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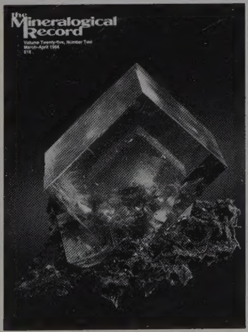
*Continued on p. 159

Articles

Columns



COVER: FLUORITE crystal, 5 cm on an edge, on matrix from Dalnegorsk, Primorski Kraj Russia. Rock Currier collection; photo by Harold and Erica Van Pelt.

Guest Editorial:

COLLECTIONS & THE INFORMATION AGE

Let me begin with a simple statement: most mineral specimens, by far, are in the hands of private collectors and dealers, not museums. This might surprise collectors who have in mind the vast collections of some of the large public museums whose holdings number in the hundreds of thousands. Those large collections, however, represent only a small fraction of public mineral collections; most such museums have only some tens of thousands of pieces.

An informal survey I did several years ago on specimens from several localities where I knew the collecting history suggested that the ratio of private to public mineral specimens was a minimum of 2:1. In fact, my experience makes me suspect that this ratio may exceed 10:1 overall, although this is almost impossible to establish. Given this fact, it is clear that the amateur community is the *defacto,* if temporary, curator for most of our mineral specimen heritage. For that reason I suggest that it is appropriate that amateurs view themselves not just as collectors, but as curators, too.

During the eighteen years that I have been a professional curator there have been many changes in the world in general and in museums in particular. The rate of change is now very fast and it is not always easy, or even practical, for curators to keep pace. One of the most rapidly expanding areas of change is in the field of information management, made possible by electronic computing. This continually evolving technology, coupled with decreasing hardware prices, has made previously unimaginable computing power accessible to the average curator and collector.

I have seen these changes first-hand. Shortly after assuming my curatorial responsibilities I designed and implemented one of the first comprehensive electronic databases for a mineral collection. That first, mainframe-based system has since evolved to a comprehensive, PC-based, image-capable system which can elegantly accommodate all types of information with virtually no practical limits. Although my own museum has been "paperless" since 1976, the recently evolved capabilities of hardware and software have resulted in some fundamental changes in how I document and use my mineral collection. Even more importantly, my perception of what the collection is for and how it may be used have also changed. My feeling is that many of these changes in perception are also relevant to the amateur collecting community.

This leads me to my theme of information technology. I will ask a question: "What types of information are embodied in mineral collections?" An excellent suggestion of this was given by Wendell Wilson in these pages in his discussion of "Connoisseurship in Minerals" (vol. 21, no. 1, p. 7–12). To put it succinctly, mineral specimens may embody all of the following types of information: technical, historical, anecdotal, geographical, economic, visual and cultural. This is a wide range of information, all of which can now be *practically* documented using off-the-shelf computer hardware and software.

Information in many of the categories above is immediate and not derivative, meaning that it is rapidly lost if not documented soon after a specimen is obtained, either in the field or from a dealer. One of the keys to collecting information is to do it interactively and continuously as specimens are acquired and used. Modern computer software makes this possible and *practical*. Remember that the computer not only minimizes the input of information, it makes a variety of output even easier. A standard "catalog," cross-referenced on the categories of your choice, can be generated with the click of a mouse.

The ways in which specimens can be used depends upon the level of documentation and how accessible that information is. Accessibility refers not only to the ability to call up the information on a given specimen, but also group data in a variety of ways, and to reveal patterns and relationships easily and quickly. Finally, true accessibility also involves the capacity to provide information to those outside the museum, in accordance with *their* needs. Again, modern computer technology provides *practical* means by which this can be accomplished.

What kind of software should you use? This matters far less than it used to. Modern, off-the-shelf database software includes products such as Superbase, Paradox, FoxPro, Access and dBase, to name a few of the best-known. All of these are extremely sophisticated products which can handle information of all types, including images. All are available in PC-based versions. To use them, however, you will have to learn some database basics, but a simple system is a simple matter. To design a comprehensive relational database, however, will require a considerable expenditure of learning time and development effort.

What are your options if you don't want to design your own system? There are currently only a few commercial mineralogical packages available, at varying levels of sophistication. I offer a museum-oriented system, for example, which is probably more elaborate and expensive than most private collectors require. So, if you want to start going electronic, find out what is available and decide whether it improves upon the system you already use. If it does, consider using it. Once your data is electronic it is a relatively simple matter to transfer the data to another "platform" in the future. A cardfile always stays a cardfile.

Mineral collections are relatively little used and among the most poorly documented in the natural sciences. In a world of diminishing resources, museums are being asked to do more with less or even redefine their function. Although this can be a productive exercise, mineral collections are vulnerable to cost-cutters because they are perceived as static and one-dimensional. For those of us who value them, making sure that they are active and vital may furnish the political clout necessary for their continued survival as a public resource.

As a bottom line of this discussion I make a number of pleas:

(1.) Document your collection as comprehensively as possible: the information in your head will not survive if it isn't written down; it is this information which may determine the long-range importance of your collection.

(2.) Use electronic means to document your collection. This makes it easier for you and also makes your collection more valuable to others, including (perhaps eventually) a museum.

(3.) If you are uncomfortable with computers, seek help to get started. Even if this help costs a bit of money, it is well spent if it makes it possible for you to take your knowledge and pass it along to the next owner of your specimen(s).

Your mineral collection is a valuable resource. During your lifetime it is personal, but at some time in the future it will (hopefully) become a part of our collective mineral heritage and thus accessible to a wider audience. Your specimens are a reflection of your passion, and good documentation will better allow that to be transmitted to future generations.

As a final comment, I want to note one more thing: a well-designed database which allows you to effortlessly view your collection in a variety of ways is a lot of fun!

Joe Nagel
Curator, M. Y. Williams Geological Museum
University of British Columbia
Vancouver, B.C., Canada

notes from the EDITOR

FOUNDER FORMS CONSULTING PARTNERSHIP

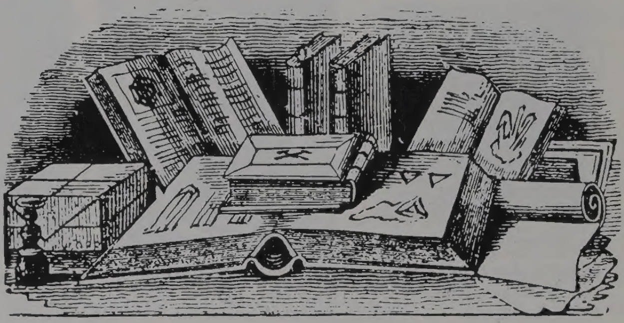
What of *Mineralogical Record* founder and former Smithsonian mineral and gem curator John Sampson White? The report of White's plan to open a retail store in the Baltimore area (vol. 22, p. 331) following his retirement from the Smithsonian after 28 years, as it turns out, was premature for he opted to begin a consulting business instead. He is teamed with Joe Nagel, of British Columbia, in a partnership called *Kustos*. The partners offer a variety of services and programs in the areas of mineral and gem collection management, exhibition and evaluation. There is such an opportunity for diversity in this work that White and Nagel also find themselves engaged in planning special shows, editing texts, fund-raising, settling disputes, buying for both museums and private collectors, and promoting a museum computer system designed by Nagel, a system that has been adopted by a number of institutions already, including the Colorado School of Mines and the Virginia Polytechnic Institute. (See the guest editorial in this issue.)

White has been particularly active, having appraised the Sams Collection at the Houston Museum of Natural Science and the Folch Collection in Barcelona. He was the technical consultant for the Discovery Channel's interactive library video disk on the "Planet Earth" series. He was instrumental in steering the Herb Zuhl petrified wood collection to the Houston Museum. He worked as an adjunct curator at the Science Museum of Minnesota (in St. Paul), resulting in the opening of a new mineral and gem gallery there in March of this year. He is currently adjunct mineral and gem curator at the New Mexico Museum of Natural History.

Internationally, White has been spreading his influence as well. He is a member of the Board of Advisors to the Jewelry Trade Center in Bangkok, Thailand. He is cooperating with Johannes Keilmann, the producer of the Munich mineral show, in attempting to attract special exhibitors from this country and in writing materials for the show catalog. He is the technical consultant and designated curator for GEMART, a French-sponsored plan to create a major exhibition of the works of the best craftsmen of Idar-Oberstein. The exhibition will travel to many cities in the U.S., Canada and probably, ultimately, Europe and Asia. White is also helping a Brazilian collector to develop and plan the display of what will be an important mineral collection in São Paulo.

Amidst all of this White still has time to write an occasional article for some of the popular journals, assist in editing manuscripts for books that are in progress, and participate in either gemstone mining in Oregon or dinosaur digging in Wyoming. He is credited with creating the concept of and participating in the development of the *Treasures at Tucson* video, and has offered assistance with some details of the new *Collecting Earth's Natural Treasures* video, both the work of Ray Albrechtsen's Creative Vision Company.

The United States address of *Kustos* is P.O. Box 332, Stewartstown, Pennsylvania 17363 (telephone 717-993-6930; fax 717-993-9036). Joe Nagel can be reached at 2961 Semiahmoo Trail, Surrey, British Columbia V4A 1H4, Canada (telephone 604-531-6879).



BACK ISSUE SETS

Those of our readers who have subscribed just in the last few years, and who daydream about someday assembling a complete set of back issues, may feel a bit intimidated by the size of the task before them. We are, after all, about to complete a quarter century of publication, and that's a lot of back issues! But take heart! The very fact that we have been around as long as we have means that some of our earlier subscribers are now getting on in years, and that they (or their executors) are more often putting complete sets on the market than we used to see. Prices seem to range between $1,200 and $1,600 (bearing in mind that condition is important). People wishing to purchase a complete set should put their name in with book dealers who advertise in these pages; a set will more than likely become available in a reasonable period of time.

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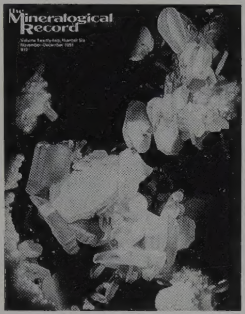

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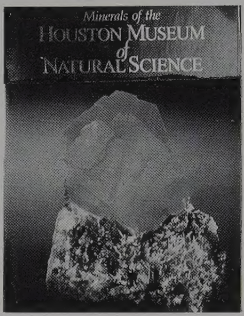

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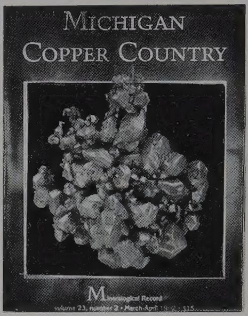

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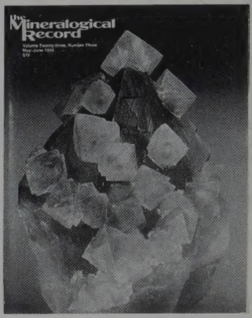

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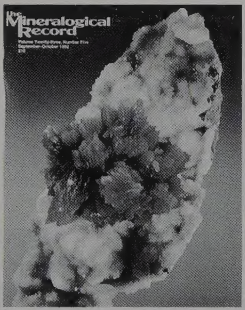

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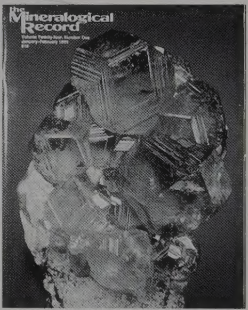

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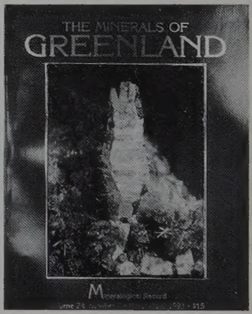

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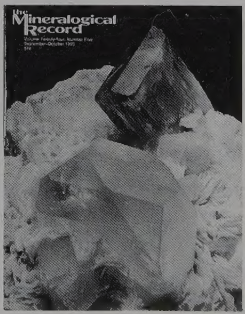

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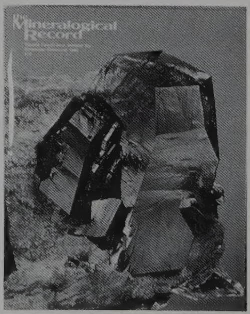

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QUASICRYSTALS:
NOVEL FORMS OF SOLID MATTER

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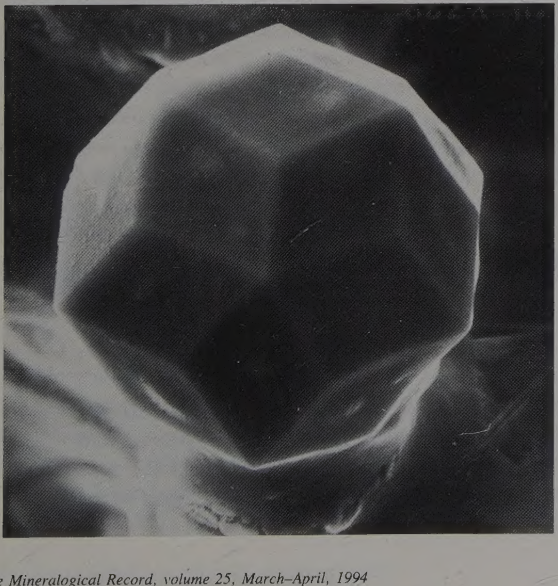
An ordered state of solid matter called quasicrystalline, discovered in the early 1980's, possesses symmetries forbidden in crystals. The growing number of quasicrystalline compounds and the variety of methods used to synthesize them in the laboratory suggest that quasicrystals may be an as yet undiscovered facet of the mineral kingdom.

INTRODUCTION

Since the time of René Just Haüy (1743–1822) it has been generally recognized that the wonderful polyhedral shapes of crystals and their naturally occurring planar faces are a manifestation of their internal atomic order. On the other hand, amorphous solids (glasses) such as obsidian have a very disordered internal structure, and do not naturally occur in the polyhedral shapes we so readily identify with crystals. Until the recent discovery of "quasicrystals," solids have been identified as being either crystalline or amorphous. Quasicrystals, however, are less ordered than crystals but are more ordered than glasses. Perhaps their most striking feature is their appearance as certain polyhedral shapes that are *not* allowed in crystals. For examples, the shape of the Al-Li-Cu quasicrystals in Figure 1 is called a triacontahedron, possessing 30 equivalent faces and six axes of 5-fold rotational symmetry (Fig. 2), a symmetry forbidden in crystals.

BACKGROUND

In his works, Haüy championed the theory that for a given mineral, any of its varied crystal shapes could be constructed by the appropriate stacking of many identical building blocks or integrant molecules (*molécules intégrantes*) of the same orientation (Fig. 3). Based on such constructions, Haüy proved that the regular icosahedron and dodecahedron (Platonic solids which possess 5-fold symmetry) violated his law of rational intercepts, and thus are impossible shapes



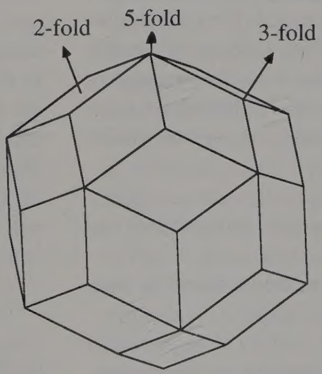


Figure 2. **An idealized triacontahedron with one of its six 5-fold axes indicated.**

Figure 1. **SEM photo of an isolated, triacontahedral quasicrystal of $Al_{5.1}Li_3Cu$ made at AT&T Bell Laboratories. The grain is 0.1 mm across. SEM photo courtesy of A. R. Kortan, AT&T Bell Laboratories.**

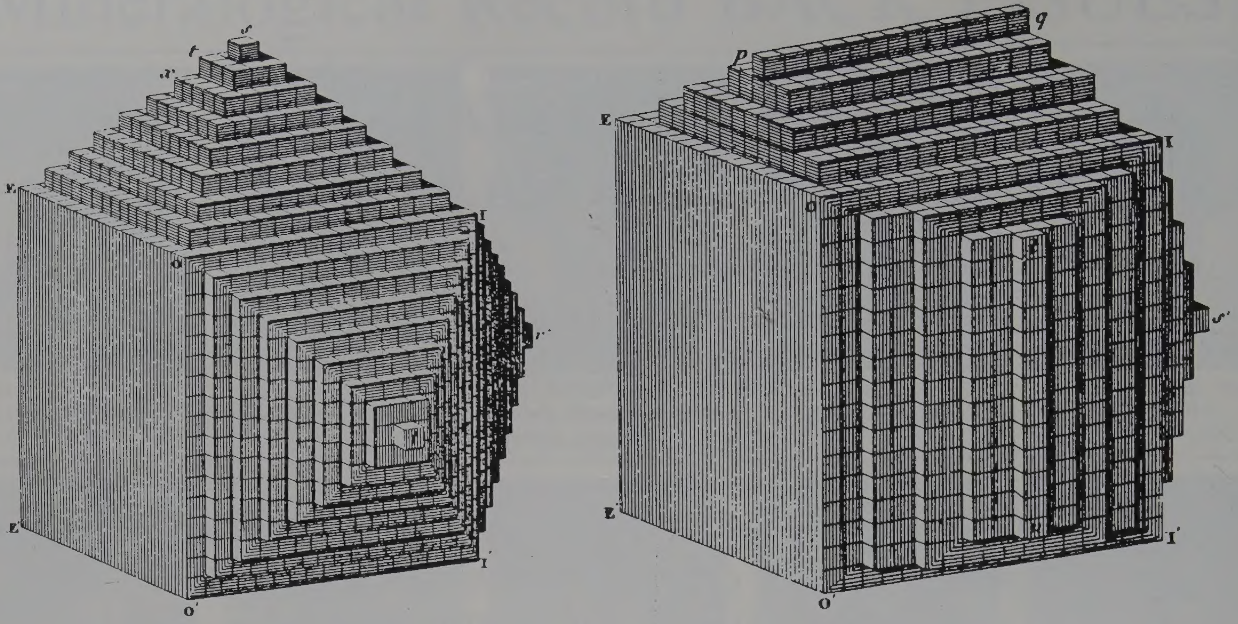
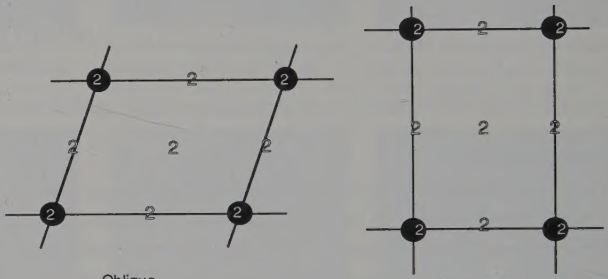


Figure 3. **An illustration of Haüy showing how stacking integrant molecules can account for the habit of crystals (Haüy, 1801).**

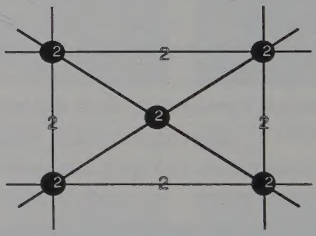
for crystals (Haüy, 1801).[1] Subsequently, the existence of flat faces on crystals has become intimately associated with their being composed of a regular stacking of a single type of building block for a given crystal. Haüy's concept of an integrant molecule has since developed into what is known today as the unit cell—a hypothetical volume decorated with atoms, which when many are stacked together in the same orientation, make up the entire crystal structure. In an infinite crystal, each unit cell has the same surroundings as every other unit cell. One can then imagine a point (say at the center of each cell) as representing the position of each unit cell. This set of regularly spaced points is known as a lattice. If one imagines moving from one lattice point to another by going a certain distance in a certain direction, one will always come to another lattice point by again going the same distance in the same direction but starting from any other lattice point—a property called *periodic translational symmetry.* Using the fact that each point in a lattice has the same surroundings as every other point, Auguste Bravais (1811–1863) showed that there are only fourteen different lattices in three-dimensional space.[2] In two-dimensional space there are only five different lattices (Fig. 4).

Throughout the early development of the science of crystallography the classification of crystals based on their external form has played an important role. Christian Samuel Weiss (1780–1856) and Frederick Mohs (1773–1839) set up classifications based on the concept of external symmetry, and laid the foundation for the mathematical treatments of the 19th century. The external symmetry of crystals[3] can be

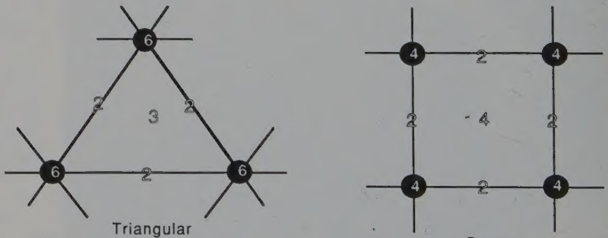


Oblique

Rectangular



Diamond



Triangular

Square

Figure 4. **The five two-dimensional lattices: square, triangular, rectangular, centered and oblique. The numbers correspond to the type and position of rotational symmetry axes of the lattice.**

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[1] For a detailed history of the science of crystals, Burke (1966) and Schneer (1977) are highly recommended.

[2] Illustrations of the fourteen Bravais lattices can be found in most introductory mineralogy texts.

[3] Since the conditions in which crystals grow, such as close proximity to other crystals or a varying chemical composition or temperature, can distort their shapes compared to what their shapes would be given enough room in a uniform environment, the following discussion refers to ideal crystals—those whose internal structures are without defects or flaws, and that grew in such a way that their external form is consistent with their internal symmetry.

understood in terms of two basic symmetry operations: rotation and reflection. A crystal has rotational symmetry about an axis (an imaginary line through the center of the crystal) if it repeats itself in appearance[4] one or more times as it is rotated one complete revolution about that axis. Axes of rotational symmetry are classified according to the number of times a crystal repeats itself in appearance during such a rotation about the axis. For example, a crystal with 3-fold symmetry will repeat itself in appearance three times when rotated by 360 degrees about a 3-fold axis. A crystal has reflection (or mirror) symmetry if a plane can be found which divides the crystal into two halves which are mirror images of each other. The cube, for example, has six mirror planes perpendicular to its six 2-fold axes, and three mirror planes perpendicular to its three 4-fold axes. Other symmetry operations can be derived by combining rotations and reflections into a single operation, e.g., inversion symmetry can be thought of as a 2-fold (180 degree) rotation followed by a reflection through a plane perpendicular to the rotation axis.[5] Various minerals possess different groupings of the symmetry operations, and it is these groupings which determine a crystal's allowed forms, such as cube, tetrahedron, pinacoid, etc. Johann F. C. Hessel in 1830, and Bravais independently in 1848, mathematically proved that there were *only* 32 possible different groupings of the symmetry operations in crystals. These different groupings are known as the *32 crystal classes* (Buerger, 1956; Boisen and Gibbs, 1985).

There are two main reasons why the number of crystal classes is limited to only 32. First, the set of symmetry operations in a class must not generate an infinite number of equivalent crystal faces. This would occur, for example, if one combined a 4-fold axis perpendicular to a 6-fold axis. The second reason is more basic to the very nature of crystals. Since by definition crystals are composed of a stacking of identical unit cells on a lattice, only 1-fold, 2-fold, 3-fold, 4-fold and 6-fold symmetry axes are allowed. These are precisely the rotational symmetries of the fourteen Bravais lattices. To illustrate why the concept of a lattice limits the rotational symmetries, consider the two-dimensional lattices in Fig. 4. All of the allowed rotational symmetries are represented. Notice that each unit cell (lattice point) has identical surroundings as every other unit cell (lattice point), as is required. Figure 5, on the other hand, illustrates what happens when a unit cell with 5-fold symmetry is used to try to form a lattice. Here, the pentagonal "tiles" neither fit together to fill the plane, nor do all the pentagonal tiles have the same surroundings as every other tile. While some tiles have five tiles bordering them, others have as few as two. Furthermore, some pentagons actually overlap each other. Similar problems occur when one tries to form a lattice out of unit cells with 7-fold or higher symmetry. Thus, 5-fold, 7-fold, and higher rotational symmetries are not allowed in crystals.

One might wonder why the concept of the lattice has been kept since it is so restrictive. After all, is nature *constrained* to grow ordered solids based on lattices or a single unit cell? In 1912 Max von Laue predicted that the orderly arrangement of atoms on a lattice should diffract a beam of X-rays in a mathematically predictable pattern of spots that could be verified by exposing a photographic plate to the diffracted X-rays (Arem, 1971). Within the year von Laue, Walter Friedrich and Paul Knipping confirmed the hypothesis experimentally and set the concept of the lattice on firm ground (Ewald, 1962). In addition, the symmetries of the crystal are clearly evident in the symmetry of the diffraction patterns. Since amorphous materials diffract X-rays in only diffuse rings, it became commonly believed that only structures that were based on a lattice could produce a diffraction pattern of spots. In the following years, X-ray analysis proved to be immensely successful in determining the crystal structure of hundreds of thousands of compounds. Thus, in a system where crystals are defined as being structures based on a lattice, the empirical *observation* that 5-fold symmetry did not seem to occur in solids became a law that ordered solids *could not* have 5-fold symmetry.

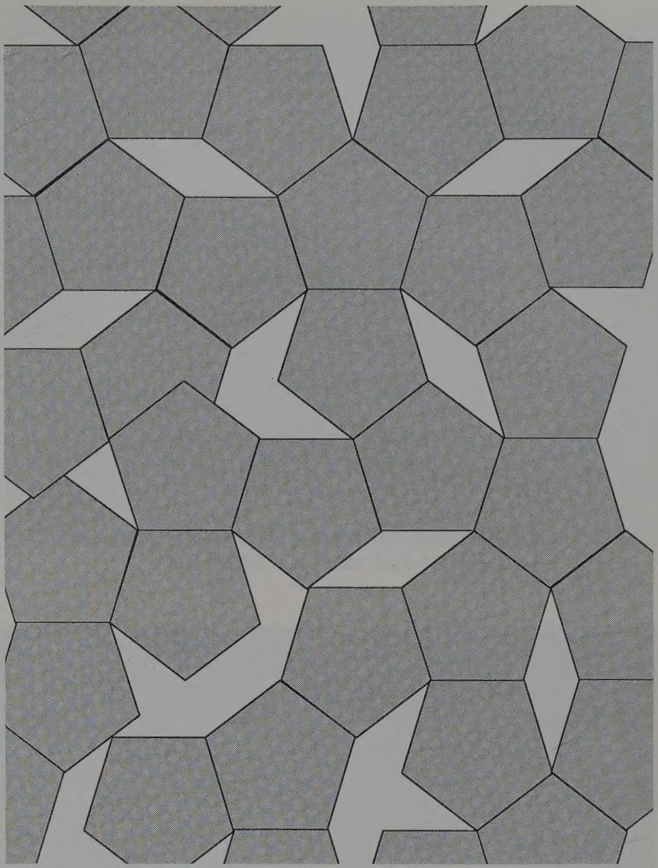

***Figure 5.* A two-dimensional pattern formed by trying to "tile the plane" with cells that have 5-fold symmetry.**

A NEW ORDERED STATE OF SOLID MATTER

Given the mathematical foundation and the phenomenal experimental successes of crystallography, it is no wonder that the world of crystallography was taken by surprise in November, 1984 when D. Shechtman, I. Blech, D. Gratias and J. W. Cahn at the U.S. National Bureau of Standards (now the National Institute of Standards and Technology) announced that they had observed 5-fold symmetry in rapidly cooled alloys of aluminum with 10 to 14 atomic percent manganese, iron or chromium (Shechtman *et al.*, 1984). Using electron diffraction (which is similar to X-ray diffraction) these alloys were shown to have the symmetry of the icosahedron. The icosahedron is a Platonic solid with six 5-fold axes through the vertices, ten 3-fold axes through the centers of its triangular faces, and fifteen 2-fold axes through the edges (Fig. 6). A sample diffraction pattern is shown in Fig. 7. Because the quasicrystals also possess inversion symmetry, the diffraction pattern along a 5-fold axis appears to have 10-fold symmetry.[6] A diffraction technique called "convergent beam" electron

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[4] More precisely, the rotated crystal *structure* must appear to be in the same orientation as the unrotated structure in order to truly possess the symmetry. For example, even though pyrite forms cubes, its structure does *not* possess 4-fold symmetry. This fact is revealed, for example, when pyrite cubes are striated, or by the pyritohedron itself.

[5] See Arem (1971) pp. 63, 192 for illustrations.

[6] It is interesting to note that, in 1956, X-ray photographs of a disordered crystal of bushy stunt virus showed a symmetrical pattern of 10 spots among diffuse rings (Caspar, 1956). D. Shechtman first observed the 10-fold diffraction pattern of his Al-Mn alloy on April 8, 1982 (La Brecque, 1987/8).

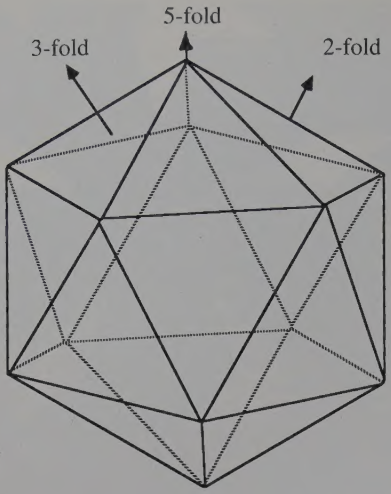

Figure 6. **The icosahedron showing one of its 5-fold axes, 3-fold axes and 2-fold axes.**

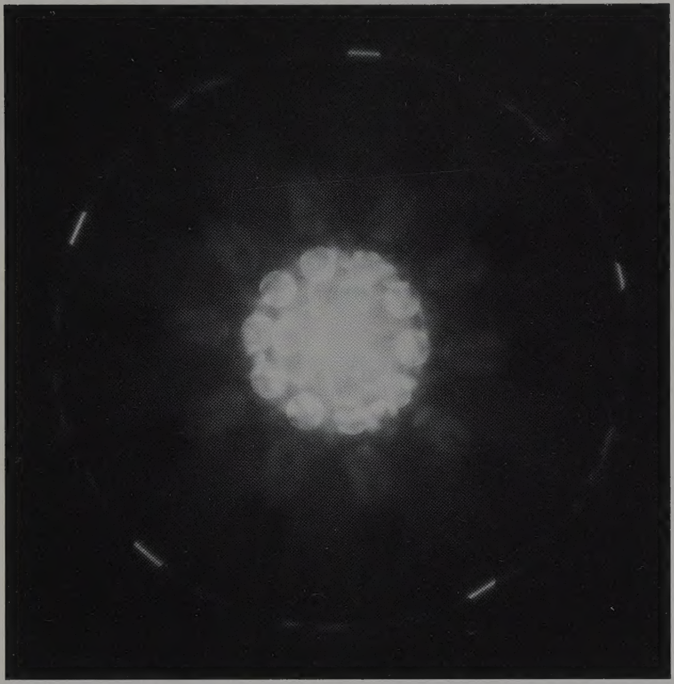

Figure 8. **Convergent beam electron diffraction pattern of Al_6Li_3Cu along a 5-fold axis. Note the clear 5-fold symmetry in the outer diffraction ring. Courtesy of Frank W. Gayle, Reynolds Metals Co.**

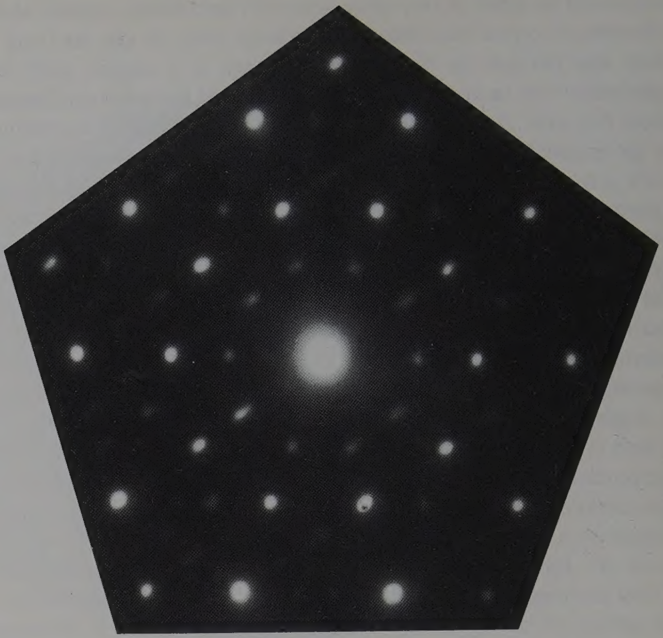

Figure 7. **Electron diffraction pattern of Al_6Li_3Cu along a 5-fold axis. Courtesy of Frank W. Gayle, Reynolds Metals Co.**

diffraction can distinguish the difference between 5-fold and 10-fold and clearly shows the 5-fold symmetry in Fig. 8 for the Al-Li-Cu alloy.

Since 1984, immense interest has been generated among crystallographers, chemists, physicists, mathematicians, metallurgists, and materials scientists in this new class of compounds that exhibits symmetries forbidden in crystals. Through all the effort, dozens of alloys have been synthesized which possess 5-fold (icosahedral), 8-fold (octagonal) (Wang *et al.*, 1987), 10-fold (decagonal) (Bendersky, 1985; Chattopadhyay *et al.*, 1985; Schaefer and Bendersky, 1986; Kortan *et al.*, 1989b), and 12-fold (dodecagonal) (Ishimasa *et al.*, 1985; Chen *et al.*, 1988) symmetries. Among the icosahedral alloys, which comprise the largest group, are compositions Al-M (where M = Cr, Mn, or Fe), Al-Cu-Li, Al-Cu-Fe, Al-Cu-Ru, Ga-Mg-Zn, Al-Pd-Mn, Ni-Ti-V, Pd-U-Si and others. Octagonal quasicrystals have been formed with alloys of V-Ni-Si and Cr-Ni-Si, whereas decagonal quasicrystals are alloys of Al-Mn, and Al-Cu-M, where M = Mn, Fe, Co, or Ni. Docecagonal alloys have been made using V-Ni-Si, V-Ni, and Ni-Cr. While the compounds with these symmetries can not be crystals—based on the well established framework of crystallography, their diffraction patterns of rather sharp spots (Fig. 7) reveal an ordered atomic structure. Thus, the term "quasicrystal" has generally been applied to these compounds. Nature does not, in fact, appear to be constrained to grow ordered solids based only on lattices and single unit cells. As will be discussed below, crystallographic concepts can be generalized to allow for the new structures, by allowing, for example, two or more unit cells to form the entire structure. In fact, the crystallographic concepts of space groups have recently been generalized to include the new symmetries (Mermin, 1992).

In addition to the kinds of quasicrystals produced, the methods of producing quasicrystalline alloys have also steadily increased over the years. The first quasicrystals were made by rapid solidification methods, such as spin quenching, whereby the molten alloys are sprayed onto a rapidly spinning chilled copper wheel producing metallic ribbons. Other methods have been developed which include ion-beam mixing, laser quenching, sputtering, ion implantation, solid-state reaction, and casting.

Of great current interest are the icosahedral alloys, Al-Li-Cu (Dubost *et al.*, 1986; Gayle, 1987), Al-Cu-Fe (Tsai *et al.*, 1987; Ebalard and Spaepen, 1989), Ga-Mg-Zn (Ohashi and Spaepen, 1987), Al-Cu-Ru (Guryan *et al.*, 1989), Al-Pd-Mn and Al-Pd-Re (Tsai, *et al.*, 1989) which appear to be thermodynamically stable—a property often thought to be reserved for crystals. Also of great interest is the recently discovered stable decagonal alloy Al-Cu-Co (Kortan *et al.*, 1989b). In contrast to the very rapid cooling spin quenching techniques which produce most of the other quasicrystalline alloys as metastable phases (Chen *et al.*, 1985; Knapp and Follstaedt, 1987), the stable alloys are synthesized by a rather slow-cooling casting technique—one which is conducive to the formation of faces in both crystals and quasicrystals. By this method, quasicrystals form wonderfully faceted shapes (shapes with flat faces) that are reminiscent of crystals (despite their lack of a structure based on a lattice), and which reveal their surprising 5-fold (or 10-fold) symmetry.

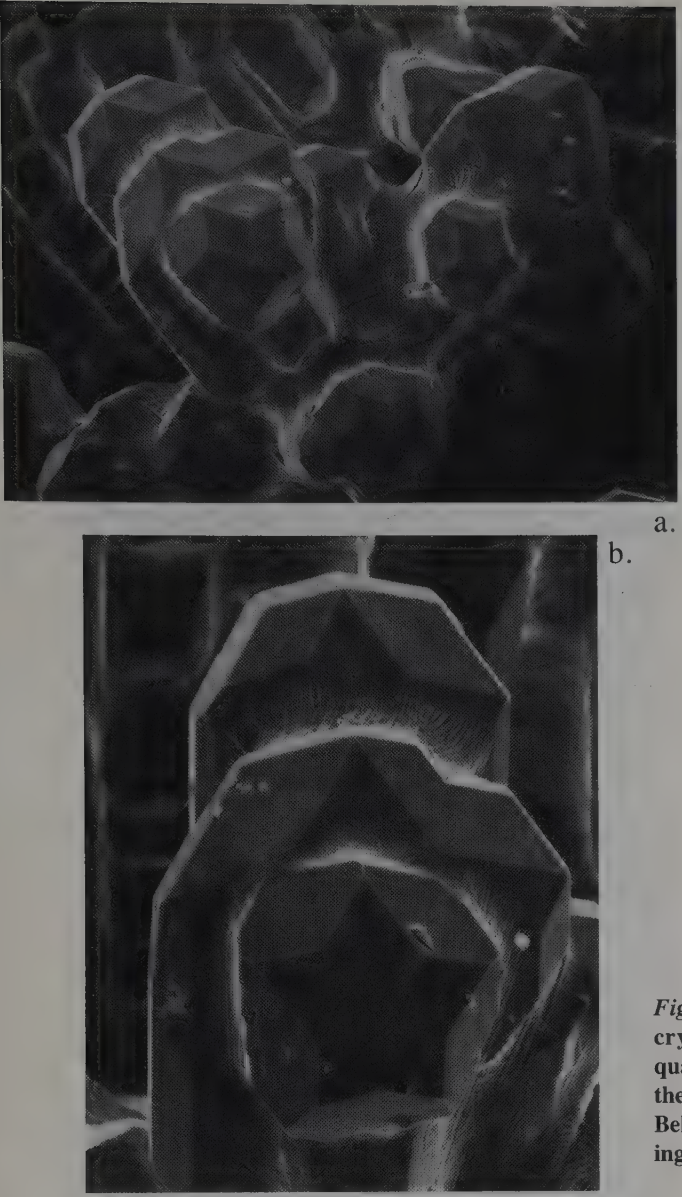

Figure 9. (a) SEM photo of triacontahedral quasicrystal dendrites of Al_6Li_3Cu made at Reynolds Metals Co. by Frank W. Gayle (Gayle, 1987), showing 2-fold faces. The grains are 0.1 mm across. (b) Same as (a) at higher magnification.

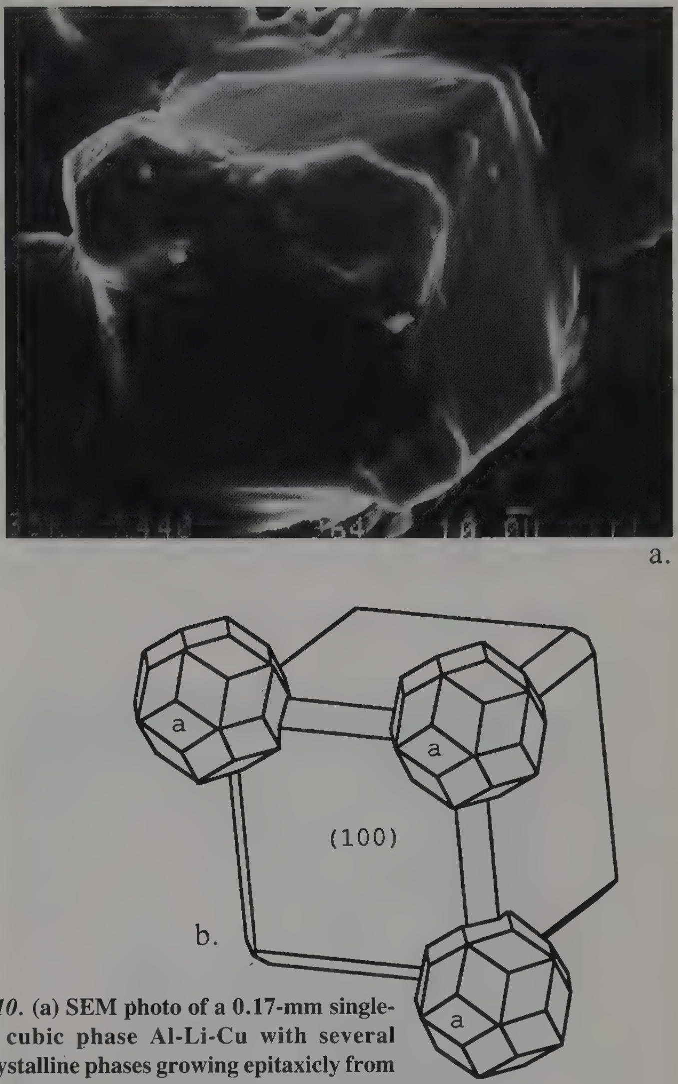

Figure 10. (a) SEM photo of a 0.17-mm single-crystal cubic phase Al-Li-Cu with several quasicrystalline phases growing epitaxicly from the corners. Courtesy of A. R. Kortan, AT&T Bell Laboratories. (b) Idealized SHAPE drawing of the epitaxic relationships in (a).

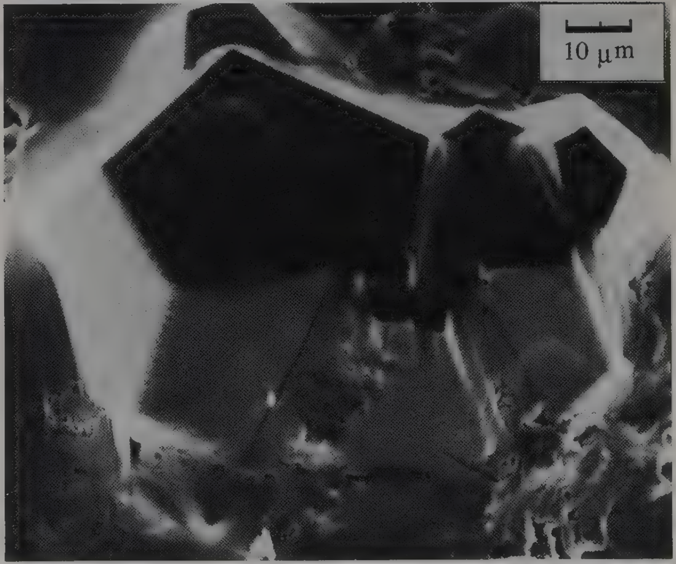

Figure 11. SEM photo of pentagonal dodecahedral $Ga_{1.0}Mg_{2.1}Zn_{3.0}$ quasicrystal, 0.1 mm across (Ohashi and Spaepen, 1987). Courtesy of Frans Spaepen, Harvard University.

Most of the early experiments synthesized, quasicrystals with interesting but highly dendritic morphologies. In 1986, however, crude pentagonal dodecahedra up to 0.01 mm on an edge were observed in Al-Mn-Si quasicrystal alloys (Ishimasa and Nissen, 1986; Robertson *et al.*, 1986). More recent papers report faceted dendrites that resemble stellated dodecahedra (Nishitani *et al.*, 1986; Nissen *et al.*, 1988). The most beautiful morphologies, however, have been observed in the stable phases mentioned above. The Al-Li-Cu quasicrystal has only been observed showing one form—the rhombic triacontahedron (Fig. 1). This 30-faced polyhedron has the symmetry of the icosahedron, as can be seen by replacing the edges of the icosahedron with diamond-shaped (2-fold) faces. The triacontahedra are typically 0.1 mm across, and usually compose coarse dendrites in shrinkage cracks of the cast alloy (Fig. 9).

A cubic crystalline phase of similar composition to the Al-Li-Cu quasicrystal is known to be composed of icosahedral clusters of atoms

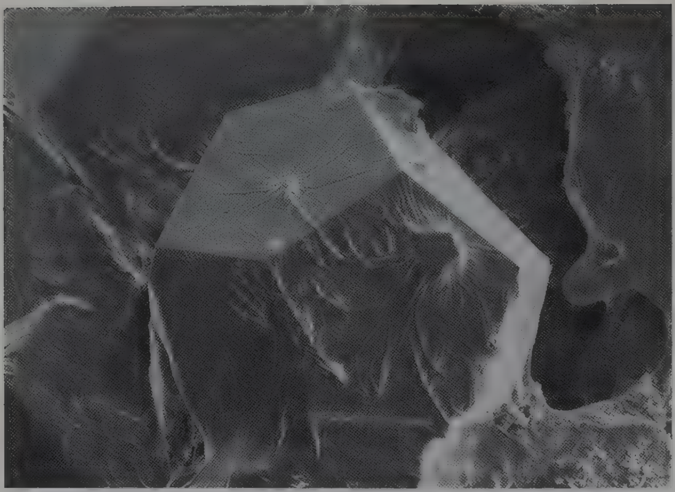

Figure 12. **SEM photo of pentagonal dodecahedral Al-Cu-Fe quasicrystal, 0.1 mm across, made at Reynolds Metals Co. by Frank W. Gayle. Note the small pentagon, rotated by 180°, on one of the pentagonal faces.**

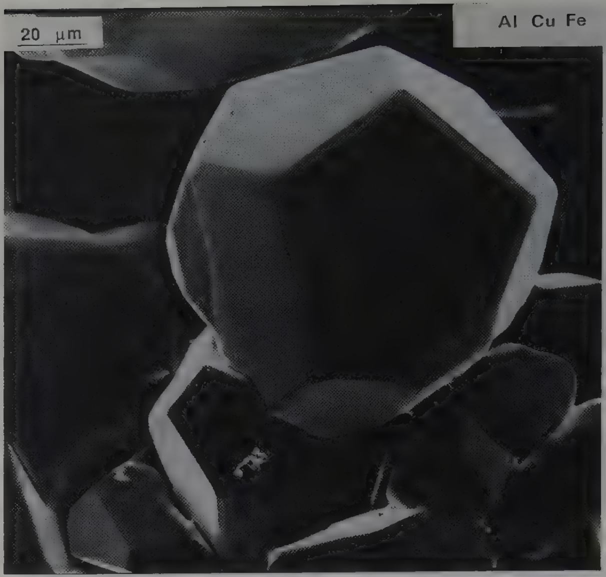

Figure 13. **SEM photo of quasicrystal grains of $Al_{63}Cu_{25}Fe_{12}$ showing 5-fold and small 2-fold faces after annealing for 15 hours at 870C. Courtesy of Annick Quivy, Centre d'études de Chimie Métallurgique, C.N.R.S., France. The size of the largest face is 0.07 mm.**

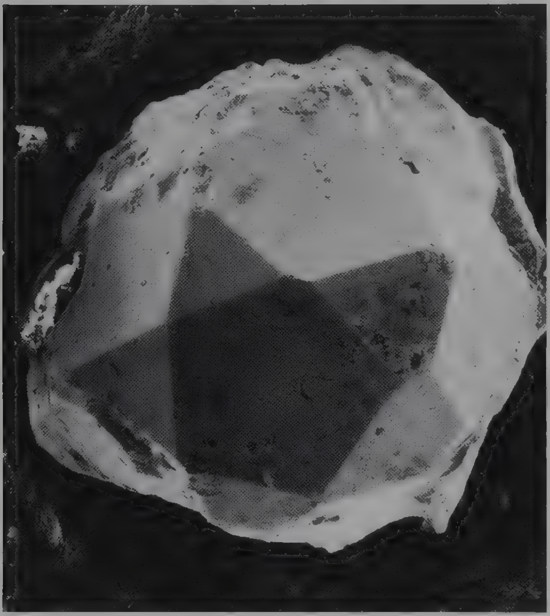

Figure 14. **SEM photo of a quasicrystal grain 0.4 mm wide of $Al_{65}Cu_{23}Fe_{12}$ showing 5-fold and 3-fold faces after annealing for 10 days at 830C. Courtesy of Peter Bancel, IBM.**

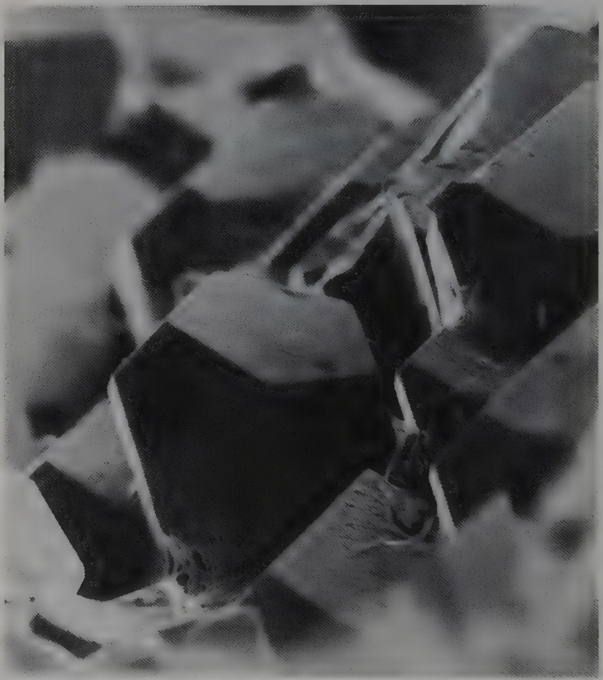

Figure 15. **SEM photo of quasicrystal grains of $Al_{75}Pd_{15}Mn_{10}$ up to 0.08 mm showing 5-fold faces. Courtesy of A. P. Tsai, Tohoku University.**

stacked in a body-centered-cubic lattice (Audier *et al.*, 1986). What is most interesting is that the cubic and the quasicrystalline phases have been found to coexist, and in fact, can grow together in an oriented fashion. Figure 10 shows a single cubic Al-Li-Cu crystal with at least three triacontahedral quasicrystal grains growing epitaxicly on the crystal corners (Kortan *et al.*, 1989a), and is yet another demonstration that the quasicrystals have ordered internal structures.

In contrast to the Al-Li-Cu alloys, Ga-Mg-Zn (Fig. 11), and Al-Cu-Fe (Fig. 12) quasicrystals form regular pentagonal dodecahedra, with faces in the orientation of the icosahedral vertices (i.e., normal to the 5-fold symmetry axes). Recently, the Al-Cu-Fe quasicrystal has been observed to possess faces related by 2-fold axes and faces related by 5-fold axes on a single grain (Fig. 13). In another grain, faces related by 5-fold axes occur with the first observed icosahedral faces related by 3-fold axes (Fig. 14). Very recently, grains to 0.3 mm of icosahedral Al-Pd-Mn alloys have shown either faces related by 5-fold axes, or a combination of faces related by 3- and 5-fold axes, depending on the composition and cooling rate (Fig. 15).

The recently discovered decagonal alloy of Al-Cu-Co, shown in Fig. 16, exhibits elongate 10-fold prisms that are terminated by dimpled pinacoids. The 10-fold faces are often striated and show growth steps. These decagonal quasicrystals are some of the largest yet grown, reaching up to 4 mm in diameter (Kortan *et al.*, 1989b). These remarkable alloys are interesting because their structures are periodic in the direction parallel to the 10-fold axis, but are quasiperiodic in the planes perpendicular to that axis.

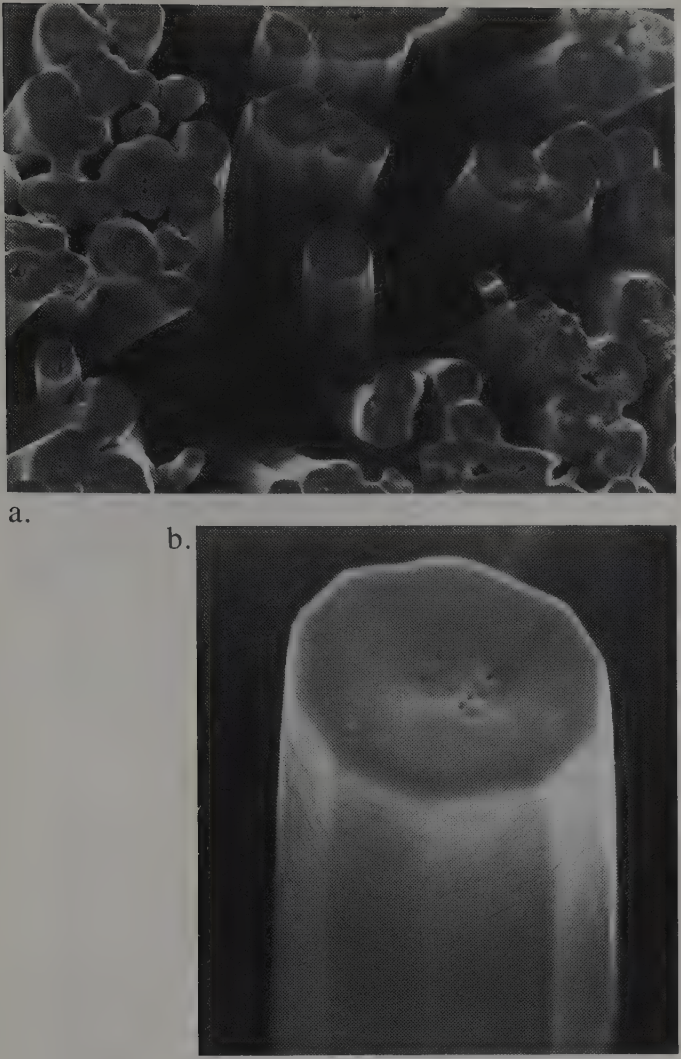

Figure 16. **(a) SEM photo of decagonal grains of Al-Cu-Co which are approximately 0.07 mm across. (b) Enlargement of the decagonal grain in the center of (a). Courtesy of A. R. Kortan, AT&T Bell Laboratories.**

MODELS

Inspired by the *local* icosahedral order in dense liquids (Steinhardt *et al.*, 1981), Dov Levine and Paul J. Steinhardt, independently and simultaneously to the experimental discovery of quasicrystals, found that the ordered yet *aperiodic* Penrose tiling (Fig. 17) and its three dimensional generalizations would yield crystal-like diffraction patterns despite their lack of periodic translational symmetry (Levine and Steinhardt, 1984, 1986). Also independently, Alan MacKay had pondered about the physical realizations of a Penrose tiling as early as 1982 (MacKay, 1982), and Peter Kramer and R. Neri considered three-dimensional generalizations of the Penrose tiling well before the discovery of Schectman *et al*. (Kramer and Neri, 1984).

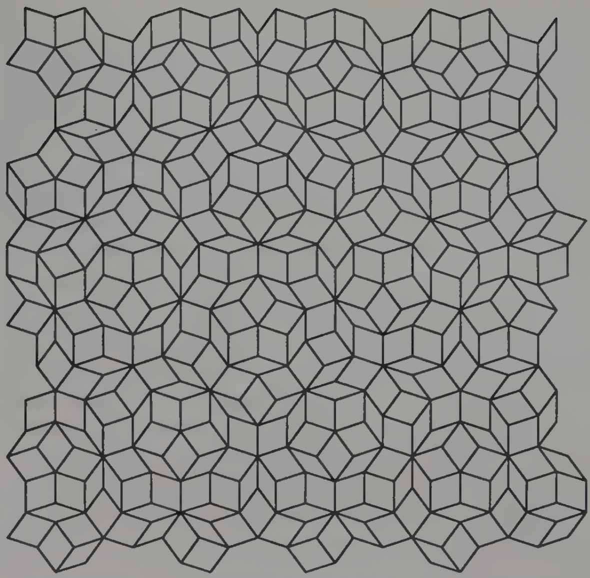

Figure 17. **A portion of the Penrose tiling, made up of only two types of tiles—fat and thin rhombi.**

Penrose tilings, named after their inventor, Oxford University mathematical physicist Roger Penrose, are marvelously beautiful patterns that are constructed out of *two* types of "unit cells" (referred to as tiles) that completely tile the plane in an *aperiodic fashion*.[7] Many of their wonderful mathematical properties have been discussed by Gardner (1977). In these tilings, any particular pattern of any given size always repeats itself again elsewhere in the tiling. Though not periodic, this is a kind of long-range translational order. Another important property is that all of the tile edges are oriented in one of ten directions everywhere in the tiling—a property called *long-range orientational order,* which is 10-fold in the Penrose tiling. Crystals also have long-range orientational order, but as a consequence of their periodic translational symmetry. Ho *et al.* (1987) have shown that the long-range orientational order, and not necessarily periodic translational order (i.e. a lattice), is sufficient for solids to exhibit faces. One can see a special order in the Penrose tiling, and even how faces might be able to exist in structures based on them, by noting the layer-like structure which is manifest when one shades all tiles with edges parallel to a given direction (Fig. 18). It is particularly interesting to note that some shaded layers touch adjacent layers, while others do not. The

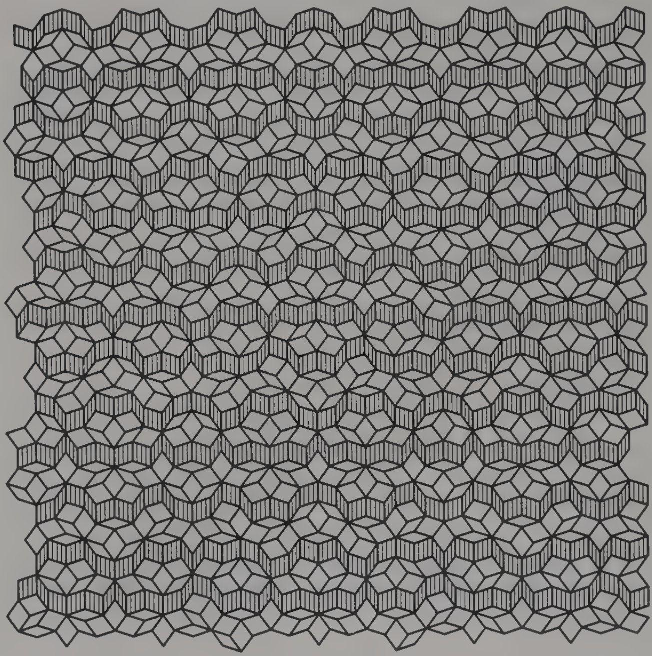

Figure 18. **A Penrose tiling showing a layer-like structure when all tiles with edges parallel to one direction are shaded.**

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[7] A pentagonal aperiodic tiling, related to the Penrose tiling, covers the Blue Tomb at Maragha, Iran, built 1196–1197 A.D. (Makovicky, 1990).

order in which adjacent layers touch or not is not random, but can be described mathematically by the so-called Fibonacci sequence, named after the thirteenth century century mathematician who first studied the sequence (Steinhardt, 1986). Since this order is neither random nor periodic, the Penrose structures are known as quasiperiodic. There are strict matching rules which govern how to assemble the tiles to make a Penrose tiling, and controversy exists over how real quasicrystals can grow while maintaining these complex matching rules (Onoda, *et al.*, 1988, 1989; Jarić and Ronchetti, 1989).

Other models for quasicrystal structure are based on more random systems, or glasses, analogous to the one illustrated in Fig. 5. Glass models constructed by randomly packing icosahedra in the same orientation have been shown to generate fairly sharp diffraction patterns in computer calculations (Shechtman and Blech, 1985; Stephens and Goldman, 1986). These glasses also possess long-range orientational order, and might be expected to form faces as well. However, the glass models appear to have too great a degree of disorder to adequately explain Al-Cu-Fe and Al-Cu-Ru quasicrystals. By flipping groups of tiles in a Penrose tiling (thus breaking the matching rules), a complete spectrum of possible structures can be shown to exist between the ordered Penrose tiling models and the more disordered glass models. These "random tiling models," which fill space in contrast to the glass models, but do not satisfy the strict order of the Penrose tiling, are currently popular because it is suggested that they may be stabilized by entropy (Strandburg *et al.*, 1989).

The atomic structure has not yet been conclusively solved for any of the quasicrystalline alloys, despite extensive studies using X-ray, electron and neutron diffraction, high resolution electron microscopy, and field-ion microscopy. The task is clearly more complicated than for simple crystals since the latter can be described by the periodic repetition of a single unit cell. Quasicrystals do not have a single unit cell, and local structures are not periodically repeated throughout the quasicrystal. The situation is further complicated by the fact that the different quasicrystalline materials may belong to rather different structural classes. It is generally believed, with the exception of supporters of the multiple-twin model (Pauling, 1987), that the icosahedral quasicrystals are some kind of *aperiodic* packing of icosahedral clusters of atoms. A great deal has been learned about the local atomic structures of icosahedral quasicrystals by means of comparison with the known structures of similar crystalline materials which have very large unit cells containing icosahedral clusters of atoms. In particular, the complicated structures of *crystalline* Al-Mn-Si and Al-Zn-Mg compounds, solved some time ago, are body-centered-cubic packings of clusters of atoms. These clusters are composed of two shells of atoms, have icosahedral symmetry about their centers, and are all connected along their 3-fold and 2-fold axes in the crystalline phases. An overall icosahedral order is achieved when crystallinity conditions are relaxed, and the clusters pack more randomly. The close relationship between the crystalline and quasicrystalline phases of Al-Li-Cu alloys (similar to the Al-Zn-Mg alloys) is demonstrated by the epitaxic growth in Fig. 10.

SUMMARY

A new ordered state of solid matter been discovered, which is neither crystalline nor amorphous, and has generally been called quasicrystalline. A wide variety of quasicrystalline compounds, manifesting several new rotational symmetries, have been produced by a number of different techniques. Several stable quasicrystalline materials have been synthesized using conventional slow-cooling methods, and show beautifully faceted surfaces that are reminiscent of crystals. The stability of quasicrystalline materials, their ease of manufacture and their variety of compositions suggest that quasicrystals may be an as yet undiscovered component of the mineral kingdom awaiting the careful inspection of a diligent mineral collector who does not disregard 5-fold symmetry *a priori*.

ACKNOWLEDGMENTS

I am indebted to Drs. Frank Gayle, Frans Spaepen, Peter Bancel, Denis Gratias, Annick Quivy, A. Refik Kortan and An-Pang Tsai for supplying copies of their papers and especially for the wonderful SEM photographs of faceted quasicrystals. Thanks are due also to Frank Gayle for supplying electron diffraction patterns and some actual faceted quasicrystal grains. The encouragement and collaboration of Drs. William F. Saam, Jason Ho, Ying-Hong Li and Bin Yang are also gratefully acknowledged.

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ADDITIONAL READING

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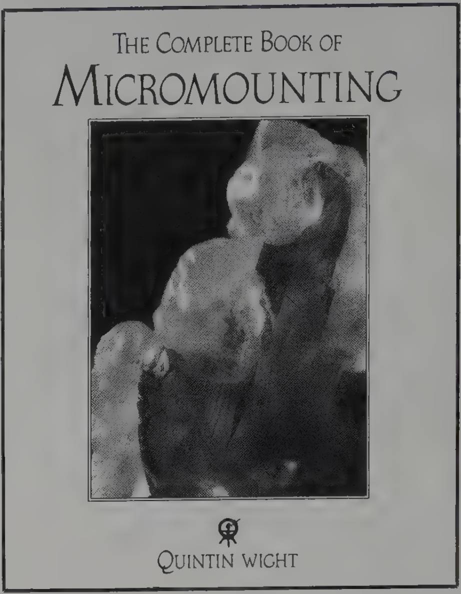

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A COMPLEX BASE-METAL ASSEMBLAGE FROM THE STERLING MINE NEW JERSEY

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The Sterling Hill Cu-Zn-Pb occurrence known locally as the "Chalcopyrite Room" is remarkably complex, with 50 species presently confirmed. The assemblage includes one phase new to Sterling Hill, tetrahedrite, and two additional species—bianchite and rosasite—whose occurrence at Sterling Hill had previously been questioned, but is here verified. A number of the species occur in well-formed microcrystals.

INTRODUCTION

The occurrence of base-metal sulfide minerals and their oxidation products has long been known from Sterling Hill, New Jersey (e.g. Palache, 1935), but these interesting and often colorful minerals have received relatively little attention in the literature of the deposit, perhaps because of their overall volumetric and economic insignificance or because they would appear to have little bearing on the genesis of the zinc orebody. This report therefore describes the geology, mineralogy and paragenesis of a remarkably complex Cu-Zn-Pb veinlet assemblage from the south opening of 1250 stope, a locality known to local collectors as the "Chalcopyrite Room." The name derives from the most prominent, if not most abundant mineral in the exposure at the time of discovery. The name is used for convenience here to distinguish the location from the north opening of 1250 stope, where a second and somewhat different base-metal assemblage occurs which is still under investigation.

The Chalcopyrite Room lies below the east terminus of the 1220 crosscut, 700 level (Fig. 1), along the hanging wall of the East Vein of the Sterling orebody. Secondary base-metal minerals are bracketed by approximate mine coordinates 1225N, 710W and 1290N, 708W, at depths ranging from 770 to 870 feet. Coordinates thus define a total volume of about 35 cubic meters, of which less than 10% is mineralized with the described assemblage.

The site was discovered by personnel of the Sterling Hill Mining Museum in October 1990. Samples were collected extensively until March 1991. The occurrence is now flooded.

GEOLOGY

The geology of Sterling Hill has been discussed by many authors (e.g. Metsger *et al.*, 1958; Callahan, 1966; Metsger *et al.*, 1969). Data bearing on the origin of the deposit have been added by Squiller and Sclar (1980), Carvalho and Sclar (1988), and Johnson *et al.* (1990). Hague *et al.* (1956) and Drake (1990) have given summaries of the regional geology. The reader is referred to these earlier workers for discussion of these general topics. This section will briefly describe only the geologic occurrence of the Cu-Zn-Pb assemblage of the Chalcopyrite Room. A geologic map[1] of the occurrence is shown in Figure 2. Only a portion of the east wall of the stope is shown here.

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[1] North in the New Jersey Zinc Company (NJZC) grid system is 19°5′ east of True North. All locations or structural directions given in this paper are relative to "NJZC north." Also, structural directions

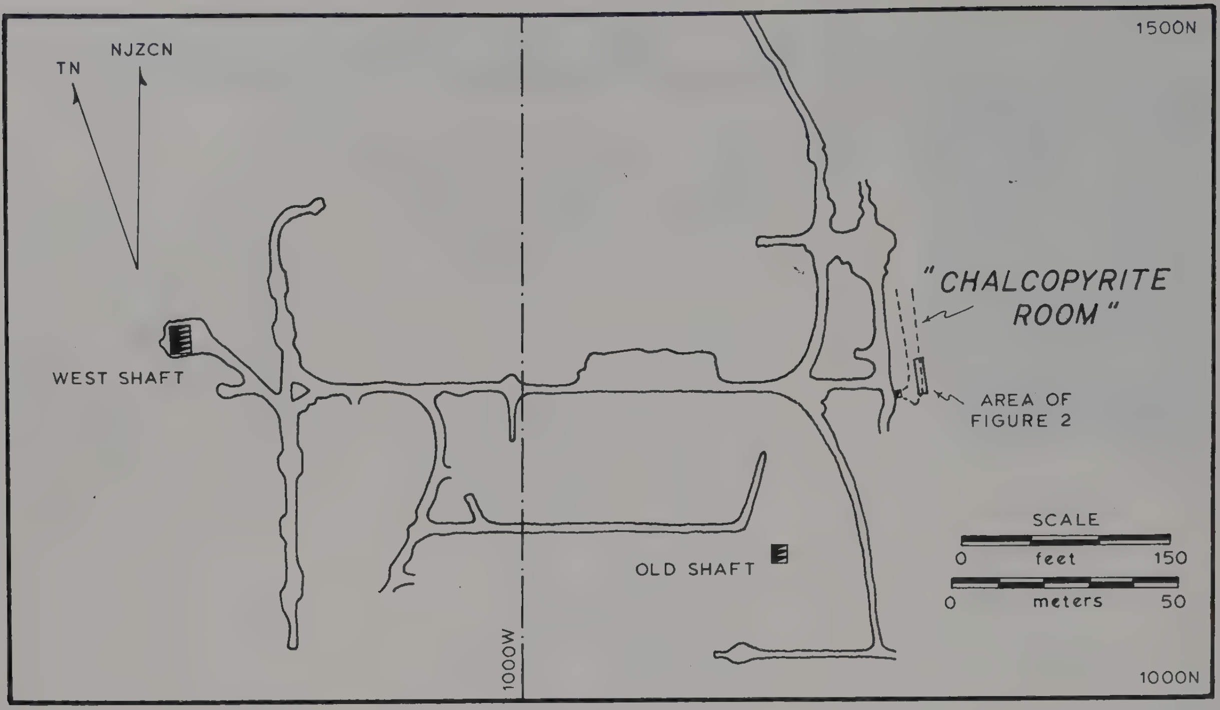

Figure 1. **Drift outlines on the 700 level and location of the Chalcopyrite Room, 70 feet below, Sterling mine (1979–1986, New Jersey Zinc Company mapping, courtesy of Sterling Hill Mining Museum).**

The base-metal assemblage of the Chalcopyrite Room is restricted to the Franklin Marble, at and near the hanging wall contact of the orebody. It is *wholly separate* from the great zinc-iron-manganese orebody which has made Sterling Hill famous. (Note that the term "ore" will hereafter be used to denote the mixture in variable proportion of franklinite, willemite and zincite in calcite which have constituted the economic minerals of the deposit.) Sulfide minerals occur (1) in a shallow trough in the ore-marble contact, generally in marble breccia lying along the contact, (2) in two steeply dipping fractures striking about N35°E, which penetrate that trough, and (3) in several fractures striking about N10°W, parallel to the strike of the orebody, but dipping in the opposite direction. The contact trough is apparently a primary fold of very low amplitude.

Sulfide minerals have formed by open-space filling and by replacement of marble and of one another. They occur as discontinuous stringers, as replacements of breccia matrix, and as more massive lenticular bodies, ranging up to 7 x 40 cm in cross-section. The main segregations of sulfides occur in and near the contact trough. Narrow sulfide-filled veinlets also extend about 20 meters northward from the trough.

Oxidation of the sulfide minerals produced a richly varied suite of secondary minerals. These occur on residual sulfides, dispersed in solution vugs, along fractures, and within calcite cleavage planes. Deposition of secondary species appears to have been controlled by some of the N10°W-striking fractures. Other N10°W-striking fractures are filled with (a) massive secondary carbonate minerals, (b) thin mats of serpentine and earthy red hematite with or without brucite, (c) serpentine plus secondary willemite, or (d) serpentine and intermixed calcite and zincite, the latter the variety known locally as "calcozincite." Secondary ore minerals occur only where openings penetrate ore, and it is a notable feature of the site that where fractures containing secondary ore minerals pass into marble, those species disappear abruptly, and sulfides appear instead. Such abrupt changes from secondary ore minerals to sulfides across the ore-marble contact are not unique to the Chalcopyrite Room but have been documented before, in the 970 stope, East Vein, on the 1000 level at Sterling Hill (E. R. Verbeek and M. A. Grout, written communication, 1991).

Some massive carbonate in fractures appears to be younger than sulfide oxidation, in that oxidation minerals occur on sulfide aggregates cut by those fractures but not in the carbonate filling. Minor alteration of the ore minerals is present adjacent to the sulfide occurrence, including thin hematite rinds on a few franklinite grains and a little serpentine replacing willemite. It is not certain when this alteration occurred.

MINERALOGY

General mineralogy of the Chalcopyrite Room, together with the relative abundance of species, is shown in Table 1. Although sulfide minerals do not occur in ore, the latter species are included in the table because many specimens consist of masses of ore attached to sulfide-replaced marble. Phases of particular mineralogic-paragenetic significance or special collector appeal are described individually below.

The stope exposure and about 600 hand specimens were examined for this study. Of the hand samples, some 60 were studied in detail. To make preliminary mineral identifications, all specimens were ex-

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have been established by distance measurement to planar or linear features, using the south end of the stope as a baseline, drawing rough maps, and later establishing orientation by comparison to NJZC mine level and stope maps, now in the possession of Sterling Hill Mining Museum. Because of errors in the rough drawing, the angular deviation estimated for this process is ±5°.

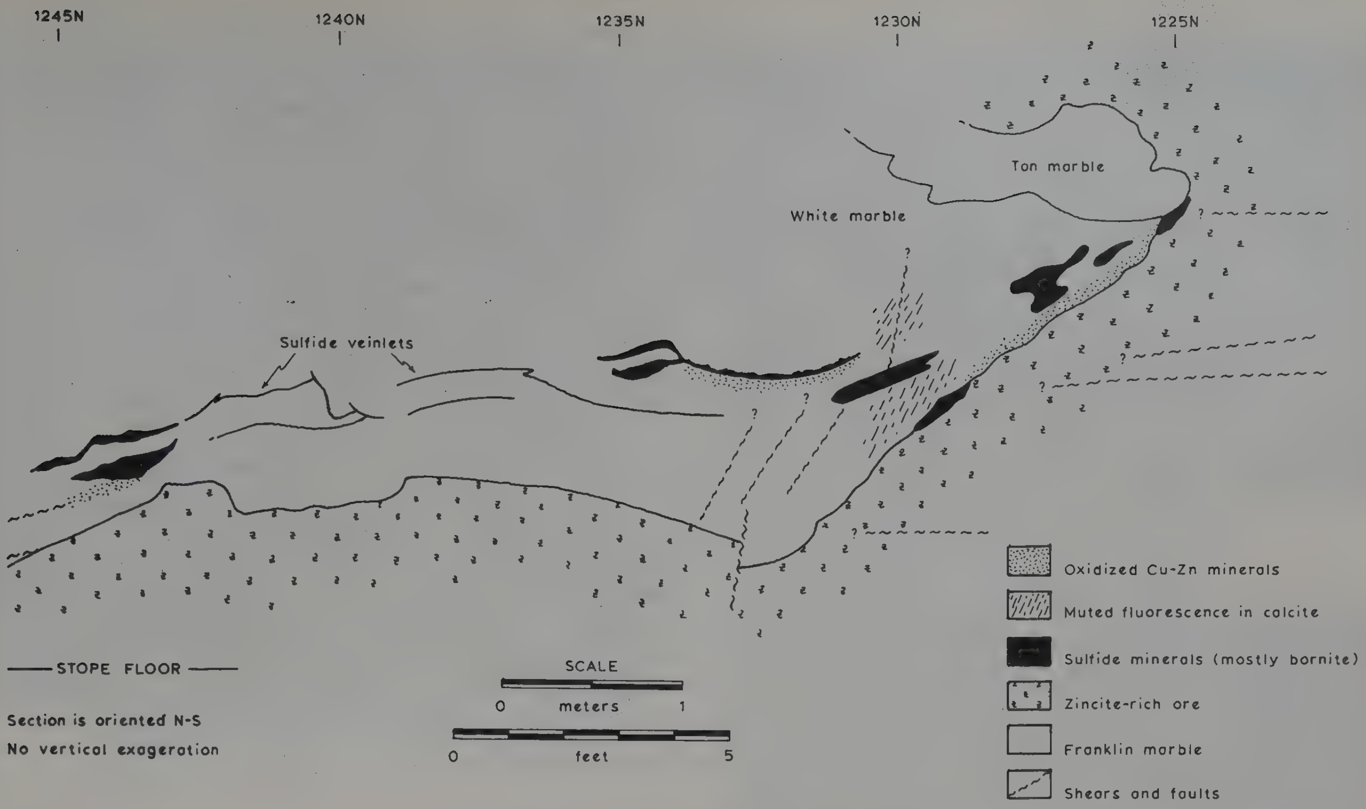

Figure 2. **Geologic map of the east wall of the Chalcopyrite Room, i.e. a vertical section, showing the sulfide occurrence and related features (mapping by Jenkins and Misiur, February 1991).**

amined with a binocular microscope, and in the case of some sulfide-rich samples, polished surfaces were studied with a metallographic microscope. Selected portions of specimens were then studied employing the following methods and instruments: scanning electron microscopy (JEOL JSM-840), electron probe micro-analysis (JEOL JXA-35, with KEVEX EDS detector, DEC PDP-1173 hardware control, and using TRACOR-NORTHERN software), X-ray powder photography and diffractometry (modified Philips Automated X-Ray Diffractometer, with DEC VAS-II hardware control and accepting 114-mm Gandolfi camera).[2] All specimens were checked for fluorescence, under both shortwave and longwave ultraviolet radiation, using Ultraviolet Products UVG-11, UVG-54 (both shortwave), UVL-21 (longwave), and Raytech LW-18L (also longwave). Also used was an experimental UVP lamp, fitted with a new generation filter, belonging to Mr. Richard Bostwick. All samples were studied by a combination of methods, but minerals are only considered verified where positive X-ray diffraction results have been obtained. Two species, although confirmed elsewhere in the Franklin-Sterling Hill area, remain unvalidated in the Chalcopyrite Room and are so noted in the table. Metal ratio data reported for bianchite and tetrahedrite-tennantite were measured using the TRACOR "SQ" semi-quantitative analysis program and the JXA-35 electron microprobe.

All instrumental work was done by the senior author at the Central Research-Experimental Station laboratories of E. I. DuPont de Nemours and Company. Mineral abundances and luminescence characteristics were documented by the second author, subsequent to laboratory investigation.

Aragonite $CaCO_3$

Aragonite occurs in lenticular solution vugs in calcite as coarse, radiating spherules as much as 2 cm in diameter. The solution cavities are very narrow, and the larger spherules are thus generally incomplete. Hematite, goethite, secondary rhombic calcite and quartz are associated in the openings, with aragonite the latest phase among them. All hand specimens containing aragonite also contain hemimorphite, hydrozincite and sparse malachite, but the paragenetic relationship of these minerals to aragonite is unknown. Aragonite from the Chalcopyrite Room is pale yellow to golden brown and fluoresces intense pale yellow in shortwave ultraviolet radiation. The longwave response, in contrast, is white to very pale yellow, and of moderate to bright intensity. No phosphorescence from aragonite was observed, but some specimens exhibit a brief red phosphorescence from inclusions of calcite after longwave excitation. Some also appear to contain nearly microscopic inclusions of orange-fluorescing sphalerite, although the identity of the latter was not verified instrumentally.

Aurichalcite $(Zn,Cu^{2+})_5(CO_3)_2(OH)_6$

Aurichalcite is relatively rare in the Chalcopyrite Room. It is present as typical blue-green fibers and fibrous aggregates, ranging from 1 to 5 mm in maximum dimension. It is associated with malachite and rosasite, and is deposited on calcite and corroded sphalerite. The fibrous aurichalcite on white calcite matrix makes handsome specimen material.

Bianchite $(Zn,Fe^{2+})(SO_4)\cdot 6H_2O$

Bianchite was first reported from Sterling Hill by Edwards (1971), based on an identification by John Hendricks some years earlier. No details of the method of confirmation, nor provenance of the material, were given. Later, a white efflorescent phase occurring abundantly on drift walls in red ore of the East Branch of the West Vein, 1100

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[2] Abbreviations used: SEM = scanning electron microscope, EDS = energy-dispersive spectra, and BSE = back-scattered electron.

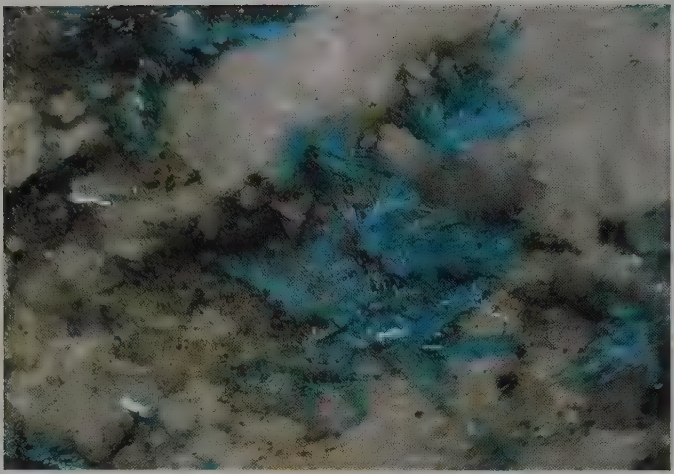

Figure 3. **Aurichalcite rosettes on etched calcite; field of view is 3 x 4 mm; specimen J9133, Gary Grenier photograph.**

Figure 4. **Dick and Elna Hauck sampling aurichalcite and rosasite from an oxidized sphalerite-chalcocite veinlet at mine coordinates 776-1236N-710W.**

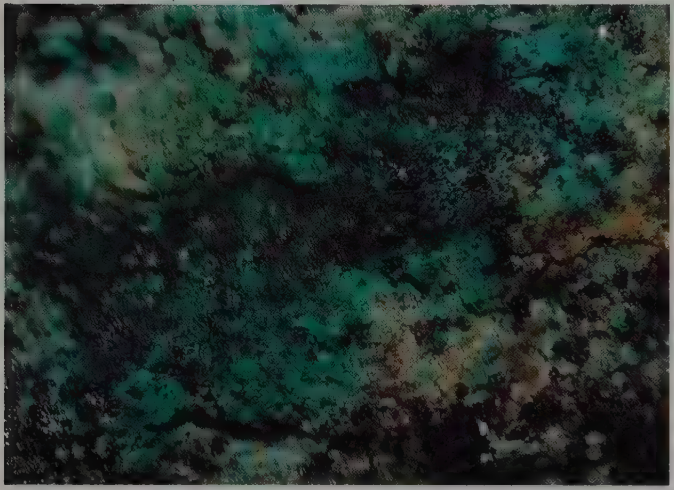

Figure 5. **Brochantite spherules on chalcocite-digenite-covellite in a vug in etched calcite; field of view is 3 x 4 mm; Gary Grenier specimen and photograph.**

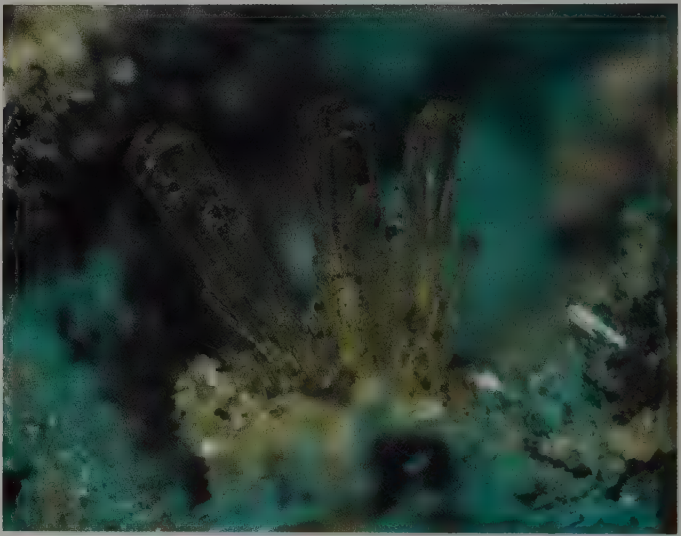

Figure 6. **Radiating hemimorphite aggregate on etched calcite; field of view is 3 x 4 mm; specimen J9175, Gary Grenier photograph.**

level (J. L. Baum, personal communication, 1992) was examined by Cook (1973) and reported to be bianchite. Still later, Dunn (personal communication, 1992) re-examined the Baum-Cook sample and showed the efflorescent species to be hexahydrite. Bianchite is now reinstated as a Sterling Hill species and has been confirmed from the Chalcopyrite Room by both X-ray powder pattern and semi-quantitative analysis (atomic ratio, Zn:Fe:Mn approximately 55:45:5, no Mg or Cu detected for 100 seconds counting time). The mineral occurs as jackstraw aggregates of 20 to 30-micron needles or thin blades. Aggregates reach a maximum dimension of 2 mm, but most are much smaller and have the megascopic appearance of powdery coatings. Bianchite is white to yellow-white and is deposited on secondary calcite or on sulfide minerals. It has been confirmed on only one specimen, but white coatings showing similar EDS signature have been noted on a number of other samples. Bianchite is a very late, probably post-mining mineral.

Bornite Cu_5FeS_4

Bornite is the most abundant of the copper sulfide minerals and is present on about 85% of the specimens examined. Generally it forms disseminated grains either on etched calcite or imbedded in drusy quartz, but on several samples it is present as masses measuring up to 6 x 8 cm in cross-section, with the typical lavender-metallic luster and color. Much bornite has been replaced by other sulfide minerals in boxworks described under chalcocite, and some is rimmed by chalcocite, digenite or djurleite. Marble adjacent to bornite-rich sulfide masses in many places exhibits a muted shortwave fluorescence, pink to dull red to violet-red. Bornite appears to be the earliest of the copper-bearing minerals, although its relationship to tetrahedrite-tennantite has not been established.

Brochantite $Cu_4(SO_4)(OH)_6$

Brochantite is the most abundant sulfate phase among the oxidation minerals and was found on about 10% of the samples. It is present as emerald-green to forest-green radiating globules and radial groups measuring up to 1 mm in diameter. It occurs in cavities in chalcocite-digenite-covellite boxwork masses and, less abundantly, in solution vugs in calcite. It is associated with malachite, devilline, friedelite, and locally hemimorphite. The luster of brochantite is distinctly higher

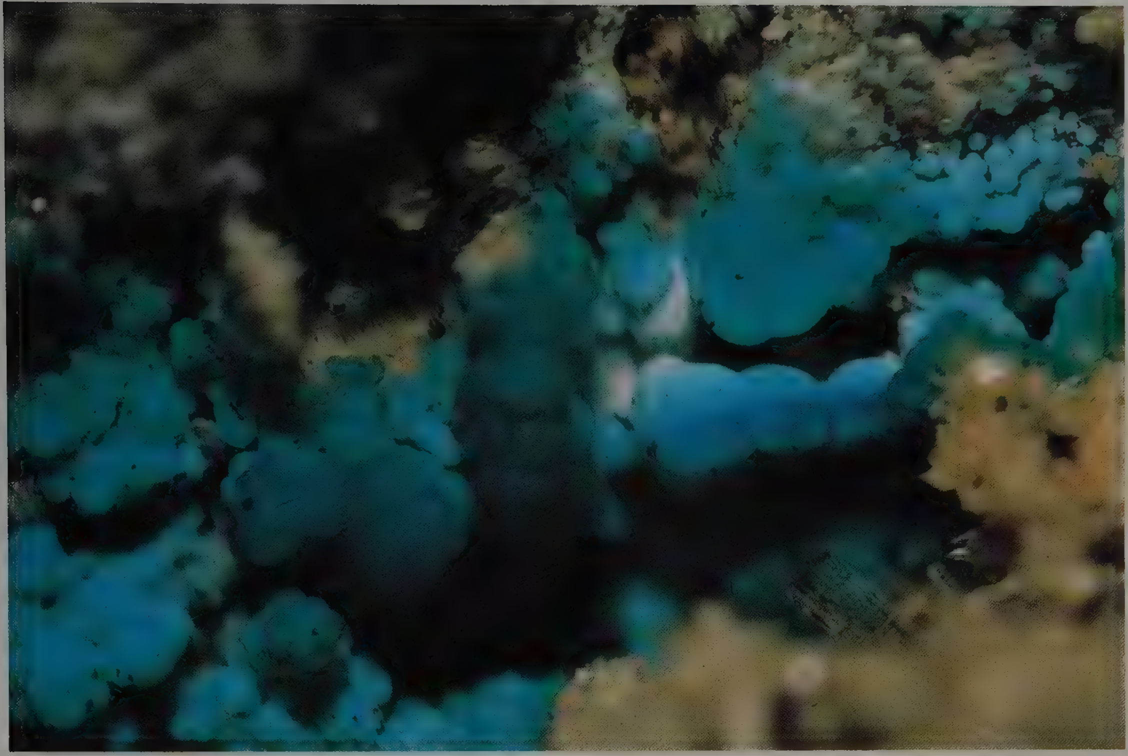

Figure 7. **Spherules of rosasite on chalcocite-digenite-covellite; field of view is 3 x 4 mm; specimen ST770-1250S-11, Gary Grenier photograph.**

Figure 8. **Chalcopyrite-tennantite veinlet on ore-marble contact. Note replacement embayments in sulfide-calcite contacts; field of view is about 35 cm across; specimen CO241.**

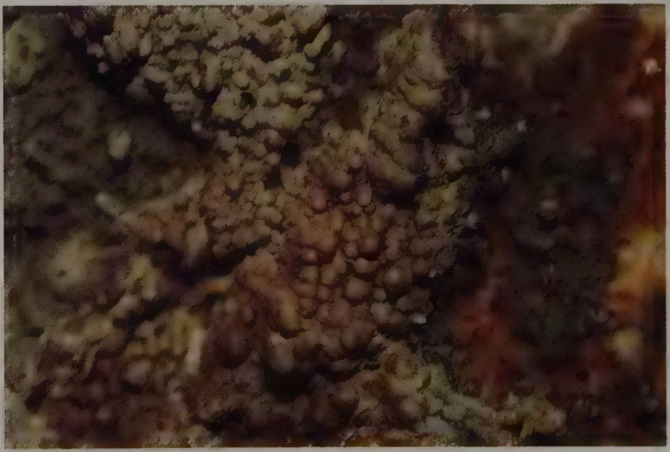

Figure 9. **Microstalactites of wurtzite on etched calcite; field of view is 3 x 4 mm; specimen J9335, Gary Grenier photograph.**

than that of the malachite with which it is associated.

Brucite $Mg(OH)_2$

Brucite, in white flakes as much as 0.5 mm across with typical pearly luster, is a minor constituent of the serpentine veinlets which fill some of the N10°W-striking fractures, lying near the orebody-marble contact.

Calcite $CaCO_3$

Calcite is common in all assemblages shown in the general mineralogic table, and the succeeding description applies only to the secondary mineral association with the oxidation products of the sulfide minerals. Secondary calcite is white to yellow-white or colorless. It occurs as rhombohedra or, more rarely, as scalenohedra, both as long as 1.0 mm. Rhombic calcite was deposited atop various minerals, including sulfides, brochantite, friedelite and malachite, and is itself coated with hydrozincite, malachite, aurichalcite and, very rarely, bianchite. Scalenohedral calcite has been observed only as crusts deposited on etched calcite marble, on goethite, and on secondary rhombic calcite. Secondary rhombic calcites from the Chalcopyrite Room fluoresce very pale pink in shortwave ultraviolet radiation with no longwave response. One unusual specimen of the scalenohedral material, ST770-1250S-3, shows a similar shortwave response, but exhibits bright pale yellow fluorescence in longwave radiation with characteristic brief red phosphorescence. Massive carbonate, filling N10°W-striking veinlets from the site, is also calcite. This material contains variable but generally large amounts of Mg, Mn, Fe and Zn.

Chalcocite/Digenite/Covellite $Cu_2S/Cu_9S_5/CuS$

Chalcocite, digenite and covellite are found together in complex aggregates which replace earlier chalcopyrite and bornite and commonly contain relicts of those two minerals. The aggregates range up to 10 x 15 cm in cross-section, with average size of about 3 x 5 cm. Individual copper sulfide grains measure 0.5 to 1 cm in length. The three minerals are not contemporaneous. Embayments in grain contacts (Cary texture) indicate that covellite replaces digenite, which in turn replaces chalcocite. Precursor copper-iron sulfides have been completely removed from parts of the aggregates, creating void space and leaving boxworks whose copper sulfide walls apparently follow the original chalcopyrite or bornite grain or fracture boundaries. Traces of chalcocite also occur with sphalerite in veinlets as much as 8 meters north of the principal sulfide concentration.

Chalcopyrite $CuFeS_2$

Chalcopyrite occurs as disseminated grains, veinlets and masses as large as 5 x 18 cm in cross-section. Some chalcopyrite probably developed by open-space filling, in that it is deposited against calcite cleavages, but most has replaced bornite or calcite marble. Veinlets and elongate masses of chalcopyrite strike N10°–15°W. Chalcopyrite contains inclusions of pyrite and galena and, like bornite, is partially replaced by chalcocite, digenite and covellite.

Devilline $CaCu_4(SO_4)_2(OH)_6 \cdot 3H_2O$

Devilline occurs as powdery, pale blue to pale green-blue coatings on chalcocite-digenite-covellite boxworks. Devilline coatings are seen to consist of jackstraw to parallel aggregates of 20-micron blades at SEM magnifications. The mineral is most commonly associated with brochantite and friedelite.

Djurleite $Cu_{31}S_{16}$

Djurleite is most interesting for its restricted occurrence, as thin (±1 mm) alteration rims on a few specimens of otherwise fresh bornite. The rims are metallic in luster, medium gray in color, and are visually indistinguishable from tetrahedrite—tennantite from this site. The apparent absence of djurleite as a component of the chalcocite-digenite-covellite boxworks would appear to suggest highly localized conditions for formation of the mineral.

Friedelite $Mn_8Si_6O_{15}(OH,Cl)_{10}$

Friedelite is present as yellow to golden orange crystal crusts, which are seen to consist of simple trigonal to hexagonal plates, trigonal prisms, and lacy aggregates of indistinct habit at SEM magnifications. Maximum crystal size is about 0.1 mm. Friedelite occurs both on residual sulfides, where commonly it is coated with devilline, or on etched marble, where some is coated with secondary calcite. Although friedelite is fairly abundant in the assemblage, it only occurs in the main sulfide mass and in vuggy calcite up to 20 cm northward.

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

Hemimorphite is not common in the Chalcopyrite Room, but it is one of the more attractive minerals from the location. It occurs as radiating groups of colorless blades, ranging from 0.5 to 2 mm in diameter. In cavities in altered sulfides it is associated with brochantite, devilline, malachite and, more rarely, with friedelite and siderite. In solution vugs in calcite marble it is associated with malachite and hydrozincite.

Hydrozincite $Zn_5(CO_3)_2(OH)_6$

Hydrozincite is very common, and is present on about two thirds of the samples examined. It generally occurs as white microcrystalline material lining vugs or partially filling fractures. On one exceptional specimen it is present as white spherules with radiating internal structure, ranging from 0.1 to 1.5 mm in diameter. Hydrozincite from the site fluoresces intense blue-white under shortwave ultraviolet radiation.

Malachite $Cu_2(CO_3)(OH)_2$

Malachite is the most common oxidized copper species in the assemblage, and is present on nearly half of the specimens examined. The mineral occurs on both sulfides and carbonates. On sulfide matrix malachite is generally associated with (but is later than) brochantite. On carbonates malachite is locally the only copper-containing species but elsewhere is associated with aurichalcite and, rarely, rosasite. Malachite occurs as medium green globules, as radiating masses, and as microcrystalline coatings. Globules and radiating masses average about 0.5 mm in diameter, whereas coatings cover areas up to a few cm^2. Malachite occurs over a wide area of the east wall of the stope, up to 10 meters northward from the principal sulfide mass.

Quartz SiO_2

The Chalcopyrite Room assemblage contains quartz in relative abundance. The quartz is present as drusy crusts of white to colorless crystals as long as 1.0 mm lining solutions vugs, and as massive replacements of calcite marble along fractures. It is intimately associated with the early sulfide minerals, bornite and sphalerite, but only rarely with their oxidation products. This suggests that some quartz-containing fractures were sealed prior to passage of the oxidizing fluids, perhaps by deposition of quartz itself.

Rosasite $(Cu,Zn)_2(CO_3)(OH)_2$

Rosasite was originally reported from the Sterling mine by Cook (1973), but in the mineral heretofore had been considered unconfirmed. The present study thus provides the first verification of this species from Sterling Hill. Rosasite occurs as green-blue spherules as much as 0.2 mm in diameter, associated with malachite and aurichalcite on corroded sphalerite in a N10°W-striking veinlet about 3.5 meters north of the main sulfide segregation. It also occurs within openings of sulfide boxwork masses and on tetrahedrite-tennantite in narrow veinlets. Rosasite was observed both in place and on several hand specimens, but it must be considered very rare. It is distinguishable from malachite of similar habit by the distinctive green-blue color.

Silver Ag

Native silver occurs as 0.5 to 1.0-mm sheets, tarnished black and intergrown with altered chalcocite, implanted on secondary calcite in solution vugs in bornite-rich hand specimens. Although the color of the chalcocite is slightly more bluish than that of the silver, the only certain methods of distinguishing between the two species are X-ray diffraction or chemical analysis.

Sphalerite ZnS

Sphalerite is present as typical yellow-brown to gray-black and submetallic cleavage masses and, very rarely, as crude crystals. There are two generations of the mineral. Sphalerite of the earlier generation is yellow-brown and occurs in veinlets intergrown with or deposited on quartz. Similar yellow-brown sphalerite in some hand specimens forms elongate clasts in quartz-cemented breccia. The sphalerite of this early generation is free from inclusions of galena and pyrite. Sphalerite of the later generation, in contrast, is gray to black, less abundant, and contains numerous inclusions of galena and pyrite; commonly it is intergrown with other sulfides, notably bornite, chalcocite and chalcopyrite. Most sphalerite of both generations is nonfluorescent, but some exhibits a dull orange longwave response. Early yellow-brown sphalerite is more likely to fluoresce than the second-generation material.

Tetrahedrite-Tennantite $(Cu,Fe)_{12}(Sb,As)_4S_{13}$

Both tetrahedrite and tennantite occur in the Chalcopyrite Room. Tennantite was previously reported from a Sterling Hill veinlet assemblage by Palache (1935), but the antimony-rich member of the series had gone unrecognized. Tetrahedrite is now confirmed from the Chalcopyrite Room by both X-ray powder pattern and semi-quantitative analysis. Sb:As ratios for tetrahedrite range from 80:20 to 65:35,

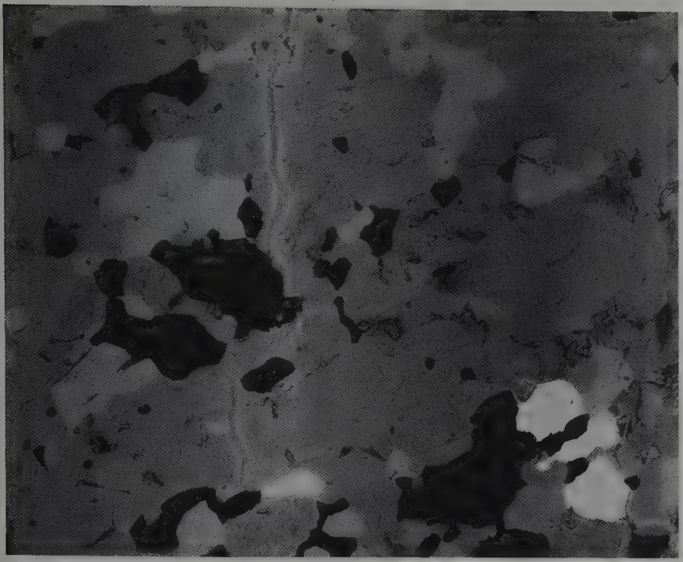

Figure 10. **Back-scattered electron image, tennantite (pale gray) replacing chalcopyrite (darker gray), both replaced by galena (white), in calcite; scale at base; specimen ST770-1250S-21.**

whereas the ratio for tennantite is 15:85. The two phases are megascopically indistinguishable and occur as steel-gray, granular masses as much as 1 cm across, associated with chalcopyrite, sphalerite, galena and nonfluorescent barite. Tennantite and the more As-rich varieties of tetrahedrite occur with chalcopyrite and galena, but the most Sb-rich tetrahedrite is associated with sphalerite and barite. Tetrahedrite and barite penetrate calcite of the marble along cleavages and fractures, producing embayments and indicating that both minerals have replaced calcite. A similar texture suggests that both minerals have also replaced early sphalerite. Tetrahedrite and barite appear however, to be contemporaneous. Tennantite replaces chalcopyrite and, in one specimen, is itself replaced by galena.

Wurtzite (Zn,Fe)S

Wurtzite was identified on several specimens from the Chalcopyrite Room. It occurs as aggregates of golden brown hexagonal scales as much as 20 microns across on quartz, and as dark brown microstalactites, some masses of which reach 3.0 cm in maximum dimension. Material of both habits has been confirmed as wurtzite by X-ray diffraction analysis. It is deposited on calcite or, more rarely, on sphalerite. The specific polytype of Chalcopyrite Room wurtzite has not been determined. Wurtzite from the site is easily confused with some friedelite or with goethite coatings, and X-ray diffraction is the only certain means of identification.

DISCUSSION

The nature of the varied suite of minerals in the Chalcopyrite Room and its association with a well-defined fracture system suggest that those minerals have been derived by precipitation from hydrothermal fluids. The minerals have clearly not been formed through any single process, but rather have been formed through a succession of processes, some perhaps overlapping in time and others separated by episodes of fracturing or fracture reactivation. A possible sequence of events might be as follows:

(1) N10°W-striking fractures were developed across the ore-marble contact.

(2) Calcite was etched and quartz-sphalerite deposited along and within these early fractures.

(3) N35°E-striking fractures and associated breccias were developed in the area of the trough in the ore-marble contact before the close of quartz deposition.

Table 1. **General mineralogy and phase abundances of the Chalcopyrite Room.**

Assembl.[1]	*Rarity*[2]	
CS	R	Andradite
S	R	Anglesite
S	R	Antlerite (?)
S	R	Aragonite
S	C	Aurichalcite
S	C	Barite
S	A	Bornite
S	R	Bianchite
S	C	Brochantite
S	R	Brucite
All	A	Calcite
S	R	Cerussite
S	A	Chalcocite
S	C	Chalcopyrite
S	R	Chrysocolla
M	R	Clinochlore
S	A	Covellite
S	C	Devilline
S	A	Digenite
CS	R	Diopside
S	R	Djurleite
S	R	Dolomite
S	R	Fluorite
O	A	Franklinite
S	C	Friedelite
S	A	Galena
S	C	Goethite
S	R	Greenockite
S	R	Gypsum
S	A	Hematite
S	C	Hemimorphite
S	A	Hydrozincite
S	R	Kutnohorite (?)
S	A	Malachite
CS	R	Microcline
M	C	Phlogopite
S	C	Pyrite
S, CS	C	Quartz
S	R	Rosasite
M	R	Rutile
S	C	"Serpentines"
S	R	Siderite
S	R	Silver
S	R	Smithsonite
S	A	Sphalerite
S	R	Tennantite
O, CS	R	Tephroite
S	R	Tetrahedrite
M	R	Uvite
O, CS	A	Willemite
S	R	Wurtzite
O	C	Zincite

[1] Assemblages: S = secondary; O = ore; M = marble; CS = calc-silicate; All = occurs in all assemblages

[2] Rarity estimate is based on an examination of about 600 hand specimens. Species found on less than 10 specimens are considered rare (R); on 10 to 99 specimens, common (C); on 100 or more specimens, abundant (A).

Queries (?) denote species for which there is strong indication by SEM imaging and EDS signature, but for which no X-ray diffraction confirmation has been obtained.

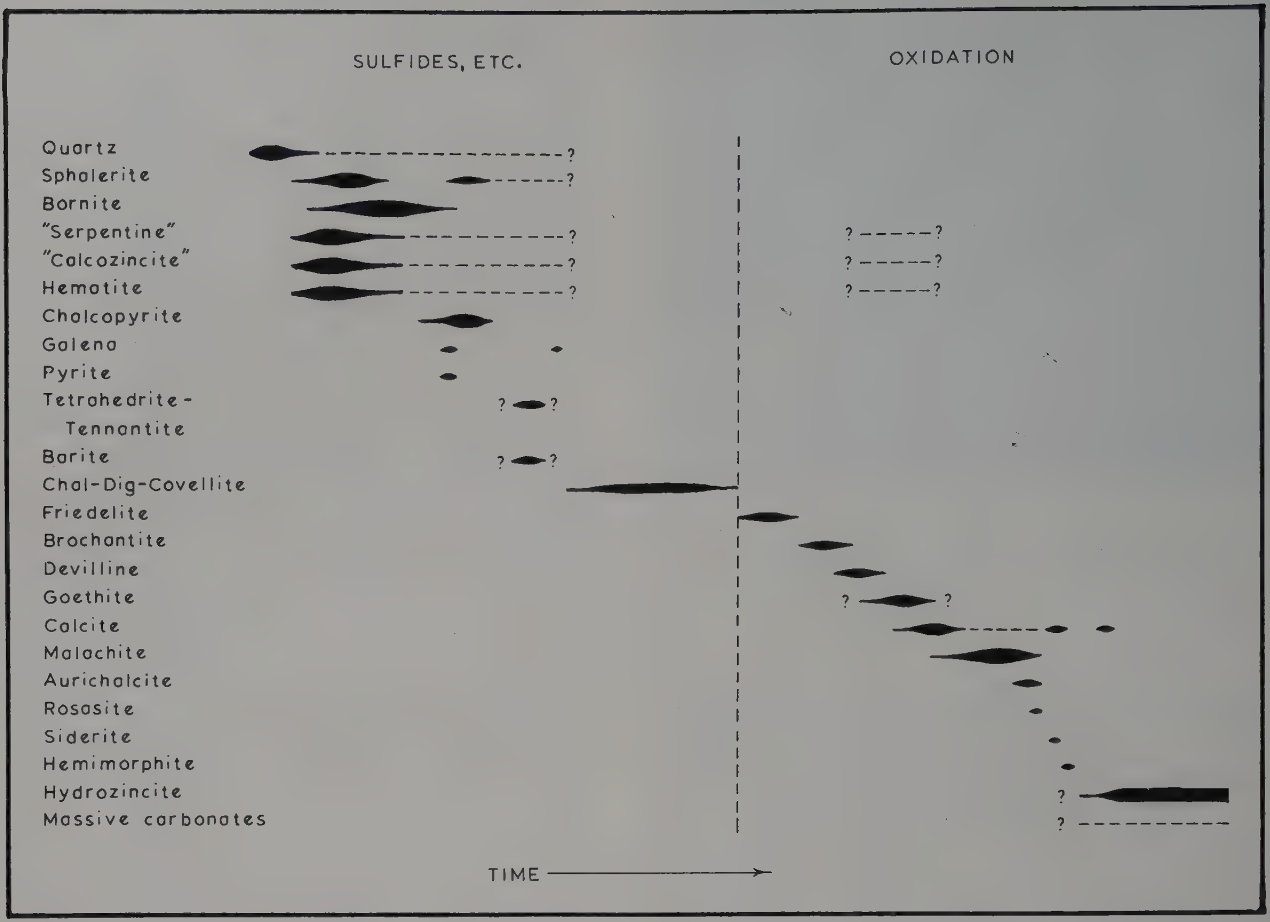

Figure 11. **Mineral paragenesis in the Chalcopyrite Room (area of symbols roughly proportional to phase abundance; dashed or queried where not certain; some minor species not included).**

(4) Bornite, sphalerite, chalcopyrite, pyrite, galena, tetrahedrite-tennantite and barite were deposited in the contact trough, breccias, and N35°E-striking fractures. Very limited deposition of the same sulfides also took place in earlier N10°W-striking openings in the same vicinity. Quartz was still a stable phase.

(5) Perhaps contemporaneous with (4) above, fluids interacting with ore minerals along fractures produced serpentine, secondary willemite and "calcozincite."

(6) The same (or perhaps other supergene) fluids enriched the copper-mineral suite to yield chalcocite-digenite-covellite boxworks, replacing bornite and chalcopyrite, and also the djurleite rims on bornite. The spatial effect of enrichment was very limited, again probably localized by the N35°E-striking fractures. There may have been little separation in time between enrichment and introduction of the earlier minerals. Note that greenockite, silver and perhaps wurtzite were probably formed during oxidation (see no. 8 below).

(7) Some N10°W-striking fractures were reactivated or new fractures of the same orientation formed.

(8) Oxidation of the sulfides and deposition of the various sulfate and carbonate species took place in and adjacent to N10°W-striking fractures. Sulfates, such as brochantite and devilline, formed only in contact with residual sulfides, whereas carbonates formed on sulfides, sulfates, and abundantly in the marble, the latter at distances up to 10 meters north from the principal sulfide concentration.

(9) Massive carbonates were deposited in other N10°W-striking fractures.

These processes are summarized in the paragenetic diagram shown in Figure 11.

The sulfide and oxidation mineral assemblages of the Chalcopyrite Room are classic examples of rock-dominated hydrothermal fluid systems (E. R. Verbeek and M. A. Grout, personal communication, 1991), which is to say the ratio of the mass of fluid affecting mineralization and alteration to the mass of rock affected is relatively low, and the precursor mineralogy of rocks through which fluids have passed has had a profound influence on new minerals precipitated. This is reflected in the abrupt changes in sulfide-silicate mineralogy where fractures pass from marble to ore, the deposition of sulfate oxidation products directly on sulfides, and of carbonates on marble as well. It probably also explains the lack of pervasive hydrothermal alteration of the ore minerals. Excellent general discussions of the geochemistry of hydrothermal systems, including the effects of varying water:rock ratios, are found in Barnes (1979).

In a gross sense the oxidation paragenesis in the Chalcopyrite Room follows a typical trend of increasing pH with time, as indicated for example, by the deposition of carbonates atop sulfates. In a low-fluid system, however, where equilibrium may not be maintained over the entire volume being oxidized, it is conceivable that some carbonates may have formed at one location at the same time as sulfates at another.

(Continued on p. 104)

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Dr. Wendell Wilson in his video review in *M.R.,* Nov/Dec 1992, p. 504, says "The collector of aesthetic mineral specimens will find much to savor in Keith Proctor's video catalog of his collection. . . . It really delivers in terms of extraordinary mineral images and specimen information and will stand for many years to come as a historically valuable documentation of one of the great private collections of our time."

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Photo by Earl Lewis, Los Angeles

The same argument might be advanced relative to the precipitation of Cu minerals at one site, while Zn phases were forming at a second.

The mineral suite from the Chalcopyrite Room is unusual in two respect. It is remarkably varied, about 40 hydrothermal or oxidation phases occurring within a volume of no more than a few cubic meters. Also, as already noted, quartz is a relatively important component of the paragenesis.

Beyond these two differences, however, the sulfide assemblage of the Chalcopyrite Room is similar in mineralogy to a large number of such occurrences scattered throughout the Franklin-Sterling region (Cummings, 1978, 1988). The oxidation paragenesis contains essentially no elements whose presence cannot be explained in terms of original sulfide or marble constituents. The number of species is perhaps best explained by three factors: overprint of mineralizing events; again, the low amount of fluid relative to rock affected, which aided spatial separation of different species; and by the relative abundance of various cations in solution at any given time, which would cause, for instance, Cu rather than Zn to be incorporated into a precipitating mineral and vice versa.

Quartz is not uncommon in the general area of the East Vein in which the Chalcopyrite Room workings lie. Quartz veinlets, replacement masses, and drusy coatings in cavities are widespread in all host rocks along the 700 level for distances of at least 10 meters south and 100 meters north of the presently described locality. The quartz-depositing event may also have assisted in preparation of open space for later precipitation of copper sulfide minerals, in that quartz is readily precipitated from relatively acid solutions, whereas calcite is dissolved, creating porosity.

Timing of the formation of the Chalcopyrite Room sulfide assemblage is unknown, but may relate to the development of larger scale structures not shown on Figure 2, such as the Nason Fault, a few tens of meters to the west, and a collapse-breccia body, perhaps a portion of a pipe, which intersects the orebody and separates the two openings of the 1250 stope. One or perhaps both of these structures may have served as a trunk conduit for the transmission of hydrothermal fluids into the Chalcopyrite Room vicinity, with subsequent migration of the fluids into the minor fractures in which mineral deposition took place. Metsger (1990) describes one collapse-breccia pipe at Sterling Hill and shows that its probable age is Ordovician. The age of the Nason Fault is uncertain. Oxidation is probably a relatively recent phenomenon. Metsger (1990) also describes the occurrence of oxidized copper minerals associated with the Mud Zone, a large saprolite body which partly replaces the Sterling Hill core from the surface to a depth of about 207 meters. He shows that saprolite and oxidized copper minerals have formed within the last 2 or 3 million years.

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THE FRENCH CREEK MINE

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The French Creek mine has been a popular and prolific mineral collecting locality for over a century. Chalcopyrite occurs at the mine in spectacular specimens which are included in the most prominent museum, university and private collections. Also notable are the fine cubic and octahedral pyrite crystals and octahedral magnetite crystals.

EARLY HISTORY

Early colonists arrived in America with a basic knowledge of ore deposits and rudimentary mining and smelting skills. Pennsylvania possessed the required natural resources—iron ore deposits, water and forests—and, by the mid-18th century, became the leading iron-producing colony.

The iron industry in Pennsylvania began in the French Creek Valley shortly after Samuel Nutt arrived from Coventry in Warwickshire, England, in 1714. On October 28, 1717, he obtained a 250-acre tract in Warwick Township, Chester County, Pennsylvania, that contained an iron mine. The orebody was exposed at the surface and was worked by pick and shovel. The ore was smelted and worked at local furnaces and forges. In July of 1720, Nutt established an iron forge near French Creek at Coventryville. In partnership with John Branson and John Potts, he erected Reading Furnace, a charcoal iron furnace near Coventryville around 1736 (Futney and Cope, 1881).

The French Creek mine was not only the most significant iron mining venture in the French Creek Valley but was also the most economically significant underground mine in Chester County. It produced an estimated 1 million tons of ore during its 84 years of actual operation (Smith, 1978). More than 60 years have passed since the French Creek mine was last worked. The workings are now inaccessible, and forest has reclaimed the land. The tranquil Victorian village of St. Peters is just a short distance south of the old mine site.

Two orebodies were mined at the French Creek mine: one located near the top of the hill, and another near the bottom. The mine near the top of the hill was called mine no. 1, Keim's mine, or the Elizabeth mine. The mine near the bottom of the hill was called mine no. 2. The main shafts are about 183 meters apart.

In March of 1845, Samuel Crossley, a stage coach driver, purchased 105 acres of land along the north branch of French Creek near a scenic spot known as the "falls of French Creek." Samuel Keim, a neighboring farmer, discovered iron ore on Crossley's land in 1846. Crossley started mining the ore in several shallow pits, which became known as Crossley's Iron Ore Pits. Crossley entered into a partnership with

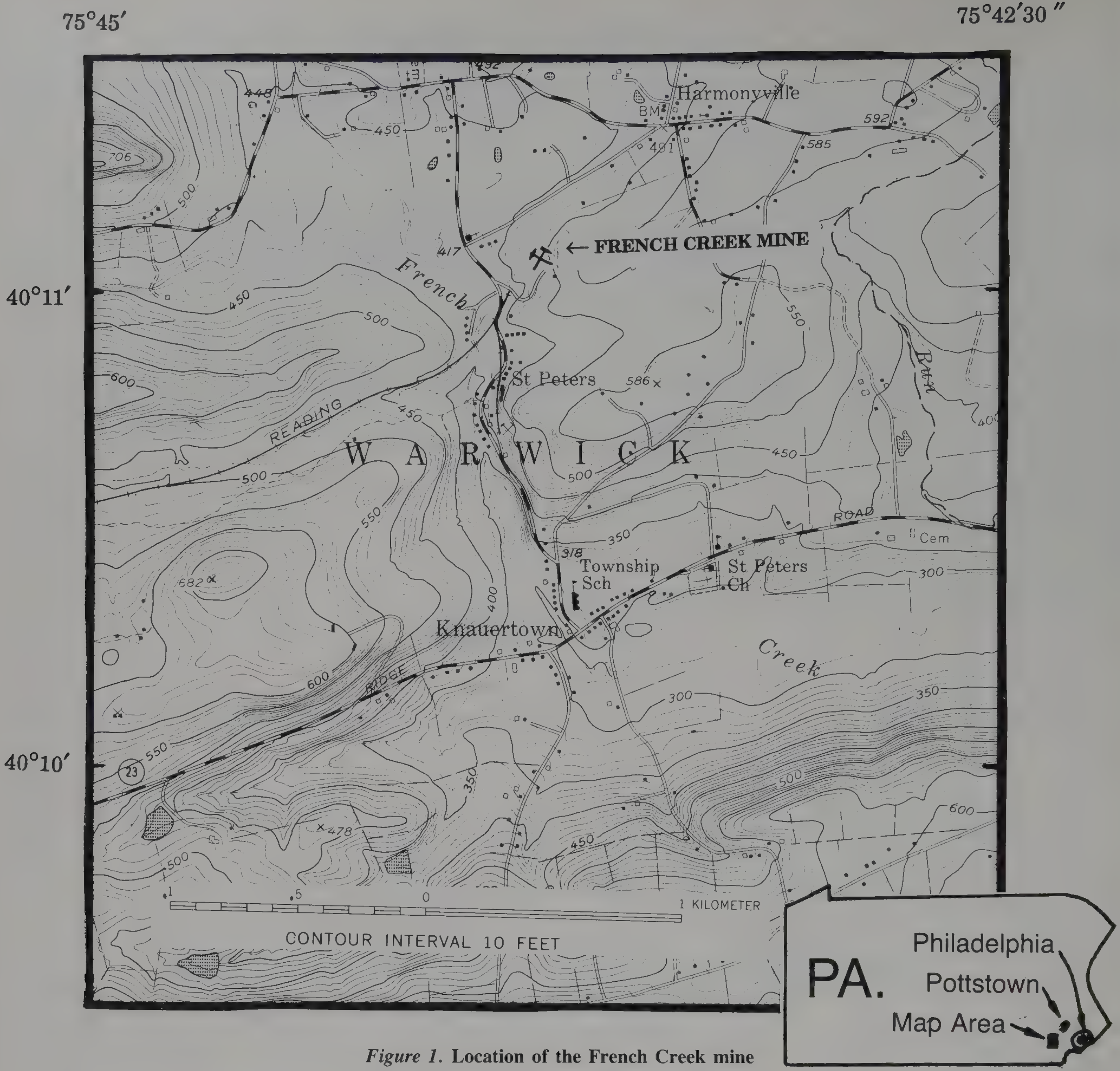

Figure 1. **Location of the French Creek mine on the U.S.G.S.** ***Pottstown*** **7.5-minute topographic map.**

his father-in-law Abraham Hesser, Pottstown nurseryman Jonathan Keim, and a Mr. McKewen to expand and work the mine. The partnership engaged in little mining, and Crossley sold the entire 105-acre tract to Jonathan Keim (spelled Kimes on the deed) in April of 1847. The mine then became known as Keim's mine and was referred to as such by Dana (1854).

In May of 1848, Keim sold the mine property to Edward, George and Elizabeth Brooke of the E. and G. Brooke Company of Birdsboro. The Brookes owned several iron mines in the vicinity and a smelter in Birdsboro. They named the mine the Elizabeth mine in honor of Elizabeth Brooke and leased it to a copper company. Henry Darwin Rogers, first State Geologist of the First Pennsylvania Geological Survey, visited the Elizabeth mine in May of 1854. Rogers referred to the mine as being on the Knauertown copper lode (Rogers, 1858). At the time of Rogers' visit, the engine shaft was 47 meters deep with a 14-meter-deep subshaft. From the bottom of the subshaft, crosscuts ran 8.5 meters south and 6.7 meters north to the orebody. The orebody was mined for a length of 17 meters. Rogers described the ore as magnetite, pyrite and chalcopyrite. Chalcopyrite was most abundant next to the northern wall of the orebody. Mining ceased with little production just before Rogers' visit. After the copper company ceased operations, the mine was idle for several years. In March of 1856, the Phoenix Iron Company of Phoenixville acquired a half interest in the property.

During the Civil War, demand for copper sparked a renewed interest in the Elizabeth mine. On March 16, 1863, the mine was leased to the New York–based French Creek Copper Company. R. H. Richards was President and Treasurer, R. Roberts was Secretary and Captain R. T. Willis was Mine Superintendent. The shaft was cleared and the machinery restored. Mining resumed on May 14, 1863. By the end of 1863, the mine had produced 1,000 tons of iron ore and 45 to 50 tons of copper ore. Despite this seemingly successful year, the French Creek Copper Company experienced financial trouble because of the difficulties encountered in transporting the ore to market. Horse teams

Figure 2. **French Creek mine no. 1, 1881. Photograph courtesy of Hopewell Furnace National Historical Park.**

had to carry the ore over rough roads to the railroad in Pottstown, and less than 500 tons of iron ore was sold in 1863 (*Village Record,* June 4, 1864). The mining equipment and the unexpired mining lease of the French Creek Copper Company were sold at Sheriff's sale on June 23, 1866.

In 1877, Charles M. Wheatley, who operated the Wheatley mine and other lead mines in the Phoenixville area, leased the Elizabeth mine from E. & G. Brooke and the Phoenix Iron Company for mining copper, but operated it for only a short time (*Daily Local News,* June 27, 1877).

It is not known exactly when E. and G. Brooke and the Phoenix Iron Company opened the no. 2 mine, but it was probably in full operation by 1875. Edward Brooke died in 1878, and George Brooke took over as President of the firm. He reorganized the company as the E. & G. Brooke Iron Company. Under his direction, kilns for roasting the ore to remove the sulfur were installed at the mine in 1878 (*Daily Local News,* November 7, 1879). The roasted ore was shipped to iron furnaces in Birdsboro and Hopewell by 18 four-horse and six-horse teams (*Daily Local News,* March 14, 1879).

Edward Brooke also served as the first President of the Wilmington and Northern Railroad. In 1880, the railroad completed a branch line to the French Creek mine. The railroad called the station at its terminus St. Peters Station. At that time, only Knauer's iron forge was south of the mine, and the little village of St. Peters did not exist. In 1881, the first two houses were built in St. Peters, and in 1882, the St. Peters Hotel opened. The village grew rapidly when several diabase quarries were opened in and near St. Peters in 1885. The diabase quarries produced paving blocks, curb stone and dimension stone. The village housed quarry workers and contained a variety of shops; it provided services to the iron miners as well.

In the 1880's and 1890's, William Noble was Superintendent of the French Creek mine. In 1880, he erected a general store in nearby Harmonyville for the convenience of the miners and was involved in several other local business enterprises. He also erected two stone houses in Harmonyville to house the miners (*Daily Local News,* December 11, 1880). In March of 1883, the no. 3 mine, known as the Calamity shaft, was sunk on the western side of French Creek. The shaft encountered a sudden large inflow of water, flooded and was abandoned (*Daily Local News,* April 18, 1889). In 1884, the no. 2 mine reached the 76-meter level, and a crosscut was driven to connect the eastern and western stopes. An 18-meter-high crusher that crushed, screened and loaded ore was installed in 1885. Production was cited as 1,000 tons per month (*Daily Local News,* April 28, 1885). At this time, the mining operation experienced its first labor dispute. Laborers who loaded the cars underground called a strike. They demanded a wage increase from 6 cents to 8 cents per ton of ore. In addition, they demanded that the company provide their candles. Thirty miners were idled by the strike (*Daily Local News,* September 9, 1885).

The year 1889 was a year of misfortune for the French Creek mine. In March, the miners in the no. 2 mine struck a large solution opening in the marble, and a large quantity of water rushed in. A miner described the inflow: "The water suddenly poured into the shaft, the flow being about the thickness of a barrel" (*Daily Local News,* March 22, 1889). The miners made a hasty retreat from the mine. Three pumps could not control the inflow, and the mine flooded. New pumps were installed and the mine was dewatered, but the mine was filled with muck too soft to send up in cars. John Matters, the Mine Foreman, had his men remove the muck by mixing it with water and pumping it out (*Daily Local News,* April 18, 1889). Before mining resumed, a fire destroyed the engine house, pumping machinery, boiler house and some of the mining equipment. The shaft timbers burned to a depth of 38 meters, and the mine flooded again. The shaft was retim-

Figure 3. **French Creek mine no. 2, 1881. Photograph courtesy of Hopewell Furnace National Historical Park.**

bered and the surface plant rebuilt. The mine was again dewatered and resumed operation.

The French Creek mine closed in 1895 because the E. & G. Brooke Iron Company found it more economical to import iron ore than to mine it (*Daily Local News*, June 14, 1895). At the time the mine closed in 1895, the no. 1 mine had been developed to the 76-meter level. The shaft of the no. 2 mine reached the 110-meter level. The shaft was vertical to the 73-meter level and inclined 45° to the 110-meter level with crosscuts to the orebody at depths of 24, 40, 61, 73 and 110 meters (Bascom and Stose, 1938). The orebody in the no. 2 mine was 6.1 meters wide and had been mined for 91 meters along its inclination, starting from a point 30 meters below the surface; the orebody was not exhausted. E. & G. Brooke removed the pumps and machinery and abandoned the mine in September of 1900.

LATER HISTORY

After a 17-year lapse, new activity began at the French Creek mine in 1912. In a report to the E. & G. Brooke Iron Company, the Mines Management Company estimated 83,000 to 117,000 tons of ore between the 110-meter and 186-meter levels of the no. 2 mine (Mines Management Company, 1912). After reviewing the report, E. & G. Brooke reopened and modernized the no. 2 mine; they agreed to pay a 25-cent-per-ton royalty to the Phoenix Iron Company. The mine was dewatered, the shaft retimbered and the mine equipped with electricity and compressed air. The shaft and slope were remodeled into a compound shaft and extended for 30 meters along the footwall, reaching a vertical distance of 148 meters. Production began on June 15, 1914.

With the outbreak of World War I in 1916, the demand for iron increased, and a new 43° inclined shaft was started at mine no. 2. The new shaft was sunk 137 meters southeast of the old shaft and was located 30 meters back in the footwall. Encountering difficulty in contracting the work, Manfred Hoster, Mine Superintendent, and William Madden, Mine Foreman, undertook the sinking of the shaft themselves (Evans, 1963). In 1918, mining began through the new three-compartment inclined shaft. The shaft was expected to intersect the orebody at depth, but the orebody flattened below the 229-meter level, and the angle of the shaft was decreased to 33° at the 244-meter level (Smith, 1931). When the new shaft went into operation, the old shaft was used as an auxiliary and ventilation shaft. Cross cuts from the new shaft to the orebody were run at 61, 79 and 107 meters and every 30 meters below 107 meters to 381 meters. In 1922, a connecting tunnel at the 168-meter level was driven southwest and a 61-meter rise connected the no. 2 mine with the no. 1 mine. The no. 1 mine shaft was retimbered and used as an auxiliary and ventilation shaft. All ore was hoisted through the inclined shaft of the no. 2 mine.

In 1926, when the no. 2 mine orebody was nearing depletion, E. & G. Brooke hired several consultants to search for a new orebody. A surface geophysical survey and test drilling failed to reveal one.

In 1928, the no. 2 mine reached the 381-meter level where the orebody ended abruptly against a 60-cm dike of hornblende syenite gneiss. A drift was extended for 61 meters beyond the dike, but only unreplaced marble was encountered. Drilling along the drift showed that the diabase was more than 30 meters below the gneiss footwall and that the marble pinched out without encountering the diabase (Smith, 1931). With the orebody depleted, the French Creek mine was abandoned in 1928.

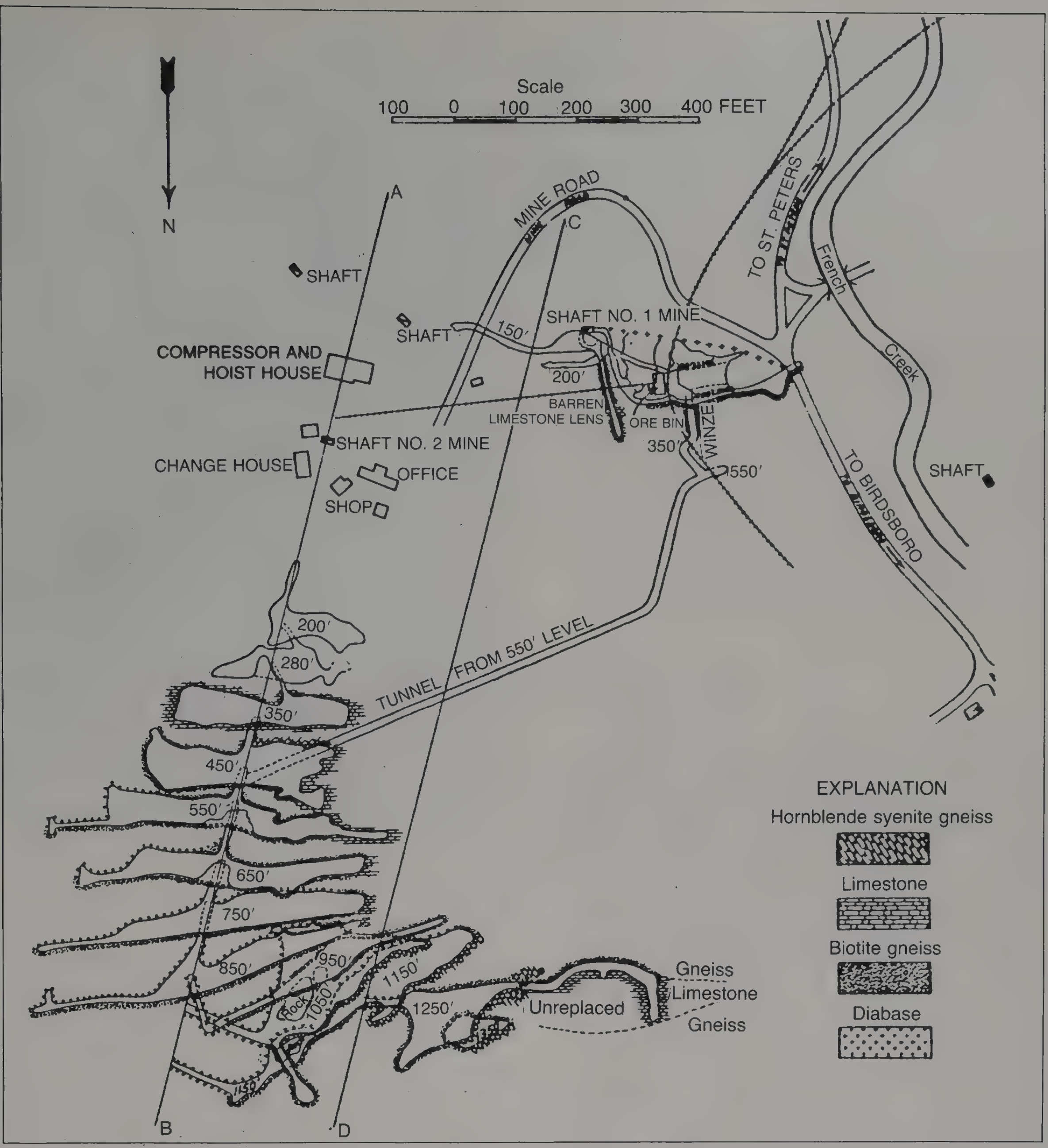

Figure 4. **Plan of workings, French Creek mine. From Smith (1931).**

GEOLOGY

Regional

The French Creek deposit is one of nearly 50 contact metasomatic magnetite skarn deposits occurring in a 150-kilometer-wide band in and adjacent to the Newark and Gettysburg basins of Triassic and Jurassic age in southeastern Pennsylvania. The deposits were named Cornwall-type magnetite deposits by Spencer (1908), after the large iron ore deposit at Cornwall in Lebanon County, Pennsylvania. These deposits are classified as iron calcic skarn deposits by Einaudi and Burt (1982). Cornwall-type magnetite deposits are formed as replacements of carbonate rock mainly overlying early Jurassic diabase sheets and dikes. Lithostatic pressure was low, approximately 500 to 1,000 bars, and the main period of ore formation probably occurred at temperatures of 500° C or less. Similar deposits of note near the French Creek mine are at the Jones mine 3 miles to the west in Joanna, Berks County, and the Grace mine 4.5 miles to the southwest in Morgantown, Berks County.

The French Creek orebody was formed by replacement of marble lenses in granulite-facies graphitic felsic gneiss of Precambrian age in contact with diabase of early Jurassic age. The marble was formerly called the Franklin Marble (Bascom and Stose, 1938), but its exact correlation with the Franklin Limestone of northern New Jersey is doubtful. The unreplaced marble is white to gray, very coarsely crystalline, and is characterized by numerous disseminated graphite flakes. Apatite, quartz, diopside, limonite, hematite and pyrite are accessory minerals in the marble.

The diabase, part of the St. Peters–Birdsboro sheet, is a quartz-normative tholeiite classified as a York Haven–type diabase by Smith (1973). It is a dark gray, fine-textured rock composed of plagioclase, chlorite, augite, hypersthene, minor olivine and rare pigeonite. Accessory minerals include quartz, apatite, magnetite, ilmenite, pyrite and chalcopyrite. The texture of the diabase becomes finer within 3 to 3.6 meters of the contact with the orebody and within 1.2 to 1.5 meters of the contact with the gneiss. In the lower levels of the mine, the diabase is cut by pegmatite veinlets 4 to 12 mm wide (Smith, 1931).

The graphitic felsic gneiss is a medium-grained to coarse-grained

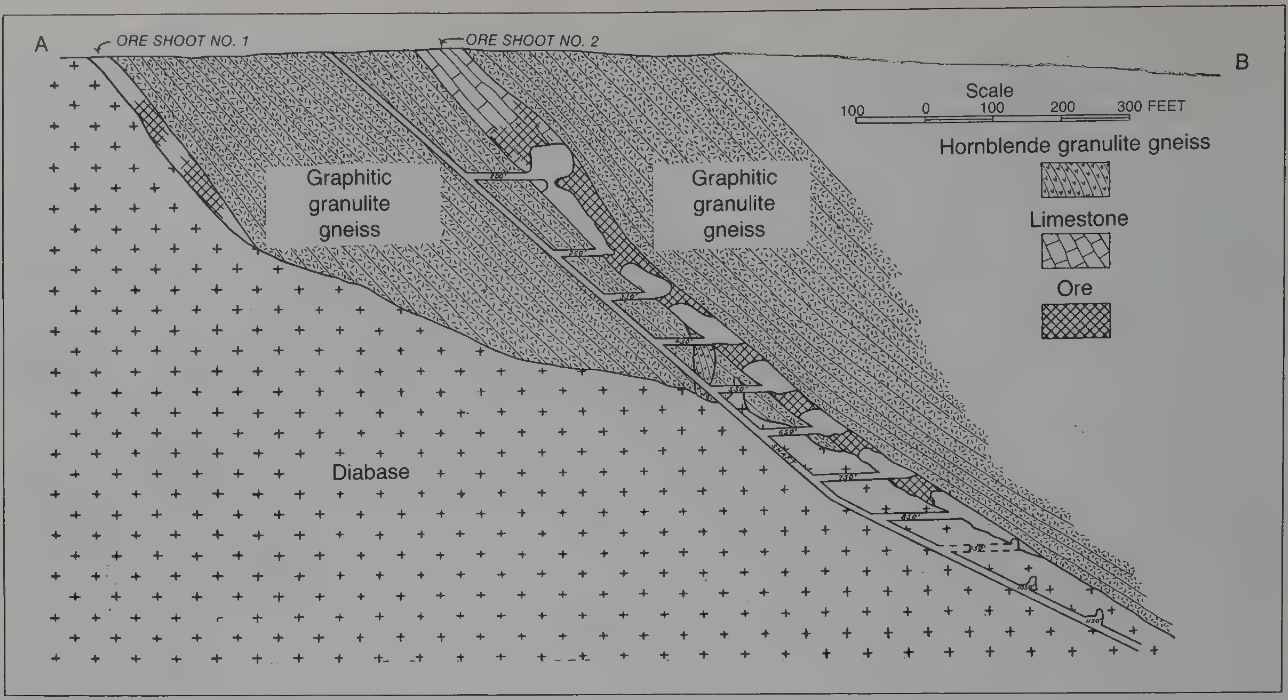

Figure 5. **Geologic cross-section of the west end of the French Creek mine no. 2. From Smith (1931).**

quartz-plagioclase-mesoperthite-hypersthene-graphite felsic gneiss (Thomann, 1977; Crawford and Hoersch, 1984). It is characterized by the presence of orthopyroxene and graphite. The gneiss is banded with alternating pale gray to pink and dark gray bands. Accessory minerals include pyrite, limonite, hematite, apatite, zircon, biotite and chlorite. The gneiss is part of a granulite-facies gneiss complex (Crawford and Hoersch, 1984) widely exposed in the Honey Brook Upland of northern Chester County. It was formerly called the Pickering gneiss (Bascom and Stose, 1938).

Dikes of hornblende syenite gneiss and associated pegmatite were encountered between the 137-meter and 168-meter levels and below the 320-meter level (Smith, 1931). The hornblende syenite gneiss, a dark, massive to thinly foliated rock consisting of hornblende and feldspar, cuts across the banding of the graphitic felsic gneiss. Accessory minerals include microcline, plagioclase, biotite, quartz, apatite, epidote, garnet, chlorite, magnetite and pyrite. Coarsely crystalline pink to gray pegmatite is interbanded with the gneiss. The gneiss gradually grades into the pegmatite as hornblende decreases and feldspar increases, until the rock consists entirely of intermixed pink and gray feldspar and quartz and exhibits a typical pegmatitic texture.

The Stockton Formation, of late Triassic age, which consists of interbedded sandstone, siltstone, shale and mudstone, crops out just north of the French Creek deposit. The Stockton has been thermally altered by the intruding diabase for 150 or more meters from its contact with the diabase.

The Deposit

At the French Creek mine, the major ore mineral is magnetite. Large quantities of pyrite and some chalcopyrite are associated. The principal gangue constituent is calcite. Other gangue minerals include chlorite, actinolite, talc, mica, garnet, epidote, graphite, augite, pyrrhotite and apatite (Smith, 1931).

The no. 2 mine orebody dips 45° northeast and strikes nearly east-west. On the 290-meter level, it dips 35° to 40°. The orebody is about 137 meters wide and was mined for 518 meters along its length (Smith, 1931). The hanging wall is gneiss. Where the marble was completely replaced, the ore is in contact with the gneiss. The footwall is gneiss to the 168-meter level. Below this level, diabase forms part of the footwall and is in contact with the ore. On the eastern end of the mine, the orebody pinches out where the diabase is in contact with the gneiss at the 259-meter level. On the western end of the mine, the gneiss forms both the hanging wall and footwall on the lower two levels.

The marble is not completely replaced by ore. Most of the marble has recrystallized into coarsely crystalline calcite. The calcite contains scattered pockets and stringers of magnetite, and the ore contains disseminated masses of calcite. In the lower levels, replacement is more nearly complete. In the upper levels, calcite becomes increasingly abundant; above the 61-meter level, the orebody ends in calcite. In the narrow part of the orebody between the 229-meter and 259-meter levels, the marble is entirely replaced from footwall to hanging wall. In some places, unreplaced marble is in contact with diabase.

The magnetite ranges from densely massive to coarsely granular. The coarse-grained magnetite is more common in the upper levels where replacement of the marble is less complete. Fine-grained or dense, massive ore is more common in the lower levels where almost total replacement of the marble occurred. The dense ore may be hard and compact, but usually contains enough calcite to make it crumbly. The ore eventually disintegrates after exposure to the atmosphere because of the oxidation of pyrite, which produces sulfuric acid that dissolves the calcite.

Typical ore consists of massive magnetite containing some pyrite, chalcopyrite and silicate minerals. Analyses of magnetite ore show 51.78 to 57.78% Fe, 2.42 to 3.10% S and 7.10 to 13.51% SiO_2 (Smith, 1931). An analysis of ore containing considerable chalcopyrite and octahedral pyrite showed 15.30% Cu, 0.19% Co and 0.04% As (Bascom and Stose, 1938). A recent analysis of a composite of ore material (chalcopyrite and magnetite) from the dumps by Smith and others (1988) showed 1% Cu, 345 ppm Co, 160 ppm Ni and 85 ppm As; the analysis also showed 0.008 ounces Au and 0.16 ounces Ag per ton.

The paragenetic sequence is (1) garnet and augite; (2) actinolite; (3) epidote as an alteration product of garnet; (4) chlorite, talc and

Figure 6. **French Creek mine no. 1, 1993.**

mica; (5) magnetite; (6) pyrite; (7) chalcopyrite; (8) zeolite minerals. Although some pyrite is earlier than magnetite, most is not (Smith, 1931).

Spencer (1908) first recognized the method of deposition of Cornwall-type orebodies. He stated that the ores were "formed by more or less metasomatic replacement of sedimentary rocks by iron minerals precipitated from heated solutions set into circulation by the invading diabase." The model for ore deposition was developed by Eugster and Chou (1979). During the early Jurassic, diabase intruded the Paleozoic and Triassic rocks. Convective hydrothermal cells driven by temperature gradients were established by the intruding diabase. Fluids, consisting mostly of ground water, but including some connate brine and late-stage diabase differentiates, were set into motion. The circulating fluid coupled three spatially separated reactions: (1) formation of HCl by conversion of muscovite, quartz and KCl to K-feldspar and HCl in the hottest, deepest part of the cell; (2) dissolution of Fe-bearing minerals; and (3) precipitation of magnetite, pyrite and chalcopyrite in the marble.

The heated HCl solution leached Fe, Cu, Co and other elements to form an $FeCl_2$ solution containing some H_2S. Fe is relatively soluble in a Cl-rich solution at 500–650° C (Chou and Eugster, 1977). The $FeCl_2$ solution flowed by convection to the carbonate host where magnetite, pyrite and chalcopyrite were precipitated by neutralization. Solubility of Fe and Cu in an acidic Cl-rich solution rapidly decreases on neutralization (Crerar and Barnes, 1976). Rose and others (1985) estimated that ore deposition occurred over the 4,000 years necessary for the diabase to cool from 600° to 350° C.

A substantial quantity of Fe may have been leached from a large volume of diabase in the vicinity of the orebody. This would account for the relatively high concentrations of Co and Cu in the orebody, elements also found in the diabase. Smith and others (1975) found 47 ppm Co and 120 ppm Cu in York Haven–type diabase near Cornwall-type magnetite deposits; these concentrations are higher than those of the gneiss or marble. Smith and others (1988) show a similar Au/Cu ratio for diabase and ore from the French Creek mine. However, the calculated sulfur and oxygen isotope composition of the mineralizing fluids are not consistent with an igneous origin for these latter elements, and much of the Fe and trace elements may have been derived from nearby Paleozoic sediments and Triassic red beds. An oxygen isotope study by Rose and others (1985) showed that the calculated $\delta^{18}O$ of fluids in equilibrium with magnetite (12.3 per mil for the French Creek mine) are much higher than the $\delta^{18}O$ of magmatic fluids expected to emanate from the diabase (7.3–7.8 per mil) and, therefore, are not considered the principal source of the fluids that formed the orebody.

Sulfide deposition appears to be related to the cooling of the hydrothermal fluid. The late position of sulfides in the paragenic sequence suggests that most were deposited at lower temperatures than the magnetite. The $\delta^{34}S$ of the fluid was higher than that of the sulfide minerals (Rose and others, 1985). Sulfur isotope composition of sulfide minerals from the orebody shows enrichment of ^{34}S (5.4 per mil), considerably above the 0.1 per mil average ^{34}S for diabase in the Newark basin (Smitheringale and Jensen, 1963). The sulfur isotope concentrations of the sulfide minerals in the orebody are similar to values for sulfides from nearby nonigneous rocks, indicating a nonigneous source for sulfur in the ore.

MINERALS

Chalcopyrite from the French Creek mine forms spectacular specimens and is included in the most prominent museum, university and private collections. Also notable are the fine cubic and octahedral pyrite crystals, octahedral magnetite crystals and tabular apophyllite crystals equal to the finest in the world.

Early labels and locality information, such as Dana (1854), list the French Creek mine as Keim's iron mine or Knauertown, the nearest village before the establishment of St. Peters. Labels from the late 1800's and early 1900's commonly list the locality as "Falls of French Creek." Recent labels identify the locality as St. Peters or the French Creek mine.

Bryn Mawr College in Bryn Mawr, Pennsylvania, has an exhibit of exceptional French Creek mine minerals from the Vaux collection on display in the Geology Building. The Bryn Mawr College collection is open to the public and can be seen daily during the school year. Other arrangements can be made by contacting the Geology Department. The fluorite, laumontite, mesolite and natrolite reported here were identified by X-ray diffraction analysis on specimens from the Bryn Mawr College collection.

Actinolite $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$

Fibrous actinolite is a common constituent of the orebody. Actinolite forms pale to olive-green, felty, matted, compact aggregates of acicular fibers, often forming large masses of nearly pure actinolite. Actinolite is associated with calcite, magnetite and pyrite. It penetrates calcite as long, slender needles and commonly colors calcite green ("byssolitic calcite"). Actinolite is also found as pseudomorphs after pyroxene ("uralite"). Eyerman (1911) reported that the actinolite sometimes contains Co and Ni.

Andradite $Ca_3Fe_2^{3+}(SiO_4)_3$

Andradite is abundant as brownish black dodecahedral crystals. Crystals are commonly striated, and some have truncated edges. Genth (1875) reported crystals over 1 cm in diameter from Keim's mine. Early labels also list Knauertown as the locality for superb, large andradite crystals from the French Creek mine.

Apatite Group

Apatite is an accessory mineral in gneiss and diabase.

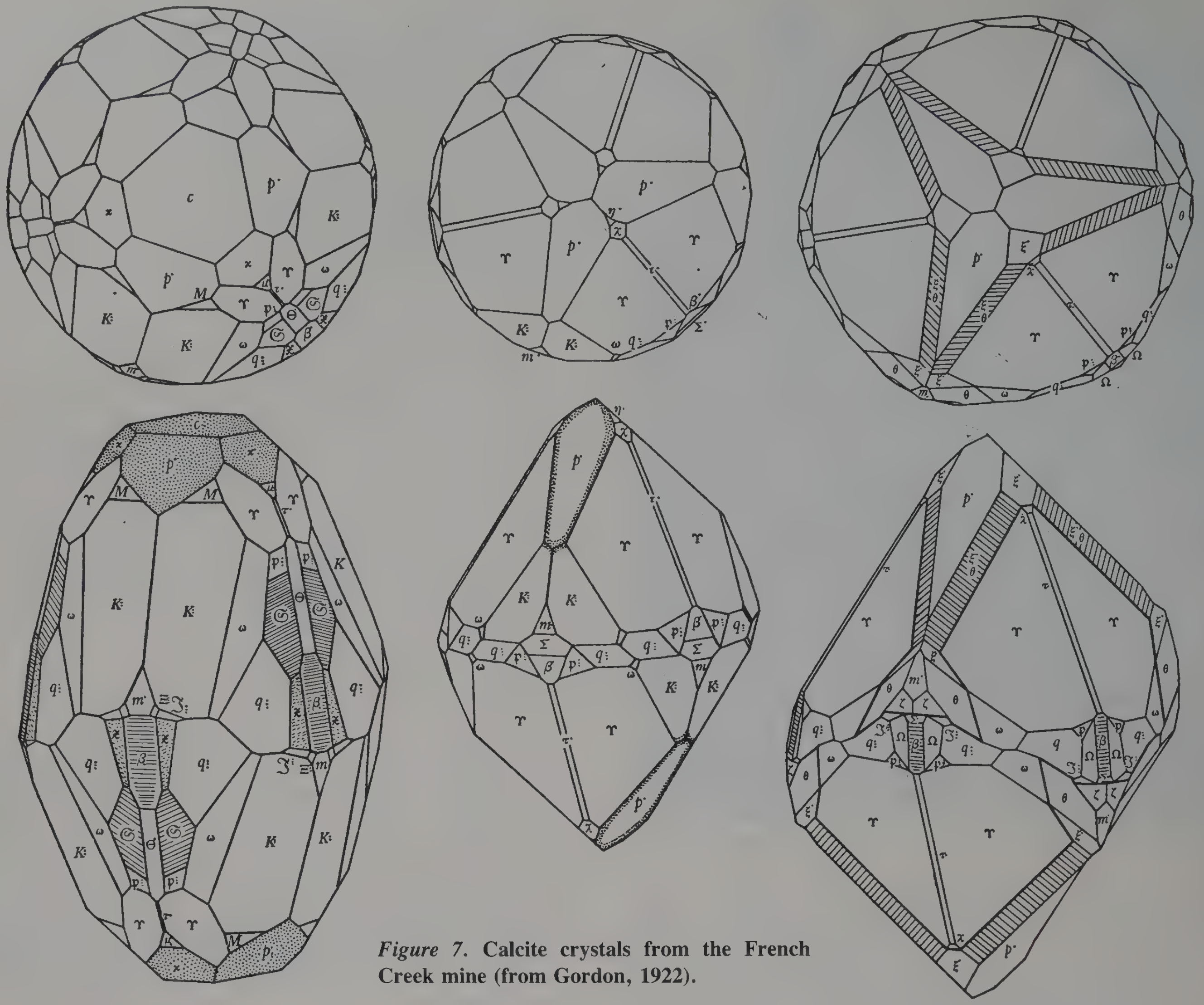

Figure 7. **Calcite crystals from the French Creek mine (from Gordon, 1922).**

Apophyllite Group

Apophyllite forms well-defined, transparent, white, yellowish and pinkish tabular and platy crystals to 5 cm in cavities in diabase associated with magnetite. The pinkish color is caused by the presence of iron oxide. Some apophyllite crystals are sprinkled with tiny pyrite crystals. Apophyllite is often associated with laumontite and sometimes stilbite. The crystals form clusters; Eyerman (1889b) reported clusters up to "2 feet square." The crystals are sometimes modified, having largely developed prism faces.

In early 1926, a small number of opaque olive-green crystals to 4 cm were found (Vaux, 1928). The green color is caused by included actinolite. These crystals display equal development of the base and pyramid and suppression of the prism faces; they resemble green dodecahedral garnet crystals. The base is characteristically pearly and built up of smaller crystals. Minute apophyllite crystals are scattered over the pyramid faces with no relation to the larger crystal. The French Creek mine, as well as the Cornwall mine, are noted world-class localities for apophyllite.

Aragonite $CaCO_3$

Aragonite is uncommon; it was reported as silky, fibrous, stalactitic and acicular crystals by Genth (1875) and Eyerman (1889b). Aragonite is much more common at the Jones mine, a Cornwall-type deposit formed by the intrusion of diabase into Cambrian-Ordovician limestone.

Augite $(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$

Dark green augite generally is massive. Eyerman (1889a) reported perfect crystals to 4.2 cm. Chamberlin (1887) described deep olive-green drusy crystals grouped into stalactitic forms. Augite is associated with hornblende and is a common accessory in the diabase.

Azurite $Cu_3^{2+}(CO_3)_2(OH)_2$

Azurite is rare as blue coatings associated with weathered chalcopyrite.

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

Biotite as black laminae is a common accessory mineral in gneiss.

Bornite Cu_5FeS_4

Bornite occurs as a copper-red, metallic material with an iridescent tarnish (Gordon, 1922) associated with chalcopyrite. It forms a coating on calcite.

Calcite $CaCO_3$

Massive calcite, in chunks weighing up to several kilograms, is very common on the dumps; calcite crystals are rare. Calcite forms transparent, white, green, gray, black, yellow and pink cleavages and transparent, green, white and yellow crystals. The color is caused by inclusions of actinolite, magnetite or iron oxides. Pink calcite is associated with the graphite-diopside host marble. Other colors are associated with the orebody. White cleavages or crystals are present

Figure 8. **Actinolite specimen, 9 cm. Bryn Mawr College collection V5027; R. Sloto photo.**

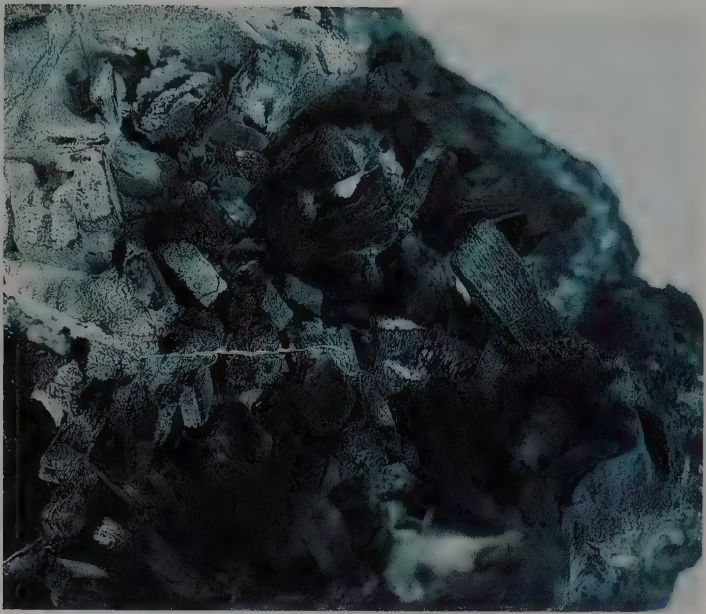

Figure 9. **Actinolite pseudomorph after pyroxene, 12 cm, with "crystals" to 2 cm. Bryn Mawr College collection V5024; R. Sloto photo.**

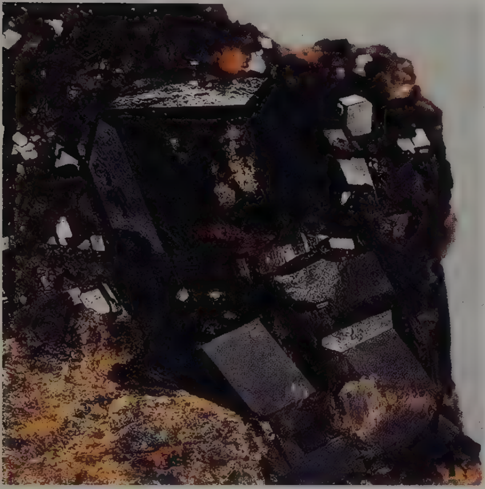

Figure 10. **Andradite specimen, 10 cm, with crystals to 2.2 cm. Carnegie Museum of Natural History collection (William Jefferis collection 2230); R. Sloto photo.**

Figure 11. **Apophyllite crystal group, 16 cm, with crystals to 2 cm. Bryn Mawr College collection; R. Sloto photo.**

Figure 12. **Apophyllite crystal group with pyrite. Bill Yocom collection; R. Sloto photo.**

in both the host and orebody. Gordon (1922) noted 31 crystal forms on French Creek calcite, and described five habits and their order of crystallization. The first crystals to form were green, positive rhombohedrons up to 35 cm. The second crystals formed were transparent, highly modified, positive scalenohedrons, sometimes doubly terminated, up to 12 cm wide and 21 cm long (Vaux, 1928); they formed as single crystals, druses, and small crystals covering rhombohedrons. Next, colorless or white, negative rhombohedrons up to 7.5 cm were formed. The fourth habit of crystals to form was colorless, negative scalenohedrons up to 1 cm. The last crystals formed were symmetrical, parallel pairs of individual crystals with different faces up to 7 cm. Some crystals are combinations of the unit prism, scalenohedron and rhombohedron up to 8 mm long and 2 mm wide (Gordon, 1918).

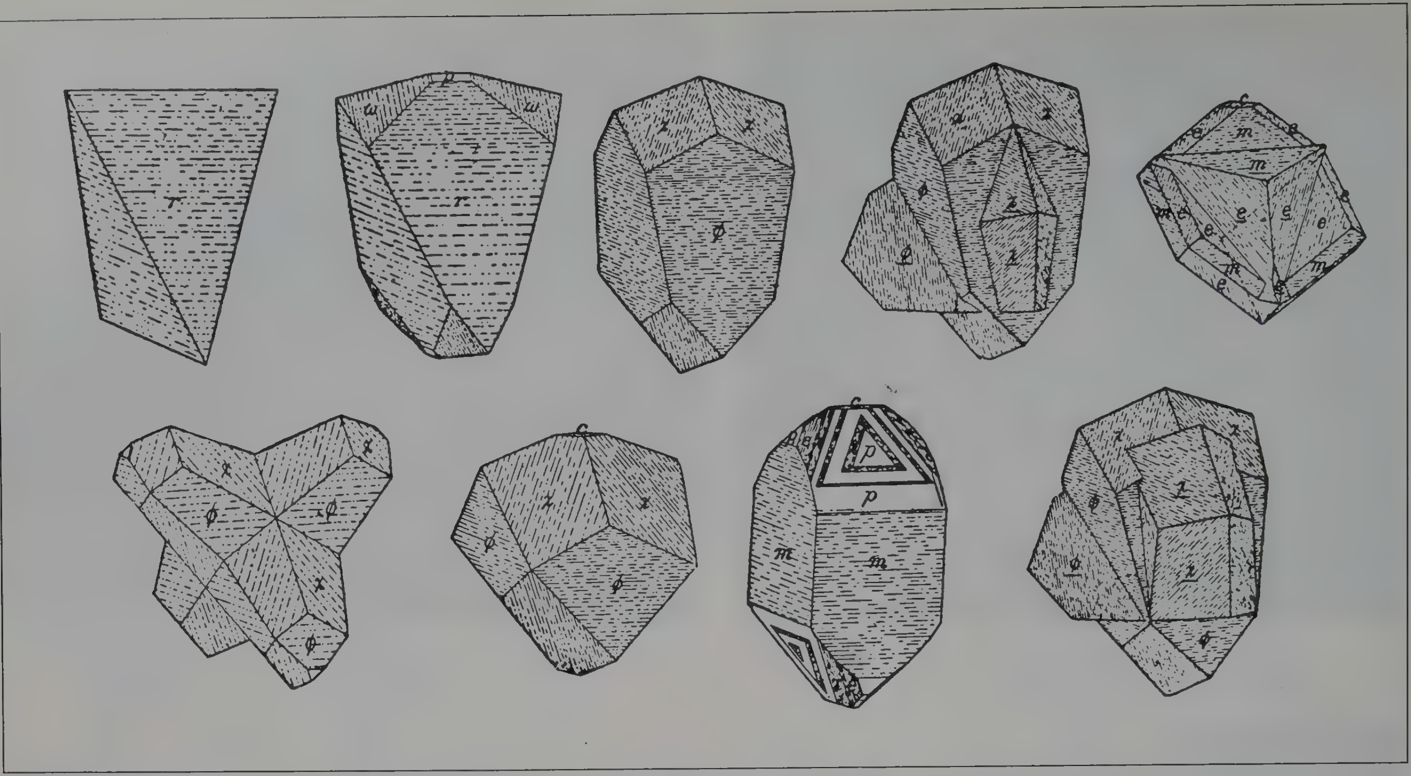

Figure 13. **Chalcopyrite crystals from the French Creek mine (from Penfield, 1890).**

Chalcopyrite $CuFeS_2$

Chalcopyrite is common as brass-yellow crystals and parallel growths of crystals associated with calcite, magnetite and actinolite. It may be coated with malachite, a purple tarnish or a black oxide. Penfield (1890) provides an excellent description of the crystal forms. The simplest form is the disphenoid; single crystals are as large as 3 cm (Eyerman, 1889b). Disphenoidal crystals are modified by the tetragonal scalenohedron. Crystal faces are commonly striated; the striations are parallel to their intersection with the positive and negative unit disphenoids and frequently cause a rounding or distortion of the crystals. Crystals are also present as pseudo-tetrahedrons with sunken or hopper-shaped faces. Parallelism of grouped crystals is developed on a grand scale. Eyerman (1889b) noted perfect crystal groups up to "2 feet square." A crystal group on display in the Hillman Hall of Minerals at the Carnegie Museum of Natural History in Pittsburgh measures 22 by 22 cm; this specimen is featured on the front cover of Geyer and others (1976). Parallel crystal groups commonly are enclosed in calcite and are exposed by etching with hydrochloric acid. Eyerman (1889b) reported a single specimen of a chalcopyrite pseudomorph after pyroxene.

Chlorite Group

Chlorite is found as small green flakes. The species has not been determined.

Chrysocolla $(Cu^{2+},Al)_2H_2Si_2O_5(OH)_4 \cdot H_2O$

Chrysocolla occurs as blue-green coatings and botryoidal crusts, mainly on calcite.

Cobaltite CoAsS

Cobaltite is rare as small silver-colored octahedrons, commonly mixed with erythrite and pyrite, and silver-gray crystal aggregates to 1.2 cm. Cobaltite is usually coated with erythrite (Grant, 1974). It also occurs as gray to pale brassy yellow crusts on octahedral pyrite (Heyl, 1984). Cobaltite usually is found in calcite and is associated with pyrite, chalcopyrite, magnetite and actinolite. Other occurrences of cobaltite in the Mesozoic basin include the Dyer quarry near Gibraltar, Berks County, in the western part of the St. Peters–Birdsboro diabase sheet, and in hornfels adjacent to diabase at the Kibblehouse quarry in Perkiomenville, Montgomery County (Smith, 1978).

Covellite CuS

Covellite coats weathered chalcopyrite.

Datolite $CaBSiO_4(OH)$

Datolite occurs as small, glassy, white crystals to 1 mm in vugs in pink feldspar (Grant, 1974). Some crystals are well-formed; others have a melted appearance. Datolite is associated with stilpnomelane. A similar occurrence of datolite is at the Cornwall-type ore deposit in Dillsburg, York County (Geyer and others, 1976), where well-formed, clear to white, modified crystals occur in vugs associated with pink orthoclase and chlorite.

Diopside $CaMgSi_2O_6$

Diopside is found as small, green, euhedral crystals in marble. Smith (1978) reported that greenish gray "melted" crystals believed to be apatite in marble were found to be diopside. Dark green euhedral crystals in marble on a specimen from the Bryn Mawr College collection were identified as diopside by X-ray diffraction analysis for this paper.

Epidote $Ca_2(Fe^{3+},Al)_3(SiO_4)_3(OH)$

Epidote is usually massive. It rarely forms small, sharp, lustrous crystals in diabase and occurs as an accessory in the hornblende syenite gneiss.

Erythrite $CO_3(AsO_4)_2 \cdot 8H_2O$

Erythrite is uncommon as a thin, pink to lavender coating on calcite and actinolite formed as a weathering product of cobaltite or possibly cobaltian pyrite. Genth (1890) reported erythrite as rose-colored microscopic crystalline groups.

Fluorite CaF_2

Fluorite on a specimen from the Bryn Mawr College collection (Rand 2490) was identified by X-ray diffraction analysis. It forms 2-mm colorless cubic crystals on diabase.

Graphite C

Graphite is abundant as disseminated flakes in marble, gneiss and calcite.

Grossular $Ca_3Al_2(SiO_4)$

Grossular occurs rarely as small, red, cinnamon-brown, gray and yellowish green dodecahedral crystals.

Gypsum $CaSO_4 \cdot 2H_2O$

Gypsum is an alteration mineral formed on the mine dumps. It is found rarely as small, clear cleavages, crystals and crystal groups associated with jarosite (Grant, 1974).

Hematite $\alpha\text{-}Fe_2O_3$

Hematite occurs as foliated micaceous plates in calcite and as an accessory mineral in graphitic felsic gneiss.

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

Heulandite was reported by Oldach (1917). It is rare.

Hornblende $Ca_2(Fe^{2+},Mg)_4Al(Si,Al)O_{22}(OH,F)_2$

Hornblende occurs as greenish black, bladed crystals and radiating masses (Genth, 1875).

Ilmenite $Fe^{2+}TiO_3$

Ilmenite is found as black cleavages in diabase (Geyer and others, 1976).

Jarosite $KFe_3^{3+}(SO_4)_2(OH)_6$

Jarosite is a secondary mineral formed on the mine dumps. It occurs as a yellow-brown coating formed by the oxidation of pyrite and other sulfides. It is associated with gypsum. Jarosite was identified by X-ray diffraction by Arthur Montgomery (Grant, 1974).

Laumontite $CaAl_2Si_4O_{12} \cdot 4H_2O$

Laumontite was identified by X-ray diffraction analysis of two specimens from the Bryn Mawr College collection (Vaux 173 and 6565). The crystals are now chalky, white and brittle. They are associated with apophyllite. Laumontite is quite common in hydrothermal veins in diabase of the Dyer quarry (Gordon, 1922; Lapham and Geyer, 1965).

Limonite $\alpha\text{-}Fe^{3+}O(OH)$

Limonite is found as coatings and as pseudomorphs after pyrite in gneiss.

Magnetite $Fe^{2+}Fe_2^{3+}O_4$

Magnetite is abundant in crystallized, platy and massive forms. Magnetite forms brilliant octahedral crystals up to 2 cm, rare dodecahedral crystals, and combinations of octahedral and dodecahedral faces. Well-formed crystals are found only along contacts with calcite or lining cavities. Platy magnetite, a pseudomorph after foliated hematite, exhibits a tabular to micaceous texture and may be curved or bent, commonly forming fan-like aggregates of thin plates. The flat surfaces of the plates exhibit a brilliant luster.

Malachite $Cu_2^{2+}(CO_3)(OH)_2$

Malachite commonly forms green coatings as a decomposition product of chalcopyrite. It was found in the upper workings and is abundant on the dumps. It coats calcite, chalcopyrite and magnetite.

Mesolite $Na_2Ca_2Al_6Si_9O_{30} \cdot 8H_2O$

X-ray diffraction analysis of several specimens from the Bryn Mawr College collection shows mesolite intergrown with natrolite. Natrolite is the dominant mineral.

Microcline $KAlSi_3O_8$

Microcline is common as pink cleavages in pegmatite and as mesoperthite in gneiss.

Natrolite $Na_2Al_2Si_3O_{10} \cdot 2H_2O$

Natrolite was identified by X-ray diffraction analysis on several specimens from the Bryn Mawr College collection. This analysis indicates that natrolite is intergrown with mesolite and that natrolite is the dominant mineral. Natrolite and mesolite have the same framework, and mesolite commonly is intergrown with natrolite (Tschernich, 1992). Natrolite-mesolite forms white, acicular crystals associated with other zeolites. Natrolite is much more common in hydrothermal veins at the Dyer quarry.

Orthoclase $KAlSi_3O_8$

Orthoclase commonly occurs as pink to pale green cleavages associated with stilpnomelane. Eyerman (1889b) reported columnar crystals to 6.4 cm radiating from a center to form a sheaf-like structure. It is found in pegmatite and gneiss.

Pigeonite $(Mg,Fe^{2+},Ca)(Mg,Fe^{2+})Si_2O_6$

Pigeonite occurs rarely in the groundmass of the diabase.

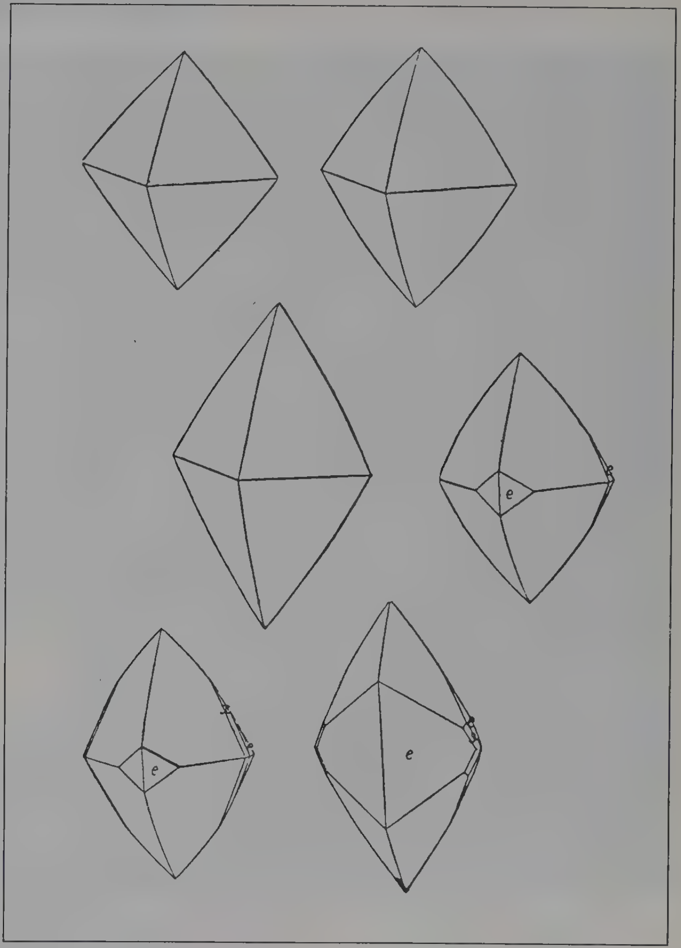

Figure 14. **Pyrite crystals from the French Creek mine (from Penfield, 1889).**

Pyrite FeS_2

Pyrite is abundant as brilliant cubes up to 2.8 cm, octahedrons up to 4.5 cm and modified crystals associated with actinolite, calcite and magnetite. Penfield (1889) gives an excellent description of crystal forms. Crystals formed on magnetite in cavities generally are cubic; crystals formed in calcite or actinolite generally are octahedral. The

Figure 15. Chalcopyrite, 2.5 cm. Joseph Varaday collection; R. Sloto photo.

Figure 16. Chalcopyrite, 15 cm. Bryn Mawr College collection 1039; R. Sloto photo.

Figure 17. Chalcopyrite, 13 cm, with crystals to 2 cm. Bryn Mawr College collection number 1046; R. Sloto photo.

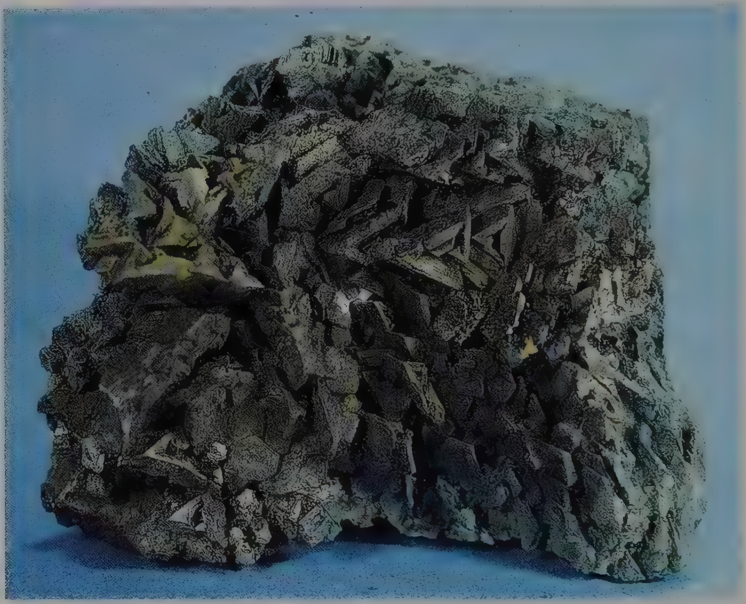

Figure 18. Chalcopyrite, 9 cm. Jay Lininger collection; R. Sloto photo.

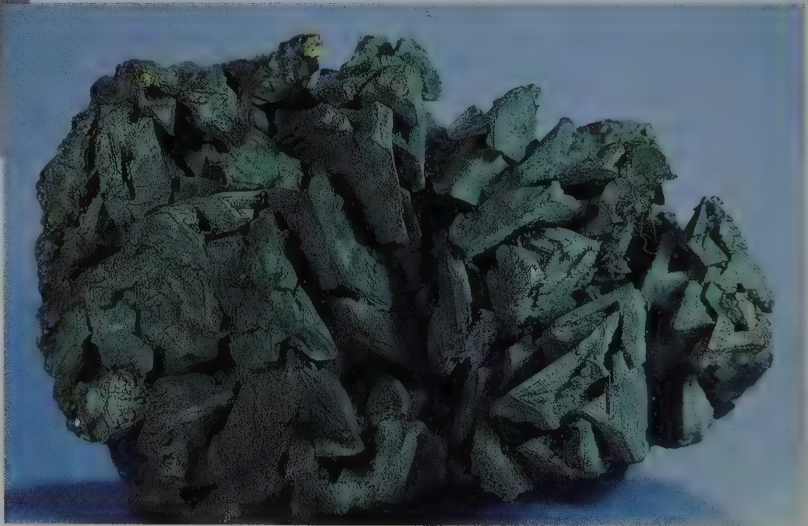

Figure 19. Chalcopyrite, 7 cm. Joseph Varaday collection; R. Sloto photo.

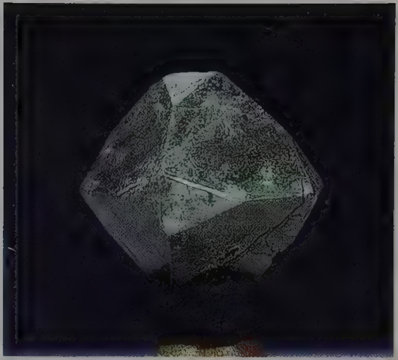

Figure 20. Pyrite crystal. 2.5 cm. Bryn Mawr College collection 1110-3b; R. Sloto photo.

Figure 21. Calcite and pyrite on magnetite, 7 cm. Bryn Mawr College collection 1080; R. Sloto photo.

Figure 22. Pyrite on magnetite; the pyrite crystal group is 3.5 cm. Bryn Mawr College collection V1114; R. Sloto photo.

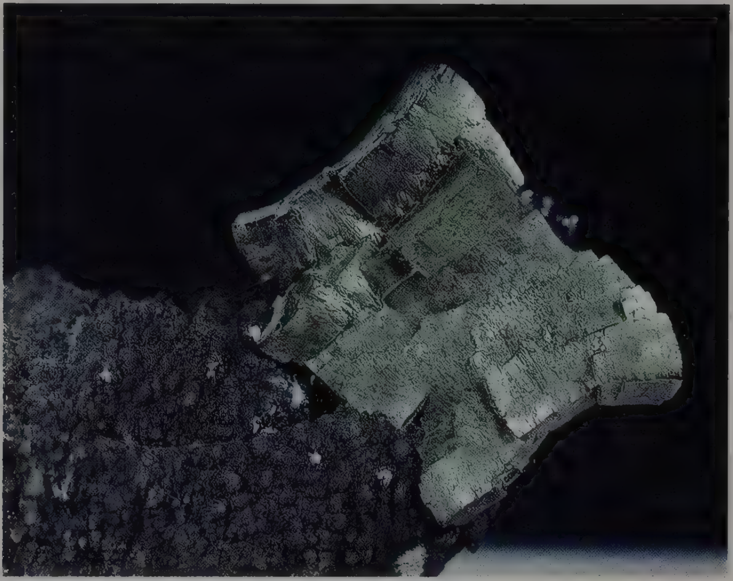

Figure 23. Pyrite on calcite; the pyrite crystal is 3.5 cm. Collected March 5, 1894. Bryn Mawr College collection 1088; R. Sloto photo.

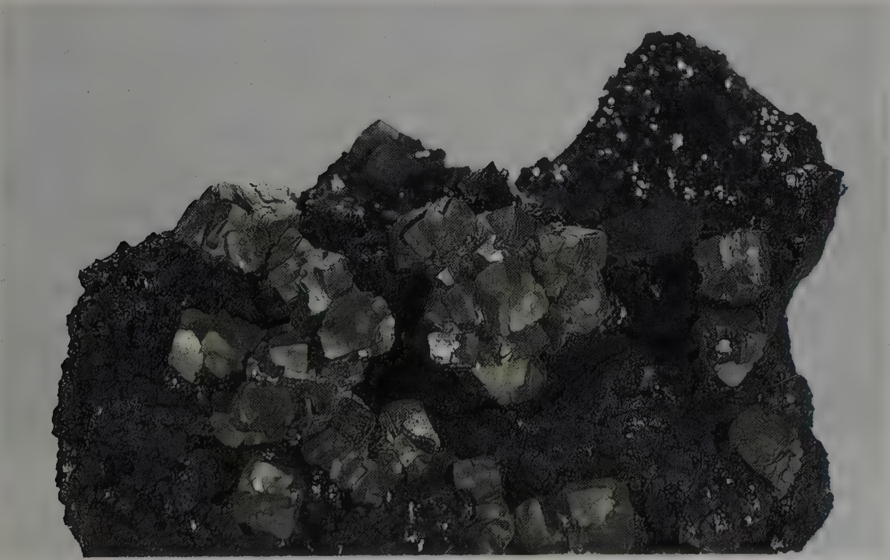

Figure 24. Pyrite on magnetite, 21 cm; pyrite crystals to 1.5 cm. Bryn Mawr College collection V181; R. Sloto photo.

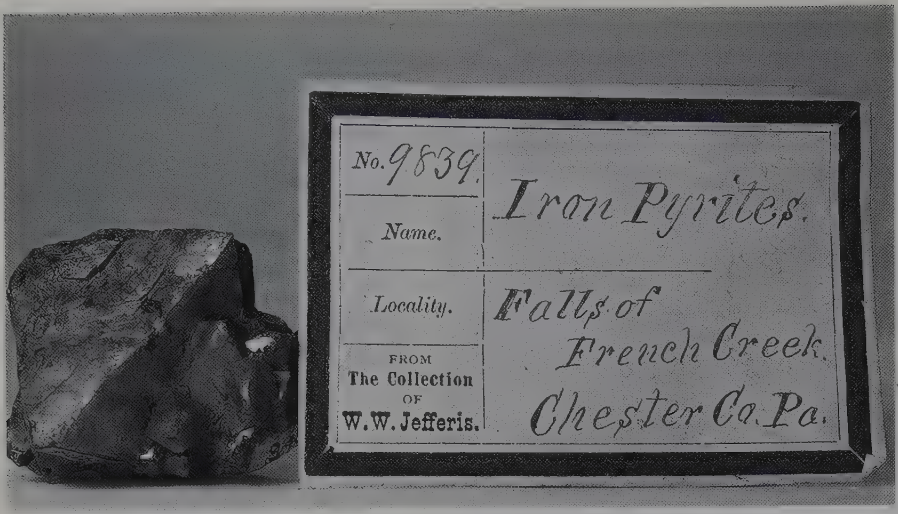
No. 9839.
Name. Iron Pyrites.
Locality. Falls of French Creek. Chester Co. Pa.
FROM The Collection OF W.W. Jefferis.

Figure 25. **Pyrite crystal group, 4.5 cm; the largest crystal is 3 cm, with Jefferis label. Carnegie Museum of Natural History collection (William Jefferis collection 9839); R. Sloto photo.**

faces of cubic crystals are characteristically curved, sometimes wavy and often dulled by etching (Wherry, 1920). Vaux (1928) reported hopper-shaped groups of modified cubic crystals up to 5 cm. Octahedral crystals are sometimes elongated and display curved, pyritohedral faces at the extremities of the lateral axes. Nichol (1904) described spinel twins of pyrite 2 mm across. The twinned crystals are equally developed octahedrons showing flattening parallel to the twinning plane. Pyrite is cobaltian; an analysis by Genth (1890) gave 1.75% Co, 1.2% As, 1.18% Ni and 0.05% Cu.

Pyrrhotite FeS

Pyrrhotite is rare. It is massive and rarely forms crystals (Lapham and Geyer, 1965).

Quartz SiO_2

Quartz is usually massive and occasionally forms small crystals.

Scapolite Group

Scapolite occurs rarely as transparent, white and grayish white columnar crystals up to 2 cm long and 5 mm thick. The crystals show combinations of the first and second order prism with the basal pinacoid. They frequently occur in groups, and the larger crystals are deeply striated. Genth (1890) reported scapolite as cavity fillings in garnet associated with magnetite and pyrite.

Schorl $NaFe_3^{2+}Al_6(BO_3)_3Si_6O_{18}(OH)_4$

Schorl is rare. It was reported by Gordon (1922) as black radiating crystals.

Sphalerite (Zn,Fe)S

Sphalerite is rarely present as small, ruby-red to dark brown crystals. Most French Creek sphalerite is iron-rich (Heyl, 1984).

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

Stilbite is rare as small crystals and crystal sheaves lining cavities in diabase associated with calcite. Crystals are up to 3.5 cm long; the larger crystals are imperfect (Eyerman, 1889a). Stilbite is quite common in large, spectacular groups of crystal sheaves in seams and veins in the diabase of the Dyer quarry (Gordon, 1922; Geyer and others, 1976).

Stilpnomelane $K(Fe^{2+},Mg,Fe^{3+})_8(Si,Al)_{12}(O,OH)_{27}$

Stilpnomelane is common as small brass-brown flakes in cavities in feldspar. It is the "glauconite" of Knerr and Schoenfeld (1885) and Eyerman (1889a) and the "chalcodot" of Gordon (1922). It was correctly identified by Davis Lapham of the Pennsylvania Geological Survey in the 1950's. A darker, green-black stilpnomelane has been identified by X-ray diffraction from veins in the Dyer quarry (D. F. Hess, written communication, 1992).

Thomsonite $NaCa_2Al_5Si_5O_{20}\cdot 6H_2O$

Thomsonite was identified on one specimen by John Barnes of the Pennsylvania Geological Survey (Grant, 1974). It occurs as white, fan-shaped sprays in feldspar associated with stilpnomelane.

Tremolite $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$

Tremolite was reported by Lapham and Geyer (1965) as white, acicular crystals similar to byssolite on calcite.

Zircon $ZrSiO_4$

Zircon occurs as an accessory mineral in gneiss.

Table 1. **Minerals reported from the French Creek mine.**

Elements
- Copper (?)
- Graphite

Sulfides
- Bornite
- Chalcopyrite
- Cobaltite
- Covellite
- Pyrite
- Pyrrhotite
- Sphalerite

Fluorides
- Fluorite

Oxides
- Hematite
- Ilmenite
- Limonite
- Magnetite

Phosphates
- Apatite

Arsenates
- Erythrite

Molybdates
- Molybdenite (?)

Sulfates
- Gypsum
- Jarosite

Carbonates
- Ankerite (?)
- Aragonite
- Azurite
- Calcite
- Malachite
- Rhodochrosite (?)
- Siderite (?)

Silicates
- Actinolite
- Andradite
- Anthophyllite (?)
- Apophyllite group
- Augite
- Biotite
- Chlorite group
- Chrysocolla
- Datolite
- Diopside
- Epidote
- Forsterite (?)
- Grossular
- Heulandite
- Hornblende
- Laumontite
- Microcline
- Mesolite
- Natrolite
- Orthoclase
- Pigeonite
- Quartz
- Riebeckite-magnesioriebeckite (?)
- Scapolite group
- Schorl
- Stilbite
- Stilpnomelane
- Talc (?)
- Titanite (?)
- Thomsonite
- Tremolite
- Zircon
- Zoisite (?)

Other Minerals

Other minerals reported from the French Creek mine include ankerite (Benge and Wherry, 1908), anthophyllite and talc (Lapham and Geyer, 1965), native copper (Genth, 1875), forsterite (D. F. Hess, written communication, 1992), molybdenite (Dana, 1854), rhodochrosite (Dana, 1893), siderite (Dana, 1892), titanite (R. C. Smith II, oral communication, 1988) and zoisite (Gordon, 1922). A bluish, fibrous amphibole that occurs very rarely in gneiss at the French Creek mine and in veins in diabase at the Dyer quarry has been tentatively identified as riebeckite-magnesioriebeckite by D. F. Hess (D. F. Hess, written communication, 1992).

PRESENT STATUS

The French Creek mine has been a popular and prolific mineral collecting locality for over a century. During the late 1800's and early 1900's, collectors who visited the mine could purchase minerals from the miners. A few fortunate individuals were allowed to collect in the mine. In 1948, the E. & G. Brooke Iron Company sold 22 acres, which included the mine office, shafts and dumps, to Peter Chonka. Chonka charged collectors a modest fee to collect minerals on the dumps until he sold the property to a developer in 1988. The property is being developed (1993) as the French Creek Mine Estates, and mineral collecting is no longer permitted.

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THE BURRA BURRA MINE,
BURRA, SOUTH AUSTRALIA

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Australia's Burra Burra mine has been famous for crystalline azurite, cuprite, and botryoidal and pseudomorphic malachite specimens since 1845. Recently renewed mining operations have also revealed libethenite crystals.

INTRODUCTION

European settlement of South Australia began in 1836 and was conceived as a great social experiment: there was to be no convict labor, and the proceeds of land sales were directed into a migration fund to bring workers and their families from Europe to provide a labor pool for the new colony. The economic basis of this utopian dream was flawed, and within a few years the young colony of South Australia was on the verge of bankruptcy. It was the discovery of rich copper deposits, first at Kapunda in 1842 and then the more significant discovery at Burra Burra in 1845, which was to save the colony from financial disaster and establish it on the road to prosperity. Burra Burra was Australia's first great mine and at the time it was one of the largest and richest in the world, producing nearly 5% of the total world copper output.

HISTORY

Discovery

Figure 1. **Morphetts enginehouse after its reconstruction in 1986, with Morphetts windinghouse in the background.**

The story of the Burra Burra mine began in 1845 with the chance discovery of copper ore by a shepherd, William Steair, near Burra Creek about 160 km north of Adelaide. Soon after, a similar find was made by another shepherd, Thomas Pickett, 13 km further to the north. News of the discovery reached Adelaide, a town already infected with mining mania because of the recently opened Kapunda mine. Steair divulged the location of his find to an Adelaide merchant for £8, and the deposit became the Princess Royal mine. Pickett received

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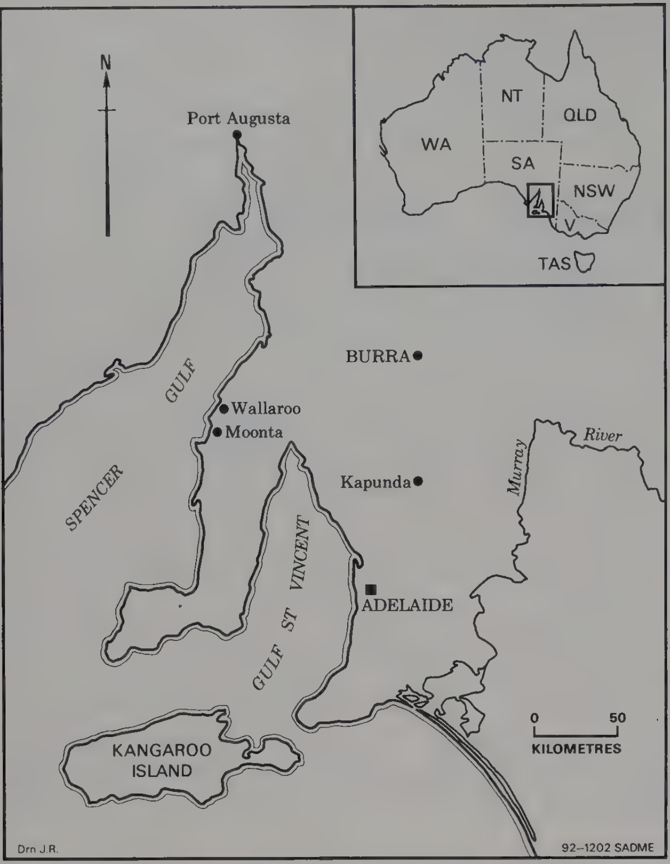


Figure 2. **Location map showing Burra and the other major copper mining centers in South Australia.**

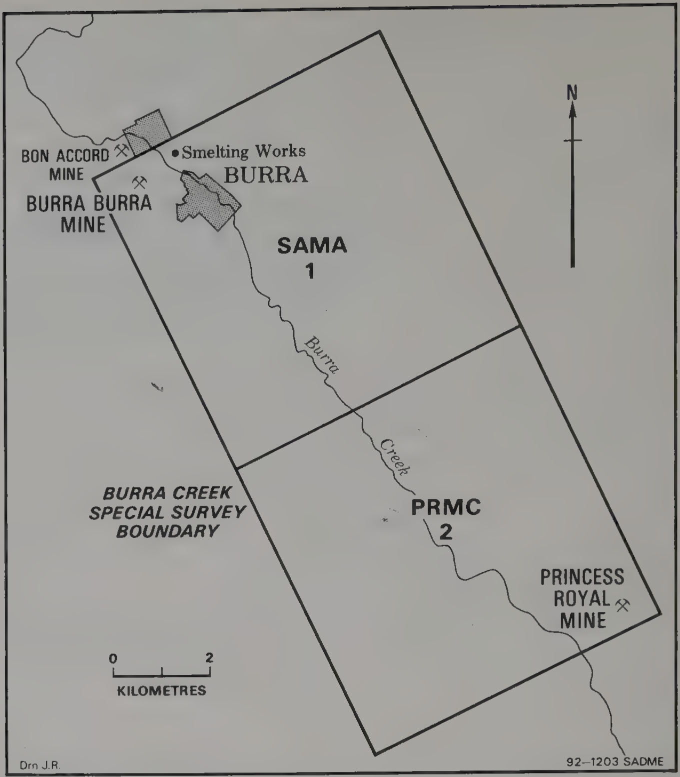


Figure 3. **Map showing the area covered by the special survey, and the location of the two copper deposits. The SAMA (the Snobs) drew the northern section and their fortunes were made by the Burra Burra mine. The PRMC (the Nobs) had the southern half of the survey area and the Princess Royal mine. Their mine had a large outcrop of rich carbonate ore but did not extend to depth.**

£10 for revealing the location of the large bubble of copper ore that he found, and this later became the Burra Burra mine. A struggle for possession of this new copper-bearing land quickly followed.

The interested parties resolved into two groups who refused to join forces, and they were immediately dubbed the "Nobs" and the "Snobs." The Nobs were capitalists and pastoralists, and included the owners of the Kapunda mine. The Snobs were the shopkeepers and merchants from Adelaide. Under existing regulations, mineral rights to the deposits could only be obtained by purchase of a special survey of 20,000 acres from the government for £20,000. A special survey was carried out and the rival groups jointly bought the land. They agreed to divide it equally, with each half containing one of the copper deposits. Neither party, it appears, had any particular preference for which deposit they mined, so lots were drawn. The Nobs drew the southern half, naming their mine the Princess Royal. The northern half, drawn by the Snobs, became the Burra Burra mine.

At first the Princess Royal was thought to be the more valuable deposit. The first large ore parcels shipped to England returned nearly 30% copper, but the deposit did not extend to any great depth. Mining reached the water table about 60 meters below the surface in 1851. The company, faced with a major capital outlay to install pumps while ore reserves were falling, was forced to close the mine. In its brief six-year lifetime it produced only 1,000 tons of copper. The mine and the rest of the 10,000-acre selection was sold freehold for grazing, and the original investors were thus able to recover 13 shillings to the pound of their original investment. (Few specimens from this mine exist in collections.)

The Snobs were shareholders of the South Australian Mining Association (SAMA), a company which had a capital of £12,320. Ten thousand pounds went to pay for their half of the special survey and the remaining £2,320 was used for working capital. This was all the capital they needed; the proceeds from mining were fabulous, and funded all future development at the mine.

Operations

Mining began in September of 1845. The rich copper carbonate ore was easily mined; it was sorted by hand and shipped by bullock wagon to Port Adelaide, a journey of 150 km which took two weeks. From Port Adelaide, the ore was shipped to Swansea, Wales, for smelting and refining. It was easy ore to smelt and sold for a premium price over the ores from Chile and Argentina. In 1849, smelters were built near Burra Creek to save on transport costs. The smelters required some 600 tons of firewood a week, and within a few years the area around the mines was almost totally denuded of trees.

By 1850, Burra had become the largest metalliferous mine in Australia, employing more than 1,000 men and boys. The management and the majority of miners were Cornishmen, and the mines were worked under the traditional Cornish systems. Production declined after 1860, and eventually underground mining ceased in 1867. From 1870 until closure in 1877 it was worked by the open cut method but this proved unprofitable. In the early years, the ore grade was more than 20% copper. During the 30 years of production between 1845 and 1877, some 700,000 tons of ore was raised which yielded over 50,000 tons of copper, an average ore grade of more than 7%. The cost of mining averaged £40 per ton of copper. The shareholders in SAMA received over £800,000 in dividends, and the Government only the £10,000 from the original special survey. Thomas Pickett the discoverer received only £10 for revealing the location of the deposit.

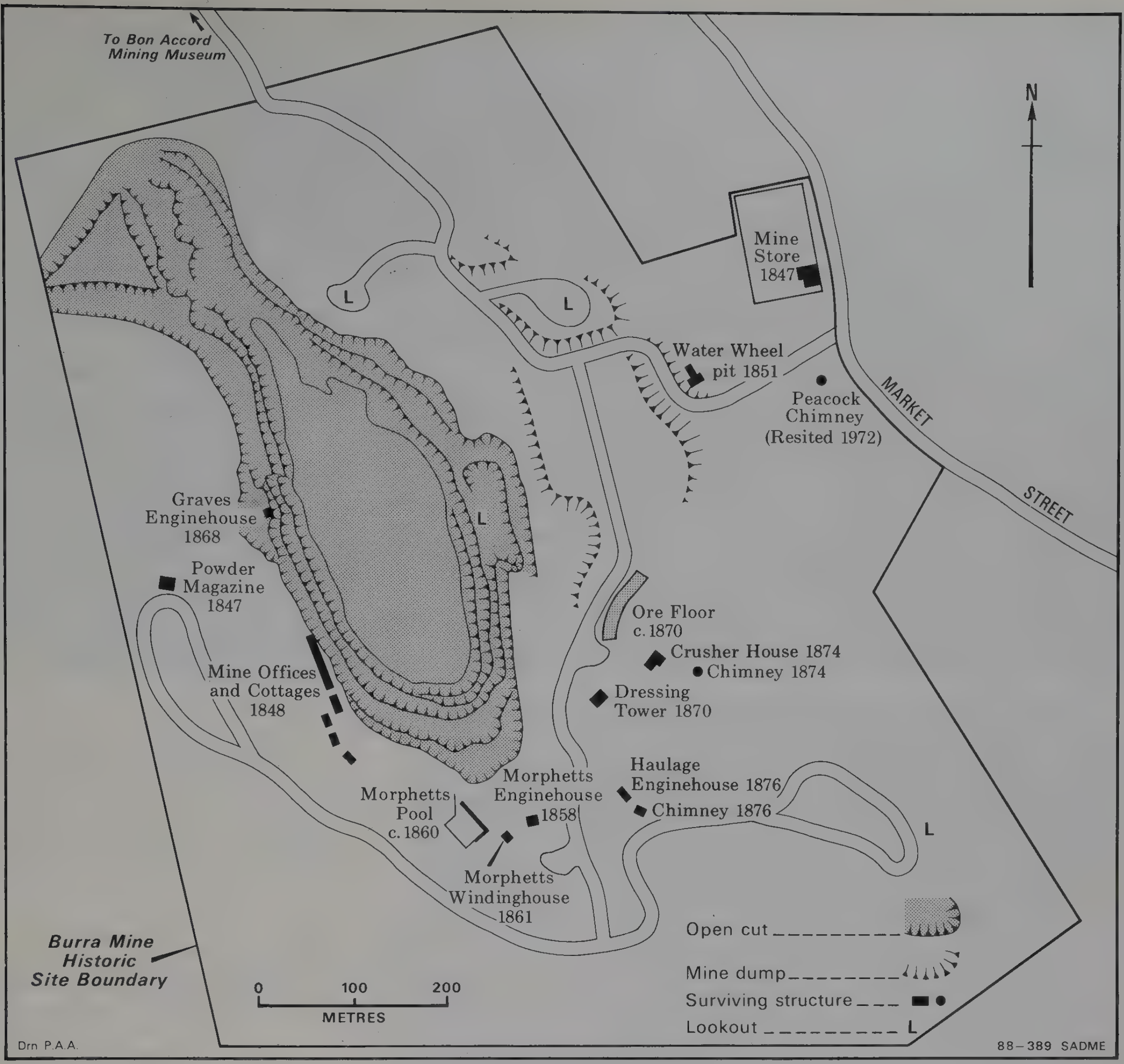


***Figure 4.* Schematic plan of the Burra Burra mine workings showing the opencut and the mine buildings.**

Water Problems

The battle against rising water levels was a major problem at all of South Australia's major copper mines. As depth of mining increased so did the problem of keeping the mines dry. At Burra, the water table is only 36 meters below the surface and was soon reached. At first, horse whims and buckets were used to control the water. In 1849, the first steam pumping engine was installed at Roach's shaft to lower the water level and allow deeper areas to be stoped. An even more powerful engine was installed on Schneiders shaft in 1852, but the gold rush intervened (see Birch, 1987) and this engine was not commissioned until 1854. For every ton of ore raised, one and a half tons of water were pumped from the mine.

The engines were Cornish beam engines derived from Thomas Newcomen's invention in the early 1700's, and improved by James Watt in the late 18th century to pump water from the copper and tin mines of Cornwall. These steam-powered engines, some with cylinders 80 inches in diameter, were exported around the world and were extensively used to control water in South Australia's copper mines. Each engine was housed in a specially built Cornish-style stone engine-house; three remain at Burra (Drew 1987, 1988).

Henry Ayers

Perhaps the best known figure associated with the Burra mine was Henry Ayers. Born in England in 1821 of humble origins and trained as a law clerk, Ayers became company secretary of the South Australian Mining Association at the age of 24; he was in effective control of the mine for most of its 30 year life. Ayers ran the mine from Adelaide, sending detailed written instructions to Captain Henry Roach, the resident manager at Burra. Not initially a large shareholder in the Mining Association, Ayers slowly acquired more shares and other business interest and held directorships in the Bank of Adelaide and a number of other companies. At his death in 1897 he was one of the wealthiest men in South Australia.

Henry Ayers entered politics in 1857; he served as a minister on eleven occasions and was Premier on seven different occasions during one of South Australia's most politically turbulent periods. Henry Ayers was knighted in 1872, and a year later Ayers Rock in central Australia was named in his honor by the explorer W. C. Gosse. In 1881 he presented a fine collection of specimens from the mine to the South Australian Museum; some of those specimens are figured in this article.

Figure 5. **Burra Burra mine, ca. 1868. The view shows Morphetts enginehouse (left) and windinghouse. The remains of Schnieders enginehouse can be seen at the right of center. At the left is a crusher house and carpenters' shop powered by a 21-meter waterwheel and an ore dressing shed in the front.**

Figure 6. **Sir Henry Ayers, ca. 1880. He was in effective control of the Burra Burra mine for nearly 30 years. He was also active in colonial politics and was Premier of South Australia on seven different occasions.**

Recent Development

In 1969, nearly a century after the mine was closed, the great mine at Burra was reopened and worked as an open cut. Between 1969 and 1981 the mine produced some two million tons of ore, nearly three times as much ore as was mined between 1845 and 1877. The new ore, however, yielded only 25,000 tons of copper metal, the average ore grade being 1.25% metal compared with over 7% during mining operations last century. It is somewhat ironic that it was the change to opencut mining in the 1870's that caused the mine to close.

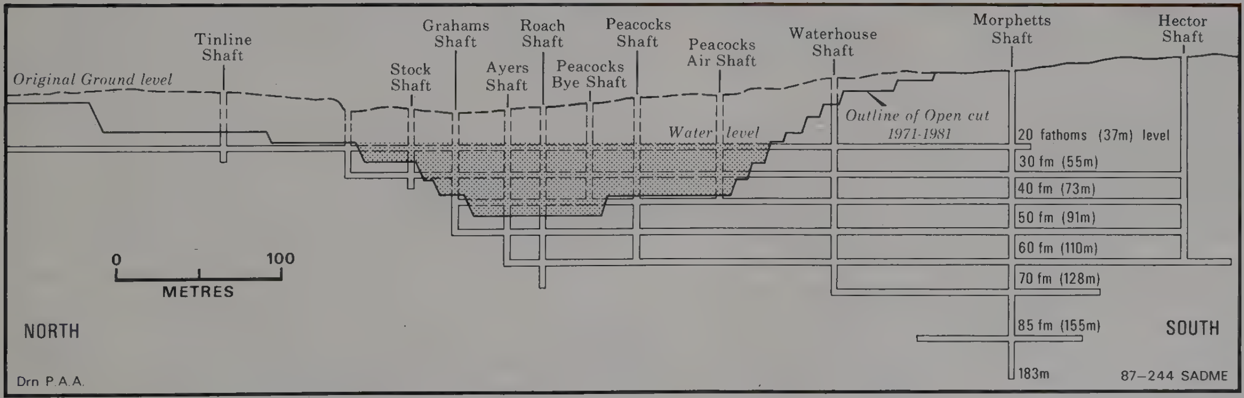
Today the mine site is historically important for the substantial remains of mid-nineteenth century copper mining and processing operations on a greater scale than in any other site in Australia. The Burra Mine Museum was established in 1986 to conserve and interpret these remains in an open-air historic park environment. The most important feature of the Museum is Morphetts Enginehouse, which was restored in 1986 and is the first Cornish beam enginehouse to be restored in the world (Drew, 1987). This was followed by retimbering of the upper section of the adjacent engine shaft, and excavation and retimbering of a drainage adit. The project has continued with archaeological excavations and conservation of other ruins, including Morphetts beam windinghouse, an ore dressing tower, crusher house and powder magazine. A helpful aspect of the museum is the interpretive signposting which provides an understanding of the historic evidence through historic photographs and reconstructions.

The town of Burra has survived as one of Australia's most significant

Figure 7. View of the Burra Burra mine and opencut, ca. 1904. Material from the opencut was hauled up in inclined railway to the top of the Mullock dump (left). The tall wooden framework near Morphetts enginehouse is a drilling rig. Peacocks enginehouse, demolished in 1972, is on the extreme right.

Figure 8. View of the opencut during mining operations in 1980. The then unrestored Morphetts enginehouse and windinghouse are at the top of the picture.

Figure 9. Cross-section of the Burra Burra mine showing the extent of the mine workings.



historical towns dating from Australia's first mining era. Today it is a regional rural center, the hub of merino sheep breeding and the pastoral industry. Increasingly it has become the location of a thriving cultural tourism industry based on its mining heritage. The township and mine sites of Burra, with their magnificent collection of historic buildings, provide a comprehensive record of the methods and lifestyles of the nineteenth-century mining community (Auhl, 1986; Drew, 1988).

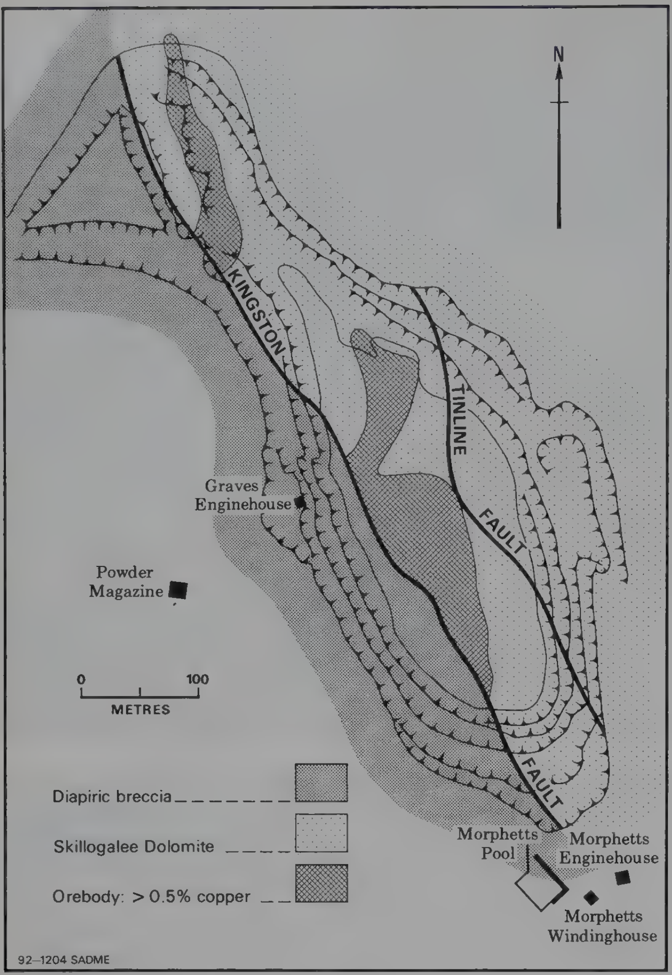


Figure 10. **Map showing the geology of the Burra Burra orebody. The orebody is confined between the Tinline and the Kingston faults.**

GEOLOGY

The Burra Burra copper orebody lies on the side of low limestone hills situated in a broad valley between prominent northwest-south-east–trending ridges in the northern Mount Lofty Ranges. The Ranges are composed of a series of folded and faulted Late Precambrian sediments of Adelaidian age which were uplifted after the Tertiary. The sedimentary succession is some 15,000 meters thick, but copper mineralization is restricted to units within the Skillogalee Dolomite, a 2,000-meter-thick series of dolomites and shales which lies toward the bottom of the sedimentary pile.

The copper mineralization in the Burra Burra deposit is further confined between two easterly dipping and northwesterly trending faults, the Kingston and Tinline faults (Dickenson, 1942; Johnson, 1963). Primary copper mineralization is associated with the intrusion of a feldspar porphyry in the early Paleozoic (Drexcell and McCallum, 1986; Nixon *et al.*, 1965). The original disseminated sulfide orebody has undergone extensive oxidation and secondary enrichment, and only very minor traces of primary sulfides have been found in the lower parts of the mine. The economic orebody, which was up to 70 meters wide, 400 meters long and extended to a depth of 100 meters, consisted of masses of banded malachite and azurite with minor amounts of cuprite, native copper, chrysocolla and libethenite. The host lithologies are dolomite breccia, kaolinized shale and siltstone. The majority of ore occurred in dolomite breccia, the remainder as veins, blebs and nodules in unkaolinized host rocks.

MINERALS

The mineralogy of the Burra Burra orebody is dominated by secondary copper minerals, particularly the copper carbonates malachite and azurite. Specimens of exceptional quality were found, both during the early period of mining and in the 1970's. Last century, fine mammillary malachite was found in considerable abundance at Burra Burra and was in great demand as a gemstone. Specimens from Burra were exhibited at most of the great exhibitions of the second half of the 19th century. The South Australian Museum has a large mass of azurite and malachite which was exhibited at the Philadelphia Exhibition in 1878. A mass of 71 kg of the finest malachite was sold at auction in Adelaide in November 1857. The prices realized were from 3 to 53 shillings per pound, a high price in comparison to a miner's weekly wage of 40 shillings at a time. The South Australian Museum has a fine collection of Burra Burra material, and this includes several collections presented by the directors of the South Australian Mining Association.

A full list of the minerals reported from the Burra Burra mine is presented in Table 1. The more important minerals from a collector's point of view are described below.

Aragonite $CaCO_3$

Aragonite was found as crystalline masses, white to pale oily green in color, with an internal radiating structure. These masses, up to 3 cm in diameter, are associated with malachite and penetrated by randomly oriented, rod-like stalagmites of limonite.

Atacamite $Cu_2Cl(OH)_3$

Atacamite was a scarce mineral at Burra Burra. It occurred as dark green, flattened crystalline nodules to 4 cm on sandstone, and also as earthy crusts and black-green crystals to 1 mm lining vuggy quartz. The large, fine atacamite crystals labeled "Burra, South Australia" found in old collections almost certainly originated from the Moonta-Wallaroo district some 90 km to the west (Pring, 1988). Atacamite crystals larger than 5 mm do not appear to have occurred at Burra Burra.

Azurite $Cu_3(CO_3)_2(OH)_2$

Azurite occurred abundantly throughout the mine and was an important ore mineral. The mine yielded spectacular crystallized examples of this species, some showing several different crystal habits on one specimen. Azurite crystals up to 5 cm in length have been found. They are typically royal-blue to blue-black in color, with a vitreous luster. The most common habit observed is translucent, flat blades in divergent sheaf-like clusters to 3 cm (but more commonly less than 1.5 cm), scattered across botryoidal malachite, pseudomalachite, or turquoise-blue chrysocolla. Specimens with the latter association are particularly attractive due to the striking contrast in color between the two species. Possibly some of the finest Burra specimens were spherical aggregates and rosettes of lustrous, platy, azurite crystals, which have been known to reach 5 cm in diameter and were typically perched on a matrix of impure chrysocolla, or tenorite-coated malachite. It is the microcrystals of azurite from the mine, however, which show the greatest diversity in habit and generally the most perfect development. Sharp, blocky to pseudocubic crystals occurred to 3 mm. Of rarer occurrence were equant crystals to 1 mm showing two periods of growth. Hollow centers of azurite nodules have been found lined with brilliant tabular or acicular crystals to 1 mm. These spherical nodules reached up to 12 cm in diameter and occurred abundantly in a soft claystone. Their surface is typically made up of the terminations of small, bladed azurite crystals and in some cases is partially altered to chrysocolla. The first recorded occurrence of an azurite pseudomorph after libethenite was described by Peisley (1980) from material found in the opencut.

Barite $BaSO_4$

Sharp, lustrous crystals of barite up to 2 cm with azurite, malachite

Table 1. **Minerals identified from Burra Burra mine, South Australia.**

Native Elements	
Copper	Cu
Gold	Au
Sulfides and Selenides	
Bornite	Cu_5FeS_4
Chalcopyrite	$CuFeS_2$
Covellite	CuS
Chalcocite	Cu_2S
Digenite	Cu_9S_5
Pyrite	FeS_2
Oxides and Hydroxides	
Cryptomelane	$K(Mn^{4+},Mn^{2+})_8O_{16}$
Cuprite	Cu_2O
Goethite	$FeO(OH)$
Hematite	Fe_2O_3
Opal	$SiO_2\cdot nH_2O$
Pyrolusite	MnO_2
Quartz	SiO_2
Tenorite	CuO
Halides	
Atacamite	$Cu_2Cl(OH)_3$
Iodargyrite	AgI
Carbonates	
Aragonite	$CaCO_3$
Azurite	$Cu_3(CO_3)_2(OH)_2$
Calcite	$CaCO_3$
Dolomite	$MgCa(CO_3)_2$
Malachite	$Cu_2(CO_3)(OH)_2$
Siderite	$FeCO_3$
Phosphates	
Fluorapatite	$Ca_5(PO_4)_3F$
Libethenite	$Cu_2(PO_4)(OH)$
Pseudomalachite	$Cu_5(PO_4)_2(OH)_4$
Sulfates	
Barite	$BaSO_4$
Brochantite	$Cu_4(SO_4)(OH)_6$
Chalcanthite	$CuSO_4\cdot 5H_2O$
Gypsum	$CaSO_4\cdot 2H_2O$
Jarosite	$KFe_3(SDO_4)_2(OH)_6$
Silicates	
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$
Halloysite	$Al_2Si_2O_5(OH)_4$
Kaolinite	$Al_2Si_2O_5(OH)_4$
Nontronite	$Na_{0.3}Fe_2(Si,Al)_4O_{10}(OH)_2\cdot nH_2O$
Orthoclase	$KAlSi_3O_8$
Tremolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

and libethenite on chrysocolla or quartzite matrix were found. The crystals, of a bladed to tabular habit, are transparent and range from colorless to pale yellow. Barite was also found as fawn-brown nodules to 7 cm across, the centers of which are vuggy and lined with minute colorless barite crystals and occasional hemispheres of malachite.

Chalcocite Cu_2S

Pseudomorphs and partial pseudomorphs of chalcocite after pyrite crystals (pyritohedra and less commonly octahedra), were relatively common in the kaolinitized feldspar porphyry at the base of the open cut. The lustrous, iron-black crystals, both individuals and clusters, occurred imbedded in the kaolinite. Individuals commonly reached 1 cm (very rarely >4 cm) and faces were typically heavily striated. In most cases the alteration to chalcocite has not proceeded very far, the chalcocite being only a thin, black patina on the pyrite crystals. Some crystals and aggregates are microfractured, the fractures being filled with earthy turquoise-blue chrysocolla, which also partially encrusts the outside surfaces of the crystals giving them a dull luster.

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

Chrysocolla was common at the Burra Burra mine, occurring in a range of colors (powder-flue, deep turquoise-blue, blue-green and olive-green) and in a variety of forms (pulverent coatings, glassy to waxy botryoidal masses, and cryptocrystalline incrustations). It was present in the mine as veins and breccia fillings in quartzite and in malachite, and also as globular stalagmites to 3 cm associated with platy azurite crystals. Concretically banded malachite and chrysocolla intergrowths were also found. Bywater (1984a) reported chrysocolla occurring as translucent vug fillings. Bywater (1984a, 1984b) also described chrysocolla pseudomorphs after azurite, cuprite, copper and libethenite. The range of pseudomorphs indicates that chrysocolla is generally a late-forming mineral at Burra.

Copper Cu

Native copper was an important ore mineral during the early period of mining. It occurred in large masses associated with cuprite and the copper carbonates, and in some cases comprised a considerable proportion of the lodes. Typically it occurred in very crudely crystalline masses with a patina of malachite and cuprite. Occasionally arborescent groups of sharp, elongated octahedra occurred with individual crystals to 1 cm. Peisley (1989) reported native copper occurring as thin foliae in kaolinitic material.

Cuprite Cu_2O

Cuprite, like native copper, was a major ore mineral in the upper oxidized zones; early reports mention masses of pure "red oxide" weighing 500 pounds, and one upwards of a ton (Auhl 1986). Cuprite was generally present as massive, gray vein fillings associated with malachite and (less commonly) azurite. Free-growing crystals occurred where such veins opened into cavities. Cuprite crystals from the mine are generally sharp, gunmetal-gray octahedra, elongated cuboctahedra, or combinations of the octahedron and the dodecahedron up to 2 cm in size. Cuprite crystals from Burra are often partially altered to velvety green malachite. Of much rarer occurrence is the bright red acicular variety which was found in kaolinite.

Fluorapatite $Ca_5(PO_4)_3F$

Prismatic crystals of fluorapatite up to 5 mm in length and ranging from colorless through pale yellow to brown were found with libethenite and chrysocolla in the lower parts of the opencut. Fluorapatite was also found as brown, crystalline, botryoidal incrustations with libethenite.

Libethenite $Cu_2(PO_4)(OH)$

Libethenite at Burra was uncommon in the earlier workings and only a few specimens are known from the last century. In 1979 a libethenite-rich zone was located between the 430 and 480-meter benches in the southern section of the opencut. It was characterized by the assemblage: libethenite, azurite, chrysocolla, pseudomalachite, fluorapatite and minor malachite (Bywater, 1984a). Within this zone sharp, lustrous crystals lining vugs in veins of massive libethenite were found in considerable abundance.

Generally pseudo-octahedral in habit, larger crystals reach up to 8 mm in length and are commonly elongated along their *a* axis. Depending on their size, the crystals range in color from deep green in crystals less than 0.5 mm to dark green-black in larger crystals. The majority of libethenite crystals from the mine are less than 2 mm across, and are commonly overgrown with turquoise-blue chrysocolla, the surface of which is commonly encrusted with large, lustrous azurite crystals. In some cases larger libethenite crystals have oriented overgrowths of microcrystalline malachite on {011} faces only, and where {011} faces are not overgrown with malachite they often show parallel

Figure 11. Group of azurite rosettes from the Burra Burra mine. The specimen (SAM G2386), measuring 14 cm, was presented to the South Australian Museum by Sir Henry Ayers in 1881. Photo by T. Peters.

Figure 12. Group of two azurite rosettes from the Burra Burra mine. The specimen (SAM G2391) is 10 cm. Photo by T. Peters.

Figure 13. Botryoidal malachite on matrix from the Burra Burra mine. The specimen (SAM G2335), measuring 16 cm, was presented to the South Australian Museum by Sir Henry Ayers in 1881. Photo by T. Peters.

Figure 14. Botryoidal malachite from the Burra Burra mine. The specimen (SAM G2334), measuring 16 cm, was presented to the South Australian Museum by Sir Henry Ayers in 1881. Photo by T. Peters.

growth steps (Noble, 1980). Hemispherical aggregates of libethenite microcrystals were also observed with a malachite alteration halo. Bywater (1984a) described azurite, chrysocolla and malachite pseudomorphs after libethenite.

Malachite $Cu_2(CO_3)(OH)_2$

The Burra Burra mine is well-known as a classic locality for fine-quality malachite. Most specimens seen in collections today were mined before 1877, though significant quantities were also found by mineral collectors during the more recent mining activities. Although many thousands of tons of gem-quality malachite went to the smelter, enough was saved so that today thousands of specimens are still in circulation.

The malachite occurred in the upper part of the oxidized zone in large masses and breccia fillings commonly of gem quality. It was the main ore mineral at the mine. Of all minerals from the Burra Burra mine, malachite shows the most diversity of habit. By far the most common mode of occurrence is as radially compact, concentrically banded masses. Polished slabs of this material make spectacular specimens. It resembles malachite from Shaba province, Zaire, and the Urals in Russia. Incomplete filling of cavities with this form of malachite resulted in the botryoidal/mammillary vug linings for which Burra is famous. An attractive feature of this form of malachite is that the botryoidal surfaces often have a natural high polish, and are occasionally encrusted with druses of lustrous, blue azurite crystals. Less common are stalagmites with botryoidal surfaces, or botryoidal masses of more fibrous malachite. Unusual masses of honeycombed, cellular malachite occurred which may have formed by partial dissolution of more compact material.

Crystallized malachite was by no means rare, though non-pseudomorphic crystals rarely exceeded 1 cm in length. Radially acicular crystals to 1 cm were found lining cavities in massive malachite. Bywater (1984b) described malachite of the same habit forming "bow-ties" to 4 mm in association with leached crystals of azurite. Tabular emerald-green crystals commonly V-shaped, are known up to 5 mm, on massive cuprite, or with libethenite and chrysocolla. Lustrous emerald-green "arrowheads" of malachite reach 4 mm, commonly encrusting botryoidal malachite. Malachite was also found as unusual pseudo-cubic crystals to 1 cm in quartz, commonly with parallel growth on {001}. Pseudomorphs of malachite after azurite crystals were found relatively often as druses with individuals to 3 cm, frequently associated with unaltered azurite crystals. These pseudomorphs exist in two main habits: as blocky prisms, and as delicate discoidal plates. Spherical nodules of earthy malachite up to 10 cm in diameter were also common. They frequently have a knobbly surface and in some cases a core of residual azurite.

Pseudomalachite $Cu_5(PO_4)_2(OH)_4$

Pseudomalachite was reasonably common throughout the deposit, but its presence was often overlooked due to its similarity to the more abundant malachite. It was found in banded, botryoidal encrustations of a deep green to blue-green color usually closely associated with malachite of a similar habit and often overgrown with chrysocolla, libethenite or large crystals of azurite. Thin grass-green coatings of pseudomalachite occurred on fracture planes in massive quartz. Bywater (1984a) reported it occurring as transparent apple-green plates to 5 mm on chrysocolla from the libethenite zone. Pseudomalachite has also been observed as rare pseudomorphs after libethenite.

Pyrite FeS_2

Pyrite of diagenetic origin was common in the mine and the surrounding area, and pyrite intergrown with chalcopyrite and closely associated with bornite constituted the primary sulfide ore. Apart from pyrite crystals partially altered to chalcocite, no other specimen-quality material is known to have occurred.

Quartz SiO_2

Quartz was common in the mine in a variety of forms and colors. Large, sharp, colorless to pale smoky crystals up to 10 cm long and 3.5 cm wide occurred with a satin surface finish, and hosted tufts and crusts of micro-acicular malachite. Druses of matte-black crystals were found with individuals to 3 cm across and with very little development of the prism faces. These druses are partially encrusted with small hemispheres and films of olive-green malachite. Chalcedonic quartz occurs in three habits: as white spherules to 6 mm with microcrystalline malachite lining vugs in concretionary limonite; as gray-blue stalagmites to 5 cm, the surfaces of which are covered with minute quartz crystals (in massive quartz vugs); and as dark blue incrustation pseudomorphs (paramorphs) after azurite crystals to 2 mm. Peisley (1989) reported quartz occurring as sherry-red crystals to 1 mm and as scepters to 2 mm in calcite.

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Saddle-Shaped Rhodochrosite Crystals from the Foote Mine, North Carolina

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In the course of an ongoing study of minerals from the Foote Mineral Company spodumene mine near Kings Mountain, North Carolina, I have occasionally encountered crystals of a rhombohedral carbonate in saddle-shaped crystals, a habit commonly thought to be characteristic only of dolomite (as shown in Fig. 1; Goldschmidt, 1916). Dolomite, however, is not likely to be found in the pegmatite at the Foote mine considering that magnesium minerals are virtually absent there. This is in spite of the fact that magnesium is abundant in the schist and amphibolite into which the pegmatite was intruded. The Foote mine crystals are essentially confined to the pegmatite and are found in solution vugs, fissures and breccias.

Both rhodochrosite and siderite have been found in abundance at the Foote mine, and a wide range of compositional variation between the two end-members is believed to exist at this locality. For the most part, specimens that are obviously rhodochrosite, those with a pale to deep pink color and more or less transparent, are found with apatite, albite, quartz and, quite often, parsettensite. They may be associated with a number of the early "tertiary stage" phases (White, 1981), particularly fairfieldite, bikitaite and switzerite (now mostly metaswitzerite). The transparency of the rhodochrosite is often masked by a frosted surface, by a crust of a carbonate of differing composition, or by an altogether different mineral. Foote mine rhodochrosite seldom occurs as simple rhombohedral crystals. Rather it is usually in groups of subparallel crystals which have an overall spheroidal shape. A few crystals with pink cores surrounded by a brown crust of presumed siderite also exist. Tiny crystals of pyrite may be sparsely sprinkled over the rhodochrosite and the minerals that it grew upon. Siderite is relatively abundant but nearly always as dark brown botryoidal forms frequently associated with vivianite. Rarely it is found in elongated rice-grain-shaped rhombohedra.

One very fine specimen of saddle-shaped crystals (NMNH #168548) was analyzed by Joseph A. Nelen, of the National Museum of Natural History, using an ARL electron microprobe. These crystals are a pale pink and are virtually identical in appearance to the pink dolomite crystals of diagenetic origin that occur so extensively in limestone and dolomite quarries throughout much of this country. The composition was found to be predominantly manganese carbonate (94.2%), but with some calcium and iron carbonate (4.3 and 2.6%, respectively). Magnesium was below the limit of detection. The crystals are compositionally quite homogeneous.

Therefore, we can confirm that the saddle habit of rhombohedral carbonates is not limited to dolomite. The mechanism responsible for producing saddle-shaped crystals of rhombohedral minerals, while not altogether understood, has been studied by many. In a recent paper, Searl (1989) suggested that it may be related to rapid edge-nucleated growth, forming "wedge-shaped extra zones between adjacent crystals," and is not, therefore, necessarily the product of chemical variations during growth leading to lattice expansion, as was proposed by Radke and Mathis (1980).

***Figure 1.* Siderite *(left)* and dolomite *(right)* in saddle-shaped crystals. (From Goldschmidt, 1916.)**

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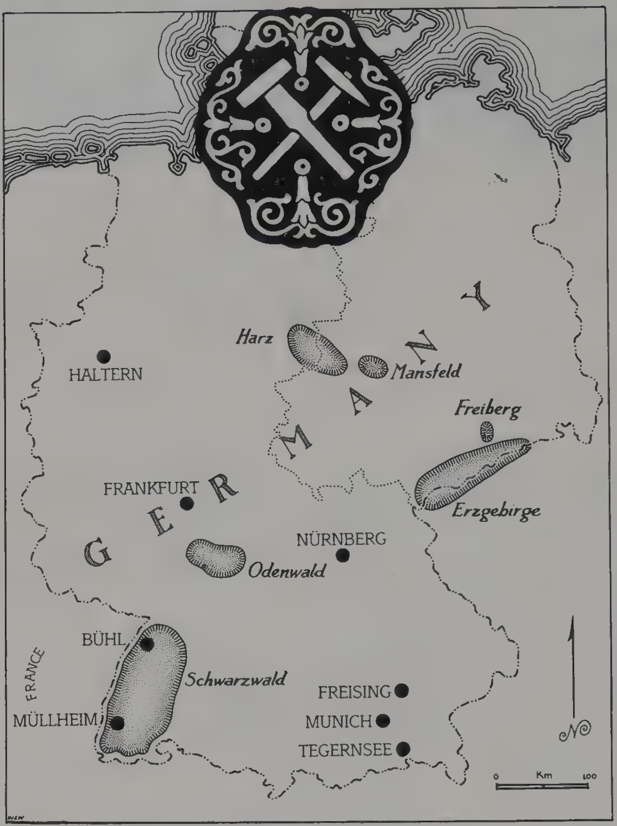

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PLUMBOAN CRICHTONITE

FROM THE FAZENDA GUARIBA, MINAS GERAIS, BRAZIL

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INTRODUCTION

Senaite, $Pb(Ti,Fe,Mn)_{21}O_{38}$, a member of the crichtonite group, was first described by Hussak and Prior (1896, 1898) from alluvial gravels near Dattas, Minas Gerais, Brazil. It was subsequently reported (always from alluvial stream gravels) from about seven additional localities (see Cassedanne, 1986, for details and references). Foord *et al* (1984) studied Zn-bearing senaite from St. Peters Dome, El Paso County, Colorado, and a specimen (DGM/DNPM no. 1651) from Dattas, Diamantina region, Minas Gerais, Brazil. Senaite is a very rare mineral, having been found in less than ten localities worldwide: (1) Brazil, (2) Nezilovo, Macedonia (Vujanovic, 1970), (3) Alinci, Yugoslavia (Bermanec *et al.,* 1992), (4) Switzerland (Stalder and Bühler, 1987), (5) Italy (Armbruster and Kunz, 1990), (6) Colorado (Foord *et al.*, 1984) and (7) an unusual rhenium-rich (2.6 wt. % ReO_2) member of the crichtonite group from an unknown location (Sarp *et al.,* 1981). Four grains of specimen DGM/DNPM 1651 proved to be senaite with about 0.5 wt. % ZnO, however, a fifth grain contained 7.7 wt. % ZnO (Foord *et al.*, 1984).

Cassedanne (1986) has described "senaite" from the first *in situ* source in Brazil, at the Fazenda Guariba, south of the village of Presidente Kubitschek, 40 km south of Diamantina, Minas Gerais, Brazil. Only a semiquantitative emission spectrographic analysis was done by Cassedanne; quantative results from this study show the material to be plumboan crichtonite rather than senaite. Many Brazilian mineral dealers have had material from the Fazenda Guariba for sale and have labeled it "senaite" according to Cassedanne's identification.

Details of the geology and access are given by Cassedanne (1986) and Chaves *et al.* (1988). Specimens of the "senaite" were provided to the senior author by Carlos do Prado Barbosa and the second author for additional study. Approximately 20 crystals of "senaite" from the Fazenda Guariba were examined chemically and all were found to be plumboan crichtonite rather than senaite.

RESULTS

Complete chemical analyses of the crichtonite (Table 1) were done by electron microprobe and laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) methods. Electron microprobe analyses were done using an ARL SEMQ instrument, 15 kV, 10 nanoamps sample current on a Faraday cup, 10 micron beam diameter, with 20 second count times on peak positions and 10 second count times on background positions. The rare-earth elements were not determined by electron microprobe because of potential interference problems. All other elements greater than atomic number 9 were measured by both electron probe and LA-ICP-AES methods. Probe standards included synthetic TiO_2 for Ti, synthetic Fe_2O_3 for Fe, synthetic $SrBaNb_4O_{10}$ for Sr and Ba, natural garnet for Mg, Mn, Ca, Si and Al, chromite for Cr and PbS for Pb. A Fisons VG PlasmaQuad 2+ instrument equipped with a Nd/YAG laser operated at 1064 nm was used for the LA-ICP-MS analysis of the crichtonite. The iron value determined from the electron microprobe analysis was used as a standard for which to compare all of the other elements determined. All

Table 1. **Chemical analyses of plumboan crichtonite from the Fazenda Guariba, Minas Gerais, Brazil.**

Oxide	Electron-probe (E. E. Foord, analyst)	LA-ICP-MS (F. E. Lichte, analyst)	Average (for elements in common)
CaO	0.1	0.14	0.12
TiO_2	59.6	59.2	59.4
Cr_2O_3	0.25	0.05	0.15
MnO	1.92	1.70	1.81
Fe_2O_3	26.70	std.*	26.70
SrO	2.9	2.90	2.90
BaO	0.22	0.32	0.27
PbO	3.3	3.6	3.45
Ce_2O_3	n.d.	0.69	(0.69)
Sc_2O_3	n.d.	0.27	(0.27)
ThO_2	n.d.	0.11	(0.11)
V_2O_5	n.d.	0.35	(0.35)
Y_2O_3	n.d.	1.95	(1.95)
Yb_2O_3	n.d.	0.13	(0.13)
ZnO	n.d.	0.50	(0.50)
Nd_2O_3	n.d.	0.04	(0.04)
La_2O_3	n.d.	0.94	(0.94)
Ho_2O_3	n.d.	0.08	(0.08)
Eu_2O_3	n.d.	0.03	(0.03)
Pr_2O_3	n.d.	0.02	(0.02)
Sm_2O_3	n.d.	0.05	(0.05)
Gd_2O_3	n.d.	0.15	(0.15)
Tb_2O_3	n.d.	0.05	(0.05)
Dy_2O_3	n.d.	0.35	(0.35)
Er_2O_3	n.d.	0.15	(0.15)
Tm_2O_3	n.d.	0.02	(0.02)
Total		100.49	100.68

Notes: Lu not determined. Na, K, Mg, Al, Si, P, and Nb looked for and not detected. $\Sigma REE = 4.65$ wt. %, $\Sigma LREE = 1.92$ wt. %, and $\Sigma HREE = 2.73$ wt. %. *—Fe_2O_3 value of 26.70 from microprobe analysis used as a reference standard for the ICP analysis. Parentheses indicate values taken from the LA-ICP-MS analysis. See chemical data of Stalder and Bühler (1987) for other plumboan crichtonites.

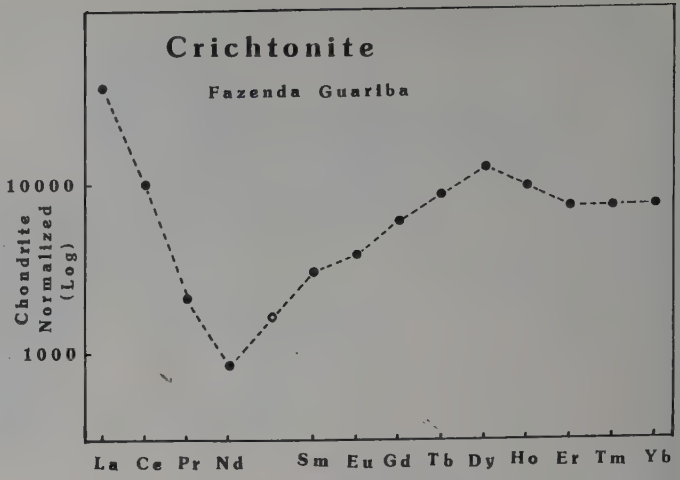

Figure 1. **Chondrite-normalized ratio (CNR) plot for plumboan crichtonite from the Fazenda Guariba, Brazil.**

elements in the periodic table were looked for except the noble gases, H, C, N and O. Ferrous iron was not determined for this crichtonite. An empirical formula, based on 38 oxygen atoms and all Fe as ferric iron, is as follows: $(Sr_{0.50}Pb_{0.27}La_{0.10}Ce_{0.07}Ca_{0.04}Ba_{0.03}Gd_{0.02})_{\Sigma 1.03}(Ti_{13.23}Fe^{3+}_{5.95}Mn_{0.45}Y_{0.31}Zn_{0.11}Sc_{0.07}V_{0.07}Cr_{0.04}REE_{0.08}Th_{0.01})_{\Sigma 20.32}O_{38}$. The cation sum of the octahedral cations is less than the ideal 21. This feature has been reported previously (e.g. Gatehouse *et al.*, 1979) for members of the crichtonite group and is believed to be real based on the number of such reported occurrences and the fact that virtually all elements were looked for in the currently studied plumboan crichtonite. Figure 1 is a CNR (chondrite-normalized ratio) plot of the REE distribution for the crichtonite. There is a distinct double-hump dis-

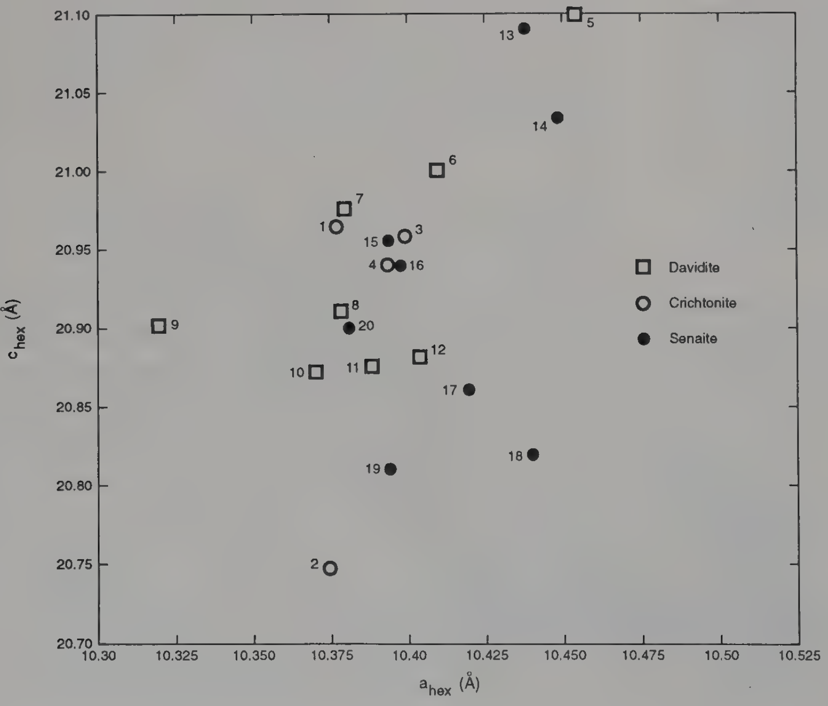

Figure 2. (left) **Cell dimensions ($a - c$ plot) for crichtonite, senaite and davidite. 1—plumboan crichtonite, Fazenda Guariba, M.G., Brazil; 2—crichtonite, Isère, Dauphiné, France (Grey *et al.*, 1976); 3—crichtonite, Wannigletscher, Switz. (Stalder and Bühler, 1987); 4—crichtonite, Wannigletscher, Switz. (Stalder and Bühler, 1987); 5—davidite (U-rich), Pizzo Cervandone, Italy ((Stalder and Bühler, 1987); 6—davidite, Kirumba, Congo (Van Wambeke, 1968); 7—davidite, Tuftan, Norway (Foord *et al.*, 1984); 8—davidite, Pima Co., Arizona (Gatehouse *et al., 1979); 9—davidite, Olary, South Australia (Foord et al.*, 1984); 10—davidite (average of 17 analyses, 6 from Norway and 11 from Ariz.) (Pabst, 1961); 11—davidite, Pima Co., Ariz. (Foord *et al.*, 1984); 12—davidite, Vishnevye Mtns., Russia (Shabin *et al.*, 1963); 13—U-rich senaite (130 K), Pizzo Cervandone, Italy, 2 domains (Armbruster and Kunz, 1990); 14—zincian senaite, St. Peters Dome, CO (Foord *et al.*, 1984); 15—senaite-crichtonite, Collonges, Switz. (Stalder and Bühler, 1987); 16—senaite, Wannigletscher, Switz. (Stalder and Bühler, 1987); 17—senaite, Dattas, Diamantina, M.G., Brazil (Rouse and Peacor, 1968); 18—Rhenium-bearing senaite (Sarp *et al.*, 1981); 19—senaite, Diamantina, M.G., Brazil (Grey and Lloyd, 1976); 20—Metamict U-rich senaite, Alinci, Yugoslavia (Bermanec *et al.*, 1992).**

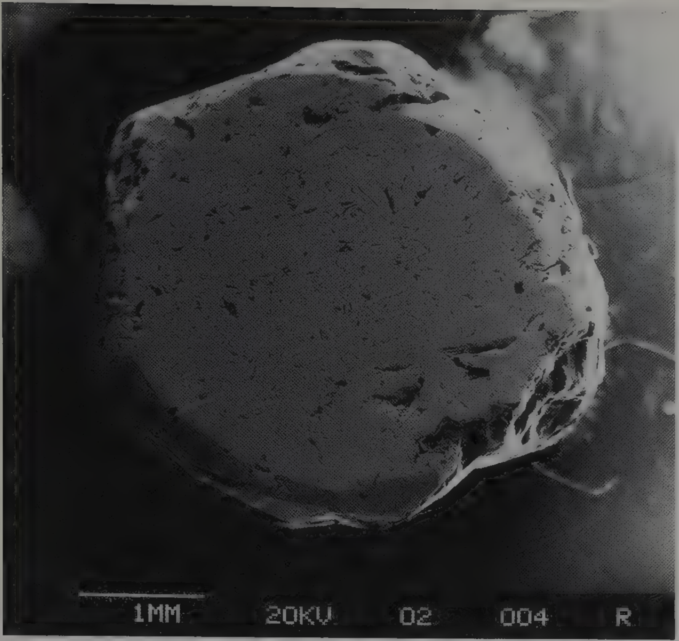

Figure 3. **Euhedral crystal of plumboan crichtonite from the Fazenda Guariba, M.G., Brazil showing {001} dominant.**

tribution pattern, i.e. a peak for the LREE's (light rare earth elements) and another for the HREE's (heavy rare earth elements). Maxima are at La and Dy. This double-hump pattern, observed in other members of the crichtonite group as well, is evidence that there are two REE sites present, large and small respectively (Gatehouse *et al.*, 1979; Foord *et al.*, 1984).

Unit-cell refinement of the plumboan crichtonite was done using an automated Siemens D500 diffractometer, Cu Kα radiation (1.54178Å), zero background quartz plate, NBS SRM 640 silicon as an internal standard, 20 second count times and 0.02° step increments. The refinement using the unit-cell program Job 9214 (Appleman and Evans, 1973) yielded a- 10.376(2)Å, c- 20.967(4)Å, V = 1955.0(7)Å^3. These cell dimensions agree well with those for other specimens of crichtonite and senaite (see Fig. 2).

The specific gravity of an unaltered grain, determined on a Berman microbalance, is 4.60(2). D_{calc} using the determined cell volume and molecular weight is 4.56 g/cm^3. Lower specific gravities were measured on other grains and are due to incipient alteration and hydration.

Habit and morphological details of the plumboan crichtonite are given by Cassedanne (1986). Figure 3 shows a typical crystal of the most common habit that occurs at the Fazenda Guariba (i.e. tabular plates).

In conclusion, senaite is present in the Diamantina region of Minas Gerais, in alluvial gravels and placers, but based on the specimens examined in this study, the mineral of the crichtonite group occurring *in situ* at the Fazenda Guariba near the village of Presidente Kubitschek is plumboan crichtonite rather than senaite as previously reported by Cassedanne (1986).

ACKNOWLEDGMENTS

We thank Kenneth Esposito and C. G. Whitney (U.S. Geological Survey) for the use of the automated Siemens D-500 X-ray system. Reviews were provided by P. J. Modreski, R. C. Erd, D. R. Peacor and P. J. Dunn.

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Letter from Europe

The Munich Show

by Michael P. Cooper

[October 29–31, 1993]

Munich is just too big for one lone reporter-photographer to cover everything, so I'll have to begin this letter by apologizing to everyone I should have talked to but missed, or told "I'll see you later" but never did. And I also want to thank everyone who helped to make my trip an enjoyable one by showing me interesting specimens, introducing me to dealers and collectors I otherwise wouldn't have met, and telling me things about minerals on display that I would otherwise never have guessed.

At this show it was my intention to seek out some of the more unusual species that don't make it into show reports as often as the ubiquitous beryl, fluorite and quartz. But I didn't do too well. Quartz, it turns out, was one of the major themes of the show, along with other Alpine cleft minerals; beryl was everywhere; and truckloads of fluorite arrived from China, the U.S., and countries of the former Soviet Union. The problem with your average unusual species is that few specimens are generally available, most of them unphotogenic at that, and paying attention to one dictates that attention should also be paid to all other similar rarities as well. This was well beyond the time constraints for one person; thanks are due to avid systematic collector Simon Howell of Manchester, who accompanied me on the trip, for scouting out much of the rare mineral information in this report.

We arrived at the show on Friday morning (wholesale day), having missed the opportunity to catch items being unwrapped on set-up day. However, a quick survey of the main hall (Halle 2) suggested that there was nothing new in quantity, although a few items previously in short supply were here in force. One usually hears people say, "you should have been here yesterday," but not this time. Other collectors confirmed this observation.

There were certainly no disappointments in the special exhibits this year. The principal theme, as mentioned, was quartz and other Alpine cleft minerals, along with minerals from similar occurrences elsewhere. Many of the displays were arranged by species. There was, for example, a large case containing dozens of huge almandine crystals of perfect form ranging up to fist size (although the odd color and luster of some was explained to me as the result of major enhancement with, among other things, shoe polish!) Another case exhibited gwindel quartz and demantoid garnet. Contributors to these displays included the Natural History Museum in London, and private collectors such as Eric Asselborn. The Natural History Museum contributed two cases of minerals and notebooks from the collection of Frederick Ashcroft (1878–1949). Ashcroft's collection, including a fine suite of Irish zeolites, has been preserved intact and kept together at the museum, a testimonial to its importance. The cataloging of his Alpine specimens constitutes a model to which we should all aspire. Ashcroft meticulously recorded the sources of his specimens in bound notebooks, with photographs of the sites, on which each specimen occurrence is carefully marked. Special labels were printed up for each major find. He was so devoted to collecting that he kept a bag packed and ready at all times should he need to leave England at a moment's notice to pursue the merest whiff of an Alpine discovery.

Eric Asselborn exhibited several cases of fine minerals, including colorless and smoky quartz gwindels, superb clear quartz (one group having a central crystal with a narrow band of smoky color where a small fragment of some radioactive mineral had lingered), axinite, and a specimen that has been given a name: "Georges." This latter piece is a huge, 18-cm octahedron of pink fluorite found by strahler Georges Bettembourg in 1975. The story of the find, complete with a photograph of the vertiginous locality on the Aiguille des Pélerins, Chamonix, is related by Eric in a chapter of the *Lapis* publication, *Fluorite, oder von dem Vergnügen, Flusspat zu Sammeln*. The smallest specimen in Eric's case was a quartz double twin, two attached Japan-law twins looking like a small, yellowish butterfly.

The various Alpine displays included many killer pieces: the world's most twisted smoky quartz gwindel; a superb quartz scepter with pyrite from King County, Washington; Ashcroft's unique pink apatites; a huge (if slightly dinged) Norwegian anatase on matrix; a suite of superb demantoid garnet crystals of exquisite color; and a flawless, 10-cm orange-yellow butterfly twin of calcite. One unusual exhibit contained a selection of quartz crystals (one of Europe's oldest mineral collections?) excavated from a Roman site in Magdalensberg, Carinthia, Austria.

There were many other individual displays to be found throughout the show, mounted by private collectors and public institutions. For example, the Houston Museum of Natural Science brought a fine selection of colorful specimens from their collection, including proustite, dioptase, rhodochrosite, purple (manganoan) adamite and the world's best phosphophyllite. Among the displays in Halle 5 was a set of 180 antique plaster crystal models of calcite. Brian Lloyd of London displayed items associated with the mineralogical exhibits in the Great Exhibition of the Industry of All Nations (which featured many mining companies and mineral dealers) held in 1851 at the Crystal Palace in London. Another case showed German galena and pyromorphite, with several excellent galena pseudomorphs after pyromorphite crystals 2 to 3 cm across.

I was delighted to see that the new Russian magazine *World of Stones* (portents of which I'd reported in last year's Munich letter) has finally come out, written entirely in English. It is well produced, despite some initial problems with paper and color reproduction. Two issues were available in Munich from the publisher, Plus Ltd. (P.O. Box 162, 103050 Moscow, Russia). There are a few minor translation awkwardnesses here and there, but it is generally fine. Articles cover modern and classic Russian occurrences, historical information on collectors, and descriptions of collections. Some are merely general introductions to a topic, but others provide more substance. A four-issue subscription is $52. (Herb Obodda, P.O. Box 57, Short Hills, NJ 07078, is their American subscription agent; order through him.)

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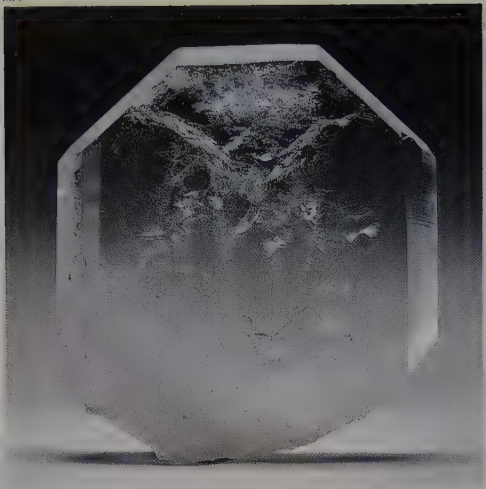

Figure 1. A colorless, tabular, 6-cm quartz crystal from the Fuyan mine, Leyang, Hunan, China. Frédéric Escaut specimen, now in the Keith Hammond collection.

MPC

Figure 2. Colorless beryl crystals to 3 cm, on mica-covered matrix, from China. Frédéric Escaut specimen.

MPC

Figure 3. Scheelite crystals to 2 cm, with colorless beryl to 4 cm, on mica-covered matrix from China. Frédéric Escaut specimen.

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Figure 4. Boracite crystals to 4 mm from the Boulby potash mine, Loftus, North Yorkshire, England. *Secured Minerals* specimen.

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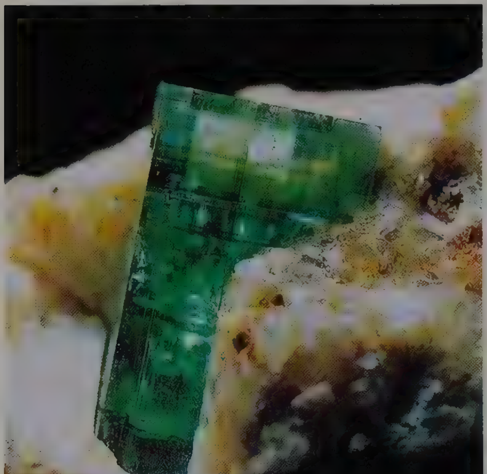


Figure 5. Beryl (emerald) crystal, 8 mm, from Pandjshir, Afghanistan. François Lietard (*Minerive*) specimen.

Figure 6. Scheelite crystal aggregate, 1.5 cm, with black cassiterite crystals to 1 cm on gray quartz crystals, from the Tenkergin mine, Chukotka, Siberia, Russia. *Plus Ltd.* specimen.

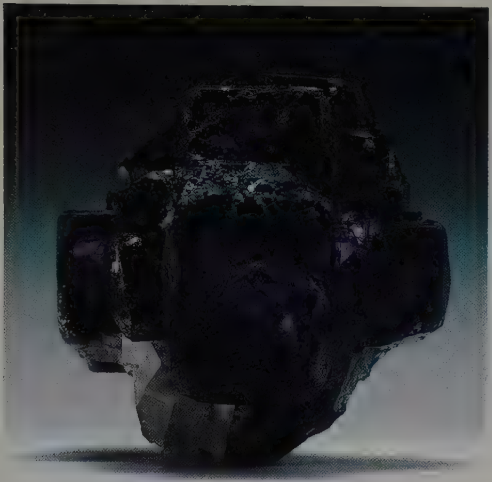


Figure 8. Fluorite crystal group, 4 cm, from Kara Oba, Kazakhstan. *Top Minerals* specimen.

Figure 9. Bertrandite pseudomorph after a 2.5-cm fluorite octahedron with rhodochrosite, from Counrad, Kazakhstan. *Top Minerals* specimen.

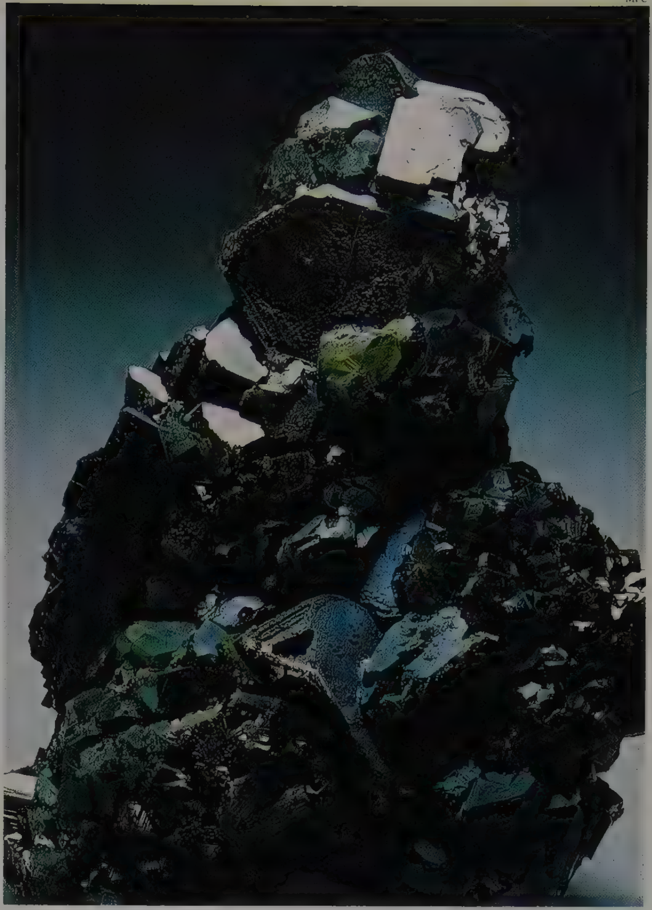


Figure 7. Sphalerite crystal to 2.5 cm with cubic galena from Ossikovo, Bulgaria. Lino Caserini specimen.

Figure 10. Blood-red wulfenite crystals to 1.5 mm, from Ajaguz, Kazakhstan. *Top Minerals* specimen.

I was hoping that *World of Stones* might help me with the complexities of Russian and C.I.S. (Commonwealth of Independent States) locality names, a subject fraught with difficulties. For one thing, the names of many localities have changed over the years. And the transliterations from Cyrillic to Roman letters vary according to the language of the translator. The two issues of the journal did help somewhat, but would have benefitted by better locality maps. In any case, I managed to discover through various sources that Dalnegorsk, Tetiune, and Tetyukhe all refer to the same place. Further, that Dzumbul or Dzambul equals Kara Oba in Kazakhstan, and that Tenkergin (currently a source of fine scheelite and cassiterite) is also known as Volchye. These are genuine confusions of old and new names, and I assume that there are many more. A collector would be well advised to carefully compare similar specimens said to be from two different localities. Similarity is not definitive, of course. Fluorite on dolomite from the Shangbu and the Shangbao mines (two distinct localities with similar names), both in Hunan, China, are very much alike in appearance. The latter mine, according to dealer Peter Bosse, is closed and flooded but the former is still producing specimens.

One provenance problem I didn't solve was that of **calcite** labeled Sarbay-Sokolov in Kazakhstan. *Wilke Mineralien* had scores of these specimens, showing pseudo-cubic honey-brown crystals to 5 cm. The larger faces are frosted but the edge modifications are clear and lustrous, revealing a flawless interior. The few specimens I saw at last year's show were labeled as having come from "Rudnui," Kazakhstan.

The *World of Stones* publishers also had mineral specimens for sale, including **scheelite** and **cassiterite** from Tenkergin, Chukotka, Russia. Examples could also be seen in several other booths. The locality is in a remote part of eastern Siberia, very near Alaska, and is locked in permafrost. Collecting is hampered by the solid ice which fills crystal vugs, but a recent thaw aided in the extraction of some specimens. Orange scheelite crystals from here reach 4 cm, and are commonly associated with lustrous black cassiterite crystals and large quartz prisms. Ferberite, löllingite and beryl are also found (though none of these was available in Munich). Specimen quality varies widely, and many of the specimens show some damage. Really aesthetic examples were scarce and highly priced.

Scheelite from China continues to be in good supply, including some fine orange bipyramids to 2 cm scattered on mica and, in a few cases, associated with colorless **beryl** crystals. Frédéric Escaut had a batch of these, all of which sold at the show, along with some nice groups of colorless beryl crystals alone on matrix. The locality was given only as "Hunan"; commercial interests are apparently obfuscating for proprietary reasons. Perhaps a more precise locality name will be forthcoming in time.

Another interesting **beryl** occurrence is the emerald deposit at Pandjshir, Afghanistan; François Lietard (*Minerive*) had specimens in his booth. Although specimens have been known from this area for 20 years or so, they are still rare. Lietard's best example is a pretty matrix piece bearing a small but well-colored prism sharply zoned parallel to the *c* face.

For my traveling companion, Simon Howell, this was his first trip to Munich and he was ecstatic about the variety of rare species available. Bits of nondescript black glittery stuff in matrix have little appeal to me as a photographer, but I must nevertheless admit to a lingering respect for certain sulfosalts; it was interesting to see several dealers selling suites of new Lengenbach material. Helga and Horst Geuer (Am Sonnenhang 39, D-53639 Konigswinter, Germany) had the new thallium mineral **edenharterite,** along with several other Lengenbach specialties including **hatchite, imhofite, trechmannite** and **rathite.** Christian Rewitzer (Stadtplatz 17, D-93437 Furth, Germany) had a supply of **cylindrite** from a new find in the Santa Cruz mine, Poopo, Bolivia. Prices started at about $18, which got you a nice 3 to 4-cm piece showing good cylinders. He was also offering attractive, crystallized leaf **gold** from the classic occurrence at Verespatak, Romania.

While speaking of rarities I should mention that Falko Baatz, often noted in these reports for his excellent Russian and C.I.S. cabinet specimens, also stocks an extensive selection of rare species from those countries. At Munich he had dozens of rare minerals, many from type localities. To choose just the most difficult to pronounce, there was **tsaregorodtsevite, parakeldyshite, reedmergnerite, preobrazhenskite, mushistonite, paraumbite,** and a runner-up on my list of favorite mineral names: **tetraferriphlogopite** (hopelessly outclassed by outright winner hexatestibiopanickelite, but I didn't see any of that in Munich).

From closer to (my) home, the British dealership *Secured Minerals* (Patricia and Lindsay Greenbank, 16 Sedburgh Road, Kendal, Cumbria) had some fine examples of the new **boracite** from the Boulby mine, North Yorkshire, England, mentioned in my previous letter. In the main these show globular masses of greenish boracite to 1 cm across encrusting the surface of massive nodules, but the specimens offered at Munich also included a few with excellent, apple-green, modified tetrahedral crystals to over 5 mm, much better than anything I'd seen before.

Returning to sulfides and sulfosalts, Italian dealer Lino Caserini (Via Don Giuseppe del Cortno no. 1, I-20132 Milano, Italy) had a small selection of gemmy green **sphalerite** from Ossikovo, Bulgaria, which he'd acquired at the recent Prague Show. These consist of dark green sphalerite crystals to around 2 cm, with frosty cubes of galena. Among Peter Bosse's display of interesting Chinese minerals was a fine **chalcopyrite** crystal measuring 2.5 cm and some promising **cosalite** and **bournonite** specimens, the latter having crystals up to 2 cm. These are from the Chenzou mine, Hunan, a site known for wolframite, scheelite, calcite and quartz. Finally, to round off this round-up of rarities, Helga and Horst Geuer offered some specimens of **tucekite** crystals embedded in **ullmannite** from the Adler mine, Eisern, Siegerland, Germany; these are the first euhedral crystals known for the species, from the first recorded European occurrence.

Toward the end of my last full day at the show I came across the booth of *Top Minerals,* operated by Rene Triebel (Rudolf Hawel-Gasse 21, A-27000, Wiener Neustadt, Austria), which was laden with fine Russian and C.I.S. material. Rene's minerals were certainly not cheap, but each piece was of excellent quality and several were most unusual. He had some of the nicest small cabinet pieces of Tenkergin **scheelite** and **cassiterite** at the show, and told me that he had been the first dealer to bring yellow-green beryl from Wolodarsk-Wolynsk, Ukraine, to the Western market. I borrowed a few of his pieces for photography, including an intriguing **bertrandite** from Counrad, Kazakhstan, pseudomorphically replacing a 2.5-cm fluorite octahedron, with a partial covering of small, lenticular, bright pink **rhodochrosite** crystals. I've been told that the best of the Counrad rhodochrosite is extremely fine. From Kara Oba (formerly Dzumbul), Kazakhstan, there were **fluorite** crystals of curious form: rough octahedra composed of smaller stacked cubes, a habit known from several localities worldwide. The unusual thing about these is that instead of hundreds of small cubelets these crystals are composed of the minimum of one large cube per octahedron corner, looking as much like six cubes stuck to the six faces of a central cube. The two specimens I saw were nice: a green fluorite crystal perched on a blade of **wolframite,** and a deep purple floater crystal. *Top Minerals* had several other very fine Kara Oba fluorites in crystals of more typical octahedral habit clinging to the prism faces of large quartz crystals. They are very attractive, sculptural pieces, but many of the quartz crystals have very rough, milky surfaces. Rene explained that this was probably because miners or collectors had cleaned the fluorite with hydrofluoric acid, damaging the quartz in the process. (Much of the currently available Kazakhstan calcite has also been acid dipped.)

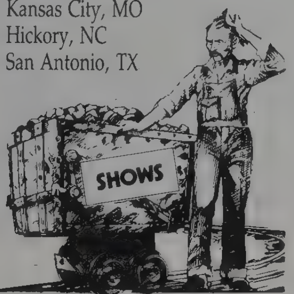
Other notable specimens at the *Top Minerals* booth included a doubly terminated, 25-cm **calcite** scalenohedron with blotchy red **cinnabar** inclusions, from Kadamtschai, Kirgizia, and some good **celestine** crystals from near Archangel, Siberia, showing two generations of crystal growth: colorless with brown zones, and blue. The crystals reach about 5 cm in length. I was also pleased to see desirable specimens of **wulfenite** from Ajaguz, Kazakhstan: brilliantly lustrous, bright blood-red bipyramids to 1 mm encrusting small pieces of matrix. Several dealers carried this material, which has actually been around in small quantities for a while, but the best of the new lot is the cleanest I've seen. It is spectacularly colorful in comparison to the quieter tones of much of the Russian and C.I.S. material currently available. Incidentally, it might be worth noting that one booth (probably operated by Russians but I didn't get a chance to talk to them) had what appeared to be a *recently mined* lot of **crocoite** from the Urals. Is the old Berezov locality producing again? Thereby might hang a tale.

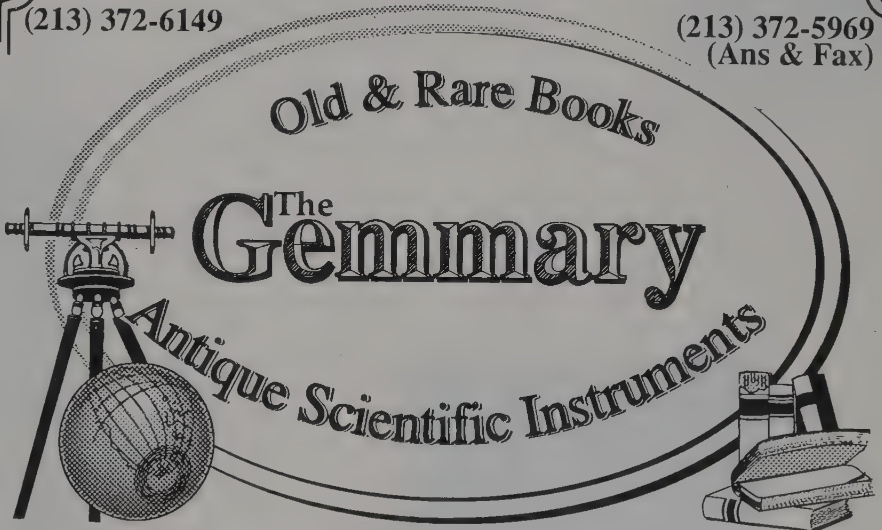
I also managed to pay a quick visit to the Barcelona dealer Jordi Fabre, who is always good for something interesting. True to form, Jordi had some unusual material that (if time had permitted) would have made a good photo: **curienite** from Akashat, Iraq . . . not a country you see much from these days. The crystals are found on the inside surfaces of fossil brachiopod molds, the minute, bright yellow needles showing up well against the ribbed surface of the fossil.

To finish off this report, I can testify that the fastest major sale of the show may well have been the one I witnessed at the booth of Ennio Prato. Ennio regretted that he had nothing really new to show me, but would I like to see a fine old Moroccan vanadinite? Well, you bet I would. Ennio produced a large black box from under the table, and began pulling the tissue paper packing out of it like a magician at a sideshow. Several passers-by stopped and waited to see what would be revealed. Presto: a beautiful mass of lustrous, white, cockscomb barite about 30 cm long, liberally studded with finest-quality blood-red vanadinite crystals. "How much?" I asked. "Ten thousand dollars," he replied. I turned to my companion and remarked that this seemed like a good price. While my back was momentarily turned, one of the bystanders reached into his pocket, peeled off $10,000 from a thick wad of notes, and away went the piece. Ennio grinned sheepishly. That's business. But I'm still waiting for my commission . . .

Well, that's a brief survey of what I saw in Munich, but there was a lot more that I glimpsed only in passing. Apart from the minerals, there were books, database programs, fossils, gems and jewelry, but you'll have to go see them for yourself. There are also the various Munich museums with their own mining and mineral displays, not to mention the world-famous art galleries. And the local *Weissbier*, like Dublin's black equivalent, has to be drunk in its home town to understand why it has such a fine reputation. But enough of the travelog. I'll end with one last request: it might prove productive if more dealers dropped me a note before the major European shows to advise me of any new finds they'll be offering. A few do this already, and I find it very useful. I'd be glad to hear from anyone who can spare the time to put a few words together.

Mick Cooper
41 Albany Road
Sherwood Rise
Nottingham NG7 7LX
England





Letters

COLLECTING IN ARGENTINA

Here's a report on a 1-week collecting trip to Argentina that I've just come back from: A vagrant Argentinian student of native Indian languages stopped at my house in Cochabamba, Bolivia, for a few days and then invited me to visit him at his home in Córdoba, a city of 2 million people in central Argentina. I was very happy to take him up on the offer, since the *Mineralogical Record* once mentioned blue cobaltian genthelvite from Cerro Blanco, Tanti, near Córdoba, and the *Encyclopedia of Minerals* mentions bermanite from the same locality, and I really wanted to see what kind of mine would produce both of those together. So after a 50-hour bus ride from Cochabamba . . . I find myself in Córdoba, a city looking far more like Europe than South America, and with prices to match (e.g.: $1 for a cup of coffee; $5 for a meager lunch of 2 slices of pizza with a bottle of beer). A couple hours of touring several bookstores resulted in no maps and no books on mineral localities, so I decided to hit up the museums for information instead, and found no less than *three* mineral museums in Córdoba and its suburbs! (Okay, they're not the Smithsonian but they're pretty good by South American standards.) And they had lots of specimens from Tanti, a village 40 km West of the city and with frequent bus service to it.

From Tanti it's another 10 km West to Cerro Blanco, which looks remarkably like the San Diego County pegmatite areas—semi-arid, brush-covered hills strewn with large granitic boulders. Even the weather was like Ramona's. The hill has two large pegmatite quarries and many small prospect pits. There weren't any fences or no-trespassing signs, so I just wandered around banging on rocks. Other collectors had obviously been there before. There seems to be a real *collector* community in Argentina, not just the pseudo-collector would-be-dealers prevalent in Bolivia. Anyway, most of the pegmatites seem to be the usual quartz-muscovite stuff, exploited for [industrial] quartz and specimen quartz crystals in various shades (colorless, white, smoky, pale rose, and even some amethyst) and for ore-grade beryl. All the accessible good stuff in larger sizes was gone, but I found a lot of interesting well-crystallized microcrystals and thumbnails. There were some long narrow "tunnel" pockets with large still-undamaged quartz crystals, and a muscovite plate with sprays of brilliant malachite needles squeezed between the cleavages. Looks like an Arizona oxide zone mixed up into a Black Hills phosphate pegmatite! The cobaltian genthelvite occurs as bright cavansite-blue 1 or 2-mm crystals in a pod of friable scaly hematite in the pegmatite wall.

After I got back to Córdoba, I traded some third-rate Bolivian cassiterite and vivianite for some more Córdoba area specimens, including a small (1 cm) pegmatite amethyst crystal with a movable bubble in it; and from other parts of Argentina a couple half-inch opal pseudomorphs after fossil palm tree seeds, and some rare ugly borates from Salta (and some thumbnail rhodochrosite stalactites from Catamarca). The species identified so far in the material I found at the Cerro Blanco pegmatites, or got from there in trade with Argentinian collectors, are: "cleavelandite" albite, bermanite, chalcedony (fluorescent white), chrysocolla, "dufrenite," blue genthelvite, goethite crystals, hematite, malachite, muscovite, phosphosiderite, pseudomalachite, quartz in various habits and inclusions, triplite (massive) and turquoise (massive). Other species reported from this locality, but which I haven't found yet in the pile of stuff I brought back, not all of it checked out yet, are: apatite, beryl, violet fluorite and strengite.

So, in summary: the weather and scenery were lovely, the collecting was fun and varied, the locals were friendly and helpful, but there wasn't much of economic interest to a dealer. The quartz and beryl are better in Brazil; the rare microcrystalline phosphates and genthelvite would only make you yawn. From the dumps I could have filled a few flats with green malachite-stained muscovite plates (quite different from the green Brazilian "fuchsite" muscovite) which might sell well if you had other stuff too for a bigger sea shipment (like Catamarca rhodocrosite?). The museums showed some nice well-crystallized garnet-diopside cabinet specimens from marble quarries near Córdoba, but I didn't get to visit those.

On the way back to Cochabamba I stopped in Santa Cruz for a couple of hours to check out the jewelers' shops, which occasionally have a good Bolivian specimen for sale hidden among piles of cut and uncut junk. There I picked up one nice gemmy 10-cm "ametrine" crystal, mostly yellow, with a clearly defined longitudinal violet stripe, for $20. There were several of these, although mostly too opaque for me to buy, each with a strange rough-flat "c"-termination.

Then a miracle appeared: one Swiss jeweler (the kind of chap who sells cut quartz as "imperial topaz") had Potosi phosphophyllite in his case! There were 2 pieces of gray, cabinet-sized, tabular matrix. One had a gemmy 1-inch typically twinned crystal, but unfortunately lying flat on the matrix, so it would not be possible to backlight it like the standing specimens on display in Tucson. The other specimen had many tiny phosphophyllites scattered over it, but would be broken up into several (10?) poor thumbnails with matrix. On the off-chance that he might not know what they were, I asked the price. Unfortunately, he knew very well what they were, and wanted $400 for the better one and $100 for the poorer. I put on a distressed facial expression and moved over to his cassiterite shelf, feigning lack of interest. On one of his shelves I found a broken danburite crystal! He did not appear to know that it came from Chapare and I didn't tell him. I asked whether he ever sold Bolivian minerals in Switzerland. He said, yes, he did, especially a large quantity of deep green translucent chrysoprase ("imperial jade" of course) that he'd found, dug and cut himself in Santa Cruz, and he'd like to take other minerals to Zurich if he could get good quality specimens in quantity. So, I ask, how would he like to have 50 good doubly-terminated danburites in exchange for his better phosphophyllite? To my surprise, he agreed right away! Now I've got to get myself back down to Santa Cruz with the danburites before he changes his mind.

Alfredo Petrov
C.P. 1728
Cochabamba, Bolivia

MICHIGAN SILVER

While I realize that Michigan copper and silver specimens have received significant attention in the *Mineralogical Record* during the past few years, I have recently acquired a silver specimen that may be interesting enough to deserve at least an honorable mention. The piece measures 14.5 x 13.5 x 7 cm, and has a mass of 2 kilograms. One side of the specimen shows a 9 x 7 cm slab of glacially-polished crystallized silver surrounded by conglomerate matrix. The other side is more delicate, with a 10 x 5 x 4 cm pocket filled with hundreds of small "granular" silver crystals. Remarkably, the specimen was found in 1992 as a placer nugget in the Ontonagon River, probably starting out as a piece of glacial "float" which eroded from nearby till exposures. Other specimens continue to be found in this region of Ontonagon County, but are generally the more typical large float coppers, occasionally with minor traces of silver. According to local authorities, this may be the first documented discovery of a large well-crystallized native silver with conglomerate matrix from a Michigan river.

Shawn M. Carlson
Crystal Falls, MI

CONKLIN AD

Do you remember when the newspapers carried the comics just inside the last page? It appears to me from the November-December issue that the *Mineralogical Record* has decided to run a comic section, only on the back cover. How could you possibly have been taken in by Conklin's stupid ego trip and let such an absolutely ridiculous ad dilute the long-standing dignity and credibility of the *M.R.*? I think that if he had included "PhD" after his name I would have to look elsewhere for my mineral news.

F. W. Bowman, Jr.
Sonoita, Arizona

Sorry that you didn't fully appreciate the intended tongue-in-cheek humor of that ad. The story behind it is that Larry suffered a serious coronary thrombosis (nearly fatal) in January of 1993 and missed the Tucson Show. He was laid low for some months following while he slowly recovered, and is now doing quite well again. However, his business fell off markedly because many people figured he'd actually died. He decided that he needed a big one-time attention-getting ad to let people know he was still above ground and in business. But he wanted to keep it light-hearted (no pun intended), hence the final result. I enjoyed it, and I'm sure it got the job done. Superficially it may appear egotistical, but it's just Larry's way of making a joke about himself, and not taking himself too seriously. And he is all of those things listed around the margin. (Including Novi Eboracian *which, in case you don't have a Latin dictionary at hand, means* New Yorker*!)*

One prominent mineralogist wrote in to say that the ad should have included "egotist" in the list; he then went on to say that he immediately thought of running such an ad for himself, but that he "quickly realized that the back cover of the Record *would provide inadequate space to list all my own virtues and talents." (He got the joke.)*

Historically we've always gotten mixed reactions to the occasional humorous touches, probably just because they are so rare and unexpected. For example, more recent subscribers may not have seen Rick Smith's famous (or infamous) "Catering to your needs" ad in the May-June 1974 issue. (See above.) It drew similar reactions of either amusement or outrage. Then there was the famous/infamous nude miner ("expect the extraordinary") in the May-June 1975 Pala Properties ad. We got letters about that one too. Then-editor John White was originally planning to run it uncensored, but lost his nerve at the last minute. (See below.)

CATERING TO YOUR NEEDS...

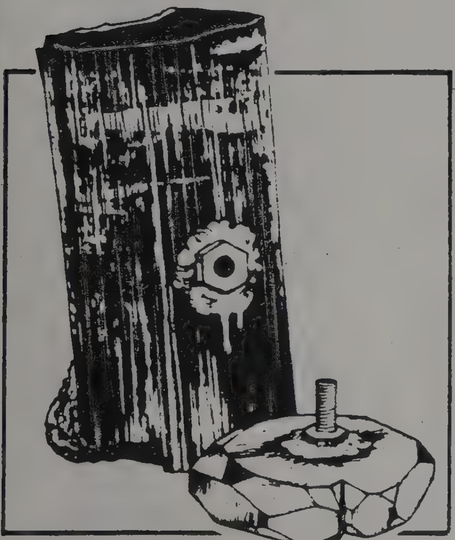
- Minerals expertly repaired
- Suitable matrix supplied for loose crystals
- Old labels faithfully copied
- Indistinguishable copies made of your favorite specimen
- Broken crystals artfully terminated
- Pornographic and scatological specimens our specialty
- Minerals for Zodiacs, anniversaries, Bar Mitzvahs

We assemble "Famous old collections" to order.
Reply in confidence.

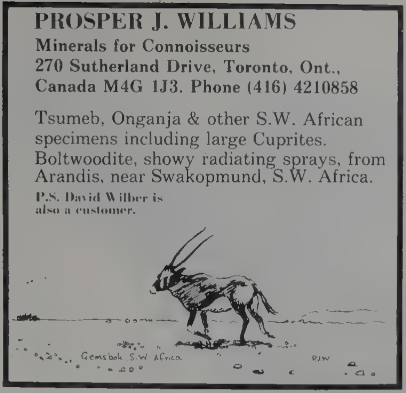
F.L. SMITH MINERALS
Box 46
Short Hills, New Jersey 07078

"Pala California: specialist removes gangue minerals in search of tourmaline pockets."

Occasionally the joke is on a prominent dealer, as in Rock Currier's Jewel Tunnel Imports *ad for July-August 1980; it shows a sketch of Dave Wilber's famous "postage stamp tourmaline," like the photo in Dave's back-cover ad except that someone has detached and made off with the central tourmaline crystal. In another Rock Currier ad we see Keith Proctor's famous California morganite-on-tourmaline, but with the morganite crystal screwed off like a big lug nut! Neither of these gentleman knew what was coming before Rock showed them a copy of the magazine; their reactions were, shall we say, memorable, but they took the ribbing like good sports.*



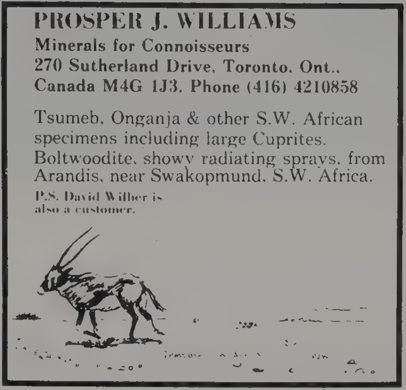
Other pranks have been a bit more subtle, as with the sketch of the galloping antelope in Prosper Williams' 1975–1976 ads. In each successive issue it moved a bit, until it had run off the margin! The idea was to see how long it would take for Prosper to notice that his illustration was making a break for freedom. (Answer: quite a while.)


PROSPER J. WILLIAMS
Minerals for Connoisseurs
270 Sutherland Drive, Toronto, Ont.,
Canada M4G 1J3. Phone (416) 4210858

Tsumeb, Onganja & other S.W. African specimens including large Cuprites. Boltwoodite, showy radiating sprays, from Arandis, near Swakopmund, S.W. Africa.

P.S. David Wilber is also a customer.

vol. 6, no. 3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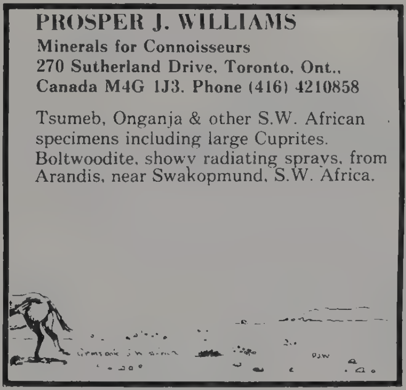
vol. 6, no. 5


PROSPER J. WILLIAMS
Minerals for Connoisseurs
270 Sutherland Drive, Toronto, Ont.,
Canada M4G 1J3. Phone (416) 4210858

Tsumeb, Onganja & other S.W. African specimens including large Cuprites. Boltwoodite, showy radiating sprays, from Arandis, near Swakopmund, S.W. Africa.

vol. 6, no. 6

Even Larry Conklin's early full-page ads, with their cheerful, sometimes self-aggrandizing text, were meant as much to amuse as to advertise. The editor even received a cash offer from a reader to pay for Larry's ad not *to be run!*

I can't promise that such mischief won't recur in these pages from time to time. Sensitive readers, we hope, will bear with us nevertheless.

The Editor

P.S. No, "Grolierite" is not a mineral; it refers to membership in the Grolier Club of bibliophiles. And, yes, Larry does know how to spell "Entrepreneur."

BARITE AFTER ALSTONITE

I write to correct your review (vol. 24, no. 5) of the Costa Mesa show, by Bob Jones and Jeffrey A. Scovil.

With regard to the paragraph on minerals displayed by the *Scott Williams Mineral Company*, the references to the pseudomorphs were all wrong. The barite pseudomorph after alstonite was from Nentsberry Haggs mine on the High Raise Second Sun vein in the Admiralty Flatts, not Brownley Hill (Bromley a misspelling dating back to the early nineteenth century, and the early name for alstonite was bromlite). The calcite pseudomorph after witherite was from Nentsberry Haggs (not Higgs mine, Netsherry?), on the crosscut from the High Raise vein to Treloar vein.

With regard to the actual material, it is contemporary. How do I know? I found the hole where the barite after alstonite pseudomorphs came from. The hole is now 6 feet long, 4 feet high and 4 feet wide, and was full of crystallized jet-black sphalerite and galena, the largest specimens extracted being over 1.5 feet long. The floor of the hole was a layer of barite which yielded ice-clear barite in crystals up to 4 inches long, some with spheres of honey-yellow witherite attached, and many with crystals of barite after alstonite on top. The barite pseudomorphs occurred generally with small crystals of sphalerite and generally were restricted in distribution to the back right portion of the hole.

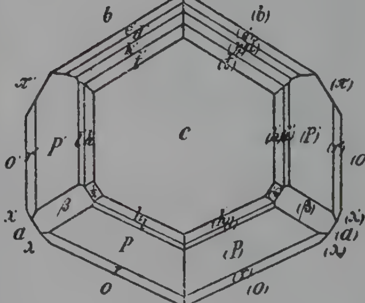
Robert Lawson
Castle Douglas, Scotland

ERRATA

In the Sanford deposit article (vol. 24, no. 5, p. 363) the caption to Figure 8 describes the specimens as a "scheelite octahedron." The correct description would be "pseudo-octahedron" or "tetragonal bipyramid," considering that scheelite is tetragonal rather than isometric in structure. This was an oversight attributable to the editor and not the authors.

In the Parker mine article (vol. 24, no. 5, p. 371), under the heading "Ferroan Spinel," for "trapezahedron" read "trapezohedron." Also note that {321} should be described as a hexoctahedron rather than a trisoctahedron (trisoctahedrons would be 221, 331, etc.).

In Tom Moore's Denver Show Report (vol. 25, no. 1, p. 62) the Chinese realgar shown in Figure 6 is indicated in the caption as a "John White specimen," but was actually acquired by him on behalf of the Julio Landmann collection.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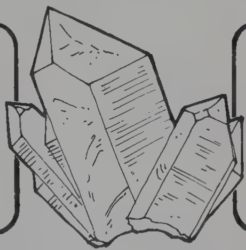
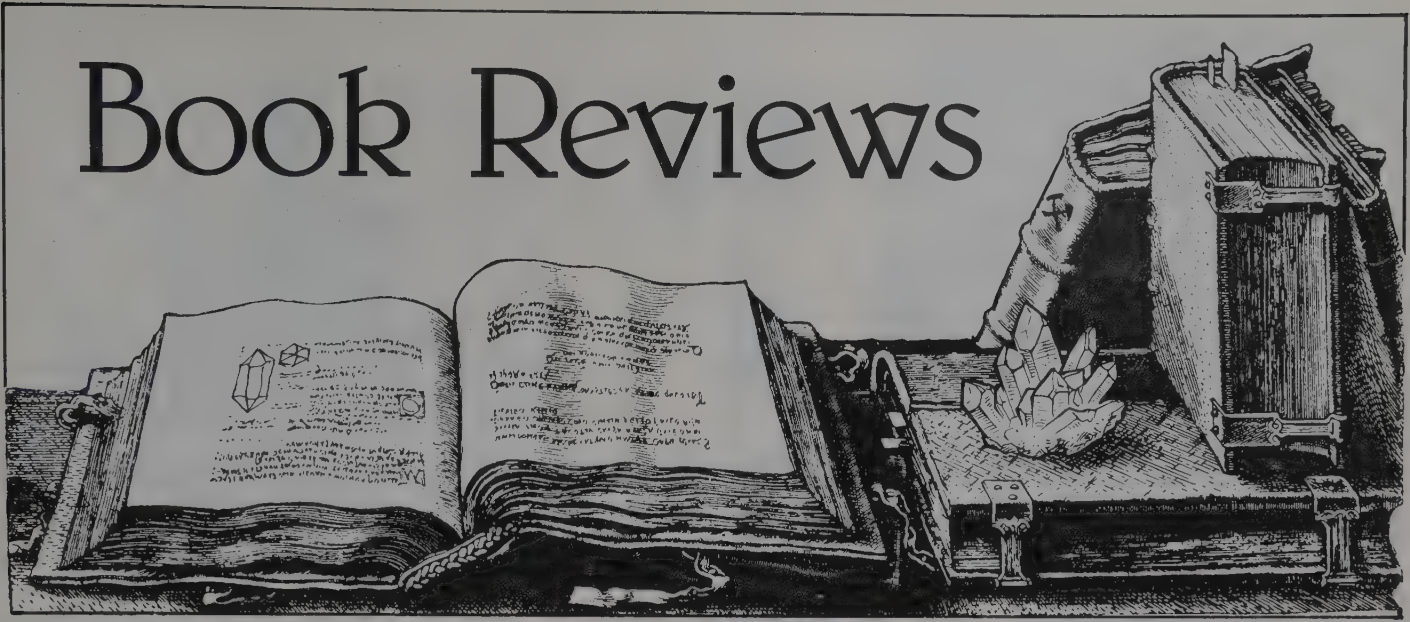


Book Reviews



Antero Aquamarines . . .

. . . Minerals from the Mount Antero-White Mountain Region, Chaffee County, Colorado, by Mark I. Jacobson. Published (1993) by L. R. Ream Publishing, P.O. Box 2043, Coeur d'Alene, Idaho, 83816-2043. Hardcover, 18 x 26 cm, 126 p., $34.95 + $2.00 shipping and handling; softcover, 18 x 25 cm, 126 p., $19.95 + $2.00 shipping and handling. ISBN 0-928693-08-2.

Mark Jacobson's book on *Antero Aquamarines* sets an example of thorough research and comprehensive documentation which should be emulated by other authors who aspire to write similar articles. The book is organized into seven chapters (not including the glossary and bibliography): Gems, Collecting and Scenery; History of Mineral Collecting and Mining; Geologic History and Rocks; Pegmatite Genesis; Mineral Paragenesis and Beryllium Geochemistry; Field Collecting; and Descriptive Mineralogy. His comprehensive treatment of these topics is noteworthy, but perhaps most impressive is the prodigious amount of historical information that has been assimilated. Collectors and their activities are documented in almost minute detail, from the earliest era of collecting up to the present. Amusing anecdotes and factual accounts have been drawn from interviews with as many collectors, mine operators and others with Antero stories as could be found. The geological treatment is equally complete, including not only the requisite overview of regional geology, but a detailed discussion of pegmatite and mineral genesis, including numerous illustrations of all types of vein and cavity structures that contain crystallized minerals within the pegmatites. Jacobson has gone to great length to relate structure and geology to mineral occurrence; to the astute collector this information provides not only insight as to *why* things are found where they are, but also clues as to *where* they might be found in the future.

Although the Mount Antero-White Mountain locality may not produce much in the way of world-class specimens (at least compared to some pegmatite minerals from Brazil or Pakistan), it definitely is a noteworthy North American locality, if not on a basis of gemstones, then most certainly on a basis of elevation (about 13,000 feet) and rigorous collecting conditions. Indeed, there is almost a mystique to surviving a trip to this site, and even more so when a crystal-filled cavity is found. The chapter on field collecting gives the prospective visitor all the essential information needed to plan a successful trip and prepare for the rigors of high-altitude collecting. Included in this chapter are paragraphs on camping, weather, road permits and altitude sickness, in addition to the usual prospecting tips and collecting methods.

The book is abundantly illustrated. An eight-page color insert with 18 color photos features numerous aquamarines, as well as fluorite, topaz and phenakite. There are over 90 black and white illustrations including maps and drawings; the black and white photos depict historical as well as contemporary events, showing localities, minerals and collectors. There are numerous maps and diagrams showing regional and local geology, pegmatite structures and features of beryllium geochemistry.

If there is any aspect of this book that could be construed to be wanting, it is the overall quality of the illustrations. Admittedly, the source of many of the photographs was from individual contributors (i.e., pictures illustrating hoardes of crystals on a bedsheet), and consequently they are of variable quality, but these add to the character and the historical nature of the book. On the other hand, photographs of individual specimens show wads of clay and/or poor lighting, and the reproduction of many black and white photos seems somewhat hazy. The color separations are poor; illustrations of aquamarine and topaz give an unnaturally accentuated color, beyond anything that actually occurs at this locality. Some of the diagrams of vein and cavity structures are so crowded with detail that they are difficult to interpret, but this does not overly compromise the information that needs to be conveyed. The only other item that might have been added to this comprehensive book would be an abridged version of Richard Sharp's map of Mt. Antero and vicinity (U.S. Geological Survey map MF-810, 1976). This map, in my opinion, is the single most useful map of the area, giving not only the geology, but also the location of almost all of the known pegmatite sites.

Antero Aquamarines is written in an easy-to-read narrative that will satisfy a wide range of reader ability, and a glossary provides a concise definition of the technical terms for those not well versed in the geologic sciences. The extensive bibliography makes this publication a valuable reference for both researcher and collector; the nominal price and overall quality warrants that it be included in any library.

D. E. Kile

TITLES RECEIVED

Bibliography of Colorado Mining History

by Arthur E. Smith, Jr. Published (1993) by L. R. Ream Publishing, P.O. Box 2043, Coeur d'Alene, Idaho 83816-2043. Softcover, 21 x 28 cm, 45 pages, ISBN: 0-928693-09-0, $9.95 plus postage.

Denver 1994

Over 700 Dealers!

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September 16-18
Denver Merchandise Mart
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Museum Exhibits, International Dealers
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200 Top Quality Mineral & Fossil Dealers. Museum Benefit Auction on Wednesday
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Gems, Minerals, & Fossils
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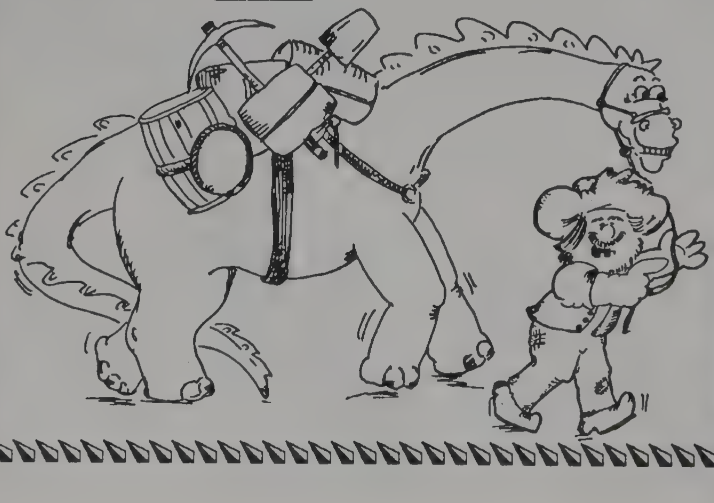

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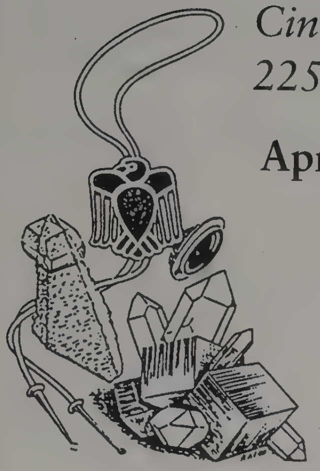

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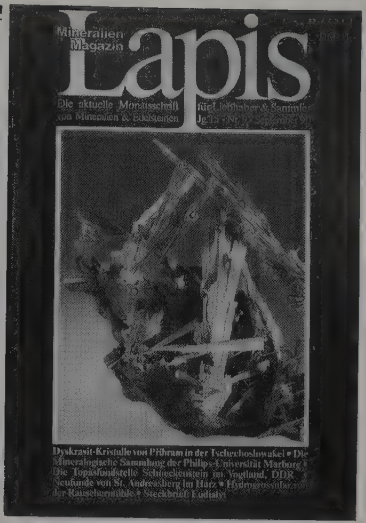

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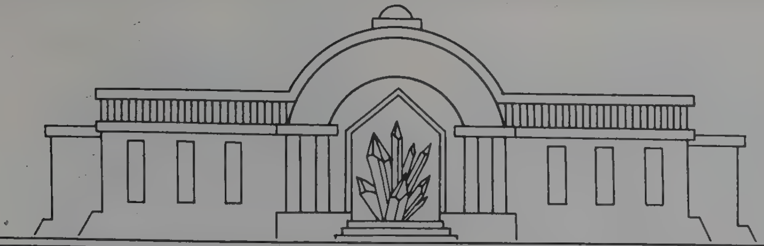

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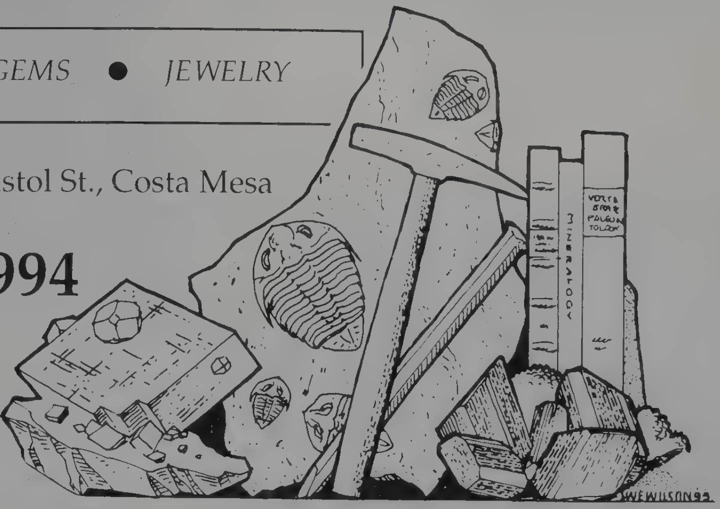

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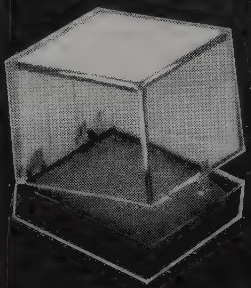

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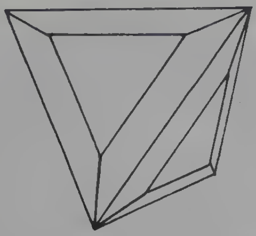

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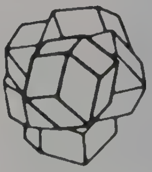

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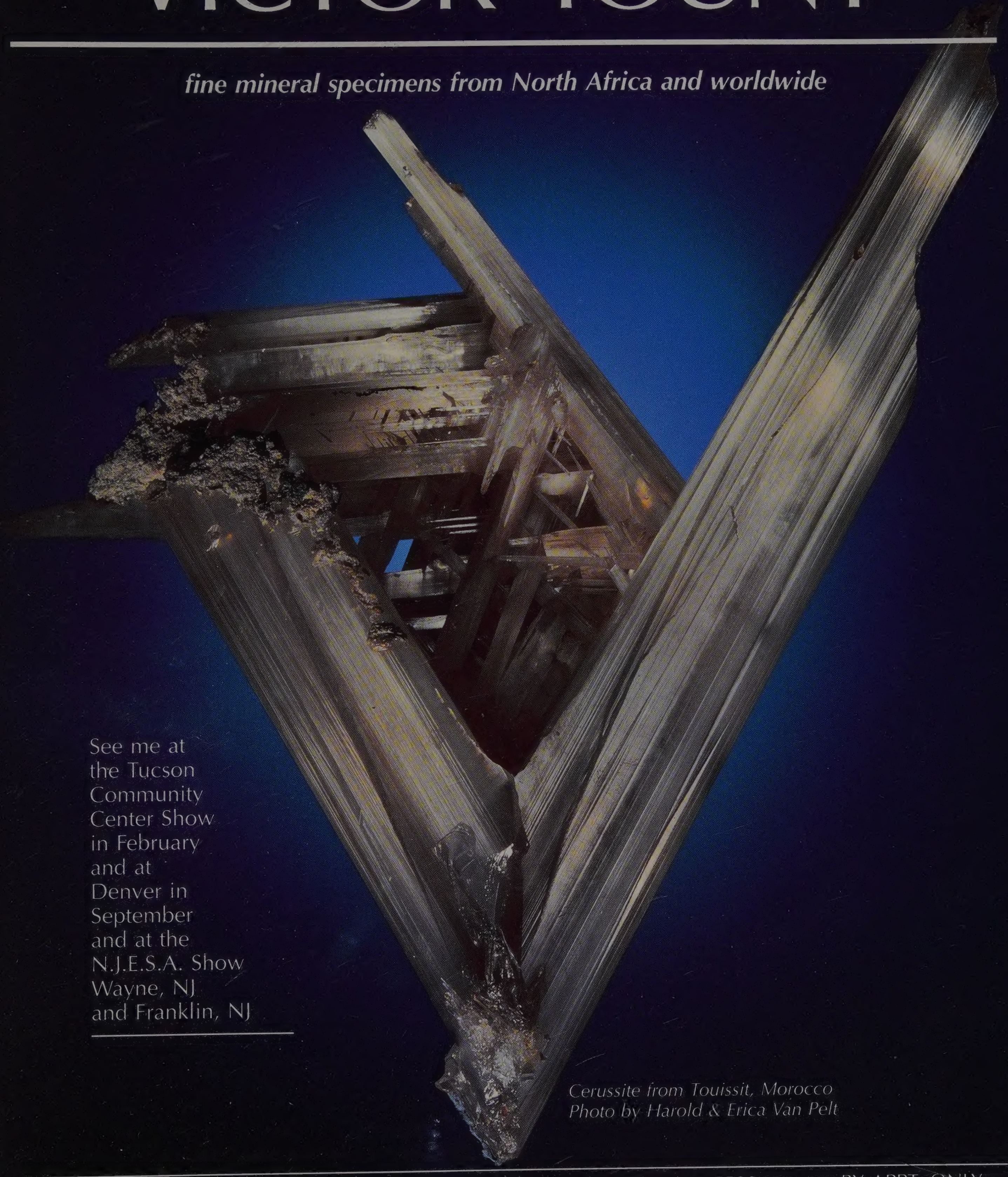

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