the Mineralogical Record

Volume Twenty-two, Number Two
March–April 1991
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The Mineralogical Record magazine is published by the Mineralogical Record Inc., 7413 N. Mowry Place Tucson, Arizona 85741

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Articles

Columns

COVER: CINNABAR crystal, 2 cm, on dolomite matrix, from Fenghuang, Hunan, China. Anna Chrapowicki specimen; photo by Wendell E. Wilson.

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THE DISCREDITATION OF MINERAL SPECIES

Pete J. Dunn
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Smithsonian Institution
Washington, D.C. 20560

The following statement was endorsed by the Commission on New Minerals and Mineral Names, IMA, which has jurisdiction concerning the subject matter.

INTRODUCTION

Most mineral species, once described, remain valid, and additional studies serve to enhance our knowledge of the species, their crystal structures, solid solution relations, stabilities, phase relations, etc. However, not all original descriptions are correct. Some were based on incorrect data, some on incorrect interpretations, and still others on insufficient data, mixtures of data sets, or mixtures of minerals. In some cases, the errors can be rectified, new data can be obtained, and the mineral redefined; approval of the redefinition, if needed, can be obtained, and a correction can be published in the literature. However, some such attempts to redefine a mineral, as well as attempts to restudy older minerals, result in the conclusion that the description of the substance as a unique mineral is invalid, and this finding requires formal discreditation of the mineral.

A discreditation does not necessarily imply that the original work was not good or was incorrectly done. Many such discreditations are the result of the application of new technologies to substances not formerly recognized as mixtures, or to the chemical analysis of elements very difficult to determine in earlier times. In many cases the original work was as good as could be done at the time; indeed, in many cases the work was excellent, and thus some historical perspective is needed in evaluating and criticizing sources or causes of error.

The literature is replete with mineral discreditations, ranging in quality from the very careful and formal to the truly careless and casual; indeed, some are done cavalierly and some are even incorrect, requiring subsequent correction and revalidation of the mineral. This paper provides guidelines for the proper discreditation of a mineral species. It should be emphasized at the outset that all discreditations require the approval of the IMA Commission on New Minerals and New Mineral Names (CNMMN). Just as a mineral name requires formal international certification before birth and publication, so too does it need a death certificate and a proper burial in the literature. Many of the notes refer equally to the redefinition or revalidation of mineral species.

THE LITERATURE

It is very important that the original description be obtained and read in full; reference to abstracts or compendia is insufficient and is fraught with potential for further error. If the description was written in a language in which the investigator is not competent, a translation must be obtained, preferably from a person familiar with scientific writing and the protocols of presenting technical data. After obtaining the translation, counsel from mineralogists in the country where the mineral was described might be sought regarding unclear sections of the text, incomplete locality designations, and other complications. It is imperative that the original description not only be read, but be understood fully, before discreditation is undertaken. If the original description was in an obscure journal, it is useful to repeat publication of at least the original critical data in the discreditation paper.

TYPE SPECIMENS

It is imperative that the type material (the same material used in the original description), if it still exists, be utilized in the discreditation of a mineral species. This matter is of paramount importance and cannot be overstated. The general and specific definitions of type specimens were given by Dunn and Mandarino (1987), and the discussion paper by Embrey and Hey (1970) has useful insights and gives much perspective. The methods utilized in a search for type specimens should be part and parcel of the training of a mineralogist, but this training is seldom offered currently, so a few guidelines are offered here.

If the senior author of the original description resided in a nation with a national museum, the curator of that museum is the most likely person to be of assistance. Such individuals can usually be identified by that nation's representative on the IMA Commission on Museums (CM), and that representative, in turn, can be identified by the seeker's national representative on the CM. If there is no such museum in the host nation, resource can be had to the curators of regional museums. Additionally, very large research-oriented museums, such as the British Museum (Natural History) and the Smithsonian Institution, have extensive collections that contain many hundreds of type specimens.

If such museum endeavors are unsuccessful, inquiry might be made of the institution where the senior scientist was employed at the time the original work was done. Postmortem memorials in the journals in which the scientist commonly published (usually a society-published journal in his home country) may be informative sometimes as to the places he worked and disposition of his collections. Interim studies of the mineral, subsequent to its original description, may offer some guidance as to the disposition and location of the original type specimens. If the mineral comes from a famous locality (Tsumeb, Långban, Crestmore, Franklin, etc.) the mineralogists specializing in the mineralogy of such deposits are usually well informed and might be of assistance.

If all these efforts fail, it may well be that there is no type material. The preservation of type mineral specimens, clearly marked or designated as such, is a relatively recent development in mineralogy; for a vast number of the older mineral species no type specimens exist. Some specimens in old collections are marked "original material" or "original stuff," sometimes in the handwriting of the author, but such material and handwriting need careful physical and historical evaluation by local curators before they can be identified positively as what now is called type material. If type material cannot be obtained, it may not be possible to be certain about what material was described, and formal discreditation therefore may be impossible.

There are, however, instances where clear, unambiguous type specimens cannot be found, yet much authentic material from the type locality exists in systematic collections. Although an uncommon happenstance, discreditation is sometimes still possible, but usually a number of specimens would have to be studied, and a higher standard of proofs would have to be met in argument, such that all possible weaknesses in the presentation are straightforwardly addressed. If one cannot locate holotype or cotype material, that fact should be stated, together with a description of the attempts made to find it. If one has other specimens that might be a satisfactory match for the species in question, one should state why they are adequate and describe them fully, together with any supporting documentation. Lastly, they should be identified by means of accession numbers or other identifiers for future reference and preserved in a national museum. By these procedures, the discreditation itself could be reexamined in the future, if need be. A very few discreditations are found to be in error, and revalidation then requires the use of the same specimen.

It is important to remember that once one has obtained type material and discredited the species (or failed to), the specimen is still the type material. It will be kept by repositories in perpetuity as a type specimen, so that it can be restudied if needed. If, at the conclusion of the discreditation study, the type specimen is deposited in a different collection than that from which it was obtained, this information and the new catalogue number or numbers should be published in the paper.

Having obtained all the type specimens, it is necessary to ascertain mineralogically that they are indeed the type material, and that they correspond to the original description. Regardless of the quality of the documentation, cataloguing, numbering, and labels with the specimen, and disregarding the often very considerable effort expended, if the extant material does not match the original physical description, such that it can be clearly identified as the original material, then all may be for naught. Mislabeled specimens abound in the best of collections (Bentley *et al.*, 1986), and type specimens, like any other specimens, are subject to this problem (Dunn, 1978). When the documentation described above does corroborate and support all observations and support the integrity of the type material, those facts should be clearly noted in the paper. One should also be cautious concerning fake specimens (Dunn *et al.*, 1981); although an uncommon occurrence, type specimens have been faked.

The above-described methodology represents cases wherein the written descriptions were done reasonably well. However, some descriptions in the literature were poorly done, a few horribly so, making it very difficult in some instances to ascertain the nature of the mineral described. Nickel and Mandarino (1987) noted:

> If a type specimen exists and if the original description, though faulty, represents a reasonable approximation to material on the specimen, the mineral is to be defined by reference to the type material rather than to the original description. This means that errors in the original description cannot be held to discredit a mineral unless the original description was so grossly inaccurate that, in the words of J. D. Dana, "a recognition of the mineral by means of it is impossible."

Most such cases result in redefinitions of species rather than discreditations.

DISCREDITATION

In many cases the true identity of the material is initially established by the investigator on nontype specimens, and this result then prompts the search for type material so as to permit a formal discreditation. When the type specimen is obtained, a few simple tests may serve to confirm earlier findings and provide conclusive proofs. Indeed, in some instances, much more effort is expended in obtaining type material than in its examination and definition.

However, it is best to define the type specimen as well as possible, and to describe it as completely as possible. The use of modern techniques commonly provides the opportunity to describe the specimen in more detail than was originally possible, and this information should be added. If the discreditation is successful, this study might well be the last time the specimen is ever intensively examined. The comprehensiveness of the effort will vary from investigator to investigator, but certain criteria should be met in all cases. First, the physical appearance of the specimen should be redescribed, and its agreement with the original description noted, thereby convincing the reader that this is the original material.

Certain parts of the discreditation procedure are critical; most species are defined on the basis of one or more prime discriminatory factors that serve to give the species unique status. Commonly, the discriminating property will be the chemical composition or crystallographic symmetry. In such cases, that property must be explicitly examined, which is to say, for example, that a species based on a chemical distinction must be reanalyzed chemically, and one based on a symmetry distinction must have its symmetry reexamined. These factors are paramount, but other aspects should also be investigated. In cases of mixtures, if any component of the mineral has solid-solution relations known or possible, or indicated by the initial description, they should be examined. Every attempt should be made to identify all components of mixtures. It is not sufficient to show that the mineral is not what it was purported to be; it is also required that a clear new definition of the mineral or minerals present be given. If the "mineral" being discredited is a synthetic compound, that too should be addressed.

Rarely, a mineral being discredited will be found to consist of a mixture of a known mineral and a new mineral as yet undescribed. By tradition, in such cases the old mineral name commonly is applied to the new mineral that is a part of the original specimen (Nickel and Mandarino, 1987). This tradition may be set aside, with the concurrence of the CNMMN, if a misnomer or other confusion would result.

It is useful to attempt to ascertain the errors in the original description; they may be single or multiple, simple or complex. the new investigator may be the person best qualified to provide an interpretation of the original study. Much can be learned by such an attempt and, in addition, it lends much weight and credence to the discreditation. The reinterpretation of faulty analyses, or of analyses of mixtures, is often possible and should be done. Recalculations of analyses, both of isochemical mixtures and of minerals with different chemical elements, can often be done and should be. Subtle or gross distinctions in symmetry, missed in the earlier study, should be pointed out and clarified, as well as errors in the measurement of optical and physical data.

In describing such errors, it is a professional courtesy to our predecessors to do so sympathetically, with a considerate eye on what was possible at the time and keeping the original investigator's best intentions in mind. If the original investigator is living, advice and counsel may be sought; in any case, the rules of the CNMMN require that the original investigator, if living, be consulted.

Occasionally, a mineral, although invalid, will be reported a second or third time from other localities. In such instances, it is advisable to attempt to acquire such specimens and reexamine them. In almost all such cases the second or subsequent description will be based upon erroneous information in the initial study, and the examination of type material will commonly reveal the sources of error in the secondary descriptions. These other occurrences should be critically discussed; most are trivial and contain little or no data, but inasmuch as the subject will likely not be revisited by one as close to the problem as the current investigator, it is wise to clear up all loose ends.

Upon completion of the study, the results should be submitted to the Commission on New Minerals and Mineral Names, as indicated by Nickel and Mandarino (1987). After consideration and subsequent voting by the Commission, the results and all comments of voting members will be sent to the senior author of the discreditation. Such comments commonly contain insights that assist substantially in the preparation of the paper to be published.

If formally approved, the discreditation can and must be published. It is best to publish a discreditation as a separate paper so as to have a distinct focus and to ensure that the work is captured by all abstracters and authors of subsequent compendia. If the discreditation is part of a larger study and is best published as such, the discreditation should at least be clearly indicated in the title of the paper and noted as a separate paragraph of the abstract.

STRUCTURE OF PRESENTATION

Each study is a unique one, with unique problems, and subject to the effects of insights, work style, and the writing habits of the individual scientist. Nonetheless, the extreme unevenness and sparseness of many published discreditations prompts the following suggested outline as a guide:

1. A statement of the problem and citation of all of the relevant literature.
2. The integrity of the type specimen or specimens and descriptions.
3. The correct definition of the mineral being discredited.
4. Discussion of the errors in the original work.
5. Conclusion and statement of CNMMN approval.

ACKNOWLEDGMENTS

The writer is indebted to the members of the Commission on New Minerals and Mineral Names for many helpful suggestions and endorsement. This paper was improved as a result of helpful critical readings by Drs. John L. Jambor and James L. Munoz.

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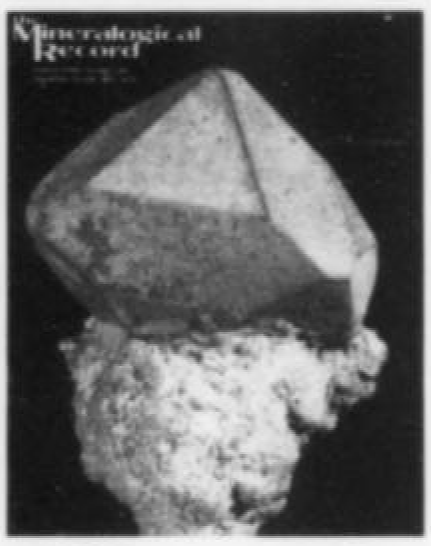

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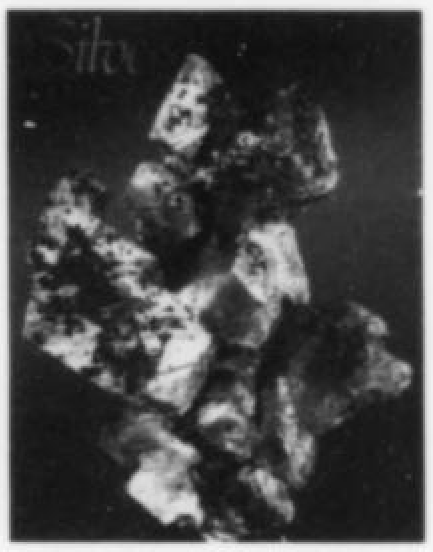

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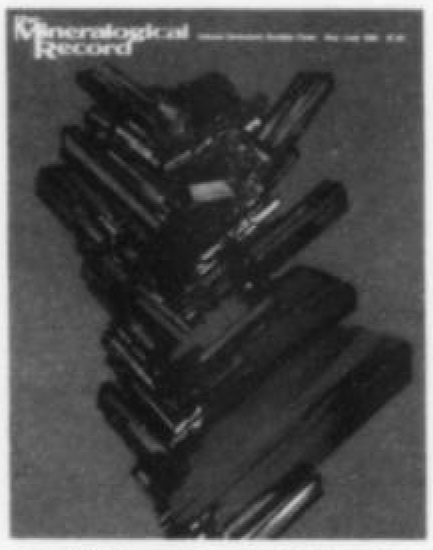

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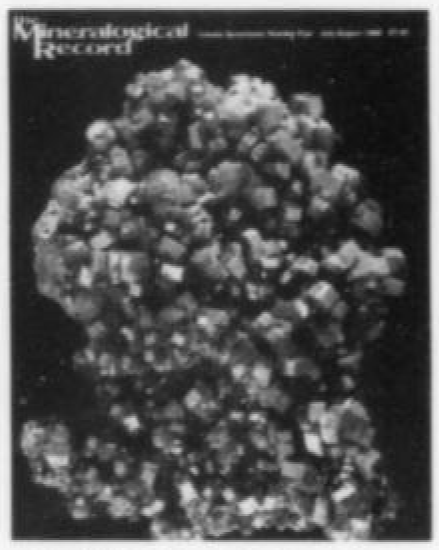

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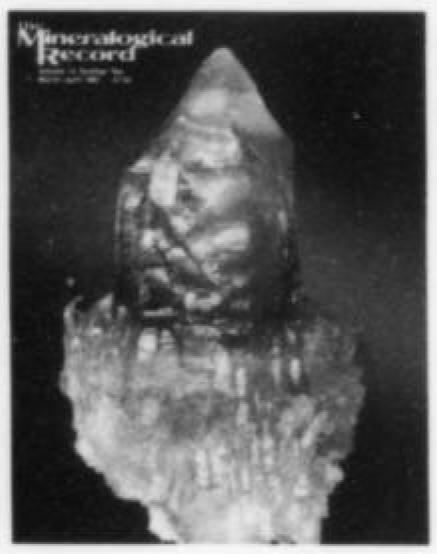

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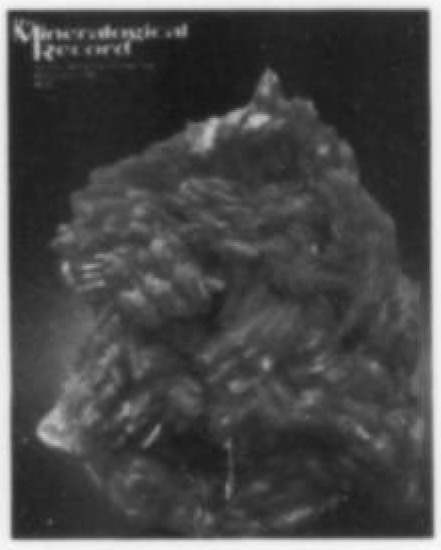

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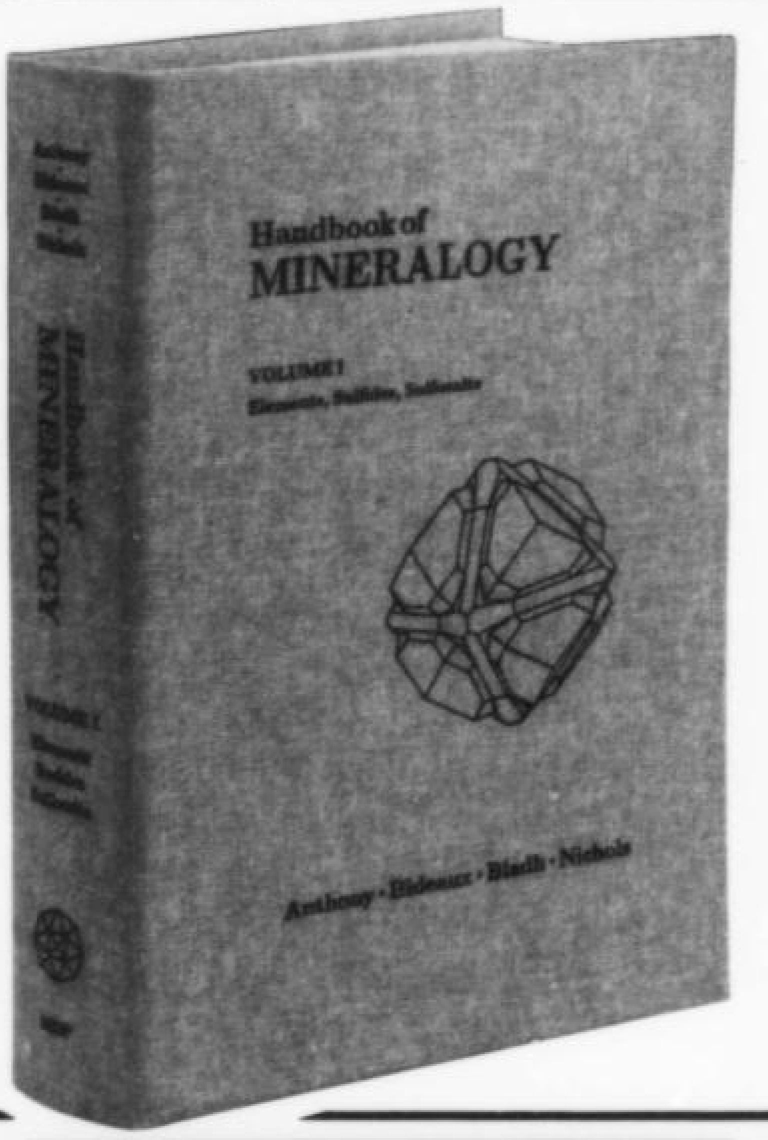

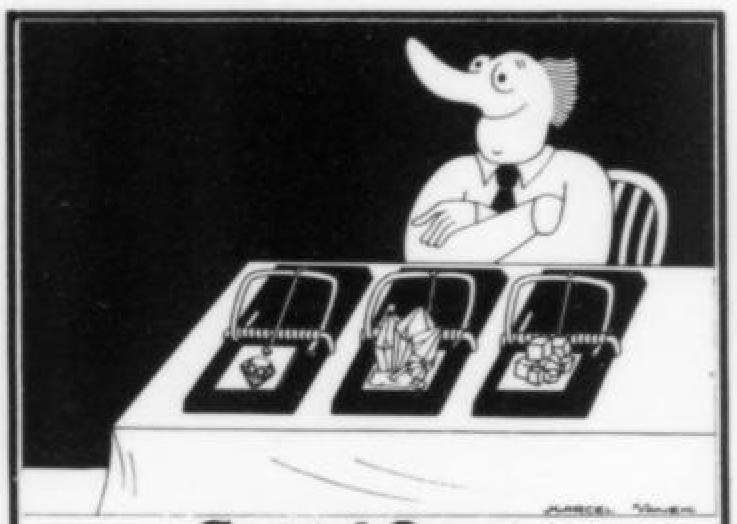

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MEŽICA

Famous Mineral Localities:

THE MEŽICA MINE
SLOVENIA, YUGOSLAVIA

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The Mežica mine in northern Slovenia has exploited one of Europe's greatest lead-zinc deposits for well over three centuries. Along with Austria's famous Bleiberg mine just 19 km to the north, it is also one of Europe's few important wulfenite-producing areas. Fine specimens of Mežica wulfenite may be found in prominent museums and private collections worldwide.

LOCATION

The Mežica mine, actually a consolidation of many mines, is located between Mežica and Črna (formerly Schwarzenbach, Austria, prior to 1918) in northern Slovenia, Yugoslavia, just 3 kilometers from the Austrian border and 19 km southeast of the famous lead deposit and wulfenite occurrence at Bleiberg, Austria (see Niedermayr, 1986). Specimens from the mine have sometimes also been labeled "Mies" or "Crna." It is about 60 km northeast of Ljubljana, at the southeastern extremity of the Alps. Access is by way of Klagenfurt, Austria, or Maribor, Slovenia.

The principal mine workings are situated on the west bank of the Meza River, between the Mala Peca and Polena Mountains.

HISTORY

The following historical summary is abstracted primarily from Društvo (1965).

Lead ore outcrops in the Mežica-Črna area were probably known to the Romans, like those at Bleiberg. However, the earliest recorded mining dates back to 1424. The oldest surviving official document pertaining to the occurrence is a letter[1] written in 1644 by Matheus Ludinger, manager of a gold mine at nearby Kliening, petitioning the Court for the right to prospect and develop the Mežica deposits. In

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[1] Preserved in the Kärntner Archive in Klagenfurt, Austria.

Figure 1. **A large stope on the 330-meter level. Photo by P. Bancroft.**

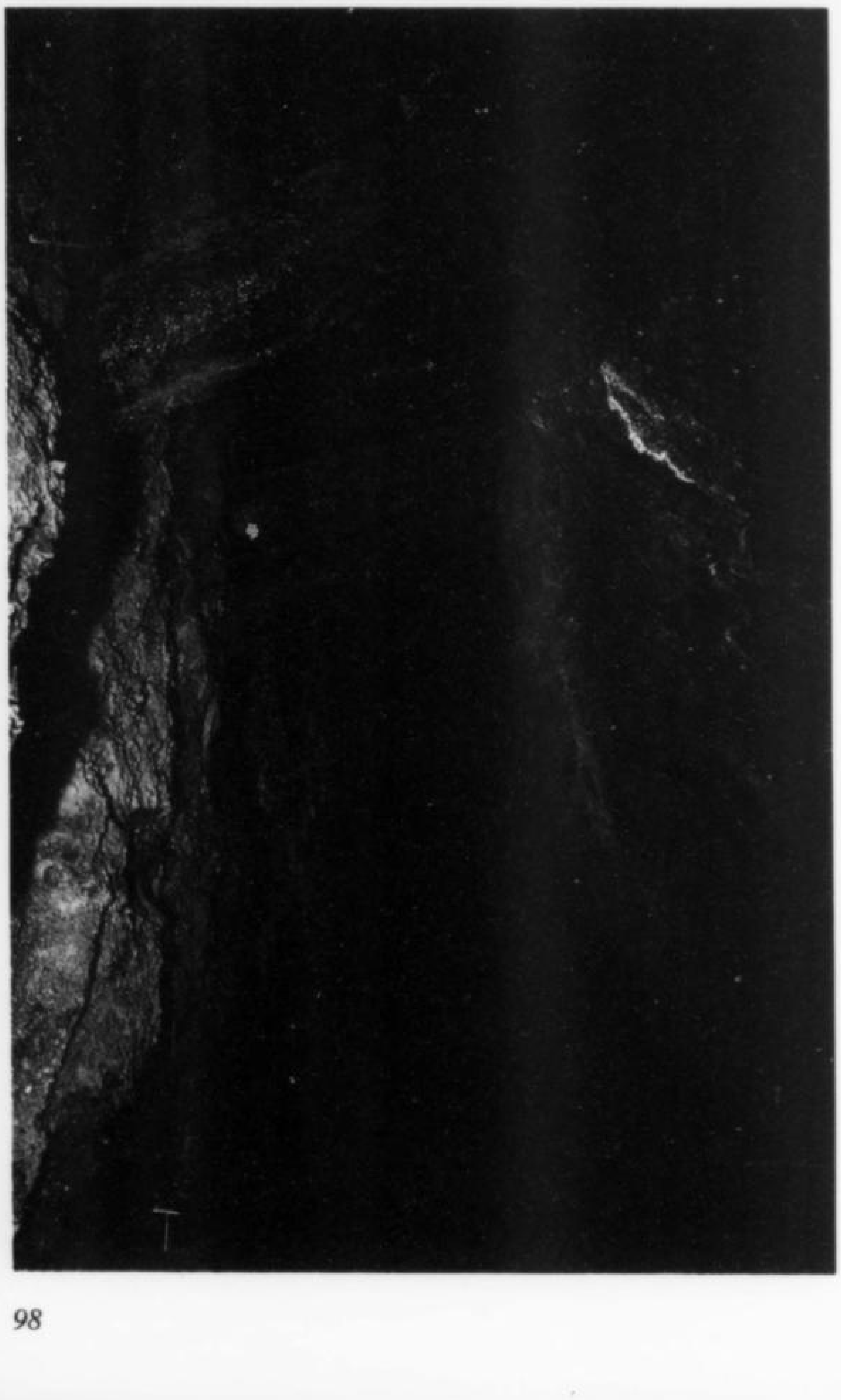

Figure 2. **Old adit with rotting timbers. Photo by P. Bancroft.**

the following year his request was granted, and he was awarded exclusive mining rights at Mežica. History does not record how successful he was.

In 1706, Count F. L. Thurn was granted the right to do exploratory work in the area. He was unable to find anything valuable himself, but he subsequently hired an able administrator named J. K. Gajčnik to continue the search. For unknown reasons, Gajčnik preferred to go by the name of von Schlangenberg. He had the good fortune to locate high-grade lead ore near an abandoned shaft at Sv. Helena, about 3 km south of Mežica. A mill and smelter, complete with workers' quarters, was constructed and the operation eventually produced 270 tons of lead. Upon von Schlangenberg's (Gajčnik's) death, his wife took over management of the operation, but she was unable to generate a profit.

The Napoleonic wars of the early 1800's caused a near shut-down of the Bleiberg mines. Although unaffected at first, the Mežica mines soon became more active due to the partial paralysis of their principal competitor. A newly formed company, Brunner-Kompoš, acquired the Mežica properties, built new milling and smelting facilities and improved efficiency. For a time the Brunner-Kompoš enterprise prospered, as did the little town of Mežica.

After the fall of Napoleon at Waterloo, less expensive and higher quality English lead flooded the European market. In response, Mežica's production fell by 66%, and Bleiberg's dropped by 85%. With continental European lead mining threatened, efficiency needed to be greatly improved to guarantee survival. Leopold Prettner, a former manager and mine owner at Bleiberg, joined the Brunner-Kompoš staff and proposed that a consortium of Mežica mine owners be formed to work the lead mines together. Accordingly, operators of the Peca,

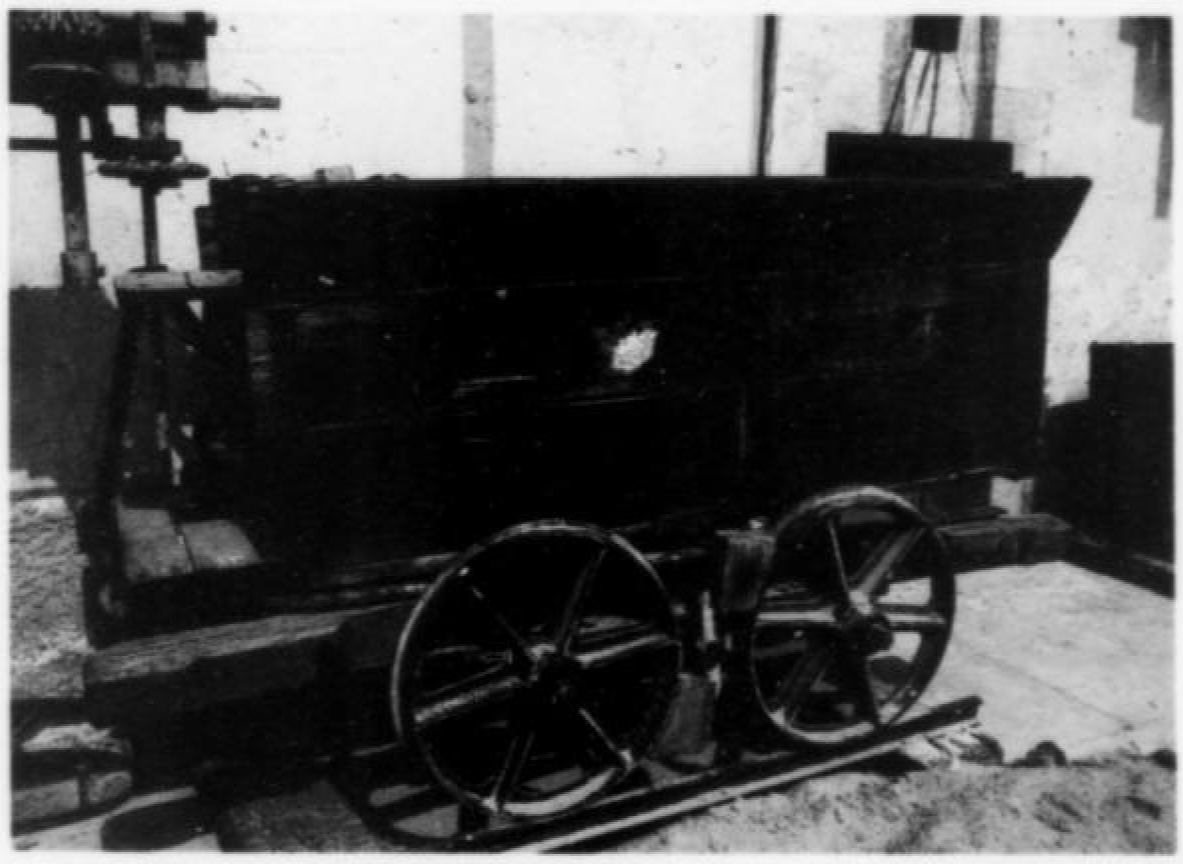

Figure 3. **Ore car, 1860's, in the Mežica mining museum. Photo by P. Bancroft.**

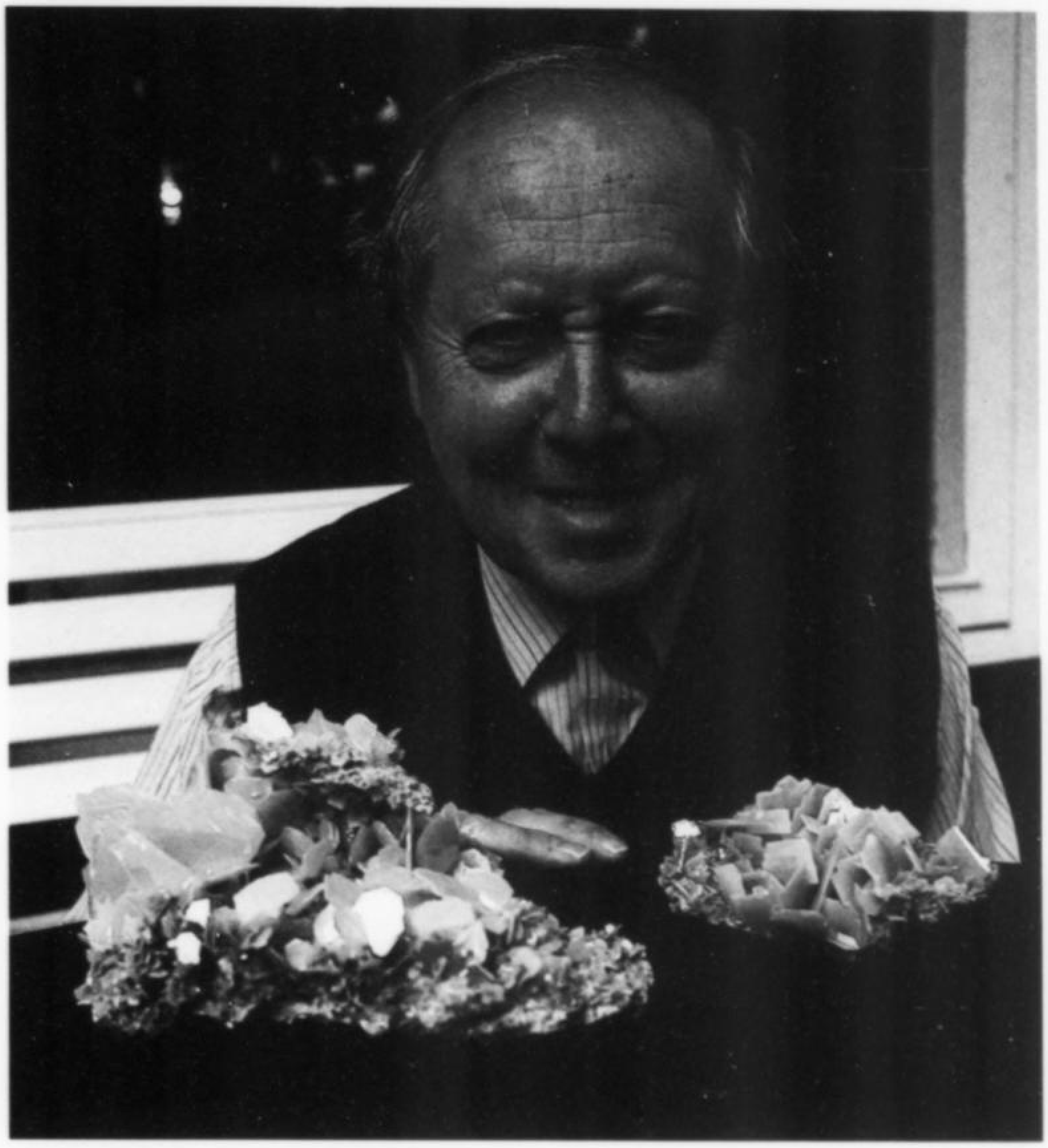

Figure 4. **Helmuth Sommermann, mineral collector from Bobengrün, Germany, with two prized Mežica wulfenite specimens. Photo by P. Bancroft.**

Igrče, Mučevo, Bosjakovo, Čemernikovo, Matozovo, Osterčnjakovo and Junčarjevo mines joined the new alliance. By 1823, the mines of the consortium had doubled their production, and in 1827 the consortium purchased all remaining independent mines and facilities from the Thurn family, thus completing the district's consolidation under one management. Production increased rapidly thereafter, and the Meža River was dammed in 1834 to provide additional water for ore processing.

The new mining boom encouraged another round of prospecting, and a series of fresh discoveries was made. In 1842 a number of lead mines and mills were opened near Žerjav, about 3 km south of Mežica, and more than 60 working lead mines dotted an area in the Peca Mountains.

Observing the success of the Mežica mining consortium, Bleiberg mine owners at last decided to join forces in 1866, forming the Bleiberger Bergwerks Union (BBU). Within a short time, the lead mines at Dobrač and Rabelj in southwestern Carinthia joined the union as well. In 1893 the Bleiberger Bergwerks Union purchased the Brunner-Kompoš consortium and the Rainer mining company, uniting for the first time all lead mines in the Bleiberg-Mežica area.

One of BBU's first decisions was to begin recovering zinc, a metal formerly discarded as waste. New separating plants were built, and other facilities were consolidated. The Glančnik shaft was begun, ultimately to connect the Fridrih, Helena and Igrče mines. By 1900 Mežica lead production surpassed that of the Bleiberg district, and BBU had constructed a modern smelting and metallurgical complex at Žerjav. For the next 15 years the BBU operation was smooth and profitable.

With the outbreak of World War I, BBU was forced by the government to greatly increase lead production. The richest veins and support pillars were selectively removed, causing a deterioration in the mine, and consequently by 1918 production had fallen below prewar levels.

At the Saint-Germain Peace Conference in 1919 it was decided that Yugoslavia as a nation would be strengthened by owning all mines outright. BBU stocks were seized, but before the mines could be officially nationalized, BBU concluded a merger with British-owned Bewick-Moreing corporation and new headquarters were established in London. The new company was called Central European Mines Ltd. (CEM). Plans to nationalize the mines were dropped.

Under the direction of Georg Bargate and Geoffrey Leader, new milling facilities had been built by 1921 and once again the mines were being preferentially stripped of their highest grade ore.

Just prior to the outbreak of World War II, the Yugoslavian government invalidated the CEM contract and restored BBU as the

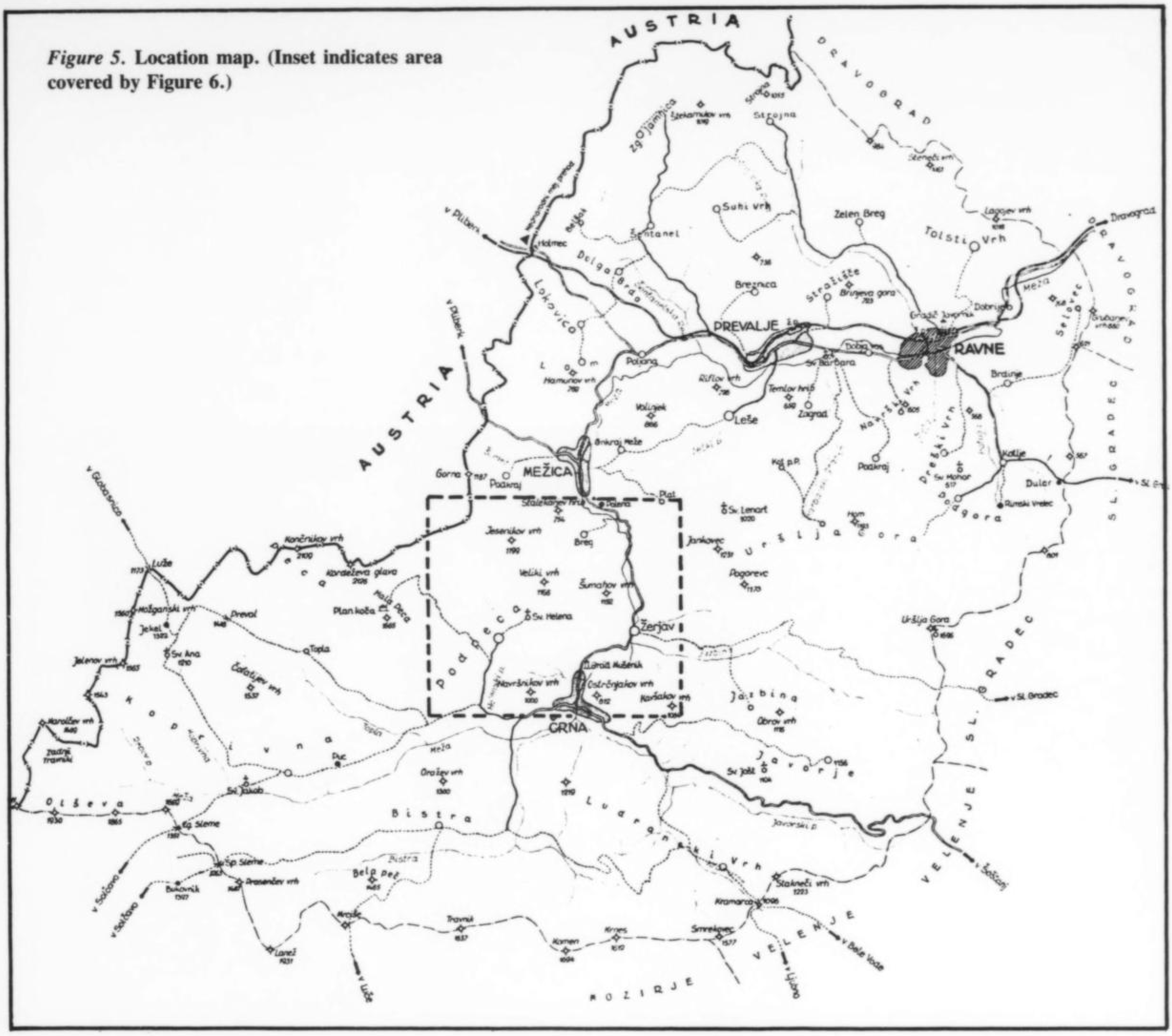

Figure 5. **Location map. (Inset indicates area covered by Figure 6.)**

operator of the district. In 1945 the Mežica Valley was liberated by the Yugoslavian Army, and a new management, Srednjeevropski Rudniki, was installed to operate the properties. In 1950 the mines were formally nationalized by the Yugoslavian government.

Since that time, a flotation mill and a heavy-liquid separation plant have been constructed in order to rework the old dumps. On-site industries were also developed, the most important being the fabrication of automobile batteries.

Today over 700 km of underground workings are known to extend under 10 square kilometers in the Mežica-Črna area. Although ore grade fell from 11% lead in 1900 to around 3% in 1964, production remained high. A total of 14 million tons of ore have yielded nearly a million tons of lead, plus over 200,000 tons of zinc, and 400 tons of metallic molybdenum refined from wulfenite.

All known high-grade ore reserves in the district have been exhausted, and current mining centers on low-grade lead stringers. Plans call for the closure of the Mežica mines in the near future.

GEOLOGY

The Mežica deposits occur in the Alpine Metallogenic Province, along several horizons in Triassic carbonate rocks. The genesis of the Alpine hydrothermal ores (diagenetic vs. hydrothermal) is still controversial and debated (Jankovic, 1982; Drovenik, 1985, 1988; Grafenauer, 1958). The degree of mineralization in the various lithostratigraphic horizons is variable; the richest ore was found in the upper part of the Wetterstein Dolomite, below the Raibler Shale, on the west bank of the Meža River. Mineralization ranges from 260 to 970 meters above sea level (Zorc, 1955; Štrucl, 1971).

There are several general ore-types in the district: (1) stratabound orebodies in dolomite and limestone, (2) hydrothermal veins, (3) reefbound ores, and (4) ores associated with post-Triassic faults.

Galena and sphalerite are the main ore minerals, accompanied by minor pyrite, marcasite, rare arsenopyrite and typical secondary minerals.

MINERALOGY

The following descriptions are taken in part from information supplied by F. Krivograd (personal communication, 1990).

Wulfenite $PbMoO_4$

Wulfenite is the most common secondary mineral in the mine, and the principal species of collector interest. Once mined as an ore of molybdenum, it is more abundant in the higher levels, especially in fissures in the Union section, and in highly oxidized zones in galena. The largest and best crystals were found in the uppermost levels of the mine.

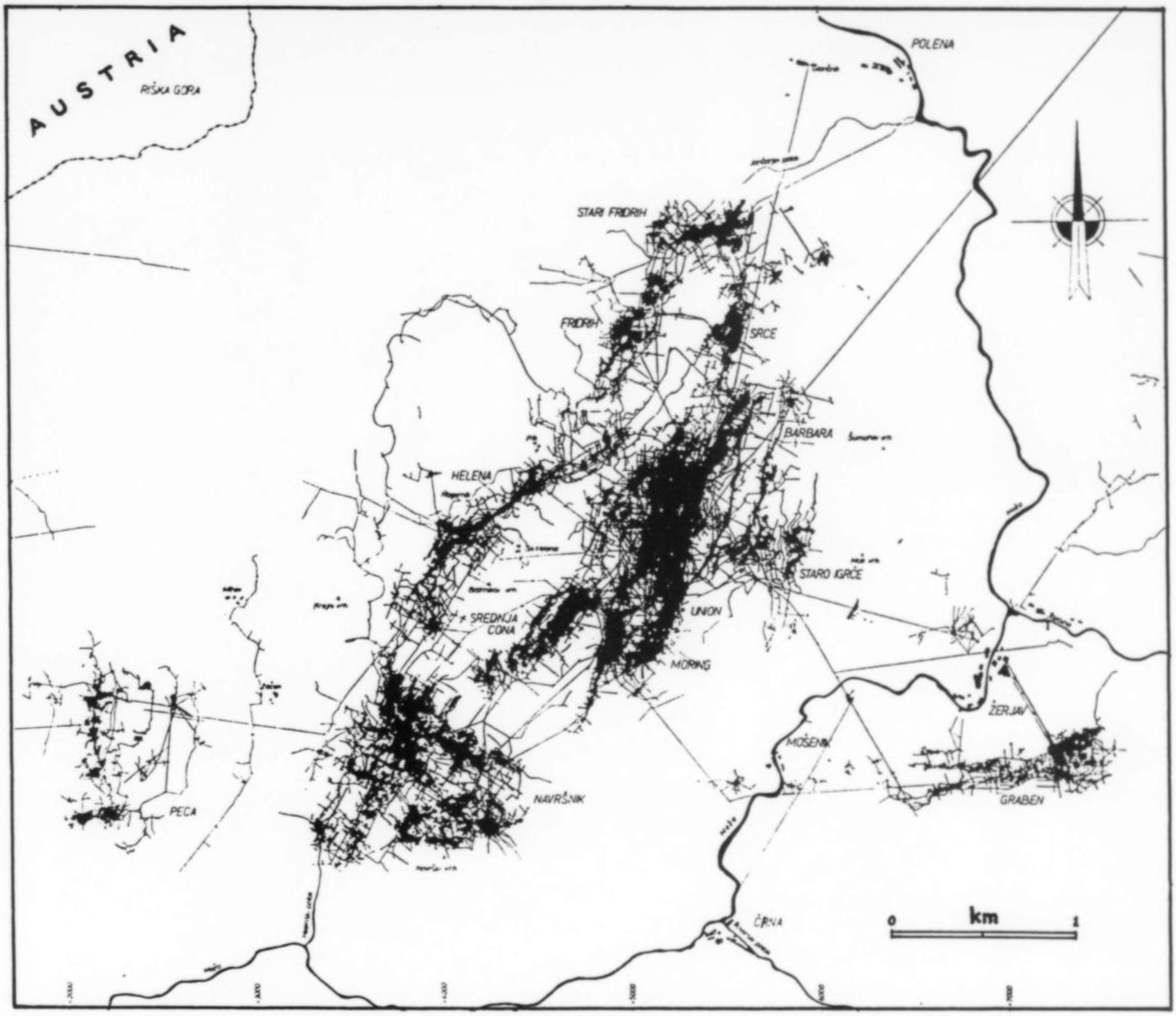

Figure 6. **Map of the underground workings as of 1964.**

The habit ranges from pyramidal to thin tabular. Edge forms modifying the tabular crystals tend to be very lustrous whereas the large *c* faces are almost invariably dull. A peculiarity characterizing some Mežica wulfenite is the development of second-generation pyramids, different in color, on one or both sides of a tabular crystal to form a "sandwich."

Crystal size is typically around 5 to 10 mm, but crystals up to 4 cm have been found, and clusters to 50 cm and more were not uncommon in the mine's heyday.

Colors range from pale yellow to yellow, orange-yellow, brownish red and (rarely) brown. The brownish red crystals occur on galena. Most crystals are relatively opaque to translucent, but some specimens having gemmy 2-mm crystals on limestone are known. A few rare specimens of large wulfenite crystals on well-crystallized calcite on limestone matrix are also known.

Although new finds of good wulfenite crystals in the Mežica mine proper are rare, some Yugoslavian collectors recently discovered opaque, well-formed, barrel-shaped crystals to 5 mm in the mountainous area high above the mine. Some of the wulfenite crystals are perched on tiny calcite rhombohedrons.

Other Minerals

Anglesite $PbSO_4$

Anglesite has been found in brilliant, well-formed, white to gray prismatic crystals to 4 cm in size. They were discovered a few years ago, on galena and limonite. Generally, however, anglesite is rare at Mežica.

Calcite $CaCO_3$

Calcite is common throughout the mine, in almost every fissure, geode and cavity. Transparent to translucent or milky crystals have been found, in some cases with inclusions of clay or galena. The typical habit is elongated prismatic, and also scalenohedral; twins are common.

Cerussite $PbCO_3$

Cerussite occurs as adamantine crystals, 5–10 mm in size (sometimes as trilling twins) in cavities in galena.

Descloizite $PbZn(VO_4)(OH)$

Descloizite, usually in association with wulfenite, occurs as tiny (<1 mm) yellowish to reddish brown crystals having good transpar-

Figure 7. **Anglesite on galena with goethite, 5 x 6 cm. M. Žorž collection and photo.**

Figure 8. **Wulfenite crystal to 2.5 cm. Smithsonian collection.**

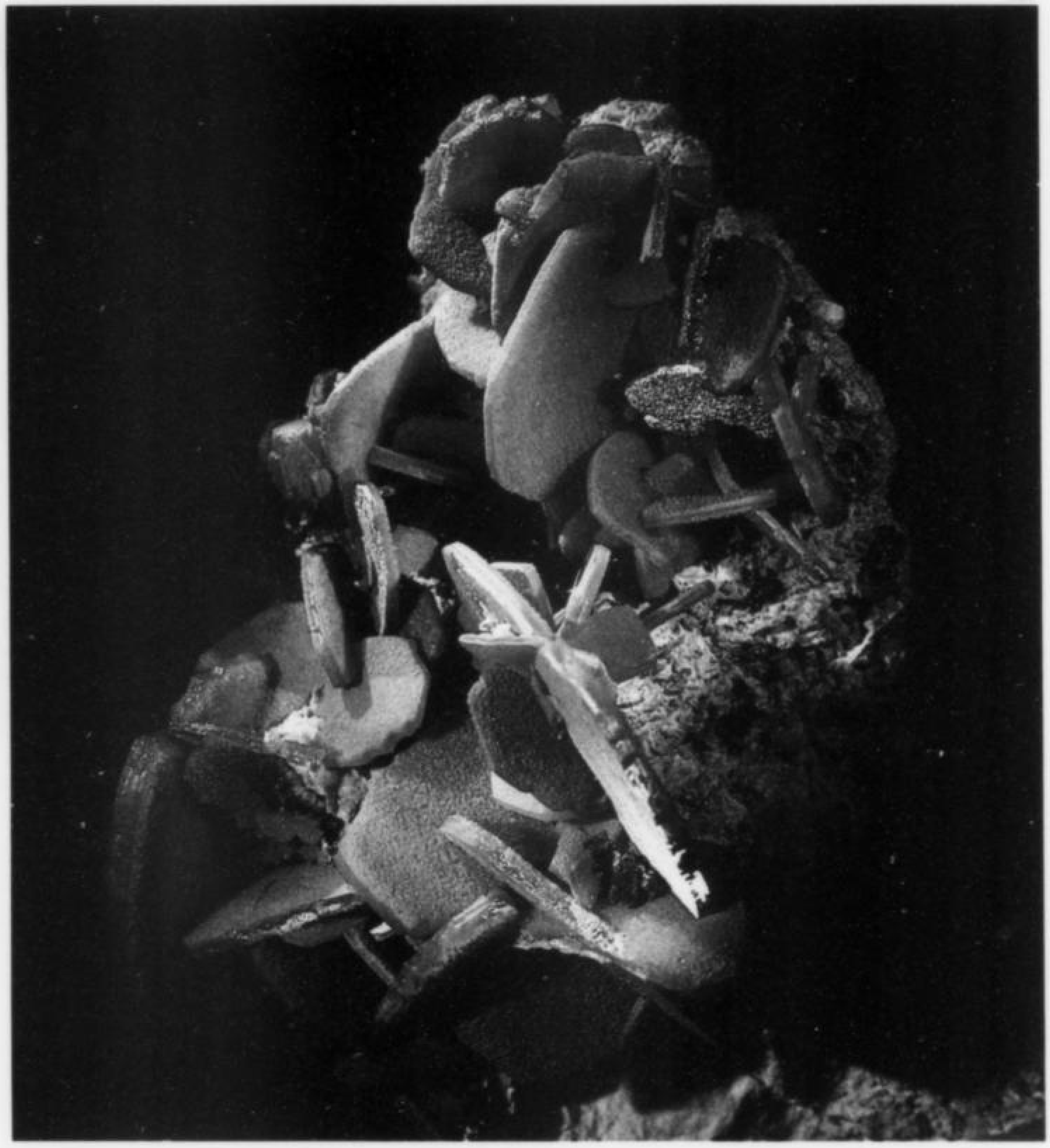

Figure 9. **Wulfenite crystals on goethite matrix, 8 cm. M. Žorž collection, Dragan Arrigler photo.**

Figure 10. Wulfenite, calcite and brown descloizite specimen, 7 cm. M. Žorž collection and photo.

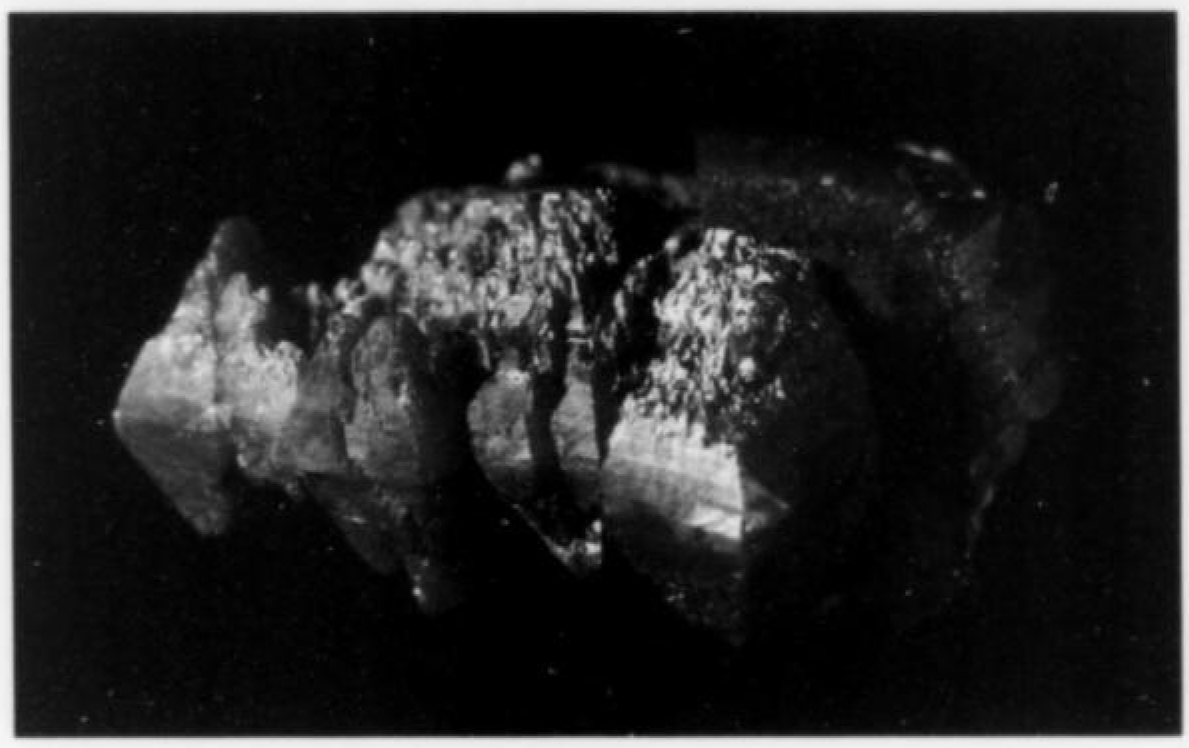

Figure 11. Bipyramidal wulfenite group, 4 cm. M. Žorž collection and photo.

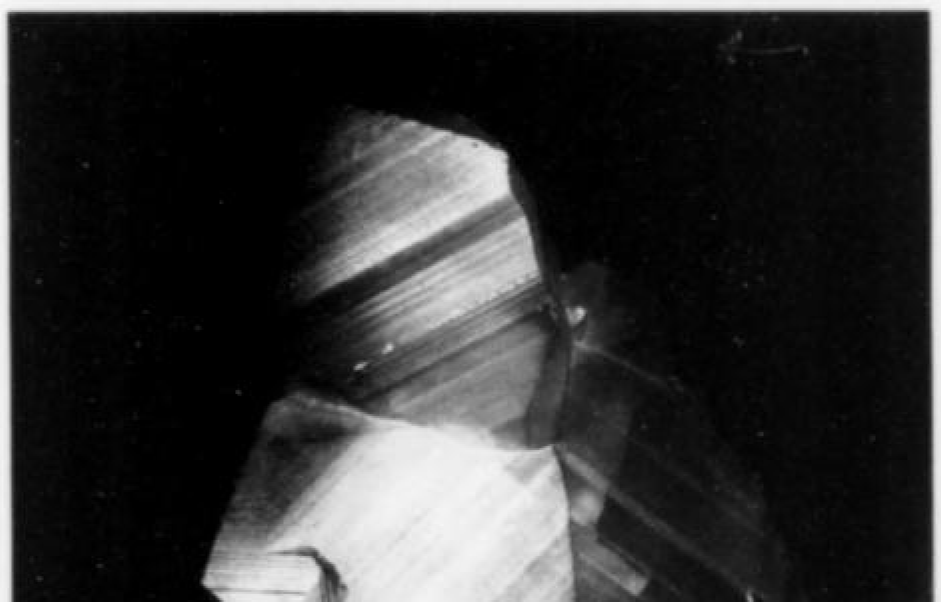

Figure 12. Calcite crystals to 5 cm. M. Žorž collection and photo.

Figure 13. Wulfenite crystals to 1 cm, Helena mine. G. Robinson photo; Canadian Museum of Nature collection.

ency and crystal form. Descloizite druses typically occur coating wulfenite and calcite crystals.

Epsomite $MgSO_4 \cdot 7H_2O$

Epsomite crystals can be found as post-mining encrustations on the walls of old workings.

Galena PbS

Galena is the main ore mineral at Mežica, usually occurring as formless masses but in some cases as poorly formed crystals in coarse intergrowths, and rarely as specimens showing octahedral faces on the surfaces of lumps.

Greenockite CdS

Greenockite occurs rarely as a yellow powdery coating on sulfides.

Gypsum $CaSO_4 \cdot 2H_2O$

Elongated gypsum crystals can be found embedded in marl or clay, and also as thin coatings on limestone and sulfides.

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

Hemimorphite is quite rare at Mežica. It typically occurs with smithsonite as fibrous crystals in vugs.

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

Hydrozincite is more abundant than hemimorphite. It forms large, white, curtain-like sheets and small stalactites associated with smithsonite. It sometimes occurs as vug fillings in galena and sphalerite, and shows a strong fluorescence under ultraviolet light.

Marcasite FeS_2

Marcasite is present throughout the mine, in large and small veins and lenses in schist. Pyrite is typically associated.

Melanterite $FeSO_4 \cdot 7H_2O$

Melanterite crystals can be found as a post-mining growth on the walls of old workings.

Pyrite FeS_2

Pyrite is ubiquitous in veins and lenses of all sizes, especially in schist.

Smithsonite $ZnCO_3$

Smithsonite, always with hydrozincite and hemimorphite, occurs in limestone cracks and fissures near high concentrations of sphalerite. It forms crusts and tuberous conglomerations.

Sphalerite (Zn,Fe)S

Sphalerite, the principal ore of zinc at Mežica, occurs primarily as small grains imbedded in calcite and dolomite, and as veins and lenticular aggregate. Well-formed crystals are unknown.

CONCLUSION

Although the days of active mining at Mežica are numbered, and the lower levels will immediately fill with water when pumping stops, many kilometers of upper-level workings may remain accessible. Additional possibilities for discovery exist in the higher elevations above the mine where mining has not taken place. The great specimens for which Mežica is famous, however, are most likely never to be found again.

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Famous Mineral Localities:

PYROMORPHITE GROUP MINERALS FROM THE CALDBECK FELLS, CUMBRIA, ENGLAND

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Metalliferous deposits in the Caldbeck Fells have been worked for lead, copper and silver for several centuries. The early miners did not value the oxidized ores which occurred there in large quantities, but during the 19th century hundreds of tons of "colored lead ores" were raised: some of the finest pyromorphite and mimetite specimens in the world were included in material saved from the crusher.

INTRODUCTION

The Caldbeck Fells mining district is a loosely defined area covering some 25 square km to the south of the village of Caldbeck in the northeastern corner of the English Lake District, about 12 km north-northeast of Keswick. Before the county boundary changes of 1974, the Caldbeck Fells were part of the ancient county of Cumberland now absorbed into the new county of Cumbria.

For the most part the Caldbeck Fells (the word "fell" generally refers to an upland pasture, moor or high plateau) consist of rolling, treeless moorland dissected by numerous watercourses running in steep-sided valleys known locally by the old Norse name of "gills." It was in these gills that the majority of mineral veins worked by the early miners were discovered.

The area is part of the Lake District National Park, and vehicular access is restricted; however, many of the mines may be reached without too strenuous a walk, the main hazard being the weather which is apt to be wet and dismal. Away from the mine dumps the Caldbeck Fells have a subtle beauty rarely seen by the countless casual visitors and tourists who flock to the central Lake District. It is surprising that despite hundreds of years of commercial exploitation and study by generations of mineralogists and collectors, the mineral localities continue to produce new discoveries of common and exotic mineral species (Cooper and Stanley, 1990).

MINING HISTORY

A brief historical review is given here. A fuller version will be found in Cooper and Stanley (1990) and further detail may be gleaned from Postlethwaite (1913), Eastwood (1959), Shaw (1970), and Adams (1988). Standard works concerning the Elizabethan mining enterprise in Cumberland are Collingwood (1912) and Donald (1955). Production statistics for 1845–1913 given below are taken from Burt *et al.* (1982).

Sixteenth Century

Although mining probably began much earlier,[2] the existence of mines in Caldbeck is not definitely known before 1537 when the presence of a silver mine in the parish was reported by a Royal Commission into the northern estates. This aside, the documented

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[1] Formerly known as the British Museum (Natural History). The name may be abbreviated NHM below.

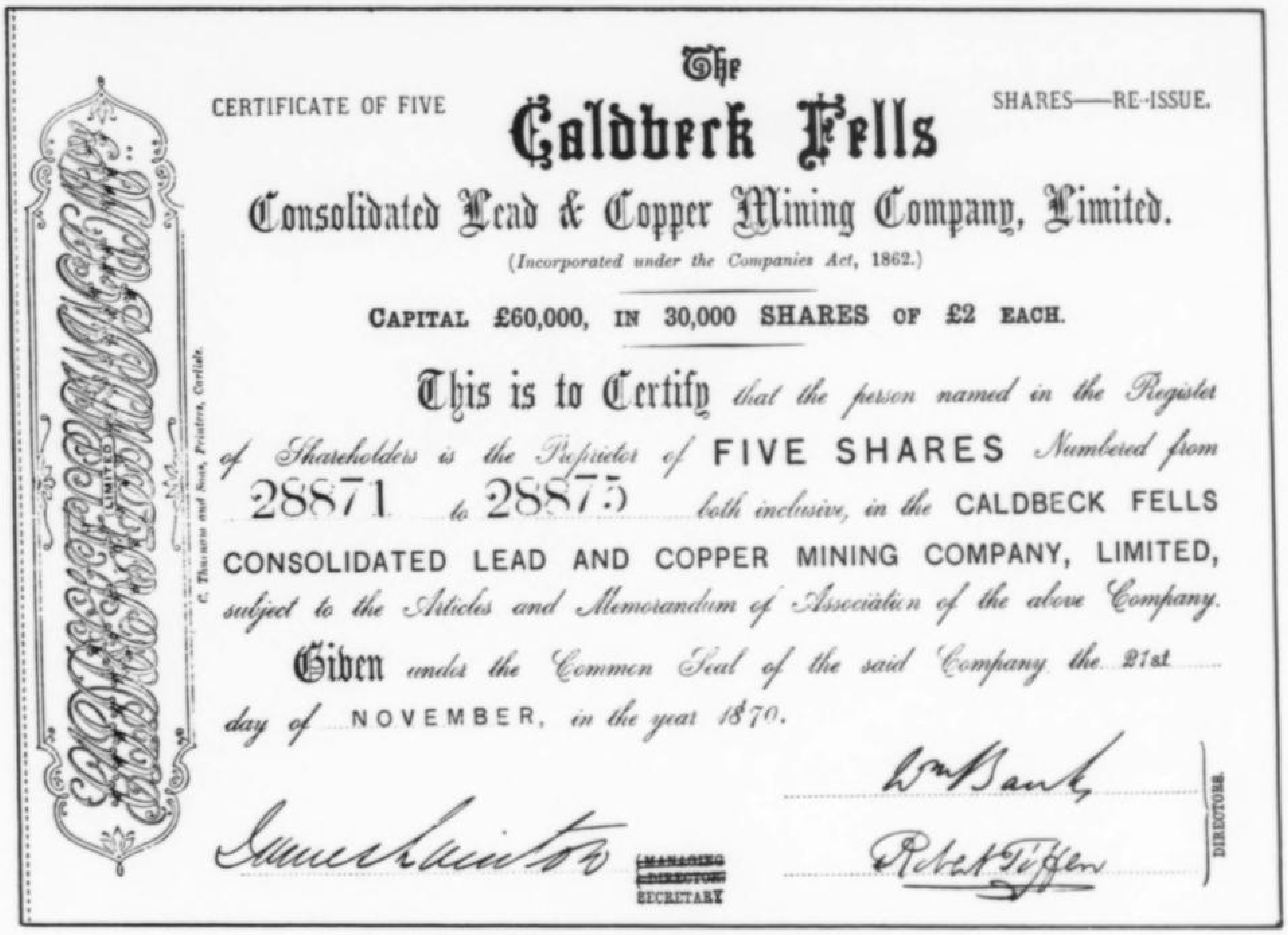
[2] The earliest known reference to the ancient mines in Silver Gill, Caldbeck, may be the order of Edward III in 1331 concerning Robert de Barton, "whom the King has appointed . . . keeper of a mine of silver and lead in the parts of Minerdale and Silverbek Co. Cumb." (quoted by Raistrick and Jennings, 1965). But thereafter records are silent for over 200 years.

Figure 1. **Dale Beck Valley: looking south towards Iron Crag (in the center of the photograph). To the right of the Crags are Roughton Gill and Silver Gill and on the extreme left is Blockley Crag or Crown Point, below which are the levels of the Mexico mine. Much of the rubble in the bed of the beck is derived from the dumps below the crags. Photo: MPC.**

history of the Caldbeck mines really begins in 1563 when, at the behest of the English Crown, copper deposits throughout the country were investigated by experts from Germany. In Cumberland the prospectors found much to excite them, and their favorable report led to the foundation of the Company of Mines Royal, incorporated by Royal Charter in 1564. England turned to Germany not only for technical expertise—16th century German miners and smelters led the world—but also for capital. Shares in the new company were more or less equally divided between the Germans and the English, the latter including prominent government officials and members of the aristocracy. The situation looked very promising, both sides anticipating vigorous business and large returns. The result was a disaster. A vast investment program was begun to open or reopen the Cumbrian mines and to set up a large administrative and processing complex near Keswick. Here the company built the biggest smelter in Europe and coordinated a large network of suppliers of fuel, food, transport and other necessities. In 1567 the first copper metal was produced, the process taking 18 weeks and 5 days from dressed ore to "perfect copper." Most of the copper ore came from mines to the west of Keswick but the Caldbeck mines were also producing ore. Copper and argentiferous lead ores were raised; the latter, of value principally for its silver, was also used to desilver copper ores from the other mines.

The smelting works were prodigiously expensive and much delay was caused by the complex Cumbrian ores which tested the Germans' expertise to the limits. Copper output never reached the first optimistic forecasts and sales were disappointingly slow. The company also had to contend with many social and legal difficulties, but, although most of their problems were eventually resolved in the company's favor, the slow progress and continuing cash-flow problems eventually caused the English shareholders to reconsider their commitment. The huge operating deficit, compounded by serious economic problems at home, proved too much for the German shareholders who withdrew completely in 1577, leaving the Company of Mines Royal in the hands of the English shareholders and such of the original German staff who chose to remain.

Chief among those Germans who remained with the company was Daniel Höchstetter, founder of a dynasty of master smelters and miners who worked the Cumberland mines for many years. From 1580–1597 the company leased the Cumberland mines to the Höchstetters and others rather than bear the financial responsibilities of running them themselves. Improved methods and economies allowed the lessees to make a reasonable living after paying the company's rent. The position of the Caldbeck mines during this period is uncertain because complete records do not exist. They were reported as closed in 1581: "the rich lead mine at Caldbeck, w'ch holdeth good quality of silver, and hath cost the company great sommes of mony: Lieth now unwrought" (quoted by Abrahams, 1899–1901). In 1600 they were being cleaned out with a view to reopening, but the miners considered that they "have no hope of comfort in this work of Caudbeck, but think the cost . . . bestowed there utterly lost" (quoted by Collingwood, 1928). Other Cumbrian mines, however, were certainly worked. The Höch-



CERTIFICATE OF FIVE SHARES—RE-ISSUE.

The

Caldbeck Fells

Consolidated Lead & Copper Mining Company, Limited.

(*Incorporated under the Companies Act, 1862.*)

CAPITAL £60,000, IN 30,000 SHARES OF £2 EACH.

This is to Certify *that the person named in the Register of Shareholders is the Proprietor of* FIVE SHARES *Numbered from* 28871 *to* 28875 *both inclusive, in the* CALDBECK FELLS CONSOLIDATED LEAD AND COPPER MINING COMPANY, LIMITED, *subject to the Articles and Memorandum of Association of the above Company.*

Given *under the Common Seal of the said Company the* 21st *day of* NOVEMBER, *in the year* 1870.

Wm Bank

Robt Tiffen

DIRECTORS.

~~MANAGING DIRECTOR~~ SECRETARY

C. Thurnam and Sons, Printers, Carlisle.

***Figure 2*. Stock certificate of the Caldbeck Fells Consolidated Lead and Copper Mining Company. Not a good buy in 1870. M. P. Cooper collection.**

stetters and their colleagues made a profit in their first lease but went on to lose money in subsequent leases. Such patterns of profit and loss were to be typical of workings on the Caldbeck Fells veins right up to the closure of the last lead mine at the end of the 19th century.

Seventeenth Century

For most of the 17th century the state of the Caldbeck mines is little known. It is certain that attempts were made to work them and that recommendations were made from time to time to drive new adits to unwater old levels, but little seems to have been done. Certainly, by the outbreak of the Civil War in 1642, all the Cumberland mines and the smelt works at Keswick were at a standstill. Cromwell's army is usually blamed for the destruction of the mills and mines and the death or conscription of the miners but there is little evidence to support this claim. It is likely that the mines were run down or even abandoned before this date and that financial or technical, rather than violent restraint was responsible for the collapse of the mining and smelting (see Hammersley, 1973).

The Caldbeck mines were investigated by several people in the 1680's with a view to reopening them but nothing came of it. By this time technological improvements in mining and smelting were making many old prospects potentially economic and the repeal of the Mines Royal Act in 1693 (whereby the Crown lost its prerogative for mines yielding precious metals) stimulated private investment in metal mining. The newly formed Company of Royal Mines Copper leased the Caldbeck mines in 1692; ten years later they merged with another Quaker-owned company to form what was to become the London Lead Company. They were still smelting lead from "Caudbeck" in 1702.

Eighteenth Century

Records for the 18th century are fragmentary but suggest a substantial interest in the Caldbeck mines. In the early part of the century one Thomas Hillary was chief agent to lead mines throughout the district and accounts for his workings from 1724–26 survive. These workings may have continued at least until 1730 (Cooper and Stanley, 1990) but thereafter nothing is known of workings in Caldbeck until 1785 when Jos. Scott was working a copper mine in Hay Gill (in the north of the district). Scott continued until at least 1792 (Adams, 1988). By 1794 smelters had been built at Roughton Gill and Driggith and by 1800 mining was probably in full swing throughout the district.

Nineteenth Century

The period 1820 to 1860 saw the golden age of mining in the Caldbeck Fells. During these years almost all the metal deposits were tried, some with great success, and some mine owners made fortunes stripping rich ore from the deposits and then selling out. But, in general, those who lingered lived to regret it and the lives of most of the mines ended in recriminations and bankruptcy. Much expense was incurred in development work ignored by previous owners intent on quick profits. These financial problems were compounded by the complexity of the ores (which even the most up-to-date and expensive milling equipment could not handle successfully), by difficulties with drainage, and by incompetent management. As the century wore on ores became progressively leaner and more difficult to extract as the mines became deeper, and self-draining adits became uneconomic or impossible to sustain. The death blow came with the catastrophic slump in metal prices in the 1870's. The market was flooded with cheap ore, much of it from America, and the remaining Caldbeck mines were forced to close.

Twentieth Century

By 1876 the last lead mine had been abandoned, its owners bankrupt. From that time hardly any lead or copper has been raised, except as an occasional by-product of working the rich barite deposits in the north of the Fells. The last of these, at Potts Gill, closed in 1966. The Carrock tungsten mine has been the only commercial operation since then, and that only an intermittent working during the 1970's

Figure 3. **Dry Gill mine. Looking west along the Dry Gill vein with the entrance of the Pattinson level (driven in 1846) in the foreground. Photo: MPC.**

and early 80's. It is unlikely that Caldbeck will see the return of miners in the foreseeable future.

MINES

There are dozens of mines and prospects in the small area covered here. Although almost all of the mines produced some pyromorphite or mimetite, only those yielding good or unusual specimen material will be described below. For a fuller description of these and other mines see Cooper and Stanley (1990) and Adams (1988).

Brae Fell mine

Almost nothing is known of this mine. It was worked from two short crosscuts (now caved) to an approximately NNW-SSE vein, and the associated dumps suggest, in local terms, a relatively extensive operation. The mine was last opened in the mid-19th century but this was merely a trial operation and nothing came of it.

The present dumps are almost barren of specimen-quality minerals, although pyromorphite and cerussite are common in small amounts. The occurrence here of mattheddleite (see below) is only the second locality known for this new species.

Brandy Gill Lead mine

An east-west lead vein crosses Brandy Gill just over 500 meters upstream from the Carrock mine, and has been tried from levels in both banks of the gill. The two levels in the west bank have been explored in this century and shown to be mostly barren, although the lower level does show some stoping. With no evidence to the contrary, this mine is assumed to be the working in Brandy Gill referred to below.

Records for lead and copper mining in Brandy Gill date from the early 18th century, but thereafter there is no known record of mining before 1852. The mine was operated sporadically until about 1873 but only a few tons of lead and copper ore were raised.

J. G. Goodchild, of the Scottish Geological Survey, found wulfenite here in 1875 but the locality only really became of interest to collectors in the 1950's following the reporting of a suite of rare supergene minerals including bayldonite, duftite, beudantite, carminite, lindgrenite, etc. (see Hartley, 1984). Stolzite was also found here, the first authenticated British occurrence.

Carrock mine

The Carrock mine is the only British tungsten deposit outside of southwestern England that has been worked commercially. It was only intermittently economic, notably during World War I. Its last period of operation was in the 1970's. The north-south tungsten-bearing veins, a well known source of fine scheelite, apatite, and other minerals, are cut by east-west lead veins; interaction between the two mineralizations has resulted in the formation of some interesting supergene minerals, of which only vanadinite is discussed here.

Driggith mine

This mine is little known to mineral collectors outside the United Kingdom but has produced some interesting and characteristic pyromorphite-mimetite as well as a suite of unusual rarities. It exploits a continuation of the Roughton Gill (South) lode from levels in the Driggith valley and from lower levels over the fell at Sandbeds.

Ore minerals in the Driggith-Sandbeds vein were predominantly galena, sphalerite and chalcopyrite in a gangue of quartz and barite

Figure 4. **Red Gill mine: looking southwest across Swinburn Gill with three levels of the mine marked by their waste heaps on the spur by Red Gill. The ore was dressed just below the confluence. Photo: MPC.**

(Stanley and Vaughan, 1981). The intimate association of galena, sphalerite and barite, especially in the deeper levels of the mine, caused insurmountable problems for the gravity separators used for ore-dressing in the Victorian workings and was a major cause of the failure of the mine.

The earliest records of mining at Driggith are in documents from the early 18th century but information is scanty until the turn of the 19th century. The mine was profitably worked in the first decades of the century but thereafter, despite brief profitability in the 1850's, the mine was worked at a loss by successive operators, most of whom ended up bankrupt. The mine was effectively finished by 1874. Several attempts to rework it in this century for lead or barite were defeated by the dilapidated state of the workings or the problems of ore separation. The last operation was in 1948. Production statistics are incomplete but the mine produced at least 3800 tons of lead ore from 1845 to 1907, yielding some 2500 tons of lead and 40,000 ounces of silver. Small amounts of copper, zinc and barite were also raised.

Dry Gill mine

Of little commercial significance, this mine is one of the most famous mineral localities in the world. Lead minerals consisting predominantly of phosphatian mimetite (*campylite*) in a gangue of quartz, barite and manganese oxides were deposited in an east-west vein. Other minerals occur rarely, the most well-known being plumbogummite.

Although mimetite specimens from Dry Gill are recorded from at least 1830 there is no record of commercial ore mining here until a lease was taken by Hugh Lee Pattison, inventor of a cupellation process for the desilvering of lead. Pattison began work in 1846, driving an adit on the vein where it crosses Dry Gill beck near the foot of the gill. He raised a few hundred tons of "colored lead ore" but gave up the work in the 1850's. The property was subsequently tried by various

Figure 5. **Hugh Lee Pattinson (1796–1858). Cumbrian-born master smelter and chemical manufacturer, Pattinson was lessee of the Dry Gill mine from 1846–ca. 1852. From Lonsdale (1873).**

Figure 6. **Roughton Gill mine: the remains of the entrance to the 60-fathom level crosscut can be seen beneath the rowan tree to the left of the waterfall. This level is reputedly the source of the mine's finest pyromorphite. Photo: MPC.**

operators, none of whom had much success. The mine was last worked in 1869.

The finest mimetite specimens were collected in the 19th century but, although increasingly hard to find, some fine material has been obtained since, particularly in the 1970's. However, the mine is notoriously unstable, cold and wet, and there have been a number of accidents involving collectors. No one has been critically injured but the incidents have highlighted the dangers of the old workings in the Caldbeck Fells.

Mexico mine

This property is adjacent to the Roughton Gill mine and exploits the eastward extension of the Roughton Gill (South) vein. It was begun in 1845, and three crosscuts were driven south to cut the vein. Although promising shoots of pyromorphite and cerussite were found early on, the mine proved to be a financial disaster. The crosscuts, a shaft and levels parallel to the vein were all cut on the assumption that rich primary ores would be found when the vein was opened up. In fact the lode was almost barren and the heavy investment, largely made by the Caldbeck Fells Consolidated Lead and Copper Mining Company, was wasted. The mine was abandoned in 1868.

In the mid 1970's the Cornish mineral dealer Richard Barstow opened a vein exposure near the High Level of the Mexico mine and made a find of excellent pyromorphite of "old time" quality. The locality was subsequently worked by other collectors and further good material was discovered. The site is now backfilled.

Old Potts Gill mine

Workings in the head of Potts Gill date from about 1870 when attempts were made to work the outcrop of the prominent east-west veins for lead. Very little lead ore was found in the predominantly barite-filled vein but the latter mineral was worked from the outbreak of World War I. The mine closed in 1947.

The barite mined was almost all massive and very little material of specimen quality was found. The deposit is of interest primarily for a suite of rare copper and lead minerals reported from the dumps of the "Old No. 1 level" workings by Kingsbury and Hartley (Hartley, 1984). These minerals, which included vanadinite and many rare supergene copper minerals, may have originated from crosscutting copper veins encountered in the barite workings. Unfortunately there is no detailed record of the source *in situ* and the origin of Kingsbury's specimens must remain conjectural.

Red Gill mine

The Elizabethans are supposed to have worked this mine but no specific records remain. Workings in Red Gill are mentioned in early 18th century documents but thereafter there is nothing known of the locality until the 19th century. The best-documented operations are those of the Red Gill Mining Company, which leased the property in 1861. The company extended the Red Gill mine and opened several other prospects nearby, but recorded production was very small. The company went bankrupt in 1871, having raised no more than 28 tons of lead ore and 45 tons of copper ore. From that time there has been no commercial exploitation of the mine.

The Red Gill vein runs northwest-southeast and was worked from several levels in the spur between Swinburn Gill and Red Gill. Principal ore minerals were chalcopyrite and galena, closely associated

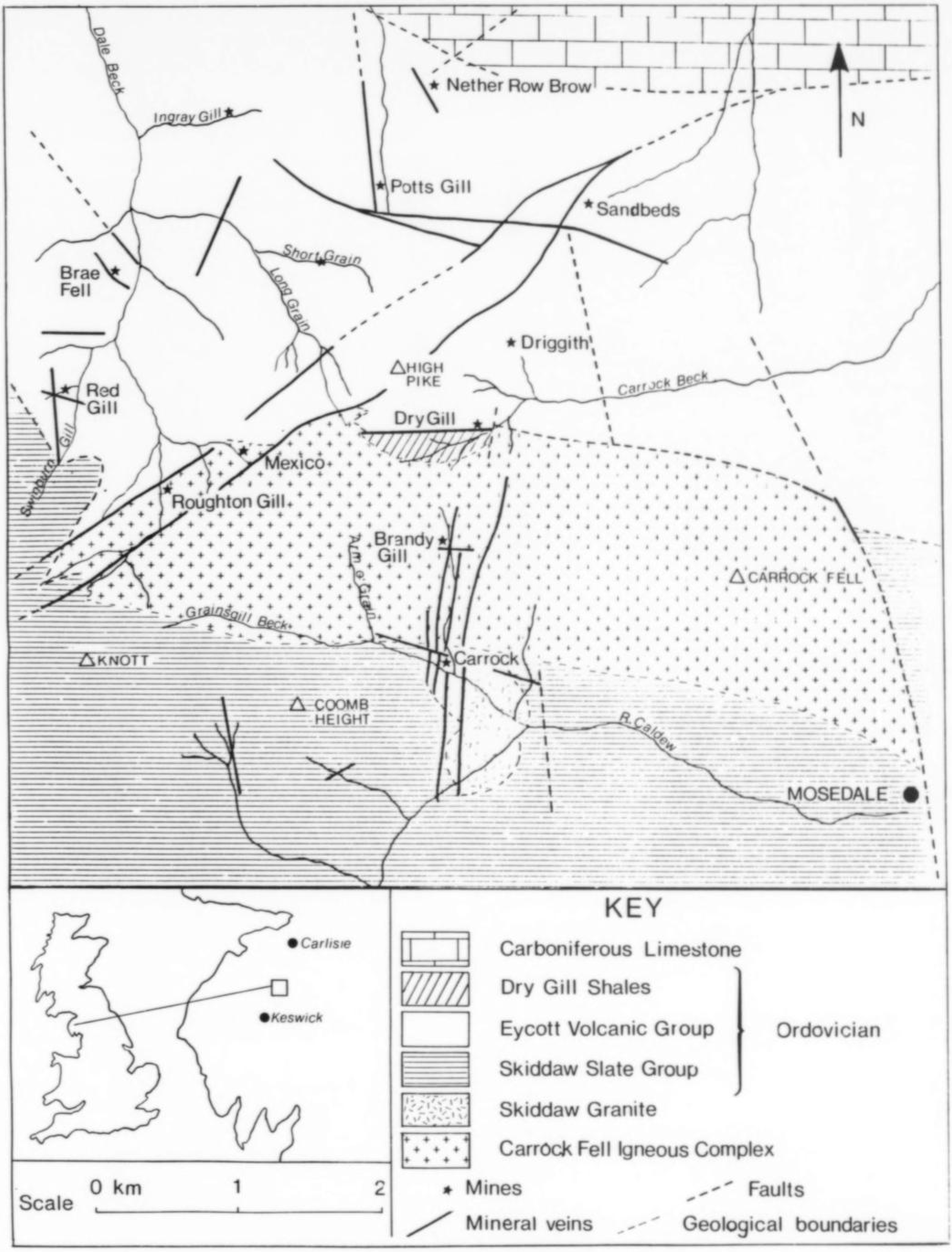


Figure 7. **Caldbeck Fells. Sketch map of the geology showing principal localities mentioned in the text.**

in a gangue of quartz and barite. Intense oxidation resulted in a remarkable assemblage of supergene lead and copper sulfates including fine specimens of linarite, caledonite and leadhillite. The best specimens of these species were found while the mine was working; very few have been found this century but specimens of rarities such as macphersonite, mattheddleite (Cooper *et al.*, 1988) and queitite (Braithwaite *et al.*, 1989) have been found recently on the otherwise almost barren dumps.

Roughton Gill mine

Roughton Gill is supposed to have been the site of the principal Elizabethan workings at Caldbeck, although its present name does not appear in documents as a mining site before the end of the 18th century. Some workings are, however, undoubtedly ancient as hand-cut levels can still be found in the higher workings.

The mine exploited two large lodes known as the Silver Gill and Roughton Gill lodes. The former was named after the valley to the west where it was once extensively and (legend has it) very profitably worked. These names have fallen somewhat into disuse and the veins are now generally known by geologists and mineralogists as the Roughton Gill North and South lodes respectively. This terminology leads to some confusion because these terms were used by the old miners to denote branches of the Roughton Gill vein proper. We have given preference here to the older terms to save having to switch nomenclature between our historical and mineralogical descriptions.

The principal ore minerals at Roughton Gill were argentiferous galena and chalcopyrite with lesser, though occasionally valuable, amounts of pyromorphite, cerussite and malachite. The gangue was mostly hard quartz but, in an occurrence unusual in the Lake District, large quantities of calcite were associated with the richest shoot of ore in the Roughton Gill (South) vein. The ore deposits were apparently richest where gabbro formed one of the walls of the vein, this and other country rocks being intensively altered for a considerable distance from the lode.

The earliest trials and levels are found in the higher reaches of Roughton Gill where the outcrop of the strong Roughton Gill (South) vein was worked from opencuts and short drives on the lode. In later years crosscuts were driven lower down the gill. There has been no access to the mine in living memory and this, along with the almost complete absence of any contemporary mine plans, means that the full extent of the workings is now unknown.

From about 1820 fortunes were made by successive owners but by 1865, when the mine was leased to the ill-fated Caldbeck Fells Consolidated Lead and Copper Mining Company, the richest ores were gone and the mine was in decline. The construction of the most up-to-date ore milling equipment and an expensive attempt to prove the mine below the 90-fathom adit level on the Cornish principle by the use of an engine shaft failed to improve the output or reserves. The lead price crash of the 1870's brought the company to bankruptcy in 1876. The mine closed and, apart from some interest shown by the Cleator Iron Ore Company, which worked barite and limonite ("umber") in the Caldbeck Fells, Roughton Gill was effectively finished as a metal mine.

Records of production in the early period are vague. Output from the Roughton Gill workings alone are not recorded before the 19th century; the production figures are complicated by changes in ownership and were often given in combination with other mines worked by the same operator. Peak annual production of dressed lead ore was some 650 tons in 1851. From 1845 (the start of official output records) to the close of working in 1876 some 10,500 tons of lead ore were raised, yielding over 6,000 tons of lead and about 13,000 ounces of silver. The mine also produced over 1,300 tons of copper ore in the same period; 39 tons of zinc ore are recorded for 1873–74.

Other localities

Some smaller sites are mentioned in the mineral descriptions below: **Short Grain** and **Ingray Gill** are shallow valleys in the northwestern part of the Fells. Each contain several small prospects for lead or barite or both (see Adams, 1988). These workings probably date from the mid-19th century and are of small extent and little economic consequence.

GEOLOGY

Useful reviews of the geology of the Caldbeck Fells can be found in Eastwood *et al.* (1968) and in Moseley (1978), while the mineralization of the Lake District in general is reviewed by Stanley and Vaughan (1982).

Briefly, the oldest rocks in the Caldbeck Fells are the contact metamorphosed chiastolite-bearing and cordierite-bearing slates of the Skiddaw Group of Lower Ordovician (Arenig) age. To the north, these are overlain by a sequence of interbedded volcanic and sedimentary rocks of Llanvirn age: the Eycott Group. The volcanic rocks are predominantly basalts, basaltic andesites, and tuffs which have undergone intense alteration. These sediments and lavas have been intruded by the Carrock Fell Igneous Complex—a layered intrusion of late Ordovician to Silurian age—and by the Skiddaw Granite of Lower Devonian age. A small outlier of calcareous ashy mudstones and shales (the Dry Gill Shales) lies unconformably on the north flank of the Carrock Fell Igneous Complex. Their fossil fauna indicates an Upper Ordovician or Caradocian age. Around the village of Caldbeck itself, Carboniferous Limestone overlies the Eycott Group unconformably.

Many authors (e.g. Eastwood, 1959) attribute the variety of minerals encountered in this area to the variety of host rocks, and to some extent this is true, for a number of quite distinct mineralizing events have occurred.

Apart from a minor concentration of ilmenite in the basal gabbro of the Carrock Fell Igneous Complex, the earliest mineralization (Lower Devonian) is that which forms the north-south veins cutting the greisenized Skiddaw Granite, the hornfelsed slates, and the gabbros and granophyres of the Carrock Fell Igneous Complex. Predominantly this deposit is of quartz, wolframite, scheelite, apatite and arsenopyrite with minor amounts of bismuth, bismuth tellurides and sulfides, pyrrhotite, chalcopyrite and sphalerite; it formed from late stage fluids derived from the granite (Shepherd *et al.*, 1976).

The deposits of copper, lead and zinc are found almost entirely in veins formed along faults in the volcanic and plutonic rocks of the Eycott Group and the Carrock Fell Igneous Complex respectively. Most of the veins have a simple primary sulfide mineralogy dominated by galena, chalcopyrite and sphalerite with minor pyrite. Bournonite, native antimony and argentian tetrahedrite are common as microscopic inclusions in galena. Dominant gangue minerals are quartz and barite. Calcite is locally abundant in the Roughton Gill (South) vein and the Carrock tungsten veins but uncommon elsewhere in the Caldbeck Fells. Fluorite is very rare. Isotopic evidence (Ineson and Mitchell, 1974) suggests that the main period of copper-lead-zinc mineralization occurred in Upper Devonian to Lower Carboniferous times (ca. 360–330 million years). The later barite mineralization of the area was assigned an Upper Carboniferous to Permian age (ca. 290–260 million years).

The formation of the secondary minerals, for which the Caldbeck Fells are renowned, resulted from a hydrothermal event which altered the host rocks and the primary mineral assemblages, and for which Ineson and Mitchell (1974) suggested dates of 190–180 million years on the basis of isotope determinations.

MINERALS

The Caldbeck Fells contain a greater variety of mineral species than any other area of comparable size in Great Britain. Approximately 175 valid mineral species have been recorded from the metalliferous veins (see Table 1); a further 40 are known from the country rocks. Although the area has yet to be distinguished as a type locality for any species, there are about a dozen species for which it was the second or third world occurrence and over 30 that were, when first recorded, new to Great Britain (Cooper and Stanley, 1990).

Members of the pyromorphite group that occur here are mattheddleite, mimetite, pyromorphite and vanadinite. The first three occur in excellent specimens; vanadinite is found here very rarely, its occurrence is of importance only given the extreme scarcity of this species in Great Britain. Other species for which the area is a renowned source of collector specimens include plumbogummite, linarite, hemimorphite, caledonite, leadhillite, scheelite and apatite.

Mattheddleite $Pb_{20}(SiO_4)_7(SO_4)_4Cl_4$

Mattheddleite, a new species from Leadhills, Scotland (Livingstone *et al.*, 1987), was first identified from the Caldbeck Fells shortly before the description of the species was published. In all specimens seen, mattheddleite is obviously late, if not last, in the paragenesis; no other species have been seen on mattheddleite. These occurrences were briefly described by Cooper *et al.* (1988).

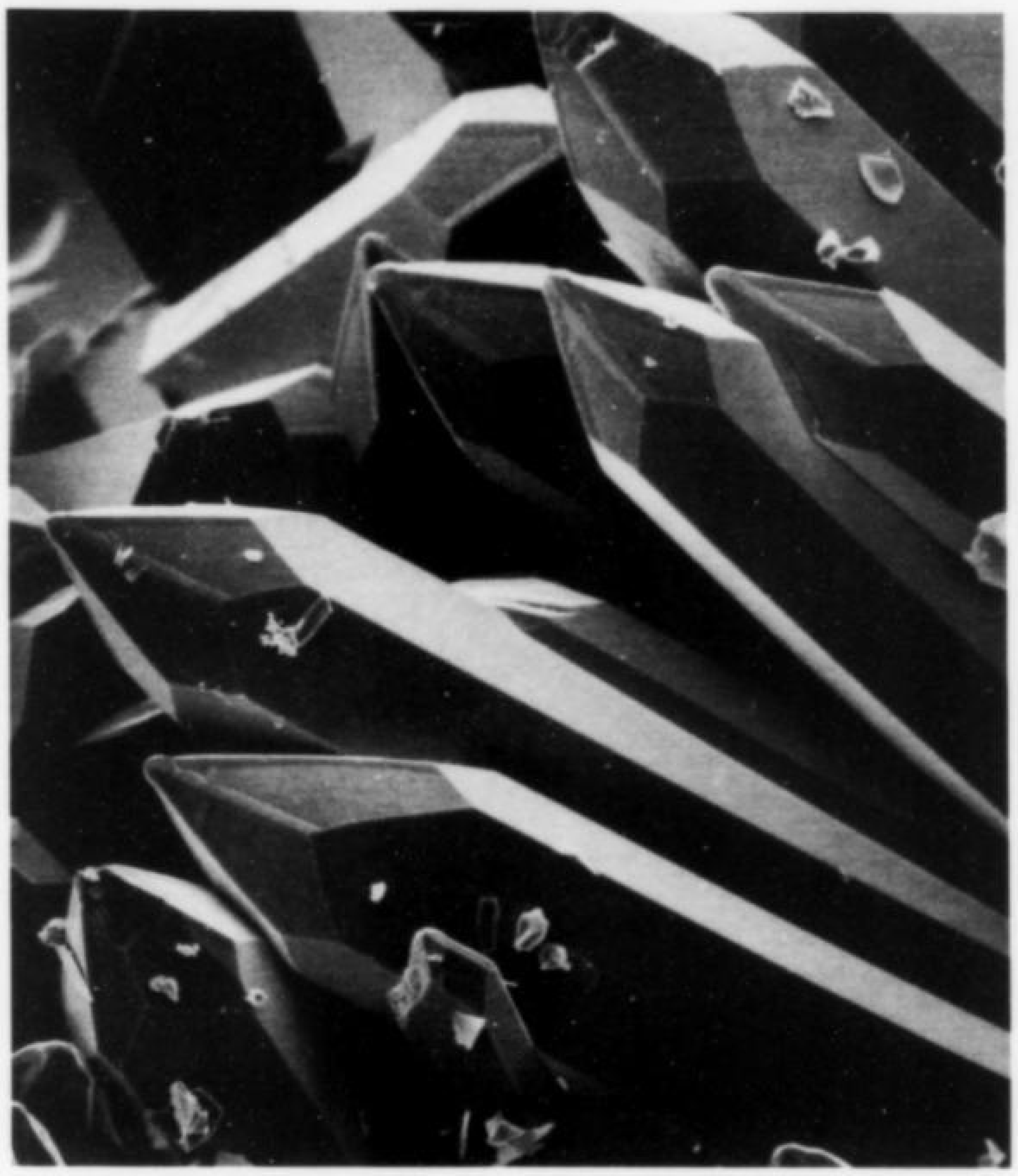


Figure 8. **Mattheddleite, Brae Fell mine. Prismatic crystals with characteristic pyramidal terminations. SEM photo; scale bar is 20 µm. A. W. G. Kingsbury collection, NHM. Photo: Don Claugher.**

Brae Fell mine

Only two specimens are known, both discovered in museum collections, in which mattheddleite occurs either as etched prisms and pinkish masses on leadhillite and cerussite or as sharp prismatic crystals with typical pyramidal terminations encrusting lanarkite.

Red Gill mine

The Red Gill mine has been the most productive locality in the district. Many recently collected specimens from the "Old Dutch level" have been identified as mattheddleite. It forms crystals 0.25–0.5 mm long in sprays and crusts with caledonite, leadhillite and susannite on quartz, or occupies cavities in etched galena with minute sprays of pale blue lanarkite. Surprisingly, the species has not been identified on older specimens in museum collections examined by the authors. Although this may suggest that the mineral has formed post-mining, its occurrence seems restricted to the interior of cavities in the veinstone and it has never, as is common with many dump-formed minerals, been seen on the exterior of matrix fragments.

Roughton Gill

An outcrop of the Roughton Gill (South) vein in the higher reaches of the gill has yielded some good specimens of mattheddleite in minute needles with caledonite, lanarkite, leadhillite, hydrocerussite, etc. A very rare associate is the sulfite scotlandite, this being its second published locality (Green, 1989).

Short Grain

On one specimen from an old prospect in the north bank of the gill, mattheddleite occurs as minute sparkling crystals lining small (<5 mm) cavities in solid barite. The terminations of these crystals are severely etched.

Mimetite $Pb_5(AsO_4)_3Cl$

Mimetite is known from many of the lead mines and prospects in the Caldbeck Fells, particularly those in the eastern half of the district. Only the principal localities will be discussed below.

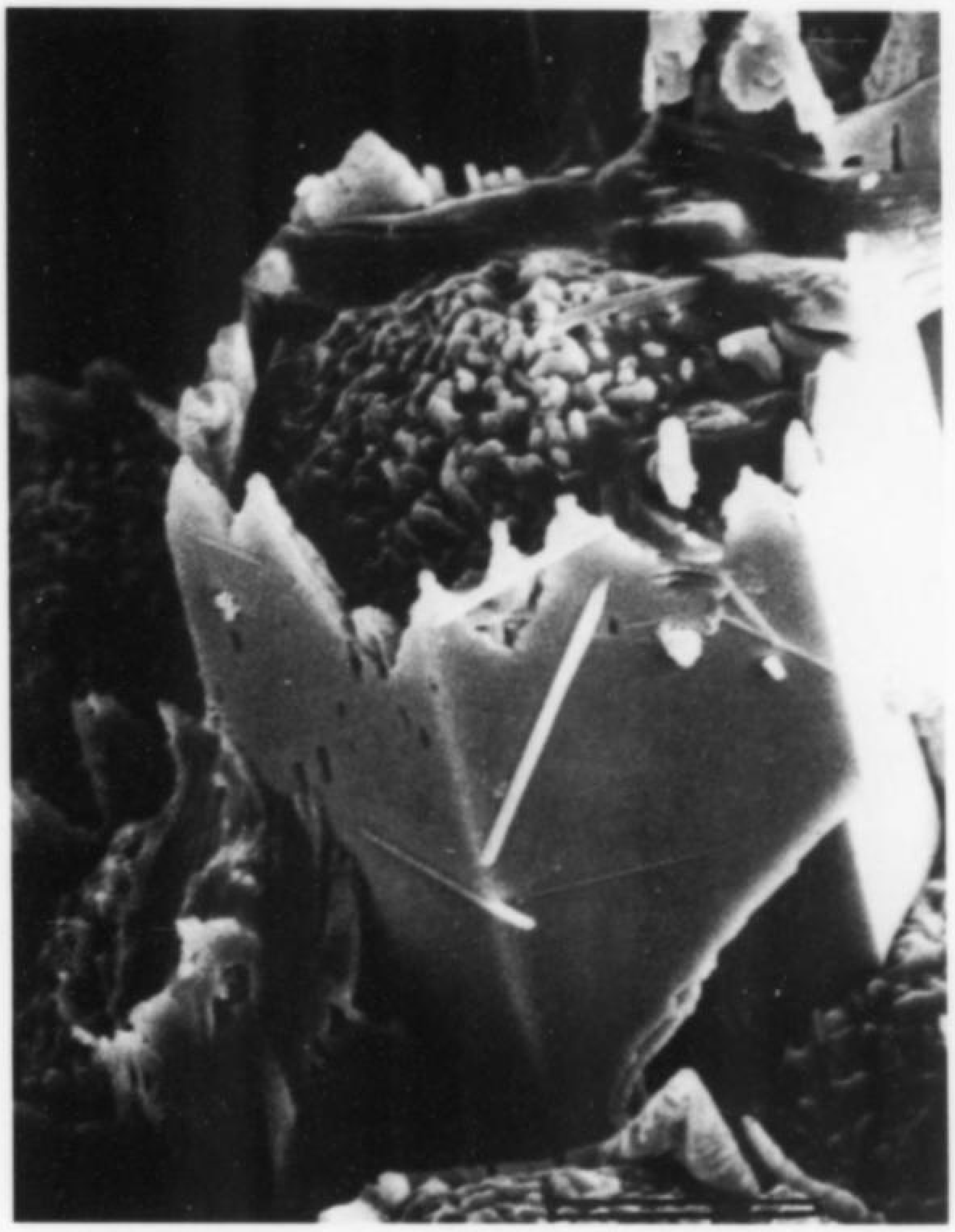


Figure 9. **Mattheddleite, Short Grain. The extremely etched termination of this crystal is typical of mattheddleite from this locality. SEM photo; scale bar is 5 µm. M. P. Cooper collection (87–62). Photo: Mike Rothwell.**

Figure 10. **Mattheddleite, Red Gill mine. Prismatic crystals with (partially resorbed?) blunt terminations on altered galena. SEM photo; scale bar is 100 µm. M. P. Cooper collection (89–49). Photo: Mike Rothwell.**

Brandy Gill Lead mine

Mimetite has been found at the Brandy Gill Lead mine in small amounts as gray to pale green tabular to prismatic crystals rarely above 5 mm long. Duftite, bayldonite, beudantite and carminite are occasionally seen as epimorphs after small mimetite crystals.

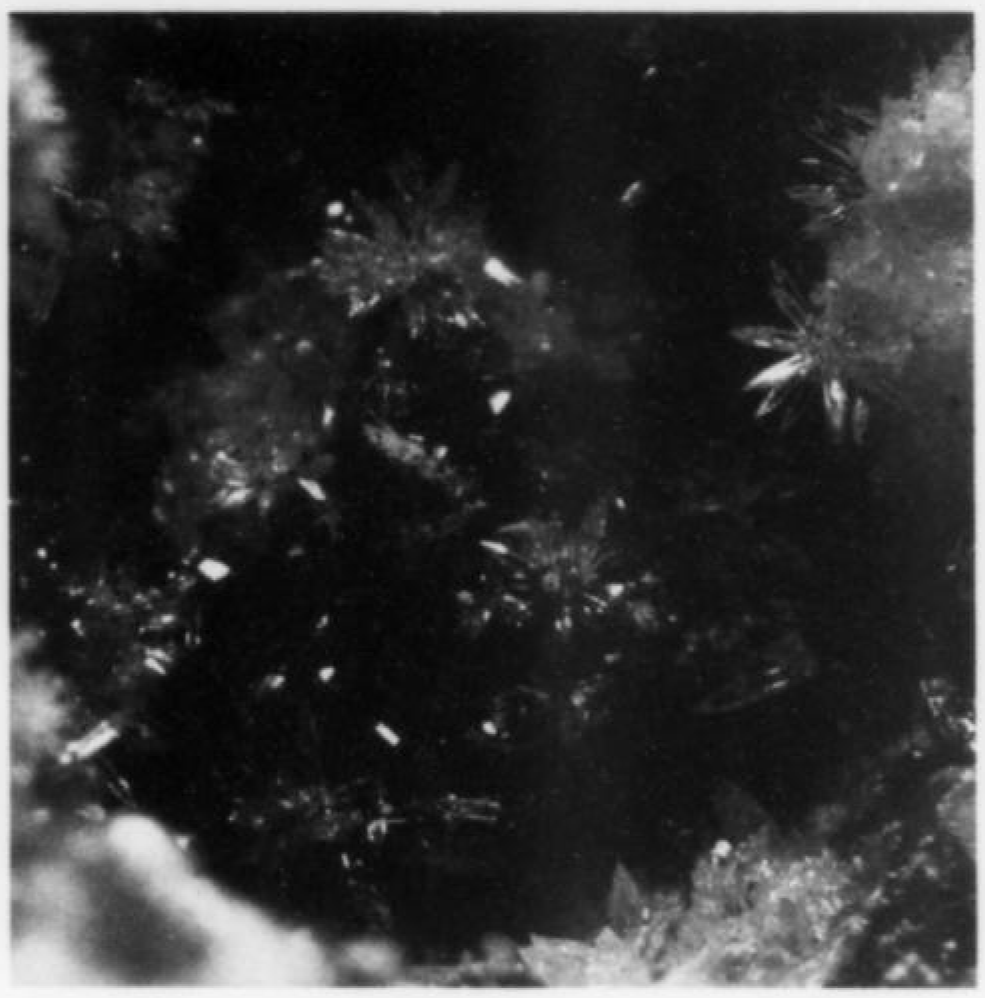


Figure 11. **Mattheddleite, Red Gill mine. Sprays of prismatic crystals to 0.25 mm on caledonite on galena and quartz. David Middleton collection. Photo: MPC.**

Figure 12. **Mattheddleite, Red Gill mine. Minute sprays of blunt prisms to 0.15 mm with bladed caledonite on quartz. David Middleton collection (15–7). Photo: MPC.**

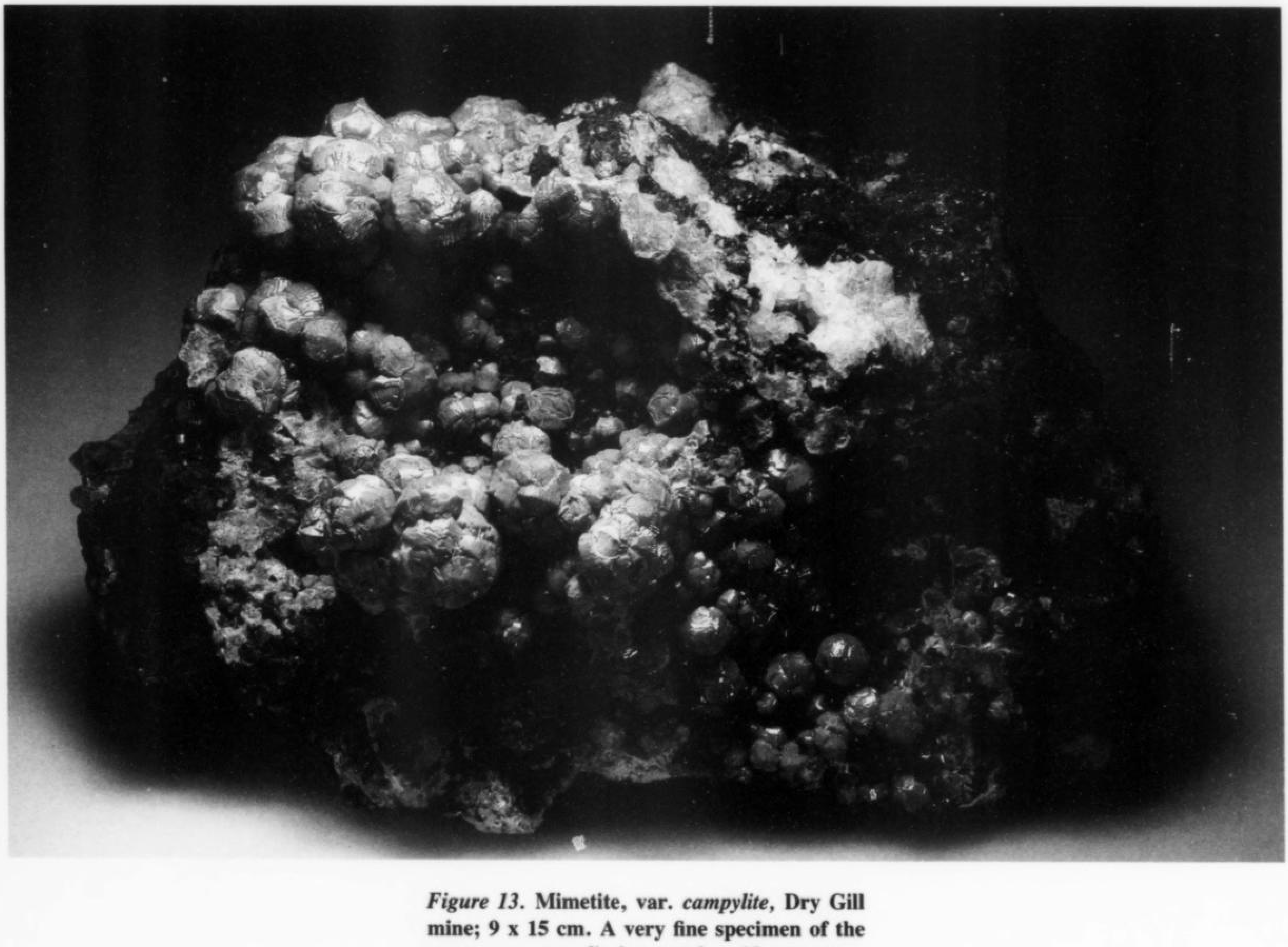


Figure 13. **Mimetite, var. *campylite*, Dry Gill mine; 9 x 15 cm. A very fine specimen of the rare green *campylite* in crystals to 10 mm across on a matrix of quartz and manganese oxides. Collected ca. 1850. Ralph Sutcliffe collection. Photo: MPC.**

Figure 14. Mimetite, Dry Gill mine. A detail of the largest known specimen from Dry Gill mine showing crystals 2 to 2.5 cm across encrusting a large quartz matrix. This remarkable specimen was donated to the Museum of Practical Geology, London (now the Geological Museum) by the mine's lessee, Hugh Lee Pattinson, in about 1852. The collection was amalgamated with that of the NHM, London in 1985. Photo: Frank Greenaway.

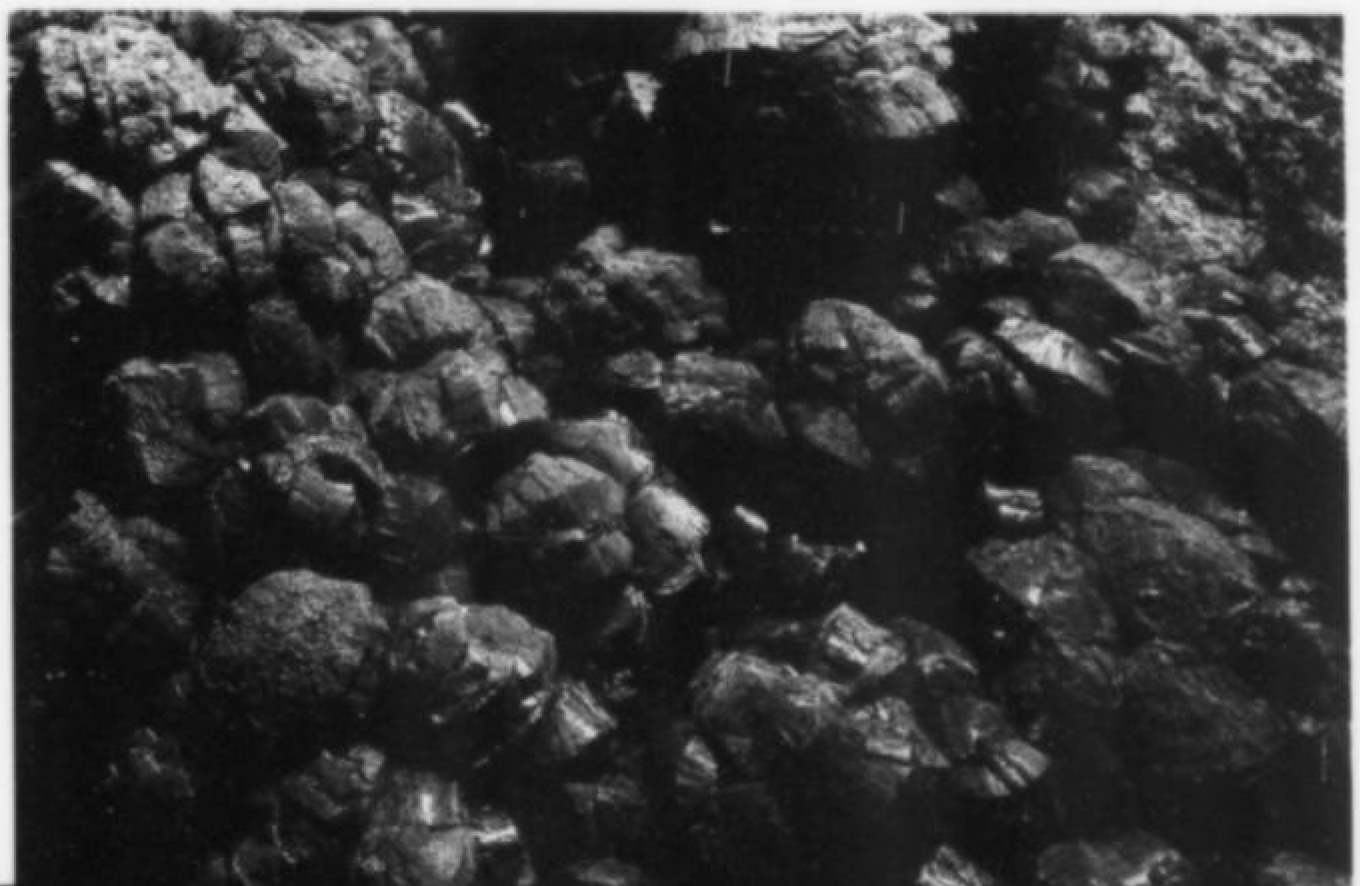


Figure 15. Mimetite, var. _campylite_, Dry Gill mine. Bright orange-brown crystals coating a 6-cm matrix. Bob King collection, National Museum of Wales, Cardiff (NMW 83.41G.M/K9077).

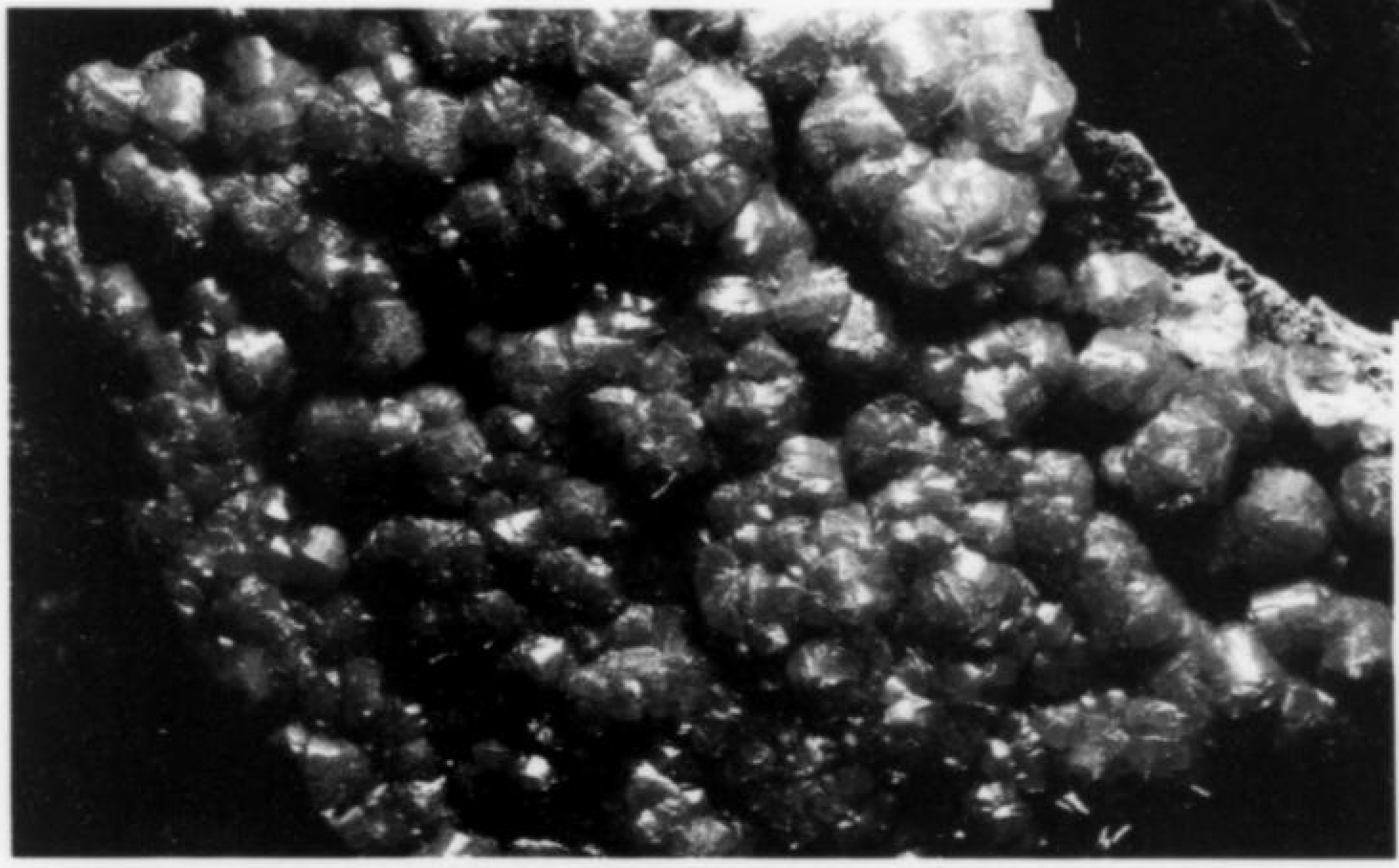


Figure 16. Mimetite, var. _campylite_, Dry Gill mine; 4 x 6 cm. An exceptional small cabinet specimen collected in 1984. Ralph Sutcliffe collection. Photo: MPC.

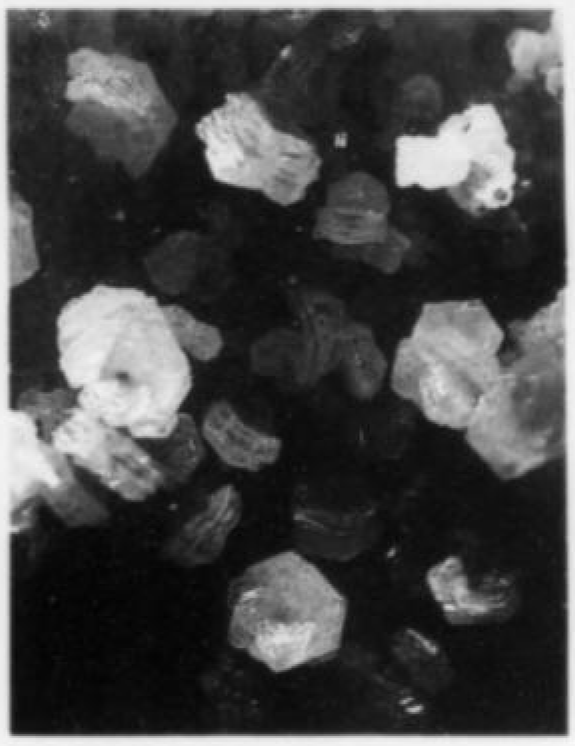


Figure 17. Mimetite, Potts Gill mine. Translucent white crystal rosettes to 1 mm. Neil Hubbard collection. Photo: MPC.

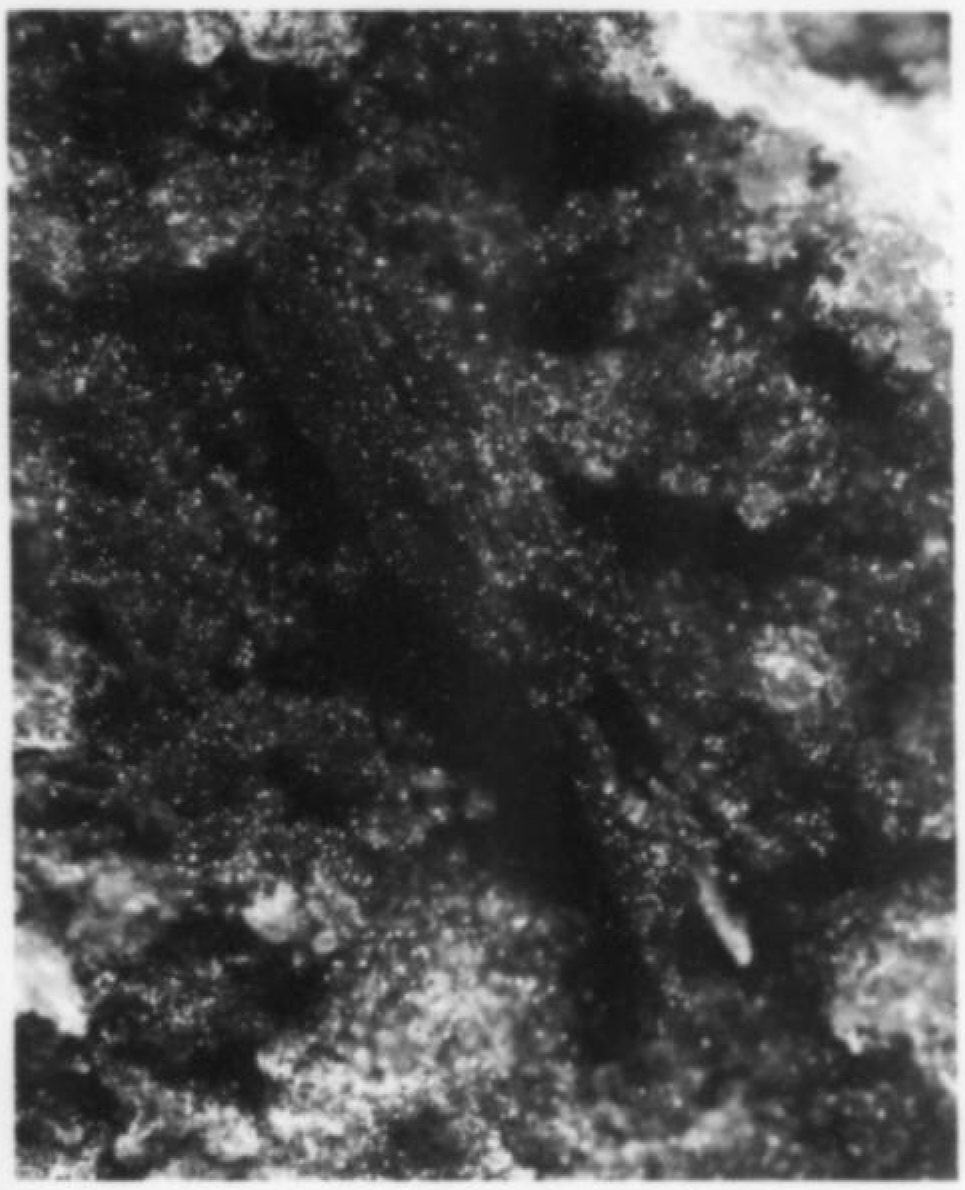


Figure 18. Carminite pseudomorph after a 3-mm mimetite crystal. From a small outcrop near the Brandy Gill Lead mine. M. P. Cooper collection (88–68) and photo.

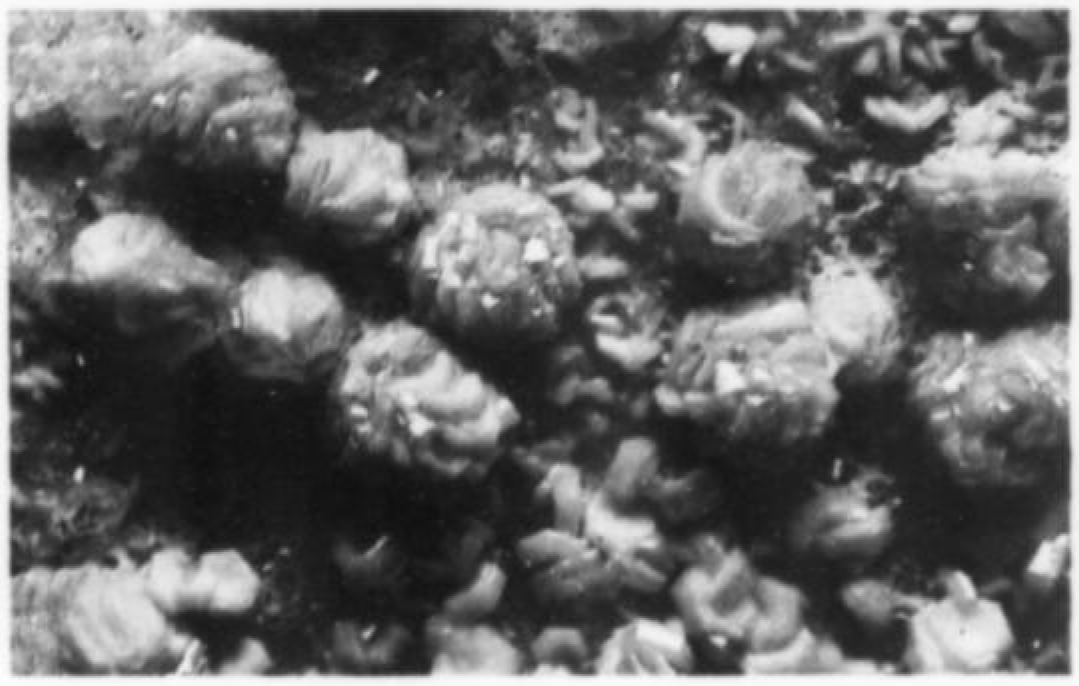


Figure 19. Mimetite, Dry Gill mine. Yellow tabular crystals and aggregates to 5 mm on quartz. Peter Briscoe collection. Photo: MPC.

Driggith mine

Mimetite occurs here as small, rounded, greenish to khaki crystals encrusting quartz. The mineral frequently contains a high proportion of phosphate and passes insensibly into pyromorphite. Many specimens are of intermediate composition (see pyromorphite below).

Dry Gill mine

The quantity and specimen quality of mimetite found at the Dry Gill mine makes the occurrence one of the most remarkable in the world: the deposit consists almost exclusively of mimetite and pyromorphite in a gangue of quartz, barite and manganese oxides.

Specimens of mimetite from Dry Gill in the collections of the Natural History Museum, London, date from 1830, but the locality does not appear in the literature until Breithaupt described "campylite" (from the Greek *campylos,* a barrel) as a new species in 1841. However, although he did not specify a more precise locality, the "arseniate of lead" described by Allan (in Phillips, 1837) from Caldbeck ". . . aggregated in opake, orange-yellow coloured individuals, which consist each of three hexagonal prisms curved towards their terminations in a manner often beautifully symmetrical" was undoubtedly "campylite" from the Dry Gill mine; the Allan Collection contains several specimens of typical mimetite from this mine.[3]

"Campylite" is discredited as a species name (= phosphatian mimetite) but lingers amongst collectors as a descriptive term for the most characteristic habits of mimetite at Dry Gill, where it varies from rounded barrel-shaped crystals to globular aggregates. Mimetite also commonly occurs as tabular and short to long prismatic crystals. Color varies from yellow to orange or, rarely, green; "campylite" is now most commonly found in shades of brown although excellent green "campylite" is known, usually on nineteenth-century specimens. Color zoning and chemical zoning are common, brown "campylite" often being paler, sometimes yellow or orange, within. Yellow acicular crystals, often found encrusting brown "campylite" or embedded in crusts of plumbogummite, are usually labeled mimetite but most, if not all, such specimens are pyromorphite.

Crystals are generally in the range 5–10 mm but exceptionally reach as much as 3 cm across and have been found thickly coating matrix pieces to over 20 cm. Excellent stalactitic specimens (to over 5 cm long) were also found in the 19th century.

Mexico mine

Mimetite from the Mexico mine was first mentioned by Greg and Lettsom (1858). Brown, rounded crystals similar to, but distinct from, Dry Gill "campylite" have been found on the dumps from the High Level.

Roughton Gill mine

"Wax-yellow crystals, well defined" were noted from Roughton Gill by Greg and Lettsom (1858). Mimetite is not as common here as pyromorphite but there is little hard data on the distribution of the two species at Roughton Gill, and mimetite may be more widespread than is supposed. Some fine specimens are known in old collections.

Pyromorphite $Pb_5(PO_4)_3Cl$

Some of the world's finest pyromorphite has come from mines in the Caldbeck Fells. It is almost ubiquitous in the district. At Driggith mine it constituted a valuable ore of lead in the higher level workings; at Roughton Gill it was found throughout the mine.

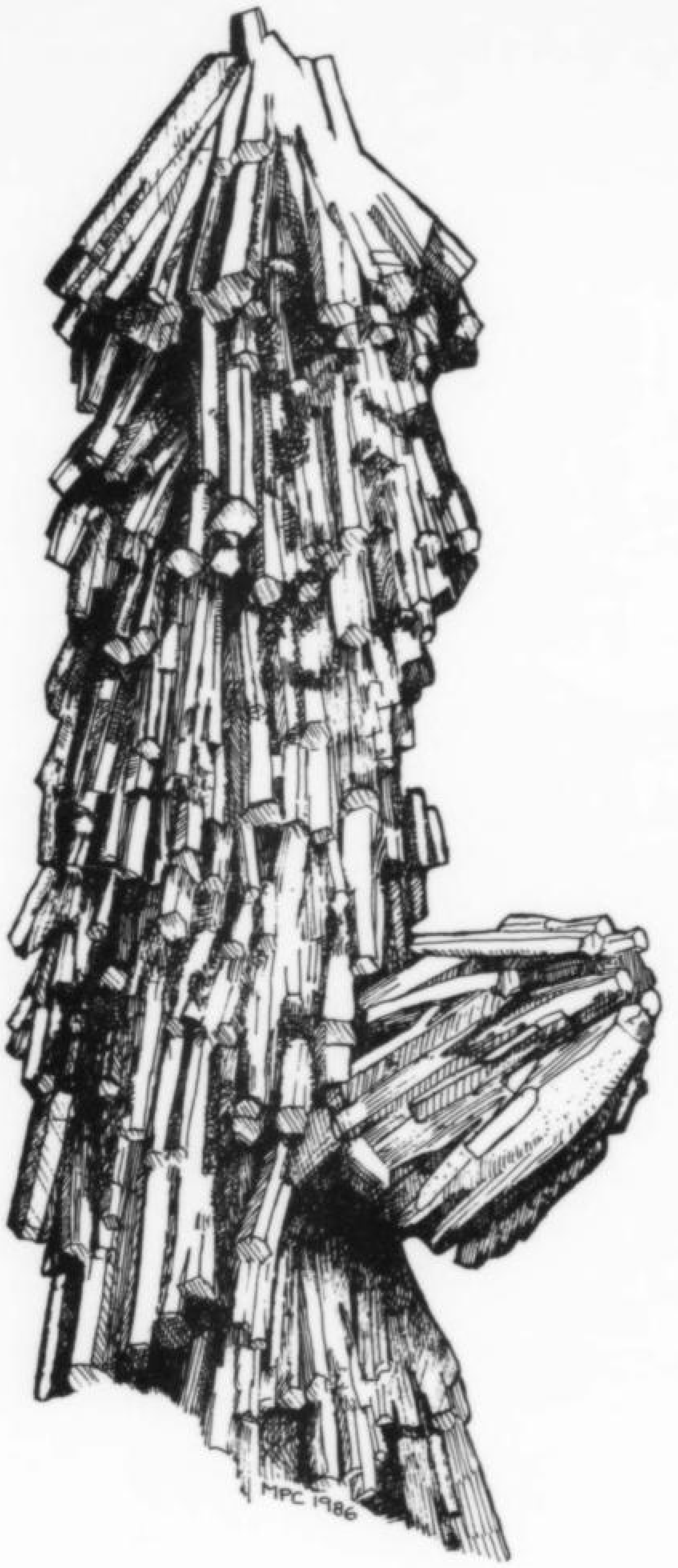


Figure 20. **Pyromorphite, Roughton Gill mine. A 6-mm-long prism completely overgrown with smaller prisms in semi-parallel growth. Oxford University Museum collection. Drawing from a photo by F. B. Atkins.**

Driggith mine

Considerable quantities of pyromorphite are reputed to have been raised from the upper levels of the Driggith mine (Postlethwaite, 1913). The mineral is still common in the outcrops of the vein, generally forming small (<5 mm), opaque, rounded or seed-like, green to khaki crystals encrusting quartz. Specimens are often found to have a 1:1 phosphate:arsenate ratio and should be labeled "pyromorphite-mimetite." A very characteristic form first recorded from the outcrop workings in the 1940's consists of masses of coarsely fibrous pyromorphite with pitted reniform surfaces, indistinctly color-zoned in shades of greenish yellow to yellowish green.

Mexico mine

The earliest workings on the Mexico mine levels revealed substantial amounts of "phosphate ground" which was regarded as an indicator of rich primary ore below. Such hopes were never fulfilled. Pyromorphite is still the most abundant lead mineral to be found in the Mexico mine dumps. Characteristic of the locality are small bicolored (orange and green) crystals, most commonly found on the Low Level dumps in Todd Gill. Pyromorphite has also been found on these dumps,

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[3] Thomas and Robert Allan's collection of minerals was bought by Robert Hyde Greg in 1835 and enlarged by the latter's son, Robert Phillips Greg, coauthor, with W. G. Lettsom, of the *Manual of the Mineralogy of Great Britain and Ireland* (1858). The Allan-Greg Collection was bought by the British Museum in 1860 and is now incorporated in the collections of the Natural History Museum, London.

***Table 1*. Chemical classification of vein minerals from the Caldbeck Fells.**

Elements
- Antimony
- Bismuth
- Copper
- Gold
- Silver
- Sulphur

Sulfides Arsenides & Tellurides
- Acanthite
- Arsenopyrite
- Bismuthinite
- Bornite
- *Breithauptite**
- Chalcopyrite
- Chalcosite
- Covellite
- Cubanite
- Digenite
- Djurleite
- Galena
- Hedleyite*
- Ingodite*
- Joseïte-A*
- Joseïte-B*
- Löllingite
- Marcasite
- Molybdenite
- Pyrite
- Pyrrhotite
- Sphalerite
- Stibnite
- *Sylvanite*
- *Tetradymite*

Oxysulfides
- *Kermesite*

Sulfosalts
- Aikinite*
- Berthierite
- Boulangerite*
- Cosalite*
- Fülöppite*
- Jamesonite
- Krupkaite*
- Semseyite
- Tennantite
- Tetrahedrite
- Zinckenite*

Oxides & Hydroxides
- Bismite
- Cassiterite
- Coronadite*
- Cuprite
- Goethite
- Hematite
- Manganite
- 'Psilomelane'
- Pyrolusite
- Quartz
- Romanèchite
- Rutile
- Senarmontite
- Stibiconite
- Tenorite
- Tungstite
- Uraninite

Halides
- Atacamite*
- Chlorargyrite
- Fluorite

Carbonates
- Ankerite
- Aragonite
- Aurichalcite
- Azurite
- Bismutite
- Calcite
- Cerussite
- Dolomite
- Hydrocerussite
- Hydrozincite
- Malachite
- Rosasite*
- *Siderite*
- Smithsonite
- *Strontianite*
- Witherite

Carbonates with Sulfate
- Caledonite
- Leadhillite
- Macphersonite
- Susannite

Carbonates with Halide
- Phosgenite

Silicates
- Chrysocolla
- Dioptase*
- Hemimorphite
- Hisingerite
- Palygorskite
- Planchéite*
- *Rhodonite*
- Tremolite

Alumino-Silicates
- Allophane
- Beryl
- Carpholite*
- Microcline
- Muscovite
- Orthoclase
- *Prehnite*

Boro-Silicates
- Tourmaline group

Silicates with Sulfate
- Mattheddleite
- Queitite*

Tantalates
- Mangano-columbite*

Phosphates
- Beraunite
- Cacoxenite
- Dufrenite
- Libethenite
- *Parahopeite**
- Plumbogummite*
- Pseudomalachite
- Rockbridgeite*
- Strengite*
- Turquoise
- Vivianite

Arsenates
- Adamite*
- Agardite
- Arseniosiderite*
- Bayldonite
- Carminite
- Chenevixite
- Conichalcite
- Cornwallite
- Cornubite
- Duftite*
- Erythrite
- *Kipushite*
- *Liroconite*
- Olivenite
- Pharmacosiderite
- Philipsburgite*
- Schultenite*
- Scorodite
- Symplesite*

Vanadates
- Descloizite
- Mottramite

Phosphates, Arsenates & Vanadates with Other Anions
- Apatite group
- Beudantite
- Chalcophyllite
- Corkite*
- Hedyphane
- *Hidalgoite*
- Hinsdalite*
- Mimetite
- Pitticite
- Pyromorphite
- Tsumebite*
- Tyrolite
- Vanadinite

Antimonates
- Bindheimite

Sulfates & Sulfites
- Alunite
- Anglesite
- Antlerite
- Barite
- Beaverite
- Brochantite
- Cyanotrichite
- Devilline
- Elyite
- Gypsum
- Jarosite*
- Lanarkite
- Langite
- Linarite
- Plumbojarosite*
- Posnjakite
- Scotlandite
- Serpierite*
- Wroewolfeite

Sulfates with Halide
- *Connellite*

Chromates, Tungstates & Molybdates
- *Crocoite*
- Ferrimolybdite
- Hübnerite*
- Lindgrenite*
- Powellite*
- Scheelite
- Stolzite*
- Wolframite
- Wulfenite

Species requiring confirmation are listed in *italics*.
*An asterisk denotes first recorded occurrence in the United Kingdom.

associated with pale smoke-brown plumbogummite or with small plates of wulfenite.

The finest pyromorphite to be found in the Caldbeck Fells in the last few decades was that extracted in the 1970's from an outcrop of the Roughton Gill (South) vein just west of the Mexico mine High level. The original find was made by the late Richard Barstow; further material was dug by later collectors. This occurrence yielded many fine cabinet specimens displaying oil-green prismatic crystals to over 2.5 cm in solid masses or on quartz matrix. Later finds included pale yellow-green prisms to 2 cm or so and emerald-green botryoidal encrustations on matrix. On occasion several habits and colors were found in the same cavity. The locality is now worked out and back-filled.

Roughton Gill mine

The Roughton Gill (South) vein contained one of the most remarkable deposits of pyromorphite on record; so much was collected from part of the 60-fathom level workings that it became known as "the specimen stope." Unfortunately most specimens collected when the mine was working have no details of their precise source within the mine.

The most characteristic material is that exhibiting tapering yellow-green to oil-green prisms (resembling spindles when doubly terminated), either in solid masses or encrusting cavernous quartz; oil-green pyromorphite in association with smalt blue plumbogummite is unique to the locality. Prismatic crystals may reach over 2 cm long but are generally less than 1–1.5 cm. Solid masses to 15–20 cm across are known in collections but it probably occurred in much larger masses in the vein. Stalactites are rare (only 19th-century specimens are known to the authors) and may be very attractive when coated with sparkling crystal faces. The full range of color encompasses shades of green (from oil-green to emerald), yellow, gray, white, brown and orange.

The most common associate is quartz and the most characteristic (and highly prized) is plumbogummite, particularly when the latter is of a deep blue shade. Rarely, small pyromorphite crystals are seen embedded in crusts of blue botryoidal hemimorphite and very rarely pyromorphite is found associated with small rounded mottramite crys-

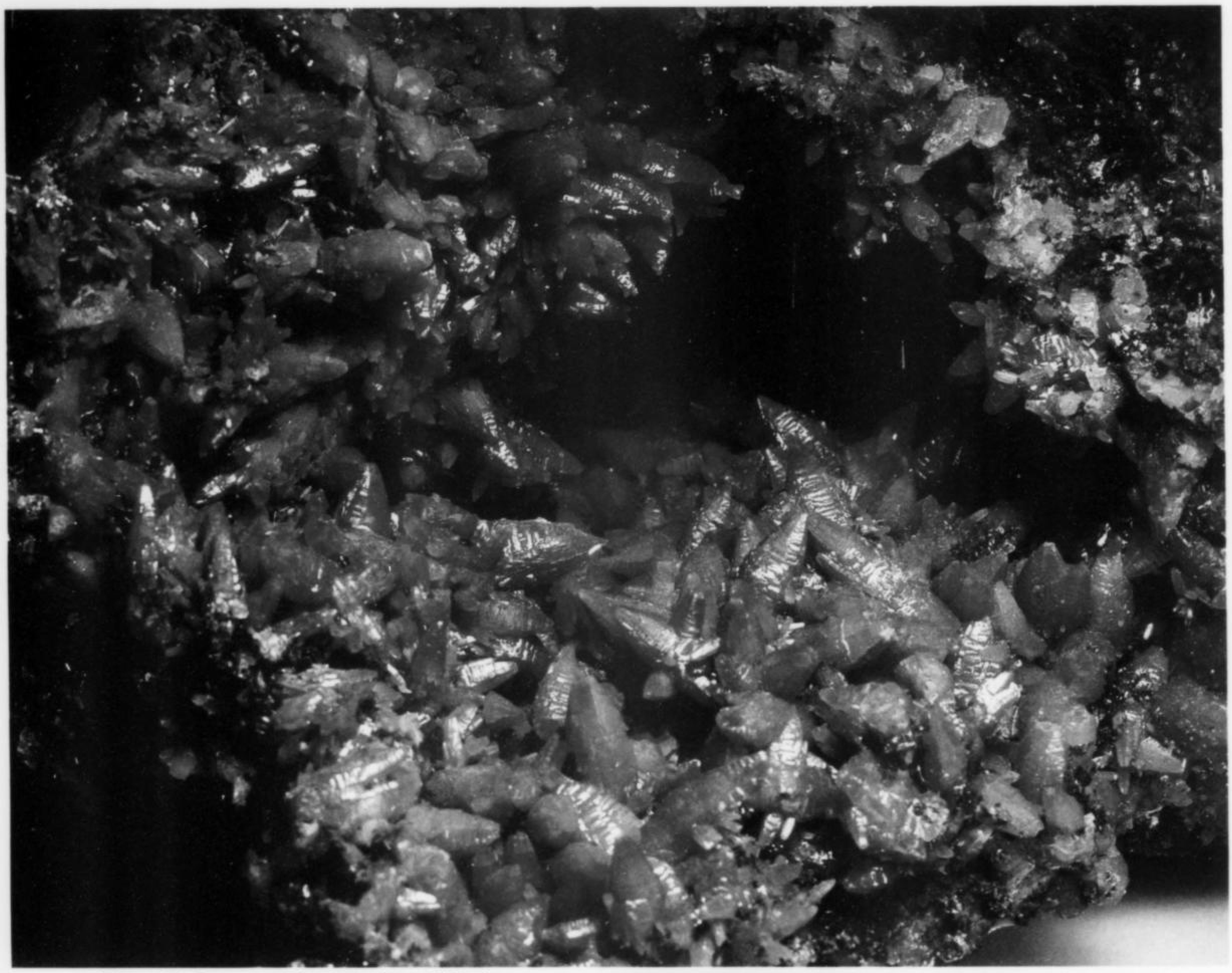

Figure 21. **Pyromorphite, Roughton Gill mine. A unique specimen, obtained through exchange by Cornish dealer Richard Barstow as a presumed solid mass; judicious splitting revealed this 9-cm cavity lined with tapering oil-green crystals to 1.5 cm. Ralph Sutcliffe collection. Photo: MPC.**

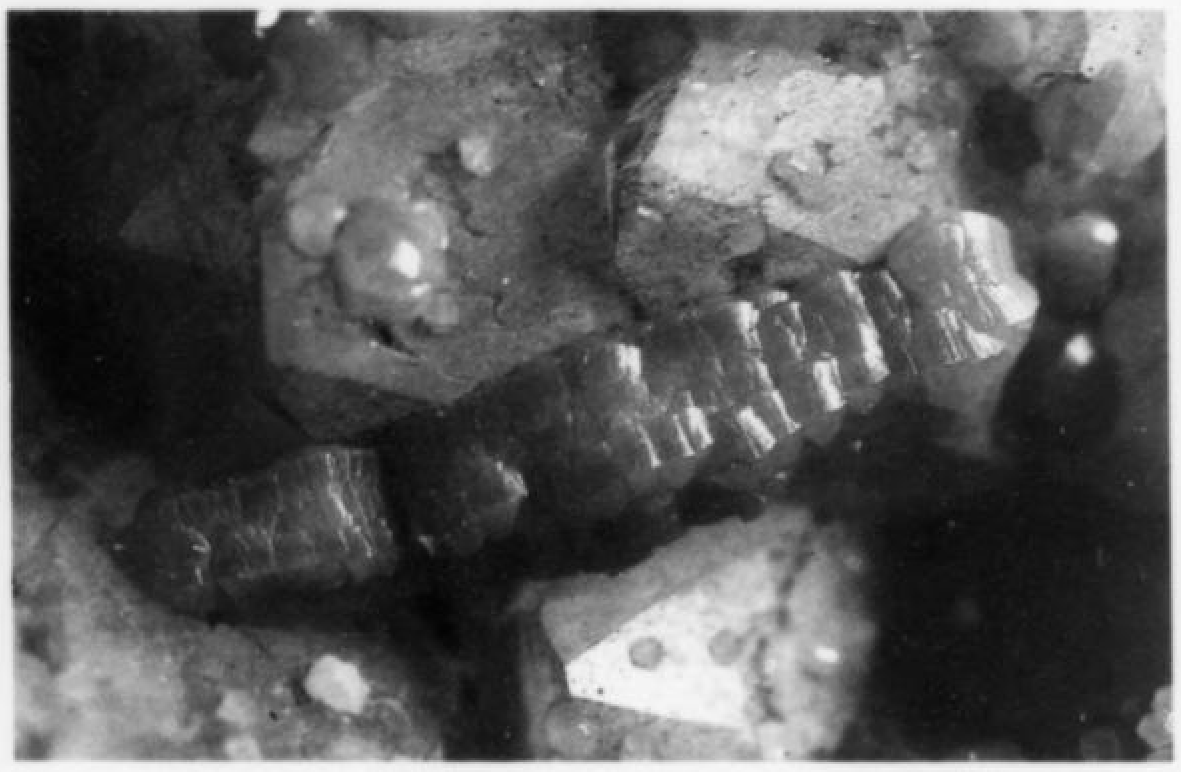

Figure 22. **Pyromorphite-mimetite, Caldbeck Fells. A 12-mm crystal with typical complex overgrowths on an old and—as is so often the case—unlocalized specimen. Department of Geology, Leeds University (LU 41722/1).**

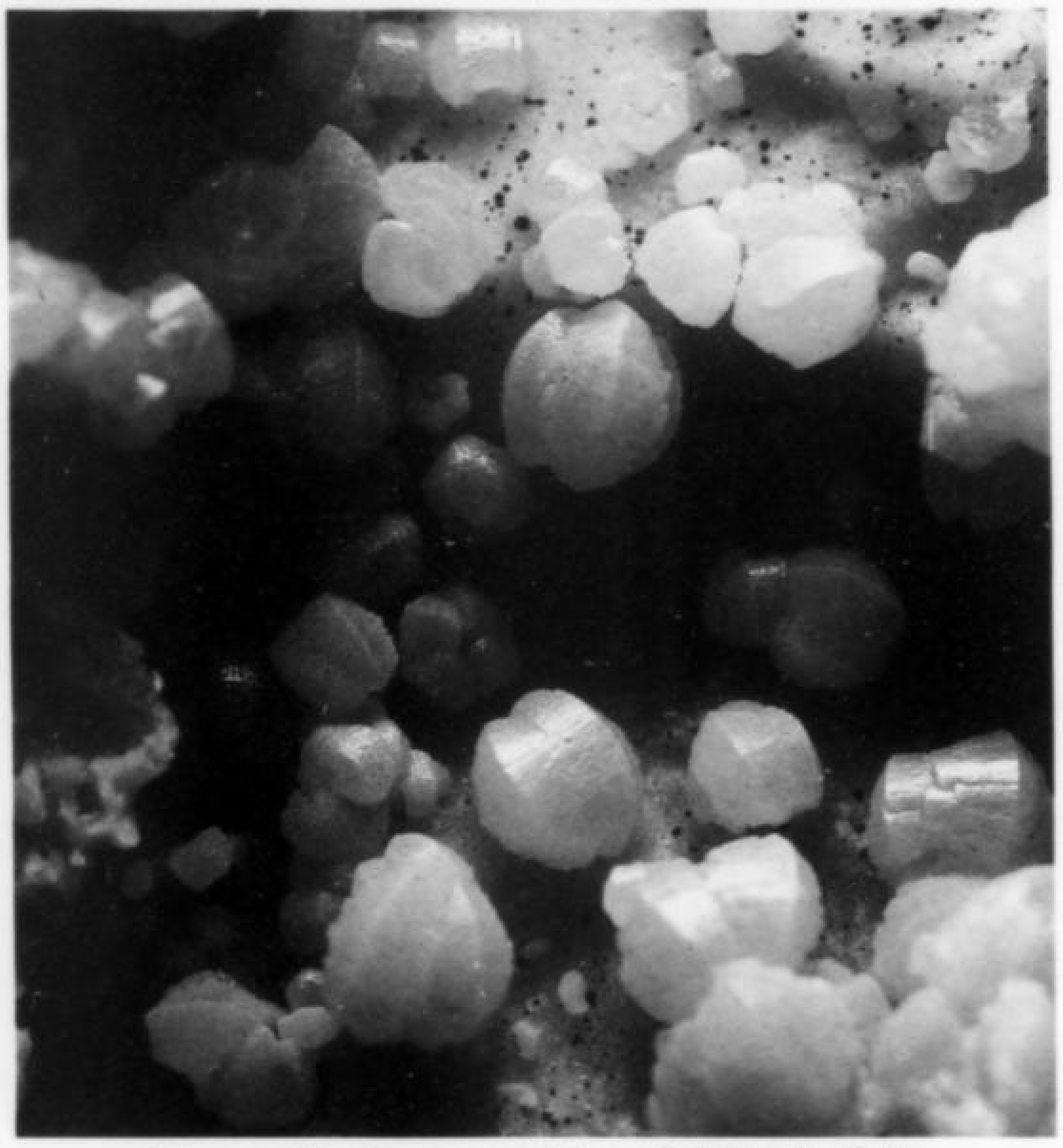

Figure 23. **Pyromorphite, Caldbeck Fells. Rounded crystals to 2 mm on cavernous quartz. Collected in the mid 19th century. M. P. Cooper collection (72–35) and photo.**

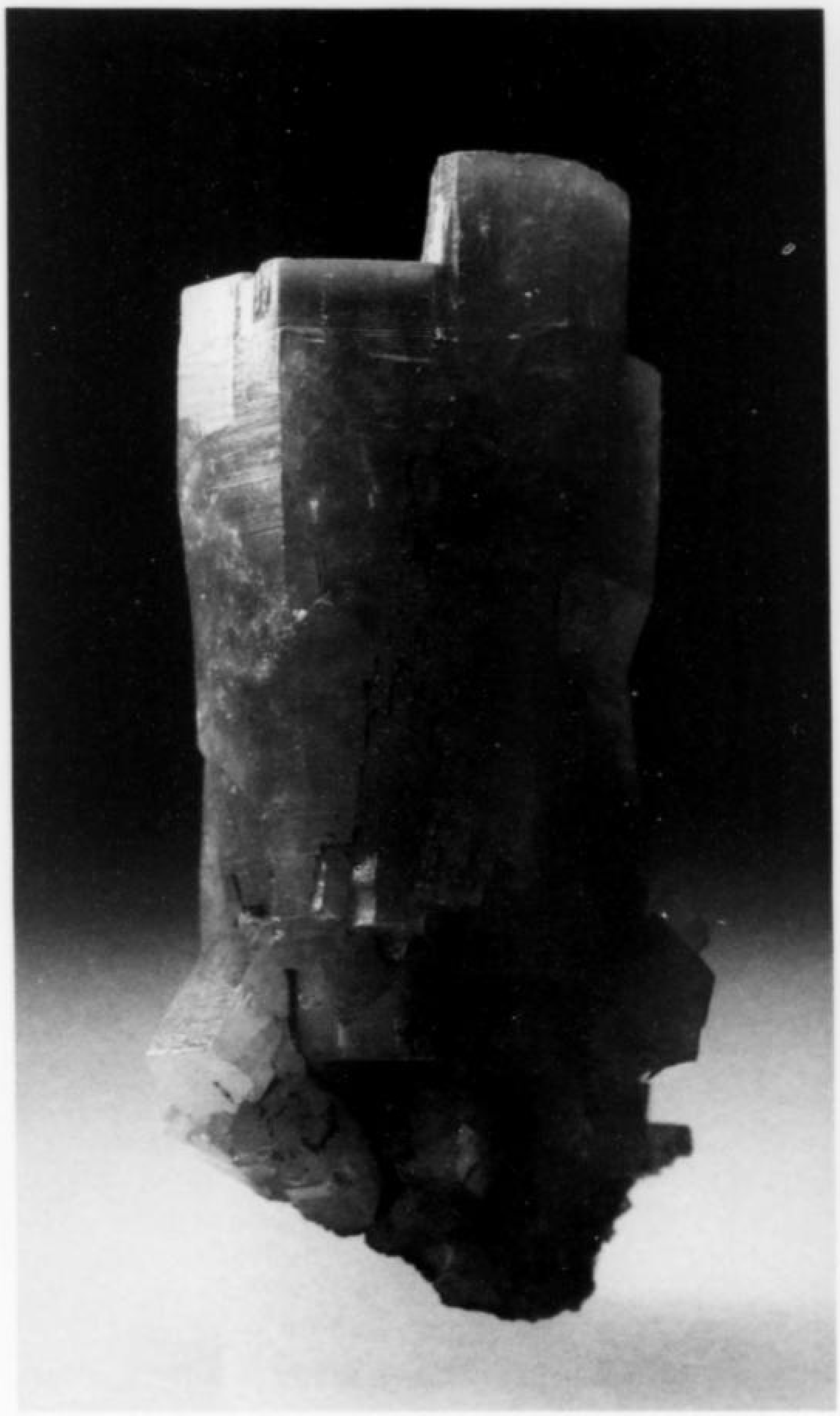

Figure 24. Pyromorphite, Mexico mine. A 27-mm-long prism from an outcrop near the High Level. J. G. Wilson collection.

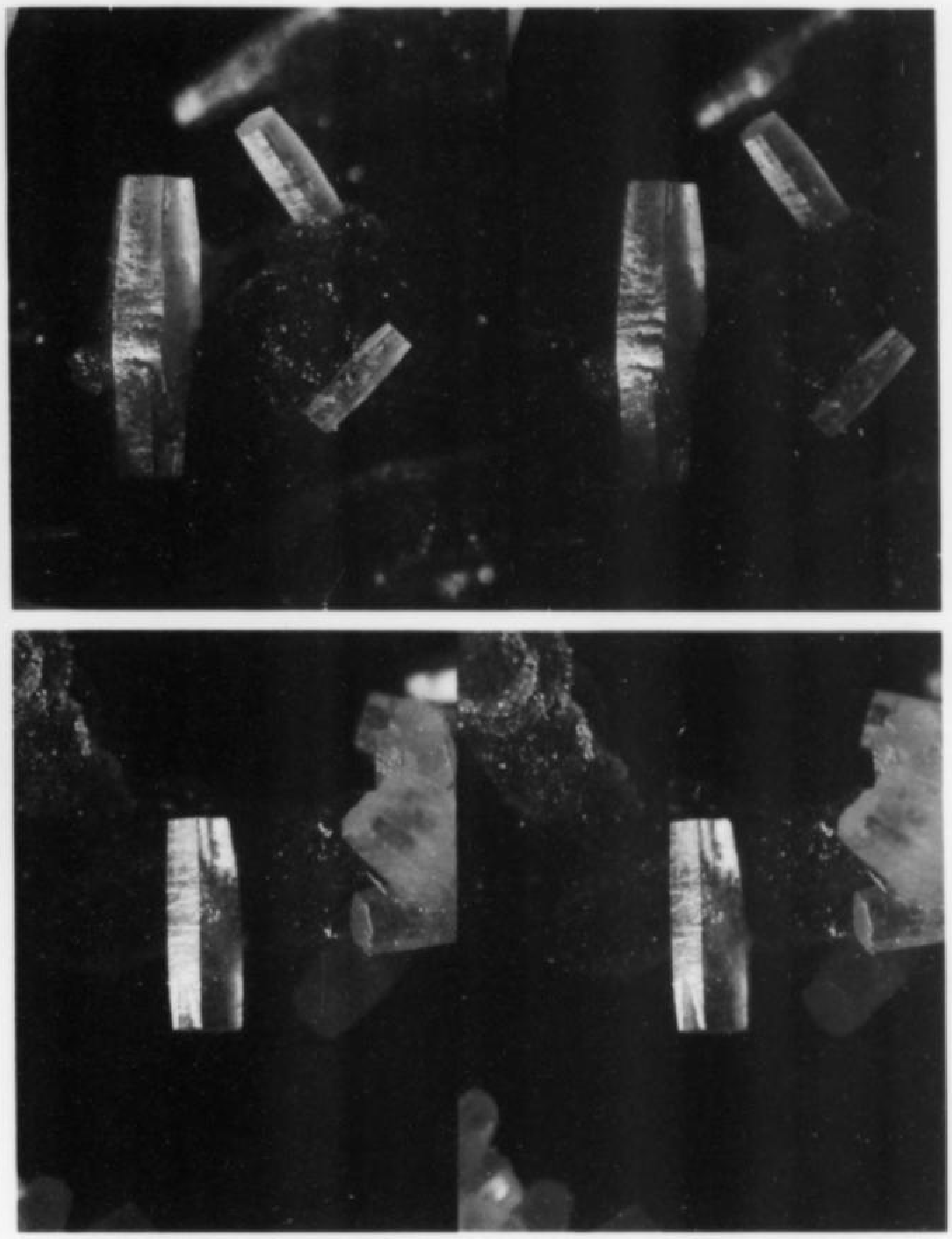

Figure 25. Pyromorphite crystals to 2 mm on minutely drusy plumbogummite, Roughton Gill mine. Collected by Bob King from the main dumps in 1947. King collection, National Museum of Wales, Cardiff (NMW 83.41G.M7818/K256) [stereo pairs].

Figure 26. Pyromorphite, Roughton Gill mine. A solid mass of bright yellow-green crystals to 2 cm; part of one of the finest known specimens from the mine. Ralph Sutcliffe collection. Photo: MPC.

Figure 27. Plumbogummite epimorphs after pyromorphite, Roughton Gill mine. The "dumb-bell" crystals of pyromorphite are up to 3 mm long, and coated with plumbogummite. The exaggerated terminations of the pyromorphite crystals seem to have been more thoroughly altered than the body of the prisms. M. P. Cooper collection and photo.

tals. Pseudomorphs of pyromorphite after cerussite have been found and, in turn, plumbogummite forms epimorphs after small prisms of pyromorphite. The latter were first described by Blum (1843) as hemimorphite (*keisel-zinc*) pseudomorphs after pyromorphite—a very common nineteenth-century error.

As with most occurrences of minerals in the Caldbeck Fells, the finest specimens were found in the 19th century. When the mines declined, the supply of fine pyromorphite rapidly tailed off; as early as 1875 the dealer Bryce M. Wright, Jr. lamented that pyromorphite, once "the most common of Cumberland minerals [was] now very scarce" (Wright *in* Jenkinson, 1875). Nevertheless, even as recently as the 1940's and 1950's, fine specimens could still be collected from the dumps; one can only surmise the quantity of specimen-grade material available 100 years previously! In the last 50 years the thorough working over of the sites by dealers and collectors has stripped away almost all of the cabinet-quality material to be found in the old dumps.

Vanadinite $Pb_5(VO_4)_3Cl$

Vanadinite is extremely rare in the district and known almost exclusively from specimens reported by Arthur Kingsbury (Kingsbury and Hartley, 1956; Hartley, 1984; Kingsbury Collection, NHM), the one exception being a specimen collected by T. Wolloxall from Brandy Gill Lead mine. In all these occurrences vanadinite is visually indistinguishable from mimetite.

Brandy Gill Lead mine

Kingsbury and Hartley (1956) reported vanadinite as cream to gray-colored, short-prismatic to globular crystals and masses with mottramite or descloizite. On the only other specimen known it occurs as cream-colored radiating crystals on iron-stained quartz (Cooper and Stanley, 1990).

Carrock mine

Specimens in the Kingsbury Collection (NHM) show small short-prismatic crystals, zoned pale brown and cream, on a compact fine-grained reddish rock, remarkably similar to some material from Hillsboro, New Mexico.

Ingray Gill

Vanadinite from Ingray Gill is listed in a manuscript note by Kingsbury (Dept. of Mineralogy, NHM), but no specimens are known.

Old Potts Gill mine

Kingsbury's specimens of vanadinite from the Old Potts Gill mine show small brown prisms on quartz (Kingsbury and Hartley, 1956).

COLLECTING

Modern field collectors in the Caldbeck Fells area must, in most instances, content themselves with small and relatively insignificant specimens of the species for which the area has been a classic source. However, some of these species can still be found as beautiful micromount-quality specimens. Good cabinet specimens of pyromorphite from the Mexico mine and "campylite" and plumbogummite from Dry Gill were found *in situ* in the 1970's and early 1980's. The area is also known for its variety of rare and exotic species, several of which have been found relatively recently for the first time in otherwise almost barren dump material. In some cases these species have been found on only a few specimens. Examples of species (other than mattheddleite) recently found here in but their second or third world localities include macphersonite (Cooper *et al.*, 1988); philipsburgite (Braithwaite and Ryback, 1988; Young *et al.*, 1990); scotlandite (Green, 1989); and queitite (Braithwaite *et al.*, 1989).

The Caldbeck Fells have belonged, since 1976, to the Lake District Special Planning Board (LDSPB), the planning authority for all the land within the Lake District National Park. The LDSPB carefully monitors visitor activity within the district and has laid down guidelines for mineral collectors. These may be summarized as follows:

1. Vehicular access is restricted.
2. Collecting is restricted to the old dumps.
3. Collecting should be done with restraint; worked areas should be restored as much as possible by backfilling holes and replacing any disturbed vegetation.
4. Commercial collecting is not allowed.
5. Entry into the underground workings, where this is possible, is banned.

The story of Caldbeck Fells' mining and mineralization is by no means complete and it is certain that new information will continue to come to light. The authors would be grateful to hear of any further discoveries made by mining historians, collectors and mineralogists, whether in the field or in existing collections and archives. Information on notable specimens of any Caldbeck Fells minerals, especially those in foreign collections unknown to the authors, is always welcome.

ACKNOWLEDGMENTS

This article has been derived from information and photographs collected by the authors for their recently completed book, *Minerals of the English Lake District: Caldbeck Fells,* and gives us opportunity to use a further selection of specimen pictures. Our book started life as a proposed article on the district for the *Mineralogical Record* but rapidly outgrew its modest intentions (and schedule). Many private and public mineral collections and archives were examined during our research; their collectors and curators in all cases were most helpful and informative. Our thanks to them all and especially to the following who were of particular assistance in the narrower confines of the present article: Peter G. Embrey, the late John Fuller, Bob F. Symes, Peter Tandy and Alan D. Hart of the Department of Mineralogy, Natural History Museum, London; Brian Atkins and Monica Price of the University Museum, Oxford; Bob J. King, Richard Bevins, and Jana Horák of the National Museum of Wales, Cardiff; and David Clarke of the Tullie House Museum, Carlisle. The private collectors David R. Hacker, David R. Middleton, Ralph Sutcliffe and J. George Wilson were especially generous. Analytical work was carried out for the authors by John G. Francis and Alan Hart both of the Natural History Museum, London; by David I. Green of Leeds University; by Mike Rothwell of Unilever Research, Liverpool; and by Richard S. W. Braithwaite of UMIST, Manchester. John Adams' assistance with aspects of the mining history was invaluable. We thank Alan Criddle and Paul Henderson for their comments on the typescript.

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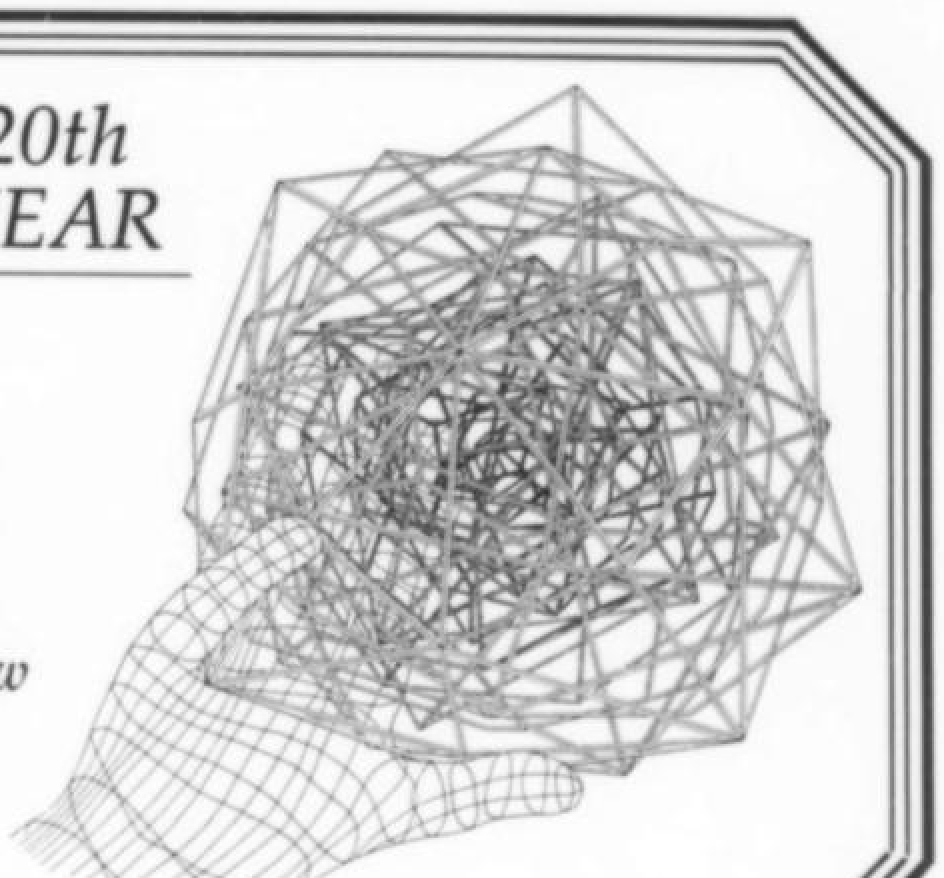


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THE MINERALOGICAL RECORD

The State of the Science:

SCANNING ELECTRON MICROSCOPY

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Since the first instrument was constructed in 1938, the scanning electron microscope has opened up a new world to scientists in general. However, the instrument has proved especially useful to the mineralogist, who can now photograph microcrystals and other mineralogical phenomena with unprecedented clarity and depth of field over a wide range of magnifications.

INTRODUCTION

Since the first instrument came onto the market in the mid-1960's, use of the scanning electron microscope (SEM) in materials-characterization laboratories has grown at an enormous rate around the world. Its application to mineralogy has proved particularly useful, and it has become one of the main tools involved in the discovery and description of new mineral species.

In principle, the SEM is analogous to the reflected-light microscope, but differs in that it uses a beam of electrons instead of visible light for image formation. In addition, the much shorter wavelength of electrons compared to that of visible light enables a much higher resolution to be achieved than can be obtained with the optical microscope, which in turn permits much higher magnifications without loss of detail.

One of the main attractions of the SEM is its ability to maintain focus across a field of view regardless of surface roughness. This extraordinary "depth of field" makes the instrument ideally suited to the direct observation of rough surfaces and mineral specimens in particular. In fact, one of the surprising aspects of the SEM is the ease with which photos taken of three-dimensional objects can be interpreted by newcomers to the field of microscopy, even the layman unfamiliar with the instrument itself. The addition of X-ray microanalytical facilities adds to the versatility of the instrument, and a properly run SEM can provide a wealth of information on a wide range of materials. As a result, papers and articles using the results of SEM studies are now widely dispersed throughout both the scientific and popular literature.

Such is the popularity of the SEM that there are presently at least nine manufacturers competing in the marketplace.

HISTORY

Investigations into the usefulness of the interaction of an electron beam with a specimen surface to provide high-resolution images began in the late 1920's (Postek *et al.*, 1980), eventually leading to the development of a whole family of electron beam instruments, including the transmission electron microscope (TEM) and the electron microprobe. However, although the operation of a scanning-type electron microscope was envisioned as early as 1929, and the first instrument was built by von Ardenne in 1938 (von Ardenne, 1938), it wasn't until 1965 that the scanning electron microscope became available commercially, well after the first TEM. Since then, significant improvements in instrument design have enabled higher resolution and greater dependability. Present-day design improvements are being directed towards a greater degree of computer control of microscope functions, so that future instruments will become even easier to use. The history of SEM development is covered more thoroughly in Wells (1974).

PRINCIPLE OF OPERATION

A schematic outline of the components of a typical SEM is shown in Figure 2.

The conventional source of electrons is a cathode in the form of a heated tungsten hairpin filament located at the top of the column of the instrument. Tungsten filaments are popular because of their ability to operate under less than ultrahigh vacuum. They are also inexpensive and easy to exchange. Non-conventional electron sources include field emission (FE) and lanthanum hexaboride (LaB_6) guns, both of which provide brighter images as well as advantages for high-resolution imaging due to the smaller beam diameters produced. However these

Figure 1. **An example of a modern scanning electron microscope. The Philips SEM505 installed at the Newcastle Laboratories of Broken Hill Proprietary Co. Ltd. Research Division. Photo by Murray McKean of the Newcastle Laboratories Photography Group.**

non-conventional sources are more expensive and require an elaborate vacuum system.

A voltage applied to a metal shield (called a Wehnelt cylinder) enclosing the filament narrows the electrons into a beam, which is then drawn toward an anode held at a high voltage difference with respect to the electron-emitting cathode. This *accelerating voltage* is usually continually variable between about 0.5 and 50 kilovolts, depending on the make of instrument, so that the number of electrons drawn from the cathode can be varied. After passing through the anode aperture, the electron beam passes down the column towards the specimen. In effect this *electron gun* assembly acts as an electrostatic lens in producing the imaging beam.

Electromagnetic lenses located within the column are used to focus the electron beam in much the same way as glass lenses are used in an optical microscope, and the terminology used in both technologies is similar. A *condenser lens* system is used to focus the electron beam into a very fine spot which is then electromagnetically scanned across the specimen surface by coils mounted in the microscope column (hence the name "scanning" electron microscope). An *objective lens* is used to defocus this narrow electron beam onto the sample surface to provide a range of spot sizes. Signals produced by interaction of the electron beam with the specimen are collected by various detectors arranged around the specimen chamber at the bottom of the instrument column.

Unlike either the optical microscope or the TEM, there is no actual image formed within the microscope column itself. Details of signal intensity received by the detectors are used to electronically adjust the brightness of the spot on a cathode ray tube (CRT) used to display a television-like image of the specimen. The spot creating the CRT image scans exactly the same pattern and is precisely synchronized with the electron beam spot scanning the specimen. Thus the formation of an SEM image actually consists of constructing a map of signal "brightness" on the CRT (Fig. 3) (Goldstein *et al.*, 1981).

Magnification is achieved by varying the size of the area scanned, and thus also the scale of the signal brightness map on the CRT. For example, in Figure 3, if the variation in signal brightness along line "l" on the specimen is mapped along length "L" on the CRT, the magnification is equal to the simple relationship L/l. Since the CRT scan length is fixed at between 10 and 20 cm (i.e., the longest side of the phosphor-coated tube), increase in magnification is achieved simply by decreasing the length "l" on the side of the area scanned by the electron beam on the sample surface.

In a normal SEM the entire electron column, including the electron gun at the top and the specimen chamber at the base, is kept under high vacuum (at least 1 millipascal) during operation. Hence, unless a specially designed cold stage has been fitted to the instrument, specimens placed within the chamber must be dry and free from any volatiles which may evaporate under the heating effect of electron bombardment. Low-melting-point or highly volatile materials, such as elemental sulfur, mercury, bromine compounds and oils, are avoided because of the risk of contaminating the electron column. Contamination may lead to loss of resolution, vacuum problems and the production of spurious element peaks in the X-ray spectra.

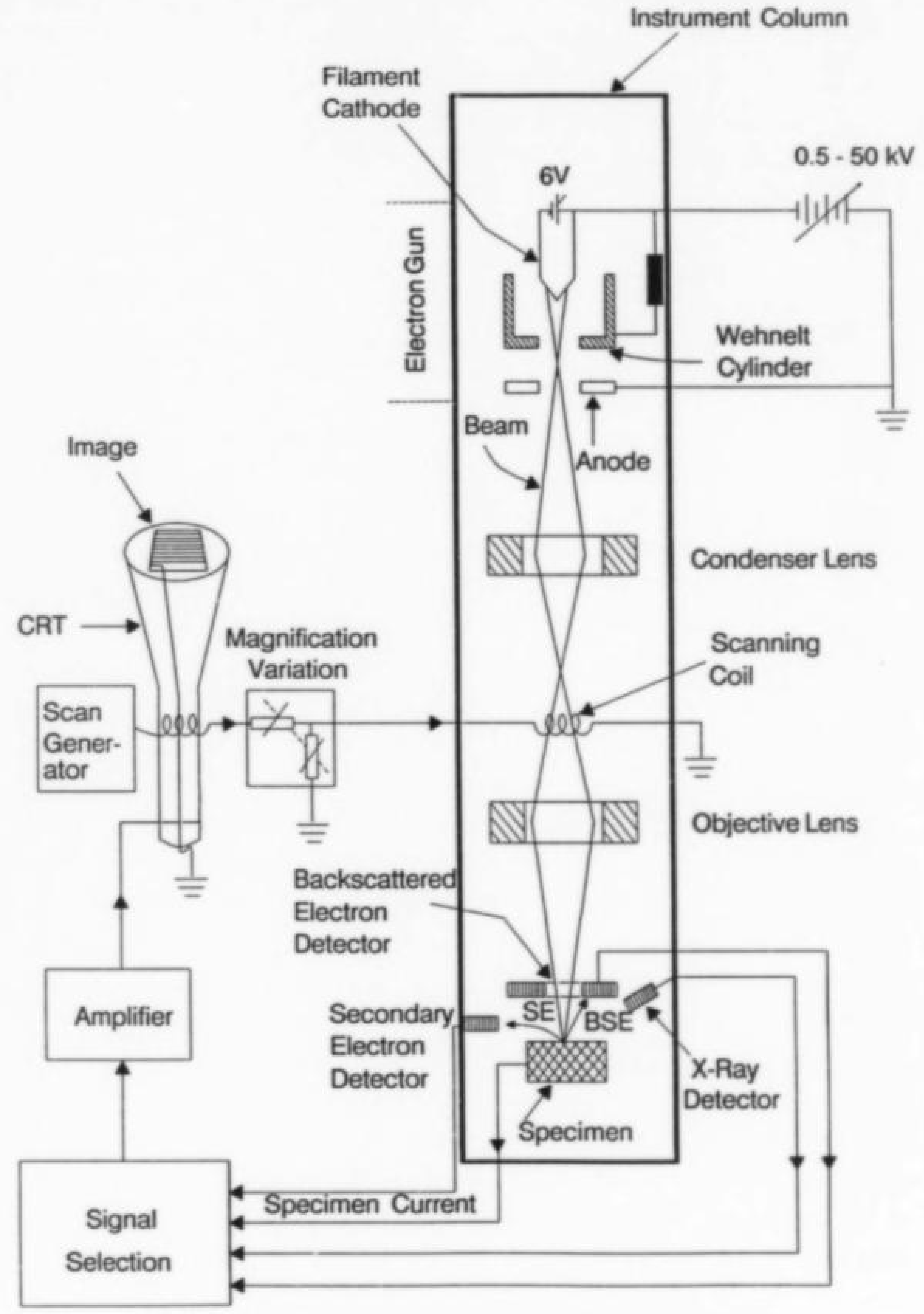


Figure 2. **Schematic outline of SEM construction. Modified from Brinkies (1984).**

New developments in SEM design include modifications to the sample chamber and vacuum system to enable "environmental cell" operation (Robinson and Nickel, 1979), and more recently the construction of an atmospheric or "environmental" SEM (ESEM) (Danilatos, 1986). Both allow specimens to be examined wet or unprepared under very-low-vacuum conditions (although in the former only the backscattered electrons can be used for imaging).

RESOLVING POWER and DEPTH OF FIELD

Resolution is defined as the ability to distinguish two adjacent image points as separate points, and is often expressed numerically by the distance separating the two points. This is more correctly termed the minimum resolved distance (MRD), which can be expressed mathematically by the Abbe formula:

$$\text{MRD} = \frac{\lambda}{2\text{NA}}$$

Where λ = wavelength of the illumination used to form the image (this is around 0.005 nanometers for an electron beam) and NA = the "Numerical Aperture" of the electron optical system. The term Numerical Aperture is used to quantitatively define the angular aperture or light collecting properties of a lens and is represented by the equation:

$$\text{NA} = n(\sin\alpha)$$

Where n = the refractive index of the medium between the lens and the specimen and α = half the intake angle of the lens. In the case of both optical and electron microscopes the value of n is assumed to be one.

In the light microscope the numerical aperture of the lens systems is the most important factor determining resolution and image quality, and from the Abbe formula it is seen that the NA should be as large as possible in order to keep the MRD value small. In light-microscope objective lenses, NA values of up to 1.4 are attainable (with oil immersion systems). However the inability to correct electromagnetic lenses for spherical aberration seriously limits their effective diameter

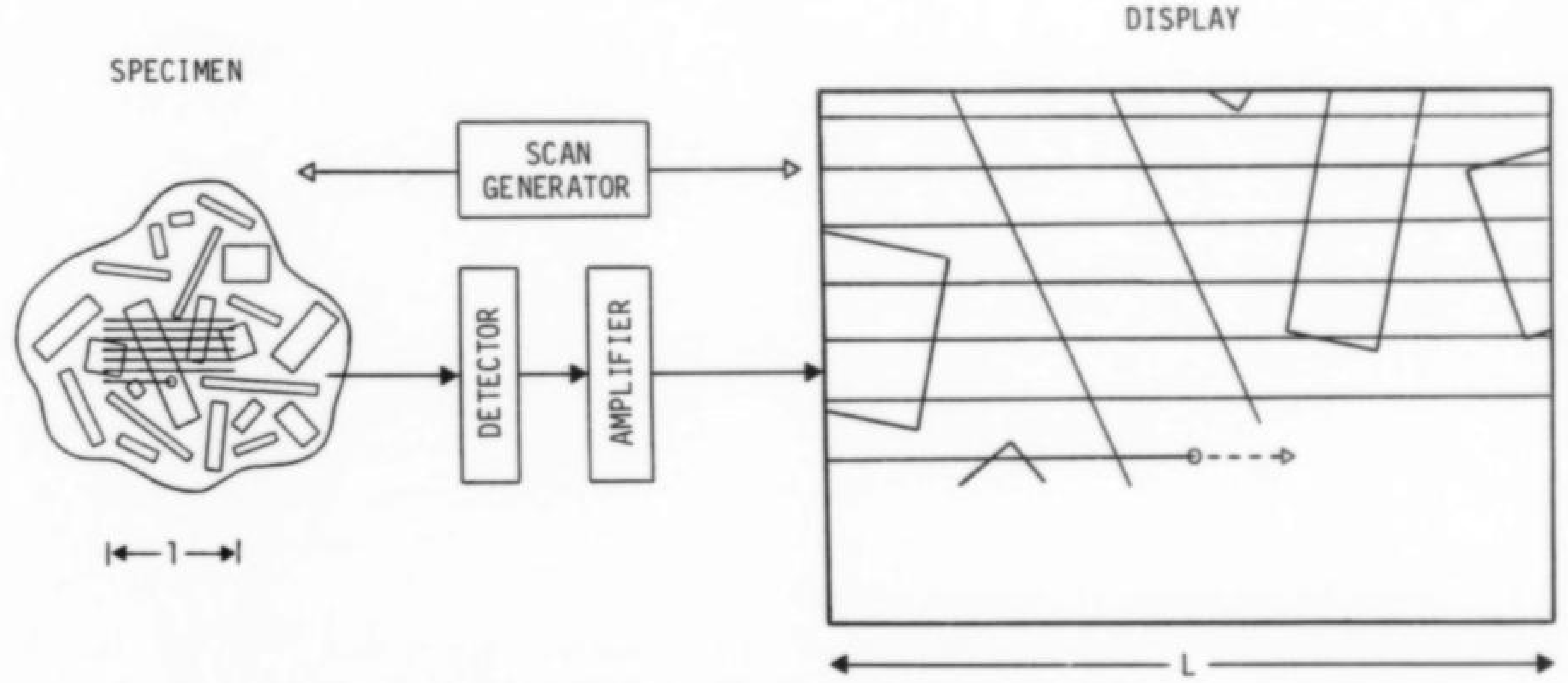


Figure 3. **Image formation and magnification in the SEM.**

so that α is extremely small, resulting in NA values as low as 0.0025 (Oldfield, 1986). However, despite these low NA values, resolutions calculated from the Abbe equation for electron microscopes may be as high as 0.21 nanometers (0.21×10^{-9} meters) (Postek *et al.*, 1980). Hence electron microscopes in general owe their very great resolving power to the extremely small wavelength of electrons.

In the SEM the resolution obtained is principally dependent on the diameter of the electron beam at the sample surface (spot size) as well as the distance between the final aperture, just below the objective lens, and the sample surface (working distance). Spot size is normally variable over a wide range (typically 4 to 1000 nanometers), depending on the make of instrument. Most instruments also allow some variation in the working distance. High resolution requires the selection of the smallest spot size practicable and the shortest possible working distance. However, in reducing spot size a point is reached where there must be a trade-off between increased resolution and deteriorating signal-to-noise ratio, due to a decreased number of electrons reaching the sample.

Resolution values of around 5 nanometers are normally obtainable with modern SEMs, although resolutions as high as 0.8 nanometers are available on some makes in which significant design modifications have been made. In these instruments, the working distance has been effectively reduced to zero by placing the specimen within the final lens. However, the resolution of the SEM is still low compared to values of about 0.35 nanometers or less attained by the TEM.

The depth of field obtained in SEM images is very much greater than is possible with light microscopes. Here the principle is the same as that observed in the 35 mm camera, where the smaller the aperture of the lens the greater the depth of field. The diameter of the final aperture at the base of the electron column in the SEM is typically around 200 micrometers (200×10^{-6} meters) or less, so that the primary electron beam striking the specimen is in the form of a nearly parallel, very fine cone of electrons. Depending on the final aperture and working distance used, the resulting depth of field may vary from several centimeters at around 10X to about 1 micrometer at 100,000X.

MAGNIFICATION

Continually variable magnifications of from 10X or less to around 200,000X are available on most commercial SEMs, although some specialized models offer up to 800,000X. However, for most mineralogical applications, magnifications of more than a few thousand times are rarely necessary.

Magnification is calibrated against diffraction gratings of known spacing, and a readout (in the form of a calibrated scale bar and/or numeric value) can be displayed on both the viewing screen and on the margin of photomicrographs.

ELECTRON-SPECIMEN INTERACTIONS

When an electron beam strikes the surface of a specimen a number of interactions occur, providing at least five signal types which can be detected and used in mineralogical investigations (Fig. 4). Each of these signal types is described in detail below. The relative depths at which the various signals are derived from within a specimen are shown in Figure 5.

Secondary Electrons

Secondary electrons (SE) are very-low-energy electrons (less than 50 electron volts) ejected from the surface of the specimen. They are generated by ionization of atoms in the specimen surface and, because of their relatively low energies, can only be emitted from a depth of less than 10 nanometers within the specimen. This decreases for materials with higher average atomic number (Z), such as metals. Because of their small exit depth it is the secondary electron emissions which provide the sharpest images of rough specimen surfaces.

Contrast is provided by the greater probability of SE generation with increasing path length of incident electrons in the surface layer of the specimen. Hence those surfaces which are more steeply inclined to the incident electron beam will produce higher SE emissions and brighter image areas. For the same reason, significantly greater overall SE emission can be achieved with higher specimen tilt angles. SE emission also tends to increase with increasing atomic number, since the contribution of backscattered electrons in generating secondary electrons in the surface layer becomes increasingly significant in higher atomic number materials.

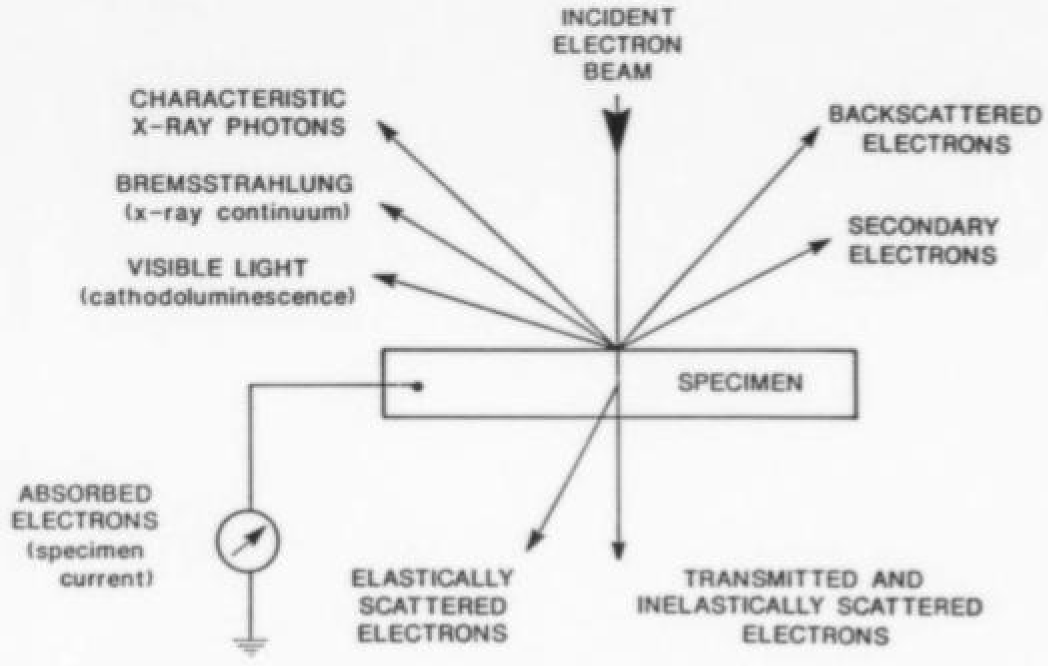


***Figure 4.* Signal types generated by electron-specimen interactions.**

Secondary electrons are usually detected using a collector-scintillator-lightpipe-photomultiplier system (Everhart and Thornley, 1960; Gabriel, 1985). The scintillator is held at a voltage of several kilovolts, while a positive bias of up to several hundred volts applied to a metal grid known as a Faraday cage (or collector) enveloping the scintillator attracts the low energy SE from the specimen towards the detector, without influencing the higher energy backscattered electrons (BSE). When these accelerated electrons strike the scintillator surface, very small flashes of light (photons) are produced. These photons are fed via the lightpipe to the photomultiplier where they are converted to an electrical signal which is then processed and amplified to produce an SE image on the display screen.

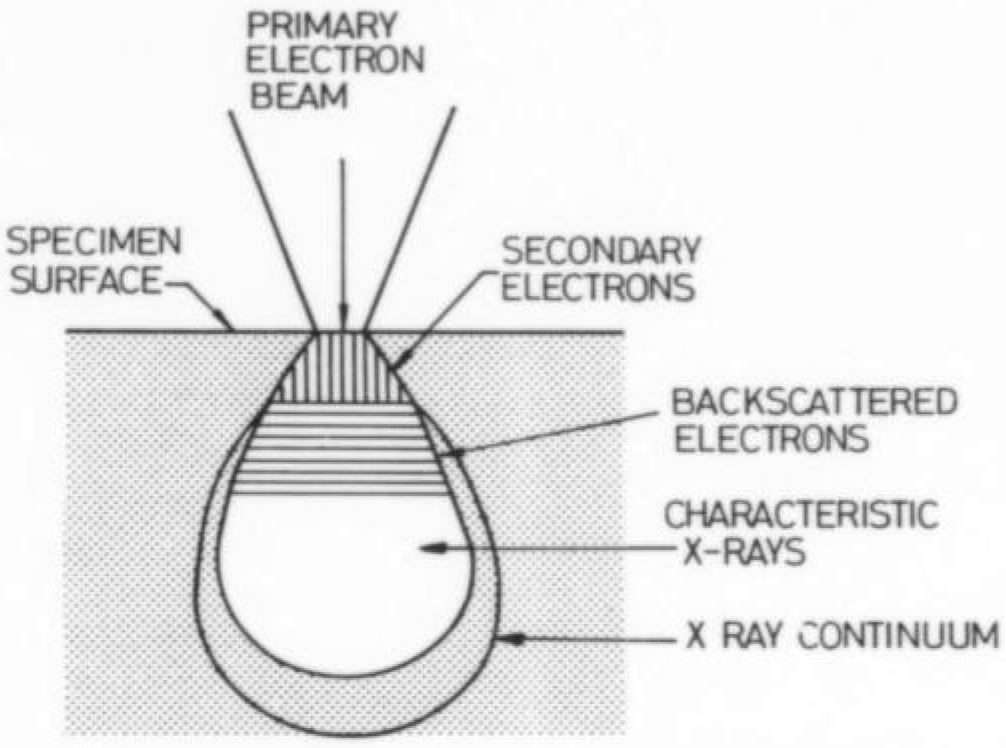


***Figure 5.* Schematic illustration showing the volume within a specimen from which the various signal types originate.**

By reducing the bias voltage on the collector, only high-energy SE are able to reach the scintillator, and fewer electrons are collected. These electrons tend to originate from those parts of the sample facing the detector. The low collector voltage SE (LCV-SE) image produced represents the energy range between normal SE and BSE and is orientation dependent. This results in very useful contrast effects, quite

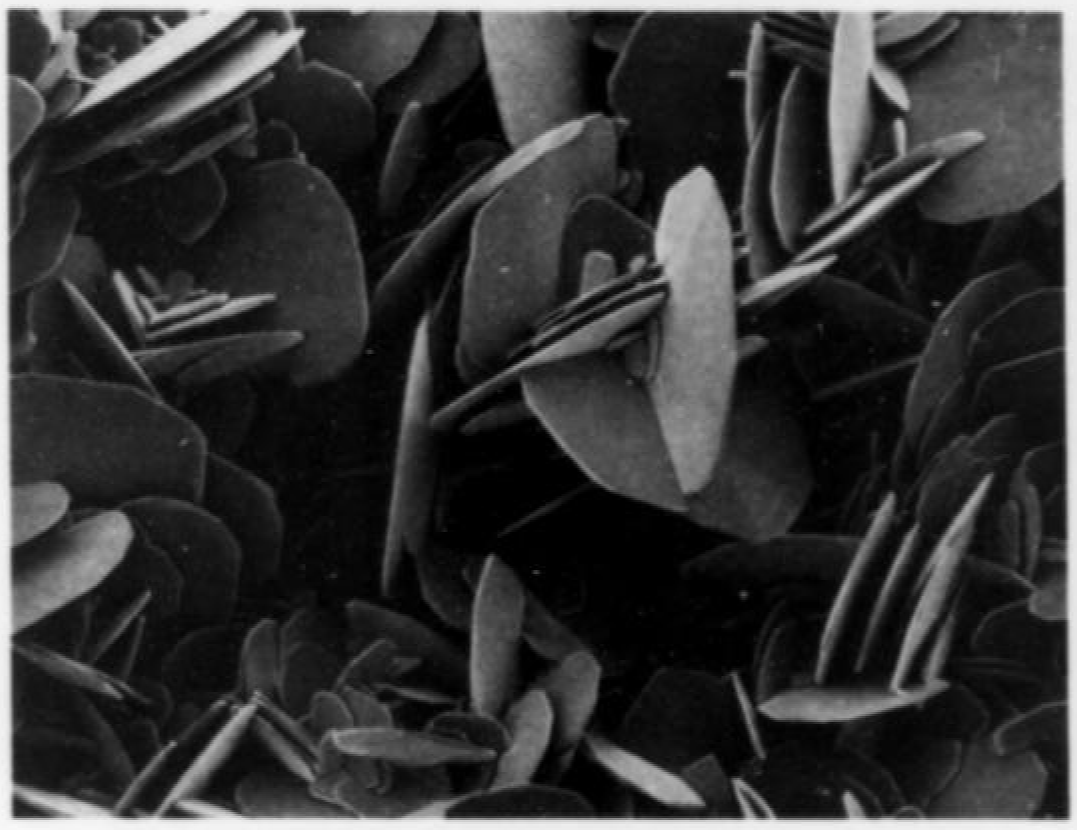


Figure 6. Crystallized hematite lining a syneresis fissure in dense hematite ore from Mount Newman, Western Australia. Secondary electron image. Field of view is 0.5 mm across. Author's specimen and micrograph.

Figure 7. Crystals of ulrichite on quartz from the Lake Boga granite quarry, Victoria. Secondary electron image. Field of view is 0.5 mm across. Author's specimen and micrograph.

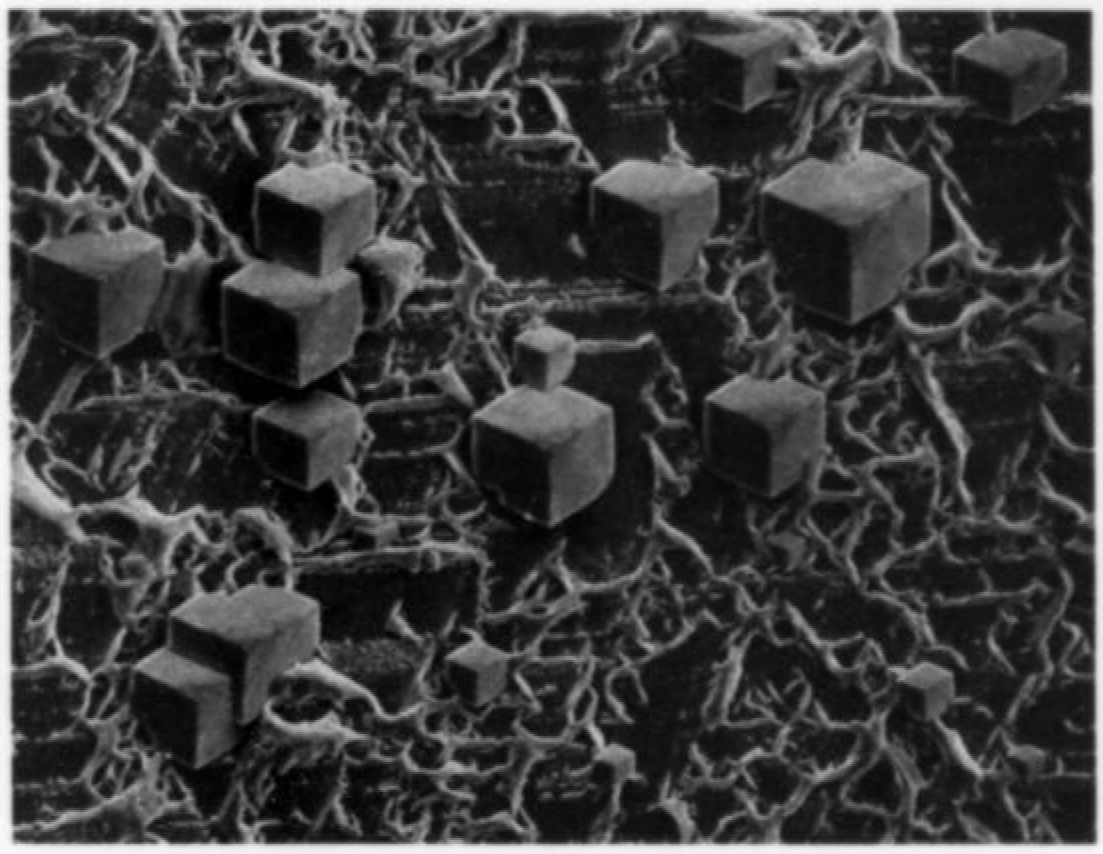


Figure 8. Trigonal growth hillocks and calcite rhombohedra in parallel growth on the *c*{0001} face of a thin platy calcite crystal from an outcrop of latite near Unanderra, New South Wales. Secondary electron image. Field of view is 0.2 mm across. Author's specimen and micrograph.

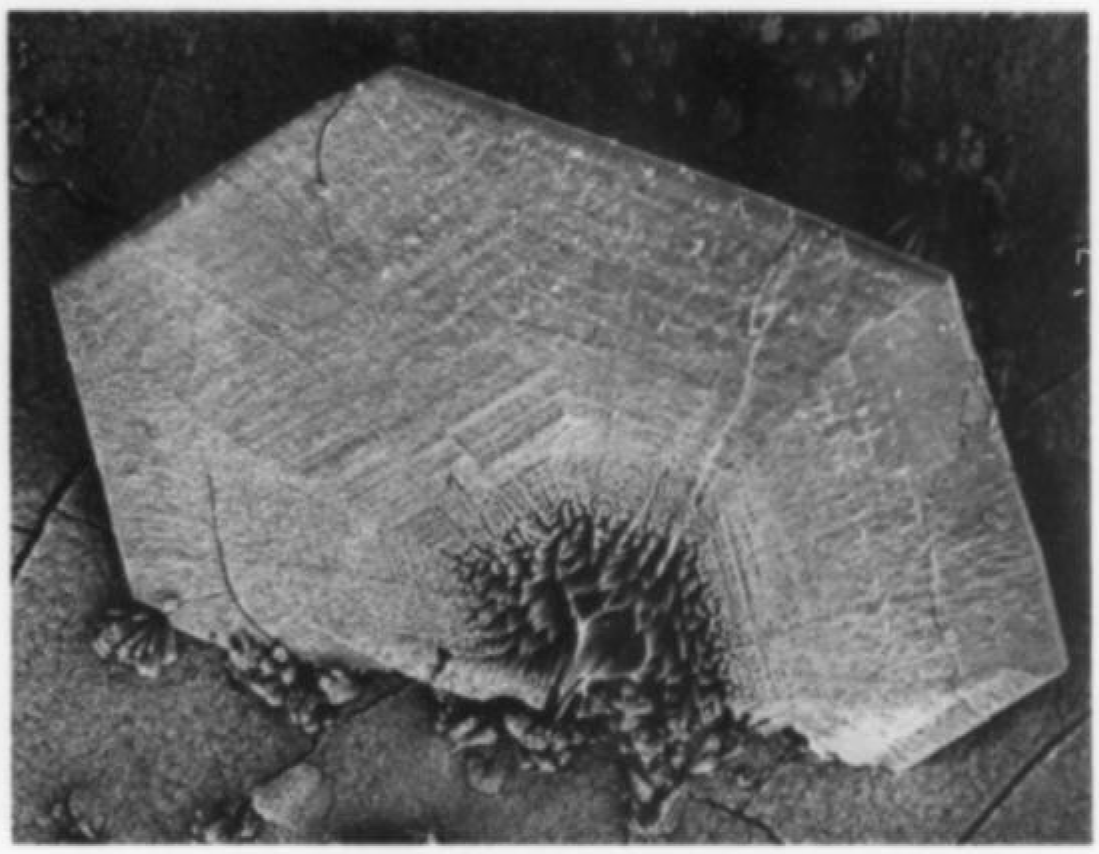


Figure 9. Offretite overgrowth on a levyne crystal from Willy Wally Gully, near Merriwa, New South Wales. Secondary electron image. Field of view is 1 mm across. Author's specimen and micrograph.

different from the normal SE image (Antonovsky, 1984).

The ability of SE imaging to produce superb, sharply defined micrographs of rough surfaces is well known and most of the SEM photos of microminerals published in the mineralogical literature have been photographed in this mode. Examples of SE images from a variety of mineralogical subjects are shown in Figures 6 through 12.

Backscattered Electrons

Backscattered electrons (BSE) are primary beam electrons backscattered from the specimen (Fig. 13) with an average energy of approximately 80% of the primary beam energy. These electrons may result from interactions comparatively deep within the specimen and convey both atomic number and surface topography information. The depth at which the BSE are emitted from the specimen depends on sample composition and the accelerating voltage of the electron beam. In a polished section, where topographic relief is reduced to a minimum, the quantity of BSE produced (and hence image brightness) depends on the average atomic number of the mineral species under the electron beam, showing a continuous increase with increasing Z (Fig. 14).

Most BSE detectors are of the semiconductor type, consisting essentially of a photodiode array (Gabriel, 1985), or a scintillator-photomultiplier system mounted close to the final aperture of the SEM (Robinson, 1974; Jackman, 1980). Many of the photodiode-type detectors only operate well at low-image-scan speeds. To be able to use

Figure 10. **Offretite overgrowth on the *c*{0001} face of a levyne crystal from vesicular basalts at Willy Wally Gully, near Merriwa, New South Wales. Secondary electron image. Field of view is 0.45 mm across. Author's specimen and micrograph.**

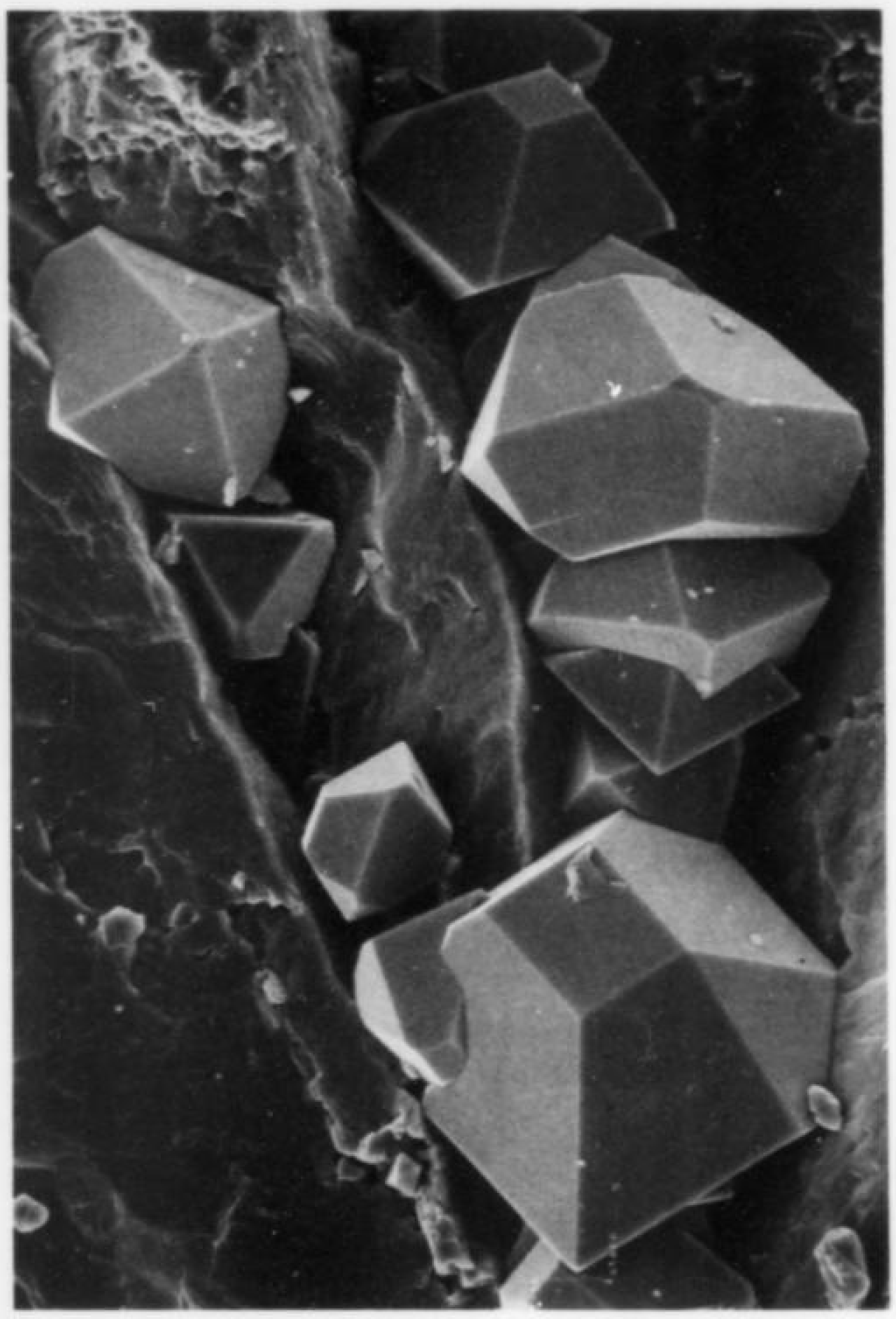


Figure 11. **Scorodite crystals on quartz. Kingsgate molybdenite-bismuth mines, near Glen Innes, New South Wales. Secondary electron image. Field of view is 0.12 mm across. Author's specimen and micrograph.**

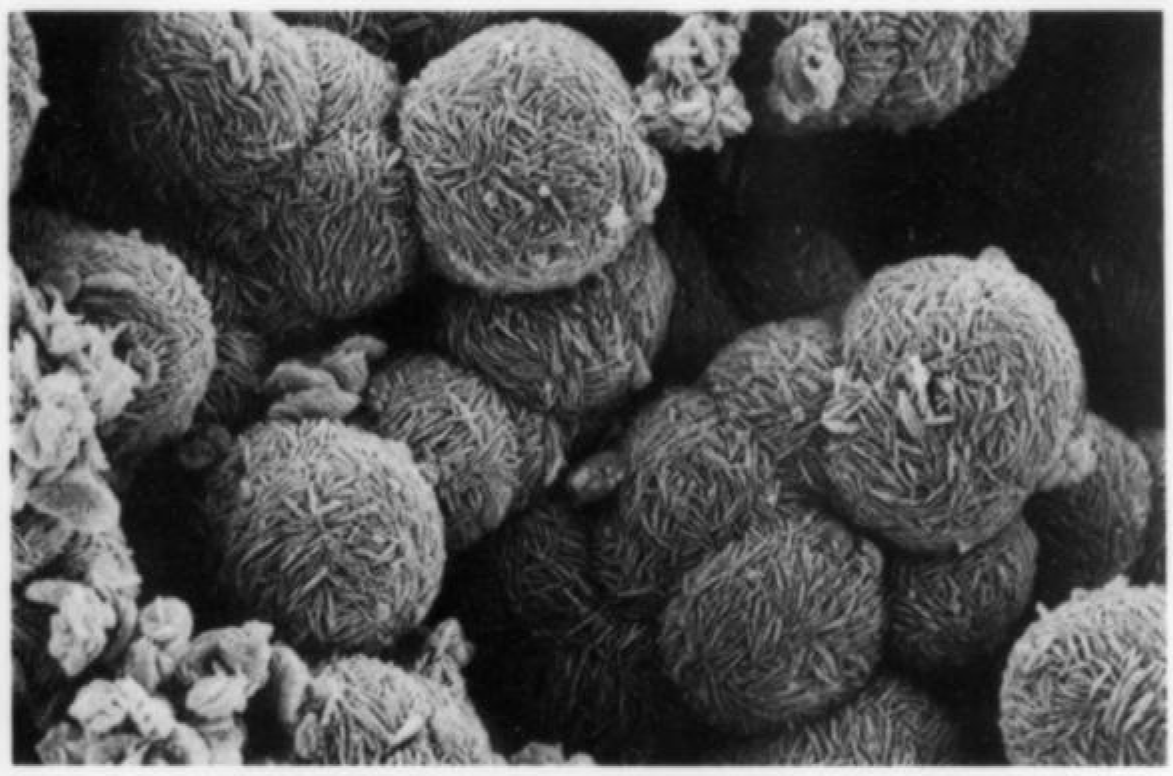


Figure 12. **Spherulitic hematite in a cavity in dense hematite ore from Yampi Sound, Western Australia. Secondary electron image. Field of view is 50 micrometers across. Author's specimen and micrograph.**

the BSE signal in image formation, secondary electrons must be prevented from reaching the BSE detector. This can be achieved by applying a slightly negative bias voltage to the detector to repell secondary electrons, or by screening the scintillators with a thin layer of evaporated aluminum which the SE have insufficient energy to penetrate.

With most BSE detectors, areas within a sample differing in average atomic number by somewhat less than one can be differentiated (Fig. 15). Because of the greater exit depth of BSE and the broadening of the incident electron beam by multiple scattering at these depths, spatial resolution is inferior to that achievable with SE. However at low magnifications (where high resolution is unnecessary) BSE can provide superior image contrast (Pfefferkorn *et al.*, 1978), particularly with relatively smooth specimens. This is due to the straight line path of BSE compared to SE, resulting in sharper shadowing effects, as

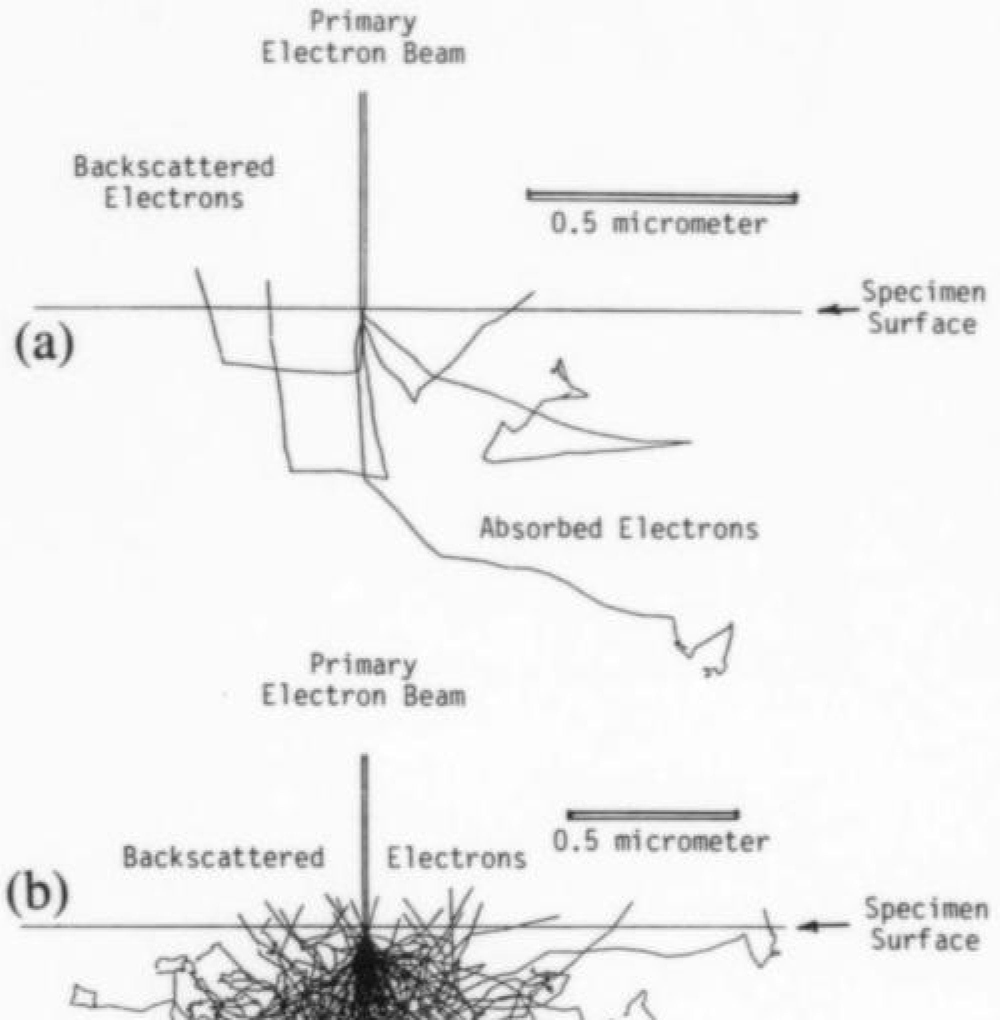


Figure 13. **Computer-generated model showing electron paths through a sample struck by an electron beam. (a) Only 5 paths shown. (b) Plot of 100 paths. From Goldstein *et al.* (1981).**

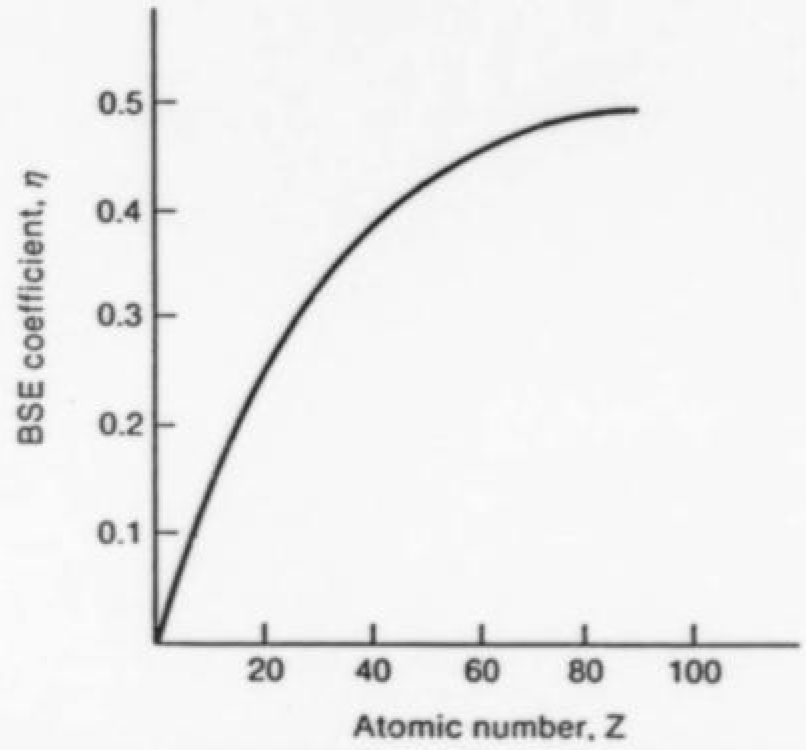


Figure 14. The relationship between BSE emission and atomic number for pure elements. BSE coefficient is (Z − 1.5)/6.

Figure 15. Backscattered electron image of a polished section of iron ore from the Middleback Range in South Australia showing intergrown hematite (dark) and magnetite (light). The difference in average atomic number between these two minerals is around 0.5 absolute. Field of view is 0.7 mm across. Author's specimen and micrograph.

Figure 16. Crystallized hematite lining a syneresis fissure in dense hematite ore from Mount Newman, Western Australia. Backscattered electron image. Since only one mineral (hematite) is present there is no atomic number contrast (compare with Figure 6). Field of view is 0.5 mm across. Author's specimen and micrograph.

Figure 17. Greywacke from the Hunter Valley, New South Wales. Backscattered electron image of a polished section showing angular grains of quartz (gray) and albite/K-feldspar (mottled) in a fine kaolinite matrix. Field of view is 1 mm across. Author's specimen and micrograph.

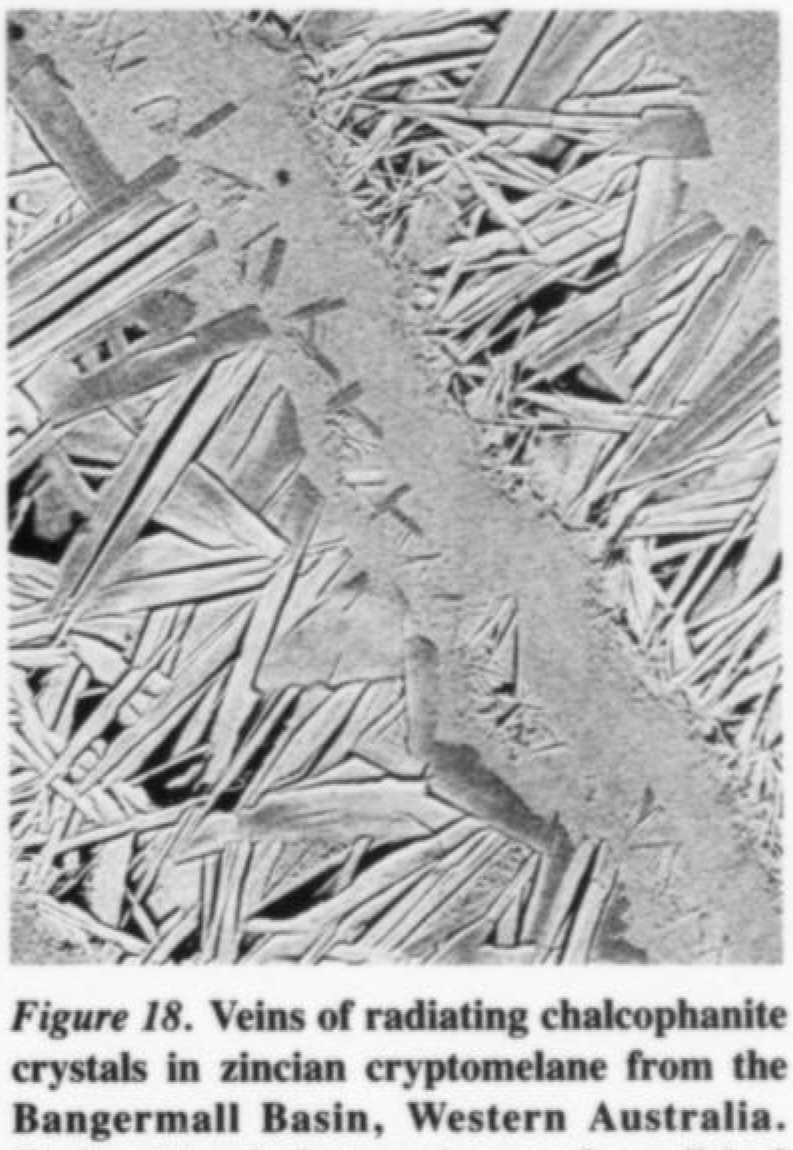


Figure 18. Veins of radiating chalcophanite crystals in zincian cryptomelane from the Bangermall Basin, Western Australia. Backscattered electron image of a polished section. Variation in gray tone within the chalcophanite reflects different levels of zinc and nickel replacing divalent manganese. Field of view is 0.4 mm across. Author's specimen and micrograph.

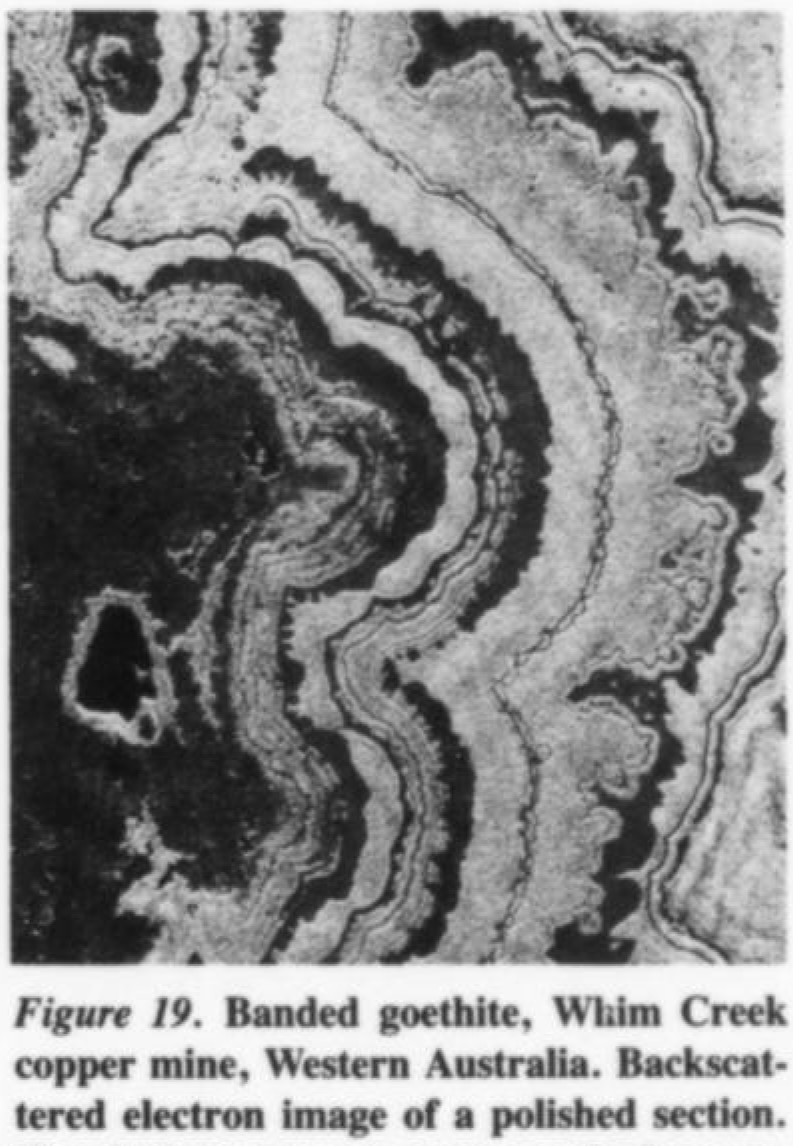


Figure 19. Banded goethite, Whim Creek copper mine, Western Australia. Backscattered electron image of a polished section. The darker zones are composed of porous earthy material. Field of view is 1 mm across. Author's specimen and micrograph.

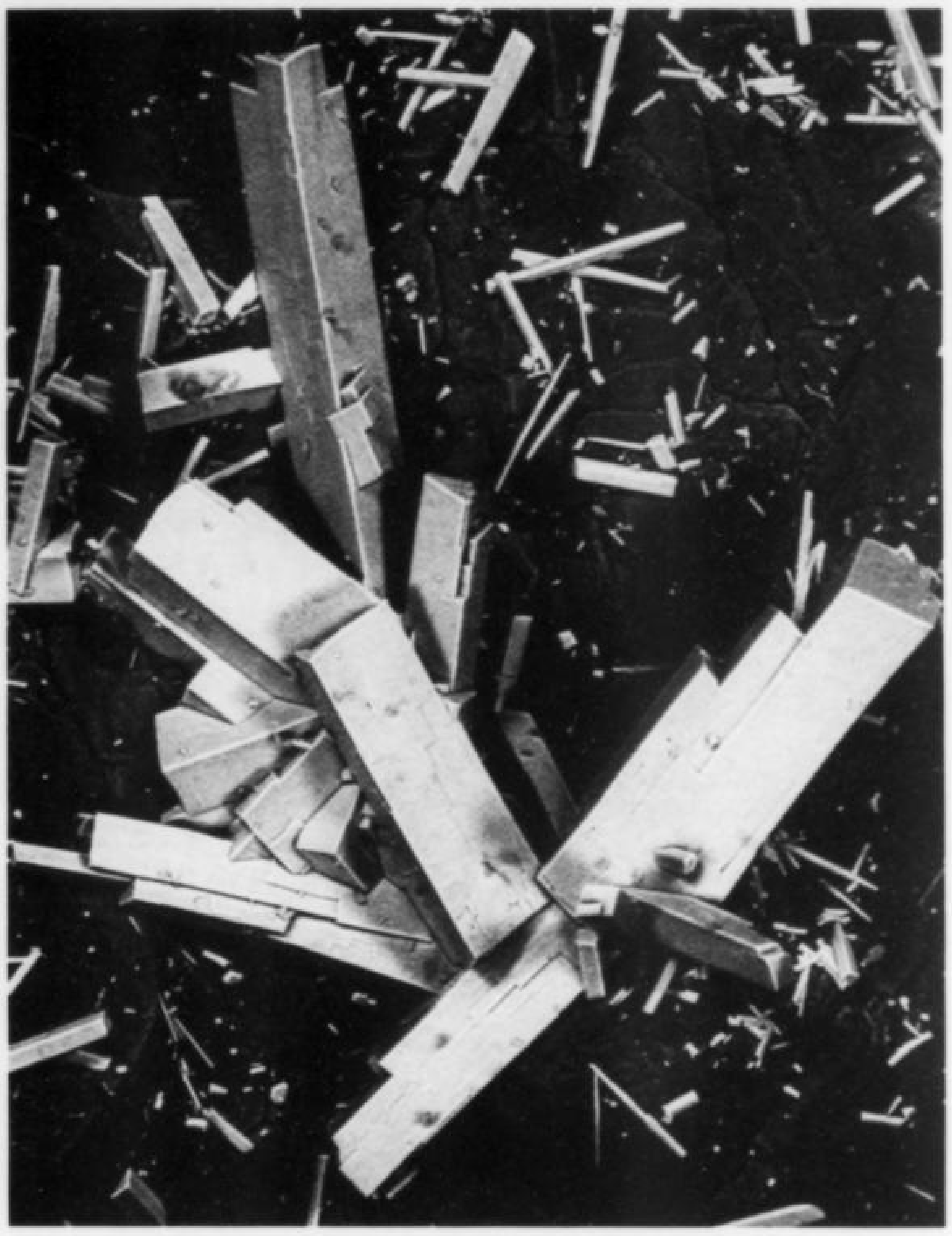


Figure 20. **Malachite crystals on quartz, Olary district, South Australia. Backscattered electron image showing both topographic and atomic number contrast. Field of view is 0.6 mm across. Author's specimen and micrograph.**

can be seen by comparing Figures 6 and 16. With most BSE detectors an MRD (minimum resolved distance) of a few tens of nanometers should be attainable.

The BSE imaging mode is extremely useful in mineralogical investigations, such as sedimentary petrology (Krinsley *et al.*, 1983), where mineral species in BSE micrographs of polished sections can be quickly identified by their relative brightness once initial identification (usually by microanalysis) has been carried out (Fig. 17). BSE images can also be used to detect compositional zoning within the same species in a specimen, as shown in Figures 18 and 19. Where the different minerals present in a rough specimen have significant differences in average atomic number, interesting and often spectacular contrast effects can be produced (Figs. 20 to 22).

The use of BSE detectors with an SEM modified for "environmental cell" operation enables an even wider range of applications, including the examination of porous and volatile materials. The use of BSE in earth science applications is discussed in more detail by Hall and Lloyd (1981).

Specimen Current

A significant proportion of electrons from the primary beam are absorbed by the sample (Fig. 13) and an electric current will flow if the specimen is grounded. This current can be measured by connecting a very sensitive ammeter between the sample and the earth. For imaging, currents of substantially less than one nanoamp (1 x 10^{-9} Amp) are normally encountered, while for microanalysis currents of 50 nanoamps or more are not uncommon.

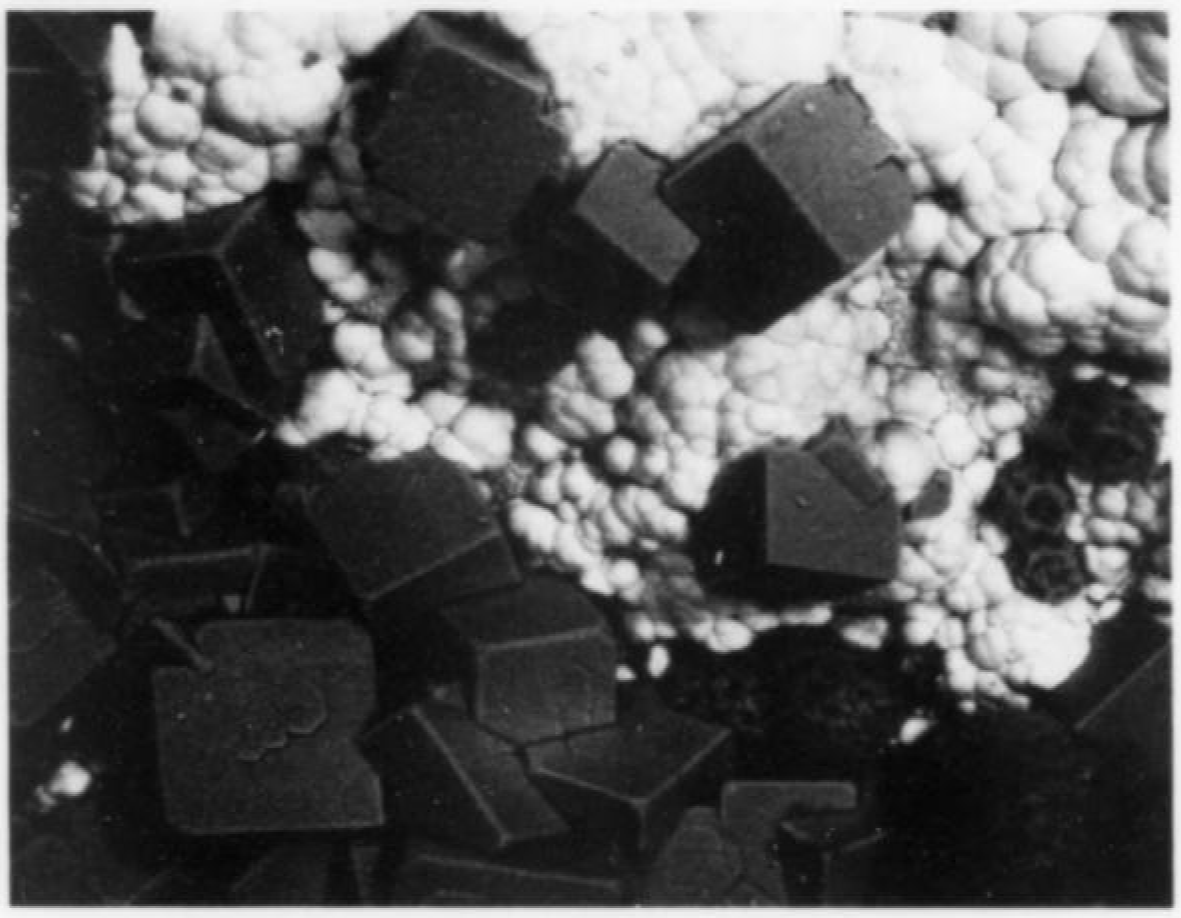


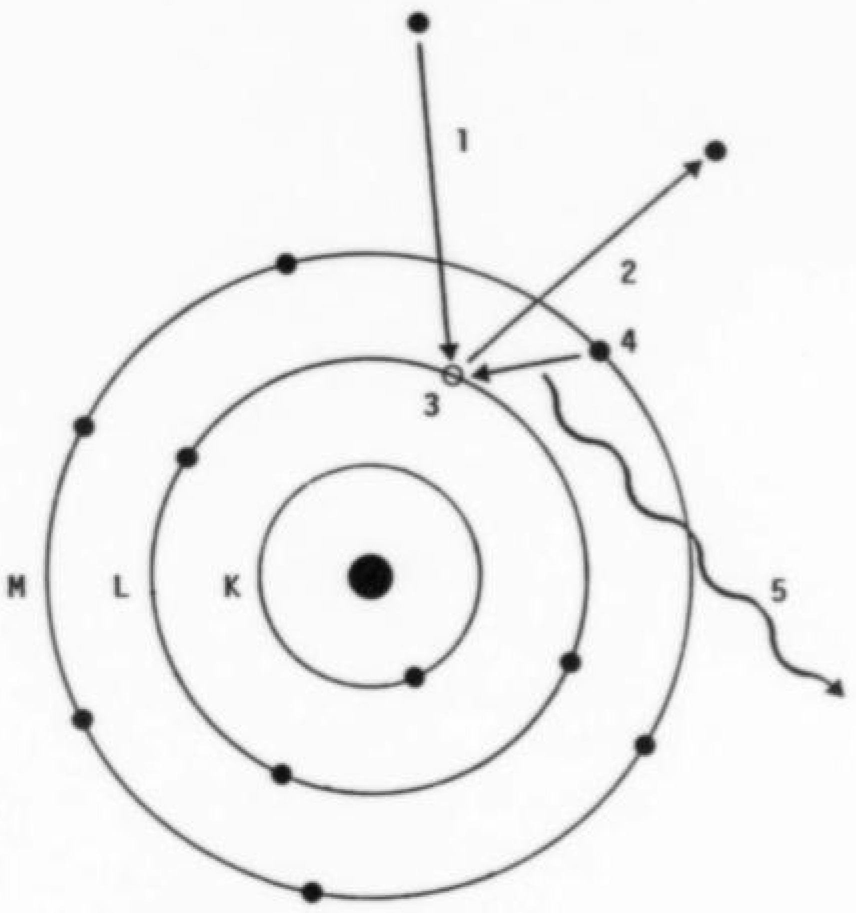
Figure 21. **Crystals of alunite with an unidentified magnesium aluminum silicate on botryoidal goethite from Iron Monarch, Middleback Range, South Australia. Backscattered electron image showing both topographic and atomic number contrast. Field of view is 0.6 mm across. Author's specimen and micrograph.**

Figure 22. **Heavy minerals extracted from beach sands near Port Macquarie, New South Wales. Backscattered electron image showing both surface morphology and atomic number contrast. Minerals present are monazite (white), zircon (pale gray), rutile (medium gray) and quartz (dark gray). Field of view is 3 mm across. Author's specimen and micrograph.**

The magnitude of the specimen current generated for a given point on the specimen is the difference between the total beam current and the emissive current (the sum of all currents leaving the specimen by emission of electrons). Therefore a change in the intensity of backscattered or secondary electron signals will inversely affect the specimen current signal. Hence an image formed using the specimen current signal will be the negative equivalent (black and white interchanged) of the backscattered electron image. In practice the BSE image is generally more useful and the specimen current detector is used primarily to measure the intensity and stability of the primary electron beam during quantitative microanalysis.

Cathodoluminescence

When irradiated with an electron beam some substances fluoresce, producing light in the ultraviolet, visible or infra-red region of the electromagnetic spectrum. Normally cathodoluminescence (CL) in the wavelength range 350–500 nanometers can be detected using a variety of *optical* systems, providing relatively good resolution and focal depth. It is also possible to spectrographically analyze the wavelength of CL emissions to provide species identifications. Cathodoluminescent areas appear bright in photos against a dark background, and such areas are easily correlated with an SE or BSE image. The phenomenon is comparatively rare but extremely specific and hence a valuable diagnostic feature in mineralogical studies (Remond, 1977; Hold and Datta, 1980; Ruppert, 1987).



1. Incident electron
2. Ejected orbital electron
3. Vacancy created in L Shell
4. Vacancy filled by electron from outer M Shell
5. Energy released as characteristic X-ray

Figure 23. **Schematic diagram illustrating the production of characteristic X-rays as a result of electron bombardment.**

Characteristic X-rays

All materials will emit X-rays when irradiated with an electron beam of suitable energy. These X-rays are characteristic of the individual elements within the specimen and are produced by transitions between inner electron energy levels (shells) in the excited atoms. To allow this transition, a vacancy must first be created by the removal of an inner shell electron. Such ionization is produced when the atoms are bombarded with charged particles such as electrons. This process is shown schematically in Figure 23. With the attachment of microanalytical facilities to the SEM, the wavelength or energy of these characteristic X-rays can be analyzed to provide qualitative and/or quantitative chemical data for very small selected areas on a specimen.

PHOTOGRAPHY WITH THE SEM

Although other formats (such as 35 mm) are in common usage, standard equipment on virtually all SEMs includes a Polaroid camera back (usually 4 x 5-inch format). The camera is mounted over a special recording monitor which, compared to the visual display screen, is coated with a very short-persistence phosphor to avoid fogging of the micrograph by afterglow. Of the Polaroid films available for 4 x 5-format cameras, the most commonly used are *Type 52* (print film with 35–40 lines/mm resolution) and *Type 55* which gives a print and a negative. The *Type 55* negative has a resolution of 150–160 lines/mm and is especially suitable for enlarging. Despite the major disadvantage of high cost compared to 35 mm and plate films, Polaroid film has become thoroughly accepted by scanning electron microscopists for providing a high-quality image with minimum time and effort. Photography using the SEM is covered in detail in Gabriel (1985).

Because electron illumination does not produce visible color (except in the case of cathodoluminescence), only black and white images are possible in any electron microscope. However, false-color images can be obtained in a number of ways. Digital computer image processing is commonly used to provide pseudo-colorization, with colors assigned according to image gray tones. In an SEM technique developed by Ari Antonovsky at the CSIRO Division of Chemical Technology, Melbourne, a color picture is formed in the same way as the image on a color television. Three different detector images are used to encompass the entire range of electron energies produced by scanning the sample. The BSE, SE and LCV-SE are assigned to red, green and blue primary colors respectively and by overlaying the three distinct SEM images a high-definition color image can be built up directly on color film. Adjustment of the relative intensity of the different signals provides natural tones (Antonovsky, 1984; Antonovsky and Sandy, 1984).

Optimum imaging conditions for a given specimen are governed by the accelerating voltage, electron beam diameter, and focus. Working distance and specimen tilt also strongly influence image quality. Many makes of SEM also allow various degrees of signal processing, in which electronic manipulation of the electron signal can be performed to improve image clarity by enhancing certain features (while suppressing others) and improving the signal-to-noise ratio. Stereo imaging is also possible.

The SEM is usually provided with sample-stage tilt and rotation controls which allow the sample (especially microcrystals) to be manually oriented in the optimum position for photomicrography.

SPECIMEN PREPARATION

Samples used for SE imaging are usually freshly broken chips of ore or rocks, crystallized microminerals, etc., which are firmly mounted to sample stubs using any one of a variety of commercially available electrically conductive adhesives. Sample size is governed by the SEM stage construction, maximum possible movement in X and Y directions and the size of the specimen chamber, different makes of SEM having different requirements.

For BSE imaging of compositional differences and for quantitative microanalysis, samples are mounted in an epoxy resin, sectioned, and polished to produce an optically flat surface. Sample preparation is identical to that used in reflected-light microscopy and, providing SEM sample size limitations are adhered to, the same sample can be used for both techniques. In fact, where microanalysis is required, it is often useful to first examine the specimen under a reflected-light microscope to locate the most suitable areas for analysis. Hence a good optical microscope is considered an essential part of any earth science SEM laboratory.

Most mineralogical specimens are non-conductive and must be coated with a conductive layer to carry away the negative electrical charge built up on the sample surface by the absorption of electrons from the primary electron beam. Uncoated or poorly-coated specimens cause a variety of annoying artifacts which reduce the quality of photomicrographs. The most common artifact is caused by small areas of localized charging. This is observed as very bright regions accompanied by dark lines parallel to the scanning direction. Excessive charge built-up may cause large areas of the specimen to act as very effective electron reflectors, resulting in almost total loss of image detail in SE mode. Charging may also cause sample drift, resulting in poorly focused and/or distorted micrographs, especially at high magnifications. For optimum SE imaging, samples are usually coated with around 20 nanometers of gold. However, where microanalytical data may be required, specimens are coated with carbon, but this usually provides inferior SE emissions. Specimens in which excessive charging cannot be overcome may be more easily photographed in BSE mode, which is less affected. Difficult specimens may be examined uncoated using an SEM modified for environmental cell operation (Robinson and Robinson, 1978; Robinson and Nickel, 1979). Sample preparation techniques and the problems involved are covered in more detail by Gabriel (1985) and Postek *et al.* (1980).

CONCLUSION

The SEM has proved to be one of the most versatile tools of modern science and has even been accepted by the non-scientific community in general as a window on an otherwise invisible world. The outstanding contributions of the SEM to mineralogy have stemmed from its ability to combine high magnification and great depth of field. It provides a number of useful imaging modes not available with other techniques, and its wide range of magnifications bridges the gap between light microscopy and transmission electron microscopy (TEM). The technique is able to handle a wide range of sample types with minimal prior preparation. With the addition of microanalytical facilities, the SEM is leading determinative mineralogy away from the more traditional polarized light microscopy, which has been the mainstay of the science since the first use of rock thin sections by Sorby in 1849 (Clark, 1988).

ACKNOWLEDGMENTS

Appreciation is expressed to the Management, BHP Research, Newcastle Laboratories, for the use of the equipment and resources of the laboratories. Ken Turner, of the above laboratories, reviewed the original manuscript and offered suggestions for improvement.

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LOCALITY SPECIES LISTS

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For every mineral locality that has been discovered there is a "specimen base," that is, the sum total of all specimens which have been collected there. From this base a list may be compiled, showing all mineral species that have been identified, as well as unknowns which may represent species new to science, and which have yet to be formally approved, described and named.

Mineralogists have prepared and published such lists for some localities, but, with time (sometimes very little time), these published lists become outdated. Lists for other localities have been compiled and circulated, amended and revised at long intervals, as succeeding generations of collectors and enthusiasts summon the necessary energy to get the job done.

These lists constitute prime, basic documents on the overall chemistry of deposits, and are of critical importance to a full understanding of the mineralogy of specific occurrences. The process of list compiling causes people to be more aware of the overall composition of a locality, and engenders more respect for the deposit. The resultant lists also reflect the compilers' attention to details; some lists are a joy to read, while others are compromised in one way or another. It follows that, in general, the preparers of such lists have a responsibility to be systematic and well-informed in order to assure maximum accuracy in these important documents.

For all but a few mineral localities, such lists of species are the significant contributions of local mineral collectors, sometimes with the assistance of involved and interested local professionals. The persons best qualified to edit locality species lists are usually senior collectors or mineralogists who have collected at the localities for many years. Nevertheless, whole clubs or societies can become involved in a group effort, adding a sense of cohesiveness and accomplishment to the group's activities. Indeed, some societies have played a major role in the scientific documentation of specific localities which they have adopted as their chosen province of activity or focus.

With the attention of today's mineralogists now increasingly drawn to more complex endeavors, the relatively simple task of list-making by collectors becomes even more critical. Their observations, based so heavily on experience with large numbers of specimens, especially those seen *in situ* before being collected, will probably never be duplicated by professional mineralogists. Consequently, mineral collectors find themselves in possession of unique and highly valuable information which may be lost to science indefinitely if they do not record, compile, update and publish or distribute it themselves.

There can be no universal standard covering all possibilities involved in the compilation of locality species lists. Needs vary from locality to locality, and each is more or less unique. But attention to three basic criteria can make all lists more useful and more worthy of respect:

Define the Geographic Scope

Each list must pertain to a specific geographical area having specific boundaries. These boundaries must be clearly spelled out, with reference to relatively permanent and easily located features such as roads, geology and topography. Trees, property lines, buildings and even political boundaries are transitory and geologically meaningless (unless based on topographic features which can, in such cases, be cited instead).

Clarify the Locality Nomenclature

Accessory information on historical names for a locality can be essential in assuring the usefulness of the list. Mines or occurrences which have undergone consolidation or a succession of name changes may be reported in the literature in conflicting ways. A summary of these will aid others in reconciling the list with the specimen base.

Define the Mineralogical Scope

If the list concerns minerals from a particular ore deposit, zone or vein, that should be clearly stated. Similarly, if the list includes several deposits taken together, that should be stated. If minerals from overburden, gossan or adjacent country rock are to be included, or alluvial additions unrelated to the main mineralization of interest, that must also be stated. Post-mining minerals may also need to be specified.

There are many choices to be made in compiling a good mineral list. And, due to local needs and preferences, as well as the competence of the compilers, the comprehensiveness of such lists will vary. There will be no attempt made here to give detailed rules. What is critically important is that the title and collateral information state clearly what the list covers. Decisions involved, criteria employed, symbols used (and their definition), and other elements of methodology must be clearly stated in the introductory or appendant paragraphs attached to the list. Doing so will assure that the list will be of maximum value to others.

Some additional factors to be considered for adoption are noted below. They are offered as selected guidelines, and are not meant to be comprehensive.

(1) State who the compilers were, and who was in charge of editing decisions. State if it was a society-sanctioned effort.

(2) Date the list; date any updates of it; retain old copies for historic purposes.

(3) List only valid mineral species, according to a standard reference work of all species (state which one was used and the edition); employ symbolism, varying typestyles, or parentheses to indicate varietal names. State the methodology employed in this decision, and be rigorous and consistent in its application, both in the original work and in the updates.

(4) List unconfirmed species (if at all) in a separate section. If they are included in the principal listing, use a symbol to identify their status. Generally, they are best ignored until confirmed, but if they are in the literature, it's useful to include them.

(5) Use symbols (such as *, **, #, etc.) to indicate qualifying or site-specific information. Such symbols must be carefully defined,

preferably as a footnote or appendix. The use of symbols is a local decision, but they are particularly useful in designating specifics such as:

(a) minerals first described from this locality,
(b) minerals added in an update,
(c) minerals from a specific geologic unit, such as a specific host-rock.

(6) Capture awkward information, which does not fit the list format well, in addenda at the end.

(7) Invite other collectors to share in the task. For efforts like this, a collective approach is almost always better than an individual effort.

(8) Updates to lists may be made at any time, and are most useful if they clearly designate what changes are being made. If species are added, they might be shown in boldface. Along a similar line, if updates to a list result in the deletion of a once-listed species, it is useful to add a footnote explaining, and dating, the deletion.

(9) Consider presenting several lists instead of one. Although the master list might be alphabetical for ease of use, lists of minerals according to chemical class (phosphates, etc.) are very useful and educational. For a classic locality, a list of species for which it is the type locality is useful. Others can be useful as well.

(10) Distribute the list by depositing copies in the society's archives, and by sending a bound copy to all local libraries, mineral museums, geological survey offices, and university libraries. Circulate it freely. Write down what you know and give your knowledge away.

(11) Arrange for the formal publication of the list in society newsletters or in periodicals of wider distribution.

CONTAMINATION OF THE SPECIMEN-BASE

When pristine, the specimen-base is an accurate indicator of the nature of the deposit, and has great value. However, in many cases the specimen-base has been contaminated to some extent by species from other deposits, and the information about some of the species reported from the locality is in part erroneous. If published, these errors should be corrected in a formal published manner.

Most contamination has been on a small scale, and occurred inadvertently. Some may have occurred through simple mislabeling, the "mislocation" concept, which is the incorrect attribution of provenance by a label-writer. (See Bentley *et al.*, *Mineralogical Record,* **17**, 99–104 (1986) for a more detailed discussion of such errors.) Fakes, too, have played a role, albeit a minor one, as described by Dunn *et al.*, *Mineralogical Record,* **12**, 197–219 (1981).

Aside from accidental mislabeling and fakes, the possible sources for physical contamination are varied. In some instances, mining companies have back-filled one mine with waste-rock from another, resulting in a gross pollution of the specimen base of the recipient mine. In other cases, mineral collectors have cleaned out knapsacks or the trunks of cars at a mineral locality, carelessly discarding unwanted material from another locality. Mining companies which processed ore at the mining site sometimes imported quantities of other minerals used in the processing operations. Many other sources of contamination surely exist, and this list is intentionally partial.

Whatever the source, if such misinformation has been circulated in any way, it should be responsibly corrected, and addenda to mineral lists provide a ready mechanism for doing so. Such contaminant species should never be included within the principal list, but can be mentioned as contaminants in footnotes so as to call attention to past errors and set the record straight.

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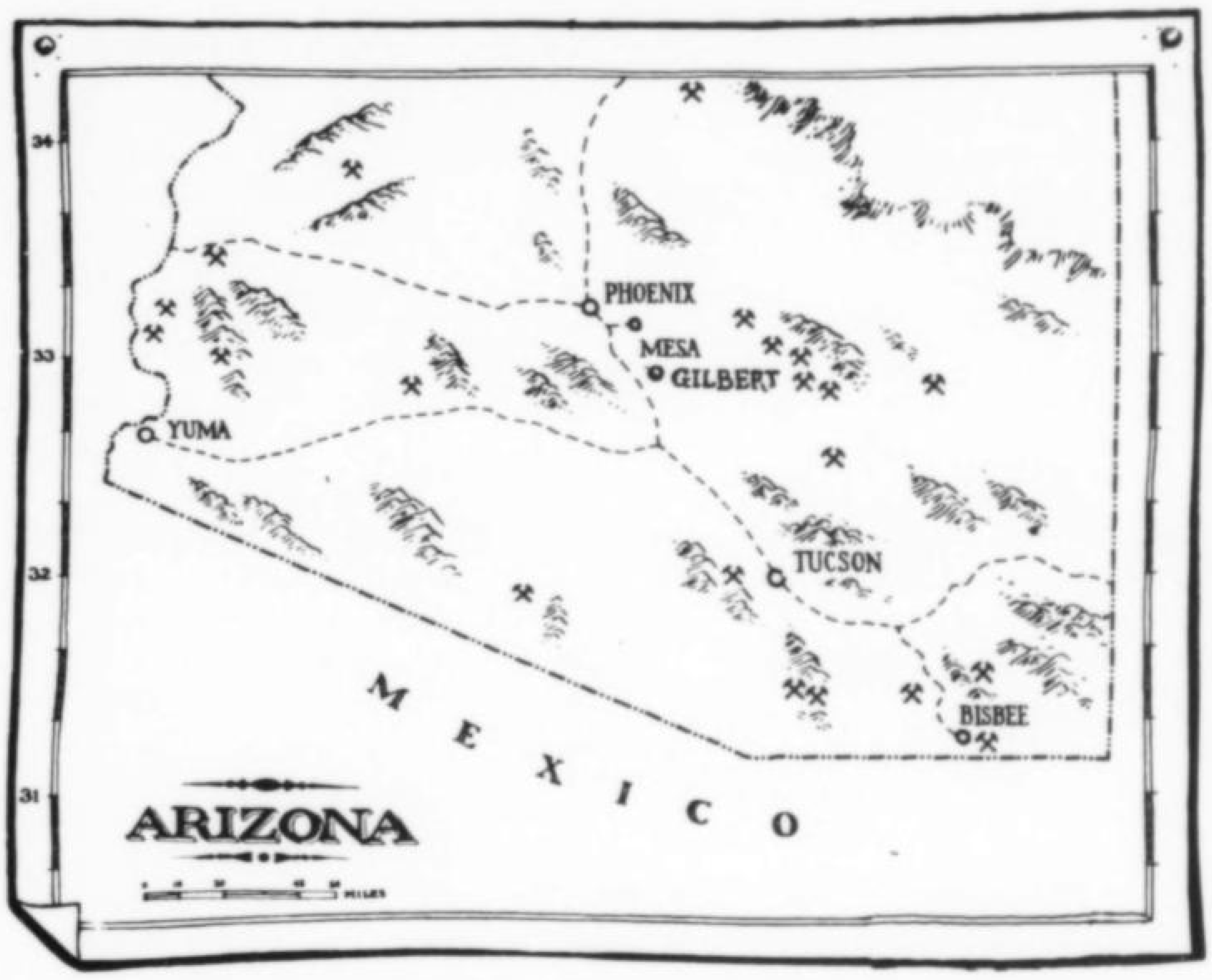

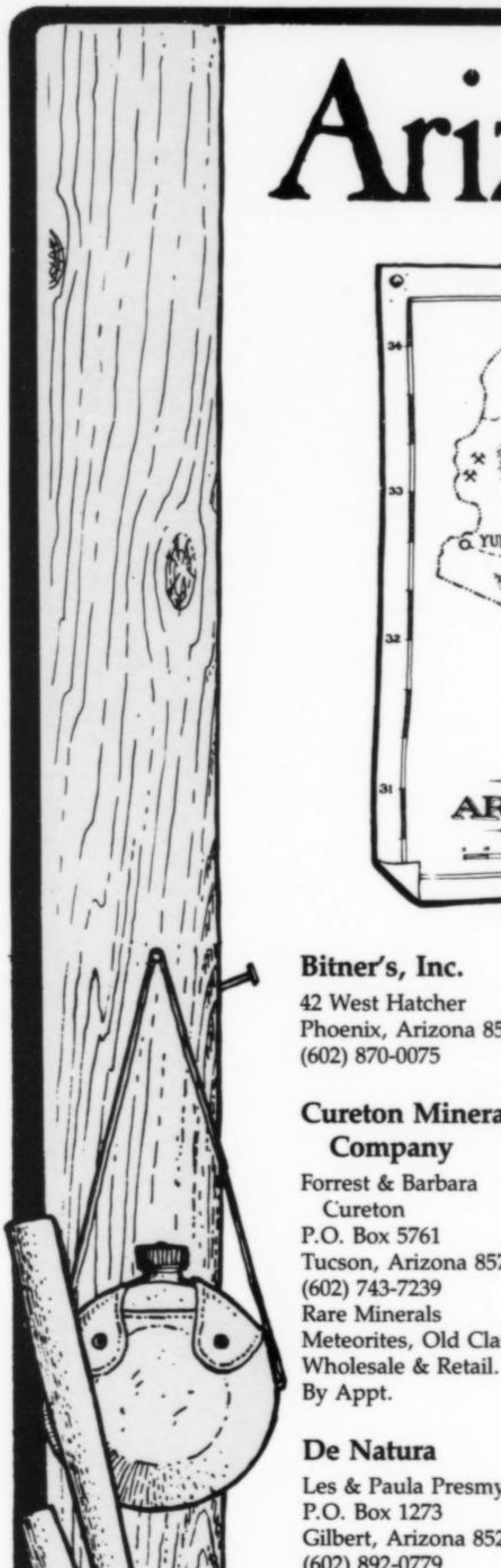

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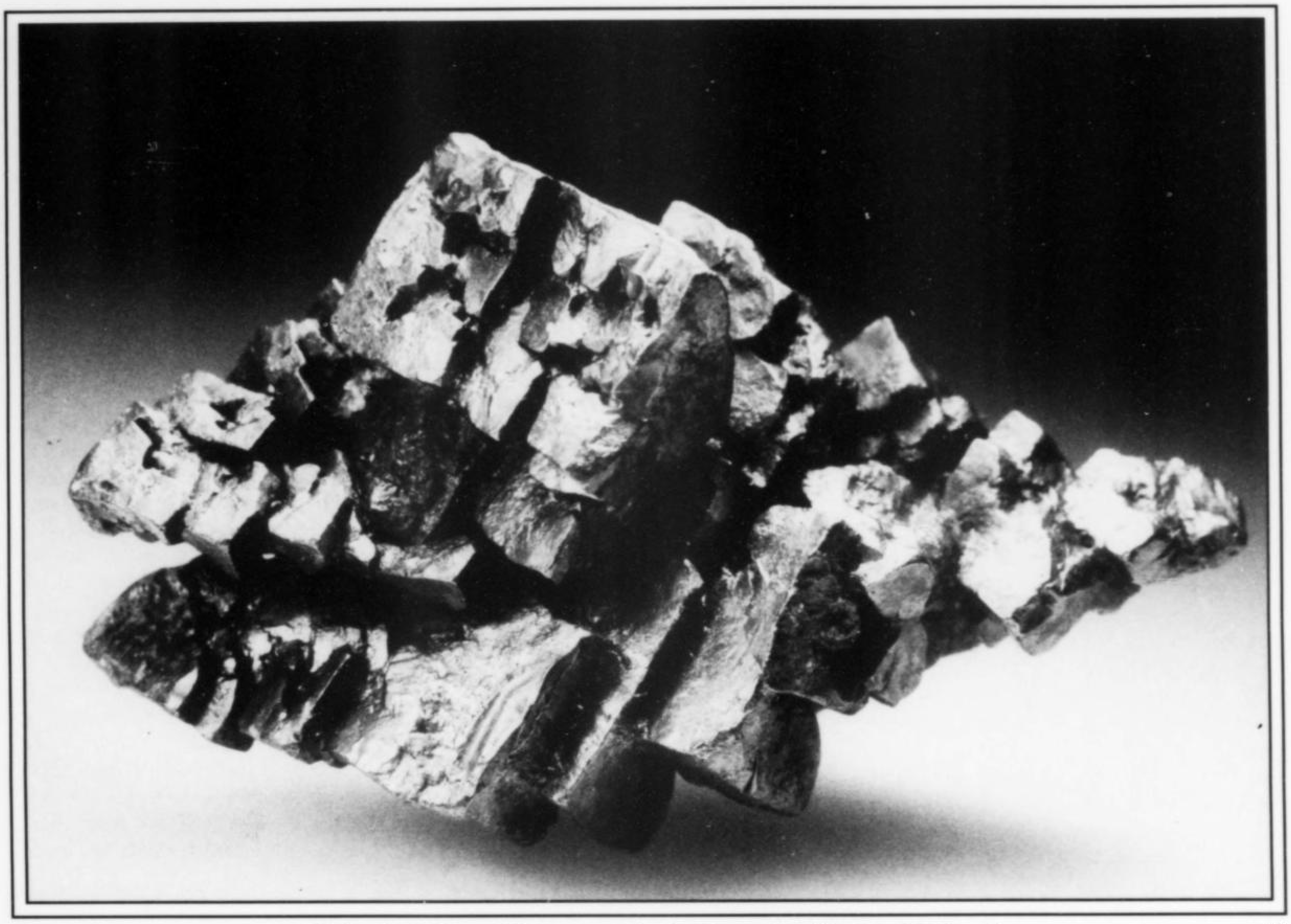

Bolivian Acanthite—6.2 cm—now in the Carnegie collection, Pittsburgh

WEW

THE EUGUI QUARRIES NAVARRA, SPAIN

Miguel Calvo and **Emilia Sevillano**
Fernando El Catolico
24 Dpdo, 6° Dcha.
50009 Zaragoza, Spain

During the last 20 years the Eugui magnesite quarries have yielded thousands of specimens, including the finest dolomite crystals in the world. The locality is still active.

INTRODUCTION

Magnificent dolomite crystals from quarries near Eugui, Navarra, Spain, first reached the mineral market around 1965, and were immediately hailed as new "classics." The large, lustrous, gray, twinned crystals and groups are considered by many to be the finest large examples of the species. Although the best crystals came out in the 1960's, quarrying continues at the site and specimens are still periodically recovered.

LOCATION

The two magnesite quarries near Eugui are located approximately at the km-33 and km-34 markers on the Comarcal 135 Road. The nearest town is Eugui, 4 km to the south, in the municipio of Esteribar, Navarra province.

One quarry consists of a large, flooded pit with small, active workings around the margin. The other (western) quarry is more important from a specimen standpoint. The quarries are operated by Magnesitas de Navarra, which owns a treatment plant at Zubiri, 15 km south of the quarries. There the magnesite is purified by heavy-liquid separation and is sintered at 1800° C to produce refractory bricks.

The locality name given to this occurrence on some old labels and in early published reports is "Asturreta" (Gonzalez and Arrese, 1977; Gomez de Llarena, 1965).

HISTORY

An unusual discovery was made along the Arga River near Eugui, Navarra, Spain, in 1945. It was found that the river sand was composed mainly of the mineral magnesite, $MgCO_3$. A detailed geological reconnaissance of the heavily forested area was undertaken as a result, and beds of magnesite were discovered along the southwest bank of the river. The first quarry to be opened there was named *Cantera de los Militares* ("Quarry of the Soldiers") (Gomez de Llarena, 1952).

Quarrying operations under the direction of Chief Engineer Juan Cordoba encountered large, crystal-filled pockets measuring up to 50 meters square and 20 meters deep. Fortunately, Cordoba recognized the great mineralogical value of the beautifully crystallized dolomite, and took steps to preserve a large number of specimens. These he sold to major museums throughout the world and also to private collectors, beginning around 1965.

Following Cordoba's death in 1970, the supply of specimens quickly diminished. Some pockets were salvaged by quarrymen around 1978, but since 1980 most specimens reaching the market have been recovered by private collectors. The quality of recent material is inferior


Figure 1. **Location map.**

Figure 2. **Western quarry, Eugui, in 1988.**

to that of the old specimens preserved by Cordoba; the crystal faces tend to be frosted instead of lustrous, are sometimes more deeply corroded, and are usually stained by iron and manganese oxides.

The quarries are still active. At the present rate of exploitation, ore reserves are expected to last 30 to 60 years (Vazquez, 1983). Consequently it is still possible that new pockets will be encountered, and may perhaps contain specimens equal to those of earlier times.

GEOLOGY

The magnesite-dolomite deposit crops out in the Paleozoic rocks of the Western Pyrenees (the Aldudes-Quinto Real massif), in the Namurian (Carboniferous) horizon (Gomez de Llarena, 1952). A sequence of carbonate rocks was folded during the Hercynian orogeny, resulting in magnesite outcrops associated with the Asturreta anticline (Pilger, 1974; Gonzalez and Arrese, 1977). The carbonate units reach a thickness of 180 meters, and occur between units of Namurian shale.

The origins of the magnesite beds is still unclear. One hypothesis suggests direct precipitation of magnesite in a lagunal environment (Gomez de Llarena, 1952, 1965). The absence of talc indicates a low temperature of formation, probably below 350° C. More recent theories suggest a metasomatic origin in which original dolomitic sediments are replaced by magnesite through the action of Mg-rich hydrothermal fluids (Gonzalez and Arrese, 1977). A period of partial re-dolomitization is said to have followed (Gonzalez *et al.*, 1978).

The large pockets of dolomite crystals (perhaps formed during the re-dolomitization phase) are found in zones permeable to groundwater, and have no preferred pattern of distribution within the quarries.

MINERALOGY

The mineralogy of the Eugui deposit is a relatively simple assemblage of carbonates (aragonite, calcite, dolomite, magnesite) plus very rare, disseminated sulfides and their alteration products.

Aragonite $CaCO_3$

Aragonite has been found in the Eugui quarries as colorless, and white to brown crystals forming fan-shaped aggregates up to 10 cm

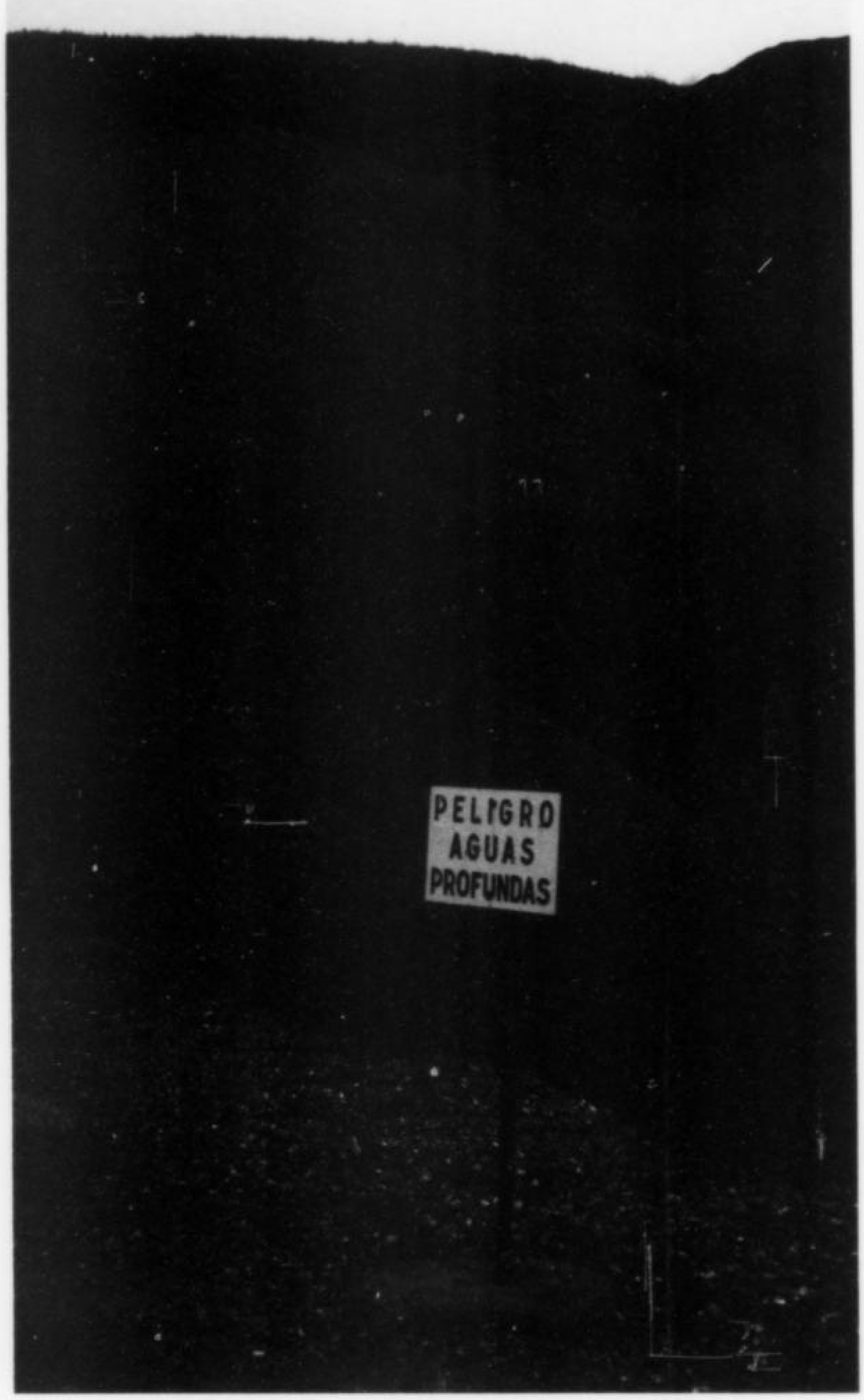

Figure 3. **Eastern quarry, Eugui, in 1988. The sign warns "Danger, Deep Water."**

Figure 4. **Magnesite crystal group, 12 cm, from Eugui. Museu Mollfulleda de Mineralogia collection; photo by J. M. Sanchis.**

Figure 5. **Eugui dolomite crystal group, 45 cm across, considered to be one of the best specimens ever recovered from the locality. It was found in 1967 by the quarry foreman, Imaori, and sold to a French collector; it was acquired by the Sorbonne in 1987. Photo by Nelly Bariand.**

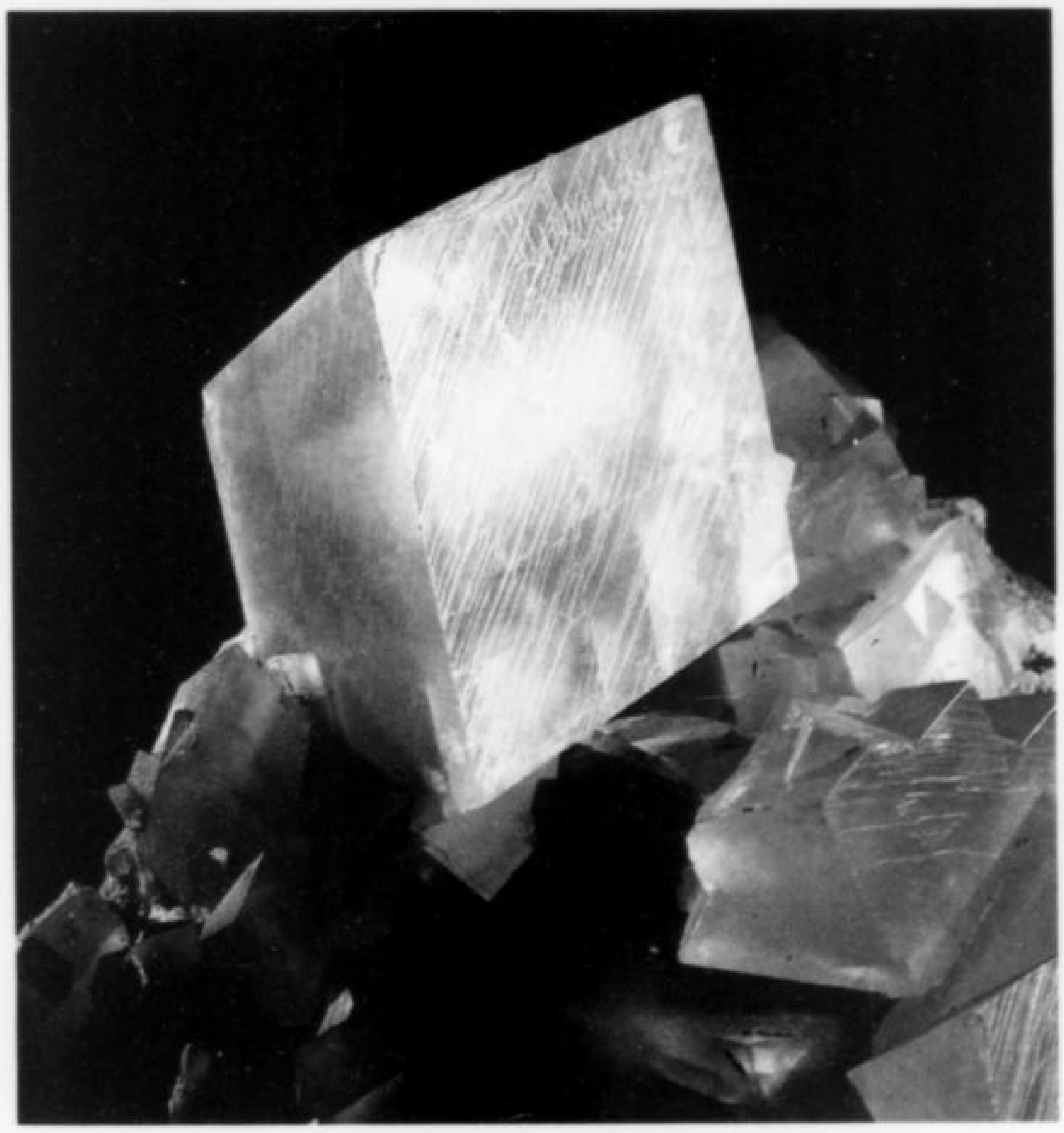

Figure 6. **Dolomite crystals to 6 cm, from Eugui. Museu Mollfulleda de Mineralogia collection; photo by J. M. Sanchis.**

Figure 7. **Dolomite twin, about 7 cm, from Eugui. Sorbonne specimen; photo by Nelly Bariand.**

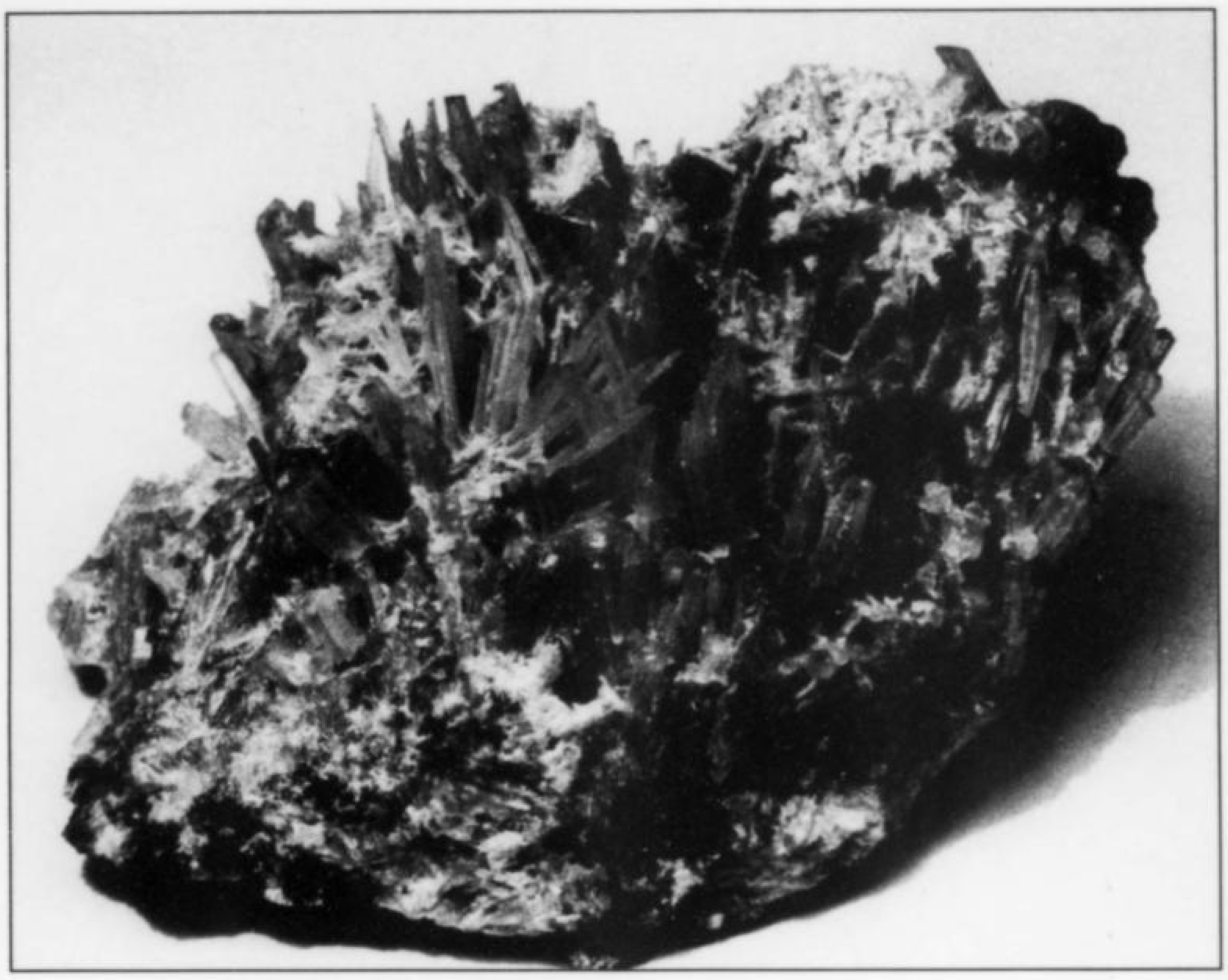

Figure 8. **Group of white acicular aragonite crystals, 8 cm across.**

Figure 9. **Colorless, water-clear and well-terminated aragonite crystal from Eugui. The length as shown is 5 mm.**

in size, with individual crystals reaching 4 cm. In some cases, the aragonite crystals show sharp terminal faces, but acicular crystals with cloudy terminations are most common.

Calcite $CaCO_3$

Calcite is very rare, occurring in small quantities with dolomite and as small crystals in geodes. The material named "calcita" by miners is actually dolomite.

Chalcopyrite $CuFeS_2$

Small crystals of chalcopyrite up to 5 mm in size have been found, associated with dolomite crystals. Some crystals have a superficial coating of chalcocite. Small masses up to 2 cm across are sometimes found scattered through massive dolomite.

Dolomite $CaMg(CO_3)_2$

Dolomite occurs as beds intercalated with magnesite strata. Four major crystal habits have been found, which correspond to four different generations of growth.

First-generation dolomite crystals occur lining fissures in massive dolomite. The crystals are white, or rarely a pale pink or yellow where stained by iron oxides. Crystal size is commonly around 1 cm, reaching a maximum of 4 cm, and the crystal faces are curved in the manner typical of dolomite. Twins are rare, but parallel growth is common, and many larger "crystals" might better be described as parallel aggregates of smaller crystals.

The second-generation dolomite crystals are the ones which have made the locality world-famous. These can reach up to 20 cm (nearly 8 inches!) on edge (Schubnel and Skrok, 1984), and have a distinctive pale gray color. The gray color is usually irregularly distributed, but in some cases is zoned. The crystal faces are faintly striated parallel to the long diagonals. Most crystals are more or less translucent; water-clear transparency is uncommon. Transparent crystals have a high birefringence, 0.179, and exhibit double-refraction as seen with calcite "Iceland spar." Some transparent specimens have yielded fine cut stones (Baquero, 1989).

The typical crystal form is the rhombohedron $\{10\bar{1}1\}$, in some cases modified by $c\{0001\}$. Other forms are seen only rarely and, where present, are small and frosty. Penetration twinning is very common.

Figure 10. **Small rusty crystals of third-generation dolomite, on second-generation crystals. Specimen size is 3 cm across.**

Groups with only a few small contact points have been collected from large cavities in dolomite. The crystals occur imbedded in red clay which helps protect them from damage during extraction and transport. Individual pockets can reach several meters in size.

Pockets found in recent years have yielded only frosty-lustered crystals. Many of these are heavily included with clay in the outer zones and are therefore relatively unattractive. Some collectors have attempted to flake off the cloudy outer layer of dolomite, but the resulting crystal surfaces are not as smooth as might be desired; some people attempt to conceal this by oiling the surface, a practice generally condemned by responsible collectors.

The third generation of dolomite is an "angel wing" habit reminiscent of Mexican "angel wing" calcite. These are relatively uncommon, most of them having been found in 1978. The final, or

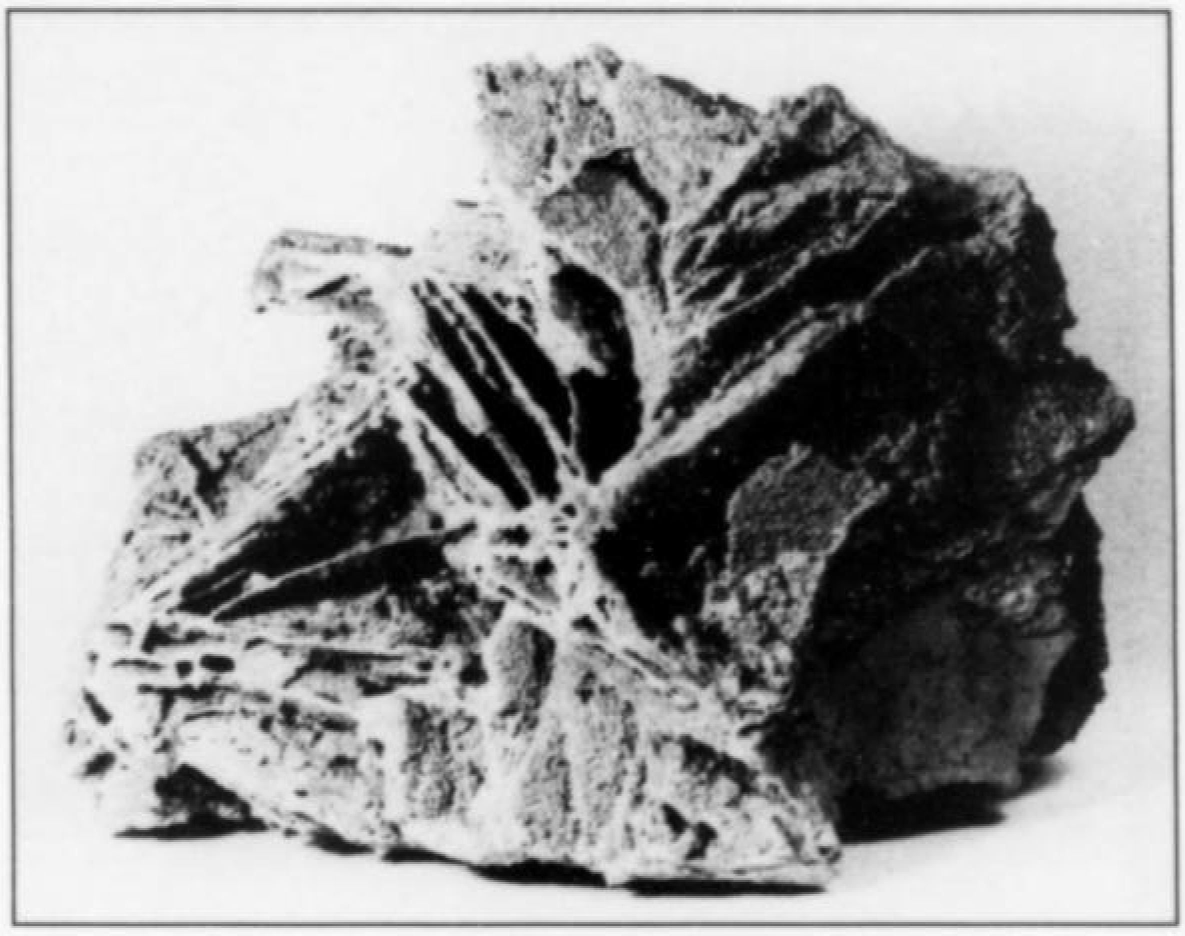

Figure 11. **Dolomite "angel wings" partially covered by microcrystals of dolomite and calcite, and with yellow color caused by iron oxides. Overall size is 10 x 14 cm.**

fourth-generation, dolomite consists of small, iron-stained, millimeter-sized crystals which can occur encrusting or sprinkled on crystals of all previous generations.

Goethite α-$Fe^{+3}O(OH)$

Goethite occurs as botryoidal crusts and masses in fissures in dolomite.

Graphite C

Graphite occurs as a component of carbonaceous matter which forms thin seams separating magnesite strata. In some areas it forms lustrous layers of pure graphite.

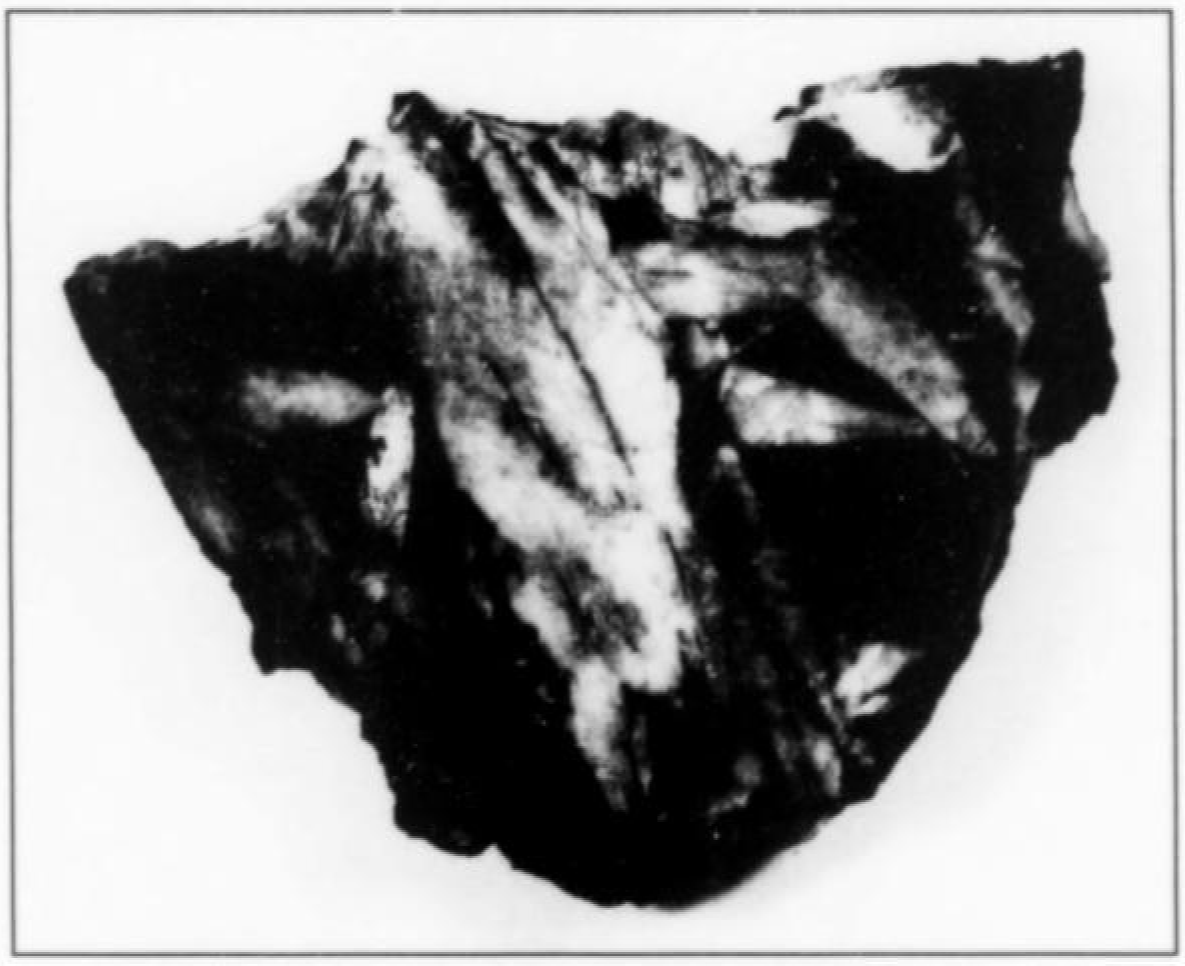

Figure 12. **Magnesite crystals illustrating the typical habit from Eugui. Overall size is 4 x 5 cm.**

Magnesite $MgCO_3$

Magnesite is the economic mineral responsible for the quarrying operations. It occurs as thin strata, usually 1–5 cm thick but occasionally reaching 10 cm. Thousands of such concordant strata form the orebodies.

Each stratum consists of lenticular magnesite crystals preferentially oriented perpendicular to the bedding plane. Free-growing crystals in vugs are very rare. Normally the imbedded crystals take the shape of pine nuts ("pinolites"), in some cases forming radiating groups. Broken and recemented magnesite strata are also known. Crystal size can be as large as 5 cm (Schubnel and Skrok, 1984), but the normal range is 5 mm to 3 cm.

Malachite $Cu_2(CO_3)(OH)_2$

At least two habits of malachite have been found at the Eugui quarries. Pseudomorphs after chalcopyrite crystals to 3 mm have been found, some of them hollow and filled with limonite. Well-formed malachite crystals to 4 mm have also been found, in parallel growth.

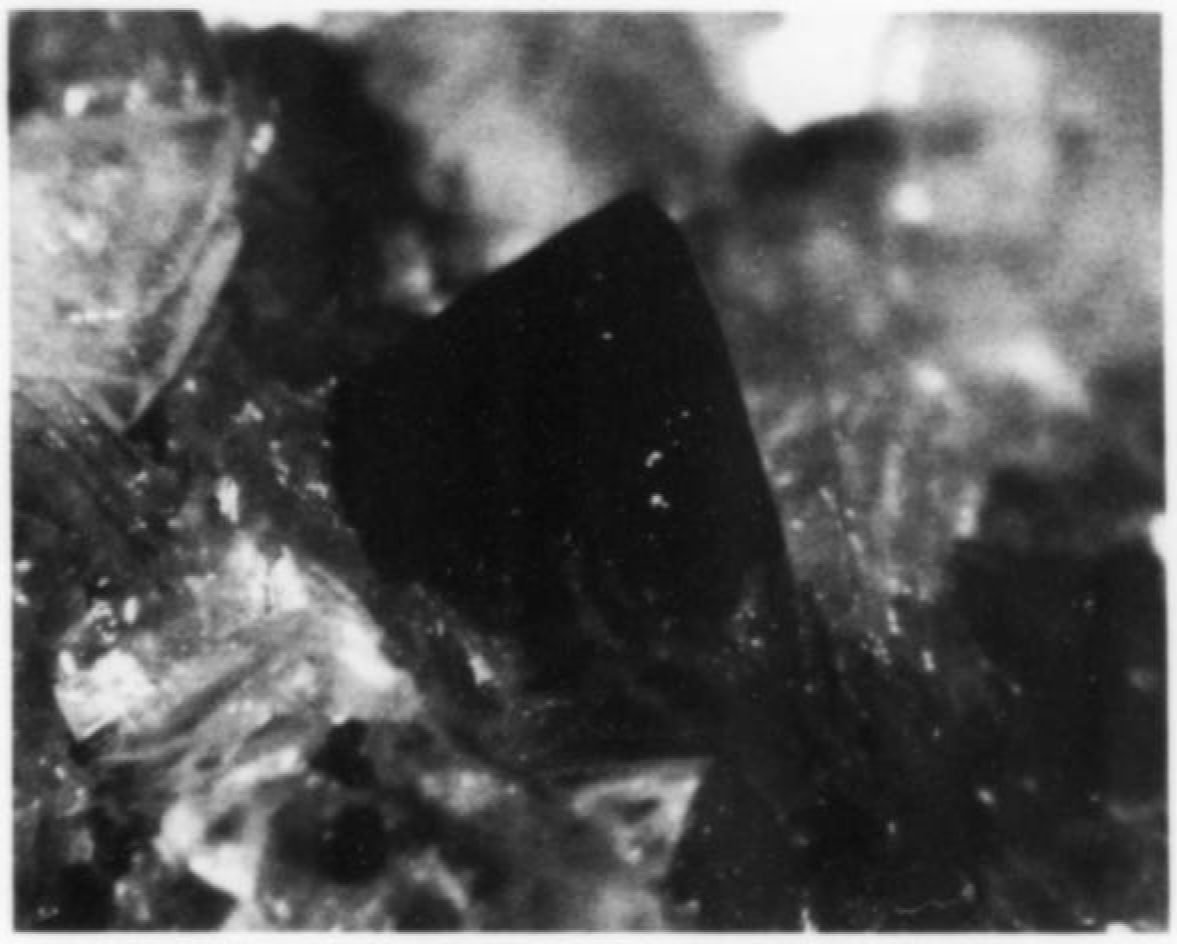

Figure 13. **Parallel growth of malachite crystals resembling a single crystal, on dolomite. Size is about 1.5 mm.**

Pyrite FeS_2

Pyrite microcrystals occur in the carbonaceous seams between magnesite strata. Rare dolomite crystals can be seen to contain a myriad of minute pyrite pyritohedrons as inclusions. Pyrite crystals up to about 5 mm are known.

Quartz SiO_2

Black chert nodules occur in some magnesite strata.

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

Rare crystals of tetrahedrite up to 5 mm in size have been found on dolomite crystals.

Wad manganese oxides

Unidentified manganese oxides occur as thin films on dolomite crystals.

CURRENT STATUS

As in most active mining operations, collectors are usually not permitted access. In some cases special permission has been granted, but the good dolomite pockets are so infrequently encountered that most visits are liable to be fruitless. The use of explosives for mining tends to shatter or fracture most crystals. The current operators have no system for recovering mineral specimens during mining, but their policy may change if great pockets like those found in the 1960's appear.

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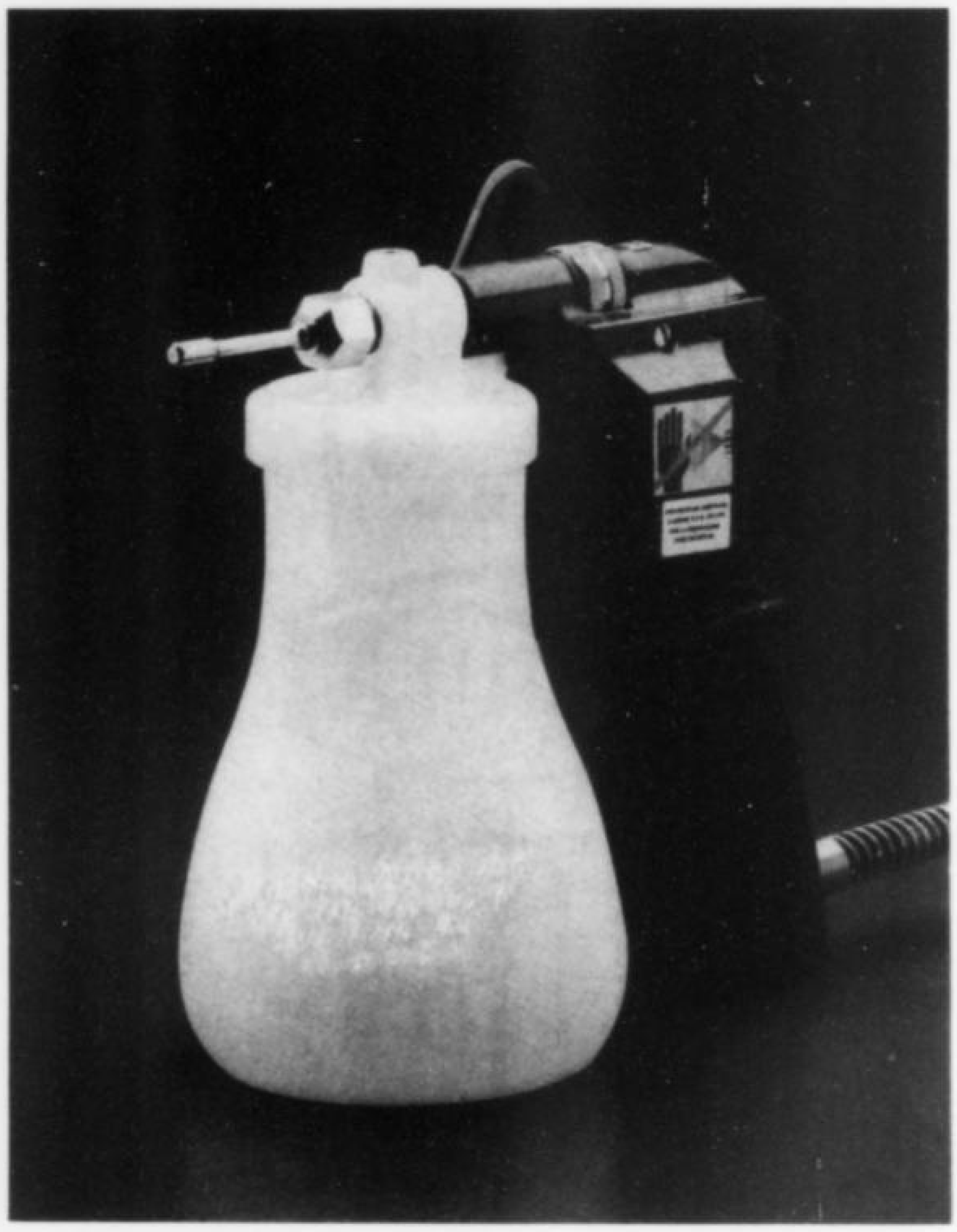

friends of mineralogy

Marcelle H. Weber, Past President
1172 West Lake Avenue
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BEST ARTICLES AND THEIR AUTHORS

Projects are the *raison d'être* of organizations. Adopting a project is the easier part; carrying through promptly and repeatedly is more difficult.

One of FM's scientific and educational purposes in the field of mineralogy includes promoting "the dissemination of information about minerals, mineral localities, collections and mineral investigation." FM has been affiliated with the *Mineralogical Record* since its founding. The project to award a lifetime *Mineralogical Record* subscription to the "senior author of the best article to appear therein each year, beginning with volume 11" served the purposes of both organizations.

In the beginning, the Award Committee, chaired by the Vice-President, was made up of non-board members from across the country who reviewed the articles and selected a short list from which a ballot was prepared for final vote by the Committee. The procedures have varied slightly and evolved to the time when the Vice-President selects a panel of five, different each year, from the United States and Canada, professionals, non-professionals, men and women. Each member selects first, second and third place articles—more if desired. The top three articles are resubmitted to the panel for a final decision. The first article to receive a unanimous first-place vote was "Minerals of the Carrara Marble." "Famous mineral localities: The Uranium Deposits of the Shaba Region, Zaire," was the second.

By 1984, the lifetime subscription was discontinued as an award. A Certificate of Award was presented to each author, and $100.00 was contributed to the *Mineralogical Record* in the name of the author(s). In 1989, the contribution was increased to $200.00.

It is notable that most of the articles selected are in the "Famous Mineral Localities" category.

1980—"Famous mineral localities: Tiger, Arizona"

(First Arizona issue, vol. 11, p. 155–181)

Richard A. Bideaux was awarded the first Friends of Mineralogy award. It was presented at the 1981 annual meeting and later by Fred Pough at the awards program Saturday night of the Tucson Gem & Mineral Show. The following comments were included:

> The committee members were impressed with the thoroughness of the article and the high percentage of original observations. It isn't merely a review of the literature interspersed with photographs and crystal drawings. Everyone involved with developing the award program was pleased that Bideaux's Tiger article set an appropriately high standard for the award.

Richard Bideaux received a BS from the University of Arizona and an MA from Harvard. He is a long-time, past member of the Tucson Gem & Mineral Society. He has collected at many of the Arizona localities and has helped describe several new Arizona minerals. He is co-author of *Mineralogy of Arizona* (1977) and co-author and publisher of the new *Handbook of Mineralogy* (1990). Among his published works are a column, "The Collector," in early issues of the *Mineralogical Record*, and a notable review article on wulfenite in *Rocks & Minerals* (January-February 1990).

Dick has been a computer consultant for mining companies. He was a co-founder and first President of FM. The mineral bideauxite was named in his honor.

Richard W. Graeme

1981—"Famous mineral localities: Bisbee, Arizona"

(Third Arizona issue, vol. 12, p. 258–319)

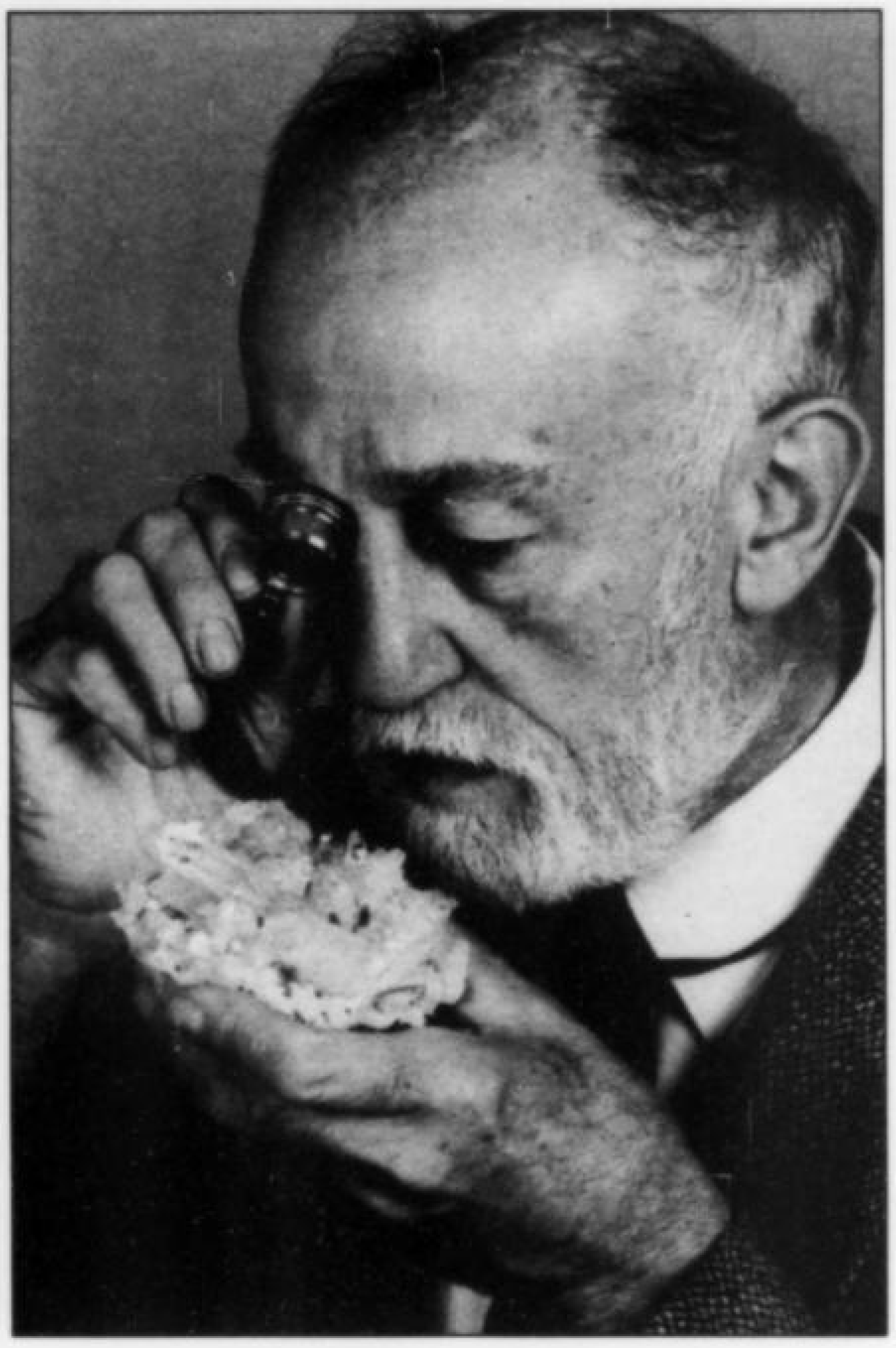
Richard W. Graeme received the award in 1982 for his Bisbee monograph, the only article as of that time to fill a complete issue. He and his wife were introduced at the FM meeting and at the evening awards program.

Dick Graeme is a third-generation Bisbee native and is the fourth generation of his family to work in the mines there. Bisbee was his home from his birth in 1941 until the mines closed in 1975. He first went underground collecting at about the age of six, and minerals subsequently became an important part of his life.

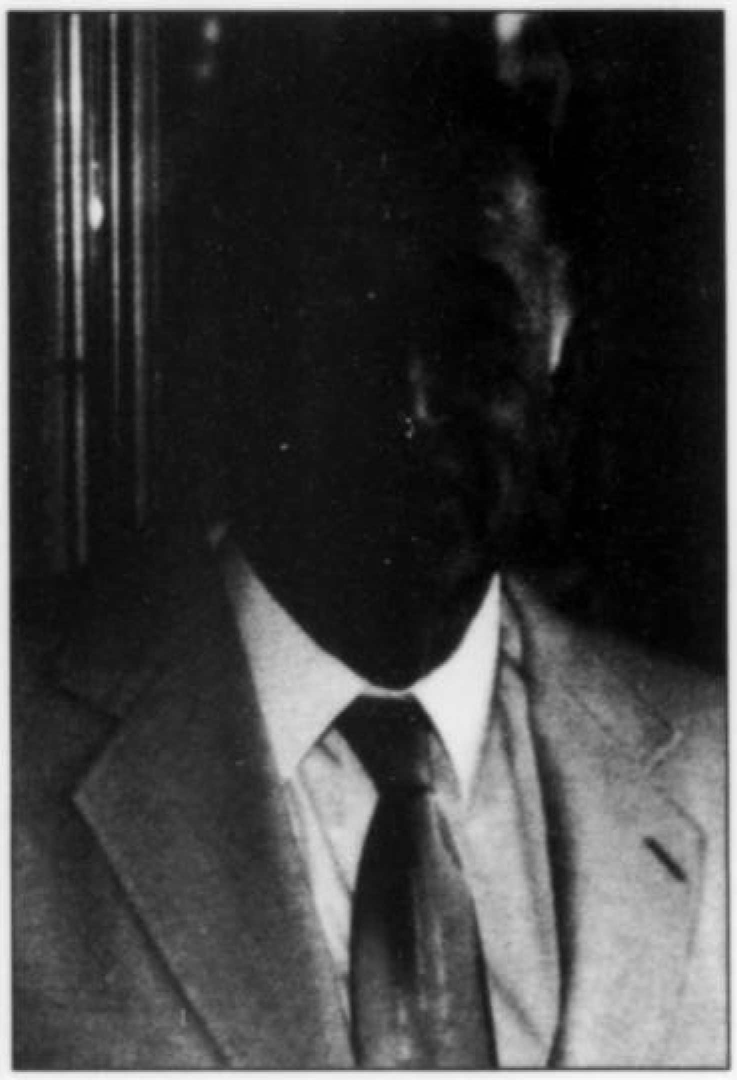
Dick worked underground as a miner in Bisbee from 1960 until 1972, much of the time at night, while going to school in the day. He was graduated from the University of Arizona in 1972 with a BS in Geological Engineering. For three years, until the mines closed, he was resident geologist for the Copper Queen branch of Phelps Dodge Corporation, following which he transferred to Ajo, Arizona, where he became the general foreman at the New Cornelia mine. In 1979, leaving Phelps Dodge, Dick joined Sharon Steel Corporation's mining division and became manager of a copper mine in New Mexico, manager of a coal mine in Utah and manager of their Alaskan gold operations in Nome.

He left Sharon Steel in 1984 to become manager of the Ortiz Gold mine in New Mexico, and later the Mesquite mine in California, for Gold Fields Mining. In early 1989, Dick rejoined Sharon Steel as Vice-President of Operations.

Dick's mineral collection is restricted to minerals from Bisbee and contains 400 high-quality specimens, including many he collected as a child. The mineral graemite was named for him in 1974, described from a specimen collected while he was in high school.



Robert J. King



William J. Thomas

Ronald B. Gibbs

1982—"The Boltsburn mine, Weardale, County Durham, England"

(vol. 13, p. 5–18)

Robert J. King was the award recipient in absentia in 1982. Not only was the subject material other than Arizona, the site was overseas.

The locality described is known throughout the world for its prized fluorite specimens. Since the 1800's, fine specimens have come from the Boltsburn mine.

Bob King earned a PhD from the University of Leicester, where he subsequently served as a member of the geology faculty until his retirement. He had been a museum associate in geology at the National Museum of Wales for several years, then became curator of the John Moore Countryside Museum in Tewksbury, near Gloucester, Great Britain.

For more than 40 years, Bob worked to assemble "one of the most extensive and finest contemporary collections of British minerals," which now forms the core of the collection of the National Museum of Wales in Cardiff. A protégé of the late Sir Arthur Russell, he founded the Russell Society and was the first editor of its journal. Bob is an expert on the topographic mineralogy of Britain, and on the conservation of mineral collections.

Bob resides in Tewksbury with his wife, Sally, and their two children. He is building a second collection of minerals, with a special focus on quartz. He is also an active gardener and chorister.

1983—"Famous mineral localities: The New Cornelia mine, Ajo, Arizona"

(Fifth Arizona issue, vol. 14, p. 283–298)

The 1983 winners returned attention to Arizona. This was the first article to win with more than one author.

The New Cornelia mine at Ajo is the type locality for ajoite and papagoite. Many fine specimens of azurite, cuprite, copper and gem-quality shattuckite have come from the district.

William J. Thomas's father was an apprentice blacksmith who came from England and worked in the Southwest, at one time at the Vulture mine near Wickenburg, Arizona. His parents met there and were married in Prescott. Jim was born in Arroyo Grande, California, and was taken to Globe, Arizona, when he was two. He received his degree in Mining Engineering from the University of Arizona in 1940. While studying at the university, he also worked at Miami Copper Company's Ruby mine near Nogales. Between 1940 and 1941, he worked at Ajo. After serving five years in the Air Force, attaining the rank of Captain, he returned to Ajo, retiring there in 1980.

Jim is a mineral collector. He still lives in Ajo with his wife, Charlotte.

Ronald B. Gibbs was working at the New Cornelia mine when he and Jim wrote this article. His father was a member of the Santa Clara Gem & Mineral Society and his field collecting began on the club's field trips.

Ron wrote: "I have always been interested in rocks and minerals." He became even more active after receiving his degree in Geology from Humboldt State College, Arcata, California, in 1972. His collecting activities have centered primarily in California and Nevada.

In 1978, after four years in the Navy, Ron was graduated from the University of Nevada, Reno, in Mining Engineering and went to work for Phelps Dodge Corporation at Ajo. In 1984, he transferred to the Tyrone Branch of Phelps Dodge in New Mexico and is presently at Phelps Dodge's Chino mines in that state.

Ron enjoys micromounting but also collects miniatures and thumbnail specimens. His articles about the places he has collected and worked have added to the pleasure and knowledge of many other collectors.

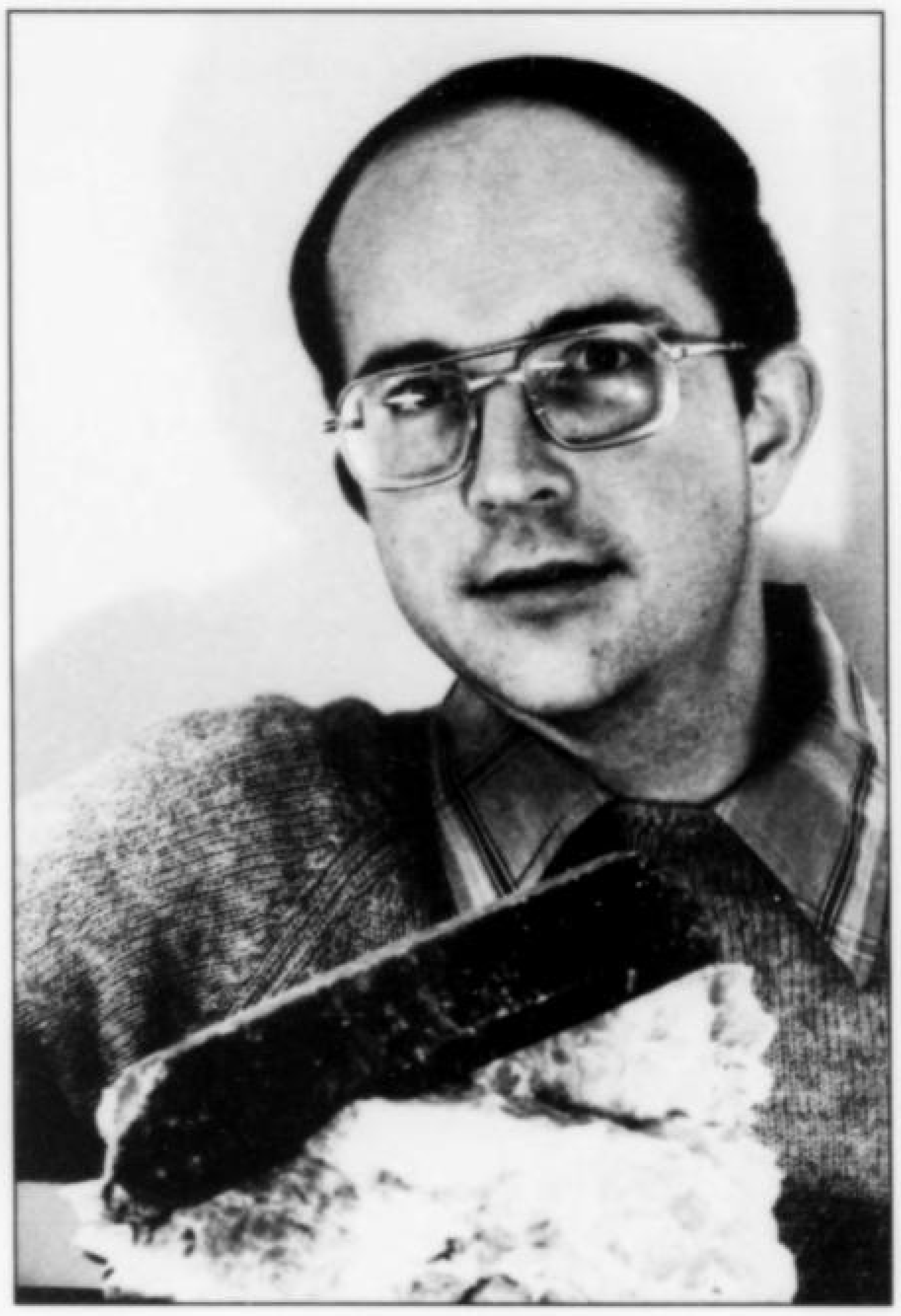
1984—"Famous mineral localities: the Sterling mine, Antwerp, New York"

(vol. 15, p. 199–216)

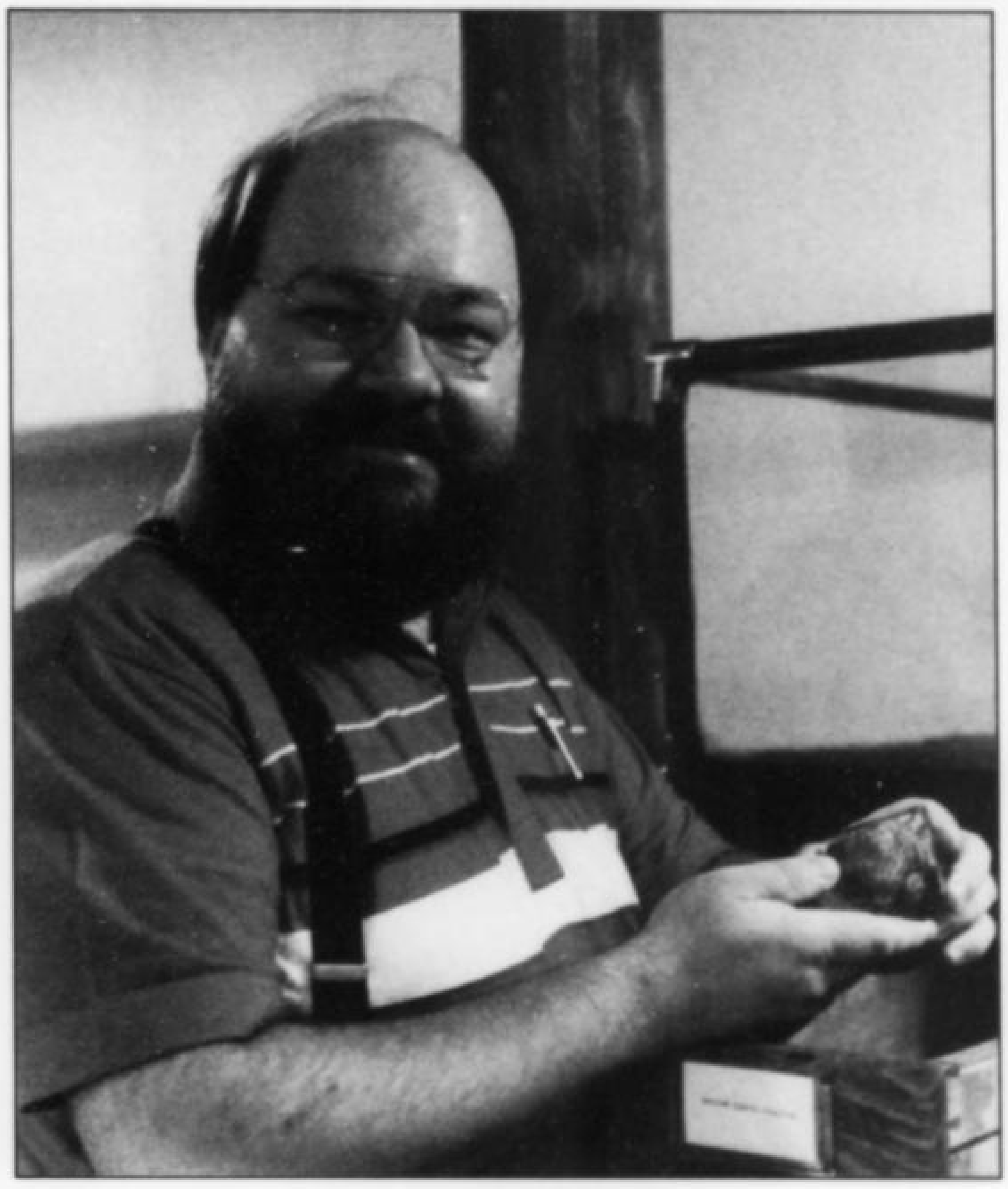
The authors call attention to the history and minerals of the Sterling mine in New York, the first and foremost locality for the nickel sulfide millerite. This mine has produced specimens for over 150 years; in more recent years, collecting activity has uncovered specimens of pecoraite pseudomorphs after millerite.

George W. Robinson earned a PhD from Queens University in Kingston, Ontario. For several years, he was a mineral dealer in Ogdensburg, New York. He is currently a curator in the Mineral Sciences Division of the Canadian Museum of Nature (formerly the National Museums of Canada) in Ottawa.

An expert in regional mineralogy, George is an active field collector on behalf of the museum. With others, he has described several new mineral species, including geerite, tiptopite and erhlite. The core of his personal collection, rich in self-collected specimens from New



George W. Robinson



Steven C. Chamberlain

York and Canada, is now at the CMN. He was instrumental in bringing the William W. Pinch collection to the CMN, and is presently engaged in planning new exhibits in geology and mineralogy.

George and his wife Susan, a noted artist, are familiar figures at the mineral shows in Denver, Tucson and Rochester, where George conducts the annual "What's New in Minerals" program. George is an associate editor and a member of the board of directors of the *Mineralogical Record*. He is also an avid pilot and photographer. He and Susan live in Manotick, south of Ottawa, Ontario.

Steven C. Chamberlain earned a PhD from Syracuse University, where he is currently Professor and Chairman of the Department of Bioengineering. His mineral collecting activities began in high school under the tutelage of the late Davis M. Lapham of the Pennsylvania Geologic Survey. In addition to his research on vision and hearing, in recent years he has begun professional work in mineral biogenesis and regional mineralogy, describing the first occurrence of biogenic witherite and investigating the origin of Herkimer "diamonds." As a field collector, he is a specialist in the regional mineralogy of New York State.

Steve is co-chairman of the Rochester Mineralogical Symposium, a consulting editor of *Rocks & Minerals* and the *Journal of the Russell Society*, and volunteer curator of the Oren Root Collection at Hamilton College.

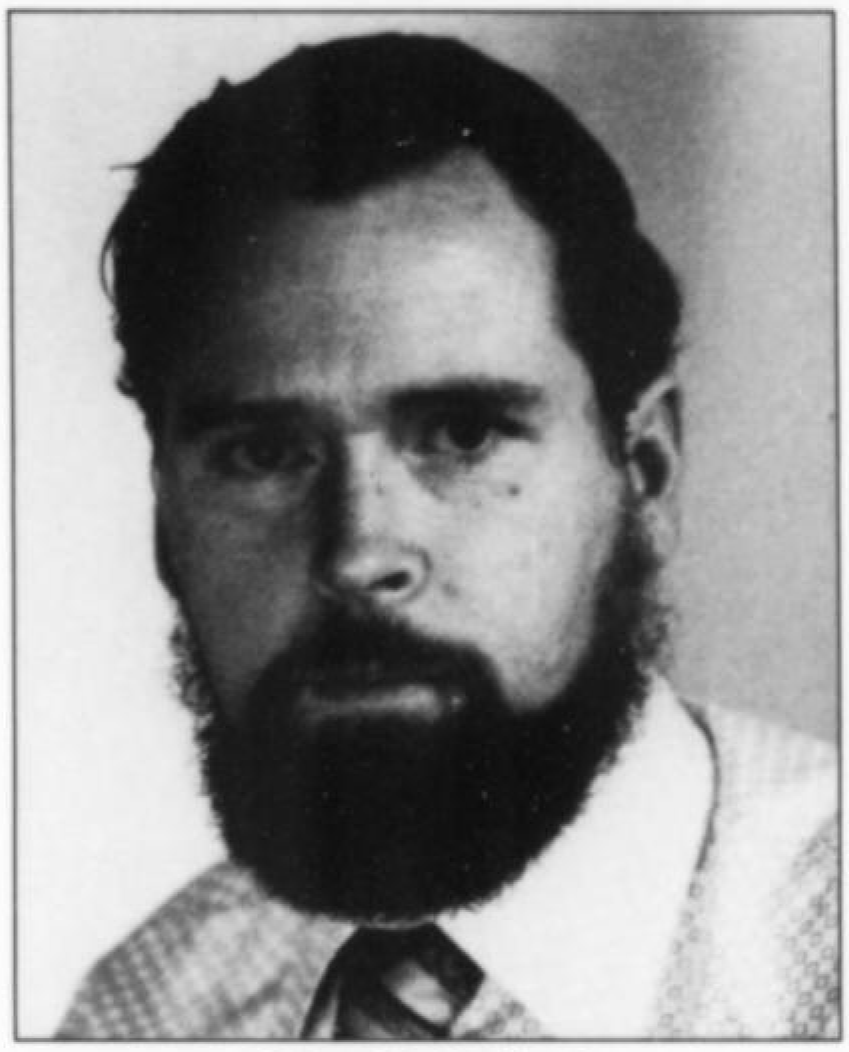
He resides with his wife Helen and his mineral collection in Manlius, New York. He is also "an addicted photographer and opera buff."

1985—"Famous mineral localities: The Kingsgate mines"

(vol. 16, p. 265–289)

Australia's leading producers of molybdenite and bismuth in the early 1900's were the quartz pipe deposits of the Kingsgate mining area in New South Wales. This is the only article, other than "The Boltsburn mine, Weardale, County Durham, England," to win without color illustrations.

Brian M. England wrote this article as the culmination of several years of work on the minerals of the Kingsgate mines which he had first visited as a schoolboy in 1962. At the time, the abandoned dumps were virtually untouched. He made several of his trips with old-time miner Jack Lawlor of Glen Innes, who taught him the mining history of the area.



Brian M. England

Brian's interest dates to his early childhood, fed by visits to museums in Sydney, and encouraged by his parents. That support undoubtedly faltered a little when he and a clergyman's son "wagged school" to dig up leaf fossils in a local quarry.

Formerly an avid field collector, he now purchases most of the specimens for his display-quality collection.

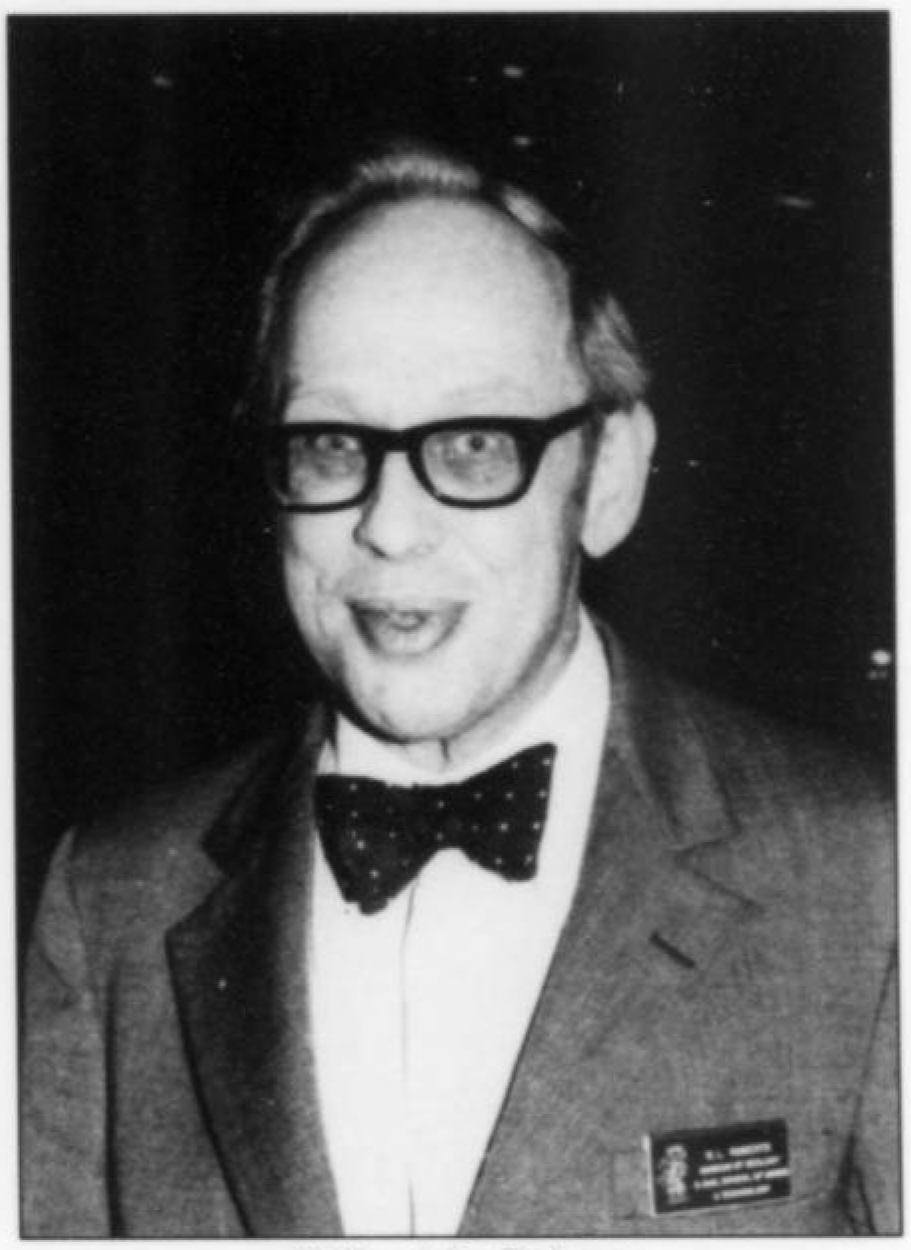
Brian received his Certificate in Metallurgy from Newcastle Technical College in 1968; a Gemmological Association of Australia Diploma in Gemmology in 1971; and a BSc in Earth Sciences from Macquarie University, Sydney, in 1986.

He is employed as a Research Officer (Geologist), BHP Research and New Technology, Central Research Laboratories, Shortland, New

South Wales. Since 1969, he has contributed over 50 papers on Australian mineralogy to journals worldwide. He has just completed a book (updating a 1982 publication) on the Hunter Valley Region of New South Wales.

Brian is a member of the editorial review board of the *Australian Mineralogist*; Research Associate of the Australian Museum, Sydney; and valuer (mineral specimens) for the Federal Government Committee on Taxation Incentives for the Arts.

Further, he is a member of the Geological Society of Australia, the Mineralogical Society of NSW, the Australian Society for Electron Microscopy, associate member of the Mineralogical Society of Great Britain, and a Fellow of the Gemmological Association of Australia.



Willard L. Roberts

1986—"Phosphate Minerals from the Tip Top mine, Black Hills, South Dakota"

(vol. 17, p. 237–254)

The Tip Top pegmatite, in the 1880's considered a tin prospect, has since yielded over 50 phosphate minerals, including ten new species, and many specimens which are the finest known for their species.

Thomas J. Campbell is currently an exploration geologist for Homestake Mining Company in Lead, South Dakota, and is working on his PhD in Geology at the South Dakota School of Mines & Technology.

Originally from Ohio, Tom became interested in minerals at an early age, through friendship with the late Frank Mabry, operator of a large jewelry firm in the Akron area, who had an extensive gem and mineral collection. His interest grew while he was studying minerals and geology at the University of Akron, where he earned a BS in 1980. He received an MS in geology from the South Dakota School of Mines & Technology in 1985. While there, much of his research was directed by his "friend and mentor, the late Bill Roberts, one of the finest men and best classical mineralogists anyone could hope to be associated with." Their joint fascination with pegmatites and pegmatite mineralogy led to their investigation of the Tip Top pegmatite near Custer, South Dakota. Their study culminated in Tom's thesis and this prize-winning article.

Tom discovered the minerals tiptopite, fransoletite and pahasapaite, and helped characterize several other new species during his work with Bill Roberts.

The author of numerous publications, Tom recently compiled the second edition of the *Encyclopedia of Minerals* with co-authors George Rapp, Jr., and the late Willard L. Roberts. With his co-workers, he has also completed a publication for the U.S. Geological Survey on the Homestake gold mine.

At the February 1985 FM-MSA Symposium at the Tucson Gem & Mineral Show, Tom received an award from FM for the best student paper submitted. It was entitled "Phosphate minerals from the Tip Top pegmatite and some new phosphates from the Black Hills, South Dakota."

Professional affiliations include the Mineralogical Society of America, Mineralogical Association of Canada, and the Society of Economic Geologists. He is a member of Sigma Xi.

Tom's interests, aside from minerals, include astronomy, archeology, body-building, nutrition, hiking, camping, fishing and other sports. He resides in Black Hawk, South Dakota, with his wife Cindy and two young daughters.

Willard L. Roberts was born February 12, 1923, in Epworth, Iowa. His maternal grandfather introduced him to mineral and fossil collecting at the age of five, and his interest grew. He graduated from high school in 1941 and attended the South Dakota School of Mines for a year. From 1943 to 1946 he was a noncommissioned administrative officer in the Air Corps, stationed in England and France. On returning home, he married in 1946 and began a career as an official in the government of Rapid City, Iowa, which lasted until 1966, when his full-time employment at the School of Mines began.

In the 1950's, Bill took technical courses at the South Dakota School of Mines and pursued an extensive program of self-education. He started at the Museum of Geology as research associate (part time 1963–66), and was subsequently appointed senior curator of mineralogy and invertebrate paleontology until his death on March 23, 1987.

Bill was involved with the description of at least 19 new minerals. Robertsite, one of the South Dakota phosphates, was named for him.

Bill's personal records were the principal source of data for *Mineralogy of the Black Hills* (1965) by Roberts and Rapp. He again collaborated with George Rapp, with extensive help from his wife Jean, in compiling the *Encyclopedia of Minerals* (1974).

Bill was a member of Sigma Xi, the Mineralogical Association of Canada, the American Association of the Advancement of Science, the American Institute of Mining, Metallurgical & Petroleum Engineers, and several other societies.

Bill was also active in athletics, excelling in tennis, pole vaulting and gymnastics.

1987—"Minerals of the Carrara Marble"

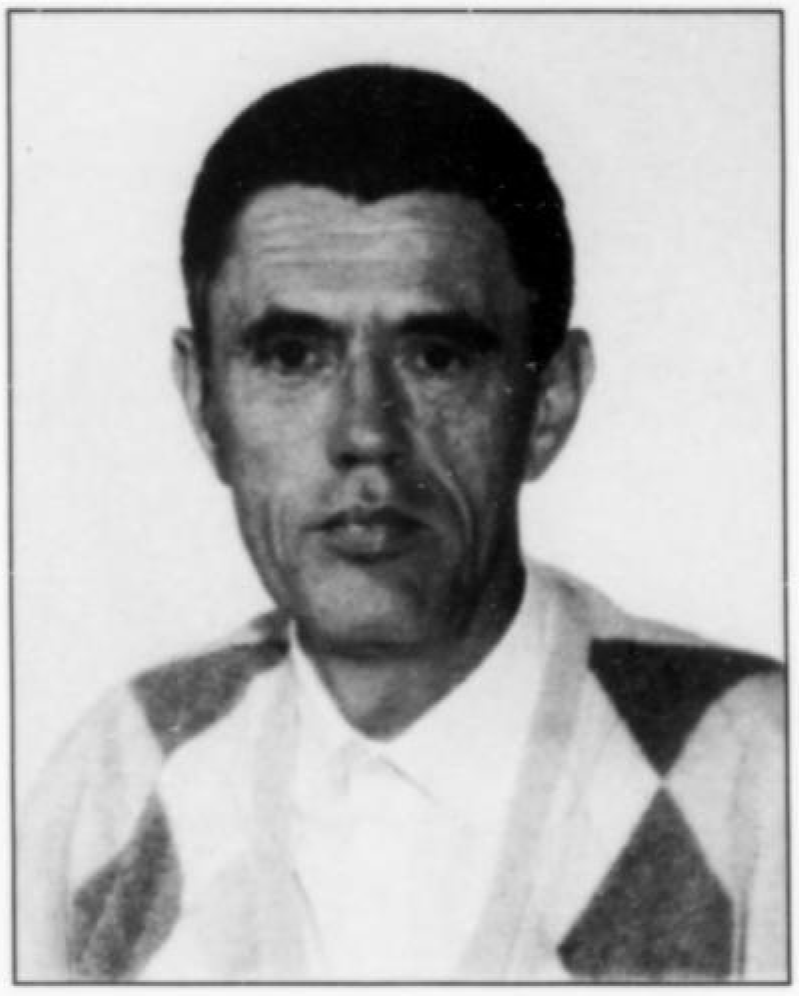
(vol. 18, p. 263–296)

Renato Pagano (Milan, Italy), who prepared the English translation of this article, hand-carried the Certificates of Award back to Italy and sent them to the four authors, M. Franzini, P. Orlandi, G. Bracci and D. Dalena.

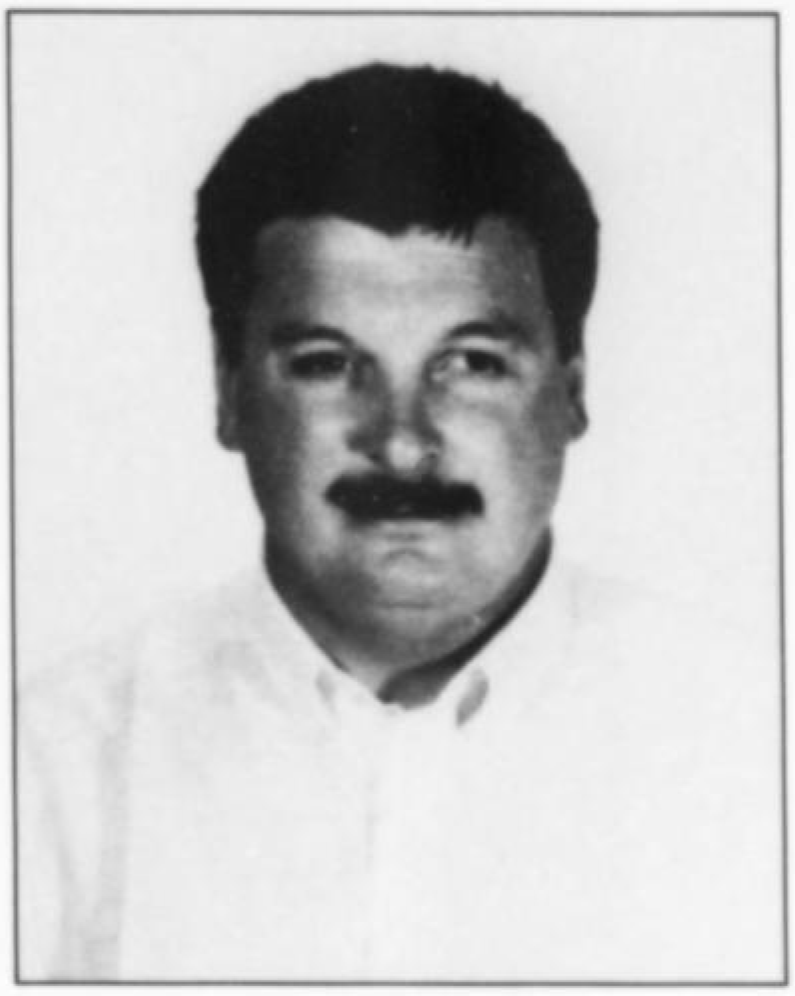
Dr. Pagano compiled a review of the species totals (see below) and the biographies of these four men, and secured their pictures, thus bridging any possible language barrier.

The article is based on a previous work published in 1982 by *Rivista Mineralogica Italiana*, issued by a consortium of Italian mineral clubs. The original work was issued in book form, 110 pages with about 60 photographs and additional diagrams and crystal drawings. It was written by the same authors who wrote the up-dated version for the *Mineralogical Record*. Both articles are the outcome of a project carried out by the authors at Pisa University, to review and up-date all information on the minerals of Carrara.

In 1911, only 18 species were known from Carrara, most of them identified by Giovanni d'Achiardi. By 1967, over 50 years later, only three species had been added to the list, bringing the total to 21. The


Marco Franzini


Paolo Orlandi


Giovanni Bracci

species listed in *Rivista Mineralogica Italiana* in 1982, 15 years later, number 48. Four of the 27 added species were identified by D. Dalena and described in his thesis, and the other 23 species were identified and described by P. Orlandi. Fifty-seven species are described in the *Mineralogical Record* article, the nine additional species having been identified by P. Orlandi.

In the last three years, 15 more species have been added to the list: adamite, chalcopyrite, chlorite group, connellite, cuprite, halloysite, kesterite, magnetite, marcasite, muscovite, smythite, smithsonite, thorogummite, uraninite and vaesite. In the meantime, "gibbsite" from Carrara has been re-examined and shown to be nordstrandite, so the total number of species from Carrara now stands at 71.

Marco Franzini, senior author, was born in Florence in 1938. A student of Prof. Stefano Bonatti, he graduated in Geological Sciences at Pisa University, became Professor of Mineralogy and, later, Director of the Natural History and Territory Museum of Pisa University.

Professor Franzini has written a crystallography textbook and more than 60 scientific papers on structural crystallography, X-ray analysis, Tuscan regional mineralogy, and weathering of marble in monuments. He was awarded the Lincei Prize for Earth Sciences in 1978.

He supervised the writing of the original work and this article, contributing most of the introduction and history sections, and the quartz and albite entries.

Paolo Orlandi, born in 1946, was a student of Prof. Franzini at Pisa University. He graduated in Geological Sciences in 1971. Curator of the University Mineralogical Museum for about ten years, he is now Associate Professor of Systematic Mineralogy at Pisa University.

Orlandi, a specialist in the minerals of Tuscany and particularly of Carrara, has described 15 new species, and has about 60 scientific papers to his credit.

He carried out the re-examination of the Carrara specimens in the Pisa University Mineralogical Museum, and, with the help of his former students G. Bracci and D. Dalena, wrote the descriptions for most of the species in the article.

As a former mineral collector, he is an observer of the rare and unusual.

Giovanni Bracci, born in 1954, earned his Doctor of Geological Sciences degree at Pisa University in 1978. His thesis was on mineral genesis in geodes in the Carrara marble, from the mineralogical, petrographic, geochemical and structural viewpoints.

Bracci worked for several years in oil exploration and is now in charge of the Geology Department of the Pisa Province. He has written 13 papers on mineralogy, sedimentology and related subjects.

His main contribution to this article is the section on the origin of the marble cavities and the related minerals.


Domenico Dalena

Domenico Dalena, born in 1954, graduated in 1978 from Pisa University. His Doctor of Geological Sciences thesis was on mineral species of the Apuan marble formation. He has had 11 scientific papers published on this subject, and made a substantial contribution to the species descriptions in this article.

Dalena is active as a geology consultant and has worked in Italy as well as several foreign countries.

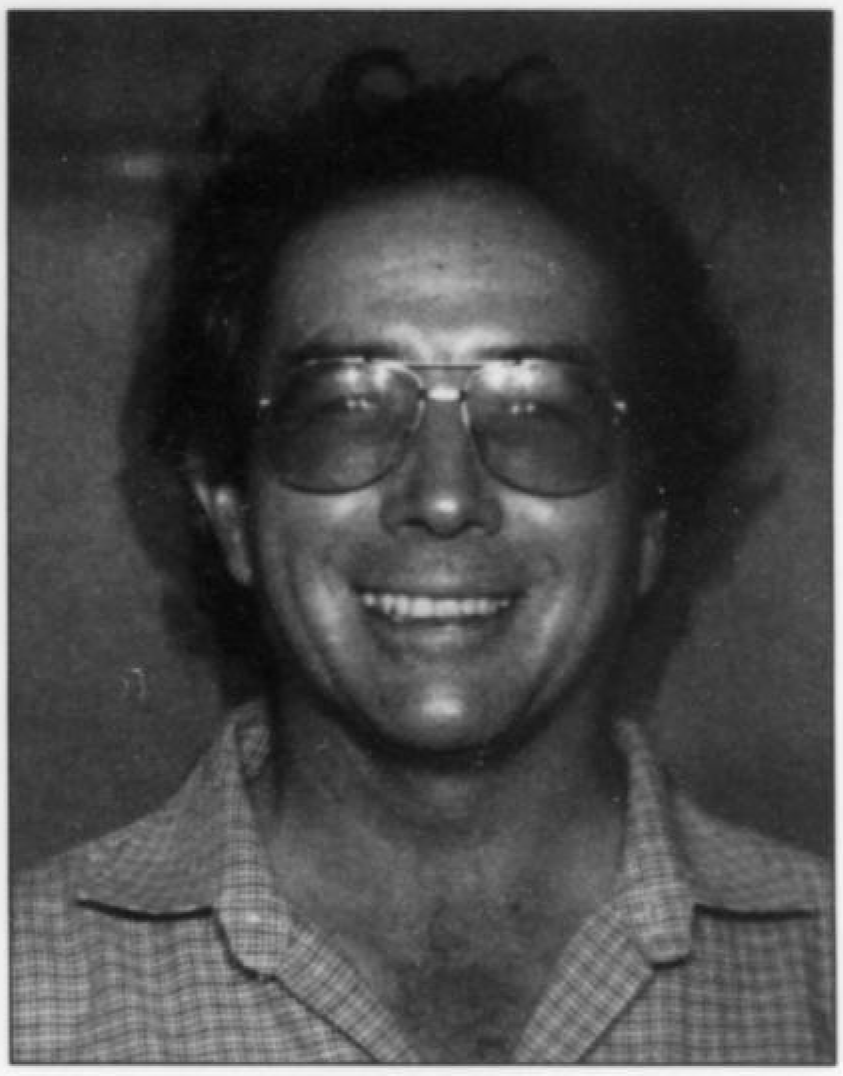
1988—"Volcanic Zeolites and associated minerals from New South Wales"

(Australia issue, vol. 19, p. 389–406)

Extensive outcrops of volcanic rocks occur throughout the eastern part of New South Wales. Vesicles in many of these outcrops are lined with zeolites and associated secondary minerals.

This article brought the Friends of Mineralogy Award to **Brian M. England,** the senior author, for the second time, the only author thus honored. (See 1985—"Famous mineral localities: the Kingsgate mines.") He was in Tucson to receive the Certificate of Award for himself and for his co-author.

Bill Birch of the Museum of Victoria in Melbourne, solicited "Zeolites of New South Wales" for the Australia issue. Brian provided the mineral descriptions and illustrations (except for the section on Kyo-



F. Lin Sutherland

gle). Lin Sutherland provided the geological framework on which the continuity of the article depended.

F. Lin Sutherland was born in 1936 in Calcutta, India, of Scottish and Australian parents. Having completed Launceston High School, Tasmania, Lin attended the University of Tasmania at Hobart, and earned a BSc (Hons) degree in 1962 and MSc in Geology in 1968. He was employed at the Queen Victoria Museum, Launceston, and later at the Tasmania Museum as a geologist, 1962–1972. He was also involved in setting up the Zeehan Pioneers Mineral Museum in West Tasmania.

Lin was Lecturer in mineralogy and petrology at James Cook University, Geology Department, North Queensland, 1970. He was appointed Curator of Minerals at the Australian Museum in 1973 and presently holds the position of Senior Research Scientist in that institution. He received a PhD from James Cook University in 1980 for studies in petrology and high-pressure minerals in North Queensland volcanic rocks. He is a Founding Patron and Life Member of the Mineralogical Society of New South Wales.

Lin is married, with three children; two girls and a boy.

1989—"Famous mineral localities: The Uranium Deposits of the Shaba Region, Zaire"

(vol. 20, p. 265–288)

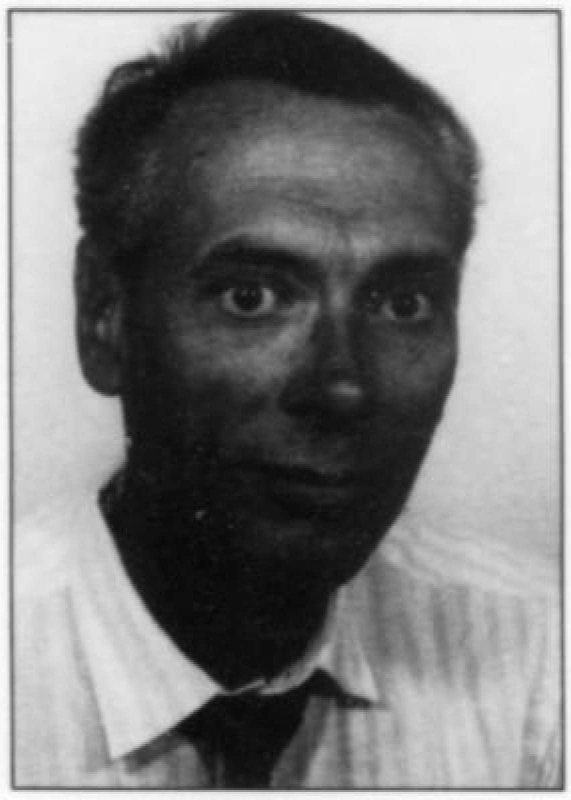
Gilbert Gauthier, senior author and well-known mineral dealer, was present at the 1990 Awards Program to receive his Certificate of Award and those of his fellow authors. He also secured the following information and pictures of these gentlemen.

Since the 1850's, Shaba (Katanga) has been known to be a great mineralized area. Some of the finest and rarest crystallized uranium minerals ever found have come from Musonoi and Shinkolobwe. Nelly Bariand supplied the photography; Wendell Wilson arranged for the English translation and edited the separate works of the four authors into one article.

Gilbert T. Gauthier was born in 1924 in Belgium. He attended the University of Louvain, Belgium, where he earned a degree in Mining Engineering in 1949, and then the Institute Français de Petrole, France, where he graduated as a petroleum drilling engineer (1961). His activities have taken him mainly to Africa, specifically Zaire, Kenya, Angola, Morocco, Gabon, Algeria and Nigeria. In Belgium he worked as a mineralogist assistant and later mineralogy professor; in France he served as chairman of Foramines S.A., Paris. He is currently a semi-retired freelance consulting mining engineer.

Gilbert T. Gauthier

Armand P. François



Michel Deliens

Paul Piret

Armand P. Francois was born in Belgium in 1922. His degrees earned at the University of Liege, Belgium, are Mining Engineer (1946), Geologist Engineer (1948) and Doctor of Science (1972).

From 1949 to 1967, Armand was field geologist at the Union Miniere du Haut-Katanga, Shaba; from 1967 to 1977, Manager of the Geological Department of Gecamines, Shaba; and from 1983 to 1984, consulting geologist at the Societé Miniere de Tenke-Fungurume, Shaba. In Belgium, he served as consulting geologist at the Union Miniere, Brussels, from 1978 to 1983. He is currently a freelance consulting geologist.

Armand has had numerous geological articles published.

Michel Deliens was born in 1939 in Belgium. He holds degrees from the University of Brussels (Licensee in Mineralogy and Geology Sciences, 1961) and the University of Louvain (Doctor in Mineralogical and Geological Sciences, 1972).

From 1964 to 1986, he was employed at the Musée royal de l'Afrique centrale, Tervuren, Belgium, and from 1987, served as Chief of the petrographic and mineralogical section, Institut Royal des Sciences Naturelles de Belgique, Brussels. His specialization involves secondary mineralization of V, Cu, Co and Ni.

Michel has described 31 new species in collaboration with Paul Piret. He is also the Belgian delegate to the Commission on Museums of the I.M.A. He has written numerous mineralogical articles and the famous book, *Les minéroux secondaires d'Uranium de Zaire,* the latter in association with P. Piret and G. Comblain.

Paul Piret was born in Tournai, Belgium, in 1932. He received a degree in Chemistry Science in 1954 at the Catholic University of Louvain (Leuven-Belgium) and a Doctor's Degree in Science in 1956 from the same university. He is currently Professor of Crystallography at Louvain-la-Neuve University, Belgium.

ACKNOWLEDGMENTS

A compilation such as this requires the cooperation of many individuals. An expression of gratitude is due Dr. Steven C. Chamberlain who supplied not only his own biography but those of Dr. Robert J. King and Dr. George W. Robinson, and photographs of Dr. Robinson and of himself; Dr. Renato Pagano for his additional information on the Carrara minerals and for obtaining biographies and pictures of the authors; Gilbert Gauthier for serving as go-between with his co-authors; and each and every author who responded. It is acknowledged that many of their words and phrases are used herein without quotation marks.

And a thank you goes to Dr. Wendell Wilson for his suggestions and encouragement.

Sources of information include the winning articles themselves, "The Memorial of Willard Lincoln Roberts" by James J. Norton in the *American Mineralogist*, **74**, 1397–1398, and in the *Mineralogical Record*, **12**, 186.

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Systematik in der Mineralogie

MINERAL STORIES

Laurence H. Conklin

This new column we plan to devote exclusively to anecdotes from the mineral world. Naturally the first few will have to be drawn from my own experiences, but I hope these will inspire many of you readers to write in with your own . . . practically everybody has a favorite story to tell. If you lack a polished writing style, don't worry; as Wendell Wilson has always said, "That's what editors are for."

My Shot at the Detroit Challenge Cup

One September in the late 1970's or early 80's I was called by an officer of the Detroit Mineral Show committee and asked if I would consider competing for the Detroit Challenge Cup.

Well, this was somewhat awkward because I had never competed in minerals before, do not personally believe in mineral specimen competition in general, and did not (and still do not) have a personal mineral collection with which to compete. It is my belief that it is unprofessional for mineral dealers to collect, thereby competing with their clients for the best specimens. I could never understand how collectors handle that double-standard, but perhaps that is another story.

I explained to the show official that in the interest of cooperation I would agree to set up a case of minerals, but the quality therein would be a direct reflection of what I had in inventory before I left for Detroit. This was promptly and unconditionally agreed to.

Now, I needed an effective but simple way to display my specimens—I was not about to fuss too much. I went to my trusty "nest" of tin cans; a collection of varying-sized empty tins that, when stood up-side-down, made nice pedestals for displaying specimens, and the "nesting" feature made them conveniently portable.

The tin cans worked nicely for the pieces I had chosen, but of course, they (the cans) had to be covered with a sheer fabric, sort of draped all over the case. I confess that I waited until the last minute to go to my local fabric store, and that the selection of suitable cloth was highly limited. I further confess that what I was forced to purchase would have looked better made into a Hawaiian bowling shirt, but heck, it's the minerals that count, isn't it?

Then, labeling became a problem. I simply couldn't affix an individual label to each fabric-covered tin can, so I devised a thoroughly legible key giving all the pertinent information on a single 8½ x 11-inch sheet of paper that was to be affixed to the back of the case.

I trust that by now the reader has realized I did not take the "uniform rules" too seriously; if the project didn't provide fun, why would I do it?

In the end, my case earned a *record score*. It was the *lowest* score ever awarded a case of minerals in the history of the Detroit Challenge Cup! The judges, Paul Desautels and Bill Pinch, were appalled at the fabric (I knew that would happen), did not care for, and particularly criticized, my labeling technique (efficiency, you know) and were not impressed with the variety of my specimens (six beryl crystals, albeit, fine ones, equalled too much duplication for them). But I had the last laugh.

Considering that this was a display case and not a booth, I still had the absolutely best Detroit show, as far as sales are concerned, that I ever had; and that includes two years on the floor at the main show and I-can't-remember-how-many years at the satellite shows.

I sold almost half of the contents of that case, including one major specimen (a superb Cheshire, Connecticut, barite) to *one of the judges* himself.

Free Advice

One morning sometime in the 1960's I was sitting at my desk when the telephone rang. The caller announced that she was Helen Snyder of *Highlights,* on Second Avenue in New York City, and did I want to visit her store and buy some Tsumeb mineral specimens that she had just brought back with her from Africa?

I had known of Helen Snyder, who had serious-collector-quality specimens for sale only very occasionally, but I had never met her. She specialized in assembling large mounds of rock crystal quartz specimens with the help of plaster-of-paris cement and occasionally tinted in a colored ink bath, for use as lamp bases. They brought handsome prices to the interior decorating trade. A few years before, however, one of my clients had shown me a large, superb Lake Jaco, Mexico, grossular crystal of a rich pink color that he had purchased from Helen. I immediately sent him back to her for all that she had; and were they lovely! Each was about soft-ball size and brilliantly lustrous. They had to be that classic locality's best productions of all time. I found homes for them all over the world, but the only one that comes immediately to mind is currently in the American Museum of Natural History. These specimens Snyder claimed to have collected herself at the locality, and there was no reason to doubt her.

Well, needless to say, I lost no time in getting to her shop to see the Tsumeb things. When I entered the front showroom it was easy to see that a large Tsumeb shipment had arrived. Specimens were scattered everywhere, on tables, chairs, shelves and even in trays on the floor. I looked around quickly, picked up one piece, and inquired "how much would you have to get for this?" Snyder replied by asking if that was the only piece that interested me. I said "no," the truth was that I had wanted to test the pricing structure quickly. She then suggested that I go through all the pieces carefully, pick out those that interested me, and she would then make me a lot price. That seemed like a good idea.

I worked at the selection process for at least an hour and possibly two while she went about her work in the rear of the store. When I had completed my selections I had two trays filled with 50 to 75 specimens for which, I had decided, I could pay a maximum of $800, a not inconsiderable sum for those days; $500 would have been better, but I would go to the top price if I had to.

Upon my informing her of the completion of the task she came back to the front room, looked at the two full trays of minerals I had selected, and said, without more than a cursory glance at the specimens: "I'd have to get $7,500 for those." I was shocked and dumbfounded—this could not be real. Was there even that kind of money in the whole mineral business? In my wildest dreams I couldn't have *sold* those pieces for more than one quarter of that figure.

Eventually, resigned to having wasted a morning, I casually remarked that I would return the specimens to their original places on the shelves, etc., before I left. "Oh, no," she said in a voice too forceful and determined for the occasion, "it's okay, just leave them where they are." Then the obvious hit me. I had been invited down there as an unpaid professional mineral specimen expert to highgrade her shipment, and I never really had a chance at buying anything! All she needed to do was to request such an accommodation and reasonable terms could have been arranged, but no, she chose to be foxy.

Realizing that I had to try to recover at least a modicum of my dignity, I asked her if I might look around at the other, mostly Mexican minerals in her showroom with an eye to a possible purchase. "Certainly," she said, and left to go about her business, leaving me alone as before.

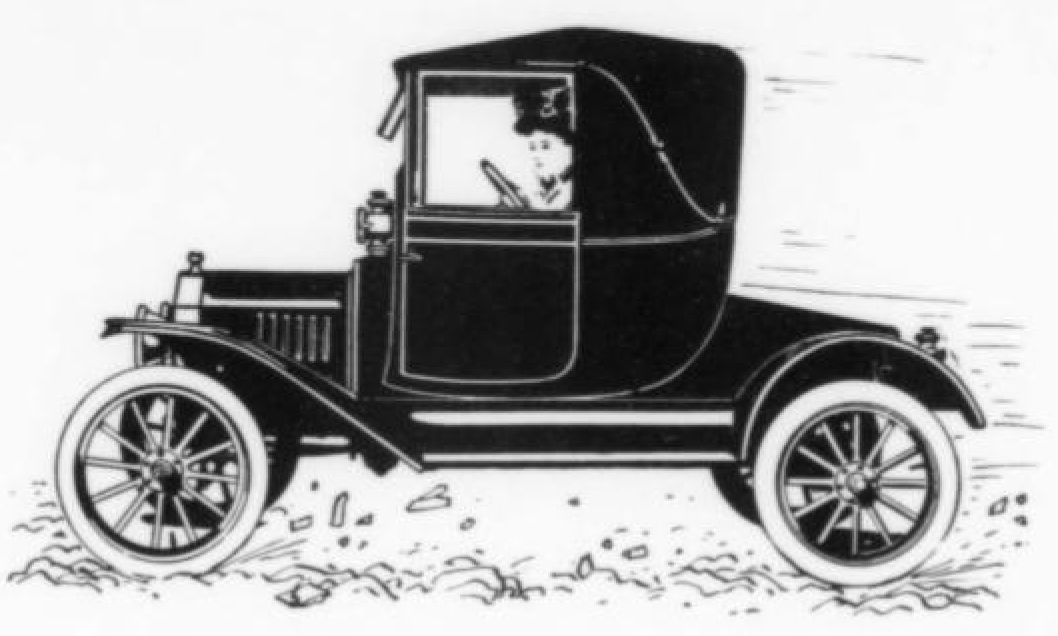
As soon as she left I went speedily and silently about the task of redistributing those selected Tsumeb specimens back to their original, or similar, hiding places on backs of shelves, on chairs, on tables and on the floor. Then I departed without a word.

I never spoke to her again, but some 20 years later I received a telephone call from a young man whose first name was Doug. He told me that Helen Snyder had died and that he was her heir. Clear written instructions had been left regarding her stocks, bonds and real estate, but the only guidance he had been given by her about the disposition of her mineral collection (and this advice offered on her deathbed, and only when it was specifically asked for) was to "call Larry Conklin."

I like to think of this incident as an example of professional respect, but in any case the collection was a fine one. I purchased most of it and arranged for the heirs to donate the balance to the American Museum of Natural History.

The Visiting Experts

I am constantly hearing complaints from my collector-clients about their feelings of isolation. Collecting minerals, or anything else for that matter, in a vacuum, as it were, is not very satisfactory for most people. They truly enjoy sharing their treasures with others capable of enjoying and appreciating them. And this phenomenon operates at whatever level of collecting we can discuss. This is not a new complaint, and it reminded me of a story told to me by my uncle, Anthony Schumacher, the gentleman to whom I owe my introduction to minerals. He began collecting minerals immediately after World War I, and died in 1965.



He, too, suffered from a lack of mineral fellowship and never passed up an opportunity to show off his collection. One day his wife (my aunt, Marie Conklin Schumacher) told him of an impending visit by two ladies of her earlier acquaintance who lived in Maine. "Maine? Maine!" my aunt heard him exclaim. "Certainly people from Maine know what minerals are!" So, he spent the next three days sprucing up the collection, cleaning all the glass doors on the cabinets, replacing burnt-out light bulbs, and so forth, in the winterized back-porch-cum-mineral-room.

The "visitation" day arrived and my uncle sat, not too patiently, out on the porch, he too all spruced up, awaiting his moment. My aunt later confessed that she almost forgot about him, but his constant throat-clearing and shuffling finally caught her attention. She told her guests of her husband's mineral collection as she ushered them out to the mineral room. There was my uncle, gesturing towards his beautiful minerals (and he did have a superb collection), and managing to mumble the word "mineral." Whereupon one of the ladies remarked to the other: "Minerals, oh, minerals, yes," immediately eliciting an expression of relief upon my uncle's face. "Mabel, you know what they are"—now my uncle's expression turned to one of joy—"when we ride in the country, they bounce up and hit the car."

Lawrence H. Conklin
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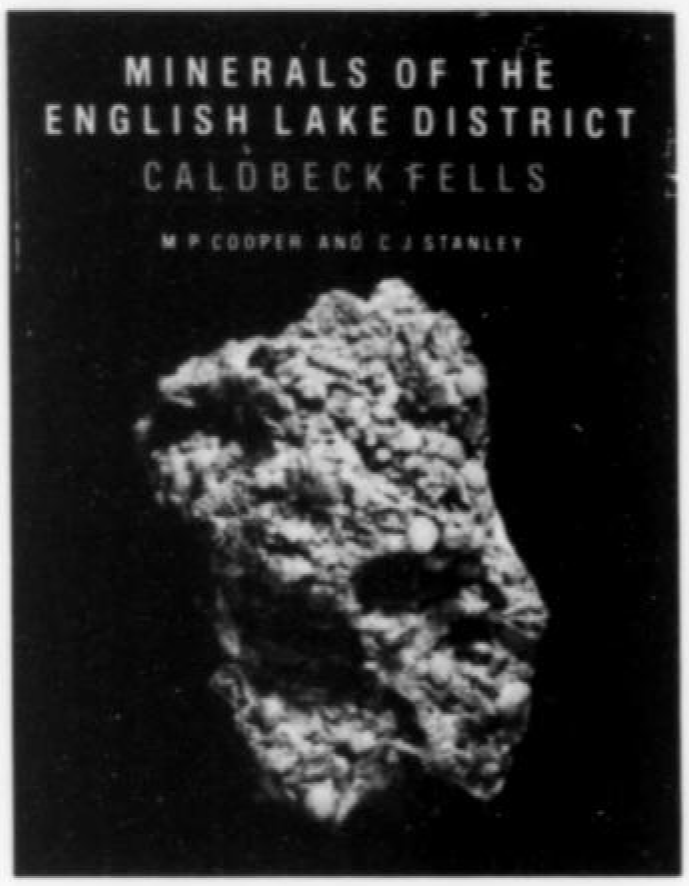
Book Reviews



MINERALS OF THE
ENGLISH LAKE DISTRICT
CALDBECK FELLS
M P COOPER AND C J STANLEY

Minerals of the English Lake District: Caldbeck Fells

by M. P. Cooper and C. J. Stanley. Published (1990) by the British Museum (Natural History), Cromwell Road, London SW7 5BD England. Softcover, 22 x 27.5 cm, 160 pages, ISBN 0-565-01102-2, £14.95.

This excellent survey of the history, geology, mines, minerals and collecting heritage of Britain's famous Caldbeck Fells district began as a famous locality article planned for the *Mineralogical Record* and got out of hand. By the time the authors had finished assembling all the information, their project had grown to book-length. And a fine book it is; patterned more or less after Embrey and Symes' *Minerals of Cornwall and Devon* (1987), it is filled with fascinating information and beautiful color specimen photography. The minerals from the various mines in the district are described, and there is an extensive bibliography.

Caldbeck Fells is known primarily as a classic locality for mimetite and pyromorphite (see the article on these species by the same authors in this issue), but a wide range of other minerals occur there as well. Like Embrey and Symes' book, this monograph is everything the collector could ask for. We can only hope that future books on British mineral districts will meet the same high standard.

W.E.W.

Gems, Granites, and Gravels; knowing and using rocks and minerals

by R. V. Dietrich and Brian J. Skinner. Published (1990) by Cambridge University Press, 40 West 20th Street, New York, NY 10011 (additional offices in Cambridge, England and Melbourne, Australia). Hardcover, 18.5 x 26 cm, 173 pages plus 32 pages of color photos, ISBN 0-521-34444-1, $24.95 excl. postage.

Gems, Granites and Gravels looks and reads somewhat like a beginning college text, designed to introduce students in an interesting way to basic aspects of crystals, mineral chemistry, petrology, soil science, ore mineralogy, and the non-metallic commercial building stones. It may be spread a bit too thin for the beginning mineral collector; on the other hand, the range of topics is insufficient for a beginning course in earth science, and *Dana's Manual of Mineralogy* is far superior for a formal course in mineralogy. Consequently, I have difficulty perceiving the intended audience for this book.

W.E.W.

Der Mineralienführer Ostharz

[Mineral Guide to the Eastern Harz Mountains] by Frank Klose. Published (1990) by A. Klose, Rollberg 39, D-3360 Osterode/Harz, Germany. Softcover, 15 x 21 cm, 139 pages, DM 29.80 postpaid in Germany, add DM 2.90 for postage to the U.S.

Mining areas in the eastern Harz Mountains, Germany, are described and their geologies explained. Twelve separate mineralized districts are identified and located on area maps, with sketches of mine areas where appropriate. There are some black and white photographs, and a useful bibliography. Over 40 mineral species are recorded from the area.

Michael O'Donoghue

Mineralfundstellen im Raum Bad Lauterberg

[Mineral Localities in the Bad Lauterberg Area] by Heinrich Hotze, published (1989) by Doris Bode Verlag, Dürnberg 2, D-4358 Haltern 4, West Germany; part of the "Mineraliensammeln im Harz" series. Softcover, 14.5 x 21 cm, 48 pages, ISBN 3-925094-25-3, price DM 16.80.

Following a discussion of the geological history of the western Harz Mountains, minerals are listed in chemical order for each of ten different mines. Notes on the mining history, and color photography of mineral specimens are included. The area, which was primarily a copper mining district, has yielded fine specimens of fluorite.

Michael O'Donoghue

Le Lapis Lazuli

by Claire da Cunha, published (1989) by Editions du Rocher (28 rue Comte-Félix-Gastaldi, Monaco), as part of their "Lumière des Gemmes" series. Hardcover, 17 x 25 cm, 138 pages, ISBN 2-268-00844-4 (price unavailable at press time).

As far as I can ascertain, this is the only monograph to be devoted to lapis lazuli, at least in recent years. Although most of the book deals with geological and mineralogical aspects, there is a substantial section on historical uses of lapis lazuli, and another on testing methods applicable to lapis and its many synthetic imitations and natural substitutes. There are good-quality color photographs and an extensive bibliography.

Michael O'Donoghue

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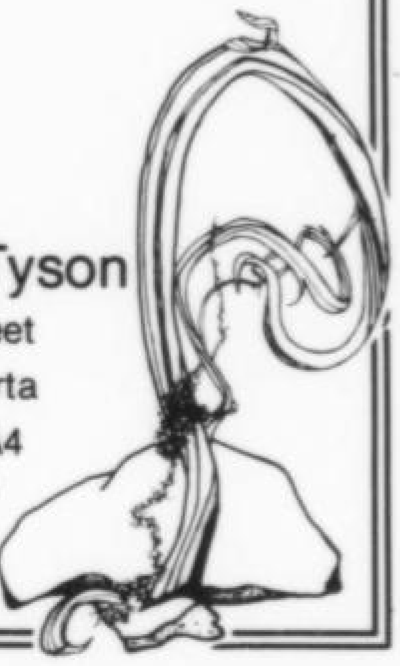

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Letters

ZAIRE MINERAL STAMPS

Enclosed [see above] is a set of mineral stamps issued in Zaire in 1983. The **dioptase,** if from Zaire, could only have come from Tantara (near Shinkolobwe); but it is most likely from Tsumeb or the Congo. The **cuprite** is from one of the Kamoto pits. The **"bournonite"** is undoubtedly plancheite with malachite from the M'Sesa open pit (Kambove). The **malachite** could have come from many deposits in the Shaba Crescent. The **gold** must have come from Kilo-motc in northern Zaire. The **cassiterite** is probably from Kivu province. And the specimen of **uranium** minerals is from Shinkolobwe.

J. Lhoest
Liege, Belgium

IN APPRECIATION

I am writing this letter in appreciation for your magazine. I've been involved with minerals for 55 years. Fifty years ago I drove a Model T up to the Stewart Lithia mine in Pala [California]. Then I moved to Pauma Valley near the tourmaline mines. I worked in the Vanderburg mine for George Ashley, in the Himalaya mine for Ralph Potter, and in most of the other mines as well. I once missed a major pocket in the Tourmaline Queen mine by 2 feet. We also missed a pocket of kunzite spodumene in the Pala Chief mine by 6 feet. So you can see I haven't been too lucky working the pegmatites.

When your first Gold Issue came out (vol. 13, no. 6) I ordered 30 copies, and within the following year sold them all for the face-value price of $5. Little did I know they would increase to $50 in two years! I worked in the 16-to-1 mine and other gold mines, but for a while now I am sidelined. All my life I did two men's work, and as a result I have worn my hips out. As you read this I will be in the Veteran's Hospital in Palo Alto getting a new hip on my left side. A year ago I had my right side done. So I hope to be on the road again digging and dredging for gold next year. Thanks again for your beautiful magazine.

Maurice McKinney

ARKANSAS QUARTZ

We would like to thank people for their participation in the Forest Service Quartz Contract program. Stemming from federal legislation enacted in September 1988, this has been the first program of its kind anywhere on Federal lands, and it has been very successful.

We thought you might appreciate having some information on it:

In the 18 months since the program was introduced, people have obtained **186 contracts** for quartz on the Ouachita National Forest, covering approximately 3,732 acres of Forest lands across five different Ranger Districts.

In the past 18 months, over $25,000 from the contract fees and bonus bids paid under this program have gone back to the State for local counties to be used specifically in school and road programs.

There have been 5 competitive quartz sales held so far, including the first one held in June 1989.

In the first competitive quartz sale, 90% of the successful bidders were from Arkansas. However, in the 4 subsequent sales held so far, 100% of the bidders have been from Arkansas.

In the first two competitive sales, both held in 1989, the nominator was the successful bidder in 73% of the quartz parcels they bid on. However, in the 3 subsequent sales, all held in 1990, the nominators have been the successful bidders for every quartz parcel sold (100%).

With regard to those who cancelled quartz mining claims to obtain the Forest Service quartz contracts, claimants relinquished over 500 mining claims in exchange for contracts.

District Rangers and their staffs at the five Ranger Districts where the quartz contracts have been issued, are now better able to provide more efficient and personal service to the quartz mining community.

Again, we thank everyone for their participation in this important Forest program, and wish you success in your endeavors.

John M. Curran, Forest Supervisor
Ouachita National Forest
P.O. Box 1270, Hot Springs, AR 71902

SPECIALIZATION

I was delighted to see the editorial by Dunn and Francis (November-December 1990) entitled "Specialization in Mineral Collecting," and their list of ways to arrange collections. Those methods are similar to the ways that stamps are exhibited at stamp shows (and the only way to win a medal). They are also the best ways to exhibit minerals. The reason is that it demonstrates that the exhibitor has knowledge of his collection, and that the minerals are more than just natural *objets d'art*. Some mineral exhibits have been shown this way (and I have also), but the most common way, alas, is by size. The AFMS rules for mineral exhibiting should move towards this end and eventually the Educational category could be eliminated; all exhibits would be educational.

Henry H. Fisher
Columbus, Ohio

NEW MICROMOUNTERS DIRECTORY

The 15th Edition of the *International Directory of Micromounters* will be published by the Baltimore Mineral Society at the time of its Micromount Symposium in September of 1991. To ensure that the *Directory* will be as up-to-date and accurate as possible, the following information is needed.

1. The full name and address of any micromounter who would like to be listed in the *Directory*. If the entry is for a married couple, please provide both names. There is no fee for any listing in the *Directory*.

2. Corrections for names and/or addresses of listed persons whose names or addresses (or both) have changed since their publication in the last *Directory* (September 1989).

3. Identification of each person listed in the 14th edition whose mail is undeliverable at a given address. This can be done by removing the face of each envelope returned by the post office and mailing same to this editor.

4. The correct postal code (if any) for each micromounter, if changed or found to be in error in the 14th edition.

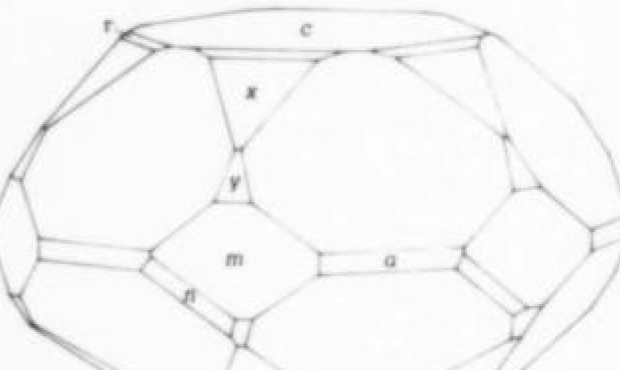
5. Special line of information for each micromounter. Please refer to the Introduction to the 14th edition of the *Directory*.

6. If you are a member of a group, club or society which has five or more members who are active micromounters, please send (or ask the secretary to send) an up-to-date list of such members to this editor. Please include the name of your organization and the name of a member willing to serve as a contact person.

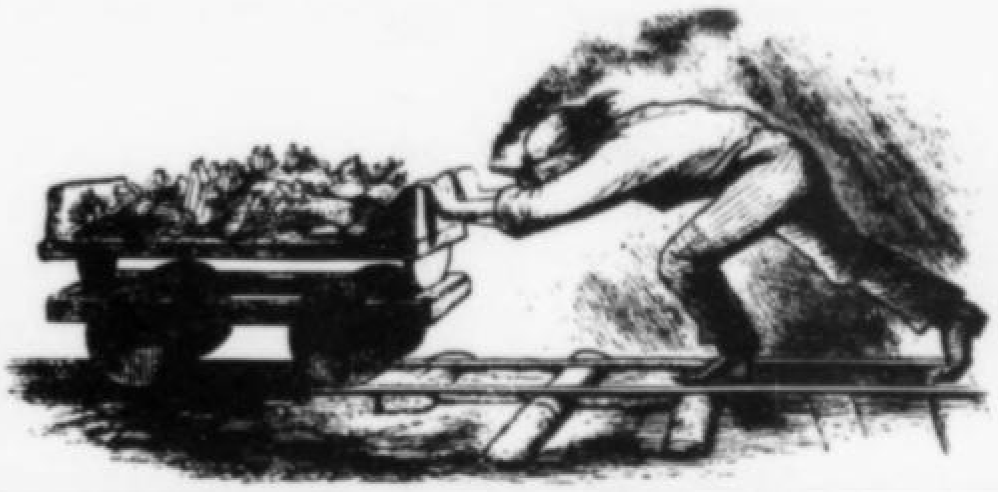
7. The full name and address of each dealer (and the name of his firm) who sells micromounts, micromount material and/or tools and who would like to be listed in the Directory of Dealers, which is part of the *Directory of Micromounters*. Please include a statement as to what the dealer offers and whether or not periodic lists are available. Dealers who use the *Directory* for business purposes can help to keep this *Directory* up-to-date by complying with item #3 above.

The cost of a copy of the 15th edition of the *Directory* is $3.50 PLUS postage and handling. Postage rates in the U.S.A. will be increased early in 1991. As soon as these rates become known, this information will be published. All information and inquiries should be addressed to:

International Directory of Micromounters
c/o Roy I. Grim, Editor
9155-A Hitching Post Lane
Laurel, MD 20723



Colorado Dealers



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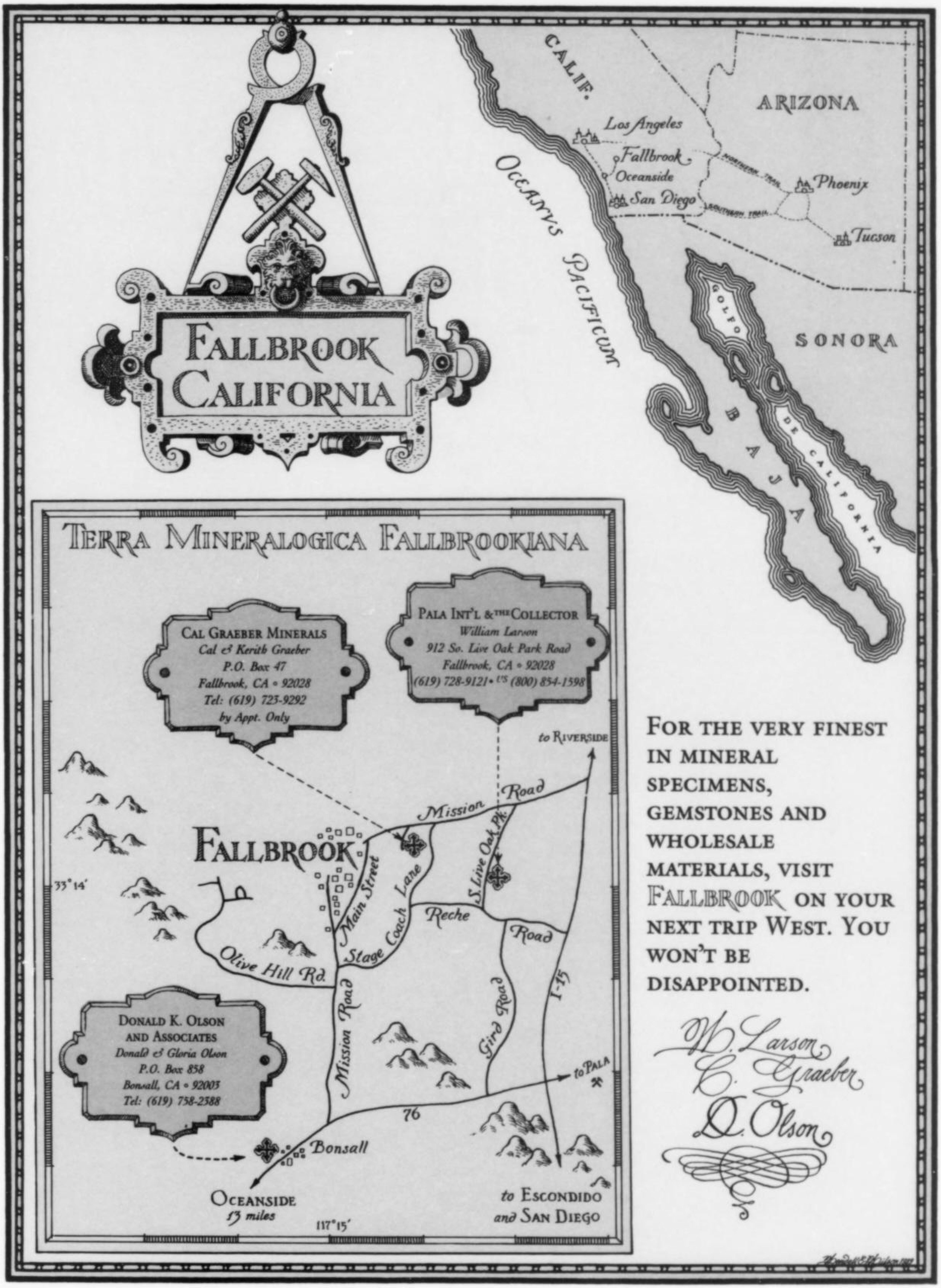
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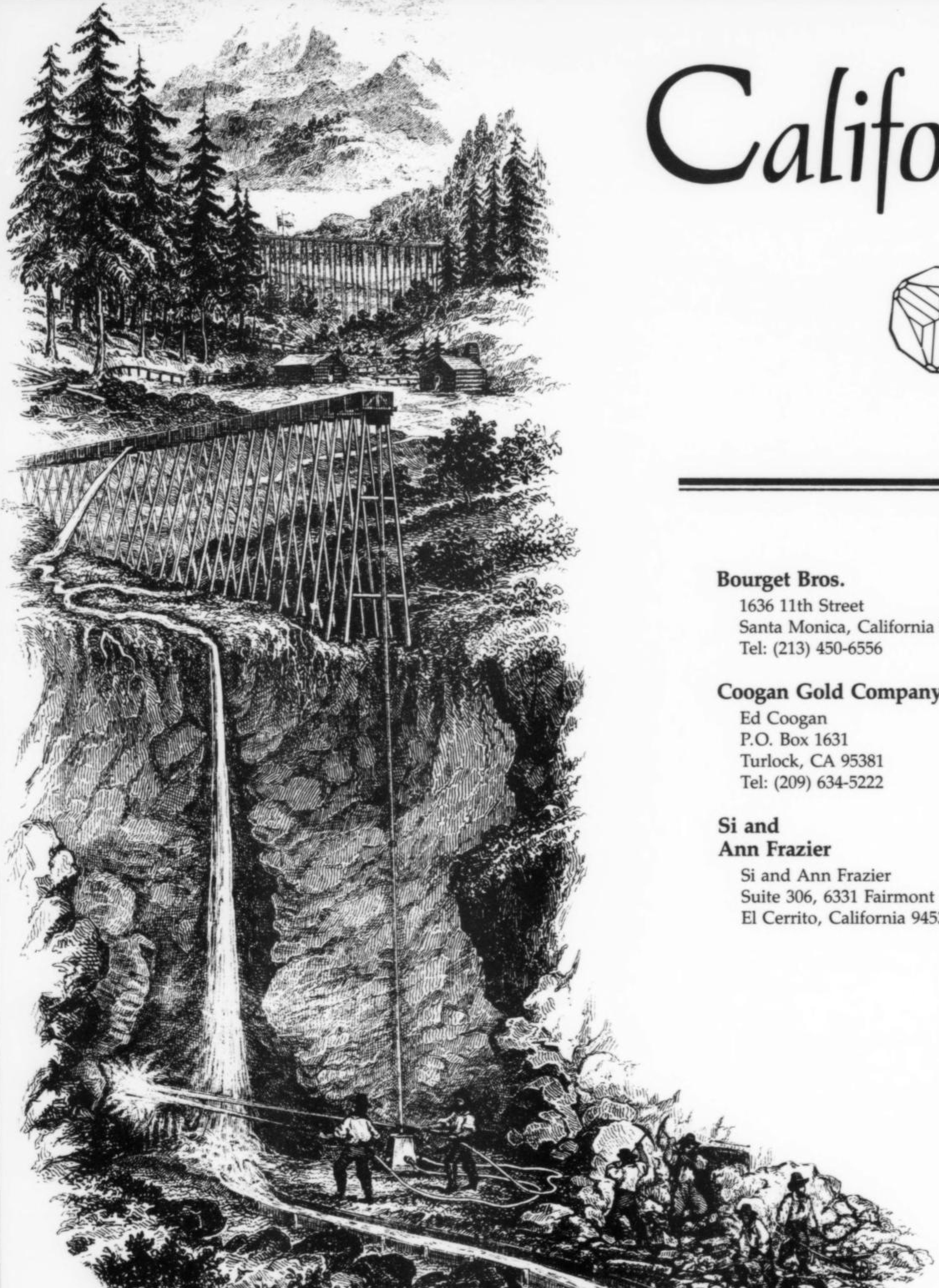

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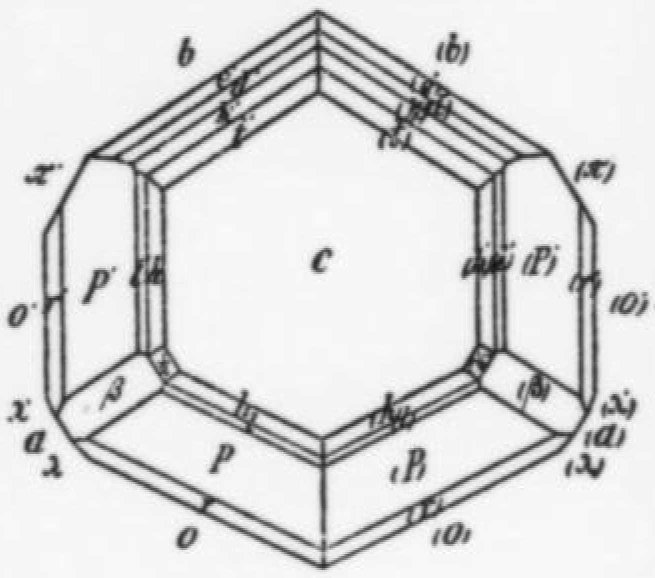

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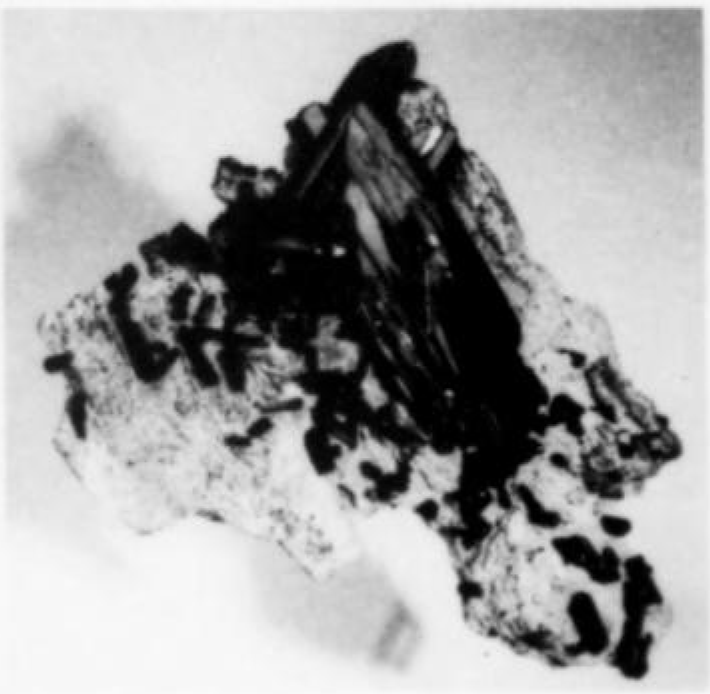

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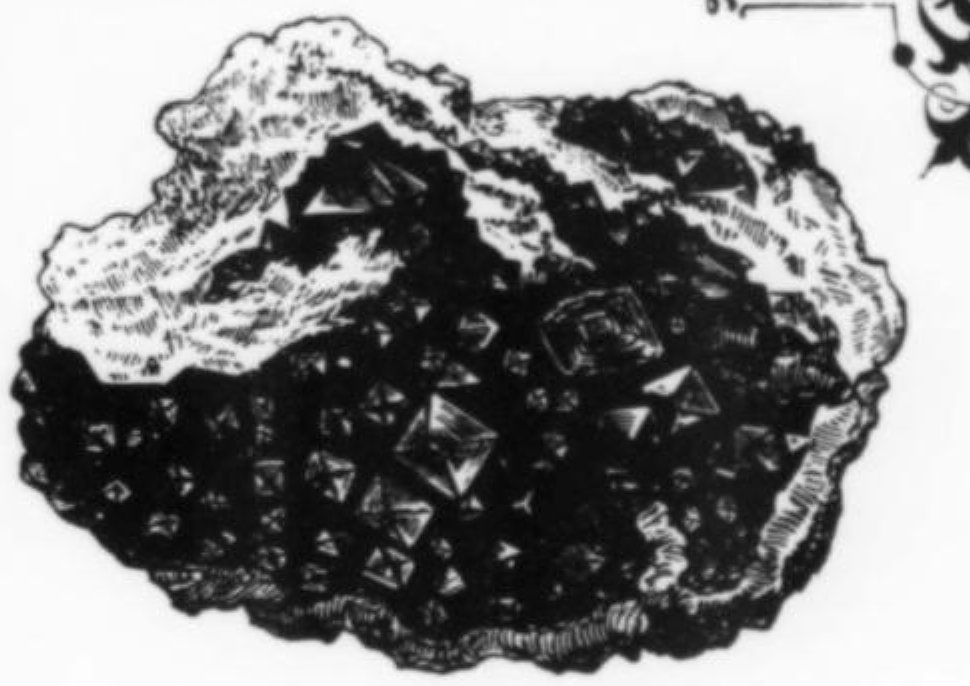

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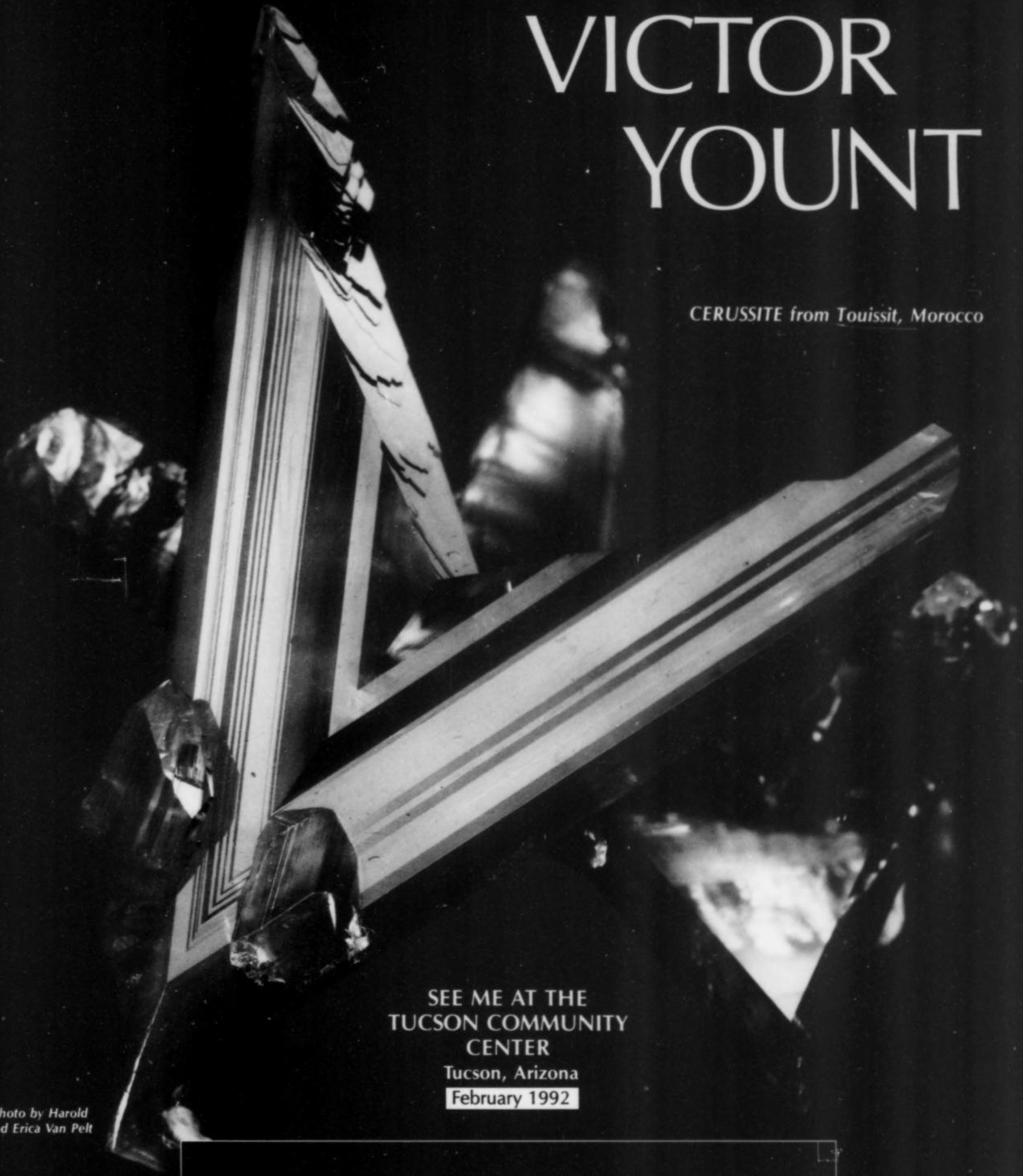

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