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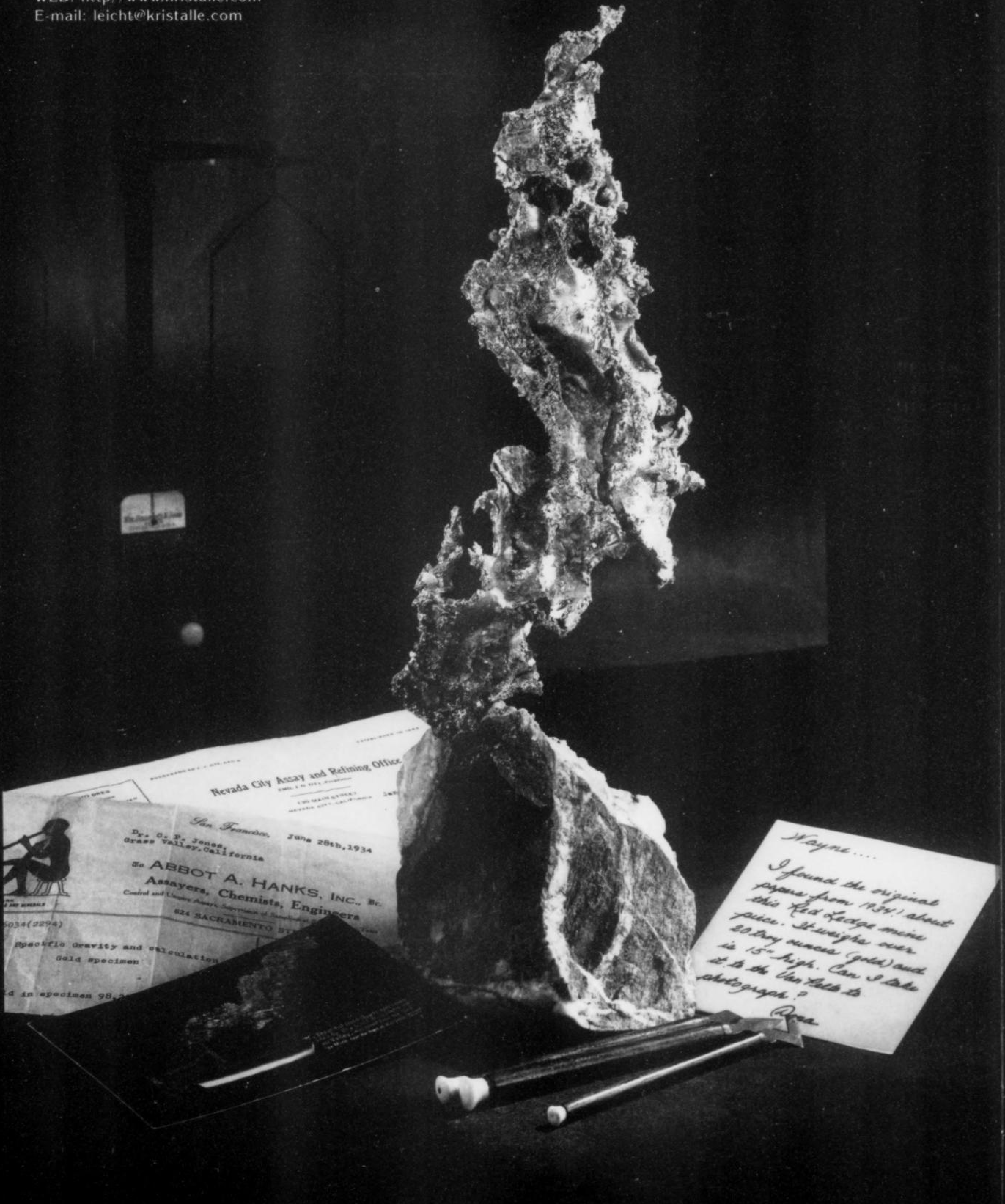

Wayne....

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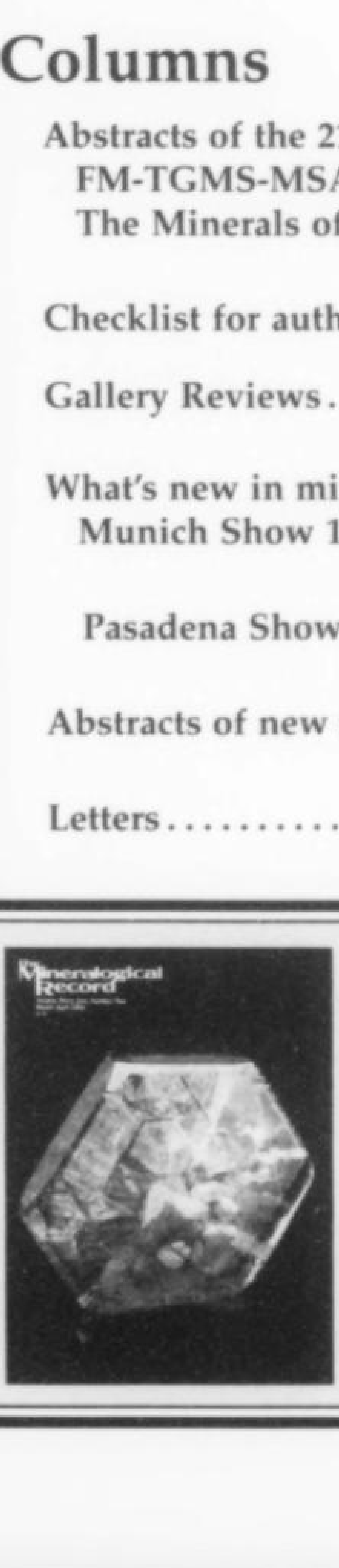
THE MINERALOGICAL RECORD

Articles

Columns



COVER: FLUORAPATITE crystal, 3.2 cm, from the Shigar Valley, Pakistan. Gene Meieran collection; photo by Jeff Scovil.

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Guest Editorial

CURATORS IN GLASS CAGES

There can be no doubt that the museum world has changed profoundly in the late 20th century. It used to be that museum curators answered to no one, except perhaps their immediate superiors. Major decisions with respect to the creation of new exhibition halls, for example, were all made "in-house" and were, to a large extent, very much patterned after what everyone else was doing at other museums. External critiques were unheard of. If colleagues at other institutions had anything at all to say, it was probably *pro forma* complimentary. Collectors, in particular, had no voice. There were no journals available with broad national or international circulation in which the collector's fraternity might be emboldened to express opinions about their regional museum's mineral and gem display. This means that curators could be moderately indifferent to the reactions of those who might care the most about the integrity of the exhibits they were creating.

Times have changed. Both curators and museum directors must now be aware that their work is probably being evaluated by people other than just their own museum's staff and/or administration. At least that is the way I feel it should be. If curators fail to pay proper attention to important details, they should be criticized for it. If they produce an inferior exhibit, they should be called to account for it. If they have been outrageously wasteful in squandering large sums of money on senseless acquisitions for displays, that fact should be publicized. Most are, after all, working with public funds, or money that is the result of public benevolence, and like every other civil servant they are obligated to use such funds prudently. I feel that it would be a very good thing if museum curators began to sense that there are people out there beyond the walls of their institution who care about what they are doing, and who are going to comment publicly.

This applies to the management of collections as well. Today, mineral collectors are an active lot. They have more and better means of communication among themselves than ever before, and they are taking advantage of this fact. They travel more and are more likely to go wherever they must in order to see important new museum displays. Also, major mineral shows are much bigger, they attract a huge international attendance, and they last longer than ever before, so there is far more exchange of information possible than in the past. Collectors from any major city or its environs are more apt to be aware of how the curators at their local museums are disporting themselves at shows. Are they participating? Do they spend major amounts of time scouting minerals and interacting with collectors, dealers and curators? Are they buying, and are they doing so sensibly? Are they contributing articles or even bits of museum news for the leading hobby publications? In other words, do they possess the necessary curatorial skills, and are they being as active and productive as they should be?

No longer should curators be allowed to operate in obscurity, for things have indeed changed, and the changes are only the beginning. I feel that collectors should take more of a proprietary interest in what their local museum is doing. Curators, believe it or not, can benefit from such advocacy. Remember, and this fact is not generally known, that curators are virtually *never* "trained" as curators. Nearly all of those involved in mineral curation come out of graduate schools with advanced degrees in mineralogy or geology, but they haven't a clue what proper curating is all about. In reality, they aren't even hired for their curatorial prowess; instead, they are expected to produce "scientific research." If it turns out that they happen to function reasonably well in their *curatorial* role, then that museum is among the fortunate.

Those museums and curators that are most fortunate are the ones where there is a staff overlap, so that a seasoned curator has the opportunity to pass along to a new curator the skills and the lore that have been acquired over the course of what is usually a long career. In most museums, unfortunately, there is little or no such overlap, which means that a new curator is forced to acquire all the requisite skills independently, with little or no direction from the museum administration. If ever there was a situation that invites failure, it is this one.

So, come on collectors! Let your local curator know that you are watching, but also that you stand ready to offer various forms of support if the opportunity presents itself. You have every right to expect that the precious and largely irreplaceable minerals and gems placed in the hands of this individual receive responsible care, and you are within your rights to let it be known that you might indeed kick up a storm if you perceive that, through terrible mismanagement, everything is headed down the wrong road; that the displays are not up to par, that opportunities to acquire important specimens are missed, that irreplaceable specimens are being traded or sold out of the collection. This is not only your right as a citizen; as a concerned friend of minerals, it is your duty.

John S. White
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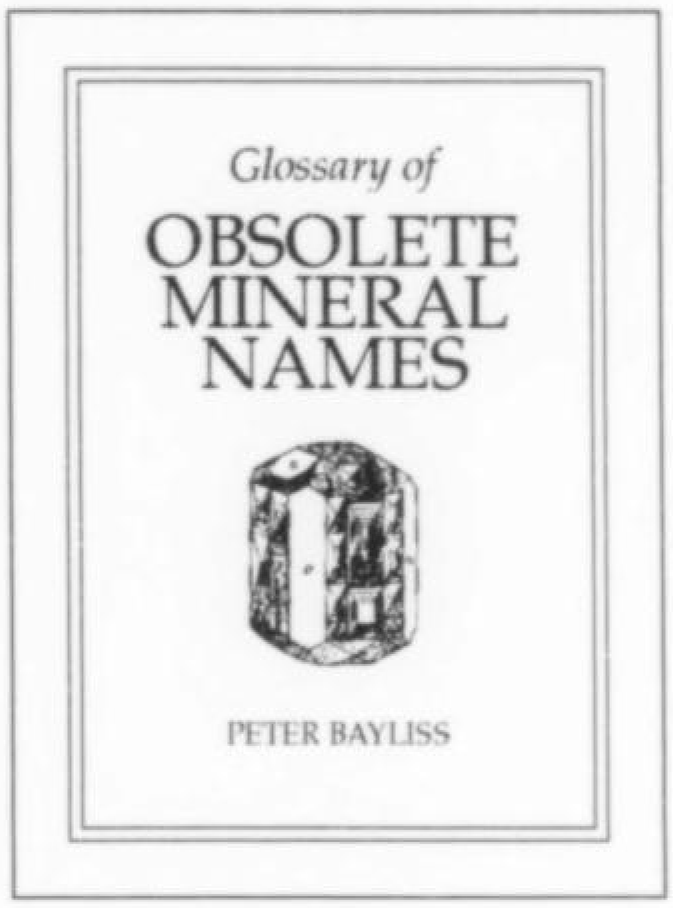

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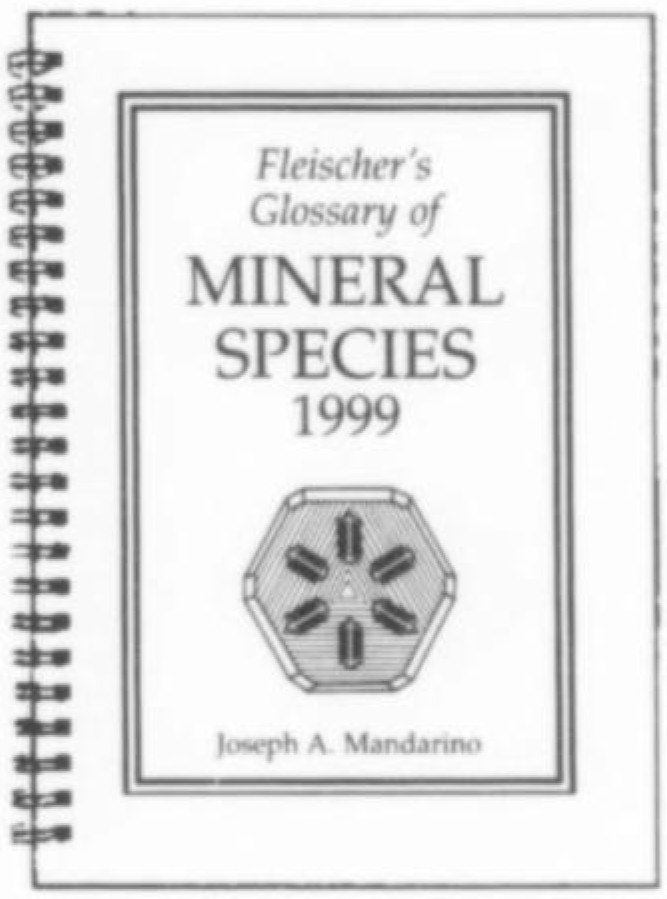

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ELONGATED TWINS OF SODALITE AND OTHER ISOMETRIC MINERALS

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47 Robin Ridge Drive
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154 Morgan Street
Oberlin, Ohio 44074

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Sodalite family minerals frequently form pseudo-hexagonal twins elongated parallel to their [111] twin axes. This habit, which is almost unique to these minerals, is caused by (a) the predominance of dodecahedral faces on their crystals and (b) their propensity to twin by rotation about a three-fold axis.

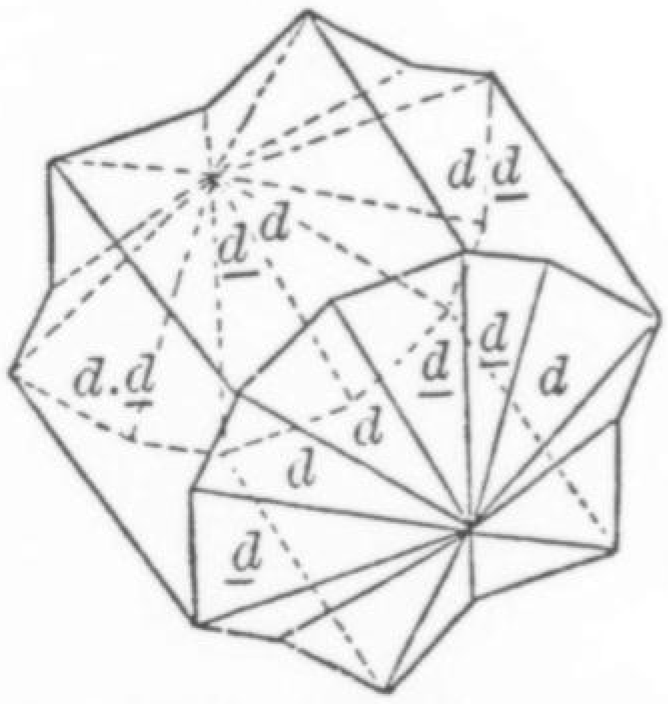

Figure 1. **Sodalite, twinned dodecahedron; Figure 432 taken from *Dana's Textbook of Mineralogy* (Dana and Ford, 1932).**

INTRODUCTION

Tens of thousands of mineralogists reading the various editions of Dana's System or Textbook have seen the drawing of a sodalite twin reproduced here (Fig. 1). The projection used in the drawing does not make it clear that such twins are almost invariably elongated along the pseudo-hexagonal axis of the twin. The twins are elongated because of the predominance of dodecahedron faces in these species, and the special geometric properties of a dodecahedron twinned about a three-fold [111] axis.

CRYSTAL MORPHOLOGY OF SODALITE FAMILY MINERALS

The sodalite family is composed of the minerals sodalite, nosean, haüyne and lazurite; cubic aluminosilicate species with the formula $(Na,Ca)_{4-8}Al_6Si_6O_{24}(SO_4,Cl,OH,S)_{1-2}\cdot nH_2O$. The members of the group are most frequently found in association with nepheline or leucite in nepheline syenites or phonolites and related undersaturated rocks. Beautifully crystallized examples are found in volcanic ejecta at a number of localities.

The predominant crystal form for all four species is the dodecahedron, as illustrated by the nosean crystal on biotite in Figure 2 and the beautiful, blue haüyne crystal in Figure 3. Modifying forms are the cube as on the haüyne shown in Figure 4 and the octahedron. The sodalite from Mount Vesuvius in Figure 5 shows major dodecahedron faces plus a rectangular cube face. In addition traces of the {211} trapezohedron are present as the very narrow, highlighted lines at the intersection of the dodecahedron faces. On rare occasions, the cube and octahedron are the major or only forms present. As the sodalite family minerals are all isometric, untwinned crystals are almost always equally developed along all three crystal axes; i.e., they are equant.

The four species have an amazing propensity to form twins such as those of sodalite from Monte Somma, haüyne from Mendig in the Eifel District, and nosean from the Alban Hills shown in Figures 6–8, respectively. The frequency of twinning is far higher than that for most other minerals, and the authors estimate that perhaps half the crystals seen from all localities are twins. As an

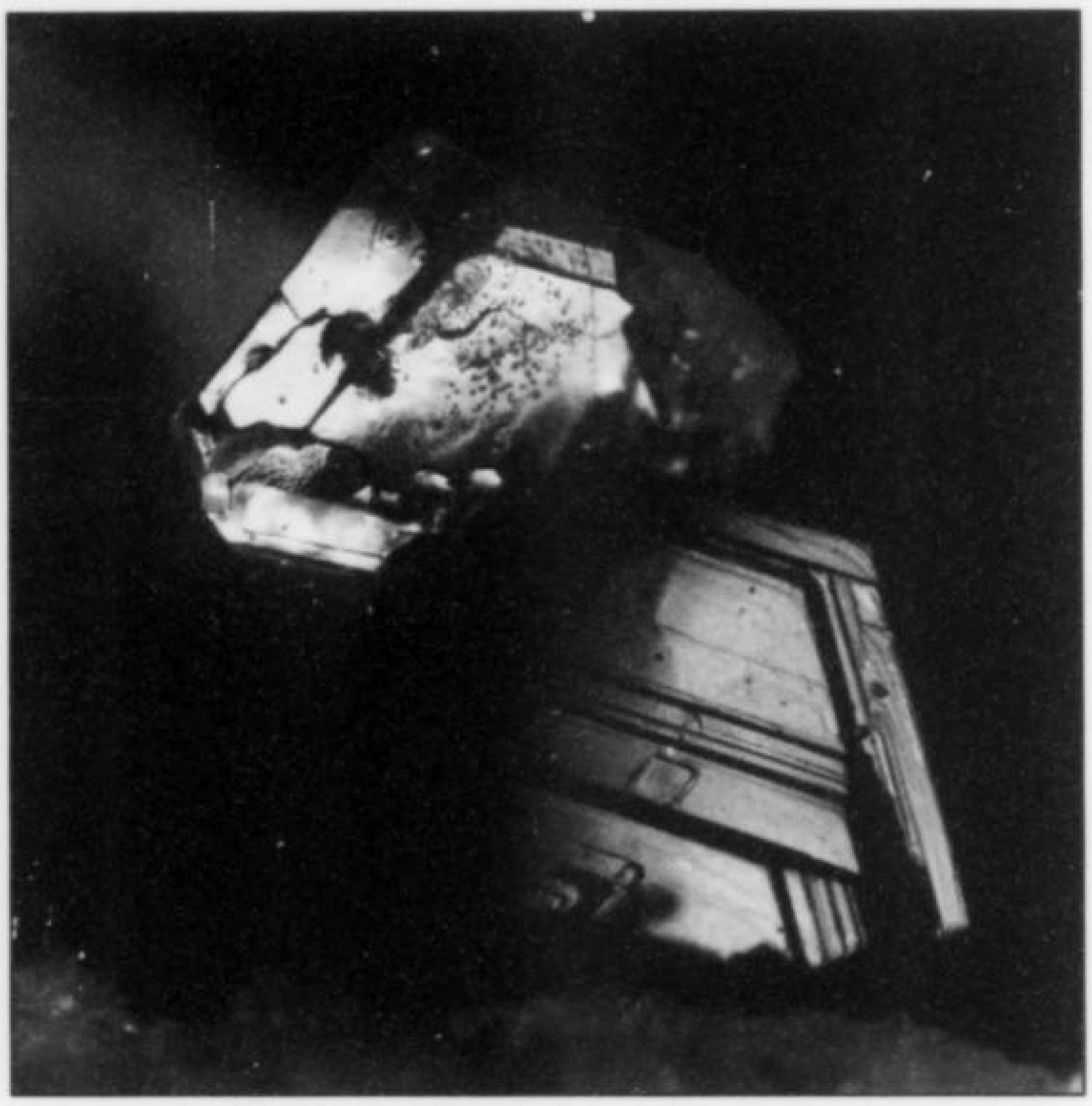

Figure 2. **Nosean, dodecahedral crystal on biotite from Mendig, Eifel district, Germany. Collection of Berndt Ternes; photo by E. van der Meersche.**

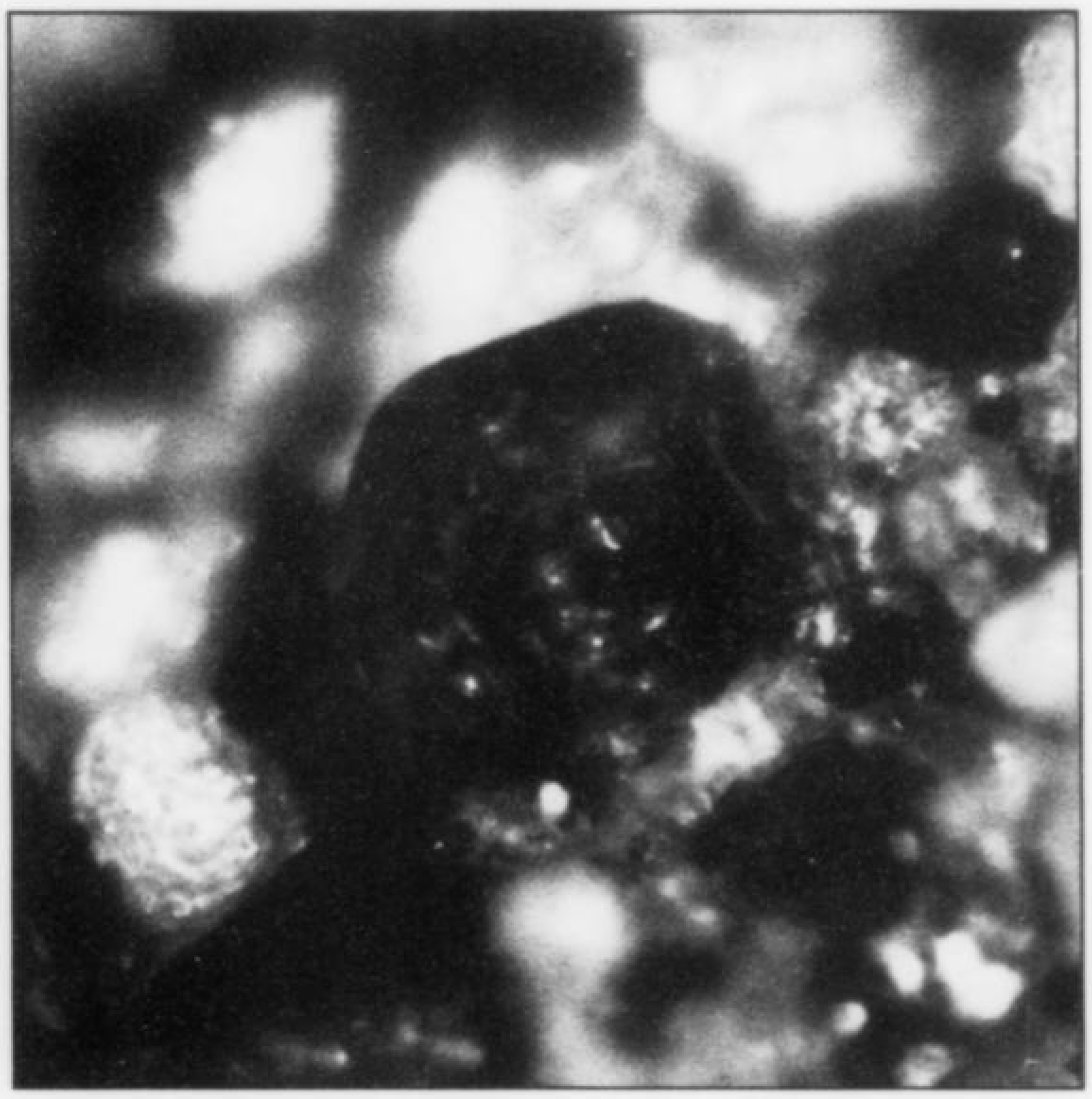

Figure 3. **Haüyne, deep blue, dodecahedral, 0.4-mm crystal from Mendig, Eifel district, Germany. Collection and photo WAHJr.**

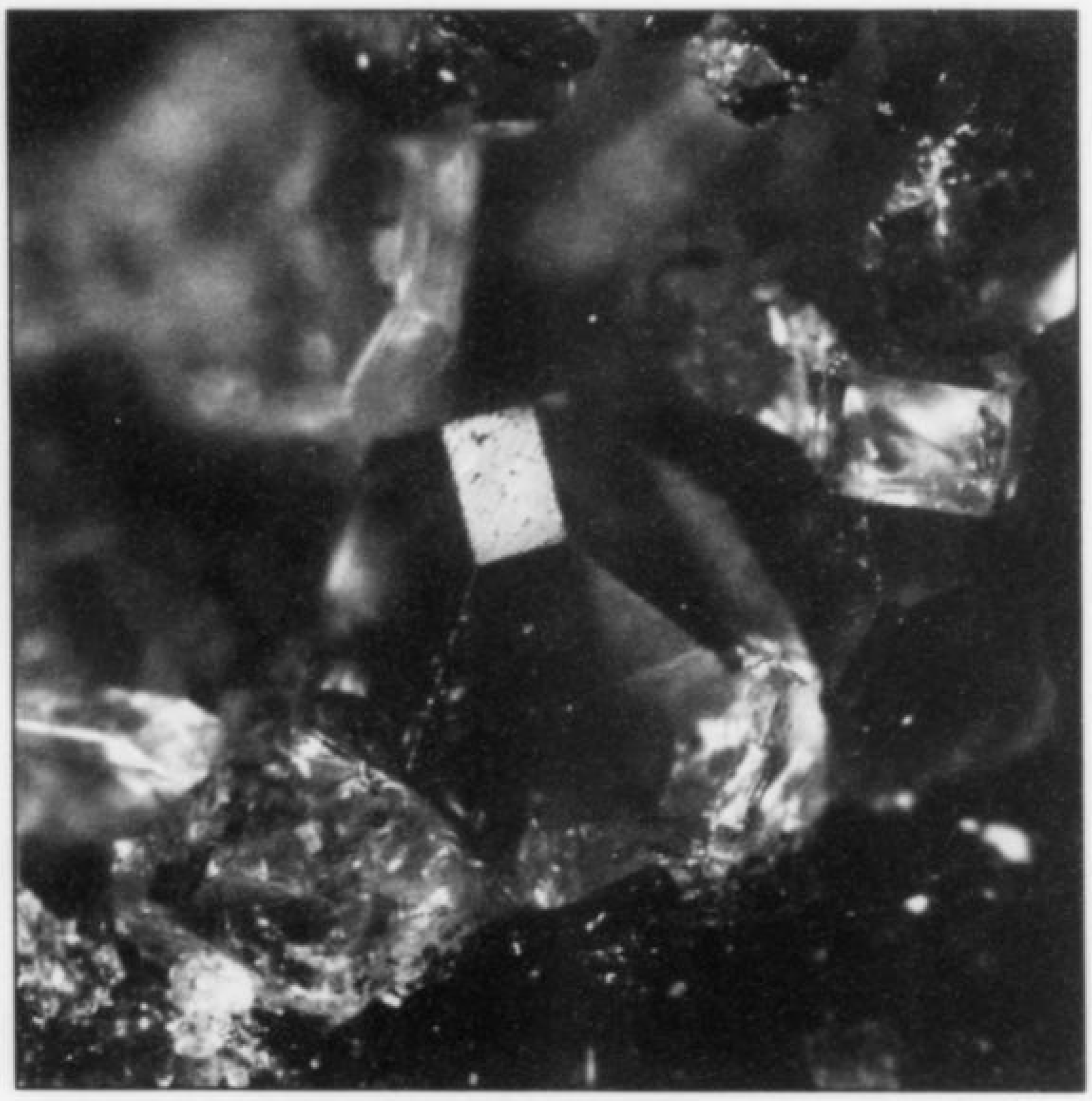

Figure 4. **Haüyne, pale blue, dodecahedral crystal of haüyne with minor cube faces from Laacher Kessel, Mendig, Eifel district, Germany. Eugen Rondorf specimen; photo by E. van der Meersche.**

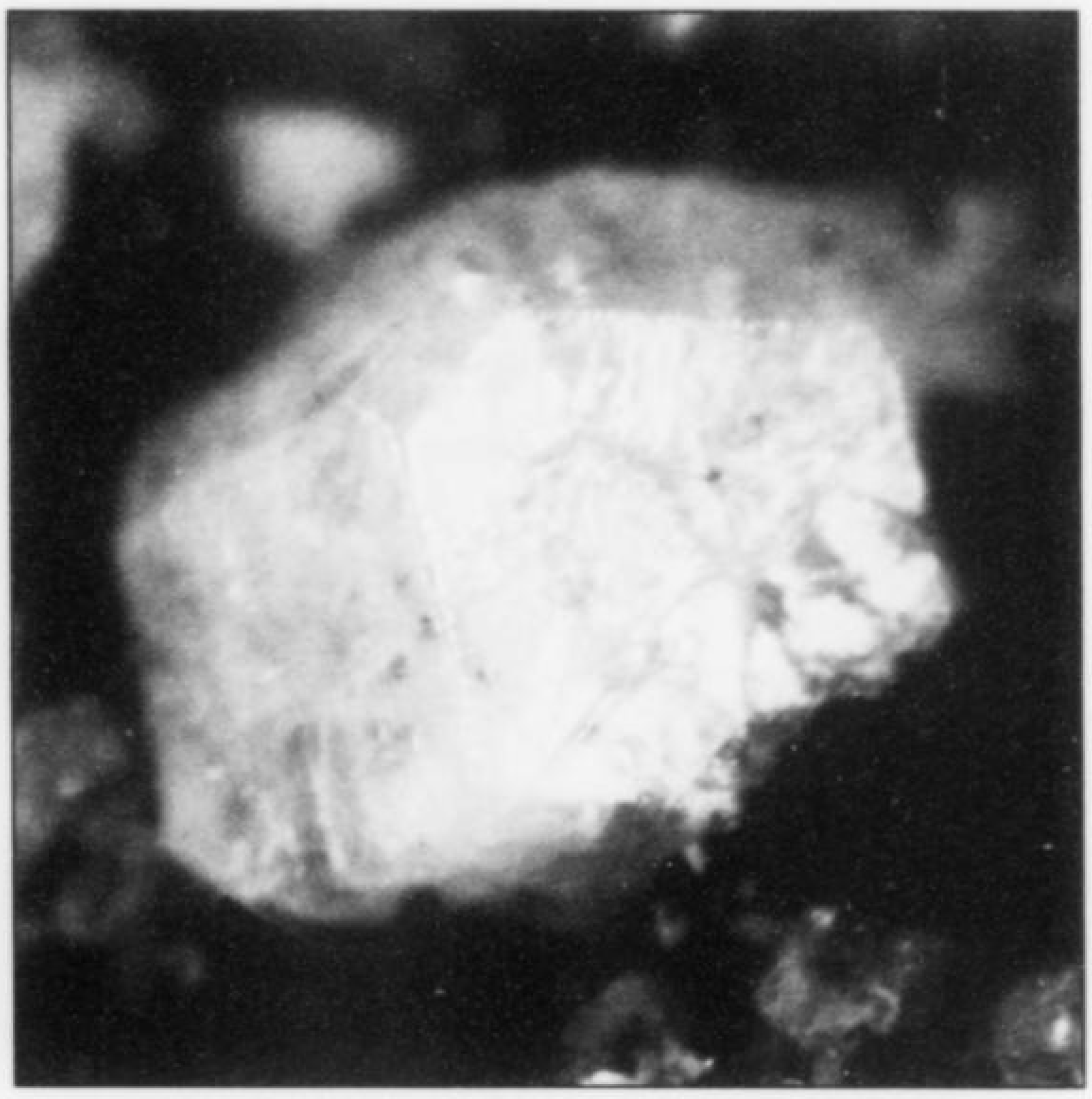

Figure 5. **Sodalite, colorless dodecahedron modified by the cube, 1.2 mm in size, from the Pollena quarry, Monte Somma/Vesuvius, Napoli, Campania, Italy. WAHJr photo.**

extreme, *all* the nosean crystals from Mendig seen by the authors have been twinned.

Twinning occurs about a three-fold, i.e., a [111] axis, to give forms approximating the idealized drawing shown in Figure 1. Twinned crystals are almost invariably elongated, with length to width ratios varying from about 2:1 (Fig. 6) to as much as 5:1 and rarely 10:1, with smaller ratios being most frequent. Typical examples are those in Figures 6–8, showing beautiful, elongated twins of sodalite, haüyne and nosean, respectively.

The progression from untwinned dodecahedron (a) to twinned crystal (b), and then rotation to a more convenient, pseudo-hexagonal orientation and elongation (c) is shown in Figure 9. The twin axis, [111], is shown in 9a and b. Note the reentrants at the terminations of the crystal and the co-planarity of the d and d' faces

Figure 6. **Sodalite, elongated, twinned crystal, 2.8 mm long, from Cave San Vito, Monte Somma, Napoli, Campania, Italy. WAHJr photo.**

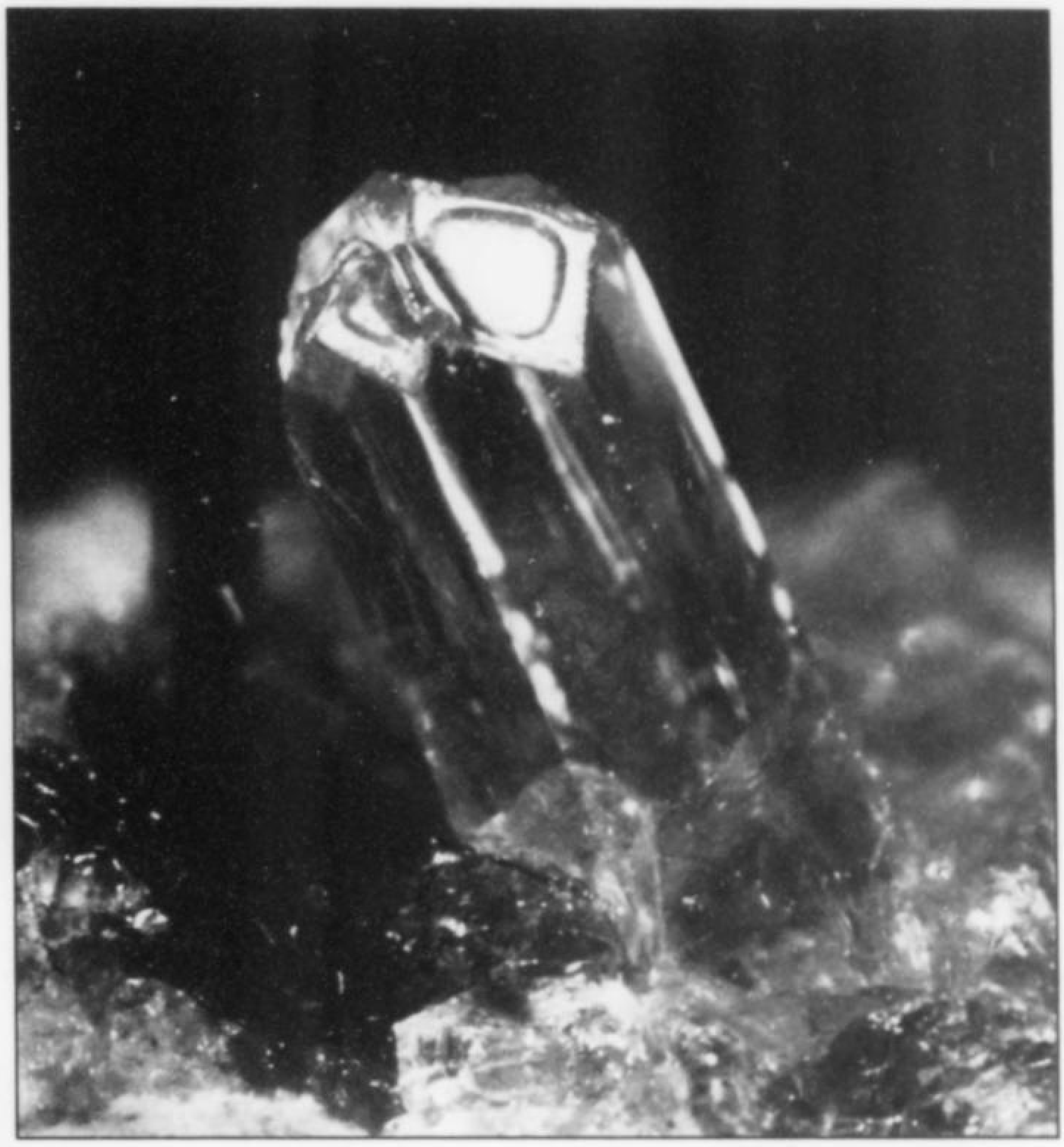

Figure 7. **Dodecahedral haüyne, pale blue, elongated twin from Laacher Kessel, Mendig, Eifel district, Germany. Berndt Ternes specimen, photo by E. van der Meersche.**

Figure 8. **Nosean, colorless, elongated, twinned crystal with prominent reentrants, 1.2 mm long. From the Alban Hills, Roma, Lazio, Italy. Specimen #2960, Cahn Collection, Yale University; WAHJr photo.**

in the "prism" zone in Figures 9b and c, similar to those on natural crystals in Figures 6–8. In a geometric sense, most of any such "prism" face belongs to both halves of the twin simultaneously. In a real crystal, any spot must belong to one half or the other, but the actual pattern of intersection between the two halves may be very complex, much as it is on a Dauphiné-twinned quartz crystal.

As stated before, dodecahedra of sodalite family minerals are frequently modified by minor cube and octahedron faces. Twins of such modified crystals may involve remarkable and somewhat confusing juxtapositions, shapes and numbers of cube and octahedron faces.

The faces in an untwinned cube can be envisioned as being arrayed in two groups of three about opposite ends of a threefold [111] axis. If twinning occurs about this axis as in Figure 9, two sets of six cube faces are generated, and these are arranged like two crowns around opposite ends of the elongated twin as in Figure 9d!

Octahedron faces, with their three-fold symmetry, are present in untwinned crystals such that the crystals' three-fold axes emerge at the centers of the faces. That is, in Figure 9a, an octahedron face would be an equilateral triangle at the intersection of the three dodecahedron faces where the twin axis emerges. On twinning, that octahedron face and the one at the opposite end of the crystal appear as the sums of pairs of equilateral triangles rotated 180° with respect to each other; i.e., as symmetrical, six-pointed stars! The resultant twin of a dodecahedron modified by cube and octahedron is shown in Figure 9d, and, viewed down the pseudohexagonal axis, in Figure 9e. Discerning readers may wish to know what happened to the 12 remaining octahedron faces, since only 4 (2 from each half of the twin) have been accounted for. The answer is that they lie in the interior of the crystal relative to portions of the dodecahedron from the other half of the twin, and are thus not expressed on the twin's exterior.

Returning now to real crystals, fine examples of twinned nosean crystals with modifying cube faces from Mendig are shown in Figures 10 and 11. SEM photos showing modifying cube faces are

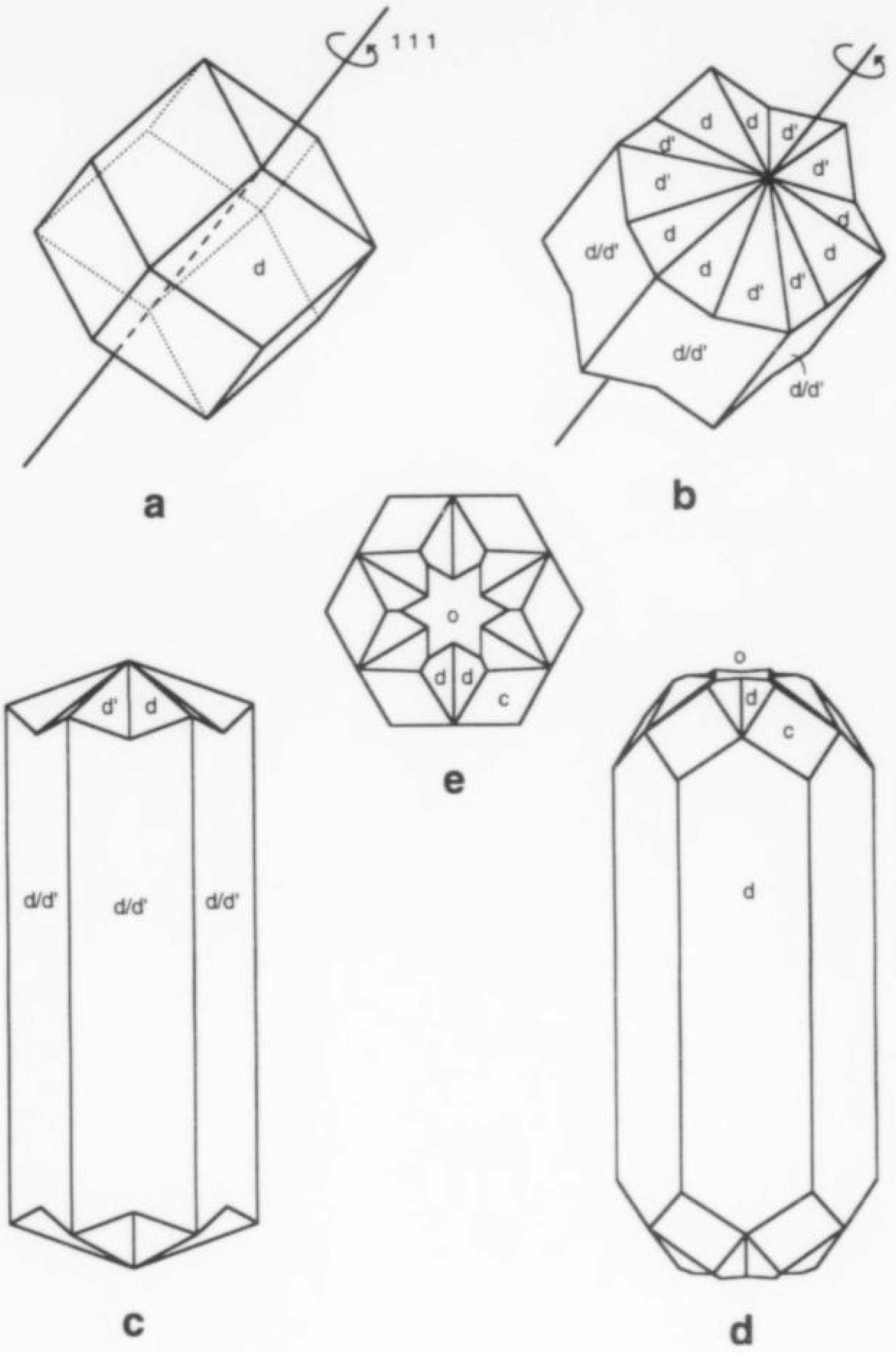

Figure 9. **Mechanism of twinning of dodecahedral crystals about a [111] (three-fold) axis showing (a) the untwinned dodecahedron; (b) the pseudo-hexagonal twin resulting from rotation about a [111] axis; (c) the same twin but elongated and oriented as for hexagonal crystals; (d) the twin modified by the cube (c) and octahedron (o); and (e) the same twin as in (d) viewed down the [111] twin axis. SHAPE drawings by RPR.**

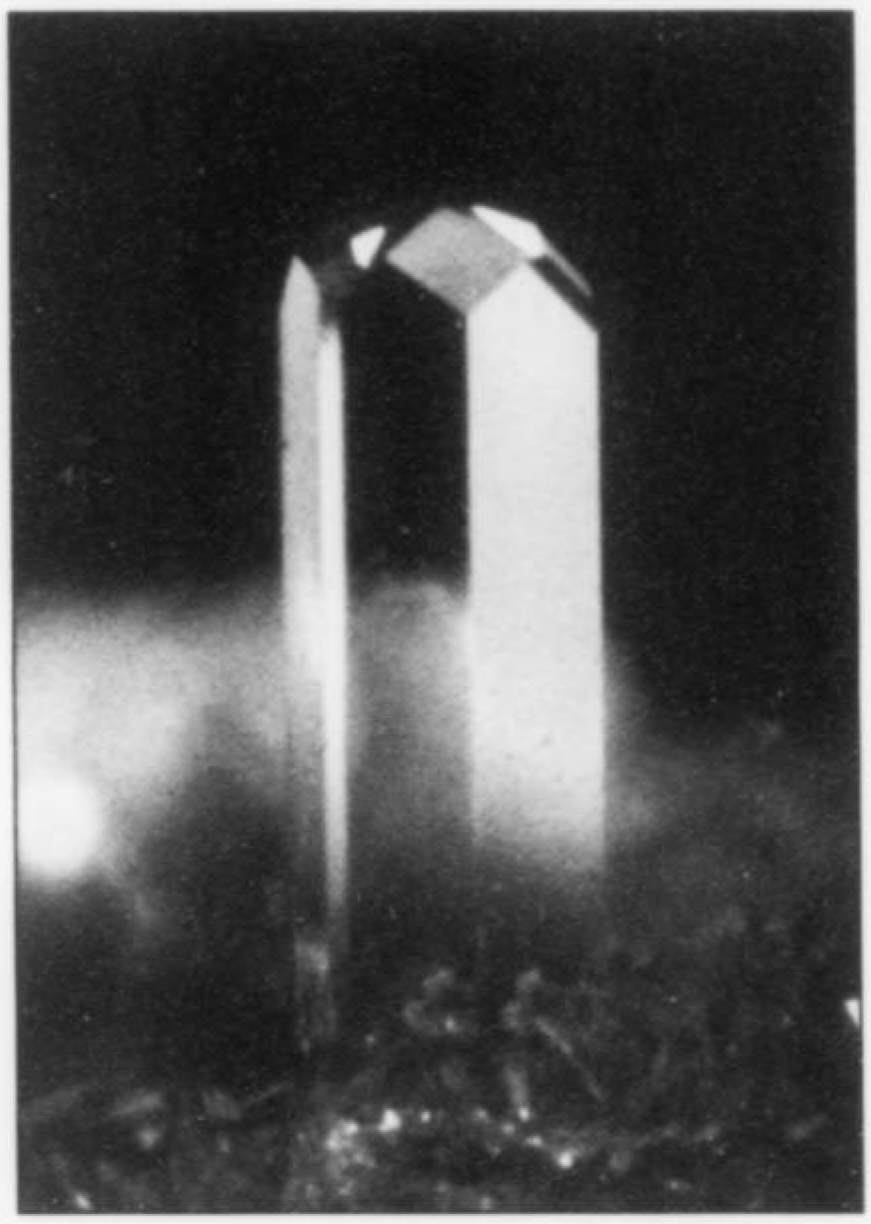

Figure 10. **Nosean, colorless, elongated twin with modifying cube faces, from Wannenköpfe, Eifel district, Germany. Berndt Ternes specimen; photo by E. van der Meersche.**

shown in Figures 12 and 13. An incomplete (four-rayed, instead of six-rayed) twinned octahedron face appears on the crystal in Figure 13. The end-on view of the same crystal in Figure 14 shows more clearly the incomplete nature of the six-rayed star and the irregular growth of the crystal. It is regrettable that nature so seldom presents us with ideally grown, symmetrical crystals! Yet imperfect crystals are quite common, and not infrequently illustrated in crystal drawings from the older literature.

Numerous other examples of such twins could be illustrated by the authors, as shown by the citations in Table 1. No less than nine localities for twinned sodalite, two for haüyne, and four for nosean are known to them, and there are doubtless many more. It is interesting that the reported localities are so closely associated with volcanic regions; the Eifel District in Germany, and areas north of Rome and on Mount Vesuvius in Italy; all noted for their undersaturated, pyroclastic rocks. Surely there are examples of elongated twins of sodalite minerals from other areas, and the authors would appreciate word of them.

Elongated twins of sodalite family minerals have been reported repeatedly and since very early times. For example, vom Rath (1866) described elongated twins of sodalite from the Alban Hills in Italy, and Hubbard (1887) reported elongated nosean crystals from the Eifel district in Germany. Photographs of such crystals (including the nosean shown in Figure 15, taken from Hentschel (1987)) have also appeared in the literature. While some drawings depict equant twins of sodalite family minerals, we know of no

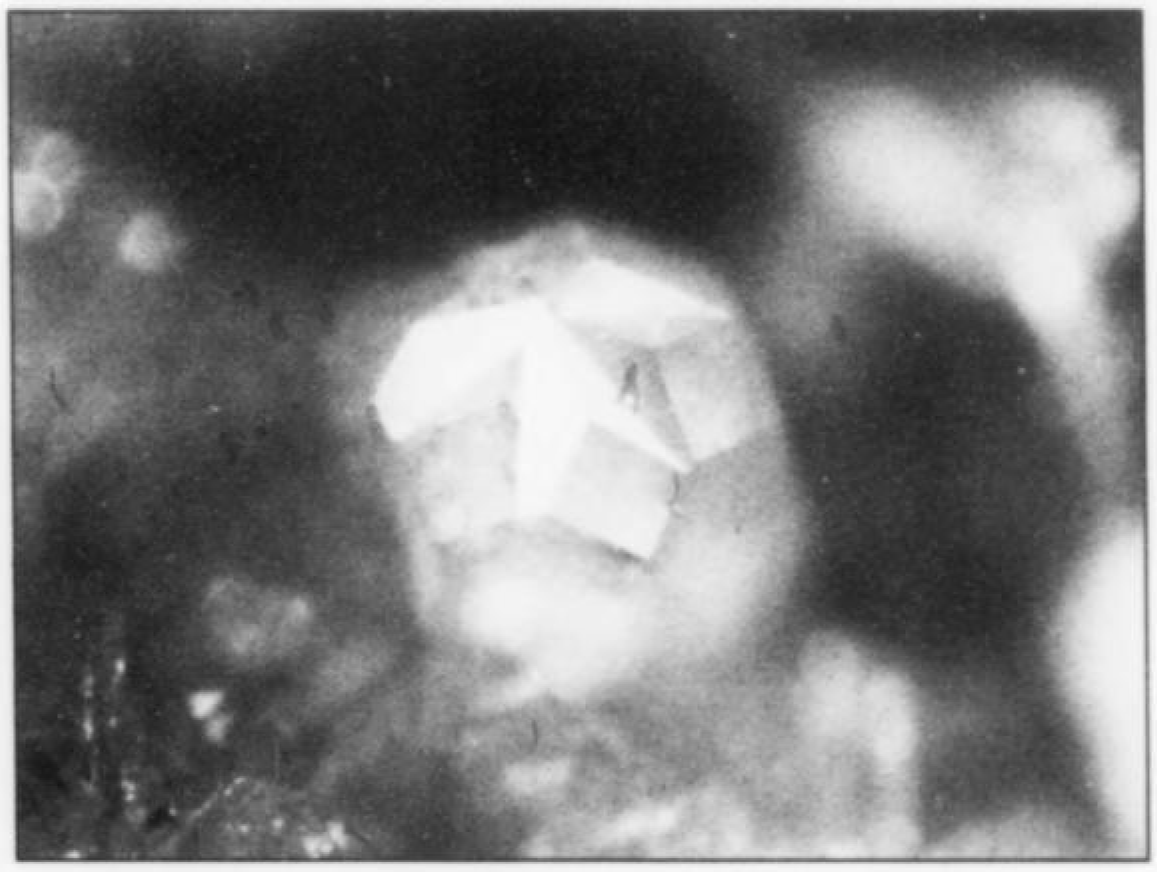

Figure 11. **Nosean, termination of a colorless, twinned crystal with dodecahedron and cube faces; from Laacher Kessel, Mendig, Eifel district, Germany. E. van der Meersche specimen and photo.**

Figure 12. **Nosean, SEM photo of a 2.2-mm crystal from Mendig, Eifel district, Germany, showing dodecahedron and cube faces and a single reentrant. Photo by DGH.**

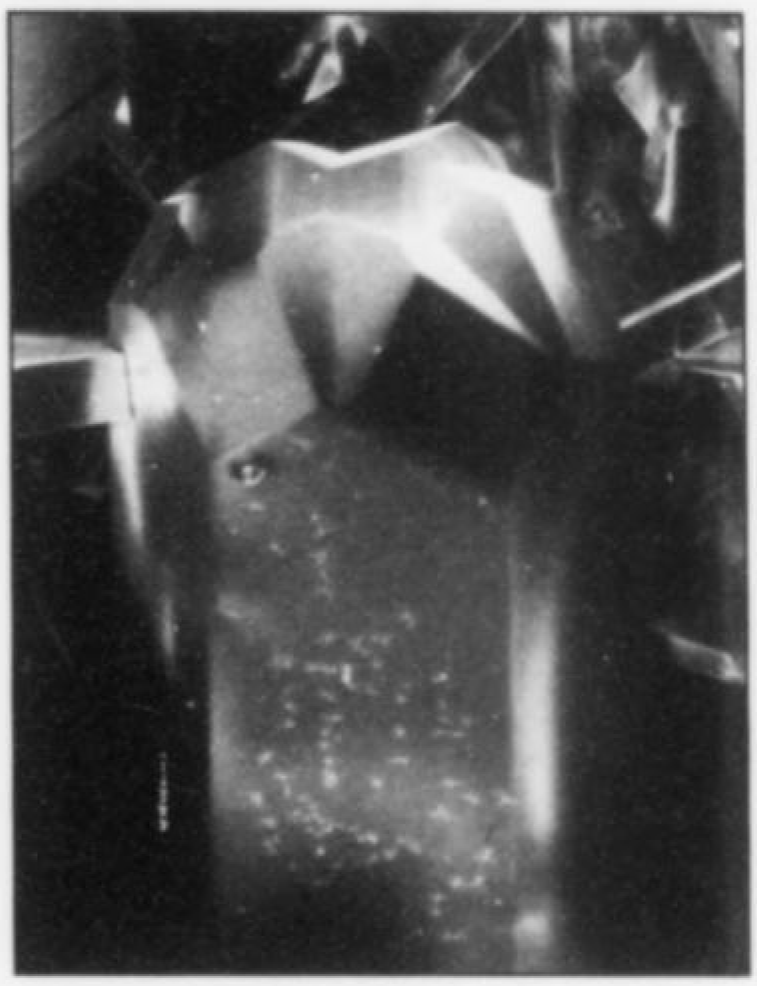

Figure 13. **Sodalite, SEM photo of 0.8-mm twin, showing dodecahedron, octahedron, and cube faces; from Wannenköpfe, Eifel district, Germany. DGH photo.**

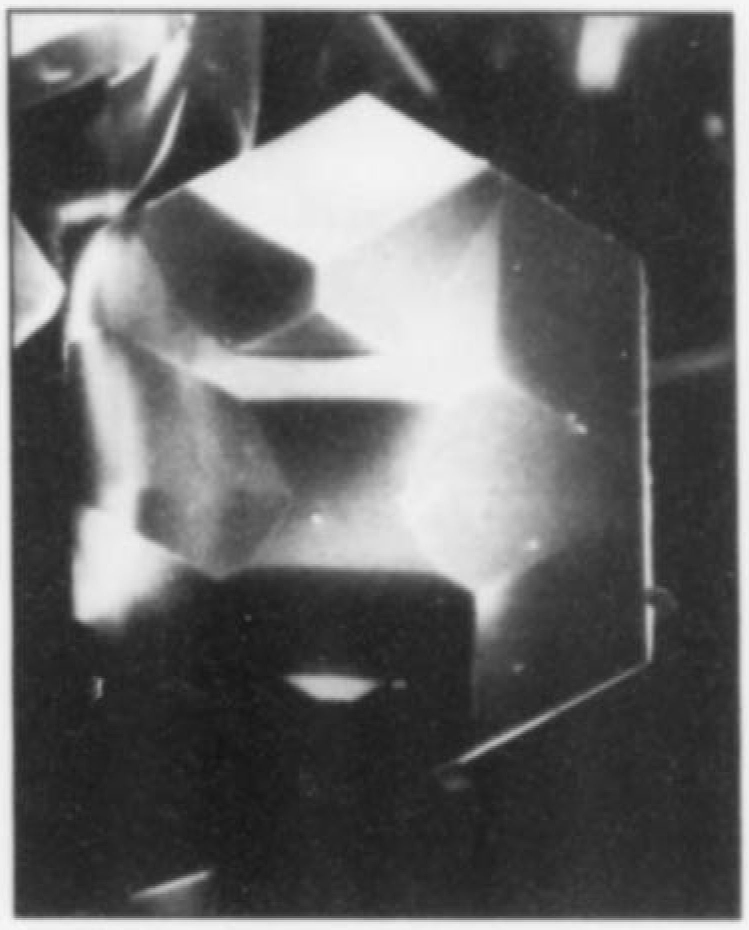

Figure 14. **Sodalite, same crystal as in Figure 13 photographed down the pseudo-c-axis, and showing four of the six rays of the terminal octahedron face.**

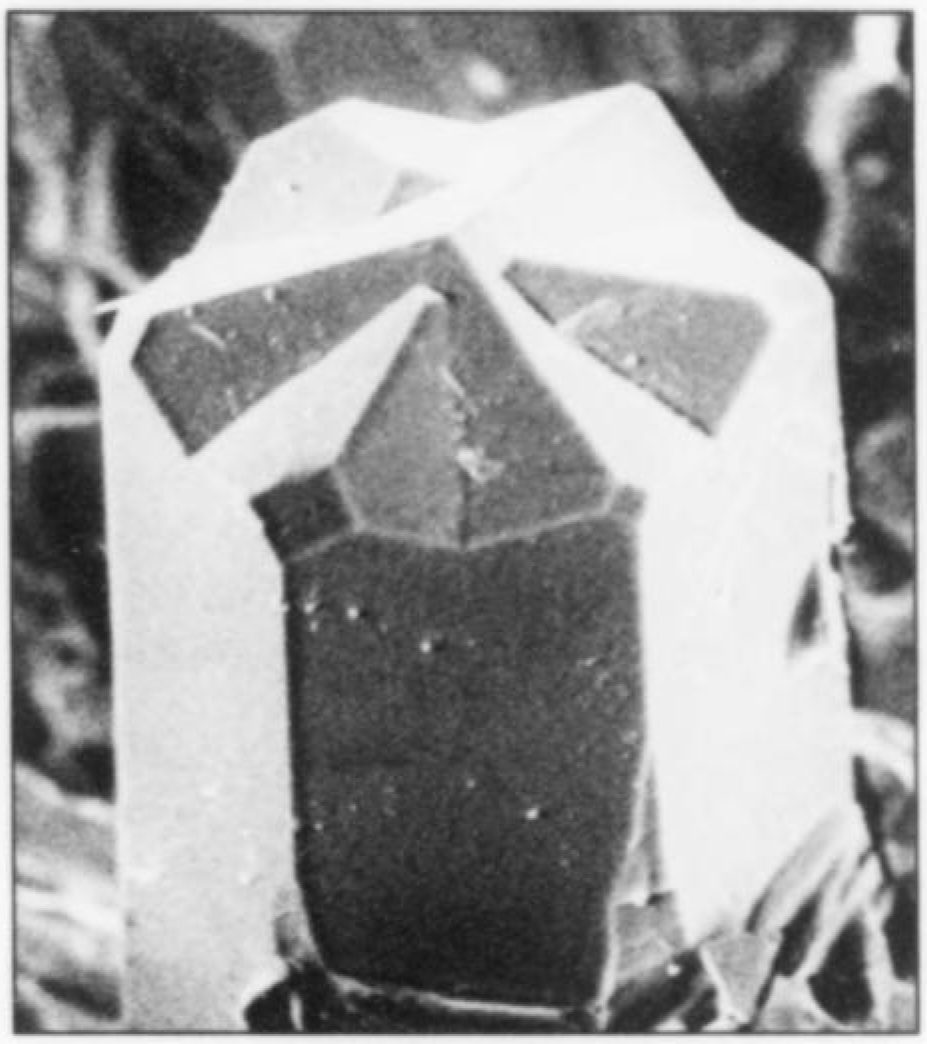

Figure 15. **Nosean, twinned dodecahedron, with modifying cube faces from Mendig, Eifel district, Germany, taken from** ***Die Mineralien der Eifelvulkane*** **(Hentschel, 1987). SEM photo by Paul Rustenmeyer.**

instance of an author explicitly stating that the twins are not elongated.

In spite of the ubiquity of elongated twins, no source known to the authors comments on the cause of the elongation. A plausible mechanism for elongation follows.

CAUSE OF ELONGATION IN TWINNED SODALITE FAMILY MINERALS

Elongation of twinned sodalite family minerals is a kinetic phenomenon; i.e., it is caused by relatively fast growth of the terminal faces compared to the relatively slow rate of growth of the "prism" faces of the twin. This in turn is related to the ease with which new growth layers can be formed in a growing crystal. Thus, the final crystal form is kinetically (rate) controlled, and is not the normal, equant, equilibrium-controlled form.

Consider growth of the top face of the crystal shown schematically in Figure 16. Each small cube can be considered as either a single atom or a "unit cell" of the complete crystal. Initiation of a new growth layer involves deposition of a new cube at position 1. Such a cube, attached on one side only, adheres only very weakly to the crystal. In fact, at low degrees of supersaturation, such a building unit skitters about on the crystal surface, and will most likely fly off the crystal face before more cubes can adhere next to it. Once begun, though, a partially completed growth layer creates a ledge as shown in Figure 16. Along the ledge newly deposited cubes such as 2 and 3 are attached on two or three sides,

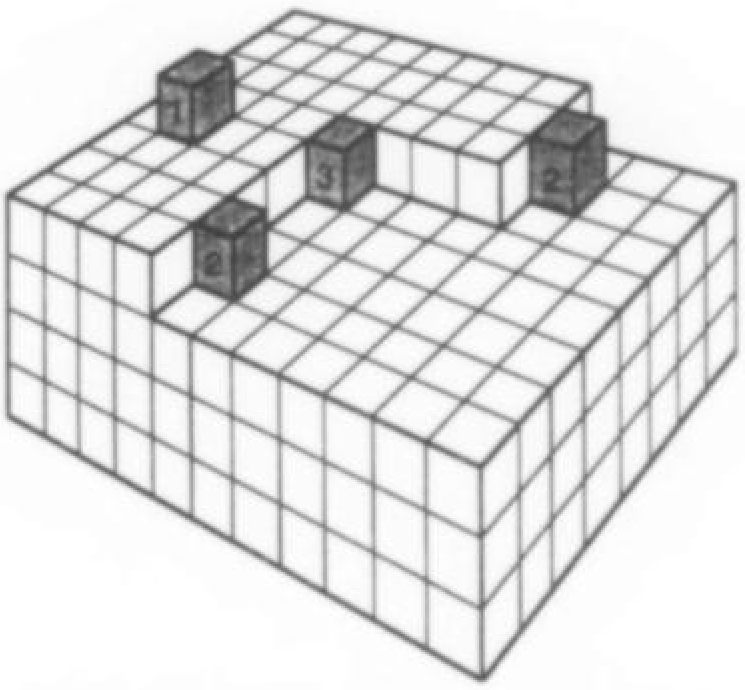

Figure 16. **Schematic model of layered crystal growth by preferential addition of new atoms to the edges and corners of growth layers. RPR drawing.**

***Table 1.* Localities for elongated twins of isometric minerals.**

Species/Locality	*Elongation**	*Source/Reference*
Sodalite		
Wannenköpfe, Eifel district, Germany	+	Coll. WAHJr.
Pollena quarry, Monte Somma, Napoli, Campania, Italy	+	Coll. WAHJr.
San Vito quarry, Mount Vesuvius, Napoli, Campania, Italy	+	Coll. WAHJr.
Mount Vesuvius, Napoli, Campania, Italy	+	Goldschmidt, 1922; Scacchi, 1847
	–	Hintze, 1879
Monte Cavalluccio, near Sacrofano, Roma, Lazio, Italy	+	Coll. WAHJr.
Castellaccio de Petrignano, near Vetralla, Viterbo, Lazio, Italy	+	Coll. WAHJr.
Carcarelle, near Vetralla, Viterbo, Lazio, Italy	+	Coll. WAHJr.
Alban Hills, Roma, Lazio, Italy	+	Goldschmidt, 1922; vom Rath, 1887
	–	Hintze, 1879, 1892
Insel Laven, Langesundfiord, Norway	+	Klein, 1879; Goldschmidt, 1922
Synthetic	+	Dana, 1892
Haüyne		
Mendig, Eifel district, Germany	+	Coll. WAHJr.
	+	Coll. E. van der Meersche
Alban Hills, Roma, Lazio, Italy	–	Liotti, 1994
Nosean		
Mendig, Eifel district, Germany	+	Hentschel, 1987
Laacher See, Eifel district, Germany	+	Goldschmidt, 1922; Hubbard, 1887
Alban Hills, Roma, Lazio, Italy	+	Yale Univ., Cahn Coll. #2960
Tobia, near Vetralla, Viterbo, Lazio, Italy	+	Coll. WAHJr.
Sal Ammoniac		
Arniston, Midlothian, Great Britain	–	Goldschmidt, 1922; Shand, 1910
Eruption of 1872, Mount Vesuvius, Napoli, Campania, Italy	+	Scacchi, 1874
Synthetic	+	Palache *et al.*, 1951
Sphalerite		
Pontpean, France	–	Goldschmidt, 1922; Lacroix, 1897
Harz Mountains, Germany	–	Niggli, 1927

* The symbol + indicates that (1) crystals observed by the authors were elongated, or (2) the text and/or figures of the referenced papers stated and/or showed elongation. The symbol – indicates that neither the text nor the figures showed elongation to be present. It should be noted that some authors may not have considered elongation to be of significance, and may have deliberately drawn an equant twin.

respectively. Since bonding at these points is much stronger, cubes such as 2 and 3 are much less likely to detach themselves, and accretion to the growing face along the ledge is much faster than the initiation of a new growth layer as at one-contact positions such as 1. Hence, the limiting factor in crystal growth is the creation of new growth layers or, put differently, the creation of ledges. It should be remembered, here, that the above argument applies only under conditions of low supersaturation of the solution from which the crystal is growing. At high supersaturations, the rate at which material is deposited at points such as 1 is so high that the rate at which such atoms or cubes fly off again is no longer limiting.

Under what conditions can growth ledges be maintained or created? A prime example is the presence of a screw dislocation in a crystal (Fig. 17). The self-propagating ledge ascending in a spiral about the screw dislocation promotes continuous and rapid growth in that direction, while the absence of growth ledges on the side faces causes little or no growth laterally. Whisker crystals with length to width ratios of 10:1 or 1000:1 are thus created (Henderson and Francis, 1989). Note that, except in the immediate neighborhood of the screw dislocation axis, the packing of unit cells is perfectly normal and strain free. In a real crystal, extending thousands of unit cells in all directions, strain at the screw axis is not important.

As shown in Figure 18, twinning can also afford a self-perpetuating growth ledge. This two dimensional representation

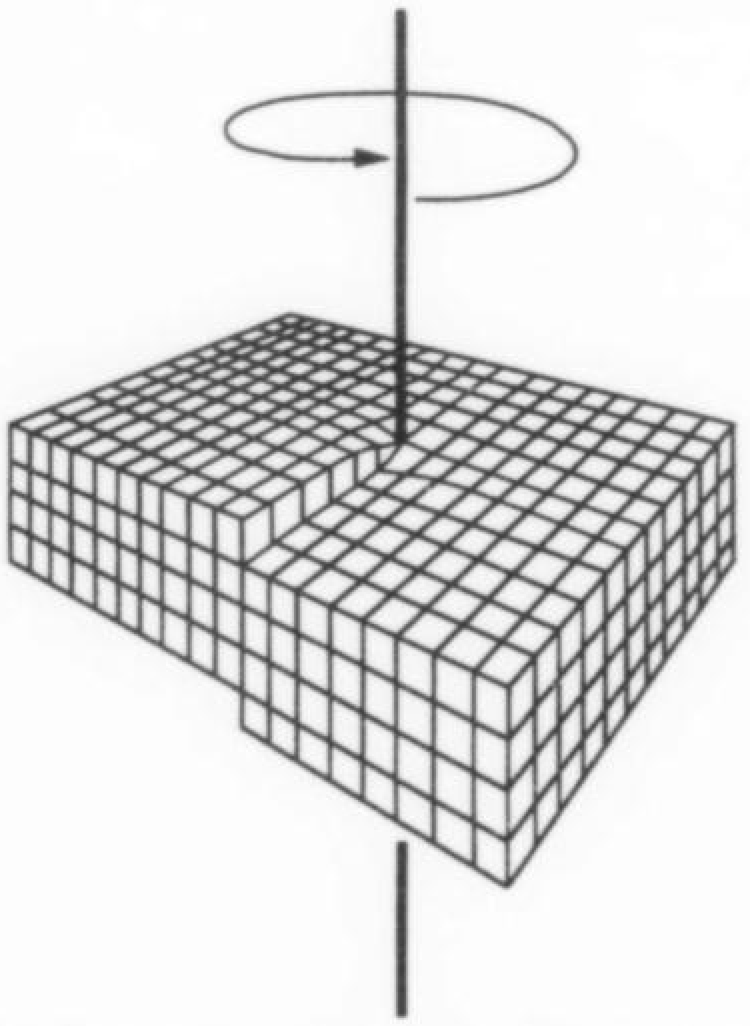

***Figure 17.* The role of screw defects in crystal growth is to provide a growth layer with permanent edges, greatly accelerating the rate of growth parallel to the screw axis by removing the rate-limiting step of creating new layers. RPR drawing.**

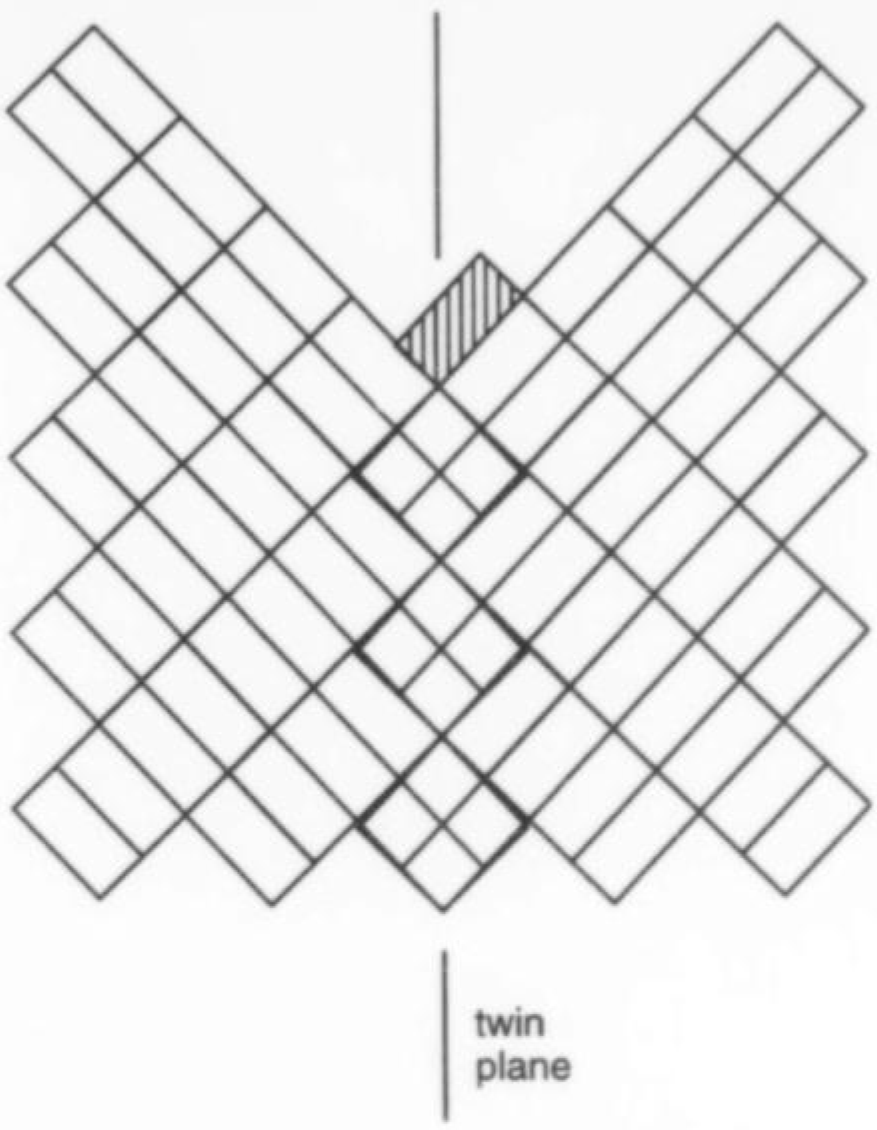

***Figure 18.* The structure of a twinned crystal, showing how the twin plane provides a favored site for the nucleation of new growth layers. RPR drawing.**

shows that, at a twin reentrant, the first "cube" of a new growth layer is attached on two sides, not just one. This critical increment in stability makes the rate of growth within the reentrant faster than growth where no reentrant exists.

Returning to sodalite family twins, then, it could be said that the reentrants in the terminations of these twins promote relatively fast growth in the direction of the pseudo-hexagonal axis, while the absence of such reentrants in the prism zone causes growth to be slower laterally. This is not strictly correct, however, since growth in the twin reentrants has a vector component in the lateral direction as well as the longitudinal one. The correct way to put it is that the reentrant causes relatively rapid growth of the *two faces comprising each reentrant,* while the "prism" faces, each composed of two coplanar faces, one from each half of the twin, have no reentrants, and grow only slowly. The slow-growing prism faces act as boundary limits for, and limit the lateral growth of, the faces of the reentrant, and elongated twins result.

Note that the "fit" of a new cube within the reentrant of a twin is not as perfect as for a cube deposited at a partially completed growing ledge, or at a screw dislocation edge. The misfit can be either an angular one or a dimensional one, depending on the geometry of the reentrant. For this reason, the strength of attachment of such a cube is not as great as for one added to a ledge at a screw dislocation. Perhaps this in turn explains why the aspect ratio of whisker crystals formed by screw dislocations can be 10:1 to 1000:1, while that of elongated sodalite family twins is rarely even 10:1.

All the above is discussed in terms of a crude, diagrammatic model. In actual fact, accretion of material on a real crystal face or ledge is controlled by complex electromagnetic interactions. These can be and have been considered by various authors (e.g. Grigor'ev, 1965), and results of their calculations of attachment energies parallel those from the above much cruder model.

It might be pointed out that while rapid growth in twin reentrants only rarely produces elongated twins such as these, it commonly produces flattened twins. Good examples are spinel twins of isometric minerals such as diamond, magnetite, gold, and silver; and unusually flat twins of rhombohedral carbonate minerals such as calcite, siderite and rhodochrosite. Similarly, while the two halves of Japan twins of quartz may have undistorted, hexagonal cross sections, the area between the two limbs is often filled in by rapid growth within the twin reentrant, giving tabular crystals (Henderson and Francis, 1989).

Recognition that twinning can stimulate or accelerate the rate of growth of crystals and crystal faces is by no means new, and has been commented on by Tertsch (1926), Frank (1949) and Grigor'ev (1963) in fairly recent times. The importance of the reentrant angle of twins to their growth kinetics was already known to Becke (1889), and was stressed again by Frank (1949).

ISOMETRIC FORMS OTHER THAN THE DODECAHEDRON WHICH MIGHT FORM ELONGATED TWINS

The question arises as to whether forms in the hexoctahedral class of the isometric system other than the dodecahedron can yield similar, elongated twins. The prime requirement for such elongated twins is that the twinning operation yield a pseudo-hexagonal prism zone (hereafter called a belly band) of faces, each of which is made up of two coincident faces, one from each half of the twin. The twinning operation, of course, is a rotation of 180° about a three-fold, i.e., [111] axis. To meet the above conditions, it is sufficient to show that faces of the form lie in the zone [111], i.e., are parallel to the twin axis. To show that a face (hkl) lies in the zone $[uvw]$, the zonal equation

$$hu + kv + lw = 0$$

must be satisfied (Dana and Pord, 1932, pg. 63). In the present case, $[uvv]$ is equal to [111] and by substitution into the equation above, the condition becomes

$$h + k + l = 0, \text{ or } h = -(k + l).$$

That is, one index must be equal in value but opposite in sign to the sum of the other two. Because of the symmetry properties of the hexoctahedral class, this condition is equivalent to $h = k + l$, where $\{hkl\}$ are the indices of the **form,** listed in their conventional order with $h>k>l\geq0$.

Symmetry considerations then show that, if one face of the form satisfies the above equation there will exist a belly band of six (or twelve) faces which lie in the zone of the twin axis. Forms of the hexoctahedral class of the isometric system have the symmetry $\frac{4}{m}\,\bar{3}\,\frac{2}{m}$. They are characterized by having three axes of four-fold symmetry, four axes of three-fold symmetry (one of which is our twin axis), six axes of two-fold symmetry, nine planes of symmetry, and a center of symmetry (Dana and Ford, 1932). Of these, the three-fold axes and center are of importance to our argument. First, a face shown by the zonal equation to be parallel to the [111] twin axis must, since this is a three-fold axis, have two more faces 120° apart from it in the zone. Second, by virtue of the center, each of these three faces must have one opposite it (180° apart from it), generating a group of six faces 60° apart from each other and lying in the twin-axis zone.

Alternatively, readers who are geometrically and mathematically inclined can reach the same conclusion as to the presence or absence of a belly band of faces at 60° from each other using Miller Indices alone. This can be done for the various isometric forms by the following sequence of operations: (a) choose a [111] twinning axis on a crystal model or drawing; (b) identify faces which may make up a belly band on twinning; (c) show that the Miller Indices

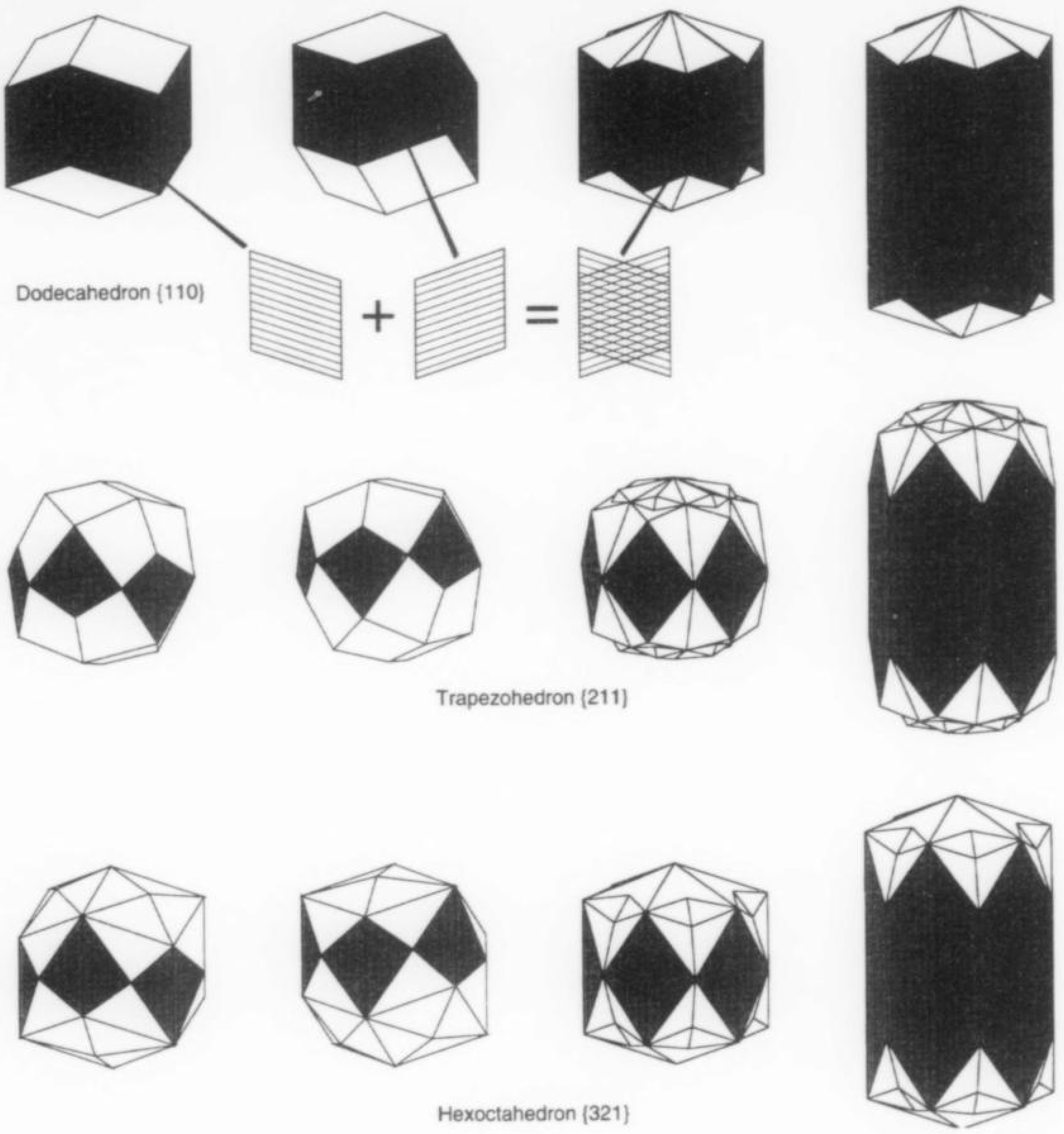

Figure 19. **Examples of isometric forms which have a prismatic habit ("belly bands") when twinned by rotation on [111]. In each row, the left drawing shows an untwinned crystal with the [111] axis vertical. The next drawing shows the same crystal rotated 180° about the [111] axis. The third drawing shows the penetration twin formed by the intersection of the two crystals to the left. The drawing on the right shows the same twin elongated parallel to the [111] axis. SHAPE drawings by RPR.**

of a chosen face apparently parallel to the twin axis do indeed satisfy the zonal equation as before; and (d) show that an adjacent face with a similar orientation is 60° from the first face. The last step can easily be done using the equation for calculating the angular distance between the poles of two faces, P (*hkl*) and Q (*pqr*) as given in Dana's Textbook (Dana and Ford, 1932, pg. 90):

$$\cos PQ = \frac{hp + kq + lr}{\sqrt{(h^2 + k^2 + l^2)\,(p^2 + q^2 + r^2)}}$$

This can be simplified and, on substituting $\cos PQ = \cos 60° = \frac{1}{2}$ reduces to:

$$\frac{1}{2} = \frac{hp + kq + lr}{h^2 + k^2 + l^2}$$

Actually, it can be shown algebraically that any form which satisfies the zonal equation will also satisfy the interfacial angle equals 60° requirement, thus making step (d) superfluous. That is to say, the same conclusion is arrived at using Miller Indices as is obtained by consideration of symmetry elements. It would be most disconcerting if this were not the case!

For those not wishing to do the calculations, the following conclusions are presented. The cube {100}, octahedron {111}, all trisoctahedra {*hhl*}, and all tetrahexahedra {*hk*0} do *not* yield belly bands since they cannot satisfy the zonal equation. As shown earlier, the dodecahedron {110} has a belly band of six faces. Of all the possible trapezohedra, {*hll*}, only the simplest, {211}, yields a belly band; again one of six faces. All those hexoctahedra, {*hkl*}, where $h = k + l$ yield belly bands with twelve, not six, faces. An infinite number of hexoctahedra including {321}, {431}, {532}, {743}, {853}, and {20.13.7} satisfy this condition. However, the empirical observation that forms with low indices are far more common than those with high indices suggests that only the first two or three hexoctahedra listed above will occur as elongated twins with any frequency.

The shapes of the belly bands (shaded) for the dodecahedron, the {211} trapezohedron, and the {321} hexoctahedron are given in Figure 19, along with the shapes of the (extended) belly band faces in their twins on [111]. The shapes of the belly band faces change in the twins because (a) they are the sum of two such faces, and (b) they must be extended to follow the rapid growth of the terminal faces parallel to the pseudo-hexagonal c-axis. Their faces are delineated by their line of intersection with the fast-growing terminal faces, while the terminal faces are limited in their lateral extent by the line at which they intersect the slow-growing prism or belly band faces.

As can be seen from the shaded drawings below the first row in Figure 19, the faces which produce the prism have a large degree of overlap in the twin. This is fine in a geometric construction, but it is impossible in a real twinned crystal, because any small region of the twin must have a structure which corresponds to just one of the two orientations. The surface along which the two halves of a twin actually meet cannot be predicted by geometric construction, and may be quite complex. For this reason, these faces are labeled d/d' in Fig. 9, indicating that they are composed of contributions from each half of the twin.

In the pseudo-hexagonal frame of reference, the belly band faces of the untwinned dodecahedron can be assigned to the second order hexagonal prism $\{11\bar{2}0\}$. The belly band of the {211} trapezohedron then corresponds to a hexagonal prism, but one that is rotated 60° with respect to the prism of the dodecahedron; i.e., it is the first order hexagonal prism $\{10\bar{1}0\}$. Thus, an elongated twin of a crystal with both dodecahedron and {211} trapezohedron faces would exhibit a belly band of twelve faces derived from the two prisms. The interfacial angles in the prism zone would all be 30°.

For the {321} hexoctahedron, using the pseudo-hexagonal frame of reference, a belly band of not six but twelve faces is observed. The calculated interfacial angles between adjacent pairs of prism faces alternate between 38°13′ and 21°47′, so that the sum of the two is exactly 60°. This belly band constitutes a dihexagonal prism, $\{41\bar{5}0\}$, the angles of which are exactly those reported above. For the general case of hexoctahedra $\{hkl\}$ satisfying the zonal equation $h = k + l$, the Miller Indices of the corresponding dihexagonal prism are $\{2l + k\ k\text{-}l\ 2k + l\ 0\}$.

The terminal faces of the isometric forms referred to a pseudo-hexagonal axis system are various positive and negative rhombohedra and scalenohedra. Thus, we find that the isometric forms which can produce twins with belly bands composed of pairs of coplanar faces, one from each half of the twin, are limited to the dodecahedron, the {211} trapezohedron, and those hexoctahedra for which $h = k + l$. (A more general treatment of forms and faces analyzed in the dual framework of the isometric and hexagonal systems is available on request from the second author.)

ELONGATED, TWINNED CRYSTALS OF OTHER ISOMETRIC MINERALS

Having observed that elongated twins of sodalite-family minerals are very common, we might ask whether other minerals also form elongated twins on [111]. A brief commentary on the subject follows.

First, it should be noted that the authors have not yet seen elongated, twinned dodecahedra of the fourth mineral of the sodalite family, lazurite. Perhaps it is significant that neither Dana's System nor any of several other standard references mention twinning of lazurite, while twinning is always noted for the other three members of the group. Still, the existence of elongated lazurite twins is quite probable.

Are there other minerals occurring in dodecahedra and reported to form such twins? The answer is yes. Just such a twinned dodecahedron of sal ammoniac is pictured in Dana's System of Mineralogy (Palache *et al.*, 1951). Very similar twins of sal ammoniac were reported from Arniston in Great Britain by Shand (1910), and from Mount Vesuvius in Italy by Scacchi (1874). The perspective used in the crystal drawings of Palache *et al.* and Shand (Figs. 20 and 21) makes it difficult to tell whether these twinned dodecahedra were elongated, and the text in all three cases fails to mention elongation. We determined elongation by drawing an unelongated twin using SHAPE, rotating and sizing it to match these drawings, and superimposing the two in the computer. As it turns out, Fig. 20 shows a somewhat elongated crystal (aspect ratio about 1.5:1), while Fig. 21 shows no elongation.

Figure 20. **Sal ammoniac crystal drawing taken from *Dana's System of Mineralogy* (Palache *et al.*, 1951) showing the dodecahedron twinned on [111].**

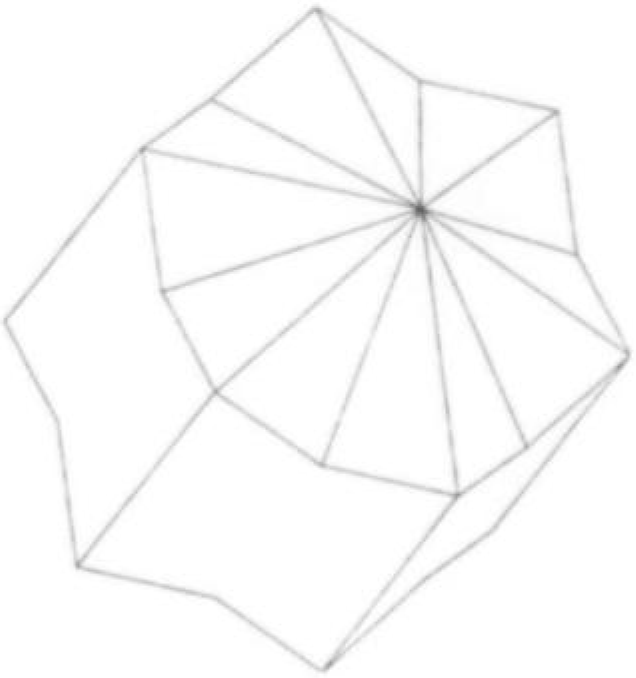

Figure 21. **Sal ammoniac, crystal drawing of a pseudo-hexagonal twin from Arniston, Midlothian, Great Britain (from Shand, 1910).**

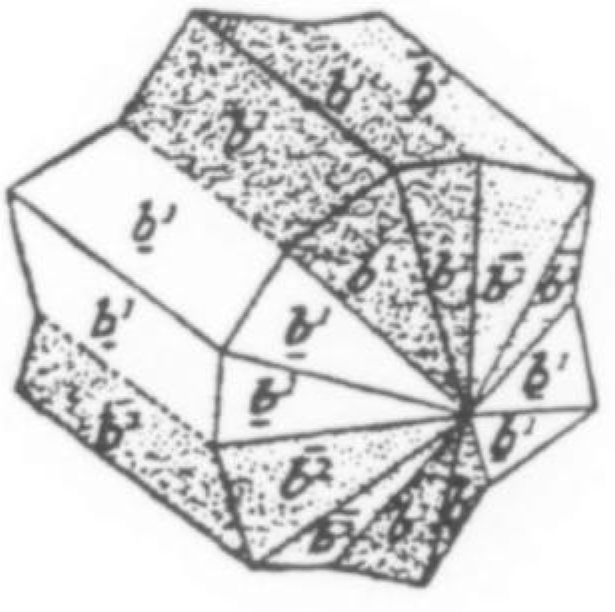

Figure 22. **Sphalerite, crystal drawing of a twinned crystal from Pontpean, France (from Lacroix, 1897).**

Sphalerite too has been reported to form twinned dodecahedra. Lacroix (1896) reported and figured such crystals from Pontpean in France (Fig. 22), while Niggli's Tabellen (1927) includes a crystal drawing of such a twin from the Harz Mountains in Germany. Again, in neither case is elongation mentioned. Our procedure shows these crystals to be drawn without elongation.

It should be noted that sphalerite has a lower (tetrahedral) symmetry than the hexoctahedral minerals discussed above. The dodecahedron and cube are permissible forms on sphalerite crystals and would appear in twins formed by rotation about a three-fold axis just as they do in sodalite, for example. However, the octahedron is not a permissible form on sphalerite crystals, and is replaced by faces of the positive and negative tetrahedra. Often, only one tetrahedron is present. If a sphalerite crystal with faces of the dodecahedron and one tetrahedron were twinned, it would display a single six-pointed star at one end of the crystal but not at the other. The pseudohexagonal twin would appear to be hemihedral!

What other isometric minerals might form elongated, dodecahedral twins? Those most likely to do so must (a) occur frequently in dodecahedra and (b) form twins by rotation about a [111] axis. Members of the garnet family come immediately to mind as frequently forming crystals where the dodecahedron is the sole or dominant form. However, garnets are not reported to twin about [111]. Fluorite and boracite are excellent possibilities as each occasionally forms dodecahedra, and twinning about [111] is known. It is quite possible that elongated twins exist somewhere in collections. In the spinel family, magnetite offers a possibility. The other 16 common, isometric minerals listed in Dana's Textbook (Dana and Ford, 1932, Appendix B) do not occur often in dodecahedra and/or do not twin on [111].

Are there elongated twins of the {211} trapezohedron or the permitted hexoctahedra? Analcime and the garnet family minerals frequently form {211} trapezohedra, but neither is reported to twin. Leucite occurs predominantly in {211} trapezohedra and is frequently twinned, but does not twin by rotation about [111]. Perhaps diamond, which twins on [111] and is found occasionally in hexoctahedra, offers some possibilities.

As it happens, the authors' predictions as to what isometric forms can generate belly bands, and what isometric minerals are likely to form elongated twins, were in part anticipated by work done 120 years ago. After the above was written, the text of the original paper by Scacchi (1874) on twins of sal ammoniac was finally obtained. In it, he not only described simple twinned dodecahedra of sal ammoniac; he also showed and correctly interpreted sal ammoniac twins with far less common forms. His crystal drawings (reproduced here as Fig. 23) do not show just another example of a twinned dodecahedron; rather, they show a twinned {211} trapezohedron! It is interesting that some of the trapezohedron faces which might have appeared in the crystal's termination are missing (but are shown in our Figure 24). Had they been present, the crystal would have had a much less pointed termination. Also reported by Scacchi (his crystal drawing, reproduced here in Figure 25) were twins with dodecahedron *and* {211} trapezohedron faces! Note that the drawing shows the pseudo-dihexagonal prism comprised of twelve faces predicted by the authors. And finally, he noted that, very rarely, he even observed the {321} hexoctahedron in combination with the above forms! He also measured and calculated interfacial angles for the forms he postulated, thus confirming his interpretation.

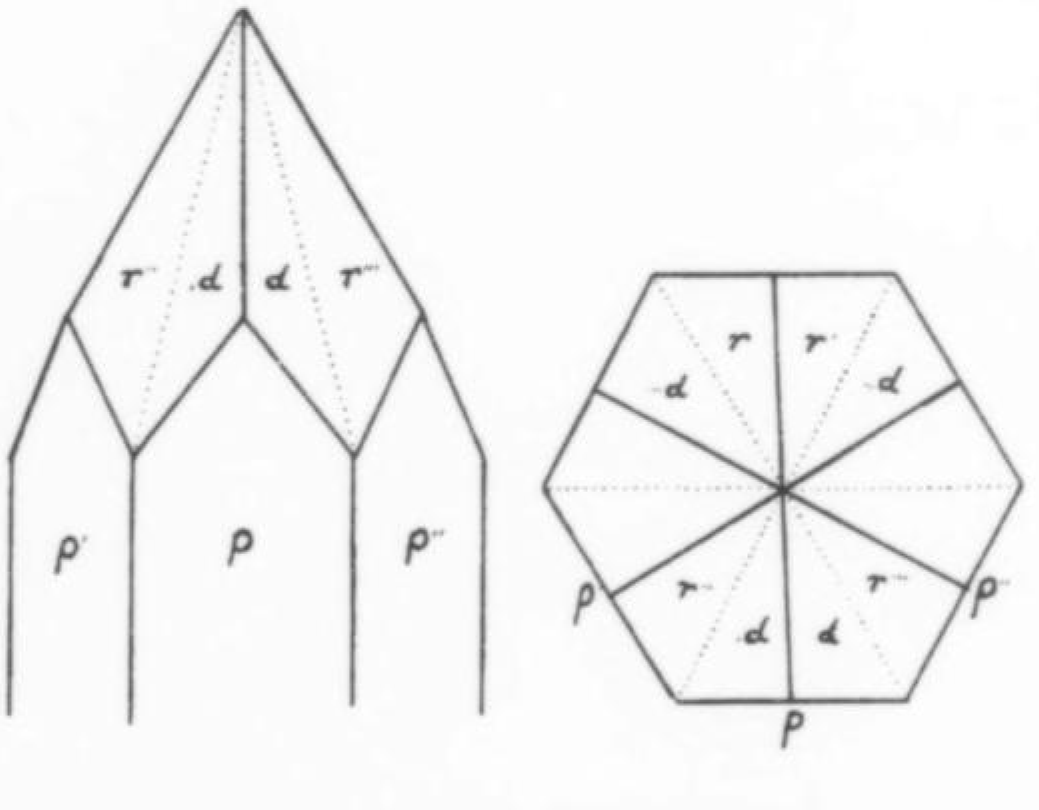

Figure 23. **Sal ammoniac, crystal drawings of a twinned crystal from Mount Vesuvius, Italy (from Scacchi, 1874). All 12 terminal faces and the 6 prism faces are the trapezohedron {211}.**

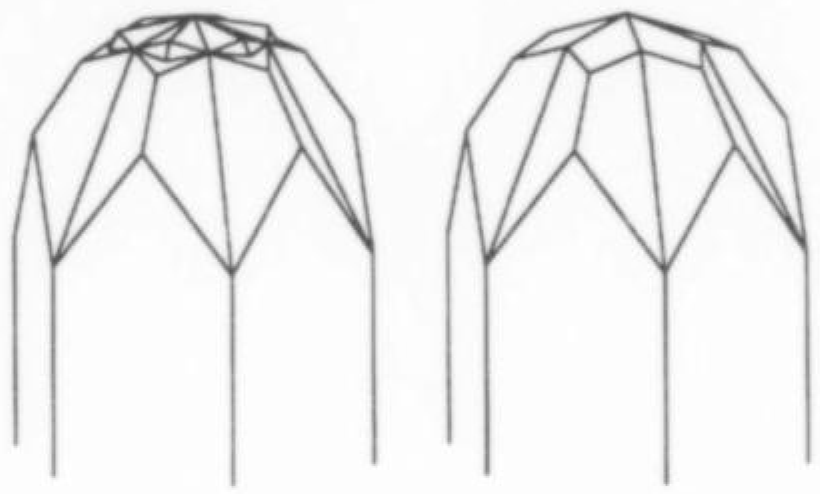

Figure 24. **Sal ammoniac, crystal drawings of hypothetical twinned crystals, showing the faces not present in Figure 23. The geometrically complete crystals, shown on the left, would have a set of six wedge-shaped terminal segments. We speculate that these would not develop on a real crystal, and instead the twins would have the morphology shown on the right. SHAPE drawings by RPR.**

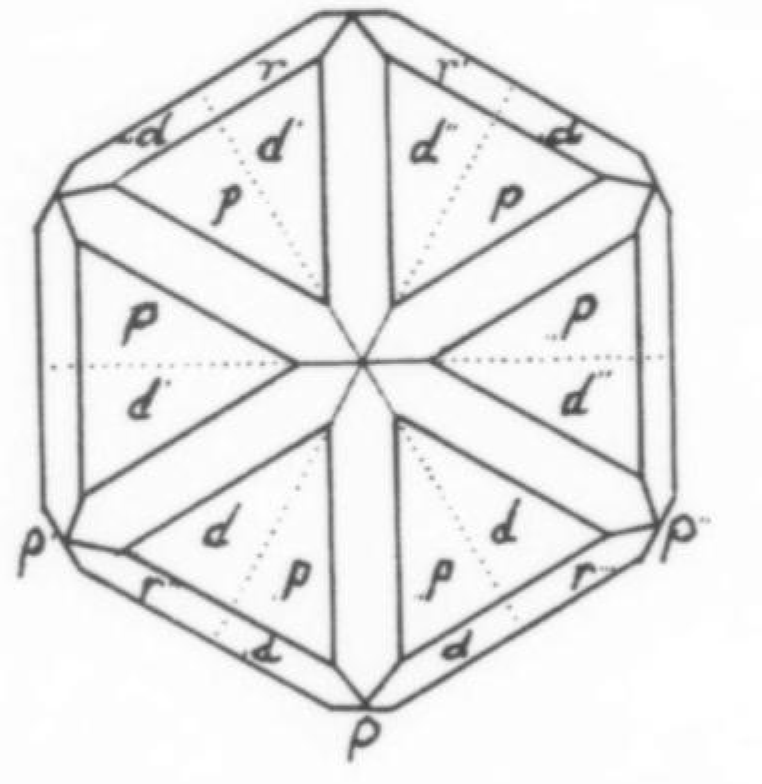

Figure 25. **Sal ammoniac, crystal drawing of a twinned crystal from Mount Vesuvius, Italy, with faces of the dodecahedron (*d*) and {211} trapezohedron (*p*) (from Scacchi, 1874).**

In addition, Hintze (1892) described sodalite crystals from the Alban Hills near Rome as shown in his crystal drawing reproduced in Figure 26. Along with the fairly common dodecahedron and cube faces of such twins, he also shows the much rarer {211} trapezohedron. Interestingly, while Scacchi's sal ammoniac crys-

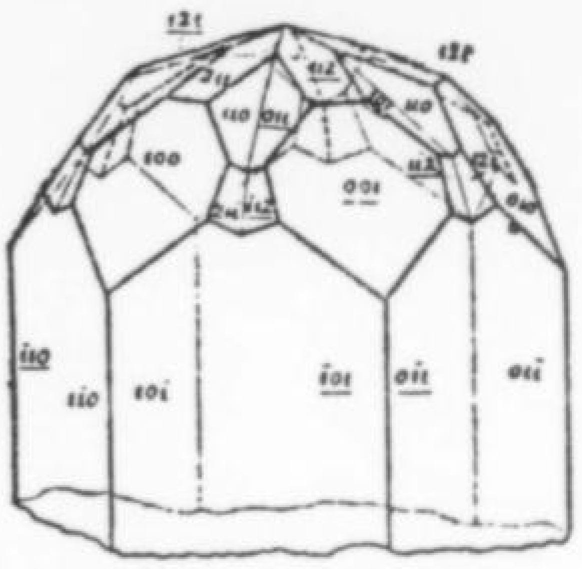

Figure 26. **Sodalite, crystal drawing of a twinned crystal from the Alban Hills, Italy, showing cube, dodecahedron, and {211} trapezohedron faces (from Hintze, 1892).**

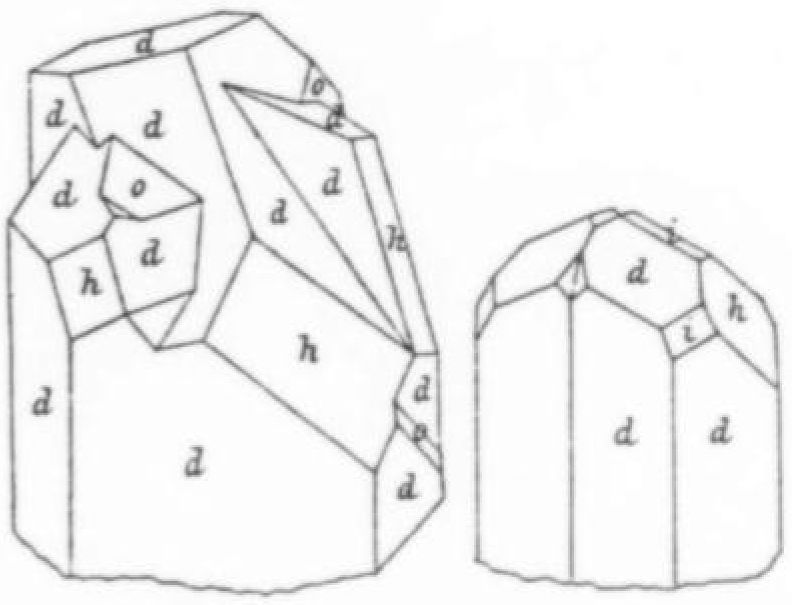

Figure 27. **Sodalite, crystal drawings of twinned crystals (from Hintze, 1879).** ***Left:*** **a contact twin;** ***right:*** **a complexly intergrown penetration twin. Forms are** ***d*****: dodecahedron {110},** ***h*****: cube (Hexaeder in German) {100},** ***o*****: octahedron {111}, and** ***i*****: trapezohedron {211}.**

tals lacked the set of terminal {211} faces mentioned above and thus were quite pointed, Hintze's sodalite crystals retained both sets of terminal {211} faces and thus had a very blunt termination. On the other hand, Hintze's crystals with both {110} and {211} faces lacked the set of six {211} trapezohedron faces in the prism zone which were present in Scacchi's crystals. It is not clear what Mother Nature's rules are as to whether certain faces of a form are present or missing.

Hintze (1879) also illustrated sodalite twins from Mount Vesuvius which include the dodecahedron, trapezohedron, cube, and octahedron (Fig. 27). The illustration on the right is of a symmetric contact twin, rather than the penetration twins which are the focus of this paper. The one on the left is of a much more complex intergrowth, with missing or unevenly developed faces and complicated interfaces between the twinned individuals. This one reminds us of one of the hazards of crystal drawings: it is often hard to tell whether the drawing is of an actual crystal or an idealized one!

Scacchi, Hintze and the other crystallographers of long ago deserve great credit for the fine work they did with far poorer tools for measurement and computation than we have today.

CONCLUSION

The sodalite family minerals are by far the best exemplars of the elongated twins of isometric minerals. There are isolated examples of similar twins of sphalerite and sal ammoniac, but only a few other species are likely to form such twins.

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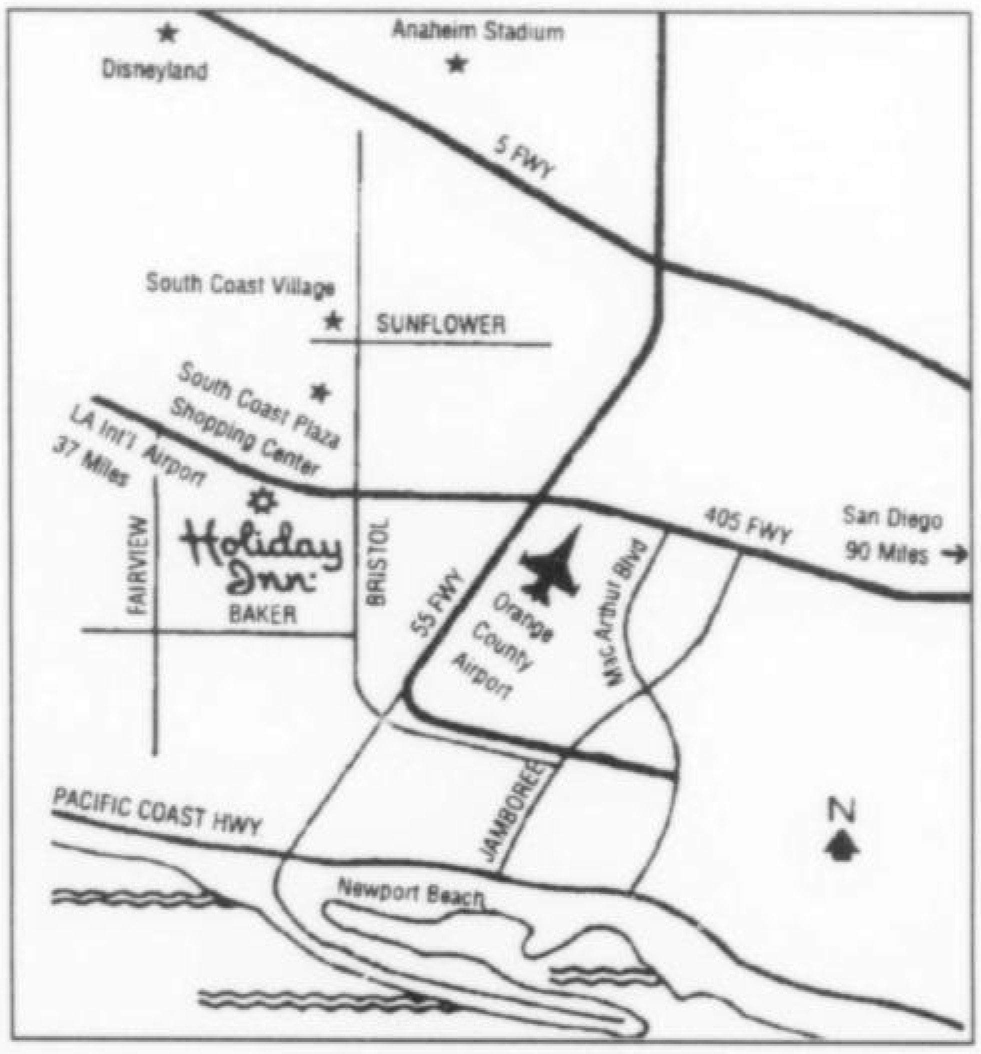
Petrov, Alfredo - Bolivia
Rincon Minerals
Rocks of Ages
Rocksmiths, The
Rotonda Rock, Inc.
S & K Enterprises
Samstone, Inc.
Schowalter, Todd, Fossils Plus
Scovil, Jeff, Photography
Seibel Minerals
Skoublov, Gene - Russia
Southwest Meteorite Lab.
Stevens, George, Minerals
Stone Flower Co. - Russia
Su's Creations
Sunnywood Collection, The
Superb Minerals (India) Pvt. Ltd.
Top-Gem Minerals
U.S. JEM, Inc.
Usman Imports
Valadares Minerals - Brazil
West Coast Mining
Wolfe, Tom, Minerals
Wright's Rock Shop, Inc.
XTAL - Dennis Beals
Yakhont
Zeolites India



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THE PEZINOK ANTIMONY MINE

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The Pezinok mine, an antimony deposit mined since 1940, has yielded hundreds of specimens of some of the world's finest kermesite, excellent valentinite and stibnite, and rare species such as chapmanite and garavellite. Nearly 50 species are currently known from the locality.

INTRODUCTION

The Pezinok antimony mine in southwestern Slovakia is a relatively small ore deposit, but it is important for its unusually large and beautiful crystals of kermesite, a red antimony sulfoxide. Kermesite at other world localities usually forms pink to purple fine-grained powdery aggregates, and occurs only rarely in well-developed larger crystals, e.g., at Bräunsdorf near Freiberg (Saxony, Germany) and Que-Que (Zimbabwe). The first large kermesite crystals to come from the Pezinok area were found in the Krížnica mine near Pernek between 1915–1922, but the crystals from the Pezinok mine are of better quality and are among the best specimens of the species in the world. Hundreds of top kermesite specimens are preserved in numerous private collections, mainly in Slovakia, the Czech Republic, Austria and Hungary, as well as museums in Bratislava and Prague. A variety of other primary and

Figure 1. **Location map showing the Pezinok antimony deposit.**

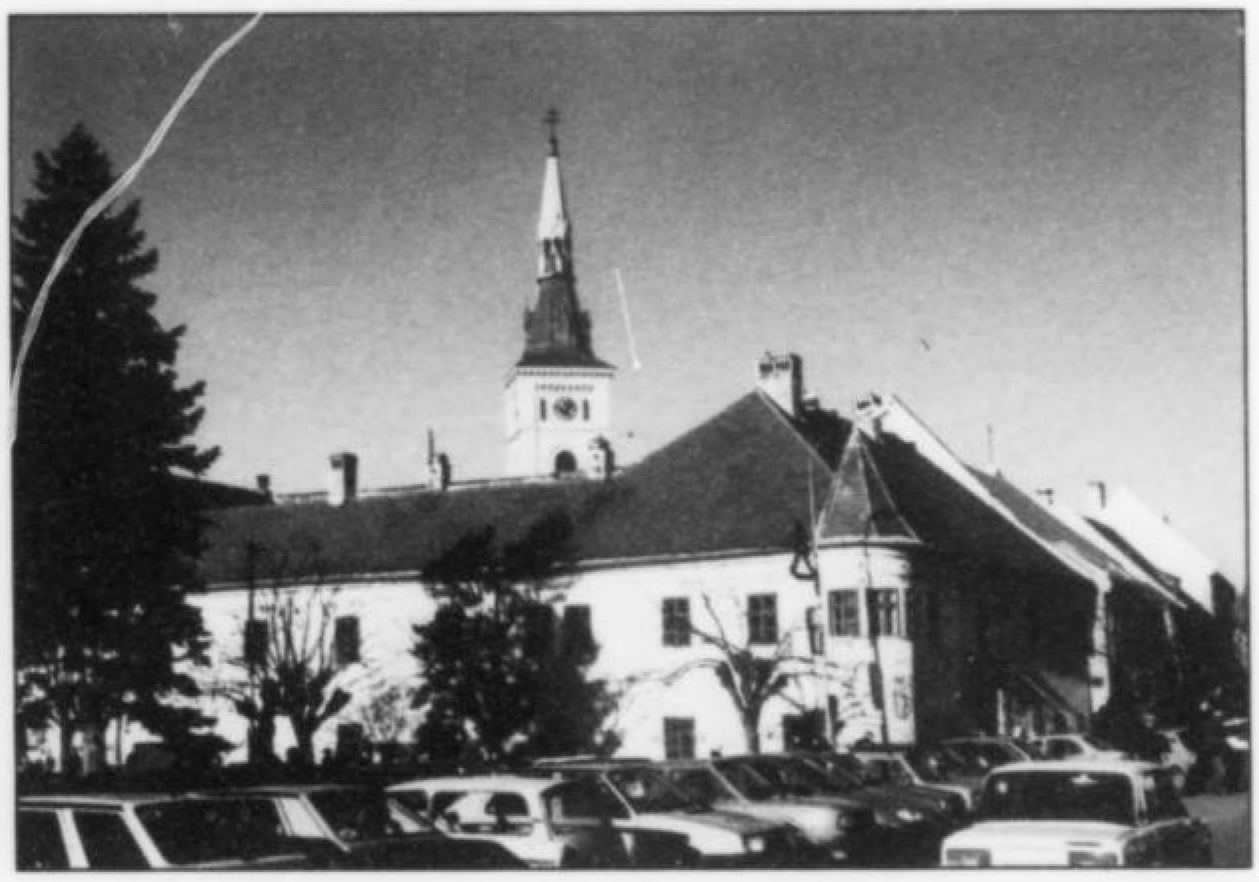

Figure 2. **The Pezinok City Hall (17–18th century) and tower of the Lutheran Church (18–19th century).**

Figure 3. **Pezinok antimony deposit; the open pit.**

secondary minerals from the Pezinok antimony deposit are also very interesting for collectors. This article will examine the history, geology and especially the minerals of the Pezinok antimony deposit.

LOCATION

The Pezinok mine (also known as the Kolársky Hill deposit) is situated about 4 km northwest of downtown Pezinok, a historical town in southwestern Slovakia, about 10 km northeast of the city limits of Bratislava, the capital of the Slovak Republic. Pezinok is a picturesque little town (population: ca. 25,000) with many medieval historical monuments. The town lies at the foot of the granite slopes of the Malé Karpaty Mountains; the area is well-known for its many vineyards producing excellent white and red wines.

The Pezinok antimony mine is situated on the southeastern slope of the Malé Karpaty Mountains, between 260 to 400 meters above sea level, in a forested area of the Hrubá Valley. The mine can be reached by a car road from Pezinok or Pernek. The deposit has been exploited by a 50 x 300-meter open pit and several underground galleries. The New Alexander tunnel is the longest; it measures about 1 km. The Staré Mesto deposit, an old gold mine in Pezinok, is situated only 2 km northwest of the antimony deposit.

Figure 4. **Pezinok antimony deposit; old adits in the open pit.**

Figure 5. **Pezinok antimony deposit; the New Alexander gallery, adit portal.**

HISTORY

The long history of mining in the Pezinok area has been documented in a manuscript by Bergfest (1952). The first record of the mining activity in the area dates to 1339, when Hungarian king Carol Robert of Anjou claimed the gold mining rights for the family of Earls of St. Georg and Pezinok. The Earls owned the mines during the 14th to 16th centuries. Renewed mining activity began in the 18th century, when eight galleries were reported at the Staré Mesto (Old Town) gold deposit in 1779. Unfortunately, the production of gold from thin quartz veins was small (maximum 2 kg/year) and the uneconomical mining expired in 1861, when only 49 grams of Au and 6 grams of Ag(!) were produced.

The earliest record of the mining of antimony in the Pezinok deposit is much more recent, in 1790. Ignatz Lill, the Mayor of the Mining Court of Pezinok, visited the mine and reported that the Francisci stope and the Joseph pit were 10 meters deep. In 1810, 11,100 kg of stibnite were recovered. Stibnite occurrence in the Pezinok area near Kolársky Hill (Wagnerberg) was also reported by Andrian and Paul (1864), but this first attempt at antimony mining ended during the 19th century. The exploitation of antimony was renewed around 1906, when a flotation plant, the first of its type in Austria-Hungary, was built. However, mining activity ended after World War I.

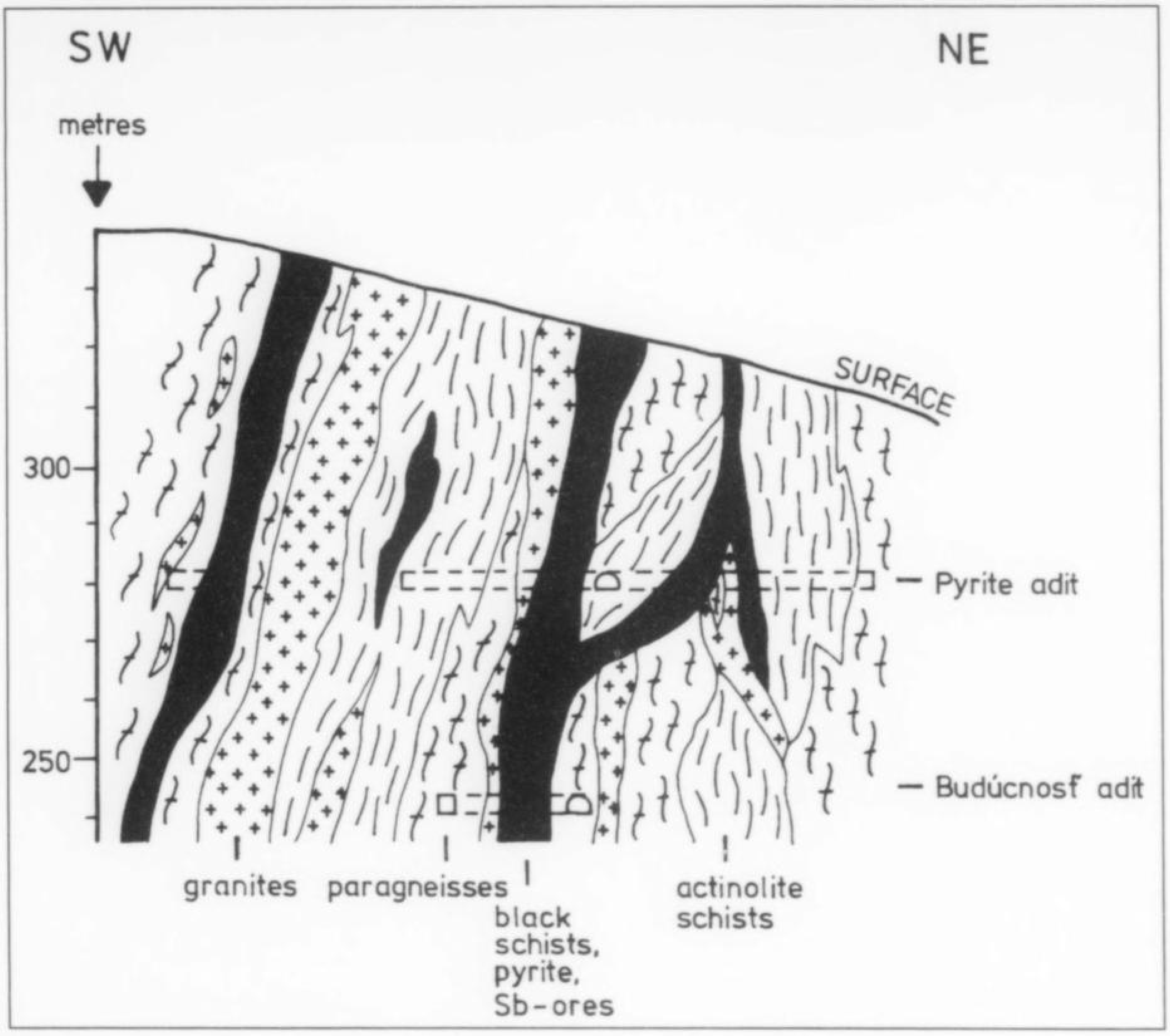

***Figure 6.* Geological section of the Pezinok antimony deposit (modified after Mikula, 1994).**

A modern operation for recovery of stibnite ore began in 1940, during World War II, when the demand for antimony as a "war metal" was high. During this year, the German company *Antimon-Aktion-Gesellschaft* built a new mine with a railway to the ore dressing plant. After a short break in 1947–1951, the exploitation of antimony ore at the Pezinok mine continued until 1991, when the mine was closed for economic reasons, and the technologically unfavorable composition of the ore.

GEOLOGY

The geology of the Pezinok antimony mine (the Kolársky Hill deposit) has been dealt with by numerous authors; we will summarize here mainly from data of Cambel (1959), Polák and Rak (1980), Andráš (1983), Chovan *et al.* (1992) and Grecula *et al.* (1996). The mine occurs in Lower Paleozoic (Silurian to early Carboniferous) metamorphosed black shales (with a basic pyroclastic volcanic admixture and pyrite ± pyrrhotite bands), actinolite schists, amphibolites and phyllites to paragneisses, locally penetrated by two-mica granites of the Bratislava Massif.

The ore-bearing zone is about 3.5 km long and 50 to 100 meters thick; it has a folded anticlinal structure oriented northwest-southeast, and dips southwest 60–90° (Fig. 10). The stibnite deposit has been worked over a length of 430 meters, to a depth of between 10 and 40 meters (Mrákava 1987). Vertical thickness of the central orebody reaches 65 meters (Andráš 1983). The ore-bearing zone is associated with a large low-angle fault or thrust zone which tectonically amputated the deposit. A two-mica granite with numerous pegmatite veins from the Bratislava Massif (Rb-Sr isotope age 348 ± 4 Ma, Cambel *et al.*, 1990), which intruded into sillimanite-garnet-biotite paragneisses, lies in tectonic contact below the ore-bearing metamorphic zone. The Staré Mesto gold deposit occurs directly in these leucocratic granites.

The antimony ores form irregular nests, lenticular bodies, small veinlets and veins and impregnations. They are situated in subvertical (up to 20-meter-thick) stratabound structures, referred to as "veins" (due to their vein shape), composed of metamorphosed black shales with basic pyroclastic material, quartz, pyrite/pyrrhotite and arsenopyrite. From southwest to northeast, the Zlatá (Gold), Karolina, Centrálna (Central) and Plochá are the principal "veins" or structures.

Four mineralization stages of hydrothermal Sb-Au-As mineralization in the Pezinok mine have been distinguished (Andráš 1983, Chovan *et al.*, 1992, slightly modified by the authors):

(1) **quartz-arsenopyrite**, with gold incorporated in arsenopyrite and pyrite;

(2) **quartz-pyrite-arsenopyrite**-(löllingite-tetrahedrite-chalcopyrite);

(3) **quartz-carbonate-stibnite**-(gudmundite-pyrrhotite-pyrite-sphalerite-Pb, Sb-sulfosalts-berthierite);

(4) **stibnite-kermesite**-(antimony-valentinite-barite).

The origin of the Pezinok antimony mine (Kolársky Hill deposit) is suggested as hydrothermal epigenetic, and of Hercynian (Upper Paleozoic) in age. The Bratislava granite intrusion caused a contact thermal metamorphism of adjacent metalliferous black shales with pyrite bands, the generation and migration of ore-bearing hydrothermal solutions, and their precipitation in available subvertical tectonic zones. Negative sulfur isotopic composition in sulfides ($\delta^{34}S = -1$ to -13.5 ‰) indicates the important role of biogenic sulfur, and corroborates the leaching of sulfur and metals from metasedimentary black shales with synsedimentary pyrite, plus their interaction with endogenous granite-related fluids (Kantor 1974). Also the negative isotopic oxygen and carbon values ($\delta^{18}O =$

−17.5 to −13.6 ‰, $\delta^{13}C = -11.8$ to −9.7 ‰) indicate a mixing of meteoric and endogenous solutions and exchange reactions between the fluids and country rocks (András 1983). The estimated metamorphic conditions: T = 350–450 °C and P = 3.5–5.5 kbar, were sufficiently intense for the mobilization of the ore compounds (Grecula *et al.*, 1996). The study of gas-liquid inclusions in quartz gave homogenization temperatures between 320° and 150 °C for the (1) to (4) mineralization stage of the Pezinok antimony deposit (Chovan *et al.*, 1992).

The Pezinok mine was the second largest antimony deposit in Slovakia, after the Dúbrava mine in Central Slovakia. More than one million metric tons of antimony ore (with 1.3 to 2.5 weight % Sb) was recovered during the 1951–1991 period, which represented ca. 20,000 metric tons of pure antimony metal. The Pezinok mine flotation dressing plant produced an ore concentrate with 18–25 weight % Sb, 3–5 weight % As, 15–30 ppm Ag and 6–10 ppm Au (Andráš 1983), but considered to be poor quality due to the admixture of 15 to 20 other minerals (mainly graphite, arsenopyrite and pyrite).

MINERALS

Numerous authors have studied the minerals of the Pezinok antimony deposit, from the first reports of Leonhard (1843), Zepharovich (1859) and Andrian and Paul (1864), through the special monograph of Cambel (1959) to the recent papers of Chovan *et al.* (1992) and Andráš *et al.* (1993a, b). All of the mineralogical data through 1980 are reported in *Topographic Mineralogy of Slovakia*, Part 2 (Koděra *et al.*, 1990); we have supplemented the data in this worth with citations of other authors and with notes on our own observations.

Primary Hydrothermal Minerals

Albite $NaAlSi_3O_8$

Albite is a very rare mineral at the Pezinok mine; it occurs with carbonates in the Pyrite stope (Cambel and Böhmer, 1955).

Ankerite $Ca(Fe^{2+},Mg,Mn)(CO_3)_2$

Although pure ankerite has not been identified, a mixture of calcite, ferroan dolomite and ankerite is suggested by some chemical analyses of carbonates in the Pezinok mine (Cambel 1959). These carbonates form small veins, veinlets and irregular nests, and they cemented fissures in the country rocks. Ankerite and other carbonates form granular aggregates with quartz, stibnite and other sulfides; the maximum size of crystals is about 1 cm.

Antimony Sb

Native antimony is a relatively common mineral in some parts of mine. The mineral forms irregular, fine-grained aggregates with white color and metallic luster. The size of aggregates is commonly several millimeters but has been found locally in monomineralic aggregates up to 10 cm. Antimony occurs in association with stibnite, gudmundite, arsenopyrite, quartz and carbonates. Andráš *et al.* (1993) described an interesting example of replacement of antimony and stibnite by secondary senarmontite along a contact. The electron microprobe analyses show practically pure antimony (99.8 weight % Sb, Andráš *et al.*, 1993b).

Arsenopyrite FeAsS

Arsenopyrite is among the most common hydrothermal minerals in the Pezinok antimony mine. It occurs in older and higher-temperature ores of the first and second hydrothermal stages. The mineral forms irregular aggregates, small veinlets and massive monomineralic aggregates in blackish gray quartz. The grain size is up to 5 mm; aggregates can reach from several cm to 50 cm. Prismatic, 1–2 mm crystals of quartz are associated rarely. Fine-grained euhedral arsenopyrite from the first stage is a principal carrier of sub-microscopic gold in the Pezinok deposit. The gold content ranges up to 170 ppm, averaging 120 ppm (Andráš *et al.*, 1988). Mössbauer spectroscopy has confirmed the presence of gold in arsenopyrite (Andráš *et al.*, 1993c, Chovan *et al.*, 1994). Locally, a stibian arsenopyrite with up to 9.2 weight % Sb was reported (Dadák 1983).

Barite $BaSO_4$

Although barite from the Pezinok mine is not reported in any of the published papers, it occurs locally as tiny white crystals on stibnite, together with kermesite, and as massive aggregates. The mineral probably formed during the most recent (4) mineralization stage.

Berthierite $FeSb_2S_4$

Berthierite is a relatively widespread mineral at the Pezinok mine, associated mainly with stibnite and gudmundite. The mineral forms irregular nests, veinlets, and aggregates of small (up to 3 mm), columnar to acicular crystals. Fresh berthierite is a pale steel-gray color; a bluish iridescence forms on exposure to the air.

Bismuth Bi

Stibian bismuth (with 8.6 to 15.6 weight % Sb) forms rare microscopic, 10 to 60-µm separated grains and thin, short veins with bismuthinite and garavellite in gangue quartz. It also forms along the contacts of stibnite with sphalerite and pyrite (Andráš *et al.*, 1993a).

Bismuthinite Bi_2S_3

Sb-rich bismuthinite having an empirical formula close to $Bi_{1.5}Sb_{0.5}S_3$ was described from Pezinok as very rare microscopic (≤20 µm) intergrowths with native bismuth and garavellite in stibnite (Andráš *et al.*, 1993).

Boulangerite (?) $Pb_5SB_4S_{11}$

Boulangerite from the Pezinok mine has been identified only by ore microscopy (Cambel, 1959). The mineral forms rare microscopic fibrous intergrowths with jamesonite and berthierite in 3-mm-thick veins.

Calcite $CaCO_3$

Calcite occurs in intergrowths with ferroan dolomite and ankerite, veins and irregular masses with quartz and sulfide minerals. Calcite also forms rare rhombohedral crystals to 1 cm with stibnite.

Chalcopyrite $CuFeS_2$

Chalcopyrite occurs as scarce, small (≤0.5 mm), anhedral grains and aggregates in quartz.

Dolomite $CaMg(CO_3)_2$

Dolomite forms a mixture with calcite and ankerite in veins and irregular masses. Small veins of dolomite fill a tectonic fissure in the Kolárska adit (Cambel, 1959).

Garavellite $FeSbBiS_4$

The Pezinok antimony mine is the second known locality for garavellite in the world. The mineral forms very rare, microscopic (only ca. 10 µm) intergrowths with stibian bismuth in stibnite (Andráš *et al.*, 1993a).

Gold Au

Besides the gold from the nearby Staré Mesto gold deposit, and chemically bonded Au in the arsenopyrite structure, discrete gold grains are exceptionally rare at the Pezinok antimony mine. Only a

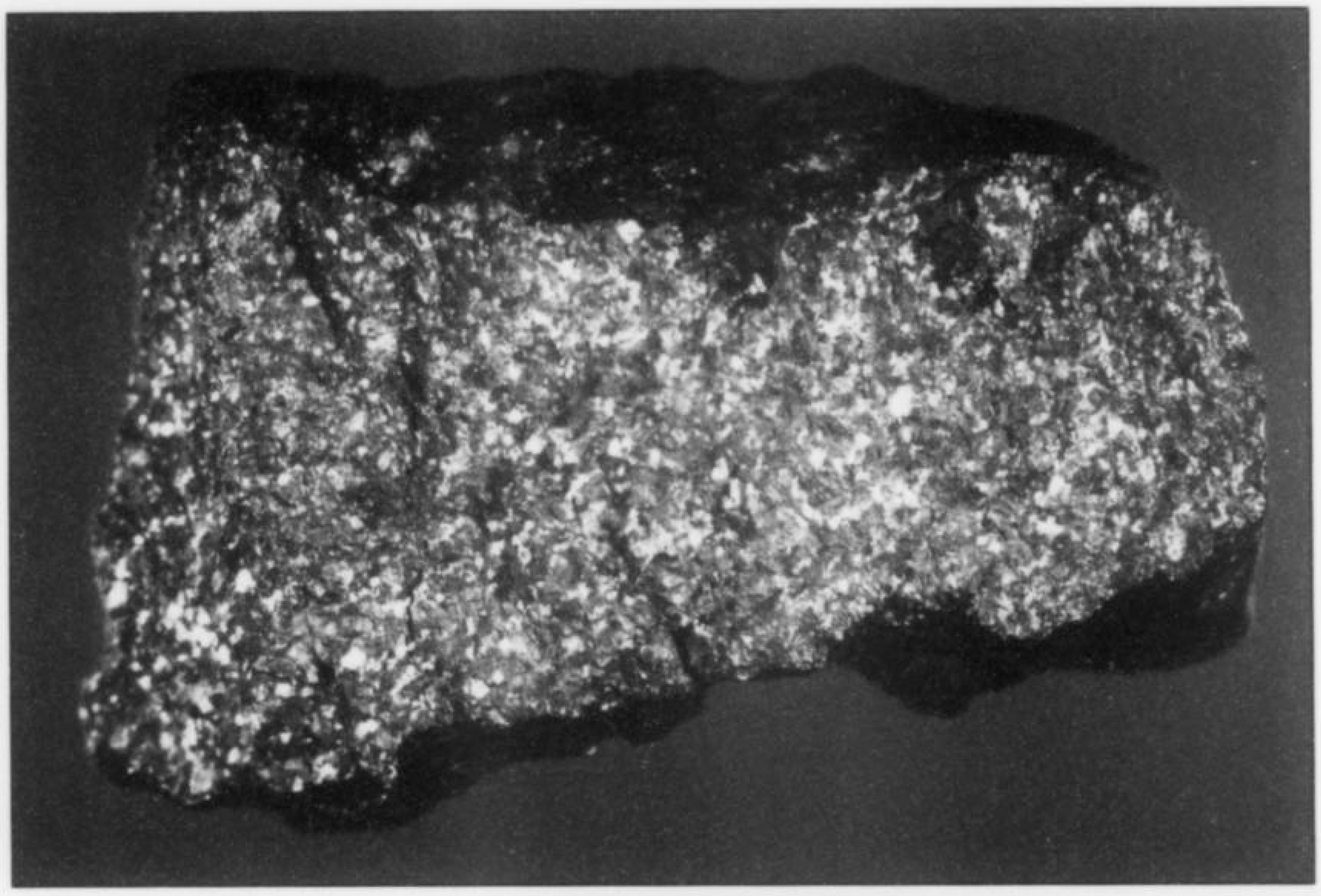

Figure 7. **Fine grained aggregate of native antimony (96–97 weight % Sb), 5 cm, 980 grams. Silvio Michal collection; Ladislav Osvald photo.**

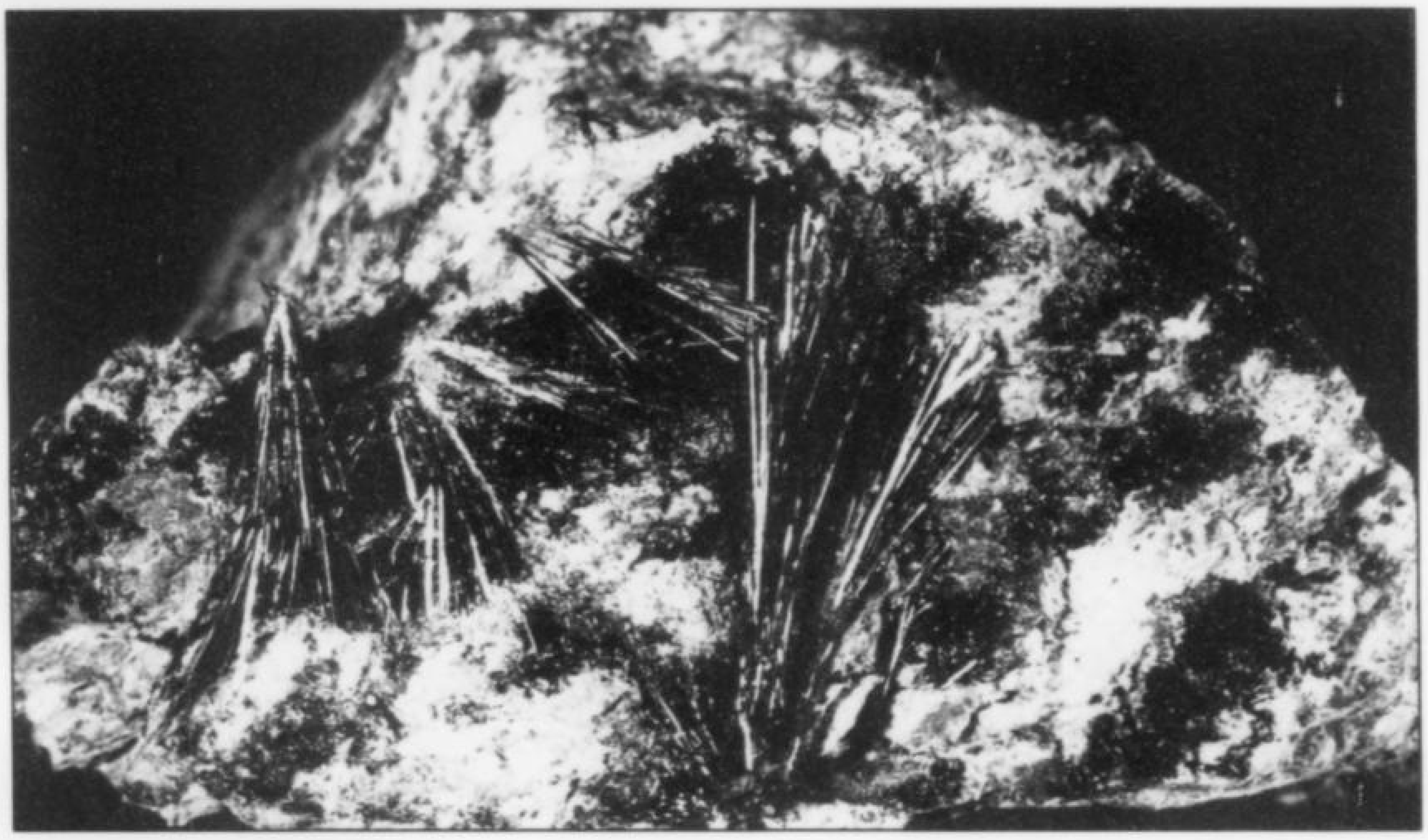

Figure 8. **Acicular kermesite crystals, 2–3 cm long. Jiří Vitáloš collection; Ladislav Osvald photo.**

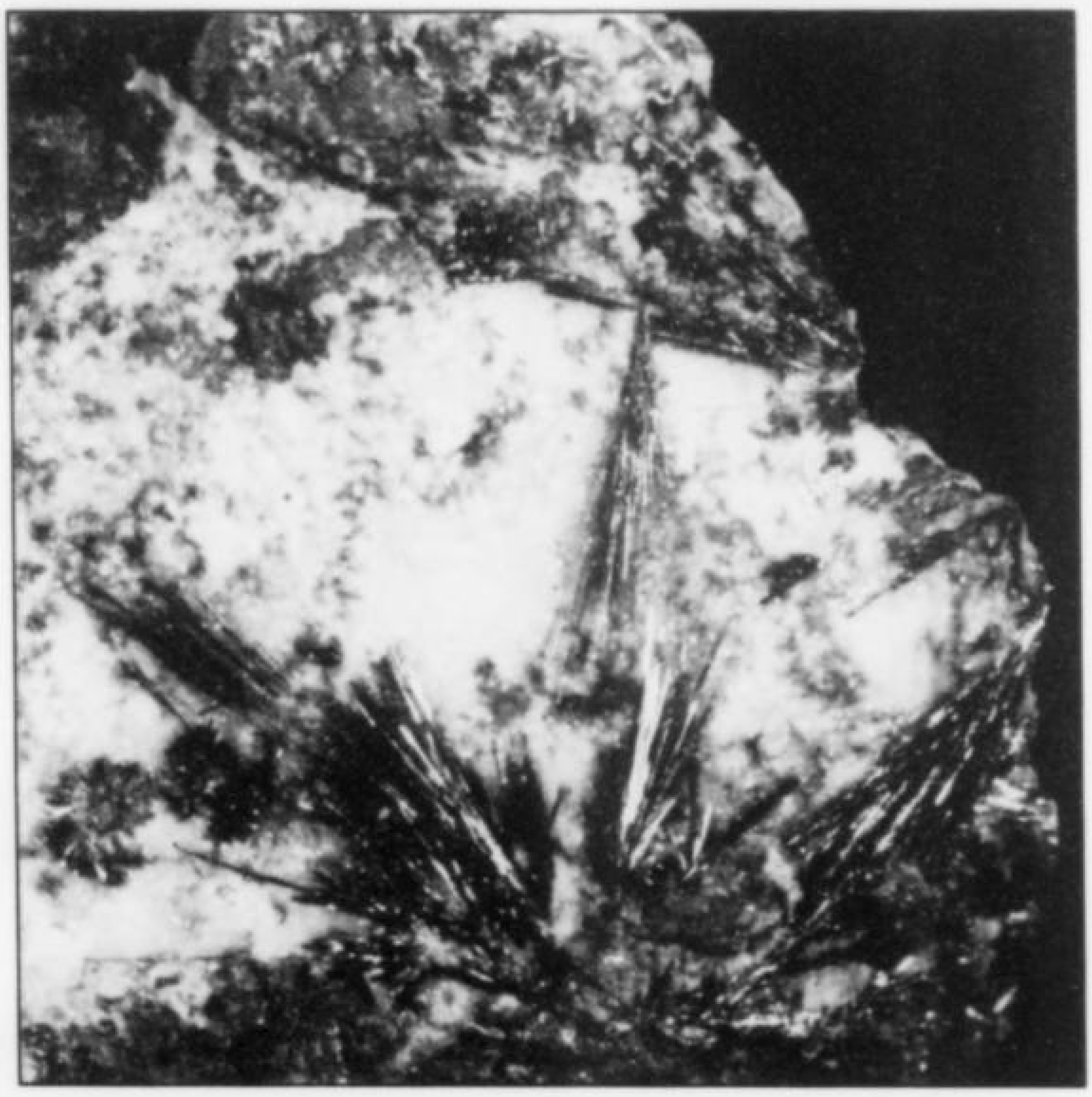

Figure 9. **Acicular kermesite crystals, 2 cm long. Jiří Vitáloš collection; Ladislav Osvald photo.**

few needle-shaped wires of native gold, 5 to 10 µm in length have been described from a carbonate vein (Andráš, 1983).

Graphite C

Graphite is a relatively widespread mineral in the Pezinok mine. It forms irregular nests, veins and lenses in and around hydrothermal minerals, and it is an important component of the older stratiform pyrite-pyrrhotite mineralization in the deposit. The mineral forms very fine-grained, poorly crystallized aggregates.

Gudmundite FeSbS

Gudmundite occurs commonly as isolated, anhedral, isometric grains to 2 mm and in aggregates to 5 mm, mainly in stibnite, berthierite, quartz and carbonates. Fin-shaped prismatic crystals up to 1.5 mm long in carbonates are less common (Cambel, 1959).

Jamesonite $Pb_4FeSb_6S_{14}$

Jamesonite is among the rare minerals in the Pezinok mine. It forms typical acicular intergrowths (≤1 mm) with berthierite and boulangerite (?) in small veins (Cambel, 1959).

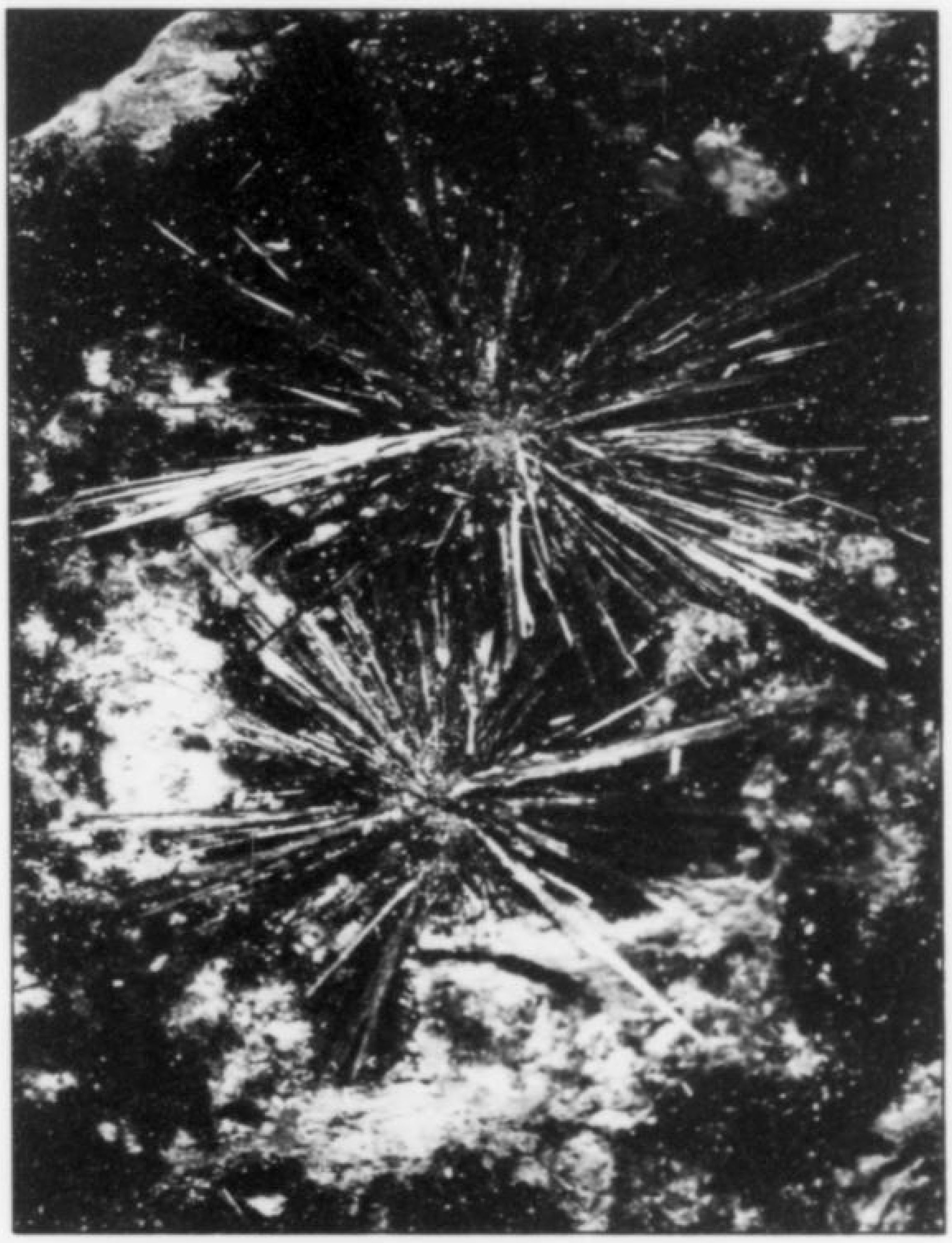

Figure 10. **Radiating kermesite rosettes, 3 and 4 cm in diameter. Jiří Vitáloš collection; Ladislav Osvald photo.**

Kermesite Sb_2S_2O

Kermesite is the most famous mineral from the Pezinok antimony deposit. The mine has produced some of the world's best specimens of this species. It forms excellent radial aggregates of acicular crystals, commonly 1 to 4 cm but rarely up to 14 cm long (Huber and Huber, 1985), with deep cherry-red to reddish violet color and strong metallic to adamantine luster. The kermesite crystals are up to 0.5 mm thick and are transparent under strong light. The radial aggregates of crystals are usually flat, because they form fracture fillings, however superb free-growing crystals have been collected. The best examples of kermesite were found in the New Alexander stope during the 1970's and 1980's. Kermesite occurs together with tiny stibnite crystals, and rarely also with valentinite. The paragenetic relations between these minerals indicate a primary hydrothermal origin for kermesite during stage-4 mineralization, through the mixing of ascending sulfur-rich and descendent oxygen-rich solutions.

Löllingite $FeAs_2$

Löllingite forms in metamorphosed black shales as independent, monomineralic, nest-shape aggregates to several cm, and rarely over 10 cm in size. Locally, löllingite occurs associated with arsenopyrite, pyrite and stibnite. The aggregates consists of fine-grained, 0.02–0.03 mm grains of löllingite, which form pseudomorphs after pyrite (Cambel, 1959).

Marcasite FeS_2

Marcasite is a relatively rare mineral at the Pezinok mine; it occurs as concentric and colloform aggregates with calcite (Chovan *et al.*, 1994).

Pyrite FeS_2

Massive stratiform lenses of pyrite with pyrrhotite form the older metamorphosed deposit at the Pezinok antimony deposit. On the other hand, pyrite also occurs in Sb-As-Au mineralizations in several generations. The oldest pyrite of the stage-1 mineralized period contains about 40 ppm of Au on average (Andráš, 1987). In the antimony mineralization, pyrite forms small 0.5 to 1-mm cubic or pyritohedral crystals and anhedral grains in quartz, carbonates and sulfide minerals (Cambel, 1959). In addition, we have found rare, unusual, stalactitic aggregates of pyrite, confirmed by X-ray diffraction.

Pyrrhotite $Fe_{1-x}S$

In addition to the metamorphic (mainly hexagonal) pyrrhotite of the older stratiform pyrite-pyrrhotite deposit, the mineral also occurs as aggregates to 3 mm of microscopic ($\geq$0.1 mm) grains and columnar crystals or myrmekitic pyrrhotite-gudmundite intergrowths (Cambel, 1959). It is associated mainly with carbonates, gudmundite, pyrite and stibnite.

Quartz SiO_2

Although quartz is a very common mineral in the Pezinok mine, it is not an interesting mineral from a collector's point of view. Gray or white quartz forms an important part of hydrothermal veins, veinlets and irregular nests, commonly with carbonates, stibnite and other sulfide minerals. The mineral is usually massive, and anhedral; tiny crystals in vugs are rare.

Rutile TiO_2

Microscopic rutile inclusions in arsenopyrite have been reported by Andráš (in Chovan *et al.*, 1994).

Scheelite (?) $CaWO_4$

Although scheelite has been briefly noted by the earliest authors (Leonhard, 1843; Zepharovich, 1859), recent confirmation is lacking at the Pezinok mine.

Sphalerite (Zn,Fe)S

Sphalerite is not a common mineral in the Pezinok deposit. It forms 0.05 to 1-mm grains with stibnite, arsenopyrite, pyrite and pyrrhotite (Cambel, 1959).

Stibnite Sb_2S_3

Stibnite is the most important economic mineral in the Pezinok mine. The stibnite-bearing ore masses reach thickness up to 40 meters, locally with 1 to 2-meter-thick nests of fine-grained stibnite-rich to monomineralic stibnite aggregate (Cambel, 1959; Mrákava, 1987). This economically important stibnite aggregate consists of anhedral grains to 0.5 mm.

A second type of stibnite is economically insignificant, but is interesting for collectors. It forms tiny hemispheric or flat radial aggregates of acicular stibnite crystals, usually 2 to 5 mm long. These crystals are commonly associated with kermesite and valentinite.

Tetrahedrite $(Cu,Fe,Ag,Zn)_{12}Sb_4S_{13}$

Tetrahedrite is very rare mineral at the Pezinok mine, where it forms 30-µm inclusions in pyrite of stage 3 (Andráš, 1983).

Valentinite Sb_2S_3

Hydrothermal valentinite is one of the most beautiful minerals in the Pezinok mine. It forms white radial aggregates of flat acicular crystals, commonly 0.5 to 1 cm, but rarely 2 cm long. Rich valentinite rosettes cover rock in areas of several tens of cm^2, locally with kermesite and stibnite crystals.

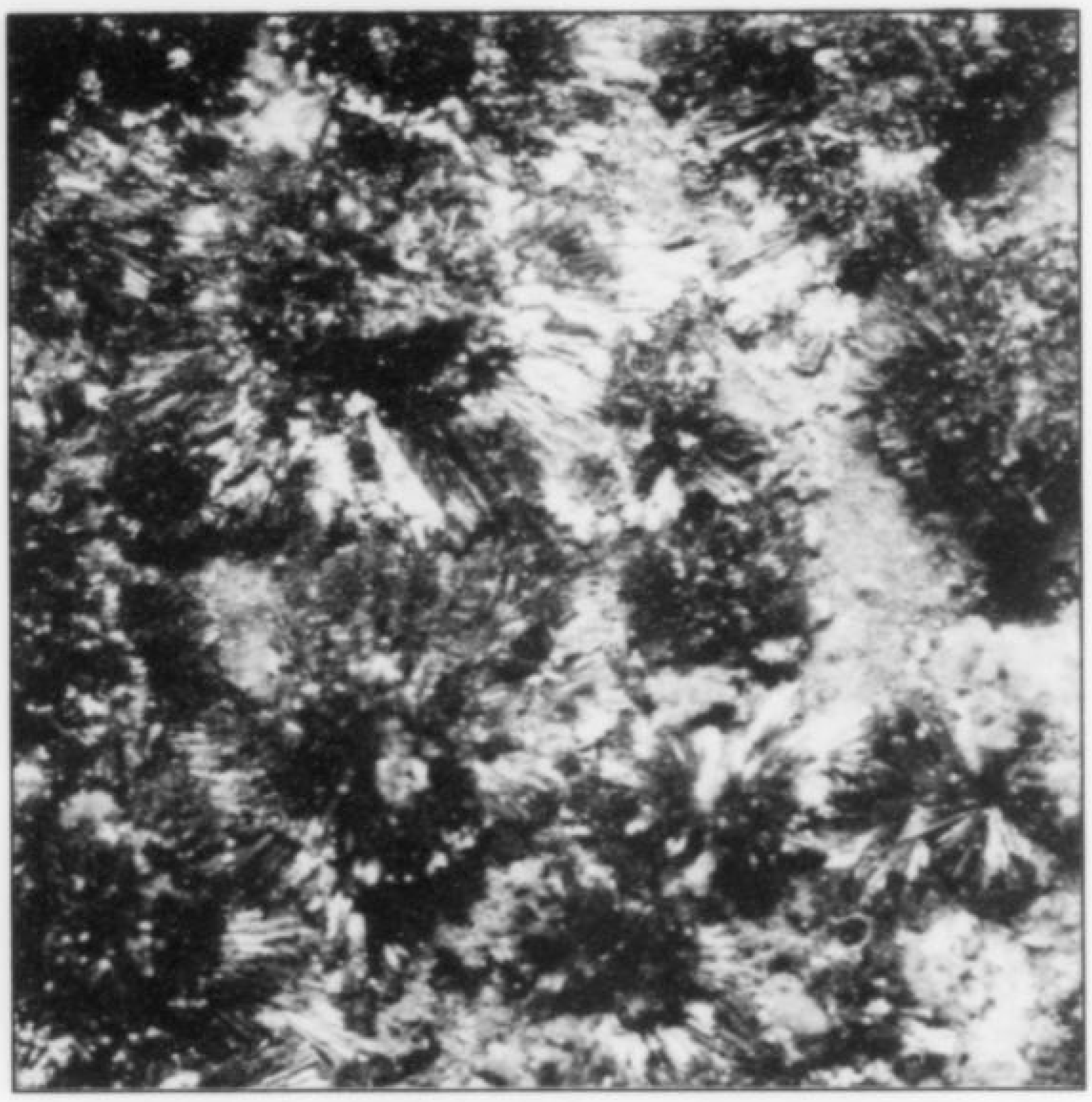

Figure 11. **Radiating stibnite rosettes to 1 cm in diameter. Pavel Uher collection; Ladislav Osvald photo.**

Figure 12. **Radiating rosettes of valentinite to 1 cm in diameter, with kermesite needles 2–3 cm long. Jiří Vitáloš collection; Ladislav Osvald photo.**

Secondary Minerals

Allophane $Al_2O_3 \cdot 1.3\text{-}2SiO_2 \cdot 2.5\text{-}3H_2O$

Allophane forms fine, earthy and glassy white to yellow-brown masses in vugs with kaolinite, halloysite and limonite, covered by cervantite and stibiconite aggregates (Andráš, 1983). It contains 1.8 weight % Sb_2O_3 and 2.75 weight % Fe_2O_3. Spherical structure is visible under SEM; sphrerules are only a few µm in size (Harman, 1969).

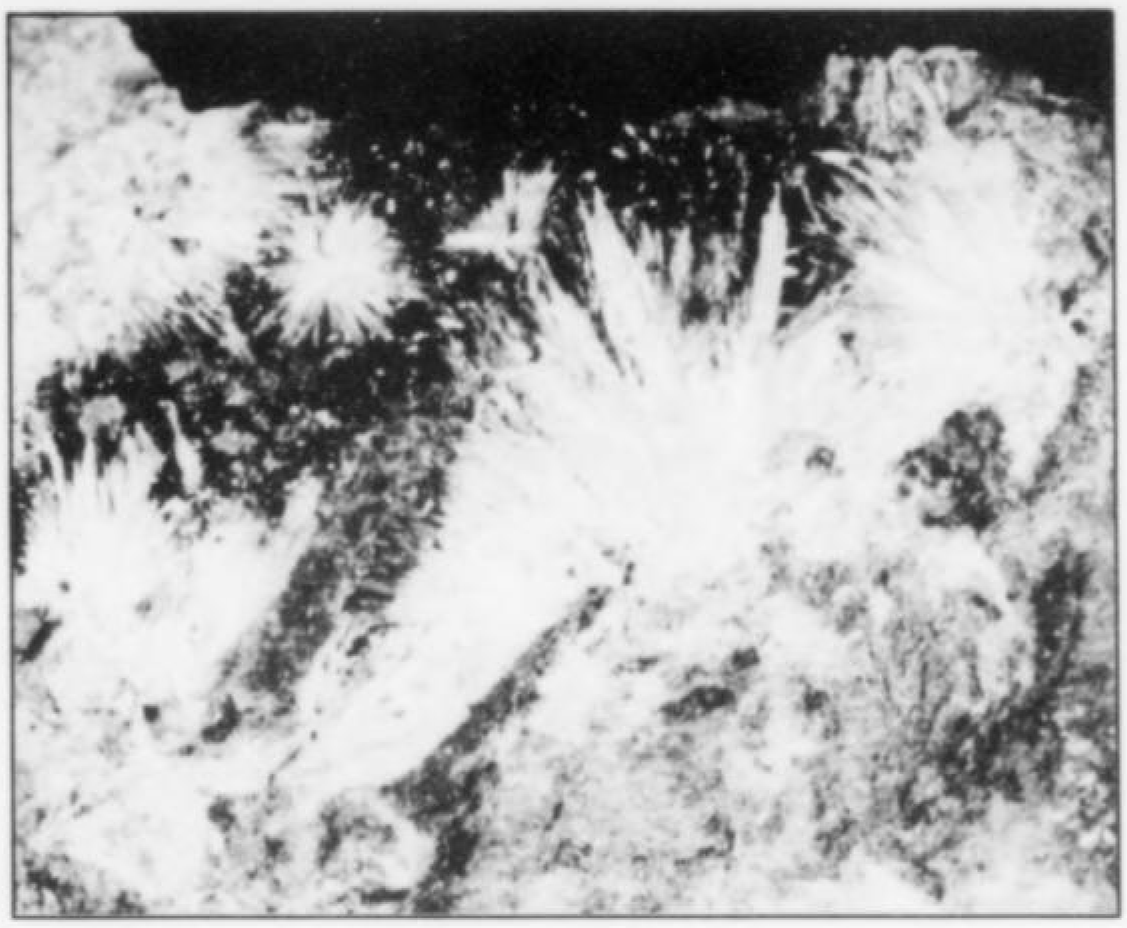

Figure 13. **Radiating acicular valentinite, 1.5 cm in diameter. Jiří Vitáloš collection; Ladislav Osvald photo.**

Figure 14. **Irregular columnar chapmanite crystals, 2–4 µm long, on rock. Pavel Uher specimen; Ivan Holický SEM.**

Cervantite $Sb^{3+}Sb^{5+}O_4$

Cervantite occurs as white concretional aggregates after senarmontite (Ružbacká, 1968) and as yellowish to brownish coatings on stibiconite (Andráš and Chovanec, 1985).

Chapmanite $Sb^{3+}Fe_2^{3+}(SiO_4)_2(OH)$

The rare mineral chapmanite was first described from the Pezinok mine by Polák (1983, 1988) as pale, yellow-brown, powdery aggregates on metamorphosed black shale from the Sirková stope and the Stanislav horizon. Under SEM, chapmanite forms irregular aggregates of columnar crystals measuring up to 0.5 x 4 µm.

Destinezite $Fe_2^{3+}(PO_4)_4(SO_4)(OH) \cdot 5H_2O$

Destinezite occurs here as powdery pale yellow-brown concretions (Mitáček, 1980). Under BSE, diadochite shows well-shaped

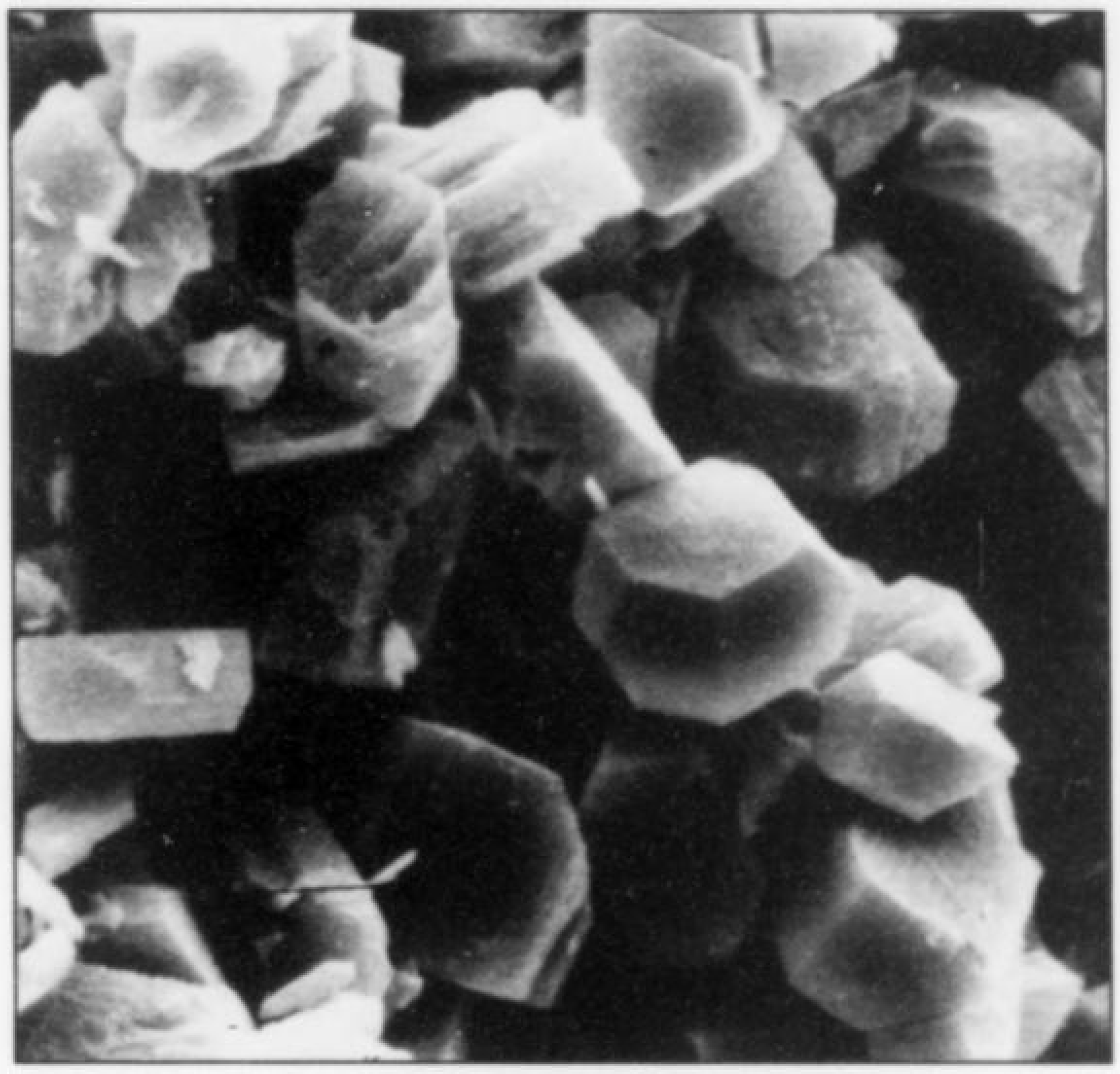

Figure 15. **Aggregate of destinezite crystals, 5–15 μm. Pavel Uher specimen; Ivan Holický SEM.**

5–15 μm, pseudohexagonal (triclinic) tabular to columnar prismatic-pyramidal crystals which locally resemble feldspars.

Goethite $Fe^{3+}O(OH)$
Brown crusts and coatings of what is probably goethite "limonite" are very common on the stope walls, and on the dumps of the Pezinok mine.

Gypsum $CaSO_4{\cdot}2H_2O$
Gypsum is a common alteration product of pyrite and other sulfides; it forms small, colorless to white crystals and crusts.

Halloysite $Al_2Si_2O_5(OH)_4$
Halloysite occurs together with allophane in rock vugs (Ružbacká, 1968; Harman, 1969).

Hematite Fe_2O_3
Hematite forms compact, finely crystalline masses together with "limonite" (Ružbacká, 1968).

Jarosite $K_2Fe_6^{3+}(SO_4)_4(OH)_{12}$
Jarosite occurs as yellow-brown crystals on the walls of stopes, and on the dumps.

Kaolinite $Al_2Si_2O_5(OH)_4$
Kaolinite forms microscopic, pseudohexagonal tabular crystals, visible under SEM (Harman, 1969).

Kermesite Sb_2S_2O
Secondary kermesite differs from hydrothermal material by its pink to cherry red powdery appearance in vugs of rocks (Ružbacká, 1968; Andráš and Chovanec, 1985).

Malachite $Cu_2^{2+}(CO_3)(OH)_2$
Rare green coatings of malachite occur in the oxidation zone of the Pezinok antimony deposit.

Opal $SiO_2{\cdot}nH_2O$
Opal has been found as thin, white to white-blue films, and rarely as colorless hyalite on rocks.

Senarmontite Sb_2O_3
Secondary senarmontite occurs with cervantite (Ružbacká, 1968).

Schafarzikite (?) $Fe^{2+}Sb_2^{3+}O_4$
Schafarzikite was described as a new mineral from the neighboring Pernek antimony deposit (Krenner, 1921). In the Pezinok deposit, schafarzikite is present as tiny, 0.1–0.3 mm crystals with valentinite. The electron microprobe did give only Fe and Sb peaks, but the amount of the material was insufficient for X-ray identification (Andráš and Chovanec, 1985).

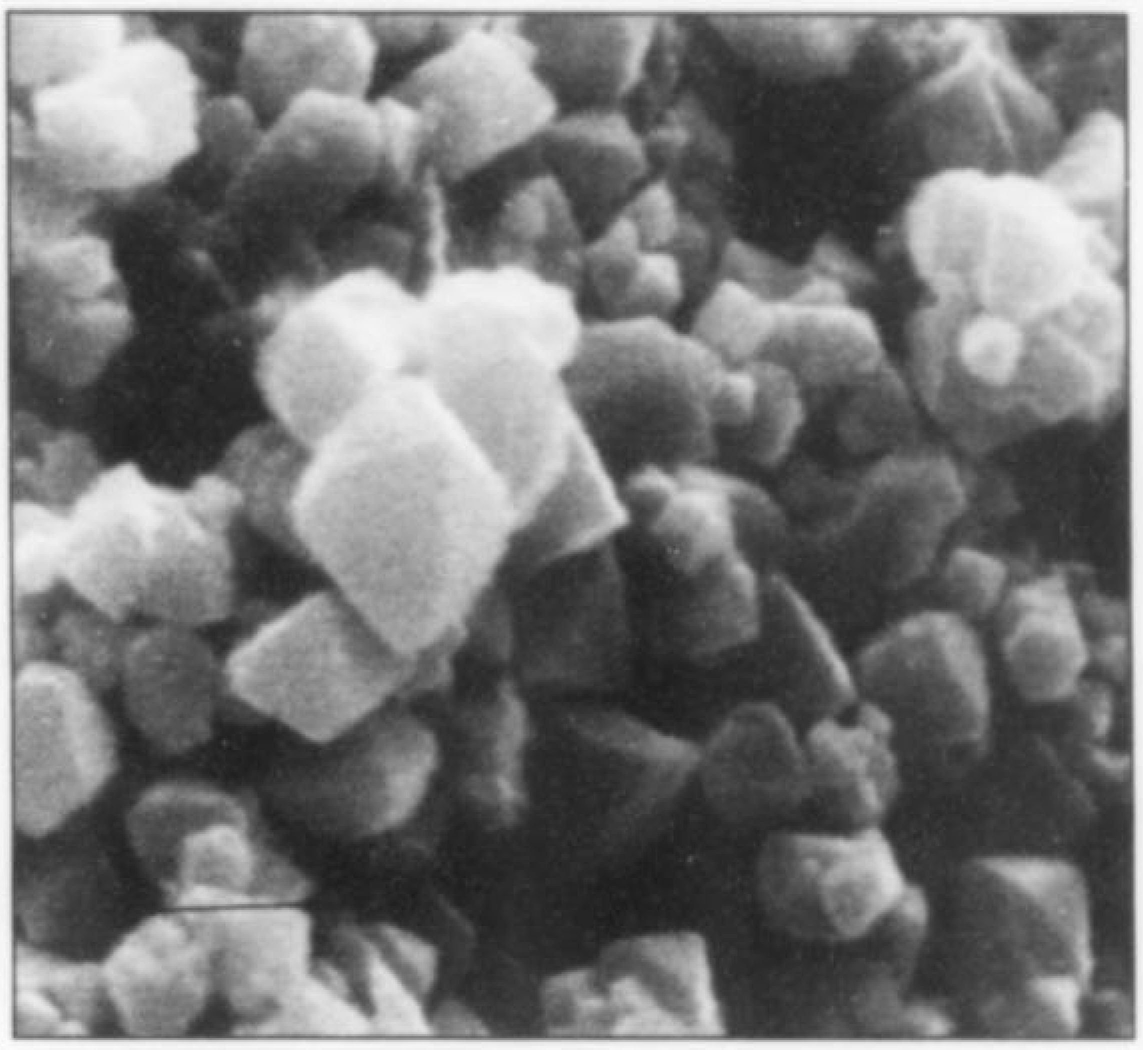

Figure 16. **Dipyramidal crystals of scorodite to 1.65 μm. Pavel Uher specimen; Ivan Holický SEM.**

Scorodite $Fe^{3+}AsO_4{\cdot}2H_2O$
Scorodite forms pale white-green coatings on arsenopyrite and black quartz (Ružbacká, 1968; Uher, 1990). SEM reveals rich, well-crystallized aggregates of dipyramidal, rarely prismatic scorodite crystals to 2 μm.

Senarmontite Sb_2O_3
Senarmontite is a product of hypergene alteration of stibnite and native antimony, occurring along the margins of these minerals (Andráš *et al.*, 1993b).

Siderite $FeCO_3$
Unusual, secondary siderite forms veins to 3 cm thick and fillings in brecciated rocks (Polák 1988).

Slavikite $NaMg_2Fe_5^{3+}(SO_4)_7(OH)_6{\cdot}33H_2O$
Recently, slavikite has been identified by X-ray analysis in the dumps of the open pit in the Pezinok mine (Trtíková, personal communication, 1997).

Stibiconite $Sb^{3+}Sb_2^{5+}O_6(OH)$
Stibiconite forms white crystalline aggregates to 0.8 mm thick on stibnite from the Antimony adit (Andráš and Chovanec, 1985).

Valentinite Sb_2O_3
Secondary valentinite occurs as relatively common white to yellowish coating and fan-shaped aggregates on stibnite and native antimony (Cambel, 1959; Andráš and Chovanec, 1985).

COLLECTING STATUS

The mine has been abandoned since 1991, and entrance into the old workings, open pit and dumps is still forbidden for common visitors. The area is fenced and watched by a guard. The mine is still a property of the Rudné Bane (Ore Mining) Co. and access to the dumps is possible only with special permission. Thus, collecting minerals in the Pezinok mine is today practically impossible; all high-quality specimens were found in the stopes, especially the New Alexander stope, during mining between 1940 and 1991, especially in the 1970's and 1980's. It is still possible, however, to find rare new species on the dumps.

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1796

THE MINERALS OF ALUM CAVE BLUFF

⚒

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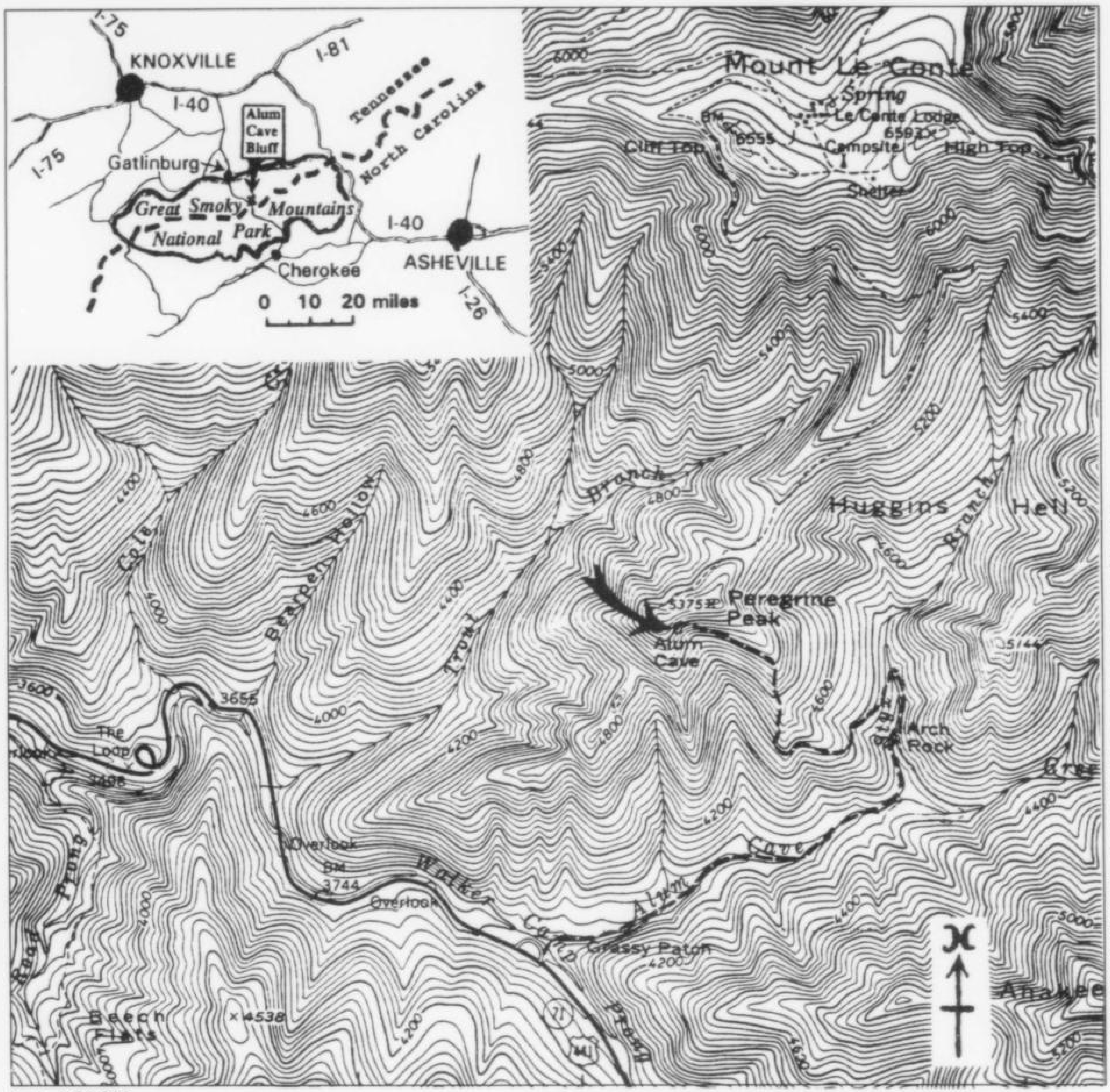
Alum Cave Bluff, a Dana locality for apjohnite, epsomite, melanterite and potash alum, has yielded good microcrystals of several rare sulfate minerals, including three new rare-earth sulfates, and is the first North American occurrence of slavikite.

INTRODUCTION

Alum Cave Bluff in the Great Smoky Mountains must be considered a classic locality, inasmuch as *Dana's System* (Palache *et al.*, 1951; Dana, 1892) lists four unusual minerals (potash alum, epsomite, melanterite and apjohnite) from "Alum Cave." The locality was studied during the 1800's (Brown, 1884); however, the authors have found no record of any studies during this century, and a revisit for a modern investigation is therefore long overdue.

In 1981 one of the authors (TDC) became intrigued by the Dana mention of apjohnite and hiked up to Alum Cave Bluff to investigate. Although there was little to see at first, digging into the dirt at the base of the cliff uncovered chunks of white massive and fibrous salts. Curiosity about these chunks spurred this investigation. Melanterite and epsomite were easily identified (especially after some exquisite microcrystals disintegrated to an opaque white powder), and the hair-salt series of minerals (pickeringite/apjohnite/halotrichite) was not difficult to recognize, but the identity of a tiny greenish smear on one sample was not at all obvious. A glance through a binocular microscope showed that the smear was not salt-tolerant algae, but a scattering of tiny, clear, sharp, yellow-green crystals. One of the crystals was mounted in a Gandolfi camera and a distinct powder pattern was obtained. A search of the powder-pattern files revealed that the mineral was *slavikite*, a ferric magnesium sulfate previously unreported from North America. Since then the authors have continued to study the minerals from Alum Cave Bluff as opportunity has permitted, discovering three new rare-earth sulfates along the way.

Alum Cave Bluff is on a southern spur of Mount Le Conte in Sevier County, Great Smoky Mountains National Park, Tennessee, at an elevation of about 1,600 meters (Fig. 1). No cave exists; Alum Cave Bluff is a rock shelter about 30 meters high and 10 meters deep (Fig. 3). The site is 3.6 km by moderately steep but well-maintained trail from a parking lot on the main transmountain



From U.S.G.S. 7.5' Mount Le Conte, Tenn. - N.C., topographic map

Scale 1:24,000
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Figure 1. **Location of Alum Cave Bluff in the Great Smoky Mountains National Park, Tennessee.**

highway (U.S. 441). The hike is delightful, through Appalachian cove forest and heath bald with good panoramic views from the higher elevations, and Alum Cave Bluff is deservedly one of the most popular hiking destinations in the park.

HISTORY

Salts at Alum Cave Bluff have been known since at least 1837 (Jenkins, 1988), and gave the site its name. In that year three farmers (Ephraim Mingus, Robert Collins, and George W. Hayes) from Oconaluftee, North Carolina, applied at the Sevier County land office for a grant of a 50-acre tract of land including the bluff and its salt deposits. Tennessee sold the tract to the men on December 6, 1838. The Epsom Salts Manufacturing Company was subsequently formed to exploit the deposit. According to Jenkins, "the minerals of Alum Cave, contiguous to each other, include alum [mostly hair salt (?); see below], epsom salts [epsomite], saltpeter [?], magnesia [?], and copperas [melanterite]." Many tons of alum and epsom salt had accumulated. Water vats and log hoppers were set up for the purification of the salts and the manufacture of further salts [true alum?]. The minerals were hauled through the rhododendron thickets and down the mountainside to a crude transmountain turnpike to Sevierville and thence to Knoxville. According to Brown (1884), "the alum is used by the country people for dyeing their homespuns a reddish brown, and by them [is] preferred to the commercial alum because of the darker red it gives." The easily accessible salts were depleted by the mid-1840's, and the difficult access and diminishing rewards discouraged further work at the deposit. The company was sold, and mining activities gradually tailed off. During the Civil War mining resumed, not only for the alum and epsom salts, but also for saltpeter (identified as "nitrate of lime"). All attempts to mine the salts ceased after the war.

Alum *sensu stricto* is a 12-hydrated isometric double sulfate of a small trivalent metal (Al, Fe, Cr) and a large monovalent ion (K, Na, NH_4, Tl, Ag) (Honig *et al.*, 1953), and is uncommon at the locality. However, the "hair-salt" series, which is abundantly present, can be used to perform the traditional functions of alum (a mordant in home dyeing, and an astringent in home medicine). These minerals, now classified as pseudo-alums (Honig *et al.*, 1953), were called alums in the broad (and original) usage of the term (Palache *et al.*, 1951). When Safford (1869) visited the locality in 1855, he saw "wagonloads" of alum and Epsom salt lying on the ground awaiting removal. That Safford used the term "alum" in its broad sense is shown elsewhere in his work, where he applied the name to halotrichite ("iron alum"). In view of the abundance of hair salt at Alum Cave Bluff, and the small amount of true alum present, it is probable that Safford was not referring to alum in the present strict sense. Although some true alum is present, analyzed samples have no potassium and are therefore probably tschermigite (ammonium alum).

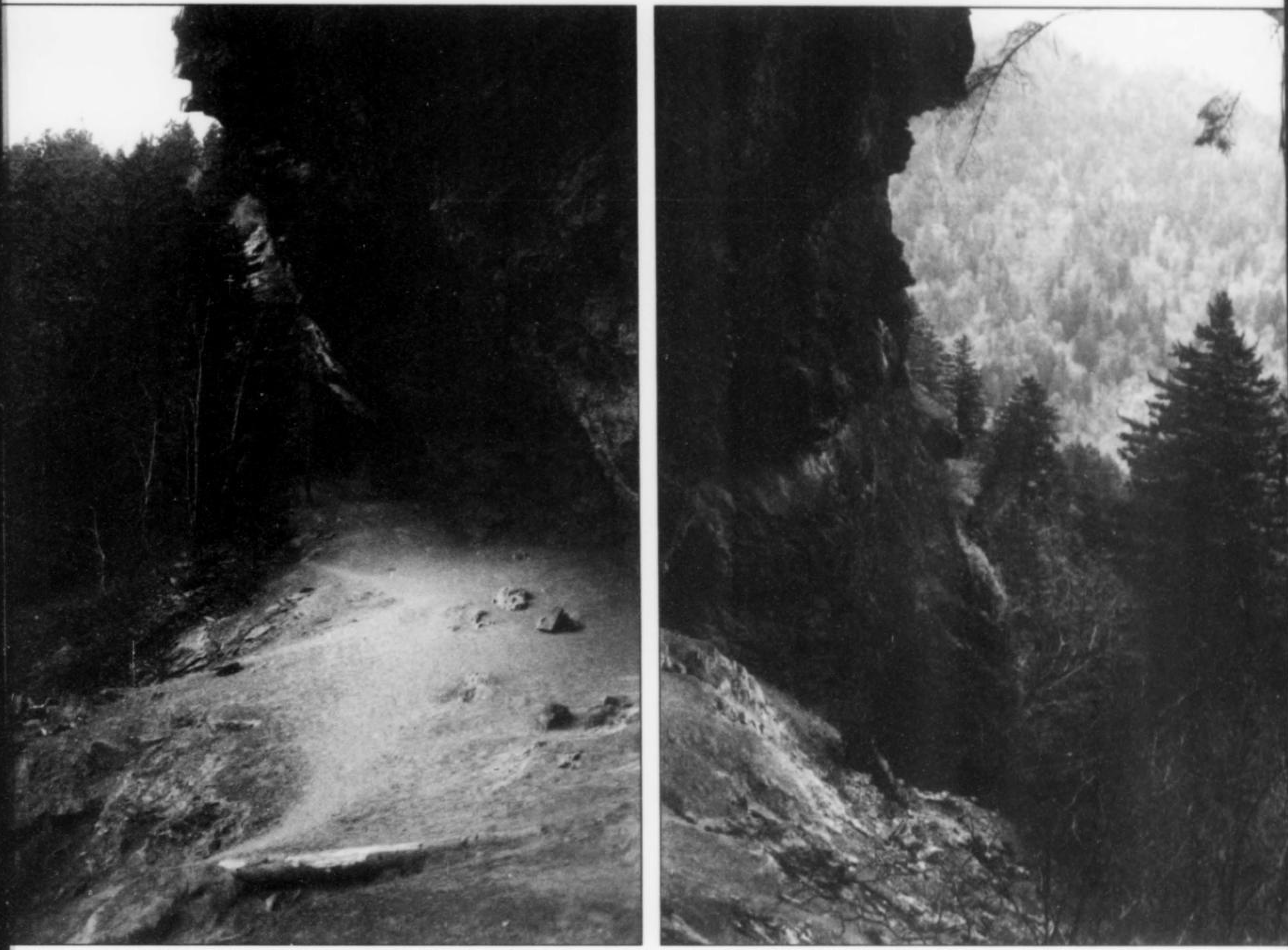

Figure 2. **The Alum Cave Bluff site.**

Dana References

Because Alum Cave Bluff is a Dana locality, it is of interest to review references to it in the early Dana editions. Palache *et al.* (1944), in the seventh edition of *Dana's System of Mineralogy*, mention potash alum from "Alum Cave, Sevier County, Tennessee," which is unquestionably a reference to Alum Cave Bluff. The sixth edition (Dana, 1892) refers to "kalinite" or potash alum as follows:

> Formerly described from the caves of the Unaka Mountains, Eastern Tennessee, in Sevier Co., is mentioned with analysis [under apjohnite]; masses a cubic foot in size have been obtained.

Under "apjohnite," or manganese alum, we read that:

> The mineral of analysis 3 [SO_3 35.47, Al_2O_3 10.03, MnO 8.73, H_2O 44.78, FeO 0.39, MgO 0.30, (Co,Ni) 0.29, CuO 0.02] is from Alum Cave, Sevier Co, Tennessee; it had been earlier called kalinite. The cave is situated at the headwaters of the Little Pigeon, a tributary of the Tennessee River; it is properly an overhanging cliff 80 or 100 feet high and 30 feet long under which the alum has collected. It occurs in masses, showing in the cavities fine transparent needles with a silky luster. Epsomite and melanterite also occur with it.

Under "epsomite" is the statement:

> At the Alum Cave in Sevier, Tenn., on the headwaters of the West Fork of Little Pigeon River, masses of nearly pure epsomite, almost a cubic foot in volume, have been obtained (Safford's Rep., 119).

This is at first an apparent reference to J. M. Safford's report on *The Geology of Tennessee* (1869), but the same information and reference appears in the fifth edition of *Dana's System*, dated 1868. Under "kalinite" the locality is given as:

> In the caves of the Unaka Mountains, Eastern Tennessee, especially at Sevier, masses a cubic foot in size may be obtained.

No specific mention of Alum Cave appears in the fourth edition of 1854. However, in the third supplement to the fourth edition, published in the *American Journal of Science* (Sept. 1856), Dana cites under epsomite:

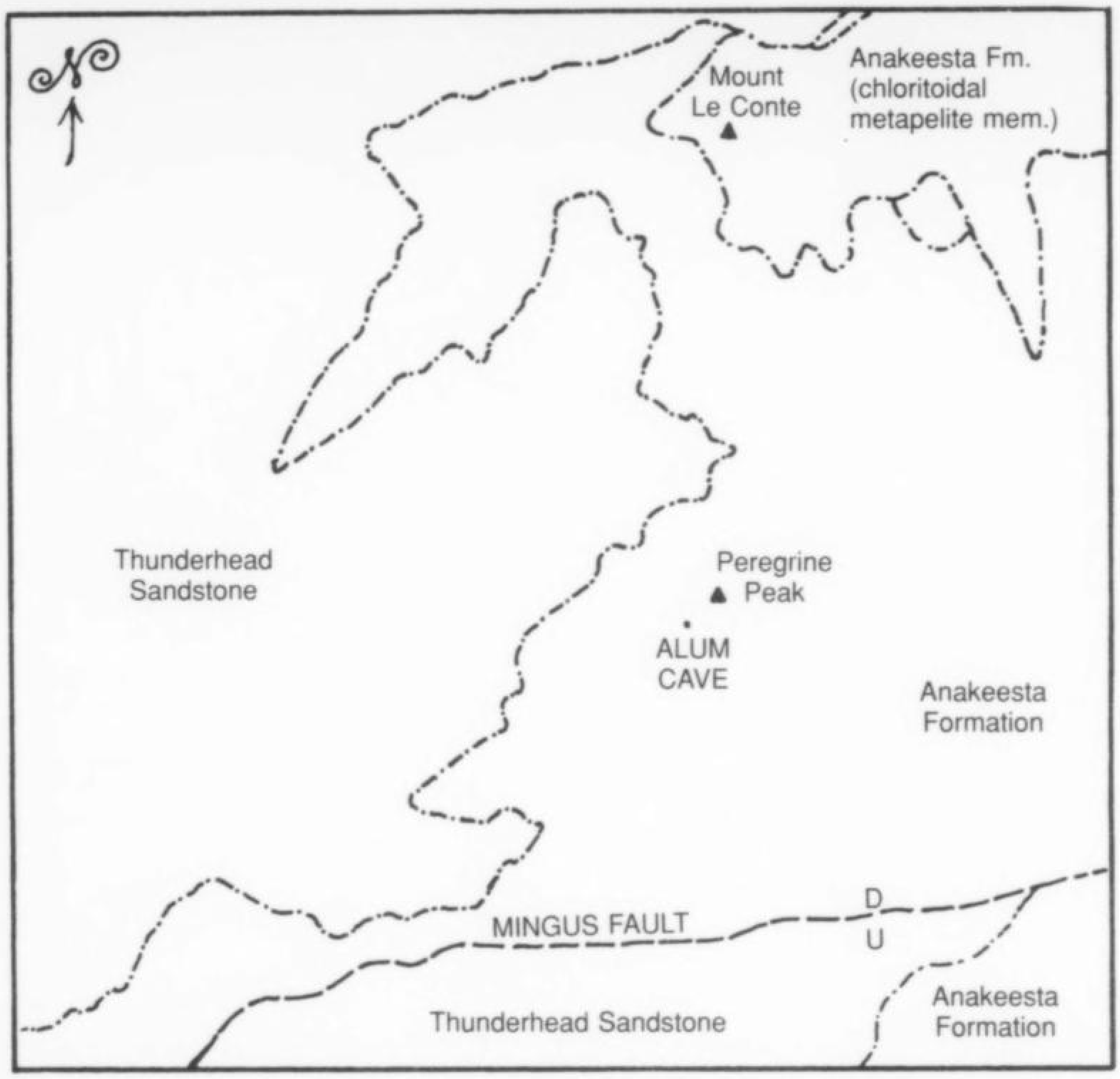

***Figure 3.* Geologic map of the Alum Cave Bluff area.**

> Occurs in Tennessee, at different places, and most remarkably at the Alum Cave in Sevier, in a mountainous region . . . Safford's Rep., p. 119.

Here at last we find that the reference is Safford's *Geological reconnaissance of the State of Tennessee, being the author's first biennial Report* of 1856. Dana makes a less specific reference in his third edition of 1850, and second edition of 1844:

> The floors of the limestone caves of Kentucky, Tennessee, and Indiana are, in many instances, covered with Epsom Salt, in minute crystals, mingled with the earth.

No reference is given for this statement, but it is interesting to note that the identical sentence occurs in the first edition of 1837, but *without* mention of Tennessee. Therefore, the occurrence of epsomite in Tennessee came to Dana's notice sometime between 1837 and 1844, before Safford's report of 1856, and may well have originated with the newly opened Alum Cave occurrence then being operated by Mingus, Collins and Hayes.

The discovery of alum minerals at Alum Cave may actually have taken place even earlier than 1837. Parker Cleaveland, in the first mineralogy text to be published in America [dated 1816], states:

> In the United States, native alum has been observed in several instances, especially in Tennessee and Pennsylvania.

The reference to Tennessee alum, however, is oddly missing in his second edition of 1822. From whom did it originate?

In Samuel Robinson's *A Catalogue of American Minerals, with their Localities* (1825), Tennessee is listed as a source of *Nitrate of Potash* in the Cumberland Mountains:

> Numerous caves found in this mountain and other parts of Tennessee, have been very productive of the nitrate of potash.

Under Sevier County, Robinson lists only barite. But under Warren County he describes:

> Native Plumose Alum, in a cave, in Cumberland Mountain. These beds . . . are always either in natural caves, or under the brow of a bluff, where they are sheltered from heavy rains.

Robinson cites Archibald Bruce's *American Mineralogical Journal* (1814). There at last we find the first mention of alum minerals in Tennessee, from a cave in Cumberland Mountain, Warren County, about 190 km west of Alum Cave.

Bruce's source of specimens and information was Dr. Thomas I. Wray of Augusta, Georgia. Wray sent Bruce specimens of melanterite and "native plume alum," and reported that such material in Tennessee is always found "in natural caves or under the brow of a bluff, where they are sheltered from the influence of heavy rains or torrents of water." This *general* statement may stem also from some knowledge of the Alum Cave occurrence after all, even though the specimens supplied were from Cumberland Mountain.

Interestingly, it appears that Native Americans may have worked or at least known about the Tennessee alum occurrences long before the incursion of white men. Wray writes:

> The specimens I herewith present you, were taken from the very cave where some time ago were found two [mummified] human bodies (a male and a female) which were carefully rapped up in a curious fabric constructed principally of feathers, and the whole enfolded in dressed deer skins; an accurate account of which was published in several newspapers and some of our scientific repositories. When first discovered they were in a state of perfect preservation. . . . Unfortunately they were found by illiterate laborers, who set no value whatever on their discovery, and who allowed every visitor that wished it, to break off parts to be totally destroyed on the spot or taken away.

GEOLOGY

Bedrock at Alum Cave Bluff, and upslope from the bluff, consists of the Anakeesta Formation, a dark gray phyllite of late Precambrian age. It is rich in carbon and pyrite, as is true of much of the Precambrian rock of the area (Merschat and Larson, 1972). The Anakeesta was originally a thick sequence of clay, silt and sand deposited in fairly deep water. It has graded bedding on a scale of centimeters, and much of it was probably deposited by turbidity currents. It is a part of the 4,000 to 12,000-meter-thick Great Smoky Group, a clastic wedge laid down at the edge of the continent well over half a billion years ago. The presence of pyrite and (probably organic) carbon indicates that the water contained little or no oxygen. During the early Paleozoic stages of the Appalachian Orogeny, when the old Atlantic Ocean was beginning to close up, the rocks of the area were thrust northwestward along the Greenbriar Fault, and then metamorphosed at a rather low temperature and pressure (upper greenschist facies). Toward the end of the Paleozoic, the collision with Africa thrust the beds higher and farther to the northwest along the Great Smoky Fault as the Appalachian Orogeny reached its climax. The geology of the area is described by Hadley and Goldsmith (1963) and King *et al.* (1968). The geology in Figure 3 is from Hadley and Goldsmith.

Minerals in the rock are chiefly muscovite, biotite, chlorite, quartz and pyrite. Chloritoid is commonly observed as 1 to 2-mm crystals in the finer-grained beds. An X-ray fluorescence (XRF) analysis showed it to be near the iron end-member; both manganese and magnesium are very low. Tiny spessartine garnet dodecahedra ($sp_{75}al_{20}py_{5}$; Hadley and Goldsmith, 1963) are also present. A few dolomitic layers are interlayered in the unit. A bulk chemical analysis of one sample of Anakeesta phyllite is given in Table 1; note the comparatively high manganese content, which accounts for the existence of spessartine garnets in the greenschist-facies rock and the presence of apjohnite among the secondary minerals.

Table 1. **Bulk chemistry of the Anakeesta Formation (Hadley and Goldsmith, 1963).**

SiO_2:	55.80	CaO:	0.52	CO_2:	0.09
Al_2O_3:	23.24	Na_2O:	2.41	P_2O_5	0.13
Fe_2O_3:	1.28	K_2O:	4.37	SO_3:	—
FeO:	2.58	H_2O^-:	0.14	S:	1.30
MnO:	1.07	H_2O^+:	2.73	C:	2.78
MgO:	1.39	TiO_2:	0.68	BaO:	—
					100.51

PARAGENESIS

The pyrite-rich Anakeesta Formation is presently exposed to weathering, and oxidation of the pyrite produces a weak solution of sulfuric acid and ferrous sulfate, according to the following reaction:

$$\underset{\text{pyrite}}{2FeS_2} + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

The acid solution then attacks the other minerals of the rock, as below:

$$16H^+ + \underset{\text{chlorite}}{Mg_5Al[AlSi_3O_8(OH)_8]} \rightarrow 5Mg^{2+} + 2Al^{3+} + 3SiO_2 + 12H_2O$$

$$10H^+ + \underset{\text{muscovite}}{KAl_2[AlSi_3O_{10}(OH)_2]} \rightarrow K^+ + 3Al^{3+} + 3SiO_2 + 6H_2O$$

$$12H^+ + \underset{\text{garnet}}{(Mn_2Fe)Al_2Si_3O_{12}} \rightarrow 2Mn^{2+} + Fe^{2+} + 2Al^{3+} + 3SiO_2 + 6H_2O$$

$$4H^+ + \underset{\text{dolomite}}{CaMg(CO_3)_2} \rightarrow Ca^{2+} + Mg^{2+} + 2CO_2 + 2H_2O$$

In addition, the ferrous iron is partly or completely oxidized to ferric iron, as follows:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \quad \textit{or}$$

$$4Fe^{2+} + O_2 + 6H_2O \rightarrow 4FeO(OH) + 8H^+$$

The ferric iron in solution also acts as an efficient oxidizing agent, as shown below (Nordstrom, 1985):

$$14Fe^{3+} + \underset{\text{pyrite}}{FeS_2} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

The net result is that acidic water bearing dissolved Fe, Mg, Al, K, Na, Ca, Mn and sulfate trickles down the face of the bluff. In laboratory tests, similar leachate through pyritic Great Smoky Group rocks has reached a pH level of 2.0 (Jago, 1989). When the acid solution passes beneath the overhang of the bluff, it becomes concentrated by evaporation in the arid microclimate of the rock shelter, and eventually begins depositing sulfate salts. Some of the evaporation and deposition takes place on the face of the rock, but most occurs after the seepage reaches the dirt floor. The minerals are thus slowly but constantly renewed. The suite of minerals deposited at any one place depends on the relative concentrations of the metal ions and on the pH; these constantly change as various salts are precipitated or redissolved, so that the suite of salts varies in time and space. A sequence of such changes for an iron-sulfate assemblage in Nova Scotia coal mines is documented by Zodrow *et al.* (1979).

Three new rare-earth-element (REE) sulfate-oxalates found during our study—*coskrenite-(Ce)*, *levinsonite-(Y)*, and *zugshunstite-(Ce)*—are now being studied for formal description (the names have been approved by the International Mineralogical Association). Minute amounts have been found as tiny crystals in masses of hair salt in the soil. The rare-earth elements were leached from the Anakeesta, the only rock unit upslope from the deposit; it is surprising that the REE concentration in the leachate was high enough to precipitate these remarkable minerals. No REE analyses are available for the Anakeesta, but it probably contains the usual trace amounts (around 200 ppm REE). A part of the explanation may be in the efficient mobilization of REEs through oxalate chelation. The oxalate ion may have originated from the leaching of decaying organic material. The affinity of oxalate for REEs, as demonstrated by the existence of these minerals in the absence of other oxalate minerals, may have some bearing on the mobility of REEs under weathering conditions (Coskren *et al.*, 1996).

The radii of REE ions, much larger than the radii of other trivalent ions at the locality (Al^{3+} and Fe^{3+}), make them unsuitable for substitution into the structures of the other salts at the locality. The low temperature (probably among the lowest temperatures for any known REE minerals) further lowers the tolerance of the structures for foreign ions. Moreover, the low temperature should permit a more complete fractionation of the REEs between minerals, a prediction supported by the preliminary data afforded by the XRF analyses.

Slavikite, a rare (or rarely identified) mineral worldwide, appears to form near the surface of masses of mixed hair salt and epsomite, and is probably produced by a reaction such as that below:

$$\underset{\text{epsomite}}{28MgSO_4\cdot 7H_2O} + \underset{\text{halotrichite in hair salt}}{20FeAl_2(SO_4)_4\cdot 22H_2O} + 5O_2 + 4Na^+$$

$$\rightarrow \underset{\text{slavikite}}{4NaMg_2Fe_5^{3+}(SO_4)_7/(OH)_6\cdot 33H_2O} +$$

$$\underset{\text{pickeringite in hair salt}}{20MgAl_2(SO_4)_4\cdot 22H_2O} + 50H_2O + 4H^+$$

The minerals at the locality are not conspicuous, and the first indication that there may be anything of interest is a sulfurous odor (especially on a hot day). Small yellow and white masses of iron sulfates might be noticed on a few rock faces and in crevices and white masses of (mostly) epsomite and hair salt project locally from the ground, but most of the salts are in masses beneath the surface, to be seen only with some small amount of excavation (a few centimeters). Even if the minerals are found, identification of many of the salts must await examination under the microscope. Epsomite and melanterite and their dehydration products are fairly easily found, and the hair-salt series is very common. Magnesiocopiapite is easily found and identified by its bright yellow color. The distinctive yellow-green hue of slavikite can perhaps be noted by the sharp-eyed, but the amounts are generally so small that it is difficult to find.

Many of the sulfates discussed here are highly soluble in water. Exceptions are ammoniojarosite and destinezite (nearly insoluble); gypsum (slightly soluble); and slavikite (slowly soluble with decomposition). Descriptions of the various definitely and tentatively identified minerals (and unknowns) are given in the mineral list below and in Table 2. As indicated in the descriptions, most identifications were based on physical appearance, crystal morphology, and semi-quantitative analysis (X-ray fluorescence in the scanning electron microscope). All identifications except destinezite are by the authors, and all photographed minerals came from the senior author's collection.

The historical report of saltpeter suggests that one or more nitrate minerals may be present (or may have been present), but no nitrates were seen during this study. However, small amounts of disseminated nitrate could easily escape notice.

MINERALS

Aluminite $Al_2SO_4(OH)_4\cdot 7H_2O$

Aluminite occurs at Alum Cave Bluff as uncommon masses of white to yellow-stained matted fibers (~0.2 mm) (Fig. 4; see also Polyak and Provencio, 1998) associated with gypsum and iron oxide. It was identified by SEM/XRF (Al:S ~2:1; acicular/fibrous habit).

Alunogen $Al_2(SO_4)_3\cdot 17H_2O$

Alunogen is found as thin colorless plates with elongated pseudohexagonal outline (almost micaceous in aspect), about 0.3 mm in size, associated with magnesiocopiapite on rock surfaces and crevices. This identification is consistent with semiquantitative SEM/XRF results (only Al, S detected; S>Al). The mineral is uncommon at Alum Cave Bluff.

Ammoniojarosite $(NH_4)Fe_3^{3+}(SO_4)_2(OH)_6$

Ammoniojarosite is common as crusts and aggregates of yellow to red-brown crystals (rhombohedron and pinacoid, or pseudocubic rhombohedron) to about 0.2 mm (Figs. 6, 7). It was first identified as a jarosite-group mineral based on color, habit, and insolubility; the current identification is based on XRF (no K or Na detected in samples analyzed). Some could be jarosite and/or natrojarosite, although neither was present in the five "jarosites" analyzed by XRF.

***Table 2*. Systematic list of secondary mineral species at Alum Cave Bluff.**

Native Elements	
Sulfur	S
Oxides	
Manganese Oxide	
Schwertmannite (?)	$Fe_8O_8(OH)_6(SO_4)$
Nitrates	
Nitrocalcite (?)	$Ca(NO_3)_2\cdot 4H_2O$
Carbonates	
Calcite	$CaCO_3$
Hydromagnesite	$Mg_5(CO_3)_4(OH)_2\cdot 4H_2O$
Phosphates	
Mineral D	
Sulfates	
Aluminite	$Al_2SO_4(OH)_4\cdot 7H_2O$
Alunogen	$Al_2(SO_4)_3\cdot 17H_2O$
Ammoniojarosite	$(NH_4)Fe_3^{3+}(SO_4)_2(OH)_6$
Apjohnite	$(Mn,Mg)Al_2(SO_4)_4\cdot 22H_2O$
Basaluminite	$Al_4SO_4(OH)_{10}\cdot 5H_2O$
Botryogen	$MgFe^{3+}(SO_4)_2(OH)\cdot 7H_2O$
Coskrenite-(Ce)	$(Ce,Nd,La)_2(SO_4)_2(C_2O_4)\cdot 8H_2O$
Destinezite	$Fe_2^{3+}(PO_4)(SO_4)(OH)\cdot 6H_2O$
Epsomite	$MgSO_4\cdot 7H_2O$
Gypsum	$CaSO_4\cdot 2H_2O$
Hexahydrite (?)	$MgSO_4\cdot 6H_2O$
Halotrichite	$FeAl_2(SO_4)_4\cdot 22H_2O$
Jurbanite (?)	$AlSO_4(OH)\cdot 5H_2O$
Levinsonite-(Y)	$(Y,Nd,Ce)Al(SO_4)_2(C_2O_4)\cdot 12H_2O$
Magnesiocopiapite	$MgFe_4^{3+}(SO_4)_6(OH)_2\cdot 20H_2O$
Melanterite	$FeSO_4\cdot 7H_2O$
Pickeringite (?)	$(Mg,Mn)Al_2(SO_4)_4\cdot 22H_2O$
Rozenite	$FeSO_4\cdot 4H_2O$
Slavikite	$NaMg_2Fe_5^{3+}(SO_4)_7(OH)_6\cdot 33H_2O$
Tschermigite	$(NH_4)Al(SO_4)_2\cdot 12H_2O$
Zugshunstite-(Ce)	$(Ce,Nd,La)Al(SO_4)_2(C_2O_4)\cdot 12H_2O$

***Figure 4*. Aluminite (?) crystals to 25 µm; Alum Cave Bluff.**

Apjohnite $(Mn,Mg)Al_2(SO_4)_4\cdot 22H_2O$

Apjohnite occurs commonly as clear needles and silky masses of typical hair-salt appearance; most specimens of hair salt were identified as magnesian apjohnite by semiquantitative analysis

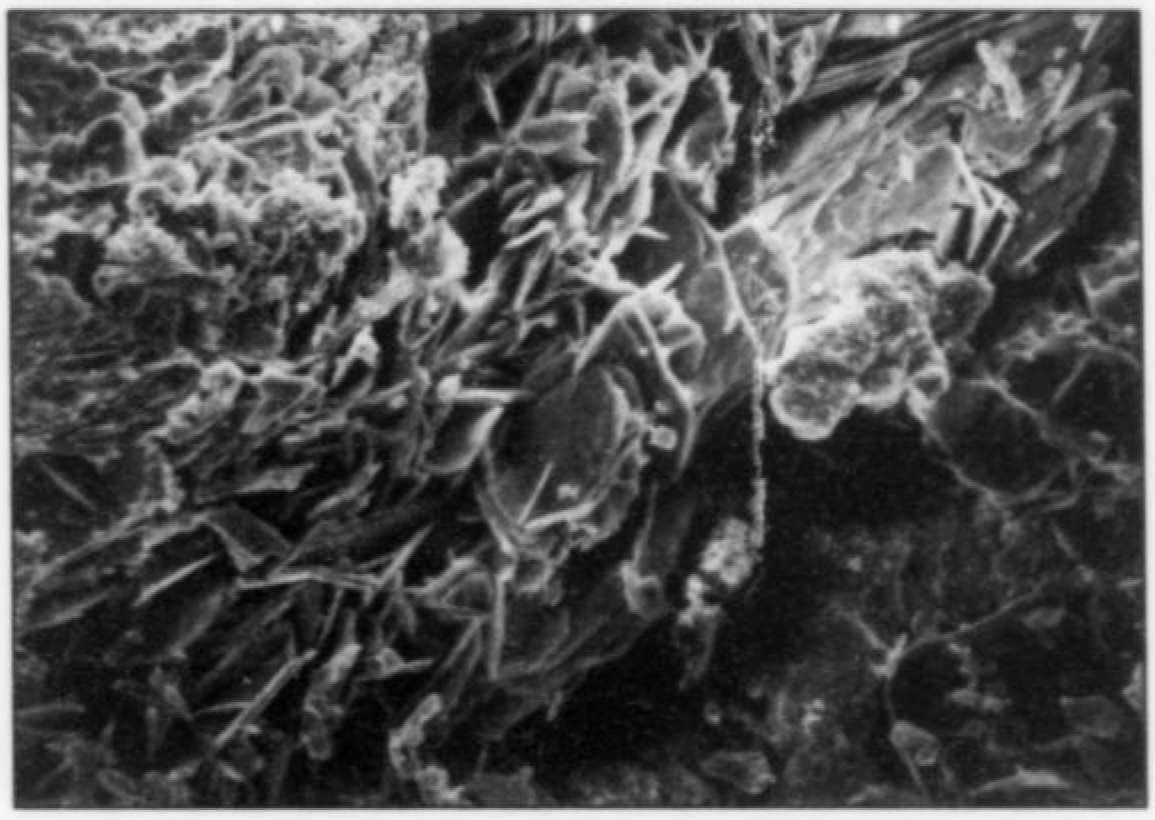

Figure 5. **Aluminite (?) crystals to 25 µm; Alum Cave Bluff.**

Figure 6. **Ammoniojarosite (?) crystals to about 15 µm; Alum Cave Bluff.**

Figure 7. **Jarosite (ammoniojarosite?) crystals to about 60 µm; Alum Cave Bluff.**

with SEM/XRF (most analyses higher in Mn than Mg, with little or no Fe). It was first reported by Brown (1884) as "hydrous manganous aluminic sulphate."

Basaluminite $Al_4SO_4(OH)_{10}\cdot 5H_2O$

Creamy-white fine-grained masses of basaluminite occur with gypsum. SEM/XRF (Al:S ~4:1) shows well crystallized foliated crystals (Fig. 8; see also Polyak and Provencio, 1998).

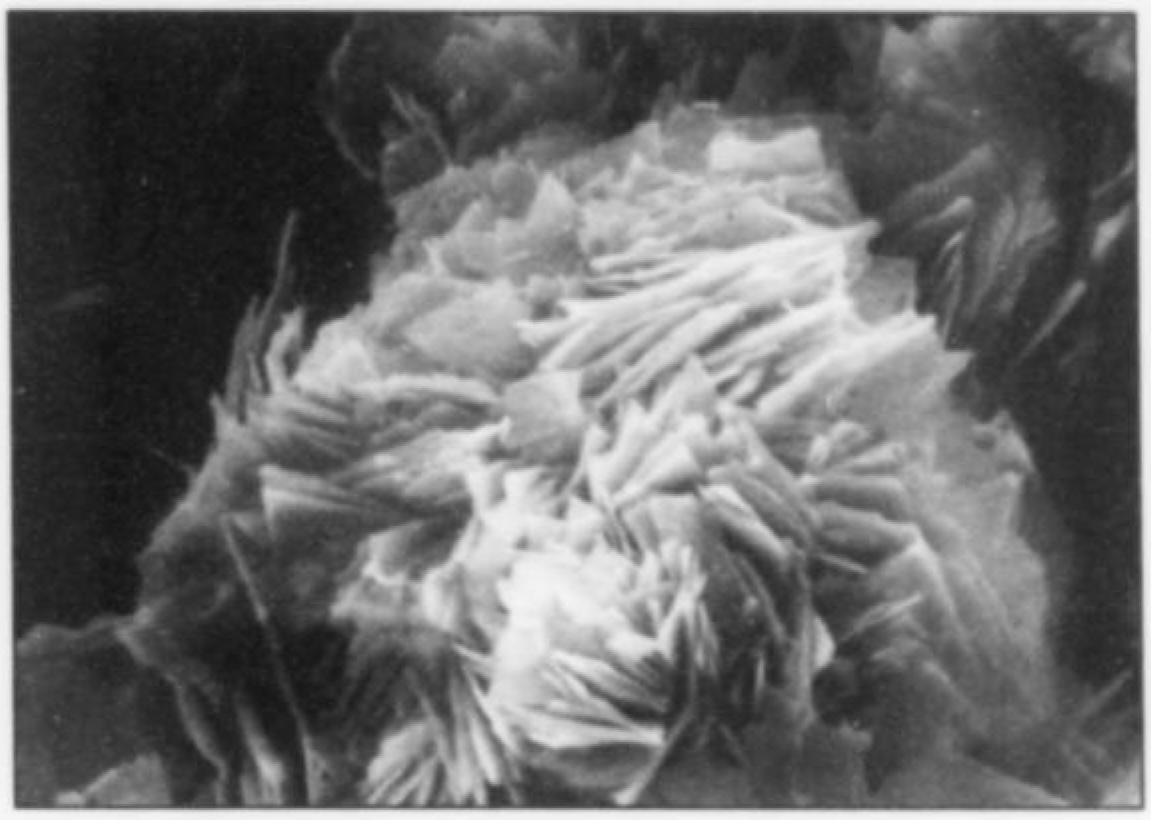

Figure 8. **Basaluminite (?) in foliated crystals about 10 µm across; Alum Cave Bluff.**

Figure 9. **Ferroan botryogen (?) rosette, about 100 µm across; Alum Cave Bluff.**

Botryogen $MgFe^{3+}(SO_4)_2(OH)\cdot 7H_2O$

Very tiny rosettes of bladed pale-orange botryogen crystals have been found (Fig. 9) associated with hair salt. Mg, Fe, and S were detected by SEM/XRF in approximately 1:1:2 ratio. The radiating habit is consistent with botryogen.

Calcite $CaCO_3$

Crusts of rare, tiny (<0.1 mm) crude brownish gray translucent rhombohedral calcite crystals, of no great collector interest have been found locally on vertical joint surfaces with hydromagnesite, but no iron sulfates (incompatible solution chemistries). Calcite and hydromagnesite (identified by XRF and acid reaction) belong to an earlier generation of secondary minerals.

Coskrenite-(Ce) $(Ce,Nd,La)_2(SO_4)_2(C_2O_4)\cdot 8H_2O$

Tiny (~0.8 mm) squarish to wedge-shaped platy crystals of the new species coskrenite-(Ce) have been found, often with lozenge-shaped cross sections (Fig. 10). The mineral shows good cleavage normal to plates, and is found associated with magnesian apjohnite and epsomite, and sometimes with slavikite, ammoniojarosite, tschermigite, levinsonite-(Y), or zugshunstite-(Ce). Some is in radiating masses embedded in hair salt. Most crystals are pale pink under incandescent lights, pale blue-gray under fluorescent light, and nearly colorless in sunlight (alexandrite effect, due to cerium); a few are cream-colored. Coskrenite-(Ce), levinsonite-(Y), and zugshunstite-(Ce) are the first naturally occurring rare-earth sulfates or oxalates, and the first mixed oxalates known to science.

Figure 10. **Coskrenite-(Ce) in cream-colored crystals to 100 µm; Alum Cave Bluff.**

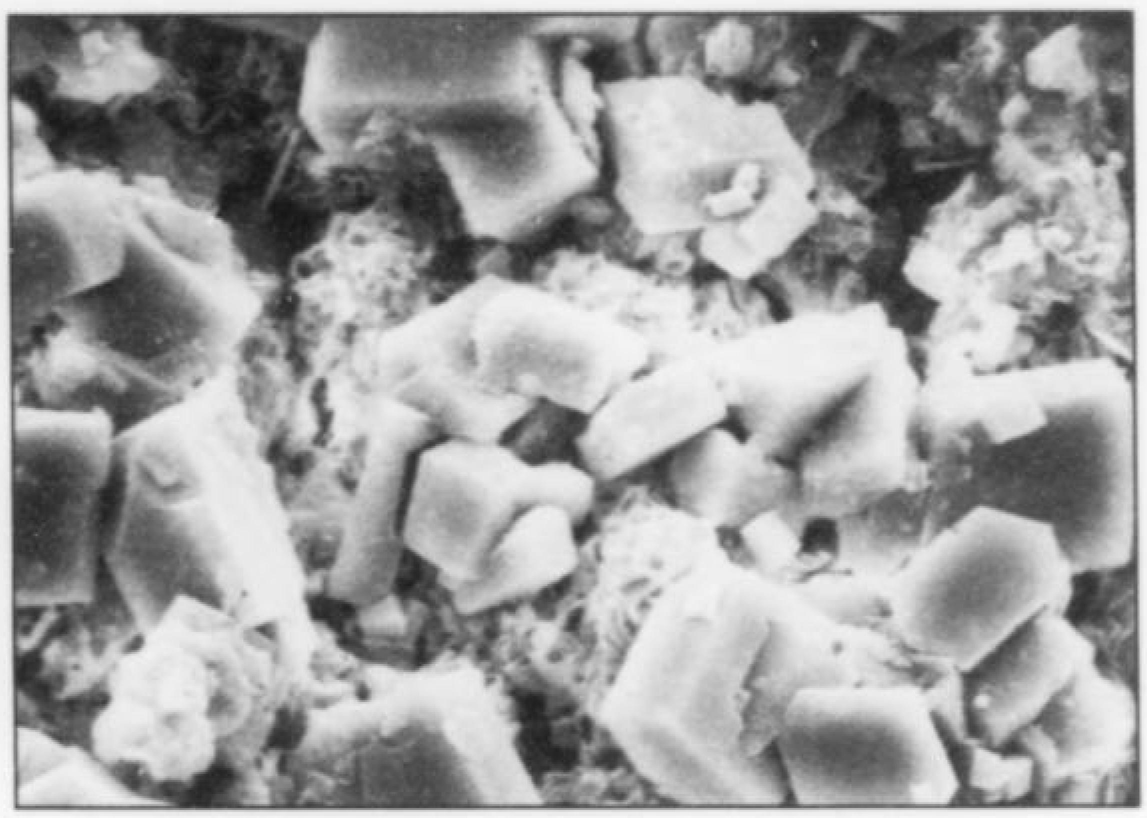

Figure 11. **Destinezite crystals to 20 µm; Alum Cave Bluff.**

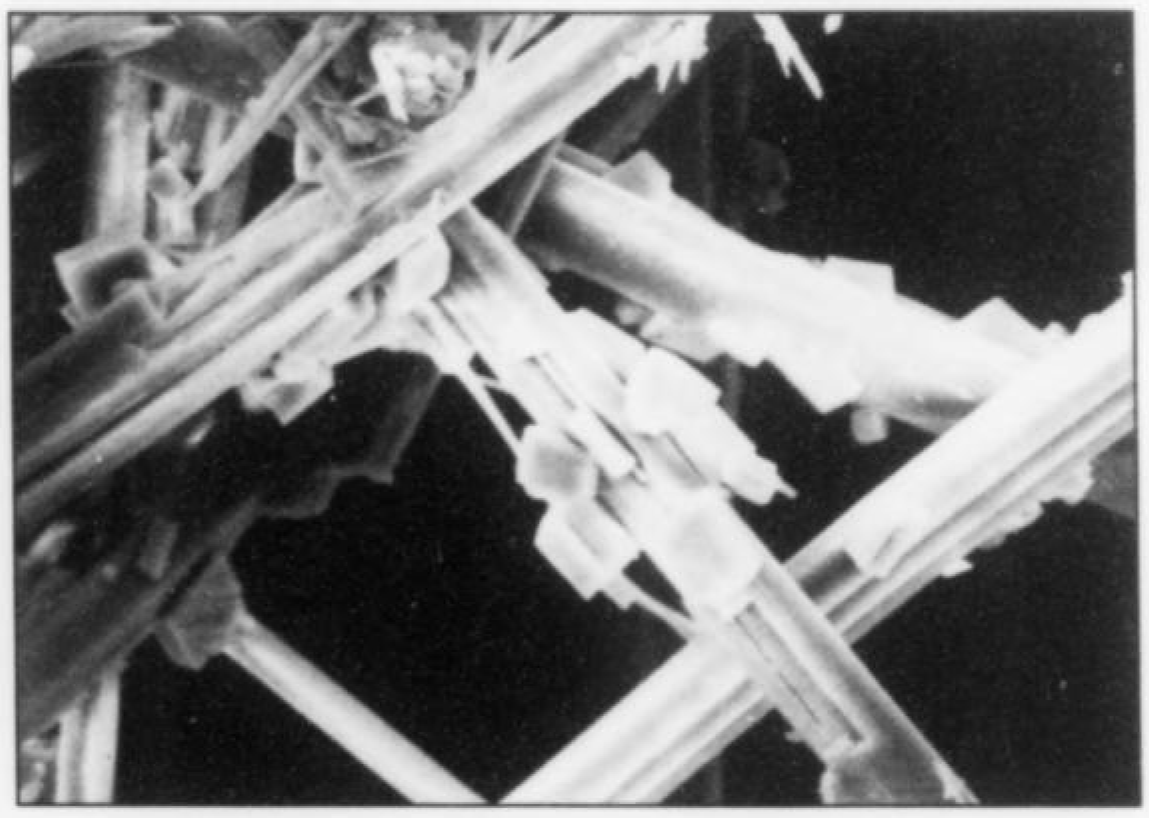

Figure 12. **Destinezite crystals to about 1 µm on acicular gypsum; Alum Cave Bluff.**

Figure 13. **Epsomite crystals to 1 µm; Alum Cave Bluff.**

Figure 14. **Epsomite crystals to 1 µm; Alum Cave Bluff.**

Destinezite $Fe^{3+}_2(PO_4)(SO_4)(OH)\cdot 6H_2O$

Destinezite occurs in buff to salmon masses of minute powdery (few tens of microns) crystals and rare tiny (100 microns) blocky euhedral crystals (Figs. 11, 12); it was identified by XRD and SEM/XRF. The mineral is locally common on rock in soil with acicular gypsum crystals, and in soil salts. Formerly called diadochite, the name destinezite has been reinstated for well-crystallized material after study of the Alum Cave Bluff material. The formula with six waters of hydration instead of five has been determined by a crystal-structure analysis (Peacor *et al.*, 1997).

Epsomite $MgSO_4\cdot 7H_2O$

Epsomite is common as glassy-clear, fibrous to columnar masses, and as euhedral prismatic terminated crystals (matching commercial Epsom-salt crystals) to 5 mm (Figs. 13, 14). It alters to opaque white pseudomorphs in dry air, both in nature and in collections. Re-hydrated crystals do not regain clarity or sharpness. Epsomite is often found intergrown with hair salt. It was originally identified by taste and distinctive habit, and by its unstable nature; the identification was confirmed by SEM/XRF. The presence of abundant ferrous iron salts locally leads one to suspect that the dominant iron member of the series (tauriscite) might also be present. Epsomite was reported by Safford (1856, 1869), but was locally recognized earlier.

Gypsum $CaSO_4\cdot 2H_2O$

Crusts of sharp, euhedral, glassy-clear gypsum crystals to 2 mm have been found to be locally common on rock surfaces, and common but sparse in soil salts. Many crystals have the familiar acutely pointed, bladed shape, but others are acicular and could be mistaken for one of the hair salts. It was identified by habit, cleavage, and flexibility, and confirmed by SEM/XRF.

Hexahydrite (?) $MgSO_4\cdot 6H_2O$

Hexahydrite occurs as opaque white pseudomorphs and pow-

Figure 15. **Halotrichite crystal bundles to about 10 µm; Alum Cave Bluff.**

dery masses after epsomite, which readily re-hydrate to epsomite. It may be a mixture of lower hydrates, including starkeyite (Mitchell, 1978). Ferrohexahydrite could also be present.

Halotrichite $FeAl_2(SO_4)_4 \cdot 22H_2O$

Halotrichite forms silky white to yellowish fibrous masses and free-standing acicular crystals with no visible faces on terminations (Fig. 15). It was originally identified as hair salt by silky fibrous appearance and astringent taste, but is distinguished from other hair salts by its common association with melanterite. The identification was confirmed by SEM/XRF. Halotrichite forms under reducing conditions, whereas most of the hair salt minerals exist under oxidizing conditions and have little or no Fe.

Hydromagnesite $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$

Hydromagnesite occurs as rare sprays of clear, colorless, bladed crystals typical of the species, to almost 1 mm, on rock surfaces with calcite. It was identified as a carbonate by acid reaction, and this species by its habit.

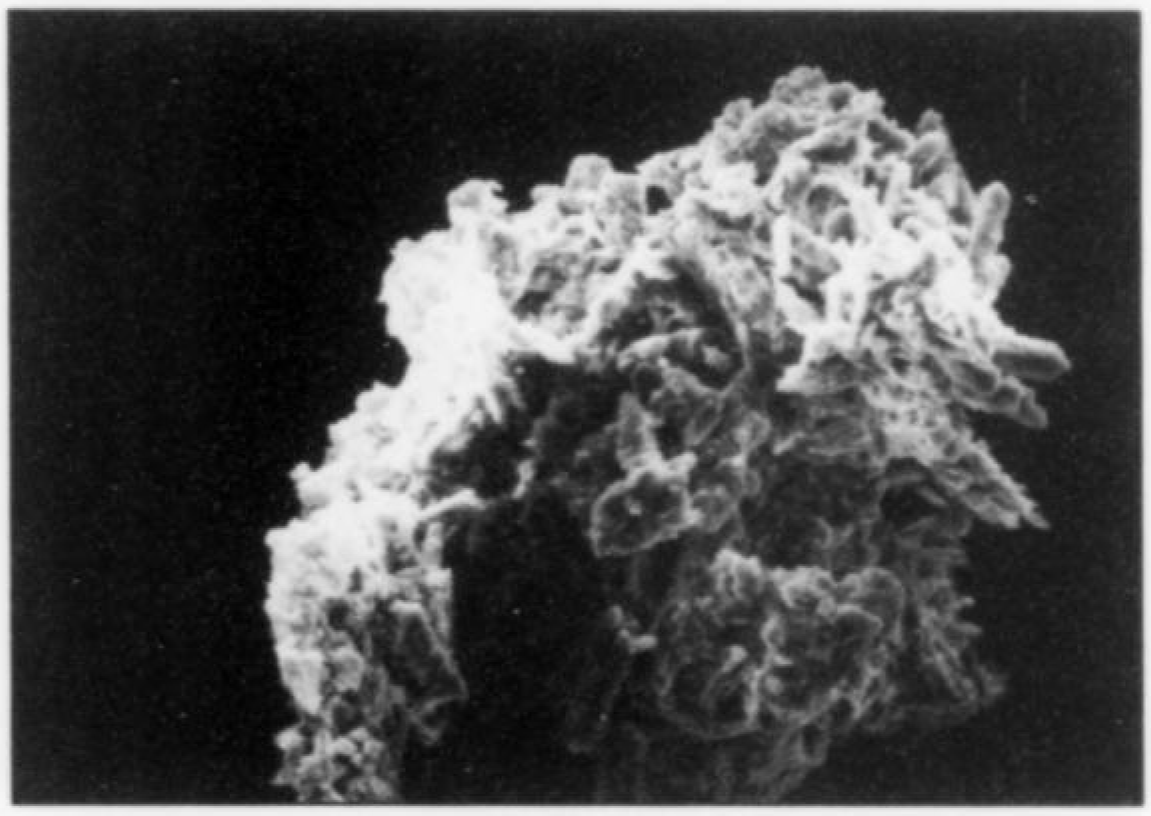

Figure 16. **Jurbanite (?) crystals to 70 µm; Alum Cave Bluff.**

Jurbanite (?) $AlSO_4(OH) \cdot 5H_2O$

Tiny colorless prismatic crystals in soil salt (Fig. 16) have been tentatively identified as jurbanite by SEM/XRF (Al:S ~1:1). Only one specimen has been found; but because the mineral is indistinguishable on sight from other colorless granular minerals (e.g., epsomite), it may be commoner than realized.

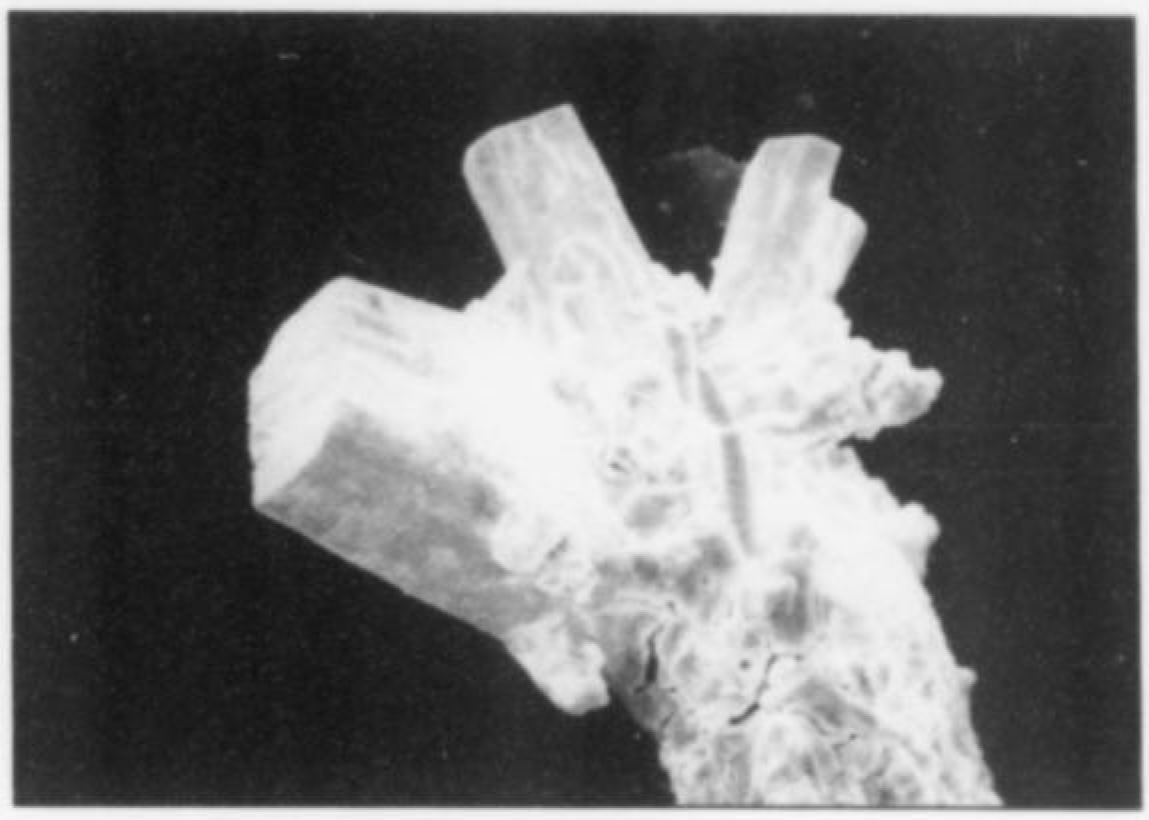

Figure 17. **Levinsonite-(Y) crystals to 150 µm; Alum Cave Bluff.**

Levinsonite-(Y) $(Y,Nd,Ce)Al(SO_4)_2(C_2O_4) \cdot 12H_2O$

Levinsonite-(Y) occurs rarely as sharp, euhedral, colorless to white prismatic crystals with orthorhombic aspect, like tiny 2-by-4's with transverse striations, to about 0.8 mm (Fig. 17) It also occurs in a second habit as slightly elongated rectangular tablets embedded in soil salts. It has comparatively low solubility, and was discovered projecting from a partially dissolved mass of hair salts. Levinsonite-(Y) and zugshunstite-(Ce) have the same formula except for the nature of the dominant REE. Both minerals are present within a centimeter of each other in one specimen, and this occurrence may represent a rare example of the stable coexistence of Ce-dominant and Y-dominant minerals (monazite and xenotime are another such pair). XRF analyses suggest that Nd-dominant minerals mat also exist.

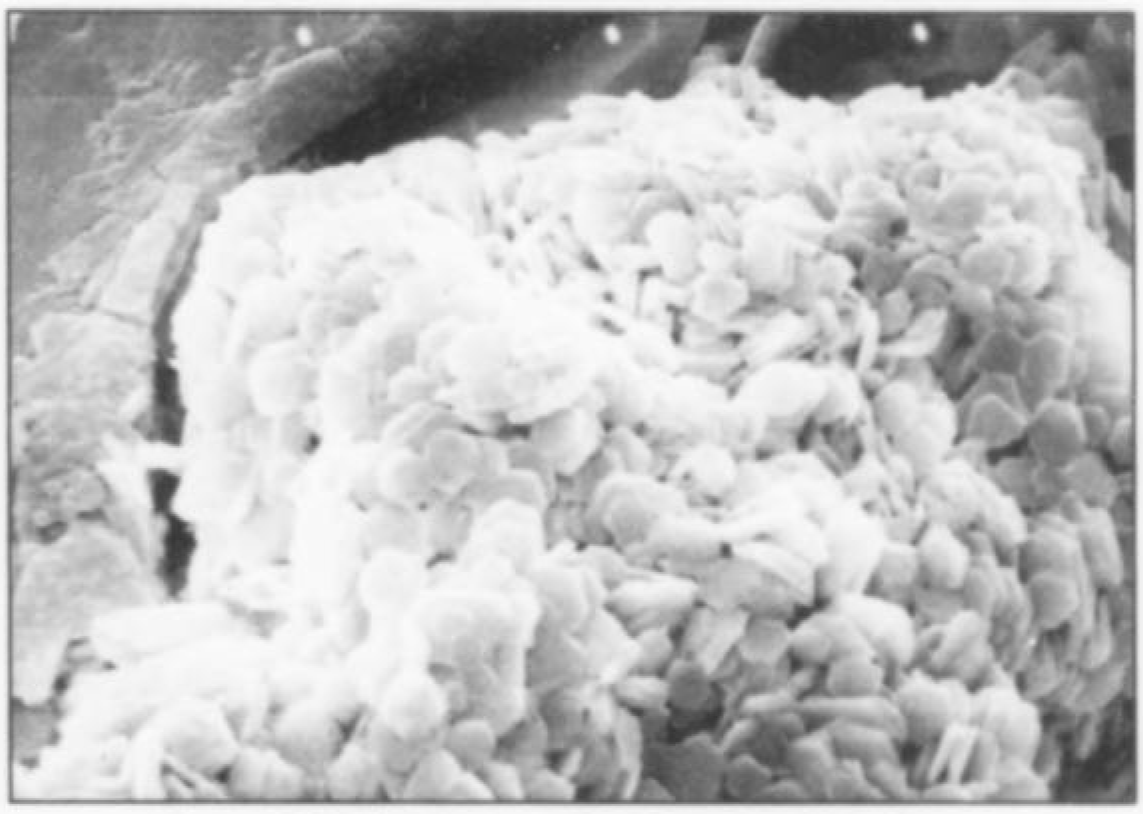

Figure 18. **Magnesiocopiapite crystals to 5 µm; Alum Cave Bluff.**

Magnesiocopiapite $MgFe^{3+}_4(SO_4)_6(OH)_2 \cdot 20H_2O$

Magnesiocopiapite forms crusts and masses of tiny yellow flakes (Figs. 18, 19) which are locally common on rock surfaces and in crevices. It was identified by color, habit and (two specimens) SEM/XRF. Copiapite *sensu stricto* may be present where ferrous iron is dominant over magnesium, but samples analyzed have high magnesium.

Melanterite $FeSO_4 \cdot 7H_2O$

Melanterite occurs very commonly as glassy clear, pale green to colorless, pseudo-octahedral to prismatic, euhedral crystals (to

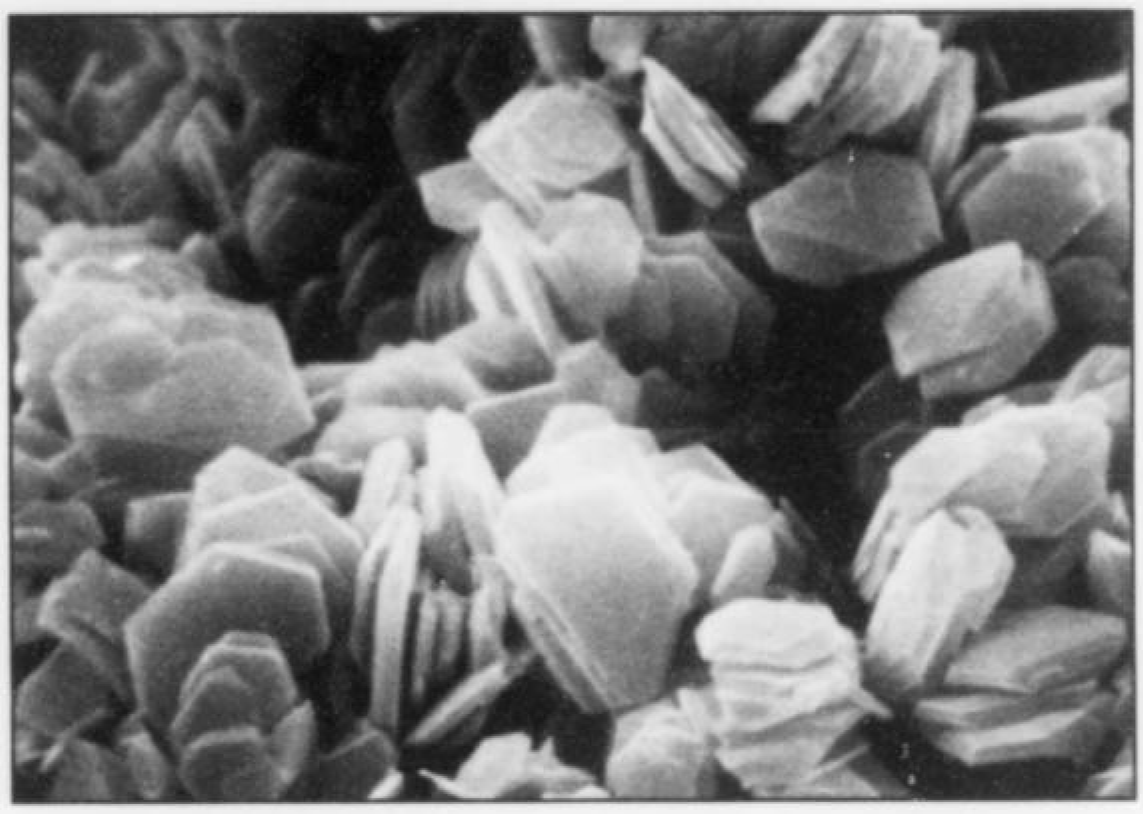

Figure 19. **Magnesiocopiapite crystals to 10 µm; Alum Cave Bluff.**

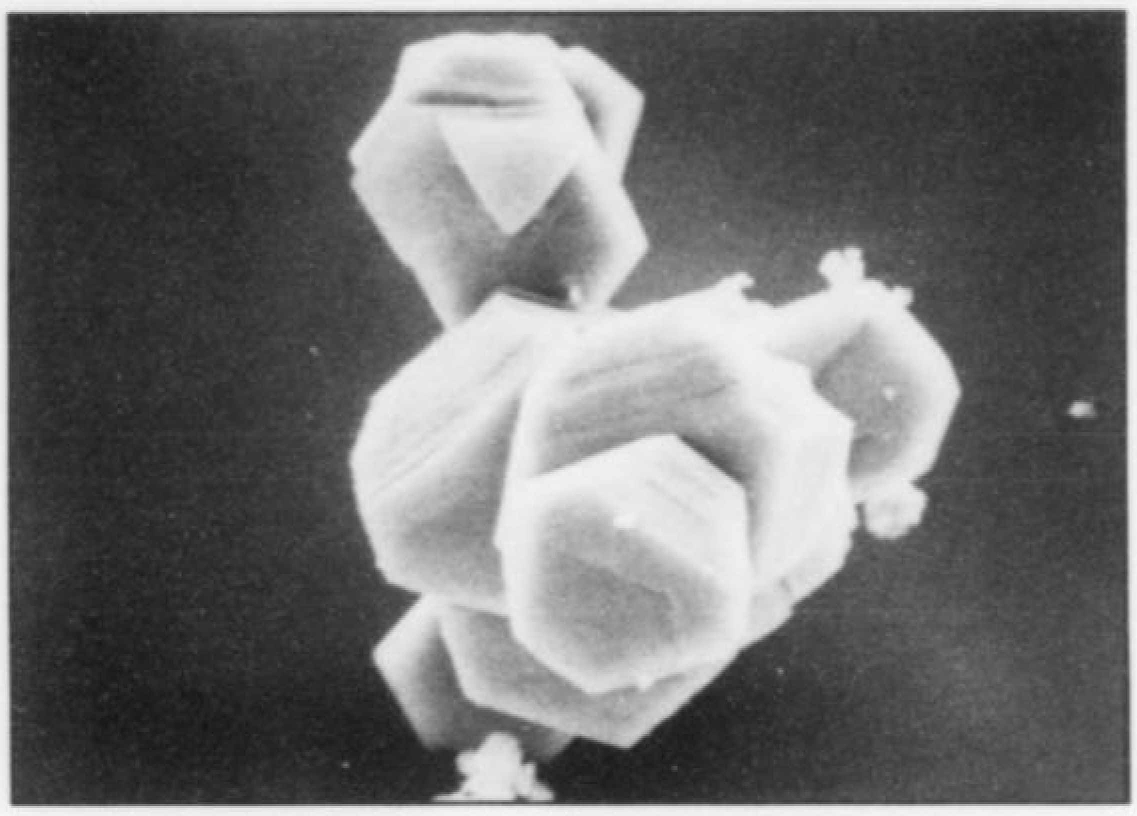

Figure 20. **Slavikite crystals to 70 µm; Alum Cave Bluff.**

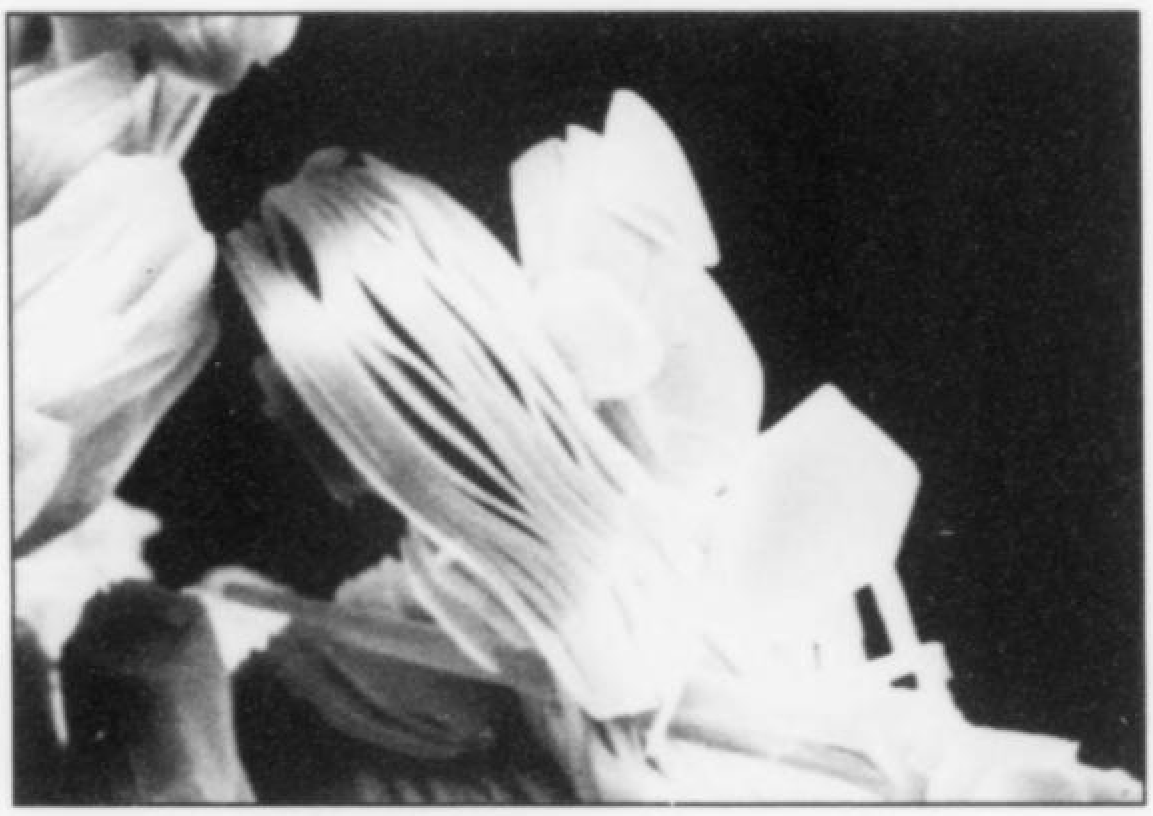

Figure 21. **Slavikite crystals separating into basal-cleavage laminae about 2 µm thick; Alum Cave Bluff.**

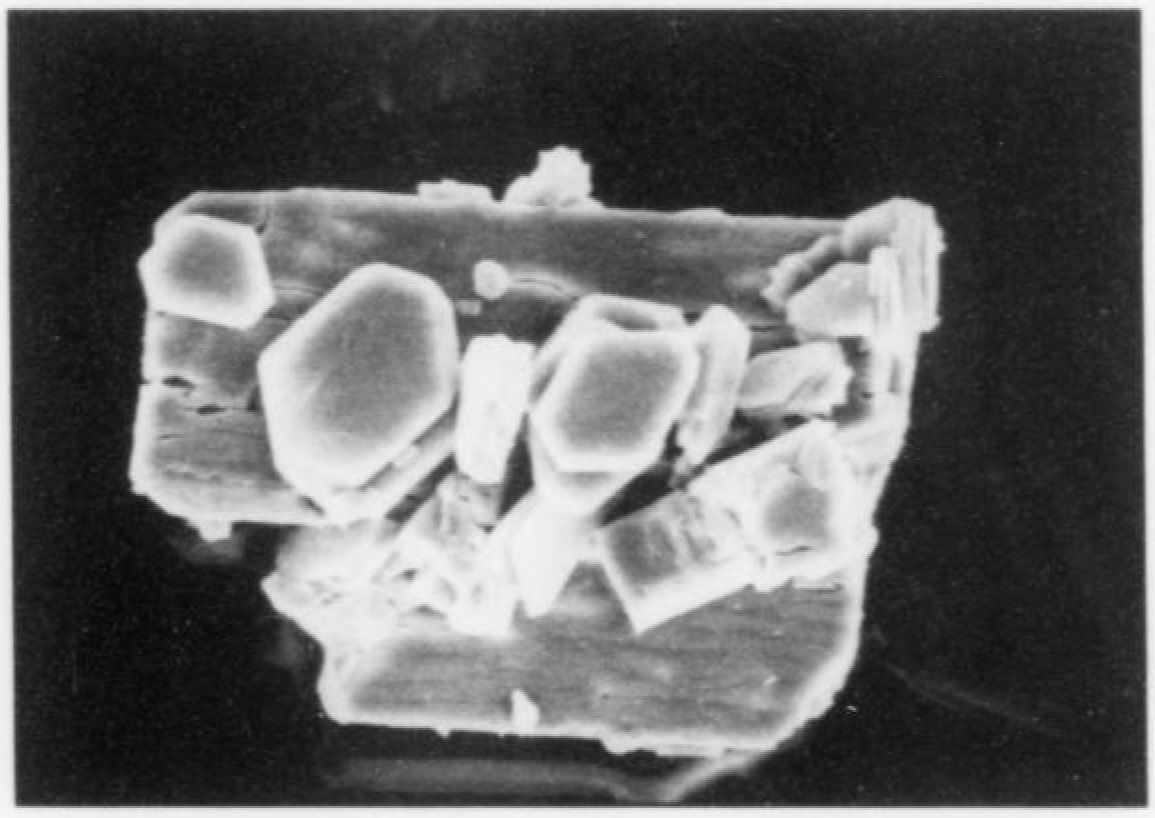

Figure 22. **Slavikite crystals to 2 µm on a levinsonite-(Y) crystal; Alum Cave Bluff.**

5 mm), ram's-horn fibers, rounded masses, and coatings which alter to opaque white pseudomorphs in dry air. As with epsomite, re-hydrated melanterite remains opaque white and tends to lose sharp crystal definition. It can be identified by its taste, color, and distinctive habit, and by its unstable nature. It is very common in rock fractures, less common in soil salts. Melanterite was reported by Brown (1884), but was locally recognized earlier ("copperas").

Nitrocalcite (?) $Ca(NO_3)_2 \cdot 4H_2O$

"Saltpeter" was mined at Alum Cave Bluff during the 1860's. According to Jenkins (1988), the material was "nitrate of lime"; no basis for the identification was given. However, most nitrate in Tennessee cave soil occurs as nitrocalcite (Glenn, 1918). No nitrate minerals were found during this study; but disseminated material could easily escape notice, and substantial masses may have been mined out.

Pickeringite (?) $(Mg,Mn)Al_2(SO_4)_4 \cdot 22H_2O$

Silky white fibrous masses of manganoan pickeringite were identified as hair salt by their appearance and astringent taste; it forms a solid solution with halotrichite and apjohnite, and is distinguishable with certainty only by analysis. Even many samples intimately associated with epsomite proved to have Mn>Mg; by inference, Mn is strongly fractionated into the hair-salt structure relative to Mg. Some XRF analyses of hair salt show approximately equal amounts of Mg and Mn, with Mg slightly greater than Mn, but a definite confirmation of pickeringite awaits a more precise analysis.

Rozenite $FeSO_4 \cdot 4H_2O$

Rozenite has been found as opaque white pseudomorphs and powdery masses after melanterite; the mineral re-hydrates to melanterite (Ehlers and Stiles, 1965; Mitchell, 1978). Some may be a mixture of lower hydrates.

Schwertmannite (?) $Fe_8O_8(OH)_6(SO_4)$

Reddish brown crusts and masses of hydrous iron oxides, some translucent with resinous luster, are present on some rock surfaces. A significant sulfur (sulfate) content was found by XRF analysis; the composition of this material corresponds to that of schwertmannite, a recently-described (but common) sulfatian ferric oxyhydroxide (Bigham, 1994). Ferrihydrite and goethite have been reported under similar conditions by Jago (1989), and could also be present here.

Slavikite $NaMg_2Fe_5^{3+}(SO_4)_7(OH)_6 \cdot 33H_2O$

Slavikite occurs in sharp, euhedral, glassy-clear, greenish-yellow (fresh) to translucent orange (altered) tabular crystals with a combination of rhombohedron and pinacoid (Figs. 20, 21, 22). Crystals measure about 0.1 to 0.3 mm. This material was identified by XRD. It is sparse, but fairly common in small quantities in masses of mixed hair salt and epsomite, and has been found in small, pure masses of crystals (resembling bird droppings) on the ground, fallen from a cliff face. Alum Cave Bluff appears to be the only known North American locality for slavikite. An SEM/XRF scan of these crystals did not detect sodium, so they may have a different cation (possibly ammonium?). Gordon (1941) also reported a lack of sodium in his (Argentine) material. A trace of manganese was also present.

Crystals of slavikite from Alum Cave Bluff show a slight pearly luster on the basal pinacoid, related to a perfect basal cleavage which has not been recorded in earlier descriptions. The SEM photographs show the crystals splitting into thin, flexible lamellae along this cleavage. Slavikite has a sheet sulfate structure akin to that of some other ferric sulfates, such as jarosite, kornelite, and rhomboclase, with magnesium and sodium (or another cation?) in an interlayer position (Süsse, 1975).

Sulfur S

Sulfur has been found in tiny (mostly <0.1 mm), sharp to rounded clear crystals, some highly modified. It is fairly widespread, but very sparse, occurring mostly on rock surfaces with ammoniojarosite. The mineral was identified by its color, luster and habit, and confirmed by SEM/SRF.

Figure 23. **Tschermigite (?) in crude octahedral crystals to 100 µm; Alum Cave Bluff.**

Tschermigite $(NH_4)Al(SO_4)_2 \cdot 12H_2O$

Tschermigite occurs as tiny (~0.2 mm), sharp, clear, colorless octahedra and cuboctahedra on hair salt (Fig. 23). Cube faces are sometimes slightly frosted; octahedron faces are clear. Our material was first identified as potassium alum because of its morphology, association, and optics (isotropic, n = 1.456 ± 0.002), but XRF analysis found no potassium. Thus far it is uncommon; a few specimens have been identified in soil salts.

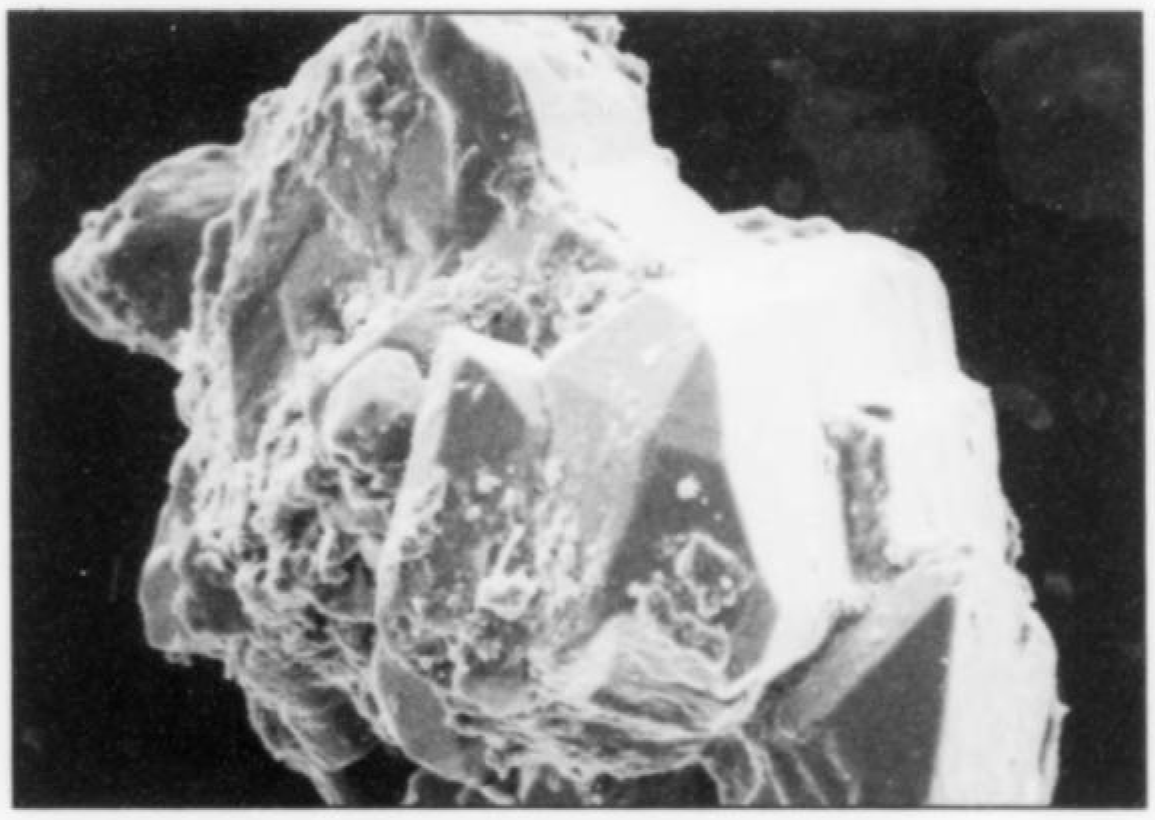

Figure 24. **Zugshunstite-(Ce) crystals to 250 µm; Alum Cave Bluff.**

Zugshunstite-(Ce) $(Ce,Nd,La)Al(SO_4)_2(C_2O_4) \cdot 12H_2O$

Zugshunstite-(Ce) has been found as sharp, glassy-clear crystals with blocky habit and monoclinic in aspect (reminiscent of blocky feldspar crystals) (Fig. 24). It occurs as a component of hair salt. Crystals are large, (almost 2 mm). The mineral shows the same colors as coskrenite-(Ce), but is slightly paler: very pale pink under incandescent lights, pale blue-gray under fluorescent light, and nearly colorless under sunlight. It is very rare; so far only nine specimens have been identified in soil salts.

The coexistence of zugshunstite-(Ce), coskrenite-(Ce), epsomite, and hair salt, and the assumption that the minerals are in equilibrium, permit the following equation to be written:

$$\underset{\text{coskrenite-(Ce)}}{Ce_2(SO_4)_2(C_2O_4) \cdot 8H_2O} + \underset{\text{pickeringite in hair salt}}{MgAl_2(SO_4)_4 \cdot 22H_2O} + C_2O_4^{2-} + H_2O$$

$$\rightarrow \underset{\text{zugshunstite-(Ce)}}{2CeAl(SO_4)_2(C_2O_4) \cdot 12H_2O} + \underset{\text{epsomite}}{MgSO_4 \cdot 7H_2O} + SO_4^{2-}$$

The equilibrium constant for this equation is given by $k = [a_{eps}][SO_4^{2-}]/[a_{pick}][C_2O_4^{2-}]$. If the epsomite is (nearly) pure, the activity of water is taken to be (near) unity, and the hair-salt solution is taken to be ideal ($a_{pick} = x_{pick}$), then the equation simplifies to $k = [SO_4^{2-}]/[x_{pick}][C_2O_4^{2-}]$. The equilibrium is determined largely by the sulfate/oxalate ratio of the solution. For a high ratio (as exists for the salt deposit at Alum Cave Bluff), the equilibrium of the chemical equation will be pushed to the left. This may explain the rarity of zugshunstite-(Ce) relative to coskrenite-(Ce).

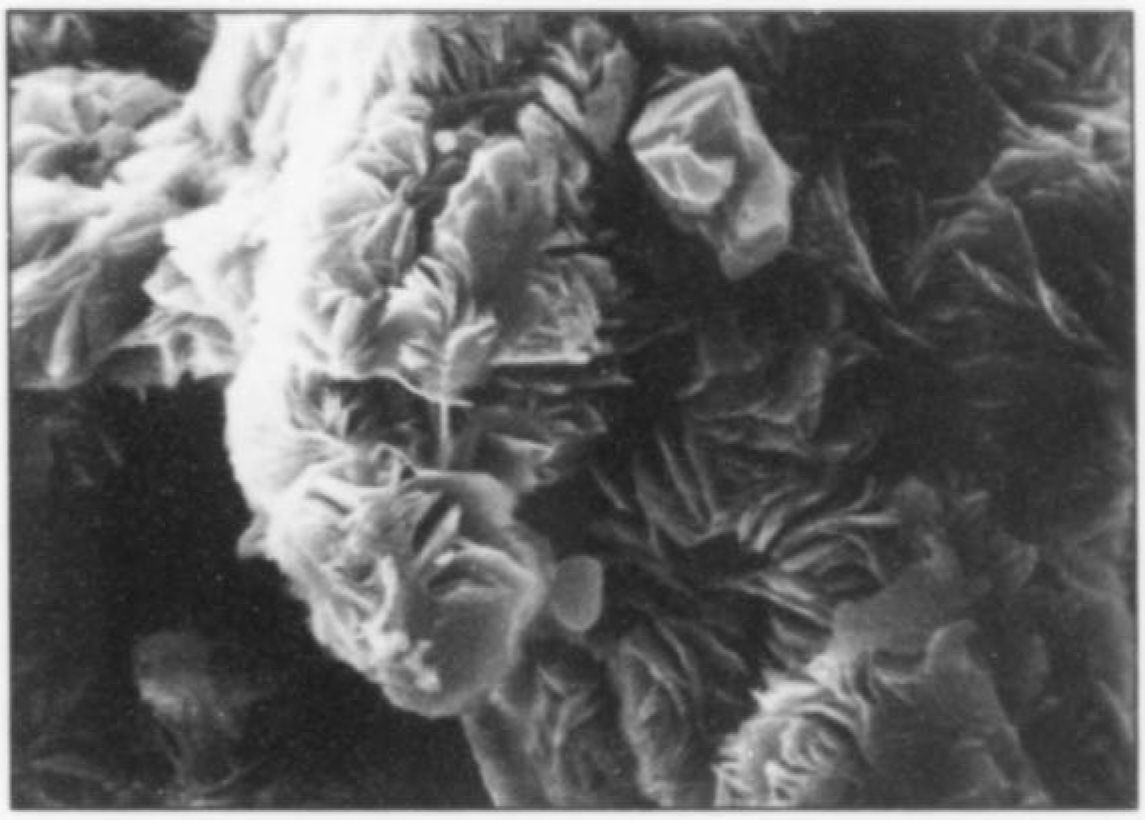

Figure 25. **Unknown iron phosphate mineral (Fe:P≅2.1) in flakes about 10 µm across; Alum Cave Bluff.**

Mineral D iron phosphate

Fine grained pale-green coatings and botryoidal masses (to 0.1 mm of an unidentified iron phosphate occur in soil salts, commonly on phyllite fragments. SEM shows a ragged flaky habit (Fig. 25). XRF analysis gives Fe = 2P, with some S and a trace of Al (impurities?). It is rather widespread at Alum Cave but extremely sparse.

Manganese oxide

Tiny (~0.1 mm) black botryoids of a manganese oxide occur on rock surfaces with apjohnite and destinezite.

Unknown Copper Minerals

Several unidentified copper-bearing minerals have been found in trace amounts. The first was noted as fine-grained green coatings and tiny masses on phyllite fragments. XRF analysis gave only Cu and a trace of Fe; SEM showed a ragged flaky habit. The anion was not detected in the XRF analysis, and is therefore not sulfate or phosphate. Three additional copper minerals were detected by electron microprobe analysis of thin sections (Donald Peacor, personal communication). The minerals were a copper-zinc sulfate, a copper-zinc mineral without sulfate, and a copper-zinc-aluminum sulfate (possibly glaucocerinite?).

DISCUSSION

The list of secondary minerals occurring at Alum Cave Bluff is undoubtedly incomplete. Not only is this study not exhaustive, but also the minerals that are present are subject to change over short periods of time, depending upon the conditions. The variety (if not the size) of secondary sulfates that has been found is sufficient to earn the locality an honored place among American sulfate localities, ranking it with Jerome, Arizona; the Dexter No. 7 mine, Utah; and Sulfur Hole at Borate, California. It is remarkable that such a productive soluble-salt locality should exist in one of the wetter places in the country (over 60 inches of annual rainfall).

Jago (1989) studied secondary minerals produced by weathering of sulfidic Great Smoky Group strata in road fill west of the park. In laboratory leaching studies he reported the following sulfates: jarosite, alunite, melanterite, copiapite and yavapaiite. Yavapaiite was also reported to be present in the field in naturally leached fill material. Identifications in that study were made by X-ray diffraction. The minerals found in the Jago study may also prove to be present at Alum Cave Bluff.

A surprising feature of the mineral assemblage at Alum Cave Bluff is the absence of potassium or sodium in the salt minerals, and the presence of ammonium equivalents (ammoniojarosite, tschermigite, possibly slavikite?). The parent rock contains sufficient alkali metals (K_2O, 4.37%, and Na_2O, 2.41%, for the analysis in Table 1) to yield alkali-bearing salts (e.g., potassium alum, jarosite) in evaporites derived from its weathering. An explanation may lie in the production of ammonia from decaying vegetal material, and its conversion to ammonium in acidic surface-water runoff. Vegetation-derived ammonium may be sufficient to overwhelm alkali metals derived from weathering. There is nothing unusual about the geochemistry of this locality; if this explanation is valid, then ammoniojarosite may be more common than is recognized, and with its low solubility, it may prove to be an important unrecognized reservoir of nitrogen in low-pH soils.

COLLECTING

Today Alum Cave Bluff is within a national park; therefore, collecting at the locality is *not* freely allowed. Unauthorized collecting may result in Federal prosecution. The samples used in this study were obtained under a collecting permit for scientific study.

Conditions at Alum Cave Bluff are favorable for the deposition of these salts, but not uniquely so. Similar suites of (in particular) iron sulfates can be found beneath overhangs where pyritic rocks have weathered. Such minerals have rarely been studied or collected because they are usually unattractive in hand specimen; moreover, some have a tendency to deliquesce, dehydrate, oxidize, and generally self-destruct (e.g., melanterite, epsomite, coquimbite, mirabilite). Nevertheless, in my experience many of them can be found in good microcrystals, and several are attractively colored; they warrant more attention from collectors than they have heretofore received.

Preservation of even fragile species is possible with ingenuity. One method is to coat the crystals with an impermeable transparent film. However, it is difficult to do this with micromounts while retaining the original pristine appearance; high magnification tends to make the coating obvious. Controlling the temperature and humidity is important; keep good melanterite and epsomite in the refrigerator with an open pan of water (*not* sealed with a lid—some specimens absorbed water from an overly-humid atmosphere and dissolve!).

Although collecting at Alum Cave Bluff is restricted, as explained above, many of the minerals can be found easily at similar localities elsewhere. Honaker and Miller (1954) mentioned water-soluble minerals at localities in east Tennessee (including Alum Cave Bluff) and western North Carolina, and reported several species. Excellent voltaite, metavoltine, melanterite, copiapite and halotrichite, have been found at outcrops of pyritic Chattanooga Shale in Kentucky and at roadcuts exposing pyritic coal beds in Kentucky, Tennessee, and Pennsylvania (e.g., Coskren, 1981). A similar Canadian occurrence of soluble sulfates was described by Zodrow and McCandlish (1978) and Zodrow *et al.* (1979). An attraction of these mineral localities is the renewable nature of the resource: they can never be permanently depleted. Seek and ye shall find!

ACKNOWLEDGMENTS

Thanks for assistance over the course of twelve years are due to the administration of Great Smoky Mountains National Park, for permission to collect; to the University of Kentucky (Geology Department), for use of the X-ray diffraction unit; to Eastern Kentucky University, for the early SEM study of the slavikite; and to Otto Kopp and the University of Tennessee (Department of Geological Sciences), for use of a petrographic microscope. GeoMarine, Inc., provided encouragement and material assistance in the development of this paper. We are grateful to Donald Peacor for permission to use preliminary data on the new REE sulfates, now being studied by his group at the University of Michigan. George Robinson's curiosity about an obscure buffy powder and his willingness to pursue the matter led to his identification of the destinezite. The identification of ammoniojarosite was confirmed by Fred Wicks. S. Y. Lee provided an analysis of the slavikite. Kathleen Manscill, Museum Curator for Great Smoky Mountains National Park, was very helpful in tracing the mining history. Elise White provided a constructive criticism of the text.

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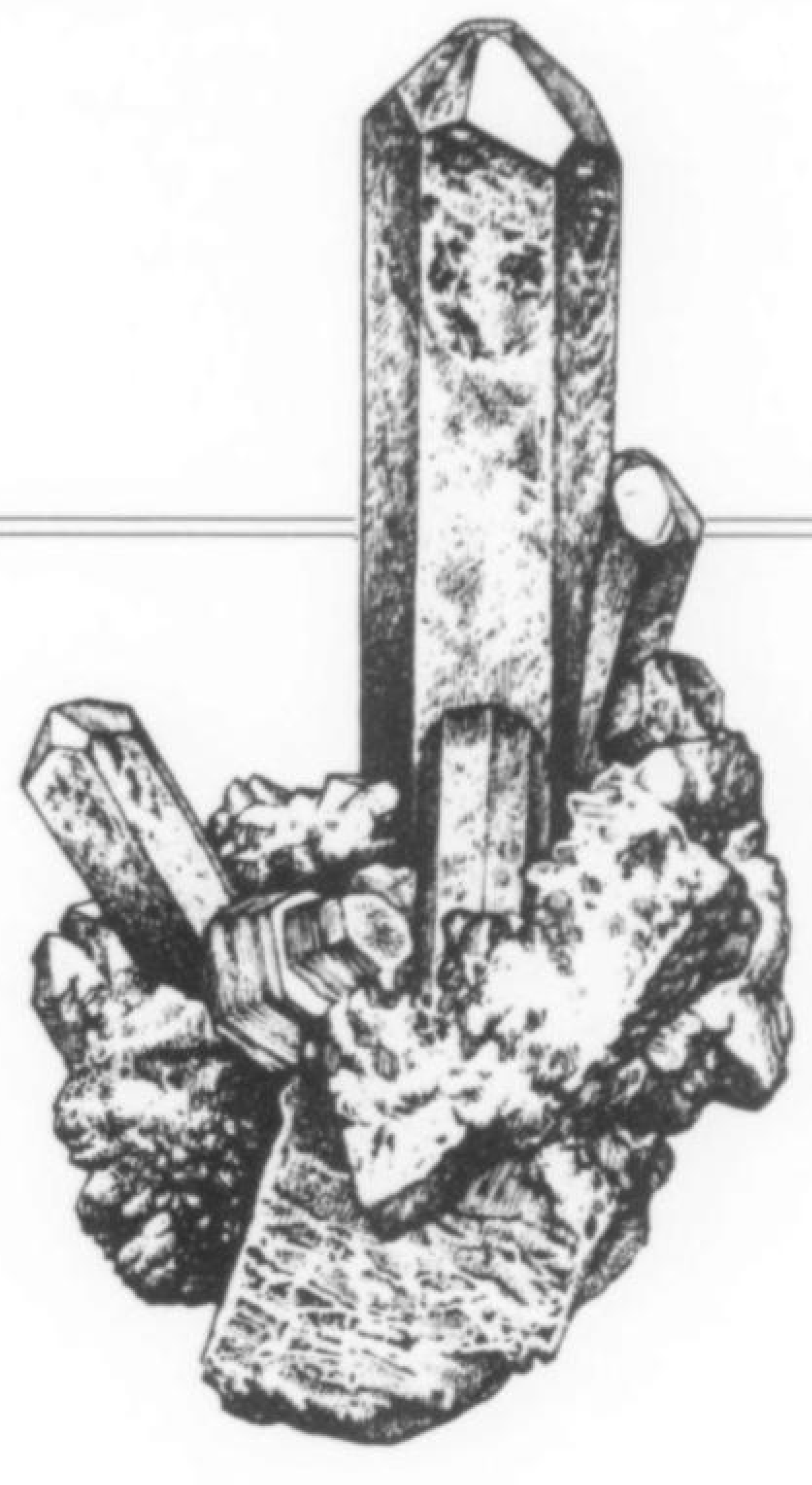
THE MINERALS *of* BRAZIL



INTRODUCTION

The 21st Annual Tucson Mineralogical Symposium, sponsored by the Friends of Mineralogy, the Tucson Gem and Mineral Society, and the Mineralogical Society of America, was held in conjunction with the 46th Tucson Gem and Mineral Show on Saturday, February 12, 2000. *Minerals of Brazil* were the feature of the 2000 Tucson Show and were the subject of the 2000 mineral symposium.

Brazil is the fifth largest country in the world and the largest in South America, comprising nearly half of that continent's area. Perhaps it should not be surprising that Brazil has yielded considerable mineralogical wealth. What never fails to amaze, however, are the beauty and significance of many of the wonderful minerals and gems that it continues to produce.

Many of the papers presented at the symposium dealt with minerals from the pegmatites and related rocks in the state of Minas Gerais. Several others, however, dealt with deposits in other parts of the country, from amethyst deposits in the far south to pegmatites and skarns in the northeast.

This symposium was dedicated to Dr. Richard V. Gaines (1917–1999), whose love affair with minerals spanned more than seven decades. Richard's work on tantalum and beryllium deposits took him to pegmatites all over the world. He made 22 trips to Brazil, studying deposits and collecting minerals and friends. Several of the contributors to this year's symposium were good friends of Richard's, and other friends of his responded to the call for papers, saying that they wished they had something to offer. We all owe Richard a debt of gratitude for a life dedicated to enriching the professional and amateur mineralogical community in many ways.

Anthony R. Kampf and William B. Simmons

Minas Gerais—Past and Present

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The name Minas Gerais means "General Mines" in Portuguese, and with good reason. By the mid-18th century, the area around Diamantina was the largest producer of diamonds in the world and that around Ouro Preto was Brazil's largest producer of gold. The wonderful baroque architecture of both of these cities dates to this period.

Though the first pegmatite gem discoveries date even earlier, the majority of these deposits were first exploited for strategic minerals such as muscovite, quartz and beryl during WWI and especially WWII. Gemstones and gem mineral specimens remained largely by-products of this mining for many years, but, thanks to adventurous mineralogists and mineral dealers, including such Americans as Allan Caplan, Martin Ehrmann, Fred Pough and Dick Gaines, our knowledge of and access to Brazilian minerals has blossomed during the last six decades.

In recent years, the search for gems has reached into the extensive metamorphic terrain of Minas Gerais, netting rich deposits of emerald, alexandrite and more. Today, Minas Gerais stands out as one of the world's foremost producers of fine gems and minerals. For this, we are indebted to the Brazilian gem spirit epitomized by the industrious *garimpeiro* and guided by enlightened entrepreneurs such as Jules Sauer, Kahlil Elawar and Agenor Tavares.

Throughout the gem centers of Belo Horizonte, Ouro Preto, Governador Valadares, Teófilo Otoni and Araçuai, and in the backcountry, one senses a continuing excitement as the search for gem treasures goes on.

The Eastern Brazilian Pegmatite Province

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The Eastern Brazilian Pegmatite Province (EBPP) encompasses the entire state of Minas Gerais and also the southern part of the state of Bahia, the western margin of the state of Espirito Santo and the northern part of the state of Rio de Janeiro (Paiva, 1946; Putzer, 1976; Correia Neves *et al.*, 1986). In northeastern Brazil, the much smaller pegmatite province of Borborema is also known (Beurlen, 1995; Da Silva *et al.*, 1995).

Around 1500, rumors of very rich occurrences of precious stones, which included green tourmaline mistaken for emerald, induced the Portuguese *bandeirantes* (pioneers/adventurers) to follow the great rivers Rio Doce, io São Mateus, and Rio Jequitinhonha upstream to the center of what is now the state of Minas Gerais and the EBPP to search for the fabulous "Serra das Esmeraldas." The pegmatites of the EBPP are found (in many cases concordant) in Proterozoic mica-schists and amphibolites. The major pegmatite-forming event took place between 525 and 545 million years ago (Brasiliano event) and is coeval with the intrusion of important post-tectonic granites. Mining of the pegmatites in the EBPP is mostly done by *garimpeiros* (diggers) in search of precious stones (multicolored tourmaline, aquamarine, topaz, brasilianite, kunzite), and subordinately for cassiterite, columbite-tantalite, spodumene and pollucite. Most of the gem material is traded in the cities of Teófilo Otoni and Governador Valadares. Pegmatite mining is strongly influenced not only by market prices, but also by the climate. In periods of drought and consequent bad crop production, dormant *garimpos* (diggings) are reactivated as a source of income. In some of the larger pegmatites, feldspar is produced by small mining enterprises in partly mechanized open pits and sold to the Brazilian ceramic and glass industry.

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The History of Brazilian Pegmatite Gem Mining

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The northeastern portion of the state of Minas Gerais, Brazil, contains the world's greatest concentration of complex granitic pegmatites, which are especially noted for the production of gem beryl, chrysoberyl, topaz, tourmaline, garnet, kunzite and brazilianite. Because of the geologic environment of these deposits, this region of Brazil is the greatest laboratory workshop in the world for the study of pegmatite geology, crystallography and gemology.

Pegmatite gemstones were first found in this region over 400 years ago; in the last 100 years, Brazil has produced most of the world's supply of these superb gem crystals and cut gemstones. Early exploration was spurred by a quest for gold and precious stones, but the search for and exploitation of deposits was hampered by the coastal mountains and dense interior forests. A key factor in the modern development of gem mining was the colonization of the Teófilo Otoni area by German immigrants during the latter half of the 19th century and by Lebanese during the first part of the 20th century.

Although mining today continues to involve simple methods, larger operations often employ modern equipment. An appreciation for the geologic processes involved in pegmatite formation and subsequent weathering to form secondary deposits is important in considering the range of mining methods necessary for the harvesting of gem crystals.

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The Development and Present Geologic Environment of the Most Important Gem Crystal Mines of Minas Gerais, Brazil

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Minas Gerais has produced the world's finest examples of gem tourmaline (red, blue, green and multicolored), gem beryl (aquamarine, green, heliodor and morganite), topaz (blue and imperial), kunzite, brazilianite, hydroxyl herderite and rose quartz.

The primary sources of these gems are pegmatites that were emplaced approximately 490 million years ago. Subsequent periods of uplift and erosion under largely tropical climatic conditions have exposed the primary pegmatites deposits and have produced several types and variations of secondary deposits referred to as eluvial, colluvial and alluvial.

Among the primary pegmatitic deposits, several of the most famous are the Cruzeiro, Xanda, Jonas, Corrego do Urucum, Golconda and Medina mines. The secondary deposits include the Barra de Salinas, Ouro Fino, Santa Rosa, Morro Redondo, Frade, and Hematita mines.

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The Famous Tourmaline, Aquamarine and Kunzite Mines of Minas Gerais, Brazil, and Their Greatest Gem Crystals

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Thirteen of the more prominent gem mines in Minas Gerais have produced many of the greatest gem crystal specimens of tourmaline, aquamarine and kunzite. These include the primary deposits at Cruzeiro, Jonas, Xanda, Limoeiro, Golconda, Medina and Corrego do Urucum and the secondary deposits at Barra de Salinas, Ouro Fino, Santa Rosa, Morro Redondo, Frade and the Pioneer mine in the Tres Barros region near Marambaia.

Beyond an appreciation of the mineralogy and geology of these deposits, it is particularly rewarding to consider the exciting personal stories of the miners and mine owners who were the movers and shakers in the greatest gem crystal discoveries at these mines. For gem crystal lovers, these stories are part of the mystique and lore that make mineral collecting so exciting.

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The Chemical Composition of Biotite from Granitic Pegmatites and from Metamorphic Emerald Deposits in the Eastern Brazilian Pegmatite Province

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In the discussion of the genesis of "schist-type" emerald deposits, two theories are still under debate. The first explains the formation of emerald by exometasomatism, i.e. a reaction during the intrusion of Be-rich pegmatitic melts and fluids with chromium-rich rocks (Fersman, 1929). The second theory relates the crystallization of emerald to a regional, and in most cases multistage reaction between already-emplaced Be-rich and alkali-rich rocks, predominantly pegmatites, with chromium-rich ultrabasic rocks (Gundmann and Morteani, 1989; Nwe and Morteani, 1993). Emerald usually occurs in biotitites which formed at the border of pegmatite bodies. However, biotite-rich zones are also found in the border zone of pegmatites without emerald mineralization. Biotite in biotitites reaches a grain-size of up to 2 cm, whereas biotite crystals found in the border zone of pegmatites are up to 1.5 m in length.

In the Eastern Brazilian Pegmatite Province (Paiva, 1946; Correia Neves *et al.*, 1986), many pegmatites with conspicuous biotite megacrysts in border zones lacking emerald mineralization as well as biotitites that do include emerald mineralization are found. A typical example of a schist-type emerald mineralization is the Capoeirana mine, Nova Era (Minas Gerais). Biotite from this emerald deposit shows markedly lower Fe/(Fe+Mg) ratios and typically higher F contents compared to biotite from emerald-barren pegmatites. These differences in composition indicate that the two biotite types crystallized under different physiochemical conditions. This suggests biotite and emerald formation occurred during a regional metamorphic event with the metasomatic formation of a blackwall-zoning. However, biotite in the border zone of the many emerald-barren pegmatites formed from the pegmatitic melts in a single stage at the very beginning of the pegmatite crystallization with limited, if any, contribution from the country rocks.

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Descriptive Mineralogy of Inclusions in Some Faceted Gem Topaz from Brazil

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Seven faceted topaz specimens were analyzed using optical microscopy, X-ray fluorescence, and scanning electron microscopy to determine the identity and geologic significance of their mineral inclusions. Although these stones are from Brazil, their exact source is uncertain. The challenge of the study was to conduct these studies without damaging any of the lovely gemstones.

All seven gems contain inclusions visible to the naked eye; some have several varieties of mineral inclusions. An alphabetic list follows: ilmenorutile, limonite, muscovite, rutile, struverite, tourmaline, zinnwaldite, and three unknown phases. Scanning electron microscopy was performed on three of the stones that fortuitously have mineral inclusions which intersect topaz facets. This enables the confirmation of ilmenorutile, struverite, zinnwaldite, and indicated the need for further study in order to characterize the three unknown phases.

An original hypothesis that these stones originated from Virgem de Lapa was weakened because no recognizable lepidolite was observed in any of the specimens. However, a pegmatitic origin from elsewhere in Brazil is probable, as suggested by the suite of minerals represented as inclusions within the topaz and literature reports from Brazilian mineral occurrences containing these species (Adusumilli, 1991).

Recent Mineral Occurrences from Northeastern Brazil

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Some significant mineral finds have recently been made in the states of Paraíba and Rio Grande do Norte, Brazil. Red and black manganotantalites, many of which are penetration twins weighing up to 600 gms, were found at the Alto do Giz 11 and Alto des Furnas pegmatites, Equador, Rio Grande do Norte. The Alto des Furnas pegmatite also produced manganotantalite pseudomorphs after simpsonite up to 5 cm across. Some of these pseudomorphs are quite sharp and are intergrown with red, needle-like manganotantalite of a different color. Apatite showing distinct color zoning from yellow cores to blue or green rims was found in crystals up to 12 cm in length from the Alto Feio pegmatite, Paraíba. A new species of the microlite group (fluornatromicrolite) was reported from the Alto Quixaba pegmatite, Quixaba, Frei Martinho Township, Paraíba, as bright green crystals up to 3 cm in size associated with manganotantalite, blue elbaite, lepidolite, and cleavelandite. Spectacular, perfectly crystallized cognac-colored herderites up to 12 cm in length were found in a pocket at the Alto des Flechas pegmatite near Pedra Lavrada, Paraíba. Alto des Flechas has also produced fine gem-quality golden beryl in the past. Amethyst scepters with milky quartz bases up to 5 cm in length were found near Santana de Mangeiras, Paraíba. Most scepters are single crystals, but some matrix specimens were recovered.

Brazilian Hematite

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Brazil produces world-class, beautifully crystallized specimens of hematite occurring as reniform, specular, bladed iron "roses" and martite (hematite pseudomorph after magnetite). Less than one percent of Brazil's vast hematite resources produce crystals, but hematite, as an iron ore, is critically important to Brazil and to industry worldwide.

Brumado, Bahia, is known for its spectacular, sharp, hexagonal flat plates or tabular crystals. Botryoidal or reniform hematite is best known from Cumbria, England, though comparable specimens are also found in Minas Gerais. Bladed aggregates of hematite crystals dubbed iron "roses" from Ouro Preto, Minas Gerais, are equal to those from the Alpine clefts of St. Gotthard and Binnatal, Switzerland.

Twin peaks, Millard County, Utah, is one of the most frequently mentioned localities for hematite, variety martite, though the octahedral "crystals" found in Ouro Preto, Minas Gerais, are equally noteworthy. One hematite assemblage that is probably better known from Brazil than from other localities is oriented epitaxial rutile crystals on hematite. Novo Horizonte, Bahia, is the premier locality for this stunning combination, which is often enhanced by being encased in quartz crystals. Similar associations of hematite and rutile are also found in Switzerland.

Metamorphosed, foliated, specular hematite is very common in Brazil, especially in Minas Gerais. The same type of material can be found at Forge Hill, Hawley, Massachusetts. "Rainbow" hematite from Minas Gerais seems to have no counterpart in the rest of the world. The thin film of aluminum phosphate on foliated, specular hematite is quite different from the iridescent hematite, variety turgite, found at Graves Mountain, Georgia, and Covington, Virginia.

Itabira, one of the world's richest iron ore deposits, contains an estimated 15 billion tons of high-grade ore. Over 2 million tons of iron ore are produced each year. Of Brazilian mineral exports, iron ore has been the most continuously and conspicuously successful, making Brazil the second largest producer of iron ore in the world.

Minerals of the Brumado Magnesite Deposits, Serra das Éguas, Bahia, Brazil

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The magnesite occurrence at Brumado in the Serra das Éguas district is one of the largest deposits of magnesite in the world and is host to a surprisingly species-rich mineral assemblage. The

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*Deceased

mineralized areas at Brumado are located in a syncline composed of a lower unit of dolomite marble and an upper unit of quartzite. These rocks are underlain by Precambrian gneisses, schists and amphibolites. The magnesite and associated minerals appear to be related to the intrusion of nearby igneous dikes. The igneous activity produced hydrothermal fluids that interacted with the preexisting dolomite to form magnesite. Fracture fillings of coarse-grained magnesite, quartz, alumino-silicates and other late-stage minerals also appear to be related to the same episode of hydrothermal mineralization (Bodenlos, 1954; Cassedanne and Cassedanne, 1978).

In addition to superb crystals of magnesite, dolomite and quartz, many well-crystallized accessory minerals occur at Brumado. Uvite and dravite are found as sharp crystals up to 5 cm in length with colors that range from black to green to red. Topaz occurs as fine yellow, orange, pink or purple crystals up to several cm in length. Sellaite, considered to be the world's finest, is found as crystals that exceed 5 cm in size. Hematite has been found in large, spectacular crystals in excess of 10 cm. The finest zeunerite/metazeunerite are found in crystals up to 3.5 cm on an edge. Associated with these are druses of sklodowskite that equal any previously known examples. Beryl (varieties aquamarine and emerald) has been found in crystals to several centimeters in length and was one of the minerals mined from the area before the discovery of the magnesite lode. Other minerals encountered at Brumado include: talc, goyazite, svanbergite, chernotive-(Y), wakefieldite-(Y), florencite-(Ce), anhydrite, celestite, barite and numerous other species. Brumado certainly ranks among one of the most fascinating mineral-producing areas in the world and continues to supply collectors with superb specimens.

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Composition and Color of Uvite-Dravite Tourmaline from Brumado, Bahia, Brazil

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Deep red and green tourmalines of several crystal habits are some of the most striking minerals found in the Brumado magnesite deposits. Microprobe and other analyses reported by Modreski and others (1997) show the relation of chemistry to color in these uvite to dravite tourmalines.

The most iron-rich tourmaline, containing 4 to 7 weight % Fe as FeO, is fibrous to prismatic, dark brown to reddish brown dravite. The proportion of ferric iron has not been measured but the presence of some Fe^{3+} probably accounts for the dark red and brown colors. Deep red, platy to tabular crystals, very characteristic of Brumado, are sodic uvite which contains 3 to 4 weight % FeO. Tabular, green to brown, discoidal crystals flattened on *c* are uvite to calcic dravite, with the uvite tending to be darker and brownish colored and higher in iron (0.2–1.3 weight % FeO versus ≤0.1 weight % FeO in pale green dravite). Prismatic, dominantly green but color-zoned crystals range from uvite through dravite to Na-deficient, Al-enriched dravite. Colorless tourmaline at the acicular terminations of some prismatic clusters is low-iron "Mg-foitite" in which the X-site is dominantly vacant.

Manganese content is negligible, 0.0 to 0.02 weight % MnO. Chromium content is low, 0.00 to 0.14 weight % Cr_2O_3, Cr^{3+} could play a minor role in the green color of some specimens. Titanium content is variable, 0.00 to 0.78 weight % TiO_2, but shows no consistent relation to color. Vanadium (V^{3+}) appears to be responsible for emerald-green zones in some tourmalines. Most analyzed specimens contain between 0.00 to 0.66 weight % V_2O_3, but one unusually dark greenish black tourmaline has an uvite core containing approximately 7 weight % V_2O_3 (SEM-EDS analysis) surrounded by a paler green (~1 weight % V_2O_3) dravite rim.

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Cuprian Elbaite from the Bocheiron Zinho Pegmatite, Paraíba, Brazil

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"Paraíba tourmaline" is a name used in the gem trade to describe elbaite tourmalines from the state of Paraíba in northeastern Brazil that occur in unusually vivid shades of blue and green. The first major production of this uniquely colored elbaite came from Mina da Batalha near the village of São Jose da Batalha in 1988 (Bank *et al.*, 1990; Fritsch *et al.*, 1990). Several mines in the area have since produced the distinctive blue-green elbaite, including the Mina Bocheiron Zinho. At this location, tourmalines exhibit prominent color zonation: some possess pink cores and deep blue rims whereas others have blue cores with several outer zones of purple, green, blue, or gray.

Electron microprobe analyses and X-ray mapping show the relationship between chemical composition and color. Analyzed tourmalines contain as much as 1.4 weight % CuO in the blue zones, 0.2 weight % MnO in the pale pink cores, and 1.2 weight % FeO in the deep green rims. Deep green tourmalines from the footwall portion of the pegmatite hold as much as 3.0 weight % FeO and many contain thin, platy inclusions of native copper.

The tourmaline chemistry indicates that Fe concentration was initially low, followed by fluctuations in Mn and Cu, with a late Fe and Mn enrichment that produced the dark green rims. The enrichment of copper in the pegmatites of this region is exceptional; massive chalcocite occurs as large pods up to 20 cm across in the footwall of the Bocheiron Zinho. The enrichment may be the result of contamination of the pegmatite-generating magma by copper-rich country rock. The presence of native copper, Fe^{2+}, and

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*Deceased 1998

chalcocite suggests that the conditions of formation were moderately reducing in a low to moderate pH environment.

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REE Contents of Calcite and Gypsum from Amethyst Geodes in the Lava Flows of the Serra Geral Formation (Alto Uruguai, Southern Brazil)

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Amethyst geodes which occur in the regions surrounding Irai (Alto Uruguai) are the most important source for "Brazilian amethyst." The geodes are principally found in tholeiitic basalt flows in the Lower Cretaceous Serra Geral Formation. Most geodes show a characteristic zoning, with an outer rim of agate, including rare carbonate crystals overgrown on amethyst crystals. A second generation of euhedral calcite crystals (up to 10 cm) may be found on the amethyst crystals. In the "Garimpo da Testa" mine geodes are filled by anhedral, very coarse-grained gypsum instead of calcite. The geode contact with the country rock is delimited by a very fine-grained celadonite rim. Celadonite Rb/Sr ages (107±1 to 81±1 Ma) are younger than the basalts (127 to 137 Ma) (Innocent *et al.*, 1997).

The different calcite generations show three types of REE patterns (1) patterns with a continuous decrease in the normalized REE contents from the LREE to the HREE, with a marked to strong negative Eu anomaly and no Ce anomaly; (2) patterns with a continuous decrease in the normalized REE contents from the LREE to the HREE without an Eu anomaly but with a negative Ce anomaly; and (3) patterns with or without any anomaly but with slightly to markedly increased HREE contents in comparison to the LREE contents.

The negative Ce anomaly, the reddening of the "basalto portador" (country rock), and the presence of gypsum suggest that calcite crystallized under oxidizing conditions. The negative Eu anomaly is most likely inherited from the basaltic country rocks. Calcite with increased HREE contents probably crystallized from fluids which dissolved an older calcite generation. Based on age determinations for celadonite along with the low crystallization temperature of amethyst and calcite (30–50 °C; Juchem *et al.*, 1999), it appears likely that the geodes were filled with amethyst, calcite and gypsum well after the crystallization and complete cooling of the lavas by fluids of meteoric origin.

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Skarn Minerals from Rio Grande Do Norte State, Brazil

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The Ca-skarns (tactites) in Rio Grande do Norte State host scheelite orebodies that have been exploited intermittently since World War II. Recently, renewed mining activity has resulted in discoveries of additional ore material as well as fine mineral specimens. The old mine Malhada dos Angicos near Parelhas, a deep underground mine, is an example of this revitalization.

The Ca-skarns are found as beds, layers and lenses in Mg-rich crystalline limestones that form saddle reefs. They are part of a late Proterozoid metasedimentary sequence with underlying paragneisses and overlying biotite schists intercalated in feldspathized (K-feldspar porphyroblasts) paragneisses. The origin of the skarn mineralization has been attributed to metasomatism with later high-temperature hydrothermal effects, succeeded by secondary alterations at lower temperature.

Actinolite, garnet (andradite, grossularite and almandine), calcite (fine scalenohedral crystals in vugs), diopside (salite), epidote, hematite, hornblende, magnetite, quartz, biotite, muscovite, phlogopite, microcline, tremolite, vesuvianite and zoisite occur as major minerals in the skarn bodies. In addition to the W and Mo ore minerals scheelite (occurring in white, gray, black, and yellow crystals) and molybdenite, the skarns also host a number of interesting accessory minerals including: allanite, anhydrite, chalcocite, chalcopyrite, clinohumite, covellite, ilmenite, bismuthinite, marcasite, pyrite, pyrrhotite and scapolite. Late-stage minerals and alteration products include: heulandite, analcime, aragonite, azurite (rare), bismoclite(?), bismutite, chabazite, chrysocolla, cuprite, goethite, gypsum, huntite, malachite, molybdite, nontronite, stilbite and thulite.

Among these mineral species, a large number afford fine collector specimens.

Gem Pegmatites of the Ural Mountains, Russia

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The most famous gem pegmatites of Russia are those of the central Ural Mountains. The northern region is comprised of miarolitic pegmatites carrying topaz, beryl and tourmaline in the western endo and exocontact of the Mursinka-Adui intrusions and the desilicated pegmatites surrounded by emerald-alexandrite-phenakite mineralization.

The Alabashka pegmatite field is known for fine blue topaz, associated with smoky quartz and albite, from the Mokrusha mine. Heliodor crystals come from the Golodnij, Tyazhitsnitza, Mokrusha, Staraja Mylnitsa, Starzewa Jama and the Kazionnitsa mines. One of the finest specimens ever recovered from the Staraja Mylnitsa mine (found in 1991) consisted of two parallel-growth crystals (8 x 1.5 cm) on an albite ball. From 1990–1993 the Kazionnitsa mine produced topaz and world-class green beryl and gem heliodor. The finest specimens include a flawless electric-green crystal measuring 7 x 3 cm and a color-changing transparent, blue-green crystal 15.6 x 5 cm perched on two flat smoky quartz crystals.

Gem pegmatites northwest of the village of Mursinka are enclosed in serpentinite and contain miaroles with colored tourmaline. The pegmatites to the west and southwest contain green and yellow beryl and yellow or light blue topaz. The Sarapulka and Shaitanka pegmatites are irregular thin veins containing rubellite and rhodizite in the west and green and blue aquamarines in the east. The Adui field has produced two major pockets of large green aquamarine.

The Takovaja district schists have produced large quantities of large emerald, alexandrite and phenakite specimens since 1830. In 1995 mining of an open pit at the site of the old Sretensky mine resumed, but production was low and mining has now ceased. Rare recent specimens are combinations of phenakite/emerald and alexandrite/emerald.

The southern region around Miass in the Ilmen Mountains was heavily mined during the 19th century and produced primarily clear topaz crystals (3–4 kg) of complex forms and rare green beryls (to 25 cm) associated with amazonite in miarolitic pegmatites.

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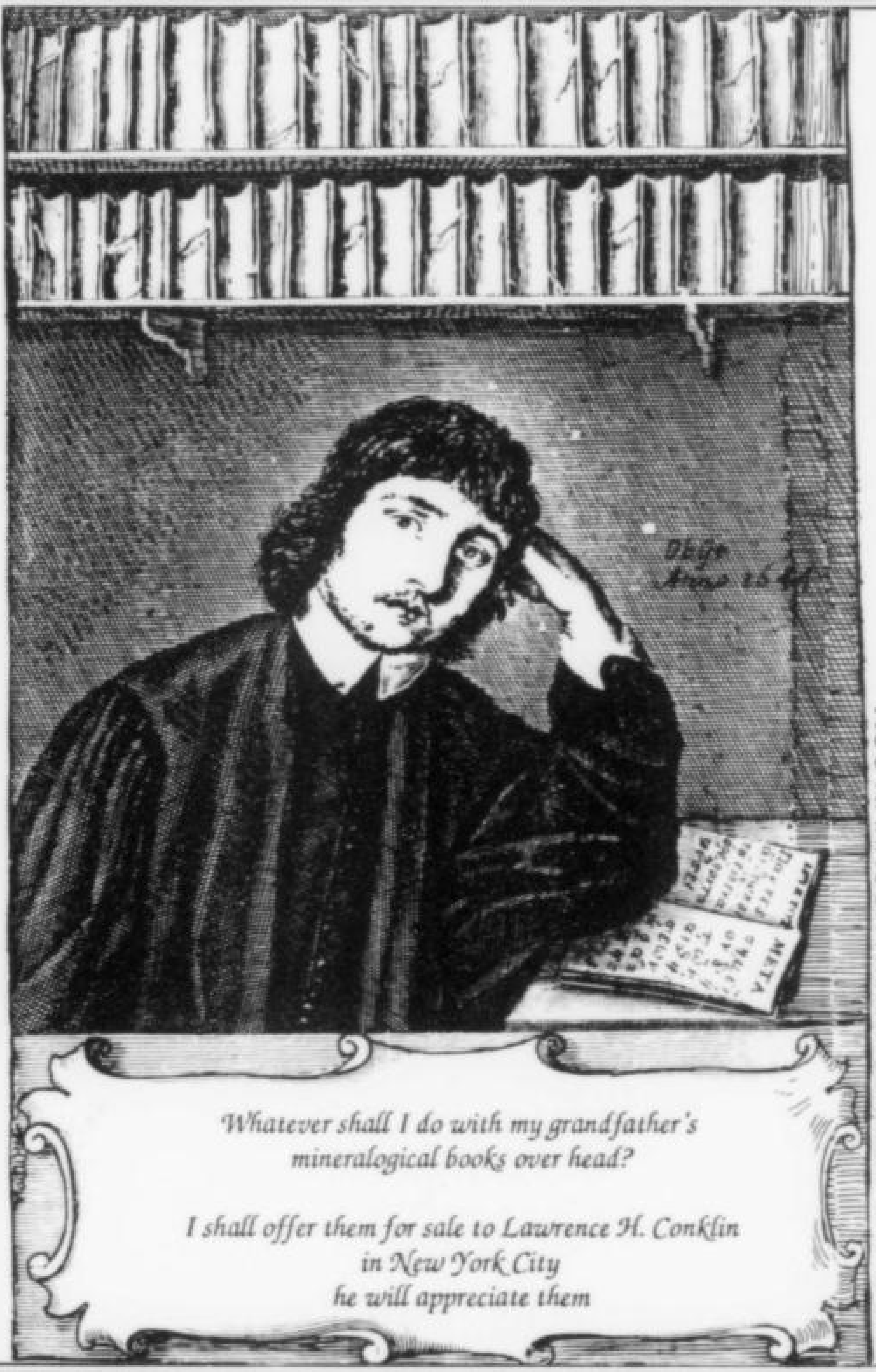

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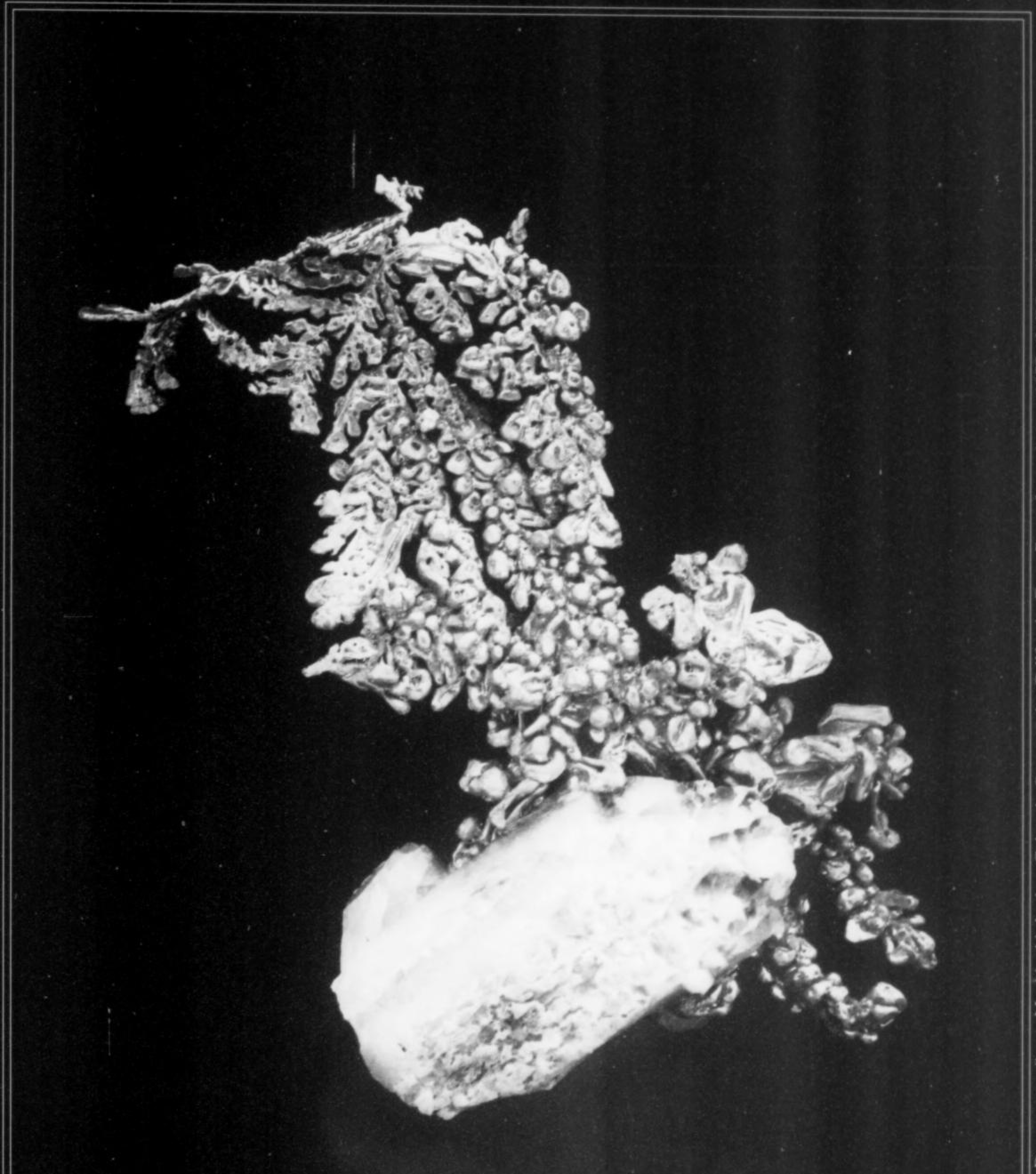

GOLD on quartz, 8 cm, Mockingbird mine, Colorado Quartz vein, California. From Bryan Lees, August 1977. (Jeff Scovil photo)

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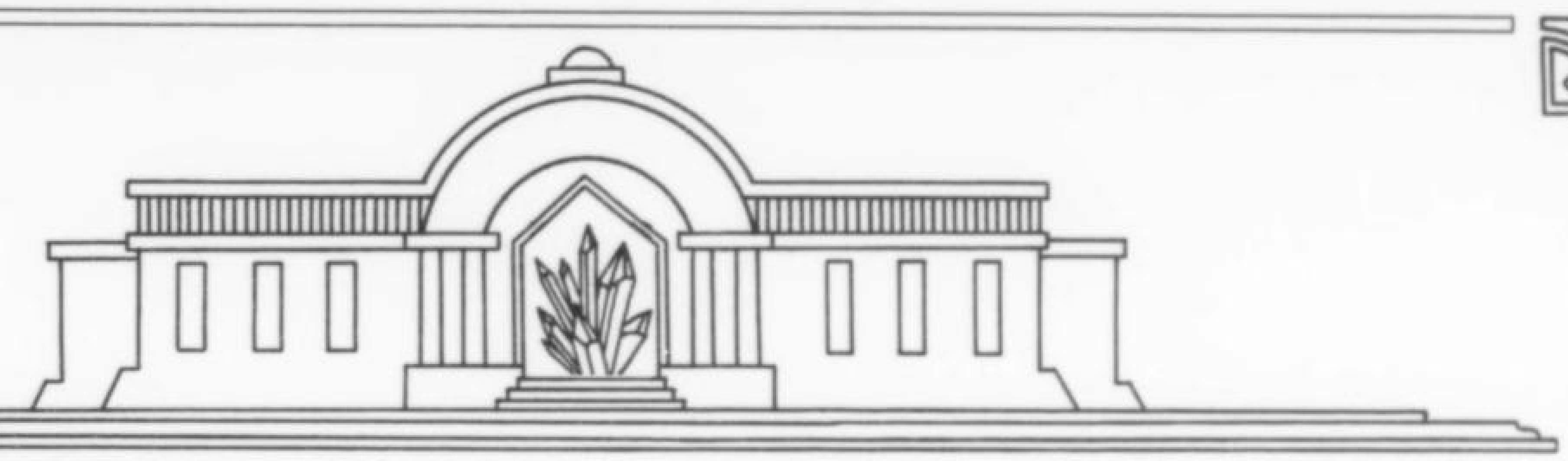

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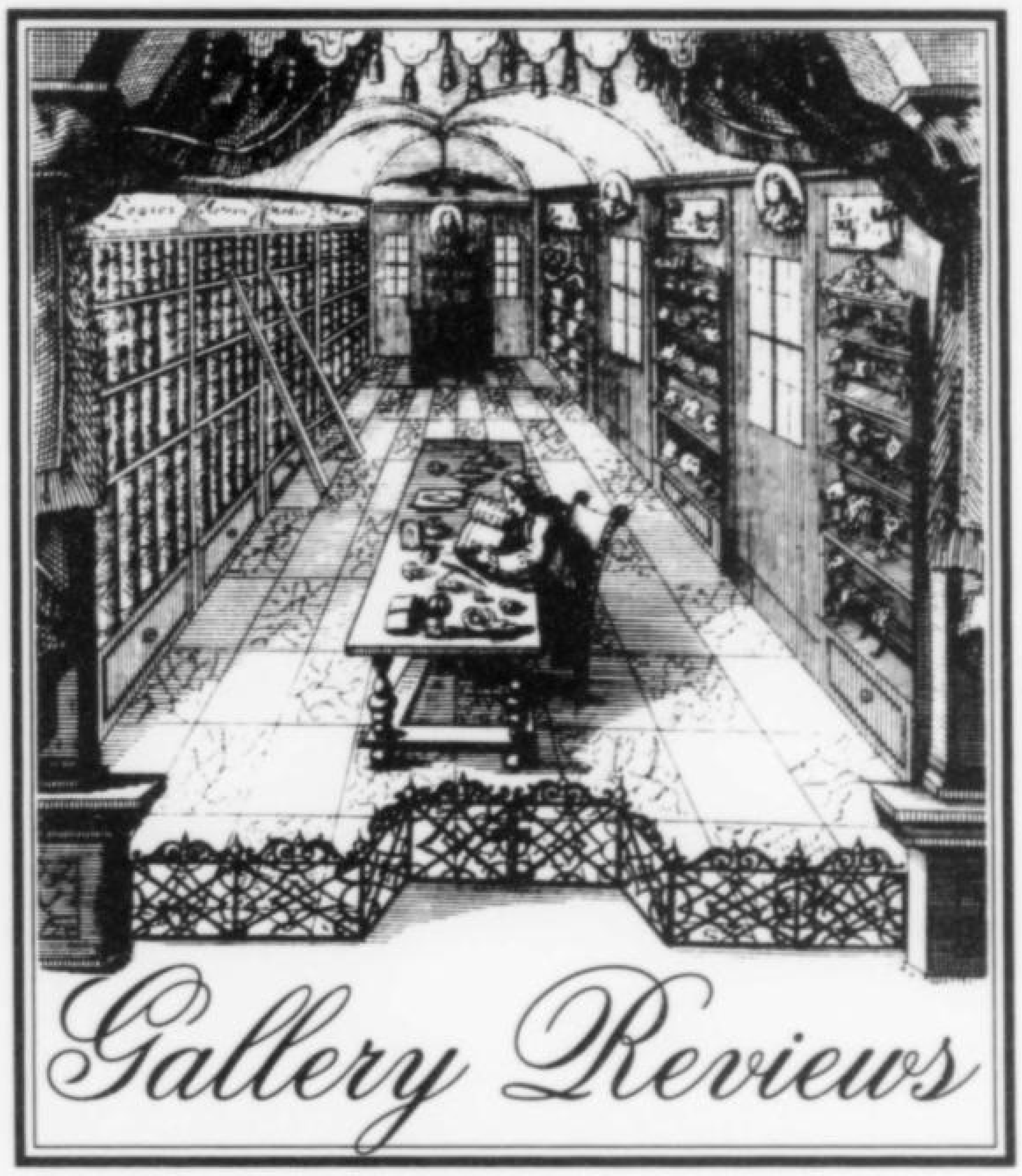

Factors in Assessing a Museum Gallery

by **John S. White**

Everyone will look at a mineral/gem gallery differently. Each person has preconceptions as to what should be found there, and those preconceptions greatly influence assessment of the success of the gallery. Mineral collectors do not enter such a gallery without expectations, as they tend to know something of the museum's reputation beforehand. Nevertheless, they must be ever mindful of the fact that the exhibits are not created and designed solely for mineral collectors; they are, or should be, designed primarily for the general public. This does not mean that collectors cannot expect to find very satisfying items in the exhibit. Whatever the theme (if there is one), a museum will always try to illustrate that theme with the very best examples in its collections. Therefore, the biggest and wealthiest collections will exhibit the finest specimens; the poorer ones will have to be satisfied with less, even if the themes of their exhibits are similar.

WHAT OF "THEMES"?

Formerly, virtually all major museums (and these were usually institutionally connected, as in universities), followed the same basic configuration with respect to the arrangement and content of their mineral exhibition. There were introductory cases illustrating what minerals are, illustrating most of the physical properties of minerals, something about crystallography, and perhaps something about how minerals are studied and identified. Inevitably this would be followed by a "systematic" arrangement of the minerals (native elements, sulfides, sulfosalts, oxides, etc.), with perhaps some token exhibits devoted to mineral paragenesis; that is, how some of the more common minerals formed. This arrangement has been standard throughout much of the history of museums and no one ever seemed to challenge the wisdom or assess the effectiveness of doing it this way.

Those museums affiliated with universities may have been better able to justify this approach because their principal focus was, after all, education; but it is not so easy to excuse municipal and state museums for adopting the same "classical" format. It would be difficult, if not impossible, to demonstrate that this arrangement has been at all effective in increasing the general public's appreciation of minerals and what they represent. This is hardly surprising since a "systematic" arrangement is usually based upon mineral chemistry, and the public's familiarity with chemistry ranks well below that of nuclear physics. It is ludicrous to think that this approach could have been successful—if, in fact, anyone even thought about it at all. Fortunately, people today have been thinking about it and, as a result, systematic mineral exhibits are almost a thing of the past, at least in the more progressive museums.

ALTERNATIVES TO "SYSTEMATICS"

It is all well and good to recognize that "systematics" is inscrutable to the general public. What, then, should museums offer in place of systematics? The extreme opposite would be simply placing on exhibit all of the best specimens in the collection, randomly, without any sort of ordering whatsoever. This, in my view, is just as bad an idea as is a systematic arrangement. It would be a shame to display fine mineral specimens without at least putting forth a small effort to help make them better understood. I am not advocating a textbook approach, with text-heavy labels that few visitors will take the time to read and comprehend. This doesn't work either. Suffice it to say, however, there are alternatives and some can be very effective. Detailing these is not the purpose of this discourse, so that will have to be saved for another discussion.

Assuming, therefore, that a museum has chosen an overall display theme, it is the task of the reviewer to identify that theme and then judge how effectively it has been carried out by use of the exhibits. A simple task, really: does it work well or not? Do the specimens support the message? Can it be expected that most visitors will depart with some knowledge of minerals, based upon the effectiveness of the overall display?

THE ATMOSPHERE

A good review need not begin by addressing the theme (or the absence of one!) that has been adopted by the museum. One's first impression of a mineral/gem gallery is the atmosphere which it creates and that might very well be the most appropriate topic with which to start a review. Is the gallery more or less dark and uninviting, or is it bright and welcoming? Do the various exhibit cases draw the viewer to them or must one impel oneself forward to view each successive case? Is there sufficient ambient lighting in the hall or does one have to wait for a short while for the eyes to accommodate themselves to extreme darkness?

JUDGING THE CASES

Are the cases brightly lit but without excessive glare? Are the minerals within well-lighted so that all of their special features can be fully appreciated? Do strong shadows interfere with the way in which the crystals and gems are exhibited? Do shadows or glare interfere with reading the labels?

The labels are critically important. Essential data, in my opinion, should include mineral name, relationships to a group (if appropriate), varietal name (if appropriate, and it should be secondary to the species name), some chemistry and crystallography, and, of course, locality. A state name is not a locality; this information should be as detailed as possible. Are the labels positioned such that there is no ambiguity with respect to which specimen goes with which label? Where labels are grouped on a single panel, is it clear which information applies to which specimen? Does every specimen have a label? If the label gives the name of a secondary mineral, is it clear which is the primary one?

Lighting of the labels is as important as lighting the specimens. Do the lights reflect off of the labels, creating an annoying glare which makes them difficult to read? Is the size of the type adequate? Is the typeface a reader-friendly one? Dark type on a light background generally is far easier to read than light type on a dark background or medium-dark type on a similar, but lighter colored, background, especially if the latter is highly reflective.

CASE CONSTRUCTION

Are the cases designed so that small children, as well as adults, may see into them? Are they more or less sealed so that dust does not accumulate rapidly within them? Are the lights accessible for replacement, or are they within the cases so that the cases must be opened (thereby exposing the specimens to theft or damage) when replacing bulbs? What of maintenance?

All too often when a new gallery is opened it is only then discovered that frequent entry into the cases is required for bulb replacement, light realignment, and dust removal. At first this task is usually taken on by someone involved with the mineral collection, someone experienced in handling minerals and who is considered trustworthy. Inevitably, this task becomes a burden and is passed on to someone on the maintenance staff, at which point the minerals and gems are very much at risk, and the prospect of this work being done regularly as needed becomes less likely.

SOUND CONTROL

Is the gallery noisy? Do the sounds of visitors echo off the walls and create a background of clatter that is annoying? Are there videos and other modern devices all running continually that add to the general noise pollution?

MISCELLANEOUS

Are there films in little offset galleries within the mail gallery? Are their inter-active videos? If so, these need to be appraised as well. How long does each last? Can lots of users be accommodated at one time, if the hall is busy? Do they interfere with traffic flow? Could they perhaps be relocated somewhere else?

Finally, and I have yet to find this in any museum, is there a contact phone number or address provided within the gallery which one may use if one would like to make an inquiry about something seen there, unseen there, or would simply like more information about minerals?

John S. White
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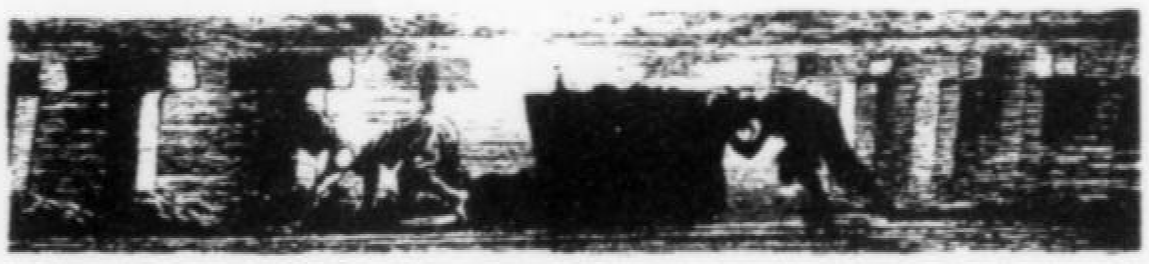

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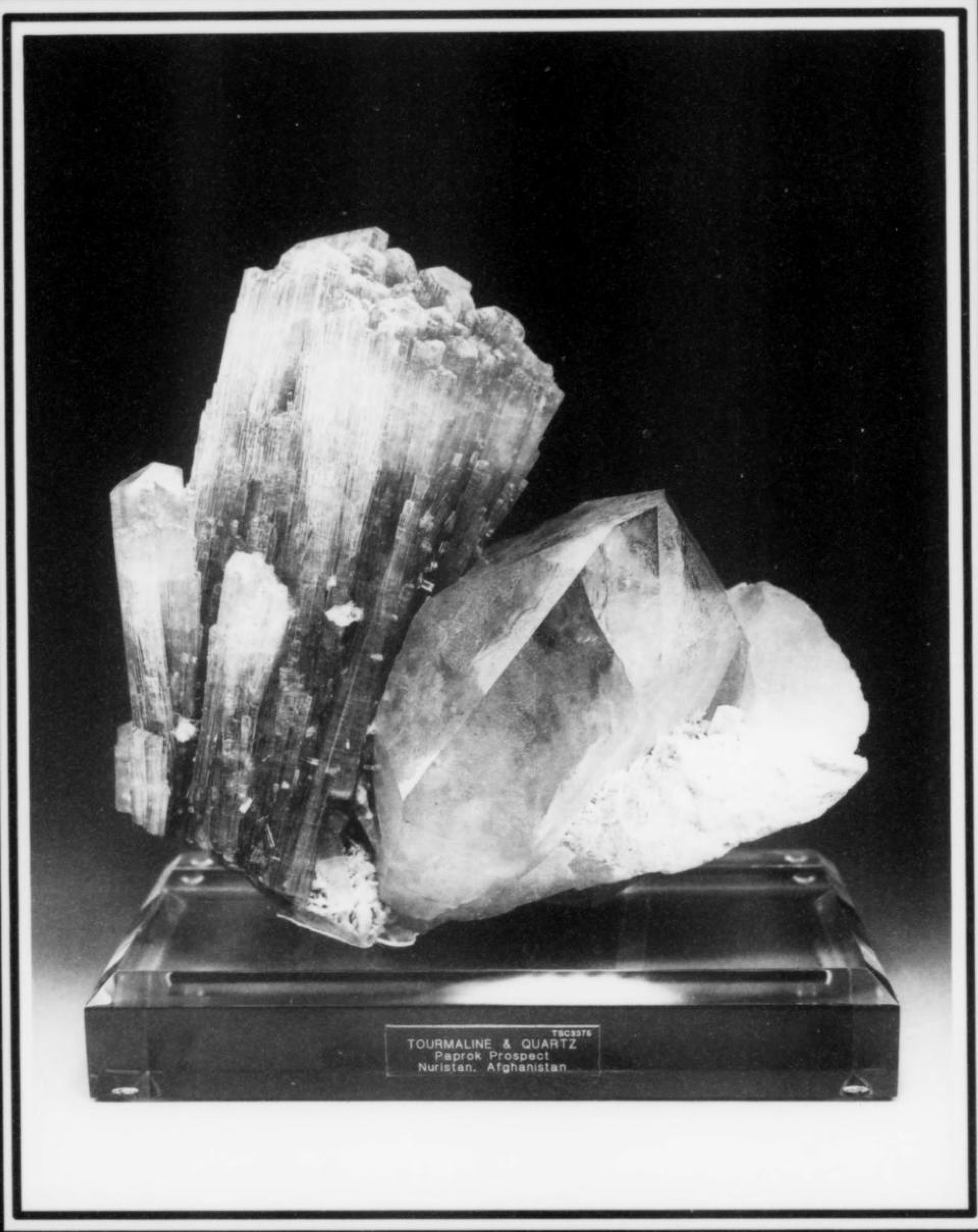


TOURMALINE ON ALBITE   PECH, AFGHANISTAN   15.5x12cm

PHOTO BY TIM STONE

What's New

in Minerals

Munich Show 1999

by **Jeff Scovil**

[October 28–31]

Munich is a great place to be in the Fall—the leaves are turning, great food, seeing old friends and wonderful minerals and it's a lot cooler than Phoenix. Europe's largest, most prestigious show was held at the new exhibit halls that have replaced the old airport. The facilities are much more spacious than the old Messegelaende, and there actually is plenty of parking. The only problem is the distance from hotels and restaurants, but since the subway now reaches all the way to the new halls, that is not much of a problem.

The dual theme in '99 was *Twins and Ammonites*. The exhibits were very impressive as usual, with superb displays from major collectors and museums from around the world. The first thing you saw upon entering the mail hall was an ammonite about 4 feet in diameter with a model of what a live one would have looked like. Numerous cases full of coiled and straight cephalopods showed them in their great variety. There was even a salt water aquarium with two live nautiluses! The crystal twin displays included the obligatory Japan Law quartzes, penetration twinned fluorites from various localities, the gorgeous new "V" twinned Chinese calcites, chrysoberyls etc. etc. As usual, a mouth-watering feast for the eyes.

In addition to the familiar specimens from well known localities, there were a few new things to think about adding to our collections. L. G. Gemme of Italy had a single 15.3-cm long **aquamarine** from Serenji, Zambia. I am not familiar with this locality, but would like to know what else comes from this pegmatite.

Last spring at the Ste. Marie Show, topaz, schorl, smoky quartz and aquamarine showed up from a new locality in the Erongo Mountains of Namibia. Not much was available, but it seems that someone has been very busy since then. Clive Queit had a large selection of **schorls** as single crystals to 8 cm long and on a matrix of blocky feldspars. He also was selling some nice **aquamarines** as singles and clusters, sometimes on matrix. The color is a light blue, but very clean and sharp with crystals up to 4 cm long.

Both Riccardo Prato and *Jeff & Gloria's Minerals* had some fine **heliodor beryls** from Dos Barras, Padre Paraiso, Minas Gerais, Brazil. The gemmy, yellow crystals, which reached lengths of 16 cm, are unique because of their pale blue caps. At the 1998 Munich Show, *Superb Minerals* unveiled botryoidal, pale yellow-green **fluorites** from Mahodari, near Nasik, Maharashtra, India. The few he had were quickly snapped up by eager fluorite collectors. This year even more were available in larger sizes and also in shades of rusty orange. Most of the best were bought early on by *Ottens Mineralien*. In Hall B2, Russian dealer Golomolzin was selling some very nice green **fluorites** from the Kent Mountains, Kazakhstan. The octahedral crystals are up to 5 cm across on rusty quartz crystals. Most of these went early also, to Spanish dealer Luis Miguel Fernandez Burillo.

Italian dealer Lino Caserini showed me a fine lot of recently mined twinned **chrysoberyl** from West Ambtomdrasata, Madagascar. The crystals are up to 8 cm across, some with attached **schorl** crystals. Mathias Rheinlander of *Mikon* has some friends living in Namibia who have been collecting at the classic **jeremejevite** locality of Cape Cross, Mile 72, Namibia. There they collected jeremejevites up to 5 cm long, and some on a matrix of orthoclase crystals.

Several dealers were carrying beautiful **quartz** crystals from Dhading, Ganesh-Himal, Nepal. The locality is an alpine-type occurrence with a schist and gneiss matrix. The quartz crystals range from lustrous, gemmy prisms, many with a tessin habit, to those totally included by actinolite. Many are associated with pericline crystals which form fine plates of crystals. I saw one 2-cm yellow crystals of **fluorapatite** on matrix. The quartz is truly impressive with individuals reaching lengths of 18 cm, most on matrix.

Miguel Burillo also showed me a small lot of prismatic **hematite** crystals from Hormoz Island, Iran. They are vaguely reminiscent of the hematites that came out of the United Arab Emirates several years ago, except that the older crystals were scalenohedral. These new crystals are all loose with no associations and a maximum size of 4 cm.

I am sure that there were a few other things that were new, but I can't always make it to everyone's booth or get all the shots I would like to. Sometimes I think that cloning would be the answer, but then, there are some people who think that one of me if enough. Auf wiedersehen!

Pasadena Show 1999

by **Jeff Scovil**

[November 20–21]

The Pasadena Show has been reincarnated once again. After several years in partnership with Martin Zinn Productions as what was popularly known as the Pomona Show, the Mineralogical Society of Southern California has returned to its roots. Those roots are in the Pasadena Center in downtown Pasadena where the show was formerly held. Although not quite as spacious as the building at the Fairgrounds in Pomona, and with parking that had to be paid for, the old facility is more aesthetic and cozier.

The displays were quite impressive with an understandably proud emphasis on minerals of the region. Most of the specimens shown were from private collections and a few dealers, but the museums were not left out. Displays from the latter included the Natural History Museum of Los Angeles County and The Houston Museum of Natural Science. A number of fine talks were given, including a memorable one by John Sinkankas on pegmatites of Southern California, with numerous photos taken in the field going back as much as 40 years.

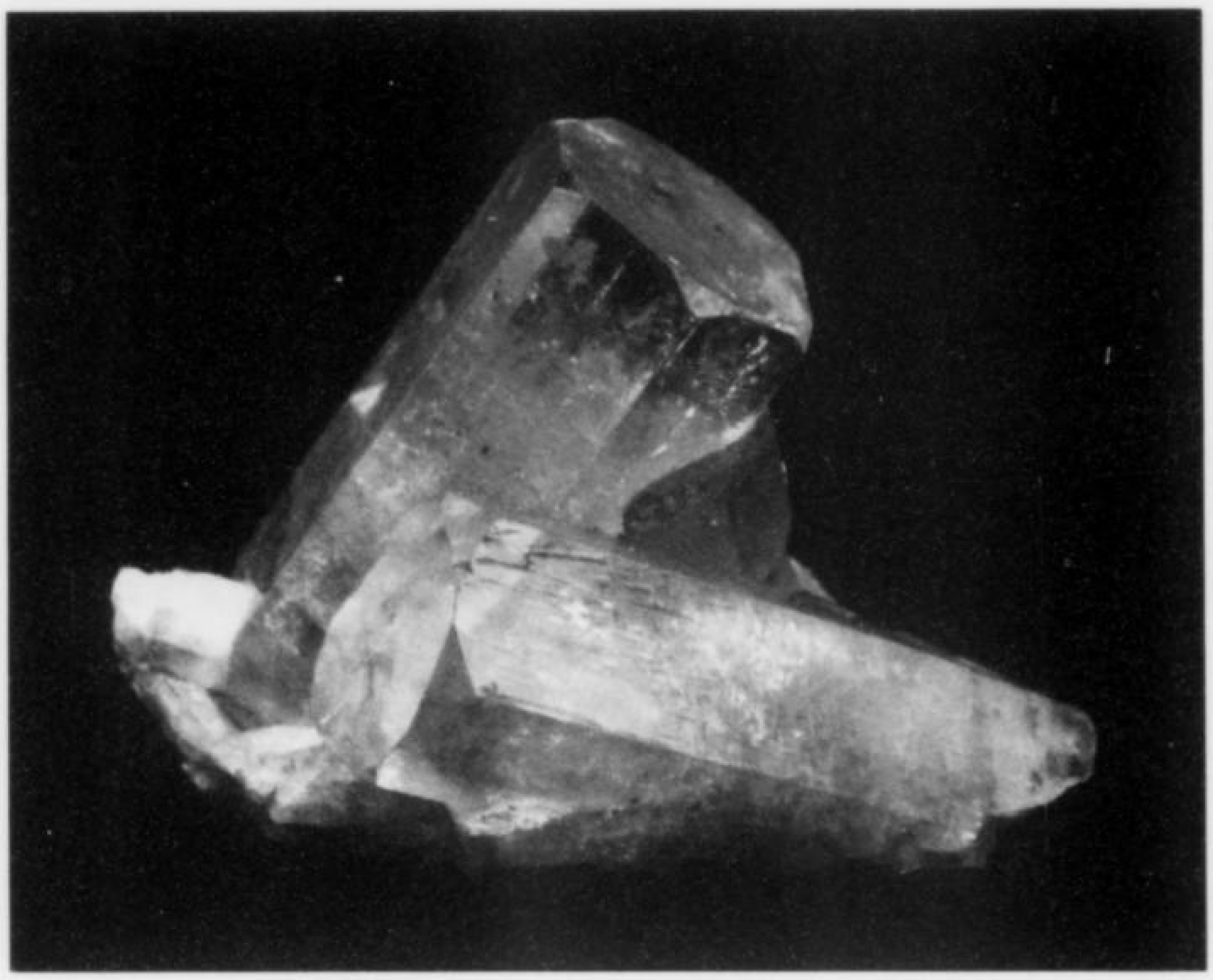


Figure 1. **Beryl, 3.8 cm, from the Erongo Mountains, Namibia. Clive Queit specimen; Scovil photo.**

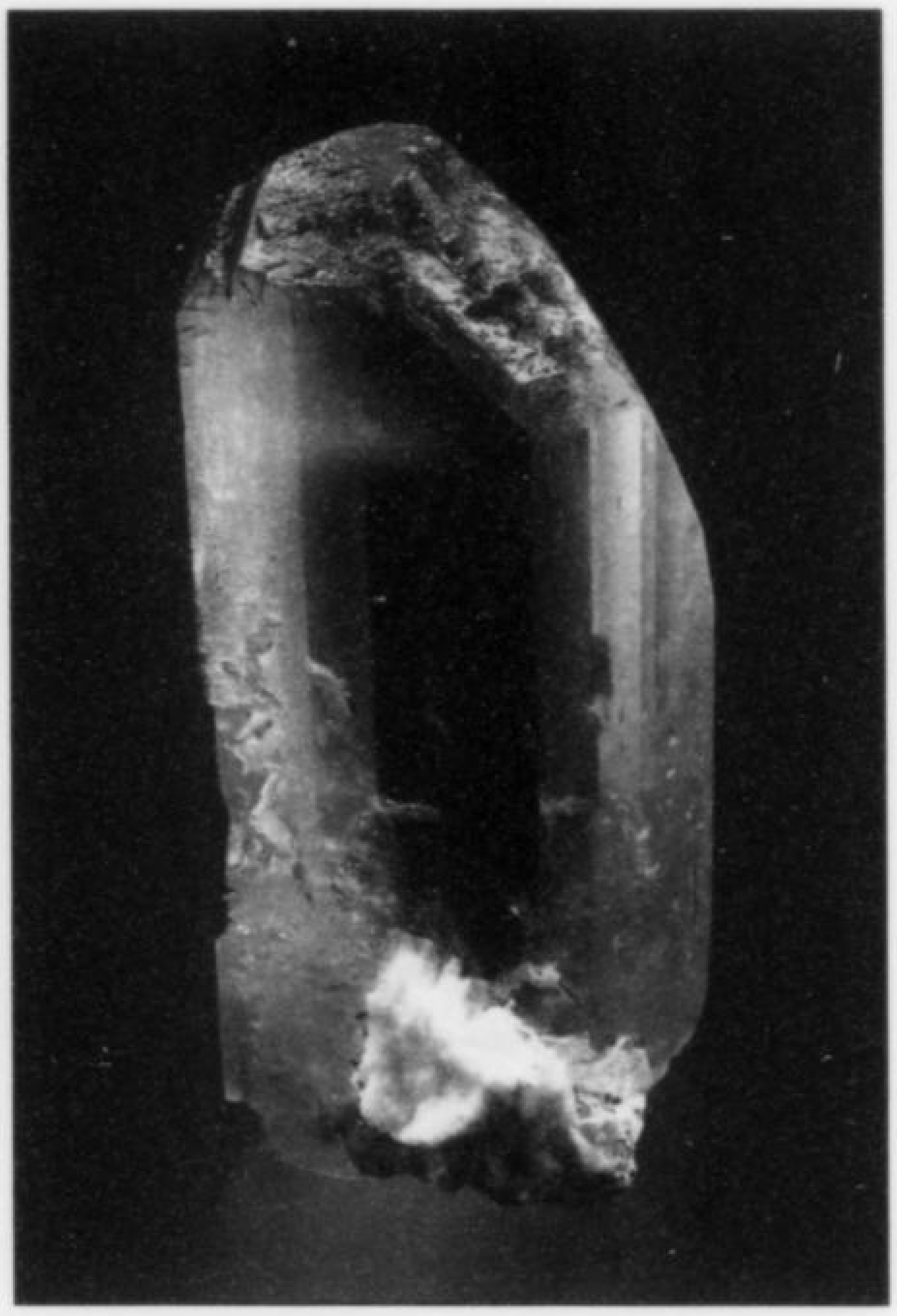


Figure 2. (right) **Topaz, 9.6 cm, from the Wah Tu Wah mine, Yunnan, China. Arkenstone specimen; Scovil photo.**

Figure 3. **Chrysoberyl twin, 5.1 cm, from West Ambotomdrasata, Madagascar. Lino Caserini specimen; Scovil photo.**

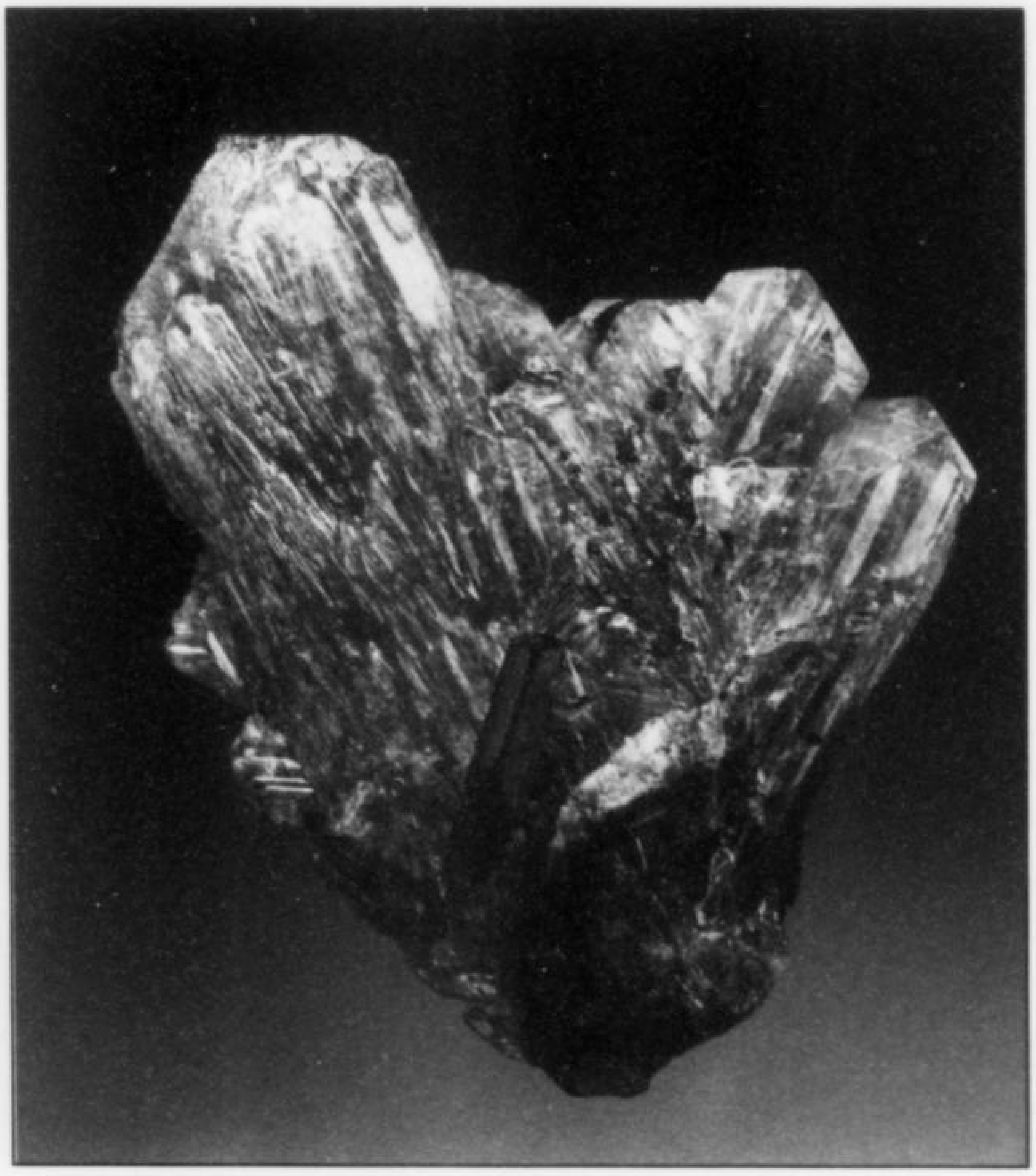
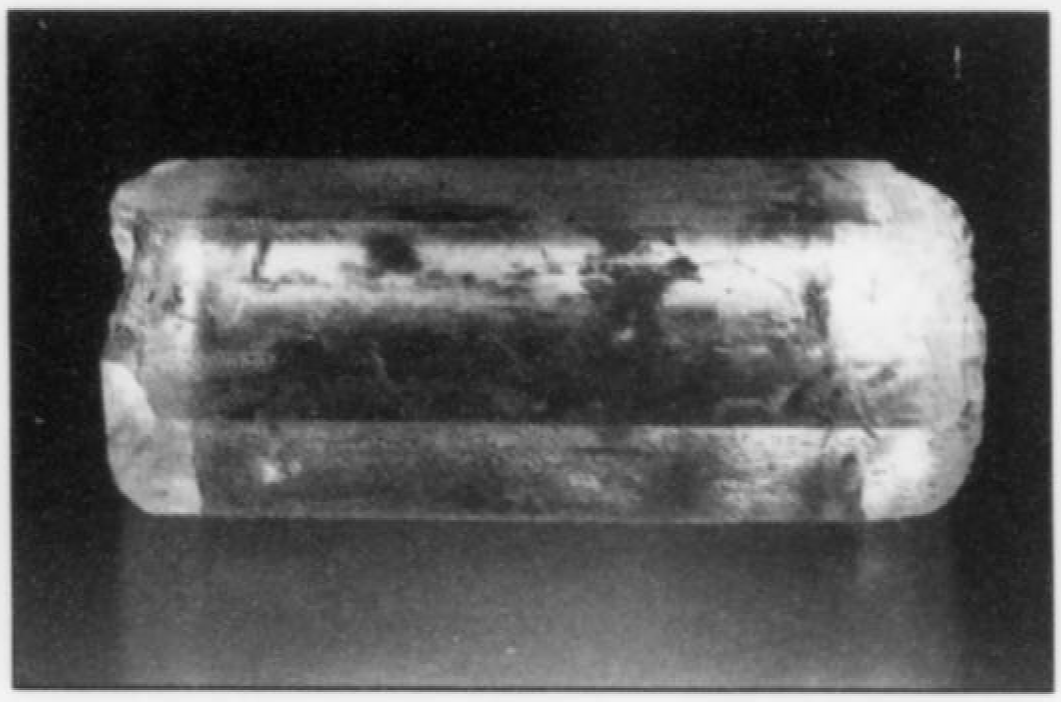


Figure 4. **Beryl,7.3 cm, from Dos Barras, Minas Gerais, Brazil. Riccardo Prato specimen; Scovil photo.**



Among the new items available at the show were **emeralds** from a new locality in Colombia—the La Pita mine, Borbur, Boyacá. The deep green beryls are quite similar to those we are familiar with from Muzo, except that the calcite crystals they occur with are a bit larger, a more uniform gray from included carbonaceous material, and have a pleasing, bright, oily luster. The specimens were brought up by Gonzalo Jara and were being sold at the booth of Cal Graeber and Leonard Himes.

One of the top field collecting dealers is John Seibel who was busy in October of 1999 at one of the old iron mines near Cedar City, Iron County, Utah. There, he hit one major pocket of octahedral **magnetite** crystals with very fine **fluorapatite** crystals perched thereon. The gemmy yellow crystals are dead ringers for the classic apatites from Cerro Mercado, Durango, Mexico, and are up to 10 cm long, though most are in the 3 to 4 cm range. Specimens up to 20 cm across were to be had, with up to seven

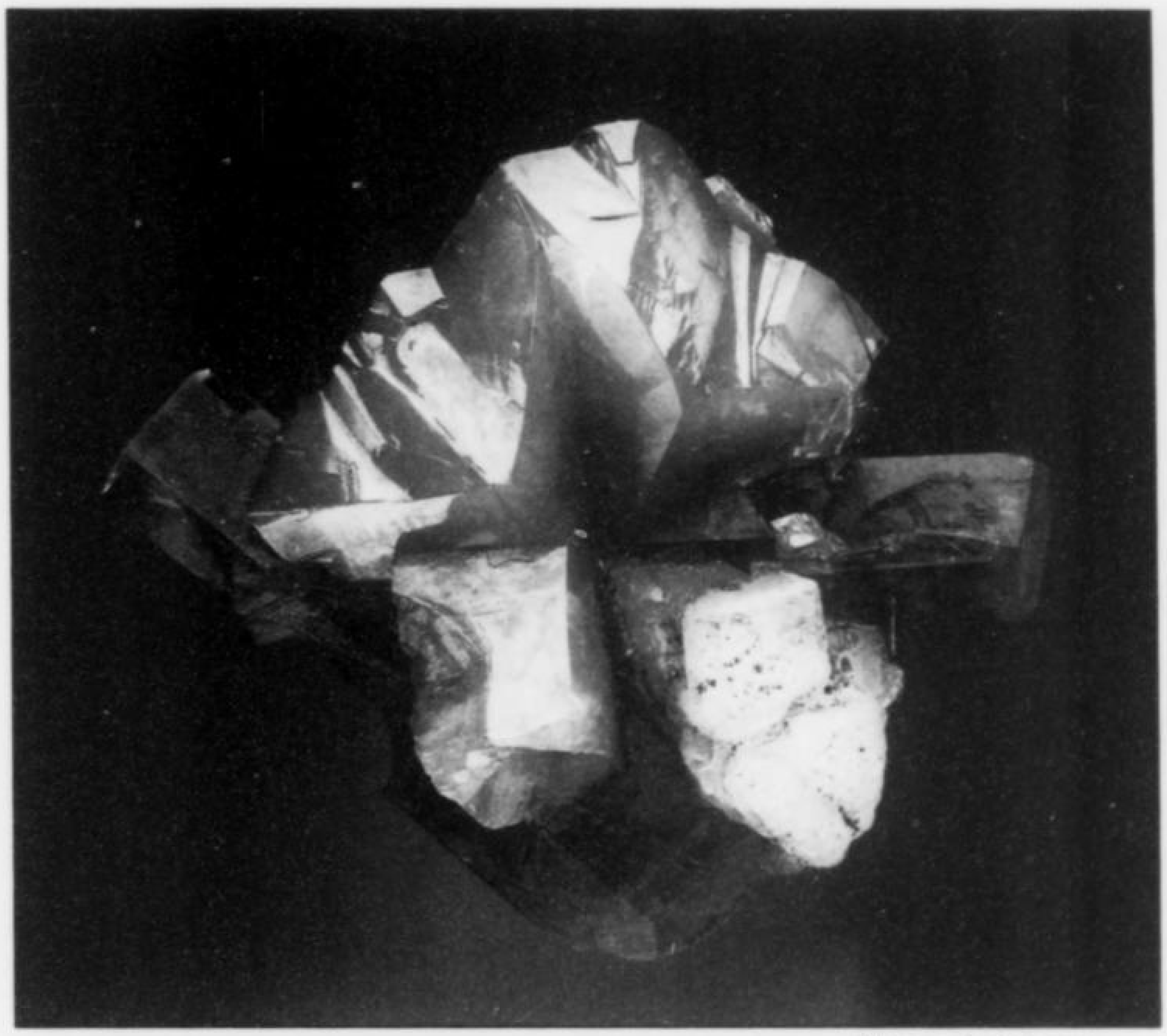
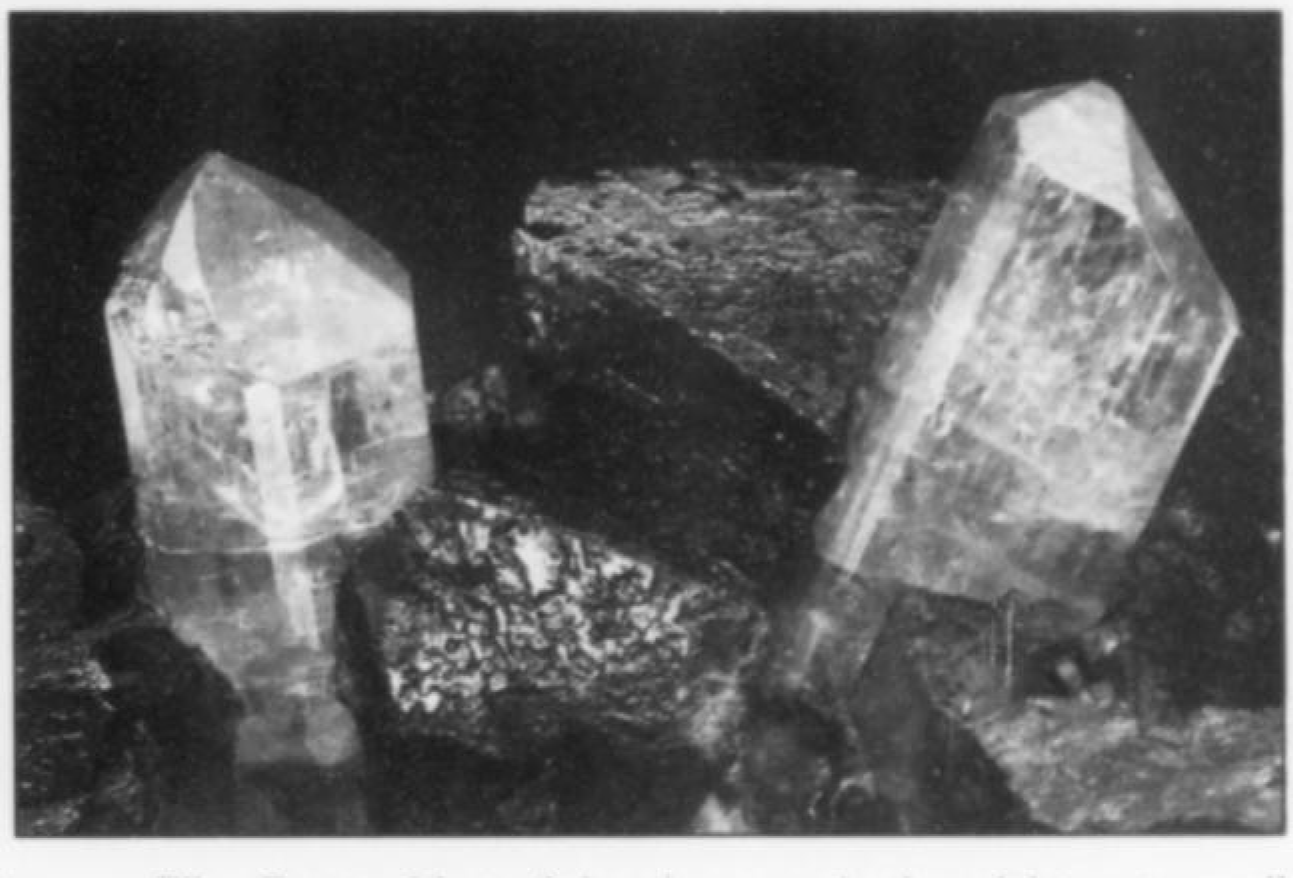


Figure 5. (above) **Emerald with calcite, 4.2 cm, from the La Pita mine, Boyacá, Colombia. Gonzalo Jara specimen; now in the L.A. Co. Museum collection. Scovil photo.**

Figure 6. **Hematite, 3.5 cm, Hormoz Island, Iran. Luis Burillo specimen; Scovil photo.**

Figure 7. **Jeremejevite crystal on orthoclase, 2.4 cm, from Cape Cross, Namibia. Mikon Mineralien specimen; Scovil photo.**

Figure 8. **Fluorapatite crystals to 1.3 cm wide, Cedar City, Iron County, Utah. Seibel Minerals specimen; Scovil photo.**



apatites sprinkled across the hills and valleys of the magnetite octahedra.

Rob Lavinsky of the Arkenstone had some very nice **topaz** crystals from Wah Tu Wah mine, Gaoli Gong Shan, Yunnan, China. The prismatic crystals are all loose, some with a bit of cleavelandite attached to their bases and of a color reminiscent of the Pakistani topaz, but with slightly different terminations. Several crystals show faint, multiple phantoms within and are up to 10 cm long.

Casey and Jane Jones of *Geoprime* have been busy in Nevada as usual, with a fine selection of **stibnites** from the Murray mine, Elko County. Most of the pieces are in the miniature to small cabinet size, often growing on drusy-quartz-covered, blocky **barite** crystals in a very aesthetic manner. They also were showing a case full of barites from a new locality—the Dee mine, in Elko County. This locality is right behind the already famous Miekle mine. The barites are the same beautiful yellow color but of a more prismatic, "chisel-shaped" habit. The crystals are also not quite as large, but still quite attractive and in clusters to 12 cm across.

Tim Sherburn has a fascination with the minerals of the British Isles and came up with some goodies from the Ton Mawr quarry, Cardiff, Wales. This is a quarry in limestone that is producing numerous pockets of **calcite** crystals of various habits made up of stacked, flattened rhombohedra. The crystals vary in color from white to yellow and various shades of orange and red, some of them showing twinning on the (0001). Most of the calcites are on matrix, with a few of the larger ones being loose, and ranging up to 9 cm in length.

Over all, the show was a fine one and I wish the MSSC good luck in the new/old show.

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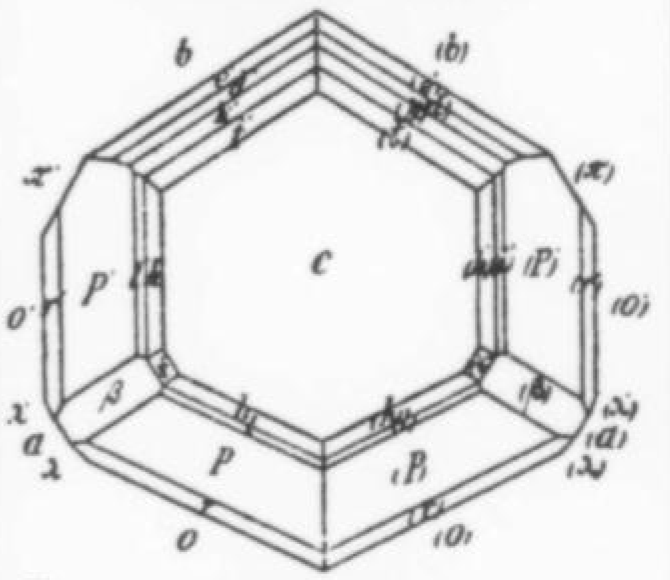
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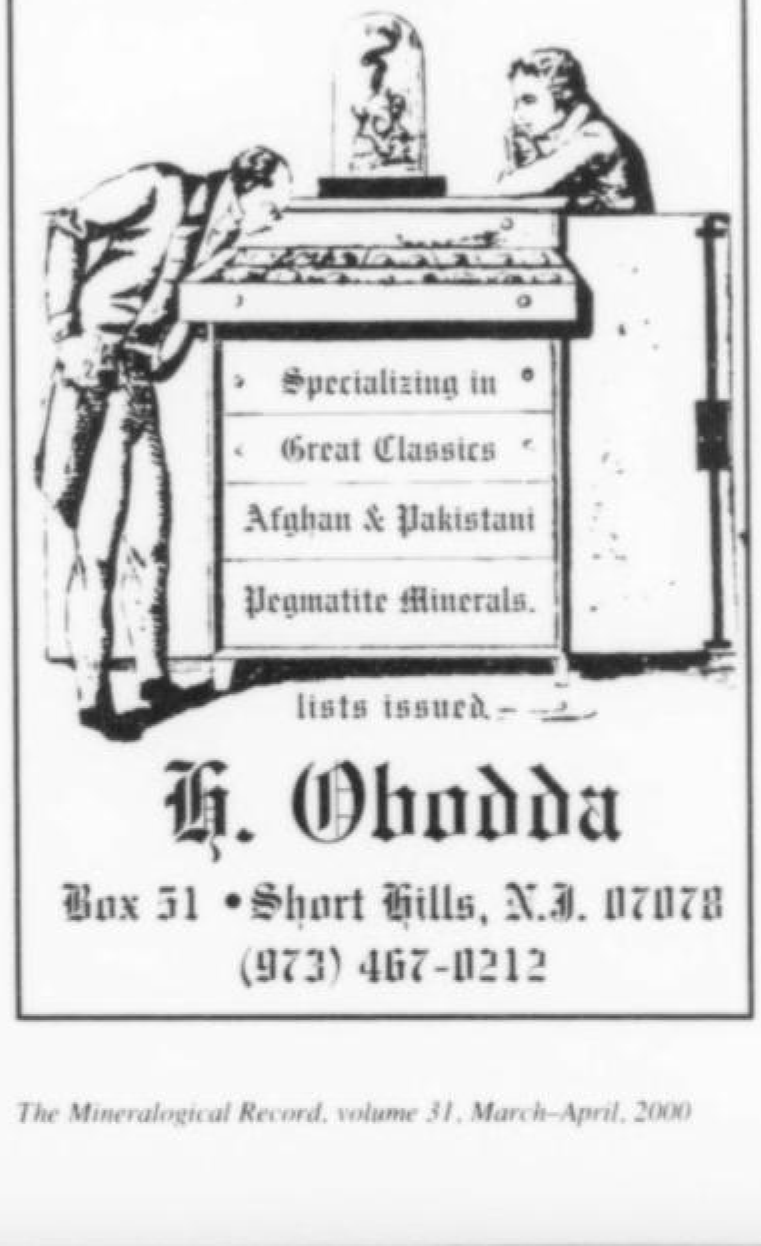
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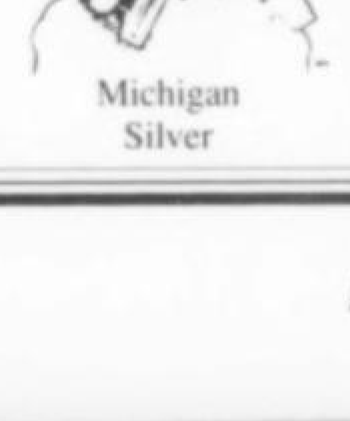
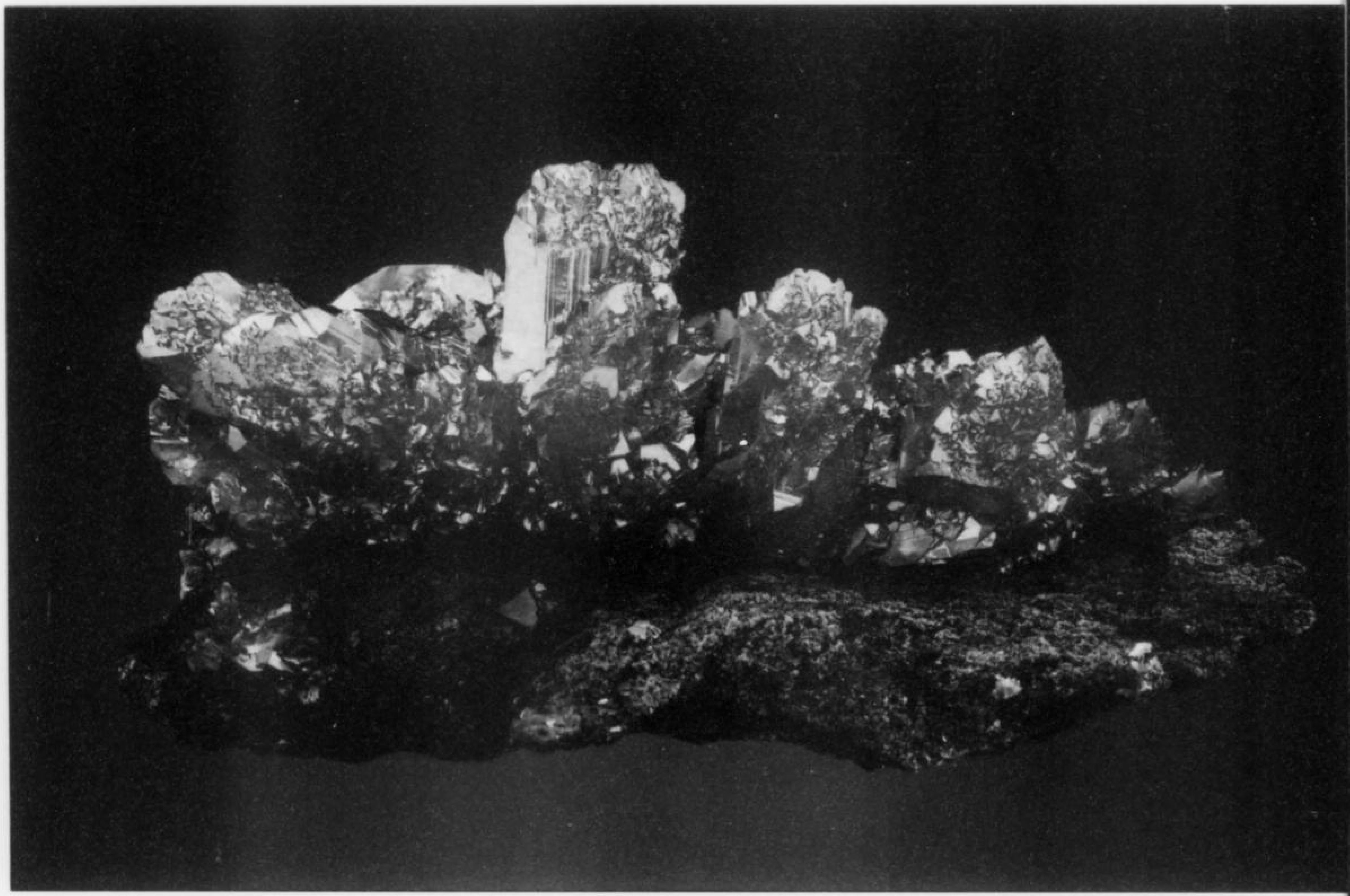


Orpiment, Twin Creeks Mine near Winnemucca, Nevada



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These fabulous specimens will be offered for the first time at the 2000 Tucson Gem and Mineral Show.

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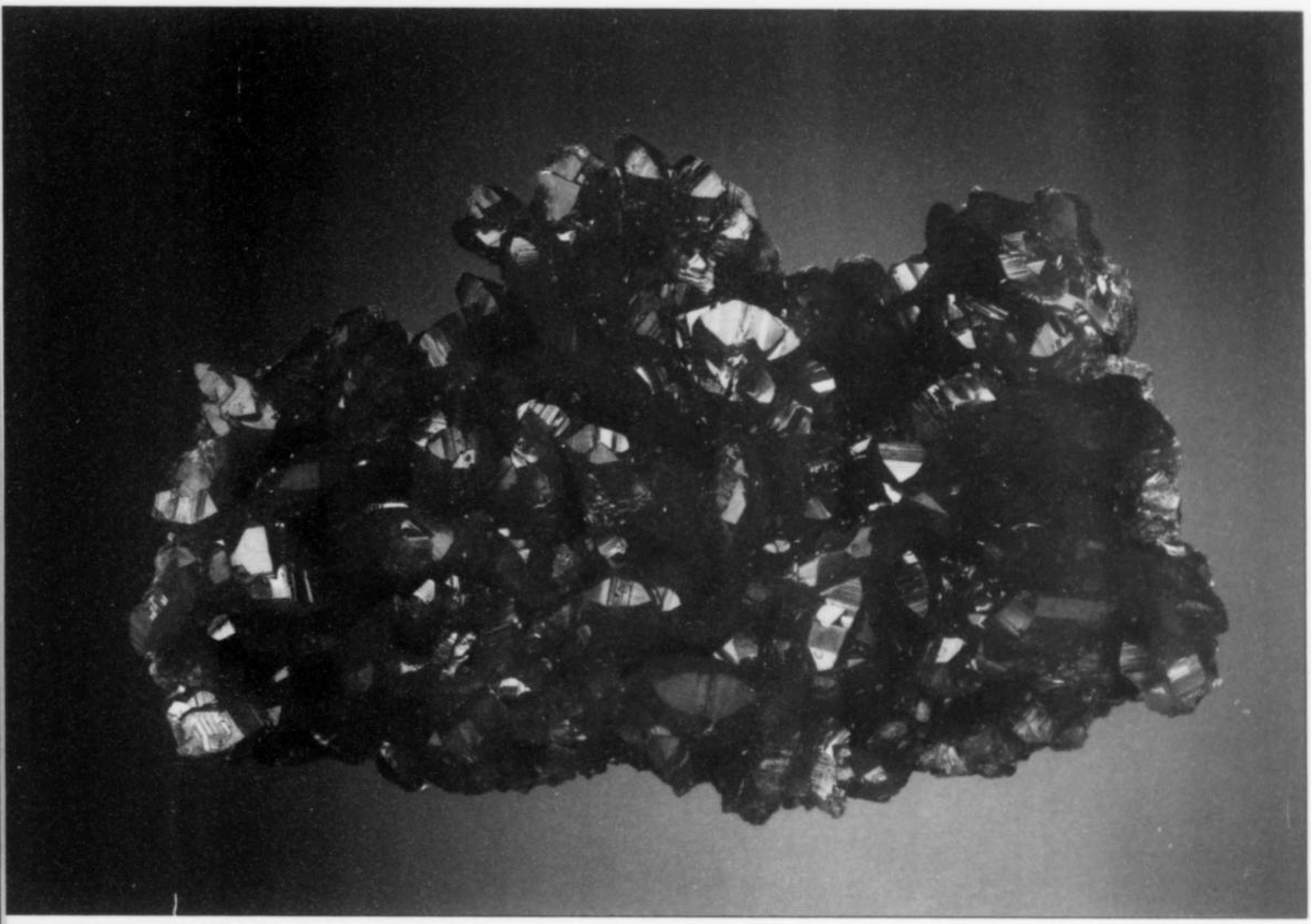

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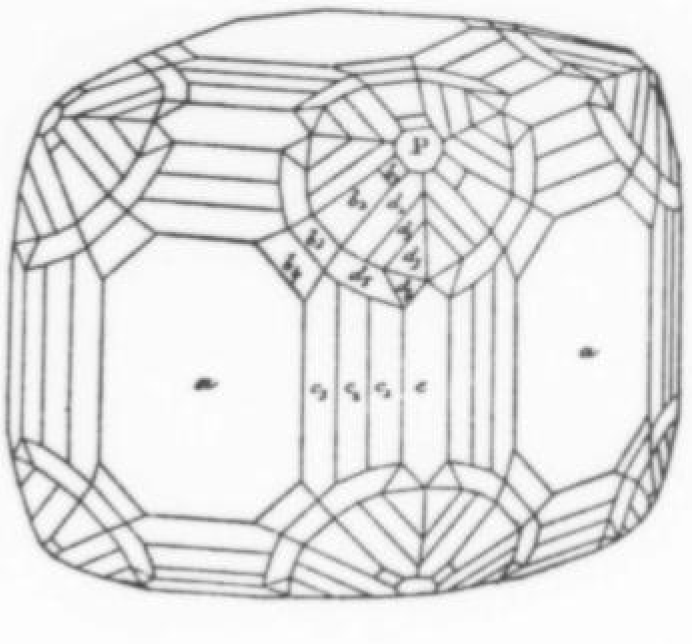

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and
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Department of Mineralogy
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Chloromenite Monoclinic

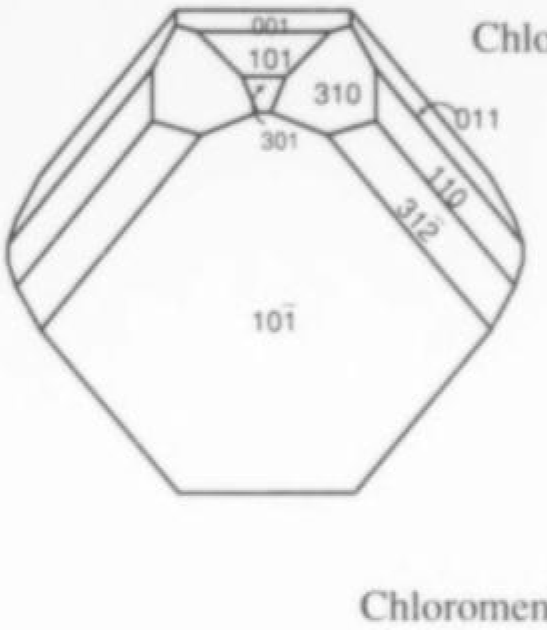
$Cu_9O_2(SeO_3)_4Cl_6$

Locality: The North Breakthrough of the Great Fissure Tolbachik eruption (1975–1976), Kamchatka Peninsula, Russia. The mineral was found in the "new" (1977) fumarole on the west border of the 2nd North Breakthrough slag cone.

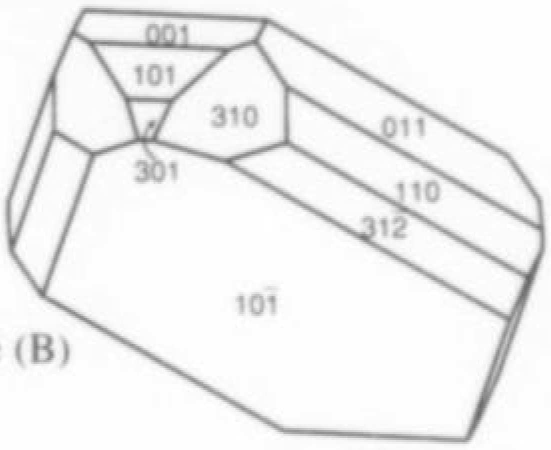
Occurrence: In a fumarole (the temperature of the gases in the fumarole in 1977 was about 700°C). Associated minerals are: melanothallite (on which chloromenite crystals have grown), an unknown selenite, an unknown scaly green mineral, and white weathering products on sophiite.

General appearance: Elongated plates (up to 0.2 mm long).

Physical, chemical and crystallographic properties: *Luster:* vitreous, but the indices of refraction indicate adamantine. *Diaphaneity:* transparent. *Color:* tobacco-green. *Streak:* yellowish-green. *Luminescence:* not mentioned. *Hardness:* VHN_5 62 kg/mm^2. *Tenacity:* plastic. *Cleavage:* {101} perfect. *Fracture:* not mentioned. *Density:* could not be determined, 4.14 g/cm^3 (calc.). ***Crystallography:*** Monoclinic, *I2/m*, *a* 14.11, *b* 6.274, *c* 13.00 Å, β 113.0°, *V* 1059 Å^3, Z 2, *a:b:c* = 2.2490:1:2.0720. Morphology: well-developed forms are {001}, {101}, $\{10\bar{1}\}$, {110}, {011}, and $\{31\bar{2}\}$; poorly-developed forms {301} and {310}; the crystals are flattened on $\{10\bar{1}\}$ and elongated on $[1\bar{1}1]$ (see Comments). Twinning: none mentioned. ***X-ray powder diffraction data:*** 11.29 (63) $(\bar{1}01)$, 5.56 (83) (011), 3.643 (25) (301), 3.450 (100) (103), 3.239 (39) $(\bar{2}04)$, 3.133 (25) (020), 2.714 (33) $(\bar{5}03)$, 2.486 (61) (303). ***Optical data:*** Biaxial (–), α 1.87, β 1.92, γ 1.94, 2V(meas.) 66°, 2V(calc.) 63°; dispersion not mentioned; pleochroism X = green, Y = light brownish-green, Z = black brownish-green, absorption Z > X > Y; Y = *b*, Z ~ *c* [therefore, X ∧ *a* ~ 23° in obtuse angle β (J.A.M.)]. ***Chemical analytical data:*** Means of four sets of electron microprobe data: CuO 46.23, ZnO 5.94, SeO_2 34.37, Cl 16.57, sum 103.11, less O = Cl 3.74, Total 99.37 wt.%. Empirical formula: $(Cu_{7.71}Zn_{0.97})_{\Sigma 8.68}O_{1.47}(SeO_3)_{4.11}Cl_{6.20}$. ***Relationship to other species:*** Chloromenite is the third copper oxide chloroselenite; the others, also found in the Tolbachik fumaroles, are georgbokiite (see abstract) and ilinskite (see abstract in *Mineral. Rec* **29**, 236).



Chloromenite (A)



Chloromenite (B)

Name: For the Greek χλωροζ (green and also indicating chlorine) and μηναζ (moon indicating selenium). ***Comments:*** IMA No. 96-048. The crystal drawing in the paper, which is a projection on (100), is reproduced here (see A) from information kindly provided by Dr. Krivovichev. A clinographic drawing also is shown here (see B) and, although the crystal appears to be distorted, this is the result of being elongated on the $[1\bar{1}1]$ direction.

VERGASOVA, L., KRIVOVICHEV, S., SEMENOVA, T., FILATOV, S., and ANANIEV, V. (1999) Chloromenite, $Cu_9O_2(SeO_3)_4$-Cl_6, a new mineral from the Tolbachik volcano, Kamchatka, Russia. *European Journal of Mineralogy* **11**, 119–123.

Ferrorhodsite Cubic

$(Fe,Cu)(Rh,Pt,Ir)_2S_4$

Locality: In gold-platinum placers in the Chadsky and Kondersky dunite massifs, Yakutia-Saha, Russia.

Occurrence: As inclusions in isoferroplatinum in dunite. Other associated minerals are: laurite, osmium, hollingsworthite and unnamed $Rh_2(Fe,Ni,Cu)_4S_7$.

General appearance: Irregular and equant grains (up to 50 x 70 microns).

Physical, chemical and crystallographic properties: *Luster:* metallic. *Diaphaneity:* opaque. *Color:* black. *Streak:* black. *Hardness:* VHN_{25} 507 kg/mm^2. *Tenacity:* fragile. *Cleavage:* none. *Fracture:* not mentioned. *Density:* could not be determined, 5.71 g/cm^3 (calc.). ***Crystallography:*** Cubic, *Fd3m*, *a* 9.89 Å, *V* 967.4 Å^3, Z 8. Morphology: no forms were observed. Twinning: none mentioned. ***X-ray powder diffraction data:*** 5.72 (7) (111), 2.99 (10) (311), 2.471 (8) (400), 1.903 (7) (333, 511), 1.750 (9) (440), 1.674 (3) (531), 1.009 (3) (844). ***Optical data:*** In reflected light: grey, isotropic. R: (41.5 %) 480nm, (41.8 %)

540nm, (41.8 %) 580nm, (41.7 %) 640nm. ***Chemical analytical data:*** Means of two sets of electron microprobe data: Rh 41.8, Ir 8.31, Pt 4.40, Fe 7.34, Cu 6.88, Ni 0.02, Co 0.02, S 31.0, Total 99.77 wt.%. Empirical formula: $(Fe_{0.55}Cu_{0.45})_{\Sigma 1.00}$-$(Rh_{1.69}Ir_{0.18}Pt_{0.09})_{\Sigma 1.96}S_{4.03}$. ***Relationship to other species:*** The iron-dominant analogue of cuprorhodsite.

Name: For the composition and relationship to cuprorhodsite. ***Comments:*** IMA No. 96-047.

RUDASHEVSKY, N. S., MOCHALOV, A. G., MENSHIKOV, YU. P., and SHUMSKAYA, N. I. (1998) Ferrorhodsite (Fe,Cu)-$(Rh,Pt,Ir)_2S_4$—a new mineral. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **127(5)**, 37–41.

Ferrotitanowodginite Monoclinic

$Fe^{2+}TiTa_2O_8$

Locality: In the San Elías and La Viquita pegmatites (about 300 m apart), Sierra de la Estanzuela, departamento Chacabuco, San Luis province, Argentina (approximately at Lat. 32°51′ S, Long. 65°06′ W).

Occurrence: In pegmatites. Associated minerals are: Ti-rich ferrowodginite, albite ("cleavelandite"), quartz, microlite and ferrotapiolite.

General appearance: Submillimetric domains intergrown with ferrowodginite as an aggregate 0.7 x 0.5 cm.

Physical, chemical and crystallographic properties: *Luster:* submetallic. *Diaphaneity:* opaque. *Color:* very dark brown to black. *Streak:* dark brown. *Hardness:* Mohs 5½. *Tenacity:* brittle. *Cleavage:* not observed. *Fracture:* irregular. *Density:* could not be determined, 7.37 g/cm³ (calc.). ***Crystallography:*** Monoclinic, *C2/c*, *a* 9.403, *b* 11.384, *c* 5.075 Å, β 90.55°, *V* 543.24 Å³, Z 4, *a:b:c* = 0.8260:1:0.4458. Morphology: no forms were mentioned. Twinning: none mentioned. ***X-ray powder diffraction data:*** 3.626 (70) (220), 2.963 (100) ($\bar{2}21$), 2.939 (90) (221), 2.484 (45) (041), 1.759 (45) (260), 1.715 (50) (402), 1.711 (45) ($\bar{4}41$), 1.447 (40) ($\bar{2}62$). ***Optical data:*** In reflected light: creamy white in air and gray in oil, abundant internal reflections (yellow, orange and purplish orange), distinct anisotropism, moderate bireflectance, moderate pleochroism. $R_{max.}$ & $R_{min.}$: (18.7, 18.2 %) 470nm, (19.1, 18.1 %) 546nm, (17.9, 16.9 %) 589nm, (16.4, 15.6 %) 650nm. ***Chemical analytical data:*** Means of eighteen sets of electron microprobe data: MgO 0.01, CaO 0.01, MnO 1.05, FeO 10.26, PbO 0.05, Fe_2O_3 2.19, As_2O_3 0.03, Sb_2O_3 0.02, Bi_2O_3 0.03, TiO_2 7.10, SnO_2 1.25, ThO_2 0.01, UO_2 0.02, Nb_2O_5 6.52, Ta_2O_5 70.68, WO_3 0.02, Total 99.25 wt.%. Empirical formula: $(Fe^{2+}_{0.87}Mn^{2+}_{0.09})_{\Sigma 0.96}(Ti_{0.54}Ta_{0.24}Fe^{3+}_{0.17}$-$Sn_{0.05})_{\Sigma 1.00}(Ta_{1.70}Nb_{0.30})_{\Sigma 2.00}O_{8.00}$. ***Relationship to other species:*** The Fe^{2+}- and Ti-dominant member of the wodginite group.

Name: For the composition and relationship to the wodginite group. ***Comments:*** IMA No. 98-028.

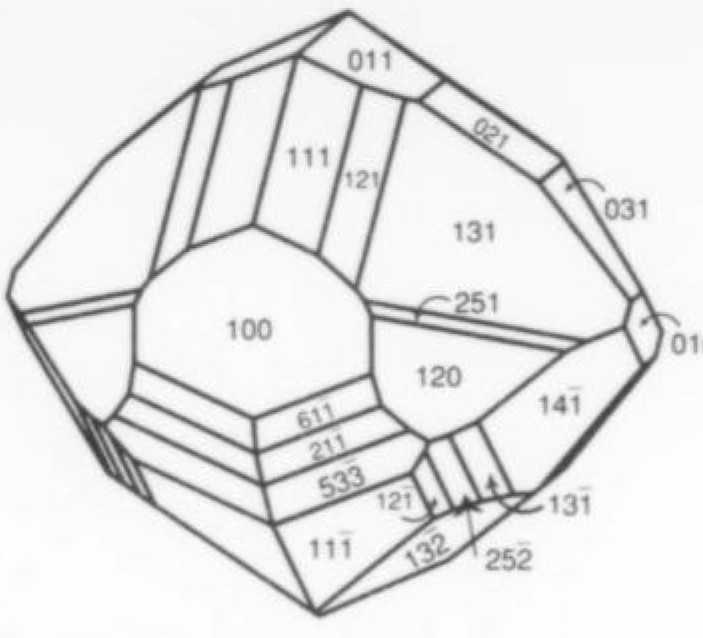
GALLISKI, M. A., ČERNÝ, P., MÁRQUEZ-ZAVALÍA, M. F., and CHAPMAN, R. (1999) Ferrotitanowodginite, $Fe^{2+}TiTa_2O_8$, a new mineral of the wodginite group from the San Elías pegmatite, San Luis, Argentina. *American Mineralogist* **84**, 773–777.

Georgbokiite Monoclinic

$Cu_5O_2(SeO_3)_2Cl_2$

Locality: The cone of the South break of the Large Tolbachik fissure eruption (1975–1986), Kamchatka Peninsula, Russia.

Occurrence: A product of fumarolic activity (Temperature 200°C). Associated minerals are: halite, Al-, Mg- and Na-sulfates, moissanite, native aluminium (probably) and two Se-containing minerals of unknown composition.



Georgbokiite

General appearance: Euhedral crystals (0.05 to 0.30 mm).

Physical, chemical and crystallographic properties: *Luster:* very strong vitreous to adamantine. *Diaphaneity:* translucent. *Color:* chestnut to dark brown. *Streak:* yellowish-brown. *Luminescence:* non-fluorescent. *Hardness:* VHN_{10} 215 kg/mm². *Tenacity:* sectile. *Cleavage:* {010} very perfect and {100} perfect. *Fracture:* not mentioned. *Density:* could not be determined, but grains sink in Clerici solution which has a density of 4.05 g/cm³, 4.84 g/cm³ (calc.). ***Crystallography:*** Monoclinic, $P2_1/c$, *a* 6.045, *b* 13.778, *c* 5.579 Å, β 95.76°, *V* 462.3 Å³, Z 2, *a:b:c* = 0.4387:1:0.4049. Morphology: forms observed {100}, {010}, {120}, {011}, {021}, {031}, {111}, {121}, {131}, {251}, {$14\bar{1}$}, {$61\bar{1}$}, {$21\bar{1}$}, {$53\bar{3}$}, {$11\bar{1}$}, {$12\bar{1}$}, {$25\bar{2}$}, {$13\bar{1}$}, {$13\bar{2}$}. See Comments. Twinning: none observed. ***X-ray powder diffraction data:*** 6.88 (68) (020), 5.511 (50) (110), 2.990 (100) (140), 2.963 (94) (131), 2.566 (67) ($\bar{2}21$), 2.296 (95) (060). ***Optical data:*** Biaxial (–), α 2.06, β 2.11, γ 2.15, 2V(meas.) 70°, 2V(calc.) 82°; dispersion not mentioned; pleochroism distinct, X = yellowish-brown, Y = straw-yellow, Z = dark brown, absorption Z > X > Y; orientation X ∧ *a* = 24° (in obtuse angle β), Y = *b*, [therefore, Z ∧ *c* = 18° (in acute angle β)]. ***Chemical analytical data:*** Means of thirteen sets of electron microprobe data: CuO 58.17, ZnO 0.22, SeO_2 33.09, Cl 10.96, sum 102.44, less O = Cl 2.48, Total 99.96 wt.%. Empirical formula: $(Cu_{4.93}Zn_{0.02})_{\Sigma 4.95}O_{1.89}(SeO_3)_{2.01}Cl_{2.08}$. ***Relationship to other species:*** A chloroselenite similar in composition to chloromenite.

Name: For Prof. Dr. Georgiy Borisovich Bokii (1909–) for his contributions to crystal chemistry and mineralogy. ***Comments:*** IMA No. 96-015. The crystal drawing which is shown here was produced from the data given in the paper and from information kindly provided by Dr. Sergey Krivovichev to whom I am indebted for other information about the mineral. I have changed the Miller indices of some of the forms to equivalent indices for clarity with respect to the indices shown on the drawing. Details of the crystal structure are given in the paper.

VERGASOVA, L. P., SEMENOVA, T. F., FILATOV, S. K., KRIVOVICHEV, S. V., SHUVALOV, R. R., and ANANIEV, V. V. (1999) Georgbokiite $Cu_5O_2(SeO_3)_2Cl_2$—a new mineral from volcanic sublimates. *Doklady Akademia Nauk* **364(4)**, 527–531.

Hexaferrum Hexagonal

(Fe,Ru,Os,Ir)

Locality: The Chirynaisky massif, Koryak Mountains, Kamchatka Peninsula, Russia.

Occurrence: In chromite segregations in dunite. Associated minerals are: "iridosmine," "rutheniridium," laurite, tulameenite, awaruite, iron, copper, zinc, oregonite, pentlandite and other sulfides. The obsolete names "iridosmine" and "rutheniridium" probably refer, respectively, to osmium and iridium.

General appearance: Cubic or octahedral (see Comments) crystals (up to 200 microns).

Physical, chemical and crystallographic properties: *Luster:* metallic. *Diaphaneity:* opaque. *Color:* steel gray with a yellow tint. *Streak:* black. *Hardness:* VHN_{50} 810 kg/mm^2. *Tenacity:* not mentioned. *Cleavage:* none. *Fracture:* not mentioned. *Other properties:* magnetic. *Density:* could not be determined, 12.01 g/cm^3 (calc.) (ruthenian variety). ***Crystallography:*** Hexagonal, $P6_3/mmc$, a 2.64, c 4.20 Å, V 25.35 Å^3, Z 2, $c{:}a$ = 1.5909. Morphology: cubes and octahedra are mentioned, but these are not possible in the hexagonal system. Twinning: none mentioned. ***X-ray powder diffraction data:*** 2.28 (5) (100), 2.10 (6) (002), 2.006 (10) (101), 1.549 (3) (102), 1.316 (3) (110), 1.195 (3) (103). ***Optical data:*** In reflected light: light gray to white, strong anisotropism, no bireflectance or pleochroism. R_1 & R_2: (49.8, 41.9 %) 480nm, (50.6, 42.0 %) 540nm, (51.4, 42.0%) 580nm, (53.4, 43.0 %) 660nm. ***Chemical analytical data:*** Means of three sets of electron microprobe data: Fe 29.40, Cu 0.22, Ni 0.09, Co 0.15, Ru 36.90, Os 20.90, Ir 9.01, Pt 0.28, Total 96.95 wt.%. Empirical formula: $(Fe_{0.50}Ru_{0.35}Os_{0.10}Ir_{0.04})_{\Sigma 0.99}$. ***Relationship to other species:*** The hexagonal polymorph of iron.

Name: For the symmetry and composition. ***Comments:*** IMA No. 95-032. It is unlikely that a mineral with hexagonal symmetry occurs as cubic or octahedral crystals. A total of eleven sets of chemical analytical data are given by the authors. This abstract contains data for only the ruthenian variety. It is unfortunate that the authors use the nonvalid names "hexaferrum (Fe,Ru)," "hexaferrum (Fe,Os)" and "hexaferrum (Fe,Ir)," for the ruthenian-, osmian- and iridian-varieties of hexaferrum.

MOCHALOV, A. G., DMITRENKO, G. G., RUDASHEVSKY, N. S., ZHERNOVSKY, I. V., and BOLDYREVA, M. M. (1998) Hexaferrum (Fe,Ru)), (Fe,Os), (Fe,Ir)—a new mineral. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **127(5)**, 41–51.

Hydrowoodwardite Trigonal

$Cu_{1-x}Al_x(OH)_2(SO_4)_{x/2}(H_2O)_n$
with $x < 0.67$ and $n > \approx 3x/2$

Locality: The St. Briccius mine, Königswalde near Annaberg, Saxony, Germany. Also found at the following localities in Saxony, Germany: the Gelbe Birke mine, Schwarzenberg; the St, Christoph mine, Bärenhecke; the St. Johannes mine, Wolkensten, near Marienberg. The mineral is identical with the incompletely described mineral from Carnarvonshire, Wales, UK (Nickel, 1976).

Occurrence: At St. Briccius it occurs on gneiss; no associated minerals are mentioned. The following information is given about the other occurrences: Gelbe Birke associated with woodwardite, schulenbergite, namuwite, brianyoungite, langite, linarite and others; St. Christoph material is a variety containing carbonate; St. Johannes associated with copper-bearing allophane.

General appearance: Botryoidal, porous crusts.

Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* translucent. *Color:* blue to pale blue. *Streak:* pale blue. *Luminescence:* not mentioned. *Hardness:* not mentioned. *Tenacity:* brittle after losing water. *Cleavage:* not discernible. *Fracture:* uneven. *Density:* 2.33 g/cm^3 (meas.), 2.47 g/cm^3 (calc.). ***Crystallography:*** Trigonal, probably $R\bar{3}m$ (by analogy with other hydrotalcite-related minerals), a 3.070, c 31.9 Å, V 260 Å^3, Z 3, $c{:}a$ = 10.3909. Morphology: no forms were mentioned. Twinning: none mentioned. ***X-ray powder diffraction data:*** 10.5 (100) (003), 5.26 (17) (006), 3.50 (6) (009), 2.60 (5B) (012), 2.46 (2B) (015), 2.23 (2B) (018), 1.524 (4) (110). ***Optical data:*** Uniaxial (presumably, sign is unknown), $n_{min.}$ 1.549, $n_{max.}$ 1.565, nonpleochroic. ***Chemical analytical data:*** An analysis by ICP-MS with water by TGA gave: Na_2O 0.10, CuO 28.39, ZnO 0.41, Al_2O_3 19.20, SO_3 15.50, SiO_2 5.60, H_2O 30.10, Total 99.30 (given as 99.39) wt.%. The empirical formula is given as: $[Cu_{0.48}Al_{0.51}Zn_{0.01}(OH)_{1.99}]$-$[(SO_4)_{0.26}(H_2O)_{1.27}$. ***Relationship to other species:*** It is considered to be the copper-dominant analogue of glaucocerinite and carrboydite and a member of the hydrotalcite group.

Name: For the relationship to woodwardite. ***Comments:*** IMA No. 96-038.

WITZKE, T. (1999) Hydrowoodwardite, a new mineral of the hydrotalcite group from Königswalde near Annaberg, Saxony/Germany and other localities. *Neues Jahrbuch für Mineralogie, Monatshefte* **1999**, 75–86. NICKEL, E. H. (1976) New data on woodwardite. *Mineralogical Magazine* **43**, 644–647.

Isovite Cubic

$(Cr,Fe)_{23}C_6$

Locality: The Is River, near the town of Is, Isovsky district, Middle Urals, Russia (Lat. 58°47′ N, Long. 59°48′ E).

Occurrence: In a gold-platinum placer. Associated minerals are: gold, platinum-group minerals, cinnabar, "chromspinels" and unnamed Cr-Fe minerals including other carbides.

General appearance: Equant or irregular grains (up to 0.2 mm).

Physical, chemical and crystallographic properties: *Luster:* metallic. *Diaphaneity:* opaque. *Color:* steel gray. *Streak:* not given. *Hardness:* VHN_{50} 1350 kg/mm^2. *Tenacity:* brittle. *Cleavage:* none observed. *Fracture:* irregular. *Other properties:* ferromagnetic. *Density:* could not be determined, 7.00 g/cm^3 (calc.). ***Crystallography:*** Cubic, $Fm3m$, a 10.65 Å, V 1208 Å^3, Z 4. Morphology: no forms were mentioned. Twinning: none mentioned. ***X-ray powder diffraction data:*** 2.38 (3) (024), 2.17 (5) (224), 2.05 (10) (333, 115). ***Optical data:*** In reflected light: white, isotropic. R: (46.5 %) 470nm, (43.7 %) 546nm, (43.2 %) 589nm, (43.9 %) 650nm. ***Chemical analytical data:*** Thirty-six sets of electron microprobe data are listed, some of which are incomplete. One sample gave: Cr 68.24, Fe 25.12, Ni 0.47, Co 0.04, Cu 0.04, Zn 0.02, Al 0.02, Si 0.02, C 6.06, Total 100.03 wt.%. Empirical formula: $(Cr_{16.71}Fe_{5.73}Ni_{0.10}Co_{0.01}Si_{0.01}Al_{0.01}$-$Cu_{0.01})_{\Sigma 22.58}C_{6.42}$. ***Relationship to other species:*** The chromium-dominant analogue of haxonite, $(Fe,Ni)_{23}C_6$.

Name: For the locality. ***Comments:*** IMA No. 96-039.

GENERALOV, M. E., NAUMOV, V. A., MOKHOV, A. V., and TRUBKIN, N. V. (1998) Isovite $(Cr,Fe)_{23}C_6$—a new mineral from the gold-platinum bearing placers of the Urals. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **127(5)**, 26–37.

Seidite-(Ce) Monoclinic

$Na_4SrCeTiSi_8O_{22}F\cdot 5H_2O$

Locality: In the Yubileinaya pegmatite vein at Mt. Karnarsut, northern part of the Lovozero alkaline massif, Kola Peninsula, Russia.

Occurrence: In hyperagpaitic pegmatites. Associated minerals are: natrolite, microcline, steenstrupine-(Ce), belovite-(Ce), vitusite-(Ce), sazhinite-(Ce), leucosphenite, mangan-neptunite, sérandite and sphalerite.

General appearance: Radial aggregates (0.5 to 1.0 cm in diameter) of tiny (0.01 to 0.05 mm wide) fibres.

Physical, chemical and crystallographic properties: *Luster:* vitreous to silky, also waxy or earthy. *Diaphaneity:* transparent under microscope. *Color:* light yellow, pink-yellow or cream. *Streak:* white. *Luminescence:* non-fluorescent. *Hardness:* 3 to 4. *Tenacity:* brittle. *Cleavage:* {100} perfect and {001} less perfect. *Fracture:* fibrous and splintery. *Density:* 2.76 g/cm^3 (meas.), 2.65 g/cm^3 (calc.). ***Crystallography:*** Monoclinic, *C2/c*, *a* 24.74, *b* 7.186, *c* 14.47 Å, β 95.25°, *V* 2561.7 Å^3, Z 4, *a:b:c* = 3.4428:1:2.0136. Morphology: no forms were observed. Twinning: none observed. ***X-ray powder diffraction data:*** 12.32 (100) (200), 3.220 (8b) $(51\bar{3})$, 3.104 (24) (420), 3.081 (16) (800), 3.058 (12b) $(42\bar{1})$, 2.705 (10) (620). ***Optical data:*** Biaxial (–), α 1.542, β 1.569, γ 1.571, 2V(meas.) 28°, 2V(calc.) 30°; dispersion none discernible; orientation X ≈ *a*, Y ≈ *c*, Z ≈ *b*. ***Chemical analytical data:*** Means of five sets of electron microprobe data (H_2O by the Penfield method and F by wet chemistry): Na_2O 9.38, K_2O 1.20, CaO 1.04, MnO 0.34, FeO 0.10, SrO 5.20, BaO 1.56, La_2O_3 4.62, Ce_2O_3 6.52, Pr_2O_3 0.54, Nd_2O_3 1.60, Sm_2O_3 0.16, SiO_2 45.62, TiO_2 6.54, ThO_2 2.96, Nb_2O_5 0.78, H_2O 10.80, F 1.52, sum 100.48, less O = F 0.64, Total 99.84 wt.%. Empirical formula: $[Na_{3.10}Ca_{0.19}(H_3O)_{0.71}]_{\Sigma 4.00}$-$[Sr_{0.51}K_{0.26}Ba_{0.10}(H_3O)_{0.13}]_{\Sigma 1.00}(Ce_{0.41}La_{0.29}Th_{0.11}Nd_{0.10}Pr_{0.03}Sm_{0.01})_{\Sigma 0.95}$-$(Ti_{0.84}Nb_{0.06}Mn_{0.05}Fe_{0.01})_{\Sigma 0.96}Si_{7.79}O_{21.36}[F_{0.82}(OH)_{0.18}]_{\Sigma 1.00}\cdot 4.80H_2O$. ***Relationship to other species:*** It acts like a zeolite by readily exchanging cations with solutions of various salts.

Name: For Seid Lake in the Lovozero massif. ***Comments:*** IMA No. 93-029.

KHOMYAKOV, A. P., FERRARIS, G., BELLUSO, E., BRITVIN, S. N., NECHELYUSTOV, G. N. and SOBOLEVA, S. V. (1998) Seidite-(Ce), $Na_4SrCeTiSi_8O_{22}F\cdot 5H_2O$, a new mineral with zeolitic properties. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **127(4)**, 94–100.

Shibkovite

Hexagonal

$K(Ca,Mn,Na)_2(K_{2-x}\square_x)_2Zn_3Si_{12}O_{30}$

Locality: In the moraine of Dara-i-Pioz glacier, Garmskiy District, northern Tadjikistan (Lat. 39°30′ N, Long. 70°40′ E).

Occurrence: In a pegmatite boulder. Associated minerals are: quartz, microcline, albite, aegirine, polylithionite, reedmergnerite, sogdianite, pyrochlore, eudialyte, and turkestanite.

General appearance: Grains (0.01 to 0.05 mm).

Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* transparent to translucent. *Color:* colorless to white. *Streak:* white. *Luminescence:* fluoresces bright red under short wave UV. *Hardness:* VHN_{50} 609 kg/mm^2, Mohs 5½ to 6. *Tenacity:* brittle. *Cleavage:* none observed. *Fracture:* step-like. *Density:* 2.89 g/cm^3 (meas.), 2.90 g/cm^3 (calc.). ***Crystallography:*** Hexagonal, *P6/mmc*, *a* 10.505, *c* 14.185 Å, *V* 1355.8 Å^3, Z 2, *c:a* = 1.3503. Morphology: no forms were mentioned. Twinning: none. ***X-ray powder diffraction data:*** 7.11 (35) (002), 3.83 (100) (022), 3.345 (60) (121), 3.304 (40) (014), 2.940 (50) (114), 2.795 (85) (024), 2.627 (35) (220). ***Optical data:*** Uniaxial (+), ω 1.561, ε 1.563, nonpleochroic. ***Chemical analytical data:*** Means of four sets of electron microprobe data: Na_2O 1.03, K_2O 8.83, CaO 6.00, MnO 2.43, FeO 0.04, ZnO 20.80, Al_2O_3 0.04, SiO_2 62.33, Total 100.50 wt.%. Empirical formula: $K_{1.00}(Ca_{1.26}Mn_{0.40}Na_{0.39}Fe_{0.01})_{\Sigma 2.06}(K_{1.21}\square_{0.79})_{\Sigma 2.00}$-$Zn_{3.01}Si_{12.01}O_{30.00}$. ***Relationship to other species:*** A member of the Osumilite group.

Name: For Viktor Sergeevitch Shibkov (1926–1992) and Nikolai Viktorvitch Shibkov (1951–1991), prominent Russian geologists. ***Comments:*** IMA No. 97-018.

PAUTOV, L. A., AGAKHANOV, A. A., and SOKOLOVA, E. V. (1998) Shibkovite—the new mineral from the milarite group. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **127(4)**, 89–94.

Simmonsite

Monoclinic

Na_2LiAlF_6

Locality: The Zapot amazonite-topaz-zinnwaldite pegmatite, Gillis Range, approximately 25 km northeast of Hawthorne, Mineral Co., Nevada, USA.

Occurrence: In an alumino-fluoride assemblage in a late-stage breccia pipe structure that cuts the pegmatite. Associated minerals are: cryolite, cryolithionite, pachnolite, weberite, thomsenolite, prosopite, ralstonite, and fluorite.

General appearance: An intergrowth with cryolite and cryolithionite of anhedral to subhedral grains from several microns to two- to three-hundred microns.

Physical, chemical and crystallographic properties: *Luster:* somewhat greasy. *Diaphaneity:* translucent to transparent in thin section. *Color:* pale buff to cream. *Streak:* white. *Luminescence:* fluoresces moderate yellow orange in shortwave UV. *Hardness:* 2½ to 3. *Tenacity:* not extremely brittle. *Cleavage:* nothing distinct. *Fracture:* subconchoidal. *Density:* 3.05 g/cm^3 (meas.), 3.06 g/cm^3 (calc.). ***Crystallography:*** Monoclinic, *P*2_1 or *P*2_1*/m*, *a* 7.5006, *b* 7.474, *c* 7.503 Å, β 90.847°, *V* 420.6 Å^3, Z 4, *a:b:c* = 1.0036:1:1.0039. Morphology: no forms were observed. Twinning: complex polysynthetic. ***X-ray powder diffraction data:*** 4.33 (100) $(111, 11\bar{1})$, 2.65 (60) (220, 202, 022), 2.25 (70) $(13\bar{1}, 113, 131, 311)$, 2.18 (40) (222), 1.877 (90) (400, 004). ***Optical data:*** Biaxial but nearly isotropic, birefringence 0.0009, n 1.359. ***Chemical analytical data:*** Means of seven sets of electron microprobe data: Na 23.4, Li (3.56), Al 13.9, F 58.6, Total 99.46 wt.%. Li was calculated to give one atom. Empirical formula: $Na_{1.98}Li_{1.00}Al_{1.00}F_{6.01}$. ***Relationship to other species:*** None apparent.

Name: For William B. Simmons (1943–), Professor of Mineralogy and Petrology, University of New Orleans, New Orleans, Louisiana, USA. ***Comments:*** IMA No. 97-045.

FOORD, E. E., O'CONNOR, J. T., HUGHES, J. M., SUTLEY, S. J., FALSTER, A. U., SOREGAROLI, A. E., LICHTE, F. E., and KILE, D. E. (1999) Simmonsite, Na_2LiAlF_6, a new mineral from the Zapot amazonite-topaz-zinnwaldite pegmatite, Hawthorne, Nevada, U.S.A. *American Mineralogist* **84**, 769–772.

Turkestanite

Tetragonal

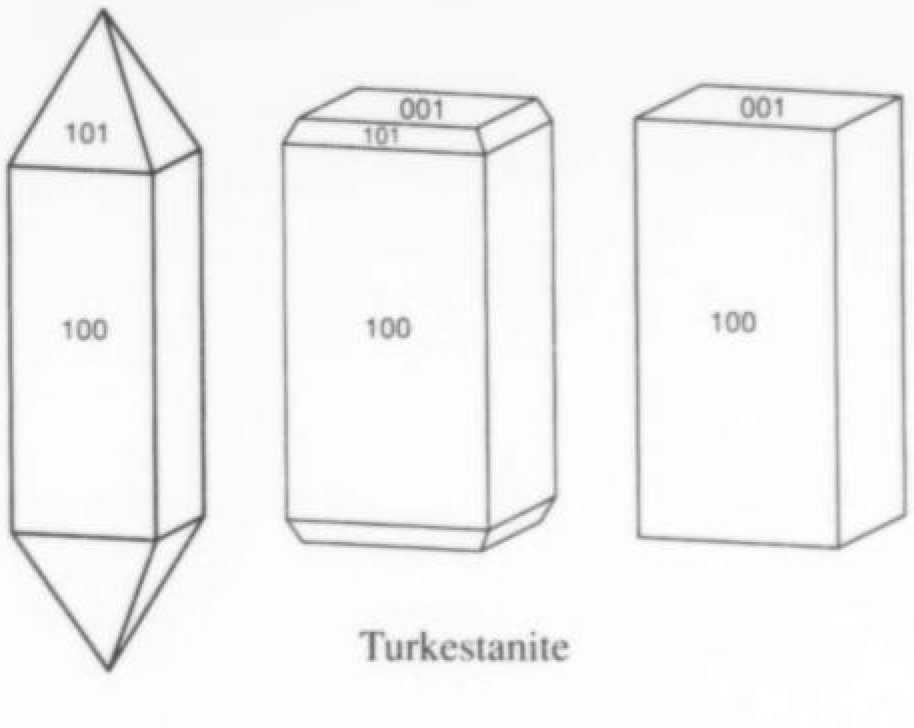
$Th(Ca,Na)_2(K_{1-x}\square_x)Si_8O_{20}\cdot nH_2O$

Locality: (1) Dara-i-Pioz massif, Garmskiy region, intersection of the Zerafshan and Alay Ranges of Southern Tien-Shan, Tadzhikistan; and (2) the Djelisu massif, Osh region, upper part of the Khodzha-Ochkan river basin, Kyrgyzstan.

Occurrence: (1) In a glacial boulder. Associated minerals are: microcline, pectolite, quartz, aegirine, calcite, fluorite, fluorapatite, titanite, and albite. (2) In albitized nepheline syenites. Associated minerals are: albite, aegirine, quartz, fluorapatite, fluorite, and titanite.

General appearance: Grains and euhedral crystals (up to 50 mm long).

Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* translucent. *Color:* apple-green to dark green



Turkestanite

and brown. *Streak:* white. *Luminescence:* non-fluorescent. *Hardness:* 5½ to 6. *Tenacity:* brittle. *Cleavage:* {111} imperfect. *Fracture:* conchoidal. *Density:* 3.36 g/cm³ (meas.), 3.39 g/cm³ (calc.). ***Crystallography:*** Tetragonal, *P4/mcc*, *a* 7.592, *c* 14.824 Å, *V* 854 Å³, Z 2, *c:a* = 1.9526. Morphology: forms, {100}, {001}, {101}, rarely {110}. Twinning: none observed. ***X-ray powder diffraction data:*** 7.59 (23), 5.36 (40), 5.31 (70), 3.40 (100), 3.33 (65), 2.654 (59), 2.175 (25). ***Optical data:*** Uniaxial (-), ω 1.611, ε 1.606, nonpleochroic. ***Chemical analytical data:*** Five sets of electron microprobe data are given; three for material from Dara-i-Pioz and two from Djelisu. One set from Dara-i-Pioz gave: Na_2O 2.89, K_2O 4.54, CaO 7.56, MnO 0.01, PbO 0.94, Al_2O_3 0.03, Fe_2O_3 0.10, REE_2O_3 1.50, SiO_2 54.58, ThO_2 23.43, UO_2 1.93, H_2O 1.76, F 0.20, sum 99.47, less O = F 0.08, Total 99.39 wt.%. Empirical formula: $(Th_{0.78}REE_{0.08}U_{0.06}Pb_{0.04}Fe_{0.01})_{\Sigma 0.97}(Ca_{1.18}Na_{0.82})_{\Sigma 2.00}(K_{0.85}\square_{0.15})_{\Sigma 1.00}Si_{7.98}O_{12.00}[O_{7.69}(OH)_{0.22}F_{0.09}]_{\Sigma 8.00}\cdot 0.75H_2O$. ***Relationship to other species:*** The calcium-dominant analogue of steacyite, $Th(Na,Ca)_2K_{1-x}Si_8O_{20}$.

Name: For the locality; Turkestan is a general term for the Middle Asia region. ***Comments:*** IMA No. 96-036.

PAUTOV, L. A., AGAKHANOV, A. A., SOKOLOVA, E. V., and KABALOV, Yu. K (1997) Turkestanite $Th(Ca,Na)_2(K_{1-x}\square_x)Si_8O_{20}\cdot nH_2O$—a new mineral with doubled four-member silicon-oxygen rings. *Zapiski Vserossiyskogo mineralogicheskogo obshchestva* **126(6)**, 45–54.

Vuoriyarvite

Monoclinic

$(K,Na)_2(Nb,Ti)_2Si_4O_{12}(O,OH)_2\cdot 4H_2O$

Locality: The central part of the Vuoriyarvi alkali-ultrabasic massif, Kola Peninsula, Russia.

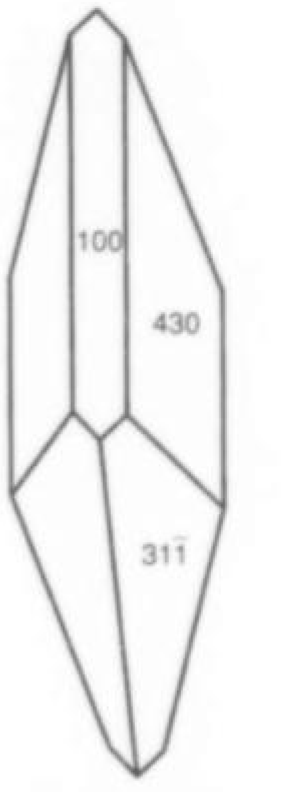
Occurrence: In dissolution cavities in veins of dolomite-calcite carbonatites which crosscut pyroxenites. Associated minerals are: calcite, dolomite, strontianite, ewaldite, minerals of the serpentine and apatite groups, pyrrhotite, pyrite, chalcopyrite, sphalerite, and pyrochlore.

General appearance: Tabular crystals (up to 0.5 x 1.0 x 3.0 mm).

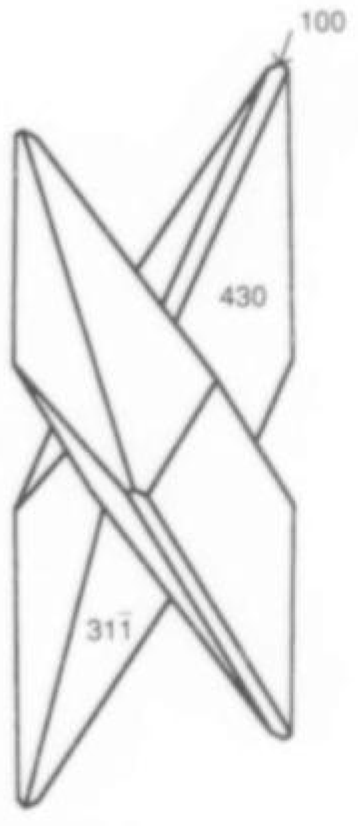
Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* translucent. *Color:* white. *Streak:* white. *Luminescence:* non-fluorescent. *Hardness:* 4½. *Tenacity:* brittle. *Cleavage:* none observed. *Fracture:* uneven. *Density:* 2.95 g/cm³ (meas.), 3.02 g/cm³ (calc.). ***Crystallography:*** Monoclinic, *Cm*, *a* 14.692, *b* 14.164, *c* 7.859 Å, β 117.87°, *V* 1445.7 Å³, Z 4, *a:b:c* = 1.0373:1:0.5549. Morphology: forms, {001}, {100}, and {h01}. Twinning: on (001). ***X-ray powder diffraction data:*** 7.10 (9), 4.98 (6), 3.262 (10), 3.151 (8brd), 2.956 (6), 2.549 (4), 1.723 (4). ***Optical data:*** Biaxial (+), α 1.649, β 1.655, γ 1.759, 2V(meas.) 20°, 2V(calc.) 28°; dispersion r < v, weak; nonpleochroic; X = *b*, Z = *c* (although not stated, Y ∧ *a* = 28° in obtuse angle β). ***Chemical analytical data:*** Means of three sets of electron microprobe data: Na_2O 2.80, K_2O 7.30, CaO 0.02, BaO 3.18, Fe_2O_3 0.03, SiO_2 36.80, TiO_2 0.81, Nb_2O_5 37.50, H_2O (11.56), Total (100.00) wt.%. The water content was calculated by difference. Empirical formula: $(K_{1.02}Na_{0.59}Ba_{0.14})_{\Sigma 1.75}(Nb_{1.86}Ti_{0.07})_{\Sigma 1.93}(Si_2O_6)_{\Sigma 2.01}[O_{1.41}(OH)_{0.59}]_{\Sigma 2.00}\cdot 3.93H_2O$. ***Relationship to other species:*** Structurally related to labuntsovite and nenadkevichite.

Name: For Lake Vuoriyarvi. ***Comments:*** IMA No. 95-031.

SUBBOTIN, V. V., VOLOSHIN, A. V., PAKHOMOVSKII, Ya. A., BAKHCHISARAITSEV, A. Yu., PUSHCHAROVSKY, D. Yu., RASTVETAEVA, R. K., and NADEZHINA, T. N. (1998) Vuoriyarvite $(K,Na)_2(Nb,Ti)_2Si_4O_{12}(O,OH)_2\cdot 4H_2O$—new mineral from carbonatite of the Vuoriyarvi massif (Kola Peninsula). *Doklady Akademia Nauk* **358(4)**, 517–519.



Wilhelmkleinite—single



Wilhelmkleinite—twin

Wilhelmkleinite

Monoclinic

$ZnFe^{3+}_2(AsO_4)_2(OH)_2$

Locality: Level 44 (about 1,500 meters below the present surface) of the Tsumeb mine, Tsumeb, Namibia.

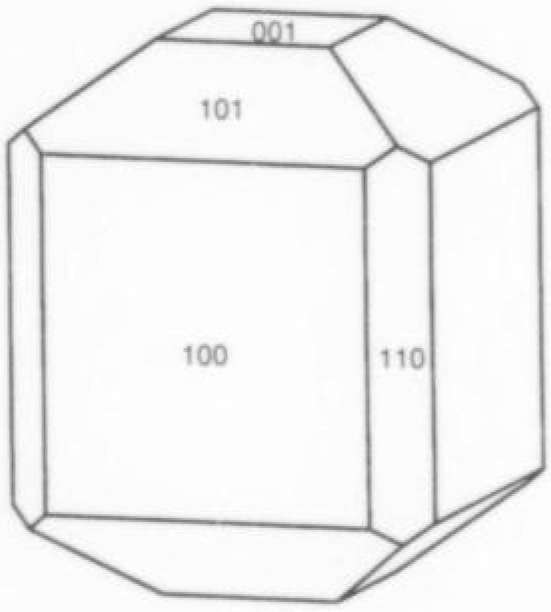
Occurrence: In an oxidation zone. Associated minerals are: scorodite, gerdtremmelite, and adamite.

General appearance: Aggregates (up to 1 x 1 x 0.5 cm) of closely intergrown spearhead shaped crystals (up to 5 mm).

Physical, chemical and crystallographic properties: *Luster:* dull, but adamantine on fractures. *Diaphaneity:* translucent. *Color:* blackish green. *Streak:* green. *Luminescence:* non-fluorescent. *Hardness:* 4½. *Tenacity:* not given. *Cleavage:* {23$\bar{2}$}, perfection not given. *Fracture:* uneven. *Density:* could not be determined, 4.36 g/cm³ (calc.) (for the ideal composition). ***Crystallography:*** Monoclinic, $P2_1/n$, *a* 6.631, *b* 7.611, *c* 7.377 Å, β 91.80°, *V* 372.12 Å³, Z 2, *a:b:c* = 0.8712:1:0.9693. Morphology: forms {430}, {31$\bar{1}$}, {100}. Twinning: interpenetration on (101). ***X-ray powder diffraction data:*** 3.385 (100), 3.315 (78), 2.939 (47), 2.839 (28), 2.381 (29), 2.331 (29), 1.660 (27), 1.652 (32), 1.621 (34). ***Optical data:*** Complete optical data are not given; n is about 1.94; pleochroism strong from olive-green and emerald-green to reddish-brown. ***Chemical analytical data:*** Means of five sets of electron microprobe data: ZnO 13.81, Fe_2O_3 33.60, As_2O_5 46.69, H_2O (5.90), Total (100.00) wt.%. Water was calculated by difference. Empirical formula: $Zn_{0.79}Fe^{3+}_{1.96}(AsO_4)_{1.89}O_{2.44}H_{3.05}$. ***Relationship to other species:*** It is chemically similar to ojuelaite, $ZnFe^{3+}_2(AsO_4)_2(OH)_2\cdot 4H_2O$.

Name: For Wilhelm Klein (1889–1939), manager of the OMEG mines, Namibia, from 1916 to 1939, and discoverer of the mineral germanite described by Pufahl in 1922. ***Comments:*** IMA No. 97-034. The mineral was collected by Charles Key in 1994. A short description of the crystal structure is given in the paper; a detailed description of the structure will be published elsewhere. A drawing of a twinned crystal is given in the paper; I am grateful to Dr. R. Peter Richards who kindly redrew it for this abstract. In addition, I have drawn a single crystal in the standard orientation using information which Dr. Schlüter was kind enough to provide.

SCHLÜTER, J., KLASKA, K.-H., FRIESE, K., ADIWIDJAJA, G., and GEBHARD, G. (1998) Wilhelmkleinite, $ZnFe_2^{3+}(AsO_4)_2$-$(OH)_2$, a new mineral from Tsumeb, Namibia. *Neues Jahrbuch für Mineralogie, Monatshefte* **1998(12)**, 558–564.



Wiluite

Wiluite

Tetragonal

$Ca_{19}(Al,Mg,Fe,Ti)_{13}(B,Al,\square)_5Si_{18}O_{68}(O,OH)_{10}$

Locality: The Wilui River region, Sakha Republic (Yakutia), Russian Federation. The mineral has been identified also from Templeton Township, Ottawa County, Quebec, Canada, and from the Bill Waley mine, Tulare County, California, USA.

Occurrence: In a serpentinized skarn. Associated minerals are: grossular, fine-grained serpentine minerals, serpentine minerals, carbonate, altered pyrite, "chlorite," and "achtarandite" (a tetrahedral pseudomorph of an unknown mineral (possibly wadalite).

General appearance: Euhedral crystals (up to 3 x 3 x 5 cm).

Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* translucent. *Color:* dark green. *Streak:* white. *Luminescence:* non-fluorescent. *Hardness:* 6. *Tenacity:* brittle. *Cleavage:* {100} poor. *Fracture:* irregular. *Density:* 3.36 g/cm³ (measured), 3.36 g/cm³ (calculated). ***Crystallography:*** Tetragonal, *P4/nnc*, *a* 15.752, *c* 11.717 Å, *V* 2907.3 Å³, Z 2, *c:a* = 0.7438. Morphology: forms {100} and {101} dominant, {110} and {001} minor. Slightly elongate on [001]. Twinning: none observed. ***X-ray powder diffraction data:*** 2.776 (100) (342), 2.617 (61) (252), 2.592 (43) (224), 2.491 (61) (260), 2.121 (20) (135), 1.66 (26) (346), 1.64 (23) (292). ***Optical data:*** Uniaxial (+), ω 1.721, ε 1.725, nonpleochroic. The mineral show "anomalous" optical properties with strong optical sector zoning: {001} sectors show a cross-hatched pattern (possibly due to twinning) and {110} and {100} sectors show fine striations. The {001} sector has low birefringence and is slightly biaxial with 2V between 0° and 10°; the {110} sectors have higher birefringence with 2V between 10° and 25°. ***Chemical analytical data:*** Means of twenty-five sets of electron microprobe data: MgO 6.48, CaO 35.54, FeO 1.21, B_2O_3 3.06, Al_2O_3 12.03, Fe_2O_3 2.28, Ce_2O_3 0.18, SiO_2 36.11, TiO_2 0.80, H_2O 0.61, F 0.50, sum 98.90, less O = F 0.21, Total 98.59 wt.%. Empirical formula: $(Ca_{18.97}Ce_{0.03})_{\Sigma 19.00}(Al_{6.55}Mg_{4.80}Fe^{3+}_{0.85}Fe^{2+}_{0.50}Ti_{0.30})_{\Sigma 13.00}$-$(B_{2.63}\square_{1.91}Al_{46})_{\Sigma 5.00}[(Si_{17.96}Al_{0.04})_{\Sigma 18.00}O_{68.00}[O_{7.19}(OH)_{2.02}F_{0.79})_{\Sigma 10.00}$. ***Relationship to other species:*** A boron-dominant analogue of vesuvianite.

Name: For the locality. ***Comments:*** IMA No. 97-026. The mineral has been considered as a variety of vesuvianite for many years and specimens are present in large amounts in museum and private collections throughout the world. The drawing produced for this abstract is based on drawings which have appeared in old textbooks. Note that the new unit cell given by Groat *et al.* (1998) requires re-indexing of the forms shown in the older drawings. The paper by Groat, Hawthorne and Ercit(1994) gives full details of the crystal structure.

GROAT, L. A., HAWTHORNE, F. C., and ERCIT, T. S. (1994) The incorporation of boron into the vesuvianite structure. *Canadian Mineralogist* **32**, 505–523. GROAT, L. A., HAWTHORNE, F. C., ERCIT, T. S., and GRICE, J. D. (1998) Wiluite, $Ca_{19}(Al,Mg,$-$Fe,Ti)_{13}(B,Al,\square)_5Si_{18}O_{68}(O,OH)_{10}$, a new mineral species isostructural with vesuvianite, from the Sakha Republic, Russian Federation. *Canadian Mineralogist* **36**, 1301–1304.

Wooldridgeite

Orthorhombic

$Na_2CaCu_2(P_2O_7)_2 \cdot 10H_2O$

Locality: Judkins Quarry, Nuneaton, Warwickshire, England, United Kingdom (national grid reference SP 346 930).

Occurrence: In a calcite-barite-Cu-sulfide assemblage within 20 meters of an unconformity between Precambrian igneous rocks and overlying Cambrian sediments. Associated minerals are: calcite, chalcopyrite, bornite, and barite.

General appearance: Intergrown crystalline aggregates and isolated well-formed equant crystals (50 to 200 microns in maximum dimension).

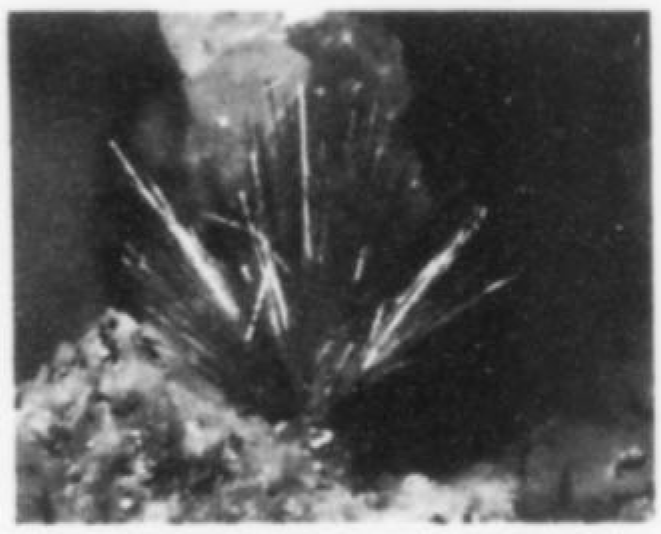
Physical, chemical and crystallographic properties: *Luster:* vitreous. *Diaphaneity:* transparent. *Color:* blue-green. *Streak:* very pale blue. *Luminescence:* non-fluorescent. *Hardness:* 2 to 3. *Tenacity:* brittle. *Cleavage:* none. *Fracture:* irregular. *Density:* could not be determined, 2.26 g/cm³ (calculated). ***Crystallography:*** Orthorhombic, *Fdd2*, *a* 11.938, *b* 32.854, *c* 11.017 Å, *V* 4321.2 Å³, Z 8, *a:b:c* = 0.3634:1:0.3353. Morphology: no forms were identified, but equant "rhombic dipyramids" are mentioned (see Comments). Twinning: none observed. ***X-ray powder diffraction data:*** 8.23 (30) (040), 6.52 (100) (131), 4.05 (40) (260), 3.255 (40) (262), 2.924 (40) (371), 2.807 (25) (173), 2.614 (20) (333, 044). ***Optical data:*** (See Comments). Biaxial (+), α 1.508, β 1.511, γ 1.517, 2V(meas.) 76.2°, 2V(calc.) 71°; dispersion none; nonpleochroic; orientation, X = *b*, Y = *c*, Z = *a*. ***Chemical analytical data:*** Means of an unspecified number of sets of electron microprobe data: Na_2O 8.33, K_2O 0.17, MgO 0.24, CaO 7.73, CuO 20.24, P_2O_5 39.37, H_2O 24.72, Total 100.80 wt.%. Empirical formula: $(Na_{1.96}K_{0.03})_{\Sigma 1.99}Ca_{1.00}(Cu_{1.85}$-$Mg_{0.04})_{\Sigma 1.89}P_{4.04}O_{14.00} \cdot 10H_2O$. ***Relationship to other species:*** It is the second pyrophosphate found in Nature; the other is canaphite.

Name: For James ("Jim") Wooldridge (1923–1995), a keen amateur mineralogist and gemmologist who discovered the mineral. ***Comments:*** IMA No. 97-037. The "rhombic dipyramids" mentioned in the paper are not permitted by the crystal class. The pseudo-bipyramidal crystals illustrated in the SEM image probably consist of two rhombic pyramids, possibly {221} and {22$\bar{1}$}. The mineral is stated to be biaxial (-), but the data show that it is biaxial (+); it has been corrected here. The paper by Cooper and Hawthorne (1990) gives full details of the crystal structure.

(continued on facing page)

MINERALS & SUPPLIES

Chalcophyllite - Rancagua, Chile



Tuperssuatsiaite- Aris Quarry, Namibia

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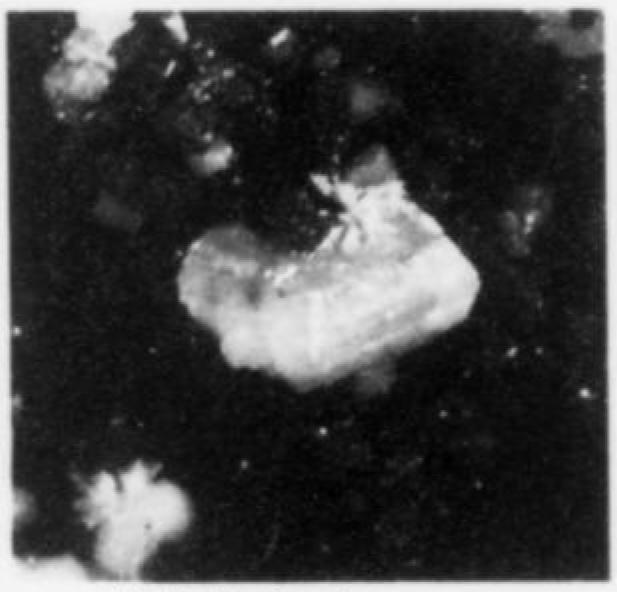

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cont. from p. 206

COOPER, M. A. and HAWTHORNE, F. C. (1990) The crystal structure of wooldridgeite, $Na_2CaCu_2^{2+}(P_2O_7)_2(H_2O)_{10}$, a novel copper pyrophosphate mineral. *Canadian Mineralogist* **37**, 73–81.

HAWTHORNE, F. C., COOPER, M. A., GREEN, D. I., STARKEY, R. E., ROBERTS, A. C., and GRICE, J. D. (1999) Wooldridgeite, $Na_2CaCu_2^{2+}(P_2O_7)_2(H_2O)_{10}$: A new mineral from Judkins Quarry, Warwickshire, England. *Mineralogical Magazine* **63**, 13–16.

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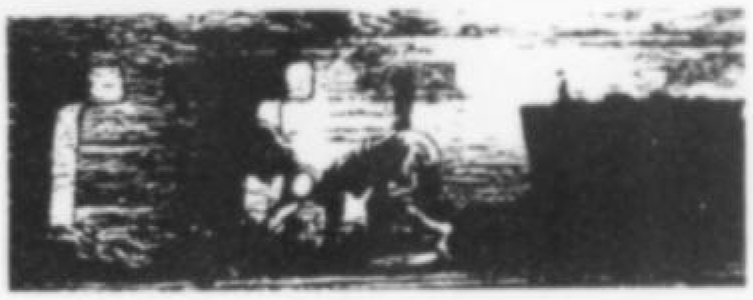

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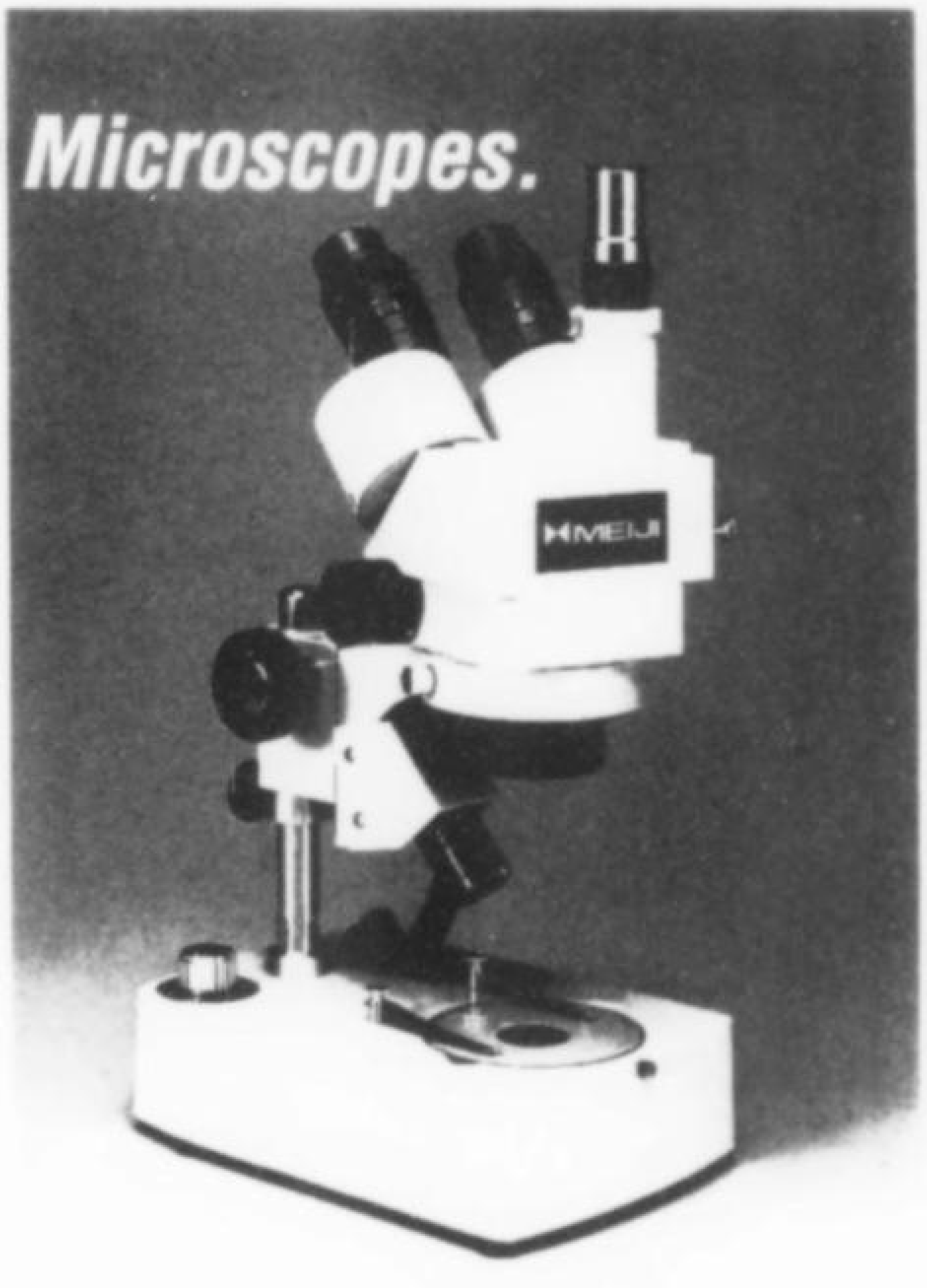
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Letters

THE EARTH GALLERIES

Your recent review of our *Earth's treasury* exhibition (vol. 30, no. 5, p. 373) was so overwhelmingly negative that it would serve little purpose to respond to it point by point. As with any complex exhibition project, there are aspects of the gallery we are not yet satisfied with and are taking action to improve. Nevertheless, the tenor of your review is so much at odds with that of other reviews and—most importantly—with the positive reactions of the visiting public and professional mineralogists alike, that we cannot allow its overall conclusions to go unchallenged.

In particular, we do not share John S. White's condescending view of the public, whom we invariably find to be challenging and discriminating. Nor do we have sympathy with his sterile approach to mineralogy, which appears to divorce the discipline both from modern earth sciences and from the real world in which we live. We take it as axiomatic, that we must not only show fine examples of minerals and gems, but that we must also explain their structure, their chemical and physical properties, the processes by which they were formed over geological time, and their use and significance in contemporary life.

Professional mineralogists and the general public alike have responded enthusiastically to *Earth's treasury*, as they have to the entire set of seven galleries that comprise the Museum's new Earth Galleries. We hope very much that your readers will visit our *Earth's treasury* and make up their minds for themselves, and also that they will continue to visit our fine systematic displays of minerals in our Waterhouse Building which, contrary to John S. White's insinuation, we have no plans to remove.

Neil Chalmers, Director
Giles Clarke, Head of Exhibition and Education
The Natural History Museum (London)

J.S. White's response:

I don't know where Drs. Chalmers and Clarke are taking their soundings, but I would like to point out that I have been overwhelmed with favorable reactions to my review of the British Museum's mineral gallery: that is, full agreement. These have come from other curators, mineral dealers and collectors, not all of them British. There has not been a single dissent, not one! Nothing I have written and published has ever generated so much supportive commentary. In addition, I have been told that museum staff report that they have been inundated with complaints, in spite of what Drs. Chalmers and Clarke choose to believe.

I guess they felt they must register some sort of protest, no matter how disengenuous. What is more disheartening than their failure to accept reality is the discovery that the designer of the British "bomb" is now trying to persuade other museums to allow him to do similar things in exhibition halls in their institutions.

Editor's comments:

I must point out that Chalmers and Clarke's second paragraph takes issue with statements not made in the review. Mr. White did not criticize the idea of having exhibits which explain mineral and gem structure, properties, uses and formative geological processes. These are well accepted features in many museums' exhibits. His complaint was about how incompetently that task and others were addressed in the Earth's treasury *gallery.*

The mineral community will be delighted to hear that the old systematic mineralogy hall is to be retained. It is a wonderful antique in itself, well worth preserving for historical purposes, and still very effective at doing one of the main things that a museum should do: showing specimens. The museum administration should be complimented for recognizing its value, and deciding to keep it intact.

We recently planned a trip to England, and expected that the highlight of our travels would be the new gem and mineral exhibit at the Natural History Museum, London. It was disappointing to read John White's critical commentary and review in the September-October issue, but we were determined not to pass up the opportunity to see wonderful specimens in a new environment. Forewarned is forearmed, so we brought with us small high-powered flashlights.

We entered the museum and found ourselves surrounded by heavy metallic architecture. The overall appearance of the hall is dark, with poorly lighted displays. We whipped out our flashlights, very thankful for John's earlier observations. Nevertheless, we were totally unprepared for the heavy metallic stands which relegated the minerals to a less important role, and our flashlights provided little help for specimens mounted ten feet from the ground. The contents of the cases were generally obscure.

Working diligently, we were still able to make out most of the specimens, one way or another. But the gallery is totally lacking in fine barite, bournonite, witherite and liroconite, and even the Weardale fluorites left much to be desired. Labels are missing or incomplete, and are not easily correlated with the specimens they describe. We did see some outstanding California golds from the Red Ledge and Eagle's Nest mines.

There was little to hold us for a prolonged visit, so we spent a while chatting with museum employees who seemed overwhelmed by the negative comments received from visitors.

Architectural design credit for the gallery is attributed to "Bentham Design." Obviously this designer does not comprehend the true purpose of such a gallery: the aesthetically pleasing presentation of fine gems and minerals in well designed cases with good lighting and labeling.

Roz & Norm Pellman
Green Valley, AZ

Having visited the new Earth exhibit at the Natural History Museum, London (not once but twice, the second time with a flashlight), we can agree completely with every word of John White's review. If anything, the experience was worse the second time, because many specimens had become rather dusty in the intervening months. And it only gets worse with prolonged exposure to the absolutely abysmal way the minerals are displayed. It serves no purpose to sugarcoat the mineralogical holocaust that has been perpetrated over there, and the powers that be should become aware of what they are responsible for. The English appear to renovate halls every century or so, whether needed or not, and so we will have generations of would-be collectors and enthusiasts turned off by the dark and dusty ill-conceived displays they have foisted on museum goers.

It was a great relief to go see the *old* mineral hall, with its bright natural light and its antique cases, liners and labels. There are still many superb specimens in that old hall.

Cal and Kerith Graeber
Fallbrook, CA

I think the review by John White does a real service. The "visible" mineral collection still on exhibit in the old mineral hall is one of the really great treasures for the study of minerals. Goodness knows how much I have learned and discovered from it over the years. The richness of forms and localities and varieties for each mineral species is extraordinary. In fact, I have been able to discover the locality, formerly lost, for many of my specimens and the specimens in my friends' collections by comparison.

One example is a large, fabulous pyromorphite that used to be in Cliff Kruger's collection. He had it labeled as from "Bersheba, Germany." There is no such place. German place names ending in "a" occur only in Thuringia and Sachsen-Anhalt, and a few in Saxony, and none are localities for pyromorphite except Tschopau (unlikely to have been misread for Bersheba). In the old British Museum exhibit I found its exact mate, from "Beresofsk," Russia, a name which, in old German script, looks very similar to "Bersheba." Cliff had obtained the old specimen from Ward's, who did not furnish an original label (which probably said simply "Beresofsk" with no country name, since everybody a hundred years ago knew that was in Russia). The Ward's labeler, unfamiliar with the locality, assumed it must be in Germany and attributed that country name.

I think the *new* displays in the gem and mineral hall were done by window dressers for a department store. Not that the labels in the *old* exhibit were always good, but at least they were there, and one could see the specimens. I remember meeting Arthur Kingsbury there in the early 1960's; he invited me to look at the exhibit with him, saying: "Let's look at the minerals and sneer at the labels!" He died only a few months later, a great loss.

Kay Robertson
Los Angeles, CA

Many of us in the UK were interested to read John S. White's well-deserved diatribe on the British Museum (N.H.)'s new mineral and gem gallery in South Kensington.

When the new exhibit was originally being planned a few years ago, many of us, being aware of the non-mineralogical personnel behind and responsible for the proposed re-vamp of the world's greatest mineral displays, were filled with apprehension over what might materialize as an outcome. Some, including myself, were moved to go into print over the known intentions and the crack-pot ideas which had inspired the projected design of the future display. What we now have has confirmed our worst fears of a few years ago.

John White, among much else, made reference to the absence of terms such as "Mineralogy, Geology, etc." from relevant exhibition literature as being considered "off-putting" to the visiting public. This is symptomatic of a latter-day pernicious creeping disease besetting our modern society—some of us call it "Dumbing Down."

Jim Knight
Manchester, England

BOGUS MINERAL STAMPS

For your stamps "mini-show" heading the *Letters* column, please avoid the bogus non-postal stickers purportedly issued by non-existent postal authorities. There are so many nice mineral stamps issued by legitimate countries, that there is no need to promote the illegitimate ones.

Sten-Anders Smebs
Uppsala, Sweden

In the September-October issue I noticed several non-legitimate postal stamps above your *Letters* column. These are labeled with the names of Russian republics which do not actually issue their own postage stamps. They are being printed by a person in England who has been passing them off as real postage. The collector value of the so-called "Cinderella" stamps is virtually zero, and they should be considered as fakes or frauds, but some people do collect them as examples of "mineral art."

Here is a list of countries for which non-legitimate postal stamps have been printed in London: Abkhazia, Adigey, Altai, Bashkortostan, Batum, Buriata, Chechenia, Crimea, Dagestan, Evenkia, Ingushetia, Jewish Republic, Kalmykia, Kamchatka, Karakalpakia, Karelia, Karjala, Komi, Kuril Island, Mordovia, Sakhalin, Tartarstan, Tuva, Turkmenistan, Udmurtia and Yakutia. (Turkmenistan does have a recognized postal authority, but they have never issued mineral stamps.) I own some stamps from places such as Sahara and Kosovo which, though not yet recognized by the United Nations as independent states, have issued their own stamps which for the moment I keep as legitimate.

Robert Nowakowski
Roseville, MI

PINK CALCITE & DOLOMITE

For collectors of Katanga minerals the articles on cobalt and cobaltoan species in your July-August issue were very stimulating. Professor Douglass must be particularly commended; by the study of the rather limited quantity of materials made available to him (supplied solely by Gilbert Gauthier), he has taught something new to us.

We knew for a long time (from R. Oosterbosch) that the pink crystals, locally called "sels roses," were dolomite, and we had really never seen cobaltoan calcite before the incredible find in Mashamba West and more incidently in Mupine (November 1984). In calcites, the color seems restricted to pink, though in variable degrees (intensity), while in dolomites the shades were quite varied, the color imparted to solid compounds by cobalt seeming to remain a real challenge.

Present and past simple acid tests based on the differences in behavior of carbonates, performed on crystal and matrix as well, confirm the results of Dr. Douglass. To attack magnesite, boiling at least once is required. That is just what was experienced with the dark magenta rounded crystal aggregates supposed to be sphaerocaltite. Likewise, a collector's method of softening the matrix before trimming cobaltoan dolomite specimens was to put their bottoms in hydrchloric acid after having protected with margarine the crystals and the portion of the matrix one wanted to keep.

The trick worked well with some pieces. But with others (at first sight those from the Western Sector) no attack could be observed. The matrix remains as hard as before. Many tests would of course be necessary to reach a firm conclusion. Nevertheless, this confirms that the matrix is quite heterogenous.

Testing the resulting solutions with ancient wet chemical methods, accessible to collectors, could also be rewarding for divalent cations. As an example, Mg is easily detected (even quantitatively) by precipitation of the ammonio-magnesium phosphate. Testing for cobalt would be much more difficult: as a transition element with two possible valences, it can give rise to many (colored) chemical complexes in solutions.

Joseph Lhoest
Liège, Belgium

CHONDRODITE INDICATOR

I found an item in Tom Moore's Tucson Show review (May-June 1999) to be most interesting. His description of the spinel with associated chondrodite from Burma and the use of chondrodite as an indicator of spinel by Burmese miners reminded me of a field observation that I've made good use of. As an avid collector of minerals in the marbles in northern New Jersey and southern New York State, I've noticed that chondrodite is a good indicator of mineralization in general and when phlogopite is present also, spinel is usually nearby. I saw the specimens available from *Miner K* at Tucson, and the calcite chondrodite matrix looked very familiar. I only wish the red, gemmy Burmese spinels looked as familiar!

Dave Wellbrock
Summit, NJ

DEER HILL CLOSED

I have just been notified by the District Ranger that Supervisor Donna Hepp of the White Mountain National Forest has closed to collecting the locality known as Deer Hill, in Stow, Maine. This area has produced fine amethyst crystals and top-quality faceting-grade amethyst for over 100 years. The present plan is to reopen the area in the spring of 2000.

I would like to represent all those who wish to see the area reopened. Please write to me [Nicholas Rochester, 403 Main St., Oxford, ME 04270]; the more letters and signatures that I can get advocating the reopening of the locality, the more likelihood there will be of success. All letters will be brought to the attention of National Forest authorities.

For additional information contact Thomas Malecek, White Mountain National Forest, Saco Ranger District, 33 Kancamagus Highway, Conway, NH 03818.

Nicholas Rochester
Oxford, Maine

COMPLAINTS WE LIKE

I have been subscribing to the Record for over 20 years. As the saying goes, "If it ain't broke, don't fix it!" The only complaint I have is that my mailbox only gets an issue once every two months. For a mineral junkie like me, that isn't quite enough of a fix! Just keep on doing what you do so well, and thanks for all the great issues you have already put out.

Alfred L. Ostrander

To address that complaint I recommend buying one old back issue that you haven't seen, every two months. Between the old and the new you then get an issue once a month, and build toward a complete set at the same time. If you already have a complete set, pull out an old issue that you haven't seen in a long time and read it over cover-to-cover. You'll be surprised what you missed the first time. Ed.

FLAMBEAU CHALCOCITE

This letter is in response to one written by Shawn M. Carlson, which appeared in the Sept.-Oct. 1999 issue. In that letter is a misleading sentence and I quote: "In truth, the potential of the Flambeau mine to be a "Wisconsin Tsumeb" was recognized long before Casey and Jane Koeppe Jones were even aware of the deposit." This is simply not true. Furthermore, the segment "Collecting History" which appeared in vol. 30, no. 2, 1999 within the excellent article co-authored by the Joneses and La Berge is indeed accurate as reported. I should know, as I was the project geologist, manager, and consultant for almost the entire project's history. I personally logged every hole drilled on site and reported in *Wisconsin Geoscience* (Vol. 1, No. 1) in 1997 that chalcocite occurs as "irregular steely masses, as thin coatings on bornite or pyrite, and as sooty films and fracture fillings." No mention was made of any chalcocite crystals as none had been noted. The *Geoscience* article did report the presence of tetragonal microcrystals of chalcopyrite on bornite. Confirmation drilling conducted in the late 1980's did reveal, for the first time, the presence of chalcocite crystals up to 1.5 mm in length.

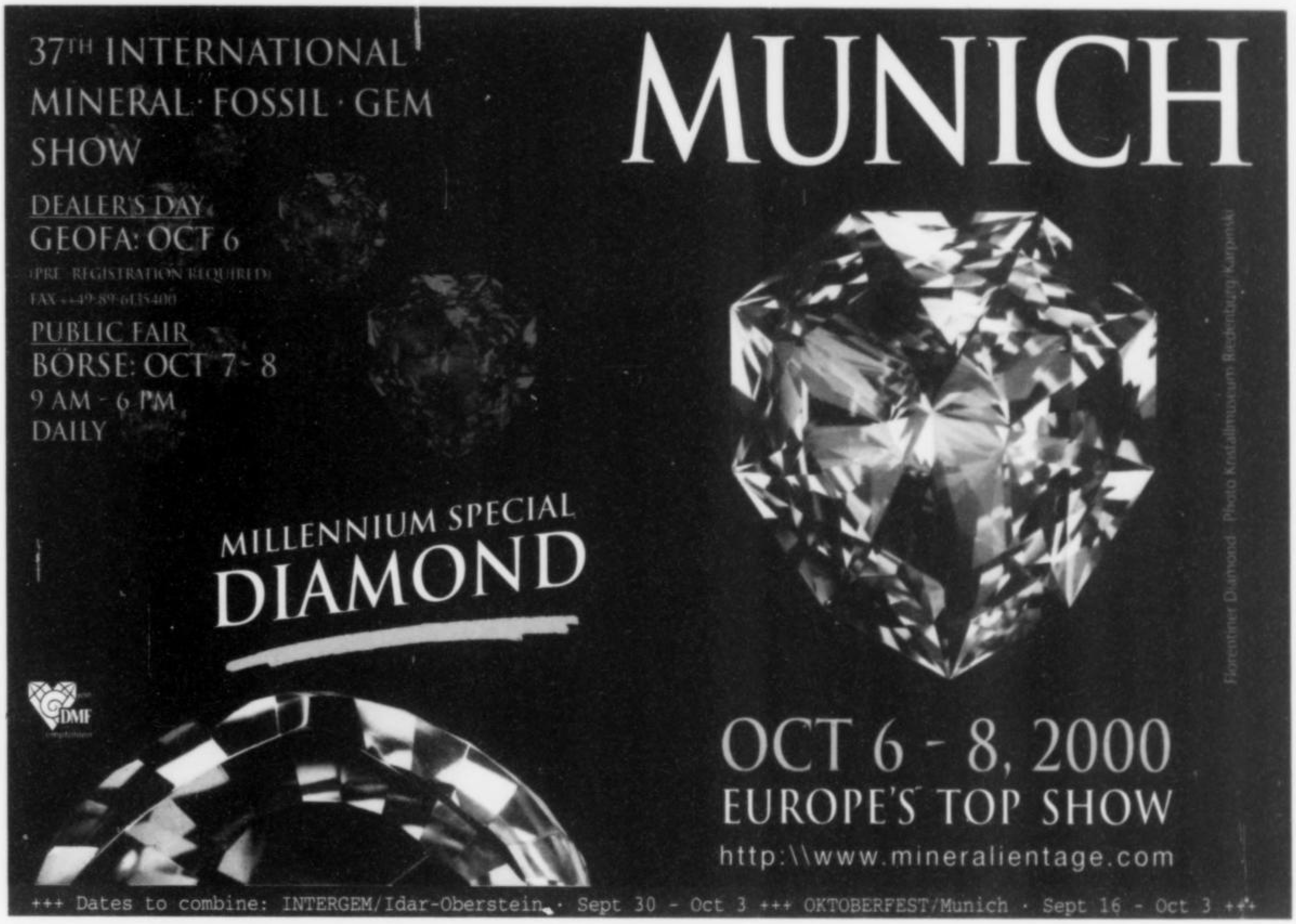
A few days before Casey and Jane contacted the mine, a small pocket of steely gray chalcocite crystals was collected. A number of these crystals reach 6 to 19 mm in length, and a specimen was placed in the mine's visitor's center showcase. This was the first indication any of us had that the Flambeau mine contained exciting and collectable crystals. None of us were prepared, however, for the quality of chalcocite that Casey and Jane recovered at the end of June from the First Pocket, nor what followed thereafter and reported in your vol. 30, no. 2.

I was also on the ad hoc mine committee that processed all requests for the right to recover mineral specimens. Yes, there was a change in management shortly before Casey and Jane contacted the mine. We refocused our search not only on potential collectors that had stature and recognition within the industry, but equally important was that such collectors had strong and proven ties to the educational community. Flambeau mine management was insistent that our supergene suite of minerals be made available as educational specimens.

All this came quickly to fruition in mid-June 1994 when the first sizeable mineral crystals of any importance were collected just before Casey and Jane contacted the mine. Their former employer was a well known supplier of educational mineral specimens, a tradition that Casey and Jane continue today through their company *Geoprime*. Casey also had nearly 25 years of fine mineral collecting, acquisitions and selling experience. After their arrival on site, Casey and Jane not only recovered and supplied world-class specimens to the serious collector but have also prepared and shipped thousands of pounds of ore samples to national and international learning institutions as far away as Sweden, Hong Kong, Germany and Japan.

In summary, Kennecott was fortunate to receive from this team a blend of fine mineral collecting expertise and genuine educational involvement. I agree with Mr. Carlson that the mining industry and mineral collecting communities do indeed owe a deep debt of gratitude. Not only do we owe gratitude to Casey and Jane, who worked sometimes under very harsh weather conditions and very tight mine schedules, but also to Greg Fauquier who as general manager had the foresight to request that a professional mineral collector be retained to preserve this invaluable mineral resource. Thanks to this vision and dedication to mineral collection excellence we today have outstanding Flambeau specimens proudly displayed in private and public collections, and students from high school and college can study this unusual Precambrian supergene mineral occurrence.

Edwarde R. May
Littleton, CO



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