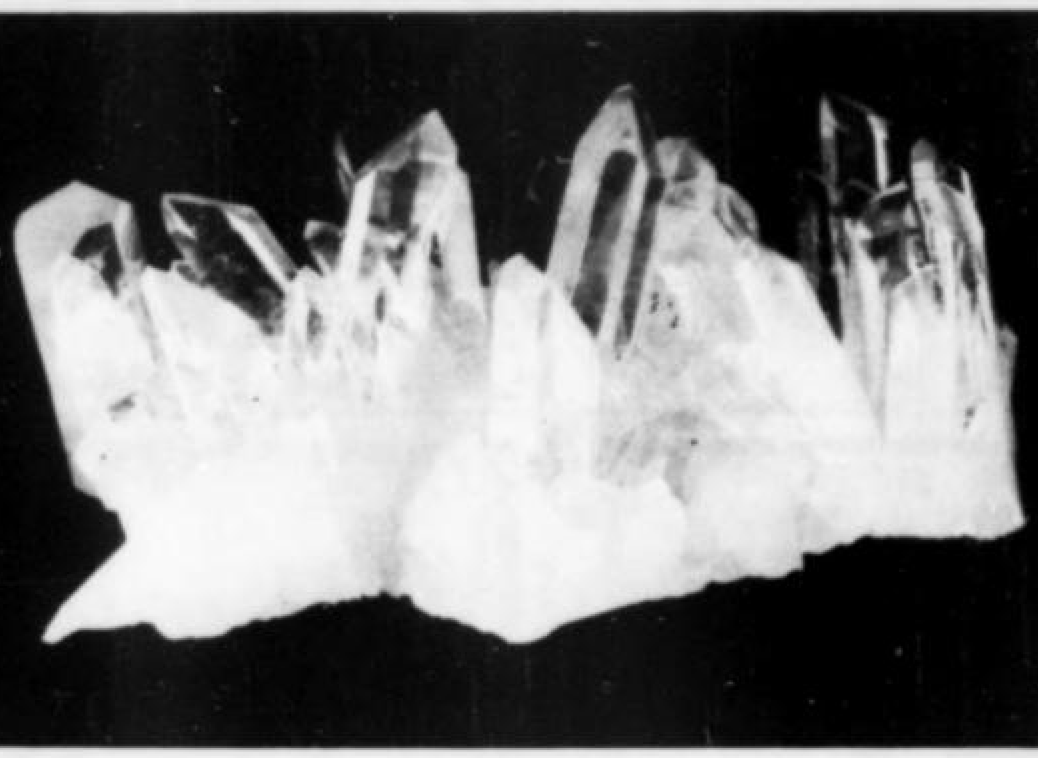

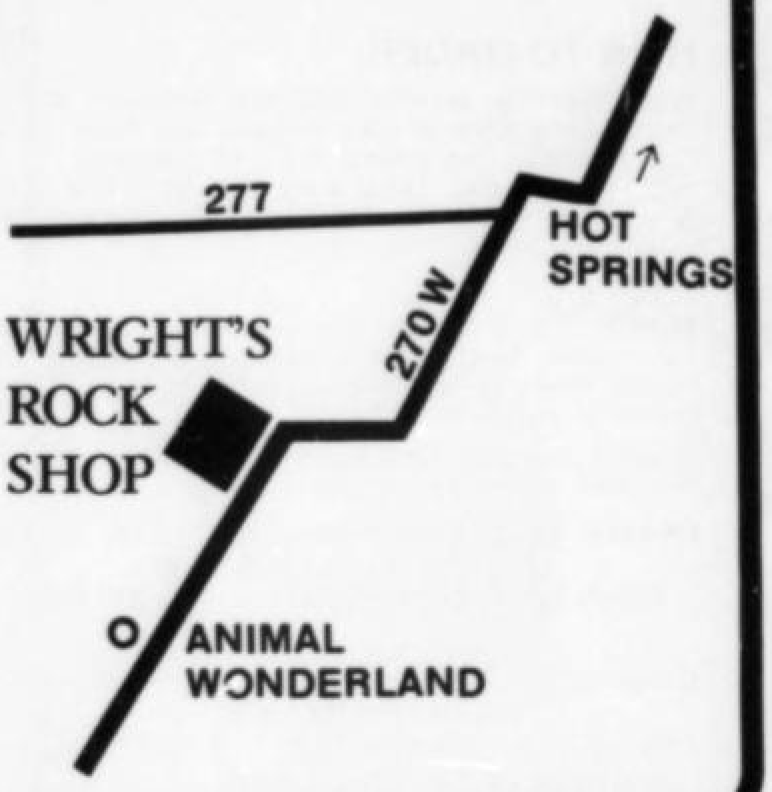

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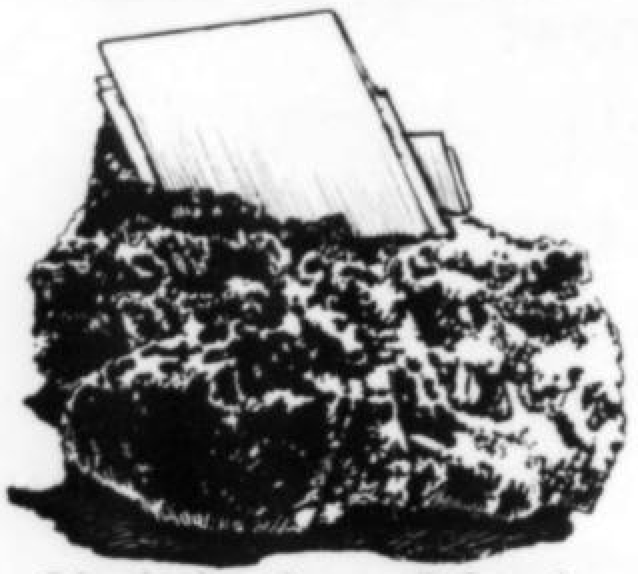

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Is there a limit to the number of minerals?

by **Brian J.** and **H. Catherine W. Skinner**
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When James Dwight Dana completed his first systematic catalogue of minerals more than a century ago, there were fewer than 600 species. The rate of new discoveries now exceeds 600 minerals to a decade and the number discovered has reached 2900 without any sign of a slowdown. Is there a limit and will the high rate of discovery continue or slow down? We soon discovered, as we debated the questions, that answers were not simple and straightforward. Even the number of minerals at any given instant is a matter of some uncertainty.

Authorities tend to differ on what constitutes a valid mineral species so counts tend to differ. For example, while all authorities agree that gems such as sapphire and ruby are simply varieties of corundum, some count forsterite and fayalite as two minerals, others as varieties of a single mineral, olivine. Similarly, one authority will be convinced by partial evidence that a certain mineral is valid, another will not be convinced. One list will therefore include the mineral, the other will exclude. Fortunately the great majority of all mineral species are unquestioned. The few species for which questions do arise are fewer than 5 percent of the total. Even with an uncertainty of ± 5 percent, it can be readily discerned how the total number of listed species has grown through the years. In Figure 1 we have plotted the number of species recorded by various authorities, against the date the record was published. The number of separate species mentioned by Fleischer in a 1969 note in *American Mineralogist* (vol. 64, p. 960), for example, is 1950; the bar representing a ± 5 percent uncertainty therefore ranges from 1853 to 2047. By plotting dates on a linear scale and the number of species on a logarithmic scale, it is readily apparent that no matter what errors are present in the counts, a distinct change in the rate at which minerals were discovered occurred during the 1920's.

Did 1920 mark a change in the intelligence of mineralogists, or was mineralogy somehow influenced by one of the great moves of 20th century science? We suggest that the break in the curve represents a historical moment of some import to mineralogy and that the 1920's saw the end of classical and the beginning of modern mineralogy. Prior to 1920 the principal aids used by mineralogists were light microscopes, goniometers and traditional techniques of wet chemical analysis. Finding new minerals was a slow and exacting process that could only be applied to relatively large specimens. In the modern era, mineralogists have increasingly used methods and devices arising from the revolution in modern physics—X-ray diffraction, electron microscopy, electron diffraction, electron microprobe analysis, X-ray fluorescent analysis and many others. The break in the curve coincides rather closely with the development of X-ray powder diffraction by Hull in the United States in 1917 and by Debye and Scherrer in Germany, also in 1917. We suggest that the availability of powder diffraction as a means of singling out materials worthy of further study was the key that opened the door to modern mineralogy; X-ray powder diffraction was as revolutionary and catalytic to mineralogists then as the newer analytical devices developed over the subsequent 50 years are to present day mineralogists.

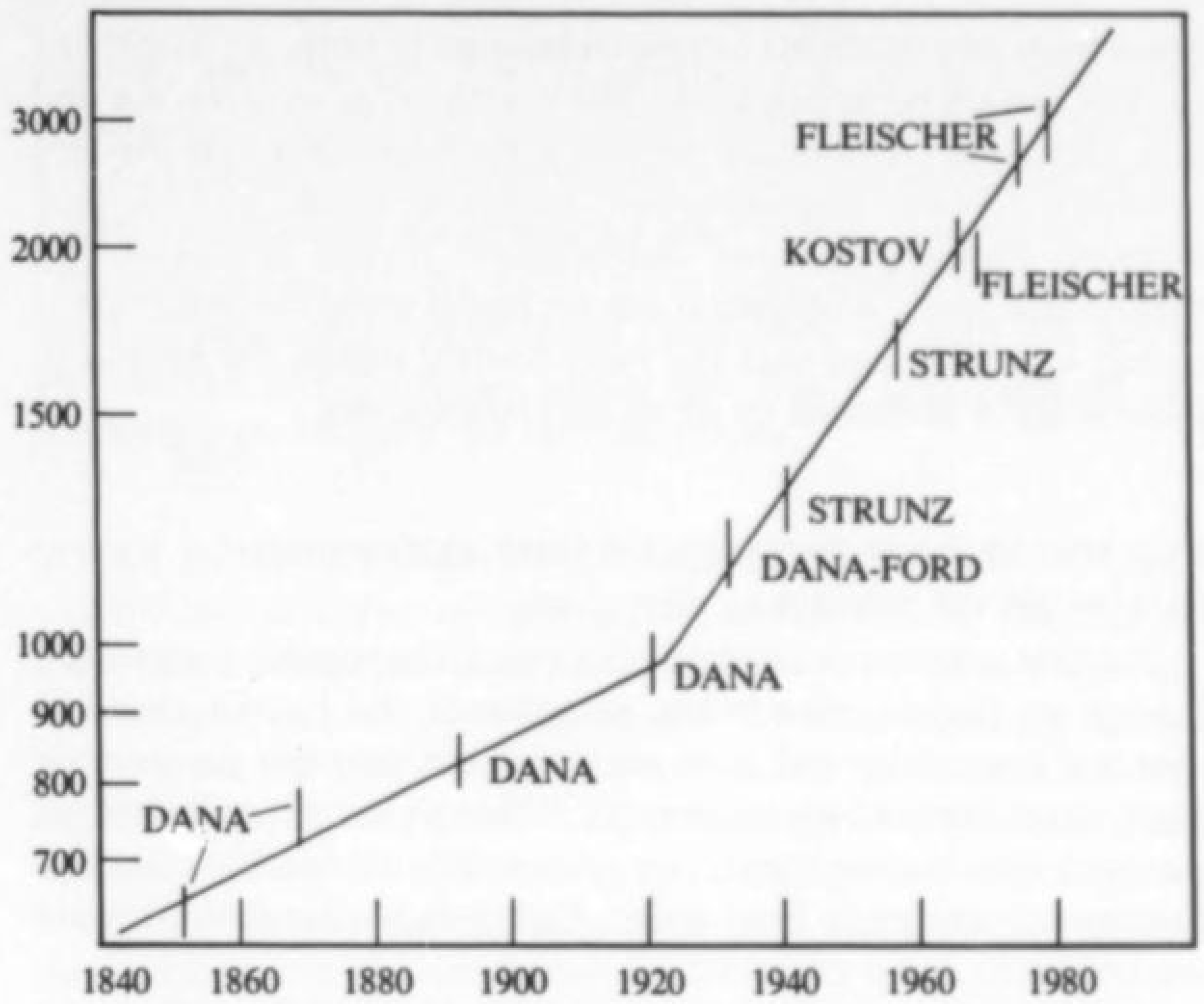

Figure 1. **The number of known mineral species (vertical axis) plotted against the date they were catalogued (horizontal axis). The number of species is plotted on a logarithmic scale to demonstrate that two discovery rates, (analogous to two compound interest rates) are present. To keep the present rate constant we must, on average, discover a greater number of new minerals each year than we did the previous year. The bars for each count represent a ± 5 percent uncertainty in each total. The four bars ascribed to Dana come from various editions of *Dana's System of Mineralogy*, Dana-Ford from the last edition of the *Manual of Mineralogy*, Strunz from two editions of his *Mineralogische Tabellen*, Fleischer from a note in the *American Mineralogist* in 1969 and from the second and third editions of his *Glossary of Mineral Species* and Kostov from the English-language translation of his *Mineralogy*.**

A property that changes with time in such a way as to yield a straight line on a semi-logarithmic plot as used in Figure 1, is said to be increasing exponentially. That simply means that the rate of increase is a constant percentage of the amount present at a given instant. The most familiar example is compound interest. Even though a *rate* of interest stays constant, the *amount* of interest received during each increment of time will be larger. Figure 1 shows that during the era of classical mineralogy, the number of species grew at a compound rate of about 6 percent per decade. In the modern era, when we have been able to examine fine-grained substances as well as the coarse-grained and to do so rapidly and accurately, the rate of discovery has been closer to 25 percent per decade. Apparently new devices such as the electron microprobe have been developed fast enough to sustain the growth rate spawned by X-ray powder diffraction and we are still apparently keeping up the rate because 76 newly discovered species were approved by the New Minerals Names Commission in 1978. But in order to maintain exponential growth the total number of new minerals discovered must increase each year. The questions then before us are, how long can this go on, will the curve come to a sudden end, or will another change in slope occur? Unless masses of new materials from other planets or presently unattainable terrestrial regions become available, we suspect the second alternative is more likely and the rate of discovery will eventually decline, perhaps to a rate similar to that of the classical era. But of course, new study tools might be developed so that presently unavailable or untestable materials might reveal new species and the rate may stay constant or even increase for a while.

To examine the possibilities of whether new minerals are likely to come from new materials or new techniques or both, we would like to raise certain questions about just exactly what minerals are and how they form. A standard definition for minerals is that they are *naturally formed, homogeneous, inorganic solids with definite chemical compositions and characteristic crystal structures.* We suggest that many ambiguities can be found when the definition is closely examined and that the most fruitful region for growth in mineralogy is embraced by those very ambiguities.

CHEMICAL AND PHYSICAL LIMITATIONS ON NUMBERS OF MINERAL SPECIES

The first question to address is the size of the possible pool we are fishing in; that is, how many compounds the known chemical elements can make and how many of the possible compounds might occur somewhere as minerals. Minerals are either individual elements (the "native" state) or compounds of specific chemical elements combined in fixed ratios. Eighty-eight chemical elements are known to occur on earth.

Each of the 88 elements can, under some set of pressure and temperature conditions, form a crystalline solid—even hydrogen and helium can do so. Of course, the needed temperatures and pressures for many elements to occur as solids are not attained on or in the earth, so the number of elements that could form minerals on earth, even if physical conditions were right, is much less than 88. There is nothing in the definition of minerals that limits us to materials found on Earth, but even when we expand our thinking to non-terrestrial materials, limited physical conditions lead directly to the first reason the number of minerals must be limited. Considering the temperatures at the surface of the sun and huge pressures at the core of a planet like Jupiter it is straightforward to calculate that the materials we call minerals have all formed at temperatures and pressures that occupy a thousandth of a percent of the total range of the temperatures and pressures attained somewhere in the Solar System. If we could devise ways to increase our samplings of the pressure and temperature range, such as from the icy heads of comets or from interior regions of planets, we would almost certainly find new compounds. Whether or not we can ever return materials from such alien and hostile environments so that they remain unchanged and available for us to study on the earth's surface remains to be seen.

Now let us look at compounds. If we consider compounds formed by two elements and we allow a given pair of elements to form only one compound, it is easy to calculate the possible number of binary compounds. If there were 3 elements the number of binary compounds would be 3; if four elements 6; if five elements, 10. This is a simple series and it says that 88 elements can combine to form 3828 compounds. We know that about 2500 minerals have been found so far and that some pairs of elements form more than one mineral—for example, Fe and O form wustite (FeO), magnetite (Fe_3O_4) and hematite (Fe_2O_3). We also know that a *great* many minerals are ternary, quaternary, quinary, or higher compounds (meaning they are combinations of 3, 4, 5 or more elements). This increases the possibilities astronomically. For example, there are 109,736 ways we can group 88 elements by threes and an enormous 2,331,890 ways of grouping them by four. When we consider quinary and larger groupings the numbers soar to the billions. With such possibilities the question becomes why are there so *few* minerals?

Certainly not because we don't search for new ones. Nor because we can't make the elements combine—we can, given suitable conditions. We've already seen that temperatures and pressures play a role, and now we discover other factors—chemical factors. Unless chemical factors are just right a compound won't form. For example, lime (CaO) does not occur as a mineral on earth because chemical conditions are more favorable for Ca and O to combine with CO_2 to form $CaCO_3$, with H_2O to form $Ca(OH)_2$, or with SiO_2 to form $CaSiO_3$ and other minerals.

Without becoming too involved in chemistry we can identify the main chemical factor as abundance, or concentration. Some elements, like iron and oxygen, are very abundant. Others, like radium and indium, are very rare. What happens of course, is familiar to every mineralogist. The abundant elements form the minerals, the rare ones are hidden in the common minerals by solid solution and so usually do not form separate mineral species.

If, by some special circumstances of nature, a chemical element does become locally concentrated, minerals of that element will form. On earth we know of many familiar cases where this is so—hydrothermal mineral deposits, for example. Indeed it is in the places of rare and unusual chemistry that mineralogists now tend to find most of their new minerals. But even so, for many of the 88 elements we find that natural chemical conditions are never quite right to form all the billions of possible compounds. Indeed, the chemical conditions, like the physical ones, are very restricted on the Earth and so the number of compounds we observe is likewise restricted.

Will future space travel find new environments? The probability of getting solid samples from the giant planets Jupiter and Saturn seems small because of their huge masses and dense atmospheres. But the small rocky objects, Mercury, Venus, Mars, Moon, the moons of other planets, meteorites, asteroids and comets are all potential searching grounds for which we already have the technical capability for visits. In each case they seem to be comprised entirely of the same 88 chemical elements discovered on Earth and for the most part the chemistries seem not to vary too much from the chemistries we see on Earth. The Moon, for example, has many subtle differences from Earth, but its chemistry is sufficiently close to Earth's that few new minerals were found in the Moon rocks; the most famous is armalcolite, named after Armstrong, Aldren and Collins, the Apollo XI astronauts. There certainly are some strange bodies in the Solar System; an example is the Jovian moon, Io, which has a sulfurous, orange-colored surface and sulfur dioxide volcanoes; another is Venus which has surface temperatures of 480°C and a dense, acrid atmosphere rich in carbon dioxide. From such environments we might one day discover many new minerals. But on Earth we suspect there are few entirely new chemical environments still to be discovered.

Man can, of course, control the chemical environment at will and so vast numbers of the possible chemical compounds have been made in the laboratory. We exclude all such laboratory materials from the mineral family by requiring in our definition that minerals be *naturally formed.* The definition, however, raises a very nice question. Most readers will probably be familiar with the oxychloride minerals of lead from Laurium in Greece. These minerals formed because Greeks, during the fourth and fifth centuries B.C., dumped slags from their lead and silver mines into the sea, thus creating an unusual chemical setting that unaided nature does not duplicate. The slag compounds are not minerals but the alteration products are—a nice point. Should we aid nature a little more by creating future mineral localities? Why not create an environment in which cesium minerals form by putting piles of glass of suitable composition into a place such as Great Salt Lake, or form indium and ruthenium minerals by dropping fine-grained masses of the metals into sulfurous harbor muds, there to react slowly and create great mineral hunting in the future? Our remarks are facetious, of course, but they do emphasize that even the term "naturally occurring" can be pushed to ambiguous limits.

ANALYTICAL LIMITATIONS ON THE NUMBER OF SPECIES

We may think we know the meaning of the terms crystal and crystalline, but do we? A crystal is a solid compound bounded by planar faces which bear a defined geometric relationship to each other. The external morphology reflects an internal order in the arrangement of the constituent atoms—the ordered arrangement is the crystal structure. By passing light rays, X-rays, electron beams, neutron beams or other collimated rays or streams of particles through solids we can detect and decipher the internal atomic order even though external crystal faces may not be present. If atomic order is detected, we say the solid is crystalline.

If we use light rays to detect internal crystalline order, we will only be successful if the light can pass at least 6000 Å through a mineral. This simply reflects the fact that you cannot detect order with a device coarser than the order being sought (we say it is below the resolving power of the instrument and the wavelength of light is between 5000 and 6000 Å). Thus, to detect internal crystalline order by light; the particle must be larger than 6000 Å (0.0006 mm) in diameter—preferably much larger. But definitions of minerals do not specify the distance over which order (or crystallinity) must occur. Neutron and X-ray diffraction employ wavelengths below 3 Å and can, under special circumstances, detect order in samples as thin as 20 Å. In many cases, however, it is impossible to detect crystallinity below 10 atomic diameters (about 20 Å). We are limited by our detection methods. Small sizes and thin layers become an area of experimental uncertainty with respect to the term crystalline. In fact, there is a region of small particles and short-range order that is still inaccessible to mineralogists.

Supposing a device were built by which we *could* study short-range order and extend the region of "crystallinity," would we discover new compounds? We suspect we would, for two reasons—(probably there are more reasons, but two come readily to mind). First the possibility that in micro-environments such as the surface of tiny particles, the necessary chemical conditions might occur for some of the millions of missing compounds to be found. As an example, we suggest there are still undiscovered compounds on the intergranular surfaces of the manganese minerals in deep-sea nodules. The surface phase would, in a sense, be two dimensional which means it would have a large area but a small volume. Detecting and isolating such a phase will of course be exceedingly difficult.

The second possibility is another unexplored micro-environment, one that lies on the surface of any cleaved or broken mineral. When a mineral breaks, chemical bonds between atoms are snapped and the unsatisfied charges remain on the two broken surfaces. Two things happen. The atoms on the surface move slightly in response to the now unbalanced tugs from the atoms in the body of the crystal. Physicists have observed that under certain conditions and for some simple compounds such as TiO_2 (rutile) the movement can occur in a regular fashion so that a short-range order is produced on the surface, and the order is different from that in the body of the crystal. The new layer is only a few angstroms thick. Does such a layer satisfy the definition of crystallinity and is the layer a different phase or not? The second thing that happens on the new surface is that atoms such as oxygen or molecules such a CO_2 or H_2O, become adsorbed on the surface, held there by the newly formed bonds. We don't know if such adsorbed surface layers on minerals can be ordered or if their adsorption causes regular changes in the surface of the mineral itself, but if either thing should happen, would the new surface layer qualify as a mineral? We suggest that surface layers do indeed fall within the bounds of the definition of a mineral and should be considered as minerals even though we cannot now detect and identify them. The day is coming when we can.

Just as surfaces and tiny particles push us to the limits of our definition of crystallinity, so do the possibilities of ordered stacking faults lead to crystals with extraordinary large repeat units. Mineralogists have, by informal agreement, tended to leave the compounds with stacking faults outside the accepted area of individual minerals even though new symmetries can be generated. The substances are called polytypes rather than polymorphs. The best-known example is ZnS which occurs in nature as sphalerite, with a 3-layer repeat and wurtzite with a 2-layer repeat. But regular stackings of sphalerite-like and wurtzite-like layers lead to polytypes with much larger repeats and different symmetries. Perhaps it is just as well not to give polytypes names but surely they meet all the presently stated criteria for mineral species.

WHAT IS IMPLIED BY THE TERM INORGANIC?

We come finally to the last part of the definition, the requirement that compounds must be inorganic. As originally applied, mineralogists apparently meant to exclude the compounds formed by living matter. But so many minerals are in fact formed or influenced to form directly or indirectly by living matter, it is once again difficult to draw a line. For example, oxygen is in the atmosphere because of the photosynthesis by green plants. Should we consider the oxides of iron and manganese formed from atmospheric oxygen as organic or inorganic? Of course we consider them inorganic because the actual reactions that combine oxygen with manganese or iron do not require the direct involvement of the living cells of animals or plants.

But surely we can apply the same reasoning to the precipitation of a nodule of $CaCO_3 \cdot H_2O$ or one of the calcium phosphates in the body of an animal? The actual precipitation of such a material occurs because the solubility of that compound in body fluids is locally exceeded. The precipitation is, therefore, inorganic in the sense that the material is extra-cellular—it did not form an integral part of a living cell, but organic in the sense that it formed from fluids whose chemistry was influenced by the cells. Once again we have a region of uncertainty. It is our contention that any compound that meets the criterion of crystallinity and is not found as a functional part of a living cell, should be called a mineral. This means that some compounds now generally rejected as minerals should, we feel, be included. The compounds present in urinary calculi are obvious examples. Other examples come from diseased bodies, because it has long been known that internal but extracellular, sites in a body can accumulate crystalline compounds during disease states. Examples are metallic copper in the eye and tellurium in the brain. Why should they not be called minerals? Perhaps mineralogists are already becoming more liberal where organic compounds are concerned because the New Mineral Names Commission has, in the recent past, approved abelsonite (a nickel porphyrin), guanine, uricite and urea as minerals. As Michael Fleischer remarked, when he reviewed this paper, "If urea is mineral, I can't think of any organic compound that is excluded."

CONCLUSION

We maintain that there are no predictable limits to the number of minerals. The only way to have a fixed and definite number of minerals is to restrict the definition in such a way that as exploration continues of the still unsampled regions of the Solar System, of surfaces and of unusual chemical regimes, the new compounds are not minerals. What a mistake that would be. To be so restrictive would be an anathema to the scientist and so would ring the death-knell of mineralogy as a branch of science. The future would then be limited to dusty curatorial activities, the collecting of pretty specimens and refining measurements made during the great days of mineralogy. Far better that there be few, if any, restrictive limits and that mineralogists be flexible, not rigid where the definition of a mineral is concerned and so be encouraged to explore the far boundaries of the science. They will find new and interesting compounds as they do so and guarantee that if there is indeed a limit to the number of minerals, that limit lies beyond our present comprehension.

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