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SOWERBY'S EXOTIC MINERALOGY VOL. II
ROBINSON AMERICAN MINERALS
THE LIFE OF JAMES DWIGHT DANA DANIEL C. GILMAN
BAKEWELL

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®

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COVER: SILVER, heavy wires on matrix, 7.5 cm tall, from an unknown locality in Mexico. Collection of the University of Delaware Mineralogical Museum; photo by Harold and Erica Van Pelt (see p. 322).

notes from the EDITOR

OUR COVER

Peter Leavens, curator of the University of Delaware Mineral Museum (see vol. 14, no. 6, p. 369–375), received a telephone call a few years ago from a stranger. The person, Warren Beh, wanted to know if the museum would be interested in receiving as a gift some old mineral specimens which had belonged to his deceased grandfather, who had been a mining engineer. Curators receive such calls frequently, and usually the materials offered are more or less worthless or uninteresting, so Leavens asked for more of a description of the specimens. Beh apologized for knowing nothing about minerals or how to describe them in technical terms. But one piece, for example, he said he knew to be silver from Mexico, collected around 1895, and it looked "like toothpaste coming out of a tube." (!) "I'll be right there," said Leavens. The museum gratefully accepted the specimens, and the silver is shown on the cover of this issue.

SEEING THROUGH ROCK

What field collector hasn't wished for a magical device that would allow him to see through rocks and spot hidden veins, fissures and cavities? It sounds like fantasy, but the technological problems are gradually being solved. Geophysical Survey Systems, Inc. (Hudson, NH; tel. 603-889-4841) has developed a ground-penetrating radar system that is proving useful to archaeologists as well as mining geologists.

The $20,000 device consists of two rectangular antennas in a sled-like mount which is slowly drawn across the rock surface. Radar signals from one antenna penetrate the rock and are reflected from structural features, to be picked up by the second antenna. A printout shows what the radar "sees," indicating approximate depth and size of areas having unusual electrical properties. Metalized areas (showing high conductivity) and open voids (showing none) can be resolved. The radar can be used to probe from the ground surface downward, or it can be positioned on the wall or roof of an adit to probe laterally or upward.

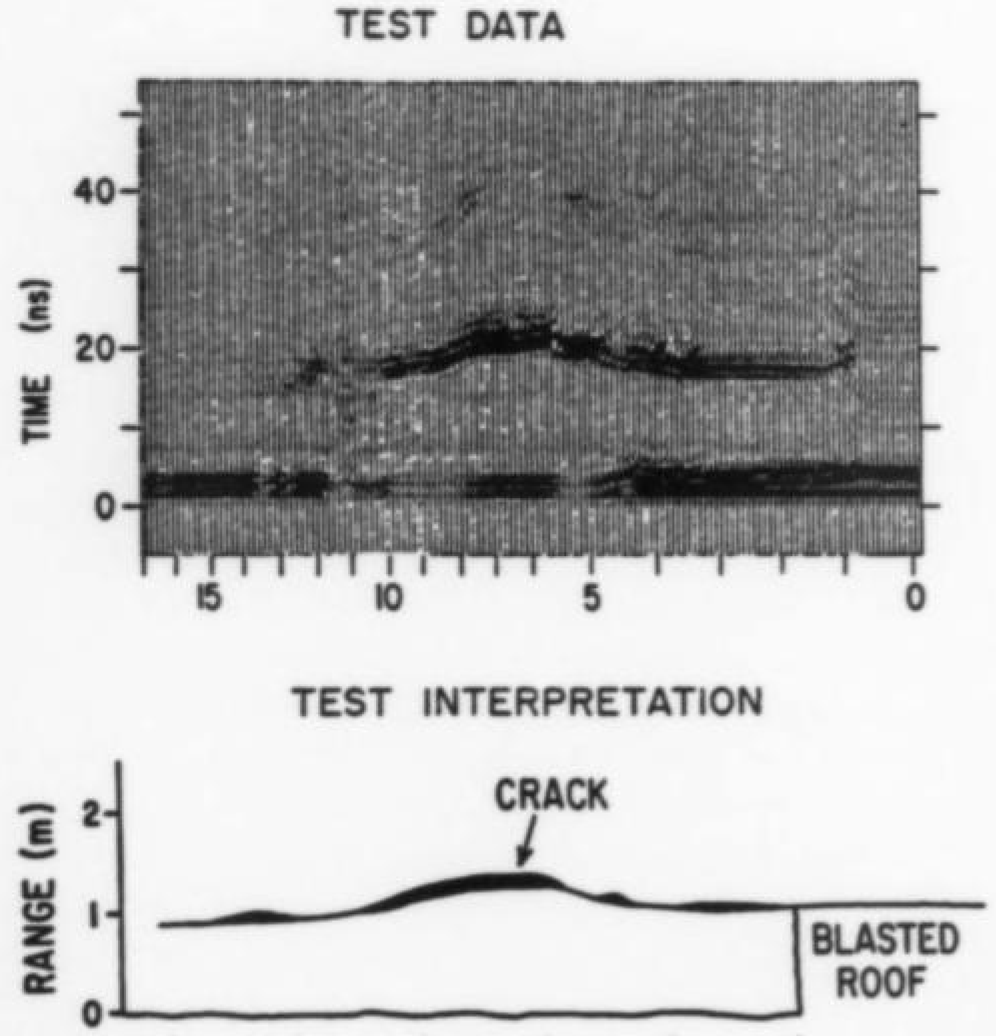


***Figure 1.* Ground penetrating radar image of a crack hidden in the back (roof) of a mine adit (from A. P. Annan *et al.* (1988) Radar sounding in potash mines, Saskatchewan, Canada. *Geophysics*, 53, 1556–1564).**

Eastern utility companies working in favorable ground have successfully imaged plastic pipes at depths of up to 33 meters; on the other hand, salty Southwestern soils can limit penetration to 1 or 2 meters. Higher frequency radar yields sharper resolution but shallower penetration. A. P. Annan and others, writing in the December 1988 issue of the journal *Geophysics,* note in their conclusions that: "While the radar responded well to cracks in the roof of the tunnel [see figure reproduced here], the cracks also posed a major difficulty in some mines. Cracks . . . on the order of 20 or 30 cm . . . are very strong radar reflectors . . . so much energy can be reflected from the crack that very little energy penetrates to deeper structure." Well, this phenomenon may be a problem in some applications but, for the mineral collector desperately wanting to know the locations of 20-cm open pockets, it's heaven-sent.

The University of Arizona's Mining and Geological Engineering Department has purchased one of the devices and, in addition to conducting their own research locating hidden tunnels, fractures and fissures, will rent it to outside parties for $500 per day. Contact Dr. Ben K. Sternberg, director of the university's Laboratory for Advanced Subsurface Imaging, for further information.

TUCSON SHOW

The Tucson Gem and Mineral Show at the Tucson Convention Center will expand to 89,000 square feet and five days (Wednesday through Sunday) for 1990. All sections (wholesale, retail, minerals, lapidary, publishers, exhibits) will be in a single, huge, rectangular room of the newly enlarged Convention Center. Occupying the adjacent hall will be a dealers-only show sponsored by the American Gem Trade Association. Adjust your plane and motel reservations accordingly. Set-up day for retail dealers and exhibitors will be Tuesday. Show hours will be shortened by one hour Wednesday through Saturday, closing at 7 p.m. instead of 8 p.m. Show dates will be February 7–11, 1990.

In my report on the 1989 show I mentioned that Gene Schlepp visited Prague, Czechoslovakia, to help select specimens for the Narodní Museum's fine exhibit at the Tucson Show. This was true, but Gene was not the exhibits chairman as I indicated. That position was ably filled (and will be again in 1990) by Peter Megaw.

CALL FOR PAPERS

The eleventh symposium sponsored jointly by Friends of Mineralogy, the Tucson Gem and Mineral Society, and the Mineralogical Society of America will be held in Tucson on February 10, 1990. The topic of the symposium will be *wulfenite,* the featured mineral of the 36th Tucson Gem and Mineral Show. Papers are invited on topics in any way related to wulfenite, including its descriptive mineralogy, associations or paragenesis, classic localities, etc. An audience of knowledgeable amateurs as well as professional geologists and mineralogists is expected. The atmosphere of the meetings is informal.

If you feel you would like to present a paper, please write immediately to Dr. Karen Wenrich, Chairman (U.S.G.S., Mail Stop 905, Federal Center, Denver, CO 80225) with your topic, a few sentences describing the paper, and an address or phone number at which you may be contacted. Presentations will be 15 or 20 minutes in length followed by a period for questions. Upon acceptance of topics all authors will be required to submit a 200-word abstract by September 30, 1989.

FLUORESCENT MINERAL SOCIETY

The Fluorescent Mineral Society was founded in 1971 to promote the collection and study of fluorescent minerals and the dissemination of information on fluorescence. (Fluorescent minerals emit visible light, sometimes attractively colored and patterned, when exposed to ultraviolet radiation.) The society has over 200 members, including scientists and hobbyists in the U.S. and 15 foreign countries.

A bimonthly newsletter, *UV Waves,* keeps members informed on fluorescent mineral news and society business. In addition, the *Journal of the Fluorescent Mineral Society* is published annually as a vehicle for more technical information. The society also undertakes research and special publishing projects from time to time.

The Fluorescent Mineral Society is a non-profit organization open to all adults and high school students interested in fluorescent minerals. The parent group meets monthly in Pasadena, California; chapters in the Northwest and Northeast hold occasional meetings announced in *UV Waves*. For further information or membership applications contact Dr. Rodney K. Burroughs, P.O. Box 2694, Sepulveda, CA 91342.

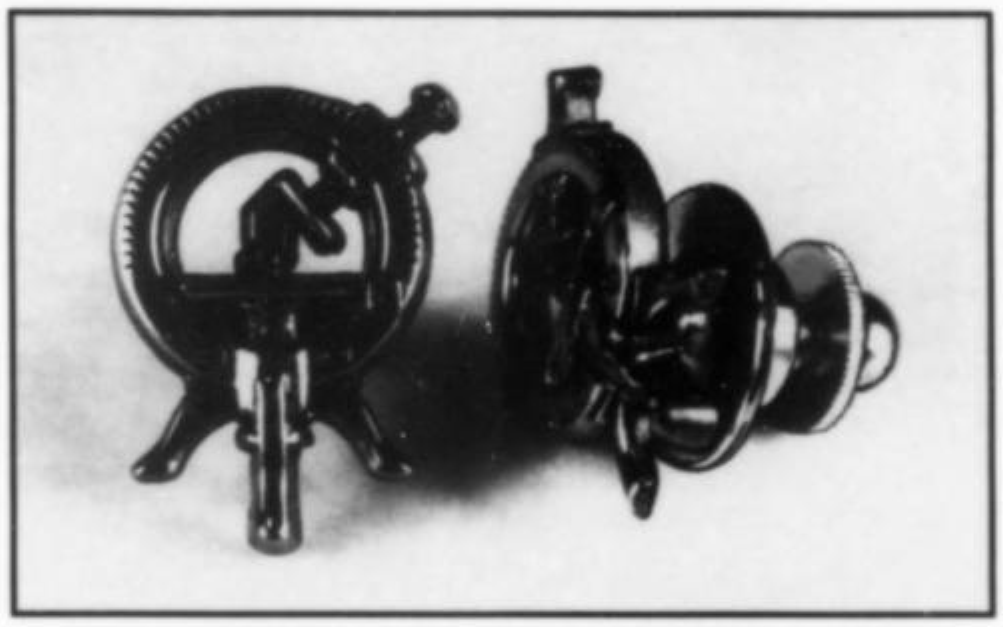


Figure 2. **Polished, cast-bronze lapel pin, 1.8 cm; $12 postpaid from the Circulation Manager.**

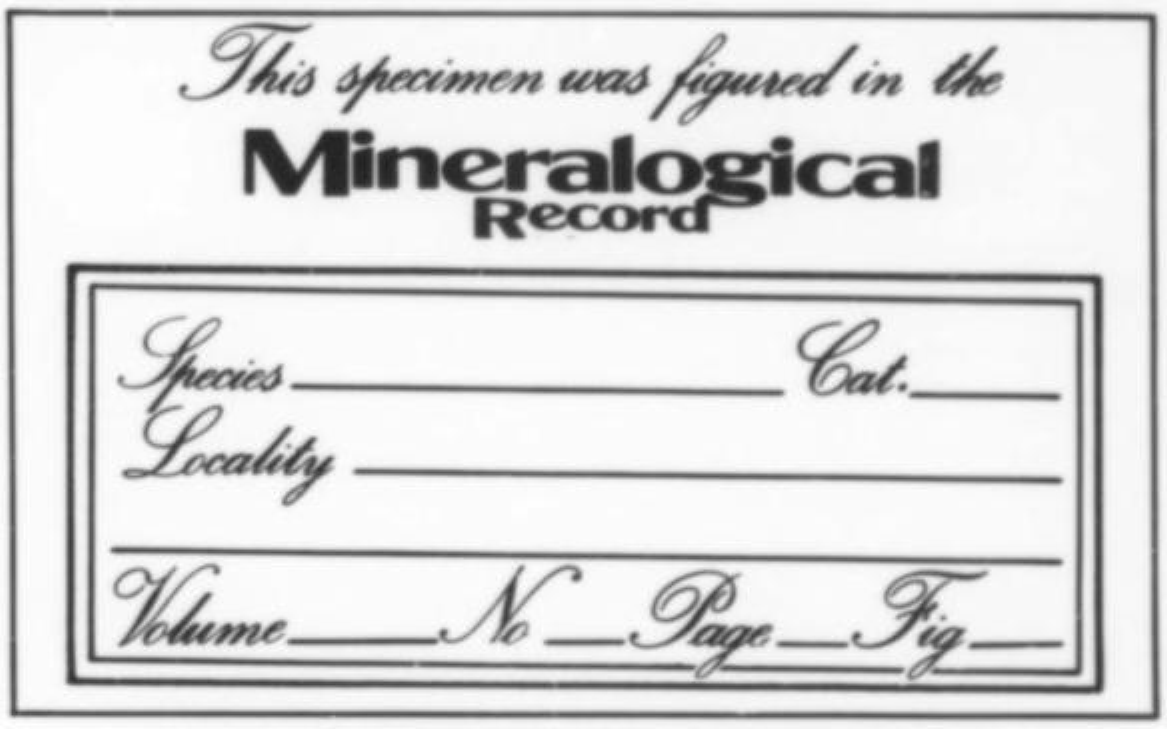
COLLECTOR PINS

Four years ago we introduced our bronze goniometer lapel pins, priced at $14 postpaid. These, we think, are a nice way of making a quiet statement about your orientation as a mineral collector (and also your support for the *Mineralogical Record*). They are made for us by Josten's, everyone's class ring company, the nation's largest consumer of gold and, I just found out, makers of the Congressional Medals of Honor as well.

We've recently reordered these again and, due to a better quantity discount, we are now able to offer them at **$12 postpaid.** And the new pins have a polished, rather than dull matte finish. Send your order to the **Circulation Manager, P.O. Box 35565, Tucson, AZ 85740.**

BLUE QUARTZ

A synthetically colored blue quartz (trade named "Aqua Aura") was being sold in large quantities at the last Tucson Show by Bob Jackson (P.O. Box 2652, Renton, WA 98056). It is apparently produced by vapor deposition of a thinly layered dot pattern of metallic gold on colorless quartz. The effect is striking, and the treated crystals are proving to be extremely popular with lapidaries and jewelers. The problem for mineral collectors is that, although Bob was providing full information to all buyers regarding the artificial nature of the color, it is possible that this information may eventually become separated from the specimens, and some people may unknowingly buy them as natural from other dealers. Not just single small crystals but large, displayable crystals and crystal groups have been treated, creating beautiful fakes. Buyer beware.



This specimen was figured in the

Mineralogical Record

Species *Cat.*

Locality

Volume *No* *Page* *Fig*

Figure 3. **Mineral label for specimens which have been illustrated in the *Mineralogical Record,* available free from the editor. (Photocopying rights granted; no permission necessary.)**

ILLUSTRATED SPECIMENS

Readers who own specimens which have at some time been illustrated in the *Mineralogical Record* can obtain free labels like the one shown above simply by writing to the editor and enclosing a stamped, self-addressed envelope. Illustrated specimens hold a special place in mineralogical science and history; keeping these cards with the specimens will help to assure that their special significance is not forgotten, especially as they change hands in the future.

TORINO SHOW

The Torino Show ad in the last two issues gave the show dates as October 7–9; the correct dates are October 6–8.

PLUGS

The *Mineralogical Record* frequently gives free publicity ("plugs") to dealers and their merchandise in columns such as *Notes from the editor, What's new in minerals?, Notes from Europe, Microminerals* and *Book reviews*. Some people may wonder about the basis on which these plugs are granted, so it bears explaining every once in a while.

In the *Notes from the Editor* column I generally cover any subjects of interest to mineral collectors *except* mineral specimens and book reviews. It's a catch-all for whatever does not fit conceptually in our other columns. Notices on the formation of new societies (or on old societies deserving to be more widely known), calls for papers for symposia, and occasional news concerning important shows are all periodically included, although we do not give free listings of forthcoming shows. Other random notes might have to do with new (nonmineral) products on the market, aids to mineral photography, computer software for collectors, mineral art, new periodicals and newsletters being introduced, recent curatorial appointments and so on. These, of course, are in addition to our usual notes on internal matters having to do with the magazine, congratulatory notes, and death notices. Contributed notes, ideas and data along any of these lines would be welcome.

The first criterion for any kind of plug is that the information given must be of sufficient interest or value to mineral collectors. This is the critical point in plugging new mineral discoveries. A find of three specimens of something, for example, will not reach as many collections as a find of 300 specimens will. People always like to read about what they own or might consider owning. On the other hand, if the quality and mineralogical interest are high enough, they may want to read about it even if they can't personally obtain a specimen. The higher the quality, the fewer specimens it takes to justify a report. In extreme cases, a single superb specimen will do.

That covers the choice of specimen material . . . what about the dealer getting the plug? This is simply a matter of the information that we (all of us who write for the *Mineralogical Record*) have at hand. If three dealers get lots of a certain discovery, and one of them contacts the *Mineralogical Record* and provides information and/or photos, or specimens on loan for us to photograph, how are we to know about the other two? Whereas we discriminate on what material will be reported, once it is chosen we would be happy to list a number of dealers carrying it.

Some people may wonder whether a "donation" is required to obtain a plug. This is certainly not true. Specimens sent for photography will be returned. Only in the case of books and magazines for review do we require the traditional complimentary review copy. This copy is kept by the person writing the review.

Occasionally the charge of favoritism arises, because people see the names of certain dealers plugged repeatedly. There are reasons for this in addition to their willingness to keep us informed. The most significant reason is that some dealers happen to be at the forefront of the business. They work harder, get luckier, and acquire more new discoveries than some other dealers . . . luck can be a major factor in dealing, but when certain dealers repeatedly get there first on new finds, one must conclude that they're doing something better. In any case, our coverage follows distribution, and the distribution of fine, new minerals among dealers is not even.

Another factor is that some dealers, by choice, do not pursue new discoveries. For example, several East and West Coast dealers concentrate heavily on buying and reselling old collections; so they get less "new" material, and more one-of-a-kind old-timer specimens which, individually, are not "news." Readers should understand that this is the reason why their names appear less frequently than their status would seem to merit.

There is no requirement that dealers plugged be advertisers in the *Mineralogical Record;* such a requirement would conflict with our first criterion, the benefit of the reader. In cases where the dealer is not an advertiser we commonly give his address or city so that readers may track him down. In total, many more non-advertisers are plugged than advertisers.

I wish it went without saying but apparently it doesn't; so I'll say it. Dealers plugged need not be personal friends of *Mineralogical Record* staff members. In fact, strangers and new-comers are particularly encouraged to contact us about mineral news because our readers will appreciate learning about new sources.

Despite these policies, there are unavoidably arbitrary factors involved. Sometimes there is simply not enough space to publish all of the information we have. Other times we haven't enough information to merit a column, so the little which we do have is shelved. Some minerals are only of very local interest, and go unreported in deference to our nationwide and international readership.

Even though reporters writing in the *Mineralogical Record* endeavor to be objective, their own personal likes and dislikes do enter into their choices of what to write about. This is not necessarily bad. Readers who are unsure of their own taste, and who are trying to develop it more fully, will be interested to know what pleases the taste of well-known writers. In deciding what *not* to discuss, the writer unavoidably becomes a critic. But, because in most cases only the "good" material is covered, the reader has no way of knowing which items the writer weighed and found wanting, and which ones he simply didn't see.

We recognize that market news and reports on new discoveries are perhaps the most important items in the entire magazine for some readers. After all, even professional research first requires the *acquisition* of samples . . . and in collecting, acquisition is the indispensable aspect. Everything follows from that, unless you are content only to admire the collections of others. Interest and private study are always stimulated by the physical object itself. Consequently we will continue to provide the best reportage we can. Criticism of our coverage, however, would be more constructively aimed at who and what we are missing rather than who is receiving too much.

Dealers wishing to submit mineral news for publication should attempt to answer as many as possible of the following questions . . . these are the things readers want to know:

(1) How much material is available?
(2) What is the average quality and the very best quality?
(3) What do the best specimens look like? (Photos are best here; if the dealer cannot supply photos he may send specimens by registered mail directly to the *Mineralogical Record* where, at the discretion of the editor, they will be photographed and measured. All such specimens will be returned, but the dealer must assume the risk of damage that may occur during handling and photographing.)
(4) What is the *exact* locality? (Is the information reliable?)
(5) When was the material collected?
(6) What are the determinable chances for the collecting of more material?
(7) How does the material compare to previous discoveries?
(8) What is the retail price range?
(9) Are there any interesting stories associated with the collecting or acquiring of this mineral?
(10) If some of the top specimens have already been sold, where might the public go to see them?
(11) Does the material have any interesting mineralogical features or aspects?
(12) What is the geological and mineralogical environment of the mineral's occurrence?
(13) What are the associated species, and how were all of the species identified?

There are some types of information which we will not publish. The *Mineralogical Record* has no free listing of coming shows (though paid ads are always welcome) . . . these are admirably covered by other magazines. The *Mineralogical Record* does not publish "press releases" having to do with personnel changes in the mineral business, shop openings, awards presented (except at the Tucson Show), or coming seminars and short courses. We avoid handicrafts, rocks (including meteorites and tektites), and fossils, and make only the rarest reference to cut or polished minerals. Items *primarily* of lapidary or gemological interest are usually not covered. Of course we reserve the right to break our own rules in special cases, but those cases will be very rare.

Show reports should not be considered as a formal place for the recognition of exhibitors. Displays which happened to catch the writer's eye will be discussed, without rigorous regard to the individual merits of all other displays, the prestige of the displaying individuals or institutions, or the distance which exhibitors had to travel. An unmentioned exhibit is not being purposely overlooked or judged inferior. Consequently, no exhibitor should feel he has somehow earned the right to be mentioned in the *Mineralogical Record*. The discussion of temporary exhibits which can no longer be seen is of far less importance to readers than the discussion of still-purchaseable minerals, so the former will not be given comprehensive coverage.

Our goal is simply to make the best use of our limited space for the mineral collector and specimen-oriented mineralogist. If this happens also to benefit some dealers (and many of our readers *are* dealers), then we are happy for them. But benefiting dealers is not specifically one of our responsibilities . . . that is what distinguishes the *Mineralogical Record* from a "trade journal." We do feel that a healthy and active mineral market is in the best interest of everyone, and we are pleased by whatever positive side-effects the *Mineralogical Record* produces in this regard. ◆

DIAMONDS IN BRAZIL

J. P. Cassedanne
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Cidade Universitária, Ilha do Fundão
21.910 Rio de Janeiro, Brazil

Since their discovery in Minas Gerais, near the town of Diamantina, Brazilian diamonds have been the objects of prospecting, mining, fables and dreams. By the end of the 1700's Brazil had become the world's leading producer of diamonds, a position it held until the fabulous South African diamond fields surpassed it in the late nineteenth century.

Officially the discovery of diamonds in Brazil is dated at 1727. Gold prospectors had found occasional diamond crystals before that date, perhaps as early as 1670, but had failed to recognize their significance or value. The arrival of the first Brazilian diamonds in Europe caused a depression in the market, and gem dealers reacted by attempting to disparage the quality and conceal the source. David Jeffries, a prominent London jeweler, wrote in his *Treatise on Diamonds and Pearls* in 1750 that "it will be impossible to settle the diamond value in Europe without denouncing the false idea that Brazil is a producer." The sheer volume of diamonds coming from Brazil soon overwhelmed these efforts, and for many years Brazil reigned as the world's leading producer. More than a century of mining eventually yielded an astounding 13 million carats or 2 metric tons of diamonds. Of these, 5.5 million carats came from Diamantina, 3.5 million carats from Bahia, and 1.5 million carats from other fields in Minas Gerais; an estimated 2.5 million carats more from these areas are thought to have been stolen and smuggled out of Brazil.

By the end of the 1870's Brazil's ranking as a diamond producer had fallen to third or fourth place. This was not due, however, to exhaustion of the deposits but to their low grade. Mechanized mining proved unprofitable; the success of earlier mining had been based on the thousands of slaves employed by the Portuguese to carefully rake every foot of soil. The abolition of slavery combined with competition from South Africa resulted in a precipitous drop in production; in 1880 only 5000 carats were officially recorded.

After many ups and downs over the years, Brazil is once again an important producer of diamonds. Thanks to new discoveries and improved recovery methods, the current annual production is around 1 million carats. These come in part from a dredging plant operating on the Jequitinhonha River, but primitive methods are employed as well. Nowadays tens of thousands of people make their living from Brazilian diamonds, directly or indirectly, most of them private prospectors known as "garimpeiros" who are thought to number more than 30,000. The mystique of precious gems and the chance at sudden wealth cause them to labor obstinately under the most unpromising conditions.

The garimpeiros comprise a strange and generally unknown society in Brazil. There are no governmental restrictions on private prospecting; one needs only to register with the authorities and obtain a permit. Any resulting discoveries are tax-free, provided the work is done alone and without mechanized equipment. Some garimpeiros do take partners and utilize pumps and other simple machinery, but the government is inclined to look the other way. The garimpeiros provide a valuable service by systematically prospecting the country free-of-charge; when discoveries are made they do not remain secret for long.

Those garimpeiros who find it too difficult to support themselves will sometimes take on a "silent partner" or backer who provides a grubstake. The prospectors live in simple shanties near the location being worked. Landowners, if any, may also take a share of any discoveries just as the backers do. By common agreement, whatever is found is immediately sold and the funds are divided up.

The generally low grade of Brazilian deposits combined, paradoxically, with the occurrence of very large stones discovered occasionally contributes to the garimpeiro's unusual, hopeful but fatalistic outlook. Everything is considered a matter of luck.

ORIGIN OF THE DEPOSITS

Brazil occupies half of the South American continent and has a surface area equal to the whole of Europe. The basement rocks consist of very old formations of complex geological evolution which have remained more or less undisturbed since the end of the Precambrian. Subsiding basin areas gradually filled with an uninterrupted sequence of sediments until the Cretaceous period, prior to the splitting apart of Africa from South America. Sediments totaling thousands of meters in thickness accumulated in some areas, along with thick basalt layers. The erosion of the Andean Cordillera following its formation during

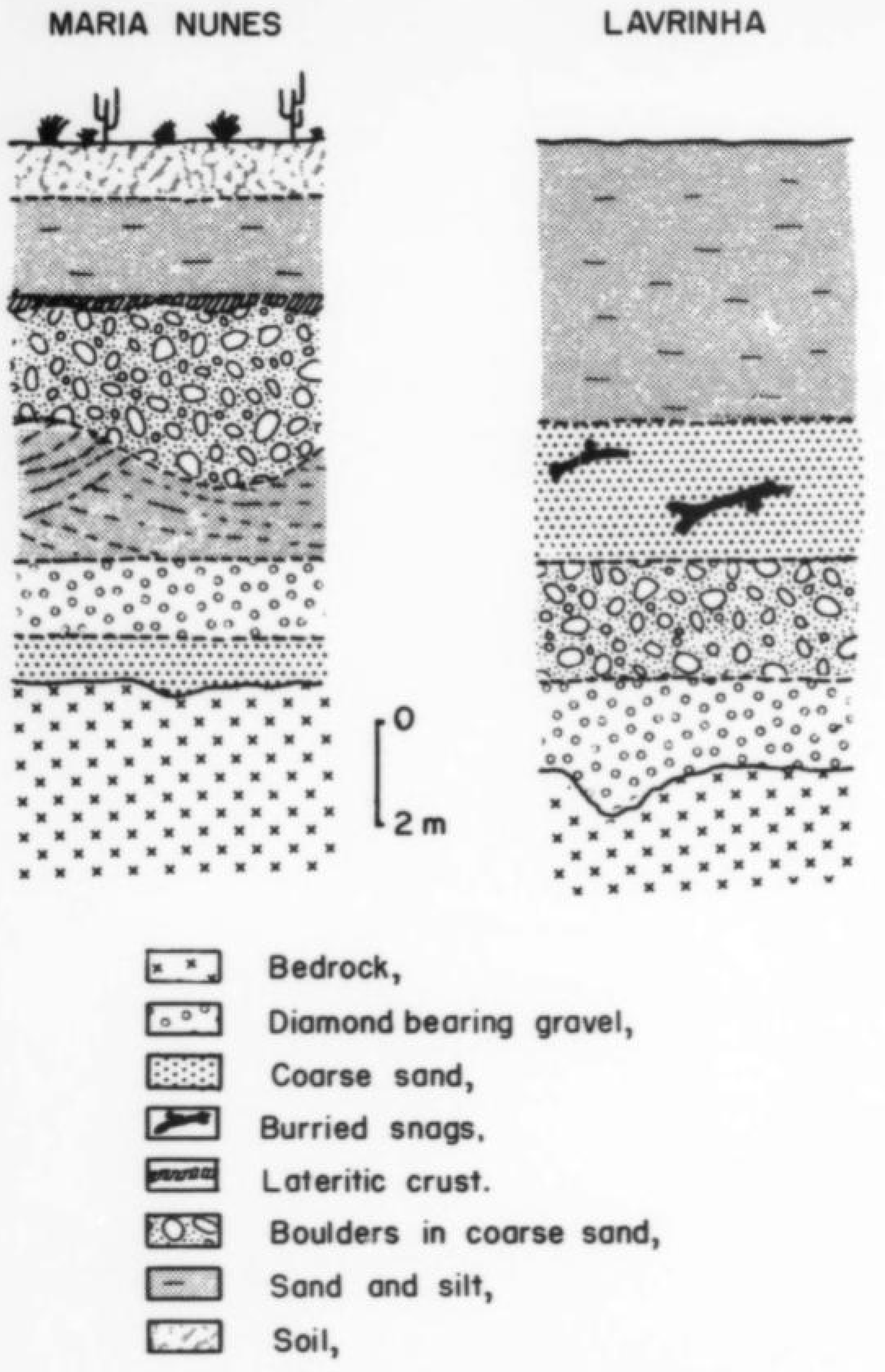

Figure 1. **Cross sections of alluvial diamond-bearing deposits in the Jequitinhonha River.**

the Cretaceous Period filled in the Amazon Basin, while other basins where deposition had ceased began to suffer erosion.

Diamonds are carried up from the earth's mantle by a unique, relatively cold volcanic process. Rocks heavily charged with carbon dioxide under extreme pressure explode into a highly mobile, non-molten slurry of breccia when weaknesses in the crust cause a sudden drop in pressure. This material intrudes rapidly upward, forming pipe deposits of a solidified rock known as kimberlite.

The existence of kimberlites in Brazil was denied for many years. Diamonds were thought to have been transported from the weathering of African diamond pipes before the continents separated, or perhaps to have been formed in pegmatites or quartz veins. But recent prospecting in the states of Minas Gerais, Goiás, Mato Grosso and Piauí has revealed hundreds of kimberlite outcrops. Unfortunately, none have proven to contain economic quantities of diamonds, and so none have been commercially mined.

Kimberlite weathers easily, releasing the tougher components such as diamond, pyrope, magnesium-rich ilmenite, zircon, etc. Local accumulations of diamond-rich soil (eluvium) may result. More commonly the loose debris is carried away by running water, sometimes being deposited nearby on the slopes of the kimberlite bodies (colluvium), but for the most part being transported some distance by streams before being deposited (as alluvium) along with weathering products from other rock types in the area.

Continued erosion and reworking which took place over the course of several geologic periods have resulted in the current distribution of diamonds. Throughout these cycles, accessory minerals originally associated with diamond in kimberlite dwindle away, to be replaced by minerals derived from other rocks. As the base levels of rivers fluctuate with time, older terraces may be stranded at higher levels or buried under more recent sediments. Erosion of pre-existing alluvial material carries the diamonds ever farther from their original source, often resulting in the deposition of "white gravels" which consist almost entirely of quartz. Some deposits have little relationship to the local hydrographic patterns.

Alluvium may become consolidated into conglomerates and other sedimentary rock types, the most well known of which crop out on the high plains in the states of Bahia and Minas Gerais. These are middle-Precambrian in age, but others from the Triângulo Mineiro, in western Minas Gerais, are Cretaceous.

Two main periods of kimberlite intrusion have been identified: one of Precambrian age (pipes are generally overlain by Upper Precambrian Bambui Group sedimentary rocks in the Rio São Francisco Valley), and one of Cretaceous age. Weathering of the Cretaceous kimberlites has given rise to many diamond fields in Piauí, Mato Grosso, Goiás and western Minas Gerais. It is currently thought that many Brazilian diamonds are of Precambrian age, though they may have been reworked during Paleozoic, Cretaceous and Recent times.

CLASSIFICATION OF DEPOSITS

Brazilian diamond deposits may be divided as follows:

(1) **Eluvial deposits** (known among miners as "gorgulho"). These are horizontal beds of sharp or poorly rounded sedimentary material in a brown to reddish or yellowish clay matrix. They extend over diamond-bearing conglomerates (called "tauá") and other mineralized rocks.

(2) **Colluvial deposits** ("grupiaras") and high terraces ("monchões"). These are located below the eluvial deposits on slopes.

(3) **Alluvial deposits** ("brejos"). Here diamonds occur mixed with clay, silt and quartz gravel, and pebbles in layered deposits. Local accumulations tend to be young in age, as indicated by the occasional inclusion of prehistoric axe heads and arrowheads in western Minas Gerais. Alluvial fields are presently the main source of Brazilian diamonds.

Alluvial deposits can be sub-divided according to stratigraphic position. The lowest materials lie directly on bedrock; the overlying units are generally gravels; and the uppermost layers may be termed overburden.

(a) **Bedrock alluvial deposits** ("Pissara," "sebo"). The bedrock on which these deposits rest may be unaltered or weathered, homogeneous or varied, sometimes furrowed or pocked with pot-holes. The surface is generally even or undulating. The irregularities in the bedrock surface act as traps for diamonds (just as they do for placer gold in other areas of the world). Scattered concentrations can develop; for example, a thousand carats of diamond were removed from a single large pot-hole in Diamantina a few years ago. Miners are careful to clean out the rugged bedrock surface thoroughly.

(b) **Gravel** ("Cascalho"). The principal ores are gravels of varying grain size and composition, deposited over bedrock to a thickness of a few decimeters to a few meters. The gravel layers tend to conform to the bedrock surface but may be discontinuous in places. Quartz is the main mineral, with various associated accessory minerals which may include tourmaline, kyanite, rutile, anatase, limonitized pyrite, sillimanite, lazulite, chert, etc. These are referred to as "satellite" minerals by garimpeiros throughout Brazil, although they have no genetic relationship to diamond and may vary from one region to another. The accessory minerals are well known to the garimpeiros by evocative miners' terms such as horse bone (sillimanite), rice straw (kyanite), black beans (tourmaline), aniline stone (lazulite), etc. Pebbles and small boulders occur irregularly. In some areas clay or sand lenses are interbedded with gravel; in other deposits the gravel fills in between quartzite boulders (as in the Lençóis area of central Bahia).

Layers that have been hardened by interstitial deposits of iron oxides or chalcedony (frosty gravel) attest to ancient groundwater levels.

(c) **Overburden.** Deposits overlying the ore gravels can be even thicker. This overburden is typically composed of silt and clay with some sand and has a brown, beige, yellow or gray color. It must be stripped away before mining of the gravel layer can take place. Black clay (with a high content of organic matter) and peat layers are irregularly interbedded, including occasional carbonized tree trunks. In some places thin gravel beds indicate periods of renewed strong erosion.

PROSPECTING

Productive gravel beds are almost always deeply buried under later deposits, and tend to crop out only along the margins of eroding terraces. How, then, do the garimpeiros locate these diamondiferous beds? There is no rational approach; dreams, intuition, fables, rumors and the memories of other prospectors are their guides. Some accessory minerals are considered to be positive indicators. The garimpeiros explore using haphazard prospect pits, sometimes keying on irregularities in the local geomorphology. The alluvial fields that have been worked to one extent or another in the past often cover extensive areas of land; consequently, most new prospecting is carried out in the neighborhood of older workings, or in areas thought to have been poorly worked.

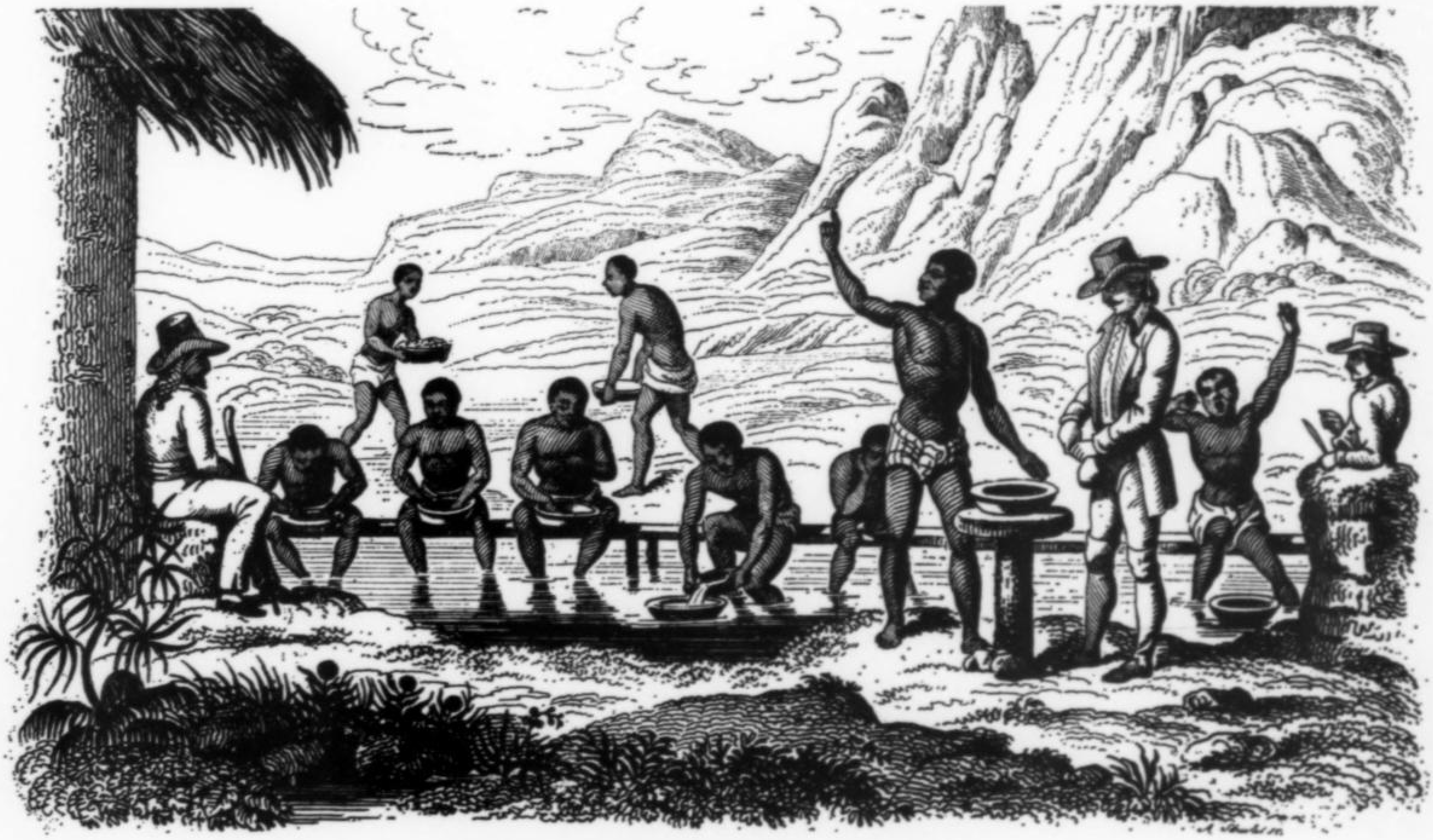

Figure 2. **Early engraving depicting Brazilian slaves washing for diamonds under the watchful eye of the overseers.**

DIAMOND RECOVERY

After the overburden has been stripped away the diamond-bearing gravels are removed and taken to concentrating areas. Transportation is by wooden troughs, baskets and wheelbarrows; there are no trucks in these remote areas, and bulldozers or dredges are used only rarely. Despite these primitive techniques, excavations more than 10 square kilometers have been locally cleared for diamond mining.

Where the overburden is too thick to be removed, diggers reach the gravel layers via pits or vertical-face quarrying. Hydraulicking is also employed in some areas. Where river beds are promising, watercourses are diverted and primitive dams are constructed. If this is impractical a group of miners may pool their resources and purchase a wetsuit and diving gear which they will take turns using.

The ore grade is always low, ranging from 1 carat per cubic meter down to a hundredth carat or less. The gravels are carefully washed and sieved, with the final recovery of diamonds accomplished by hand-picking. In western Minas Gerais we have estimated that 0.6 to 0.8 cubic meters of gravel can be processed by a single garimpeiro in one day. Placer gold exists in many of these gravels but processing does not recover it unless it is in the form of nuggets, the gold dust is washed away.

The only mechanized operation of any significance is the dredging plant in the Jequitinhonha River downstream from Diamantina. Roughly 450,000 metric tons of gravel are processed each month, with an average recovery of only 1 carat of diamond and 1 gram of gold for each 100 cubic meters of gravel.

The gem percentage varies from region to region, but generally 20% to 40% of the diamonds found are sold for use as gemstones and the others are sold as industrial diamond. Carbonado is common in some areas. Crystals recovered vary in size within statistically well defined limits. Western Minas Gerais is famous for crystals weighing hundreds of carats.

It is easy to visit almost any of the prospects, and the warm welcome of the garimpeiros helps to compensate for the long dusty or muddy dirt trails one must travel to reach them. Generally only diamonds in conglomerate matrix are for sale as specimens, and these should be checked carefully with solvent to be certain the crystals have not been artfully glued on.

MORPHOLOGY AND COLOR

The crystal habit of Brazilian diamonds is by no means constant, varying in stones from different districts. Moreover, crystals from different localities are not equally regular in form; those from the Sincorá region (State of Bahia), for example, are more distorted and misshapen than stones from Minas Gerais or the Salobro district.

Generally speaking the main forms for all localities are: the rhombic dodecahedron and the hexoctahedron (both having rounded faces and often deviating considerably from the ideal form), sometimes associated with the tetrahexahedron (Rio das Garças, Alto Araguaia district, for instance; Freise, 1930). The octahedron, frequently predominant, is also commonly distorted, sometimes appearing in the form of triangular plates (Vargem Bonita, Alto São Francisco, Rio Abaeté, Triângulo Mineiro, border area of Minas Gerais-São Paulo, Gilbués, Piauí, etc.; Oliveira *et al.*, 1984). The predominance of cubic faces is especially characteristic of Brazilian stones. The tetrahedron and other hemihedral forms, especially the hextetrahedron, are found only rarely; twinned rhombic dodecahedrons occur frequently; twinned octahedra are, on the other hand, rare. Irregular intergrowths of diamond crystals are frequently found. Svizero *et al.* (1978) report the following distribution of diamond crystal forms from the Romaria mine (formerly Água Suja, Minas Gerais):

Rhombic dodecahedron	30.2%
Irregular forms (between octahedron and rhombic dodecahedron)	26.0%
Cube	17.0%
Polycrystalline aggregates	13.9%
Octahedron	7.8%
Twins	4.8%
Others	0.3%

In the same way, Leite (1972) reports from the Triângulo Mineiro (western Minas Gerais) the following forms:

Simple	45%	Octahedron	35%
		Cube	2%
		Rhombic dodecahedron	63%
Combined	10%	Transitional = curved faces associated to {111}	78%
		Combination = {111}, {110} and {100} or {111} and {100}	22%
Irregular	12%		
Twinned	33%	Platy	33%
		Crossed cubes	4%
		Irregular	58%
		Multiple 5	

The surface of a rough diamond is either smooth and shining or rough, striated and dull. Rough stones are usually opaque or translucent, however, in some cases they are completely transparent. In the latter case they show a fine play of prismatic colors which is usually only apparent after cutting.

A wider range of crystal forms, many of them no doubt rare, including dodecahedrons and tetrahexahedrons, have been figured by Fersman and Goldschmidt (1911).

Crystals from Bahia fields are smaller, on the average, than those from Minas Gerais and they exhibit more color. Many of the colored crystals cut into white stones, indicating that the color is restricted to the near-surface zone (Cattelle, 1911).

Two years ago at auction the record for the world's most valuable mineral was set, in fact probably the world's most valuable natural unrefined substance (by weight) of any kind. A small, red Brazilian

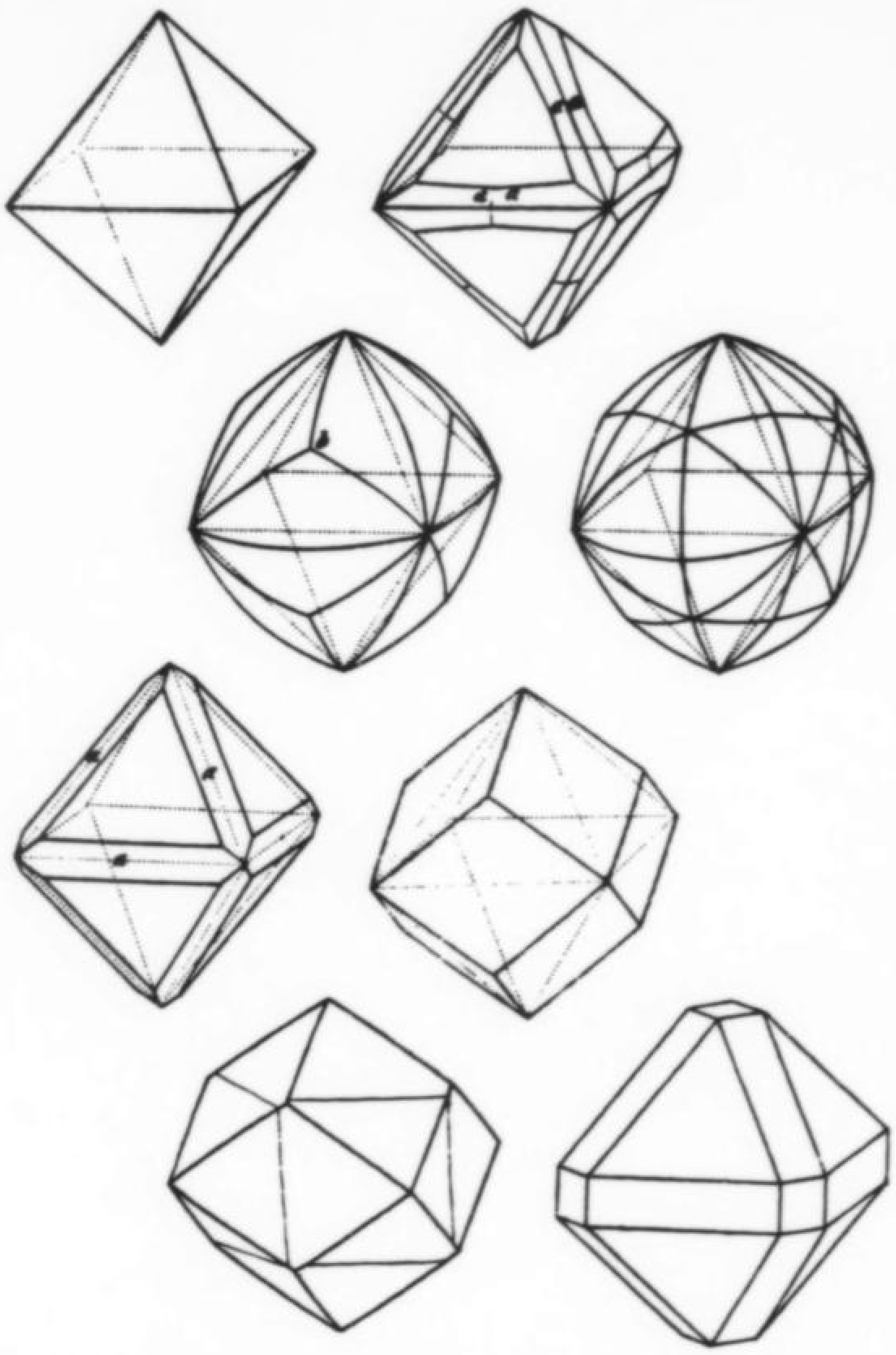

Figure 3. **Crystal habits of Brazilian diamonds (Mawe, 1812).**

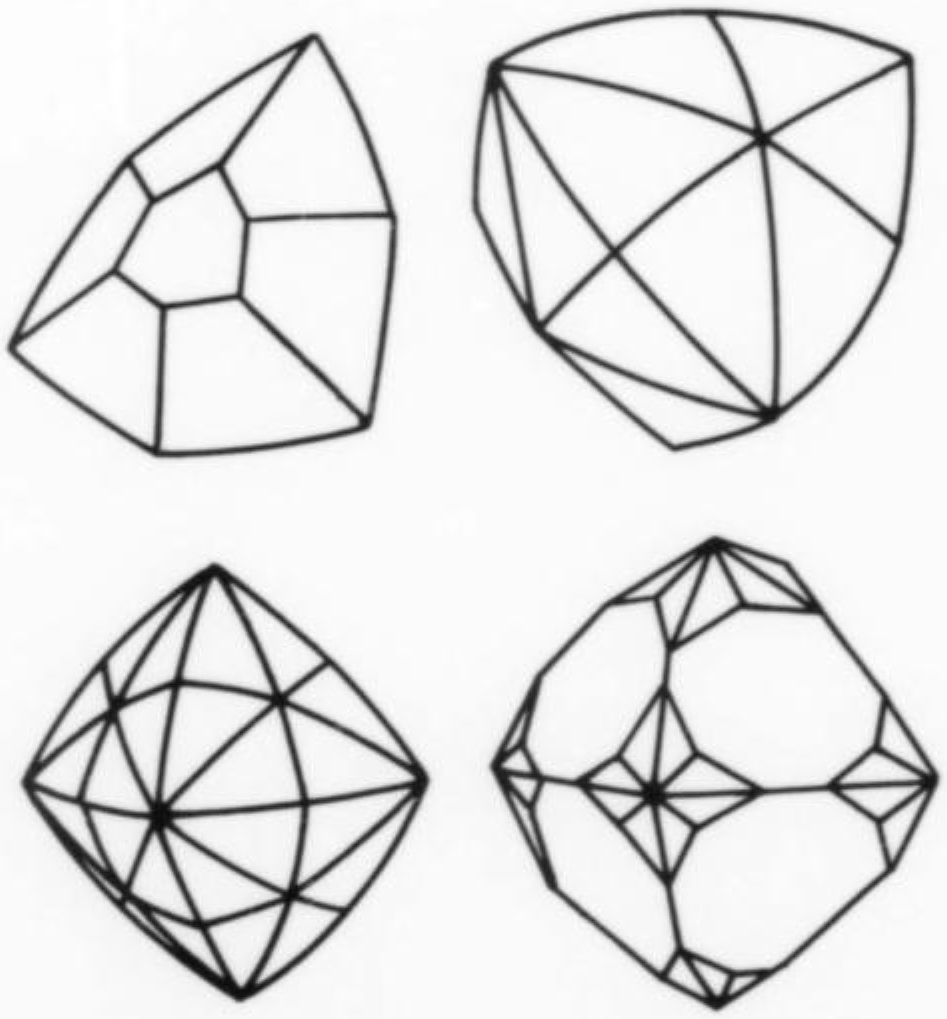

Figure 4. **Crystal habits of Brazilian diamonds (various authors, from Goldschmidt, 1916).**

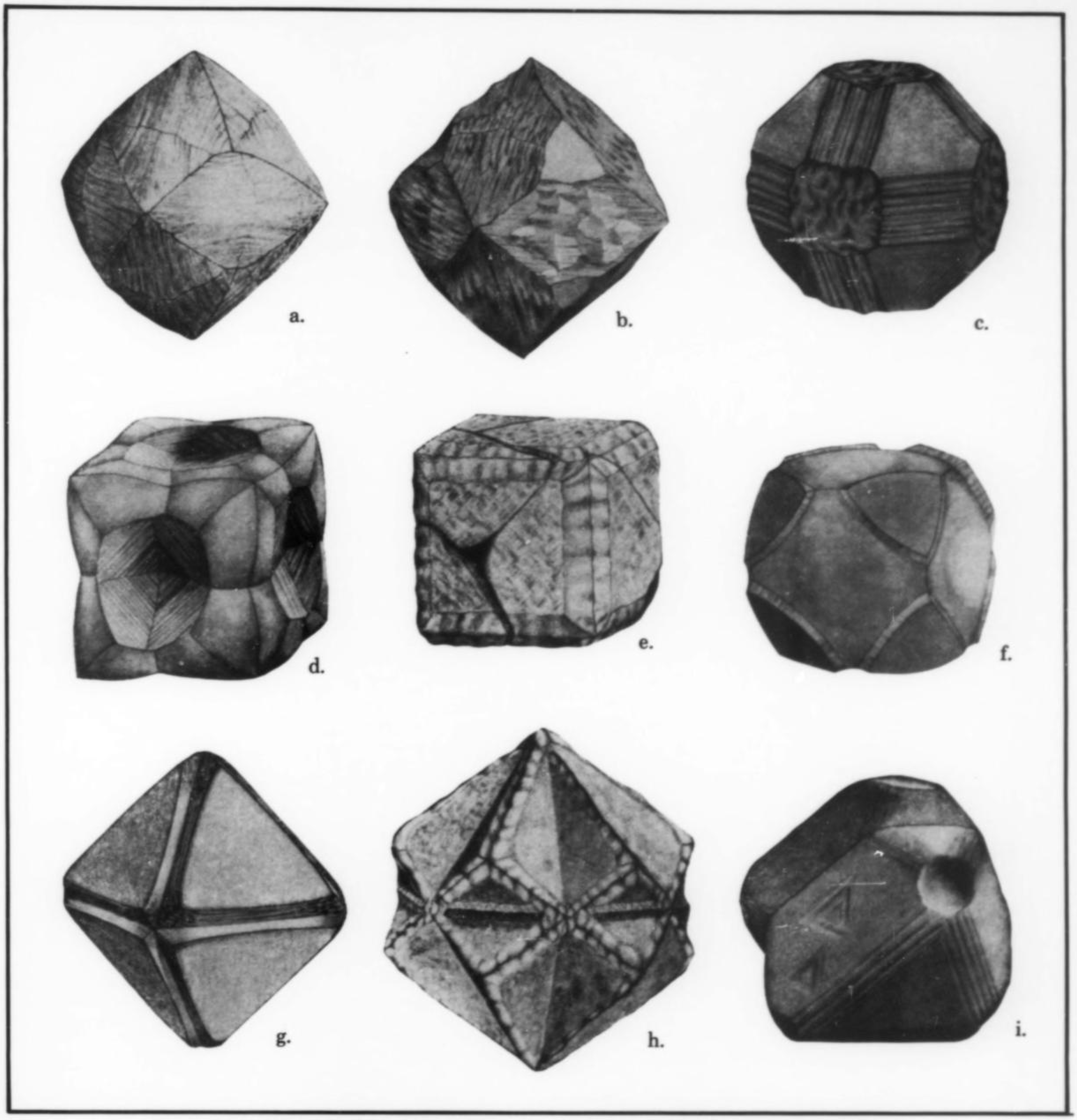

Figure 5. **Brazilian diamonds illustrated by Fersmann and Goldschmidt (1911). (Note: 200 mg = 1 carat.)**

(a) **Dodecahedron or hexoctahedron; 70 mg; from Bahia; transparent yellow-brown; V. Goldschmidt collection.**

(b) **Dodecahedron-octahedron combination; 110 mg; from Diamantina; colorless and transparent; Vienna Natural History Museum collection.**

(c) **Octahedron-cube-dodecahedron combination; 12 mg; from Bahia; transparent brown with a tinge of violet; V. Goldschmidt collection.**

(d) **Complex, hexoctahedral crystal with concave faces; 30 mg; colorless and waterclear; Vienna Natural History Museum collection.**

(e) **Cube-tetrahexahedron combination; 120 mg; from Bahia; pearl-gray and transparent along the edges; V. Goldschmidt collection.**

(f) **Cube-octahedron combination; 10 mg; reddish brown; V. Goldschmidt collection.**

(g) **Octahedral penetration twin; 5 mg; from Bahia; colorless and waterclear; V. Goldschmidt collection.**

(h) **Cubic penetration twin; 35 mg; from Bahia; cloudy, colorless; V. Goldschmidt collection.**

(i) **Octahedron (modified by cube and dodecahedron), spinel-law contact twin; 10 mg; colorless and transparent, greenish on the surface; G. Seligmann collection.**

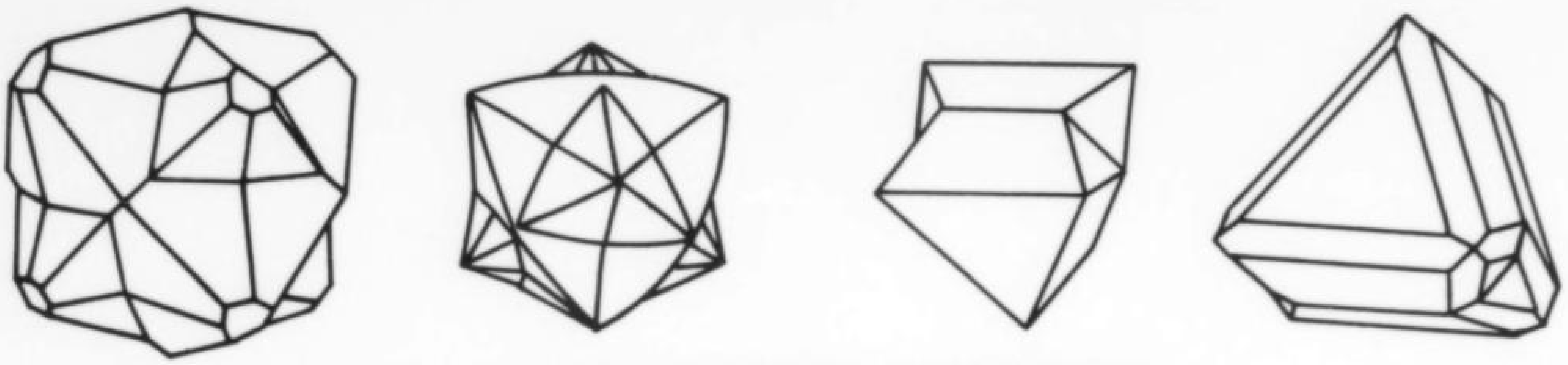

Figure 6. **Crystal habits of twinned Brazilian diamonds (various authors, from Goldschmidt, 1916).**

diamond was sold for $880,000; since it weighs a little less than a carat, this figures out to about $926,000 per carat (or $2.1 billion per pound).

The red diamond and two other smaller stones of similar color were purchased by a Montana collector in the 1950's from a Brazilian cutter who had obtained the rough at various unspecified Brazilian mines. The red color is thought to be the result of structural defects resulting from multiple parallel glide planes caused by plastic deformation of the crystal. Closely spaced planar zones of red and pink color are visible in the diamond under magnification (Kane, 1987).

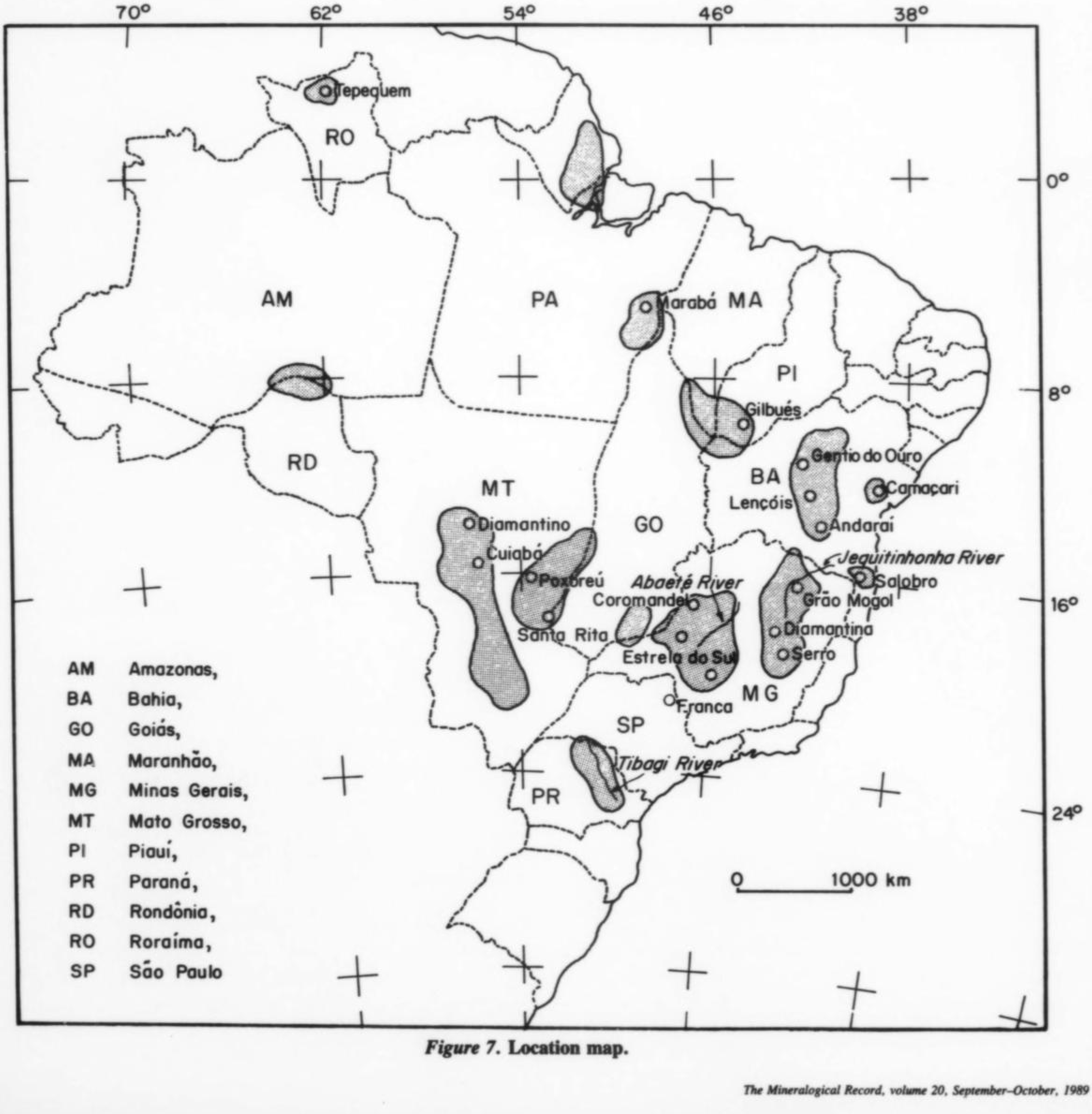

Figure 7. **Location map.**

Figure 8. **Diamond mining ca. 1900 in the bed of the Jequitinhonha River near Diamantina. The river has been diverted through a flume, laying bare the rocky river bed.**

DIAMOND-BEARING AREAS

Diamantina, Minas Gerais

Diamond recovery in the Diamantina region dates back to Brazil's colonial era. Mining camps sprang up, and many still remain today: Diamantina, Gouveia, Datas, Couto de Magalhães, Mandenha and others. The discovery of diamonds had an important influence on Brazilian history during the Colonial era, due to the economic importance diamonds had for the Portuguese government, combined with the wealth of gold being produced in central Minas Gerais, and the sugar cane being grown on the eastern and northeastern coast.

The Diamantina field covers about 10,000 square kilometers, incorporating parts of the Jequitinhonha and São Francisco River basins. Diamonds are found in conglomerates of the Sopa Formation and to a lesser extent in the overlying pelitic and quartzitic sequences, all belonging to the Espinhaço Supergroup (Proterozoic in age). Diamonds are also found in eluvial and alluvial deposits derived from the erosion of these formations.

The first reference to diamonds in the area dates back to 1714, but until 1728 diamond mining was carried out clandestinely. In that year Bernardino da Fonseca Lobo, a Portuguese mine owner (gold mines), discovered diamonds in the Córregos (Creeks) Caeté-Mirim and Morrinhos near the small town of Tijuco (later to be renamed Diamantina). The news of his discovery sparked a rush of 1500 garimpeiros into the area.

By 1729 the magnitude of diamond production forced the Minas Gerais governor to report what was happening to the King of Portugal. Consequently the King prohibited free exploitation in 1731, and established a tax on mining operations based on the number of workers employed in each concession. By 1732 mining had grown to employ 18,000 workers, marking the beginning of opulent prosperity for the region. Smuggling grew rapidly as well, due to the difficulty in controlling the flow of garimpeiros. The Crown levied a heavy tribute

Figure 9. **The Independência diamond, 106.82 carats, found in 1941 on the Tijuco River, Minas Gerais. Present location unknown. (Drawing by Wendell E. Wilson.)**

Figure 10. **Lavra Gil Bertrão, 8 km southwest of Diamantina. Jack Lowell photo.**

requirement, causing an increase in clandestine mining operations and diamond smuggling. The tribute was rescinded, but the former tax was increased eight-fold and later doubled again.

New prospecting and new discoveries led to the formation of the "Intendência dos Diamantes" (Diamond Management), which governed a well defined region surrounding Diamantina. These were difficult times, marked by many arrests, persecutions and smuggling.

In 1739 the King tried a different approach. He issued an ordinance establishing a Royal Monopoly on diamond mining, replacing the Diamond Management. Four-year concession contracts were auctioned off, which permitted the use of up to 6000 slaves and gave broad powers for the suppression of clandestine mining and smuggling. These contracts were overseen by a government magistrate, a superintendent, and the Governor General of Minas Gerais, together with the King's own Inspector General from Portugal.

The first contract was purchased by João Fernandes de Oliveira; it covered an extensive area. He brought in many slaves, bribed the supervising officials, and launched a campaign of predatory mining rife with corruption. He even purchased black-market diamonds found on his own concession, thus encouraging clandestine operations. Ten years later, in 1749, the King finally annulled the contract and sold it to a new operator, Felisberto Caldeira Brandt. But four years later Oliveira had regained the contract and continued his operations until 1771.

The contract system was abolished in 1771 and a number of Draconian measures were instituted as part of the new Royal Extraction regime. All slaves had to be registered, all traders and couriers had to be registered, transit permits good for only 44 to 72 hours were needed to enter the field, and severe punishment (deportation to Angola) was given to clandestine miners and smugglers. A Royal Management was instituted, with Directors in Lisbon controlling the sale of all diamonds.

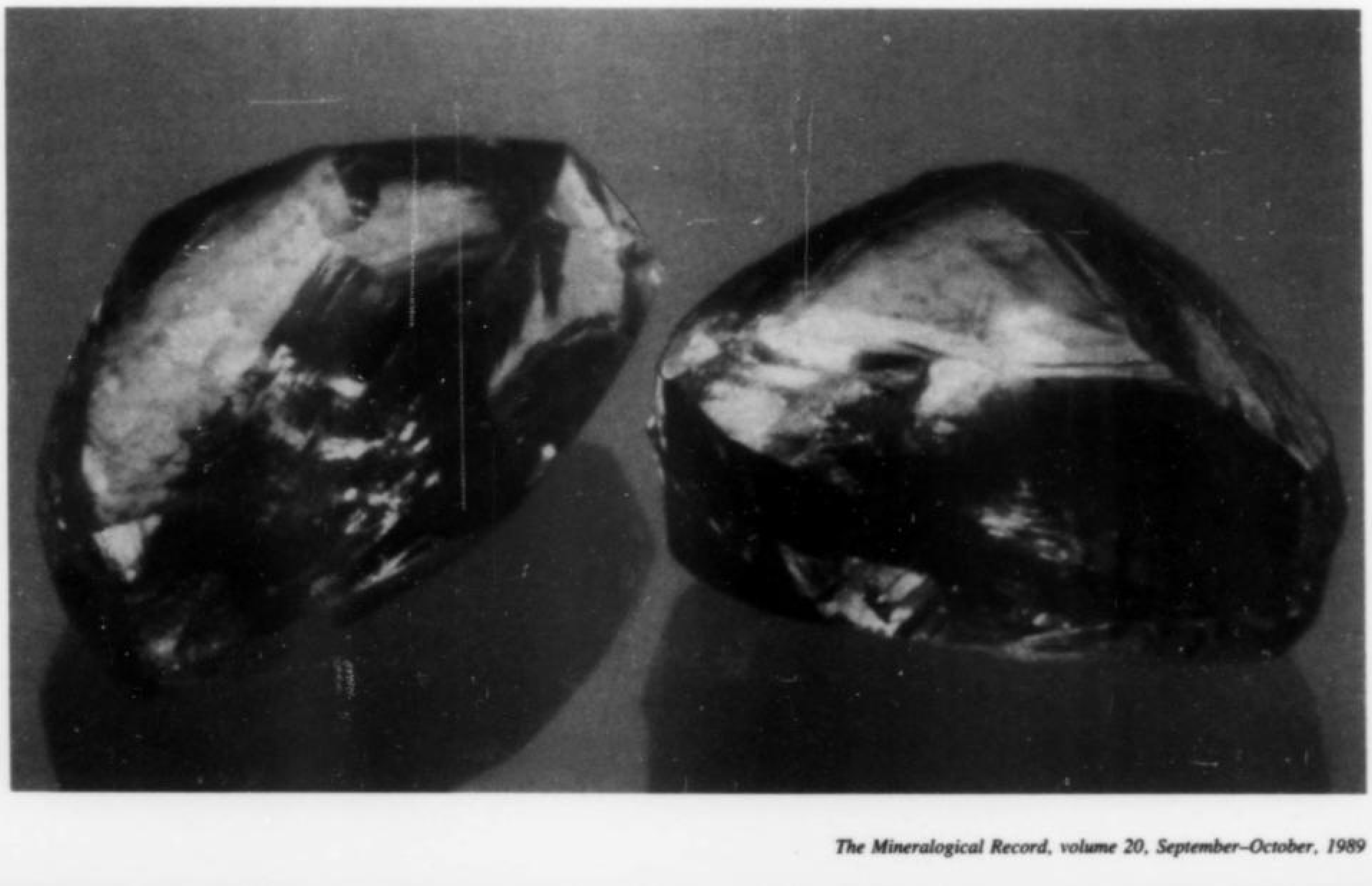

Figure 11. **Diamond crystals to 4 mm, from workings on the Rio Jequitinhonha. Jack Lowell specimens.**

Figure 12. **A 2-carat diamond crystal from Lavra Milton Queiroz on the Jequitinhonha River. Jack Lowell photo.**

Profits and losses alternated during this period and smuggling decreased, but the larger and better diamonds were always sold illegally, frequently by the managers themselves. Many large stones ultimately became part of Portugal's Crown Jewels.

When Brazil gained its independence from Portugal in 1832 the Royal Extraction systems was repealed in favor of the Free Extraction regime for Brazilians. The only exception was the Jequitinhonha River valley, which did not come under the new system until 1845. Brazilian diamond mining prospered under this regime until the South African diamond fields began to offer serious competition around 1870. The law forbidding diamond mining by foreigners was repealed, and an influx of new funds came in from investors abroad; the first major diamond mining company was founded in 1897. Many of the foreign-run enterprises proved to be fraudulent operations designed to swindle investors, and many went bankrupt in a short time.

During the first half of the twentieth century marginal mining took place by garimpeiros and small, short-lived mining companies. Around 1962 a small diamond deposit was found at Grão Mogol, an area first discovered in 1827. Today, in addition to minor activities by garimpeiros, hydraulic mining is under way at São João da Chapada, and also the dredging operation on the Jequitinhonha River.

Chapada Diamantina, Bahia

Diamond mining areas in the state of Bahia are located mainly on the Chapada (high plain) Diamantina, west-southwest from Salvador in the central part of the state. The Itapecuru and Camaçari fields yield only a very small production. Diamonds (including carbonado) are found in the Morro do Chapeú conglomerate, middle Proterozoic in age. They are worked by primitive methods in the thin eluvium, in conglomerate outcrops, in bedrock surface traps, and also in alluvial deposits.

Following the revocation of the government monopoly, a rumor spread in 1839 that someone had discovered diamonds in Tamandua, 11 leagues from Gentio do Ouro, and had called in people to help him. The Santo Inácio diamond field was discovered in 1841 by Alferes José Pereira de Matos, a Portuguese national from Diamantina. Shortly after this, the Chapada Velha diamond deposit was discovered in the Serra da Sincorá, in the Mucugê River in 1844, that overshadowed all the rest.

According to one story, the Mucugê River deposit was discovered by a modest trader named José Pereira do Prado while purchasing flour at small farms near Santa Isabel. He noticed gravels that appeared to be identical to those which yielded diamonds at Gentio do Ouro. After calling in friends to help, he found the first diamond himself while in the company of his godson, Cristiano Nascimento. The discovery remained a secret until one of his companions was arrested in Chapada Velha while attempting to sell some of the diamonds. The authorities believed he must have murdered a diamond dealer in order to come into possession of so many stones, and he was compelled to disclose the origin of the diamonds in order to be released. A diamond rush toward Serra do Sincorá followed immediately. Garimpeiros swarmed into nearby Andaraí, Palmeiras and Lençóis, and more than 30,000 of them pitched tents on the banks of the Mucugê River. Most of the recovery work was done by diving. Some pot-holes gained fame, such as Poço Rico ("rich pot-hole"), which was renamed the Death Pot-hole after six workers were killed there in a brawl. Diamonds recovered were frequently of large size, in hues of pink, green and blue.

Prior to 1871, carbonado had no commercial value. But its price increased greatly with the arrival of the French trader A. Chibaribera, who sought it out. Annual production quickly rose to 60,000 carats and helped the Bahia mines to survive South African competition, unlike other fields in Brazil. A French Vice-Consulate was established in Lençóis, and French was spoken in the bush region. Brazilian traders traveled to Europe to sell diamonds and returned bringing culture and European fashions to the arid high plains. The largest carbonado ever recorded was found at Brejo da Lama sometime between 1895 and 1905; it weighed over 3000 carats (about 1½ pounds). Another, called the Casco de Barro, weighed over 2000 carats.

Production decreased in the first decades of the twentieth century. In Moreno, in the Paraguassu Valley, for example, yield in the late 1920's dropped to 1 carat of carbonado for every 14 cubic meters of gravel, and a carat of gem-grade diamond for every 28 cubic meters of gravel. The world depression finally put an end to diamond mining there, and the region regressed into its old slow-moving pastoral life with only memories of its past splendor.

Diamonds in the Salobro River were discovered by a woodman in 1822, but were mined on only a small scale. By 1883 about a thousand garimpeiros were working a newly discovered area about 12 km from Rio Prado; the region today is abandoned.

Figure 13. **The Presidente Dutra diamond, 409 carats, found along the Dourado River in the Coromandel district of Minas Gerais in 1949. (Drawing by Wendell E. Wilson.)**

Triângulo Mineiro, Minas Gerais

The Triângulo Mineiro (The Miner's Triangle) extends over part of the Parnaíba, Grande and the São Francisco river basins in the far west of the state of Minas Gerais, between the states of Goiás in the north and São Paulo in the south. The gems were discovered in 1728 by diggers who emigrated from the Diamantina area and who had penetrated into the Abaeté forest in spite of the Royal prohibition. The diamond called "Regente de Portugal" was the first large diamond found in 1732 (or 1735) and weighed 215 carats. More than 1000 clandestine garimpeiros were working in the Abaeté Valley in the 1790's, while the western area nearby was subject to intense exploration. Free exploration began in 1842, and the "Estrela do Sul" (Star of the South) diamond of 261.81 carats was found in the nearby Bagagem River. It was a perfect rhombododecahedron. After a very active period, mining began to decline around 1860 and by 1870 was totally abandoned. A small mining company established in the 1900's only operated for 2 or 3 years. Since the first decade of the twentieth century, garimpeiro activity has been irregular, with rushes alternating with almost completely dead periods. During this time, many large diamonds weighing over 100 carats were unearthed (see Table 1), particularly the "Presidente Vargas" diamond weighing 726.6 carats. It was reported that, in 1937, 3000 garimpeiros were working in the Triângulo Mineiro. Nowadays, small mines of which a few are mechanized are in operation (with an approximate ore grade of 0.1 carat per cubic meter). The Água Suja mine uses hydraulicking on a large scale.

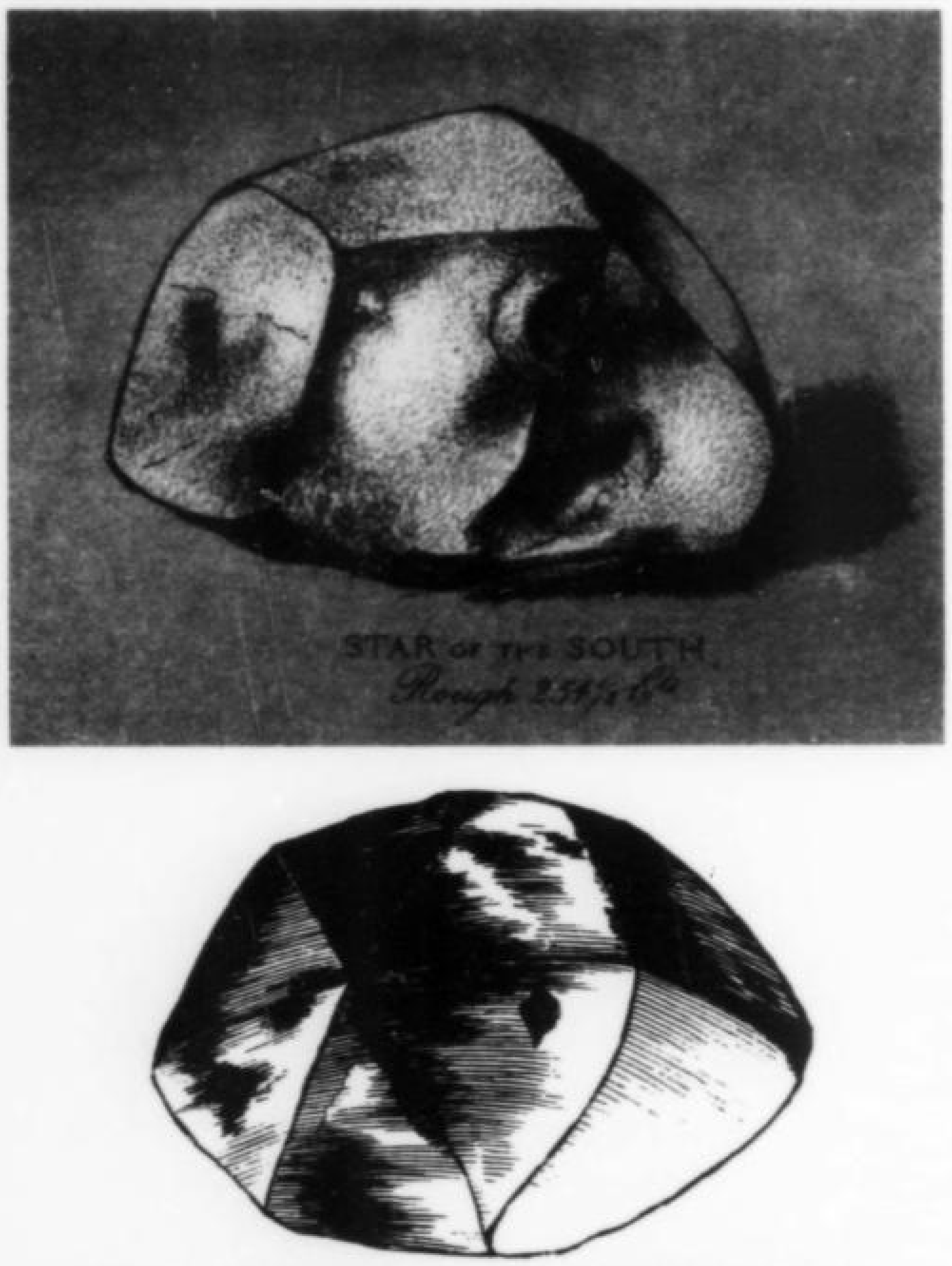

Figure 15. **Two views of the Star of the South diamond, 261.88 carats, found in the Bagagem River, Minas Gerais, in 1853. It measured 2.7 x 3 x 4 cm, and had a somewhat dull luster. The owners exhibited the uncut stone at the Paris Industrial Exhibition of 1855. (*Top:* Emanuel, 1867; *bottom:* Kurr, 1859.)**

Diamonds were discovered in 1937 in the Vargem Bonita area in the proximity of Serra da Canastra, near the sources of the São Francisco River. Three thousand garimpeiros worked in the Fazenda São Bento area, before deserting it in 1942. Around 1967 some research was carried out there but today only small mechanized "garimpos" are active.

The first kimberlite was discovered in 1969 in Vargem Bonita. Many others were subsequently recognized, mainly in the municipality of Coromandel.

Mato Grosso

Prospecting in Mato Grosso during the Colonial period was very light because of the Royal prohibition, as well as the great difficulties of access. After getting off to a good start in the beginning of the nineteenth century, diamond mining there lost its initial momentum due to the search for rubber and came to a complete standstill in the northern part of the state. It picked up again in the early twentieth century, mainly in the southern and central parts of the state where it continues to the present day.

The state of Mato Grosso in the seventeenth century was mainly inhabited by gold prospectors and slavers; diamonds at that time were a byproduct. Cuiabá, the capital, was founded on April 8, 1719, by explorers ("bandeirantes") after defeating the Coxipone Indians who wore gold. The town, formerly known as Vila Real do Bom Jesus de Cuiabá, exported up to 6 metric tons of gold between 1722 and 1726. Later, dredging which operated in 1905–1907 produced 436 carats of diamonds and 58.4 kg of gold, supporting the theory that diamonds were always a byproduct.

The main historical diamond fields in Mato Grosso are as follows:

Diamantino

A diamond field is located near the town of Diamantino, north-northwest of Cuiabá, on the slope of the Parecis high plain; it is there that the first diamonds in Mato Grosso were found. The discovery was made by gold diggers prospecting for new gold occurrences in the Cuiabá area. Gold was found in the Ribeirão do Ouro (Gold Creek) where a hamlet named Paraguai was established in 1728. This hamlet later became the town of Diamantino. Shortly after the discovery of gold, it was observed that diamonds were always associated with this precious metal. This led to the expulsion of the garimpeiros because of the Royal Monopoly regime. New gold discoveries occurred in 1746 in Córrego Grande (the hamlet of Nossa Senhora do Porto), then in the Santana and São Francisco rivers in the years 1747 and 1749. Additional mining was forbidden in obedience to the Royal orders. The result was the appearance of many clandestine workings. After long and tedious complaints, requests and petitions made to the Portuguese Crown, gold mining was authorized in the Paraguai River and its tributaries, such as the São Francisco River, but diamond mining remained forbidden. A period of excitement and wealth followed but was short-lived, ending in 1847 with the decline in gold production. In the year of 1852 the Mato Grosso Mining Society, its modern engines notwithstanding, went bankrupt. The Diamantino prospect was abandoned as a consequence of the discovery of the "Gatinho garimpo," presently known as Alto Paraguai on the margin of the Paraguai River.

Figure 14. **The Mato Grosso diamond, 227 carats, found in Mato Grosso state. Its color is said to be an indefineable brown-rose-violet, showing no inclusions under 5x magnification. Disposition unknown. (Drawing by Wendell E. Wilson.)**

Alto Paraguai

After the ban was lifted on gold mining near Diamantino, prospecting all over the area was intensified leading to the discovery of the Santa Rita–São Pedro (1820) and Rios Brumado-Pari (1821) diamond fields. In 1826 an epidemic depleted the garimpeiro population and was followed by the escape of slaves; the prospect became virtually abandoned until 1940 when some tradesmen began to set up shop in the area, resulting in a revival of diamond mining that continues to the present day.

Arenópolis

Diamonds were probably found at Arenópolis long ago by gold diggers who were looking for a route to the state of Pará along the Amazon River tributaries. Diamonds were rediscovered around 1940 in the Areia River by garimpeiros who came from Alto Paraguai.

Nortelândia

This small diamond field between Arenópolis and Alto Paraguai was found in the beginning of the nineteenth century but was quickly abandoned and forgotten. It was rediscovered in 1937 when farmers settled in the area. The Santana mine gave birth to the town called Nortelândia. Recently, in the neighborhood, Promisa S.A. evaluated 100,000,000 cubic meters of diamond gravel with an average grade of $0.4\ c/m^3$ and a 1.5-meter thickness.

Poxoreú

This town lies 204 km from Ciuabá on the slope of the Planalto dos Guimarães. Around 1924 an old digger named João Arenas, who was friendly with the Bororo Indians, discovered the São Pedro, São Paulo and Pomba River diamond occurrences. Important regional development was accomplished under a vanquished political faction that settled there and proceeded to carry on with mining in the area. Today Poxoreú is an important diamond center, with many small suction dredges.

In the neighborhood, the diamonds from the Chapada dos Guimarães derive from conglomerates of the Cretaceous period. This area was worked mainly in the beginning of the century.

Pará

In 1937 diamonds were discovered in the lower Tocantins River at Itupiranga. Alluvials from the region located between the confluence of the Araguaia and Tocantins rivers and Tucurui, are currently showing a noticeable production, mainly by diggers equipped with diving suits.

Piauí

Production began in Piauí in 1946 near Gilbués. The diamonds found there are generally small, and the actual production is insignificant. But several kimberlites were discovered in the area.

Roraima

The first diamond from Roraima was found near the Maú River in 1912, and was followed by discoveries at Serra do Tijuco (east of Boa Vista) in 1917, the Tacutu River (near the source of Rio Carangueijo) in 1925, Igarapê Suape (near the Venezuela frontier) in 1930 and Tepequém in 1937. For a few years this latter occurrence was the biggest Brazilian producer: 400,000 to 900,000 carats between 1943 and 1965. But it declined from 1965 onward. However at the end of the 1970's production increased again.

São Paulo

Diamond occurrences in São Paulo were found near Franca and São José do Rio Pardo (in the basins of the Canoas, Santa Barbara and São Pedro rivers, all tributaries of the Rio Grande). Present workings are insignificant, notwithstanding several 20 to 70-carat gems found in the past. Franca is a relatively important gemcutting center.

Paraná

Tibagi River basin is the southern-most diamond field in South America. Diamonds were discovered there around 1836 in a high terrace. Prospecting began in 1878. In 1935, 5000 diggers were working when a diamond weighing 100 carats was unearthed. Presently the diamond prospects are abandoned. The gems from this area derive from Devonian sandstone of the Furnas Group and from the Itararé conglomerate, Carboniferous in age.

***Table 1*. Some major diamonds found in Brazil.**

Name	Locality	Year	Weight Uncut (carats)
Presidente Vargas	Santo Antônio River, M.G.	1938	726.60
Goyaz	Verissimo River, M.G.	1906	600.00
Darcy Vargas	Coromandel district, M.G.	1939	460.00
Presidente Dutra	Coromandel district, M.G.	1949	409.00
Coromandel IV	Coromandel district, M.G.	1940	400.65
Diário de Minas Gerais	Santo Antônio River, M.G.	1941	375.10
Vitória	Abaeté River, Tiros, M.G.	1945	375.00
Tiros I	Abaeté River, Tiros, M.G.	1938	354.00
Bahia Black	Bahia	1851	350.00
Vitória	Abaeté River, Tiros, M.G.	1943	328.34
Patos	São Bento River, M.G.	1937	324.00
Star of the South	Bagagem River, M.G.	1853	261.88
Cruzeiro	Coromandel district, M.G.	1942	261.00
Carmo do Paranaíba	Bebedouro River, M.G.	1937	245.00
Abaeté	Abaeté River, Tiros, M.G.	1926	238.00
Mato Grosso	Mato Grosso	1963	227.00
Coromandel III	Coromandel district, M.G.	1936	226.00
Regent of Portugal	Abaete River, M.G.	1732	215.00
João Neto de Campos	Paranaiba River, M.G.	1947	201.00
Tiros II	Abaeté River, Tiros, M.G.	1936	198.00
Tiros III	Abaeté River, Tiros, M.G.	1936	182.00
Coromandel I	Coromandel district, M.G.	1934	180.00
Star of Minas	Bagagem River, M.G.	1910	179.30
Brasilia	Abadias dos Dourados River, M.G.	1944	176.20
Juscelino Kubitschek	Estrela do Sul, M.G.	1954	174.50
Tiros IV	Abaeté River, Tiros, M.G.	1938	172.90
Minas Gerais	Antônio Bonito Creek, M.G.	1937	172.50
Acaete	Brazil	1791	161.50
Coromandel II	Coromandel district, M.G.	1945	141.00
New Star of the South	Abaeté River, Tiros, M.G.	1937	140.00
Dresden Branco	Estrela do Sul, M.G.	1857	120.58
Southern Cross	Abaeté River, Tiros, M.G.	1929	118.00
Jalmeida	Bandeira River, Goiás	1942	109.50
Benedito Valadares	Córrego Coro, Estrela do Sul, M.G.	1940	108.00
Independência	Ituiutuba, Tijuco River, M.G.	1941	106.82
Abadias dos Dourados	Abadias dos Dourados River, M.G.	1940's	104.00

ACKNOWLEDGMENT

Thanks are due to Ellen R. Botler who kindly revised the English manuscript.

Figure 16. **Cross section of an alluvial diamond deposit. From bottom to top: diamond bearing gravel, organic clay, silt and sand (dark and light gray) and colluvium. Manchão da Cruz workings near Barra do Garça (Góias).**

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A VIVIANITE OCCURRENCE IN CONTRA COSTA COUNTY, CALIFORNIA

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INTRODUCTION

Vivianite, $Fe_3(PO_4)\cdot 8H_2O$, was recently identified at a new location in the city of Walnut Creek, Contra Costa County, California. The occurrence is in a newly excavated portion of the San Ramon Bypass Channel currently under construction by the Sacramento District of the U.S. Army Corps of Engineers. The site has since been covered by a concrete-lined channel and is no longer accessible.

Although vivianite has been noted previously in California in San Benito and San Diego Counties (Pemberton, 1983), this new location has yielded what may be the finest specimens of the mineral found in the state.

The author and family, along with amateur mineralogist Jon Gladwell, first visited the site in May of 1987, prompted by an intriguing specimen returned from a site inspection. Preliminary observations by Corps geologists indicated the specimen was vivianite. In addition, Jon Gladwell identified the material in the field as vivianite. The author and son returned to the site in June and August.

GEOLOGY

The vivianite occurs in a marine silty sandstone which, at this location, is striking approximately north and dipping steeply to the east, nearly parallel with the channel. Diblee (1980) indicates that the sandstone is Miocene in age, and Saul (1973) places it in the Upper Miocene San Pablo Group. Here, the sandstone is highly jointed and contains abundant pelecypod molds, casts and imprints and scattered fish imprints. Except for a very minor occurrence on the east side of the channel, most of the vivianite was exposed along 200 meters of the west side of the channel. Therefore, it appears the vivianite formation was limited to a single sandstone bed with an abundant source of phosphorus.

VIVIANITE

Along the 200-meter exposure, the majority of the vivianite occurs relatively abundantly as fracture coatings, along with limonite. The vivianite coatings consist of disc-like radiating clusters of dark bluish black prismatic crystals up to 2.5 cm long. The thicker clusters are only loosely attached to the sandstone, but the thinner clusters are firmly cemented to the fracture surfaces. Some scattered randomly oriented crystals and crystal aggregates were also observed.

A small zone of sandstone 3 to 5 meters long, with abundant open pelecypod molds to 4 cm in diameter, contains scattered rosettes and radiating aggregates of bladed, prismatic crystals of vivianite to 1.5 cm long. The vivianite is a vitreous green to a silky blue, becoming dark blue to bluish black with exposure to light. It was found in approximately one-third of the pelecypod molds. This zone, which yielded a number of fine specimens, was discovered by the author's son and subsequently named J. J.'s Glory Hole.

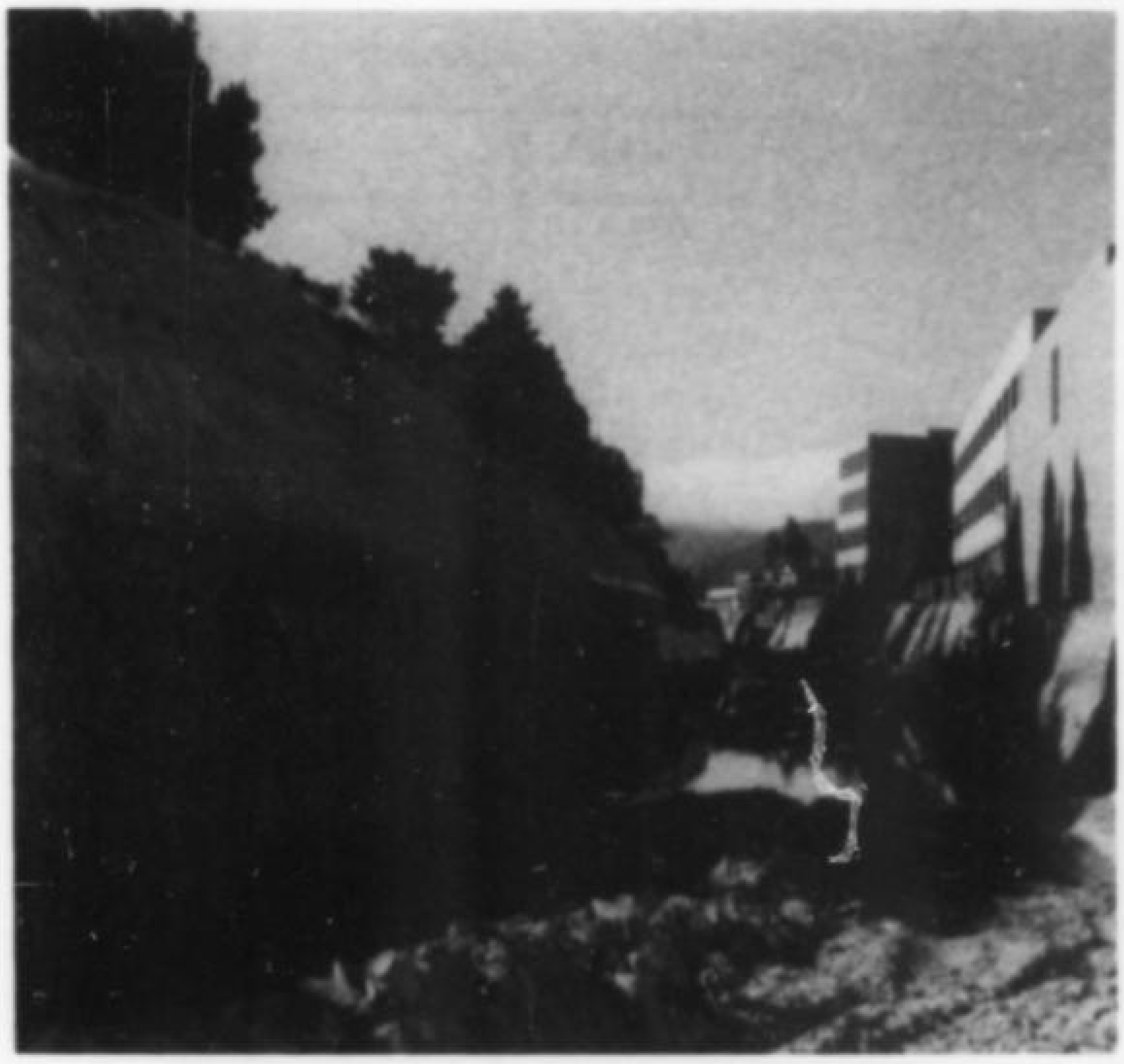

Figure 1. **The San Ramon Bypass Channel under construction.**

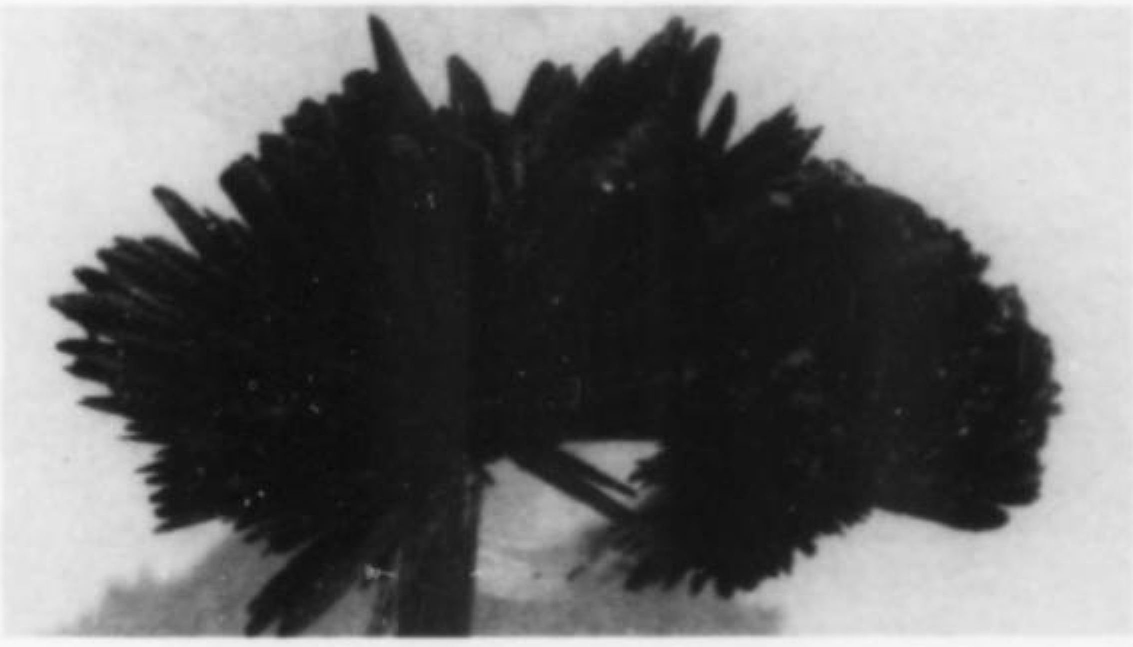

Figure 2. **Vivianite group, 2.5 cm across, dark blue in color.**

Other than the darkening to dark bluish black, the vivianite shows no signs of weathering or alteration, even where exposed for over eight months.

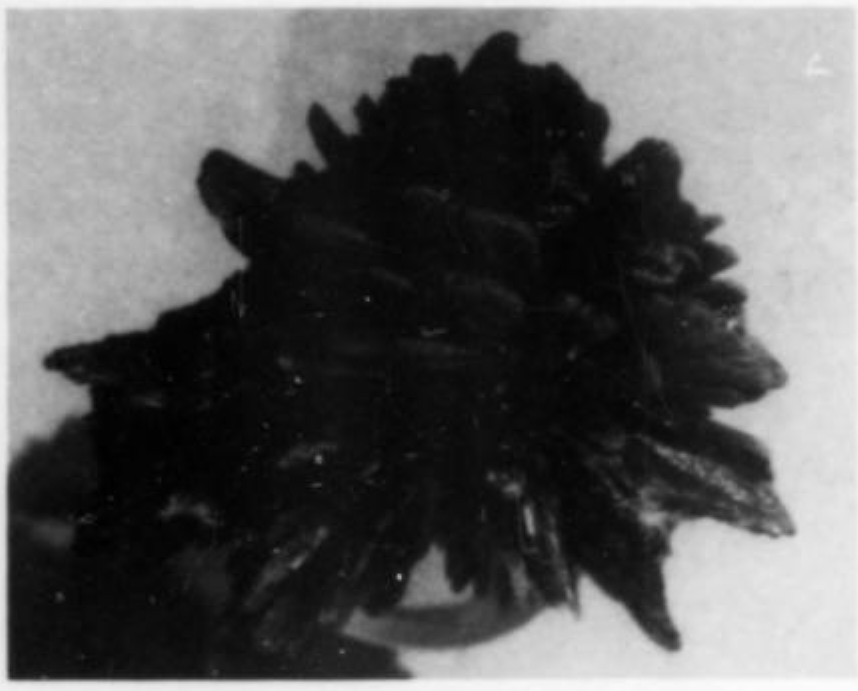

Figure 3. **Vivianite, 1.5-cm crystal group removed from a pelecypod shell mold.**

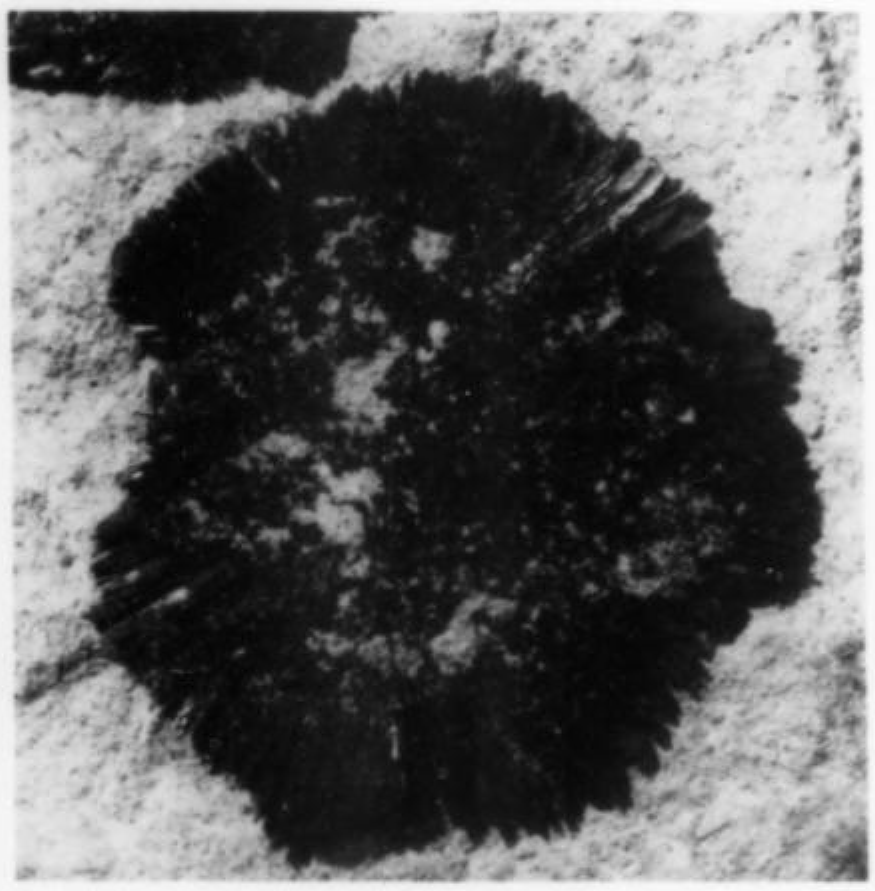

Figure 4. **Vivianite rosette, 3 cm across.**

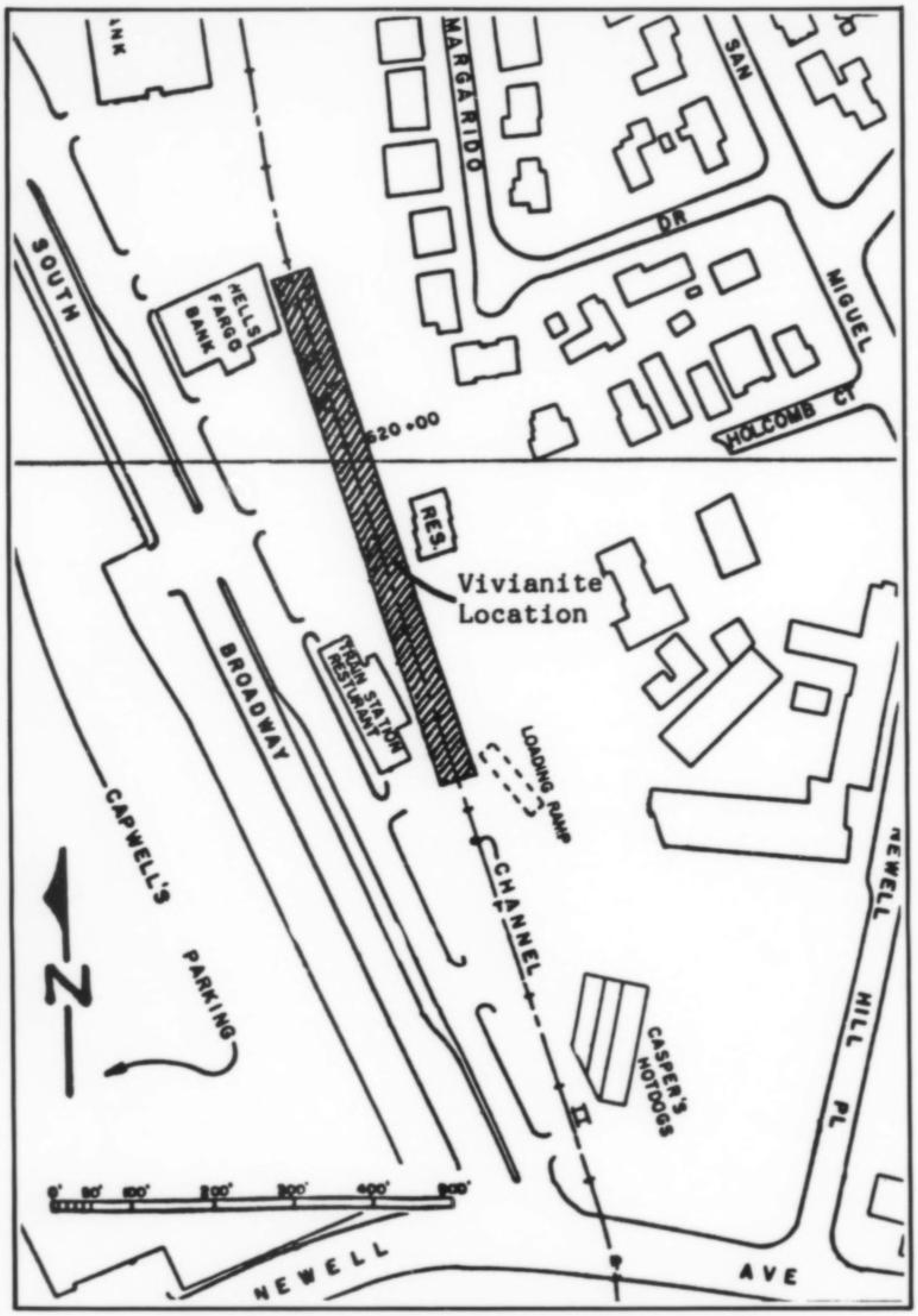

Figure 5. **Map of a portion of the city of Walnut Creek showing the vivianite occurrence in the San Ramon Bypass Channel.**

Specimens of the mineral were taken to California State University, Sacramento (CSUS), for verification. Dr. Greg Wheeler, mineralogist, confirmed that the material is vivianite. Dr. James Post performed X-ray analysis of the material and reported that the measured peaks matched Powder Diffraction File Card 30-662 for vivianite.

No additional associated minerals have yet been recognized, and only the vivianite occurrence described above has been noted. An unidentified mineral which fluoresces a light blue under shortwave ultraviolet light was observed as scattered grains within the sandstone. This mineral appears to be concentrated near the vivianite.

ACKNOWLEDGMENTS

The assistance of George Perry, Project Geologist/Engineer for the San Ramon Bypass Channel Project, is greatly appreciated. Mr. Perry donated his time to make the site accessible and point out the location to the author. The assistance of Dr. Greg Wheeler and Dr. James Post of CSUS was invaluable for definite identification. Thanks are also given to Violet Frazier for the excellent photographs. Finally, gratitude is extended to the U.S. Army Corps of Engineers, Sacramento District, for allowing access to the site as well as providing the base map used for the vivianite location map.

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ESSAY:
MINERALS AND METALS

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I love minerals. Since a boy aged twelve years, I have had an abiding fondness toward them. That means that I have pursued—some say persecuted—minerals for 33 years. During that time, I described over forty species new to scientific intelligence. My favorites include wyllieite, an anhydrous sodium-ferrous-aluminum-phosphate which occurs as large primary crystals in pegmatite; gerstmannite, a basic manganous-magnesium-zincosilicate related to a host of the basic reduced hydrothermal vein minerals at Sterling Hill, New Jersey; macfallite, a basic calcium-manganic^{+3}-silicate from the old manganese ore dumps near Copper Harbor, Michigan, where it occurs in probably ton quantities; and welinite from Långban, Sweden, an anhydrous manganous-manganic^{+4}-oxysilicate and a fundamental building block for several incredibly complex structures. But this work was tedious and not very intellectual. In fact, it proved to be positively dull, except when I collected my own new species (such as wyllieite and macfallite), which had presented to me the challenge of working out their paragenetic settings. I even solved their structures. These were, so to speak, "cradle to grave" studies.

I also love crystals and their structures. Now this activity is also tedious. Much of it is dull and frightfully repetitive. However, the grand intellectual moment would always appear when the structure had to be described. This is a difficult and subtle art. Most structures are forever "lost" on the printed page for want of adequate description. The symmetry groups, the coordination polyhedra and the sheer elegance of the assembled structure shall remain among the most aesthetically pleasing objects in the natural sciences. I was personally involved in deciphering over 120 discrete structure types. Some I "solved" before the final experiment, others took years. Mitridatite and "kakoxen" (= cacoxenite) or the "bad guest," among the most complex mineral structures known, both basic ferric phosphates, took about ten years each. Their elegance is mind-altering. Other monsters, all beautiful (there is no ugly structure!), include steenstrupine, a basic alkali-manganous-ferric-lanthanide-zirconium-thorium-phosphate-silicate, Nature's Empire State Building. Perhaps the most beautiful of all is the recently decoded "superball": ashcroftine. This basic sodium-potassium-calcium-yttrium-carbonate-silicate revealed a core, a gigantic polyanion, by far the largest ever found in a mineral. It contains the radical $[Si_{48}O_{120}]^{-48}$, a huge soccer ball based on the truncated cuboctahedron, an Archimedean semi-regular polyhedron, with 48 vertices, 72 edges and 26 faces. The faces consist of 6 octagons, 8 hexagons and 12 squares. The Si atoms reside at the vertices, 72 oxygens at the midpoints of the edges and the remaining 48 oxygens stick out from the vertices. This glittering orb is itself the basis for several condensed zeolite structures, including cubic paulingite, which has the largest unit cell of any mineral. Wonders like these structures make the blood dance in the veins of even a jaded investigator!

But my passion for structure *per se* eventually waned. For structure analyses, like new species descriptions, tend to be ends in themselves. The link of creativity with imagination is somehow missing, and one soon gets engulfed in all the "high tech" activity which is an equally deadly bore. The reason is simple: there is neither imagination nor creativity—dogged determination perhaps—but not these more noble pursuits. What was missing became obvious to pinpoint. These activities lacked integration, a *holistic* vision into the world. For did not the great father of modern genetics, Sir J. B. S. Haldane, say "Things are interesting insofar as they relate themselves to other things"? So true. So true. What is the meaning of Scientia, after all, if matters of relatedness and connectedness are not sought? What was lacking in all these years of quiet desperation in my life—all the new species, all the new structures—was this unification, this holistic picture! And yet, over the past fifteen years, I attempted timid forays in this direction: graphical enumeration, Pòlya's Fundamental Theorem applied to crystal structures, cluster enumeration and fundamental building blocks, but no unifying picture emerged. Instead, what was offered was a lot of strange mathematics: group theory and combinatory theory, which by themselves rapidly became demons or monsters. Let me go on record here by asserting that group theory is easily the most elegant branch of mathematics for the crystallographer, but still appropriate questions have to be posed. All mathematics, in the absence of an elegantly posed question, is quite useless.

Then a remarkable thing happened. For long, I had stored away thousands of crystal structures in my memory bank. There is this remarkable book, *Crystal Data* by J. D. H. and G. Donnay (1963) which arranges crystalline substances by the crystal systems according to increasing symmetry: triclinic, monoclinic, orthorhombic, hexagonal, tetragonal and cubic; and the axial ratio of each substance in that book is used as an index. The unit cells of most crystals known to that time (thousands) are given, along with a little supplementary information. Even proteins and crystalline viruses are listed separately

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*This essay was originally presented as a banquet address before the Friends of Mineralogy Colorado Pegmatite Symposium in 1986, and has been updated by the author.

at the end. I use this book very often and have worn it out through years of reference. For long—twenty years perhaps—I was intrigued that in the vicinity of certain oxysalt structure types were also listed intermetallic compounds which have similar axial ratios. For example, close to the important glaserite, $K_3NaS_2O_8$, which is trigonal (hexagonal cell) was θ–Ni_2Si, which is hexagonal. Over fifteen years ago, I noted that the ratios of large cations (3K + Na = 4) to sulfur cation (= 2) was the same as Ni:Si or 2:1. This and many others appeared throughout the book. But I didn't take it seriously, so chalked it up to coincidence. At that time, there was no theory to explain relationships between such disparate compounds, if any relationship existed at all.

Glaserite is an anhydrous alkali sulfate, a true oxysalt. According to G. N. Lewis, Linus Pauling and many others, it adheres to all the classic rules of chemical bonding for ionic crystals. Now, nickel silicide is a quite different animal. Glaserite is colorless, glassy and easily soluble in water. Nickel silicide is brittle, metallic and virtually insoluble in water. No greater contrast can be imagined. Besides, there is no anion as such, which can be identified with the silicide. At best, we can say that silicon is the more electronegative atom. But it is nowhere near oxygen which is among the most electronegative of elements, the most electronegative element of all being fluorine. In fact, neither fluorine nor oxygen occur as metallic ions or cations in crystals. These elements are greedy, and grab onto electrons to complete their electronic Lewis octet. Oxygen needs two electrons and fluorine needs one electron to complete their octets. Elements with already complete octets are the inert gases such as neon, argon and so on. They are quite unreactive as a result. Generally, as we proceed down a column in the Periodic System, the elements become increasingly metallic and decreasingly electronegative. Briefly, anions have a surfeit of electrons required to complete their octet, so are negatively charged. Cations are missing some or all of their valence electrons so are positively charged.

Now, molecular orbital theory promises to put so many descriptors on a more quantitative basis, and my colleague Professor Gerry Gibbs at Virginia Polytechnic is a leader in this field and he also loves minerals. I predict that M.O. theory will replace traditional crystallography. But this does not mean the end of established sciences. The classification of the *Crystal Classes*—the 32 point groups—was completed in the 1860's, and the 230 space groups were completed in the 1880's. But this did not detract the great Charles Palache from drawing crystal surfaces. And he didn't bother to learn about X-ray diffraction. For him, as perhaps for me, he identified science with art. And as Oscar Wilde said, "All art is quite useless."

If we look at Column Six of the Periodic System, we find oxygen, sulfur, selenium, tellurium. The first is a gas at standard conditions, sulfur occurs as several polymorphs, all solid. It readily combines with oxygen, burns easily to form the gaseous acrid oxides of sulfur. Selenium and tellurium are more metallic in appearance and melt at higher temperatures. They are weak conductors of electricity. In fact, they constitute the so-called semiconductors which along with silicon make up much of the semiconductor industry. Greedy oxygen does not like to have electrons stripped away. But the others are something else. Sulfur can lose electrons to oxygen. These electrons belong to what are called valence electrons. Sulfur's valence electrons can be lost, but the energy required increases substantially just before the last two valence electrons are lost. These last two valence electrons, called the ns^2 (n = row in Periodic Table) electrons, are inert and do not bond to the other atoms. For this reason, they are called the inert pair or lone pair of electrons.

Lone pairs of electrons on cations open up a wonderful almost unending chemistry. I have observed that all cations with lone pairs are precisely what we call the heavy metal poisons. Lone pair cations and molecules are notorious chemical carcinogens. Here are some examples: N^{+3} is an essential constituent of some three thousand known alkaloids such as nicotine, caffeine, strychnine, physostigmine, atropine, codeine, cocaine, yohimbine, mescaline, LSD. All are phrenotropes (mind-benders), all are addictive, all are carcinogenic. But so are Hg°, Tl^{+1}, Pb^{+2}, Bi^{+3}, Sb^{+3}, As^{+3}. Some of these are addictive (*e.g.*, the arsenic eaters). All these valence states involve cations with lone pairs. Another example is S^{+4}, Se^{+4}, Te^{+4}. S^{+4} as sulfite contributes to the stench around pulp mills. But mental derangement and deterioration are shared by the key heavy metal poisons as well as the alkaloids. In the past, a person who put sheen on felt hats with mercury often became 'mad as a hatter.' A whole book was recently written on lead and the effects of plumbism on the decline of the Roman Empire.

But I digress. Valence electrons and lone pairs are of tantamount importance in understanding mineralogic chemical crystallography. If all valence electrons are stripped away, as in the fully oxidized state such as S^{+6}, the sulfate group is formed with oxygens. We say the ion is fully oxidized because all that remains are bond pairs between cation (S^{+6}) and anions (O^{-2}) in the crystal. There are no lone pairs remaining. The classic Goldschmidt-Pauling rules hold for these crystals and their geometrical properties—bond distances and angles—can be directly correlated to the structure with simple rules. Most oxysalts involve bond pairs only. Exceptions are found for heavy metal ions like Tl^{+1}, Pb^{+2}, Bi^{+3}, Sb^{+3}, As^{+3}. In fact, most sulfosalts involve cations with lone pairs, because sulfosalts form in reduced environments to begin with.

What of intermetallic phases where there are no anions as such? Take θ–Ni_2Si for example. Or α–Cu_3As (domeykite) and its dimorph β–Cu_3As (metadomeykite). What holds them together? These are not garden variety simple structures. What one observes is a *large* number of bond distances from one atomic position to its neighbors. For example, in α–Cu_3As there are twelve bonds to one arsenic atom by copper atoms. Connecting the copper atoms together to form a coordination polyhedron about the arsenic, we see a distorted icosahedron. About the copper atom, there is a curious coordination: six other copper atoms form a trigonal prism and three arsenic atoms in a plane, create all together, a tricapped trigonal prism. What a mess! It contravenes our notion of simple tetrahedral, octahedral and cubic coordination so often found in oxysalts, where oxygen defines the vertices.

Now, domeykite is body-centered cubic. Its cell is smaller than another body-centered cubic crystal, garnet. Here is the shocker. If one takes *all* the atoms (48 Cu and 16 As) in the domeykite cell, they closely match the cation positions of garnet! The pyrope, $8Mg_3Al_2Si_3O_{12}$, cell has 24 Mg and 24 Si which map on 48 Cu; and 16 Al which maps on the 16 As. All atomic positions are within 0.6 Å if referred to the bigger pyrope cell. Now 0.6 Å is a relatively small distance deviation: the effective ionic radius of the O^{-2} anion is 1.4 Å! What about metadomeykite? The crystal is hexagonal and I discovered a related hexagonal oxysalt crystal which for every cation position is within 0.6 Å deviation. This is the hard, anhydrous, ruby red painite from the gem ruby fields at Mogok, Burma. This incredible structure is related to the geochemically important fluoborite, a magnesium borate fluoride; the hydroxide analog of fluoborite; and jeremejevite, a basic aluminum borate. Both metadomeykite and painite structures are known. They are related: $CuCuCuCu_3As_3Cu_3$ (metadomeykite): $CaZrBAl_3Al_3Al_3(O_{18})$ (painite).

Since these early discoveries, I found many others. Steenstrupine, $[Na_2Mn_2Fe_2PZr(OH)_2][Na_{12}RE_6P_6Si_{12}]O_{64}$ is a glamorized stuffed high quartz, SiO_2. There is a 36:1 correspondence between steenstrupine and quartz. Quartz, by the way, can be directly related to γ–Se semimetal. The lone pairs attached to Se map out the O^{-2} anionic positions in quartz. But the most outrageous example is fillowite, $18Na_2Ca\square_2Mn_7P_6O_{24}$, which is a self-similar (fractal) replicate of glaserite, $K_3NaS_2O_8$, which in turn directly relates in cation positions to θ–Ni_2Si which in turn can be derived from α–Fe—good old iron metal! The fillowite: θ–Ni_2Si correspondence is 54:1! And all these metal/cation mappings from one structure to the other are within 0.6 Å when

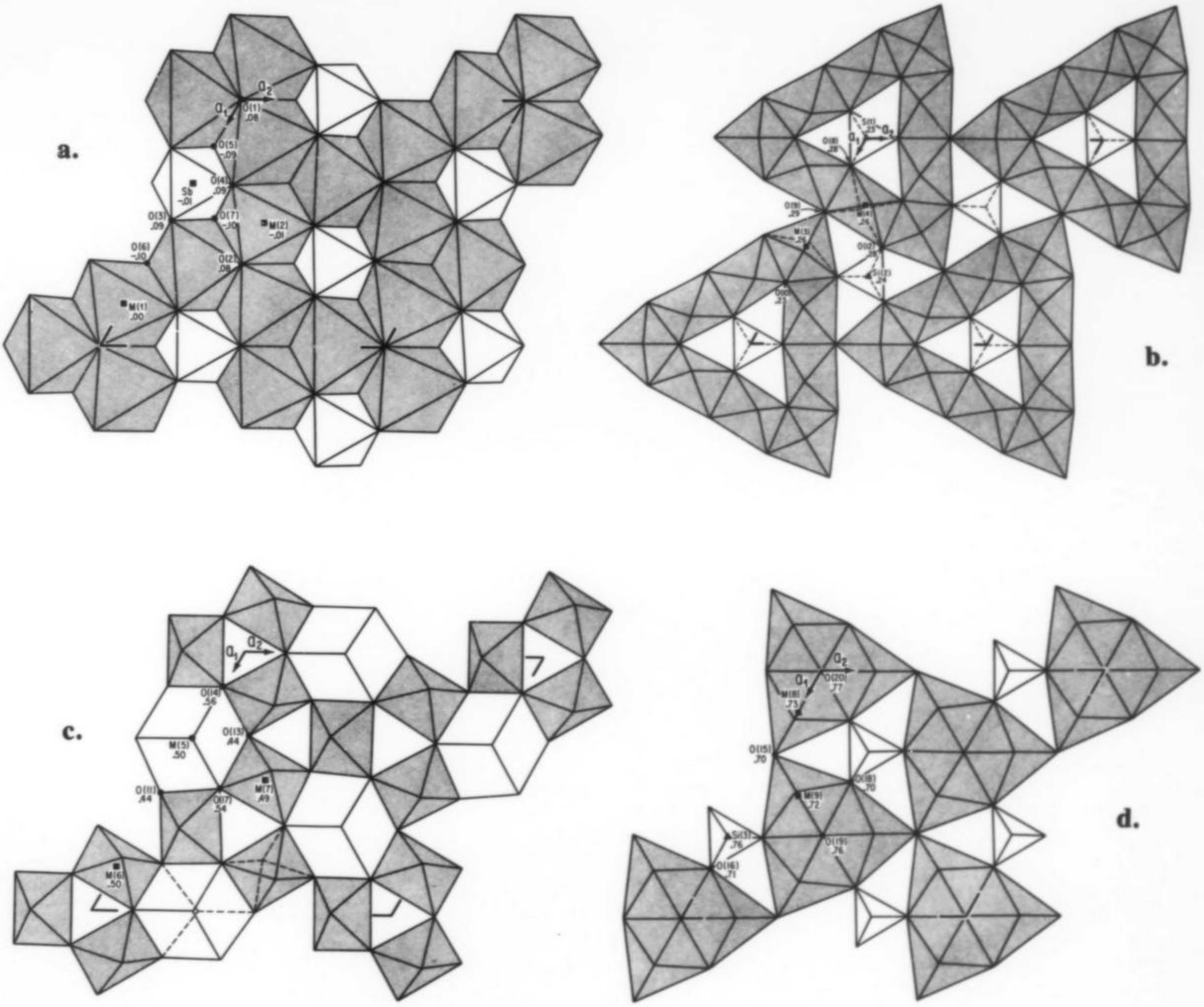

Figure 1. **The four layers of långbanite.**
(*a.*) The långbanite sheet at $z = 0$. Heights in fractional coordinates along the *c*-axis and unique atoms are labelled in this and in the other three projections. The unit cell outline, a_1 and a_2 in the plane, is shown. If the centers of stippled octahedra are connected to each other, the Kagomé {6.3.6.3} "Star of David" design results. The cation formula for this layer is $Mn_9^{+2}Sb_3^{+5}$. It is the basis of spinel along [111] with $2MgO_4$ tetrahedra instead of SbO_6 octahedra, and a host of other derived structures.
(*b.*) The långbanite sheet at $z = 1/4$. This $Mn_9^{+3}Si_3^{+4}$ sheet is closely related to the $Mn_9^{+3}P_3^{+5}O_{12}(PO_4)_6$ sheet in robertsite-mitridatite. It also occurs in schairerite, $Na_{21}(SO_4)_7F_6Cl$.
(*c.*) The långbanite sheet at $z = 1/2$. This $Mn_9^{+3}(Mn,Ca)_3^{+2}$ sheet forms the basis of the fundamental sheet in the pyrochlore (atopite) minerals along [111]. The $^{2}_{\infty}[Mn_9O_{36}]$ stippled sheet is found in the large clan of jarosite-crandallite related species. The $(Mn,Ca)O_8$ cube can accommodate other large cations such as Y^{+3} (yttrium). Connecting centers of the stippled octahedra together also results in the Kagomé "Star of David" design.
(*d.*) The långbanite sheet at $z = 3/4$. This $Mn_9^{+3}Si_3^{+4}$ sheet is an extreme example of octahedral distortion: three octahedra share three edges and one oxide anion—all nearly in a plane! Such a cluster would be neither predicted nor explained on traditional chemical crystallographic grounds. Yet the sheet is the basis of the most important cement and concrete phase: alite, $Ca_3O(SiO_4) \equiv Ca_9O_3Si_3O_{12}$. Similar sheets also occur in schairerite. How these structures—långbanite, schairerite and alite—arise is one of the marvels of contemporary chemical crystallography. From the four sheets, the fundamental building blocks of many mineral structures can be derived. In this case, långbanite is a mineralogical "Rosetta Stone."

referred to the fillowite cell!

Cations in the mitridatite sheet map onto (FeP) in the hexagonal phase Fe_2P. It possesses a 9:1 correspondence. Presently, including O'Keeffe and Hyde's work (1985), some important mineral structure types have been mapped onto intermetallic phases: feldspars (CrB_4), olivine (Ni_2In), the humites (assorted borides), wyllieite (schreibersite, a phosphide). And there are many others.

Perhaps the most florid example found thus far involves the incredibly complex crystal structure of långbanite, $Mn_4^{+2}Mn_9^{+3}Sb^{+5}Si_2^{+4}O_{24}$, a polar and trigonal mineral. This was not included in my 1986 address. Basically it consists of four independent polyhedral sheets. One sheet corresponds to a slab of spinel along [111]; the second to the Mn^{+3} oxyphosphate sheet in robertsite-mitridatite (which nobody seemed to believe when it was published!) as well as one of the seven independent sheets in schairerite, $Na_{21}S_7O_{28}F_6Cl$. The third långbanite sheet is pyrochlore (or atopite) down [111] and also serves as the basis of the "hexagonal tungsten bronze" structure and myriads of species derived from jarosite-alunite: crandallite, hamlinite, gorceixite, etc. The fourth sheet is the basis of the most important cement and concrete phase: alite, Ca_3OSiO_4! The above alone would place långbanite as one of the most encompassing and gregarious of mineral structures. Yet if all 13 non-equivalent cations in the asymmetric unit of structure are projected along the *c*-axis, they collectively define an almost perfect "topaz close-packing" or "double hexagonal close-packing" . . . ch . . . , the centers which define within 0.3 Å the atom positions of the actinides americium, curium and californium! Incidentally, I noted a curious axial ratio between långbanite and americium over fifteen years ago, and it is gratifying to realize why such a "curious" relationship existed.

Is this a coincidence? If it is, then we are in the paradoxical situation to declare that Nature's dice are loaded. Mike O'Keeffe and Bruce Hyde, both chemical crystallographers, in that aforementioned monumental paper which appeared several months back, doubted it. In that paper, they list at least fifty intermetallic structure types which map on reasonably well to the cations of mineral structures and other anhydrous inorganic oxysalt structures. I have been capitalizing on O'Keeffe and Hyde's paper, and have been finding anhydrous oxysalt mineral structures—some very strange, like $CdSb_2O_6$—whose cations map on aluminum boride, AlB_2 intermetallic. Probably the majority of anhydrous oxysalt minerals will follow this route.

I find all this terribly exciting. We could call the intermetallics the parent structures or the *aristotypes*. We could call the oxysalts *derivative structures* or *stuffed* versions of the intermetallics. And we could introduce scissors and selectively snip sheets or chains, slabs or clusters of aristotypes to form the basic hydrated oxysalts, the bulk of the mineral kingdom as we know it. These would be called *fundamental building blocks*, or units which repeat, with little change, from structure-to-structure.

But this path is equally petrous. In many cases, there are small deviations—up to 0.6 Å—between intermetallic and oxysalt. Can we exploit the valence electrons of the intermetallic aristotype and compare them with the loci of the oxygen octets in the derivative oxysalt? Is there any predictability between species of intermetallics and species of derivative oxysalt? So far, I (and presumably the others) have failed to find any "rule" to selectively sort derivatives from aristotypes. The only logic which presently works involves recall of structural similarity and more important, axial ratios. Can we predict the distortions which occur between intermetallic atoms and oxysalt cations? I think we can probe these questions through one simple example: [P_4] (white phosphorus) → [P_4O_6] (phosphorous oxide) → [P_4O_{10}] (phosphoric oxide). The geometrical relations among this series makes one giddy!

So, here is my entry into another new and uncertain world. My faith follows the maxim of Nietzsche: "Alle Wahrheit ist einfach. Ist dass nicht zweifach eine Lüge?" ["All truth is simple. Is that not doubly a lie?"] So why pursue another struggle? I suppose here I could again quote Oscar Wilde, that great master of wit and observation: "By the movement of an atom, a whole universe may be shaken." The measure of the human mind is motivation. Without motivation, life reduces to existential meaninglessness. My only consolation is that such pursuit into an uncertain world is the stuff of scientific creativity. To shirk it is cowardice, and existential inauthenticity. To embrace it may lead one to the most beautiful of understandings: how things are related to each other.

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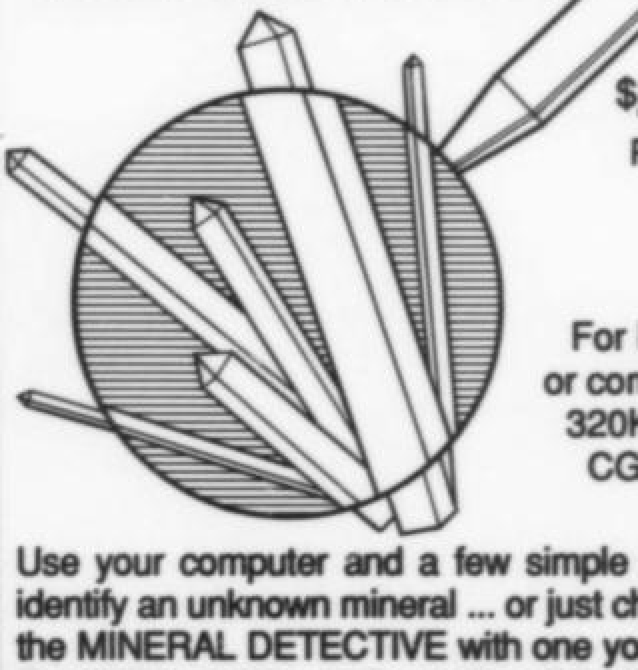

PHOSPHATE MINERALS FROM THE LEVEÄNIEMI IRON MINE SVAPPAVAARA, SWEDEN

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During 1985–1987 an interesting suite of rare phosphate minerals was found at the Leveäniemi iron mine in northern Sweden. The zone now appears to be exhausted, but many fine specimens were recovered by local collectors.

INTRODUCTION

The Leveäniemi iron mine is located about 40 km east-southeast of Kiruna in Norrbotten, Sweden's northernmost district. Norrbotten contains 86% of Sweden's iron ore reserves, much of it high in phosphorus which, along with the difficult access, has delayed exploitation.

In July of 1985 the author was contacted by Dennis Holmberg, a fellow collector, who reported finding strange-looking minerals on the iron ore dumps of the Leveäniemi mine. The following weekend we visited the site and found a treasure trove of iron and aluminum phosphate minerals. Since that time we have been working the area regularly and have collected a large number of outstanding specimens. Other collectors learned of the occurrence and have also had good success collecting there. Today relatively little remains, after three years of intensive collecting.

HISTORY

Iron deposits have been known for centuries in Norrbotten. The Junosuando orebody was discovered in 1644, and the famous deposits at Kiruna in 1736. Much early prospecting was carried out with the aid of the mine compass. Modern airborne magnetic surveys have helped to locate a few more deposits, but for the most part have only served to demonstrate how thorough and efficient the early prospectors were at locating magnetic orebodies with a simple hand-held device.

Modern mining began in 1886 with the completion of a railway from Luleå to Gällivare, allowing large-scale exploitation of Malmberget (= "Ore Mountain" or "Erzgebirge"). The railway extended from Kiruna to the shipping port of Narvik, Norway. The huge Kirunavaara orebody came into production in 1901, and the nearby Tuollavaara deposit shortly thereafter. No other operations were initiated in the area until 1964, when the Leveäniemi deposit was opened by the LKAB Company.

During its first decade, the Leveäniemi mine produced over 34 million metric tons of apatite-bearing iron ore averaging 50% iron and 0.6% phosphorous (Grip, 1978). Eventually, however, mining became uneconomical and today the workings are dormant.

GEOLOGY

A thick layer of glacial till overlies most of the district, and exposures of bedrock are few. Much geological mapping has been carried out with the aid of sophisticated geophysical surveys capable of distinguishing not only iron orebodies but a wide variety of rock types on the basis of their magnetite, pyrrhotite and graphite contents.

The greater part of Norrbotten consists of Precambrian rocks in a few places partially covered by overthrust Caledonian rocks. Almost all of the ores are related to supracrustal rocks including various volcanics and greenstones, schists, conglomerates, porphyries, quartzites, granites and granodiorites (Grip, 1978).

***Figure 1.* Location map.**

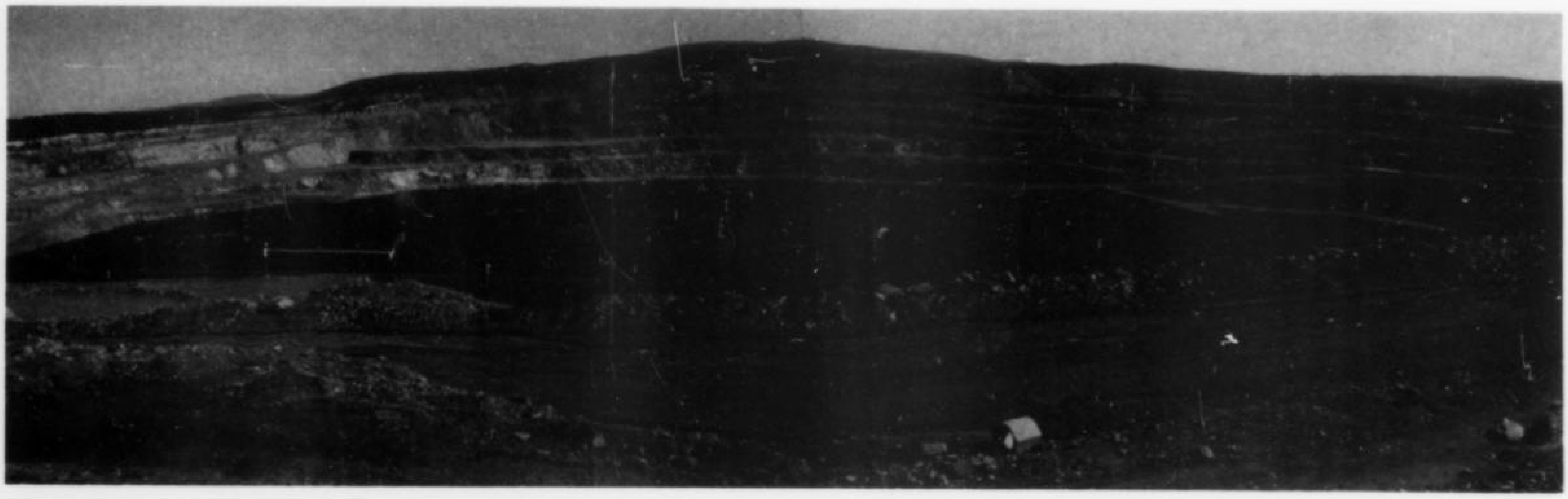

Figure 2. **A view of the Leveäniemi open pit. Photo by Åke Hedman.**

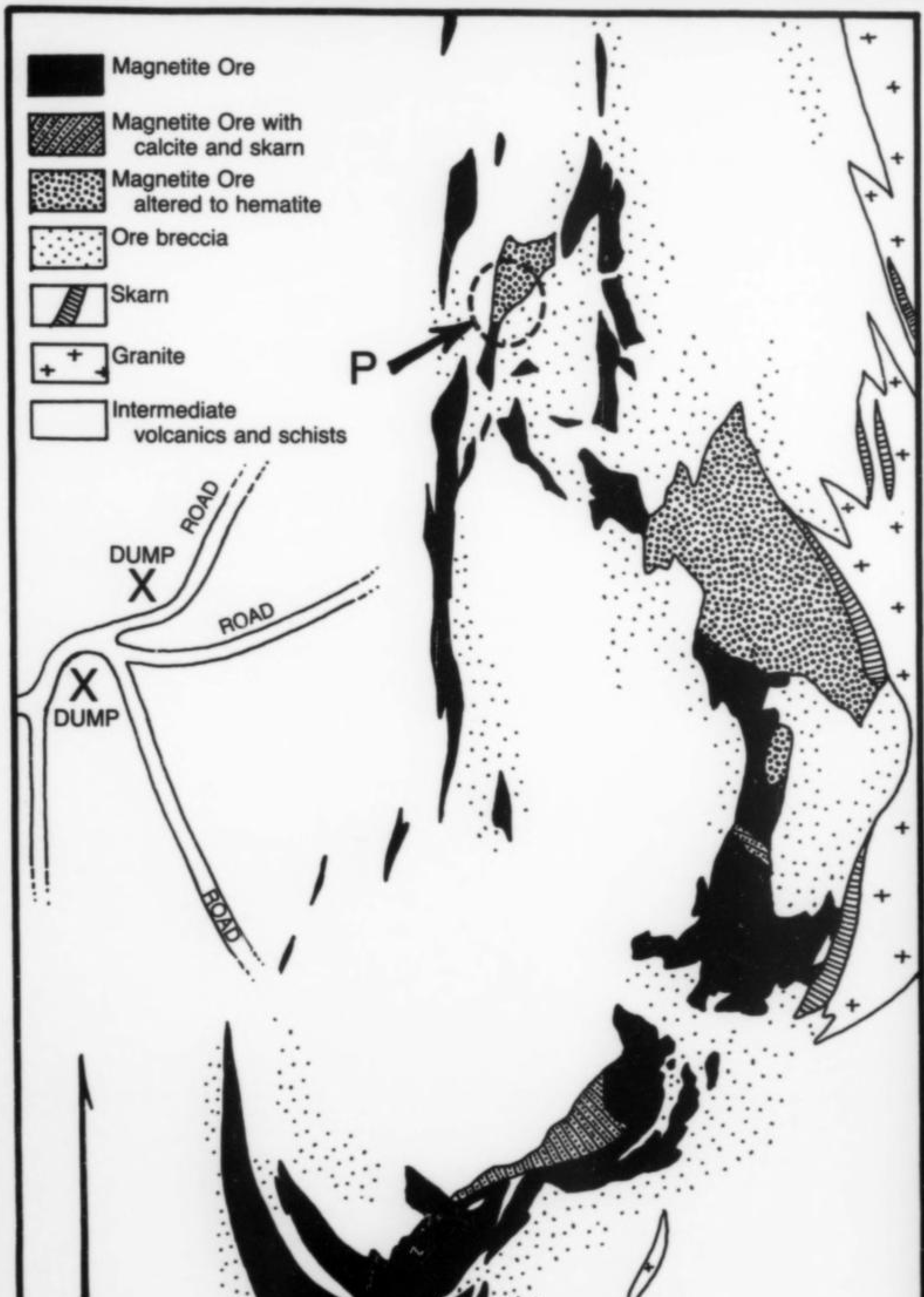

Figure 3. **Geology of the Leveäniemi orebody, modified after Parak in Grip and Frietsch (1973). Dump areas marked "x" contain phosphates. The original phosphate occurrence in the mine (according to miners) was located at "P" and is now underwater.**

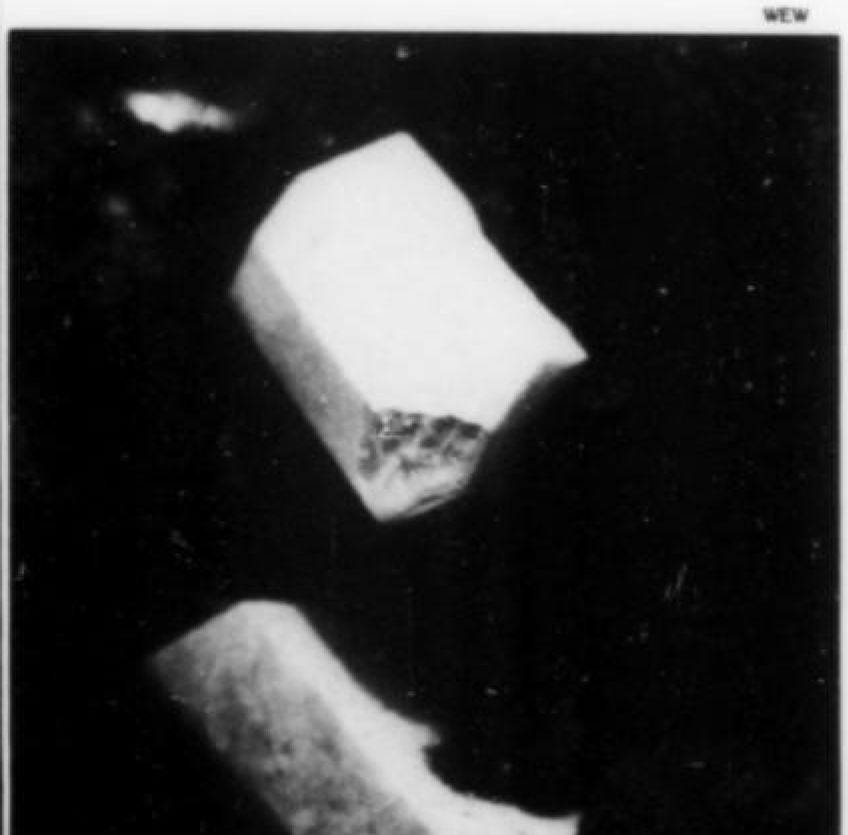

Figure 4. **Blocky, cream-colored crystals of fluellite to 3 mm. Bjällerud collection.**

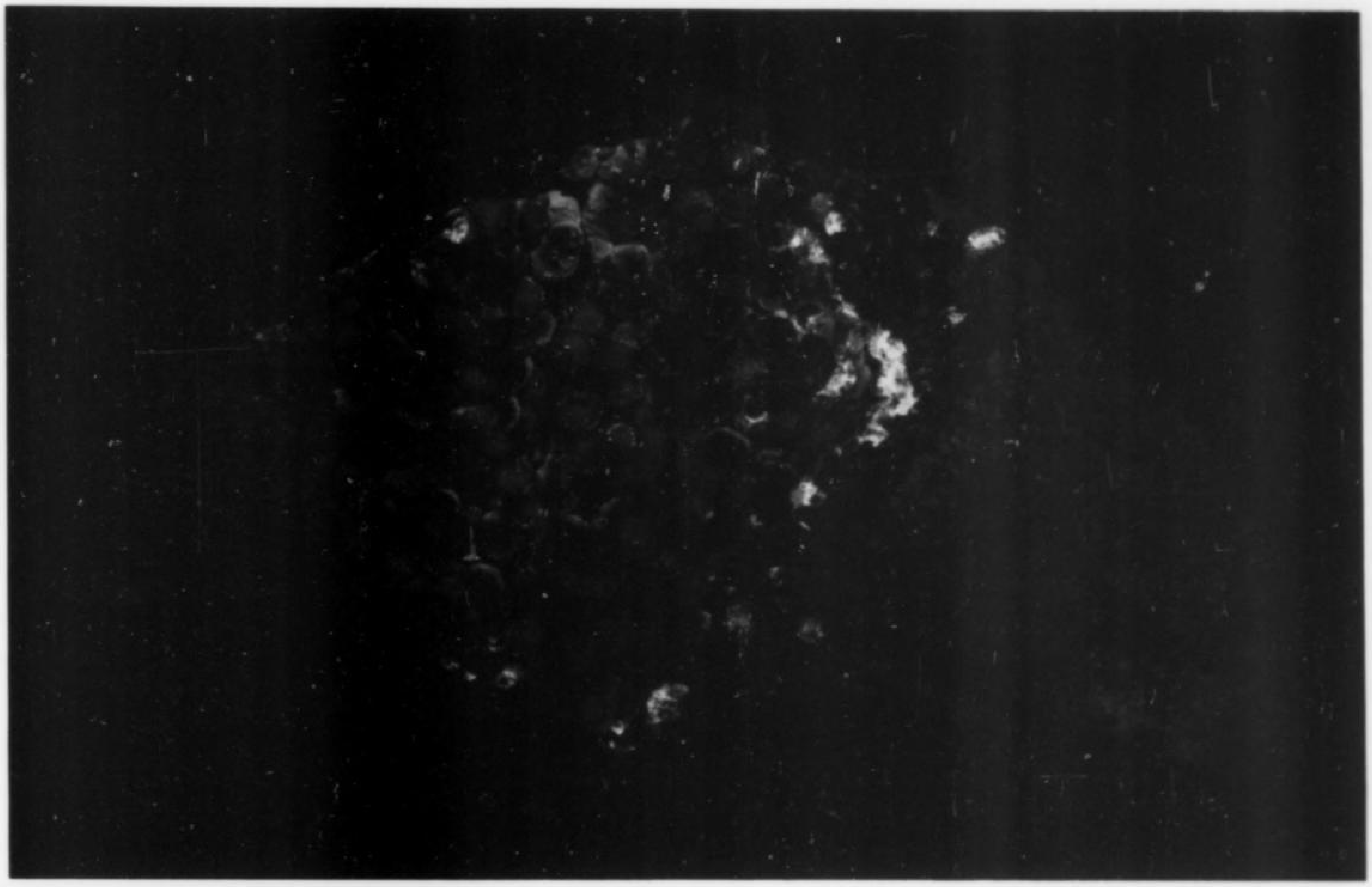

Figure 6. **Pink strengite and gray-green to blackish green rockbridgeite on black beraunite. The specimen is 12 cm across. Dennis Holmberg specimen and photo.**

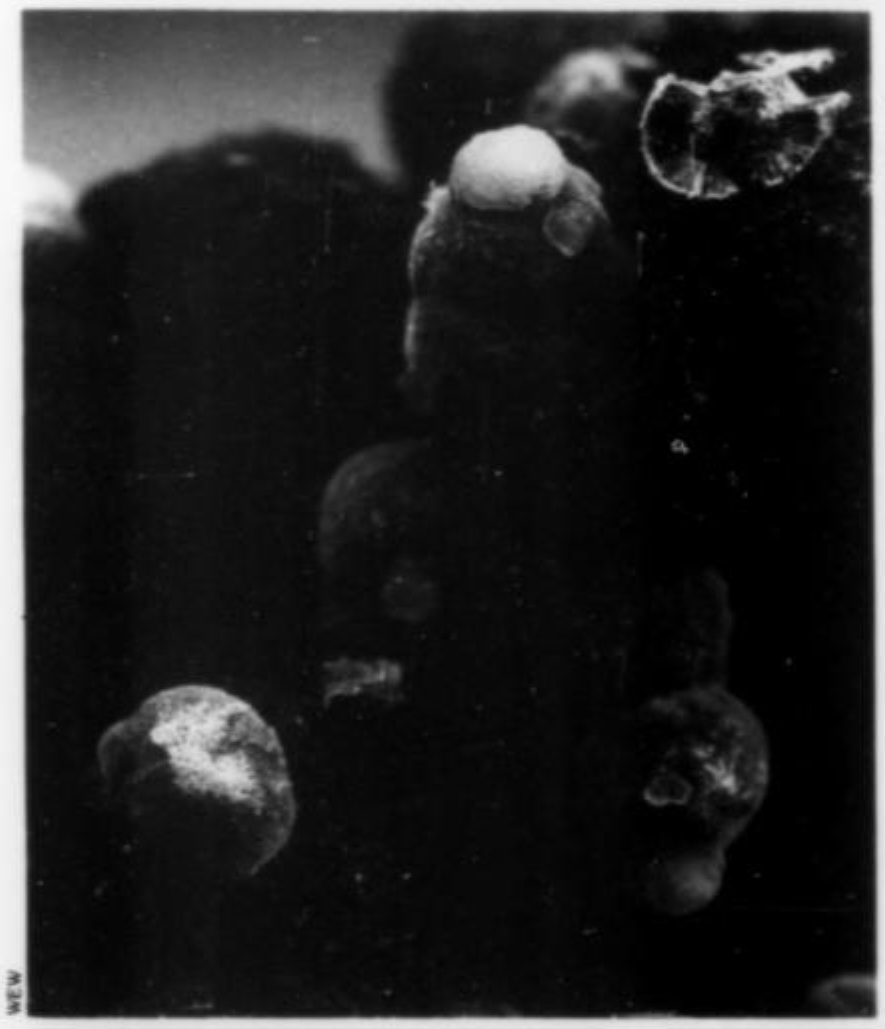

Figure 5. (left) **Velvety, dark gray-green spherules of laubmannite to 1.5 mm. Bjällerud collection.**

Figure 7. **Brilliant yellow cacoxenite needles and sprays to 2 mm with blackish green beraunite. Bjällerud collection.**

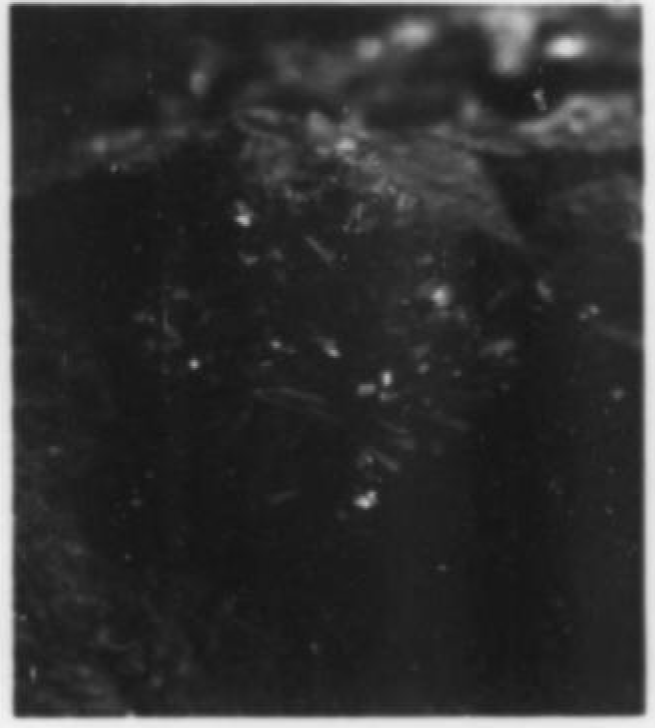

Figure 9. **Pink strengite crystal group, 3 mm across. Bjällerud collection.**

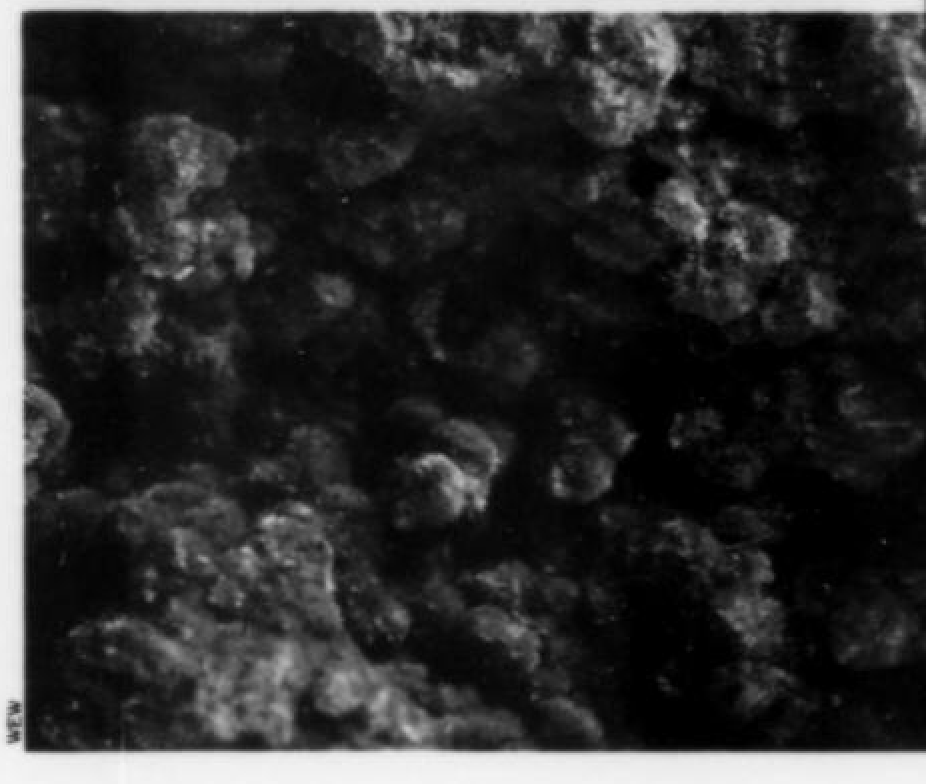

Figure 8. **Velvety, yellow green tufts of kidwellite, less than 1 mm thick. Bjällerud collection.**

The Precambrian rocks of Norrbotten contain a well-developed iron metallogenic province, with most of the deposits located in a 100-km wide belt extending about 200 km from the Caledonides in the west to the Finnish border on the east. The Kiruna and Arvidsjaur districts appear to be ancient volcanic centers which hosted the contemporaneous emplacement of apatite-bearing iron ores. These ores were previously thought to be magmatic in origin (Geijer, 1931) but more recently an exhalative-sedimentary origin has been suggested (Parak, 1975). The matter is still under debate, and has been critically reviewed by Geijer and Ödman (1974).

Composition of the ore is variable, but typically consists largely of magnetite with varying amounts of apatite and hematite. Both fluorapatite and chlorapatite have been identified. Minor amounts of amphiboles, pyroxenes and, in some cases, abundant calcite have also been observed in the orebodies.

The ores occur as extensive sheets and as an irregular network of veins (termed an ore breccia). At the Leveäniemi mine the ore breccia deposits are emplaced along one horizon in intermediate volcanic rocks occupying the core of a north-plunging syncline. The ore is mostly magnetite, in some places altered to hematite ("martite"), with occasional veins of calcite and green skarn. Gangue minerals include apatite, calcite, tremolite-actinolite, occasional diopside, biotite and chlorite (Grip and Frietsch, 1973; Grip, 1978).

Hematite ore is most common in the central part of the deposit, generally extending to a depth of 150 meters but sometimes much deeper. According to miners, the suite of unusual phosphate minerals occurred in place in the northernmost hematite ore zone (see map), now underwater. All specimens have been collected from dumps just west of the mine.

MINERALS

Beraunite $Fe^{+2}Fe^{+3}_5(PO_4)_4(OH)_5\cdot 4H_2O$

Beraunite occurs as black microcrystals to 5 mm, forming spheres and rosettes, commonly in association with strengite. An early generation of beraunite is always covered by a layer of rockbridgeite.

Cacoxenite $(Fe^{+3},Al)_{25}(PO_4)_{17}O_6(OH)_{12}\cdot 17H_2O$

Cacoxenite forms sharp, acicular yellow crystals to 5 mm, usually isolated in iron ore but sometimes in association with other iron phosphates. Rare spherical sprays have been found, as well as massive cavity fillings.

Crandallite $CaAl_3(PO_4)_2(OH)_5\cdot H_2O$

Crandallite has thus far been found in only one cavity, as white, agate-like spheres to 1.5 cm on aluminum-rich strengite.

Fluellite $Al_2(PO_4)F_2(OH)\cdot 7H_2O$

Perfect milky to transparent crystals of fluellite up to 6 mm occur in cavities in hematite, sometimes in association with beraunite and aluminum-rich strengite.

Kidwellite $NaFe^{+3}_9(PO_4)_6(OH)_{10}\cdot 5H_2O$

Kidwellite occurs as small, velvety, spherical growths up to 2 mm in size and distinctly pale green to yellowish green in color. It is commonly associated with strengite.

Laubmannite $Fe^{+2}_3Fe^{+3}_6(PO_4)_4(OH)_{12}$

Only a few small cavities have thus far been found to contain laubmannite. It occurs as small (1–2 mm) gray-green velvety spherules and masses with strengite.

Rockbridgeite $(Fe^{+2},Mn)Fe^{+3}_4(PO_4)_3(OH)_5$

Rockbridgeite is the only phosphate never found as crystals at the Leveäniemi mine. It always occurs as a thin, earthy covering layer on beraunite, and is typically light to dark gray-green in color.

Strengite $Fe^{+3}PO_4\cdot 2H_2O$

Strengite has been found as splendid crystals to 7 mm and as spherical growths of a deep violet to magenta color, grading to white as intermediate compositions approach variscite. The crystals are commonly transparent and attractive. Associations, where present, can include several of the other iron phosphates.

Variscite $AlPO_4\cdot 2H_2O$

Only a few specimens of variscite have been identified, although a range of intermediate compositions leading to strengite exists at the mine. Habit is generally botryoidal, ranging from white to pale sky-blue.

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

Wavellite is rare, occurring as yellowish crystals up to 5 mm, in spheres and rosettes.

Other Minerals

Several other phosphate species, generally less attractive than those described above, are currently under investigation.

A variety of zeolites including heulandite, laumontite, stilbite, chabazite and scolecite occur in fine crystals up to 3 cm at the mine.

Apatite crystals up to 10 cm in length have been found embedded in massive iron ore. Microcline crystals to 5 cm, scapolite to 4 cm, ferrohornblende to 4 cm, titanite to 2.5 cm, calcite to 10 cm and diopside to 9 cm, as well as hematite and magnetite crystals, have also been found.

ACKNOWLEDGMENTS

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THE MINERAL COLLECTION OF THE MUSEUM OF NATURAL HISTORY

Vienna

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Founded 240 years ago by the Emperor Franz I, the Museum of Natural History in Vienna has since grown to become one of the most important institutions in Europe. The mineral collection contains a great many fine old specimens and materials of historic as well as scientific significance.

HISTORY

Franz Stephan von Lothringen (1708–1765) was a patron of science and an enthusiastic collector of natural history objects. As Holy Roman Emperor Franz I from 1745 to 1765, and consort to the famous Austrian Empress Maria Theresia, he was in an excellent position to indulge his interests. In 1748 he acquired what was then the largest private mineral collection in Europe from a so-called "universal scientist" named Johann von Baillou. Baillou lived in Florence and had amassed an enormous array of minerals, rocks, fossils, shells and skeletons, 30,000 specimens in all! Franz Stephan moved this collection to Vienna, and retained Baillou as curator. It was installed in the Imperial residence (the *Hofburg*) for the exclusive enjoyment of the Emperor. Upon his death in 1765, Maria Theresa presented the collection to the state and formally opened it to the public.

During the following decades the collections grew steadily. The mineralogist and mining engineer Ignaz von Born (1742–1791; bornite) was placed in charge of the mineral collection, and later was assisted by Carl Haidinger.[1] Under these men the museum developed into an important center for mineralogical and geological research.

The earth science objects were first cataloged between 1797 and 1806 by Andreas Stütz, a former Augustinian monk from the Klosterneuburg Monastery in Vienna (the work is known as the *Catalogus Stützianus*).

Born and Stütz were followed by Carl von Schreibers (1775–1852; schreibersite), a prominent specialist in meteorite research, and then by Paul Partsch (partschite and partschinite, both species subsequently discredited), Moriz Hoernes (1815–1868, hoernesite), and Friedrich Mohs (1773–1839; mohsite and mohsine, both species subsequently discredited, but he is still remembered as the originator of the Mohs hardness scale). Mohs had followed Werner in 1817 as chairman of

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[1] Carl Haidinger was the father of the famous mineralogist Wilhelm Karl von Haidinger (1795–1871; haidingerite), who founded the Montanistische Museum and later became the first director of the Austrian Geological Survey.

Figure 1. **The Museum of Natural History, as seen from the Ringstrasse across the Maria-Theresien-Platz. Photo by Dr. G. Niedermayr, Vienna.**

Figure 2. **Painting by J. Kohl and F. Messmer, dated 1773, showing Franz Stephan I (seated) with the curators of his private collections. Johann von Baillou is second from left. Photo by Fotostudio Otto, Vienna.**

the mineralogy department at the prestigious Freiberg Mining Academy, but in 1826 he left to take the position of professor of mineralogy and, for a short time, superintendent of the "Naturalien Cabinet" in Vienna.

Each curator in this eminent succession maintained contacts with prominent mineralogists around the world, organized collecting expeditions, arranged for important donations and made liberal purchases of specimens.

A particularly fine opportunity for obtaining foreign specimens presented itself when the Archduchess Leopoldine, daughter of Emperor Franz II, married Crown Prince Dom Pedro of Brazil. The Emperor arranged for a number of scientists to visit Brazil between 1817 and 1835; they traveled throughout the country collecting all kinds of materials for the Imperial Museum—minerals, rocks, fossils, plants, animals and ethnographic items. As a result, a special museum called the Brasilianisches Museum was opened for a few years to contain the fruits of these expeditions. The Brazilian materials were later incorporated into the various general collections of the Naturalien Cabinet.

Other expeditions were also mounted during the 1800's. The Imperial Frigate *Novara* and the corvettes *Carolina* and *Saida* circumnavigated the globe, bringing even more exotic items back to Vienna.

In 1821 a highly placed civil servant, Staatskanzleirath von Hoppe, presented to the Naturalien Cabinet a collection of gemstones and jewelry, including what are still today the most valuable rings in the museum. In 1827 a famous mineral collection built by prominent merchant and mineral enthusiast Jacob Friedrich van der Nüll was acquired by the museum. And in 1836 the Russian Czar Nicholas I donated an extensive and valuable collection of Russian minerals, including a 17.6-ounce gold nugget from Miask in the Ural Mountains.

During the third quarter of the nineteenth century the Mineralogische Hof-Cabinet, as it was then known, was steadily enlarged by its curators. These men included Adolph Kenngott, Eduard Sues, Joseph Grailich, Albrecht Schrauf, Gustav Tscherm-Seysenegg and Ferdinand Hochstetter.

A fortunate development took place in 1857: by Imperial decree the old fortified city walls dating back to medieval times were razed, greatly facilitating the expansion of the city. In 1876 construction of a new museum building was begun in front of the old Hofburg. After several years of moving and reorganization the new quarters opened to the public on August 10, 1889—just 100 years ago! Below the cupola, at the main entrance to the new building, an inscription in gold letters dedicates the new museum "to the Kingdom of Nature and its Exploration. Emperor Franz Joseph I, MDCCCLXXXI."

Another fine collection of minerals, this one from America, was

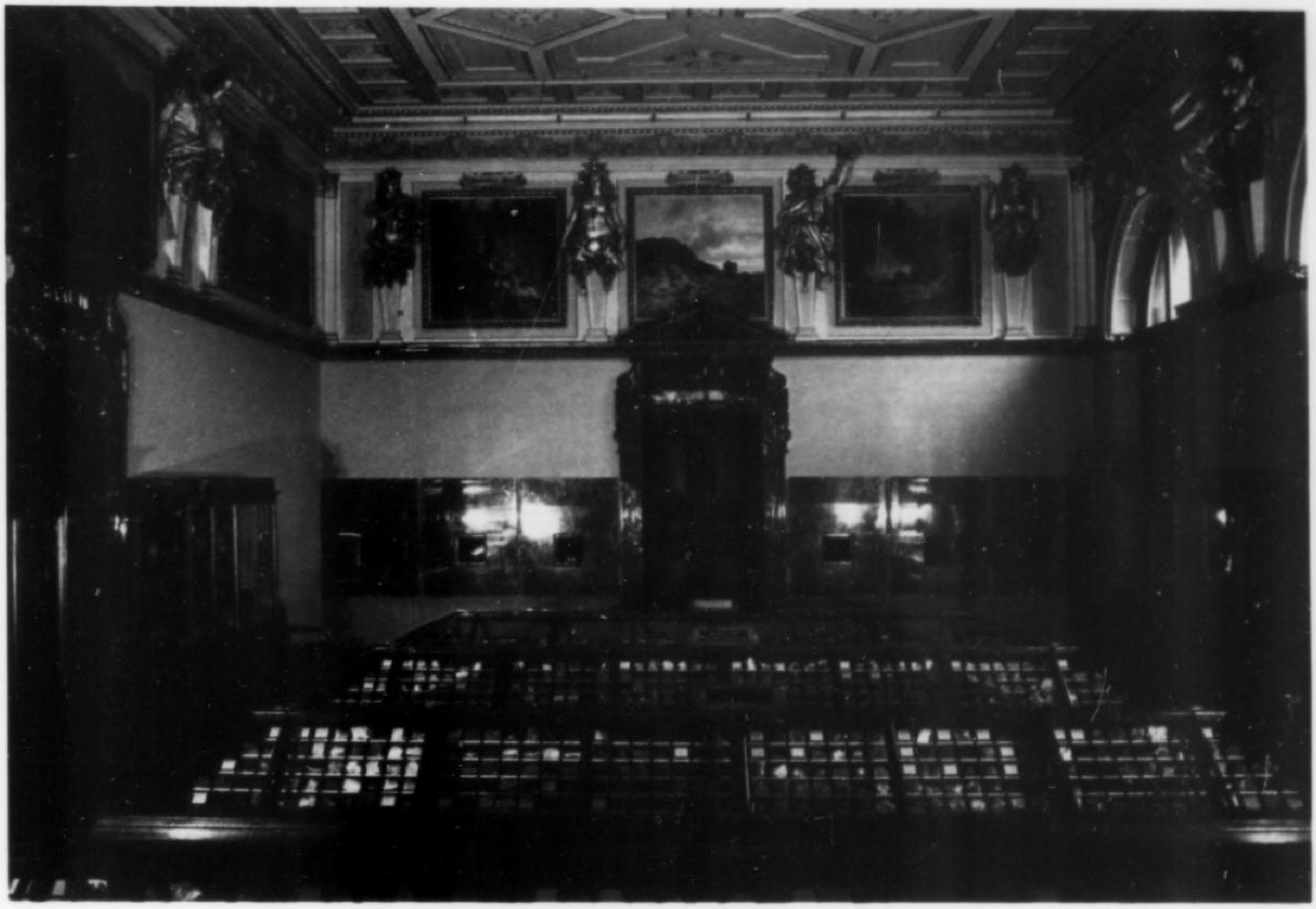
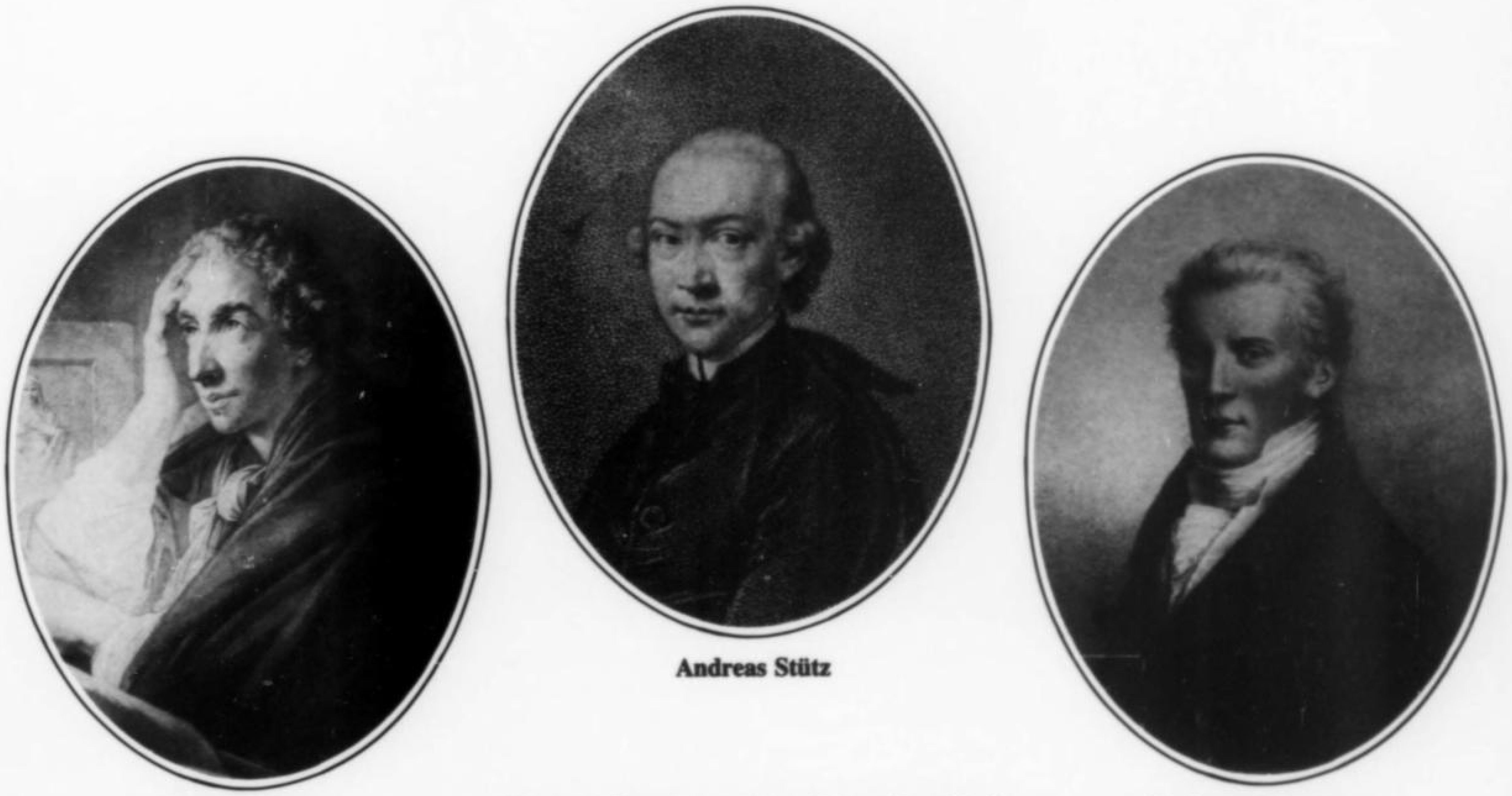


Figure 3. **Museum of Natural History, room IV, with the gem collection in the background. Photo by Dr. R. Seemann, Vienna.**



Ignaz von Born (1742–1791)

Andreas Stütz

Carl von Schreibers (1775–1852)

Figure 4. **Former curators of the mineral collection.**

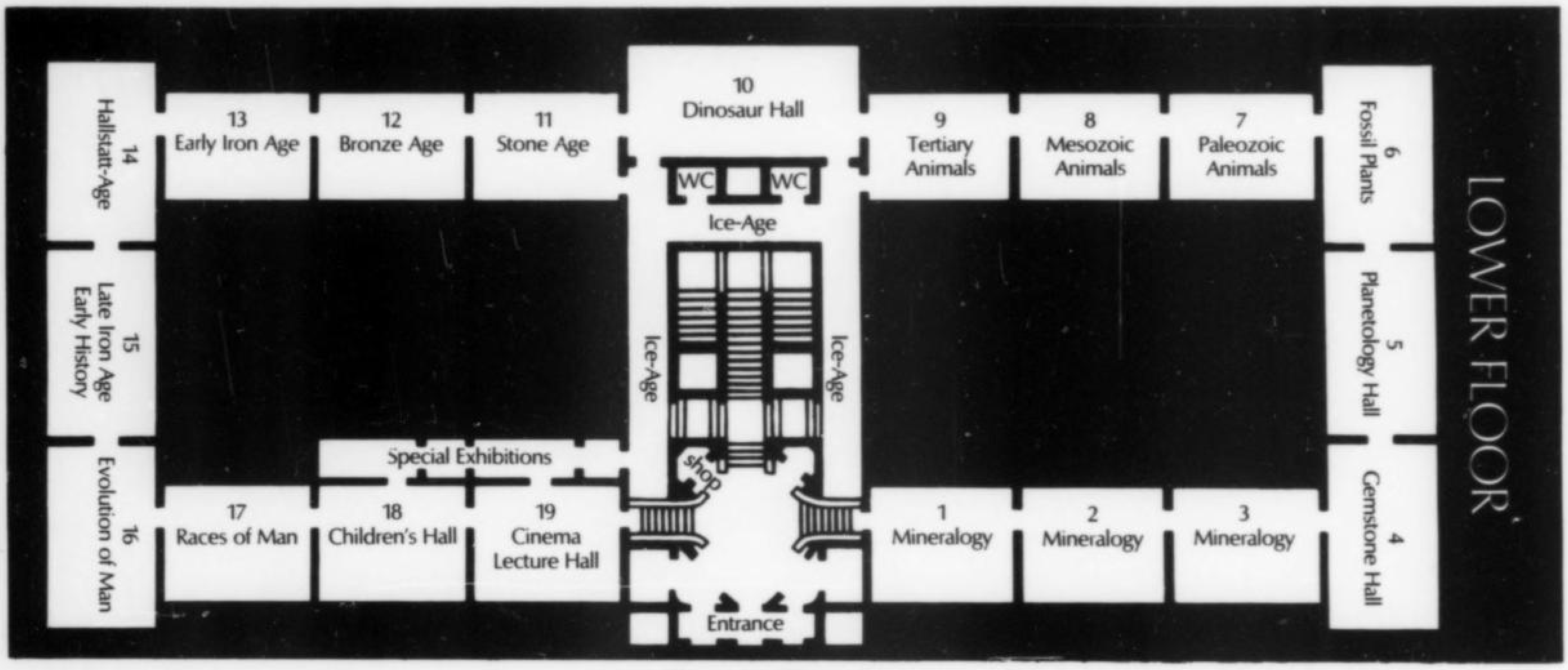


Figure 5. **Floor plan.**

acquired by the museum in 1888. William Earl Hidden (1853–1918, hiddenite) of Newark, New Jersey, sold to the museum a beautiful collection of rare and aesthetic specimens from American localities. This was, it turned out, the penultimate major collection to be acquired by the museum. Within a few years the Austro-Hungarian empire had fallen on hard times, and curators were no longer able to command significant funds for purchases.

A few important donations were nevertheless obtained in the early years of this century, including an 82.5-carat flawless diamond crystal. But, since the end of the monarchy in 1918, significant acquisitions of mineral specimens, even from Austrian localities, have been very sparse.

Figure 6. **The Hraschina iron meteorite, found in Jugoslavia, was the first meteorite to be scientifically investigated. Immediately after its fall in 1751 it was sent to Emperor Franz I. The specimen measures 40 cm and weighs 39 kilograms. Photo by Fotostudio Otto, Vienna.**

THE EXHIBITS

The mineral collection of the Museum of Natural History, both in content and in exhibition style, bears the historic flavor of an earlier time. About 20,000 specimens are currently on display; this is far more than modern trends in exhibit design would allow, considering the total floor space. Minerals occupy four rooms, and a fifth is being remodeled for a new meteorite exhibit.

Specimens are arranged systematically, according to chemical composition and crystal structure. Flat cases are arranged down the middle of each room, and the largest specimens are held in vertical cases lining the walls of two rooms. Most of these cases have their own internal lighting. Near the windows are flat cases reserved for recent acquisitions. The most valuable specimens are displayed in special vault-cases.

A comprehensive gemstone collection in one flat case and two wall cases provides a special attraction for visitors. Most of the known gem species are represented, as rough, cut and jewelry-mounted specimens.

Paintings lining the walls of the exhibit rooms depict some of the most important mineral localities from the turn of the century. These include, for example, the diamond mines at Kimberley, South Africa; gold mines in the Sierra Nevada of California; and gold mines in Transylvania.

The museum is fortunate to have survived two world wars virtually undamaged. The architecture, the artworks lining the walls, the design of the showcases and the old specimens themselves combine to create an authentic nineteenth-century ambiance which many people find appealing. There are currently no plans for future modernization which might compromise the historic atmosphere of the museum.

THE COLLECTION

The collection contains about 85,000 cataloged mineral specimens, 50,000 rocks and 8,000 meteorites. Less than a quarter of the mineral specimens are on display, representing about 1,000 species.

The high reputation of the mineral collection derives in large part from the vast quantities of specimens from classic Austro-Hungarian localities. These include the mines of Transylvania, Bohemia and parts of modern-day Germany, as well as Alpine occurrences in Austria (see Niedermayr, 1986a), Switzerland and France. Relatively little material collected later than 1920 exists in the museum.

Because of the large number of specimens on exhibit (eight or nine times as many as at the Smithsonian Institution, for example) visitors may require quite a lot of time to familiarize themselves with the collection. Interesting things will probably be noticed for the first time over the course of many visits.

Some highlights of the collection include well-formed mimetite crystals from Johanngeorgenstadt in Saxony; stephanite from Freiberg; nagyagite (in crystals to nearly 5 cm!) from Nagyag (now Săcărâmb, Romania); a fantastic hessite crystal from Botés, Romania; a whole suite of atacamite crystal groups from Wallaroo, South Australia; hauerite from Schemnitz (Banská Štiavnica, Czechoslovakia); euchroite from Libethen, Hungary; sternbergite and argentite from St. Joachimsthal; nicely crystallized devilline from Herrengrund; and a very fine argentite (acanthite) crystal group from Guanajuato, Mexico. Fine halite groups from Wieliczka, Poland, were acquired in 1901. A number of excellent wulfenites from Bleiberg were pictured in Niedermayr (1986b).

Figure 7. **Allosaruus skeleton in the dinosaur hall.**

Figure 8. **Superb argentite group from Guanajuato, Mexico. The specimen measures 7.5 cm. Photo by R. Schönmann, Vienna.**

Alpine occurrences are particularly well represented in the collection. Several epidote and fluorapatite specimens from Knappenwand, Austria, are among the best ever found there (see Seemann, 1986). Large, platy apatites from Stilluppgrund, Tyrol; one of the best hematite specimens ever found in the eastern Alps (from Mörchner Kar in Zillertal; purchased just a few years ago); a few nice hematite "iron rose" crystal clusters from St. Gotthard, Switzerland; and very fine axinite specimens from Bourg d'Oisans, France, are also present in the collection. A magnificent bornite crystal from Frossnitz, Eastern Tyrol, measures about 5 cm, and a waterclear scheelite crystal weighing well over a pound, from Habachtal, is probably one of the finest scheelites ever found in the Alps. Aragonite from the Styrian Erzberg, large brookite crystals from Frossnitz, lazulite from the type locality

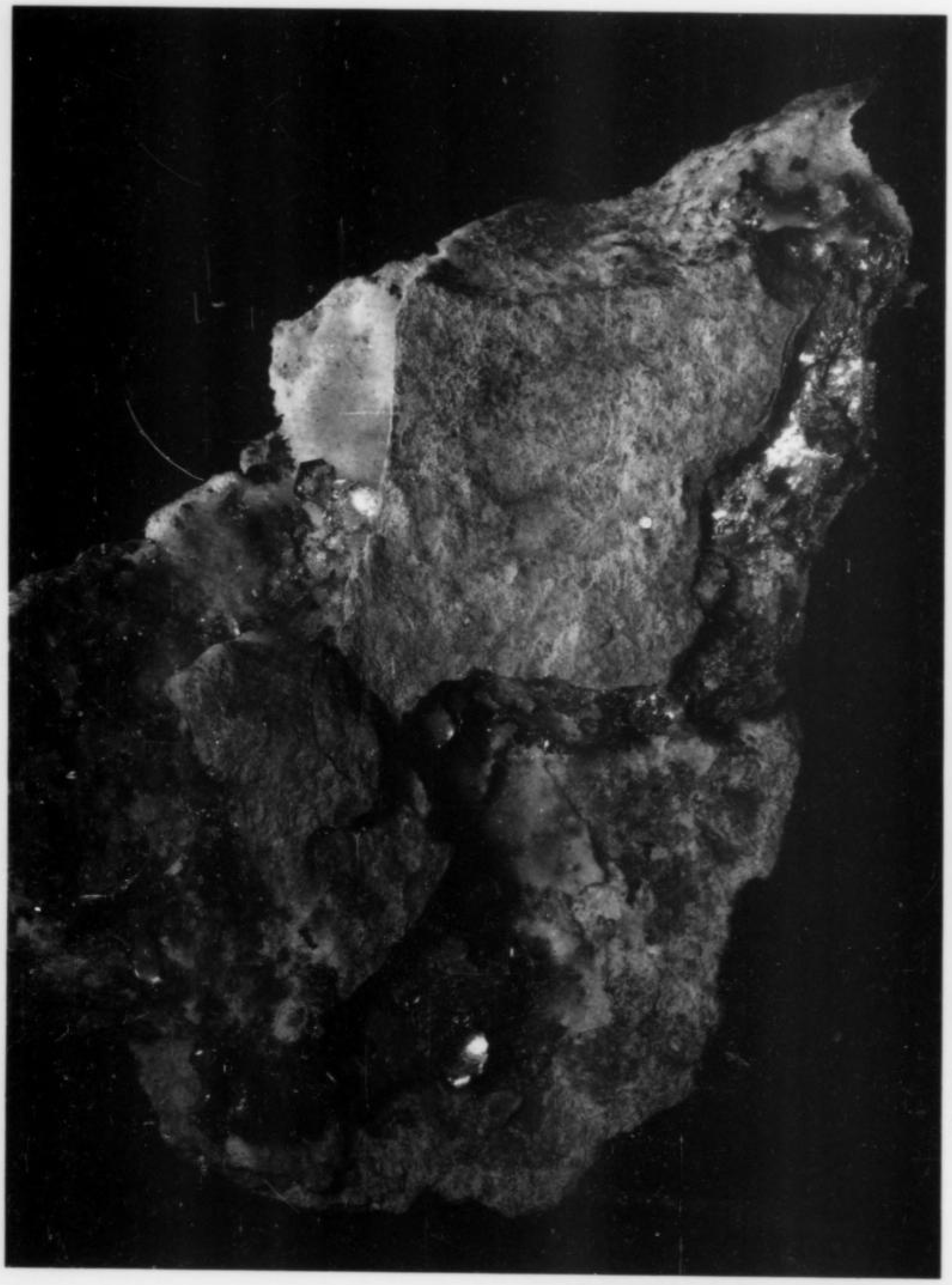


Figure 9. This gold specimen from Vulkoj in Transylvania measures 19 cm and is said to be one of the best ever mined at this locality. It was purchased by the museum in 1882. Photo by Fotostudio Meyer, Vienna.

Figure 10. Skull of an Austrian Bronze-age man (1800–800 B.C.) bearing malachite stains from the alteration of copper grave artifacts.

Figure 11. These gold nuggets came from Miask (Ural Mountains) and Ballarat, Victoria, Australia. The smaller one weighs 548 grams and was a gift from the Russian Czar Nicholas to Emperor Ferdinand in 1836. The 826-gram nugget was a present to Franz Joseph I in 1858 and came from Australia. Photo by Fotostudio Otto, Vienna.

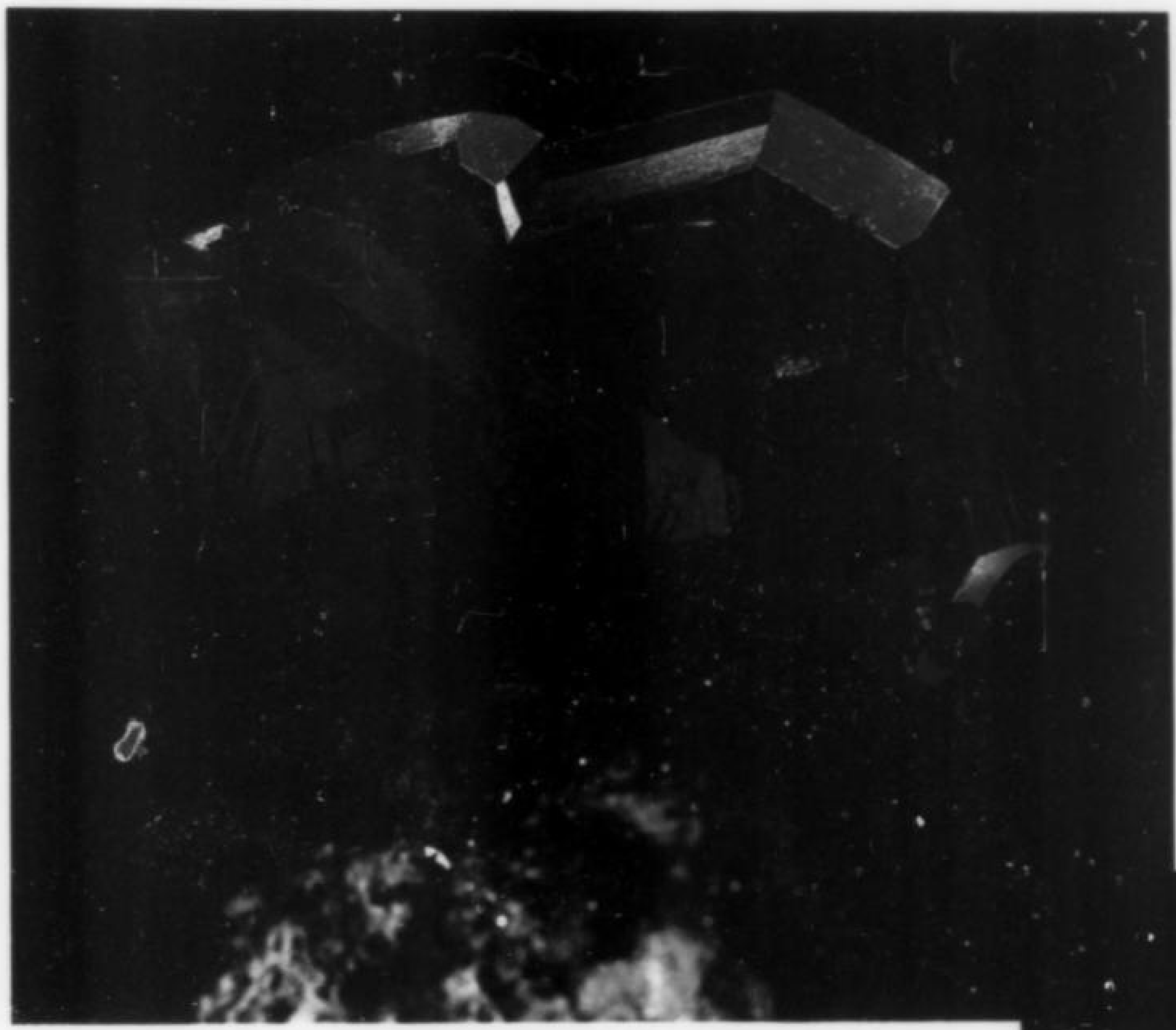


Figure 12. A spectacular 2.8-cm wulfenite crystal on matrix from the Red Cloud mine, Arizona, was obtained in 1887 from mineral dealer A. E. Foote of Philadelphia. Photo by Olaf Medenbach.

Figure 13. Platinum nugget from the Ural mountains (weighing 6.2 kilograms, more than $13^1/_2$ pounds), a gift of the Russian prince Anatoli Nikolaevich Demidov in 1859 to Curator Moriz Hoernes. Photo by Fotostudio Otto, Vienna.

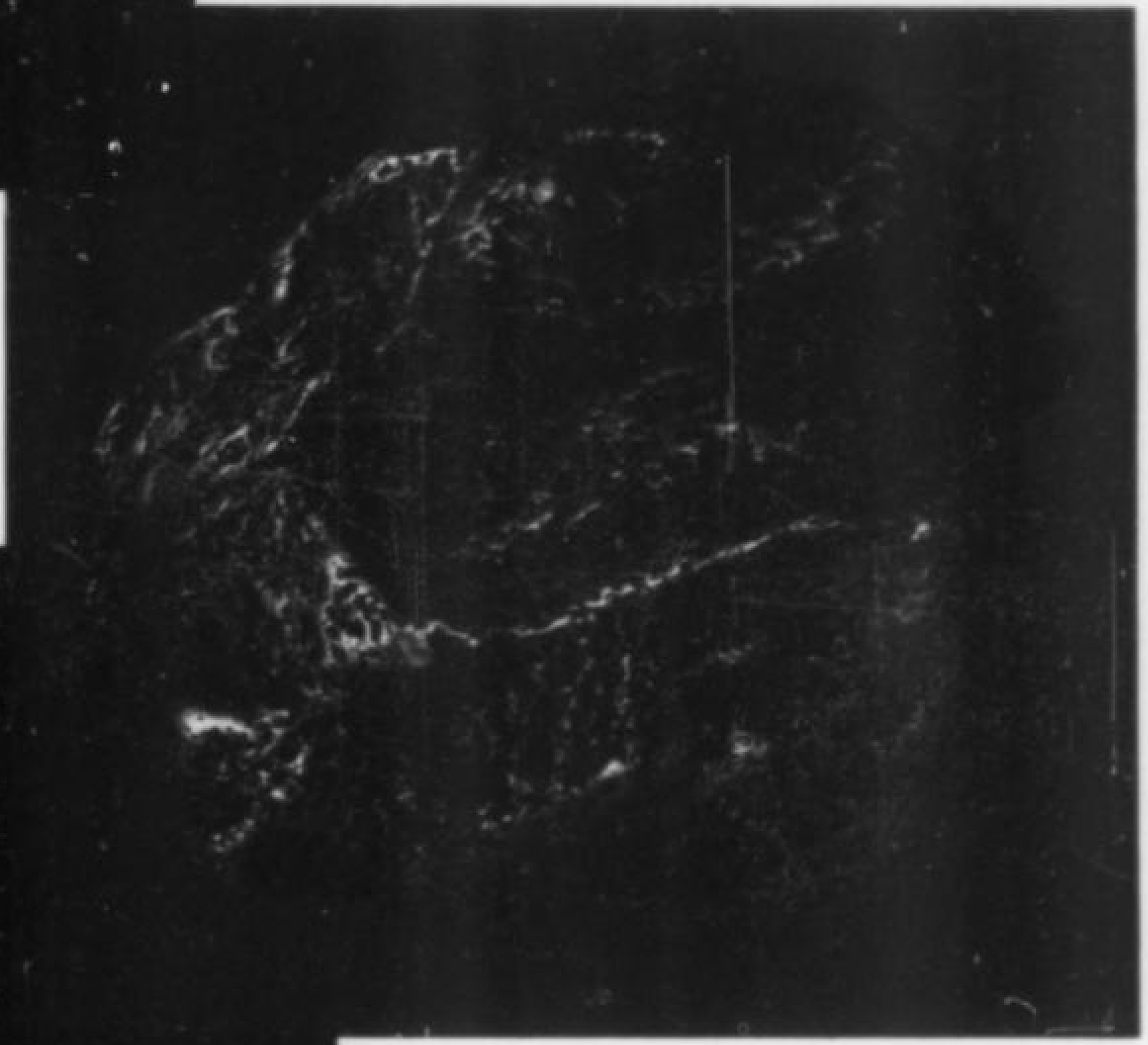


Figure 14. Emerald crystals from Muzo, Colombia (the left crystal measures 3 cm), with faceted stone set in a ring. Photo by F. Langenhagen, Vienna.

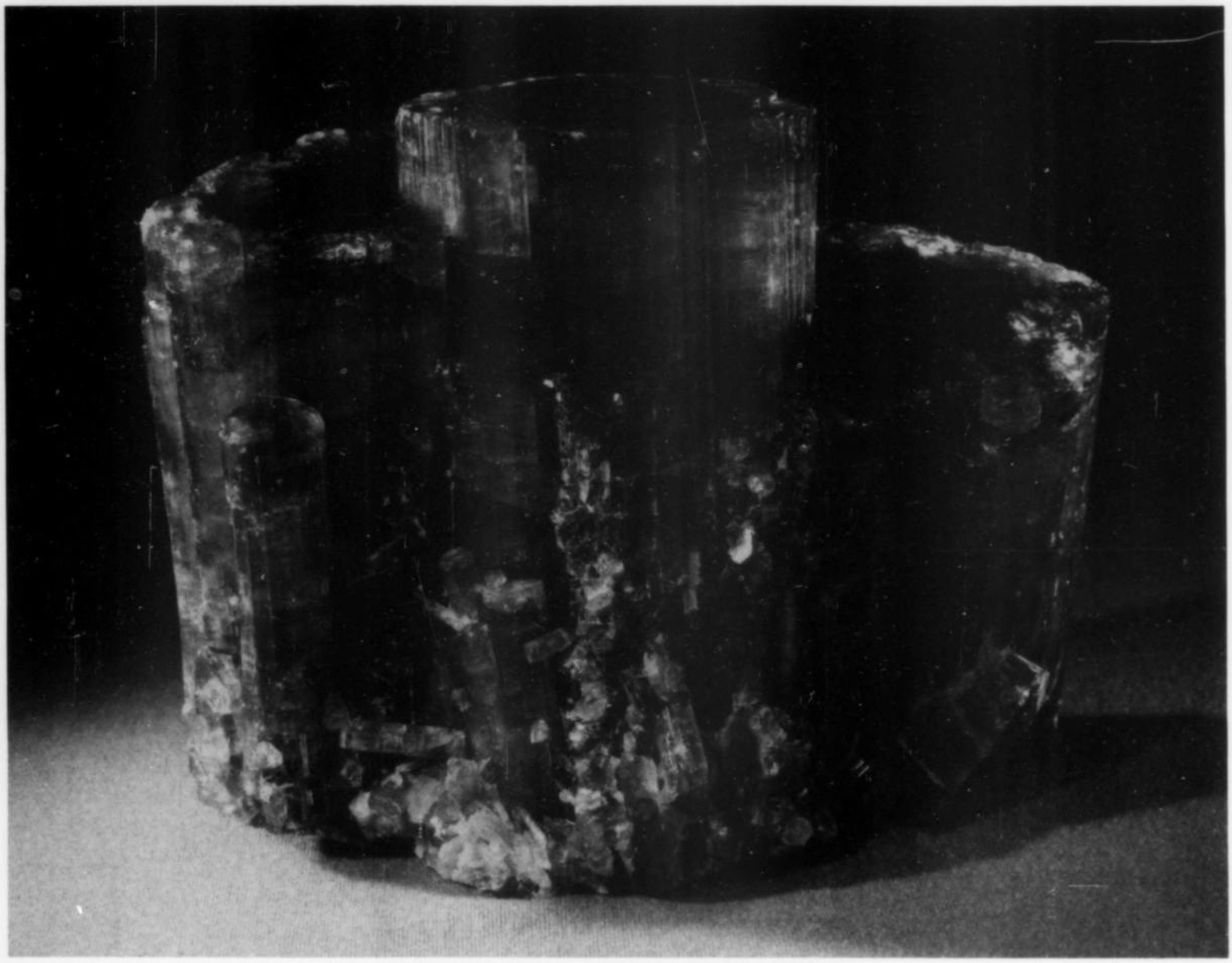


Figure 15. **This magnificent tourmaline specimen from the Tourmaline King mine, Pala, California, is pink with green terminations. Said to be the second largest ever mined from this locality, it measures 18.5 cm and was purchased in 1913 from the mineral dealer J. Böhm in Vienna. Photo by Fotostudio Otto, Vienna.**

at Salzburg, and large phenakite crystals from the Habachtal emerald mine must also be mentioned. This latter locality, incidentally, has in recent years yielded some phenakites from which flawless stones up to 50 carats have been cut.

The gemstone collection is worth special mention. Diamonds in matrix from various South African mines, fine Colombian emeralds, precious opal from Czerwenitza in Slovakia, and many other fine and rare crystals, cut stones and jewelry items are on exhibit. Among the gems, a yellowish brown, mostly gem-grade topaz crystal weighing 117 kg (258 pounds), from the Fazenda do Funil pegmatite near Santa Maria do Itabira in Minas Gerais, Brazil, was received as a donation in 1976—just 100 years after the cornerstone of the new building was laid.

A great many more interesting specimens, far too many to list here, can be found throughout the museum's vast collection (see Burchard and Bode, 1986, for more selections). The museum contains, in addition to minerals, prominent collections in the fields of paleontology, zoology, botany, prehistory and anthropology.

HOURS

The museum is open daily (except Tuesdays) from 9:00 a.m. to 6:00 p.m. There is a small admission fee, but children, students, soldiers and senior citizens are admitted free.

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PHOSPHATE MICROMINERALS
of the
INDIAN MOUNTAIN AREA

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INTRODUCTION

Indian Mountain in western Georgia and eastern Alabama is an important source of excellent phosphate microminerals including strengite, cacoxenite, kidwellite, dufrenite, rockbridgeite and beraunite. The collecting area includes 24 square kilometers of northwest Polk County, Georgia, and southeast Cherokee County, Alabama. The primary collecting areas can be reached by driving 19 km west of Cedartown, Georgia, along Prior Station Road. Borden Springs and Indian Mountain Quadrangle maps can be used to find alternative routes to the area from Cave Springs, Georgia, or Piedmont, Alabama.

Indian Mountain is part of the Weisner Ridges which are within the Valley and Ridge province of the Appalachian Mountains. The area consists of Paleozoic sedimentary rocks which have been complexly folded and faulted, and slightly metamorphosed. The area is covered with forests of thick oak, hickory and pine and consists mostly of steep slopes and narrow ridge tops.

Iron ores have been mined in the area since the mid-1800's. Open pits scattered about the area are all that remain of what was once an active mining industry. The iron ores consist mainly of limonite, with minor hematite. Washed and shipped ores are reported to have averaged between 46 and 61 % metallic iron. Impurities included Si, Al, Mn, S and P (Crawford, 1957).

The combination of Fe, Mn and P allowed the development of phosphate minerals in the Indian Mountain area; these have been collected for more than 30 years. Frondel (1949) reported that the area has been a source of dufrenite, an iron phosphate, since 1939.

GEOLOGY

The geology of the area has been described by Crawford (1957), Causey (1965), Cressler (1970) and Bearce (1982 and 1986). Indian Mountain is composed of Paleozoic sedimentary rocks and is a part of the Valley and Ridge province of the southern Appalachians. Rock units at Indian Mountain include: (1) The Chilhowee Group (Lower Cambrian) consisting of fine grained quartz sandstones, dark blue-gray shales and quartz-pebble conglomerates with minor feldspar and limestone clasts. (2) The Shady Dolomite (Lower Cambrian) consisting of cherty, light gray dolostone which weathers to vuggy ocherous clays with residual chert (Bearce, 1985). (3) The Knox Group (Upper Cambrian–Lower Ordovician) consisting of cherty dolostones and minor limestones; the Knox Group includes the Newala Limestone at the top. (4) The Frog Mountain Sandstone (Devonian) consisting of light to medium gray, fine grained feldspathic sandstone which weathers to a light brown or medium brown color. (5) The Floyd Shale (Mississippian) consisting of dark gray pyritic shale with abundant fossils.

In general, the ridges in the Indian Mountain area are formed by sandstones and conglomerates of the Chilhowee Group or Frog Mountain Sandstone. The Shady Dolomite, Knox Group and Floyd Shale underlie the lower ground and are not well exposed. Due in part to the scarcity of fossils, disagreement exists on the separation of the Chilhowee and Frog Mountain sandstones. Crawford (1957) mapped the main mass of Indian Mountain as Weisner (Chilhowee) while Cressler (1970) regarded [illegible] of this area as Frog Mountain sand-

Figure 1. **Location of the Indian Mountain area.**

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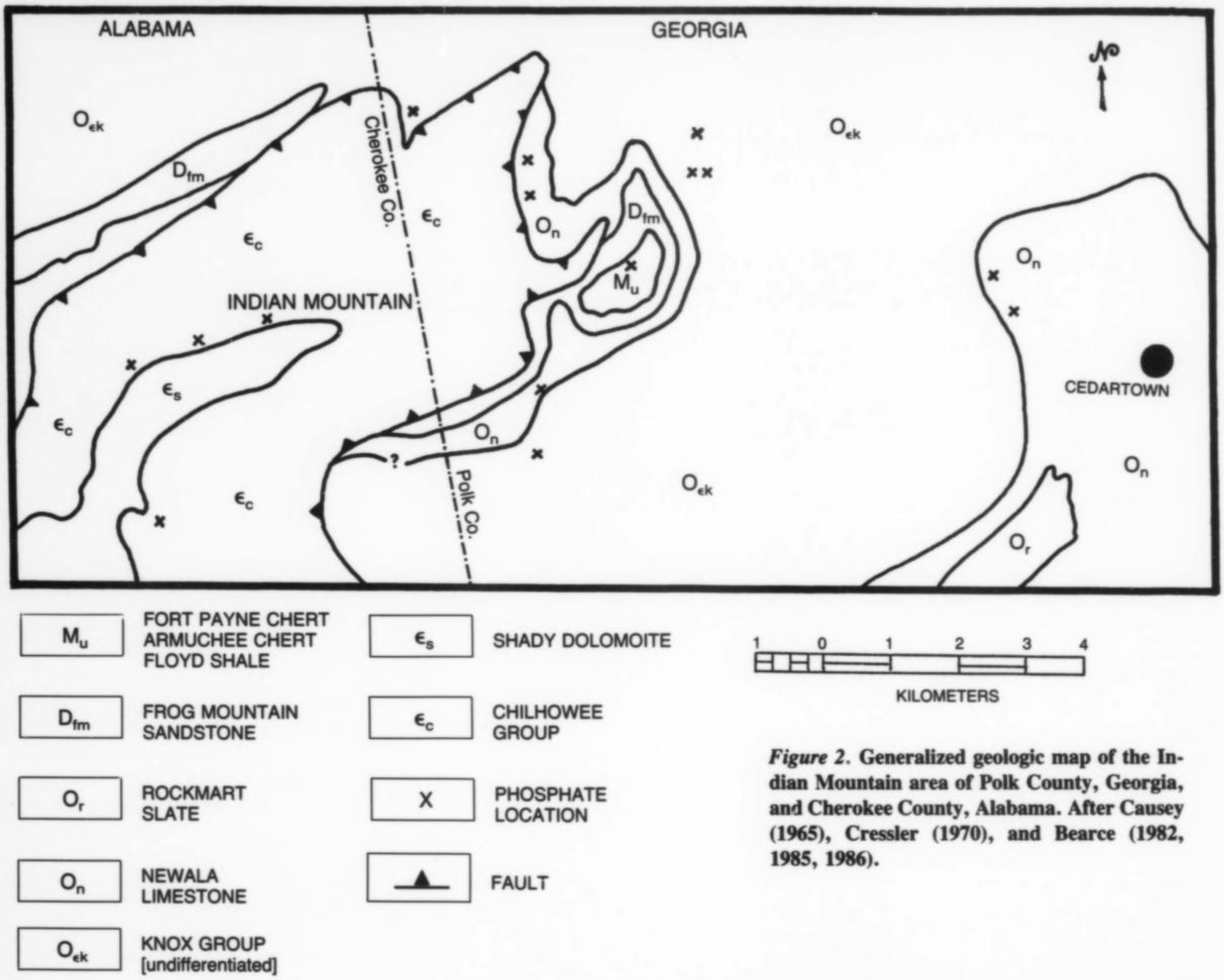

***Figure 2*. Generalized geologic map of the Indian Mountain area of Polk County, Georgia, and Cherokee County, Alabama. After Causey (1965), Cressler (1970), and Bearce (1982, 1985, 1986).**

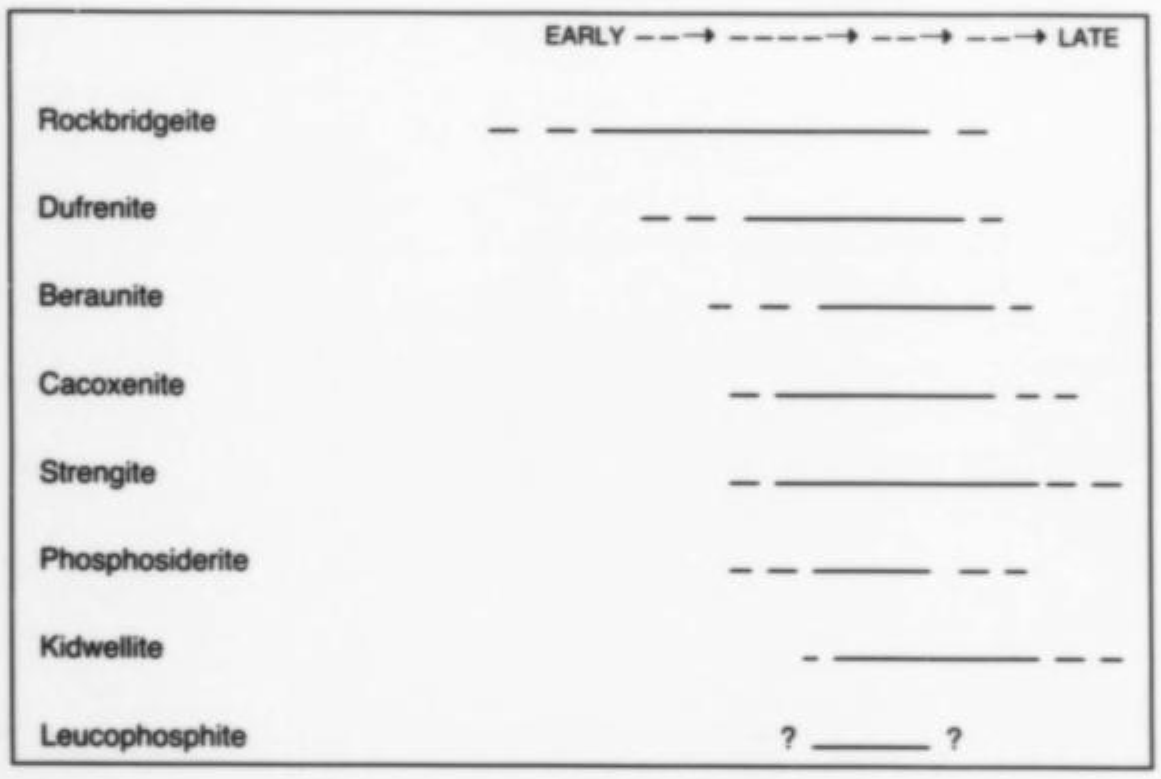

***Figure 3*. Paragenetic scheme for the origin of Indian Mountain phosphates at the main collecting pit. The paragenetic scheme differs for other collecting sites (i.e., at Rock Run Station strengite occurs both prior to and after kidwellite).**

stone. Recent mapping by Bearce (1982, 1985, 1986) suggests that the Frog Mountain is restricted to the east side of Indian Mountain, while the main ridge is Chilhowee.

The area is complexly folded and faulted (Crawford, 1957). Local sandstones and conglomerates outline a series of doubly plunging anticlines and synclines. According to Bearce (1985) the Chilhowee and Shady rocks have been thrust-faulted over the younger strata (Fig. 2). Many of the contacts mapped within the area appear to be fault contacts. This recent mapping by Bearce (1982, 1985, 1986; Tull *et al.*, 1985) indicates that the structure of the Indian Mountain area is part of a nappe system. A nappe is a large body of rock that has been moved from its original position by thrust faulting and/or folding. Bearce (1985) estimates that the Indian Mountain nappe may have been transported northwestward up to 80 km.

Iron ore deposits occur in rocks of all stratigraphic ages but are especially common in the upper part of the Knox Group (Newala) and in the Shady dolomite. Many iron ore mines and prospects, as well as the majority of the phosphate occurrences, lie close to the contact between these carbonate rocks and the overlying Chilhowee rocks. The iron ores usually occur as massive pockets of up to eight acres in size. Lesser deposits occur as bands of hard ore or as iron oxide cement in chert and sandstone breccia. Crawford (1957) indicates that these goethite ores may have formed from the oxidation of hydrothermal sulfide deposits. Many of the deposits are located along the major faults. Because the iron ores are closely associated with carbonate rocks of the Shady, Newala and Knox, their origin may be

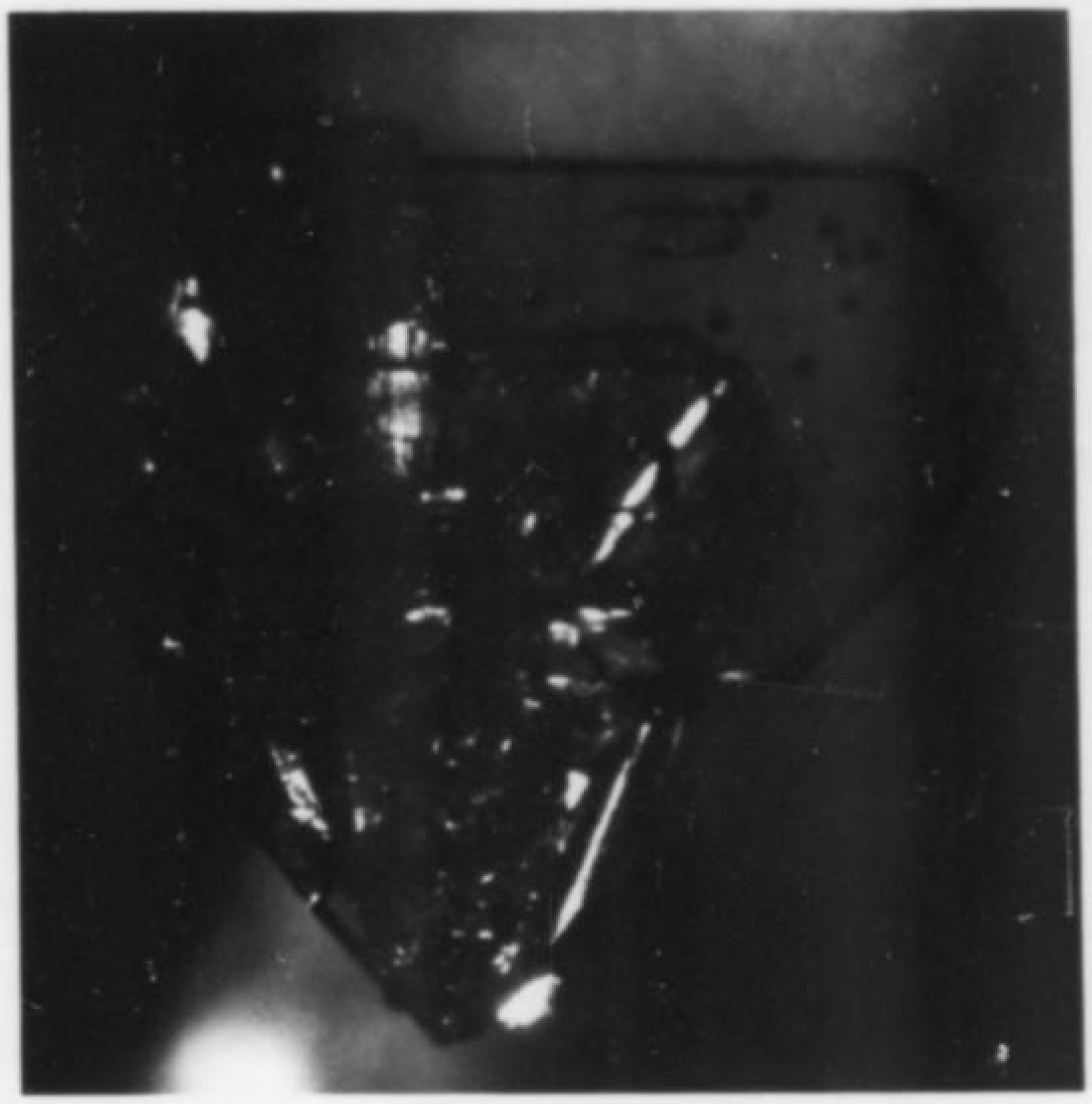

Figure 4. Strengite crystal, 0.35 mm across, with blebby inclusions of an unknown red mineral.

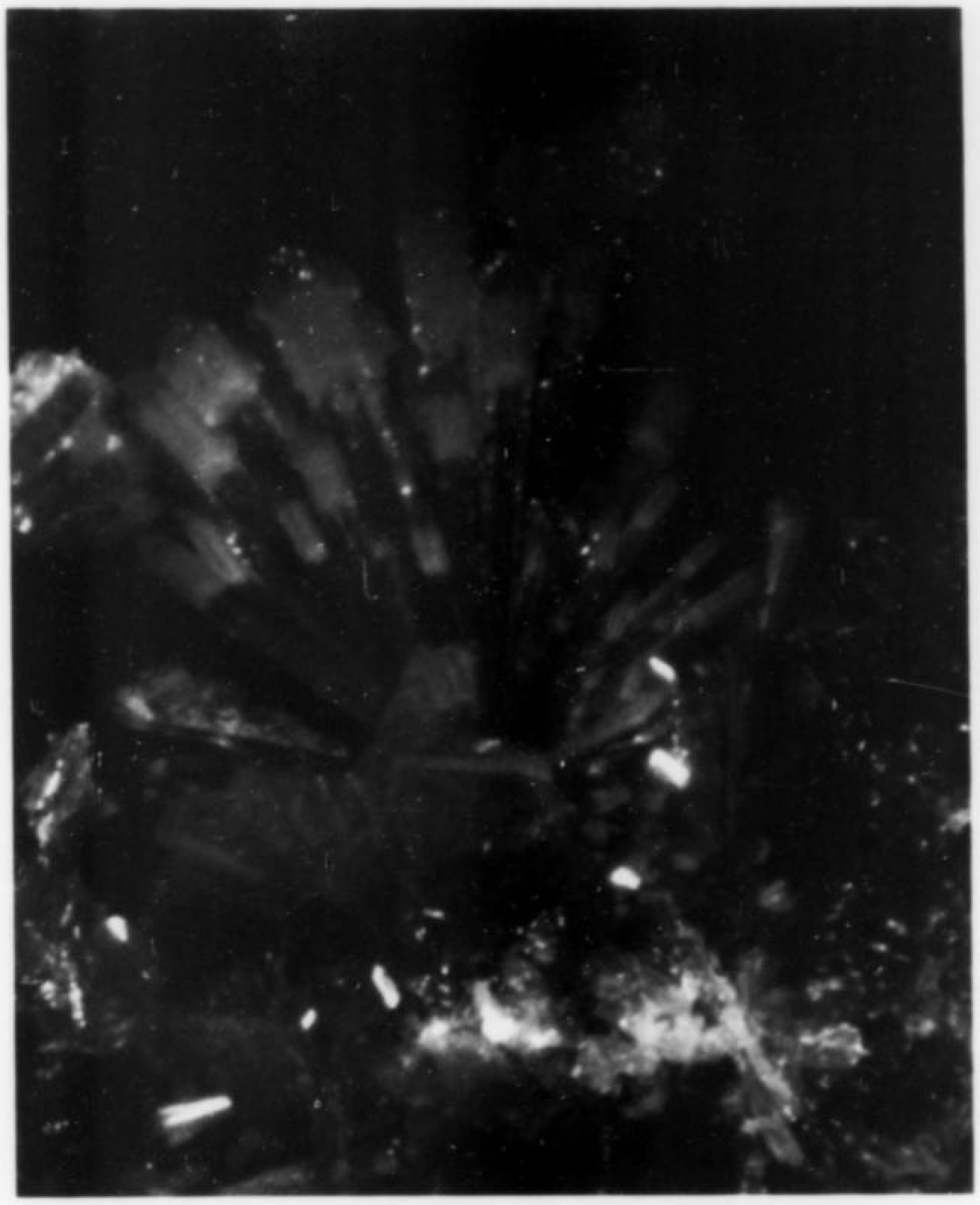

Figure 5. Strengite crystal group, 0.4 mm tall, showing second-generation overgrowth.

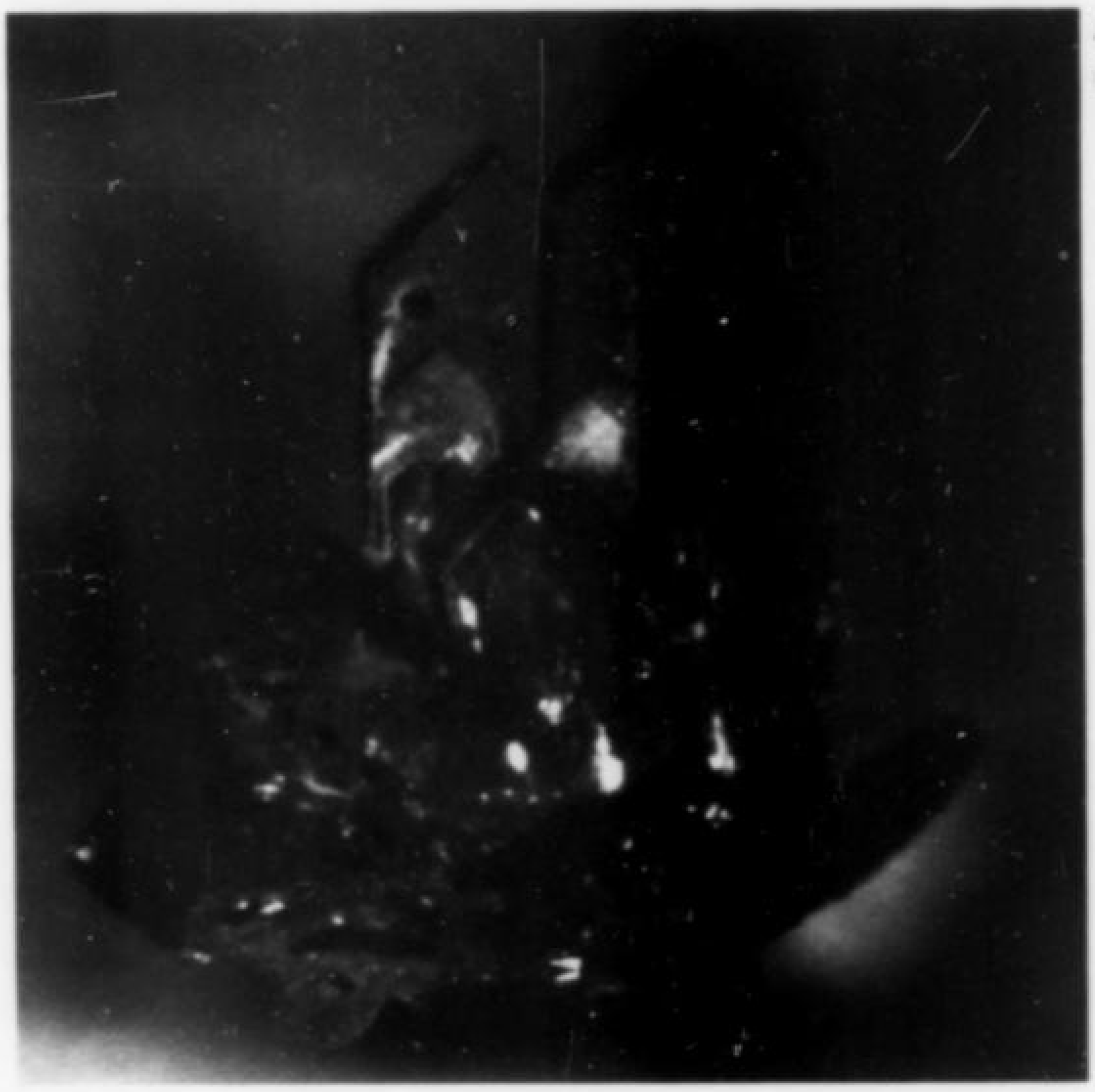

Figure 6. Strengite crystals to 0.3 mm.

Figure 7. Cacoxenite spray, 0.2 mm tall, showing alteration to strengite.

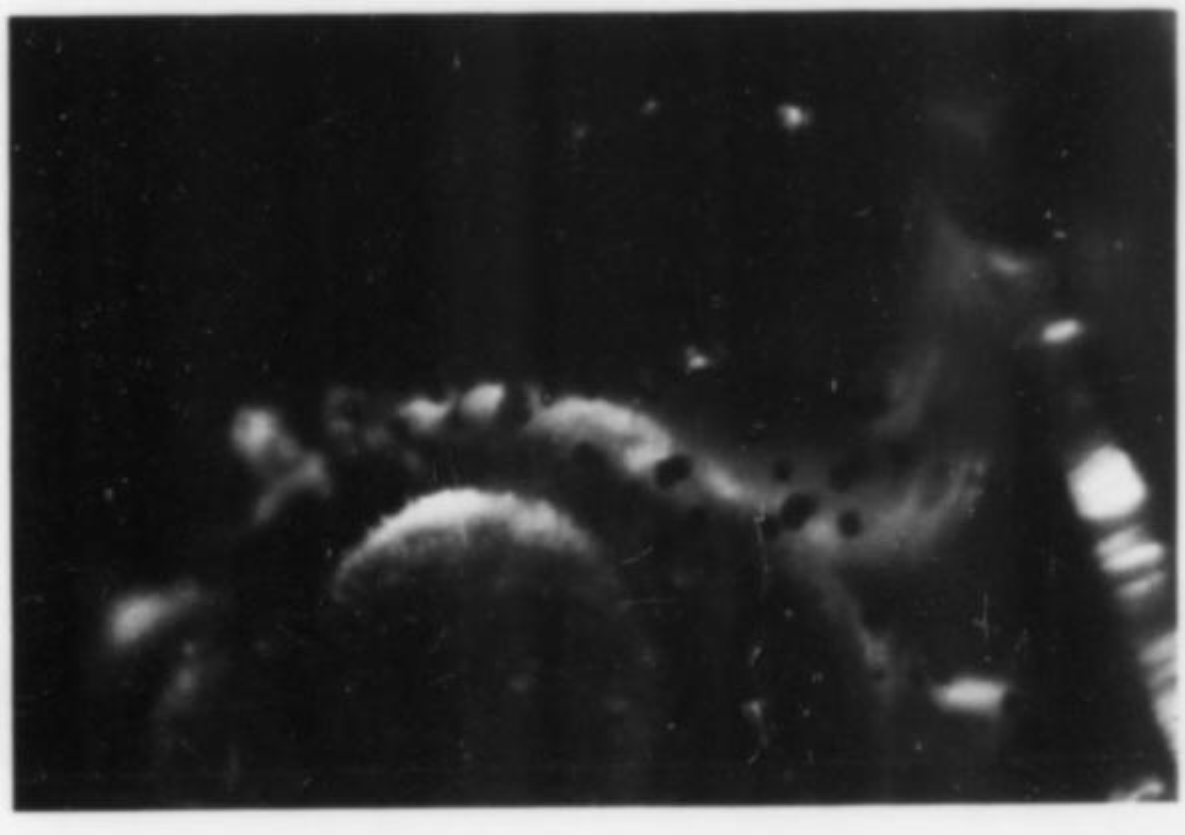

Figure 8. Velvety kidwellite spheres and blebby red inclusions of an unknown mineral in a 0.15-mm strengite crystal.

due to the extensive weathering of these units.

The origin of the phosphate minerals is related to the formation of the goethite gossans (Nriagu and Dell, 1974). The phosphate minerals were probably formed as secondary minerals by the action of phosphatic solutions on the iron deposits (Moore, 1970). The Indian Mountain phosphates are always associated with earlier formed goethite, more abundant in brecciated rocks (Moore and Ito, 1978), and are similar to the phosphate occurrences in the Ouachita Mountains of Arkansas (Kidwell, 1981).

Thin sections of brecciated phosphate-bearing rocks from the collecting site at Rock Run Station indicate that a jasperoid of microcrystalline quartz replacing a carbonate mineral (calcite, dolomite or siderite) has formed along faults. The rhombic cleavage of a carbonate is preserved as iron staining within the microcrystalline quartz.

The phosphates clearly postdate the goethite and were formed by phosphatic waters reacting with the iron oxides. The common occurrences of botryoidal textures and rhythmic color banding indicate that many of the phosphate minerals may have formed by crystallization from a gel. The earliest phosphate to appear is greenish black rockbridgeite that frequently grades outward to dufrenite, beraunite and kidwellite. Color banding within botryoidal spheres is a result of the rockbridgeite-dufrenite-kidwellite sequence of deposition. A similar rhythmic color banding in Arkansas phosphates has been described by Moore (1970). Kidwellite is one of the last phosphate minerals to form, although surface exposures show that in some instances strengite postdates the kidwellite, indicating periods of fluctuating paragenesis. Clear pink rosettes of strengite are implanted upon kidwellite globules, while in some instances kidwellite is found grown on the strengite crystals. Figure 3 indicates the probable order-of-formation of phosphate minerals in the Indian Mountain area.

MINERALOGY

Mineral identification was determined by hand-specimen examination, optical properties in thin section, X-ray diffraction and EDAX chemical analysis. A sample of kidwellite from the type locality (furnished by Albert L. Kidwell) provided a very useful standard for thin sections and X-ray diffraction.

Barite $BaSO_4$

Clear tabular crystals of barite are rare, but have been found primarily in association with goethite in cavities in the Chilhowee sandstones.

Beraunite $Fe^{+2}Fe_5^{+3}(PO_4)_4(OH)_5 \cdot 4H_2O$

Orange to red prismatic crystals of beraunite up to 10 mm occur associated with strengite, dufrenite, kidwellite and cacoxenite in cavities. Beraunite is sparse, as vein fillings and in cavities in goethite.

Cacoxenite $(Fe^{+3},Al)_{25}(PO_4)_{17}O_6(OH)_{12} \cdot 17H_2O$

Cacoxenite commonly occurs as bright yellow to golden radiating fibrous masses. It is associated with dufrenite, rockbridgeite, beraunite, strengite, wavellite and goethite. Prismatic hexagonal crystals up to 8 mm occur as fibrous masses or single crystals.

Churchite-(Y) $YPO_4 \cdot 2H_2O$

Rare, white, finely fibrous tufts of churchite occur associated with altered dufrenite and rockbridgeite; it has been noted at only one location on Indian Mountain.

Dufrenite $Fe^{+2}Fe_4^{+3}(PO_4)_3(OH)_5 \cdot 2H_2O$

Sharp brilliant crystals and green-brown fibrous hemispheres of dufrenite occur associated with goethite, strengite and beraunite. Radiating masses have been shown by X-ray diffraction and thin section analysis to be zoned mixtures of rockbridgeite, dufrenite and kidwellite. Crystals may reach 6 mm in length and 2 mm in cross section.

Goethite $FeO(OH)$

Goethite is the most common mineral at all collecting sites. It occurs as massive deposits as large as 8 acres (Crawford, 1957). Less common are bands of ore and cement in chert and sandstone breccia. Stalactitic masses occur within open spaces.

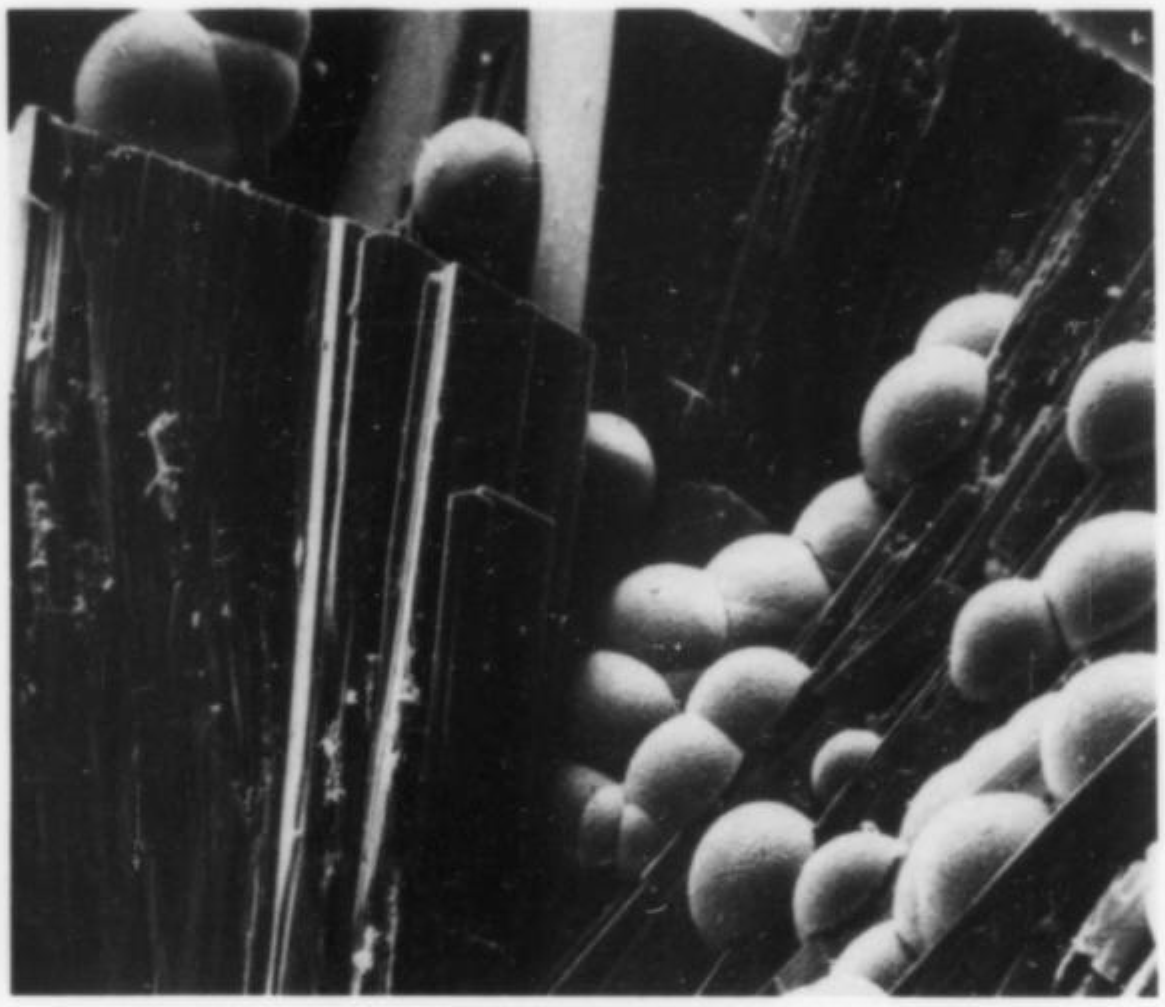

Figure 9. **SEM photomicrograph showing beraunite with botryoidal kidwellite spheres. Beraunites are dark red, vertically striated prismatic crystals. The largest beraunite crystal is 0.2 mm across. All specimens and photographs by J. Gordon. The specimen is from the main pit at Indian Mountain, Alabama.**

Figure 10. **SEM photomicrograph of golden yellow crystal aggregate of cacoxenite. Specimen from Rock Run Station, Alabama. Cluster is 0.18 mm tall.**

Gorceixite $BaAl_3(PO_4)_2(OH)_5 \cdot H_2O$

Gorceixite, though rare, may be found as crystals on quartz near the west end of Indian Mountain, Alabama.

Hematite Fe_2O_3

Deep red-brown massive hematite occurs occasionally associated with the goethite ores.

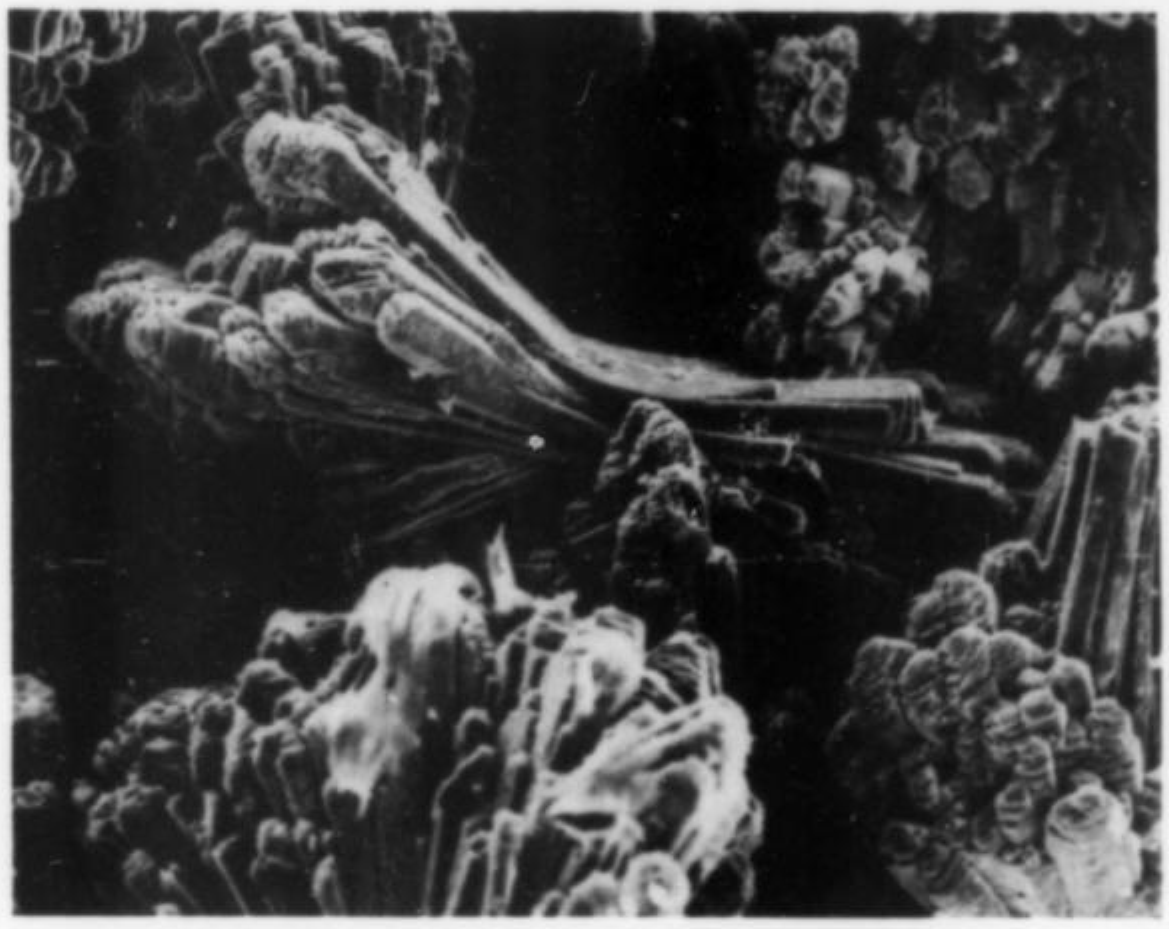

Figure 11. **SEM photomicrograph of greenish brown "bow tie" aggregates of dufrenite. Specimen from Rock Run Station. Large bowtie is 0.35 mm across.**

Figure 12. **SEM photomicrograph of end of aggregate of dufrenite shown in Figure 11. Note the buildup of successive plates. Aggregate is 0.28 mm across.**

Jarosite $KFe_3(SO_4)_2(OH)_6$

Microcrystalline brown jarosite occurs on euhedral rockbridgeite in dump material at hematite mines on the south slope of Indian Mountain (Henry Barwood, personal communication). Jarosite also occurs as yellow-brown crystals on quartz associated with kidwellite near Rock Run Station.

Kidwellite $NaFe_9(PO_4)_6(OH)_{10}\cdot5H_2O$

Pale green and yellow to bright yellow-green kidwellite occurs in boulders as spherical globules with concentric radiating structure, banded with dufrenite and rockbridgeite. Moore and Ito (1978) report kidwellite occurring as sheaves, spheres and feathery crusts and as a replacement after beraunite (often forming pseudomorphs) and rockbridgeite. Kidwellite is common at Indian Mountain and is one of the last phosphate minerals to form (Moore, 1970).

Figure 13. **SEM photomicrograph of jarosite on rockbridgeite and kidwellite. Specimen from Indian Mountain, Alabama. Largest crystal is 0.14 mm across.**

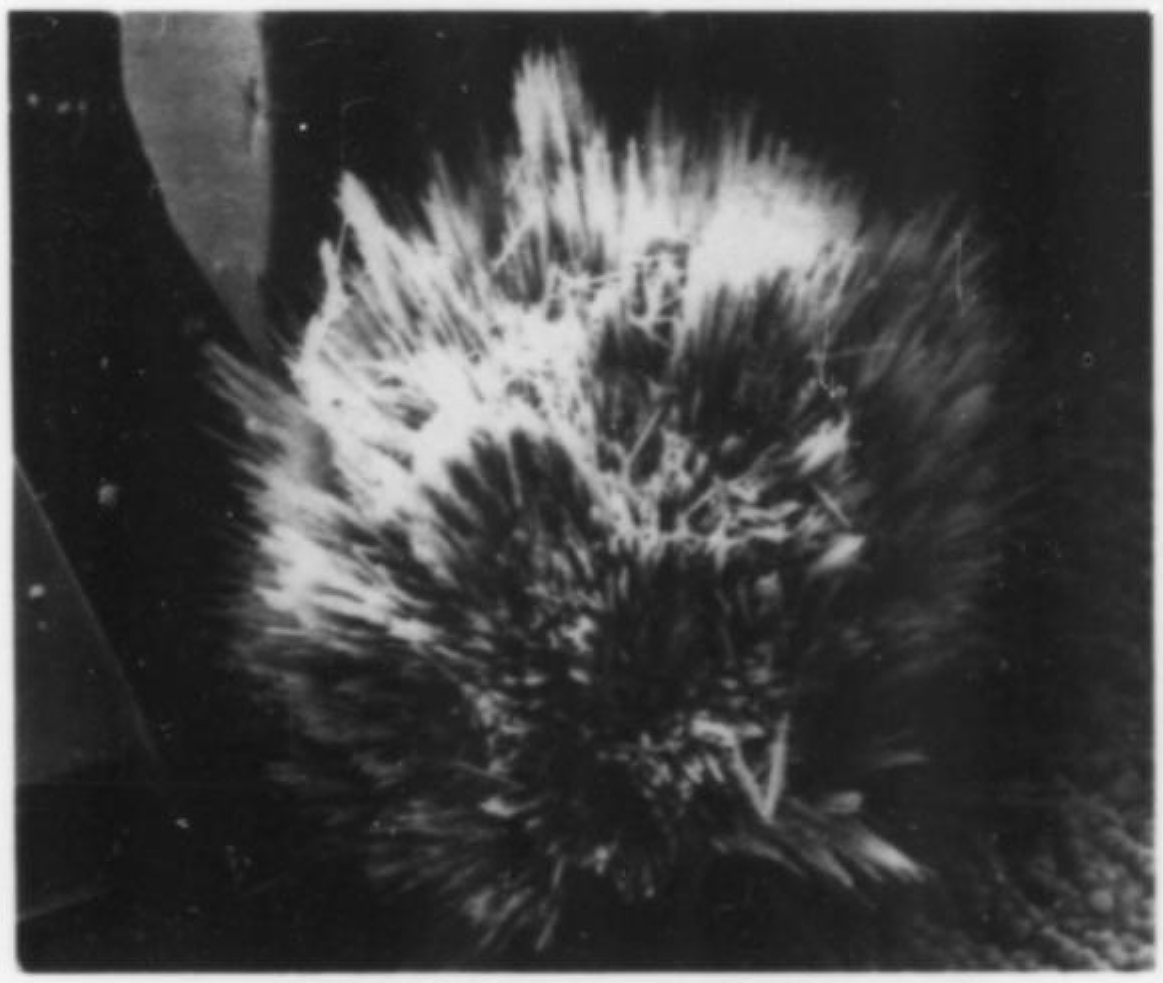

Figure 14. **SEM photomicrograph of concentric radiating light green tuff of kidwellite and platy violet strengite on massive dark green dufrenite. Specimen from Rock Run Station, Alabama. Tuff of kidwellite is 0.17 mm across.**

Leucophosphite $KFe_2(PO_4)_2(OH)\cdot2H_2O$

Light green leucophosphite crystals occur with iron phosphates at Indian Mountain as short prismatic crystals up to 2 mm in diameter (Henry Barwood, personal communication).

Phosphosiderite $FePO_4\cdot2H_2O$

Phosphosiderite is the monoclinic dimorph of strengite (orthorhombic). It occurs as small 1–2 mm pink to purple V-shaped twins.

Pyrite FeS_2

Pyrite may be found within both the Weisner sandstone and the feldspathic Frog Mountain sandstone, rarely as distinct crystals. In the Floyd Shale pyrite occurs as small, euhedral crystals, as fillings along microfractures and in some fossil casts.

Pyrolusite MnO_2

Gray to black pyrolusite crystals may be found in vugs within crystalline masses of manganese oxides replacing sandstone near Rock

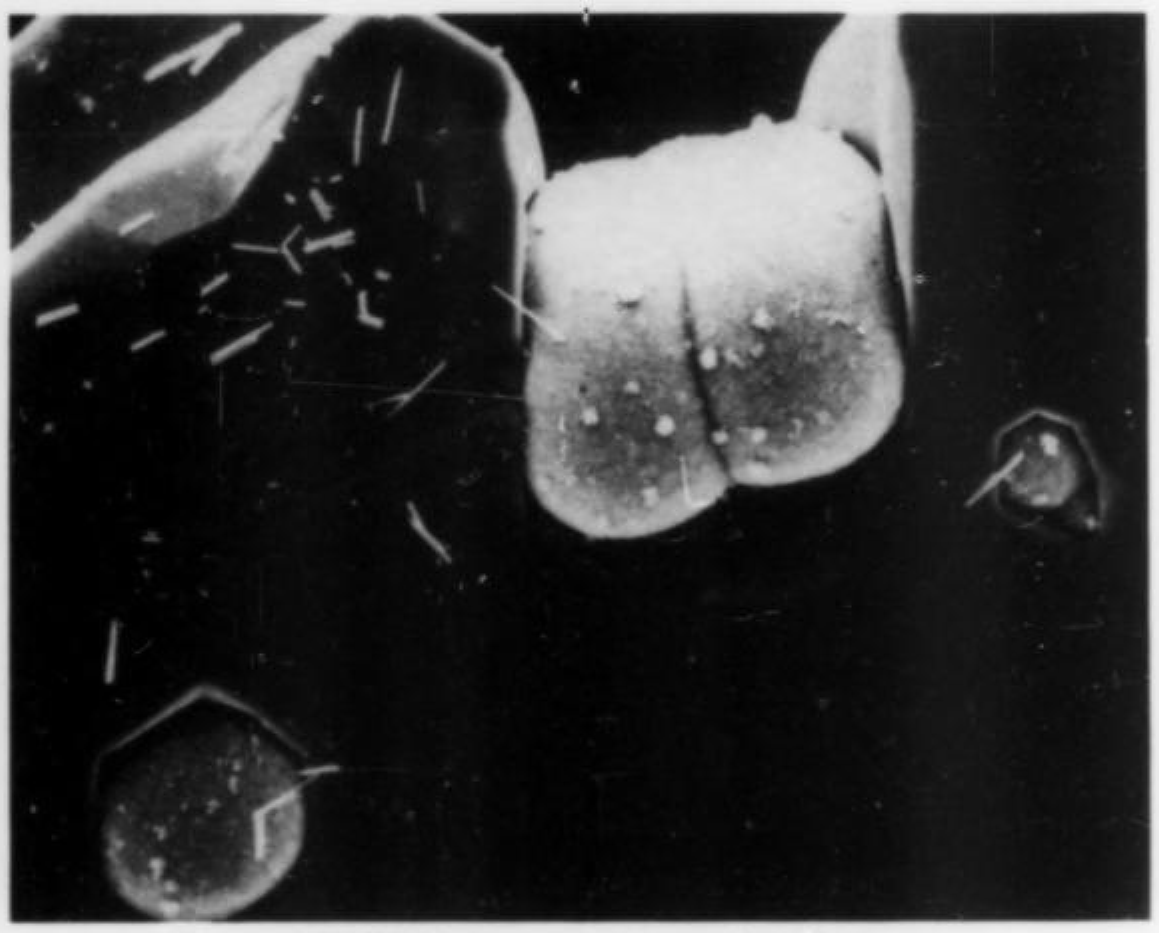

***Figure 15.* SEM photomicrograph of light green botryoidal kidwellite filling hexagonal voids in strengite. Note the unidentified prismatic crystals on both strengite and kidwellite. Specimen from Rock Run Station, Alabama. Largest kidwellite group is 0.05 mm across.**

***Figure 16.* SEM photomicrograph of dark green to black acicular rockbridgeite. The orthorhombic crystals are part of a radially fibrous spheres. Specimen from Rock Run Station, Alabama. Central tuff is 0.68 mm across.**

***Figure 17.* SEM close-up of rockbridgeite shown in Figure 16. Field of view is 0.067 mm across.**

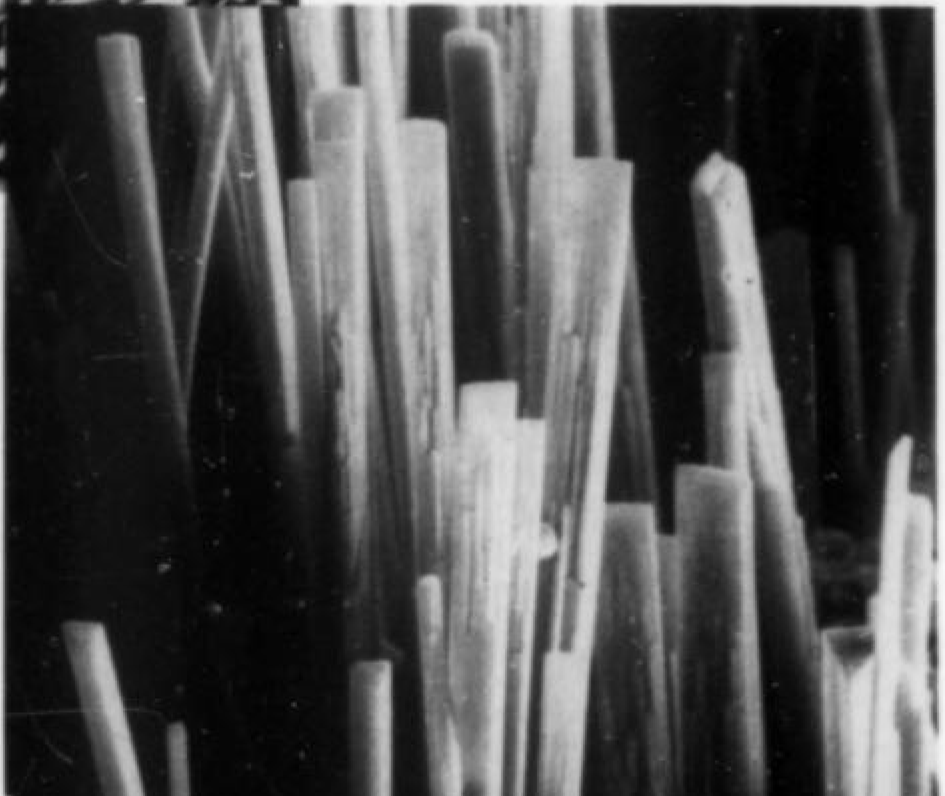

***Figure 18.* SEM photomicrograph of dark brown rockbridgeite from Rock Run Station, Alabama. Field of view is 0.125 mm across.**

Run Station. The pyrolusite is nearly always associated with white fibrous wavellite (Barwood and Hajek, 1978).

Quartz SiO_2

Quartz occurs most commonly as chert and jasperoid in the collecting area, where it is the residue from weathering of cherty carbonates and a replacement of fault breccias and vein fillings. Drusy quartz, often with phosphate mineral coatings, also is common. In the Floyd Shale quartz occurs as microfracture fillings and small, clear euhedral crystals in openings.

Rockbridgeite $(Fe^{+2},Mn)Fe_4^{+3}(PO_4)_3(OH)_5$

Rockbridgeite occurs very abundantly at Indian Mountain as brown to black radially fibrous crusts and spheres and rarely as distinct simple prismatic crystals. It occurs in iron-rich sandstone breccias and is one of the earliest phosphate minerals to form. SEM figures show alteration of rockbridgeite to other phosphate minerals.

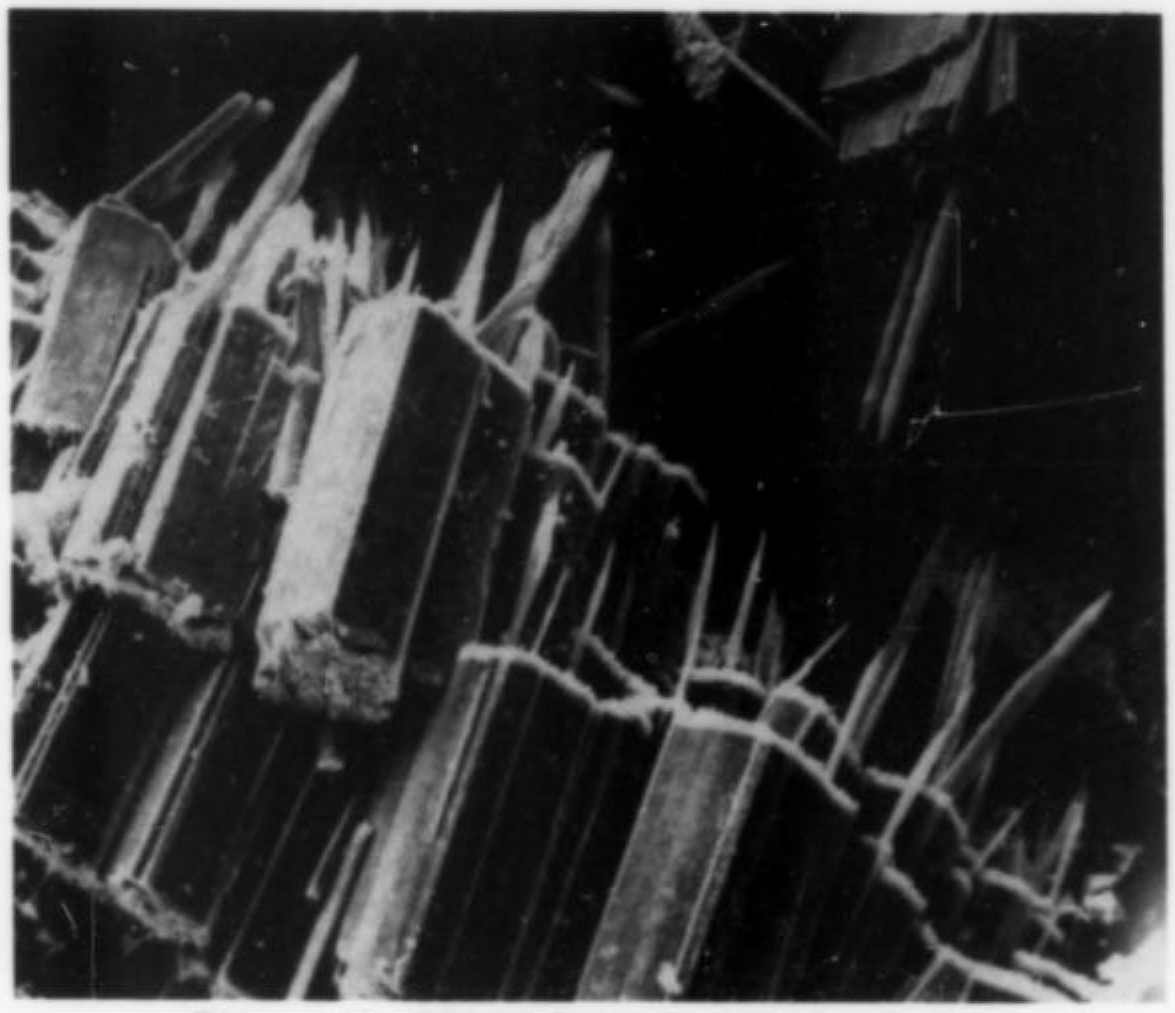

Figure 19. **SEM photomicrograph of dark brown rockbridgeite with prismatic acicular crystals of cacoxenite alteration on basal pinacoids. A Rock Run Station, Alabama, specimen. Rockbridgeite crystals are 0.096 mm long.**

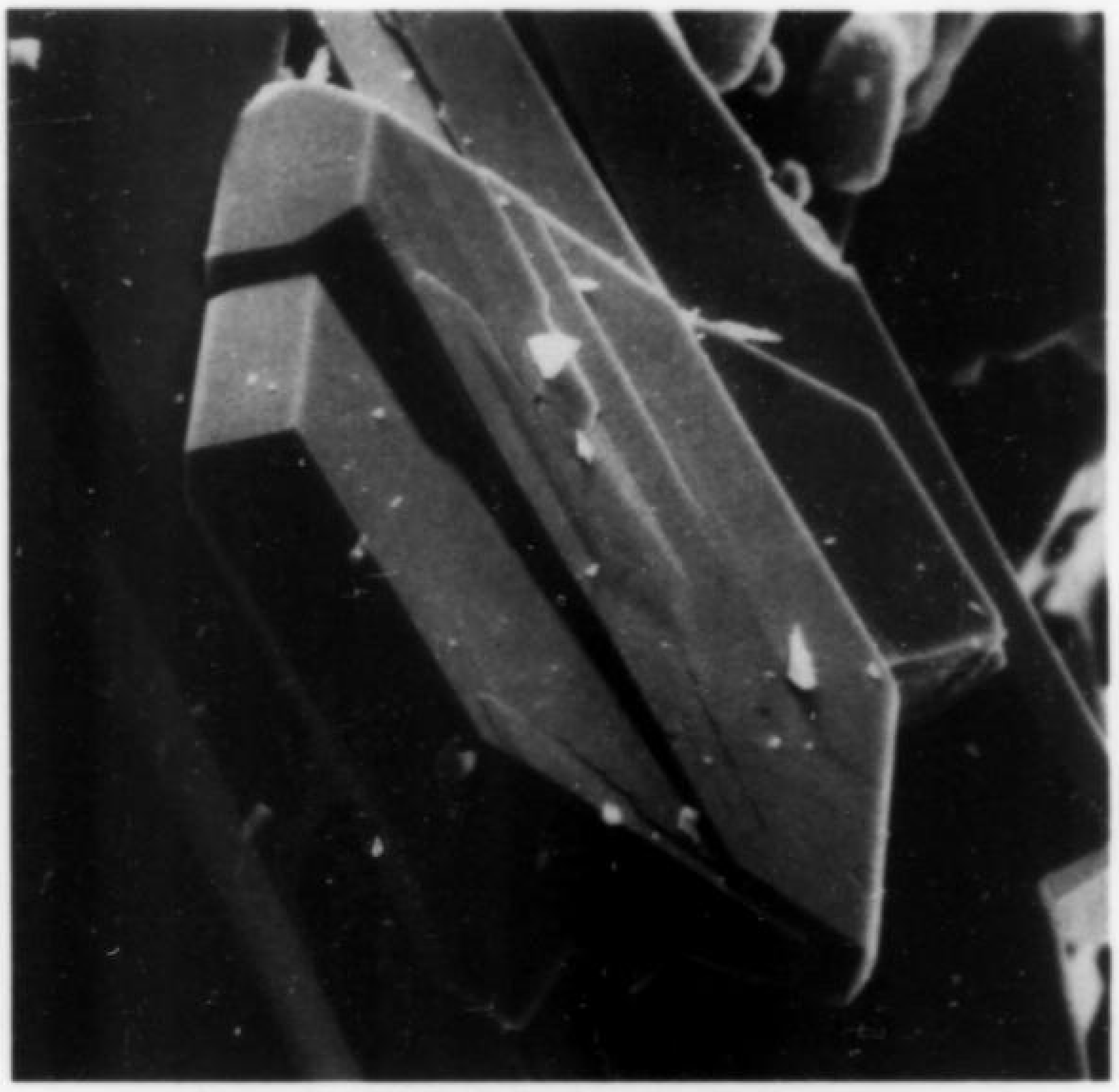

Figure 20. **SEM photomicrograph of dark purple doubly terminated strengite. Specimen from Rock Run Station, Alabama. The penetration twin is 0.125 mm in length.**

Strengite $FePO_4 \cdot 2H_2O$

Excellent strengite specimens are abundant at Indian Mountain. The crystals occur as bright pink to purple prisms and crystalline globular aggregates. Rarely strengite occurs as transparent yellow crystals. Most crystals are 2 to 6 mm and coat surfaces of breccia. Rare crystals up to 10 mm have been collected.

Variscite $AlPO_4 \cdot 2H_2O$

Minute quantities of microcrystalline, pale blue to colorless and transparent variscite have been identified by X-ray diffraction on iron stained sandstone from near Rock Run Station.

Figure 21. **SEM photomicrograph of transparent yellow strengite from Rock Run Station, Alabama. The largest crystal has a length of 0.125 mm.**

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

Cook (1978) reports white masses of radiating wavellite associated with cacoxenite at the Brewer iron mine, located 2 km (1.25 miles) from Grady Station in Polk County, Georgia. The occurrence is in vuggy goethite iron ores. The rare crystals are minute and stout to long prismatic. Wavellite associated with pyrolusite is also found near Rock Run Station.

Table 1. **Minerals of the Indian Mountain area.**

Principal Phosphates
Beraunite
Cacoxenite
Dufrenite
Kidwellite
Rockbridgeite
Strengite

Other Phosphates
Churchite
Gorceixite
Leucophosphite
Phosphosiderite
Variscite
Wavellite

Principal Ores
Goethite
Hematite

Other Species Present
Barite
Jarosite
Pyrite
Pyrolusite
Quartz

CONCLUSION

Fine phosphate microminerals are abundant at over 15 locations within the Indian Mountain area. The majority of these locations are at or close to fault zones or contacts. The fault contact between the Chilhowee Group and the Shady Dolomite contains many collecting sites. All known collecting sites are located on private land and permission to collect must be obtained in writing.

ACKNOWLEDGMENTS

Reviews by Timothy M. Chowns, Thomas J. Crawford (both at West Georgia College) and Bernard L. Murowchick substantially improved this paper. Thanks to Albert L. Kidwell for comparison specimens from the Ouachita Mountains, Arkansas, and to Henry Barwood for his help in field identification and mapping.

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Italian miner. *Harper's*

LAUEITE FROM HAGENDORF-SÜD AND THE PALERMO MINE

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An article published in this journal by Dunn (1985) presented data which showed that supposed laueites from three different locations were indeed ushkovites, with manganese largely or wholly replaced by magnesium. This article prompted responses by Segeler (1987) and Moore (1987) indicating that laueites they had examined from two of the three locations were truly laueites. Segeler (1987) supported his case with results from qualitative chemical analysis and optical data, while Moore argued from the crystal chemical viewpoint. The response by Dunn (1987) suggested that the qualitative analysis was inconclusive, that the optical determinations were not performed on the same material as analyzed, and that structure determinations made in the past were done on material that was not chemically analyzed. These interchanges prompted additional letters (Keck, 1987, and Strunz, 1988). The first provided data on additional laueites from Palermo and Hagendorf-Süd; the second took issue with a point in the reply by Dunn (1987). Interest in this ushkovite-laueite controversy led the writer to investigate specimens from two of the locations involved, the Palermo mine in New Hampshire and the Hagendorf-Süd quarry in Bavaria. Procedures used and results of this work are summarized in this article. The outcome suggests that a continuous series may exist between the end members laueite and ushkovite, and that ushkovite exists in both locations.

The Palermo specimens were loaned from the Harvard Mineralogical Museum through the courtesy of the curator, Dr. Carl A. Francis. The Hagendorf material was obtained from Mr. R. V. Lee, a Canadian mineral dealer, and the original German labels were still attached upon receipt. The Palermo specimens contained amber-colored transparent laueite crystals to 0.8 mm in vugs in a goethite matrix. Some crystals were stained a dark brown; these were not used in the study. No other minerals appeared to be present. Two specimens were available from Hagendorf-Süd, both in a black fibrous matrix. Qualitative chemical analysis of the matrix showed the presence of ferrous and ferric iron, manganese and phosphate. Given the appearance and the components, the matrix is most likely rockbridgeite. A single vug in one of these specimens contained amber-colored laueite crystals to 0.7 mm, yellow stewartite crystals to 0.2 mm, some twinned with spear-shaped terminations, and a tan crust of mitridatite. The density of the stewartite was measured by the heavy liquid method to be 2.52 g/cm³ which is in good agreement with the value of 2.48 g/cm³ calculated from the unit cell constants given by Moore and Araki (1974). Stewartite was sufficiently intergrown with laueite that no material was taken from this specimen for analysis. The other specimen also had a single vug. This contained amber-colored laueite crystals to 0.7 mm, strengite atop a violet crust of phosphosiderite, and an unidentified white opaque phase in crystals to 0.05 mm. Laueite crystals free of any contamination were removed from this specimen for chemical analysis and optical property determination.

Wet chemical analyses were conducted on selected, inclusion-free crystals aggregating to about 200 micrograms per trial. Methods were chosen to be free of mutual interference between cations, and from the phosphate anion. All determinations were made spectrophotometrically, using a Sequoia-Turner Model 340 instrument. Cations and phosphate were determined from aliquots and then the cation values were normalized to phosphate, the latter being taken as two molecules per formula unit. No attempt to determine water or the hydroxyl ion content was made. Standardization of analytical procedures was accomplished using a synthetic phosphate equivalent to a laueite-ushkovite midmember equimolar in manganese and magnesium in a solution of known concentration. The synthetic phosphate was prepared from the nitrates of the cations by treatment with the stoichiometric amount of dibasic ammonium phosphate, evaporation, gentle ignition to remove ammonium nitrate, and solution of the residue in an appropriate quantity of 0.1 M hydrochloric acid. All procedures were carried out on aliquots of this standard solution in replicate analyses and standard deviations were estimated from the results. Iron, manganese and aluminum were determined using the procedure given by Marczenko (1986). Phosphate was determined using the method developed by Zhivopistsev and Istomina (1970). Magnesium required chromatographic separation from the other ions on paper loaded with stannic tungstate (Qureshi *et al.*, 1967), with subsequent determination following Marczenko (1986). The analytical standard deviations were estimated from replicated trials as described earlier, and also from multiple samples of the mineral solutions. The errors were no larger than 5% of the amount present in any instance.

Optical determination of 2V utilized orthoscopic procedures with a spindle stage (Bloss, 1981). The angle and the coordinates for determination of the refractive indices were calculated with the aid of the computer code EXCALIBR (Bloss and Riess, 1973). The ESD in 2V is less than a degree, while the refractive index ESD is on the order of 0.002 units. Densities were determined by the heavy liquid method, with an ESD of 0.01 g/cm³.

The two Palermo specimens analyzed chemically gave identical formulas, within error, for a normalized partial formula of

$$(\mathrm{Mn}^{+2}_{0.62}\mathrm{Mg}_{0.32})\mathrm{Fe}^{+3}_{2.06}(\mathrm{PO}_4)_2.$$

The analysis of the Hagendorf material resulted in a partial formula of

$$(\mathrm{Mn}^{+2}_{0.70}\mathrm{Mg}_{0.28})\mathrm{Fe}^{+3}_{1.89}\mathrm{Al}^{+3}_{0.19}(\mathrm{PO}_4)_2.$$

The optical and density data are given in Table 1.

The analytical results suggest that all specimens examined are laueite, even when allowing for worst-case analytical errors. It is observed that the Hagendorf-Süd specimen trivalent cation values are close to those for the type material, although the magnesium content is significantly higher. The optical data for the Palermo specimens agrees well with the values reported by Segeler (1987); the agreement

Table 1. **Optical and density data.**

Specimen	Refractive Index			2V	$2V_{calc}$	Density
	α	β	γ	(deg)	(deg)	(g/cm^3)
Palermo #1	—	—	—	66.1(8)	—	—
Palermo #2	—	—	—	67.1(5)	—	—
Palermo #3	1.603	1.659	1.682	66.0(7)	63.4	2.45
Hagendorf	1.588	1.654	1.680	62.7(7)	62.1	2.49

is less good for the Hagendorf material. A number of crystals were examined from the same vug, and values for these agreed within error. There may be significant variations from specimen to specimen; ushkovite itself has been previously reported from this location (Gramaccioli, 1986).

There appears to be a paucity of quality optical data on laueite in the literature. No optical data were given by Strunz (1954) in the original publication on laueite. Fleischer *et al*. (1984) quotes 50° for measured 2V, but the values calculated from the indices are much higher and within the range of values reported here for the Palermo material. There is also a disparity between measured and calculated values of 2V for ushkovite. The adjective "around" is used for the 50° measured value given by Chesnokov *et al*. (1983), and the method of determination is not indicated. The average value of 2V calculated from the indices is 74.4°, with a range of 68.9° to 79.7° when worst-case error contributions are taken into account. Thus optical data cannot presently be used as a discriminant between laueite and ushkovite, at least based on data available to the writer.

The densities determined in this work are in good agreement with published values for laueite. In the case of ushkovite, the agreement between the measured value of 2.38 g/cm^3 and that calculated from unit cell parameters of 2.40 g/cm^3 is excellent, within 0.8% (Chesnokov *et al*., 1983). Strunz (1954) gives a range of values from 2.44 to 2.49 g/cm^3 (presumably measured) while a value of 2.56 g/cm^3 results from calculation with the ideal formula and the unit cell constants. These latter constants for the two minerals are remarkably similar, the calculated volume being 350.6 $Å^3$ for ushkovite in comparison to 346.7 $Å^3$ for laueite. Gladstone-Dale calculations, following Mandarino (1981), were made from the data given above, with the assumption that water was present in accord with the ideal laueite formula. The Palermo specimen gave a result for $1–K_p/K_c$ of 0.045; the Hagendorf specimen yielded a value of 0.059, indicating good compatibility of the data in both cases.

Given these results, it is concluded that the specimens examined from both locations are indeed laueites. However, this work shows that laueites can contain such significant quantities of magnesium that a continuous series may exist between ushkovite and laueite. The findings of Dunn (1985) and the report by Gramaccioli (1986) demonstrate the existence of the magnesium endmember at both Palermo and Hagendorf-Süd. Future work may demonstrate the existence of additional intermediate compositions in this possible series.

The crystal samples used in the optical measurements, together with pertinent data, procedures and calculations, have been deposited in the Harvard Mineralogical Museum, Harvard University, Cambridge, Massachusetts. A Palermo crystal is catalogued as HMM 130299, a Hagendorf-Süd crystal as HMM 130300.

ACKNOWLEDGMENTS

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NEW DATA ON THE CAUSE OF SMOKY AND AMETHYSTINE COLOR IN QUARTZ

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INTRODUCTION

A summary of earlier research done on amethyst in this laboratory was published in this journal (Hassan, 1972).

This paper brings our research on this subject up to date. In addition to the investigation of amethyst, several papers have also been recently published on our work on rose and smoky quartz.

Most of the material in this paper was presented at the Eighth Friends of Mineralogy Symposium on Quartz, February 15, 1987 at the Tucson Gem and Mineral Show.

DISCUSSION

Smoky quartz, sometimes known as *cairngorm* (from its occurrence at Cairngorm in Scotland), and nearly black varieties of quartz known as *morion*, occur in many parts of the world. Most quartz will turn smoky or partially smoky when subjected to ionizing radiation such as X-rays or cobalt-60 gamma rays.

In 1955, O'Brien found that the color was produced by a missing electron (trapped-hole) on an oxygen adjoining an aluminum that had replaced a silicon in a tetrahedral site in the structure. This trapped-hole is produced by exposing the quartz containing substitutional aluminum impurity to ionizing radiation. In nature, the source of the ionizing radiation is natural radioactivity. Figure 1 shows the absorption spectrum of a synthetic smoky quartz specimen resolved into a series of gaussian bands. This data must be plotted in electron-volts (eV) or centimeters $^{-1}$ (cm^{-1}) rather than in nanometers. In this figure the spectrum may be resolved into eight absorption bands. The bands of interest here are A_1, A_2 and A_3, which cause the smoky color and are produced by trapped-hole centers on oxygens adjoining the aluminum impurity. As shown in Figure 2 these optical bands are unstable upon heating and completely disappear at 460°C. They may be regenerated by treatment with ionizing radiation.

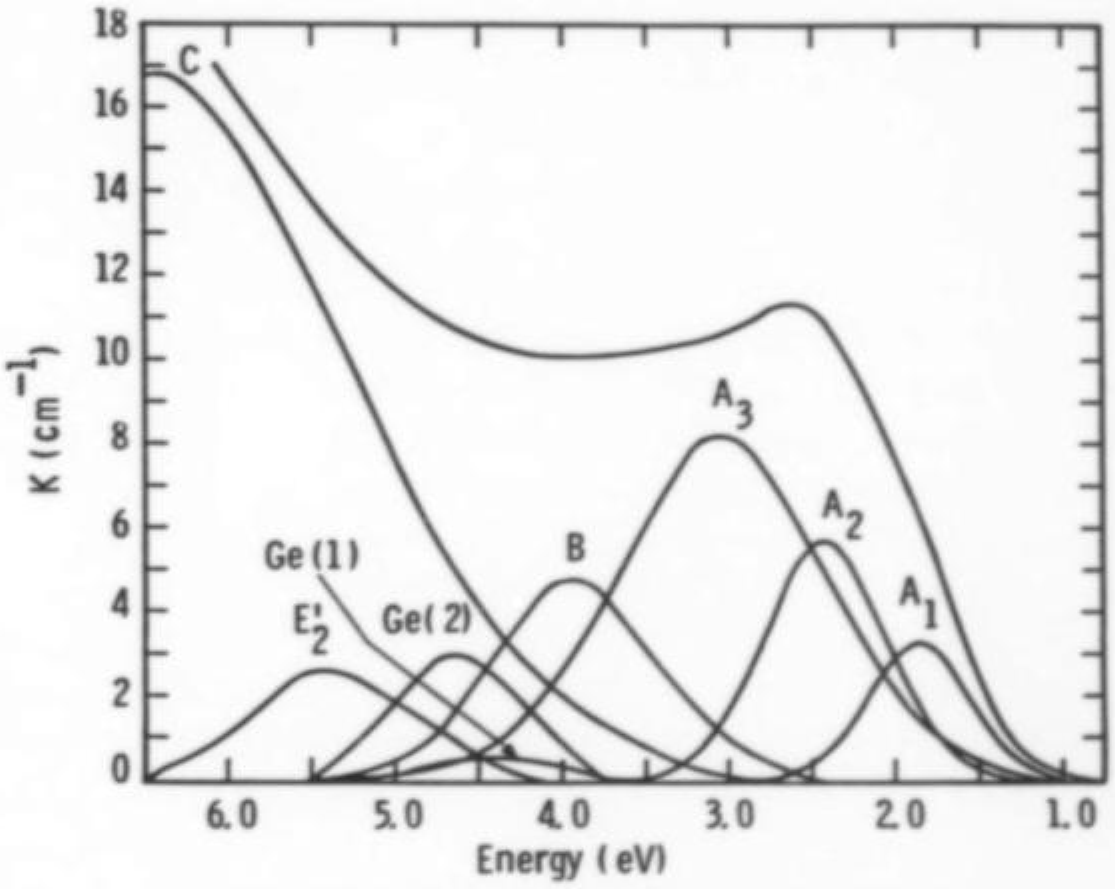


Figure 1. **Gaussian resolution of spectrum of synthetic smoky quartz sample X-542-3 after spectral saturation using cobalt-60 gamma irradiation, data recorded with light polarized along $(1\bar{2}10)$ in slice parallel $(10\bar{1}0)$, after Partlow and Cohen (1986).**

Table 1 gives concentrations of aluminum and iron atom impurity in two synthetic quartzes made smoky by X-ray or cobalt-60 treatment and in the major and minor rhombohedral regions of a uniformly-colored Brazilian amethyst obtained from the National Museum of Natural History, Washington, D.C. The Fe/Al ratios clearly show that smoky quartz has a higher relative amount of aluminum than iron and the Brazilian amethyst has higher iron content in both the amethyst zone (major rhombohedral) and in the colorless to slightly smoky zone (minor rhombohedral). The Al and Fe impurities are calculated in atoms per million silicon atoms in order to compare their abundances atom for atom. Figure 3 shows the absorption spectra of a naturally-colored Brazilian amethyst (NMNH R-1454) before and after heat bleaching, followed by regeneration of the color by up to 18.5 hours of X-ray treatment at 45 pKV and 35 ma. The band labeled θ is responsible for the amethyst color. The difference in the amethyst spectrum in the untreated natural sample and after X-irradiation for 18.5 hours following the heat bleaching is shown in Figure 4. The only difference in the spectra is growth of three bands related to smoky quartz. Since the θ band due to Fe^{+4} is more thermally stable than the absorption bands in smoky quartz, it is presumed that if they were originally present in the natural amethyst, they were thermally bleached.

It was suggested by Cohen (1985) that Fe^{+3} in interstitial sites protects against formation of the smoky quartz centers until all the iron in these sites has formed Fe^{+4}. Thus the formation of Fe^{+4} responsible for the amethyst color requires incipient Al trapped-hole centers and it is formed as a result of simultaneous quenching of these trapped holes when the quartz is subjected to ionizing radiation in nature or in the laboratory as follows:

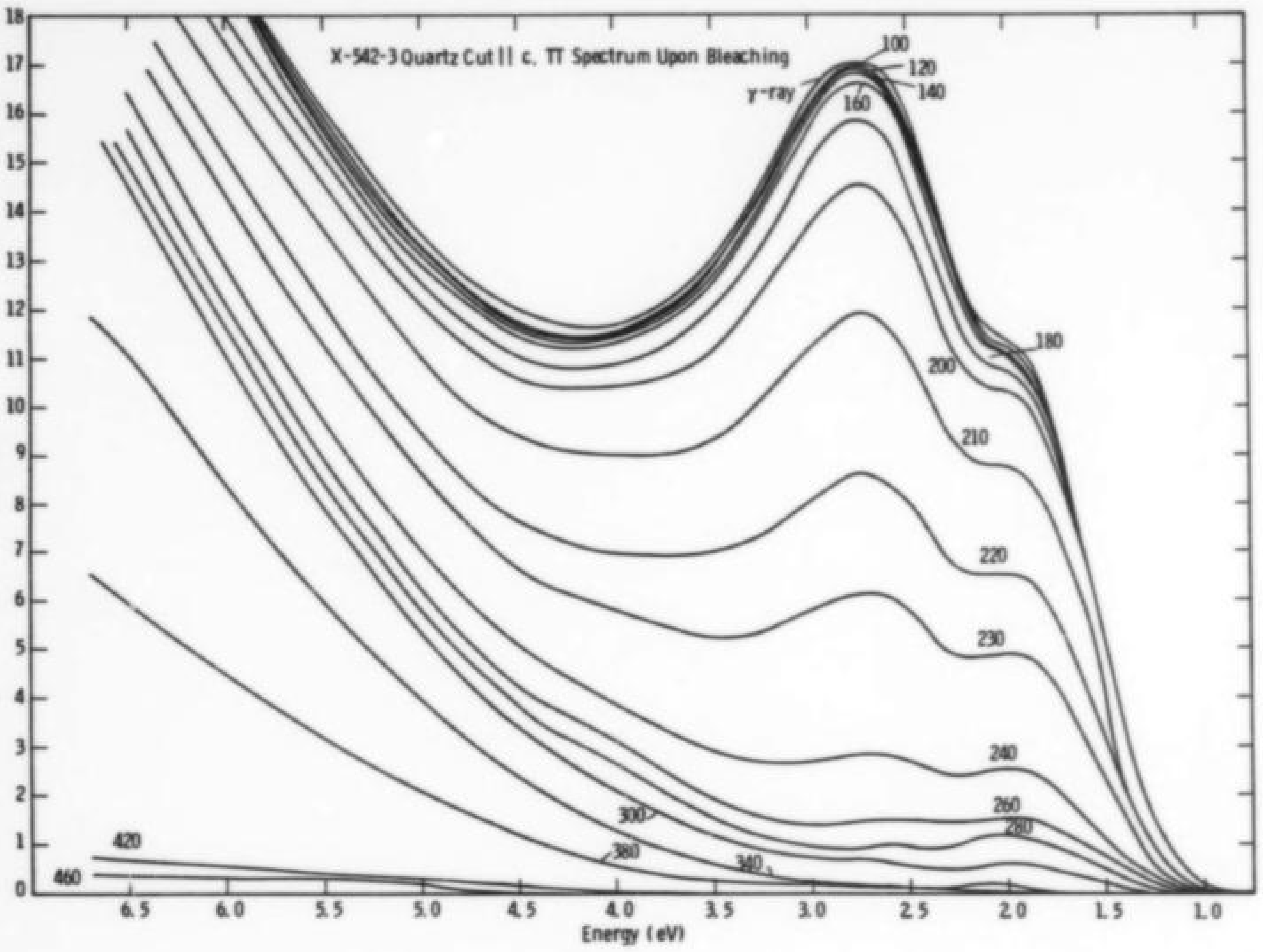
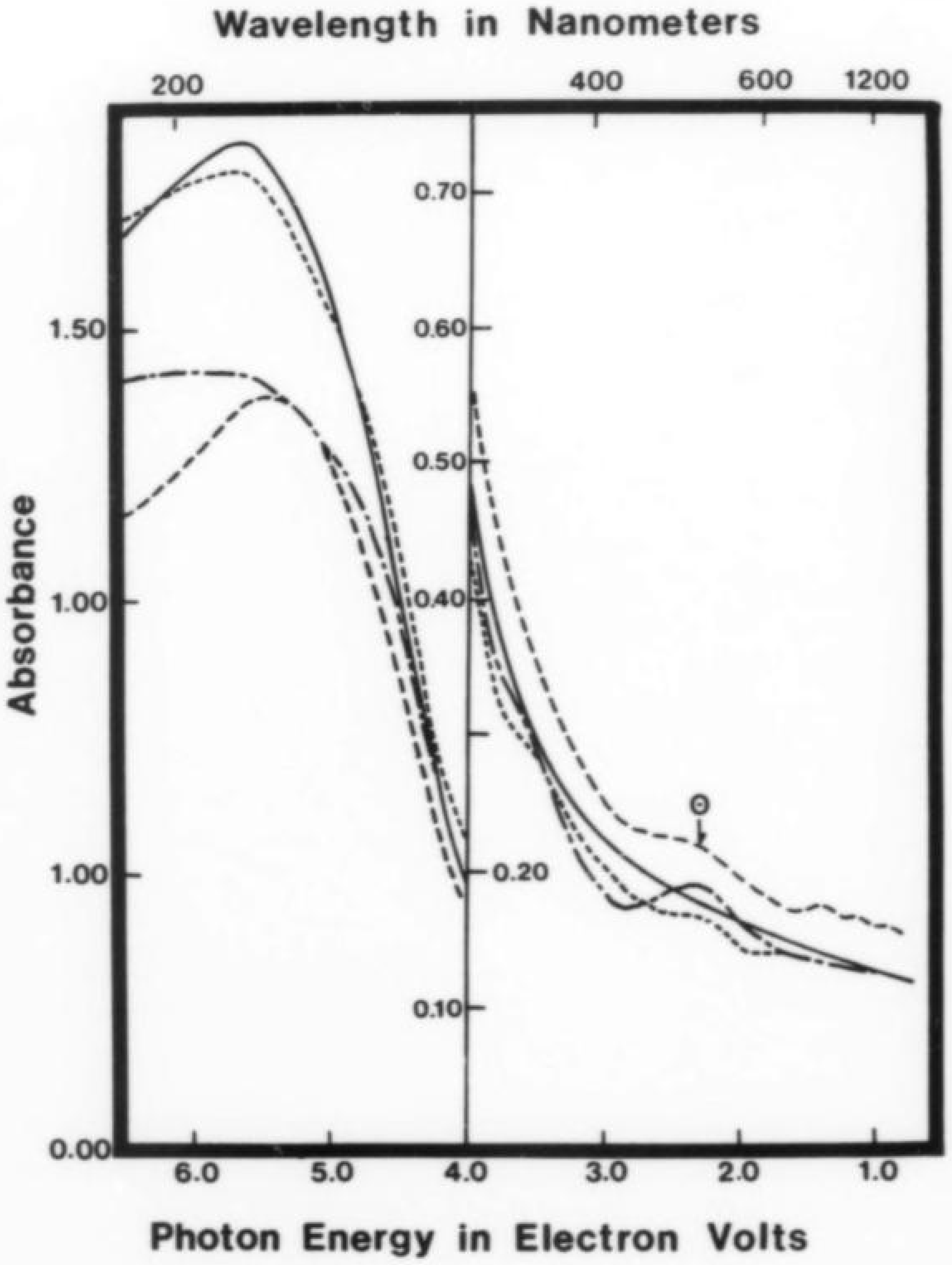


***Figure 2.* Thermal bleaching of smoky color in specimen X-542-3. Temperature in °C. D. P. Partlow, Ph.D. Thesis, 1985, University of Pittsburgh.**

***Figure 3.* Absorption spectra of Brazilian amethyst, USNM R-1454, slice cut perpendicular to *c*-axis: ------ natural spectrum, —— after heating at 500°C, —·—· X-rayed 6 minutes, — — — X-rayed 18.5 hours; after Cohen (1985).**



$\mathrm{Al-O^- \rightarrow Al-O^\circ + e^-}$
(formation of trapped hole center, smoky color)
$\mathrm{Fe^{+3} \rightarrow Fe^{+4} + e^-}$
(interstitial iron, amethyst color)
$\mathrm{Al-O^\circ + e^- \rightarrow Al-O^-}$
(quenching of hole, disappearance of smoky color).

Adekeye and Cohen (1986) have correlated the $\mathrm{Fe^{+4}}$ optical anisotrophy, Brazil twinning and channels in the basal plane of amethyst. This strongly confirms that the $\mathrm{Fe^{+3}}$ which forms the $\mathrm{Fe^{+4}}$ that is stabilized by charge-transfer with the Al trapped-hole is in intersititial sites located in the channels parallel to the *c*-axis and to the *a*-axes of the quartz structure. There are also channels perpendicular to the major rhombohedral faces that do not occur perpendicular to the minor rhombohedral faces. The occurrence of $\mathrm{Fe^{+3}}$ in these channels produces Brazil twinning to relieve strain in the quartz structure. Brazil twining as illustrated in Figure 5 is thus usually synonymous with amethyst color. Therefore yellow-colored Brazil twinned quartz will become amethyst when subjected to ionizing radiation in nature or in the laboratory. Citrine quartz color, not related to Brazil twinning such as occurs in minor rhombohedral growth where the $\mathrm{Fe^{+3}}$ is in substitutional sites for $\mathrm{Si^{+4}}$, is inert to ionizing radiation. This explains the natural occurrence of amethyst-citrine quartz, sometimes referred to as "Ametrine" at such sites as Santa Cruz, Bolivia. The major rhombohedral regions exhibiting Brazil twinning will color amethyst in the presence of trace radioactive elements in nearby minerals and the minor rhombohedral untwinned regions remain inert to the radiation and stay yellow or citrine in color. This material probably underwent heat-treatment in nature to bleach pale violet and smoky colors in the minor rhombohedral regions at a temperature too low to bleach amethyst color in the major rhombohedral regions.

A recent article (Crowningshield *et al.*, 1986) discusses the fact that synthetic amethyst can be produced that does not exhibit Brazil

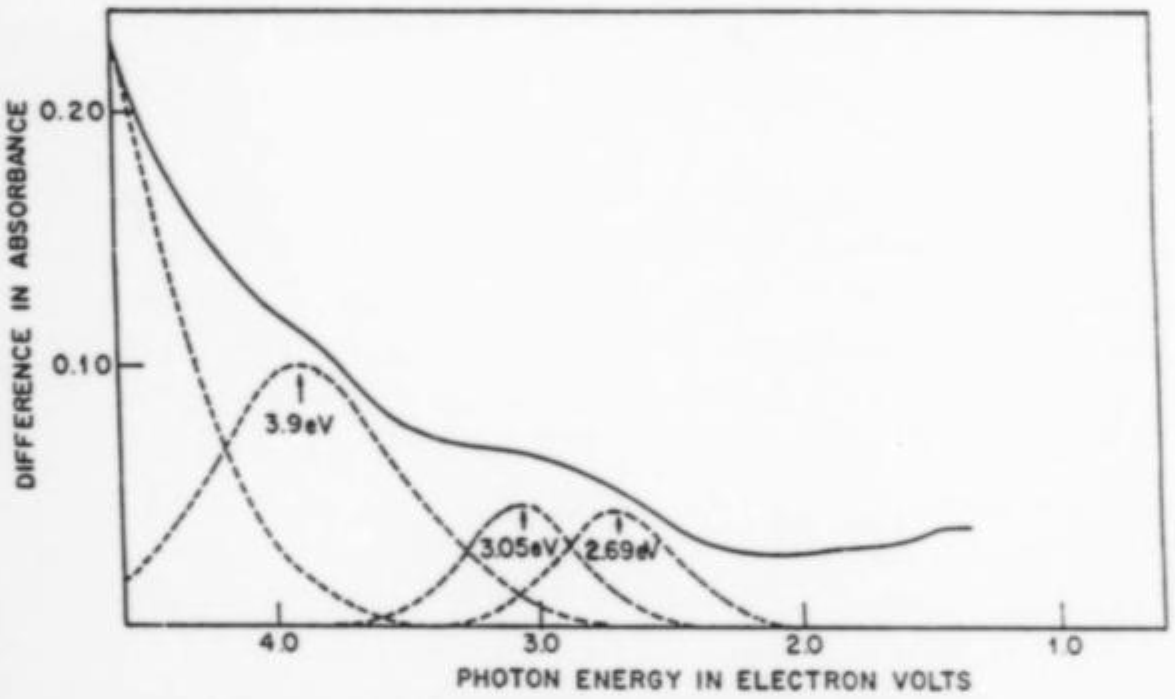


***Figure 4.* Absorption spectral difference between natural spectrum and spectrum after 18.5 hours X-ray as shown in Figure 3. The spectrum is that of smoky quartz with 3.9 eV = B band, 3.05 eV = A_3 band and 2.69 eV = A_2 band, after Cohen (1985).**

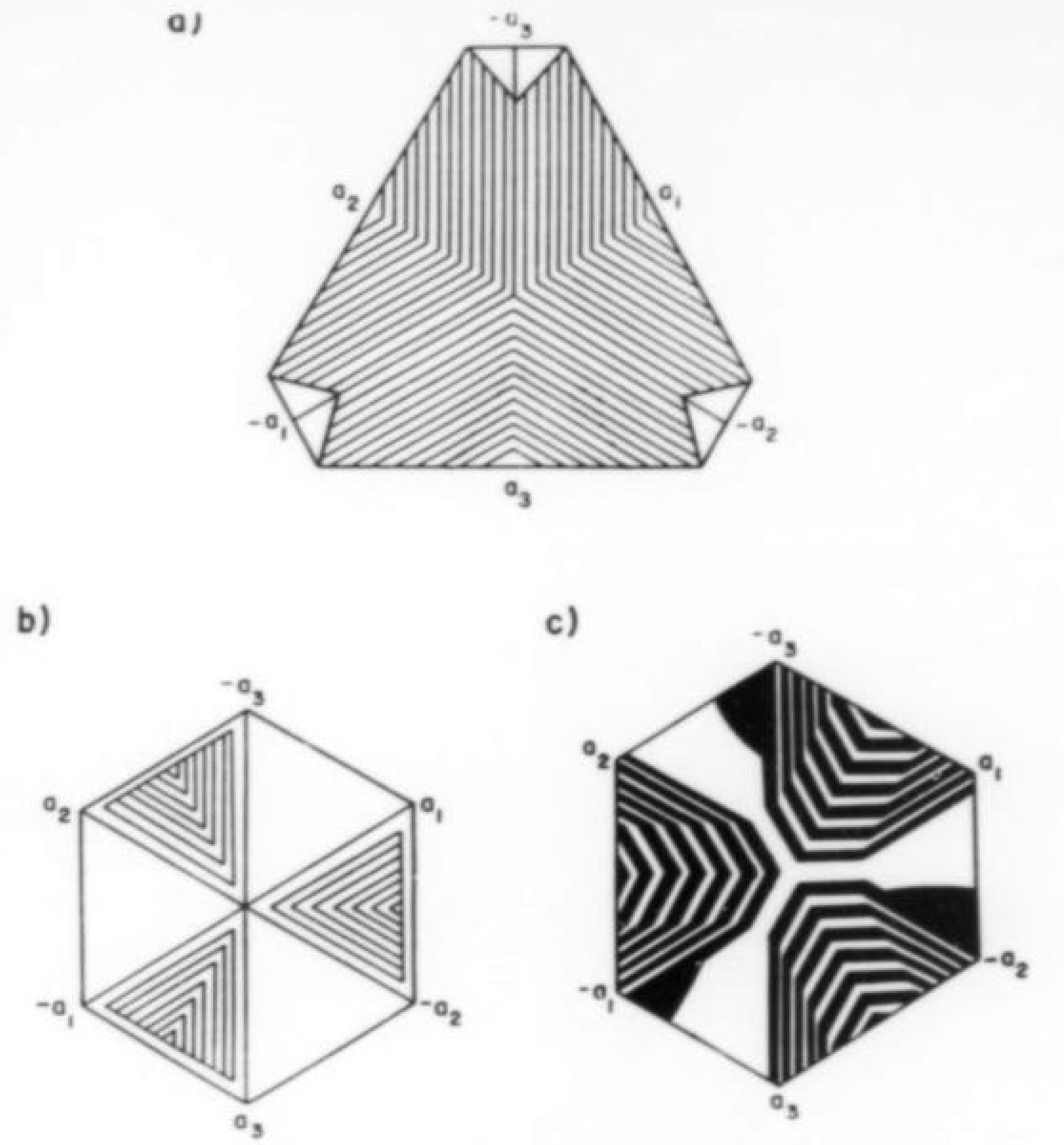


Figure 5. **Idealized lamellar Brazil twinning in basal section of amethyst with extinction bands due to d-, l- twinning observed between crossed Nicols in polarized light. Amethyst color in twin regions only. (a) Twin bands at 120° angles. (b) Twin bands at 60° angles. (c) Twin boundaries, large spacing parallel $(1\bar{2}10)$ and smaller spacing parallel $(10\bar{1}0)$, most general structure of well-crystallized amethyst recognized by Brewster (1823), after Adekeye and Cohen (1986).**

twinning. If the Fe^{+3} content of synthetic amethyst can be kept low enough so little strain is introduced into the quartz structure then the twinning need not take place as it is probably nature's way of relieving strain in the structure. Hematite is sometimes found in the Brewster fringe region of the Brazil twin boundaries indicating an excess of Fe^{+3} in the interstitial voids of the quartz. Excess Fe^{+3} introduced into synthetic amethyst will produce Brazil twinning.

Quartz which is smoky at room temperature will develop the Fe^{+4} absorption band at liquid nitrogen temperature or below (Cohen, 1985, 1986); upon warming to room temperature the quartz reverts to smoky again. This low temperature effect does not require the Brazil twinning to be present and occurs even though the aluminum content greatly exceeds the iron content. It apparently can form from both interstitial Fe^{+2} and Fe^{+3}:

$$Fe^{+2} \rightarrow Fe^{+4} + 2e^-$$
$$Fe^{+3} \rightarrow Fe^{+4} + e^-$$

Thus a surprisingly anomalous effect takes place at low temperature in smoky quartz.

SUMMARY

Cairngorm, morion or smoky quartz owes its color to the presence of trace Al^{+3} impurity in a silicon site in the α-quartz structure. If Al^{+3} is in large excess of interstitial Fe^{+3} in the structure, natural radioactivity will cause colorless quartz to turn smoky due to a trapped hole (missing electron) on an oxygen adjoining the Al^{+3}, produced by the ionizing radiation. This involves three absorption bands in the visible region of the spectrum.

***Table 1.* Comparison of the Aluminum and Iron Contents in Smoky and Amethyst Quartz.**

(atoms per 10^6 Si atoms)

Bell Labs. Synthetic* Specimen X-542-3 Smoky	Bell Labs. Synthetic** Specimen R-27 Smoky	Brazilian Amethyst*** Specimen USNM R-1454	
		Growth Region:	
Major rhombohedral growth	Rhombohedral growth	Major rhombohedral (Amethyst Color)	Minor rhombohedral (Colorless to Smoky)
Al 734	734	18 ± 1	12 ± 1
Fe 54	22	89 ± 3	69 ± 2
Ratio Fe/Al 0.074	0.030	4.94	5.75

*Emission analysis, Partlow and Cohen (1986).
**D.C. Plasma Arc Analysis, Partlow and Cohen (1986).
***Atomic absorption analysis, Cohen (1985).

If Fe^{+3} is present interstitially in major rhombohedral growth in excess of Al^{+3} in silicon sites it will effectively quench the A_2 band and possibly the A_1 band in these growth regions, by furnishing an electron to the trapped hole. Thus Fe^{+4} is created which imparts the amethyst color. The Fe^{+4} ion is stabilized by charge transfer with the oxygen of the trapped hole (Cohen, 1985, 1986). Thus one now has amethyst rather than smoky quartz.

At liquid N_2 temperatures and below trace interstitial Fe^{+2} and Fe^{+3} can undergo the same reaction, the α-quartz being partially transformed to amethyst at the low temperatures. It returns to the smoky state again upon warming to room temperature (Cohen, 1985).

Relationships among Brazil twinning, Fe^{+4}, and channels in the amethyst quartz structure strengthen the conclusion that the Fe^{+4} is located in the interstitial channels in the quartz structure.

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famous mineral localities:

The Phoenixville Lead-Silver Mines Chester County, Pennsylvania

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In the 1850's, the Phoenixville mines produced some of the finest lead minerals the world had ever seen. Especially notable, and best known to mineral collectors, is the bright green pyromorphite from the Wheatley mine. The Phoenixville deposits, discovered in 1683, today stand long abandoned, but the mine dumps are still accessible.

INTRODUCTION

A lead mining boom occurred in the Phoenixville district, Pennsylvania, during the early 1850's. Eleven lead mines are known to have operated in Chester County; however, most of these produced little ore and few mineral specimens. Only the Wheatley and Chester County mines produced significant quantities of ore and mineral specimens. This discussion of mining in the Phoenixville district is restricted to these mines, plus the Brookdale and Phoenix mines, which were on the same vein as the Wheatley mine.

The Phoenixville mines lie along an unnamed tributary of Pickering Creek south of Phoenixville in Schuylkill and Charlestown Townships, Chester County, Pennsylvania. The Wheatley, Brookdale and Phoenix mines lie in a straight line along the same vein; mining took place at intervals over a distance of 1250 meters. The Chester County mine is on an adjacent property.

EARLY HISTORY

Charles Pickering is credited with the discovery of mineralized veins near Phoenixville (Pennypacker, 1882). An Englishman who crossed the Atlantic with William Penn in 1682, Pickering traveled up the Schuylkill River from Philadelphia and thought he discovered silver along Pickering Creek. Pickering returned to Philadelphia and obtained a grant for 5358 acres of land bordering Pickering Creek. This grant became known as the Pickering or Mine Hole Tract. Pickering returned with a miner named Tinker. They mined enough ore to fill eight flour barrels and shipped them to England for assay. The results of the assay are not known but were probably unfavorable, as no commercial mining development took place until 170 years after Pickering's discovery.

In 1683, Pickering was convicted by the Provincial Council at Philadelphia for coining silver money. He was charged with "abuse to ye governmt in Quoining of Spanish Bitts and Boston money to the Great Damage and abuse to ye Subjects thereof." Although Pickering insisted that his coins were good silver, he was found guilty of counterfeiting, ordered to make restitution, and fined £40. The source of Pickering's "silver" is generally attributed to the gossans of the Phoenixville district.

THE WHEATLEY MINE

The Wheatley was the major lead mine in the Phoenixville district, and the most extensive development took place there. Known development on five levels totals 2108 meters of workings. There were six shafts, including a main engine shaft 91 meters deep. The mine was operated by Charles Moore Wheatley, who was prominently involved in mining in the Phoenixville district. At one time or another, he owned or managed most of the major lead mines.

Wheatley was born in Ongar, England, on March 16, 1822. While still a young boy, he moved with his family to Staten Island, New

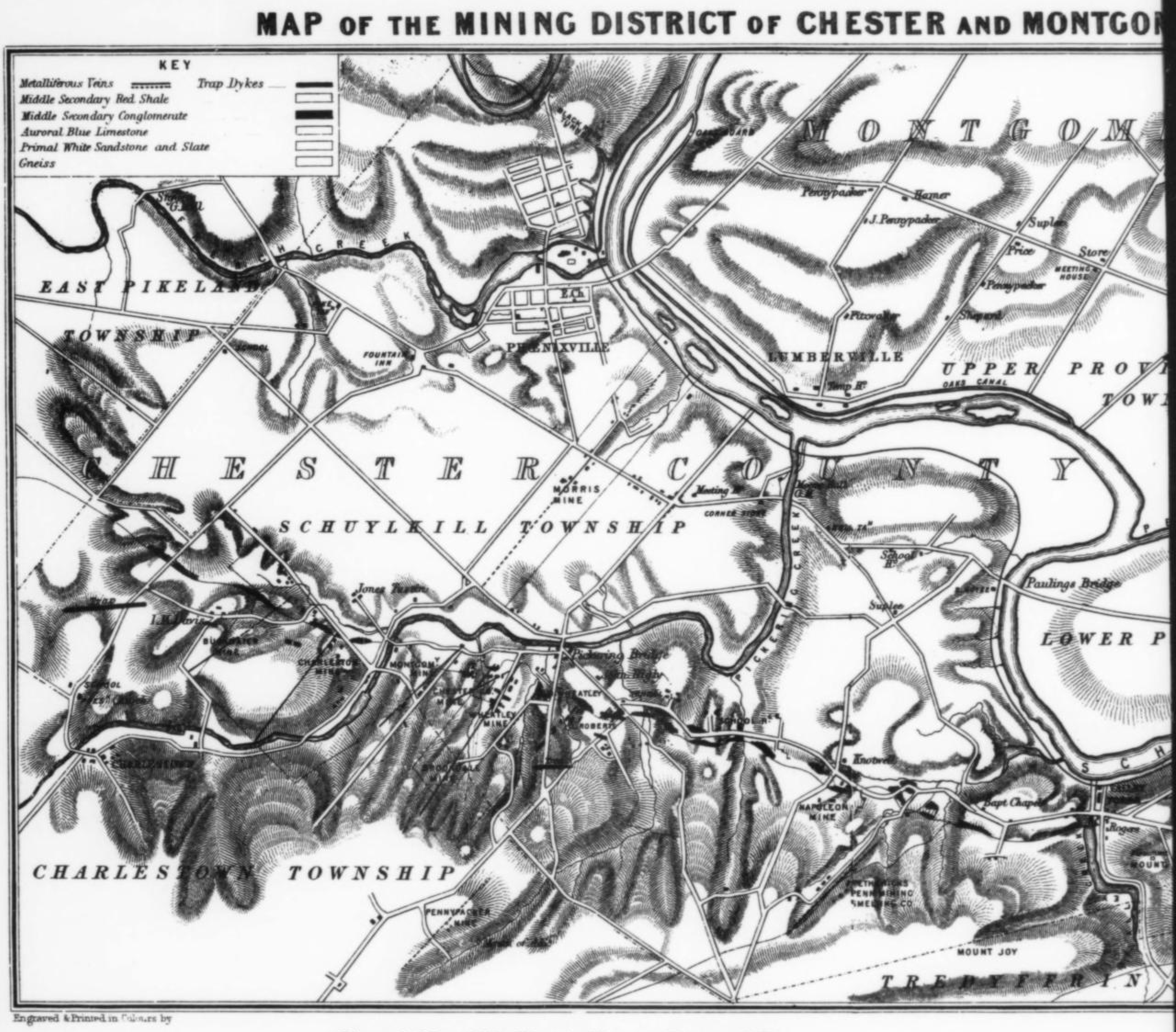


***Figure 1.* Map of the Phoenixville area (Rogers, 1858).**

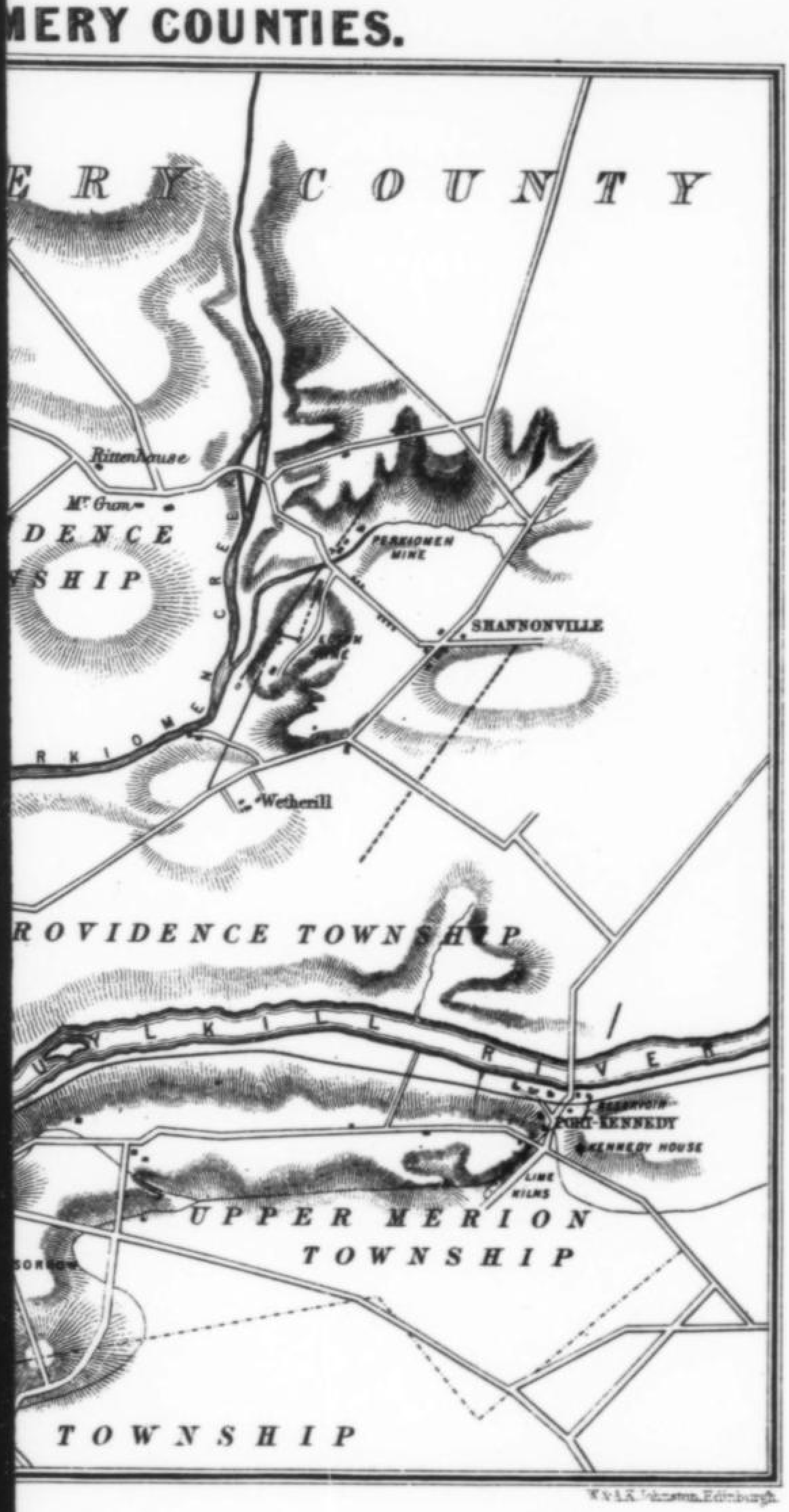
York, where he grew up. In 1846, at the age of 24, he accepted his first mining position, as Manager of the Bristol copper mine in Connecticut. He impressed the owners, who also had a large interest in the Perkiomen mines near Audubon in Montgomery County, Pennsylvania. These lead and copper mines were being reorganized, and Wheatley was appointed Manager there in 1849.

While managing the Perkiomen mines, Wheatley explored the surrounding area for lead and copper ore. Across the Schuylkill River in Chester County, Wheatley found a rich lead vein on the John Williams farm, which was part of the Mine Hole Tract. In the spring of 1850, he leased 46 acres of the Williams farm.

Early in 1851, Wheatley began sinking the main engine shaft. Initially, a 40-horsepower steam engine was used to dewater the mine, but it proved insufficient. In order to raise the capital to continue mining, Wheatley formed the Wheatley Mining Company with Edward Sanderson and John Palmer, owners of the Perkiomen mines. Sanderson was President of the new company; Wheatley was Manager. The new company purchased a 60-horsepower steam engine. In 1851, 160 tons of ore were produced.

In January of 1852, Wheatley resigned as Manager of the Perkiomen mines to work full-time at his own mine. By then, the engine shaft had reached 41 meters. In a letter to John H. Redfield dated January 20, 1852, Wheatley states that the 37-meter level was driven about 128 meters. On this level, the ore vein was 60 to 90 cm wide for over 61 meters. Wheatley wrote he had "some splendid chromates, sulphates, carbonates, molybdates, phosphates, arseniates, and other 'ates' of lead." On April 12, 1852, Wheatley purchased the land he was leasing from John Williams.

At Wheatley's request, Henry D. Rogers, first State Geologist of the Pennsylvania Geological Survey, examined and evaluated Wheatley's mines. After visits in May of 1851 and January of 1852, Rogers wrote favorable reports to Wheatley in two letters dated February, 1852. Rogers visited the mines again and reported his observations in a letter to Wheatley dated May 1, 1853. These observations were published in 1853 (Rogers, 1853) and subsequently included in volume 2 of *The Geology of Pennsylvania* (Rogers, 1858).



The strike of the Wheatley lode is 32–35° NE, with a second set of veins striking 52–54° NE. The veins dip 68° SE, cutting both the strike and dip of the country rock and are up to 1.5 meters wide (averaging about 80 cm). Rogers (1853) reported that in most places, the major part of the vein was composed of gangue material consisting of quartz, decomposed rock and ore minerals. The vein was bounded by well-defined parallel veins of a coarse, soft granitic rock composed chiefly of white feldspar and quartz. Rogers noted:

> The lode was poor in metallic ores, and indeed is almost wholly destitute of them for some feet, and in some places for several fathoms beneath the soil. Descending, we first find, mingled with the gossans or vein-stones, the phosphate, carbonate, and the other readily dissipated ores of lead; still deeper in the vein, an increasing proportion of the sulphuret or galena.

The ore was not uniformly distributed within the vein. In some places, the vein contained practically no ore minerals. At one place, the vein was 1.2 meters wide and consisted of 90 cm of solid galena. This rich ore mass extended with a decreasing thickness from the 55-meter level to the 73-meter level and below, where it was 60 cm thick. The galena occurred chiefly on the hanging wall and varied from crystalline to massive.

Rich ore also occurred in elongated vertical shoots within the vein. The shoots occurred in parallel groups and were most abundant near the Wheatley engine shaft. They ranged from a few centimeters to 1.5 meters thick and dipped 45° W within the vein. In the shoots, sphalerite was most abundant near the walls, while galena and secondary lead minerals comprised the core (Blake, 1860). Rogers (1853) described several branch veins that split from and then rejoined the main vein. These branch veins were up to 1.5 meters thick and deviated 4 meters or less from the main vein. The "horses" between the branch and the main vein were streaked with thin veins of galena and other lead minerals. The branches, containing mainly galena, were worked for ore.

***Figure 2.* Charles Moore Wheatley, 1822–1882.**

When the engine shaft was deepened in 1852, the inflow to the mine exceeded the pump capacity. Wheatley made an agreement with the adjoining Chester County Mining Company for the right to use their adit to drain the Wheatley mine to the 18-meter (adit) level and to work as much of the Wheatley lode as passed through the Chrisman property, on which the Chester County mine was located (Sharwood, 1853). This reduced the quantity of water that had to be pumped from the mine. The Chester County Mining Company also transferred a lease to the mineral rights on the adjoining Funk property to Wheatley. In return, the Wheatley Mining Company agreed to deliver free of charge 150 tons of lead ore to the Chester County Mining Company smelter and to supply 1000 tons of ore containing 50% lead at $27 per ton for 3 years.

In 1853, Wheatley began sinking Sanderson's shaft halfway between the Wheatley and Brookdale engine shafts. Wheatley planned to connect the Wheatley and Brookdale mines underground and pump both mines from this shaft with a Cornish pumping engine (Silliman, 1854). A $26,480 estimate dated April 19, 1853, for a Cornish engine is among Wheatley's papers in the American Philosophical Society Library in Philadelphia. The engine was never purchased.

In 1853 and 1854, 1000 tons of ore, averaging 60% lead, were

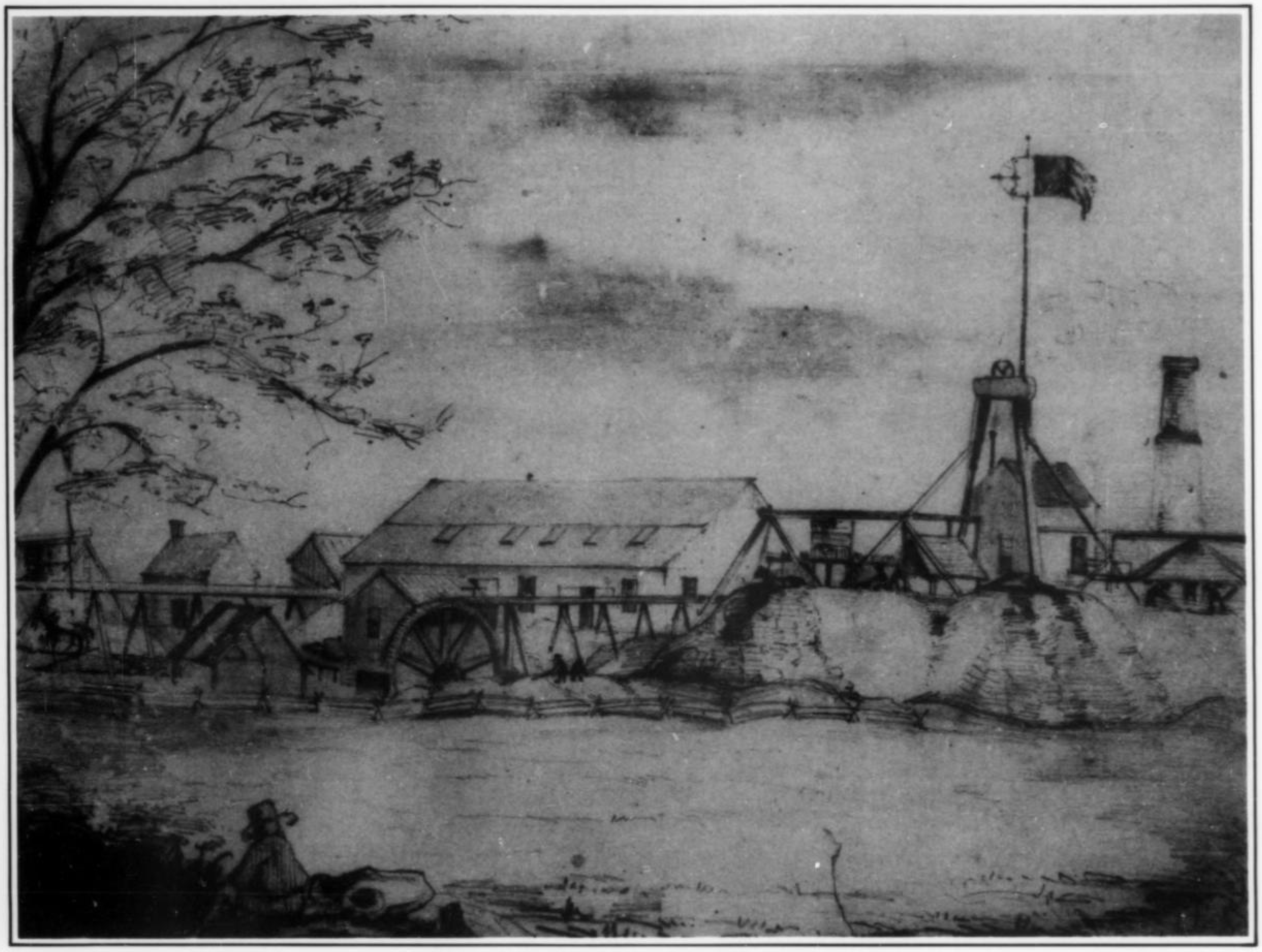


Figure 3. **Drawing of the Wheatley mine in 1853, by G. F. Folingsby.**

produced. The galena yielded 70–80% lead and contained 15–120 ounces of silver per ton. A considerable quantity of pyromorphite was mined near the surface. Blake (1860) reported that during his visit in 1854, over six tons of pyromorphite averaging 60% lead was shipped. The pyromorphite contained 5 ounces of silver per ton. Most of the ore was sold to the adjacent Chester County Mining Company for smelting.

Work was suspended for a time in 1854 because of the low price of lead. Some additional development took place in 1855. Plans were made to deepen Sanderson's shaft to the 73-meter level; however, mining was suspended in 1855 and did not resume for almost a decade. Total production from the Wheatley mine to 1855 was 1800 tons.

The stockholders of the Wheatley, Brookdale and Phoenix mines agreed to merge and create the Pennsylvania Lead Company during a meeting in New York City on September 9, 1855. John C. Beales was elected President and Charles Wheatley, Mine Manager. The Pennsylvania Lead Company sold 58,428 shares of stock for $5 a share. Edward Sanderson and Charles Wheatley were the major stockholders. The Pennsylvania Lead Company never worked the mines because of financial difficulties. At a meeting held November 10, 1856, the shareholders passed a resolution authorizing the officers to sell the effects of the company in April of 1857 if additional capital was not raised over the winter. The money was not raised, and the Pennsylvania Lead Company closed its doors in 1857.

During the Civil War, the demand for lead increased, and interest renewed in the Phoenixville mines. Wheatley purchased the property, machinery and mineral rights of the Wheatley, Brookdale, Morris and Charlestown mines on March 1, 1864. A month later on April 5, 1864, the New York and Boston Silver-Lead Company was formed with an office in New York City. Henry L. Pierson was President, and Charles Wheatley was General Superintendent. On April 16, 1864, the company offered 100,000 shares of stock for sale, and within an hour, 122,000 shares were sold. One month after the stock sale, Wheatley sold the Wheatley mine property, unexpired leases on the Brookdale, Phoenix, Chester County and Charlestown mines, and all machinery and fixtures to the New York and Boston Silver-Lead Company (Evans, 1984).

The New York and Boston Silver-Lead Company commenced operations at the Wheatley mine in April of 1864, and the mine was dewatered to the 91-meter level. Restoration work consisted of cleaning out and retimbering 465 meters of workings, reopening 110 meters of shafts and retimbering the two whim shafts.

Development by the New York and Boston Silver-Lead Company to March 19, 1865, included driving a second adit 180 meters, driving 297 meters of drifts, 223 meters of cross-cuts and sinking an additional 53 meters of shafts (Harvey, 1865). Work continued on the 91-meter level, where the vein was 80 cm wide and consisted of galena and sphalerite. By April 1, 1865, 25 tons of galena were shipped, and 14 tons of pyromorphite were ready for shipping. Another 65–70 tons of dressed lead ore and 12 tons of undressed sphalerite were ready for shipping.

It is not known exactly how long the New York and Boston Silver-

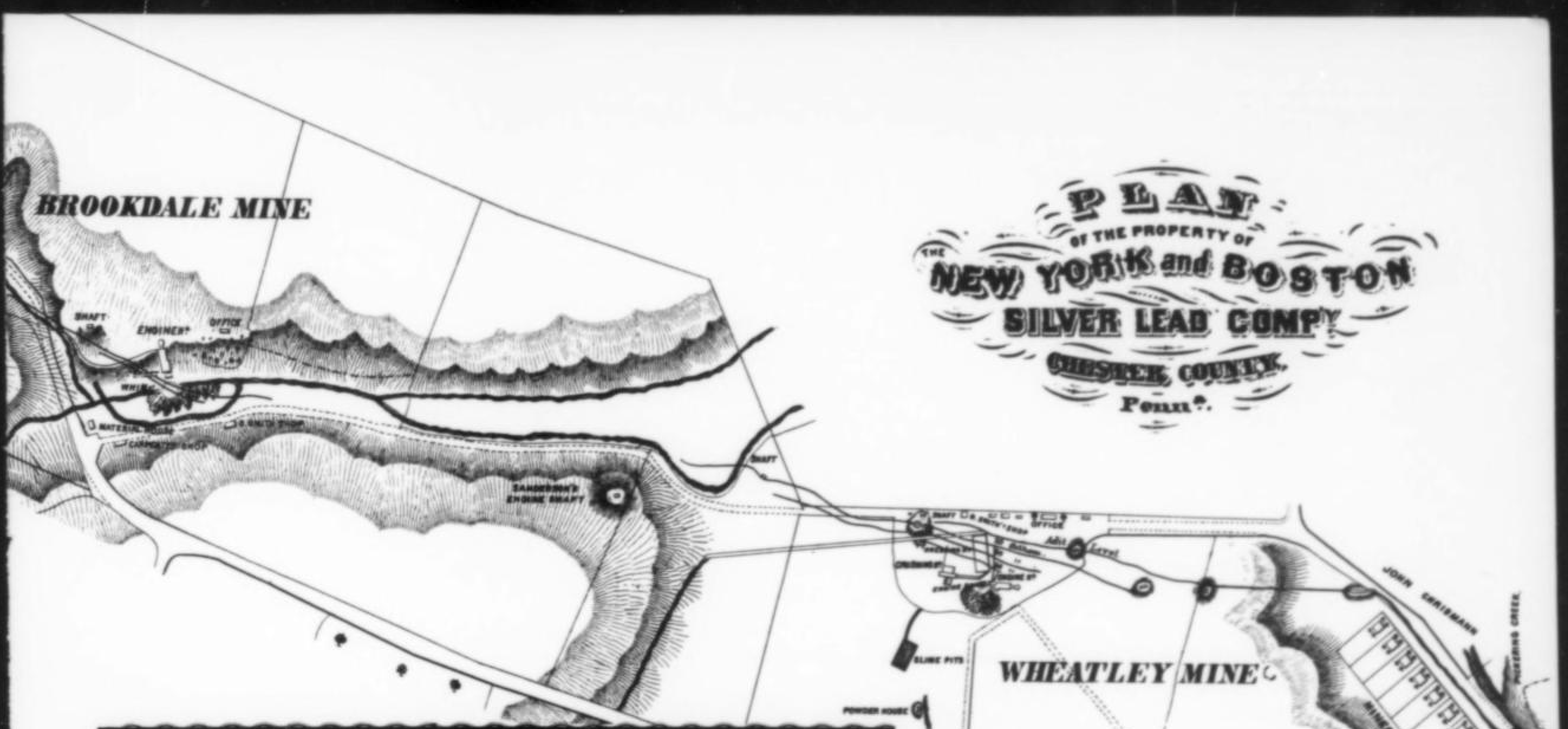
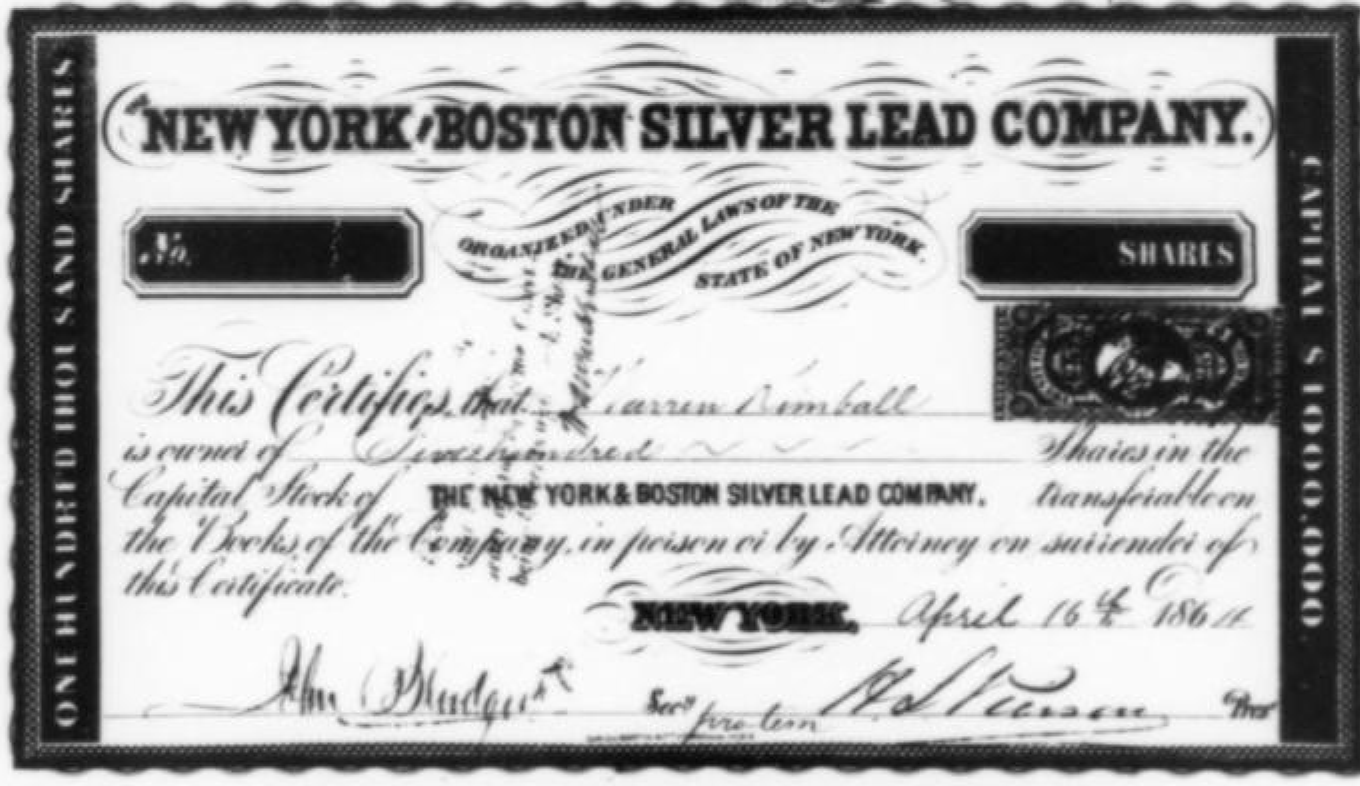


***Figure 4*. Plan of the Wheatley and Brookdale mines in 1864.**



ONE HUNDRED THOUSAND SHARES

CAPITAL $1000,000

NEW YORK & BOSTON SILVER LEAD COMPANY.

No.

ORGANIZED UNDER THE GENERAL LAWS OF THE STATE OF NEW YORK

SHARES

This Certifies that Warren Kimball is owner of Five hundred Shares in the Capital Stock of THE NEW YORK & BOSTON SILVER LEAD COMPANY, transferable on the Books of the Company, in person or by Attorney on surrender of this Certificate.

NEW YORK, April 16th 1864

John Bludgett Secy pro tem

Pres

***Figure 5*. Stock certificate of the New York and Boston Silver-Lead Company, issued in 1864.**

Lead Company operated the Phoenixville mines. No production records are available after April 1865. It is believed that all mining in the Phoenixville district ceased before 1870. The New York and Boston Silver-Lead Company was bankrupt by 1873. A stock certificate for 500 shares of the New York and Boston Silver-Lead Company in possession of the author is stamped, "Received $200. upon these Shares, paid in persuance of an order of the Supreme Court—being 40 cents upon each share. May 25 '73."

CHESTER COUNTY MINE

The Chester County mine was second to the Wheatley in size and development. Known workings total 1675 meters on three levels, not including 12 shafts and seven winzes. It was located on the John Chrisman farm, which adjoined the Wheatley mine property. Welsh miners are believed to have begun work around 1847. Production before 1850 consisted of a little over 20 tons of lead ore plus some copper ore. The mine operators were unable to smelt the ore.

Development prior to 1850 consisted of six shafts and 479 meters of workings on the adit level (Sharwood, 1851). At 213 meters from its mouth at Pickering Creek, the adit cut a 56 to 76-cm wide vein of copper ore consisting of gossan, chalcopyrite and pyromorphite. At 255 meters from its mouth, the adit cut the lead vein.

In 1850, the Chester County Mining Company was incorporated. To raise capital, 6435 shares of stock were sold for $37,225. The Chester County Mining Company began operations in June 1850. Dendy Sharwood was Mine Manager. During the Chester County Mining Company's first year of operation, 380 tons of ore were produced.

The lead ores consisted of pyromorphite, galena and cerussite. Pyromorphite was the most common ore encountered in 1850–51. This ore contained 71.5% lead and 1.6 ounces of silver per ton. Galena ore contained 82.7 to 85.4% lead and from 11.9 to 16.2 ounces of silver per ton (Genth, 1851). Assays of galena by James C. Booth gave 66–75% lead and 18 to 36.75 ounces of silver per ton (Sharwood, 1851). Cerussite ore contained 69% lead and 0.15 ounces of silver per ton (Genth, 1851). A sample of chalcopyrite analyzed by Genth contained 6.1 ounces of silver and 0.305 ounces of gold per ton (Sharwood, 1851).

The strike of the lead vein is N 53° E and the average dip is about 75° N (Genth, 1851). The lead vein was 30 to 90 cm thick at the adit level and was composed of gossan, quartz, galena and sphalerite. The principal ore was galena, averaging 80 cm wide on the 37-meter level. The vein was not uniformly rich.

A smelter with a capacity of 30 tons of ore per week began operating in June 1851 (*Village Record*, July 1, 1851). Since mine production was less than that, the furnace was not run continuously. By November 1, 1852, 453 tons of ore from the Chester County mine and 212 tons of ore from the Wheatley and Montgomery County mines were smelted, producing 334 tons of lead. Most of the ore smelted consisted of pyromorphite and cerussite. Lead production was within 4% of assay (Sharwood, 1852). No silver was recovered from the lead.

By November 1, 1852, the engine shaft was 37 meters deep. At-

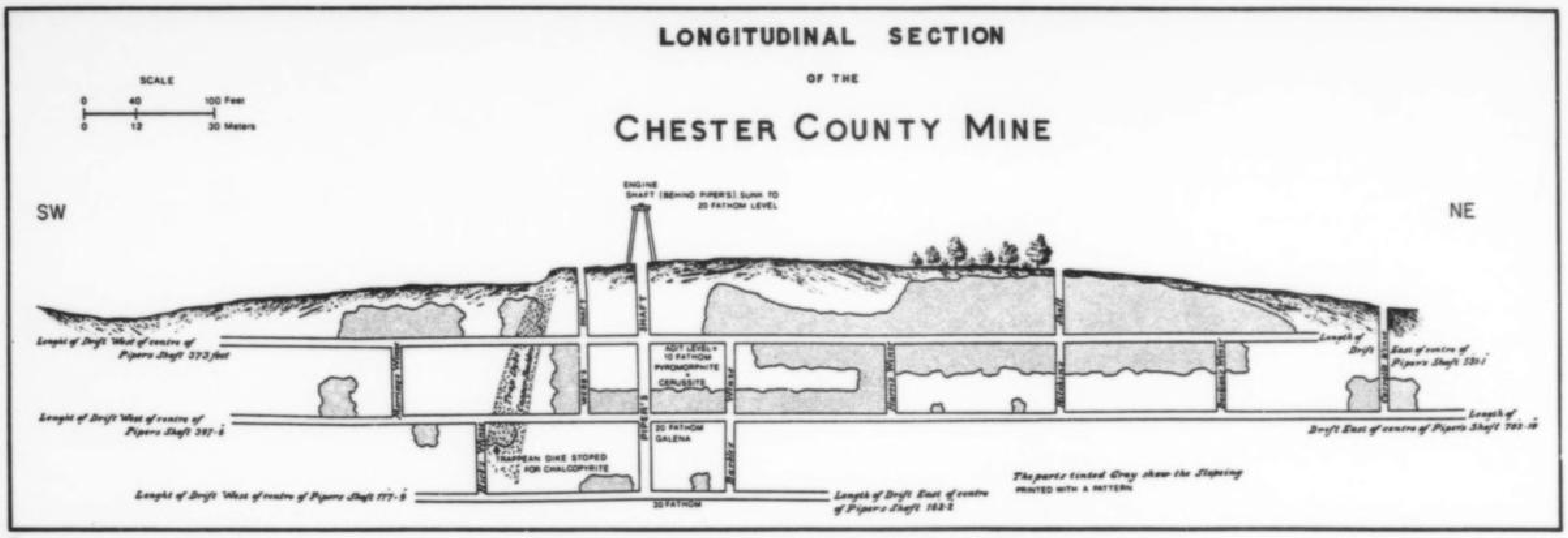


Figure 6. **Cross-section of the Chester County mine (from Sharwood, 1852).**

tempts to deepen it were abandoned because of the hardness of the rock. The engine shaft never reached the 91-meter depth where the lead and copper veins were projected to meet. The 18-meter and 37-meter levels produced 443.5 tons of ore in 1852 (Sharwood, 1852).

On June 9, 1853, the pump was shut down and the mine filled with water. Sharwood (1853) cited the reasons as an increase in labor costs and the increasing abundance of unmarketable sphalerite on the 37-meter and 55-meter levels. After June 9, mining was confined to the western end of the adit level, where a rich vein was followed into the hill west of the engine shaft (Sharwood, 1853). Mining ceased in 1854 when the price of lead fell. On September 11, 1856, the Chester County Mining Company's property, equipment and mining rights were sold at sheriff's sale. Smith (1977) estimates total production from the Chester County mine to be 1243 tons of galena plus a substantial amount of oxidized ore.

THE BROOKDALE MINE

The Brookdale mine is located on the Wheatley lode 634 meters southwest of the Wheatley engine shaft. Charles Wheatley opened the Brookdale mine in October, 1852, on property leased from Joseph Funk. Joseph Cocking was the Mine Captain. The workings consisted of three shafts and 839 meters of drifts on three levels. The engine shaft was 59 meters deep.

Cocking began exploring for ore by sinking a series of pits and tracing the vein. The engine shaft was sunk and the engine installed in December of 1852; it began pumping in March, 1853. A 60-horsepower steam engine pumped water and crushed ore. An iron Cornish steam whim hoisted ore.

An adit, beginning about 32 meters north of the engine shaft, was driven 139 meters southwest on the vein. The adit was shallow, reaching a maximum depth of 11 meters below land surface and averaging 7 meters. At the end of the adit, the vein was nearly 60 cm wide. It was streaked with pyromorphite, cerussite and galena. Above the adit, several tons of ore were stoped 6 meters below land surface (Rogers, 1853).

The vein dips 76° and is up to 1.5 meters wide. The lead vein was thicker at the Brookdale end of the lode than at the Wheatley end, but it contained more quartz (Rogers, 1853). The vein in the west end of the 26-meter level was 80 cm thick and was composed chiefly of quartz and gossan (Blake, 1860). On the east end, the vein was 1.5 meters wide and was composed of quartz "richly spotted" with chalcopyrite (Cocking, 1863).

The Brookdale engine shaft was sunk just above a dam and diversion ditch constructed on a tributary of Pickering Creek. The ditch diverted water to John Chrisman's farm, where it was used for watering livestock. Water pumped from the engine shaft was discharged to the stream. In 1853, John Chrisman sued Charles Wheatley for polluting and diminishing the flow of this stream (Supreme Court for the Eastern District of Pennsylvania, 1855). Chrisman complained that the discharge water was turbid and unfit for livestock. He accused Wheatley of throwing in "quantities of mineral ore, filth, and refuse, by which the water of the stream was corrupted." Wheatley, upon hearing Chrisman's complaint, diverted the mine pumpage to the Wheatley works. However, the mine dewatering reduced the natural streamflow, and Chrisman requested that Wheatley restore the flow of the stream. When the flow was not restored, Chrisman filed suit. On January 27,

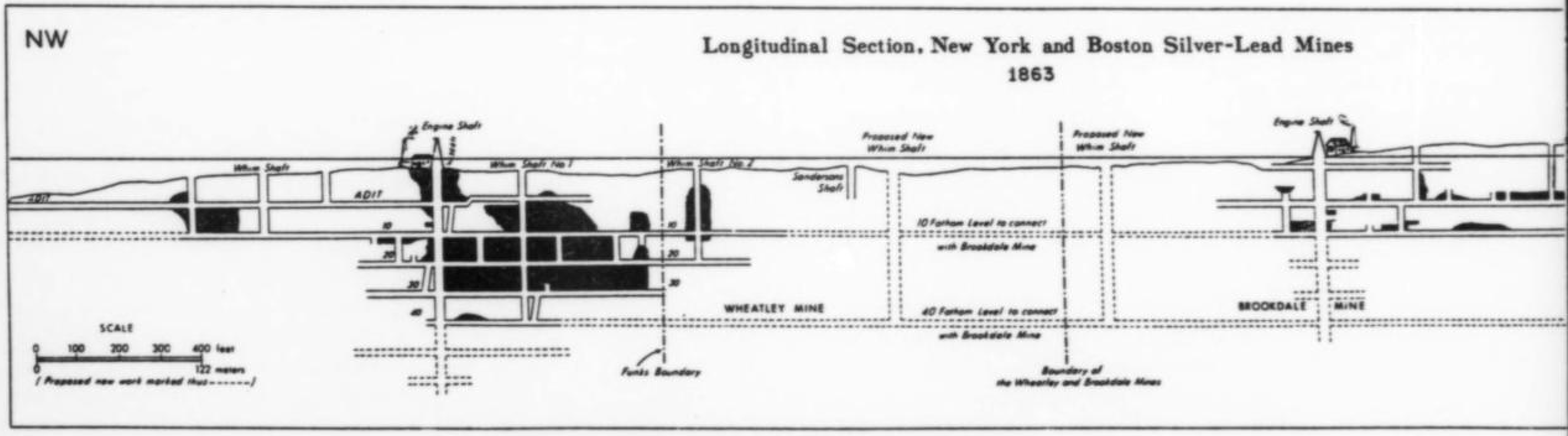
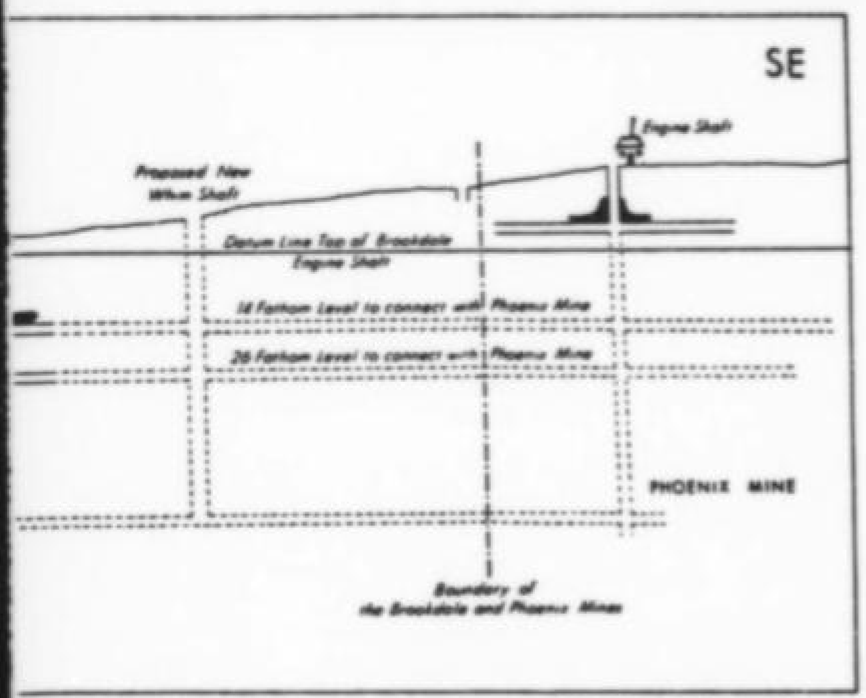


Figure 7. **Cross-section of the Wheatley, Phoenix and Brookdale mines.**

1854, a panel of arbitrators ruled in Chrisman's favor and assessed Wheatley $174 in damages. Wheatley appealed the arbitrators' decision. At the second hearing, Dendy Sharwood, Superintendent, and other employees of the Chester County Mining Company testified against Wheatley. The Chester County Mining Company used water from Chrisman's diversion ditch for washing ore, and the diminished flow interfered with their operations. On January 8, 1855, a jury awarded Chrisman $341 in damages. The Pennsylvania Supreme Court upheld the verdict in June 1855. As a result of this lawsuit, Brookdale mine operations ceased.

The New York and Boston Silver-Lead Company acquired the Brookdale mine in 1864. In Harvey's report of March 15, 1865, the pumping engine was being repaired and pumping was expected to begin within two weeks. The adit was driven another 37 meters, yielding about 4 tons of dressed pyromorphite (Harvey, 1865). It is not known if further development took place at the Brookdale mine.

Figure 8. **Smokestack of the pumping engine of the Brookdale mine, in 1988.**



Albert E. VanOlden, Cartographer

THE PHOENIX MINE

The Phoenix mine was opened and operated by Charles Wheatley. It is located on the Wheatley vein about 1067 meters southwest of the Wheatley engine shaft and about 421 meters from the Brookdale engine shaft, on the property of Joseph Funk.

Little work was done at the Phoenix mine. A steam engine was erected for dewatering. A shaft 27 meters deep was sunk and drifts were run 122 meters along the ore vein from the bottom of the shaft (Blake, 1860).

LATER WORK

The mines in the Phoenixville district were dormant from the late 1860's to 1917. The Eastern Mining and Milling Company did additional mining in the Phoenixville district from 1917 to 1920. The Wheatley mine was reopened, and the shaft was retimbered in January, 1917.

In 1918, a mine on the Chester County vein was dewatered and further developed. Smith (1977) calls this mine the Southwest Chester County mine. It is also known as the New Chester County mine. The main shaft of the Southwest Chester County mine is located 328 meters southwest of the Chester County mine engine shaft, and an air shaft is located 114 meters southwest of the main shaft. The two shafts were connected at levels of 43 and 61 meters, and about 274 meters of drifts, winzes and raises were driven. Shaft no. 1 produced mostly zinc ore; shaft no. 2 produced mostly lead-silver ore. In August, 1919, about 500 tons of ore were mined, and the daily production was reported to be about 20 tons (Bascom and Stose, 1938).

A small concentrating plant was erected at the Southwest Chester County mine. In one shipment of 100 tons made June 1, 1920, the concentrates averaged 79% lead and contained 7.5 ounces of silver per ton (Miller, 1923). Operations ceased on July 20, 1920; this was the last mining activity in the Phoenixville district.

The Wheatley lode was evaluated as part of the U.S. Bureau of Mines investigation of strategic mineral deposits. Between October, 1947, and March, 1948, eight holes totalling 860 meters were diamond-drilled along the Wheatley-Brookdale lode. The holes were drilled at a 60° incline to intercept the vein below the old workings. The cores, described by Reed (1949), contained no significant lead-zinc mineralization. One hole penetrated 1.4 meters of open stope and 1.7 meters of vein rock approximately 63 meters below land surface. About 4 meters below this opening, the hole penetrated a 15-cm vein of massive sphalerite. Smith (1977), based in part on discussions with A. V. Heyl, believes the holes may not have been well located and may not have reached the vein, especially if the vein dips more steeply than reported.

GEOLOGY and ORE GENESIS

Most of the Wheatley-Brookdale-Phoenix vein is in Precambrian leucocratic and intermediate felsic gneiss. The gneiss is a fine-grained to medium-grained microcline-microperthite-quartz gneiss with minor hornblende, magnetite and biotite. It is associated with biotite-oligoclase-microperthite-quartz gneiss and interlayered with amphibolite (Lyttle and Epstein, 1987). The ore-bearing veins cut both the dip and strike of the gneiss. The gneiss at the vein contact was decomposed to a considerable depth. Rogers (1853) described it as "a crumbling, purplish red, unctuous, and clayey material." This weathered zone made mining very easy, particularly in the upper workings. The northern part of the vein cuts red siltstone of the Triassic Stockton Formation, indicating that the veins are late Triassic or younger in age.

The orebodies in the Phoenixville district are fillings of open breccia zones that followed small-scale normal faulting. The open zones were filled by silica-bearing and metal-bearing hydrothermal fluids from

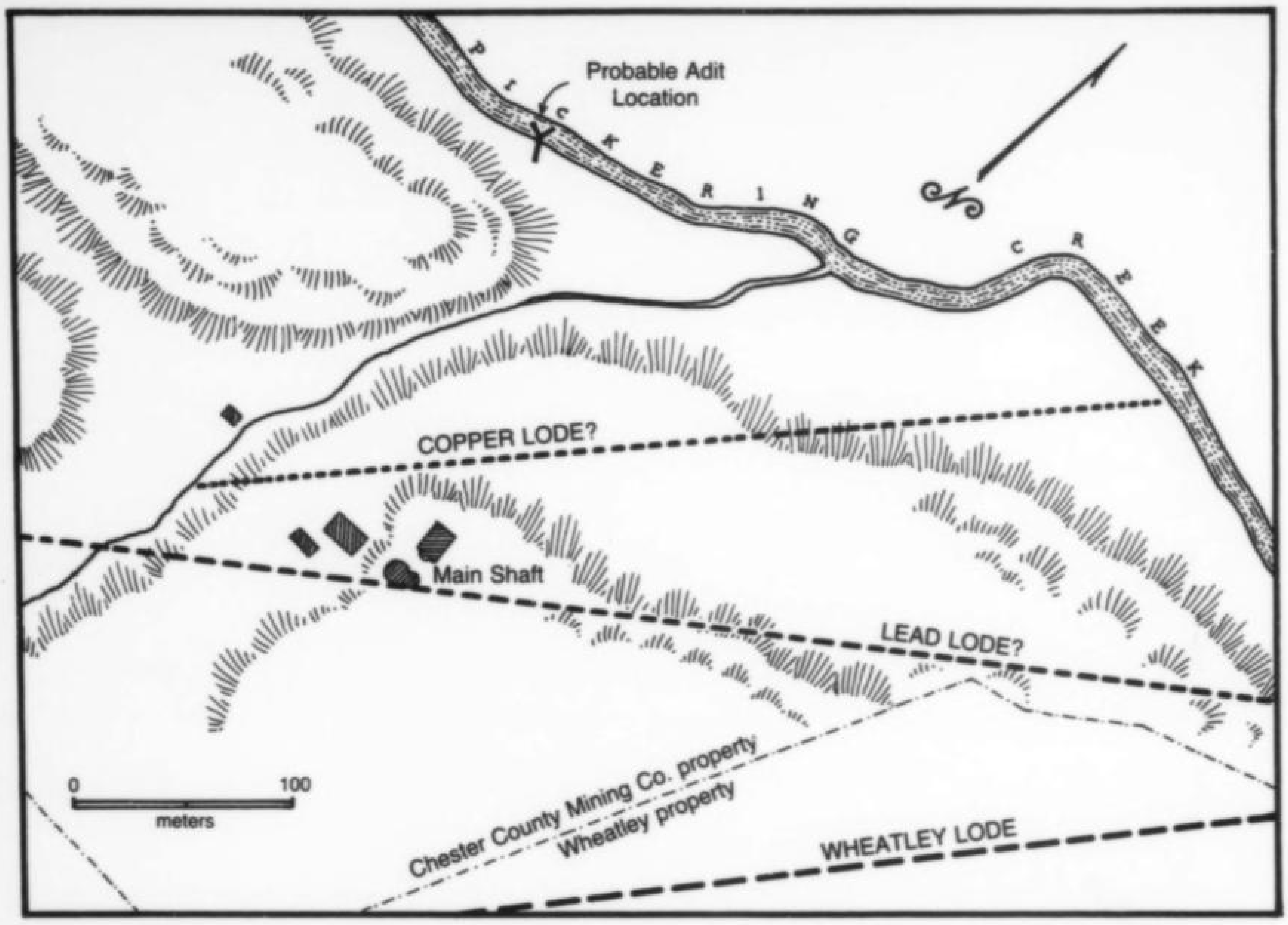


Figure 9. **The Chester County mining property, 1851, showing probable trace of the lodes (after Sharwood, 1851, and Smith, 1977).**

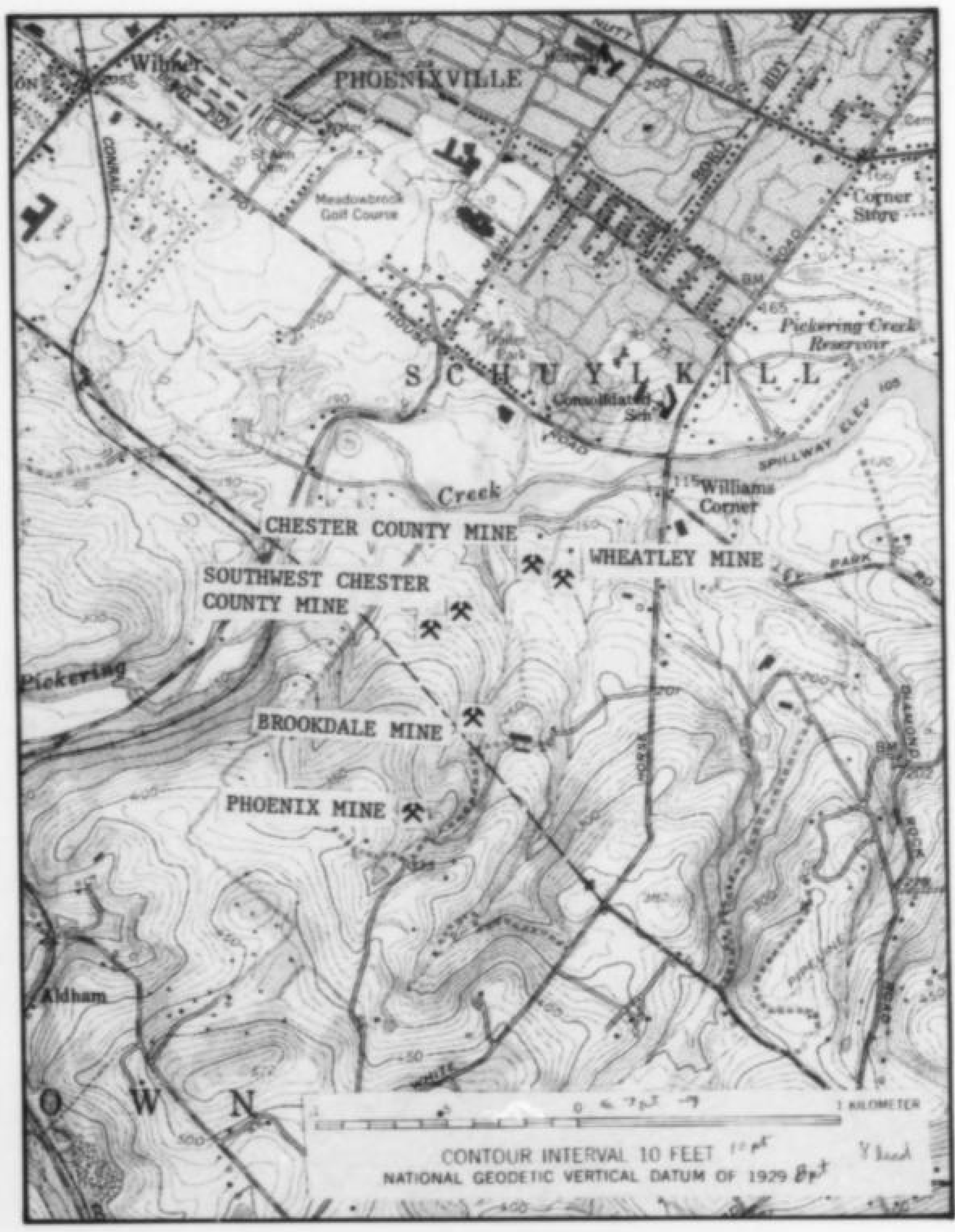


Figure 10. **Locations of the Phoenixville mines.**

below. Jolly and Heyl (1968) interpret the presence of mercury (as a trace element at 20 ppm in sphalerite) as evidence that the deposits are hydrothermal.

Heyl and Bozion (1962) classify the orebody as a direct replacement supergene oxidized zinc orebody. Direct replacement deposits are formed by oxidation of primary minerals and assume the form of the hypergene bodies from which they are formed. The modifications are internal and involve redistribution of the metals in the deposit during oxidation and leaching. The outcrop of the deposit is commonly leached to a porous gossan, and the leached metals are redeposited further downward as oxidized minerals, and still deeper as supergene sulfides. At depth, the orebody is unaltered.

At the surface, the vein consists of limonitic gossan that assayed about 10 ounces of silver per ton (Rogers, 1853). Smith (1855) described zoning of supergene lead minerals. From the surface to 9 meters, pyromorphite was the most abundant mineral with some galena and cerussite. Below 9 meters, pyromorphite began decreasing and cerussite increased in abundance. At 37 meters, wulfenite and anglesite began to appear with pyromorphite, cerussite and galena. At 55 meters, cerussite and anglesite were the major minerals, and pyromorphite was sparse. At 73 meters, galena was the chief lead mineral; sphalerite, hemimorphite and fluorite appeared with considerable dolomite; only a little anglesite and very little pyromorphite were found. Hoofstetten (1855) reported that at 91 meters, sphalerite and chalcopyrite became more abundant and galena less abundant.

The paragenesis of the Wheatley orebody given by Smith (1977) is as follows: brecciation of granitic gneiss; deposition of ferroan dolomite and chalcopyrite; quartz (the earliest with chalcopyrite, the latest with galena); galena and sphalerite; supergene minerals such as pyromorphite, anglesite and cerussite. Calcite is later than ferroan dolomite.

MINERALS

In the 1850's, the Phoenixville district produced a large number of extremely fine mineral specimens. Perhaps the finest collection of Phoenixville minerals was in Wheatley's own cabinet, which numbered over 6000 specimens.

Wheatley sent a suite of minerals from his mines to the New York Exhibition of 1853 at the Crystal Palace. In describing Wheatley's exhibit, Professor Benjamin Silliman (1854) of Yale University stated:

> We speak understandingly and without exaggeration, when we say that the sulphates and molybdo-chromates of lead, in Mr. Wheatley's collection, are the most magnificent metallic salts ever obtained in lead mining, and unequalled by anything we have seen in the cabinets of Europe.

The judges gave Wheatley the highest award, the silver medal. Bad mining investments led to financial difficulties, and Wheatley

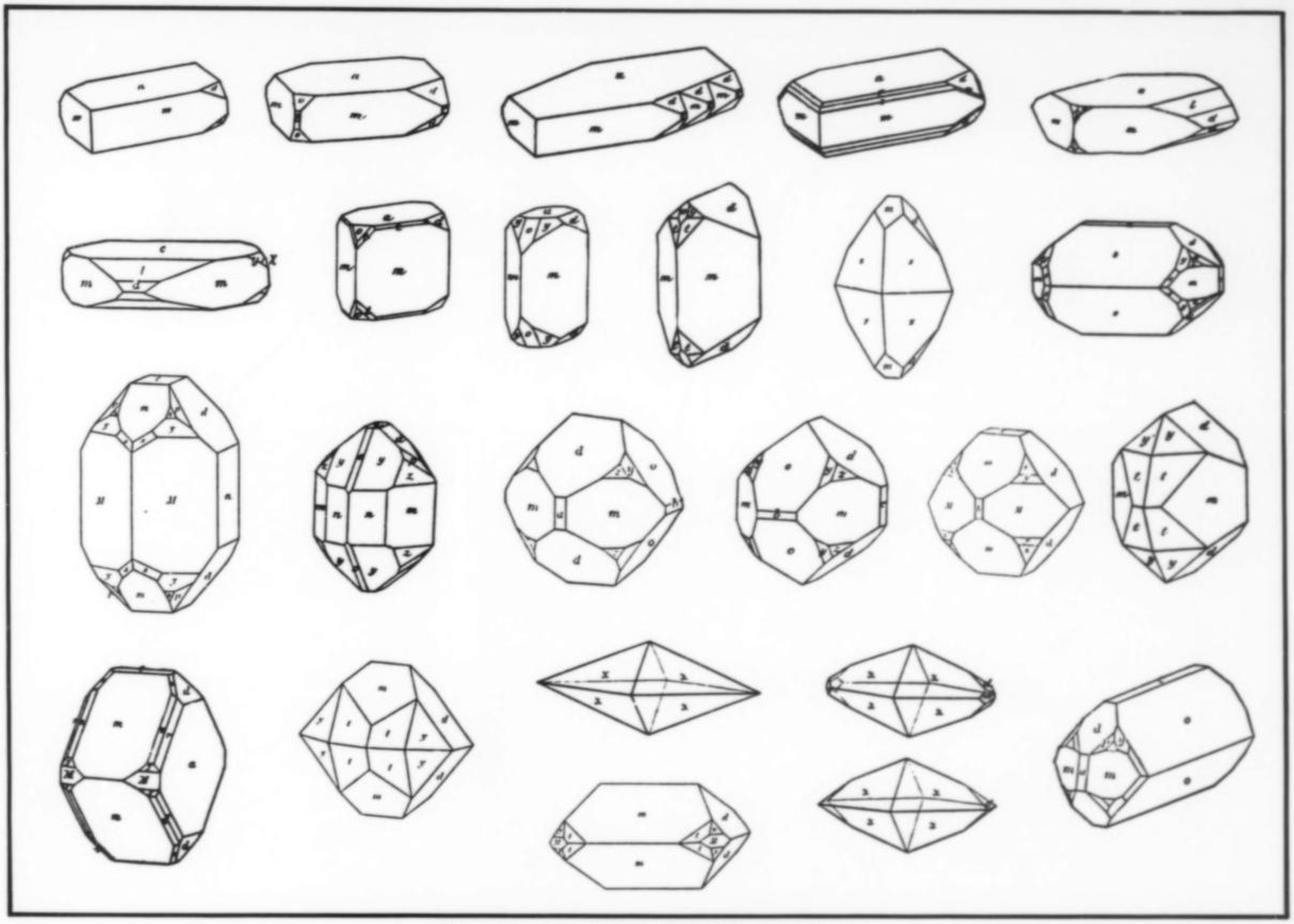


***Figure 11*. Crystal drawings of Phoenixville anglesite (from Lang, 1859; Dana, 1868; and Schrauf, 1877).**

was forced to sell his mineral collection. In 1858, both Wheatley's mineral cabinet and shell collection were purchased for $10,000 by Edward C. Delavan, who presented them to Union College. Unfortunately, much of the Wheatley collection was later stolen from Union College.

Although the Wheatley mine was the major source of mineral specimens, some labeled "Wheatley mine" or "Wheatley mines" may have come from other mines in the Phoenixville district. Since Wheatley, at one time or another, owned all of the major Phoenixville mines, some labels may not accurately differentiate among them.

The following mineral species occur at the Phoenixville mines.

Anglesite $PbSO_4$

Anglesite is common as white to clear, untwinned, pyramidal, tabular or prismatic crystals. They may be colored yellow, brown, black, green or red by inclusions of other minerals. Smith (1855) described transparent, doubly terminated crystals up to 14 cm long and 4 cm thick, weighing up to 500 grams. Anglesite is often found in limonite-lined cavities in galena. It is also associated with calcite, cerussite, chalcopyrite, copper, fluorite, pyromorphite and quartz.

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

Ankerite occurs in curved rhombohedral crystals. It is usually associated with quartz and chalcopyrite. Ankerite was most abundant at the Wheatley mine. Most of the samples studied by the U.S. Geological Survey (Heyl, 1984) from the Wheatley mine contained as much as 19.7% FeO, and produced a good ankerite X-ray diffraction pattern; further verification was made by electron microprobe. Some

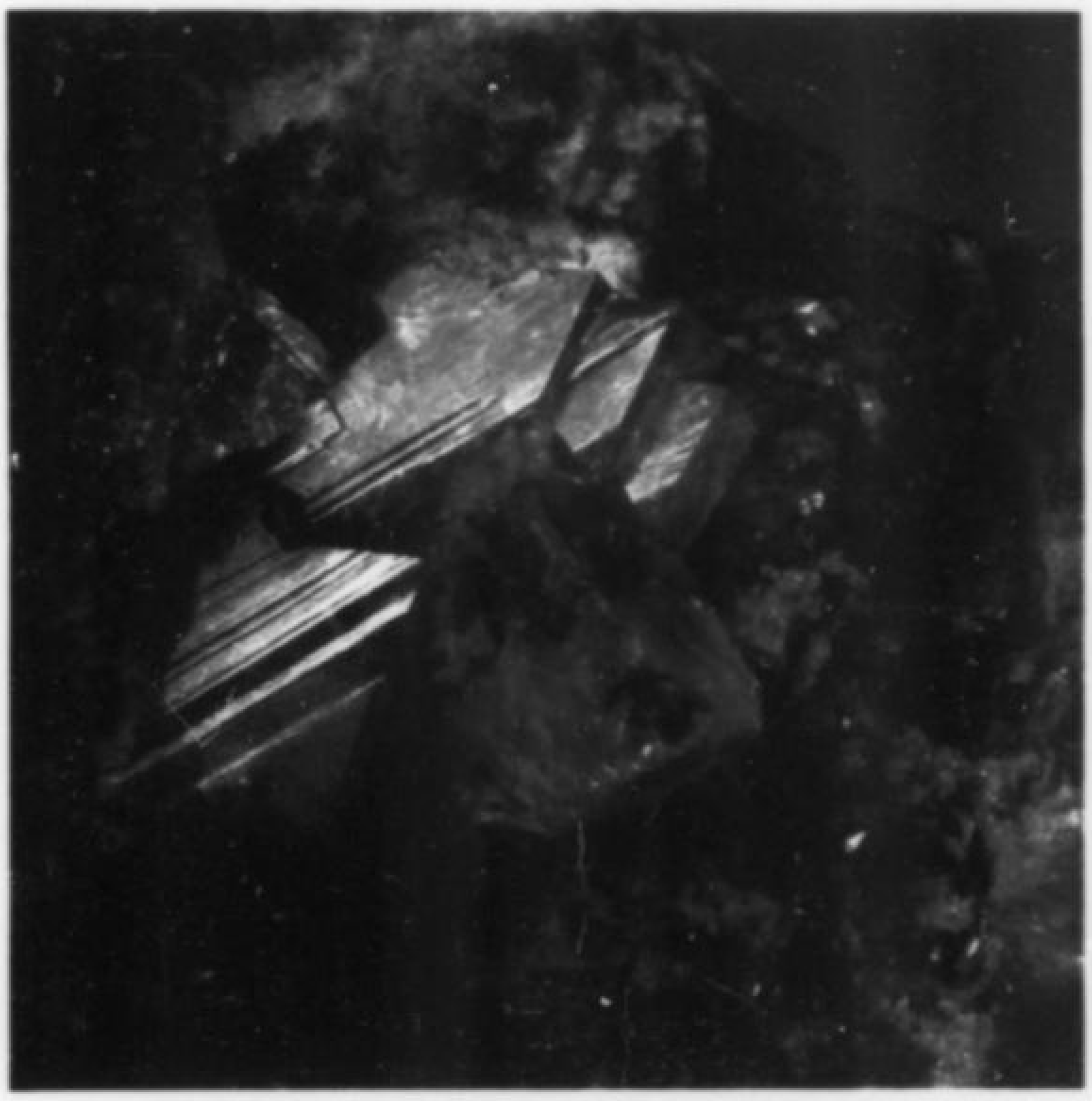


***Figure 12*. Anglesite crystals to 1.2 cm in a pocket in galena from the Wheatley mine. Carnegie Museum of Natural History collection; photo by R. Sioto.**

samples contain less FeO and are ferroan dolomite. Some ankerite analyzed by the U.S. Geological Survey contained traces of gold.

Aragonite $CaCO_3$

Genth (1875) reported groups of aragonite crystals from the Wheatley mines 1.5 to 4 cm long.

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

Azurite is rare in the Phoenixville mines; it is associated with malachite and chalcopyrite. Smith (1855) described deep blue crystals with highly polished faces 6 to 13 mm across. Azurite is also found as coatings and microcrystals.

Barite $BaSO_4$

Barite was a common gangue mineral at the Wheatley mine, occurring as white laminated crystalline masses. It also occurs rarely as gray-white bladed crystals to 2.5 cm and white platy crystals.

Figure 13. **White barite, 6.5 cm, from Phoenixville. Jay Lininger collection; photo by R. Sloto.**

Brochantite $Cu_4(SO_4)(OH)_6$

Brochantite is rare, occurring as deep emerald-green microcrusts.

Calcite $CaCO_3$

Calcite is found as cleavages and rarely as scalenohedrons and hexagonal prisms with rhombohedral terminations. It is associated with fluorite, galena and sphalerite. Cerussite and wulfenite form pseudomorphs after calcite. Smith (1855) described many spectacular specimens encountered during mining, including plates 2.5 to 3 meters square completely covered with prismatic calcite crystals up to 5 cm long and 1.3 cm thick; some were doubly terminated crystals up to 25 cm long and 6 mm wide. One specimen, 7.6 cm long and 1 cm in diameter, consisted of small prisms arranged to form a perfect double spiral around an axis with 6 mm of space between each spiral. Some calcite crystals have fluorite or pyrite crystals embedded in pits in their terminations. These crystals were developed by successive crystallizations: first a calcite scalenohedron formed; then fluorite crystallized on the calcite termination; and later the calcite was enclosed by a hexagonal prism, the termination of which never fully closed over the fluorite crystal. Prismatic calcite crystals terminated by rhombohedrons have also been found coating masses of large black dodecahedral sphalerite crystals.

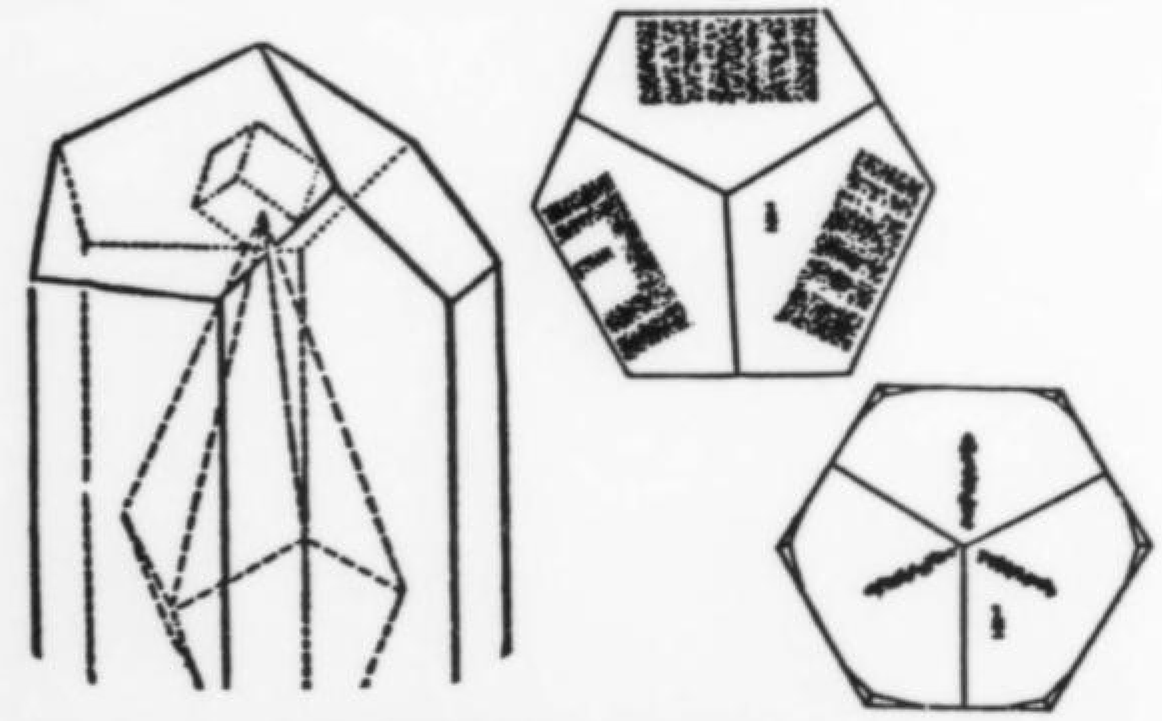


Figure 14. **Crystal drawings of Wheatley mine calcite (Smith, 1855).**

Cerussite $PbCO_3$

Cerussite occurs as single, twinned and reticulated, transparent, white, wine-yellow or gray crystals and masses. Crystals may be colored green, blue or yellow by the inclusion of other minerals. Smith (1855) described transparent twinned crystals up to 5 cm across and single crystals up to 2.5 cm long and 1.3 cm thick. Genth (1851, 1875) described pseudomorphs after anglesite that formed shells studded with cerussite crystals inside. Cerussite crystals commonly coat

Figure 15. **Crystal drawings of Wheatley mine cerussite (Dana, 1868; Schrauf, 1877).**

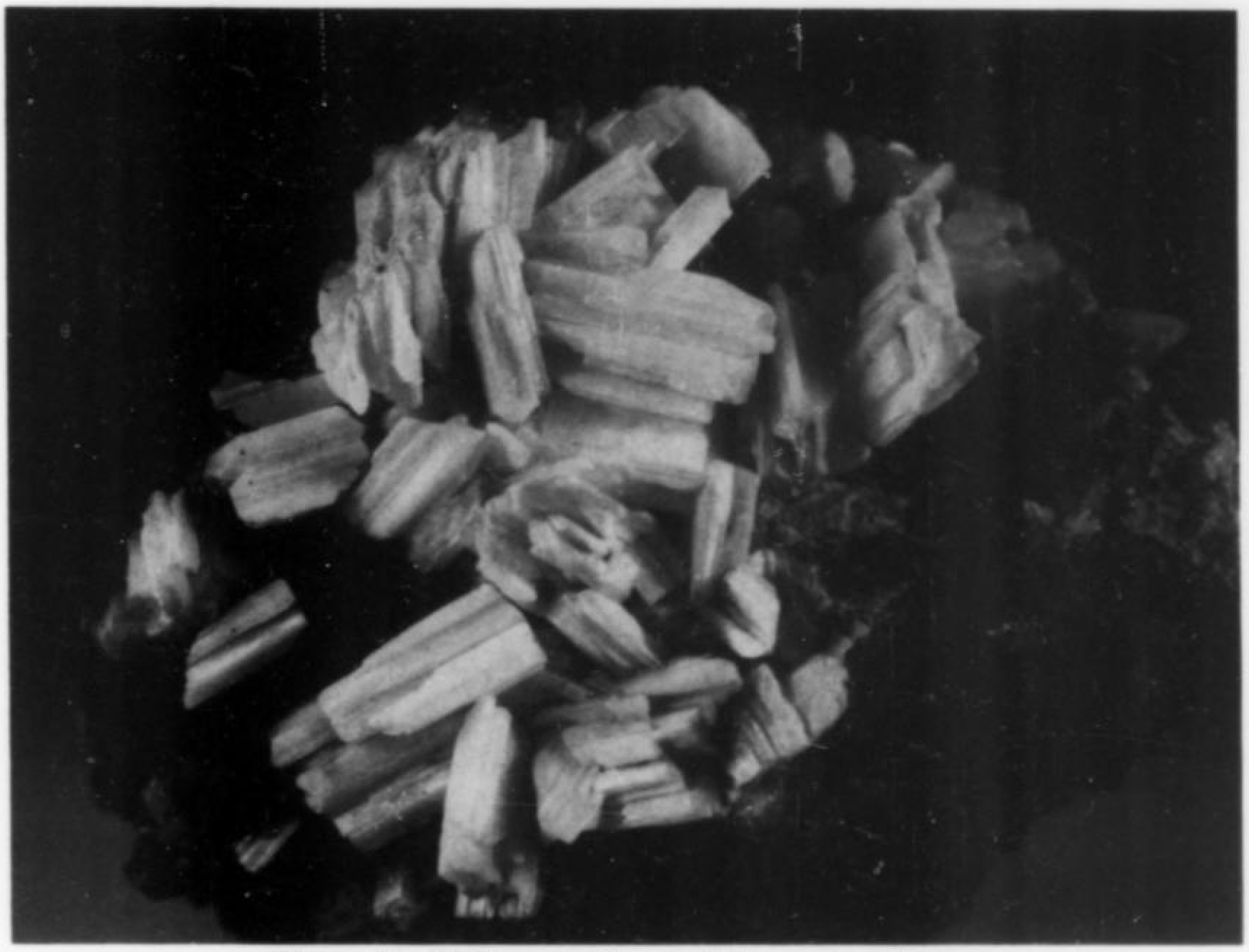


Figure 16. **White cerussite crystal group on limonite matrix, 8 cm, from Phoenixville. Bryon Brookmeyer collection; photo by R. Sloto.**

anglesite and may be coated by hematite or pyromorphite. It is most often associated with galena and is also associated with hematite, malachite, pyromorphite and quartz.

Chalcanthite $CuSO_4 \cdot 5H_2O$

Eyerman (1911) described a specimen of chalcanthite in his collection as bright blue soluble crusts. It is not common and has not been reported recently.

Chalcocite CuS

Genth (1875) reported that chalcocite occurred rarely at the Wheatley mine as shiny, black, somewhat malleable masses.

Chalcopyrite $CuFeS_2$

Chalcopyrite was found in sufficient quantities to be mined as an ore. It occurs rarely as fine, tetragonal scalenohedral and sphenoidal crystals. The scalenohedral crystals resemble tetrahedrons in appearance. It commonly occurs in masses weighing up to 180 kilograms (Smith, 1855). Chalcopyrite is associated with ankerite or ferroan dolomite, calcite, galena and quartz. An analysis by Genth (1851) showed gold in trace quantities in chalcopyrite from the Chester County mine.

Chlorite Group

Small greenish balls and greenish gray flakes of chlorite are common; the exact species has not been determined (Geyer and others, 1976).

Copper Cu

Native copper was found during mining as delicate films on hematite and quartz crystals and as a layer between hematite and chalcopyrite (Smith, 1855).

Covellite CuS

Covellite from the Chester County mine was reported by Genth (1851) as a bluish black, impalpable powder associated with malachite and cerussite. It is also found rarely as a coating on weathered chalcopyrite.

Cuprite Cu_2O

Cuprite occurs rarely as red masses and acicular crystals associated with malachite and weathered chalcopyrite (Rand, 1867).

Descloizite $PbZn(VO_4)(OH)$

Smith (1855) described the first American occurrence of descloizite from the Wheatley mine. It formed a translucent, dark hyacinth-red crystalline crust composed of minute lenticular crystals grouped in small botryoidal masses on quartz and ferruginous clay. An imprecise chemical analysis gave results close to descloizite. Smith provided some small crystals from the Wheatley mine to Des Cloizeaux, who confirmed the crystals were descloizite by crystallographic measurements (Smith, 1869). Montgomery (1965) verified descloizite from the Wheatley mine by X-ray diffraction. Descloizite is also found as small, reddish brown crystals to 0.5 mm and drusy crusts from the Southwest Chester County mine. Descloizite from the Chester County mine was verified by Arnold Fainberg with infrared spectroscopy; however, John H. Barnes and Raymond F. Grant found specimens from the Southwest Chester County mine to be intermediate between descloizite and mottramite (Reed, 1976).

Dolomite $CaMg(CO_3)_2$

Ferroan dolomite occurs as brown and yellowish white, curved, rhombohedral crystals and masses.

Erythrite $Co_3(AsO_4)_2 \cdot 8H_2O$

A specimen of erythrite from the Wheatley mine was described by Lewis (1885) as rose-pink veins and crusts. Under magnification, it appeared as minute globular rosettes of crystals and earthy fibrous masses. It was associated with fluorite and sphalerite. Erythrite has not been reported recently.

Fluorite CaF_2

Fluorite was commonly encountered during mining, as transparent, white and pale yellow to brown cubes, as twinned and modified cubes and occasionally as octahedral crystals. Fluorite cubes from the Wheatley mine are up to 1.5 cm on a side. Some are coated with drusy

Figure 17. **Galena crystal group, 4.5 cm, from the Wheatley mine. Bryn Mawr College collection; photo by R. Sloto.**

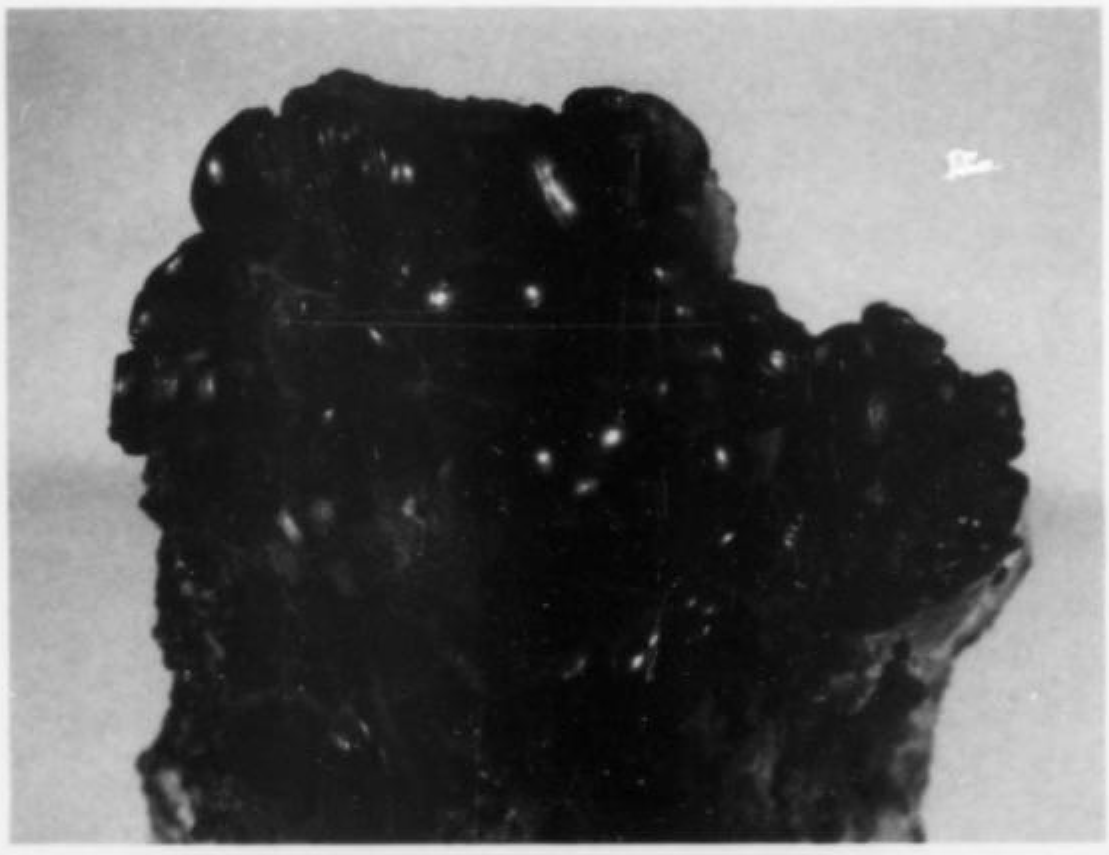


Figure 18. **Botryoidal malachite specimen, 12 cm across, from the Wheatley mine. Jay Lininger collection; photo by R. Sloto.**

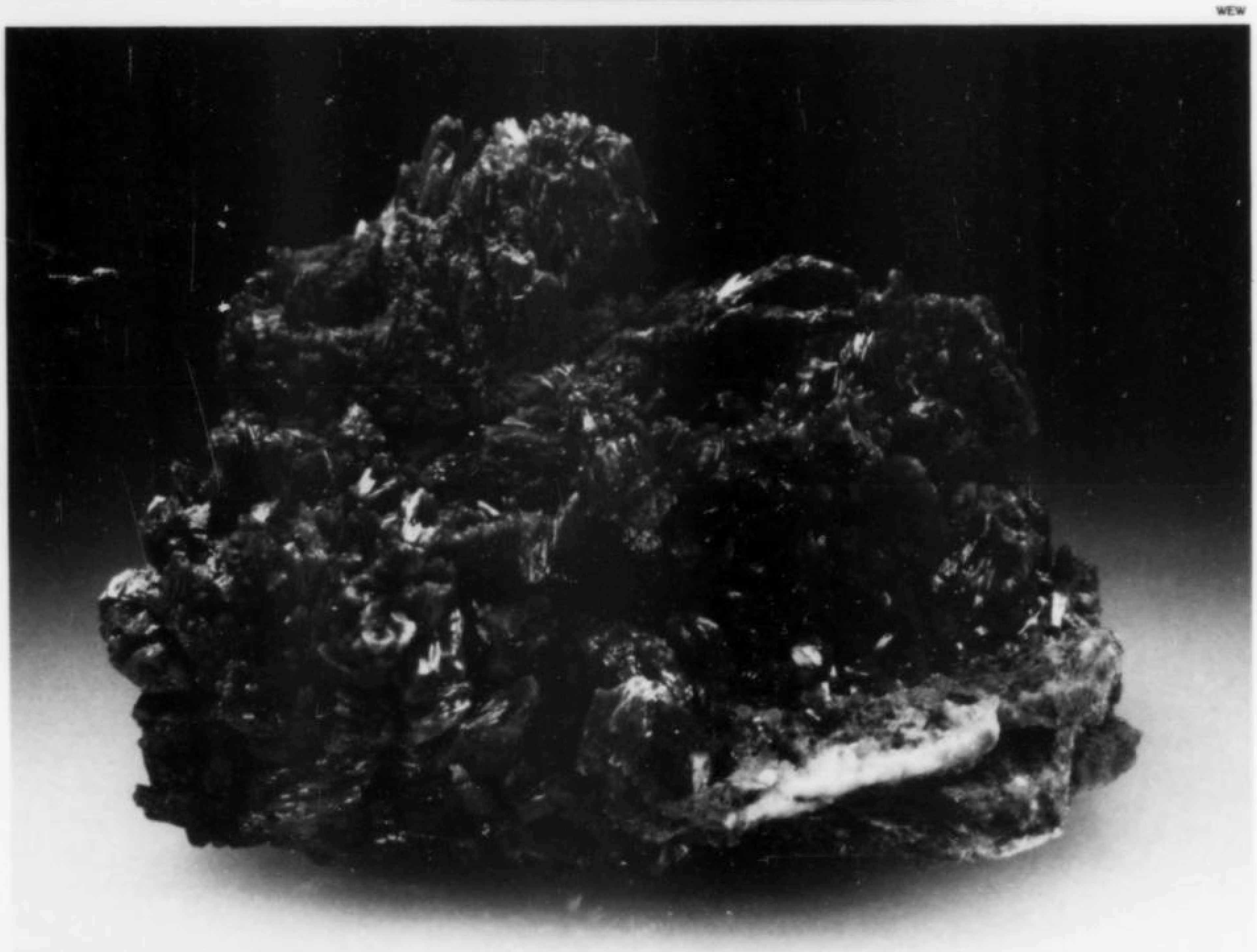
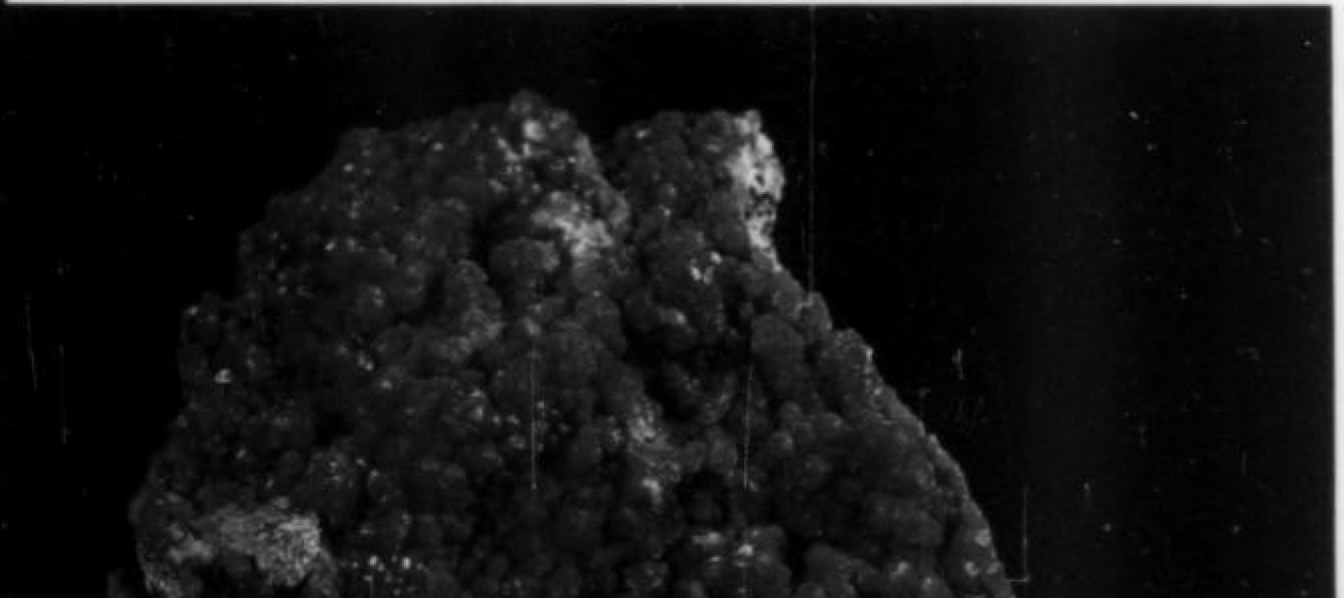


Figure 19. **Pyromorphite crystal group, 6.6 cm, from Phoenixville. Gene Schlepp specimen.**



calcite. It is also found as globular radiating concretions and crusts. Fluorite is associated with calcite, galena and sphalerite. Fluorite was encountered in abundance in the Wheatley mine at the 73-meter level and below (Smith, 1855).

Galena PbS

Galena was the major economic mineral. It is common as cleavages, and granular, compact, fibrous and radiating masses. As crystals, it forms perfect cubes or combinations of the cube and octahedron. Smith (1855) described specimens of very large cubic and octahedral crystals forming slabs "several feet" square completely covered with pyromorphite. Galena is associated with anglesite, calcite, fluorite, pyromorphite, quartz and sphalerite. Some decomposed galena is covered with cerussite crystals. Most galena is argentiferous. Some galena is associated with sulfur crystals.

Figure 20. **Botryoidal pyromorphite specimen, 7 cm, from Phoenixville. Jay Lininger collection; photo by R. Sloto.**

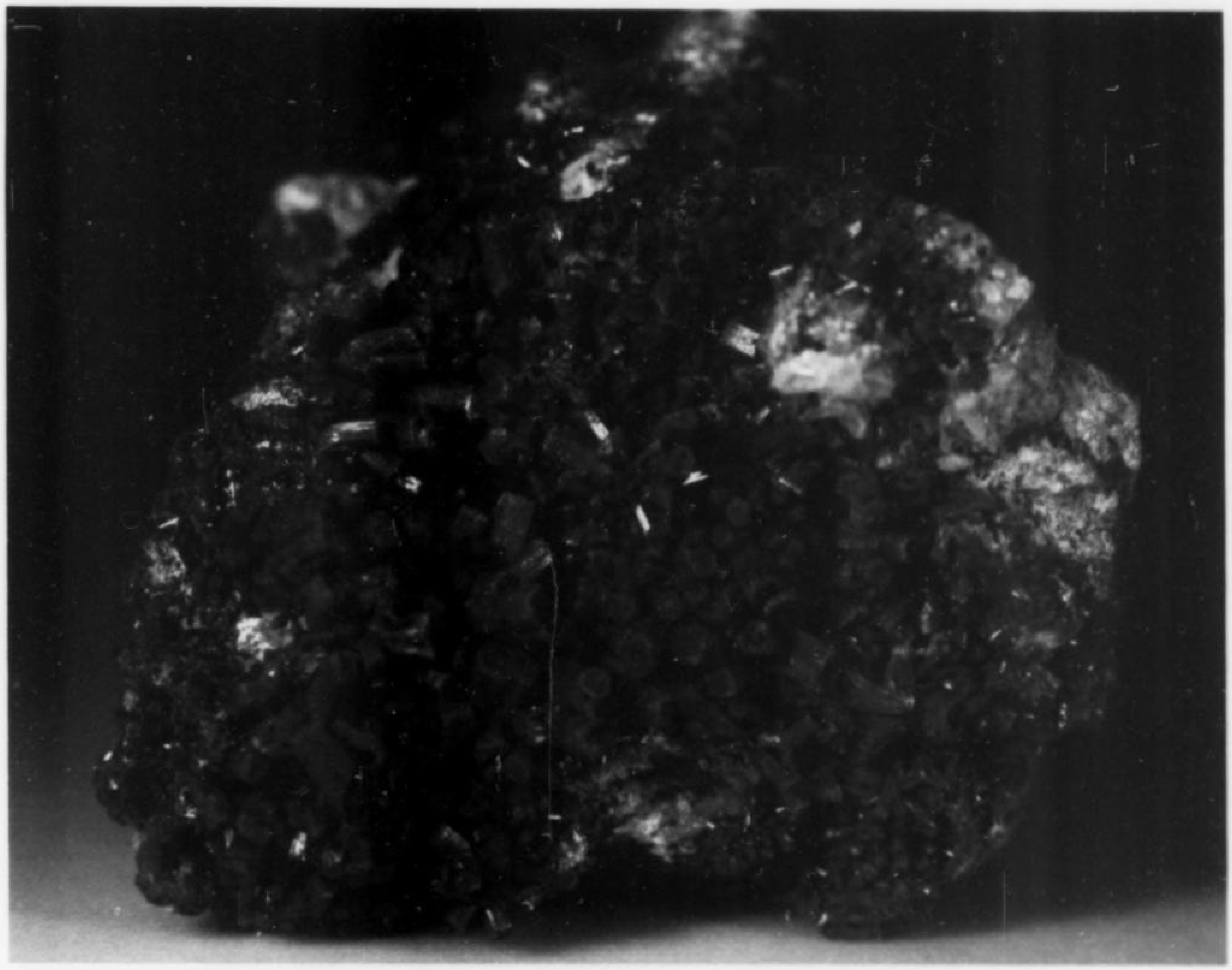


Figure 21. **Pyromorphite crystal group, 9 cm, from Phoenixville. Bryon Brookmeyer collection; photo by R. Sloto.**

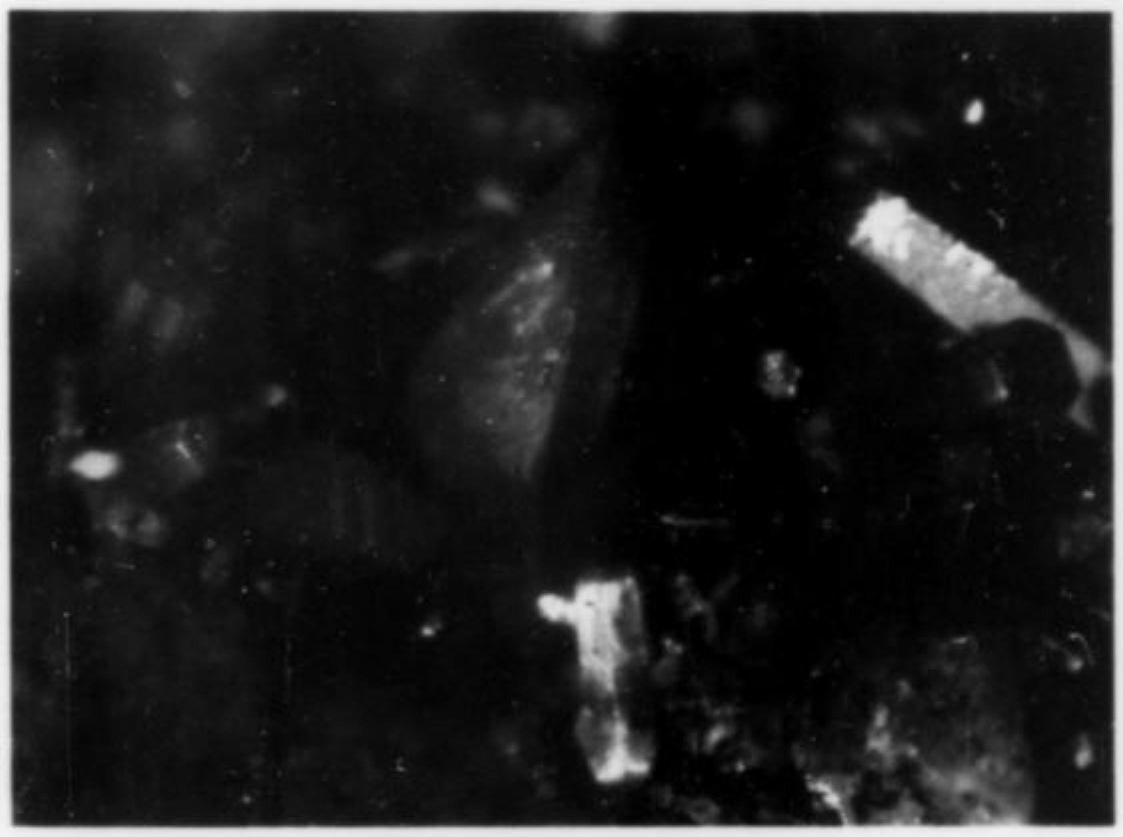


Figure 22. **Wulfenite crystal, 3 mm, with green pyromorphite, from the Chester County mine. Ralph Thomas photo.**

Figure 23. **Pyromorphite crystal group, 4 cm, from Phoenixville. Bryon Brookmeyer collection; photo by R. Sloto.**

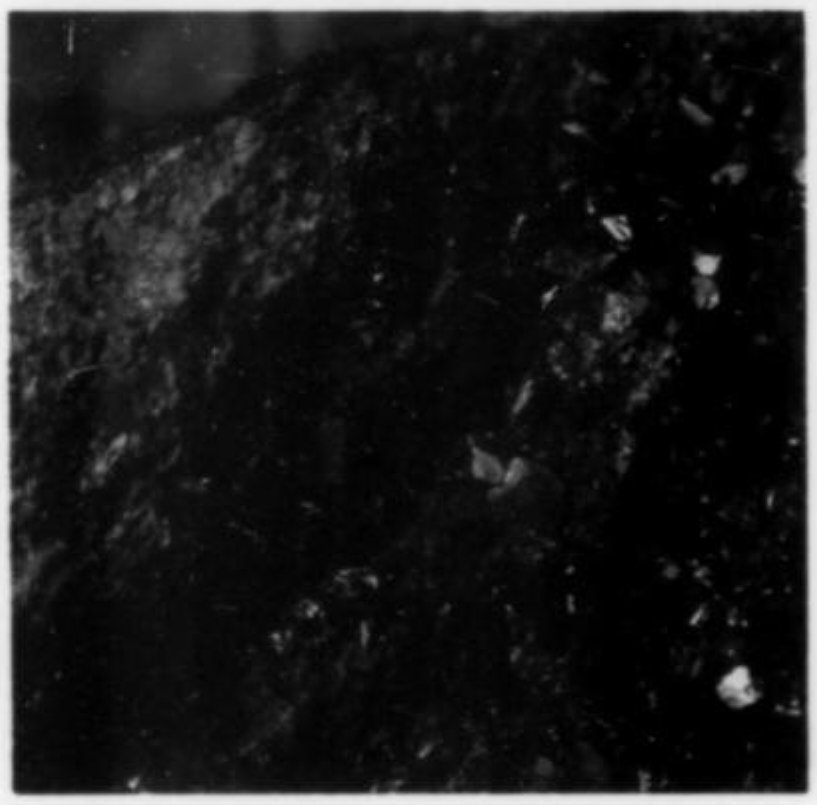


Figure 24. **Wulfenite crystals to 2 mm on green pyromorphite, from Phoenixville. Bryon Brookmeyer collection; photo by R. Sloto.**

Gersdorffite NiAsS

The only known specimen of gersdorffite was described by Genth (1859) as very small, grayish white cubes modified by octahedral and dodecahedral faces. It formed a crust on anglesite, partially decomposed galena and sphalerite and was associated with chalcopyrite, covellite and quartz.

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

Goethite forms brown, reniform masses and argentiferous gossans. It commonly lines cavities in galena, associated with crystals of anglesite and cerussite (Smith, 1855).

Hematite $\alpha\text{-Fe}_2\text{O}_3$

Hematite occurs as scaley, micaceous masses (Genth, 1875). Flakey masses and veins of specular hematite cementing granite gneiss fragments were common at the Wheatley mine (Heyl, 1984).

Hemimorphite $\text{Zn}_4\text{Si}_2\text{O}_7\text{(OH)}_2\cdot\text{H}_2\text{O}$

Hemimorphite occurs as clear, white or brown radiating crystal tufts on calcite, fluorite and sphalerite, and as platy balls. Some hemimorphite is colored blue or yellow by inclusions of azurite or hematite (Smith, 1855).

Hydrozincite $\text{Zn}_5\text{(CO}_3\text{)}_2\text{(OH)}_6$

Hydrozincite was reported by Miller (1923). It occurs as a white fluorescent coating on sphalerite from the Southwest Chester County mine.

Linarite $\text{PbCu(SO}_4\text{)(OH)}_2$

Linarite occurs sparsely as sky-blue translucent masses and small prismatic crystals from the Wheatley and Chester County mines (Heyl, 1984).

Malachite $\text{Cu}_2\text{(CO}_3\text{)(OH)}_2$

Malachite forms botryoidal crusts to 1 mm thick, small bright green acicular crystals and light green silky tufts. It is associated with azurite, calcite and quartz.

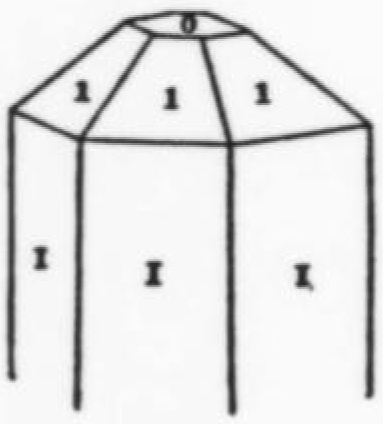


Figure 25. **Crystal drawing of Wheatley mine mimetite (Smith, 1855).**

Mendipite $\text{Pb}_3\text{Cl}_2\text{O}_2$

Mendipite occurs as white, striated, crystalline masses (Heyl, 1984).

Mimetite $\text{Pb}_5\text{(AsO}_4\text{)}_3\text{Cl}$

Mimetite occurs as colorless, lemon-yellow and yellow-green hexagonal prisms with terminations truncated by a hexagonal pyramid. It also commonly forms as yellow or yellow-green caps on pyromorphite crystals. Smith (1855) described mimetite crystals ranging from tiny hair-like crystals 6 mm long to broad, short hexagonal plates 1.3 cm across. It is uncommon. It is found on quartz and gneiss and is associated with cerussite, galena and pyromorphite.

Mottramite $\text{PbCu(VO}_4\text{)(OH)}$

Only one pure end-member specimen of the descloizite-mottramite series has been identified. Minute, black, lustrous crystals on granitic rock and quartz were verified as mottramite by Heyl (1984).

Palygorskite $\text{(Mg,Al)}_2\text{Si}_4\text{O}_{10}\text{(OH)}\cdot 4\text{H}_2\text{O}$

Only one specimen of palygorskite is known from the Wheatley mine. It forms small, white tufts of matted fibrous masses associated with ankerite, galena, pyrite, quartz and sphalerite. It was verified by X-ray diffraction by Heyl (1984).

Pseudomalachite $\text{Cu}_5\text{(PO}_4\text{)}_2\text{(OH)}_4\cdot\text{H}_2\text{O}$

Pseudomalachite from the Chester County mine is found as dark green, finely fibrous masses. It was verified by Heyl (1984) using X-ray diffraction and chemical tests.

Pyrite FeS_2

Pyrite is uncommon as pale brass-yellow masses and complex cuboctahedral crystals.

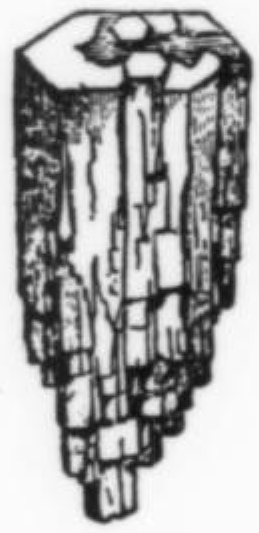


Figure 26. **Sketch of a Phoenixville pyromorphite crystal (Dana, 1892).**

Pyromorphite $\text{Pb}_5\text{(PO}_4\text{)}_3\text{Cl}$

Pyromorphite is the best-known mineral from the Phoenixville mines. It formed large masses of green crystals and was so abundant that many tons were smelted as lead ore. Pyromorphite occurs as translucent to opaque crystals in shades of green ranging from black-green to bright grass-green. It forms barrel-shaped hexagonal crystals up to 1.3 cm in diameter with flat, tapered, pointed, cavernous or modified terminations. Some crystals are hollow, existing only as a hexagonal shell. Pyromorphite also occurs as acicular crystals, botryoidal masses with a columnar structure and in globular, plumose and granular forms. It is argentiferous, containing up to 0.0054% silver (Genth, 1851). Pyromorphite is found on quartz or decomposed gneiss and is associated with anglesite, cerussite, galena and wulfenite.

Quartz SiO_2

Quartz is an abundant gangue mineral. It forms transparent to milky or yellow (iron oxide-stained) crystals. Amethyst has been reported. It also forms large parallel-growth crystals, radiating groups of crystals and white to gray massive, vein and comb quartz. Groth (1900) described many forms of quartz crystals, including multiple growth, etched, phantom, sceptered and doubly terminated crystals up to 14 cm long and 6.4 cm wide.

Silver Ag

Native silver occurs as silver-white, lustrous plates and scales, and rarely as wires in cavities in galena and quartz. Rogers (1853) listed native silver among the minerals from the Wheatley lode. Native silver was found at the Phoenix mine in the 1970's.

Smithsonite ZnCO_3

Smithsonite is found as red-brown rhombohedral crystals and crystalline crusts. It was verified from the Wheatley and Chester County mines by Heyl (1984) using X-ray diffraction and chemical tests.

Sphalerite (Zn,Fe)S

Sphalerite was the major zinc ore mineral at the Phoenixville mines. Unmarketable during the early years of mining, it was discarded on the dumps. Sphalerite forms translucent brown to dark brown, red-brown and black modified dodecahedral crystals and twins to 10 cm

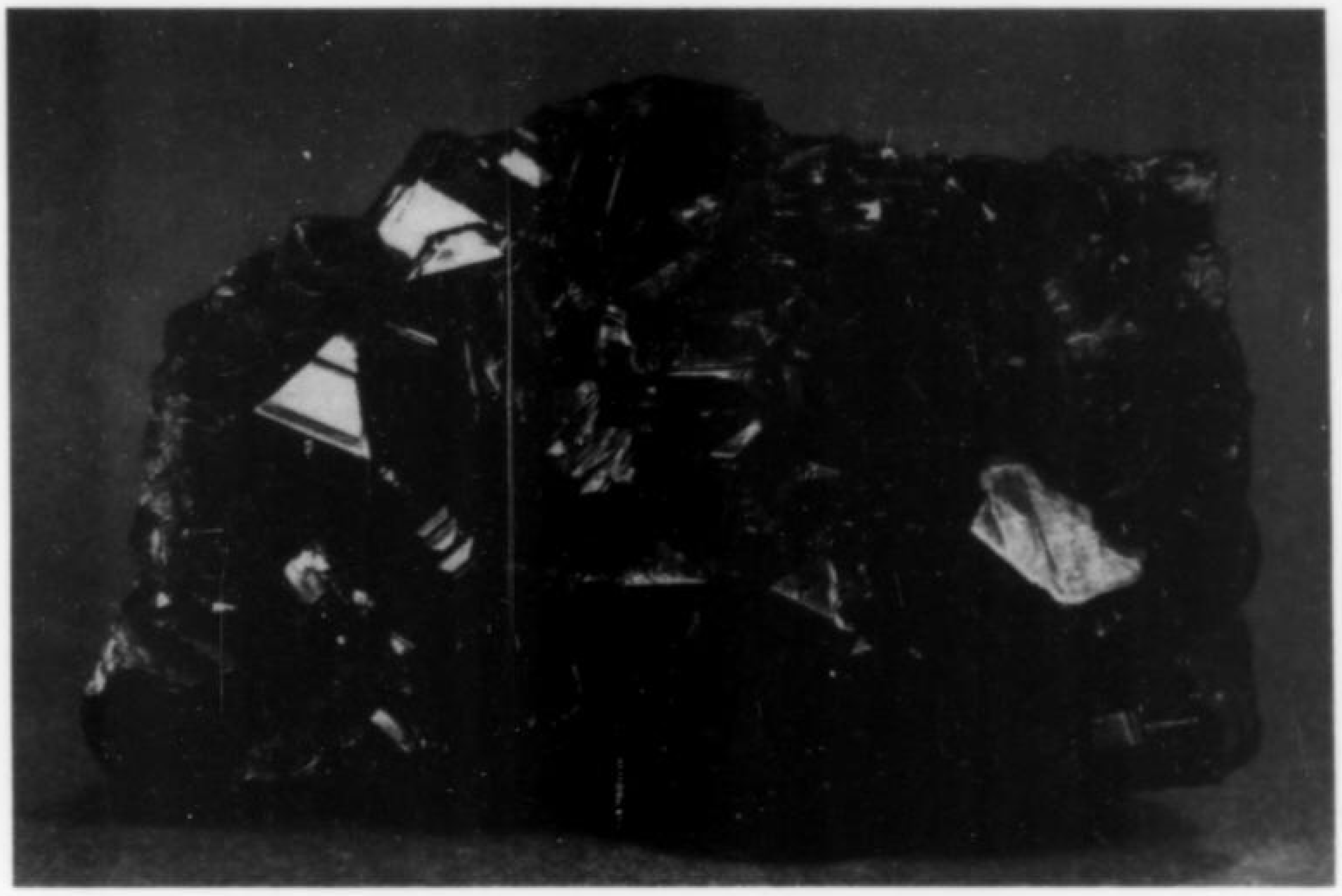


Figure 27. **Sphalerite crystal group, 9 cm, from Phoenixville. Jay Lininger collection; photo by R. Sloto.**

in diameter. Hess (personal communication, 1988) found a 5-mm, light brown sphalerite tetrahedron modified by cube faces in a vug of drusy quartz at the Chester County mine; this habit is much less common and probably of later stage than the prevailing dodecahedral habit. Sphalerite crystals are sometimes coated with calcite and often intergrown with quartz crystals and galena. Sphalerite is associated with calcite, fluorite, galena and quartz. Jolly and Heyl (1968) noted traces of silver and up to 20 ppm mercury in sphalerite from the Wheatley mine.

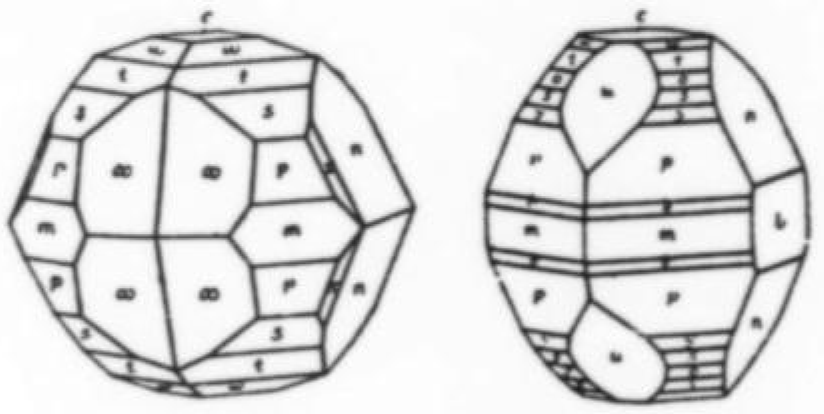


Figure 28. **Crystal drawings of Wheatley mine sulfur (Busz, 1889).**

Sulfur S

Native sulfur occurs as small (less than 1 mm), transparent, pale greenish yellow pyramidal crystals. It is disseminated through partly decomposed galena associated with chalcopyrite and pyrite.

Tenorite CuO

Tenorite was reported by Genth (1875) as massive, pulverulent masses associated with limonite, chalcopyrite and malachite.

Vanadinite $Pb_5(VO_4)_3Cl$

Vanadinite is found as red to brown hexagonal prisms to 2 mm. Individual crystals are sometimes cavernous. Although Smith (1869) first described Phoenixville vanadinite, most known specimens have been found more recently at the Southwest Chester County mine.

Wheatleyite $Na_2Cu(C_2O_4)_2\cdot 2H_2O$

Wheatleyite is known from only one specimen from the Wheatley mine. Rouse and others (1986) described wheatleyite as aggregates of bright blue, thin, acicular crystals up to 2 mm long associated with galena and sphalerite. It is unusual in being a natural salt of oxalic acid.

Wulfenite $PbMoO_4$

Wulfenite from the Phoenixville mines displays a wide variety of crystal habits and colors, occurring in every shade from bright yellow to deep red and gray. It forms stubby, square tabular, sharply pointed pyramidal, dipyramidal and cavernous crystals to 4 mm. Red, yellow and gray crystals of different habits may appear on the same specimen (Montgomery, 1969). Blake (1852) first described the occurrence of wulfenite from the Wheatley mine as beautiful cabinet specimens of small crystals on pyromorphite and cerussite. Only two or three small crystals of wulfenite were initially found in 1851, and they were mistaken for crocoite. An analysis by Wetherill (1854) showed them to be wulfenite. Wulfenite is most often associated with pyromorphite and quartz. Beautiful specimens of orange wulfenite crystals sprinkled over green pyromorphite crystals have come from the Wheatley mine. Smith (1855) described specimens in which wulfenite formed the main mass, with pyromorphite crystals scattered over the surface.

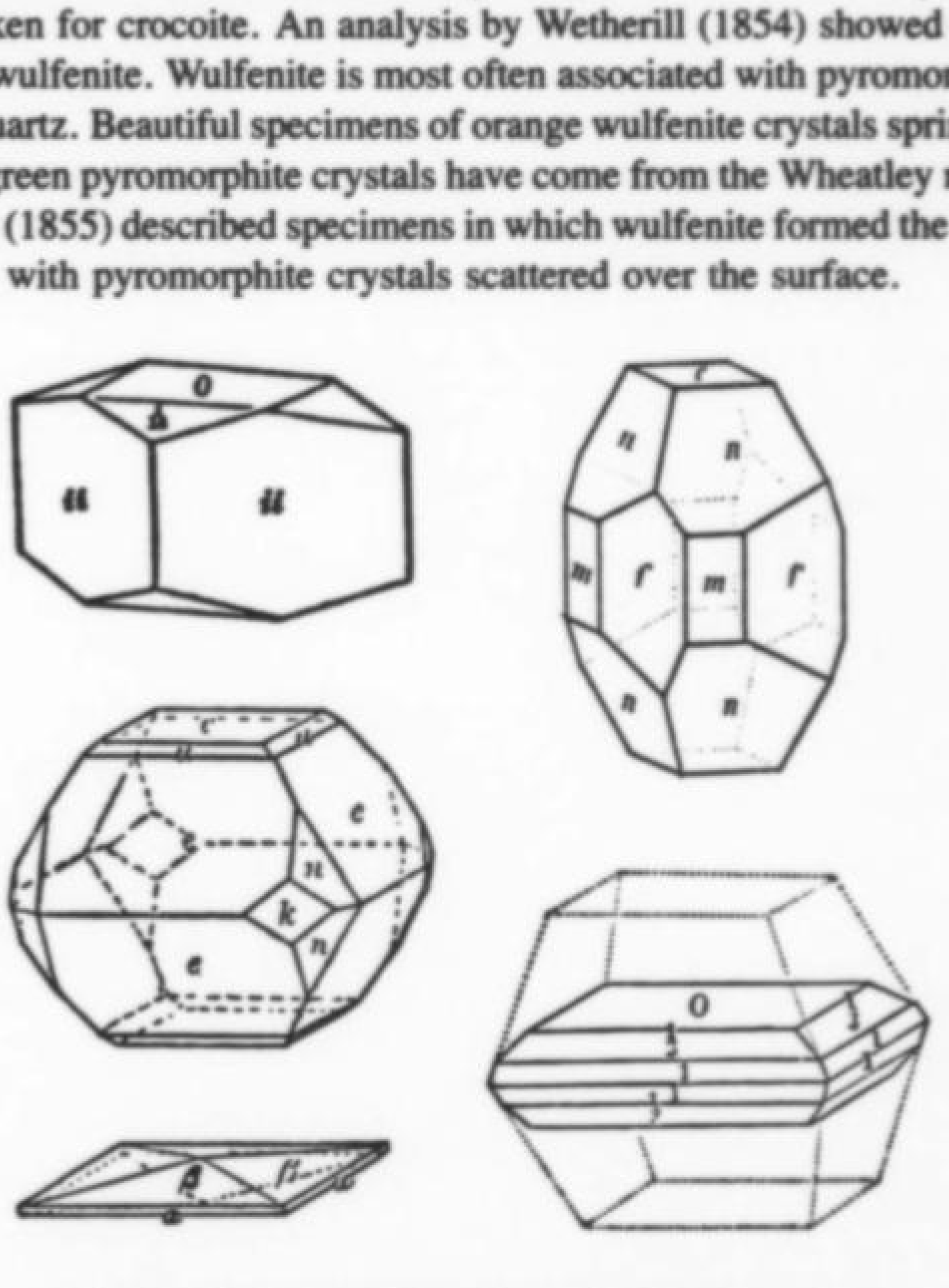


Figure 29. **Crystal drawings of Wheatley mine wulfenite (Smith, 1855; Schrauf, 1877; Dana, 1868 and 1892).**

Other Minerals

Rand (1867) described stolzite (originally thought to be scheelite) from the Wheatley mine as small, well-defined yellowish gray tetragonal octahedrons on quartz with pyromorphite and wulfenite.

Table 1. **Minerals reported from the Phoenixville mines.**

Elements
Copper
Silver
Sulfur

Sulfides
Bornite (?)
Bournonite (?)
Chalcocite
Chalcopyrite
Covellite
Galena
Gersdoffite
Pyrite
Sphalerite

Fluorides, Chlorides
Fluorite
Mendipite

Oxides
Chalcophanite (?)
Cuprite
Goethite
Hematite
"Psilomelane" (?)
Pyrolusite
Tenorite

Carbonates
Ankerite
Aragonite
Azurite
Calcite
Cerussite
Dolomite
Hydrozincite
Malachite
Siderite (?)
Smithsonite

Silicates
Allophane (?)
Chlorite group
Chrysocolla (?)
Hemimorphite
Palygorskite
Quartz

Phosphates, Vanadates, Arsenates
Descloizite
Erythrite
Mimetite
Mottramite
Pseudomalachite
Pyromorphite
Vanadinite

Sulfates
Anglesite
Barite
Brochantite
Chalcanthite
Linarite
Serpierite (?)

Molybdates
Wulfenite

Oxalates
Wheatleyite

However, X-ray diffraction analysis made by Montgomery (1965) on a specimen from the Vaux collection at the Philadelphia Academy of Natural Science showed it to be wulfenite.

Other minerals have been reported from the Phoenixville mines, but have not been verified. They include "psilomelane" (Genth, 1851); pyrolusite (Rogers, 1853); allophane and siderite (Rogers, 1858); bournonite (Hoofstetten, 1855; Eyerman, 1911); chrysocolla (Rand, 1867); bornite (Lapham and Geyer, 1959); and plumbian chalcophanite and serpierite (Heyl, 1984).

PRESENT STATUS

The Phoenixville mines have been a popular mineral collecting locality for over a century. Today, some of the mine dumps are still accessible and continue to attract collectors. The Thompson family owns the property on which the Brookdale, Southwest Chester County, and Phoenix mine dumps are located. They are to be commended for their interest in preserving these historic sites and for keeping them open to collectors. Recently, the Thompson family converted their dairy farm to the Pickering Golf Club. During the transition, they took great care to preserve the mine dumps and the smoke stack at the Brookdale mine. Permission to collect may be obtained at the Pro Shop.

The Chester County mine dumps are located on the old Pickering Hunt Club property, now a private residence. Permission to collect must be obtained from the owner.

A private residence now stands on the site of the Wheatley mine. The dumps are covered by grass, and collecting is strictly prohibited.

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I wish to thank Robert C. Smith II of the Pennsylvania Geological Survey for assistance, encouragement and critical review of the manuscript; David F. Hess of Western Illinois University and L. DeWayne Cecil of the U.S. Geological Survey for critical review of the manuscript; Lana Dickinson for editorial assistance; Juliet Reed for assistance with minerals from the Bryn Mawr College collection; and Richard A. Souza for assistance with minerals from the Carnegie Museum of Natural History collection. I thank Bryon Brookmeyer, Bryn Mawr College, Carnegie Museum of Natural History, Jay Lininger, Joseph Varady and Bill Yocom for allowing me to study and photograph mineral specimens from their collections. I also thank the American Philosophical Society, the Chester County Historical Society and the Pennsylvania Geological Survey for allowing use of material from their libraries and publications.

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Rochester, New York 14609

The following report is a summary of the *What's New in Minerals* program presented at the 16th Annual Rochester Mineralogical Symposium last April. All but a few of the most important mineral finds previously discussed in detail in the *Mineralogical Record* have been deleted; in general, only discoveries made since the previous year's symposium are discussed. As in past years, the information is presented geographically, with emphasis placed on truly new finds rather than continuing supplies of previously known materials. Addresses are given for most of those dealers who are not advertisers in the *Mineralogical Record,* or who are on the unindexed group ads.

We are indebted to the numerous collectors, curators and mineral dealers who have shared information with us enabling this report to be compiled, for without their continued support and knowledge it would have been an impossible task.

Part I: United States

ARIZONA

In addition to the brilliant yellow crystals of wulfenite collected by Peter Megaw and Jim Walker from the Tombstone district last August (*Mineralogical Record,* **20**, p. 75), there were also unearthed what may be some of the world's finest dugganite, khinite and parakhinite specimens, the best of which now reside in the collection of William Pinch of Rochester, New York.

Neil and Chris Pfaff (*M. Phantom Minerals,* P.O. Box 12011, Columbus, OH 43212) had a colorful selection of ram's horn chalcanthite at the Detroit Show. These specimens were collected from an unnamed mine near the Flux mine, Patagonia, Santa Cruz County, and are probably of a post-mining origin.

The Red Cloud mine near Yuma is still producing some of the fine wulfenite specimens for which it has long been renown. Among the best of these were those collected last summer by George Godas (*Arizona Crystals,* 6304 S. Clark Drive, Tempe, AZ 85283). George also had some very good vanadinite from the Castle Dome district, and some good junitoite from the Christmas mine available at the Denver Show.

It is just about impossible to discuss what's new from Arizona without consulting David Shannon. Each year Dave seems to turn up new and exciting finds, and this one was certainly no exception. Anyone really interested in new mineral discoveries in Arizona would do well to contact Dave, for surely he will have made several more by the time this article goes to press! A few of last year's highlights include: cabinet-sized specimens of mordenite from near Eagle Eye, in the New Water Mountains, La Paz County; a good selection of sceptered quartz crystals, also from the New Water Mountains; lustrous, centimeter-sized crystals of spessartine in cavities in rhyolite from the Aquarius Mountains; pale green, vuggy chlorargyrite from the Oriziba mine, Pinal County; jarosite crystals from the Apex mine, Dripping Springs Mountain, Gila County; some quite colorful specimens of hematite crystals with quartz and chrysocolla from the BCC claims #3, Buckskin Mountains; vanadinite crystals from the Puzzler mine, Castle Dome district, Yuma County; chrysocolla *crystals* from the Eagle Eye mine, La Paz County; and dioptase crystals on chrysocolla from the Magma mine, near Superior, which resemble small Tsumeb or Reneville specimens more than those normally seen from Arizona. John Mediz (*Copper City Rock Shop,* 556 Ash Street, Globe, AZ 85501) also had some of this material.

ARKANSAS

Art Smith of Houston, Texas, reported some interesting discoveries in Arkansas (*Mineral News,* **5**, no. 1, p. 9). Among those discussed are quartz with chlorite inclusions from a new locality in the western Ouachitas; Herkimer diamond-like quartz from the Glenwood area, Pike County, wavellite from the County pit at Mauldin Mountain, north of Mount Ida; and brookite from the Rutherford deposit near Magnet Cove.

CALIFORNIA

Wayne and Dona Leicht (*Kristalle*) have provided a continuing supply of very fine gold specimens from the Eagle's Nest mine, Placer County. Some of these specimens are indeed astonishing, and are definitely in the "must be seen to be believed" caliber.

The famous Gem mine in San Benito County is still being worked by Buzz Gray and Bill Forrest, and has produced some very fine benitoite specimens over the past year. John Seibel (*Seibel Minerals,* P.O. Box 95, Tehachapi, CA 93561) and Cal and Kerith Graeber (P.O. Box 47, Fallbrook, CA 92028) had some excellent benitoite specimens at the Denver and Tucson shows. In addition, some exceptional faceted stones were also produced.

The Christie mine in Fresno County produced some sharp, 5-mm crystals of magnetite on dolomite last summer. These were found in a large pod of dolomite in serpentine and were available at the Denver show from *Galas Minerals* (1419 N. Commons Road, Turlock, CA 95380) and *Seibel Minerals*.

Ken Gochenour (15751 California Street, Tustin, CA 92680) has been working the Lakeview Mountain pegmatite in Riverside County with some interesting results. He has come up with some outstanding trapezohedral almandine crystals (to 5 cm) in addition to some excellent xenotime-(Ce) bipyramids (to 5 mm) with monazite crystals (to 1.5 cm) in microline.

Walt Lombardo (*Southern Nevada Mineral Company,* 5000 E. Bonanza #8479, Las Vegas, NV 89110) obtained some very fine groups of lustrous colemanite crystals from the 1455-foot level, stope 1E, of the Billie mine in Death Valley.

COLORADO

Keith Williams has reported a new find of quartz pseudomorphs after calcite from the Uncompahgre mining district, Ouray County (*Mineral News,* **5**, no. 1, p. 2). The specimens were collected from a large 10-meter cavity and consist of coralloid growths of drusy white crystals up to a meter across. They are available from *Williams Minerals* (P.O. Box 1599, Idaho Springs, CO 80452) and Marty Zinn (*Crystal-Linn International,* P.O. Box 2433, Evergreen, CO 80439).

A second selection of quartz pseudomorphs was displayed at the Denver show by Robert Stoufer (*The Sandman,* 330 6th Avenue,

Figure 1. Liefite sphere, 3.5 cm, with serandite from Mont St-Hilaire, Quebec. Collected in 1988 by Gilles Haineault; photo by G. Robinson. (See p. 393.)

Ouray, CO 81427). These consist of quite sharp encrustation pseudomorphs after barite and fluorite from Gladstone, San Juan County. Additional new materials he had available included white, radiating calcite crystals with fluorite and quartz from the Camp Bird mine, Ouray County; barite from the Irene mine in Leadville; and brown, discoidal rhombohedral siderite from the Black Cloud mine, also in Leadville.

There was a small wealth of Mount Antero minerals to be seen and purchased at the Denver show last September. Some of these were recently collected, and included some very fine gem grade crystals of aquamarine, smoky quartz and topaz. Details of these discoveries are discussed by Mark Jacobson (*Mineral News*, **4**, no. 11, p. 4).

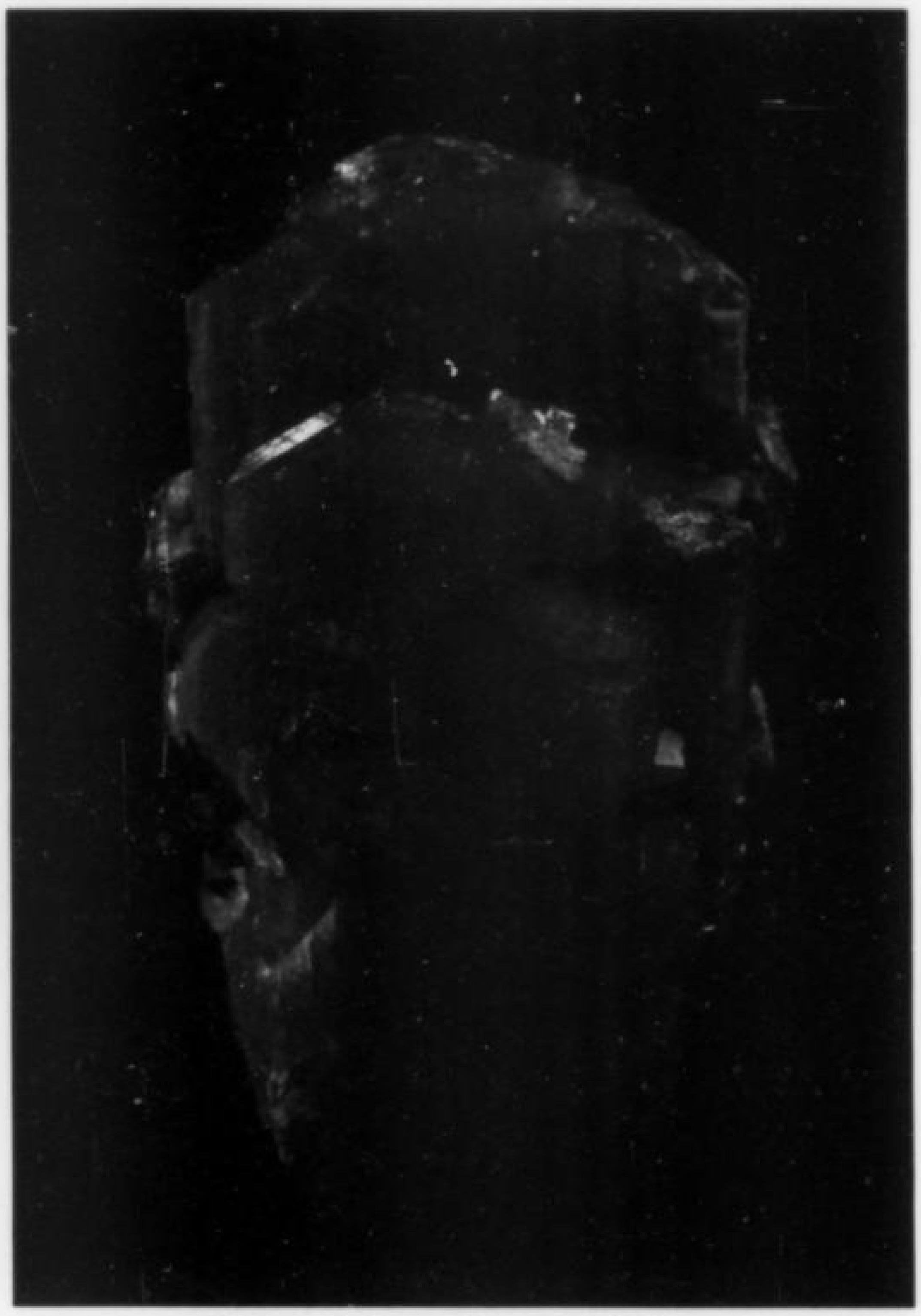

Figure 2. **Serandite crystal 7 cm, from Mont St-Hilaire, Quebec. Collected in 1988 by Gilles Haineault; photo by G. Robinson. (See p. 393.)**

Figure 3. **Brown topaz crystal on a 9-cm, doubly terminated smoky quartz crystal, with microcline from Gifu prefecture, Ena County, Japan. Jimmy McNeil specimen. (See p. 396.)**

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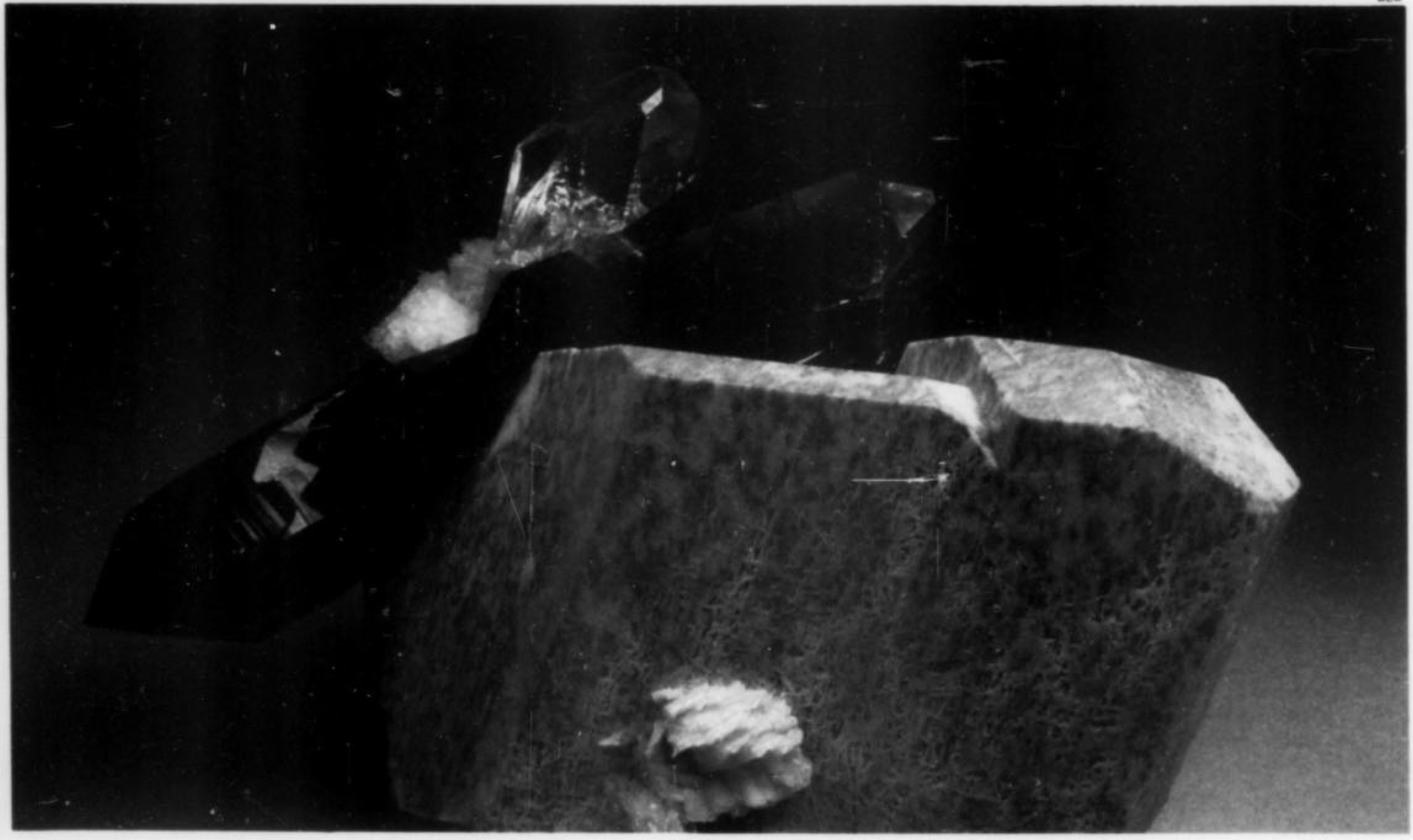

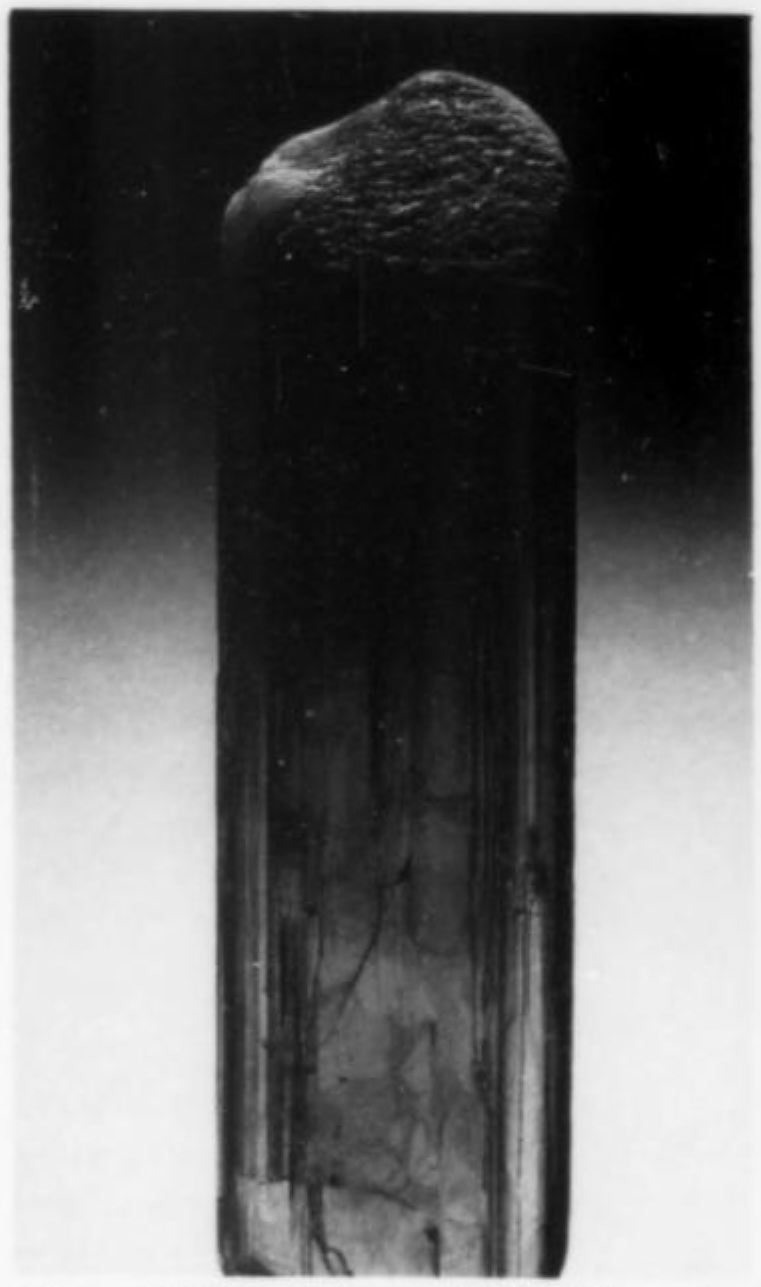

Figure 4. **Diaspore crystal, 2.5 x 10 cm, from Selcuk, Mugla province, Turkey. National Museum of Natural Sciences collection, Canada. G. Robinson photo. (See p. 398.)**

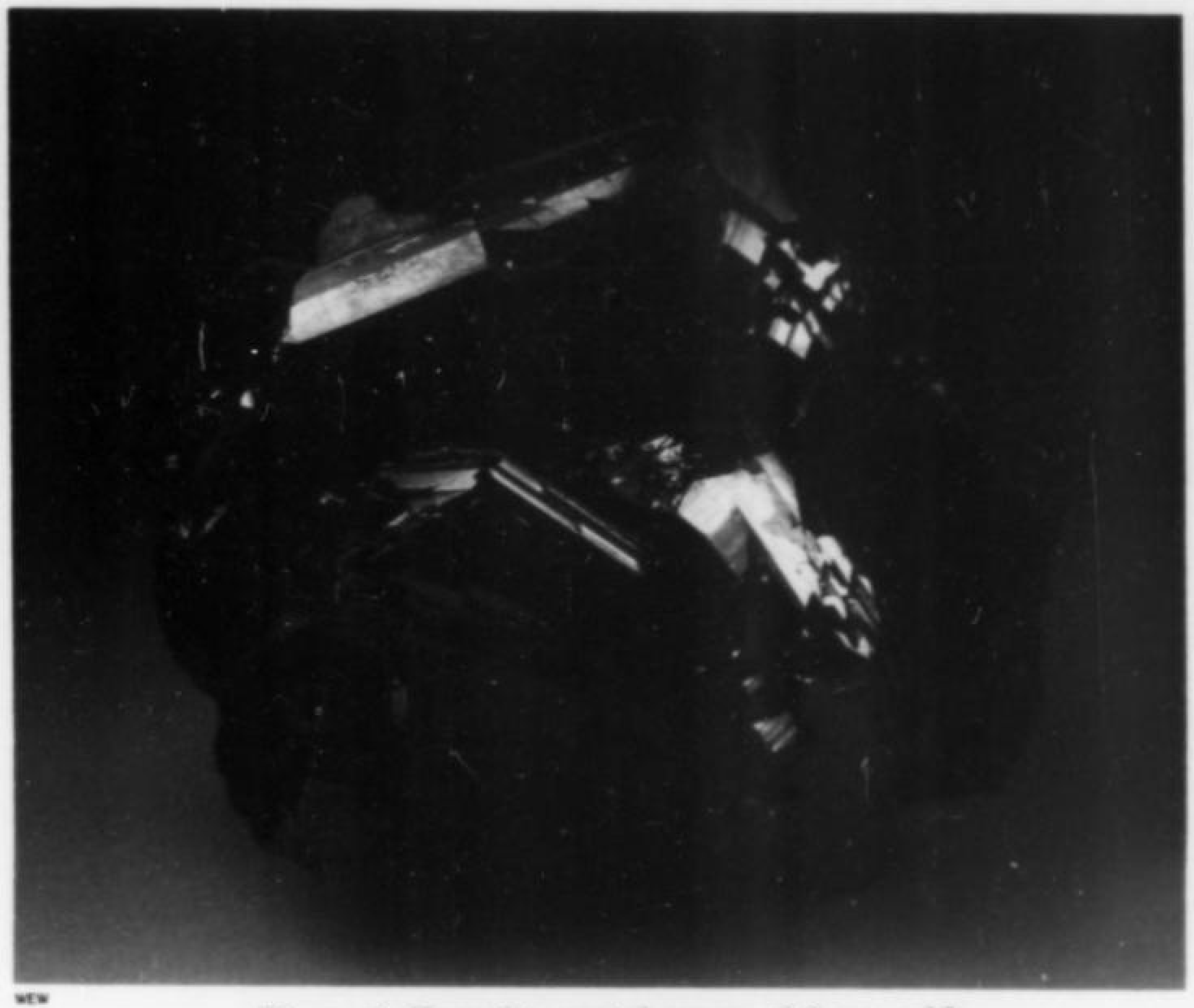

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Figure 6. **Hematite crystal group, 6.6 cm, with red andradite garnet, from Wessel's mine, near Kuruman, Cape Province, South Africa. Don Olson/Marshall Sussman specimen. (See p. 398.)**

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Figure 5. **Quartz crystals to 6 cm, colored green by inclusions of Hedenbergite, from a skarn near Mega Xhorio on the island of Serifos, Greece. Nikos Albandakis specimen. (See p. 395.)**

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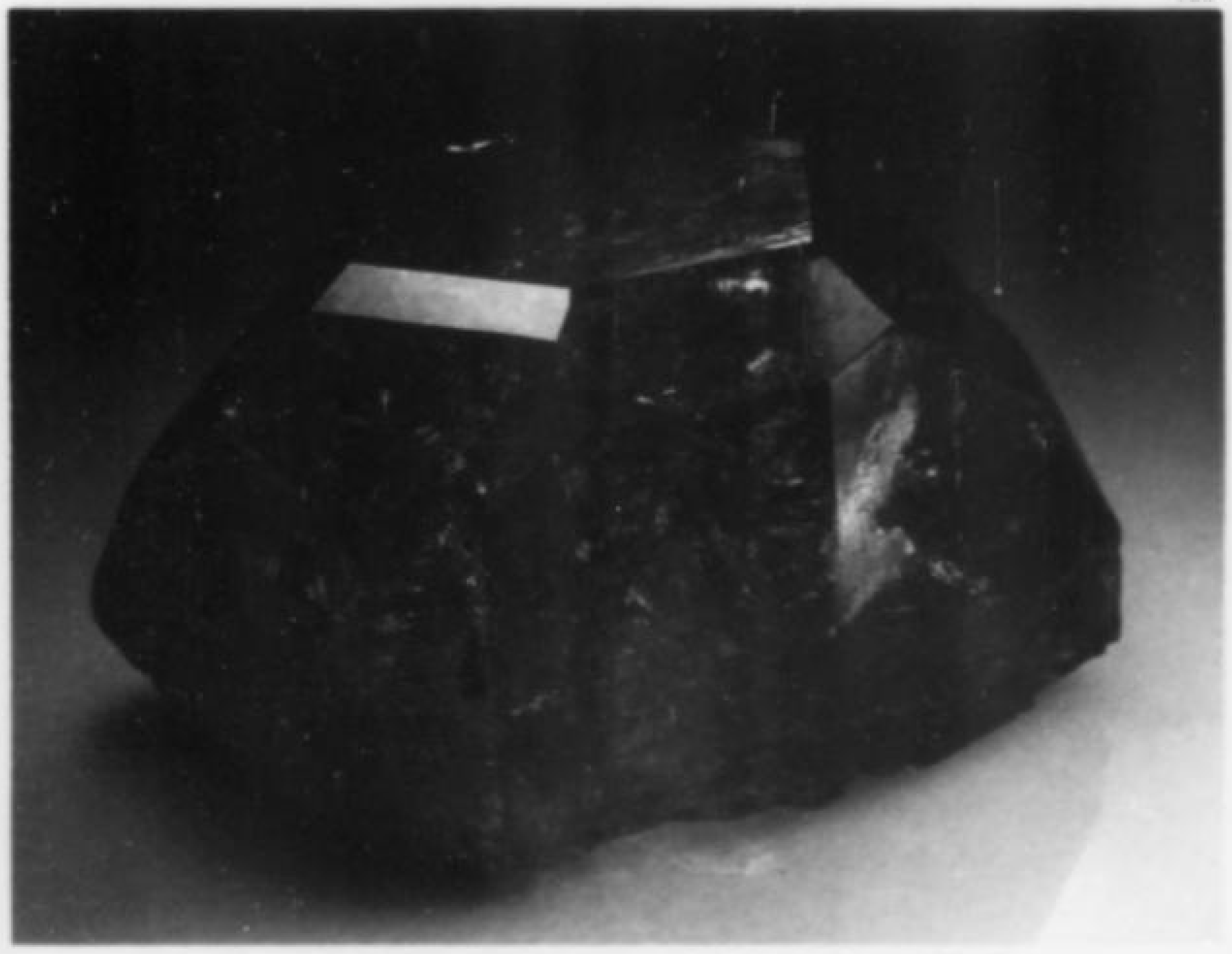

Figure 7. **Brown topaz crystal, 14 cm, from Gilgit, Pakistan. Wayne Thompson, Zee Iqbal and Mohammed Sibtaien specimen. (See p. 397.)**

A rather unusual and grand-scale discovery of calcite, aragonite and hydromagnesite was made last May in a working quarry near Clear Creek, when a routine blast unexpectedly opened a cave lined with stalactites and helictites of these minerals! What is particularly unusual about the occurrence is the fact that the host rock is *not* a limestone, but rather a Precambrian crystalline rock. There is a cooperative program in progress between the Colorado School of Mines, Denver Museum of Natural History, and the U.S. Geological Survey to conserve this material. Interested persons may contact Mrs. Ginny Mast (Curator, Geology Museum, Colorado School of Mines, Golden, CO 80401) for details.

Mark Jacobson reports that there are still some good specimens of quartz, fluocerite, columbite and other minerals to be collected from the pegmatites in the South Platte district of Jefferson County (*Mineral News*, **4**, no. 12, p. 2).

CONNECTICUT

Some lovely large groups of milky quartz and sceptered crystals of amethyst have recently been collected from the "Moosup quarry" near Plainfield, but at this time details of the occurrence are lacking.

ILLINOIS

While it is generally acknowledged that good specimens are becoming an increasingly rare commodity these days, it was certainly not apparent from the quantity of fine material produced over the past year from the southern Illinois fluorite district. Nowhere was this more evident than at the Detroit show last October, where Ross Lillie (*North Star Minerals*, P.O. Box 46212, Mt. Clemens, MI 48046-6212), Les Tolonen (*North American Minerals*, P.O. Box 581, Baraga, MI 49908-0581) and *Montgomery Minerals and Gems* (P.O. Box 42195, Cincinnati, OH 45242) displayed an incredible array of specimens. Most of these were from the Denton and Annabel Lee mines, in Hardin County. Exquisite display specimens of fluorite in a multitude of colors and associations, calcite crystals of several colors and habits, extremely lustrous sphalerite crystals, barite, celestite, chalcopyrite and galena were available. Some of the galena specimens are among the largest and best ever produced from the district.

MAINE

An unknown mineral from the Dunton quarry at Newry was submitted to the Canadian National Museum of Natural Sciences by Van King for routine identification. The mineral in question consists of 3-mm, iron-stained, platy crystals forming rosette clusters in a vug in altered siderite and albite. Although it was previously thought to be fairfieldite, X-ray and semiquantitative EDS analyses proved the mineral to be crandallite.

Plumbago Mining Company (P.O. Box 449, Casco Bank Building, Rumford, ME 04276) is currently working a new amethyst deposit near Sweden, Maine. This occurrence consists of a system of quartz veins in schist. It was originally brought to the attention of the Harvard Mineralogical Museum by the property owner, who thought he had found gem tourmaline while excavating land at his music camp. There have been a number of specimens collected, including two large plates nearly half a meter across. The crystals themselves are typically only a few centimeters across, but are of good color, and make attractive specimens perched on a white quartz matrix. Some crystals have provided gems of good, violet color in the range of 10 carats.

MICHIGAN

A fantastic copper crystal made a brief debut at the Tucson show, and though its existence has been known for about 15 years, its appearance may well qualify as new, considering that so few people have seen it. This specimen was collected many years ago by a miner who chose to keep it hidden until after he had retired from the mine. Andy Love owned the specimen for a short while in the 1970's and sold it to a private collector who only recently relinquished it. The 3-cm crystal is a sharp dodecahedron with trapezohedral modifications, and resembles in habit the famous almandine crystals from Wrangell, Alaska. The specimen was acquired by a private collector in Europe.

MINNESOTA

Keith Christy (P.O. Box 2251, Billings, MT 59104) had an excellent selection of groutite specimens available at the Tucson show. The crystals are lustrous, black individuals up to nearly a centimeter and occur as intergrown aggregates on a matrix of quartz and massive iron and manganese oxides. The crystals, which are excellent for the species, come from the Robert mine, in the Cayuna iron range.

MONTANA

Dr. Russ Boggs (19 Third Street, Cheney, WA 99004) found some free-standing crystals of cummingtonite in vugs of etched calcite from Lincoln County. Associated species include 4–5 mm crystals of arsenopyrite and minor diopside. A peculiar, colorless to pale tan, prismatic, tetragonal mineral resembling apophyllite occurs on the cummingtonite needles, which form 5–7 mm divergent, radial sprays of gray-green crystals.

Duane Johnson (P.O. Box 761, Butte, MT 59703) has some interesting brown titanite crystals to 3 cm covered by 3–4 mm microcline crystals from an undisclosed locality in Jefferson County. The same locality also produced 3–5 mm crystals of ferroaxinite associated with 5–10 mm epidote crystals.

Sharon Cisneros (*Mineralogical Research Company*) has acquired a good selection of 2–3 cm quartz crystals studded with feathery, gray-black sprays of tourmaline from the Bald Hornet claim, in King County.

David Shannon has come up with an interesting locality for unoxidized stilpnomelane. The black spherical rosettes show a circular cross-section of radially disposed plates embedded in fine, granular matrix of quartz and feldspar. The stilpnomelane occurs as individual spheres and as clotted aggregates at Blanchard Mountain in Skagit County.

NEVADA

More and better arthurite crystals keep coming out of Majuba Hill, Pershing County. *Sierra Vista Minerals* had some outstanding thumbnail to small cabinet-sized specimens with exceptionally fine, green, 2–4 mm divergent crystal sprays. The material is at least temporarily abundant. David Shannon also had some of this material, in addition to some good clinoclase and pharmacosiderite from the same locality.

Another one of David Shannon's noteworthy discoveries was a lot of centimeter-sized phenakite crystals from Wheeler Peak, White Pine County. Some of these specimens are associated with apatite crystals and a few with scheelite.

Jim McGlasson (*The Collector's Stope*, 7387 S. Flower Street, Littleton, CO 80123) had some small, blue-gray crystals of barite from the Dean mine (Cumberland adit), Battle Mountain, Lewis District, Lander County, available at the Denver show. By the time of the Tucson Show, Jim had come up with two rare species from the Bousfield level of the Dean mine: rhodostannite and canfieldite. These occur in rich, black masses associated with other sulfides in a brecciated quartz-carbonate ore.

John Seibel collected an interesting lot of nice yellow titanite and actinolite crystals on magnetite from the Metals mine in Churchill County. A few sections of purple apatite crystals were also noted by John, but no good specimens were found. Specimens of this material were available at the Denver show from both John, and Mark and Jeanette Rogers (P.O. Box 1093, Yucaipa, CA 92399).

Frank and Wendy Melanson (*Hawthorneden*) recently acquired some very fine thumbnails of crystallized gold from near Winnemucca. The crystals are elongated, skeletal cuboctahedrons up to 2 cm.

NEW HAMPSHIRE

There has been a great deal of collecting activity over the past year in the White Mountains, and indeed a banner year for one hard-working field collector. As collectors, most of us consider ourselves lucky to partake in even one major find in our lifetimes, but Peter Samuelson (R.R. 1 Box 11, Intervale, NH 03845) and his collecting partner Carlton Holt had four such finds last season alone. All this has obviously not transpired without a great deal of hard work! Since these discoveries have already been described in a series of articles by Ken Hollmann and William Metropolis in *Mineral News* (see **4**, no. 8, and no. 11, and **5**, no. 1) they will only be summarized briefly here. The first of these finds was made in May, north of Blue Mountain, near Albany, Carroll County, and consisted of a 2-meter long pocket that yielded approximately 1200 smoky quartz crystals. Some were associated with microcline crystals, and green and purple fluorite crystals up to 10 cm. One of the large matrix specimens weighs 60 kg and measures 32 x 32 x 68 cm. Several specimens of arsenopyrite crystals were also found.

Peter's second discovery occurred in June, and consisted of large amethyst crystals in the Conway Granite in Coos County. This pocket also measured nearly 2 meters, and yielded crystals up to 36 kg! Some of the crystals yielded rough from which gems have been faceted. The third happened in early September, when Peter was again prospecting in the Carroll County area, this time with his dog, Sadie, who startled a moose. The moose turned up a quartz crystal with its hoof as it left the scene of the now famous "Moose pocket," which measured nearly 2.5 meters across and yielded over 500 fine smoky quartz crystals weighing in at over 1200 kg. One of these monsters is the largest (by weight) known in the state. It measures 43.2 x 49.5 x 58.4 cm, and weighs 117.9 kg. As if all this were not enough, Peter discovered yet another pocket of similar proportions in late October. In addition to the 500 kg of smoky quartz and microcline crystals, this pocket also yielded some very different specimens from a mineralogical viewpoint, including some rhombohedral siderite crystals to 6.5 cm; zoned biotite crystals to 5 cm with altered interiors; zircon crystals to 1.5 cm; pyrochlore octahedrons to 1.4 cm; light brown bastnäsite-(Ce) crystals to 1.4 cm with fluocerite-(Ce) cores in addition to small crystals of fluorite and ferrocolumbite microcrystals.

Elsewhere in the state a consortium of collectors consisting of John Marshall, Don Wyman, Leo Vaught, Bob Whitmore, Paul Lukashuk and Bob Borofsky have obtained a three-year lease on the Wise fluorite mine near Westmoreland. Some notable specimens have reportedly been found, along with a quantity of faceting-grade rough.

NEW MEXICO

David Shannon recently acquired a small lot of choice wulfenite specimens from the Stevenson-Bennett mine, northeast of Las Cruces. Some of the thick, caramel-orange crystals resemble specimens from the more famous Glove mine in Arizona.

There was a large quantity of wire gold in calcite from San Pedro to be seen at the Tucson show. Numerous dealers and collectors had specimens available.

NEW YORK

Jeff and Val Collins (*Mohawk Enterprises,* R.D. no. 1, Box 340-C, Johnstown, NY 12095) have been reworking the serendibite locality near Johnsburg, Warren County, and have collected some good specimens of rich, blue, massive serendibite in addition to several specimens with actual *crystals* (see *American Mineralogist,* **17**, 457–465; *Rocks and Minerals,* **62**, 243–246).

PENNSYLVANIA

Last September, Ohio mineral collectors John Jaszczak and Pete Richards collected some excellent millimeter-sized orange-brown hemimorphic crystals of wurtzite at a railroad cut near Donohoe. The crystals are sharp and lustrous, and occur in calcite-filled septa in ironstone concretions. Several hexagonal and trigonal polytypes have been observed, and a few specimens show some epitactic overgrowths of unusual tetrahedral sphalerite crystals on the wurtzite.

TENNESSEE

The Elmwood mine has been a continual source of fine specimens over the last decade, and the past year's production could hardly go unnoticed at the major U.S. shows. Superb, large calcite, fluorite, barite and sphalerite specimens were available in profusion. Bob Halfacre (*Middle Tennessee Minerals,* P.O. Box 40, Elmwood, TN 38560), Gary and Mary West (Box 227, Pleasant Shade, TN) and Walt Gaylord (Rte. 2, Carthage, TN 37030) were but a few of the dealers seen with good Elmwood material.

UTAH

Gold Hill in Tooele County produced a number of interesting specimens last year. Harvey Gordon and Steve Rose (*Sierra Contact Minerals*) had some very good conichalcite from this locality, and David Shannon offered the rare species mendozavilite. The latter occurs in rich, yellow masses on fracture surfaces in a rock containing schorl and molybdenite, and is the second known world occurrence for the species.

Rex and Ed Harris (*Tina's Jewelry and Minerals,* Delta, UT) displayed a number of very fine red beryl specimens from the Wah Wah Mountains at the Denver show. This exceptional lot, which was collected in June and July, contained many crystals of good color and size (up to 3.5 cm) in addition to a quantity of faceting-grade rough and cut stones up to 2.64 carats.

David and James Lewis of *Diversified Minerals* (David Lewis, 749 E. Fort Union Boulevard, Midvale, UT 84047) had a new find of amethyst at the Denver show. These specimens, which consist of skeletal, pale amethystine crystals up to 10 cm, have fluid inclusions with moveable bubbles, and come from the Mineral Mountains in Beaver County.

Jim McGlasson had the rare species avicennite and parapierrotite from Lookout Pass, Tooele County, available at the Tucson show. These minerals form microscopic, but clearly visible, red and black masses in a siliceous matrix.

Part II: Canada

BRITISH COLUMBIA

Last summer Calgary mineral collector Ulrich Matern (2023 39th Street E., Calgary, Alberta T2B 1A4) was able to obtain some very good edingtonite specimens from the Ice River alkaline complex near Golden. Some of these specimens are reported to be as good as any ever found.

Jim McGlasson obtained a lot of the rare species wakefieldite-(Ce) from Yellow Lake. The specimens consist of black, lustrous, tetragonal crystals up to 4 mm in small vugs in an altered volcanic rock.

NORTHWEST TERRITORIES

Rod and Helen Tyson (*Tyson's Minerals*) had another excellent selection of unusual pyrite, sphalerite and calcite crystals from the Nanisivik mine on Baffin Island available again last year at the Denver show. While Rod hopes to be able to offer these in the future through his contacts at the mine, this will probably be the last of any large lots to be on the market for some time, as Rod does not plan to mine any more in quantity.

ONTARIO

Although Ontario is not generally thought of as a province known for celestine, there were at least two noteworthy finds of this mineral there last year. The first of these was made by Lenus Arnold and Harry Dryer last April in the Amherstburg quarry at Amherstburg (near Windsor), where they found and recovered intact a 25-cm vug lined with 3–4 cm blocky, blue crystals. This may be one of the best celestine specimens known from Canada. The second locality that produced good celestine specimens last year is the Dundas quarry in Dundas. Here several local collectors found good, blue crystals up to 10 cm long. The quarry is also reported to have afforded a few yellow fluorite specimens at the same time.

Many of the older classic localities (e.g., Turner's Island, Smart mine property, etc.) in addition to some newer roadcut occurrences in the Eganville area continue to produce good specimens of titanite, microcline, fluorapatite, diopside, zircon and other minerals (*Mineral News,* **4**, no. 8, p. 10).

There were a number of very good smoky quartz crystals collected at Greely last summer. Located just south of Ottawa, this occurrence is very similar to those in Middleville, New York, and many of the Greely specimens resemble Herkimer diamonds. This locality is presently under lease by Jeff Watson (P.O. Box 100, Osgoode, Ontario K0A 2W0) who has specimens available and controls access to the

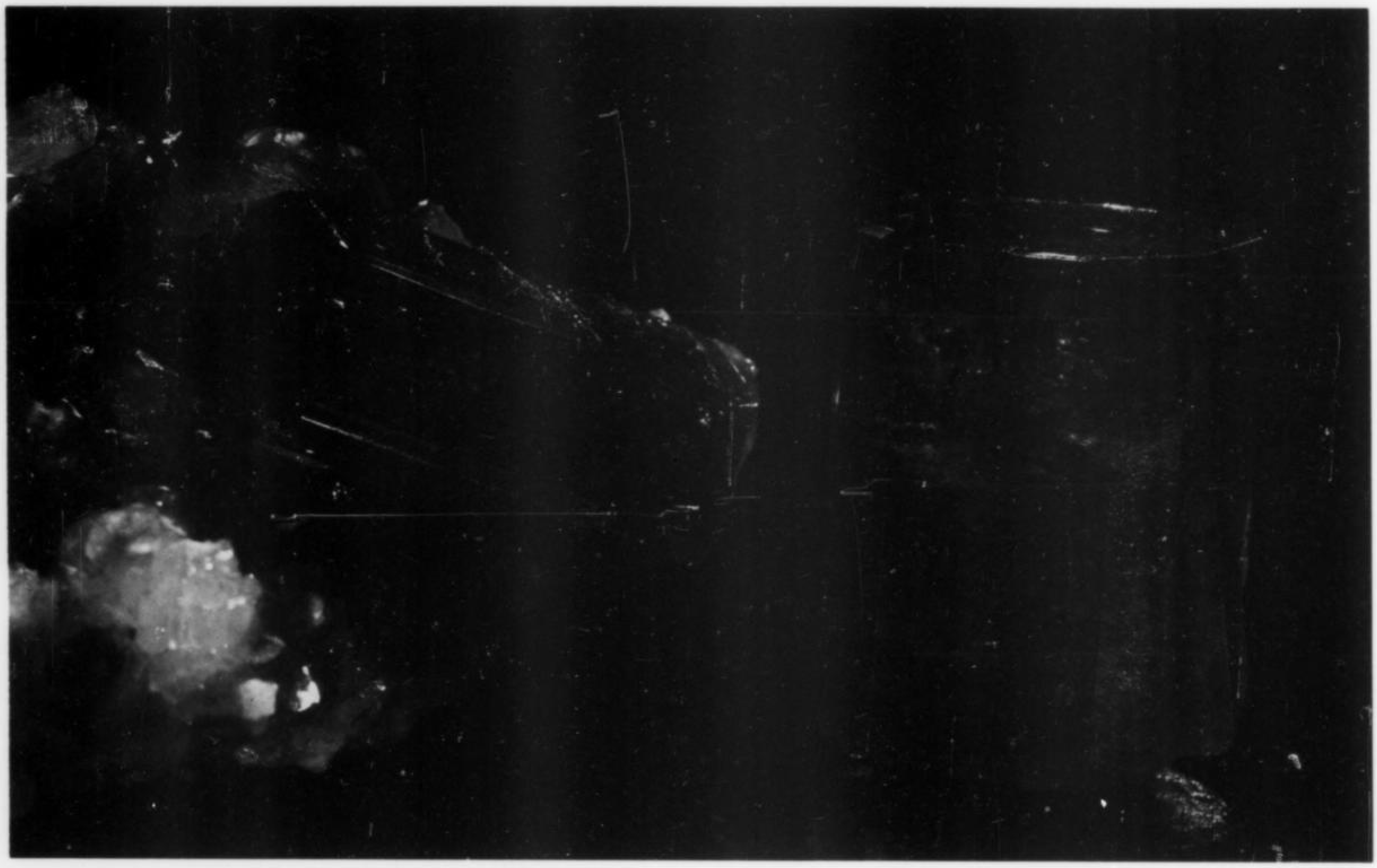

Figure 8. **Emerald crystals, 5 cm and 5.8 cm, recovered this year from the Muzo mine, Colombia. Tecminas specimens; photo by Donald Meyer, courtesy of the Natural History Museum of Los Angeles County. (See p. 394.)**

Figure 9. **Diopside crystals to 5.7 cm, from the Kunlun Mountains, southwestern Xinjiang Uyguy, China. Doug Parsons specimens. (See p. 399.)**

property. Anyone wishing to visit this locality should contact Jeff first. Rod Tyson and John Medici (7272 Macbeth Drive, Dublin, OH 43017) also have good specimens for sale.

QUEBEC

Having endured a long period of dormancy, the Jeffery mine at Asbestos is once again producing some exquisite mineral specimens. This is due largely to the renewed interest in asbestos on the Japanese market. Late last summer good grossular and vesuvianite began to appear, and by early autumn some truly magnificent purple and green vesuvianite specimens were found. The best of these must surely rank with the finest known. While certainly reminiscent of the vesuvianite find of a decade ago, the new material typically consists of smaller crystals, generally under 2 cm, though a few yellow-green crystals up to 5 cm were found. There was certainly more of the raspberry-red vesuvianite available than ever found previously, but fewer of the bicolored crystals. A very few, but excellent quality crystals of diopside and wollastonite were also found. Frank and Wendy Melanson, Celestin Arsenault (237 rue St.-Joseph, Asbestos, Quebec), *Tyson's Minerals*, Claude Begin (749 Union Street, Laval, Quebec H7X 1X7) and Bernard Borduas (1698 Duchesne, Val D'Or, Quebec J9P 6G8) all have excellent specimens available.

Further to the north in the Thetford mines area, some good specimens of grossular, vesuvianite, natrolite, scolecite and actinolite were collected by members of the Walker Club at the B.C. and Beaver mines.

On a dismal note, one of Canada's most famous mineral localities, the Henderson No. 2 mine at Chibougamau, shut down last fall. Fortunately, a few miners were able to remove the last of the last cubanite specimens that will likely ever been seen from this important locality (see *Mineralogical Record*, **14**, pp. 151–155). Probably the best of these were obtained by Rod Tyson, but Claude Begin and Bernard Borduas also had some very good specimens available at the Tucson show.

Rod and Helen Tyson had some very nice molybdenite crystals from the Moly Hill occurrence near Malartic for sale at their booth at the Denver show. The brilliant, silvery, hexagonal crystals range from about a centimeter up to nearly 3 cm in diameter and occur in a massive white quartz matrix. Some occur as attractive platy rosettes, resembling flat, silver-plated *eisenrosen*.

As usual, Gilles Haineault (*Collection Haineault*, 2266 St.-Alexandre, Longueuil, Quebec J4J 3T9) has done it again! Late last May and early June Gilles excavated a large pocket filled with serandite and leifite in the Poudrette quarry on Mont St-Hilaire. Unlike most serandite pockets in the past, the crystals in this one were extremely fresh and clean, requiring nothing more than a quick rinse in water to remove the dust from their lustrous, brilliant, orange-pink faces. Superb, terminated single crystals up to 8 cm and clusters nearly 20 cm across were collected. As if all this were not enough, the associated leifite is as good, if not better than the serandite itself, forming lustrous, white to pale lavender balls of silky crystals up to 3 cm. Equally remarkable, but unfortunately not able to be collected intact, was what was probably the world's largest villiaumite crystal. Gilles found it in a different pocket, and estimated its original size at approximately 20 cm across! Other species collected over the past year at Mont St-Hilaire include: 10-cm clusters of striated cubic pyrite crystals; mangan-neptunite crystals; pale pink masses of meionite in marble; dull, white 0.5-mm spheres of beryllonite in cavities in hornfels; pale, lemon-yellow cleavage masses and equidimensional crystals (to 1 mm) of shortite in a contact between marble and hornfels; millerite in thin, flexible acicular crystals forming divergent sprays in cavities in breccia; siderophyllite, in dark green to black foliated masses and pseudohexagonal prisms resembling biotite; clear to light gray, minute anhedral grains of cordierite as a rock-forming mineral in hornfels; dark brown to black massive crusts of rasvumite with a peculiar, cracked appearance associated with ussingite, villiaumite, sidorenkite and sodalite in xenoliths of sodalite syenite; small, spherical, white, fibrous masses of randomly oriented, 1–2 mm colorless prismatic crystals of revdite with a silky luster in sodalite syenite xenoliths; pale blue, translucent grains and vitreous masses of kogarkoite up to a centimeter across in sodalite syenite xenoliths (the kogarkoite fluoresces pale blue in ultraviolet light); colorless to pale pink, globular grains of sidorenkite to 1 mm in xenoliths of sodalite syenite; and gmelinite in a variety of colors and crystal habits.

SASKATCHEWAN

Although the province is well-known for its potash industry, few of us have ever seen a mineral specimen from Saskatchewan, much less owned one. At the Denver show, Rod and Helen Tyson had some good blue halite specimens from Lanigan. While not crystals, the cubic cleavages are of a medium blue color, and certainly from an unusual new locality for most of us.

YUKON TERRITORY

There has been a continuing supply of good lazulite and whiteite specimens available from the Rapid Creek area over the past year. Michel Brunet (6865 Boul. St.-Michel, Montreal, Quebec H1Y 2G4) and Gunther Kuhnlein (165 Marwood Circle, N.E., Calgary, Alberta T2A 2S3) both have superb specimens available. A few of these lazulite crystals exceed 2 cm across, and are some of the largest known from the deposit.

Part III: Other World Occurrences

ARGENTINA

Mike Siegel (*Aurora Mineral Corp.*, 16 Niagara Avenue, Freeport, NY 11520) had some very unusual *blue* genthelvite from Cerro Blancom Tanti, Cordoba. The mineral occurs as 1–2 mm grains and crystals in specular hematite veins that cut a pegmatite. The color is tentatively attributed to small amounts of Ni and Co (see *Revista de la Asociacion Argentina de Mineralogia, Patrologia y Sedimentologia*, Tomo **VII**, no. 3–4).

There is a continuing supply of good rhodochrosite from Catamarca on the market. Good specimens are available from Paul Cory (*Iteco Inc.*, P.O. Box 29531, Columbus, OH 43229), Jorge Alba (*Doble Minerales*, Florida 860, Gal. del Sol Local 94–97, Buenos Aires, Argentina) and others.

AUSTRALIA

The release of the Australia Issue of the *Mineralogical Record* provided many dealers an opportunity to feature their Australian minerals at the Tucson show. Forrest and Barbara Cureton (*Cureton Mineral Company*) provided a particularly fine selection. *Ikon Minerals*, *Western Minerals* and others had more of the superbly crystallized silver from the Eleura mine, Cobar, New South Wales (see *Mineral News*, **4**, no. 10, p. 7–8). Tony Jones (*California Rock and Mineral*, P.O. Box 896, Fallbrook, CA 92028) had some good cassiterite specimens from Elsmore, Inverell, New South Wales, available at the Denver show.

Some very beautiful golden-yellow wulfenite crystals have been coming out of the Whim Creek copper mine in Western Australia. The 3–4 mm crystals are remarkable in that they dramatically show the true hemimorphic symmetry so seldom observed on wulfenite specimens. Half of each crystal is composed of a steep, first-order pyramid truncated by a smaller second-order pyramid and a pedion. The other half is similarly modified by different pyramids of a more shallow angle and a negative pedion. Prism faces are rare. Specimens are available from Walter Lombardo (*Southern Nevada Mineral Company*).

There was a quantity of very fine crocoite specimens from the Red Lead mine, Dundas, Tasmania, on the market over the past year. Shane Dohnt (*Kapi Minerals*) and Graham Rowbottom (P.O. Box 9, Rosny Park, 7018 Tasmania) had a large lot of very fine specimens at the Tucson show, and Tony Jones had specimens available at the Denver show.

BOLIVIA

Alain Carion had a small lot of very fine cassiterite specimens from Villoco at the Tucson show. While these were not recently mined, they are new to the market, and better than much of what has been seen in recent years. The crystals average from 1–3 cm, and occur in lustrous groups up to about 10 cm.

BRAZIL

Carlos Barbosa (Rua Cel. Roberto Soares Ferreira 586, Bairro Vila Bretas, Governador Valaderas - CEP 35030, Minas Gerais, Brazil) has come up with many new items. Of particular note are phosphate minerals from Galileia, Minas Gerais. Strunzite was available in small clusters of 2–3 mm crystals, as were cloudy, white, elongate fluorapatite crystals with multiple terminations associated with childrenite-eosphorite crystals to 4 mm on corroded, pink microcline. Associated with some of these specimens are some interestingly color-zoned cubic fluorite crystals with clear, complexly shaped octahedral-dodecahedral nuclei overgrown on the octahedral faces by purple fluorite, while the dodecahedral edges remained clear. A third episode of growth resulted in the formation of a clear, dominantly cubic crystal with occasional minute hexoctahedral faces. These fluorite crystals occur up to about 8 mm in size and are associated with euhedral muscovite crystals. Carlos also had some beautiful pink rosettes of hureaulite crystals up to 2 cm in vugs in corroded albite from Linopolis. The associated phosphates include phosphoferrite-reddingite in tan, clear, typically striated bipyramids to about 1 mm, butterscotch-brown, millimeter-sized crystals of a whiteite-group (?) mineral and vivianite.

From Brumahdo, Bahia, Carlos had twinned, transparent dolomite crystals with basal pinacoids; semi-transparent, pseudo-cubic woodhouseite crystals (2–3 mm) on quartz crystals; and some interesting quartz encrustation pseudomorphs after an unknown, tabular, orthogonal mineral that appears to be replaced by powdery, light blue mixite. Also new from Brumahdo are some clear cabinet-sized crystals of magnesite and dolomite from the newly developed Pomba pit, acquired by Rock Currier (*Jewel Tunnel Imports*, P.O. Box 267, Arcadia, CA 91006).

In addition to the "poker chip" beryl crystals previously reported from Resplendor, Minas Gerais, there have also been found some 3–8 mm bipyramidal crystals of cassiterite on elbaite, and some colorless beryl with green elbaite. These are available from *the Rocksmiths*. *The Rocksmiths* also had an excellent lot of doubly terminated schorl crystals up to 25 cm long from Pedro Redondo, Minas Gerais, as well as a good selection of 10–15 cm amethyst scepters from Lavra Pedra Alta, Minas Gerais.

As in previous years there was a wealth of very fine quartz specimens from Minas Gerais to be seen at the Denver and Tucson shows. *Vasconcelos Ltda*. (Rua Afonso Pena 3053, P.O. Box 112, 35.100 Governador Valaderas, M.G., Brazil) had some superb large crystals of smoky-citrine color, while *the Rocksmiths, Aurora Minerals, Hawthorneden* and numerous other dealers offered a wide variety of quartz in all sizes, shapes and colors. Among some of the more memorable specimens were Rock Currier's 25-cm smoky gwindels, and the 10-cm spheres of asteriated rose quartz being offered by the *Talisman Trading Company* (P.O. Box 1895, La Mesa, CA 92041). Ken Roberts (*Roberts Minerals*, P.O. Box 1267, Twain Harte, CA 95383) had an exceptionally brilliant large specimen of amethyst from Rio Grande do Sul, and some very fine rose quartz crystals from Lavra da Ilha. There were also a number of good rutilated quartz specimens available from Itabira. Luis Menezes, Brian Cook (*Bird Eye Minerals*) and *the Rocksmiths* all had excellent specimens. Luis Menezes also had some new turquoise *crystals* from Itatiaçu. The 1–3 mm crystals generally resemble those from the more famous Lynch Station, Virginia, locality except for the matrix, which is iron ore.

There are relatively few specimens of the usual gem minerals evident this year, although Tony Jones had a superb, doubly terminated, gem-quality aquamarine crystal approximately 5 x 10 cm from Jaqueto, Bahia, at the Denver show, and Mark and Jeanette Rogers had some good specimens of elbaite from Coronel Murta and Araçuai, Minas Gerais.

BULGARIA

Ben De Wit (Box 1911, Fallbrook, CA 92028) has imported a large lot of very fine galena, sphalerite, quartz and chalcopyrite specimens from the 19th of September mine, Madan. The crystals are fresh and lustrous and occur in an assortment of aesthetically pleasing associations.

CHINA

Each year more new minerals from China keep showing up on the Western market, where they are eagerly awaited by an army of anxious collectors in search of something new. Such was the case at the room of Doug Parsons (*Parsons Minerals*, Suite 153, 2670 Del Mar Heights Road, Del Mar, CA 92014) at the Holiday Inn satellite show in Denver last year. Doug had just returned from China with a large lot of new, exciting specimens with documented localities! These included 15-cm stibnite crystals from the Xikuangshan antimony mine near Lengshuijiang, Shaoyang, Hunan; lustrous arsenopyrite crystals along with blue fluorite, cassiterite, muscovite, calcite, quartz and barite from Leiyang, Hunan; 2-cm crystals of scheelite similar to those from Korea, sharp 7-mm crystals of stannite with chalcopyrite and a 2-cm bournonite crystal from Hengyang, Hunan; lustrous black wolframite crystals reminiscent of the Peruvian or Panasquiera material associated with muscovite and quartz, also from Hengyang; large nailhead calcite crystals from Linwu, Hunan; large specimens of quartz with pyrite virtually identical to those from King County, Washington, but from Leiyang, Hunan; 2-cm doubly terminated dravite crystals from Korla, Xinjiang, Autonomous Region; Carlsbad-twinned orthoclase crystals up to 7 cm from Guiyang, Hunan; and of course, a fine selection of cinnabar crystals from several different mines. Additional species available included rhodochrosite, orpiment, beryl, dolomite, andalusite, topaz, apatite, valentinite, aragonite, realgar and others.

Bill Schneider (*Schneider's Rocks and Minerals*) had some unusual smoky quartz gwindels from Szechuan province, and Charles Key (20 Delano Park, Cape Elizabeth, ME 04107) and Frank Melanson each obtained a small lot of truly superb realgar crystals from Shimen, Hunan. These obviously did not last long!

COLOMBIA

What was being billed as "the world's finest emerald crystals" were on display early this summer at the Natural History Museum of Los Angeles County. A large (5.8 cm) single crystal and a slightly shorter (5 cm) and narrower crystal on a matrix of white calcite crystals were shown. Both were found last year at the Muzo mine in Colombia (see vol. 1, p. 142–149). According to Peter Keller, the museum's associate director for public programs, the two specimens far exceed in quality the "Patricia" emerald at the American Museum of Natural History and the "Gachala" emerald at the Smithsonian. The two new crystals were on loan from Tecminas, the company which operates the Muzo mine.

CZECHOSLOVAKIA

Ossola Ernesto (Via-N-Campi 30, 57100 Livorno, Italy) had some good blue microcrystals of langite on schist from Lubietova (formerly Libethen) at the Denver show.

FRANCE

An unidentified dealer at the Saint Marie aux Mines show had some exceptional individual hematite crystals (to 5 mm) on limonite-stained, drusy quartz crystals from Ranspach, Vosges. The lustrous crystals consist of thick, tabular, basal pinacoids with equally developed positive and negative rhombohedron faces. Also seen at the Saint Marie show were equally exceptional, snow-white nacrite crystals (to 4 mm!) in *centimeter-size* rosettes on matrix. These specimens of nacrite must rank among the best known, and were found at Lodeve, Haute Vienne.

Saint-Roy Mineralogistes (1 Rue Paul Cezanne, 75008 Paris, France) had a room full of the famous large sandstone concretions from the Fontainebleau quarry near Fontainebleau at both the Denver and Tucson shows. These stark white natural "sculptures" are unique objects d'art and disappeared quickly at both shows. While there were none of the classic Fontainebleau sand-included calcite crystals available. Alain Carion did have some very similar material from a new locality near Cabrerets, Lot.

GREAT BRITAIN

The majority of the following British finds were reported by Neil Hubbard (122 Cordery Road, Evington, Leicester, England LE5 6DF). We will begin with England. In Cornwall, a single piece of rock from Roughtor Great Consols, Altarnun, yielded some beautiful emerald-green zeunerite-metazeunerite crystals to 3 mm, individually scattered on limonite-stained quartz. The Geevor mine at Pendeen has been providing some excellent chalcocite microcrystals and twins to 7 mm. White 1–2 mm chabazite crystals in stalactitic growths to nearly a centimeter long are being found at the Deans quarry in St. Keverne. Some very fine, pale green fluorapatite crystals on albite have been collected from a granite pegmatite at Longdowns in Stithians. The habit of these crystals is nearly equant with first and second-order prisms and pyramids and a basal pinacoid. Hingston Down Consols is the type locality for arthurite. Though this mineral is typically botryoidal from there, some fine yellow-green crystal clusters to 3 mm have recently been found there. Some microscopic red carminite crystals have been found associated with a fine-grained yellow mineral that resembles corkite and malachite (?) in chalcopyrite-quartz ore at the Penberthy Crofts mine at St. Hilary. An attractive association of transparent, lustrous monazite-group crystals (to 2 mm) with tan, adamantine, rutile needles (to 5 mm) and white albite crystals (to 5 mm) occur on fracture surfaces in schist at the Lanterdan quarry, Tintagel.

On the macro scale, some spectacular green fluorite cubes up to 15 cm on light purple amethyst crystals were recovered from a large pocket found February 25, 1988, at the 15 level E in the Wheal Jane mine at Kea, near Truro, Cornwall. Associated species included pyrite and minor crandallite. Some spectacular large specimens were removed, one of which is presently on loan to the Cornwall County Museum in Truro by Mr. Alfred White. Additional fine large purple fluorite specimens were also obtained from the Fraziers Hush mine, Rookhope, County Durham. Most of these have transparent, cubic crystals that show the penetration twinning and development of small tetrahexahedron faces common to so many Weardale fluorites. Miriam and Julius Zweibel (*Mineral Kingdom*) had specimens available at the Denver show.

In Cumbria, leadhillite is being found in colorless 2–4 mm plates of quartz at the Red Gill mine at Caldbeck, and lustrous, transparent, prismatic crystals of barytocalcite to nearly a centimeter are coming out of the Blagill mine in Alston (type locality).

In Devon, langite has been found in lovely arborescent, snowflake-like crystal clusters to 7 mm on limonite at the Bedford United mine at Tavistock. The locality is also producing some excellent 1–3 mm crystals of clinoclase. The beautiful bright yellow crystal sprays (to 4 mm) found on fracture surfaces in granite at the Merrivale quarry at Dartmoor have been identified as phurcalite, and may be the best of that species to date. This material was formerly referred to as "merrivaleite," "nisaite" and other erroneous names. Brown 1–2 mm microlite crystals have been found in microcline, purple fluorite, gray-blue massive fluorapatite and minor crystallized albite at the aplite quarry in Meldon. Pale green chalcoalumite has been found as earthy masses and crusts on matrix from New East Wheal Russell in Tavistock, and transparent to white rhombohedral chabazite crystals up to 4 mm have been found on fracture surfaces in gneissic rock at the Ramsley quarry at Sticklepath.

Strontianite has been found at the British Gypsum mine at Barrow-upon-Soar, Leicestershire. The strontianite forms 1–3 mm tufts sprinkled across 3–5 mm calcite scalenohedra in veins in gray-brown limestone.

Edingtonite, usually considered a rare zeolite, has recently been found in a number of localities. One such undisclosed locality in Shropshire has produced some excellent transparent to milky crystals up to 2 cm, though most are less than half that size. Clusters to 8 x 10 cm and larger have been collected. The crystals differ from the Ice River, B.C. (Canada) ones in that they better display the classic blocky to wedge-shaped habit and sometimes reveal their twinned character by their cruciform shapes (as frequently seen on phillipsite crystals). The crystals are associated with clear, "axe-head" prehnite crystal aggregates to 4 mm on an altered, brecciated rock.

The Giant's Causeway in County Antrim, Northern Ireland, is well known not only for its columnar basalt pillars, but also for its zeolite minerals. Some very nice feathery clusters of white erionite (to 3 mm) have been found here in vesicles in the basalt. Their cottony appearance makes these specimens look more like mordenite than erionite.

In Scotland, some excellent harmotome specimens have been found in the Touch Hills near Stirling. The crystals, which are generally less than 8 mm, show sutures indicative of twinning and are associated with adularia and quartz crystals of similar size. Cloudy white levyne crystals up to 4 mm are currently collectable from The Storr in the Isle of Skye. Other zeolite minerals are being found at the Loanhead quarry, Beith, in Strathclyde, including transparent, prismatic to blocky crystals of thomsonite up to 3 mm. Leadhillite is still being found as transparent, 1–3 mm crystals in altered and slightly brecciated galena at the Roanburn vein, Leadhills, in Lanarkshire.

In Wales, there are some excellent micromount specimens of sphalerite being found at the Scotch Collary at Gilfach Goch, near Mid Glamorgan. The crystals are generally less than 3 mm, but have a high luster and show the irregularity of shape frequently associated with this species. The crystals occur in fractures in a dark brown ironstone-like matrix. Paracelsian crystals can still be collected at the type locality, the Bennallt mine, Rhiw, Gwynedd. Transparent crystals of xenotime up to 2 mm associated with orange-colored anatase crystals to 3 mm are being found in the Hendre quarry at Glyn-Ceiriog in Clwyd. The Pant-y-Gaseg quarry at Trwynbychan, Anglesey, which is the type locality for dickite, has recently provided some nice specimens of that mineral. These snow-white dickite crystals are up to about 2 mm and occur with 1–2 mm limonite-stained dolomite rhombs on clear centimeter-sized quartz crystals. Lastly, some very good crystals of orange-brown brookite up to 1 cm are still occasionally being found at the type locality for that mineral near Tremadoc.

GREECE

Gilbert Gauthier (7 Avenue Alexandra III, Maisons-Laffitte, 78600 France) and his collecting partner Nikos Albandakis (Iros Constandopoulou 112, 163 46 Athens, Greece) have continued to explore the skarn near Mega Xhorio on the island of Serifos. Recent discoveries include green, hedenbergite-included quartz crystals with tapering amethystine tips up to 17 cm; more jackstraw groupings of the green quartz to 7 x 7 cm; brown, red, and nearly black crystals of andradite; hematite *eisenrosen* up to 2 cm on quartz crystals; divergent, quartz-studded groups of ilvaite crystals to 12 cm; and some dramatically elongated hedenbergite crystals forming 5-cm "pin cushions" with andradite.

GREENLAND

Last July there was a major jointly sponsored expedition to the alkali syenite complexes in southern Greenland made by the Geological Museum of the University of Copenhagen, the Canadian National

Museum of Natural Sciences and the Museum of Victoria, Australia. Because a complete account of the expedition is in preparation for the *Mineralogical Record,* only a brief synopsis will be given here. The focus of the expedition was on collecting at the famous Narssarssuk occurrence, but several localities in the Ilimaussaq complex were also visited, including Taseq, Kvanefjeld and Kangerdluarssuk. Excellent crystals of aegirine, eudialyte, epididymite, albite and neptunite were collected along with very fine specimens of ussingite, steenstrupine, tundrite, semenovite, emeleusite, sorensenite, astrophyllite, narsarsukite and numerous other species.

ICELAND

Jim McGlasson recently obtained some cowlesite from Hvammer. The crystals are transparent to gray with a blue tint and resemble cowlesite from other occurrences, forming vug linings of botryoidal aggregates of platy crystals.

INDIA

Certainly one of the most important (and colorful!) new discoveries over the last year is Hans-Jürgen Wilke's new cavansite crystals from Poona. The liroconite-blue 2-cm spherical crystal aggregates on white stilbite crystals are breathtakingly beautiful, and at least two orders of magnitude better than anything ever found before. They are clearly the world's finest cavansites. The specimens are from a quarry owned by Mr. Balakrishna Dhoot of Poona; it is located approximately 15 km northeast of Poona on the road to Ahamadnagar (reportedly near the village of Wagoli). The occurrence was confined to a singular breccia zone in the floor of the quarry, and to date no additional specimens have been found. Wilke (Odenwaldring 44, 6116 Eppertshausen, West Germany) had many superb specimens for sale at the Tucson show.

IRELAND

Neil Hubbard has found some interesting micros in Ireland, including some excellent golden yellow cacoxenite from Ft. Lismeenagh, Shenagolden, in County Limerick, and some blocky, midnight-blue azurite crystals (to 5 mm) at the Tynagh quarry in the Galloway district. The latter are as fine as any known azurite micromounts.

ITALY

The Jeffrey Mining Company had some very interesting specimens of reddish tan, free-standing sprays of zoisite crystals in vugs in marble from Navara, at the Tucson show. At the Denver show, Ossola Ernesto offered some attractive calcite specimens from Lazio, approximately 100 km from Rome. These specimens consist of cabinet-size pieces of dark basalt with hemispherical botryoids of cream-colored calcite to 2 cm lining vesicular cavities. Some good metastibnite specimens were also available, but the locality is unknown to the authors.

JAPAN

Several very fine topaz specimens were collected three years ago at a granite quarry near the village of Hirukawa, in the Tawara area, Gifu prefecture, Ena County, Japan. One of these, shown here, was obtained by Jimmy and Hisami McNeil (1175 Mt. Moriah, Memphis, TN 38117). The crystals are very lustrous, well formed, complex in habit, and sherry-brown in color like the best crystals from Topaz Mountain, Utah. Crystal size ranges up to about 4 cm. Associations include large (9 cm), dark smoky quartz crystals, some of which are doubly terminated, and tan to gray microcline crystals of similar size.

KENYA

Mountain Minerals International recently obtained a small lot of many one-of-a-kind new specimens from several African countries. Among those from Kenya were some light golden colored calcite crystals from Mt. Elgon, some 2-cm crystals of nepheline from the Athi River Area, and some dark blue 1–2 cm crystals of corundum from Taita.

MEXICO

There seems to have been a great deal more new specimen discoveries made over the last year in Mexico than in most recent years. Among these is a quantity of new calcite specimens from Mina Salaverna, Concepcion del Oro, Zacatecas. Most crystals seen have a satiny luster and are yellow-gray to light brown in color. They average 2–3 cm in size, are commonly twinned rhombohedrons with scalenohedral modifications and form groups of crystals up to 30 cm across. Victor Yount, Don Olson (P.O. Box 766, Cedarburg, WI 53012), Neil Pfaff, *Hawthorneden* and numerous other dealers had specimens available.

Jim McGlasson had some very impressive large gold nuggets from a new find near Bacoachi, Sonora, at the Tucson Show. These are associated with water-worn milky white quartz and were available in specimens over 10 cm across! Also new from Sonora were some very lustrous single crystals of hematite, reportedly from near Ures. These 2–4 cm skeletal, tabular crystals were available from Neil Pfaff, *Bitner's* and *Mohawk Enterprises*.

Both Neil Pfaff and *Western Minerals* had some new epidote crystals from Taxco, Guerrero, at the Detroit show. Most of the specimens consist of single, dark green prismatic crystals up to about 6 cm in length, and greatly resemble those from Mineral County, Nevada. Some are associated with small titanite crystals.

Last year we reported on some Herkimer diamond-like quartz crystals from a new but undisclosed locality in Mexico. There were more of these available again this year at the Tucson show, but the exact locality details appear to be a closely guarded secret. Although many labels now state the locality as simply Oaxaca, it is presumed by most "in the know" to be incorrect, and that the true locality is in the state of San Luis Potosi. Hopefully time will sort out the truth. The crystals greatly resemble Herkimer diamonds, even down to the presence of hydrocarbon inclusions. Their size and quality is also similar, occurring in 3–10 mm brilliant, transparent, doubly terminated crystals that grade into more smoky, internally fractured crystals with increasing size. Some of the 5–10 cm crystals are skeletal in habit and resemble the crystals described above from Greely, Ontario, Canada. Good specimens were available from Si and Ann Frazier (Suite 306, 6331 Fairmont Avenue, El Cerrito, CA 94530), *Crystal Source* (2403 Dip Cove, Austin, TX 78704), *Hawthorneden* and others.

MOROCCO

There have been more fine mineral specimens coming out of Morocco again this year. Victor Yount, Alain Carion, Ossola Ernesto, Horst Burkhard (Bonn, West Germany) and numerous others had good selections from which to choose. Some of the new items include phosgenite crystals to 9 cm, large, blue-green, botryoidal smithsonite specimens and more very fine yellow anglesite and V-shaped twinned cerussite crystals from Touissit; red-brown to yellow-brown vanadinite crystals from the T-West mine at Mibladen; and fluorite, calcite and quartz pseudomorphs after anhydrite from El Hamman.

Other new finds included specimens of mercurian silver (being called by the varietal name "kongsbergite") up to 40 kg from the Imiter mine in the Dades region; clear quartz crystals with siderite from the Mefis mine near Erfud; gersdorffite crystals to 3.5 cm from Itaman; and more very good erythrite specimens from Bou Azzer, which were available from Christian Gobin (Chemin des Terres, Longues, F-13770 Venelles, France) at the Münich show and from Enrique Kucera (Comte d'Urgell 171, 08036 Barcelona, Spain) at the Tucson show.

NAMIBIA

There have been more of the dark, blue-green fluorite cubes found at the Okaruso mine. Some of these show purple color-zoning at the corners of the cubes and occur in groups up to 20 or more cm with quartz crystals. *Genesis Epoch* (P.O. Box 440356, Aurora, CO 80044) and Don Olson had good selections from which to choose.

Bruce Cairncross has reported that the Rosh Pinah mine, located in southern Namibia, recently produced some very fine golden orange barite and marcasite specimens, and that a few more good twinned cerussite crystals have been found at the Kombat mine (*Mineral News,* **4**, no. 12, p. 1).

Tsumeb had been disappointingly quiet this year, though a few good azurite, cerussite and descloizite specimens were still to be seen at both the Denver and Tucson shows. *Genesis Epoch,* Sid Pieters (Windhoek, Namibia), *Namibia Minerals* (P.O. Box 5159, Suurbekom 1787, South Africa), Don Olson and others have specimens available.

NIGERIA

Mountain Minerals International had some interesting new specimens from Nigeria at the Denver show last September. Among others were some very dark smoky quartz crystals up to 20 cm from Bui, Borno State, that showed very good scepters and skeletal growth (*fenster* quartz); amethyst crystals similar to those from Virginia and the Carolinas from Darazo, Bauchi State; amazonite and topaz from Jos, Plateau State; and a single piece of dark, emerald-green fluorite from Plateau State.

NORWAY

The Norwegian Mining Museum (Kongsberg, Norway) displayed some superb Norwegian minerals at the Tucson show last February. Along with some of the most classic Norwegian specimens (like a 20-cm wire silver!) were a number of equally incredible newly collected specimens such as lustrous, dark, steel-blue anatase crystals nearly 4 cm long! These crystals, which have an almost metallic brilliance, were reportedly found last year in an alpine cleft occurrence in a metamorphic belt that runs from Hardangerfjord on the west to Gudbrandsdalen on the east. The exact locality was not given. One 3-cm twinned crystal resembled those described from Somerville, Massachusetts (see Taf. 31, Fig. 105, Goldschmidt's *Atlas der Krystallformen*). There were also a few small matrix specimens with 2-cm blocky crystals on white adularia. In addition to the anatase, there was also a 7-cm gem-quality yellow-orange datolite crystal on display. This specimen was collected by Torgeir Garmo from the area north of Hardangerfjord. A selection of faceted stones accompanied the single crystal. The museum was promoting the 12th annual Nordic Gem and Mineral Show which was held August 12–13 in Kongsberg, and with specimens like the ones shown, one could not imagine better advertising!

Torgeir Garmo (*Fossheim Steinsenter,* 2686 Lom, Norway), who was also at the show, had a number of interesting new materials with him. Some of these were rare species such as hilairite from Bratthagen, Lagendalen, Larvik; janhaugite from Gjerdingen, Nordmarka, Oslo; and holtedahlite from Tingelstadtjerm, Modum; while others were of larger, more displayable common species like pink zoisite and piemontite from Søre Lia, Lom; hornblende crystals from Kragerø; tremolite and diopside crystals (similar to the classic Gouverneur, New York material) from Mo I Rana; rutilated smoky quartz crystals with albite and chlorite from Hardangervidda; hydroxylapatite crystals (to 3 cm) from Oksøykollen, Modum; golden yellow barite crystals to 5 cm from Styggedalsynken, Herre, Bamble; and numerous other specimens.

There was a good selection of some newly acquired zircon specimens from Seiland available at the Denver Show from Roy Masin (*Brazilian Curiosa,* Stadhouderslaan 25b, NL-3761 Ej Soestdijk, Holland). These ranged from single crystals 2 cm long to 10-cm groups of 5-cm red crystals and larger matrix specimens containing dozens of sharp crystals in biotite gneiss.

Neil Hubbard had some outstanding micromount to thumbnail-sized epidote specimens from Hotvedt, Sandefjord. The epidote is transparent and of a fine pistachio-green color. The habit is a simple rectangular prism, and twinning is evident on some of the crystals. Associated with the epidote is a pale green tremolite (?) ("amianthus") in crystals to 1 cm and some poorly developed magnetite crystals. Almost as spectacular as the epidote are the zoned albite and microcline crystals that have also been found there. Most of these are less than a centimeter, though a few larger ones are known. The cores of these feldspar crystals are composed of pale pink, opaque to translucent microcline, overgrown by transparent albite. The color zoning is striking.

PAKISTAN

There has been a large number of very fine specimens found in Pakistan over the last year. One of the most exciting new items was particularly evident at the Tucson show: aquamarine from Nagir, near Karimabad, in Hunza. These crystals are associated with bladed crystals of muscovite and greatly resembled some of the Brazilian specimens from the "good old days." The aquamarine is of a good pale to medium powder-blue color and many of the crystals are quite gemmy. Equally exciting are the dark pink, gemmy fluorapatite crystals associated with some of the specimens. Herb Obodda displayed a 7 x 12-cm pink fluorite cube along with a 248.8-carat faceted peach-colored fluorite from the same locality. In addition to Herb's fine selection of specimens, others were also available from *Siber & Siber* (Zürichstrasse 188–190, 8607 Aathal, ZH Switzerland), Giuseppe Agozzino (Viale Abruzzi 81, 20131 Milano, Italy), Wayne Thompson (1723 E. Winter Drive, Phoenix, AZ 85020) and several other dealers. Particularly memorable was the incredible display of Pakistan and Afghanistan pegmatite minerals by G. Andreas Weerth (D-8183 Rottach-Egern, Rosswandweg 11, West Germany), which featured not only the new aquamarine and muscovite specimens and a 6-cm dark pink fluorapatite crystal from Nigar, but also a 3-cm dark brown-green andradite dodecahedron from the Tribal area, a 7-cm morganite crystal on quartz with tantalite and a 15-cm doubly terminated gem kunzite crystal on quartz, both from Afghanistan. Add to these several superb, rich champagne-colored topaz crystals 10 cm across (such as the one displayed in Tucson by *Siber & Siber*!) from Skardu, groups of 5–15 cm lustrous schorl crystals (Wayne and Dona Leicht specimens), several more rare, large pollucite crystals and a 5-cm gem-quality green herderite crystal (Herb Obodda specimens), and you must admit it has been a great year for Pakistan minerals!

However, there is more. At the Denver show Miriam and Julius Zweibel had what has to be one of the finest epidote specimens to ever come out of Pakistan, or anywhere else in the world for that matter. The specimen, which comes from the Harmosh range, Gilgit, measures approximately 7 x 15 cm and is composed of several divergent gemmy green crystals. The color, luster and crystal perfection is equal to any of the best Austrian specimens. The Zweibels also had some 2–4 cm crystals of yellow-green, twinned titanite from the Harmosh Range, and *Mountain Minerals International* had groups of black, 3-cm crystals of fassaite from the same area.

International Gems and Minerals (P.O. Box 3017, Long Island City, NY 11103) had some new ruby crystals in a white to light gray, coarse marble matrix. The color of these crystals varies from excellent, deep, true ruby-red to pink. The largest crystals are about 3–4 cm, but the smaller crystals tend to be sharper. The specimens are reported to have come from the eastern Hunza region.

PERU

Having endured a relatively quiet period of specimen production over the past few years, Peru is once again producing some of the exceptionally fine sulfide minerals for which it is so famous. This was particularly evident at both Denver and Tucson. Don Knowles (*Golden Minerals,* 13030 West 6th Place, Golden, CO 80401) had an enormous selection of fine specimens available at the Denver show, including an incredible pyrite pseudomorph after enargite with crystals nearly 10 cm long, among the more typical, but excellent, specimens of pyrite, tetrahedrite, bournonite, chalcopyrite, quartz, calcite, rhodochrosite, arsenopyrite, pyrargyrite and sphalerite from all the well known localities (Huanzala, Casapalca, Quiruvilca, etc.). Many fine specimens of these minerals were also available from a number of other dealers, including Mark and Jeanette Rogers, *Willis Earth Treasures* and Marty Zinn (P.O. Box 2433, Evergreen, CO 80439), who returned from Peru with some pale yellow fluorapatite crystals (to 1 cm) associated with lustrous arsenopyrite crystals.

Worthy of special mention are the incredibly huge (up to 25 cm!) pyrite octahedrons in groups up to 100 kg from Huanzala. Although several different dealers had these at Denver and Tucson, most of the better large crystals were to be seen at Dennis Belsher's booth (*Worldwide Resources*, P.O. Box 636, Golden, CO 80402), and Rock Currier (*Jewel Tunnel Imports*) has reportedly obtained an excellent lot of these large pyrite crystals since the Tucson show. (See Rock Currier's letter about this find on page 403.)

POLAND

The Machow sulfur mine near Tarnobrzeg is still yielding very fine barite, sulfur and celestine specimens. Some of the past year's production may be among the best yet. Specimens are available from K. Fritsche (Eichhornseckerstrasse 17, D-8342 Tann, West Germany), Ben De Wit and numerous other dealers.

A completely different new item from Poland that was available from Miriam and Julius Zweibel at the Denver show was some interesting flint nodules from Kremianski, Opatowskic. These specimens consist of attractive gray and white concentrically banded slabs averaging 10 x 20 cm that resemble agate, yet are uniquely different. How many collectors have a displayable flint specimen in their collections?

SOUTH AFRICA

There were a number of very fine, large hematite crystal specimens produced from the Wessels mine in northern Cape Province last year (*Mineral News*, **4**, no. 12, p. 1). Some of the individual crystals attain 30 cm, and clusters up to 30 kg are known. Most of the crystals are of a flat, platy *eisenrose* habit, and many specimens are associated with brilliant millimeter-sized orange-brown andradite crystals. Some also have barite. Don Olson and several other dealers have specimens available.

Bruce Cairncross reports that some good stilbite specimens associated with calcite, mesolite (?) and fluorapophyllite have been found in veins in chromite in the Mooinooi mine near Brits, Transvaal (*Mineral News*, **4**, no. 12, p. 1).

Larry Introna (P.O. Box 4147, Cape Town 8000, South Africa) discovered some very interesting rhodochrosite from Aggenys. These specimens consist of "wheat sheaf" bundles of stacked rhombohedra that form clusters up to 3 cm in length.

Neil Hubbard acquired some clinoclase crystals (to 3 mm) from the Hillside quarry near Stavoren, Transvaal. The matrix is composed of a crystalline calcite breccia with olivenite crystals up to 4 mm and minor unidentified green and gray minerals.

SOMALIA

Among the numerous "one-of-a-kind" African specimens recently obtained by *Mountain Minerals International* was a 7-cm columbite crystal from Somalia. While the exact locality details were unavailable, it certainly reminds one that there are a lot more interesting new mineral occurrences out there waiting to be discovered by those willing to seek them out. What other unusual (presumably pegmatitic) treasures might there be still hidden away in Somalia awaiting their debut?

SWEDEN

There were a few more of the fine strengite, beraunite and rockbridgeite specimens from Svappavaara seen on the market last year. Although a few specimens appeared randomly in the stock of various dealers, probably the best selection was that offered by Roy Masin at the Denver show.

TANZANIA

Among their stock of African specimens, *Mountain Minerals International* had some new 6-cm albite crystals from Moshi, and some champagne-colored tourmaline crystals up to 5 cm from northern Tanzania.

TURKEY

There were some very good new chromian clinochlore ("kämmererite") crystal specimens from Erzurum available at both the Münich and Tucson shows. Specimens are available from Siegbert Zecha (Windecker Pfad 1, D-6369 Schöneck 2, West Germany) and Fetah Akar (Kreillerstrasse 68, 8000 München 80, West Germany). Sefcet Azizog (Röthelteich 13, 5828 Ennepetal, West Germany), who was with Fetah Akar in Tucson, also had a good selection of diaspore crystals from Mugla province.

U.S.S.R.

There were some notable Russian specimens available to collectors at the Denver and Tucson shows. These included a very fine 1-cm bornite crystal on quartz and calcite from Dzeskasgan in central Kazakhstan; good, purple creedite crystals similar to the recent Mexican ones from Aktshatan, 40 km south of Dzeskasgan; and some fine, large vivianite specimens from Crimea, which were available from Miriam and Julius Zweibel. Roy Masin had analcime crystals up to 7–8 cm from Iakouti, Siberia, and Tony Jones had an even larger datolite crystal also from Russia.

WEST GERMANY

Neil Hubbard recently obtained some very unusual phillipsite crystals (1–3 mm) with clear chabazite rhombs (to 2 mm) in altered basalt from Lungd, Hesse. These clear, prismatic phillipsite crystals are without any obvious external expression of twinning.

Wright's Rock Shop (Route 4, Box 462, Hot Springs, AR 71913) has acquired a new lot of very impressive, large (25–30 cm) groups of thick, pink and white, bladed barite crystals from Dreislar. Most are sprinkled with lustrous chalcopyrite disphenoids, and are exceptionally good for the locality.

ZAIRE

Certainly one of the highlights of the past year's new discoveries was the spectacular lot of cuprite crystals on chrysocolla acquired by Gilbert Gauthier from the Mashamba West mine (*Mineralogical Record*, **20**, 69, 71). However, Gilbert also had a number of other Zaire minerals that deserve mention. A former mining engineer at the Musonoi mine, and senior author of the comprehensive article on the uranium deposits of Zaire in the previous issue, Gilbert has become very well-known as a supplier of fine uranium minerals. This year was marked by a wonderful plethora of yellows, oranges and greens at his booth in Tucson, including some major specimens which had never before been offered for sale. Pale to medium green fibrous roubaultite with uranophane was present in two specimens: one from Shinkolobwe, the other from Kolwezi, in Shaba province—a quantity perhaps equal to all that had been previously known. Brilliant yellow kamotoite-(Y) was available in radial crystal sprays up to 2 cm on a black matrix from Kamoto Est, Shaba, and an exceptional 10-cm vug of medium yellow soddyite crystals to 3 mm was discovered at Kasolo, Shaba. Thick fibrous, but not prismatic, apple-green cuprosklodowskite crystals were available in a profusion not seen in recent years. Crystals to 1.5 cm in 8 x 8-cm clusters were collected. One amazing torbernite was also found. The cluster of deep, emerald-green crystals is 12 x 20 cm and is thickly clustered with 1–2 cm crystal plates with excellent three-dimensional expression. The rare species bijvoetite, oursinite and shabaite were also available in unique specimens.

Lastly, Gilbert, Ben De Wit and Larry Conklin (7 St. John Place, New Canaan, CT 06840) all had fine specimens of lustrous, botryoidal chrysocolla labeled as coming from Kakanda, Shaba. It has recently been learned by Gilbert, however, that the actual locality is probably

Kambove. The dark, electric-blue color of this chrysocolla is complimented nicely by the presence of light green malachite and black tenorite.

G.W.R. & V.T.K.

SAN DIEGO COUNTY DISCOVERIES

The gem pegmatites in San Diego County, California, are enjoying a very productive period. The White Queen mine has yielded some very promising pink beryl crystals to 13 cm, along with huge quartz crystals, pink spodumene, albite crystal rosettes on white to pink microcline, and black tourmaline. Specimens are currently being distributed by Bill Todzia (*Rincon Minerals*, 1711 E. Factory, Unit J, Tucson, AZ 85719).

The Stewart mine also yielded a pocket recently, although pockets tend to be small there. Three fine tourmaline crystals along with a sizable quantity of gem rough were taken out.

By far the biggest pocket to be found in the county in many years was opened in May at the Himalaya mine. According to Bill Larson of *Pala International*, the pocket measured nearly 4 meters long and has thus far yielded about half a ton of crystal specimens and carving rough. Many good matrix specimens (over a hundred) were taken out, the best ten having been sold almost immediately for five-figured prices. The tourmaline crystals range from pure pink to having green cores and pink exteriors. Most crystals are in the usual 7–8 cm size range, but a few reach 4 x 18 cm, with nice terminations consisting of either the pedion or the rhombohedral forms; many are doubly terminated. Platy albite (*cleavelandite*) and quartz crystals form the attractive matrix for many specimens, some of which have up to four tourmaline crystals in a single group.

CHINESE DIOPSIDE

In May, D. J. Parsons (2670 Del Mar Heights Road, Suite 153, Del Mar, CA 92014) returned from China with a 1-kg lot of fine, gemmy, green diopside crystals. The locality was given as the Kunlun Mountains, in southwestern Xinjiang Uygur autonomous region. About 200 crystals comprised the lot, none having any matrix; most are 1–2 cm in size, but some reach 5 cm and 60 grams. They are rich in faces, and clearly show their monoclinic symmetry. Luster ranges from glassy and smooth to somewhat corroded and striated. About 5% of the crystals are twinned on (100). The crystals are quite attractive, and compare well with old specimens from the classic locality in DeKalb Township, St. Lawrence County, New York. (See Fig. 9.)

W.E.W.

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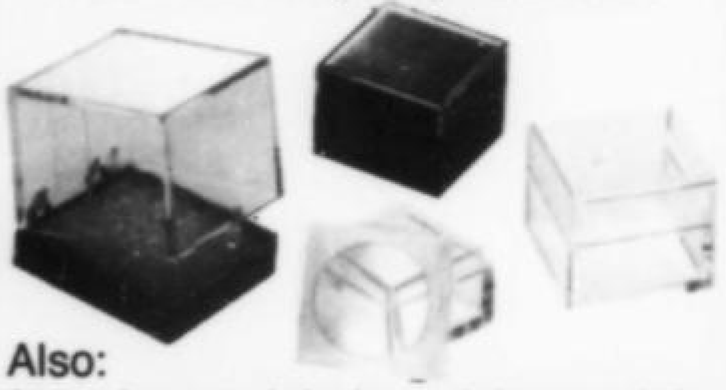

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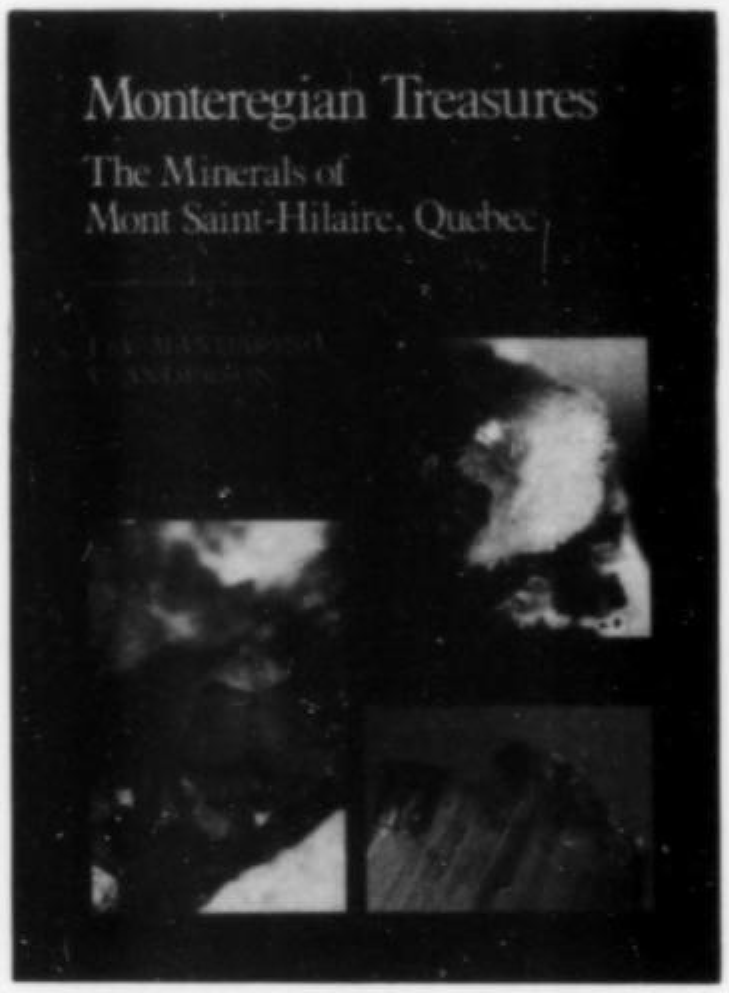
Book Reviews



Monteregian Treasures

by J. A. Mandarino and V. Anderson (1989), published by Cambridge University Press, 32 East 57th Street, New York, NY 10022 (ISBN 0-521-32632-X); hardcover, 281 pages of text plus 32 pages of color specimen photographs, 25 x 34 cm, $85.00.

Monteregian Treasures is a useful and comprehensive treatment of what is perhaps Canada's best known occurrence of rare and unusual minerals, Mont St-Hilaire, Quebec. As Curator of Mineralogy at the Royal Ontario Museum, repository of many important Mont St-Hilaire specimens, Dr. J. A. Mandarino is ideally suited to be the book's primary author. The text is amply illustrated with numerous Violet Anderson photomicrographs, 90 of which are in color; computer generated crystal drawings; and sketches by several contributors. The unusually long list of people and organizations acknowledged as contributing significantly to this work further emphasizes its importance to both amateur and professional mineralogists.

Four major "parts" comprise the book. The Introduction consists of a brief description of the general geology, petrology and geological environments of Mont St-Hilaire; a useful discussion of chemical and geochemical considerations related to the distribution of elements, chemical classes of minerals and occurrence types; and an outline and discussion of descriptive mineralogy as utilized throughout Part Two—Mineral Descriptions.

The bulk of the text is contained in Part Two and consists of alphabetically arranged mineral descriptions. Each description begins with very important Introductory Remarks and Appearance sections. These are followed by a brief presentation of the mineral's physical properties and a discussion of its specific occurrence and associated species. Excellent sections on optical, chemical and crystallographic features represent the current state-of-knowledge for most of the 221 minerals covered.

A very important aspect of this work is the set of appendices that make up Part Three. Included are single crystal and X-ray powder diffraction data, tabulations of species as distributed in Mont St-Hilaire's ten major geological environments, and a complete listing of Mont St-Hilaire minerals in a "Dana" classification format. The final appendix consists of an amazing 41 tables that contain all of the known chemical analytical data for species from Mont St-Hilaire. This major presentation of technical information is followed by Part Four—References.

For those interested in rare species and micromounting, *Monteregian Treasures* will be an indispensable guide to mineral identification, associations and paragenesis. The simple organizational format and clear presentation of data make this book unusually easy to use, particularly for persons already familiar with Roberts, Rapp and Weber's *Encyclopedia of Minerals.* The photomicrographs, while perhaps giving the incorrect impression that most interesting Mont St-Hilaire minerals occur only in microscopic-sized crystals, are equally important aids to identification. The technical data contained in the appendices make this work a primary reference for professional mineralogists and geochemists interested in the intriguing geological environments represented by the Monteregian Hills and similar terrain.

As with essentially all books dealing with complex scientific topics aimed at a varied audience, *Monteregian Treasures* has several weaknesses, all rather minor. Although the captions for crystal drawings correctly indicate the forms present, these forms are not identified on the drawings themselves, thus leaving it to the reader to guess which forms go with which faces. A simple geological map and locality photographs would have contributed greatly to the introduction, particularly for those readers not fortunate enough to have visited the occurrence. Finally, since there is great interest in Mont St-Hilaire minerals within the international mineral collecting community, a mine map showing specific important locations and a brief chronology and descriptions of the more important finds would have added color to the somewhat dry overall presentation. Although expensive, *Monteregian Treasures* is an absolute must for the serious collector. Hopefully, similar treatments of other world-class occurrences will emerge in the near future.

Robert B. Cook

The Geology of Ore Deposits

by John M. Guilbert and Charles F. Park, Jr. (1986). Published by W. H. Freeman and Company, New York; 985 p., black-and-white il-

lustrations, diagrams and maps; hardcover, $47.95.

In his book, *The Mineral Kingdom,* Paul Desautels described a serious mineral collector as someone who ". . . wants to know the life history of his [her] specimens, the conditions under which they formed, and the natural transformations and processes they have been through." A vast majority of specimens in the possession of collectors are there through the profitable exploitation of geologic bodies called ore deposits, the subject matter of the science called economic geology. For many serious collectors who want to understand their specimens' "life history," a study of economic geology can be very beneficial. The literature on economic geology available to the collector is, unfortunately, generally woefully out of date, a jumble of production statistics, or is written for the professional. One exception to this generalization, though becoming dated itself, was the textbook *Ore Deposits* by C. F. Park, Jr., and R. A. MacDiarmid (1964). This book has been rewritten and expanded by Park in collaboration with John M. Guilbert, and the end product is the superb text *The Geology of Ore Deposits.*

Meant as an introductory college text, this book is a concise, evenly written and, at times, thought provoking review of the theories and techniques of economic geology. The authors have done a remarkable job of compacting an immense amount of information into one volume. Beginning with a chapter summarizing the history of economic geology, the authors devote succeeding chapters to such topics as ore fluids, ore fluid movement, ore deposition, alteration of wall rock, and gangue. These topics are all germane to the collector because of the information they supply on mineral genesis. The chapter on ore deposition is interesting because of the discussion of depositional textures, many of which can be observed in hand specimen. *Mineralogical Record* readers unfamiliar with the concepts of paragenesis will find chapter six, on paragenesis and zoning, to be an adequate introduction (or review) of this important topic. The best feature of these introductory chapters is the blend of theory with example to form a clear view of what the authors are stressing. The examples are normally active mines or districts which give the reader a feeling for how laboratory and field geologists work in concert to formulate theories on ore genesis. This is not characteristic of most geologic textbooks which are normally dry and terminology ridden.

The best part of this book, from the perspective of the mineral collector, is the thirteen chapters relating the deposits to their geologic setting. Each of these chapters contains a brief discussion of the setting and typical characteristics of the deposits included in that setting. Following this are numerous vignettes of mines or mining districts, many very familiar to the collector. For example, chapter eleven concerns deposits related to intermediate to felsic intrusions (i.e., diorite-monzonite-granite intrusive rocks, andesite-latite-rhyolite extrusive rocks). The mines discussed in this chapter include Chuquicamata, Chile; Climax, Colorado; Llallagua, Bolivia; Magma mine, Arizona; Casapalca, Peru; and Coeur d'Alene, Idaho. For collectors of secondary minerals chapter seventeen, deposits relating to weathering, has an excellent review of supergene enrichment.

An important, and necessary, part of any reference book is the bibliography. This book has an excellent bibliography at the end of each chapter, with references as current as 1985 cited. The index is very good and easier to use than the one in the old *Ore Deposits.* Typographical errors that seem to be routine in most recent publications are almost absent here. Paper quality and type size and style are all good and make for comfortable reading.

My only complaint with this book concerns mineral nomenclature. For example, on page 233 the authors refer to schorl as the brown-black variety of tourmaline, when in fact it is a species in the tourmaline group. Also, on page 813, the authors state that stibiconite is also known as cervantite, but cervantite and stibiconite are names of two distinct species. The use of the names idocrase, instead of vesuvianite, and almandite, instead of almandine, are minor, but still noticeable errors.

The Geology of Ore Deposits is an outstanding reference for most collectors, but not for all. Collectors of pegmatite, rock-forming and zeolite minerals will find little of interest to them in this volume. As mentioned above, this is a college textbook so a basic understanding of chemistry, geology and mineralogy is assumed by the authors. I highly recommend this book for the serious collectors who want ". . . to know the life history . . ." of their minerals.

Paul Pohwat
Smithsonian Institution

Colorado Pegmatites: Abstracts, Short Papers and Field Guides from the Colorado Pegmatite Symposium, May 30–June 2, 1986

Editor: Peter J. Modreski. Published (1986) by Colorado Chapter, Friends of Mineralogy (c/o Jack Murphy, Geology Department, Denver Museum of Natural History, City Park, Denver, CO 80205); softcover, $8^{1}/_{2}$ x 11 inches, 160 p., side-stapled, $15 postpaid.

Includes 36 abstracts and short papers, plus map. Good material for the mineralogist or collector specializing in Colorado pegmatites.

Mineralogy of Precious Metal Deposits, A Symposium on the Mineralogy of Gold and Silver Deposits in Colorado and Other Areas

Editor: Peter J. Modreski. Published (1988) by Colorado Chapter, Friends of Mineralogy (c/o Jack Murphy, Geology Department, Denver Museum of Natural History, City Park, Denver, CO 80205); softcover, $8^{1}/_{2}$ x 11 inches, 190 p., side-stapled, $15 postpaid.

Contains 26 abstracts and papers, and five field trip guides (Leadville, Cripple Creek, Boulder County, Central City, Alma) plus an appendix listing all known gold and silver species.

Crystal Chemistry and Refractivity

by Howard W. Jaffe. Published (1988) by the University of Cambridge (Pitt Building, Trumpington Street, Cambridge CB2 1RP England; and 32 East 57th Street, New York, NY 10022); hardcover, 16 x 23.5 cm, 335 pages; $75.00.

A technical, graduate-level text covering the basics of atoms, chemical bonding, coordination, crystal field theory, density, unit cells, packing, refractivity, polarizability, silicate structures, and the crystal chemistry of some oxide, fluorite, sulfate, tungstate, phosphate, fluocarbonate, sulfide and arsenide minerals.

Letters

PERUVIAN PYRITE

I am writing from South America (Jan. 9, 1989) on one of my frequent buying trips. This time in Lima, Peru, I ran across evidence of a pyrite occurrence that I believe is worth recording.

My last trip to Lima was in August of 1988. At that time I bought a few specimens of what I thought was the tail end of a rather outstanding find of octahedral pyrite crystal clusters. As it turned out, however, these were just the leading edge of the find. The mine, Huanzala, soon went on strike and the stuff started to pour out, and continued to do so until about the middle of December.

According to the *pyriteros* (the guys who run back and forth from Lima to the mines, buying specimens, mostly pyrite, at the mines and selling it in Lima), the strike provided an ideal opportunity for the miners and a number of local men to spend full time collecting in the mine. During normal operations, only the miners have access to the mine, and their collecting of specimens is limited because they must attend to mining ore. They usually find a little time to collect specimens during lunch, between shifts, on Sundays, etc.

Some of these octahedral pyrites appeared last September at the Denver Show, in Denis Belcher's booth.

It was the kind of find that did not lend itself well to the production of small, choice specimens because individual crystals are so large . . . 8–10 cm on the average. I personally laid a ruler along the edge of the largest crystal I saw in Lima, and it measured 20 cm. The specimen that includes this crystal probably weighs at least 45 kg (100 pounds), but cannot be considered choice because of the amount of damage it has.

Ferdinand Zatch, a German dealer who has made Lima his home for the last few years, agreed that 20 cm is about the maximum crystal size for this find. He reported seeing one specimen of about 150 kg, but didn't buy it because the quality wasn't good enough. He estimates that the find may have produced as many as 100 specimens weighing 50 kg or more, and that 40 of these may have gone to Europe. From what I saw on the streets (in the homes and storerooms of the *pyriteros*), he is probably right. As in many big finds, however, the top specimens represent only a small percentage of the total.

In the entire find there is probably no such thing as a thumbnail or miniature-size specimen, and even good small cabinet pieces are rare. Because of the large average crystal size, the specimens will undoubtedly find their way into institutional collections as classics of their species.

The crystals have points truncated by small cube faces and other small forms; the octahedral edges are also modified to a small degree. The large crystal faces have small, angular, lustrous growth pits concentrated near the center. Some crystals are a bit dull, and some have a crust of drusy quartz centered on the growth pits. A few pyrite crystals are completely covered with gray drusy quartz, and one I saw is partially covered with black microcrystals of tetrahedrite. Some specimens show fractured and rehealed pyrite.

Judging from the configurations of some specimens, the vein must have had at least a meter of clearance in places, and must have run for many meters to yield so many pieces.

The prices for these pyrites ranged all over the map, depending more or less on the seller's perception of the buyer's wealth and experience. I saw one lot of perhaps 15 large specimens (which included some okay ones and a number of pigs) priced at $20 per kilogram. Other poor specimens went for as little as $2/kg; I got the impression that, had I pushed it, I could have bought the rubbish for $1/kg. One dollar per kilogram seems to be a sort of base price, at least for massive pyrite suitable for lapidary purposes. The cost of exporting specimens from Peru, because of government taxes and government manipulation of the exchange rate, is in excess of $1/kg, excluding the cost of shipping.

Rock Currier
Jewel Tunnel Imports

NEW MEXICO

Congratulations on the recent New Mexico Issue. The state deserves it and, as you concluded in your notes, "there is much more discovering and collecting yet to be done there." I'd like to offer some additional general information about New Mexico, and then make some specific comments about the issue.

First of all, the annual New Mexico Mineralogical Symposium in Socorro every November is a good place to learn about localities within the state. Information can be obtained from the presentations and from the many individual attendees. The symposium abstracts (which are concerned with New Mexico localities) are published in a quarterly New Mexico Bureau of Mines and Mineral Resources bulletin called *New Mexico Geology.*

Two authors in the New Mexico issue, DeMark and Henderson, mentioned the Paramount Canyon bixbyite location. In 1979 I found some red beryl microcrystals there (see *New Mexico Geology,* **2**, 15–16); because of the high prices then being obtained for faceting grade red beryl from Utah, Frank Kimbler and I placed a claim on the locality from 1979 to 1981, naming it the Beryllium Virgin. Last May (1988) I noticed some tiny yellow crystals in cavities with bixbyite; tests by Paul Hlava and Eugene Foord identified these as gasparite-(Ce) and chernovite-(Y).

The above two rare earth minerals have also been found rarely at the Squaw Creek tin mine, 7 miles due north of the Paramount Canyon occurrence. In late 1984, it was determined that two new species occur here as well, squawcreekite (see *New Mexico Geology,* **10**) and one other which was publicly announced at the last symposium (and has been approved by the I.M.A.): maxwellite (see the symposium abstracts in *New Mexico Geology*).

Orange microcrystals of durangite have been found near Boiler Peak and Turkey Run, in the same mining district as the Paramount Canyon and Squaw Creek occurrences (see *Canadian Mineralogist,* **23**, 241–246).

DeMark mentioned Wind Mountain in Otero County, New Mexico. Many nice specimens having microcrystals of rosenbuschite were collected there in March of 1985. The crystals are transparent, nearly colorless to pale tan and pale pink, and are acicular prismatic in habit.

Having collected at the Mina Tiro Estrella claim several times since 1980, I've observed that over 95% of the quartz crystals found there are colorless rather than smoky.

Patrick E. Haynes
Cortez, Colorado

TAXCO SILVER FAKES

Some silver specimens from Taxco, Mexico, were described in your report on the 1988 Tucson Show (vol. 19, no. 3, p. 210 and 213). A person in Taxco has admitted that he created them artificially [by electroplating silver onto other conductive minerals such as pyrite and sphalerite]. It might be helpful to alert collectors to this problem.

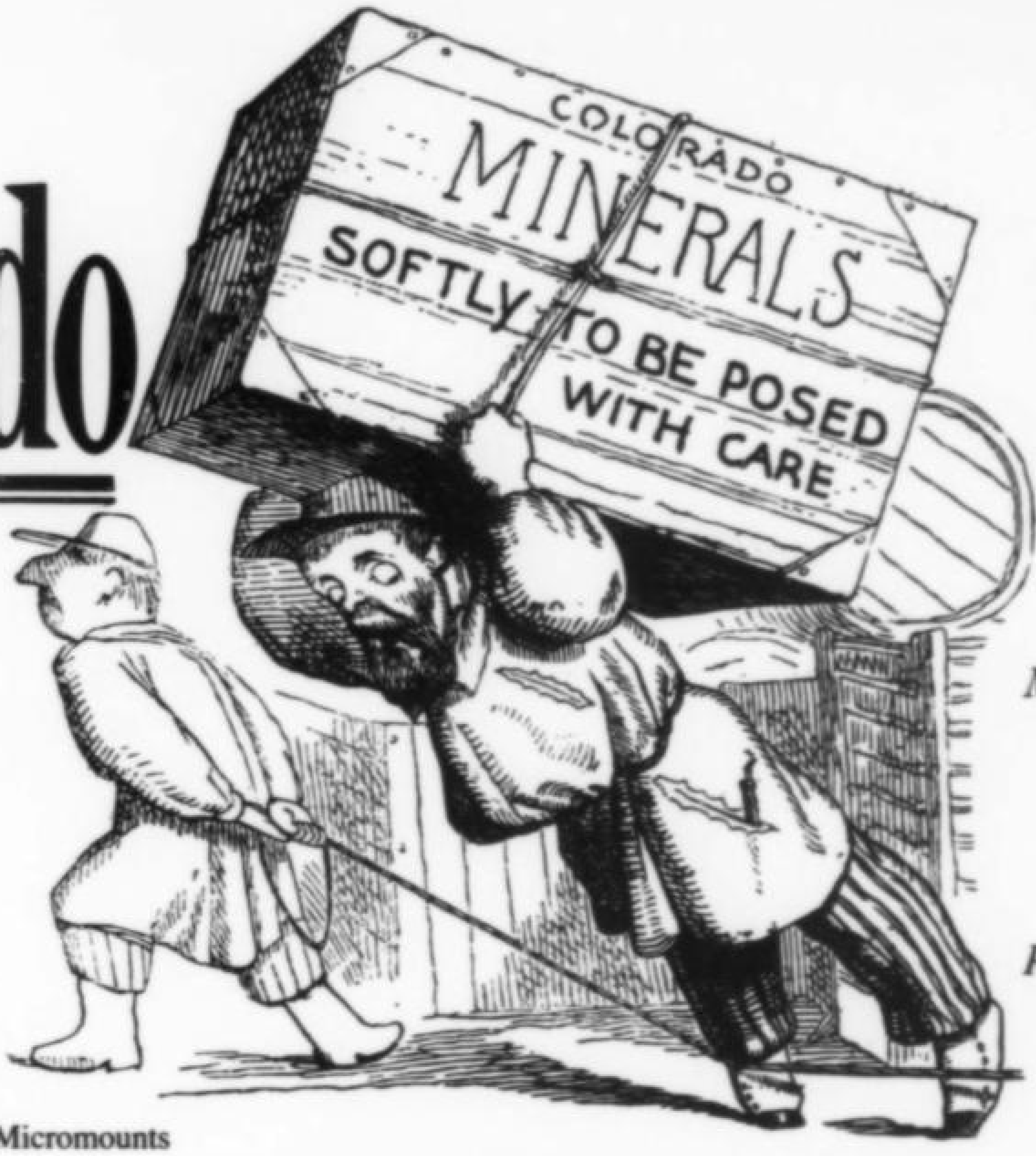
Miguel Romero
Tehuacan, Puebla, Mexico

OURO PRETO TOPAZ

The large "imperial" topaz crystal shown in the article on the Ouro Preto topaz mines (vol. 19, no. 3, p. 230, Fig. 16) is a Smithsonian specimen, and has been since 1981 (#147987, from the J. J. Trelawney collection).

John Sampson White
Curator-in-Charge
Dept. of Mineral Sciences
Smithsonian Institution

Colorado Dealers



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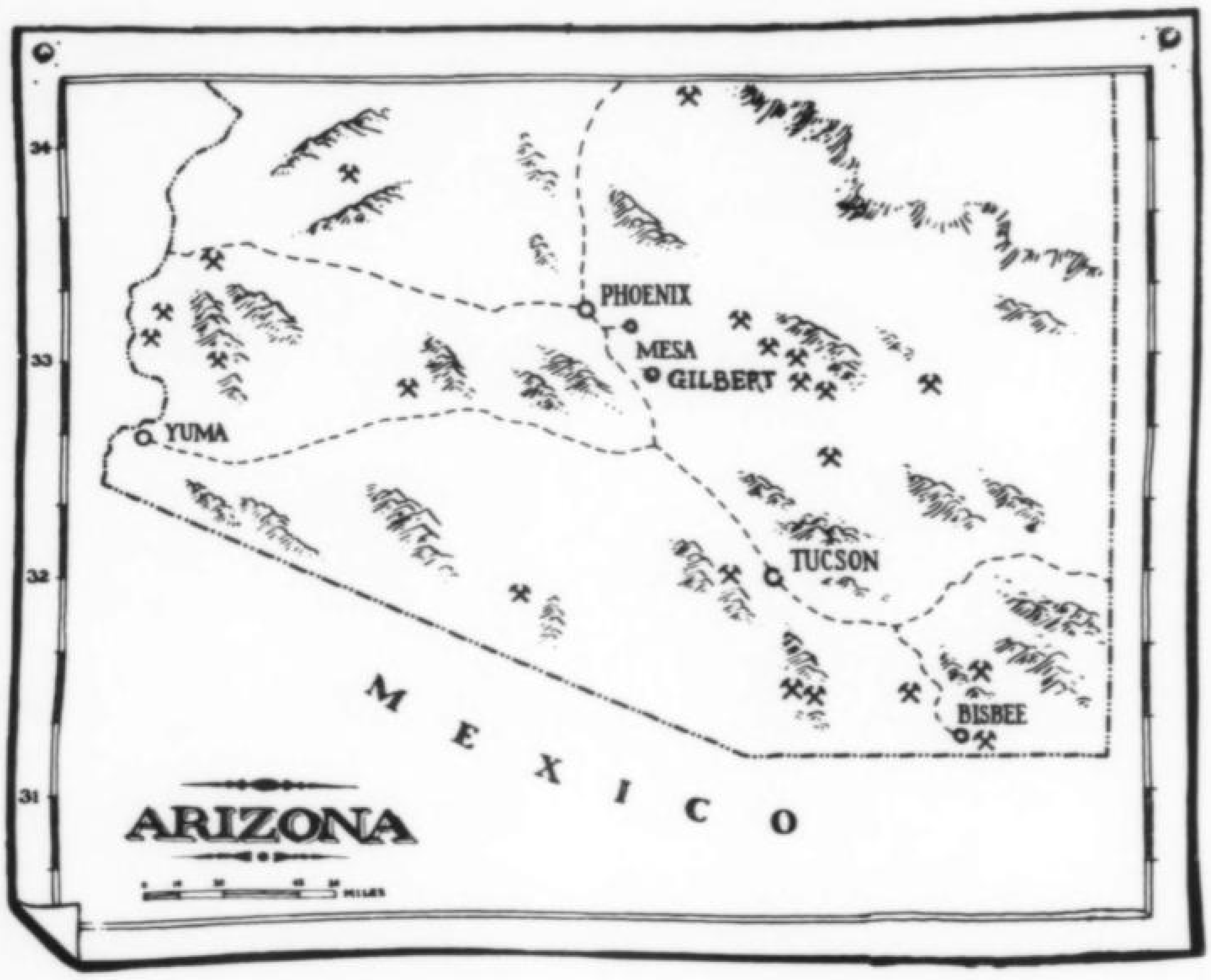

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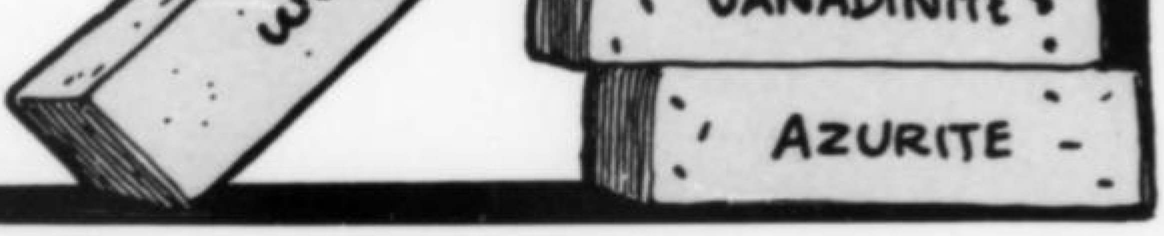

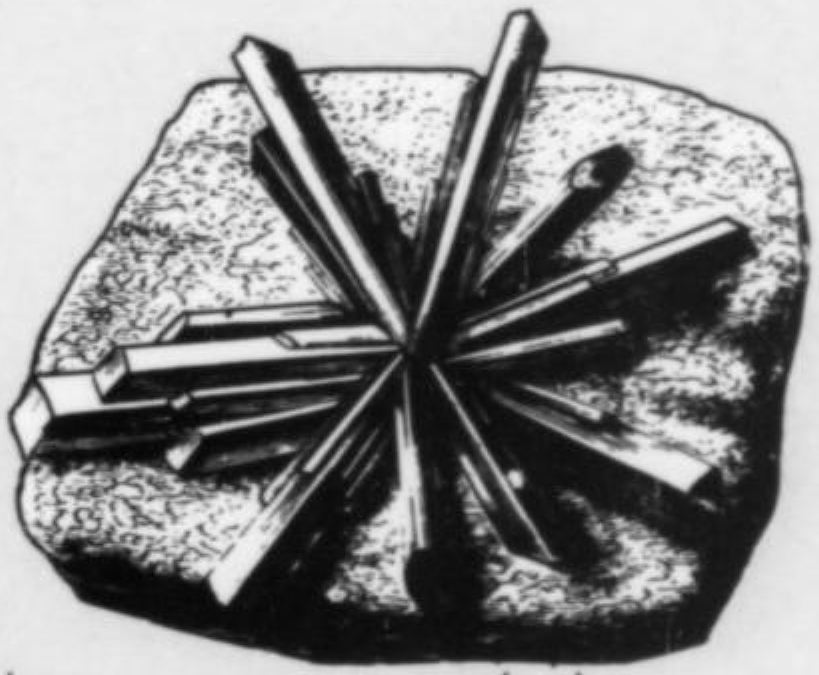

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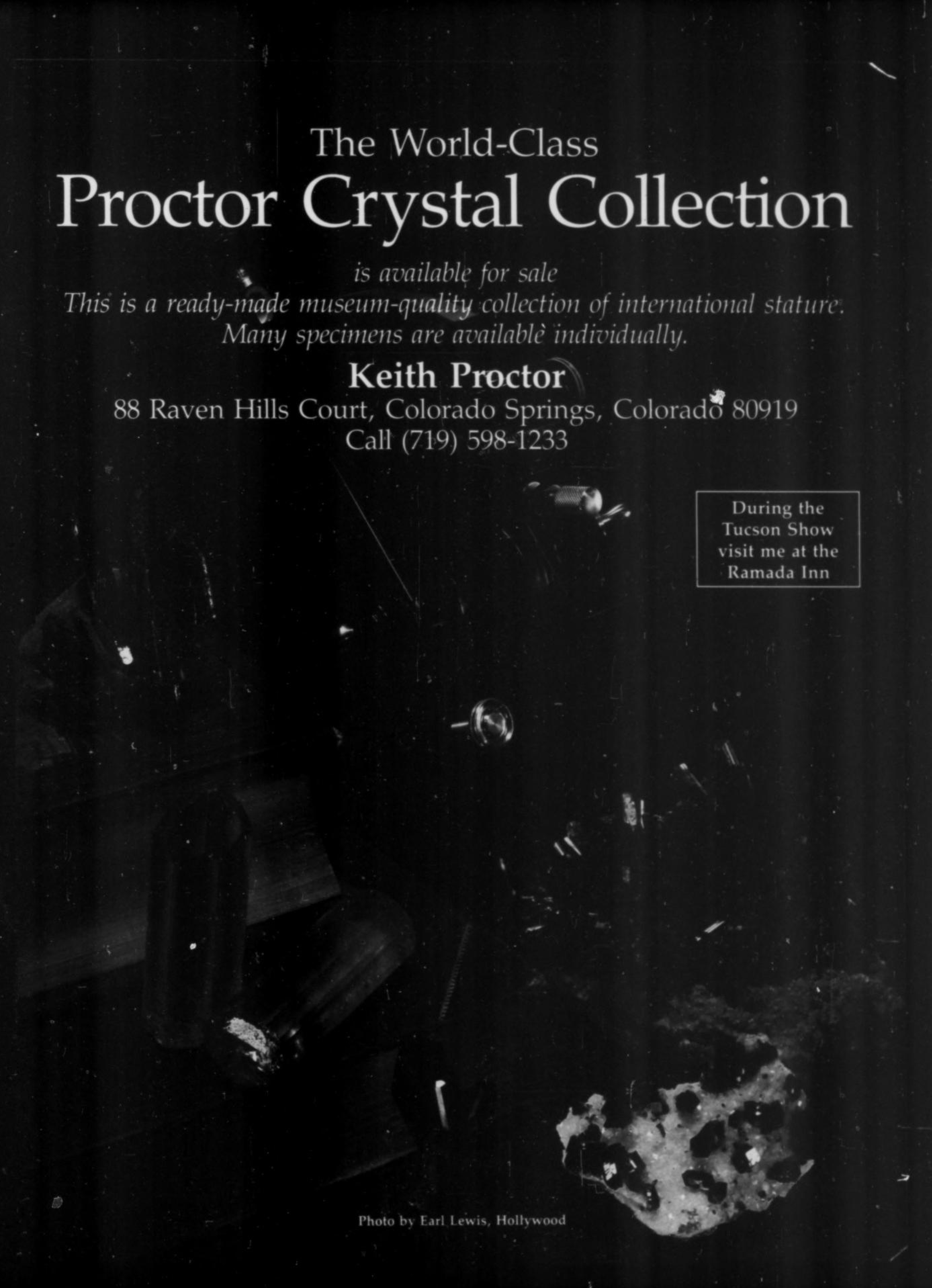

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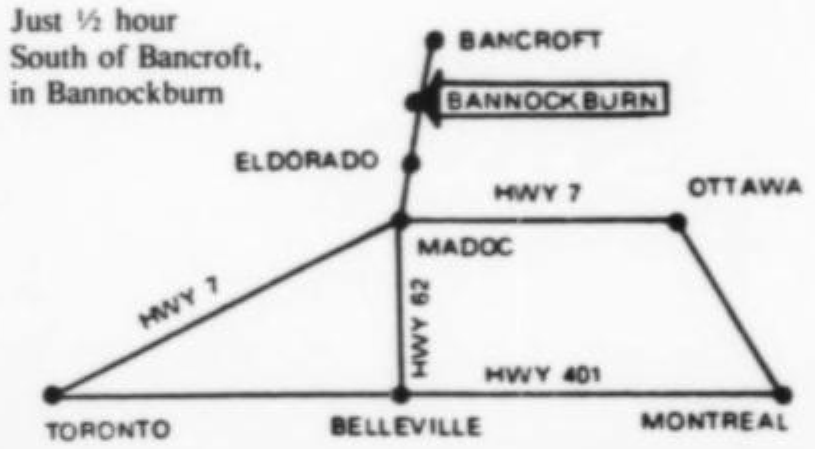
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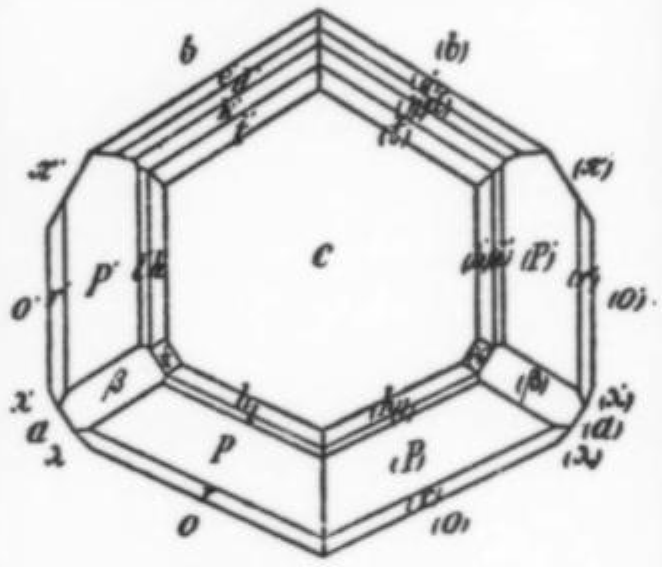

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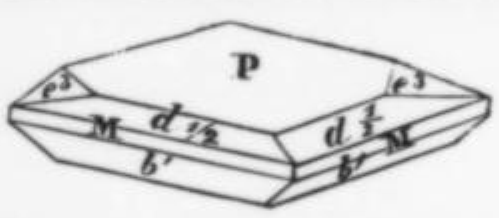

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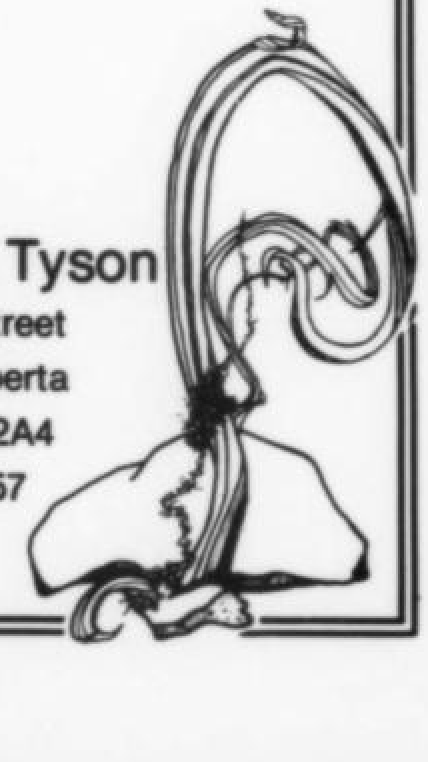

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