the Mineralogical Record

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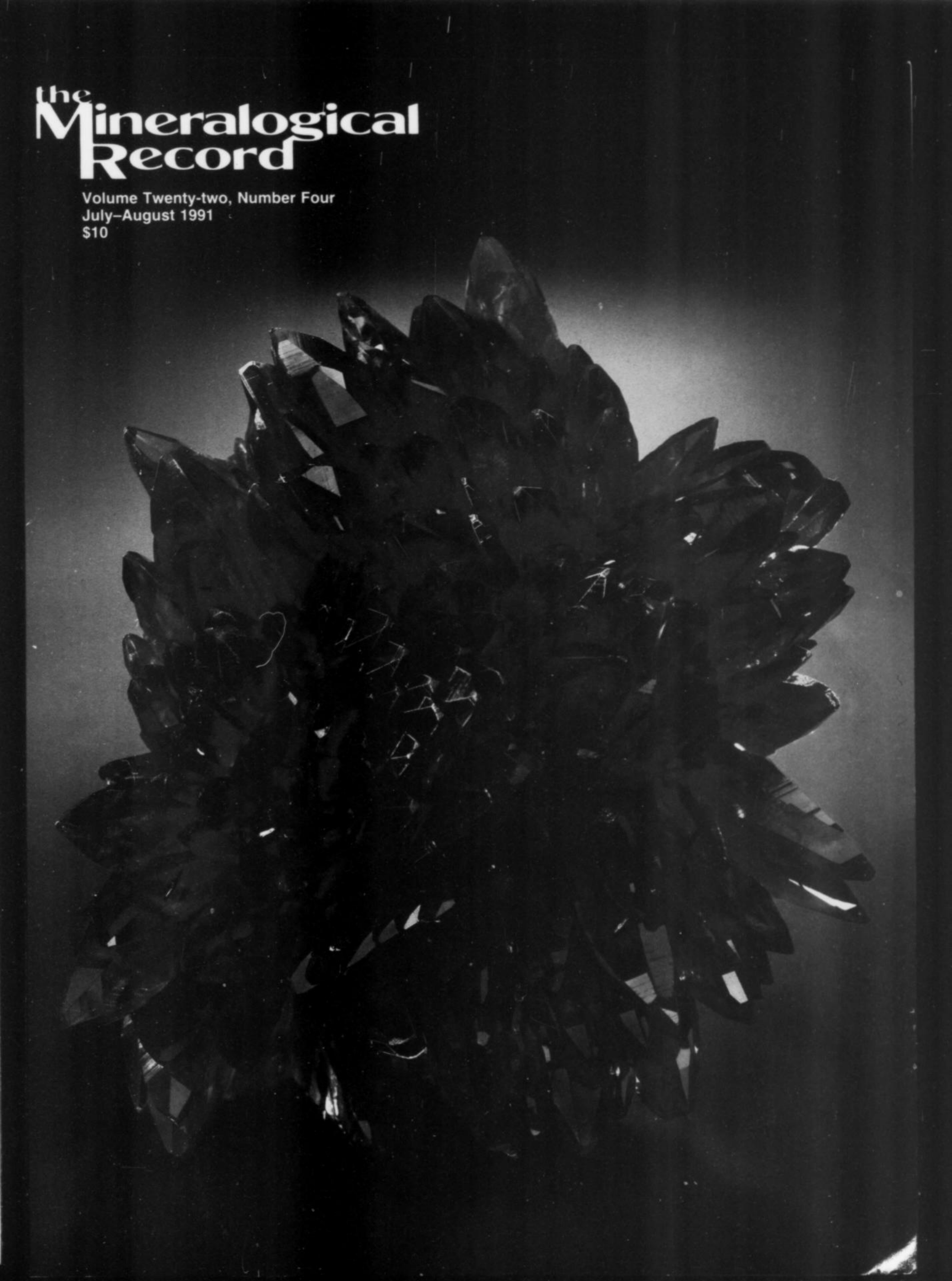

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July–August 1991
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Articles

Columns

COVER: RHODOCHROSITE crystal group, 10 cm, from the N'Chwaning mine, Kalahari manganese field, Cape Province, South Africa. (See the article in this issue, beginning on page 279.) Houston Museum of Natural Science collection; photo by Harold and Erica Van Pelt.

notes from the EDITOR

MINERAL LABEL ARCHIVE

There are numerous mineralogists and historians involved today in documenting the history of professional mineralogy. Unfortunately there is far less effort being expended to preserve the history of *private* mineral collecting, and the work of historical amateur mineralogists and dealers. Because the *Mineralogical Record* is constituted as a sort of "bridge" between the professional and amateur communities, we have a foot in both camps, and are the logical agency for the historical documentation, archiving and publication of matters involving the history of mineral collecting.

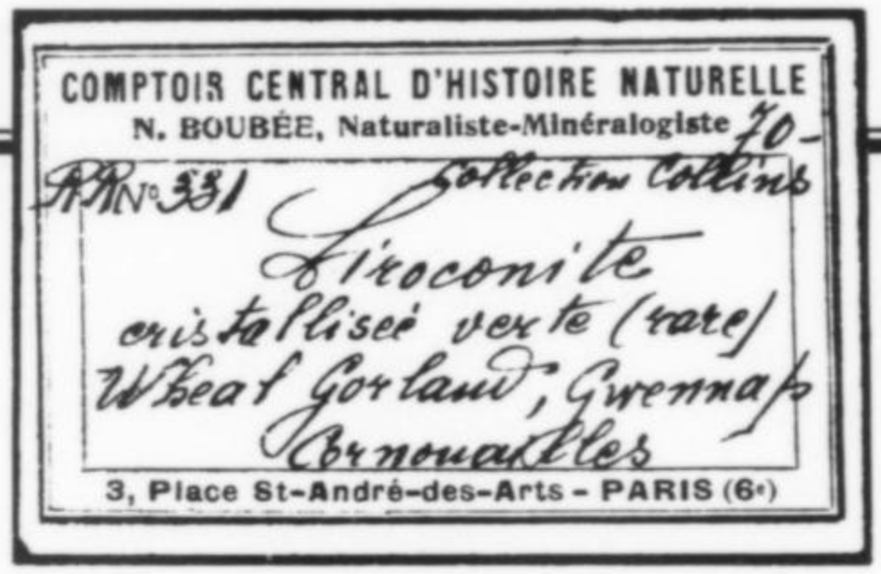
Primary historical documentation of such history is quite scarce; early *mineral labels* are sometimes the only original documents that have survived, and these are fragile things at best, easily broken, lost, destroyed or discarded. Only a few people have ever taken up the systematic collecting of old mineral labels. Neal Yedlin (1908–1977) was one such private historian, and he built up a substantial collection based largely on gifts of labels from various collectors and curators who would otherwise have thrown them away. Neal's collection was eventually acquired by Ron Bentley, who was among the first to publicly advocate the preservation of labels, in several installments of his *Historical Record* column in the *Mineralogical Record* (1977–1978). Ron has continued to expand the collection since then, so that it now numbers in excess of 5,000 specimens.

With that as preamble, the Mineralogical Record is pleased to announce the acquisition of the Yedlin/Bentley mineral label collection, to be permanently preserved as an archival division of the Record Library. We are now (as far as I know) the only non-profit institution committed to the systematic preservation of historical mineral specimen labels for their own sake. In due course we intend to publish catalogs or other compilations of the historical data contained in the archive, for the use of historians and researchers.

Certainly it is preferable for historic labels to remain carefully preserved in association with the actual specimens they describe. But many labels have become separated in one way or another from their specimens over the years, and cannot be accurately matched up again. Although many museums curate their labels as well as their minerals, some do not have a system for preserving labels, and cannot afford the staff time to curate such a sub-collection. For their purposes it suffices to transcribe the label data onto file cards or into their computer databases, thus preserving the information; the original label then becomes simply a curatorial burden without practical value to their system. Lacking a curatorial sub-system, the original labels are not easily accessible by historical researchers. Consequently, uncounted thousands of old mineral labels have been discarded by museums, and this is a real tragedy.

Private collectors these days are even more erratic in their willingness to preserve old labels. In fact, the majority of modern collectors do not even use labels of their own, much less retain the earlier labels. Mineral dealers are generally quite good about transmitting the old labels along with the specimens they sell; but often they find that the buyer simply doesn't want them.

The establishment of the Mineralogical Record Label Archive provides a formal repository where museum curators, private mineral



collectors and dealers can deposit their unwanted labels. For museums the archive represents an appropriate non-profit recipient to which museum materials may be legally transferred for scholarly purposes.

For private collectors and dealers there is the satisfaction of helping to preserve the rich history of mineral collecting, at no real cost to themselves except for the postage involved in mailing old labels to us. In dollar terms the value of old labels is quite low (label collectors have always insisted on keeping it that way), but for a significantly large batch there may even be some small tax advantage associated with the donation.

Our request is that mineral curators and dealers set aside a box into which they place all unwanted labels; periodically the contents can then be transferred into a large envelope and mailed to the Mineralogical Record. Private collectors not interested in retaining old labels are urged to do the same. In this way, everyone can help, and ultimately all will benefit.

LU WATTERS (1912–1989)

As a supplement to the description of the new species wattersite *in this issue, co-author Richard C. Erd provides the following biographical note on the person for whom the mineral is named.*

Most of the following information was given me by Ed Oyler who was a friend of Lu's and got his start in minerals and collecting from Lu. Lu Watters was a mineral collector and enthusiast for at least twenty-five years until he became ill (last five to ten years of his life). He specialized in minerals from the California Coast Ranges; these constituted about 80–90% of his collection. He was the original discoverer of the minerals deerite, howieite, and zussmanite at the Laytonville quarry in Mendocino County, California. He brought the minerals to Bill Nisson (California Division of Mines and Geology) who, in turn, brought them to the attention of the British authors (S. O. Agrell, M. G. Bown and D. McKie). Lu never received any recognition for this nor did he seek it, as he was very self-effacing. As an aside, there never was a descriptive paper for this triumvirate of minerals—only an abstract appeared in *The American Mineralogist* (v. 50, pp. 278–279, 1965). Of course, these minerals have all been extensively studied subsequently, and are the subject of many scientific papers. Nonetheless, it was Lu Watters who first noted them and recognized them as possible new phases. Unfortunately, one of the people who could corroborate this story was Charles W. Chesterman, who died suddenly on Monday, 25 March, and joins Bill Nisson at the great collecting grounds in the sky.

(continued on p. 254)

Some Aspects of Modern Mineral Collection Curation

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INTRODUCTION

It can be safely assumed that curation has been practiced as a profession for a long, long time even though it may have most often been referred to by other titles. Surely some of the earliest collectors, particularly the European nobility, had people to look after their collections, people with responsibilities for maintenance, cataloging, labeling, and inventorying. Despite the long history of curation, however, there exists today widespread confusion throughout the general public and a surprising amount of disagreement among professionals with respect to exactly what a curator does or should do, at least in terms of what occurs within the hallowed walls of natural history museums.

We are, of course, all quite familiar with the classic meaning of the term "curator" (person in charge of a museum collection), but what we find in many of the world's leading museums is a situation wherein the curator is not encouraged to engage in the traditional curatorial activities. Tasks such as collection building, exhibit planning and participation in public training programs are too often not recognized as legitimate functions. Research production at most major institutions, in the form of published papers, has become almost exclusively the activity upon which a curator's performance is evaluated. Tragically, other activities don't seem to matter. It is possible, however, that the pendulum has begun to swing in the other direction, as some major museums appear prepared to recognize once again the legitimacy of these activities.

At least some of this change may be due to political pressure, both from within and without. There has been for some years now an organization composed of mineral curators from most of the functioning museums in the U.S., Canada and Mexico. For the first time ever, curators have been able to get together at least once a year to informally share their thoughts, anxieties and experiences. Previously, these curators functioned essentially in isolation. Communication, in the form of the exchange of ideas, philosophies, concerns, etc., was minimal. Curiously, much of the impetus for the change may have come from seemingly unrelated non-scholarly directions such as mineral shows, mineral clubs, new trends in collector-oriented publications, a more active interest in museums on the part of the collectors (with attendant demands upon the museums that they be more responsive to their needs and desires), and perhaps other even more general factors such as the explosive increase in the mobility of collectors, dealers, and even curators. All of these factors have served to increase the exposure of the curator, whether desired or not. Suddenly people in the mineral world know what is or isn't going on in their favorite museum, and they care! The people who visit museums are making demands. They are no longer satisfied with whatever the museum is content to serve them. At the Smithsonian Institution the development of an ever-expanding program of public and professional involvement* has resulted in the adoption of a proprietary interest in the museum on the part of thousands of our citizens. This has created a momentum that has accelerated to the point where it would be difficult to slow it down. There are, no doubt, other reasons for these changes as well.

What all this external and internal pressure has done is to dramatically alter the nature of the perception of the curator's job. No doubt, however, the overriding factor is that of increased public exposure of the curator. The situation has changed from one in which the curator had to be concerned about no one but his museum superiors, to one in which his activities are subject to comparison by the collecting community with those of curators from other museums. This is a change, by the way, that is possibly much more welcome to the curator than to the administration which, I remind you, most often thinks primarily in terms of scientific research production. Ironically, it is the administration that has evolved a distorted view of what a curator's role should be; the public seems to have a better one. The public wants a curator who cares about collection development, public exhibits, public programs, and a high level of interaction with collectors. The public doesn't care about scientific research. It is the public, after all, that subsidizes most museums through taxes; they are paying the bills.

So, how has the curator's job changed? What is perhaps the most significant change is the perception of an increased need for improving the quality of records relating to inventory, transaction documentation, and specimen action justification (acquisitions, exchanges, deaccessions). Some of the external factors that have facilitated or dictated this particular change include (a) the advent of the computer and the

*Examples include: attendance at mineral shows by staff, the giving of talks at shows and club meetings, conducting of field trips, behind-the-scenes tours, more exposure through news releases and articles in the more popular journals, involvement with the federations (as in the American Golden topaz, the postage stamps, etc.), involvement with jewelry trade organizations and increased exposure in their publications, the Naturalist Center, the Smithsonian "Outreach Program," participation in organizations such as the Mineral Museums Advisory Council and the International Mineralogical Association.

recognition that its increasing importance cannot be denied, (b) the ascendancy of the watchdogs (auditors, registrars and nervous administrators) whose role is to keep everyone's actions above suspicion of potential misconduct, (c) the extreme escalation of the value of specimens in the ever expanding commercialization of minerals (especially the heretofore unappreciated rare and type species), and the subsequent increased threat of theft or advantage-taking in transactions with dealers, collectors, or more sophisticated museums. This latter factor has dramatically changed the way in which we handle high value specimens when loaned to other institutions or sent to shows. It was once quite casual, even while art museums had long ago evolved complex documentation systems to protect their objects and the jobs of their curators when these objects were exposed to risk. We have learned, belatedly, a great deal from the art museums. We have discovered facilities reports, condition reports, loan agreements. Our office bookshelves, once limited to mineralogy and crystallography texts, now might include such titles as:

Guidelines for the Curation of Geological Materials
Legal Problems of Museum Administration
A Legal Primer on Managing Museum Collections
Essentials of Management
Help! For the Small Museum
The Grass Roots Fundraising Book
The Foundation Fundamentals

ACQUISITIONS

It seems to me that determining the focus of an acquisitions policy or strategy is something that is seldom given the attention it deserves. Naturally, objectives will differ among different museums. That the specific objectives often aren't clearly defined would seem to be due (perhaps) to the fact that curators are by nature acquisitive and frequently tend to want everything they can get their hands on. I am aware of situations in which the volume of material accessioned has been proposed as a measure of a curator's effectiveness. The lack of a focus, all too often, reflects a failure to define a collection growth policy, with the result that acquisitions are altogether random. This is especially true when materials are donated. It is the rare curator who will turn down an offer of a collection of minerals even if they are largely redundant or outside the scope of his museum's collection objectives.

It is obvious that *major* museums, and these often are the world's "national" museums, ought to have the broadest focus in their collecting. Inasmuch as there are archival justifications for collections, beyond the beauty of the specimens, *some* institutions *must* assume the responsibility for preserving this material which often is as important historically as it may be scientifically. Since there are fewer national museums than nations, it becomes even more imperative that the biggest and most prominent of these assume a very active stance in their acquisitioning. They cannot, for example, limit their collections to the minerals that occur within their own boundaries. Smaller museums can readily justify operating with a more narrowly focused acquisitions objective and they definitely do not need to compete across the board with the larger ones. The ultimate significance of their collections may be compromised if they do.

Often when I get on this particular soapbox I find that I feel a bit defensive because I fear that my motives might be misunderstood, that my posture will be interpreted as self-serving. In reality it is anything but that. In many ways I would much prefer to work in a smaller museum with a narrower focus because it would be so much simpler a challenge. Not only would there be a smaller geographic area to be responsible for (as, for example, a county or state museum), but there would be no particular need to actively pursue 80 to 90% of the known mineral species and no need at all for type or described specimens. The exhibition challenge, too, would be correspondingly simpler. At the Smithsonian, when asked if we have a want list, we say we want everything! You can imagine how frustrating it can be to try to pursue everything.

In the course of my career at the Smithsonian there have been numerous changes in the area of acquisitions. In terms of what is generally available in the mineral market there has been a revolution, brought on, I suspect, by the proliferation of mineral shows more than anything else. The net effect is that where we once had a rather limited number of fine specimens to spend our money on, we now have literally thousands to select from. In addition, there is the burden of the rare species material. In recent years an alarming number of mineral dealers have surfaced with lengthy lists of disturbingly scarce relatively new species carrying disgustingly high prices. This market really challenges just about all of the skills of the curator . . . assuming of course, that he or she opts to get into it. This is one area where the small museum can simply conclude that they needn't be bothered. The larger ones have many serious philosophical questions to wrestle with in trying to decide whether or not this is an appropriate expenditure of time and limited funds. The species being offered are seldom visible, almost always must be verified, and usually are expensive. Do we really want to encourage such marketing by participating in it? Let me make it perfectly clear that I am supportive of mineral specimen marketing in general—it is only the selling of rare species, and particularly type specimens, about which I have serious reservations.

Having touched on the subject of *what* to acquire, and feeling there is no need to dwell upon *how* to acquire, as this hasn't really changed, I should like to turn to the procedures of accessioning (and deaccessioning). It makes good sense in these times to properly document nearly everything that comes into or goes out of the collection. Varying levels of approval of acquisitions ought to be established based upon the approximate value of the objects involved. The Smithsonian operates with such a system and it is today rigidly enforced. This has meant a difficult transition for me because it was only loosely enforced in the past, and I had greater freedom in the area of acquiring collection specimens. I now recognize the value of this system and I support it enthusiastically, even though it sometimes greatly inhibits my natural tendencies. The system operates as follows. Objects or groups of objects below a certain value are accessioned without review. Those in the next higher category must be reviewed by a departmental committee of three (of which I am one). Above that the accession must be approved by the Director of the Museum, and there are levels wherein the review may be carried all the way to the Board of Regents. In preparation for a review at any level I must draft a justification for the accession, in which I attempt to explain why I feel we need the material, I express my opinion of the reasonableness of the price being asked, and I must comment on the unlikelihood of finding similar or better material elsewhere at a lower price. With proffered gifts it is much simpler. I must state in writing that they are needed and won't simply be more of something we already have in ample representation. Collections can be accepted even if portions of them are known to be redundant as long as most of the collection is not and the whole thing must be accepted or rejected as a unit.

It is particularly important to utilize review procedures when deaccessioning objects from the collection. In accessioning, the specimens will likely always be present to speak for themselves. When things are deaccessioned, they are gone. It is far more difficult to convince a skeptic that you performed properly once the evidence is no longer around. It is much better to be absolutely certain that the appropriate review has occurred. Should the deaccession involve objects going out as part of an exchange, I strongly urge that the curator wait at least 24 hours before letting the specimens go. This is something that the review process accomplishes very effectively. It not only forces the curator to justify the proposed exchange to someone other than himself or herself, it also delays the process long enough to allow careful deliberation of all elements of the exchange.

If a museum supports the concept of collection growth through

purchases and exchanges, then it must also make a serious commitment to allowing its curator to become familiar with the mineral marketplace. It is unreasonable to expect a curator to spend large sums of money on specimens, or to exchange specimens of great value, without providing the opportunity to attend major shows in order to learn what is available and to develop a sense of what the specimens may be worth.

Because the Smithsonian has one of the world's great collections, we are a major supplier of mineral samples used in scientific studies. Supplying such samples is considered to be one of our most vital functions. The more we do of this, the more requests are received, so it is essential that we be solidly committed to the endeavor. In our acquisitions program we are mindful of this role, and so we pursue material that has significant potential scientific value. On a regular basis we seek samples of minerals that have been described in the literature. Upon placement in the collection, described specimens are given distinctive labels so they can be easily recognized. Type specimens also have distinctive labels and the types are kept together in a separate set of drawers. Our pursuit of type specimens is particularly dedicated, especially those that have been introduced by American authors.

DONATIONS

Donations have traditionally been a prime means of promoting collection growth, and there is every reason to believe that they always will be. They have been particularly significant in the U.S. where favorable tax laws have made it beneficial for citizens to contribute objects or money to museums; but the tax laws are changing, so that the tax avoidance advantages are being reduced. The curator must be prepared to work with and cultivate potential donors while understanding that it is an activity that is fraught with disappointment, for there are far more flirtations with giving than there are gifts, and a curator can invest vast amounts of time and effort in unproductive pursuits. Entire collections are sometimes offered. The offerers are usually reluctant to have their collections subdivided, which means that the museum may have to accept a collection containing much redundant or worthless material. Donors commonly expect that their gifts will be exhibited and the curator must be careful not to inadvertently let them expect too much. There should be a minimum of conditions dictated by the donor because these can become burdensome for the museum. Each museum will have to decide for itself just which demands are acceptable and which are not, but I cannot stress too much the importance of not agreeing to any that aren't considered absolutely essential. They can, and they will, come back to haunt the curator or, more likely, his or her successors.

THE COMPUTER

The computer has become an indispensable piece of equipment in the office of the modern curator. It is inconceivable that any important collection today would not be "computerized," that is, entered into some kind of computer database. The advantages are monumental. The ways in which the basic file can be manipulated are limited only by the sophistication of the computer and the skills of the programmer, assuming one has the time to utilize what is available. As mentioned earlier, our computer file was generated as a result of an inventory effort. For that reason it was done in considerable haste and with too little attention to eventual scientific use of the file. This means that we have had to perform extensive editing of the file, which is ongoing. In spite of this problem, it has shown itself to be useful beyond our expectations.

One of the greatest advantages of the computer is that it permits the preparation of printouts of a variety of lists of materials within the collection in a variety of formats. Should we desire a printout of all the minerals on exhibit at any given time, for example, we can have it in minutes. The same is true if we want a list of everything in the collection from a specific mine, state or country, or all the gem beryls over 20 carats, or everything that has been added to the collection in 1987, or the type specimens, or even the species that we don't have, as well as an estimate of the relative amounts of those we have in case we should consider buying more when away from the museum. It can be very useful indeed to be able to carry certain recently updated lists to professional meetings and others to mineral shows to help one remember exactly what is in the collection. It is helpful when offered gifts of specimens from a specific locality to be able to produce a printout of everything already in the collection from that locality. It is most helpful when offered a new gemstone to be able to refer to a current list of all the gems in the collection, a list which includes a coded quality rating as well as color, weight and dimensions for each gem.

Happily, we have found that there are curators and collectors in other parts of the world who will help us edit our file, particularly with respect to locality information. For example, we have sent printouts of the locality details of our Swedish specimens to Sweden, our Norse specimens to Norway, and our Danish specimens to Denmark. In each case a carefully edited printout has come back so we can thus correct the information in our file and eventually, we hope, derive errorless computer-generated new labels. The objective here is to produce an essentially errorless catalog of Scandinavian localities for minerals in the U.S. National Museum of Natural History. This can then be duplicated and made available to other museums.

All of our transactions are captured in the computer so that we have the ability to generate current lists of all specimens recently acquired, deaccessioned, or loaned. It is now a simple matter to produce printouts of all those collection-related activities that help to justify our existence. And, of course, the log of every specimen that enters or leaves under any circumstances is also in the file.

VOLUNTEERS

In large part because of their more intimate contact with museums, there is a growing interest on the part of the public in volunteerism. This interest is often manifested in their willingness to work without pay at virtually any task that is assigned by a curator. Such volunteers can be very valuable indeed, if one is fortunate. They can just as easily turn out to be a total waste of staff time and, if they are not meticulous, they very well can create serious problems. Therefore the curator should approach all volunteer candidates with extreme caution. As in virtually every aspect of museum work, it makes good sense to formalize a policy for handling volunteers. One must prepare candidates in the earliest stages for the possibility that they may not be needed, and will be subject to dismissal without justification. It is at times more difficult to dismiss volunteers than salaried people. There is great potential for bitterness, just as there is great potential for adverse legal action, for a range of imagined grievances such as discrimination, on-the-job injury or exposure to hazardous emanations. Volunteers need supervision and, like everyone else, their importance should be acknowledged on a regular basis.

COLLECTION UTILIZATION BY NON-STAFF

The Smithsonian has subdivided the specimens in its collections such that the very valuable and rare or unique are physically separated from the reference or study collection. The former are kept under tight security and can be seen only under special circumstances. The latter, all arranged using a modified Dana's system, are housed in one large room. With this separation we do not feel particularly uneasy about allowing students, scholars, scientists and collectors to work in the reference collection without supervision once they have received some indoctrination. Most such visitors do not require constant supervision. We do not allow mineral dealers in the collection unattended, a practice which protects them as much as it gives comfort to us.

We have received numerous benefits by providing certain collectors

with access to the study collection. There are many instances where particular qualities of certain specimens have been pointed out to us by these collectors, qualities of which we were unaware but subsequently were pleased to note in our records. Specialists in the mineralogy of a particular region have also been afforded the opportunity to study our collection and, in the course of doing so, have noted the lack of certain specimens which they soon supplied through gifts.

With scientists we find it most satisfactory to let them select their own samples when they must physically remove things from the collection. That is, they point to what they want. We are the ones who actually perform the removal, if the request is deemed reasonable and the specimen isn't too precious. Of course many of the requests are received by letter or telephone and we must then make the selections without their direct involvement.

We have also found that it may be advantageous to allow certain mineral dealers to become intimately familiar with the collection. There are several who know our collection so well that they can and will actually shop for us. They are aware of specific deficiencies which they actively work to address. Thus, when they have an opportunity to acquire a specimen that they know we need, they are likely to buy it. The dealer will be satisfied with a small mark-up since its sale to us is highly likely (but a return is always possible).

COLLECTION CLASSIFICATION

The computer has made cross-referencing of collection information as simple as it is desirable. It has even, perhaps, eliminated the need for a systematic classification but I am not aware of any major museum that has replaced the classical chemical arrangement with something new and different. In our opinion a modified Dana's system is still the best, as far as it goes.

From time to time the Commission on New Minerals and Mineral Names, IMA, presents a classification system for some major mineral group. The amphiboles, for example, were "classified" in a paper published in the *American Mineralogist* (Leake, 1978, vol. 63, p. 1023–1052). Although the amphibole effort was formally approved and adopted by the commission, it appears that little thought was given to the practical implementation of the classification, because it is of no use whatsoever to museums. In fact, the proposed nomenclature is a nightmare, for assignment of a name to any amphibole requires a complete chemical analysis of that amphibole, in some cases supported by a structure determination. Collection classifiers need a hierarchical system wherein one can advance through various levels of order depending upon how much is known about the crystal chemistry of a specimen. With the Leake classification one must know everything about the specimen's chemistry in order to place it in any category more specific than "amphibole"!

CONCLUSION

The designation of collection building as a major performance element for museum curators would, on the surface at least, seem essential. Having the responsibility for a collection, after all, is the only justification for calling someone a curator. A collection, if it is to reflect the vitality and the science of our society, must always grow. If it ceases to grow it loses its ability to make any sort of statement about contemporary society, and it too rapidly can become a historical artifact with no ties to the present. For that we don't need a curator; a librarian or an effective records manager will serve perfectly well.

I feel very strongly that a well-motivated curator cannot hope to function effectively unless there exists a clear understanding of exactly what the administration expects of the individual. A functioning museum must have curators and these must not only be *allowed* to curate, they must be directed to curate, but within a system of effective and mutually accepted guidelines.

Notes from the Editor *(continued from p. 250)*

Lu supplied many specimens of minerals to the California Division of Mines and Geology and to professional mineralogists for their preservation and study—again, never seeking any particular recognition for this service. He was a renaissance man in the sense that he was multi-talented and had abilities in many fields. As examples, he was the chief chef for a hospital (I believe in Sonoma County), was an expert on rare conifers of the California Coast, an artist with woodworking and cabinetry, an inventor, and so forth. His great talent was as a performing musician and composer, and he earned his living at this in his earlier years. His talent in mineralogy lay in a very sharp eye and the ability to distinguish minerals that might be new or worthy of study.

DIRECTORY OF MICROMOUNTERS

The 15th edition of the *International Directory of Micromounters* will be published this coming September at the Baltimore Micromount Symposium. Because of recent postal rate increases, prices have been set as follows: The cover price (at the symposium) will be $3.50. By 1st class mail (to U.S. addresses only), it will cost $5.75. Checks or money orders, payable to the Baltimore Mineral Society, must accompany all orders and should be sent to the International Directory of Micromounters, c/o Roy I. Grim, Editor, 9155-A Hitching Post Lane, Laurel, MD 20723 U.S.A.

Orders for copies of the directory may be sent from outside the United States accompanied by payment in U.S. funds only, either by international postal money order payable to the Baltimore Mineral Society, or by sending U.S. dollars (rounded up to the next higher dollar—coins should not be sent by mail) by registered mail to the editor. The former way is costlier and slower—allow about 8 weeks. The postpaid prices are as follows (first, if paid by postal money order / then, if paid in U.S. dollars): By surface mail to any country, $5.75/$6.00; by airmail to Canada, $6.00/$6.00; by airmail to most of Europe and South America, $7.50/$8.00; by airmail to Australia, New Zealand and South Africa, $8.50/$9.00.

TUCSON SHOW 1992

Although initial plans for the 1992 Tucson Gem and Mineral Show involved cutting it back from five days to four, that decision has now been reversed by the show committee. The show will again be five full days, February 12–16. The show hours each day will be reduced by one hour (Wednesday through Saturday 10–6:30, Sunday 10–5).

If you are planning to attend, make your motel reservations *immediately*. The PGA Tucson Open Golf Tournament is scheduled for the same days this year, and there may be a consequent shortage of rooms in the city. (The golf tournament will move back to January in 1993; it was shifted to February this year to avoid network television conflicts with the 1992 Olympics.)

Zeolites and Associated Minerals from the Palabora Mine Transvaal

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The Phalaborwa Complex, situated in Northeastern Transvaal, South Africa, is the site of major economic deposits of copper, phosphate and vermiculite. Swarms of dolerite dikes cut the complex, and it is in these that very attractive specimens of zeolites and associated minerals have been found.

LOCATION

Palabora mine* is located some 550 km from Johannesburg, in the great lowveld plain of northeastern Transvaal, South Africa (Fig. 1). Immediately to the east is the Kruger National Park and the border with Mozambique, with the Limpopo River and border with Zimbabwe 175 km to the north.

At an altitude of about 400 meters the area enjoys a subtropical climate, and is rich in African wildlife. It is not uncommon to find elephants browsing within 1 km of the open pit, with lions and leopards being frequent visitors to the area, particularly in the late dry season.

GEOLOGY

The Phalaborwa Complex, located in the Archean Shield of the Transvaal, is unique among the many African alkaline complexes that have been described, in that its carbonatite member is the site of a deposit of copper ore. Magnetite, uraninite-thorianite and baddeleyite are subsidiary products of the copper mining venture, while the ultramafic rocks of the complex are also hosts to economic deposits of apatite and vermiculite (Russell *et al.*, 1955; Forster, 1958; Lombaard *et al.*, 1964; Hanekom *et al.*, 1965; Heinrich, 1970; Palabora Staff, 1976). For a simple general account see Park and McDiarmid (1970). Swarms of late dolerite dikes cut all the rocks of the complex, and it is in these that the zeolitic mineralization is found.

MINERAL LOCATIONS IN THE DIKES

The dikes (Fig. 2) are of Waterberg age, some 1.6 billion years old, and vary in width from a few cm to 50 meters, trending northeast-southwest, with a nearly vertical dip. The occurrence of authigenic zeolites in fractures and joints is commonly exhibited in the form of nondescript chalk-like coatings, but in the wider fractures, and particularly in faulted areas, free-growing crystals do occur. In March, 1982, in the Main dike on bench 24 of the Palabora open pit, a series of open cavities was discovered, completely lined with beautifully crystallized material. A cross section of this occurrence is shown in Fig. 3.

This first locality consisted of a shear zone striking at right angles to the strike of the dike, some 1.8 meters in width, and made up of brecciated dike material cemented with prehnite and apophyllite. The

*The mine name is Palabora, but the geographical place name and thus also the name of the igneous complex is spelled "Phalaborwa."

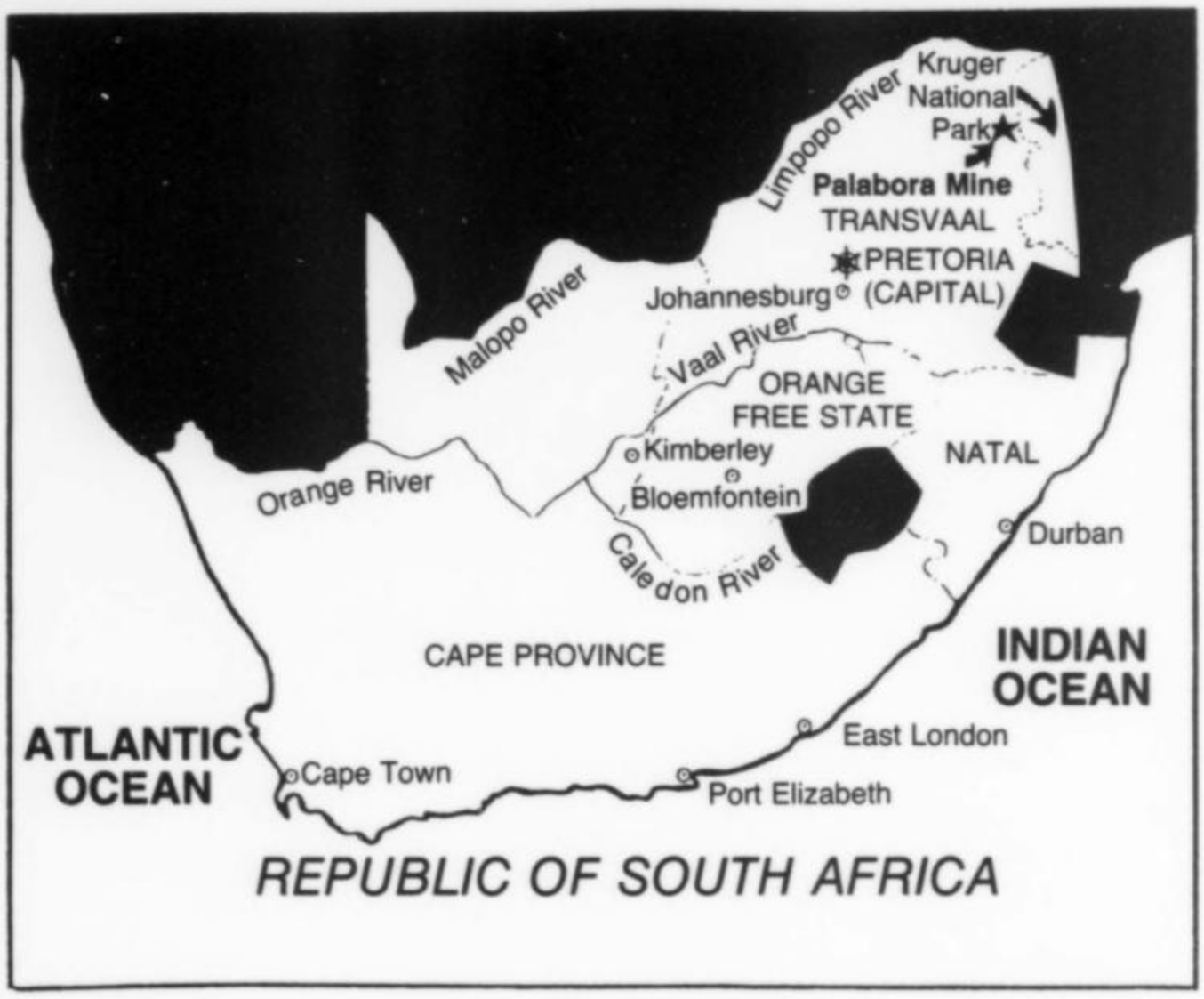
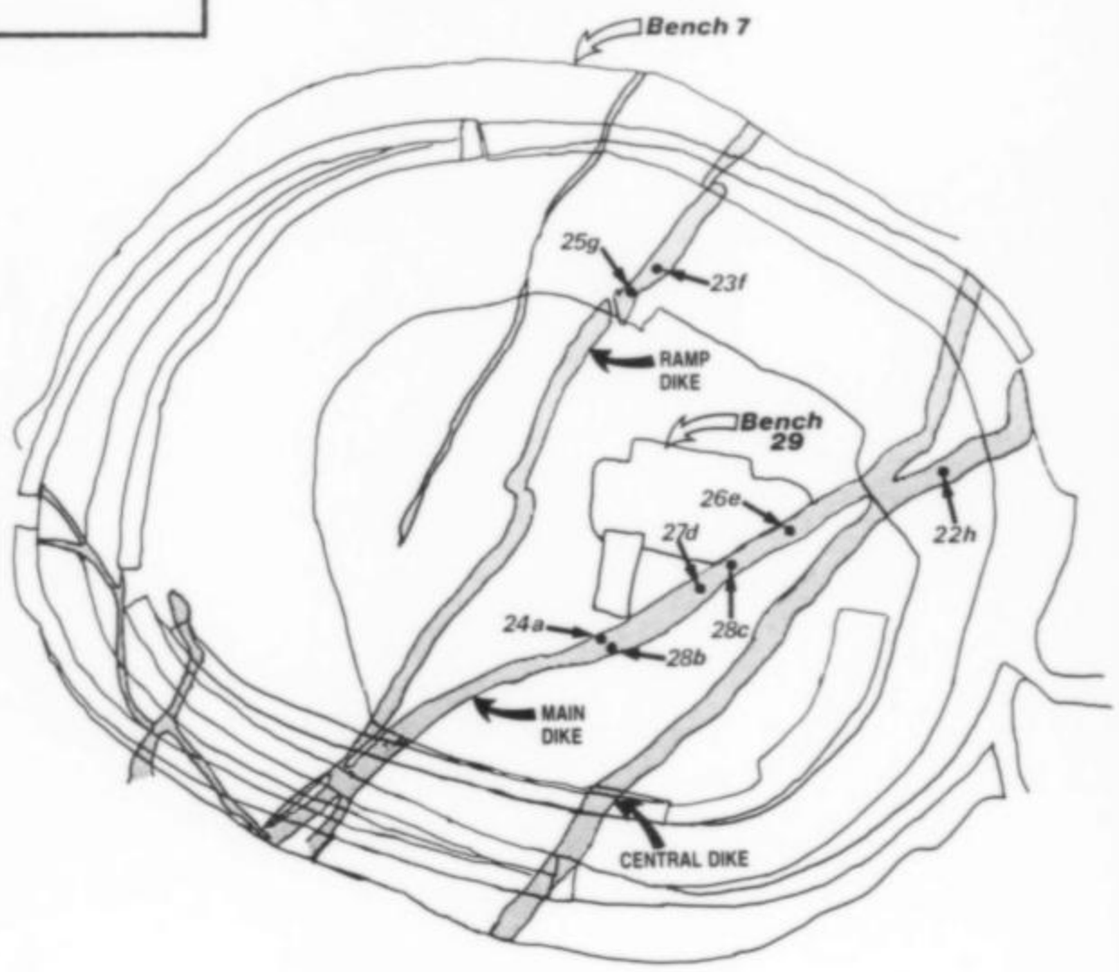


Figure 1. **Map of southern Africa, showing the location of the Palabora mine.**

Figure 2. **Plan of the Palabora open pit, showing major dikes and mineralized localities. The pit is about 2 km across.**



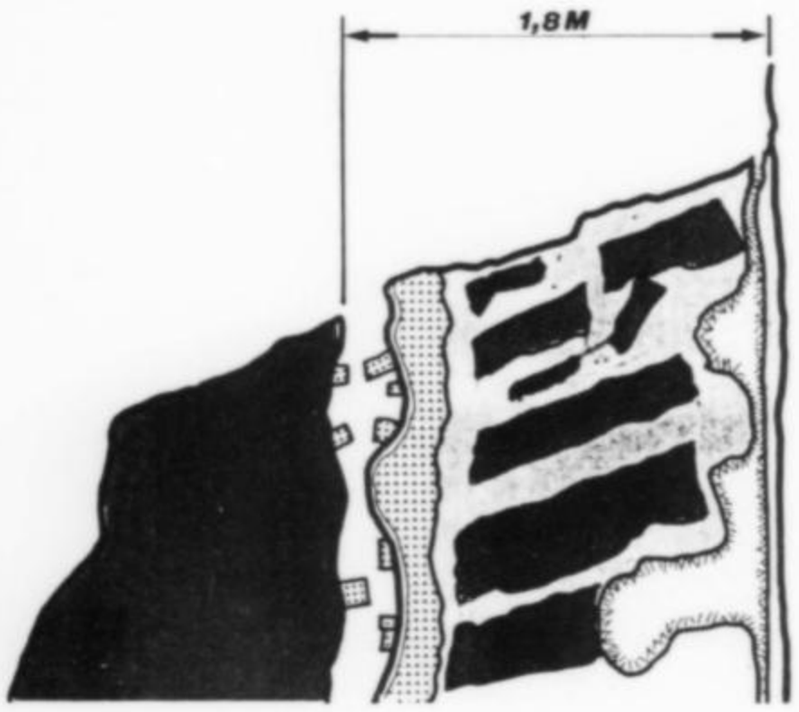


Figure 3. **Vertical section through the upper part of the Main dike.**

northern side of the zone was bounded by an open cavity lined with crystallized apophyllite and spiky mesolite, with large pseudocubic calcite crystals to 15 cm on edge. The southern boundary consisted of a series of interconnected cavities lined with forests of snow-white mesolite crystals to 2 cm. In the central brecciated zone were found small cavities lined with crystallized prehnite and transparent pseudocubic crystals of apophyllite, with the occasional transparent calcite crystal.

The fracture zone was excavated to a depth of about 2 meters and a length of some 4 meters. Many fine specimens were collected, which vary in size from thumbnail to 20 x 20 cm, many of which were extracted undamaged from totally intact cavities. Collecting was hampered by the extremely hard, tenacious dike matrix, and came to a complete halt when the area was blasted late in 1982. Evidence of its deeper extension was observed on the bench below, but few specimens were collected owing to extensive blast damage. There was no visible evidence of this mineral assemblage on the next bench down.

The Main dike is the most prolific specimen-producing dike in the open pit. Four benches (60 m) below locality 24a (28b) (see Fig. 2) none of the mineralization noted on bench 24 was evident, but instead crystals of analcime to 4 mm and heulandite to 1 cm were present in open joints. This type of occurrence was noted discontinuously for some 200 meters to the north.

Other species of particular interest in the small open joints in this dike include soft pectolite balls associated with natrolite, the latter in long thin prismatic crystals to 2 cm at locality 28c. In the same area,

but one bench higher (27d), natrolite has also been observed in an intimate mixture with mesolite as radiating groups of white prismatic crystals to 2 cm. Of particular note from the Main dike is the only occurrence of thomsonite yet found, associated with apophyllite on one boulder in a muckpile at 26e.

The mineral content of the other major dikes varies considerably. The Central dike, which is of similar dimensions to the Main dike, crosses it in the northern part of the pit, but is barren of zeolitic material. To the west, the Ramp dike is again mostly barren, but within about 100 meters either side of a lateral displacement fault in its northern part a rather different suite of zeolitic minerals is found. This includes pectolite, in both fibrous and free-standing crystals, on a number of benches, with the best specimen material on bench 23 at 23f. Stilbite also occurs in this area, usually as small crystals often in association with scolecite and apophyllite, with the best material to date being found on bench 25 at 25g.

MINERALOGY

Only the secondary minerals found lining the cavities in the dikes are considered in this section.

The species listed were identified by a combination of visual, physical, microchemical and optical methods, and most of the identifications were confirmed or supported by infrared spectroscopy. In most cases the spectra are complex and characteristic, for example in distinguishing between natrolite, mesolite, scolecite and mixtures of these.

Figure 4. **Analcime, hollow crystals enclosing laumontite, with tabular heulandite (7 mm across), elongated fluorapophyllite crystals and small white sprays of laumontite. From the lower Main dike on bench 28. R.S.W.B. specimen (85-9) and photograph.**

Analcime $NaAlSi_2O_6 \cdot H_2O$

Analcime is found as an early crystallizing phase, grown directly on the matrix in the deeper parts of the Main dike fracture zone at 28b (see Fig. 2), its place in the paragenetic sequence being taken by prehnite in the lower temperature zone nearer the surface. It forms the classical, colorless to milky icositetrahedra {211}, typically 1–2 mm, sometimes up to 4 mm across. The crystals are peculiar in that they are usually hollow, with crumbly white laumontite growing in the interiors. A possible explanation for this is in the initial crystallization of calcium-rich material (wairakite), followed by an outer zone of the isomorphous sodium-rich analcime (in the higher parts of this fracture zone the initial calcium-rich prehnite is followed by the more sodic mesolite). Continuing exposure to hydrothermal solutions at lower temperatures caused the less stable wairakitic cores to alter to laumontite (*cf.* Thompson, 1970; Liou, 1971), whereas the more stable analcime remained unaffected.

A late generation of small (less than 1 mm), transparent analcime crystals is occasionally found on apophyllite and penetrating its outer zone.

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

Thin films and tiny spherical clusters of microscopic bronze-brown platelets of secondary biotite are found, usually on early calcite and on prehnite, and sometimes on mesolite. It is also found under datolite in the hydrothermally altered wall rock of the open cavity in the upper part of the Main dike fracture zone. In the deeper parts it forms a thin film directly on the wall rock and under the zeolites.

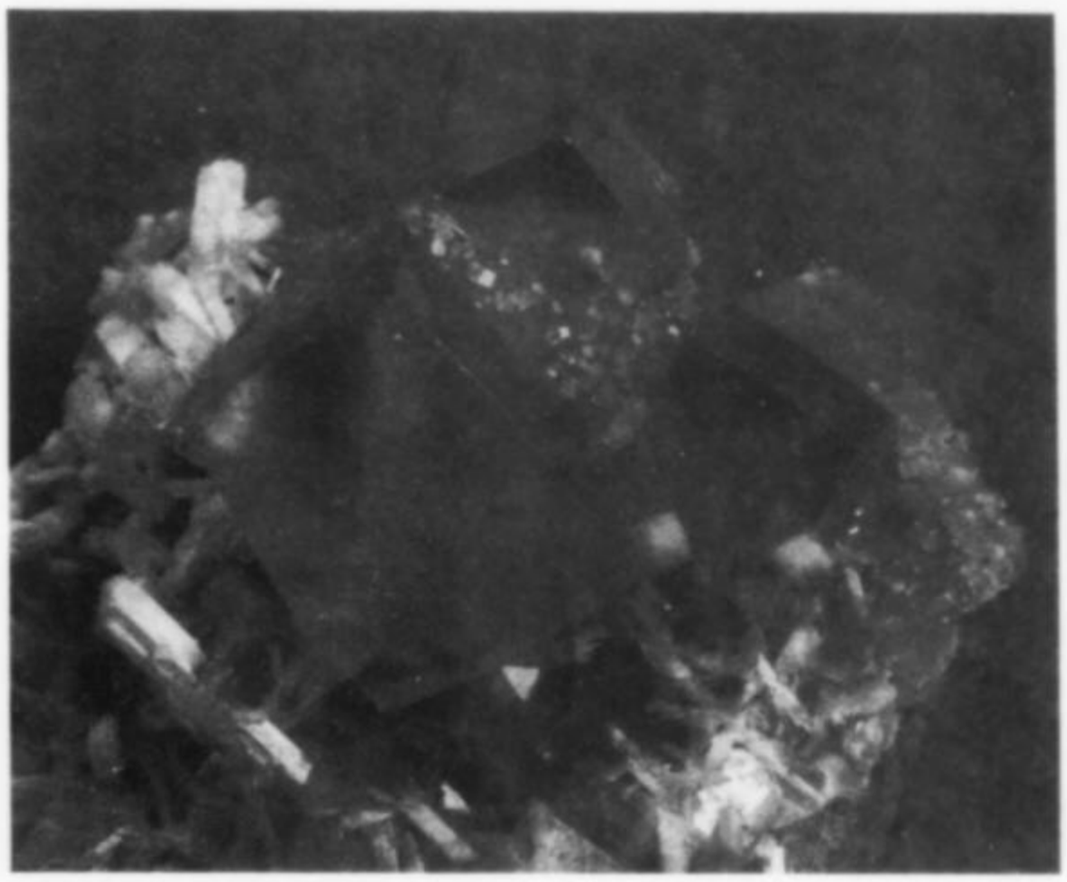


Figure 5. **Calcite crystals, 1 cm, coating earlier calcite, silky white mesolite and apophyllite. Microcrystals of fluorapophyllite are sprinkled on some of the calcite. From the upper Main dike. J. Gliddon specimen, photographed by C. Gould.**

Calcite $CaCO_3$

Calcite is commonly found in the dikes, usually as rather small, transparent, highly modified rhombohedral crystals, but also as larger obtuse rhombohedral (pseudocubic) yellowish brown crystals. In the upper Main dike fracture zone (24a) the calcite crystals show a wide diversity of appearance, from complex, gemmy, 2-cm crystals to large, brown, pseudocubic crystals to 15 cm on an edge. These latter crystals grew in the open cavity system shown in Fig. 3, but many were unfortunately damaged as a result of blast vibrations. The largest crystals recovered intact and on matrix are 8 cm on edge. Small cavities in the brecciated zone produced the most beautiful transparent pseudocubic crystals, while in the mesolite-rich cavities the crystals were translucent and commonly dusted with tiny fluorapophyllite crystals. This calcite initially grew directly on prehnite, and then in conjunction with the silky mesolite crystals, which often project from calcite crystals. Later generations were formed, overgrowing the earlier calcite and growing on the main generation of fluorapophyllite. The calcite may be converted to datolite by reaction with boron-containing hydrothermal fluids.

Chabazite $CaAl_2Si_4O_{12} \cdot 6H_2O$

Chabazite has been found only in the lower parts of the Main dike fracture zone, as colorless rhombohedra to 1 cm across, frequently in penetration twins, associated with analcime, fluorapophyllite and heulandite, and later than these minerals.

Figure 6. **Datolite spherules with mesolite, coating 1-cm calcite crystals from the upper Main dike. J. Gliddon specimen, photographed by C. Gould.**

Datolite $CaBSiO_4(OH)$

Datolite has been found rarely as 1-mm, snow-white, globular aggregates of microscopic crystals on calcite in the open cavity complex on the north side of the fracture zone (24a) in the upper part of the Main dike. The datolite is always closely associated with calcite, being found on calcite surfaces, in cracks and coating solution cavities in calcite rhombohedra typically about 1 cm across, and occasionally overlain by a later generation of similar calcite rhombohedra. The datolite is also commonly overlain by late-generation fluorapophyllite of pseudocubic habit.

Specks of datolite are also found disseminated in the soft altered dolerite of the cavity walls, with and on secondary biotite.

The datolite appears to have been formed by the action of boron-containing, silica-rich hydrothermal fluids on calcium-containing minerals, especially calcite.

Figure 7. **Cluster of 1-cm pseudocubic fluorapophyllite crystals from the upper Main dike. R.S.W.B. specimen (85-173), photographed by M. P. Cooper.**

Fluorapophyllite $KCa_4Si_8O_{20}(F,OH,Cl)\cdot 8H_2O$

Fluorapophyllite is common in all the dikes as good crystals of various sizes and habits. Often in two generations, the later consisting of smaller crystals.

The largest crystals were found in the open cavity system in the Main dike fracture zone (24a), associated with prehnite, calcite and mesolite. These are up to 2 cm across and of pseudocubic habit, with prominent equant {100} and {001} faces, sometimes with smaller {111} faces at the corners. The underlying prehnite often gives these crystals an attractive greenish tint. Small, clear, colorless pseudocubic crystals 0.5–1 mm across, without {111} faces, are often sprinkled on these larger apophyllite crystals and the associated mesolite and calcite. Very clear, colorless, 1–3 mm, late-generation crystals, prismatic {100} with pyramidal terminations {111} are found occasionally on prehnite and associated early fluorapophyllite in the absence of mesolite, as are intermediate variations in form prominence. Colorless, transparent, bipyramidal crystals {111} to 5 mm across have been found some 600 meters to the north in the same dike on bench 22 (22h), sprinkled with tiny crystals of similar habit. Their paragenetic position is unclear, owing to the absence of other associated minerals, but is likely to be similar to those from the upper fracture zone.

Fluorapophyllites from the Ramp dike, associated with stilbite and scolecite, tend to be smaller, thick tabular to pseudocubic to short prismatic, and with {111} more prominent than on crystals from the Main dike. The late generation crystals here are long prismatic {100} with pyramidal terminations {111}.

Crystals from the deeper parts of the Main dike fracture zone, associated with analcime, heulandite and chabazite, tend to be long prismatic {100}, elongated along *c*, with prominent basal pinacoids {001}, and {111} faces small to absent. The earlier, smaller crystals are up to several times as long as they are broad; later crystals tend to be larger and of more equant habit.

Four apophyllite samples of different habits and generations were analyzed for halides by Dr. R. Perry, of the Chemistry Department, University of Manchester Institute of Science and Technology, Manchester. The powdered samples were decomposed by pyrohydrolysis and total halide determined by ion chromatography, which also showed a fluoride-to-chloride ratio close to 10:1. The analyses (Table 1) show that the specimens analyzed are all fluorapophyllites, with appreciable hydroxide and a little chloride. Three of the analyses gave very similar results, yielding a formula $KCa_4Si_8O_{20}(F_{0.55}OH_{0.4}Cl_{0.05})\cdot 8H_2O$. The bipyramidal fluorapophyllite shows slightly more fluoride.

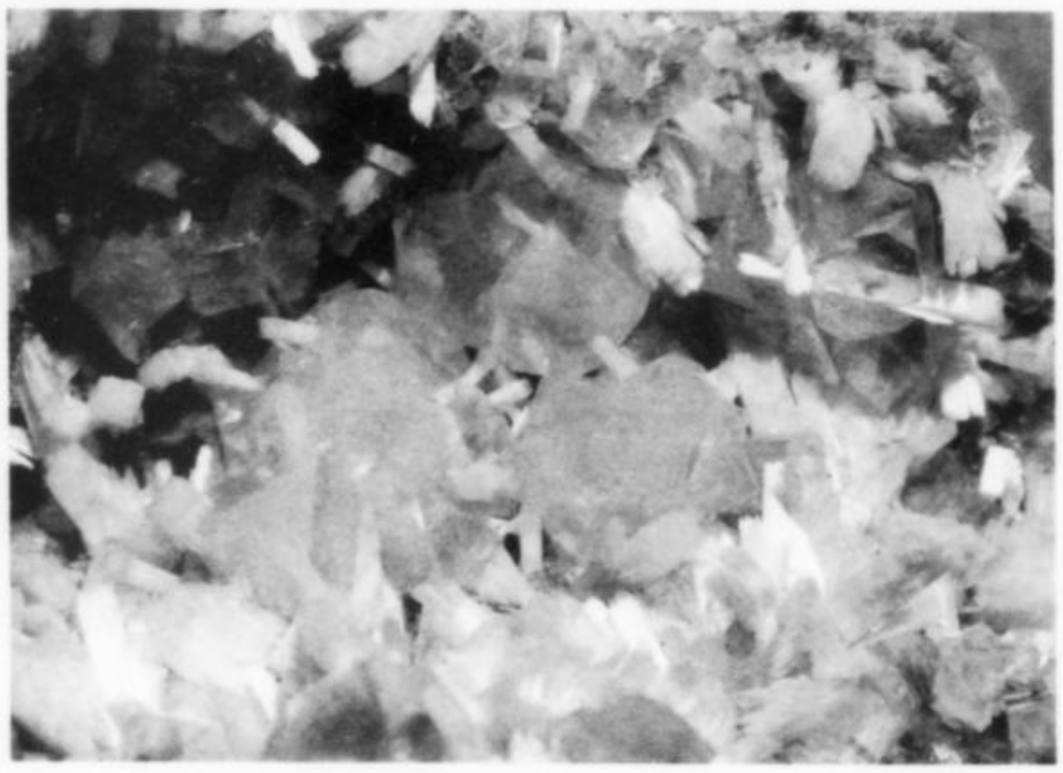


Figure 8. **Fluorapophyllite and mesolite crystals lining a 7-cm cavity from the upper Main dike. J. Gliddon specimen, photographed by C. Gould.**

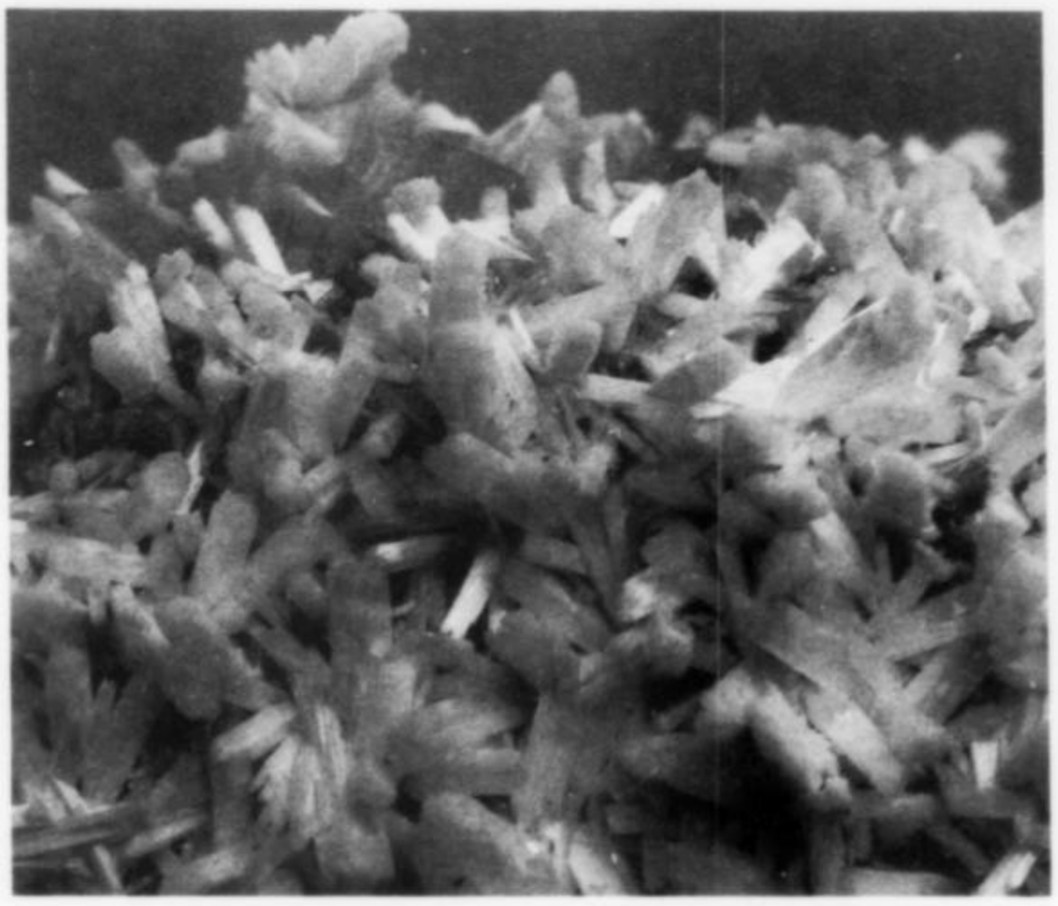


Figure 9. **Silky white mesolite crystals on pale green prehnite coated with clear fluorapophyllite from the upper Main dike. R.S.W.B. specimen (85-171), photographed by M. P. Cooper.**

Figure 10. **Long prismatic fluorapophyllite crystal (4 mm) from the lower Main dike on bench 28. R.S.W.B. specimen (85-269), photographed by M. P. Cooper.**

Figure 11. **Heulandite cluster (near center), 5 mm, with botryoidal gray-green saponite on fluorapophyllite, from the upper Main dike. J. Gliddon specimen, photographed by C. Gould.**

Table 1. **Halide analyses of Palabora apophyllites.**

Sample	$(F+Cl)^-$ %, ±0.1	F^- %	Cl^- %	OH^- %, by difference	Formula ratio
1	1.2	1.1	0.1	0.9	$(F_{0.5(2)}OH_{0.4(3)}Cl_{0.06})$
2	1.3	1.2	0.1	0.8	$(F_{0.5(7)}OH_{0.3(8)}Cl_{0.06})$
3	1.3	1.2	0.1	0.8	$(F_{0.5(7)}OH_{0.3(8)}Cl_{0.06})$
4	1.7	1.5	0.2	0.4	$(F_{0.7(3)}OH_{0.1(9)}Cl_{0.08})$

Samples 1–3 approximate to $KCa_4Si_8O_{20}(F_{0.55}OH_{0.4}Cl_{0.05})\cdot 8H_2O$.
Sample 4 approximates to $KCa_4Si_8O_{20}(F_{0.7}OH_{0.2}Cl_{0.1})\cdot 8H_2O$.

1. Pseudocubic crystal approximately 5 mm across, from locality 24a. Off RSWB 82-72.
2. Tabular crystal with prominent {111} about 5 mm across, from Locality 24a. Off RSWB 82-56.
3. Small, clear, late-generation long prismatic crystals with pyramidal terminations, from locality 24a. Off RSWB 82-183.
4. Colorless, 5-mm, bipyramidal crystal from locality 22h. Off RSWB 83-139.

Figure 12. **Fluorapophyllite crystals to 1 mm on pectolite needles, from the Ramp dike. J. Gliddon specimen, photographed by C. Gould.**

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

Heulandite has been found sporadically in the Main dike fracture zone at 24a as crystals of classical shape up to 1 cm across with pearly luster on the prominent coffin-shaped {010} faces. These occur associated with saponite, on apophyllite and on calcite rhombohedra. Heulandite is more common in the deeper parts of the fracture zone (28b), on analcime and fluorapophyllite, and followed by chabazite and stilbite. Small pseudocubic, late-generation fluorapophyllite crystals are sometimes found embedded in the outer zones of these crystals.

Laumontite $CaAl_2Si_4O_{12}\cdot 4H_2O$

Laumontite is common in the deeper regions of the Main dike fracture zone, and also in the Ramp dike, appearing at various points in the paragenetic sequence (Fig. 17). It formed as an apparently early phase, probably at the expense of wairakite, as tiny, white, crumbly masses inside hollow analcime crystals. It is also found as late-generation radiating clusters of colorless to silky white crystals of classical habit, about 0.5–1 mm long, and occasionally as larger single crystals of similar habit, sometimes doubly terminated and several mm long, around the middle of the paragenetic sequence. These single crystals sometimes have radiating clusters growing on them. Laumontite is common also as white crumbly fracture fillings.

Mesolite $Na_2Ca_2Al_6Si_9O_{30}\cdot 8H_2O$

Apart from an intimate mixture with natrolite (see under that min-

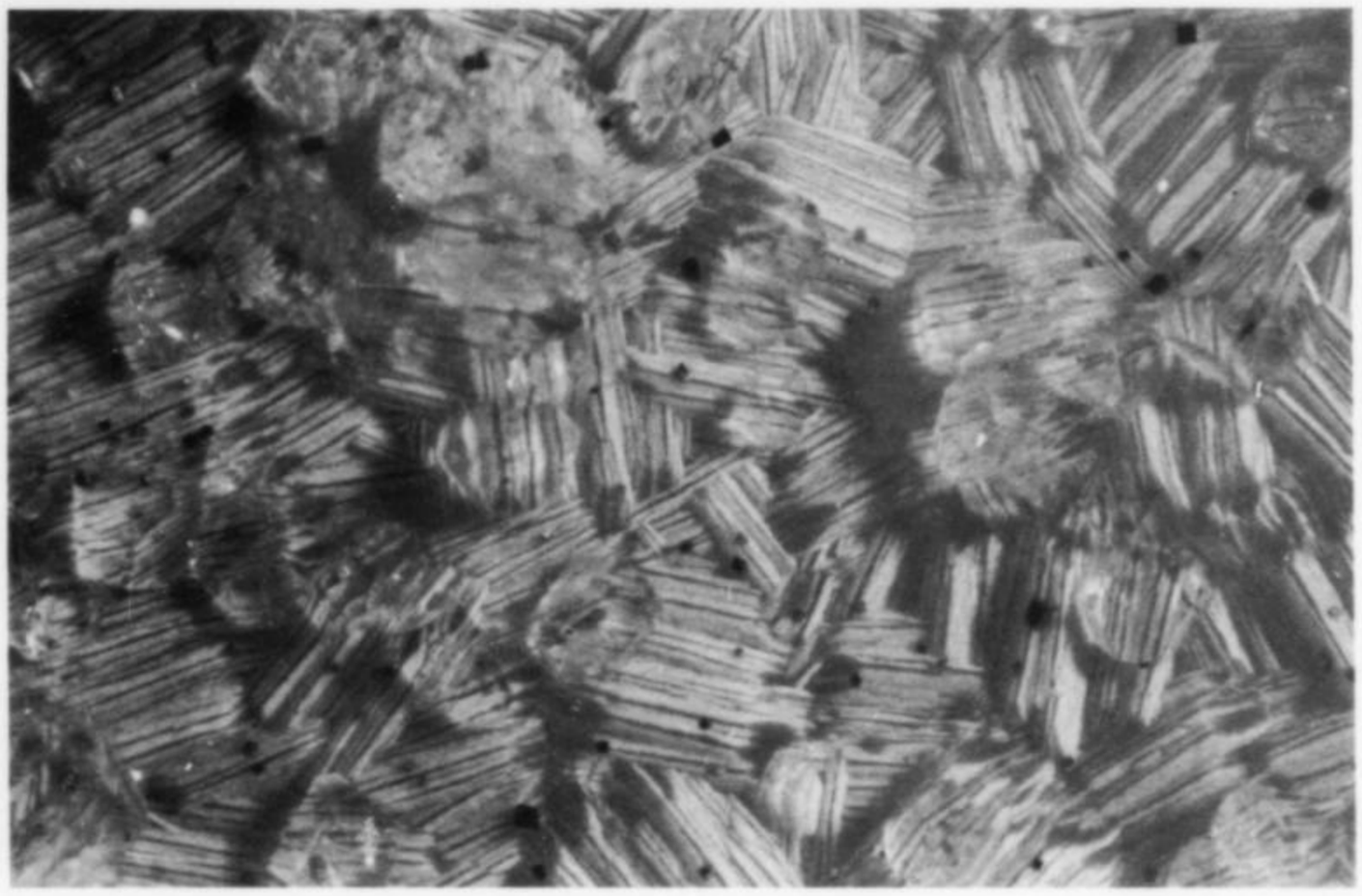


Figure 13. **Pale green prehnite from the upper Main dike, terminations about 3 mm long, sprinkled with pyrite cubes (dark) and apophyllite crystals so transparent as to be almost invisible. R.S.W.B. specimen (82-73) and photograph.**

Figure 14. **Thomsonite, 5-mm sheaves on fluorapophyllite from the Main dike. R.S.W.B. specimen (84-337) and photograph.**

eral), mesolite has only been found on bench 24 of the Main dike fracture zone (24a), usually as small crystals. In the open cavity system on the northern side at 24a mesolite was found in beautiful specimens ranging from delicate sprays of needles (to about 1 cm in diameter) to silky, snow-white composite crystals to 2 cm in length. These occur completely lining cavities or projecting through calcite or clear fluorapophyllite crystals which sometimes have a greenish appearance from the underlying prehnite. These composite crystals, composed of fine needles growing together in compact parallel growth, often have good shapes with distinct pyramidal terminations, but sometimes have indistinct fibrous terminations. Small, clear, late-generation pseudocubic apophyllite crystals sometimes decorate these mesolite crystals.

Natrolite $Na_2Al_2Si_3O_{10}\cdot 2H_2O$

Natrolite occurs rarely, in the central and northern parts of the Main dike on benches 27 and 28. Colorless, transparent, long prismatic crystals of natrolite up to 2 cm by 2 mm have been found (at 28c) embedded in opaque silky white, matted, radiating pectolite on fluorapophyllite. From 27d, translucent to silky white, compact, radiating material filling spaces between fluorapophyllite crystals, and thus of later generation, were found to be an intimate mixture of natrolite with mesolite, giving an appropriate infrared spectrum.

Pectolite $NaCa_2Si_3O_8(OH)$

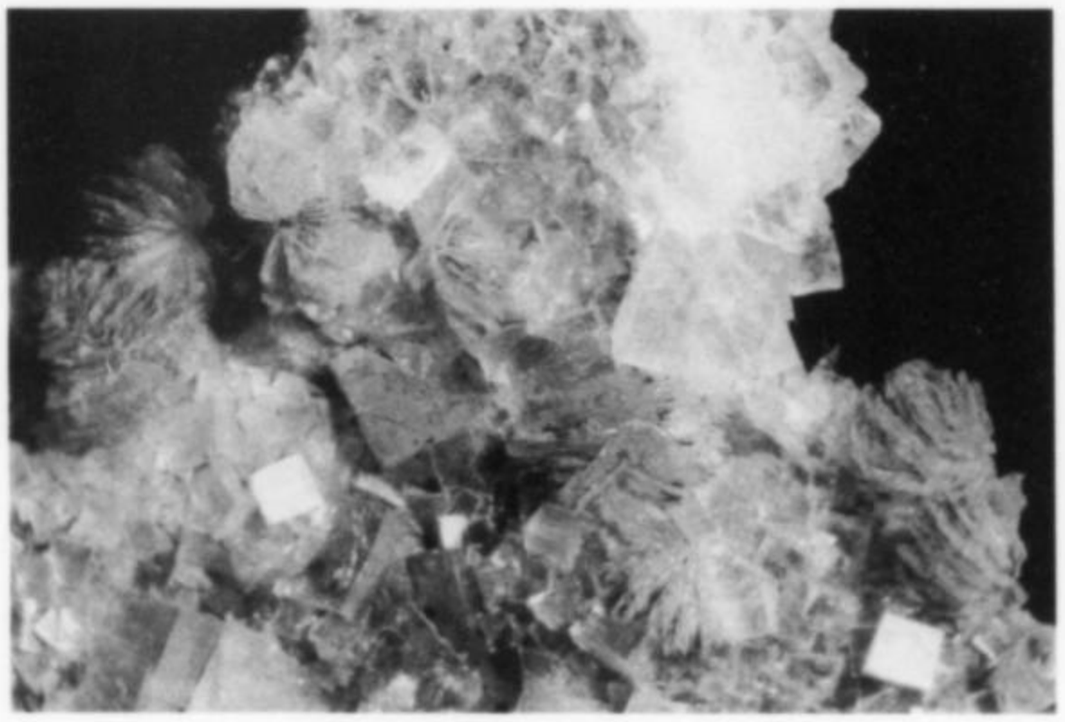
Pectolite has been found in the Ramp dike, in small cavities, most being completely filled with matted needles of pectolite. Occasional open cavities afforded delicate needles to 3 cm sprinkled with very clear, tiny fluorapophyllite crystals. Very soft, radiating balls to 5 mm have been found in the Main dike.

Prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$

Prehnite was the first hydrothermal phase to crystallize, forming directly on the matrix in the upper parts of the Main dike fracture zone, at 24a, where it takes the place of the analcime formed deeper down (28b). It forms characteristic pale green crusts, usually about 5 mm thick but up to 1 cm thick, of compact, radiating blades whose terminations form the surface of the crust. Occasionally small individual platy crystals up to 3 mm across are perched on these crusts.

Pyrite FeS_2

Primary pyrite cubes to 3 mm project from the wall rock, particularly in the deeper parts of the system. Tiny hydrothermal pyrite crystals are found dusting the surface of, and as inclusions within, the outer zones of the main generation of apophyllite crystals in the upper part of the Main dike fracture zone.



Quartz SiO_2

Quartz is rare at Palabora, having been found only in the deeper parts of the Main dike fracture zone, as two generations of similar, milky white crystals to 2 mm, of short prismatic habit. Both generations are euhedral where in contact with (and thus earlier than) sparse, long prismatic apophyllite crystals to 2 mm. Many of the quartz crystals are hollowed out internally by dissolution, and have a superficial resemblance to the analcime.

Saponite $(Ca/2,Na)_{0.33}(Mg,Fe^{2+})_3(Si,Al)_4O_{10}(OH)_2\cdot 4H_2O$

Tiny, gray-green, greasy-looking blobs of saponite are occasionally found on calcite and main-generation fluorapophyllite crystals, sometimes overgrown by late fluorapophyllite, in the upper parts of the Main dike.

Scolecite $CaAl_2Si_3O_{10}\cdot 3H_2O$

A few attractive specimens of scolecite were found in the Ramp dike, showing delicate, transparent needles to 3 mm on sheaves of stilbite crystals to 4 mm. These occur on main-generation fluorapophyllite, but penetrating (earlier than) tiny late fluorapophyllite crystals. The scolecites penetrate the outer zones of calcite rhombohedra. Small clusters of laumontite sit on late fluorapophyllite, and are the last-formed species in these specimens.

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

Stilbite is common in the northern part of the Ramp dike, in groups of small single crystals (as opposed to the more typical sheaf-like aggregates) on apophyllite. Similar, 1-mm crystals were also found in the deeper parts of the Main dike fracture zone, on larger sheaves

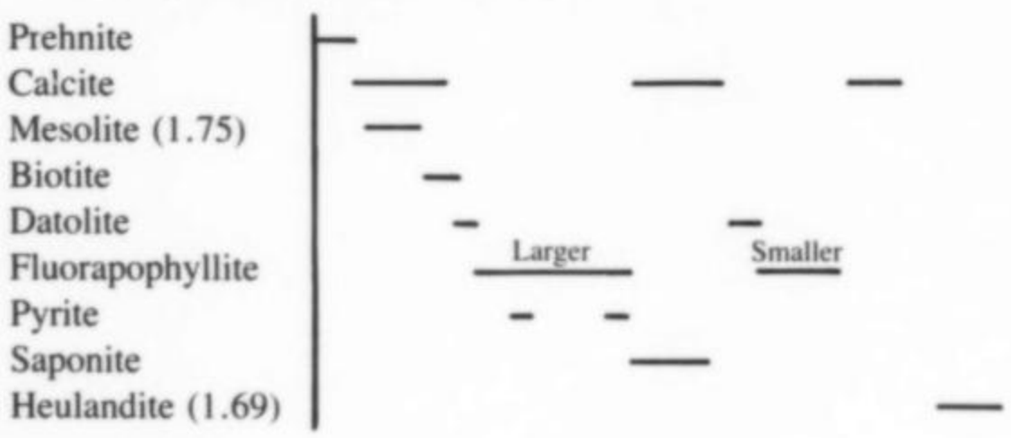
of stilbite crystals, some exceeding 1 cm in length, growing directly on matrix and on calcite. Other zeolites are notably absent from these specimens, apart from a little heulandite on one, of later generation than the small second-generation stilbite crystals, and some laumontite between the two stilbite generations.

Sheaves of stilbite to 5 mm were found in the Ramp dike on pseudocubic fluorapophyllite crystals to 5 mm, all richly sprinkled with 2-mm scolecite needles.

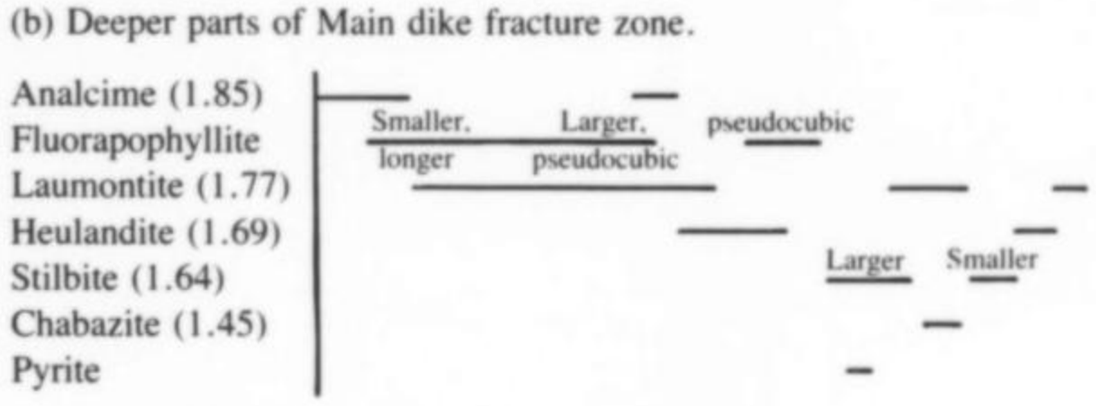
Thomsonite $NaCa_2Al_5Si_5O_{20}\cdot 6H_2O$

Thomsonite has been collected only from one boulder in blasted material from the Main dike at 26e. It forms dull, white, radiating blades to 5 mm on clear pseudocubic fluorapophyllite crystals to 8 mm. Lack of other associated minerals renders its paragenetic position unclear, apart from being later than the main generation of fluorapophyllite.

(a) Upper part of Main dike fracture zone.



(b) Deeper parts of Main dike fracture zone.



(c) Scolecite paragenesis in Ramp dike.

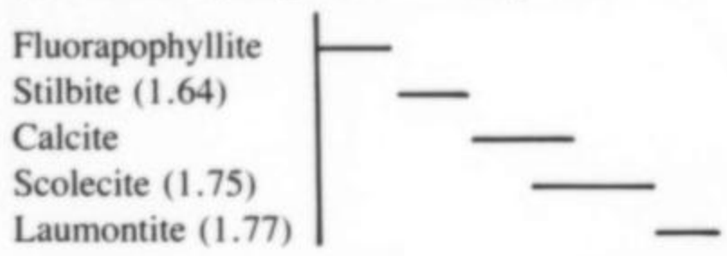


Figure 15. **Relative paragenetic sequences for the deposition of secondary minerals in the dikes at Palabora. The numbers in brackets following the species names are the zeolite framework densities in g/cm³. Lengths of bars are not to scale; time progresses to the right.**

PARAGENESIS

Careful microscopic observations of the topographical relationships between the species on a large number of specimens have suggested the paragenetic sequences shown on Fig. 17.

In the Main dike fracture zone it is apparent that prehnite, mesolite, calcite and datolite, which are common in the upper parts, are rare or absent in the deeper and presumably higher temperature zone, where analcime forms the initial phase instead of prehnite, and laumontite, chabazite and heulandite are prevalent.

Compositional trends between these zones are not strong. The Ca/Na and Al/Si ratios are generally somewhat higher in the upper regions. These weak trends may reflect ion availability as much as physical factors.

The zeolites in the Ramp dike are all Ca-zeolites, pectolite being the only sodium mineral observed.

The sequence of deposition within each zone is again likely to be sensitive to a number of factors, and trends must be expected to be rather general. The factor we have found to correlate best with paragenetic sequence is the framework density of the zeolites (a factor of the number of Si and Al framework tetrahedra per unit cell volume; see Breck, 1974), which decreases with successive generations, except in the scolecite paragenesis in the Ramp dike. The ratios (OH + H_2O) / (Si + Al) and Ca / (Na + K) also generally increase, in the lower parts at least, but Al / Si, and (cations) / (Si + Al) do not show regular trends.

The paragenetic diagrams (Fig. 17) indicate two main waves of mineralization.

SUMMARY AND CONCLUSIONS

Attractive specimens of zeolites and related minerals in interesting combinations have been found lining cavities in dikes cutting across the Palabora open pit. These must be some of the most attractive zeolitic specimens yet reported from Africa, a continent not noted for their occurrence.

The first specimens collected, from the upper portions of the Main dike, are particularly attractive, especially those with silky white mesolite crystals projecting from clear fluorapophyllite crystals set upon a matrix of green prehnite. Later specimens, from deeper down, show a wider variety of true zeolites.

The potential for collecting further specimens certainly exists, but the high-tonnage mechanized type of mining reduces the possibility of discovering intact cavities of collectible material.

ACKNOWLEDGMENTS

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BOOK DEALERS

The Lake George Antimony Mine, New Brunswick

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Discovered in 1861, the Lake George antimony deposits produced some extraordinary specimens of native antimony in the 1880's. After more than a century, fine crystals have again been recovered there. The mine is also the type locality for stibivanite.

INTRODUCTION

Large crystals of native antimony have been found at only a few localities in the world. Among them are Broken Hill, Australia (striated crystals to 1 cm from the ABH Consols mine; Worner and Mitchell, 1982); St. Andreasberg, Germany (crystals to 1.5 cm from the Samson mine; Gebhard, 1988); and the Lake George antimony deposits in New Brunswick, Canada.

The Lake George deposit is located about 24 miles west-southwest of Fredericton, between Lake George and Prince William in York County, New Brunswick. Access from Fredericton is by Highway 2 west about 15 miles, then turning south at the Kings Landing Historical Settlement and proceeding a short distance.

HISTORY

Antimony mineralization was apparently first noticed in the area in 1861. In a letter of December 1862 to Benjamin Silliman, Edward Allison, owner of the property (and perhaps the discoverer), described how the mineralization was first noticed in loose float and then traced to vein outcrops on the low ridge dividing the Lake George and St. John River watersheds. From the outcrop outward to the northeast and southwest, the vein was covered by 1 or 2 meters of overburden, and by 1862 had been delineated over a distance of about 400 meters by prospect pits. A 1-ton ore sample had been shipped to Liverpool for smelting. L. W. Bailey (1863), who forwarded Allison's letter to Silliman, commented that the antimony occurred in the sulfide form (i.e., stibnite), that it had little, if any, "crystalline structure" (i.e., discernible crystal morphology), and that it was found imbedded in irregular veins of quartz.

Between 1863 and 1869, shafts were sunk on the Adams, Hibbard and Lawrence properties. In 1876 the Lake George Mining and Smelting Company was formed by the Honorable Francis Hibbard of Magaguadavic, for the purpose of operating the Hibbard mine. This property adjoined the road to Lake George about 3 miles from Prince William. Four years later the Hibbard Antimony Company constructed the first milling and smelting facilities in the district, producing about 15 tons of metallic antimony every six weeks from sorted ore containing roughly 50% Sb. Some of the antimony was exported to the U.S. as ingots, and some was alloyed with Pb, Cu and Sn to produce Babbitt metal for industrial use (Bailey, 1898). Operations continued until the mill burned down in 1884.

In 1885 the Hibbard mine and the nearby Prince William and Lake George mines (=Adams and Lawrence mines) were consolidated under the management of the newly formed Brunswick Antimony Company, and they were collectively referred to as the Brunswick mines (Kunz, 1885). This firm lasted only a year. During 1887–1890 the Hibbard mine was worked intermittently by lessees, but in 1890 all mining in the area was shut down due to the falling price of antimony. The Hibbard mine was in the hands of trustees, and the Prince William and Lake George mines formed part of the estate of the Lawrence family (Bailey, 1898).

Operations continued sporadically during the 20th century. There was no production during the years 1899–1904 (Ingall, 1907), but in 1909 the Canadian Antimony Company was organized to work the Hibbard property, and a 50-tons/day smelter was erected. After producing 35 tons of concentrates and 30 tons of metallic antimony (McLeish, 1914) the operation was shut down because of excess arsenic in the ore (Morrissy and Ruitenberg, 1980).

The increase in antimony prices occasioned by World War I resulted in the formation of the New Brunswick Metals Company and the production of an additional 30 tons of antimony in 1915 (McLeish, 1917). High arsenic content and price fluctuations again closed the operation after one year.

The North American Antimony Company carried out work in the district between 1917 and 1922 (Morrissy and Ruitenberg, 1980), but no production was reported, and the company was reorganized as the

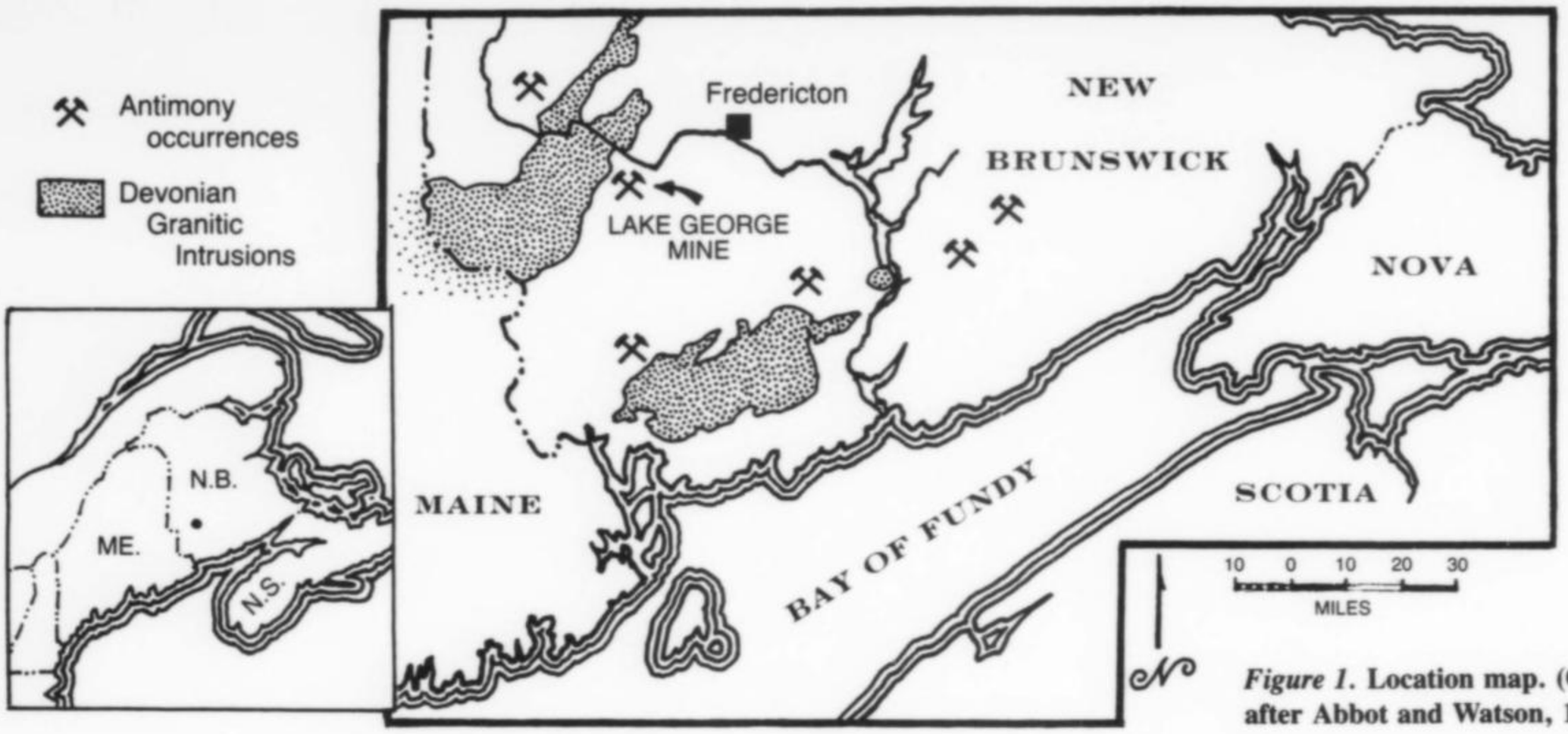

Figure 1. **Location map. (Geology after Abbot and Watson, 1975.)**

Antimony Products Corporation (Coats, 1924).

Lake George Mines, Ltd. was formed in 1929 to work the Lawrence properties, and produced ore periodically until 1938. During this time a number of quartz veins were identified for future exploration (Parsons, 1947). Exploratory drilling was carried out (Parsons, 1949; Fraser, 1960), and in 1952 Quebec Metallurgical Industries, Ltd. conducted a geological survey of the area and did some trenching which disclosed new vein intersections (Convey, 1955).

The Lake George deposits lay dormant from 1938 to 1970, when Consolidated Durham Mines and Resources, Ltd. was formed. Following the relogging of available drill cores, and an extensive new diamond drilling program initiated in 1970, mining was recommenced in 1974. The mines were shut down from 1979 to 1984, but reopened again in 1985 and operated until their recent closure in 1990. At that time, mining had reached the 1375-foot level, but a drop in the price of antimony rendered continued operation unprofitable (Allan Smith, personal communication). The Durham operation yielded a total of 1,000,000 tons of ore averaging 3% to 3.5% antimony, accounting for 15% of the Free World's production of antimony for those years (Morrissy and Ruitenberg, 1980).

The Lake George mines, now owned by Antimony and Potash of Canada (APOCAN) Inc., are currently dormant but the facilities are being refitted to produce antimony tri-oxide. Mining may resume eventually, when the price of antimony improves, but at present the future of the mine is uncertain.

GEOLOGY

The Lake George vein system cuts Upper Silurian graywackes and slates which were intensely deformed during the early Middle Devonian Acadian Orogeny. Tight, northerly trending folds with well-developed axial surface cleavage resulted. About 5 km north of the mine, rocks were intruded by the Devonian Pokiok Batholith, producing a contact metamorphic aureole accompanied by hydrothermal alteration along fractures in the intrusion. Two sets of pre-ore dikes crosscut the area (Morrissy and Ruitenberg, 1980).

A prominent (Acadian) antiform and synform are present in the mine area, plunging about 20° to the southwest. The two principal ore structures, the Hibbard and Prout veins, occupy fracture zones trending easterly across the fold trends and dipping about 30° north. The Hibbard vein (120 meters long) contains most of the ore, averaging 12.7% Sb over an average vein width of 1.6 meters. The Prout vein, which is shorter and which converges with the Hibbard vein, averages 5.2% Sb and 1.2 meters in width (Abbott and Watson, 1975). A third, very minor vein is located at the Lawrence shaft to the south; it trends due north. The ore-bearing fracture zones are deflected by competent beds toward the footwall near the synformal axis, resulting in an irregular plunging trough structure which served as the focus for 80% of the ore emplacement (Morrissy and Ruitenberg, 1980).

The antimony lodes at Lake George are lenticular in shape and occur irregularly distributed, mainly along northeast-raking zones in the Hibbard vein system. Ore emplacement is thought to have occurred during early Carboniferous time (Morrissy and Ruitenberg, 1980). The main ore zone appears to be enveloped, at least partially, by a uranium-bearing zone currently under investigation. Mineralization extends down at least as far as the 1375-foot level.

Stibnite and native antimony are the principal ore minerals, stibnite predominating in the eastern part of the mine, and native antimony in the west (Morrissy and Ruitenberg, 1980). Native antimony is also said to increase proportionally with depth (Bailey, 1898). Hydrothermal synthesis of associated Sb minerals suggests an emplacement temperature of 300° to 400°C (Nekrasov and Bortnikov, 1975), whereas the uranium minerals appear to have been deposited at a temperature of 200° to 250°C or less (Scott, 1979).

The sequence of crystallization began with quartz, pyrite and arsenopyrite. In the second stage, fine-grained quartz and stibnite, along with small amounts of tetrahedrite, chalcostibite, plagionite, fülöppite and bournonite, filled most of the remaining interstices. Third stage deposition consists primarily of cubanite, followed finally by calcite (Abbott and Watson, 1975). Pre-stibnite quartz is transparent whereas post-stibnite quartz is milky (Morrissy and Ruitenberg, 1980).

MINERALS

A number of species have been identified in ore at Lake George (see Table 1), but most of these have been observed only as small, embedded grains in polished section studies. Only those species observed in notable crystals are discussed below.

Antimony Sb

Dana (1868) mentions the occurrence of native antimony at the Prince William mine, but the first substantive description was given by George F. Kunz at a meeting of the American Association for the Advancement of Science in 1884 (Kunz, 1885, 1886). He reported that native antimony was occasionally found in large pockets or lodes in the underground workings, and that some of these pockets contained up to a ton of pure antimony. Compact, granular material was said to be the most common, in rounded or elongated masses 25 to 30 cm

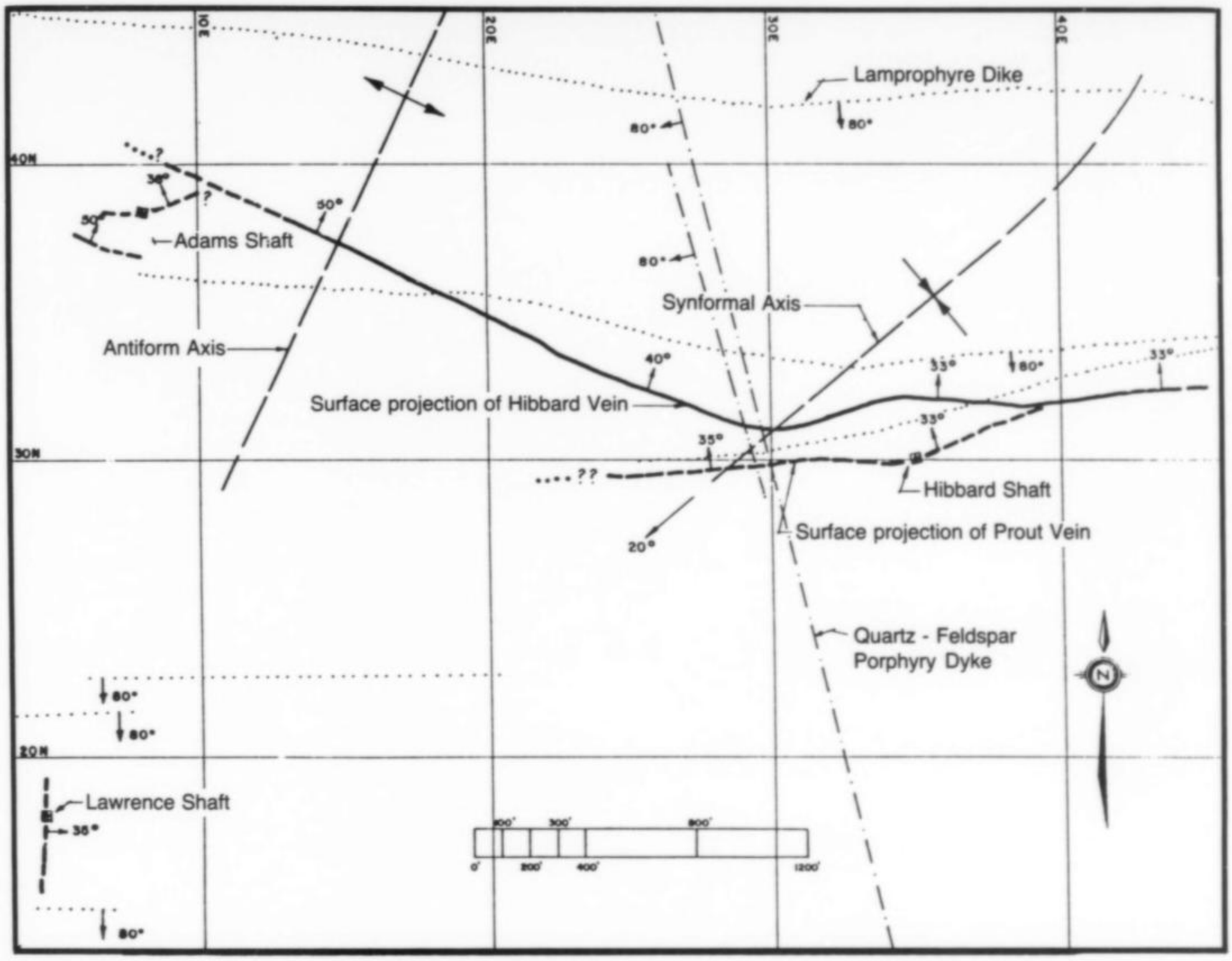

Figure 2. **Surface plan of the Lake George mine (after Morrissy and Ruitenberg, 1980).**

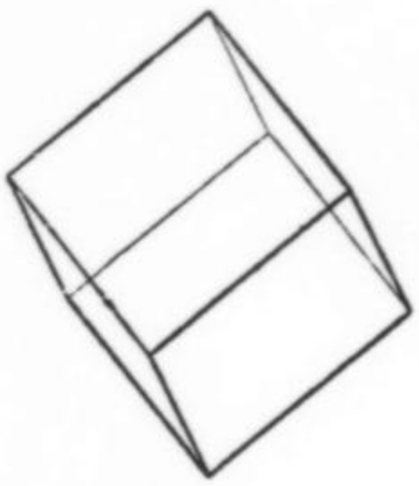

Figure 3. **The {01$\bar{1}$2} pseudo-cubic rhombohedron typical of Lake George antimony (Goldschmidt, 1913; based on a synthetic crystal).**

long and weighing 9 to 23 kg. But Kunz also had seen crystal specimens. These consisted of radiating groups of crystal plates, single blades of which were 5 to 10 cm in length and 3 mm in thickness. One group of tin-white crystals, he said, measured 15 cm across. (It is likely that these were imbedded rather than free-growing crystals, judging from old specimens in the Canadian Museum of Nature, Ottawa.) Microcrystals about 0.05 mm in size were removed from enclosing calcite with acid. Kunz observed striations which he attributed to polysynthetic twinning. C. E. Parsons, of the Brunswick Antimony Company, had furnished Kunz with specimens for examination. The Canadian Museum of Nature today has two specimens originally owned by Kunz, one of them rather massive and the other showing 3–4 cm sprays of imbedded, bladed antimony crystals fitting the above description (G. Robinson, personal communication).

In November of 1988, twenty-two specimens of antimony crystals were collected underground, in an area of active mining, by Allan

Table 1. **Minerals reported from the Lake George mines (compiled from Abbott and Watson, 1975; Kunz, 1885; Kaiman *et al.*, 1980; and G. Robinson, personal communication regarding stibiconite).**

Antimony	Sb
Arsenopyrite	FeAsS
Berthierite	$FeSb_2S_4$
Bournonite	$PbCuSbS_3$
Calcite	$CaCO_3$
Chalcopyrite	$CuFeS_2$
Chalcostibite	$CuSbS_2$
Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$
Cubanite	$CuFe_2S_3$
Fülöppite	$Pb_3Sb_8S_{15}$
Kermesite	Sb_2S_2O
Plagionite	$Pb_5Sb_8S_{17}$
Pyrite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Quartz	SiO_2
Senarmontite	Sb_2O_3
Soddyite	$(UO_2)_2SiO_4 \cdot 2H_2O$
Sphalerite	(Zn,Fe)S
Stibiconite	$Sb^{+3}Sb_2^{+5}O_6(OH)$
Stibivanite	Sb_2VO_5
Stibnite	Sb_2S_3
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
Uraninite	UO_2
Uranophane	$Ca(UO_2)_2[SiO_3(OH)]_2 \cdot 5H_2O$
Valentinite	Sb_2O_3

WEW

Figure 4. **Native antimony crystals to about 1 cm, on a 5-cm matrix with calcite crystals. Rod and Helen Tyson specimen.**

Smith, a geological technician at the mine. The occurrence was found in a calcite-lined pocket 60–70 cm wide and 2 meters deep, located about 30 meters east of the main Hibbard shaft on the 1200-foot level, in a stope designated as 12-28 or 12-29 (Allan Smith, personal communication). The crystals show what appears to be a somewhat rounded, rhombohedral $\{01\bar{1}2\}$ habit and a frosty, matte luster. Some were tarnished dark gray when found but others were bright. Crystal size is generally 8 to 12 mm, and the crystals occur in attractive groups associated with pale cream-colored calcite crystals to 2 or 3 cm. One specimen shows what appears to be a contact twin on $(10\bar{1}4)$. Although Smith regularly sampled the working face on the vein from 1986 through 1990, and commonly saw open, calcite-lined pockets, this was the only instance in which he also saw crystals of antimony.

Arsenopyrite has been reported from the mines, in euhedral crystals, but analysis has shown that much of what was being sight-identified as arsenopyrite was actually native antimony (B. Bourgoin, personal communication).

Kermesite Sb_2S_2O

Kunz (1885) reported that kermesite occurs as small tufts of crystals to 1.2 cm, in cavities in stibnite and native antimony. He also described small hemispheres found, as a rule, in cavities in antimony. The color ranges from dark cherry-red to nearly black. Abbott and Watson (1975) looked for, but could not find any specimens of kermesite for study. But specimens are said to have been found in the Lawrence vein (Allan Smith, personal communication).

Stibivanite Sb_2VO_5

Stibivanite was described as a new species from the Lake George deposit by Kaiman *et al.* (1980), and the structure was solved by

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Figure 5. **Native antimony crystal group, 2.7 cm across, on calcite. Rod and Helen Tyson specimen, now in the collection of Mark Feinglos.**

Szymański (1980). Specimens were collected in 1978 by V. Ruzicka, who brought them to the attention of Kaiman; a short time later J. D. Scott (of Eldorado Nuclear Ltd.) found specimens on dump material believed to have originated in the 453 stope; E. Zaleski (also of Eldorado Nuclear) subsequently collected specimens at an underground location 7 meters west of plug 263, in the hanging wall of the vein. The mineral was then recognized on specimens which had been collected in 1976 by Joel Grice (Canadian Museum of Nature).

Stibivanite is yellow green to deep yellow green in color, and occurs

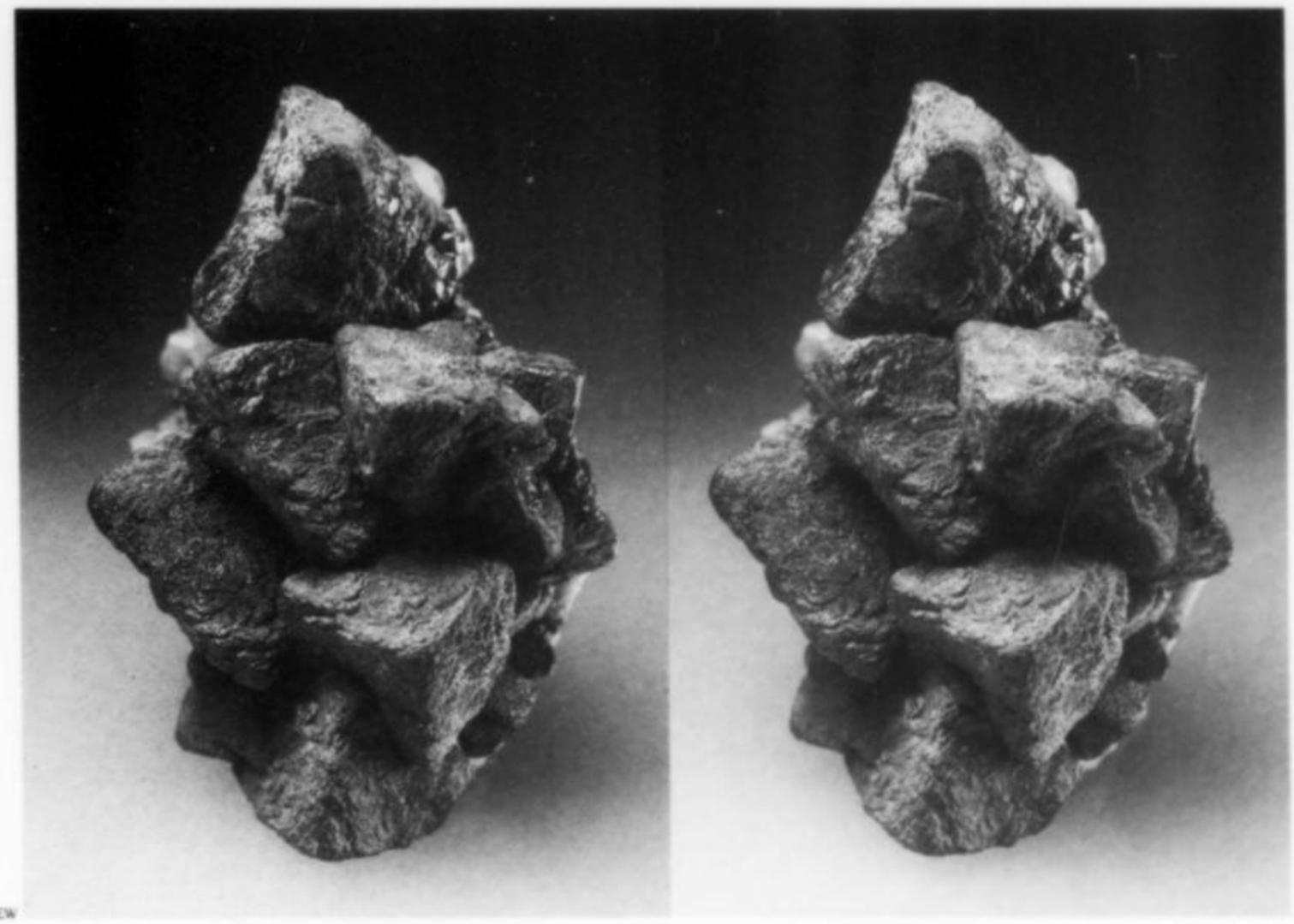

Figure 6. **Native antimony crystal group, 3.6 cm tall (stereo pair). Rod and Helen Tyson specimen, now in the collection of Barbara Cureton.**

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as radiating, fibrous crystals up to 2 mm in size. Crystals are easily split into flexible, elastic fibers. Associated species include native antimony, stibnite, senarmontite, pyrite, arsenopyrite and sphalerite.

Stibnite Sb_2S_3

Stibnite occurs as crystals to 12 or 15 cm imbedded in quartz, and as free-growing crystals in vugs. The crystals are generally a dark graphite-black in color, and freshly broken surfaces tarnish black in a short period of time (Kunz, 1885). Massive and granular material is the most common. The habit tends toward acicular. Charles Morrissy, Chief Geologist (and Mine Manager, following the departure of B. Bourgoin) found a number of attractive stibnite crystal groups, with crystals to 15 cm. These he kept for a time in the mine office and eventually gave away to visitors.

Valentinite Sb_2O_3

Valentinite occurs as massive to granular material, and also as beautiful, radiating groups of acicular crystals to 4 cm across. Small hemispheres and isolated, imperfect crystals have also been observed (Kunz, 1885).

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My thanks to Rod and Helen Tyson (*Tyson's Minerals*, Edmonton) for providing specimens for photography and study. Mr. Bertin Bourgoin, Mine Manager at the Lake George mine from 1974 until a year before its closing, kindly provided information on the recent history of the mine. Allan Smith provided first-hand information on the discovery of the antimony crystals. Drs. George Robinson and Steven Morehead reviewed the manuscript and provided helpful suggestions.

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WATTERSITE

$Hg_4^{+1}Hg^{+2}Cr^{+6}O_6$
A NEW MINERAL FROM THE CLEAR CREEK CLAIM SAN BENITO COUNTY, CALIFORNIA

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ABSTRACT

Wattersite, idealized as $Hg_4^{+1}Hg^{+2}Cr^{+6}O_6$, is monoclinic, space group $C2/c(15)$, with refined unit-cell parameters a = 11.250(5), b = 11.630(7), c = 6.595(5) Å, β = 98.16(4)°, V = 854(2) Å^3, $a:b:c$ = 0.9673:1:0.5671, Z = 4. The strongest eight lines in the X-ray powder pattern are [*d(I) (hkl)*]: 8.06 (80) (110); 5.58 (50) (200); 3.60 (50) ($\bar{2}21$); 3.300 (60) ($\bar{3}11$); 3.260 (60) (002); 2.948 (50) (311); 2.920 (50) (112,040); 2.655 (100) (202,041). The mineral is a rare constituent in a small prospect pit near the long-abandoned Clear Creek mercury mine, New Idria district, San Benito County, California. It is most closely associated with cinnabar and native mercury in a host rock composed predominantly of quartz and chalcedony. Wattersite typically occurs as thin shell-like aggregates in vugs and, less commonly, as small, less than 0.1 mm in size, discrete crystals or crystal aggregates on fracture surfaces. Individual crystals are prismatic and are elongate [001]. Forms observed are: {110}, {010}, {310}, {130}, {021}, {100}, {101}, {$\bar{4}$03}, {011}, {342}, {311}, {001}, {111}, {742}, {112}, and {312}. Crystals show simple contact twinning on {100} and the twin axis is [001]. The mineral is dark reddish brown, inclining to black in masses, and possesses a dark brick-red streak. Physical properties include: submetallic luster; opaque (masses) to translucent (thin edges of crystals); nonfluorescent; brittle; conchoidal fracture; hardness less than 5; calculated density 8.91 g/cm^3 (for empirical formula). In polished section, wattersite is moderately bireflectant and pleochroic. In plane-polarized light it is a bright, slightly greenish white to a darker lilac-gray with deep, bright red internal reflections. Measured reflectance values are tabulated, in air and in oil, for both individuals of a twinned grain. Electron microprobe analyses yielded Hg_2O = 72.1, HgO = 18.7, CrO_3 = 8.7, total = 99.5 weight %, corresponding to $Hg^{+1}_{3.98}Hg^{+2}_{0.99}Cr^{+6}_{1.01}O_6$, based on O = 6. The original HgO = 93.6 weight % value was partitioned in a ratio of 4 Hg_2O : 1 HgO after the crystal structure was determined. The mineral is named for Mr. Lu Watters (1911–1989), a well-known California mineral collector, jazz trumpeter, chef and environmentalist.

INTRODUCTION

The new mineral species described here, wattersite, was first identified both by X-ray powder diffraction and by X-ray single-crystal analysis in 1972 by one of us (RCE). The mineral had been collected by Edward H. Oyler from a small prospect pit near the long-abandoned Clear Creek mercury mine, New Idria district, San Benito County,

[1]Geological Survey of Canada contribution number 45490.

California. At that time only a few crystals of the mineral had been found, insufficient to permit a more detailed mineralogical study. The powder data could not be correlated with any known inorganic phase listed in the Powder Diffraction File. In 1987, Mr. Oyler brought RCE some additional specimens of wattersite-bearing material from the Clear Creek area. Enough material was then available for a comprehensive mineralogical study and full characterization; the results are reported here.

The mineral is named *wattersite* after Lu Watters (1911–1989), a well-known California mineral collector, jazz trumpeter, chef and environmentalist. Mr. Watters knew about the new mineral and had approved the mineral name prior to his death. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, IMA. The type material is preserved within the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada, Ottawa, under catalog number NMC 65141.

OCCURRENCE and CRYSTAL MORPHOLOGY

Wattersite has been identified in four specimens collected from a small prospect pit near the long-abandoned Clear Creek mercury mine, New Idria district, San Benito County, California (latitude 36°22′59″N, longitude 120°45′58″W). The mineral is rare and is most closely associated with cinnabar and native mercury. The silica-carbonate host rock is predominantly quartz and chalcedony with accessory opal, ferroan magnesite, goethite, ferroan magnesiochromite, montmorillonite, huntite, gypsum, dolomite and chlorite. Mercury-bearing minerals identified by X-ray diffraction analysis include edoylerite ($Hg_3^{+2}Cr^{+6}O_4S_2$; Erd *et al.*, in preparation, IMA approved), edgarbaileyite (Roberts *et al.*, 1990a; Angel *et al.*, 1990), szymańskiite (Roberts *et al.*, 1990b; Szymański and Roberts, 1990), metacinnabar, eglestonite, calomel, terlinguaite, mosesite, gianellaite, montroydite and four unnamed mercury-bearing phases that are currently under investigation. A description of the geology of the Clear Creek mercury mine is given by Eckel and Myers (1946).

Wattersite has been identified in two different varietal forms: as thin shell-like aggregates in vugs; and, less commonly, as small, generally less than 0.1 mm in size, discrete crystals or crystal aggregates on fracture surfaces. The largest known crystal, which measures 2 mm in length, is shown in Figure 1. Individual crystals are prismatic and are elongate [001]. Masses appear to be granular. The observed forms, measured by a combination of optical goniometric and X-ray single-crystal studies, are: large {110}, {010}; medium {310}, {130}; small to medium {021}; small {100}, {101}, {$\bar{4}$03}, {011}, {342}; very small {311}; tiny {001}, {111}, {742}, {112}, {312}. Twinning is ubiquitous and is found as simple contact twinning on {100}. The twin axis is [001].

PHYSICAL PROPERTIES

Individual wattersite crystals are dark reddish brown, but masses tend to look black. The streak is dark brick-red. Aggregates of crystals are opaque but individual crystals are translucent on thin edges. The mineral is brittle, possesses a conchoidal fracture and a submetallic luster, and is nonfluorescent under both longwave and shortwave ultraviolet light. The density could not be measured due to specimen size limitations and dearth of material; the calculated density, based on the empirical formula, is 8.91 g/cm^3. Neither cleavage nor parting was observed megascopically. The hardness is less than 5 (the mineral does not scratch glass), but a more precise value has not been determined.

X-RAY DIFFRACTION

Precession single-crystal studies, employing Zr-filtered Mo radiation, showed that wattersite is monoclinic, with measured and calculated unit-cell parameters: a = 11.24, b = 11.65, c = 6.581 Å, β = 98.17°. The following levels were photographed: $h0l \rightarrow h3l$, $hk0 \rightarrow hk2$, and $021^*\Lambda a^*$. Twinning by 180° rotation about a^* was noted in the $h0l$ plane. The space-group extinction conditions are compatible with the space groups $C2/c$ (15) or Cc (9), and the diffraction aspect is C^*/c. The correct space group is $C2/c$ (15) based on the crystal structure determined by one of us (YL). Details regarding the structure will be published elsewhere, but it should be noted that the structure refinement clearly shows one Hg^{+2} atom in octahedral coordination, four Hg^{+1} atoms with typical Hg-Hg bonds, and one Cr^{+6} atom in tetrahedral coordination.

Figure 1. **Wattersite crystal (at arrow) in host rock. Crystal is 2 mm in longest dimension. Blue marking adjacent to the crystal is due to a felt pen.**

The X-ray powder diffraction data are presented in Table 1. The unit cell parameters were refined using 17 powder reflections representing d-values between 3.60 and 1.651 Å for which unambiguous indexing was possible, based on visual inspection of precession single-crystal films. The refined unit-cell parameters are: a = 11.250(5), b = 11.630(7), c = 6.595(5) Å, β = 98.16(4)°, V = 854(2) Å^3, $a:b:c$ = 0.9673:1:0.5671. The powder data are unique and bear no resemblance to any other inorganic phase listed in the Powder Diffraction File. Wattersite is the second reported mercury chromate (the first was edoylerite).

OPTICAL PROPERTIES

Reflectance measurements for wattersite were made relative to a Zeiss SiC reflectance standard, no. 472, using X40 objectives, the effective Numerical Apertures of which had been adjusted to 0.26. Zeiss immersion oil, N_D = 1.515, was used at an ambient temperature of 20°C. Further details of the instrumentation and measurement procedures employed are given in Criddle *et al.* (1983). The wattersite specimen, which consists of a fractured grain, 180 by 180 microns in size, and displays simple twinning, was lightly buffed with MgO immediately before measurement.

In plane-polarized light it is moderately bireflectant and pleochroic, with R_1 a darker lilac-gray by comparison with the bright, slightly

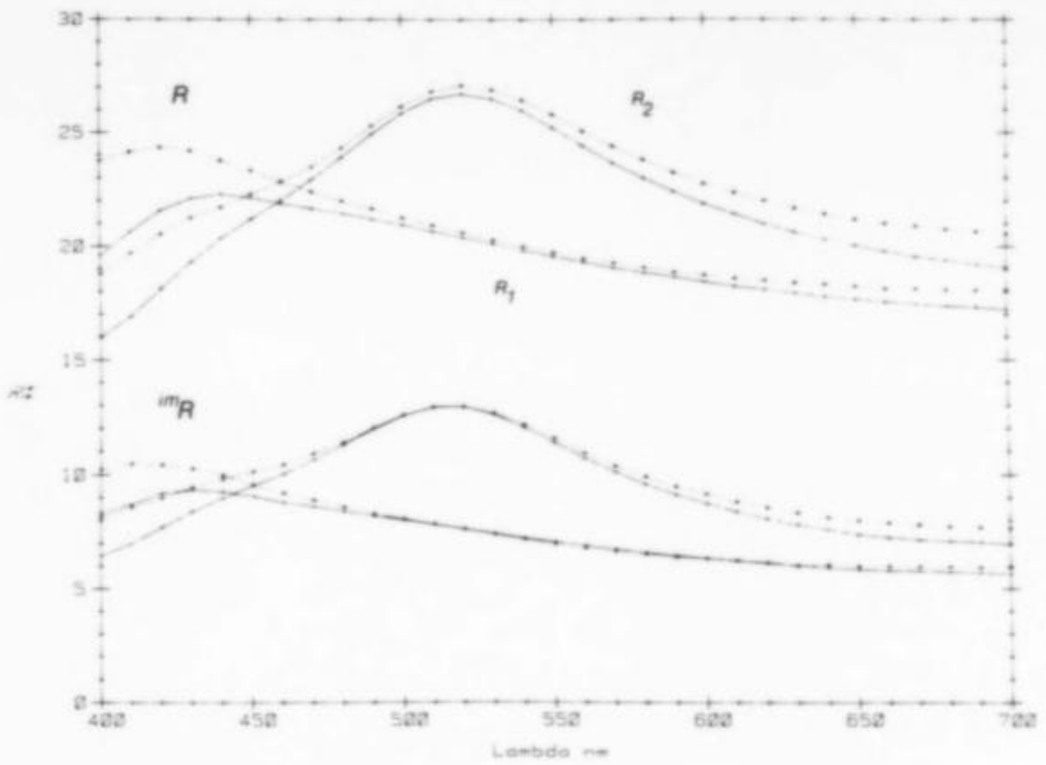

Figure 2. **Reflectance spectra measured in air and in oil (N_D = 1.515) for two grains (twins) of wattersite.**

greenish, white of R_2. Deep and bright red internal reflections, which are seen at low magnifications in plane-polarized light, are strengthened between crossed polars. The mineral displays straight (orthogonal) extinction, and is strongly anisotropic with distinctive and brilliant rotation tints: purple, dark blue, "bottle"-green/blue, turquoise-blue to a dull greenish blue. Reflectance spectra for the two twins of wattersite are shown in Figure 2, and minimum (R_1) and maximum (R_2) reflectance and color values are given in Table 2.

The bireflectance and reflectance pleochroism for the two grains (twins) of wattersite are confirmed by the reflectance spectra (Fig. 2, Table 2): the dispersion of R_1 shows a slight increase from 400 *nm* to a peak at 420 *nm* for grain 1 and 440 *nm* for grain 2, and then a gentle reduction in reflectance to 700 *nm* for both grains. This vibration direction appears lilac-gray by comparison with much more strongly dispersed and higher reflecting R_2 vibration which, peaking at about 520 *nm*, is perceived as slightly greenish white. For both grains there is a change in the sign of the bireflectance at 460 *nm* in air, and at

Table 1. **X-ray powder diffraction data for wattersite.**

I_o	d(Å)meas.	d(Å)calc.	hkl	I_o	d(Å)meas.	d(Å)calc.	hkl
80	8.06	8.04	110	5	2.173	2.171	042
50	5.58	5.57	200			2.170	$\bar{1}51$
40	5.35	5.34	$\bar{1}11$	10	2.127	2.131	151
10	4.82	4.83	111			2.126	$\bar{4}22$
5	4.36	4.34	021	5	1.998	2.002	$\bar{2}23$
5	3.68	3.66	130			1.992	511
50	3.60	3.59	$\bar{2}21$			1.980	$\bar{4}41$
10	3.54	3.54	310	5	1.974	1.976	$\bar{3}13$
60	3.300	3.302	$\bar{3}11$			1.971	350
60	3.260	3.264	002			1.961	242
20	3.014	3.008	$\bar{2}02$	5	1.944	1.947	$\bar{5}12$
50	2.948	2.947	311			1.938	060
50	2.920	2.922	112	15	1.925	1.927	$\bar{3}51$
		2.908	040	10b	1.854	1.856	600
10	2.841	2.846	022			1.849	351
5	2.785	2.784	400	25	1.833	1.833	133
40	2.677	2.681	330			1.831	260
		2.672	$\bar{2}22$	20	1.796	1.796	$\bar{4}42$
100	2.655	2.656	202	5b	1.765	1.768	620
		2.656	041			1.768	$\bar{6}21$
30	2.577	2.579	$\bar{3}12$			1.760	$\bar{4}23$
		2.577	240			1.760	$\bar{5}32$
30	2.512	2.575	$\bar{3}31$	20	1.746	1.751	313
		2.511	420			1.747	$\bar{3}52$
40	2.452	2.453	$\bar{2}41$			1.742	043
		2.451	$\bar{4}21$	5b	1.710	1.710	512
3	2.383	2.382	132	10	1.668	1.667	062
10	2.346	2.345	241	20	1.651	1.651	$\bar{6}22$
20	2.280	2.284	$\bar{4}02$	20	1.633	1.634	352
		2.277	150			1.632	$\bar{1}14$
3	2.248	2.249	421			1.632	004
		2.185	$\bar{3}32$			1.630	$\bar{2}04$

—114.6 mm Debye-Scherrer powder camera
—Co radiation Fe filter ($\lambda CoK\alpha$ = 1.79021Å)
—Pattern obtained at CANMET by Mr. Paul Carrière
—Intensities estimated visually
—b = broad line
—Indexed with a = 11.250, b = 11.630, c = 6.595Å, β = 98.16°

Table 2. **Reflectance values for two grains (twins) of wattersite: for ^{im}R, N_D = 1.515.**

Grain:	1		2		1		2	
λnm	R_1	R_2	R_1	R_2	$^{im}R_1$	$^{im}R_2$	$^{im}R_1$	$^{im}R_2$
400	23.75	18.8	19.6	16.0	10.2	8.17	8.33	6.46
10	24.1	19.7	20.6	16.9	10.5	8.59	8.70	6.99
20	24.3	20.5	21.6	18.1	10.4	9.00	9.17	7.70
30	24.2	21.3	22.1	19.3	10.3	9.45	9.34	8.39
40	23.8	21.7	22.3	20.4	9.98	9.82	9.25	8.98
450	23.3	22.3	22.15	21.2	9.56	10.1	9.06	9.53
60	22.85	22.85	21.9	22.0	9.19	10.4	8.78	10.0
70	22.4	23.5	21.7	22.9	8.88	10.9	8.60	10.6
80	22.0	24.3	21.5	23.9	8.57	11.4	8.40	11.3
90	21.7	25.3	21.2	24.9	8.29	12.0	8.20	12.0
500	21.3	26.2	21.0	25.9	8.07	12.6	8.02	12.6
10	21.0	26.8	20.7	26.5	7.84	12.95	7.83	13.0
20	20.6	27.1	20.4	26.7	7.63	13.0	7.64	13.0
30	20.3	26.9	20.2	26.5	7.41	12.7	7.45	12.6
40	20.0	26.5	19.9	26.0	7.20	12.2	7.25	12.1
550	19.8	25.8	19.6	25.3	7.01	11.6	7.09	11.4
60	19.5	25.1	19.35	24.5	6.82	10.95	6.92	10.7
70	19.3	24.45	19.1	23.7	6.68	10.4	6.76	10.15
80	19.1	23.85	18.9	23.1	6.54	9.93	6.61	9.60
90	18.9	23.3	18.7	22.5	6.40	9.49	6.47	9.14
600	18.8	22.8	18.5	21.9	6.34	9.16	6.34	8.76
10	18.6	22.4	18.3	21.5	6.25	8.82	6.22	8.39
20	18.5	22.1	18.1	21.0	6.16	8.57	6.12	8.08
30	18.4	21.7	18.0	20.7	6.10	8.34	6.03	7.82
40	18.4	21.5	17.8	20.35	6.05	8.14	5.93	7.61
650	18.3	21.2	17.7	20.1	5.99	8.00	5.85	7.39
60	18.15	21.0	17.6	19.8	5.98	7.90	5.80	7.26
70	18.1	20.9	17.5	19.6	5.97	7.82	5.77	7.16
80	18.1	20.8	17.4	19.4	5.97	7.75	5.74	7.10
90	18.1	20.7	17.3	19.2	5.96	7.70	5.71	7.06
700	18.1	20.6	17.2	19.1	5.96	7.67	5.65	6.97
Color values (relative to CIE illuminant C)								
x	0.293	0.305	0.295	0.305	0.277	0.291	0.281	0.290
y	0.298	0.334	0.304	0.339	0.280	0.334	0.289	0.341
Y%	19.8	24.8	19.5	24.2	7.02	10.9	7.03	10.7
λ_d	476	533	480	536	476	503	479	507
P_e%	8.6	3.8	7.0	4.8	16.2	6.2	13.7	6.6

440–450 *nm* in oil. There is also a change in the sign of the birefringence at 490–500 *nm*. The dispersion of the refractive indices follow the same trends as the *R* spectra, except that n_2 peaks at 2.97 at 550 *nm* rather than 520*nm*. The refractive indices at 590 *nm* for grain 1 are (n_1, then n_2): 2.52 and 2.86, and for grain 2 are: 2.44 and 2.70. Absorption peaks are found at 490–500 *nm* for R_2 (absorption coefficients > 1), and the absorption for this vibration direction is greater in the red than the blue, whereas the absorption is greater at the blue end of the spectrum for R_1.

CHEMISTRY

Wattersite was analyzed chemically by means of a CAMEBAX electron microprobe, using a 20-kV operating voltage, a 30-nA beam current, a 5-second count rate, and a 10-micron beam diameter. The standards employed were natural cinnabar (for Hg) and synthetic Cr metal (for Cr). A wavelength-dispersive microprobe scan indicated the absence of any other elements with atomic number greater than 9 except those reported here. The average of seven analyses gave HgO = 93.6(2), CrO_3 = 8.7(3), total = 102.3 weight %. After the crystal structure was determined, the HgO value was converted to Hg and then recalculated to Hg_2O and Hg) in a ratio of 4:1. This gives Hg_2O = 72.1, HgO = 18.7, CrO_3 = 8.7, total = 99.5 weight %. With O = 6, the empirical formula is $Hg^{+1}_{3.98}Hg^{+2}_{0.99}Cr^{+6}_{1.01}O_6$, or ideally, $Hg_4^{+1}Hg^{+2}Cr^{+6}O_6$ with X = 4. This idealized formula requires Hg_2O = 72.49, HgO = 18.82, CrO_3 = 8.69, total = 100.00 weight %.

The mineral heated in a closed tube gives off elemental Hg and leaves a residue of green Cr_2O_3 (the synthetic equivalent of eskolaite). Wattersite is easily attacked by cold dilute HCl to form a white precipitate of calomel.

ACKNOWLEDGMENTS

The authors thank P. Carrière (CANMET) for the X-ray powder diffraction photograph and R. D. Lancaster (GSC) for the photograph reproduced in Figure 1. The paper has benefitted from reviews by Drs. James J. Rytuba, Robert I. Tilling, Donald R. Peacor, Abe Rosenzweig and Wendell E. Wilson.

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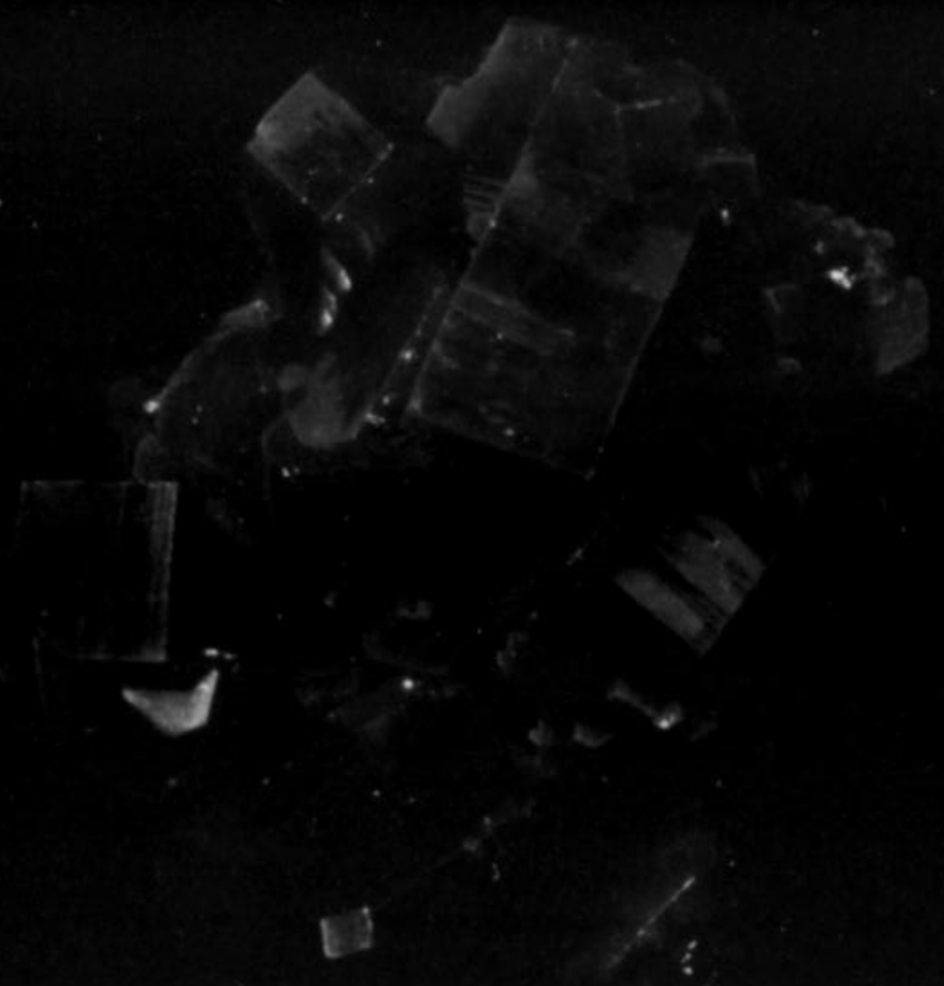

The Lead Silicate Minerals of Franklin, New Jersey: An SEM Survey

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The lead silicate minerals of Franklin, New Jersey, comprise an unusual suite of uncommon minerals. Nine lead silicate species have been found there, several in well-formed euhedral microcrystals, though many are too small to be seen with a light microscope. Scanning electron microscopy reveals some new habits and associations for several of these peculiar species.

OCCURRENCE

All the lead silicates at Franklin were found within the orebody, which has been interpreted to be a metamorphosed metal-rich depositional horizon derived from sea-floor hydrothermal activity (Callahan, 1966; Squiller and Sclar, 1980), and is enclosed within the Precambrian Franklin Marble. The microcrystals discussed here are secondary crystallizations found in vugs and fissures which crosscut the metamorphic textures of the host rocks.

The lead-bearing silicates found at Franklin all contain essential Ca, Mn or Zn (Table 1). Based on occurrence, they were broadly divided into two assemblages by Dunn (1985): an *esperite assemblage*, found throughout much of the north end of the mine; and a *restricted assemblage*, more localized in occurrence. This classification also serves to divide the group chemically. Species with essential Zn define the esperite assemblage while those of the restricted assemblage are Zn-free. Surprisingly, none of these minerals has been found at the related Sterling Hill deposit, which shares much of Franklin's otherwise unique mineralogy.

HISTORY

Species from the restricted assemblage were first encountered in 1895 during the development of the Parker mine. In 1897 the first description of roeblingite appeared (Penfield and Foote) based on specimens found on surface dumps. Subsequent study of specimens brought out from this mine resulted in the description of hancockite, nasonite and margarosanite, together with numerous other minerals. These became known (in the collector community) as the "Parker shaft" minerals, but this was a misnomer because the Parker shaft was merely the opening through which the first discovered occurrences of these minerals were removed; the Parker mine transmitted ore from various parts of the deposit. The Palmer shaft, farther to the west, replaced the Parker shaft in 1910, and was the chief opening until exhaustion of the deposit. A support pillar of ore for the Palmer shaft, left in place until the final years of mining at Franklin (1944–1954), contained by far the largest cache of species from the restricted assemblage (Frondel, 1972). Mining maps indicate that this Palmer shaft pillar area overlaps the area from which the Parker shaft drew lead silicates over 50 years earlier (Dunn, personal communication).

Esperite with associated larsenite were together described by Palache *et al*. (1928a, b), and esperite without larsenite was later found in moderate amounts throughout the north end of the Franklin orebody (Frondel and Baum, 1974). Due to the brilliant yellow fluorescence of esperite under shortwave ultraviolet light, much material was located and preserved by miners equipped with portable lamps.

MINERALS

Barysilite $Pb_8Mn(Si_2O_7)_3$

Barysilite is found as lamellar aggregates of coarsely crystallized plates up to several centimeters across, showing prominent basal cleavage surfaces. Shannon and Berman (1926) noted "occasional druses of minute pink crystals of the mineral, too small for crystallographic measurement." SEM examination of such specimens has commonly shown late crystallization of euhedral barysilite druses (Fig. 1) where small open vugs are present. In these vugs the larger barysilite plates appear to have been altered locally and to have suffered some resorption; they possess rounded, highly irregular borders. The sec-

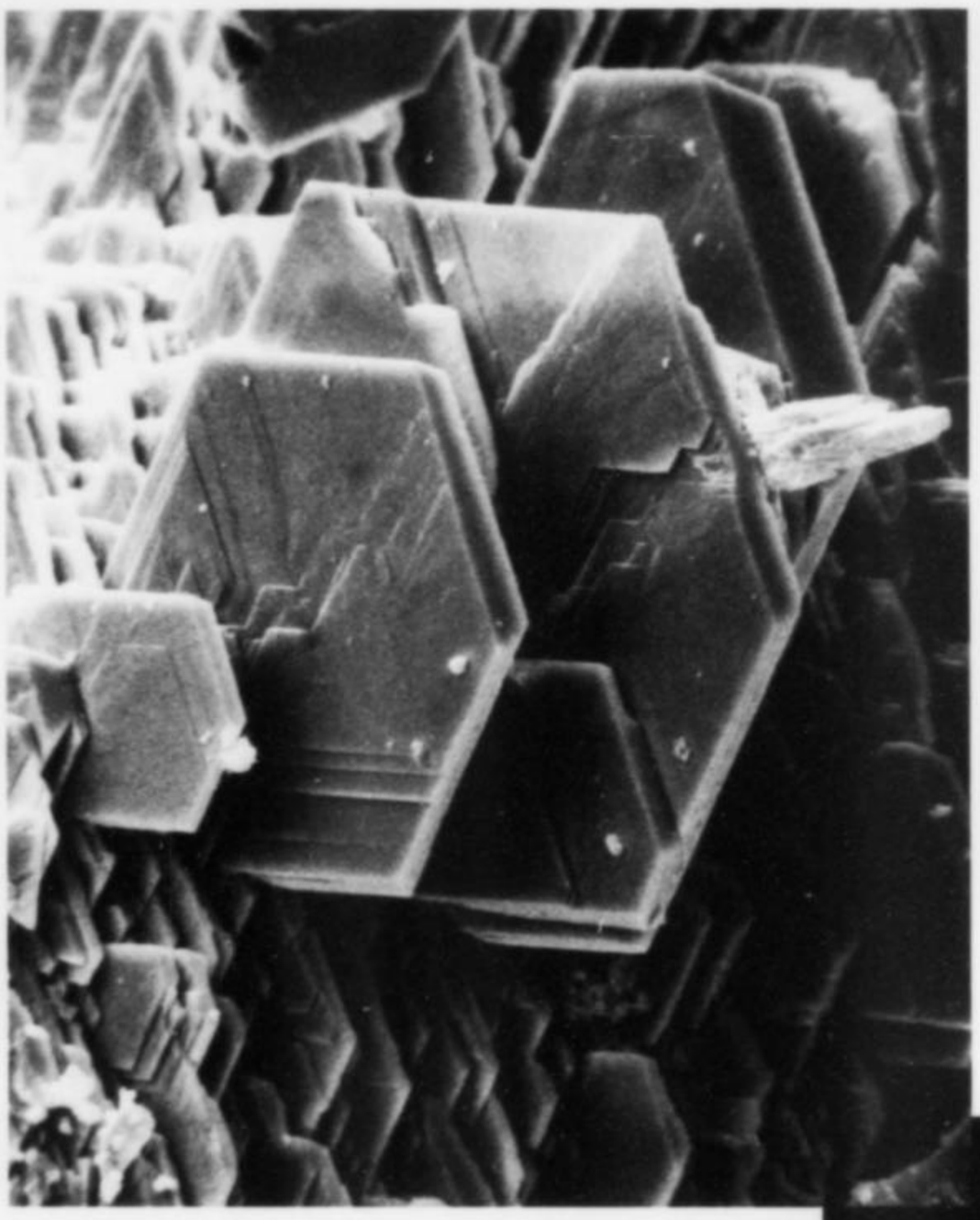

Figure 1. **Barysilite crystals, showing prominent {0001} and minor rhombohedron {10$\bar{1}$2}. (Detail, to the right and above center, of Figure 2.) Field width = 60 microns.**

Figure 2. **Barysilite druse, forming a "rind" around an irregularly bordered barysilite plate, which in turn encloses ganomalite crystals. Field width = 0.5 mm.**

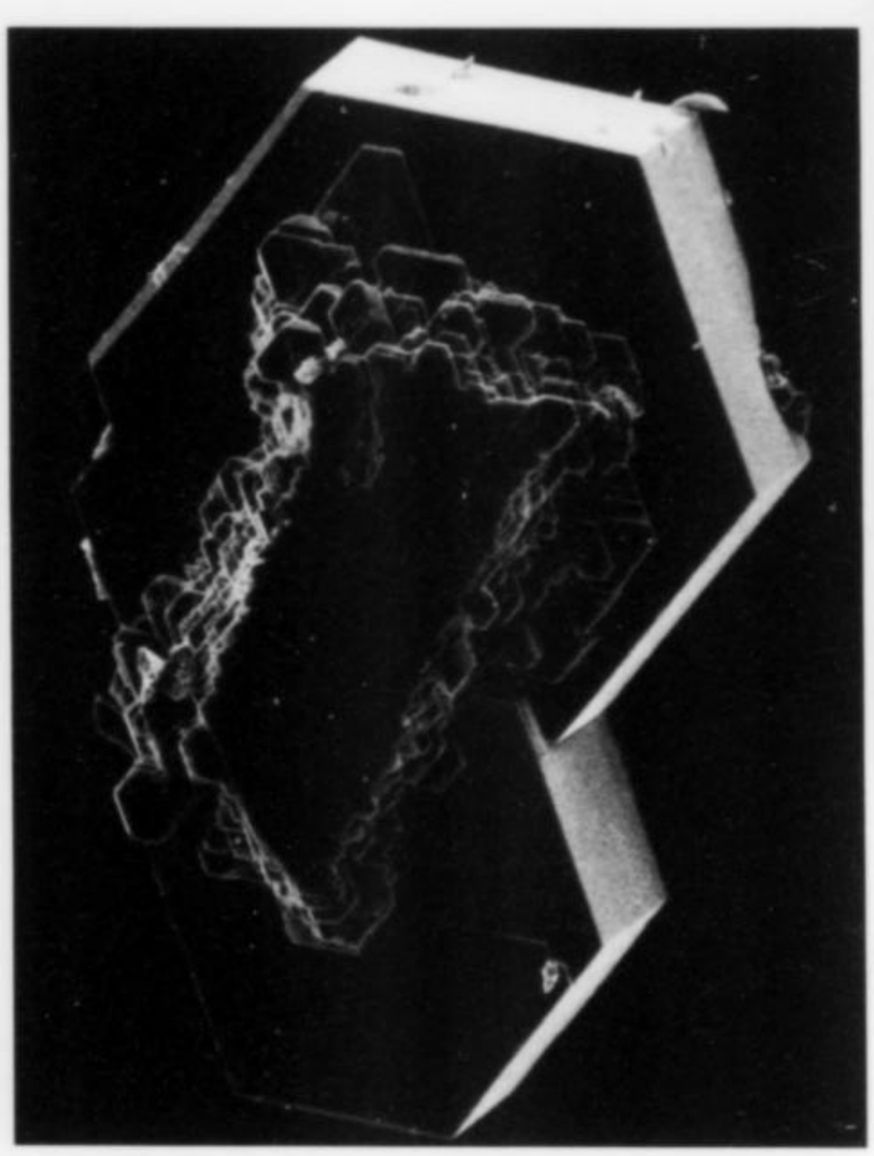

Figure 3. **Barysilite druse epitactic on ganomalite. Field width = 0.2 mm.**

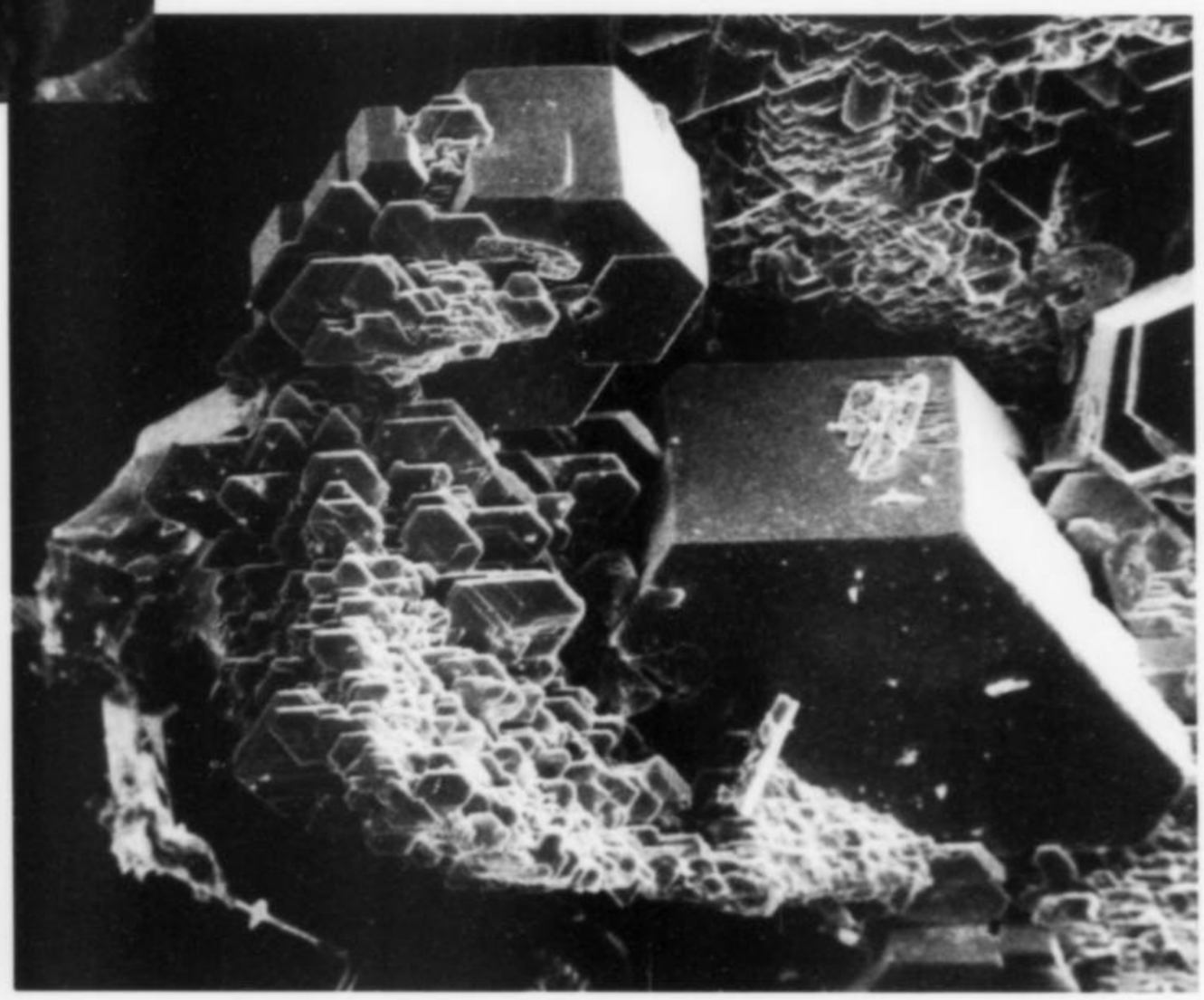

Figure 4. **Barysilite druse intergrown with ganomalite crystals, both transparent. Field width = 0.3 mm.**

ondary druse forms a "rind" around the edges of platy fragments (Fig. 2). The druse is crystallographically parallel to the larger plates; the aggregates extinguish as a unit under crossed nicols. Where intergrown with ganomalite the barysilite druse appears to be epitactic (Figs. 3, 4, 5). Measurement of oriented micrographs suggests the forms present on barysilite are {10$\bar{1}$2} and {0001}. Energy-dispersive X-ray analysis (EDX) shows the rimming druse to have elevated calcium levels relative to the larger plate fragments.

Esperite $(Ca,Pb)ZnSiO_4$

Esperite is found as anhedral, embedded grains of up to several centimeters in size. Though apparent pseudomorphs of esperite after hardystonite crystals have been found, euhedral crystals of esperite from Franklin are not known. However, interesting pseudo-hexagonal etch pits in this species were observed on an altered specimen of esperite using the SEM. Recently, a second occurrence of esperite

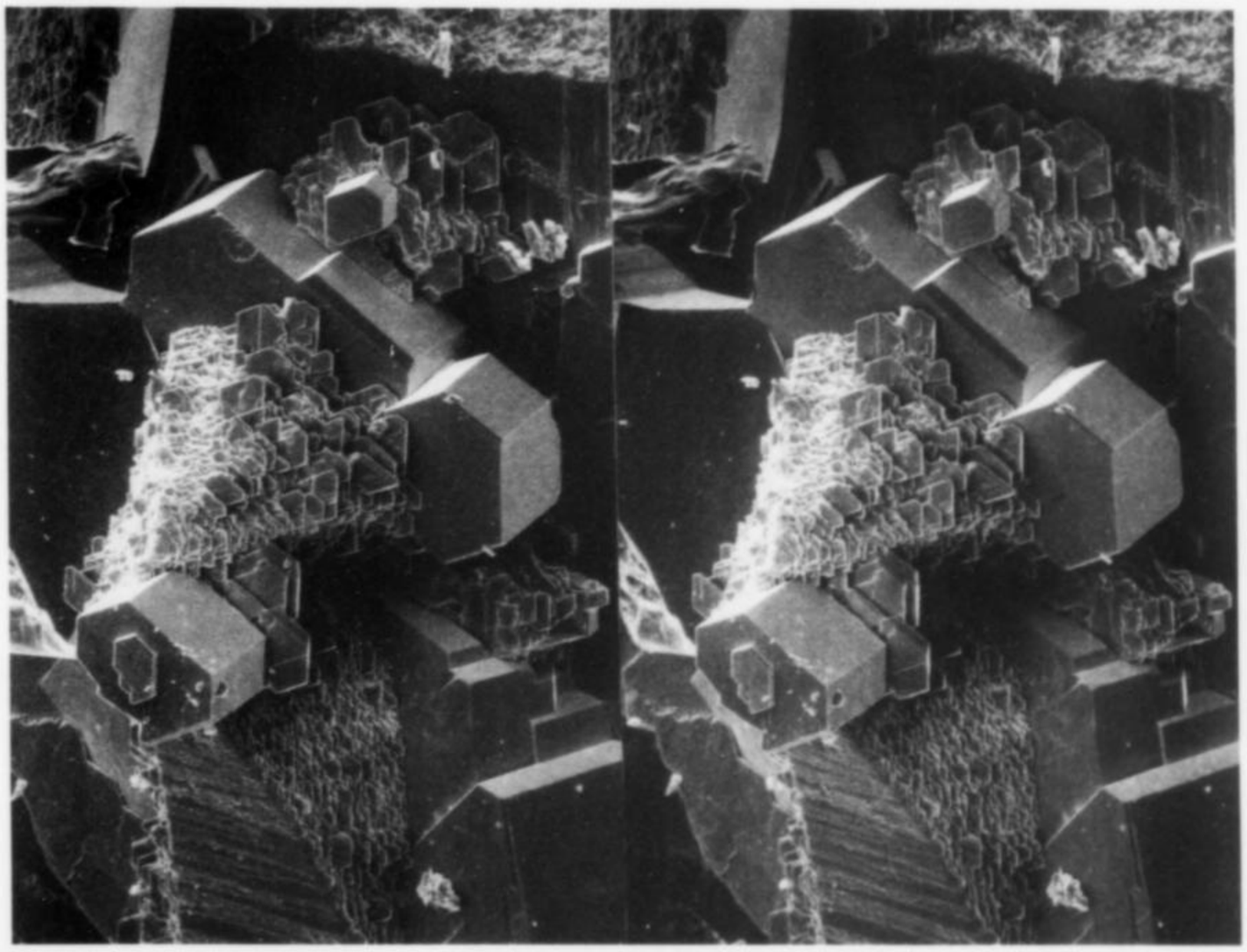

Figure 5. **Barysilite with ganomalite (stereo pair). Field width = 0.25 mm.**

Figure 6. **Ganomalite crystal showing trigonal pyramid form, on druse of barysilite. Field width = 40 microns.**

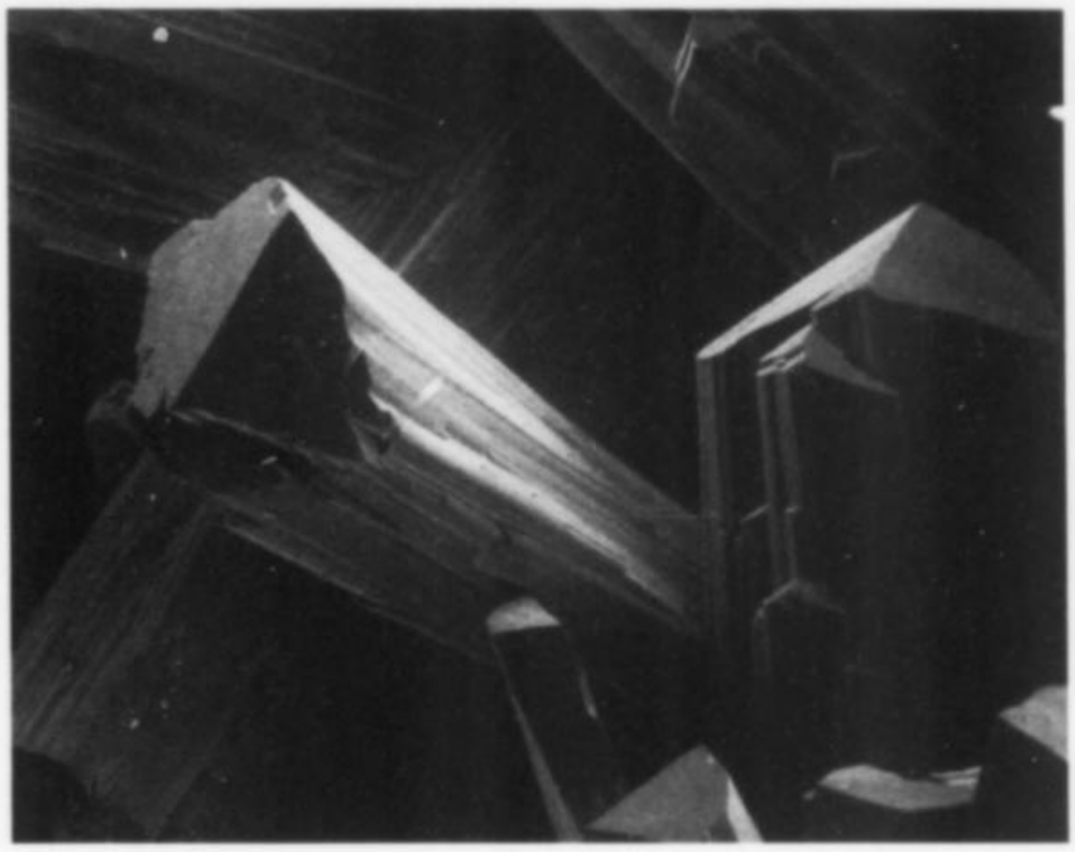

Figure 7. **Cluster of reddish brown hancockite crystals. Field width = 0.8 mm.**

has been reported from Bolivia in which the mineral is present in prismatic crystals (Grundmann *et al.*, 1990).

Ganomalite $Pb_9Ca_5MnSi_9O_{33}$

Ganomalite was reported from Franklin by Dunn (1979) as euhedral crystals intergrown with clinohedrite and nasonite. The crystals he described are tabular to equant hexagonal prisms composed only of $\{10\bar{1}0\}$ and $\{0001\}$ forms. Ganomalite euhedra have been found intimately intergrown with the secondary druses of barysilite described previously, especially where clinohedrite is present. SEM examination of these ganomalite crystals shows the presence on smaller individuals of a trigonal pyramid (Fig. 6), a form consistent with the recent structural refinement to space group $P3$ (Dunn *et al.*, 1985). Direct measurement of oriented micrographs suggests this to be the pyramid $\{10\bar{1}1\}$ or $\{01\bar{1}1\}$.

Hancockite $(Pb,Ca,Sr)_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$

Hancockite is an exotic lead-bearing member of the epidote group unique to Franklin. It forms brick-colored masses of up to many kilograms weight, typically intergrown with varying amounts of andradite, manganaxinite, hendricksite and franklinite. Specimens often contain small vugs, and these are frequently lined with secondary transparent microcrystals of hancockite, as well as numerous other species. The crystals closely resemble common epidote in habit, and are severely striated along their length (Fig. 7). Their deep red color is often unevenly distributed, with some crystals ranging in color from pale yellow to deep red-brown.

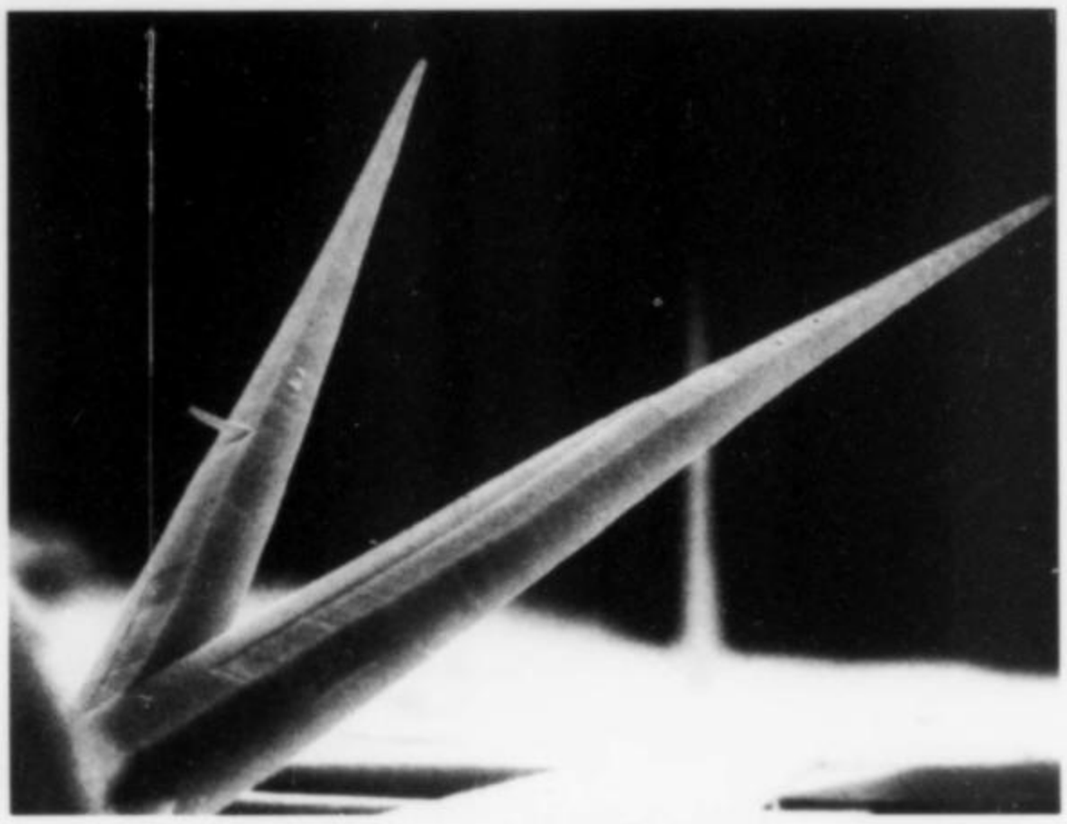

Figure 8. **Deep red kentrolite spicule. Field width = 150 microns.**

Figure 9. **Kentrolite spicules on barysilite crystal. Field width = 0.2 mm.**

Kentrolite $Pb_2Mn_2^{+3}Si_2O_9$

Crystals of the rare mineral kentrolite were reported from Franklin by Palache (1935), based solely on morphologic evidence. They were described as having crystallized together with willemite in a vug in calcite. Recently kentrolite has been found in a manganese-rich assemblage with brown andradite, hetaerolite and crystals of groutite (Dunn, personal communication).

Microscopic examination of restricted-assemblage specimens comprised largely of barysilite has disclosed the common presence of minute spicules, singly and in sub-parallel groups, often in close association with secondary willemite crystals and rosettes of a stilpnomelane-group mineral. X-ray powder diffraction shows these deep red needles to be kentrolite. This is the first known association of kentrolite with the other lead-silicate minerals at Franklin. The striking habit is very much in keeping with kentrolite's name* (Figs. 8, 9). Kentrolite has also been found during this study as sheaf-like aggregates of needles interstitial to manganaxinite crystals. Such aggregates appear very dark brown to black under the binocular microscope, and only small fragments or individual spicules show the intense red color. EDX analyses show no solid-solution towards melanotekite, and an absence of elements with $Z > 11$, other than Pb, Mn and Si.

Larsenite $PbZnSiO_4$

Larsenite was first reported from Franklin by Palache *et al.* (1928a, b) as a Pb-Zn member of the olivine group. Layman (1957) found

*From the Greek for "spike."

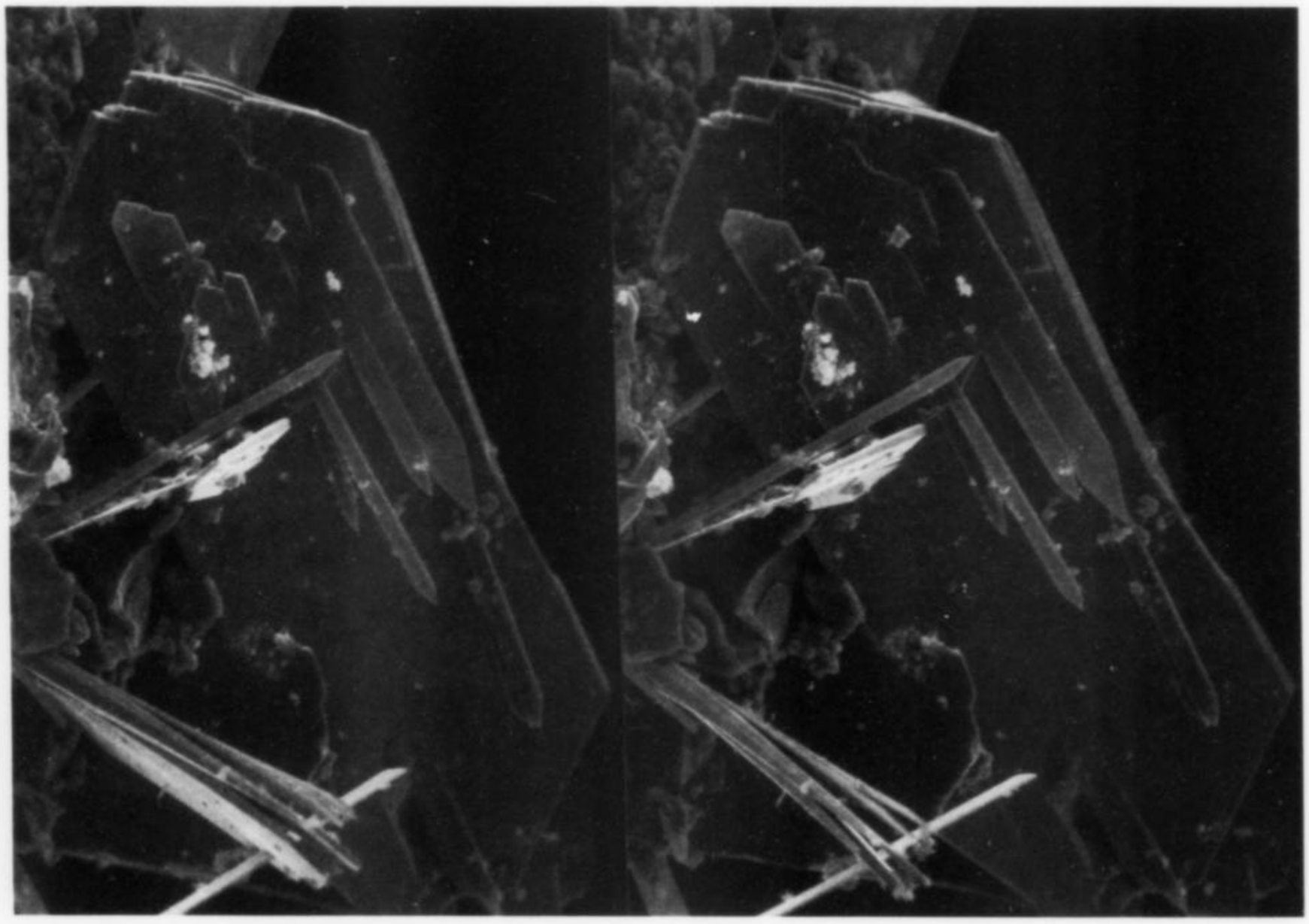

Figure 10. **Thin larsenite crystal, 0.17 mm in size (stereo pair).**

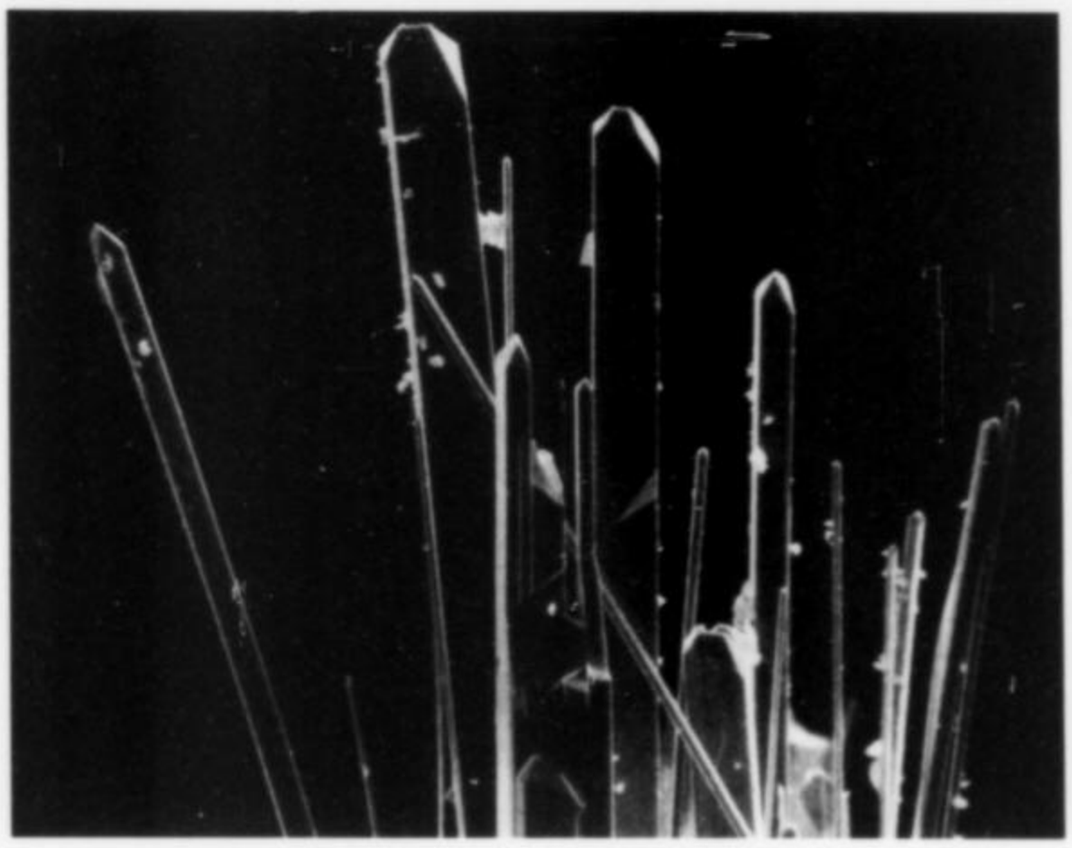

Figure 11. **Transparent, acicular larsenite crystals. Field width = 0.2 mm.**

larsenite not to be an olivine-group mineral, and during a crystal structure determination Prewitt *et al.* (1967) found it to be piezoelectric. Only a few of the crystals studied by Palache were described as having terminations; most grew from vug wall to wall and none was described as being doubly terminated.

Minute, thin-tabular larsenite crystals were observed using SEM. Doubly terminated crystals show hemimorphic development (Fig. 9), as expected for point group *mm*2. These occur on an anomalous specimen unique in containing both larsenite and esperite as well as the restricted assemblage species barysilite and ganomalite. Additionally, larsenite was seen to form extremely fine thin-tabular whisker-like crystals on several specimens (Fig. 11).

Margarosanite $Pb(Ca,Mn)_2Si_3O_9$

Margarosanite, which commonly fluoresces a vivid blue-white under shortwave ultraviolet light, is found in lamellar aggregates of pearly, slightly curved plates and as wispy disseminations in microcline. Euhedral crystals of margarosanite were not observed during this study.

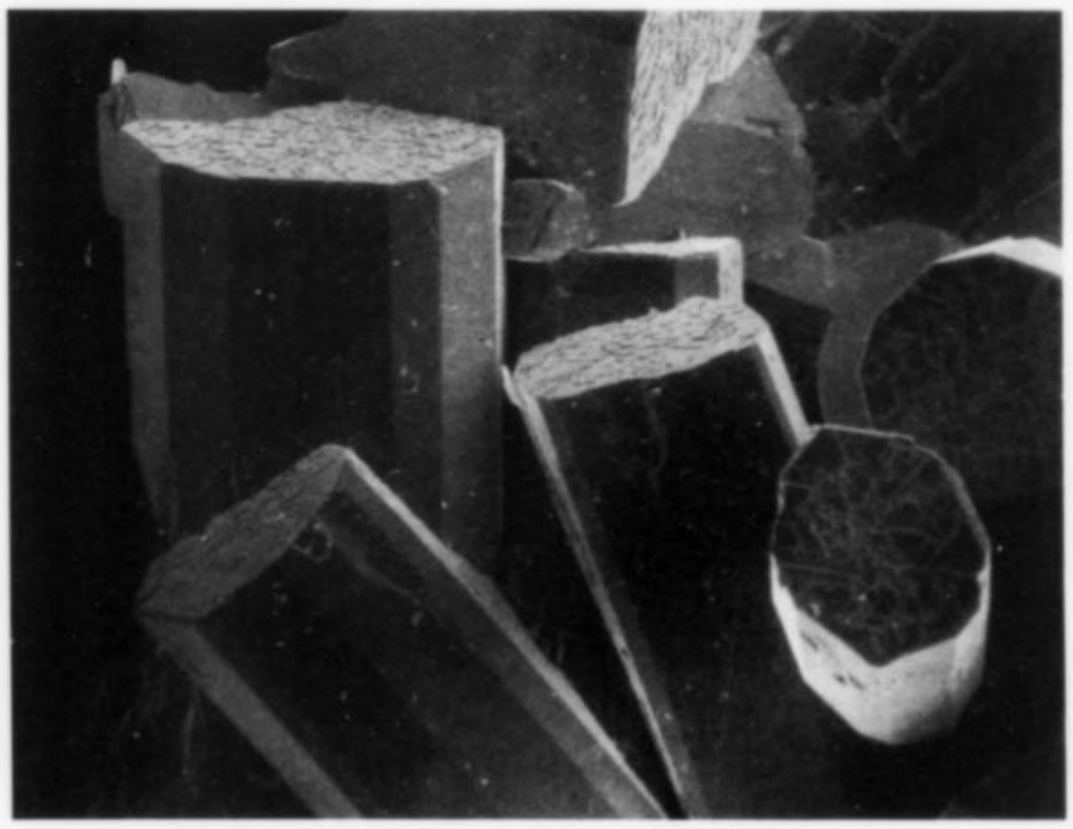

Figure 12. **Group of clear nasonite crystals. Field width = 1 mm.**

Nasonite $Pb_6Ca_4(Si_2O_7)_3Cl_2$

Nasonite is commonly found as glassy, anhedral grains and occasionally in prismatic hexagonal crystals. Microcrystal habits observed with SEM include combinations of one or two prisms with a pyramid, or more commonly with the basal pinacoid (Fig. 12). On many crystals the prism zone appears etched with shallow depressions.

Roeblingite $Pb_2Ca_6(SO_4)_2(OH)_2(H_2O)_4[Mn(Si_3O_9)_2]$

Roeblingite occurs in dense, white nodular aggregates of extremely minute lath-like crystals. Hand specimens have a porcelaneous luster, often resembling fresh unground coconut. SEM examination of such specimens shows rough anhedral surfaces, with the component crystals indistinguishable.

Table 1. **Lead silicate minerals at Franklin, New Jersey.**

Barysilite	$Pb_8Mn(Si_2O_7)_3$
Esperite	$(Ca,Pb)ZnSiO_4$
Ganomalite	$Pb_9Ca_3MnSi_9O_{33}$
Hancockite	$(Pb,Ca,Sr)_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$
Kentrolite	$Pb_2Mn_2^{+3}Si_2O_9$
Larsenite	$PbZnSiO_4$
Margarosanite	$Pb(Ca,Mn)_2Si_3O_9$
Nasonite	$Pb_6Ca_4(Si_2O_7)_3Cl_2$
Roeblingite	$Pb_2Ca_6(SO_4)_2(OH)_2(H_2O)_4[Mn(Si_3O_9)_2]$

CONCLUSIONS

Although the Franklin mine closed in 1954, and the minerals described here were not common, a great many specimens have been preserved in both public and private collections, and they continue to appear on the specimen market. SEM examination reveals many specimens to be richly speciated over distances of tens of microns, and to possess a largely unexplored scale of euhedral crystallization.

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The Kalahari Manganese Field: An Update

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Since the publication by Wilson and Dunn (1978) on the Kalahari Manganese Field, many minerals previously unrecorded from the area have been identified, spectacular specimens recovered and the new minerals sturmanite and orlymanite described. The list of identified minerals has grown from 42 to 120 species. In this article the new additions are discussed, and noteworthy new occurrences of the other minerals described.

INTRODUCTION

To the north and west of the Kuruman Hills in northwestern Cape Province, South Africa, the arid shrub savanna gives no idea of the underlying geology. Where clumps of grass and thorny acacia trees are absent, a thick layer of red Kalahari Desert sand covers the ground. The enormous manganese deposits of the Kalahari Manganese Field which underlie this cover are at least 1,100 square kilometers in extent. These deposits have become world famous for a range of spectacular minerals, and new discoveries continue to be made there.

GEOLOGY

The stratabound ore deposits of the Kalahari Manganese Field, the largest sedimentary manganese deposits in the world, represent a single episode of manganese deposition about 2,100 million years ago (Söhnge, 1977). The manganese deposits are confined to the Hotazel Member of the Griqualand West Sequence of middle Proterozoic age, and comprise part of a mixed volcanogenic-chemical sedimentary rock unit (Söhnge, 1977; Beukes, 1980).

The manganese-bearing Hotazel Member is preserved in the form of erosional relics in a number of structural basins, the Kalahari Manganese Field being the largest and westernmost example (the others being the Leinster and Avontuur basins). The base of the Hotazel Formation consists of a bright red jasper unit overlying hyaloclastic breccias and pillow-lava flows.

The jasper beds vary from massive to finely laminated cherty hematite lutites and rhythmites, the jasper containing sub-microscopic hematite dust in a cryptocrystalline chert, some of which has been transformed into fine-grained euhedral specularite and/or magnetite crystals. In some jaspilite units jasper ribbons alternate with hematite-magnetite mesobands. The jasper unit grades upwards into kutnohorite-bearing pisolitic hematite lutite, which in turn gradually grades into microcrystalline kutnohoritic pisolitic braunite lutite. The kutnohorite is concentrated in the pisoliths, which represent partially compacted, early diagenetic concretions in hematite and braunite lutite.

The sequence described above represents the lower section of the lowermost of three sedimentary cycles present in the Hotazel Member.

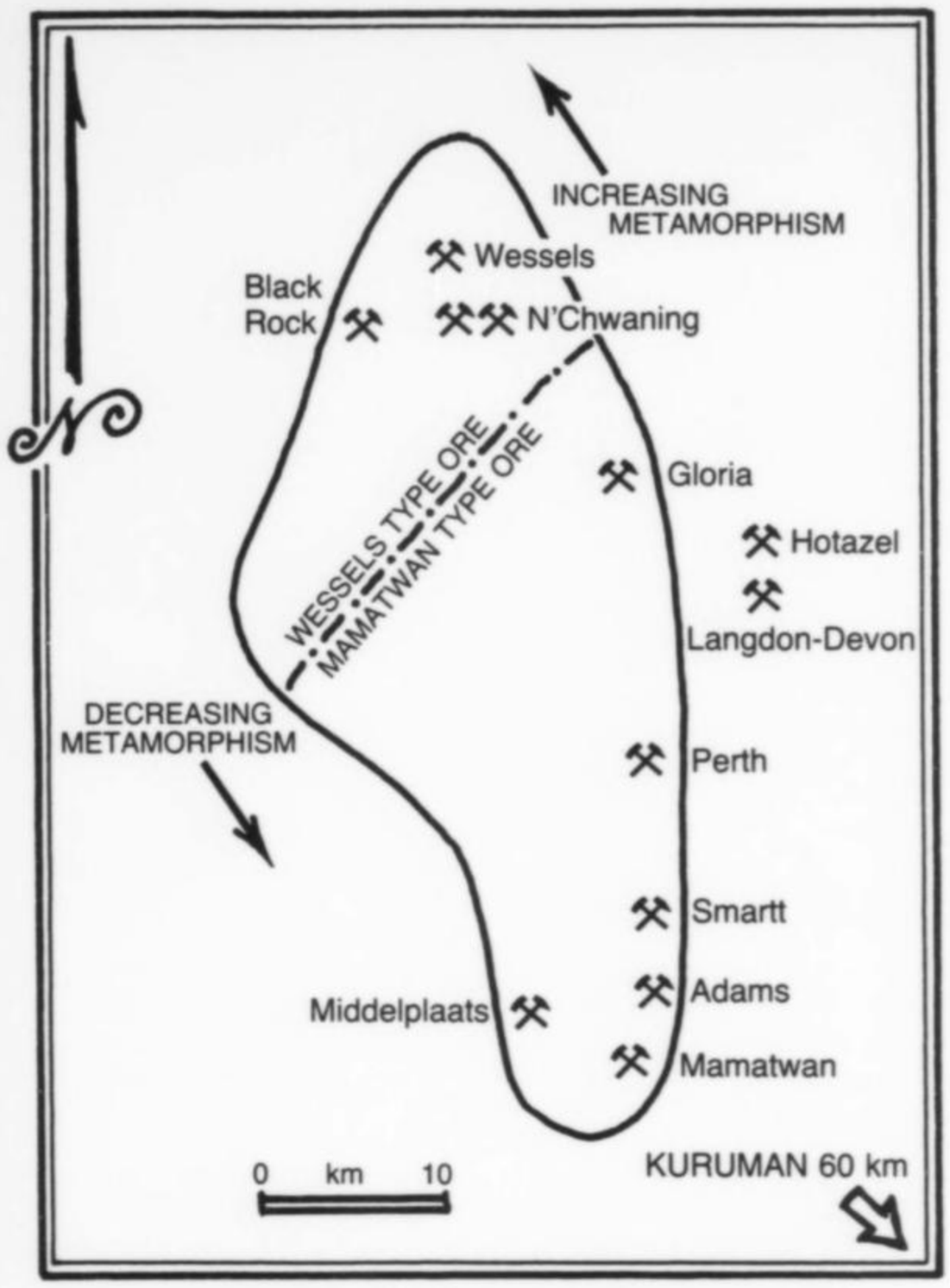

Figure 1. **Simplified sketch of the Kalahari Manganese Field showing locations of the mines relative to metamorphic grade and ore type (adapted from Kleyenstuber, 1984).**

Each of these cycles consists of jasper and/or jaspilite—kutnohoritic hematite lutite and kutnohoritic braunite lutite. The braunite lutite bed of the lower cycle is between 5 and 45 meters thick. It is the major ore unit in the Kalahari Manganese Field, and its Mn content varies between 20 and 48 weight %. The middle manganolutite unit (cycle 2) is approximately 2 meters thick and consists essentially of a braunitic hematite lutite which is of no economic significance. The upper manganese orebody, which was mined in earlier years, rarely exceeded 5 meters in thickness. Gray-colored hematitic and magnetitic minnesotaite ribbonlutites and bandlutites are present between the lower and middle manganolutite units. Thin chlorite-bearing mesobands interbedded with the iron-formations may represent altered volcanic ash layers. The association of sedimentary manganese deposits and jasper, together with the hyaloclastites and pillow lavas of the underlying Ongeluk Andesite Formation, is similar to the greenstone-jasperoid association of volcanogenic-sedimentary manganese deposits.

The delimitation by Kleyenstuber (1984) of a widespread hydrothermal event in the northwestern portion of the Kalahari Manganese Field, and the work of Dixon (1985, 1986), indicates that at about 1,300 million years ago a widespread hydrothermal event affected the Kalahari Manganese Field, reaching a maximum temperature of about 450° C in the Wessels, N'Chwaning and Black Rock areas. This had the effect of decarbonating portions of the Hotazel Member to the northwest, thus upgrading the Mn content of the ore and producing a wide range of rare minerals and unusual mineral assemblages. The presence of skarns and the extent of the hydrothermal event presupposes a magmatic source for the heat generated. At present, no evidence of the nature of this event is known.

ORE TYPES

The manganese ores in the northwestern portion of the Kalahari Manganese Field (Wessels, Black Rock and N'Chwaning mines) are braunite-rich with some hausmannite and marokite, and minor amounts of carbonate material. This is in marked contrast to the abundant primary carbonates observed in the Mamatwan-type ores to the southeast. In addition, the ores of the former contain minerals such as andradite and tephroite, as well as the development of aegirine in the iron-formation. The patterns of mineral distribution were divided into four basic types by Kleyenstuber (1984):

Mamatwan-type

Mamatwan-type ore is primarily diagenetic to low-grade metamorphic ore consisting of braunite, with small kutnohorite ooids. Minor minerals include hausmannite, jacobsite and hematite. This type of ore is found in the Mamatwan, Middelplaats, Adams, Perth, Smartt and Gloria mines, as well as in portions of the Langdon and Devon mines.

Wessels-type

Wessels-type ore has been hydrothermally altered and metamorphosed, resulting in a coarse grain size. The manganese content is higher and the carbonate content lower than the Mamatwan-type. Braunite, although still present, is less important; and what is known as "braunite II," an as-yet unnamed braunite-like mineral with higher iron and lower silica contents than braunite, together with bixbyite, hausmannite and hematite, are more abundant. Kutnohorite has largely been replaced by hausmannite, and the carbonates are mainly later secondary calcite, kutnohorite and rhodochrosite. Andradite and barite are more common. Most of the Wessels, Place Rock, N'Chwaning II and parts of N'Chwaning I mine ores are of this type.

Hotazel supergrade

The main constituents of the Hotazel supergrade ores are hausmannite with lesser amounts of the other minerals and a very low amount of carbonate. The average manganese content ranges from 60 to 70%. Although found typically at the Hotazel mine, parts of the Langdon, Devon and N'Chwaning I mines also contain this ore type.

Jacobsitic ore

Jacobsitic ore constitutes a minor fraction of the ores of the Kalahari Manganese Field but represents the major ore type in the Leinster and Avontuur basins. It is very low-grade and of little interest either economically or mineralogically.

THE MINES

Economic considerations have affected the several mines to varying degrees. Due to depressed prices for low-grade manganese ore, several mines have been closed down, and two mines of higher-grade ores have been opened. In this section features of the various mines are briefly described and the more notable, collectible minerals occurring in them are mentioned. (For locations of these mines see Fig. 1 and also the district map in Wilson and Dunn, 1978.)

N'Chwaning I mine

The N'Chwaning I is no longer in production. This underground mine had two principal different mineral suites. The northwestern areas where mining began were noted for the presence of exceptional rhodochrosite specimens associated mainly with manganite and drusy quartz. The ore here consisted mainly of the Hotazel supergrade. Later, when mining shifted to the southern areas, well-crystallized hausmannite, barite, hydroxyapophyllite, inesite, brucite and celestite were found and rhodochrosite became a rarity.

N'Chwaning II mine

The N'Chwaning II is separated from N'Chwaning I by a 60-meter downfault to the west. This underground mine resembles the Wessels mine, particularly with respect to the eastern and northwestern areas.

Sturmanite (abundant in superb crystals), brucite, hausmannite, gaudefroyite, hydroxyapophyllite, thaumasite and rare andradite are found at this locality.

Wessels mine

The Wessels mine can be divided into three areas underground: a central-southern area which is particularly rich in carbonates, primarily manganoan calcite, kutnohorite and rarely rhodochrosite; the northwestern areas with sturmanite, gaudefroyite and sugilite; and the central-eastern areas with sugilite, andradite, inesite, hydroxyapophyllite, ruizite, barite and celestite.

Black Rock mine

Although close to the Wessels and N'Chwaning mines, Black Rock is noteworthy for the absence of most of the minerals found in the former. Braunite II, chalcedonic quartz, calcite, andradite, hematite and barite are the most common minerals found at the Black Rock mine. The steep dip of the rocks may conceivably have led to a greater loss of hydrothermal fluids relative to the more horizontal strata at Wessels and N'Chwaning, which acted there as barriers to trap the fluids from which the minerals precipitated.

Hotazel mine

Hotazel is known principally for its rhodochrosite specimens, which came mostly from the central area of the mine. This orebody was originally mined as an open-pit but has since gone underground.

Langdon and Devon mines

Langdon and Devon are divided by a central east-west fracture, with the northern area having yielded the most mineral specimens. Extensive hydrothermal silicification of the ore has occurred here. The southern parts of the mines show a resemblance to Mamatwan-type ore. Small-scale mining at Langdon is continuing, but the Devon mine has been closed for years.

Mamatwan mine

Mamatwan is situated in the southeastern part of the Kalahari Manganese Field. The low-grade ores are known mainly for calcite and quartz pseudomorphs after calcite, and pyrite from a central sulfide-rich area. A good description of the mine is given by Nel *et al.* (1986).

Perth, Smartt and Adams mines

Perth, Smartt and Adams are open-pit mines which have been closed for many years. They are similar to Mamatwan in their minerals, calcite and todorokite and chalcedonic quartz being abundant.

Middelplaats mine

Middelplaats was opened in 1979 but has since closed. This underground (300–400 meters deep) mine is situated in the southwestern corner of the Kalahari Manganese Field, 60 km west of Kuruman. A detailed description of the mine is given by Jennings (1986).

Gloria mine

The Gloria mine, opened in 1978, is situated 5 km south-southeast from N'Chwaning. Ore is low-grade with a little calcite and aragonite.

MINERALS

Although there is overlap, the mineral assemblages in the Kalahari Manganese Field can be divided into two main groups. In the first group are those minerals intimately associated with the ore and often identifiable only in thin-sections. Identified by asterisk in Table 1, these minerals have been dealt with by various authors and will not be discussed here. The second group consists of minerals found in cracks, fissures and pockets. Many of these secondary mineral assemblages are indicative of an alkaline, hydrothermal environment. Late-stage filling of shrinkage cracks and solution cavities is also observed. The minerals discussed below are almost all from the second group. For some of the rarer and more unusual mineral species, some microprobe analyses are presented in Table 2 (from Dixon, 1988).

Aegirine $NaFe^{+3}Si_2O_6$

Previously described from the Black Rock mine (de Villiers, 1971), aegirine is fairly common in Wessels-type ore. Recently, some specimens consisting of thin, flat-bladed, transparent green to reddish brown aegirine crystals intergrown with pale green andradite and quartz have come from Wessels. Although most of the crystals are minute, some reach 1 cm in length.

Afwillite $Ca_3Si_2O_4(OH)_6$

At the end of 1989 some of the finest afwillite ever found came out of the Wessels mine. A horizontal fissure complex was encountered near the floor in low-grade manganese ore in the northwestern area of the east block. Crystals are well developed, clear white prisms attached to the walls of the fissure. Maximum size is 4.5 cm. Associated minerals include small brucite crystals, calcite and an unidentified white matted mineral. Portlandite was also found in the same fissure complex, but in separate areas. The number of specimens preserved is less than 50.

On re-examining some specimens of sturmanite from the N'Chwaning II mine that were found some years ago, afwillite as small crystals was found on one specimen.

Akermanite $Ca_2(Mg,Fe,Mn)Si_2O_7$

Pale pink akermanite, pale yellow iron-rich akermanite, and a very manganese-rich, pinkish brown akermanite occur as three discrete phases in the glaucochroite assemblage at the Wessels mine (Dixon 1988; analyses in Table 2).

Andradite $Ca_3(Fe,Mn)_2(SiO_4)_3$

Andradite was first described from the Black Rock and Hotazel mines, and subsequently from the Wessels and N'Chwaning mines, the best specimens being from Wessels. Colors vary from brown and red-brown to yellowish red, with smaller orange and red translucent crystals, and two occurrences from Wessels of pale-green crystals. Crystal size varies from less than 1 to 15 mm, averaging around 5 mm. Most crystals are simple rhombic dodecahedra, with a few displaying {211} modifications. Occurring with the andradite are a number of other minerals, of which some associations are described below.

From Wessels:

1. Small brilliant red to orange andradite crystals in vugs in hausmannite-hematite ore with barite, hausmannite and calcite crystals.
2. Attractive clusters of large (up to 1.5 cm) red-brown andradite with white amphibole ("mountain leather"), celestite and hematite. A few hundred specimens were recovered, and this remains the most significant andradite find to date.
3. Small, green, translucent crystals embedded in pink manganoan calcite.
4. Small, red crystals on tephroite crystals and manganoan calcite.
5. Small, cream to red andradite crystals (1–3 mm) with hausmannite, calcite, celestite and lime-yellow sturmanite crystals.

From N'Chwaning II:

1. Small, translucent crystals on clear calcite scalenohedra from pockets in ferruginous manganese ore.
2. Tiny orange garnets on and in sturmanite crystals with massive calcite and hematite.

Additional associated minerals include clinochlore, aegirine, quartz, gaudefroyite and brucite.

Aragonite $CaCO_3$

Found sporadically at N'Chwaning I and II and Wessels, aragonite occurs as white to colorless, small needles and long tapering prisms. One fissure from N'Chwaning I yielded pale-pink to purple strontium-bearing (determined qualitatively by XRF) crystals measuring up to 12 cm.

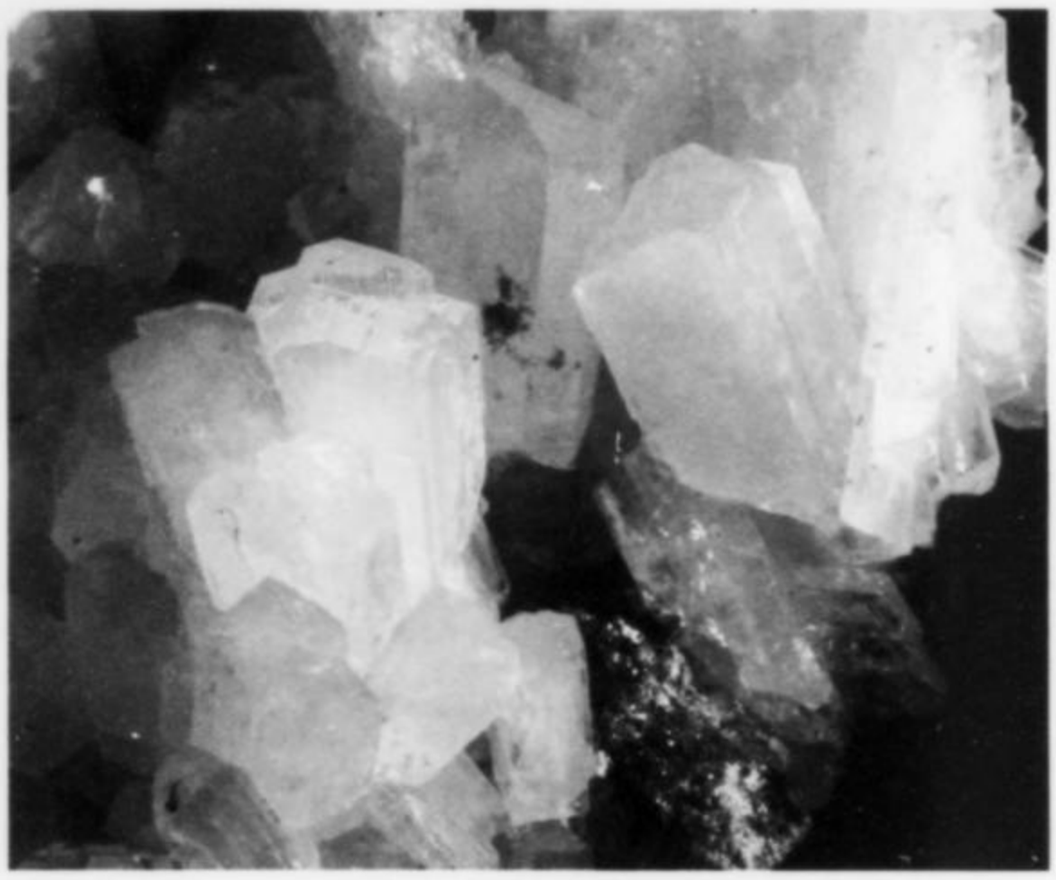

Figure 2. **Afwillite from the Wessels mine, 3-cm crystals, found in 1989.**

Figure 3. **Barite crystal group, 4.5 cm tall, on pyrite, from the N'Chwaning II mine.**

Figure 4. **Andradite crystals from the best garnet pocket found to date in the Kalahari Manganese Field. The specimen, from the Wessels mine, measures 7.5 cm across.**

Figure 5. **Black braunite crystal, 1.5 cm, from the Black Rock mine.**

Barite $BaSO_4$

Euhedral barite crystals are present at the Langdon, Hotazel, Wessels, N'Chwaning I and II mines. The small, tabular crystals from Langdon and Hotazel are water-clear. Bigger crystals are fairly common at N'Chwaning I and II, where the tabular crystals reach a size of 10 cm on edge. Wessels has produced prismatic crystals 16 cm long. Most commonly white or colorless, the barite is sometimes pale blue and rarely with a yellow tinge; inclusions and coatings of other minerals are common. Associated minerals include calcite, hematite, gageite, hausmannite, andradite, hydroxyapophyllite, pyrite, creedite, rhodochrosite, glauconite, sturmanite, gaudefroyite, clinochlore and chalcedonic quartz.

Bementite $Mn_8Si_6O_{15}(OH)_{10}$

Bementite occurs in fissures at Wessels and Gloria as massive, fist-sized lumps of a uniform, creamy brown color.

Birnessite $Na_4Mn_{14}O_{27}\cdot 9H_2O$

Previously known from several mines as "manganous manganite" (de Villiers, 1971), this micaceous mineral has been identified by Giovanoli (1984) as birnessite.

Bixbyite $(Mn^{+3},Fe^{+3})_2O_3$

Shiny black cubes of bixbyite to 0.5 mm were noted on todorokite fibers from N'Chwaning II, associated with hematite, gaudefroyite, calcite and barite. Although bixbyite is a common ore constituent in the Kalahari Manganese Field, euhedral crystals are a rarity and the above occurrence is the only one we have encountered. Large, lustrous cubes up to 2.5 cm have come from the Postmasburg manganese mines, well to the south of the Kalahari Manganese Field.

Braunite II $Ca(Mn,Fe^{+3})_{14}SiO_{24}$

The most common of the braunite-type minerals in the northern portion of the Kalahari Manganese Field, braunite II occurs as large (up to 2 cm), euhedral crystals sometimes associated with kutnohorite, calcite or sturmanite. Chalcedonic quartz is found as a coating on the crystals from Black Rock. Well-developed crystals come from Wessels, Black Rock and N'Chwaning II. Braunite II, listed by Nickel and Nichols (1991) as a polytype, is a well characterized mineral, and further information can be found in de Villiers and Herbstein (1967) and in de Villiers (1980).

Brucite $(Mg,Mn,Ca)(OH)_2$

Manganoan brucite as semi-translucent, pale, blue-green, foliated, botryoidal masses with a pearly luster has come from at least seven pockets in N'Chwaning I and II, with minor amounts from Wessels. Some specimens show flat, hexagonal crystals up to 3 cm across. Others with small, hexagonal prisms on calcite display a brown marginal stain. Some of the larger specimens are a sepia-brown color and are occasionally found covered with sturmanite crystals. Associated minerals include calcite, sturmanite, thaumasite, vesuvianite, bultfonteinite, celestine and andradite.

Figure 6. **Bultfonteinite crystals with groutite (black) from the N'Chwaning II mine. The view measures 2 cm across.**

Bultfonteinite $Ca_2SiO_2(OH,F)_4$

In 1982, we noticed some flat, plate-like specimens of a pinkish white mineral in the collection of a miner. These were identified as bultfonteinite from either Wessels or N'Chwaning II. During 1984 the mineral was found in a small fissure at N'Chwaning II, and early in 1985 another pocket was recovered. This latter pocket yielded pale salmon-pink, botryoidal specimens partly coated by white oyelite, and also some floaters up to 25 cm in diameter. Some individual crystals in botryoids are up to 3 mm long. Several more occurrences have recently been identified from Wessels. Associations include brucite, sturmanite, vesuvianite, calcite, barite, groutite, gaudefroyite and jennite. A few pockets with white or pale pink, acicular, radiating crystal clusters have been found.

Bustamite $(Mn,Ca)_3Si_3O_9$

Bands of pink, lapidary quality, very finely crystalline bustamite have been found at N'Chwaning II in association with quartz and calcite.

Calcite $CaCO_3$

Calcite is common throughout the Kalahari Manganese Field in crystals that are colorless and transparent to white and pale pink. Glassy, complex, scalenohedral crystals have been found with small but very fine gaudefroyite. Manganoan calcite is also fairly common and varies from pink to pale brown, according to the manganese content. Some pale pink manganoan calcite has mistakenly been labeled kutnohorite. This material occurs as porous masses of intergrown prismatic crystals and fluoresces a strong orange-red in shortwave and longwave ultraviolet light (Modreski, 1986). As local kutnohorite does not fluoresce, this is perhaps a reliable guide for distinguishing between the two. Problems arise when both minerals occur on the same specimen, the one often coating the other. Small single-mineral fragments are usually obtainable and can be checked separately.

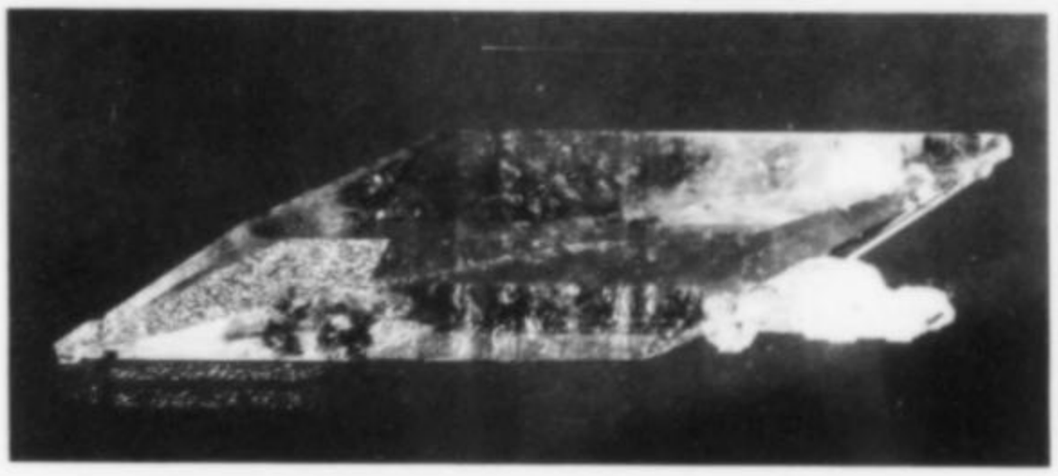

Figure 7. **Colorless and transparent calcite crystal, 5 cm, from the Wessels mine.**

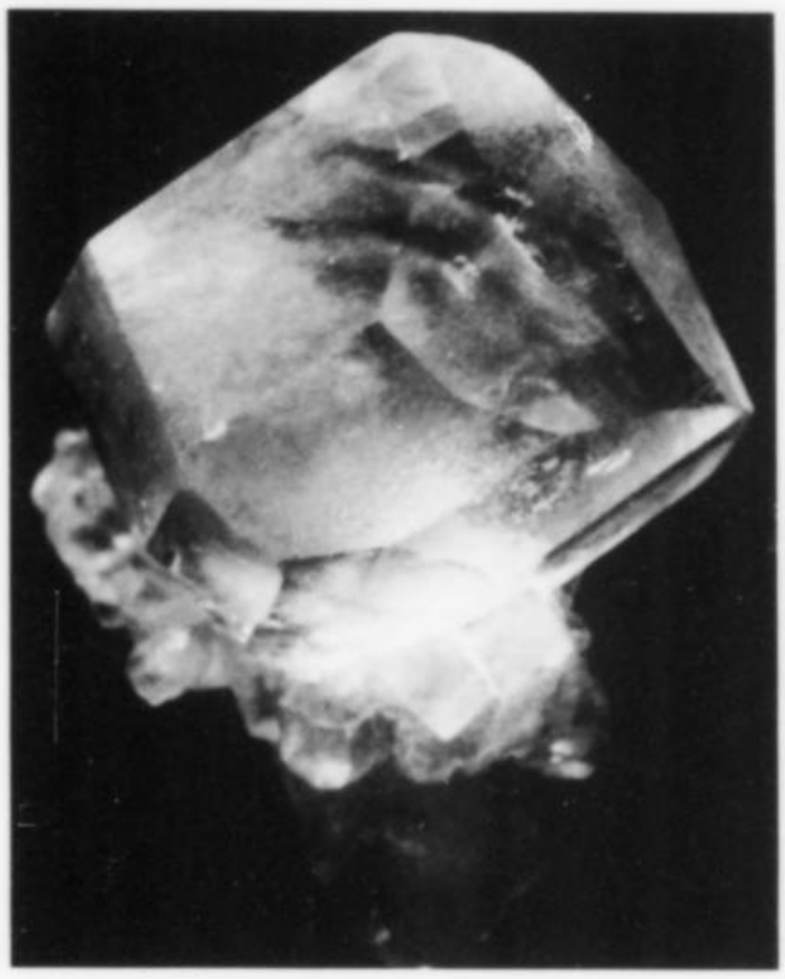

Figure 8. **Colorless calcite crystal, 1 cm, from the N'Chwaning mine.**

Figure 9. **Celestite crystals on calcite from the N'Chwaning I mine. The cluster measures 1.5 cm across.**

Caryopilite $(Mn,Mg)_3Si_2O_5(OH)_4$

Caryopilite has been identified in small cavities in manganese ore from Wessels as light-brown fibers; and caryopilite occurs at N'Chwaning I as an orange-brown coating with a sheen to it, on barite and calcite.

Celestine $SrSO_4$

Barium-rich celestine has come from Wessels and N'Chwaning I. Blocky, pale blue crystals on calcite are known from N'Chwaning I. Specimens from Wessels are pearly blue, and form slightly curved

crystals in association with hydroxyapophyllite, pectolite and barite. Superb milky blue crystals with some of the pyramid faces frosted occur with hydroxyapophyllite and datolite. Wessels has also produced several pockets containing colorless to white, slightly curved, lath-shaped crystals associated with strontium-rich calcite, hausmannite, andradite and sturmanite.

Chalcopyrite $CuFeS_2$

Isolated anhedral masses of chalcopyrite up to 5 mm in size have been found in a quartz-calcite-tremolite vein at Middelplaats.

Charlesite $Ca_6(Al,Si)_2(SO_4)_2B(OH)_4(OH,O)_{12}\cdot 26H_2O$

Charlesite, described by Dunn *et al.* (1983) from Franklin, New Jersey, occurs as colorless, transparent cores in some sturmanite crystals from Wessels and N'Chwaning II. (See under *sturmanite* for further discussion.)

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

A cross-cutting quartz vein near the northern boundary of the Langdon open pit contained some patches of chrysocolla.

Clinochlore $(Mg,Fe^{+2})_5Al(Si_3Al)O_{10}(OH)_8$

Micaceous, pinkish masses of clinochlore up to 5 mm in diameter have been identified on specimens collected at Wessels. Associated minerals include andradite, calcite, barite and hausmannite (identification by O. von Knorring).

Clinochrysotile $Mg_3Si_2O_5(OH)_4$

Thin, hairlike crystals of clinochrysotile mixed with felted masses of xonotlite and small calcite crystals have been found at Wessels. Other associated minerals include henritermierite, bultfonteinite and thaumasite.

Copper Cu

Native copper occurs as micron-sized blebs in braunite in Wessels-type ore (Kleyenstuber, 1984).

Creedite $Ca_3Al_2(SO_4)(F,OH)_{10}\cdot 2H_2O$

Small (<0.5 mm) white crystals of micaceous creedite occur with glauconite, pyrite, barite and calcite on a brecciated matrix specimen from a fissure in N'Chwaning II. The identity was confirmed by X-ray diffraction analysis.

Figure 10. **Pale blue datolite crystals to 2 cm, from the Wessels mine.**

Datolite $CaBSiO_4(OH)$

Pale pink, multiply twinned crystals of datolite up to 5 mm, perched on hydroxyapophyllite, have been found at Wessels. Recent pockets, also from Wessels, contained bluish white and purplish pink, slightly curved, crystals to 2.5 cm, densely clustered in subparallel growths.

Diaspore $AlO(OH)$

Traces of diaspore were found in association with grossular, pyrophanite and pectolite in a drill core (Kleyenstuber, 1984). Recently, deep flesh-pink, intergrown masses of bladed manganoan diaspore crystals to 1 x 4 cm were found, occurring with 1.5-cm creamy white balls of manganoan pectolite, felted ferrobustamite, scaly coatings of parsettensite and 1-cm tabular hydroxylapophyllite crystals. This association has been noted on one specimen from Wessels mine. Euhedral microcrystals of the same material occur in cavities between the coarser crystals.

Diopside $CaMgSi_2O_6$

Tabular, pale-pink diopside crystals have been found on two specimens from Wessels. The flattened, 5-mm crystals occur with calcite, hausmannite and andradite (identification by O. von Knorring).

Ephesite $NaLiAl_2(Al_2Si_2)O_{10}(OH)_2$

Small, platy, 1-mm clusters of pale pink ephesite crystals were found in fissured areas in association with massive beige andradite, hematite and hausmannite. Ephesite has also been identified in an assemblage with calcite, andradite, brucite, hausmannite and barite. Both occurrences are from the Wessels mine.

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

Occasional specimens of densely packed epidote crystals have been identified. Those from Wessels are from the banded iron-formation, while those from Hotazel occur in fissures in the ferruginous manganese ore associated with lepidocrocite. Crystals are generally small and poorly developed.

Ettringite $Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$

Small, dipyramidal white ettringite crystals on manganese ore have been identified on specimens from the Kalahari Manganese Field (R. Turner, personal communication). The ettringite crystals are less than 1 mm in size. Much of what has been called sturmanite is also ferroan ettringite, and is discussed in that section.

Feitknechtite $\beta\text{-}Mn^{+3}O(OH)$

Feitknechtite is known to occur as a brown flaky mineral in ore from Middelplaats.

Ferri-annite $K(Fe^{+2},Mg)_3(Fe^{+3},Al)Si_3O_{10}(OH)_2$

This recently described mineral of the mica group was reported by Kleyenstuber (1984) in Wessels-type ore.

Ferrobustamite $Ca(Fe^{+2},Ca,Mn)Si_2O_6$

Ferrobustamite occurs as silky needles (0.1 mm) and felted crusts of crystals coating manganoan diaspore blades and balls of manganoan pectolite on one specimen from the Wessels mine.

Foshagite $Ca_4Si_3O_9(OH)_2$

White fibrous rosettes of foshagite up to 1.5 cm in diameter occur in manganese ore, surrounded by orange orientite and calcite at Wessels.

Friedelite $(Mn,Mg,Fe)_8Si_6O_{15}(OH,Cl)_{10}$

Flesh-pink, gem-quality, cryptocrystalline friedelite showing a streaky appearance due to an admixture of carbonate minerals was found at Middelplaats in 1980 (Pienaar, 1982). We have recorded its presence at N'Chwaning II and Wessels, together with calcite, gypsum and vesuvianite. Kleyenstuber (1984) recorded the mineral from the Leinster and Avontuur basins.

Gageite $(Mn^{+2},Mg,Zn)_{42}Si_{16}O_{54}(OH)_{40}$

On some specimens from Wessels, gageite occurs as a fibrous, grayish base to rhodocrosite-coated calcite crystals, associated with short, lathlike and flattened crystals of dark red-brown leucophoenicite in rosette aggregates with pyrochroite, hausmannite and hematite. So far four pockets are known to have contained gageite. Identification was made by X-ray diffraction analysis.

Figure 11. **Galena crystals to 3 mm on calcite from the N'Chwaning II mine.**

Figure 13. **Black hematite crystal, 1.5 mm, from the N'Chwaning mine. W. Henderson specimen and photo.**

Galena PbS

As far as we are aware, galena has been found only once, at N'Chwaning II in mid-1981. Small, very attractive cubes up to 5 mm in size, some with octahedral modifications, were found on or partially enclosed in calcite. Some octahedra were noted, as well as elongated crystals. Hopper crystals were common. Associated minerals, many of them also sprinkled with galena crystals, include rhodochrosite and kutnohorite balls, a few minute white crystals of what appears to be sturmanite, pyrite, and a second generation of calcite. Galena was the last mineral to form in this paragenesis.

Figure 12. **Black gaudefroyite crystal, 6.5 mm, from the N'Chwaning mine. W. Henderson specimen and photo.**

Gaudefroyite $Ca_4Mn^{+3}_{3-x}(BO_3)_3(CO_3)(O,OH)_3$

The occurrence of gaudefroyite was noted at Wessels as long ago as 1981, but the associated minerals from these finds were not recorded. It is possible that many pockets have gone through the crushers, because gaudefroyite is difficult to recognize among the masses of black manganese ore. In fact a recent pocket was nearly missed because the miner thought he was merely seeing droplets of spilled oil! Pockets of gaudefroyite have been recovered from both Wessels and N'Chwaning II. The crystals are shiny to dull black hexagonal prisms, have well-developed pyramid faces and are often doubly terminated. Size varies from small millimeter-sized needles to finger-thickness crystals up to at least 5 cm long. Some crystals are embedded in calcite, others grow on an ore-mineral matrix, while the best specimens found have been floaters. Associated minerals include calcite, sturmanite, hematite, andradite, todorokite, bixbyite and barite. According to our knowledge, this is only the second recorded locality for gaudefroyite. Jouravsky and Permingeat (1964) originally described it from Tachgagalt, Morocco.

Glaucochroite $CaMnSiO_4$

This rare calcium-manganese olivine is present as small, bright red-orange patches to 1 mm in thin calc-silicate layers at Wessels. A representative microprobe analysis is presented in Table 2. Associated minerals include diopside, pectolite, wollastonite, ferroan akermanite, andradite and various hydrogarnets (Dixon, 1985; 1988).

Glauconite $(K,Na)(Fe^{+3},Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$

Green, massive glauconite associated with creedite, pyrite, calcite and barite occurs on a brecciated matrix from a fissure at N'Chwaning II. The identity has been confirmed by X-ray diffraction analysis.

Gonyerite $(Mn,Mg)_5Fe^{+3}(Si_3Fe^{+3})O_{10}(OH)_8$

Gonyerite, a member of the chlorite group, is fairly common in Wessels as thin brown bands in siliceous areas. Very small, bright green crystals coated with larger calcite crystals, on a hematite matrix, have also come from Wessels.

Gowerite $CaB_6O_{10}\cdot 5H_2O$

Thin white fibers of gowerite have been found in association with thaumasite crystals on specimens from N'Chwaning II. Only one fissure with this association has been identified.

Grossular $Ca_3Al_2(SiO_4)_3$

Grossular is uncommon in the Kalahari Manganese Field. In a drill core it was found associated with pyrophanite, pectolite and diaspore. At Wessels it occurred in a massive calcite band together with purple manganese-rich vesuvianite and andradite (Kleyenstuber, 1984). We have not found any euhedral grossular crystals, and published analyses indicate its rarity as opposed to the relative abundance of andradite (de Villiers, 1971; Kleyenstuber, 1984; and Dixon, 1985).

Groutite $Mn^{+3}O(OH)$

Minute, shiny, flat, black, striated crystals of groutite occur in an unidentified matrix with bultfonteinite from N'Chwaning II, where it has also been identified previously (W. S. Grobbelaar, personal communication). Small, barrel-shaped crystals and stacked rosettes up to 3 mm in size have been found at the Gloria mine.

Gypsum $CaSO_4 \cdot 2H_2O$

Transparent, colorless gypsum is known from Hotazel, Langdon-Devon, N'Chwaning I and II, and Wessels, and it appears probable that all the mines in the Kalahari Manganese Field contain varying quantities of gypsum. Euhedral crystals have come from Wessels and N'Chwaning I and II. The largest, well-developed crystal we have seen is from N'Chwaning I; it measures 29 cm across, displays phantom crystal growth, and has {010}, {120} and {011} crystal faces. Larger crystals occur, but rarely survive the explosives. Associated minerals include quartz, rhodochrosite, sturmanite, calcite, hematite, todorokite, gaudefroyite and pyrolusite.

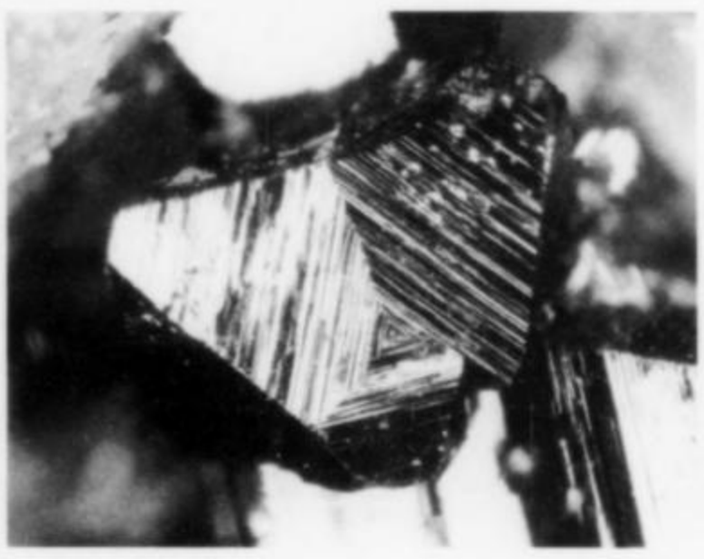

Figure 14. **Black hausmannite trilling, 1.6 mm, from the Wessels mine. W. Henderson specimen and photo.**

Figure 15. **Black hausmannite crystals, 1 cm, from the Wessels mine.**

Hausmannite $Mn^{+2}Mn_2^{+3}O_4$

Hausmannite is a common ore constituent in the Kalahari Manganese Field. The crystals from Wessels and the N'Chwaning mines are well developed, black and shiny. Crystal size is usually 1 to 2 mm but can reach 2 cm on edge. Although mostly of pyramidal habit, many of the crystals show composite growth with multiple {101} faces. Cyclic twinning is common. Faces are commonly striated parallel to the [001] axis. Unusual forms include curved, stacked crystals from a fissure in N'Chwaning II. Crystals from Hotazel are rare and show similar features, but are dull. Minerals occurring with hausmannite crystals are calcite, andradite, barite, diopside, clinochlore, hematite, sturmanite, kutnohorite, henritermierite, rhodochrosite, gageite, leucophoenicite, celestine and brucite.

Hematite α-Fe_2O_3

Hematite is a common constituent of ores in the Kalahari Manganese Field. Columnar and botryoidal hematite has been recorded from Wessels and N'Chwaning II, and superb crystals have been found at Black Rock, N'Chwaning I and II and at Wessels. Three occurrences are outstanding: crystals to 7 cm from Wessels (Wilson and Dunn, 1978); superb, shiny, flattened crystals up to 30 cm across and 8 cm thick, sometimes coated on the one side with tiny andradite crystals, calcite and occasional barite were recovered from Wessels in May of 1988, and from N'Chwaning II in 1985. This third occurrence yielded very bright, jet-black crystals to 3 cm, associated with todorokite,

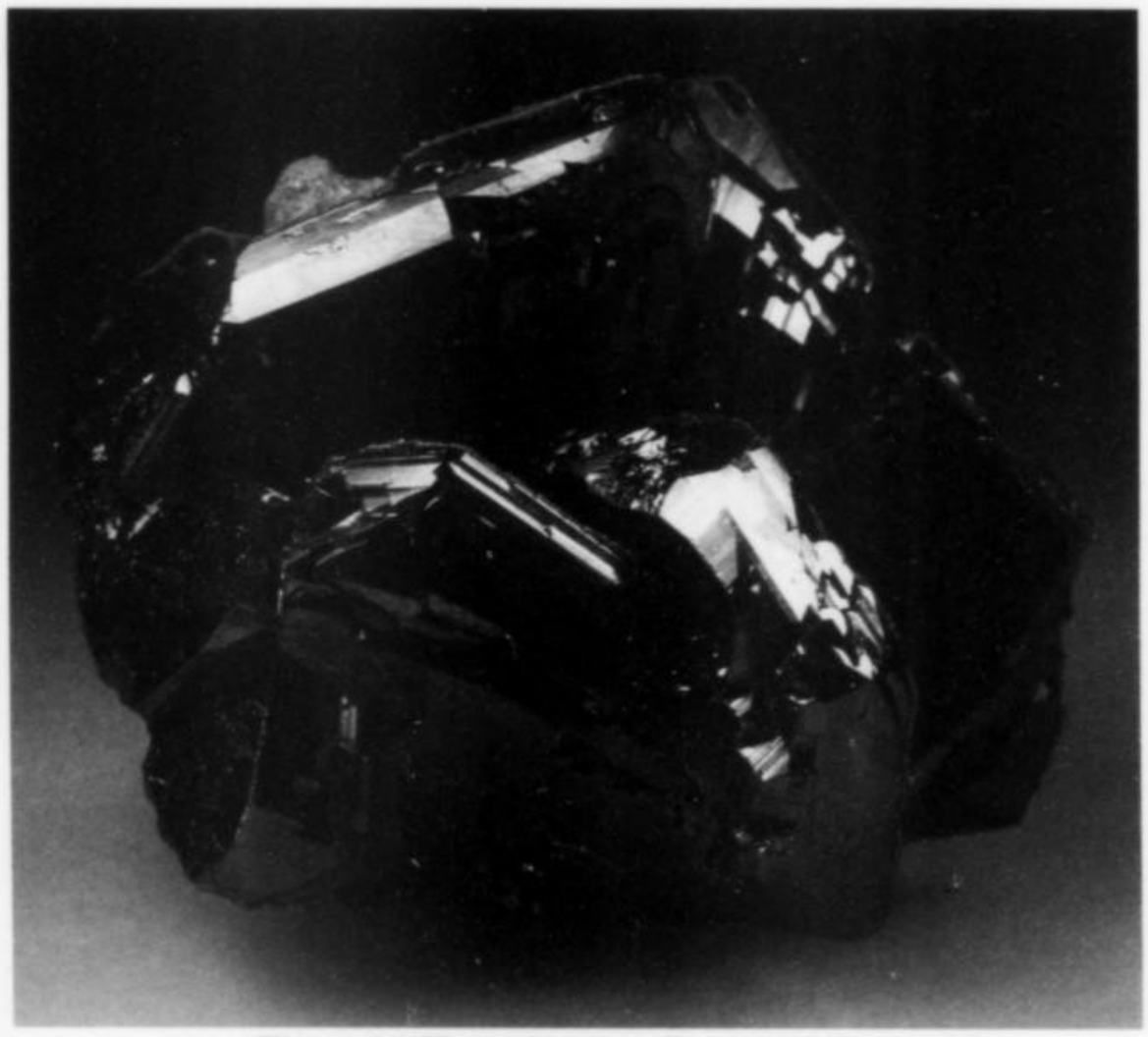

Figure 16. **Hematite crystal group, 6.6 cm, with red andradite garnet, from the Wessels mine. Don Olson/Marshall Sussman specimen.**

calcite, barite and superb gaudefroyite. Assemblages from other pockets include andradite, hausmannite, gypsum, saponite, henritermierite, sturmanite and clinochlore. Most crystals display a prismatic habit with variable pinacoid development. Pseudocubic crystals from N'Chwaning II and scalenohedra from Wessels are rarities.

Henritermierite $Ca_3(Mn,Fe,Al)_2(SiO_4)_2(OH)_4$

Isolated finds of a clove-brown, semi-transparent amorphous material with no cleavage and a greasy luster were made at N'Chwaning II in 1981, and subsequently identified (by XRD, DTA and microprobe—Dixon, 1988) as the tetragonal calcium manganese hydrogarnet, henritermierite, previously known only from Tachgagalt, Morocco (Gaudefroy *et al.*, 1969). More specimens were found from the major sturmanite find in 1982, where the mineral occurs at the base of the sturmanite crystals. Later it was identified on a number of other specimens, including some from Wessels (Dixon, 1986). Recently, perfect euhedral, dark orange crystals up to 3 mm in size were found at N'Chwaning II. These are associated with andradite, sturmanite, barite, calcite and hausmannite. The mineral has also been found with sphenoidal manganite. Small (0.5 mm), red dipyramids occur in a vuggy ferruginous manganese-ore matrix together with calcite, stur-

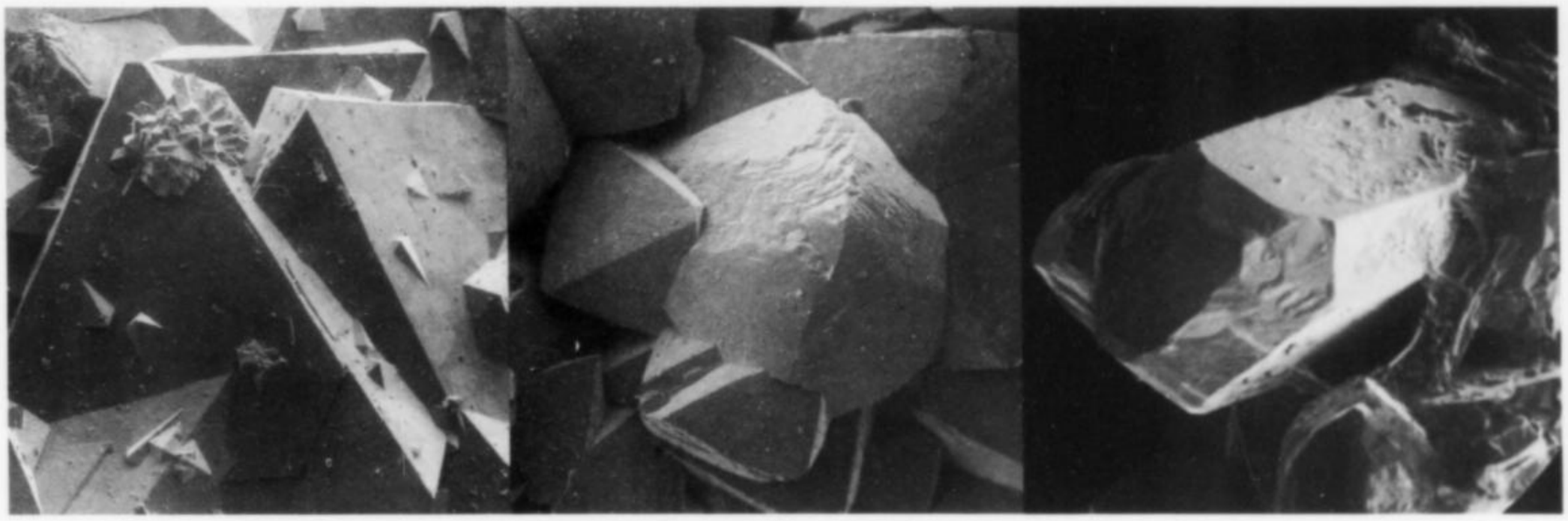

Figure 17. **Orange to dark red henritermierite crystals to 0.15 mm, from the Wessels mine (SEM photo).**

Figure 18. **Henritermierite crystals, 0.1 mm, from the Wessels mine (SEM photo).**

Figure 19. **Henritermierite crystal, 1 mm, from the N'Chwaning II mine.**

manite, hausmannite and hematite crystals at Wessels.

The larger crystals are very iron-rich and uncommon, and often have iron-poor cores. In some cases the larger crystals consist of an henritermierite core with an andradite rim, which can give rise to confusing X-ray diffraction patterns. Analyses of various garnets are presented in Table 2.

Hydrogarnets $Ca_2(Al,Fe,Mn)_2(SiO_4)_{3-x}(OH)_{4x}$

Both *hydrogrossular* and *hydroandradite* are present in an assemblage with henritermierite, glaucochroite and melilite as small anhedral grains up to 0.5 mm in size from the Wessels mine.

Hydroxyapophyllite $K(Ca,Mn)_4Si_8O_{20}(OH,F)\cdot 8H_2O$

Since the discovery of the previously described assemblages of hydroxyapophyllite with inesite, ruizite, pectolite, datolite, orientite and quartz from the Wessels mine (Wilson and Dunn, 1978), many more fissures and pockets have been found at Wessels as well as at N'Chwaning I and II. Color range is limited to pale-pink, cream and colorless, with crystals reaching up to 8 cm on edge. A fissure at Wessels has yielded pseudomorphs of pink manganoan calcite after hydroxylapophyllite up to 12 cm on edge. Each pocket to date exhibits a different crystal habit, with most crystals showing the cuboid prism or simple elongate tetragonal prism as their dominant habit. All common habits except for the prismatic crystals typical of the green Indian apophyllites are represented. The simple prism, pyramid and pinacoid are common, but unusual additional faces have been found, as seen on crystals of the first Wessels occurrence. Associated minerals (in addition to those already mentioned) include aragonite, barite, celestite, calcite, thaumasite, sugilite and xonotlite.

Inesite $Ca_2Mn_7Si_{10}O_{28}(OH)_2\cdot 5H_2O$

In addition to the inesite described from Wessels which occurred as sheeted masses of bladed crystals (Wilson and Dunn, 1978), reddish pink spheres of radiating inesite crystals were recovered in quantity from Wessels. These balls are grouped together like bunches of grapes, and are individually up to 2 cm in diameter. Several other minor pockets with similar morphologies were found at both Wessels and N'Chwaning I and II.

Jennite $Ca_9H_2Si_6O_{18}(OH)_8\cdot 6H_2O$

Minute platy crystals of white jennite occur on pale pink bultfonteinite needles on a calcite base. The jennite crystals measure 0.1 to 0.5 mm. A single pocket from Wessels carried this association.

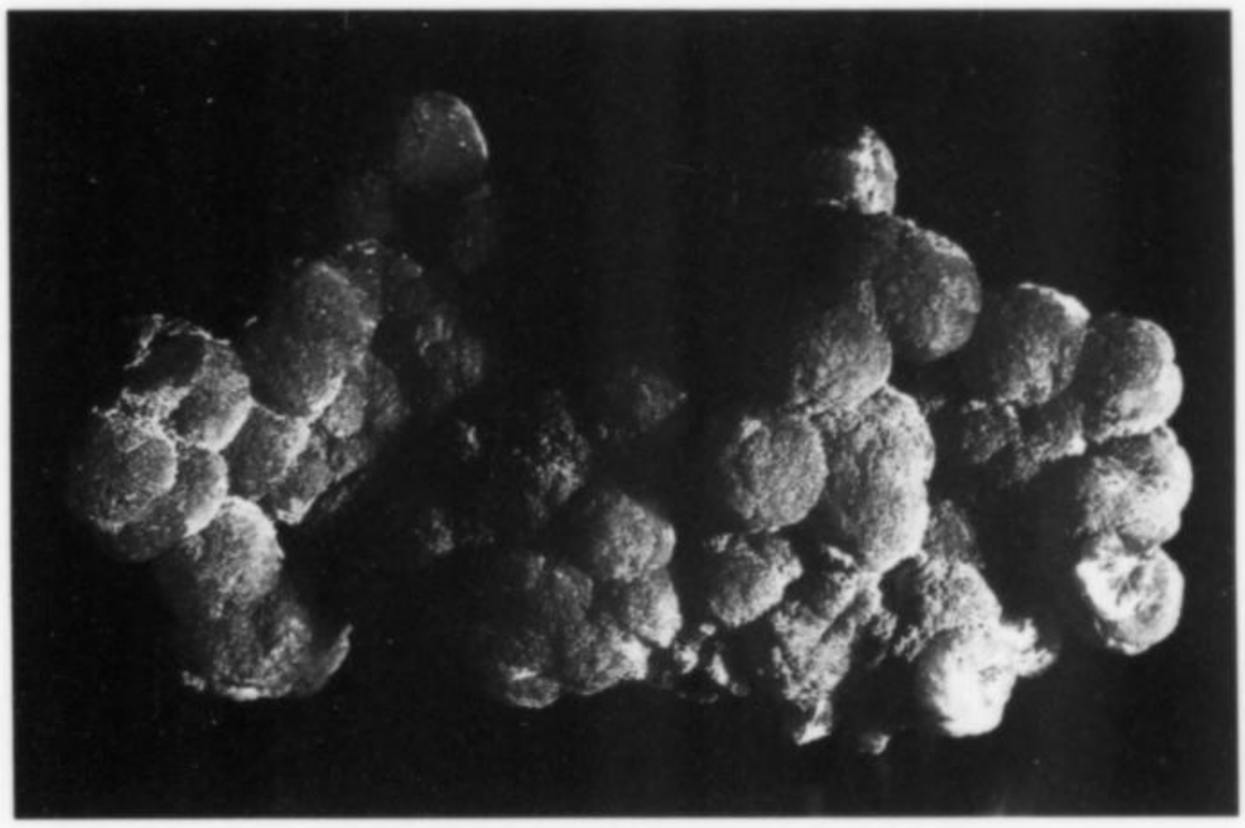

Figure 20. **Cluster of inesite balls 10.5 cm across, from the Wessels mine.**

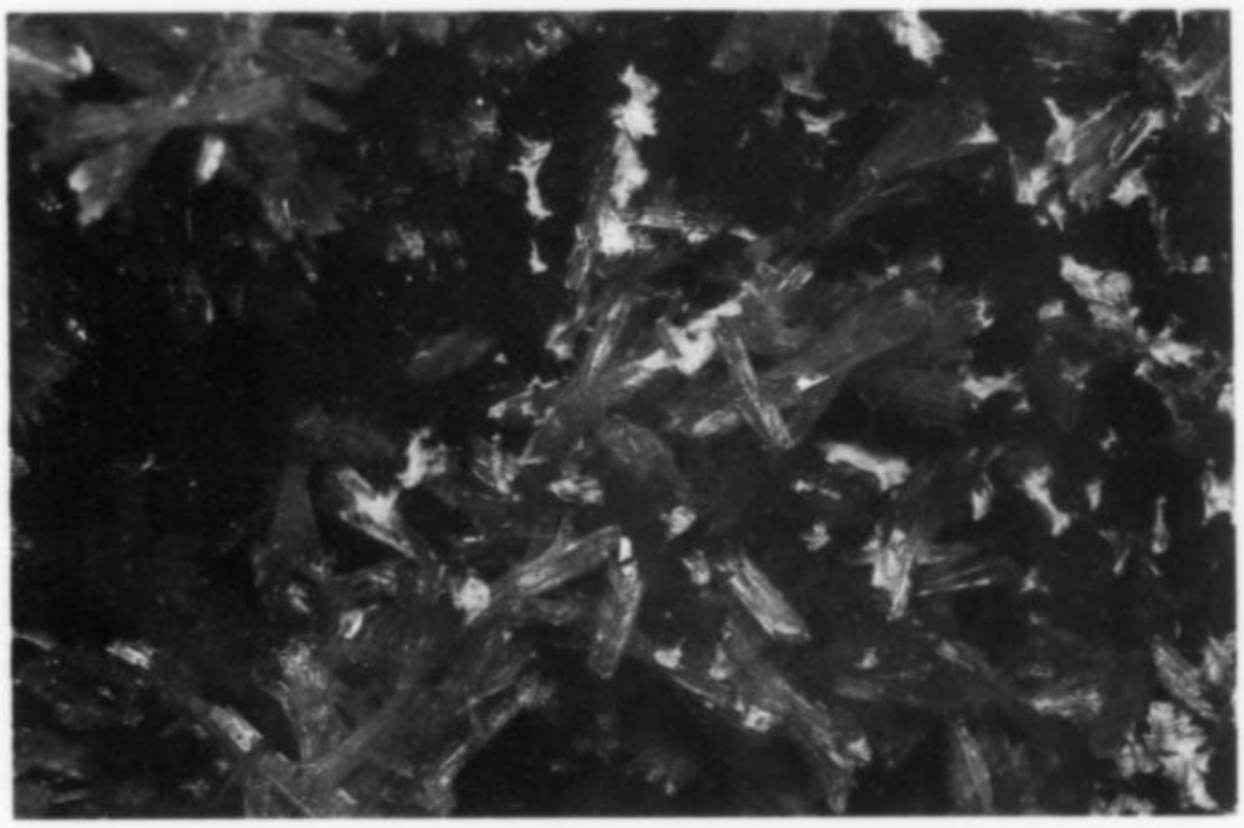

Figure 21. **Crystals of inesite to 6 mm, from the N'Chwaning II mine.**

Johannsenite $CaMnSi_2O_6$

Johannsenite occurs in the ore at Wessels as clove-brown masses together with acicular, pale flesh-pink wollastonite.

Jouravskite $Ca_3Mn^{+4}(SO_4,CO_3)_2(OH)_6 \cdot 13H_2O$

Several specimens of sugary, yellow-green jouravskite, corresponding to the original description from Tachgagalt, Morocco (Gaudefroy and Permingeat, 1965), coated by a layer of an unidentified white mineral, came from two pockets at N'Chwaning II. These specimens are up to 5 cm in diameter.

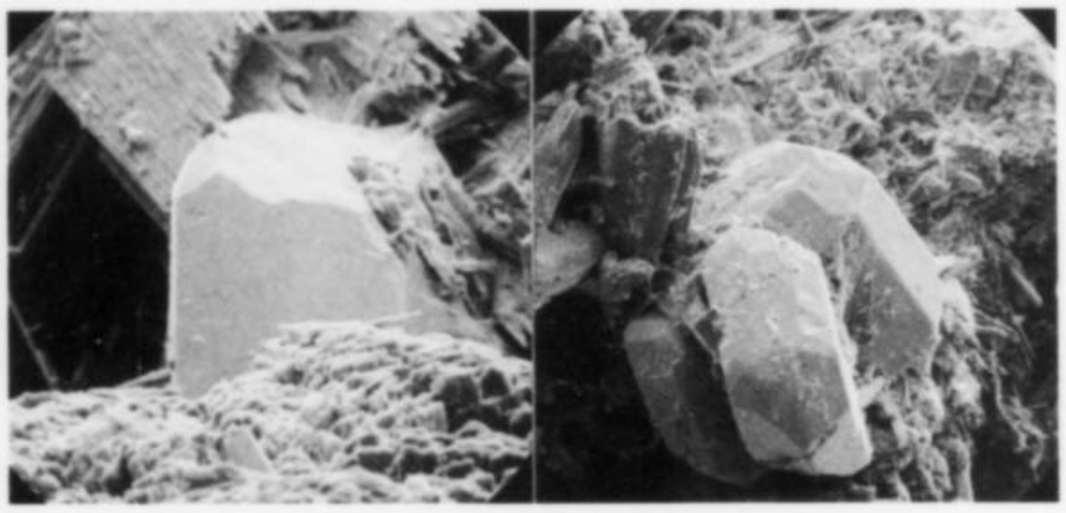

Figure 22. **Kentrolite crystals, 0.5 mm, on pectolite from the Wessels mine.**

Kentrolite $Pb_2Mn_2^{+3}Si_2O_9$

Shiny black tabular crystals and crystal clusters of kentrolite have been found on one specimen from Wessels mine. They were identified by X-ray diffraction and by qualitative SEM analysis. The crystals are small, averaging 0.3 mm with a maximum size of 1 mm, and have red internal reflections. It formed late in the paragenesis and occurs with calcite, kutnohorite, henritermierite and sturmanite.

Kirschsteinite $CaFeSiO_4$

A member of the olivine group, small dark-orange anhedral grains of kirschsteinite occur associated with glaucochroite at Wessels. Analysis in Table 2.

Kutnohorite $CaMn(CO_3)_2$

At Wessels and N'Chwaning I and II, pale-pink to beige masses commonly occur as divergent bundles of thick "fibers" or occasionally as separate crystals and balls of crystals. Kutnohorite may coat or replace other minerals. Individual crystals are small, but masses of kutnohorite can reach 20 cm or more. Kutnohorite is similar in appearance to manganoan calcite, but local material does not fluoresce. Positive identification is difficult without the aid of an analytical technique such as XRD, because the varied habits and colors of calcite, rhodochrosite and kutnohorite all overlap. It is commonly associated with calcite and quartz; other associations include barite, andradite, hausmannite, rhodochrosite and galena.

Lepidocrocite $\gamma\text{-}Fe^{+3}O(OH)$

Several specimens containing small (up to 1 mm) red translucent flakes of lepidocrocite have been found at N'Chwaning II. Associated minerals include goethite, calcite, hematite and quartz. At Hotazel it is associated with epidote.

Leucophoenicite $Mn_7(SiO_4)_3(OH)_2$

This mineral has been found in the Avontuur and Leinster basins, just north of the Kalahari basin, in the main ore zone (Kleyenstuber, 1984), and in the Wessels mine as short, dark red-brown lath-shaped and flattened crystals in an assemblage with gageite, rhodochrosite, pyrochroite, hausmannite and calcite.

Magnesio-arfvedsonite $(Na,K)_3(Mg,Mn,Fe)_5Si_8O_{22}(OH)_2$

This mineral is found together with massive sugilite at the Wessels mine and can be distinguished by its pale red and blue pleochroic colors in thin section. It has been identified by XRD and electron microprobe analysis (Dixon, 1988; see Table 2).

Malachite $Cu_2(CO_3)(OH)_2$

Small amounts of malachite were encountered during shaft-sinking

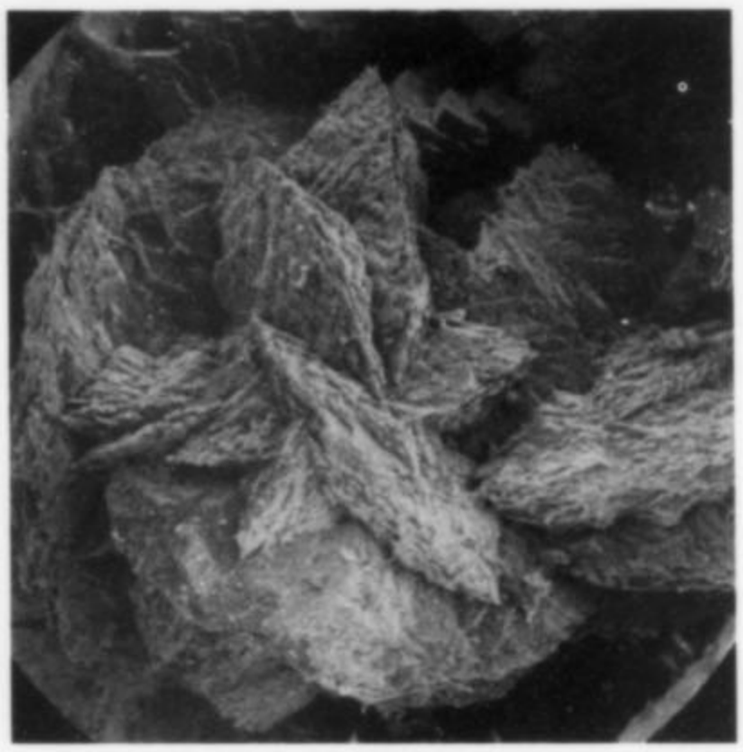

Figure 23. **Leucophoenicite rosette, 1 mm, from the Wessels mine (SEM photo).**

operations at N'Chwaning I (W. S. Grobbelaar, personal communication). We have not seen any specimens; presumably none were preserved.

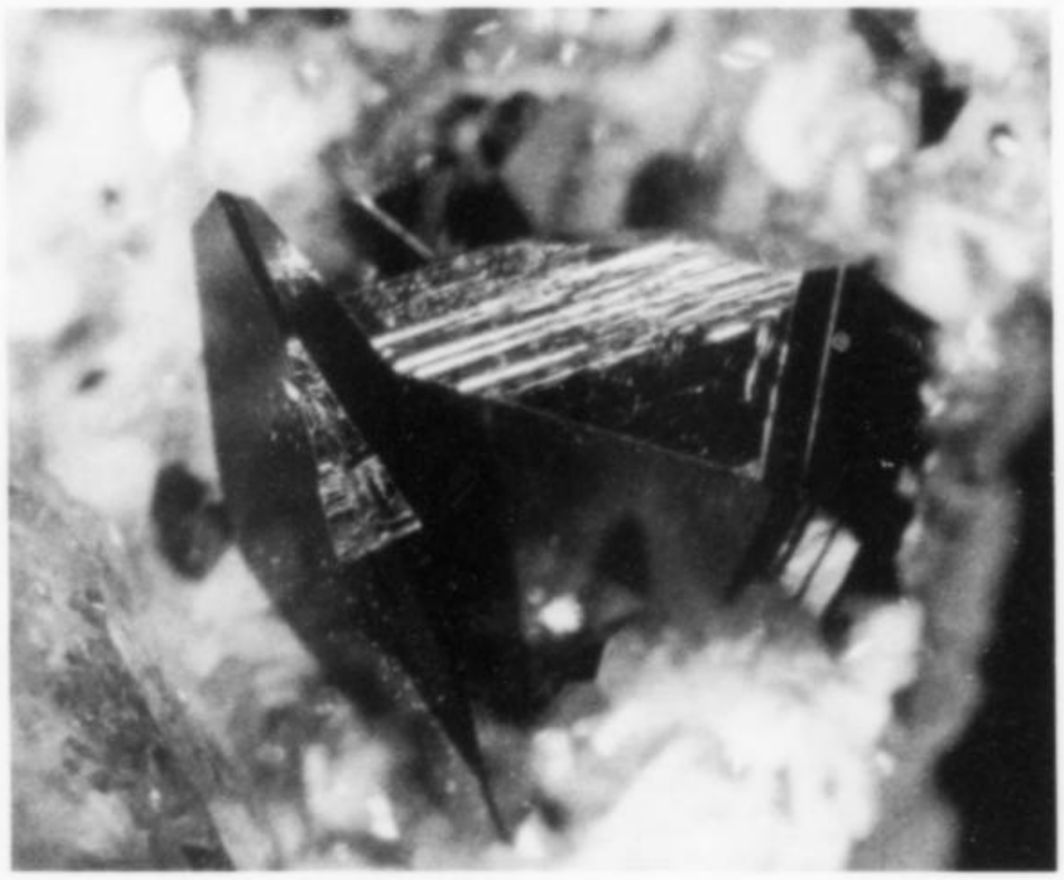

Figure 24. **Black manganite crystals, 0.8 mm, with yellow sturmanite from the N'Chwaning II mine. W. Henderson specimen and photo.**

Manganite $MnO(OH)$

Crystalline manganite from the Kalahari Manganese Field was described by Wilson and Dunn (1978). In the 1982 sturmanite pockets found at N'Chwaning II, small, black, shiny, elongated and flattened pseudorhombic dipyramids (1–5 mm, and exceptionally 1 cm) of manganite were found (identification by O. von Knorring). These crystals either coat or are partly included in the associated minerals which are henritermierite, sturmanite and calcite. They are similar in habit to the sphenoidal manganite crystals from Långban. More recently another two pockets with similar but slightly modified crystals were found.

Manjiroite $(Na,K)Mn_8O_{16} \cdot nH_2O$

Manjiroite has been identified in Mamatwan-type ore (Kleyenstuber, 1984).

Marcasite FeS_2

Marcasite, as submillimeter, iridescent blue crystals, has been found

growing epitaxially on pyrite cubes in a pocket zone in the N'Chwaning II mine in a development drive west of the main ore body. Calcite as milky white scalenohedra forms the base and secondary growth of the specimens.

Marokite $CaMn_2^{+3}O_4$

Black, massive marokite occurs in the Wessels-type ore at Wessels and Black Rock. It is a fairly common ore constituent, but no crystals have thus far been recorded.

Opal $SiO_2 \cdot nH_2O$

Opal was noted as attractive, green, chrysoprase-like specimens and as yellow, brown or orange-red masses. It is particularly well-developed at Hotazel and Langdon-Devon.

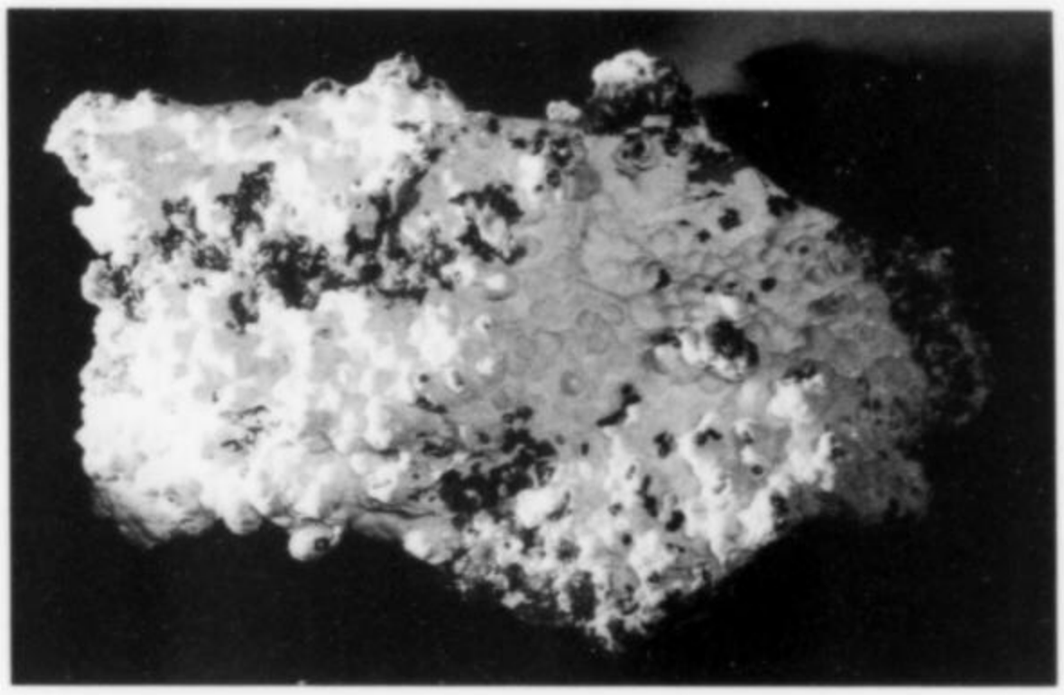

Figure 25. **White oyelite on pink-orange bultfonteinite specimen, 25 cm across, from the N'Chwaning II mine.**

Oyelite

Described from Japan in 1984 (Kusachi *et al.*, 1984), and closely related to tobermorite, oyelite has been found at N'Chwaning II in association with bultfonteinite. The acicular, densely packed white crystals a few millimeters long form sprays and coatings on and in bultfonteinite.

Pargasite $NaCa_2(Mg,Fe^{+2})_4Al(Si_6Al_2)O_{22}(OH)_2$

Pargasite has been identified by XRD and electron microprobe analysis in drill cores from the Avontuur and Leinster basins (Kleyenstuber, 1984).

Parsettensite $(K,Na,Ca)(Mn,Al)_7Si_8O_{20}(OH)_8 \cdot 2H_2O$

Parsettensite has been identified in Wessels-type ore (A. S. E. Kleyenstuber, personal communication). It also occurs as a scaly coating of microcrystals on manganoan diaspore, with pectolite and hydroxylapophyllite, from the Wessels mine.

Portlandite $Ca(OH)_2$

Portlandite is relatively common at Wessels and N'Chwaning II, and has also been recorded from Black Rock. It occurs between layers of manganese ore in the vicinity of open-fold hinges. The mineral displays a vertically fibrous habit and is translucent to white. Associated minerals are sturmanite and gypsum. In areas where portlandite occurs, marokite is also common.

The afwillite fissure complex in the Wessels mine had two separate areas: one filled with portlandite as a greenish white micaceous mineral, and one with portlandite as platy white crystals to 5.7 cm (!) standing on the fissure surface with some isolated calcite and sturmanite crystals. The number of specimens collected with crystals was limited to a less than 50.

Pyrite FeS_2

As small crystals, commonly modified cubes and octahedra, pyrite

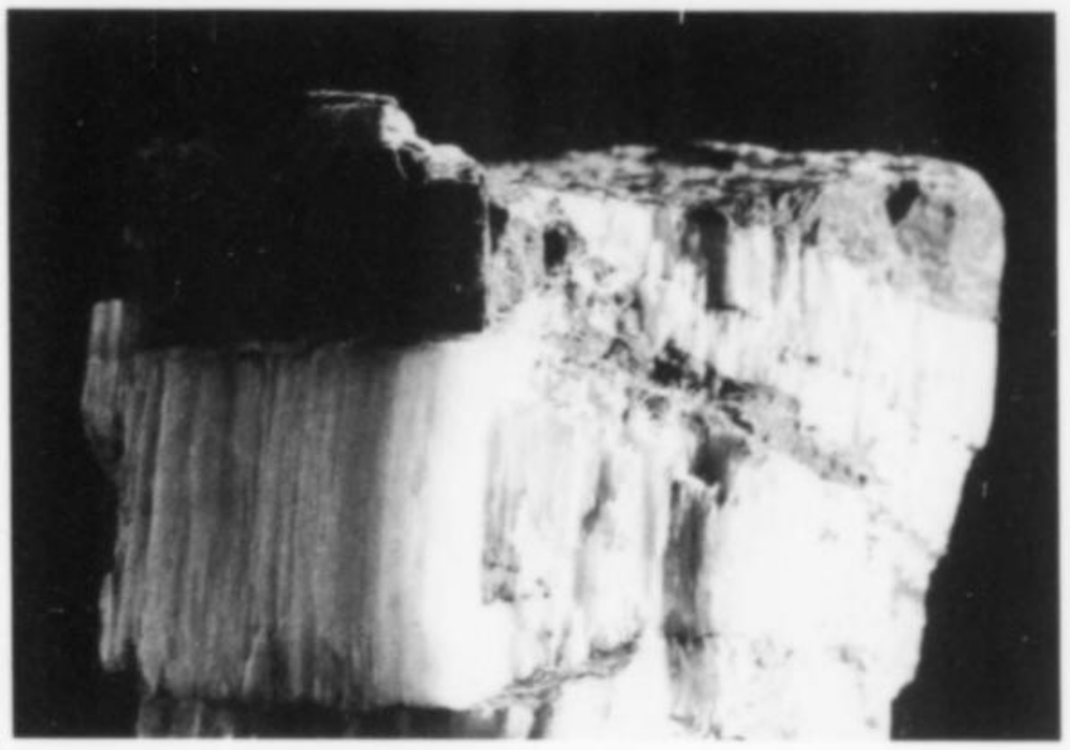

Figure 26. **White, fibrous portlandite specimen, 4 cm, from the Wessels mine.**

is part of a central sulfide-rich zone of the open pit at Mamatwan. Wessels and N'Chwaning II have produced several pockets; the best specimens were encountered when mining had to cross the banded iron-formation. Individual crystals are small, but composite crystal growths to 20 cm have been collected. The most aesthetic specimens are small pyrite rosettes on red jasper and black manganese ore. Associated minerals include calcite, quartz, barite, glauconite and creedite. Pyrite was also found included in calcite as part of the galena assemblage.

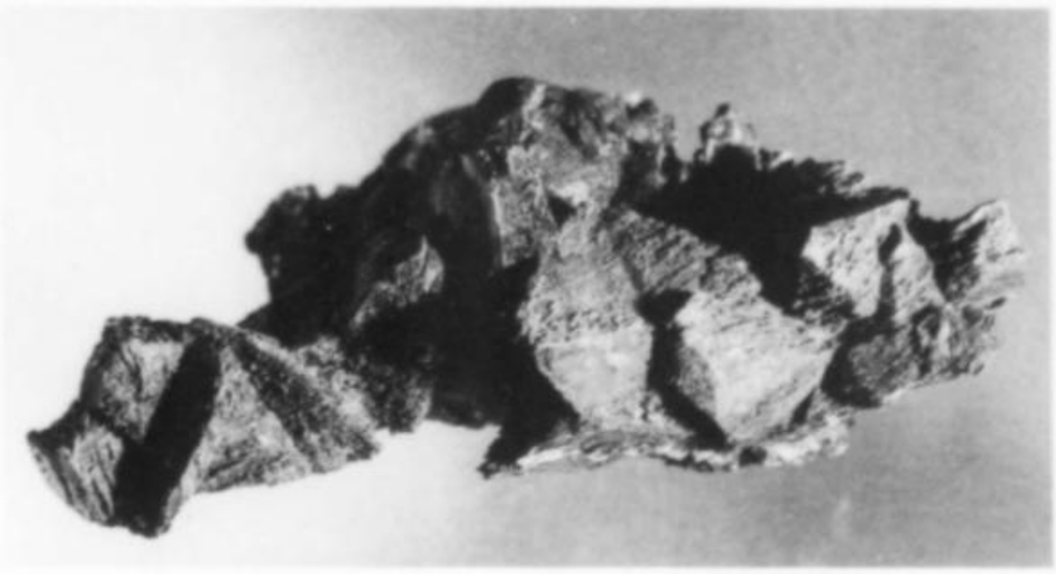

Figure 27. **Black, corroded pyrochroite crystal group, 8 cm across, from the Wessels mine.**

Pyrochroite $Mn(OH)_2$

There are several occurrences of pyrochroite at N'Chwaning II and Wessels. The typical color change (white or bluish, changing rapidly to dark brown or black on exposure to air) has not been recorded because fresh specimens were not available. The dark-brown to black micaceous flakes reach several centimeters, and large kilogram masses have been found. On some specimens pyrochroite occurs as attractive rosettes. Dull, slightly corroded rhombohedral crystals to 2 cm have come from Wessels. Calcite is also present in most pockets; occasionally, gageite, rhodochrosite, leucophoenicite and hausmannite are found in association.

Quartz SiO_2

Quartz is a common constituent of ores in the Kalahari Manganese Field, occurring as vein fillings, replacements and pseudomorphs after other minerals. Euhedral crystals are most common in the form of drusy coatings of millimeter-sized crystals, and are particularly attractive when on black manganese ore. Drusy quartz or chalcedony pseudomorphs after calcite are occasionally found at Mamatwan and Langdon. At the northern boundary of the Langdon-Devon open pit small (to 3 mm), colorless, transparent pseudocubic quartz crystals

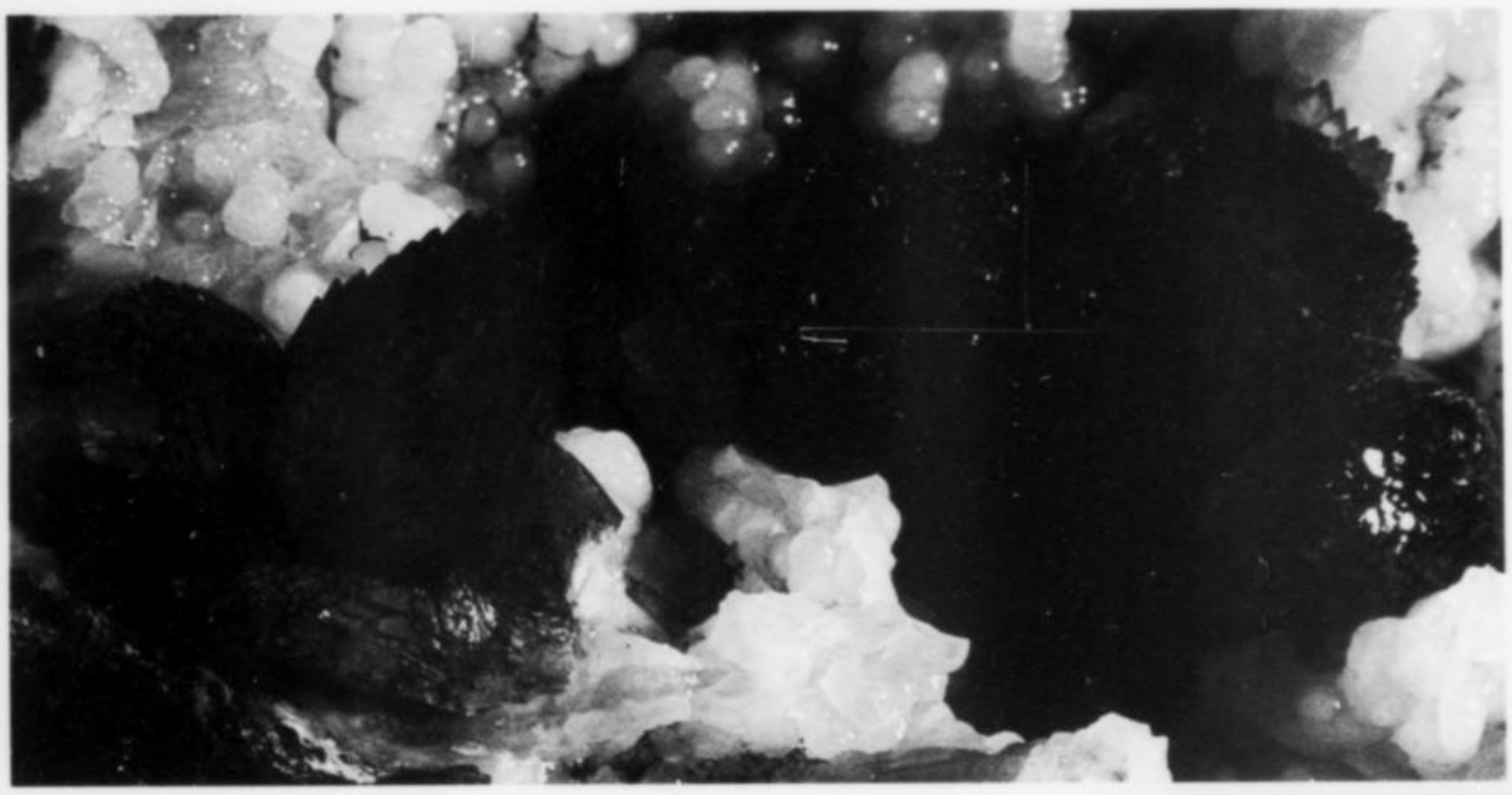

Figure 28. **Rhodochrosite sheaves 1 cm tall on chalcedony, from the Hotazel mine.**

Figure 29. (below) **Rhodochrosite barrels partially coated with drusy quartz, from the Hotazel mine. The group at the top measures 8 mm.**

showing development of $\{10\bar{1}1\}$, to the exclusion of other forms, were found. With these are clear quartz crystals of equant habit up to 1.5 cm in size, having small pseudocubes perched on some faces. These specimens occur in a wad matrix. Brilliantly clear crystals to 5 cm, associated with sugilite, pectolite and hydroxyapophyllite, have come from Wessels, some of the crystals containing inclusions of perfect sugilite microcrystals. Some crystals display striking phantom growth outlined by sugilite. Pale amethyst crystals to 3 cm were found to the north of the east-west fracture at Langdon-Devon; and at Wessels small amethyst crystals occur with calcian rhodochrosite. Chalcedonic quartz is widespread as blue, botryoidal and stalactitic masses often found together with rhodochrosite, manganite, braunite II, pyrolusite and calcite.

Rhodochrosite $MnCO_3$

Hotazel mine: During 1964–67 exquisite scalenohedral rhodochrosite crystals up to 4 cm long came from Hotazel. Although these specimens were never as abundant as those of N'Chwaning I, many were of equal quality. Previously described were rhombohedra, scalenohedra and trigonal wheat-sheaves habits. We have noted very attractive rosettes composed of scalenohedra from this period. Isolated rhodochrosite-lined fissures and pockets were found sporadically over the years and it has become difficult to separate material from these from that found later at N'Chwaning I. Some of the more recently found habits include:

1. Simple strawberry-colored composite clusters with parallel *c*-axes and tapering tips, on blue chalcedony.

2. Wheat-sheaf aggregates up to 2 cm. These are bow-tie structures and do not show the trifid divergence of previous descriptions (Wilson and Dunn, 1978).

3. Barrel-shaped aggregates consisting of stacked pinacoids. These tend to be smaller and pinker than the N'Chwaning barrels.

4. Flattened rhombohedra. These are pink with some showing a dark marginal rim. A small pocket which also contained todorokite yielded some top-quality specimens with an exceptional pink color.

5. Stalactitic growths consisting of concentric rings of various shades of pink rhodochrosite around a manganese oxide core. Size is up to 3 cm in diameter, and some specimens are coated with translucent chalcedony.

Associated minerals include manganite, chalcedonic quartz, todorokite, gypsum, barite and sussexite (the latter mineral was only found in two pockets).

N'Chwaning II mine: Since mining commenced only four occurrences have come to our attention. One pocket yielded pale red to orange spheres and is described under *galena*. The other pockets have pink, microcrystalline rhodochrosite associated with pyrochroite, some specimens showing small rhombohedra up to 3 mm. Barite and

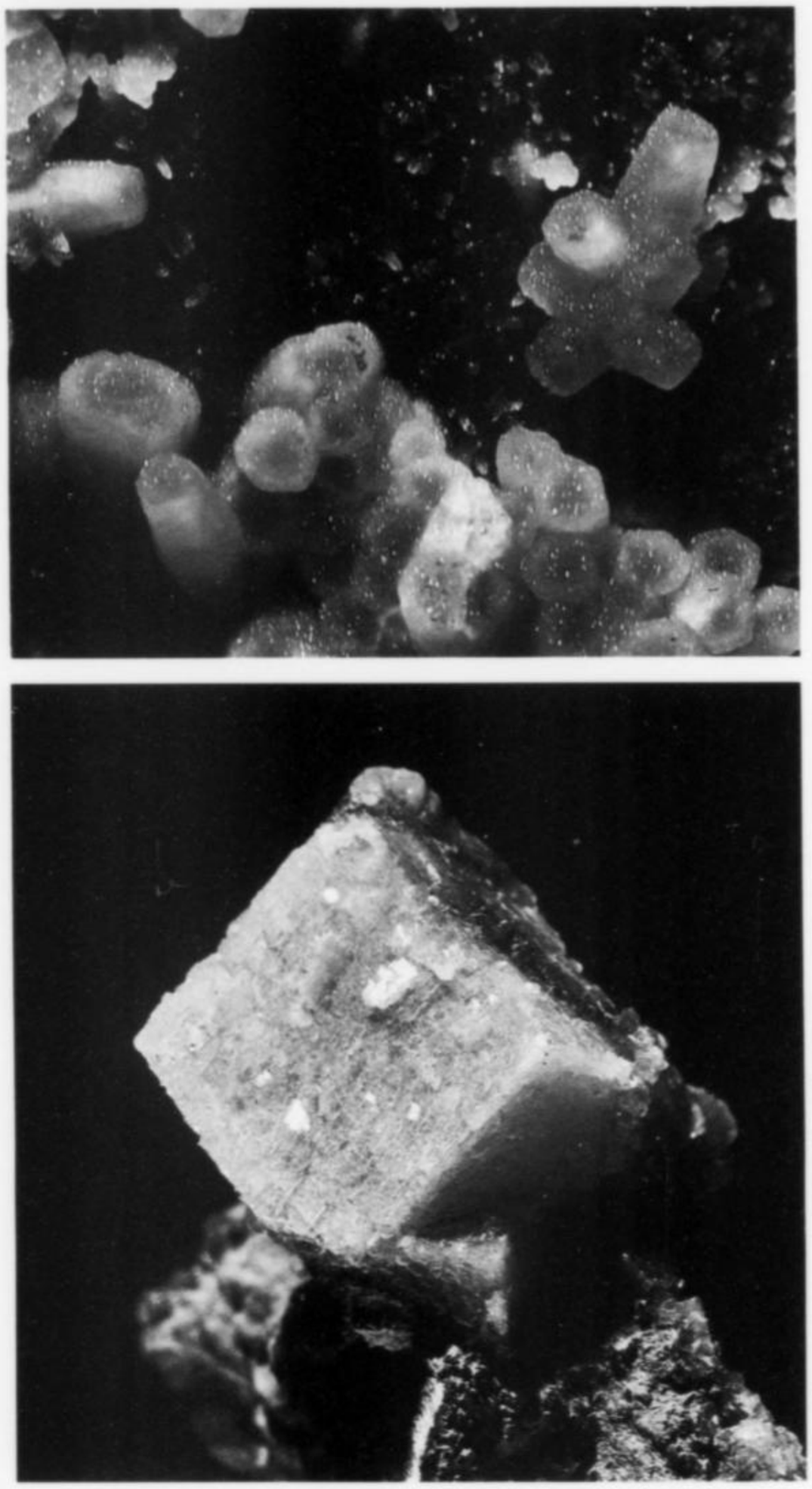

Figure 30. **Rhodochrosite of rhombohedral habit, with edges to 8 mm, from the N'Chwaning I mine. This habit is uncommon in the Kalahari Manganese Field.**

Figure 31. **"Sturmanite" and small, sphenoidal manganite crystals from the N'Chwaning II mine. The specimen measures 2.8 cm across.**

Figure 32. **"Sturmanite" composite crystal floater, 10 cm, found in 1981 at the N'Chwaning II mine.**

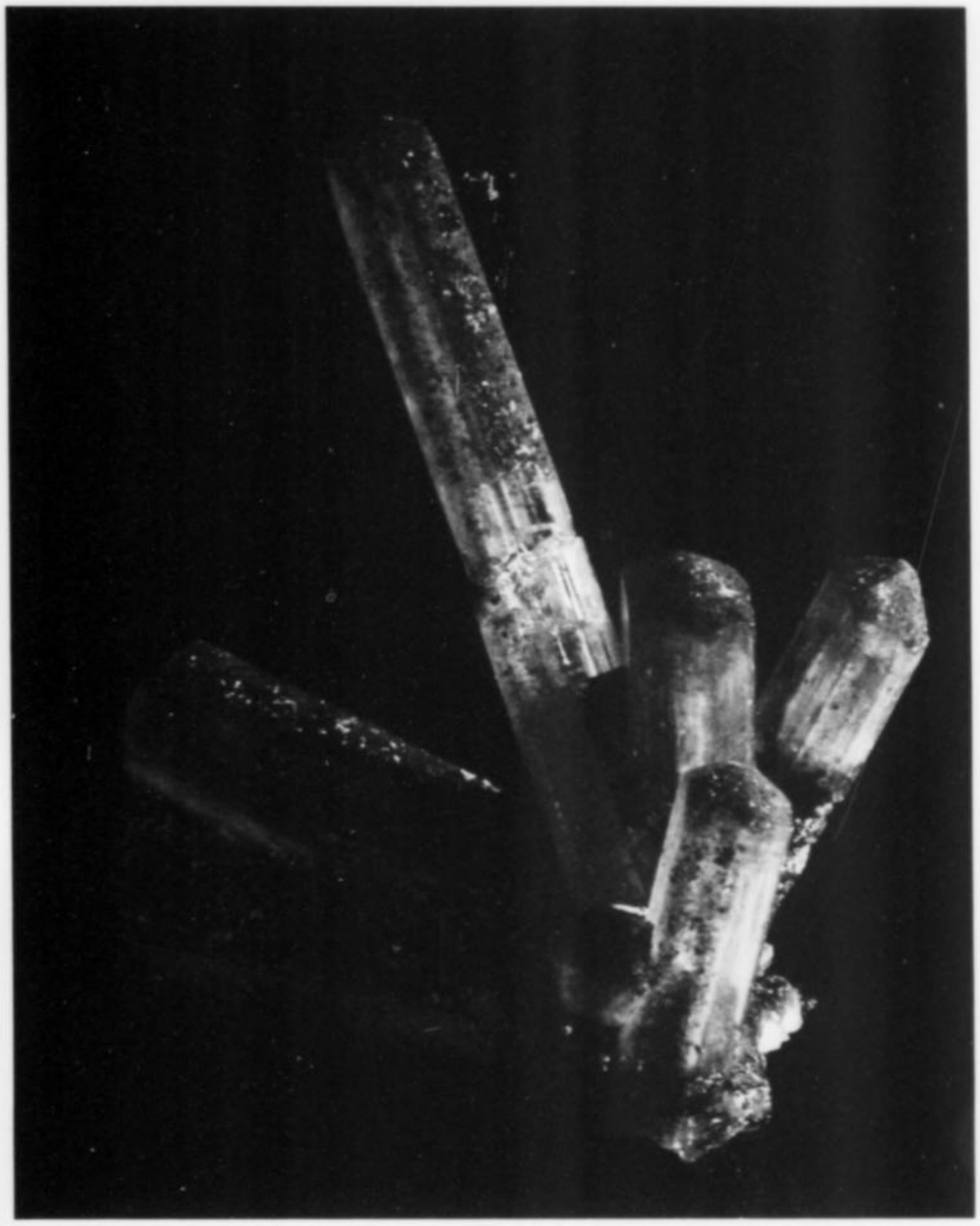

Figure 33. **Group of "sturmanite" crystals 5 cm tall, with colorless, transparent centers. The largest crystal has been repaired. N'Chwaning II mine.**

Figure 34. **"Sturmanite" crystal, 3 cm, on hausmannite matrix, N'Chwaning II mine.**

gageite were noted on some specimens. A similar pocket has been found at Wessels. The latest find (mid-1988) has produced a couple of hundred specimens, and exceptional specimens with deep pink rhombs up to 2.5 cm in size were found, some associated with barite and gageite.

Wessels mine: We examined specimens from 11 pockets during our study. These are mainly calcian rhodochrosite. Some orange-brown scalenohedra and pink zoned rhombohedra are recent finds. All specimens are from the central-southern area of the mine, adjacent to the N'Chwaning mines. Unusual associations include gageite, leucophoenicite, hausmannite, pyrochroite, quartz (amethyst) and andradite.

Rhodonite $(Mn,Fe,Mg,Ca)SiO_3$

Massive pink rhodonite has been found at the Wessels mine. It is of lapidary quality but quantity is limited. No euhedral crystals have come to our attention.

Richterite $Na_2Ca(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$

Blue potassian richterite occurs with sugilite in some specimens from Wessels (microprobe analysis by Rory Moore, personal communication; XRD, this study), and may be mistaken for blue fibrous pectolite, but its hardness is much greater.

Riebeckite $Na_2(Fe,Mg)_3Fe_2^{+3}Si_8O_{22}(OH)_2$

Riebeckite is a common constituent of the adjacent iron-formation. A few specimens with thin riebeckite veins have been found on the dumps at Langdon.

Ruizite $CaMn^{+3}Si_2O_6(OH)\cdot 2H_2O$

After the initial occurrence (described by Wilson and Dunn in the *Mineralogical Record* in 1978) only two further pockets containing this mineral have come from Wessels, the associations of which are described under *"hydroxyapophyllite."* We have seen only a few specimens and suspect that only a handful exist. A rather spectacular combination consisting of hundreds of ruizite crystals, often in clusters up to 4 mm in size, enclosed in clear hydroxyapophyllite cubes a few centimeters on edge has been found.

Serandite $Na(Mn,Ca)_2Si_3O_8(OH)$

Calcian serandite has been recorded from Wessels, in thin section, as a green mineral filling cavities between sugilite crystals. Identity was confirmed by XRD and electron microprobe analysis (Dixon, 1988).

Sturmanite $Ca_6(Fe,Al,Mn)_2(SO_4)_2[B(OH)_4](OH)_{12}\cdot 25H_2O$

When we started the present study in 1981, one of us (K.-L. von B.) noticed peculiar, yellow, bipyramidal crystals in several locality collections. All were from the Wessels mine and some had been found as far back as 1978. Specimens from at least five pockets were identified. It was probably from one of these pockets that sturmanite was described as a new mineral by Peacor *et al.* in 1983. Although the Black Rock mine was suggested as the type locality, we have been unable to verify a single specimen as having come from that mine. Similarly, no sturmanite is recorded from N'Chwaning I.

Early in 1981 a minor roof collapse in the then recently opened N'Chwaning II mine exposed a pocket with a few lemon-yellow crystals in a stacked habit. From late 1982 to late 1983 a fissure complex was encountered in this mine that contained superb, prismatic and bipyramidal crystals up to 14.5 cm long and 3.5 cm thick. Other pockets have been found sporadically since then. Recent finds include a 30-cm crystal mass that shattered on removal, a large 3-meter pocket with honey-colored bipyramidal crystals, and some compound crystals to 10 cm. In total more than 40 pockets have been found at N'Chwaning II.

The pockets that are found at Wessels tend to be of smaller proportions and have less spectacular contents. Predominantly dipyramidal in habit, there have been prismatic crystals up to 4 cm long.

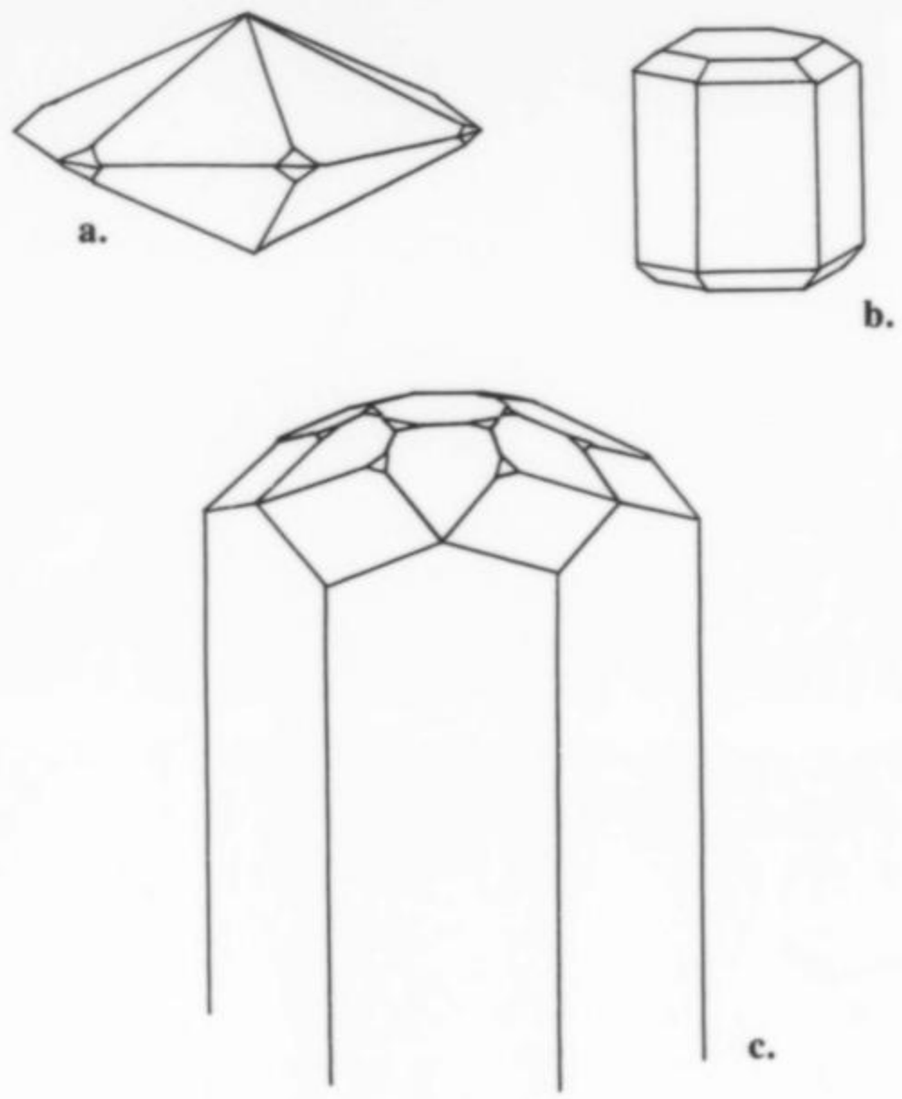

Figure 35. **Sketches showing the common habits of "sturmanite": (a) dominant {11$\bar{2}$4} faces, (b) dominant prism with pinacoid, and (c) an unusually complex crystal. (Note clinographic projections.)**

Associated minerals at Wessels tend to be different from those at N'Chwaning, and include andradite, gypsum and celestite.

The following descriptions are based on an evaluation of specimens from 52 pockets. Color varies from white to white with a pale apricot hue, lemon-yellow, bright yellow, dark yellow, oil-green and yellow-brown. Virtually all shades are represented in this range, and each fissure and pocket generally contains crystals of a distinct color and habit. Surfaces are usually vitreous in appearance, and some crystals are transparent. Streak varies from yellow to white, with the cores of zoned crystals being white. Color zoning is often sharply delineated: a thin yellow outer layer coating a white or colorless core. Crystals are brittle and soft, with cleavage parallel to the *c*-axis. Crystal habit varies from the flat dipyramids to long prismatic crystals, and in at least five pockets we noted both. A progression from the dipyramid to the prism was observed and it appears that the determinative factor here as to which habit the crystals assume is the size of the crystals, with a critical size at which this change occurs. This varies from pocket to pocket. What is responsible for this variation in critical size has not yet been accounted for, but it is obviously related to differing physiochemical environments and growth rates. The most common faces observed are the pyramid, the pinacoid and the prism. The {1124} face on dipyramids, as described in the original article by Peacor *et al.* (1983), was only identified from four pockets, two of which were from Wessels. No crystals showing only the pinacoid and the prism were found. Other features noted on sturmanite include preferential growth of associated minerals on certain prism faces, scepter growth, pitted and frosted faces and healed tectonic fractures.

Some crystals change color from yellow to a dull brown. We have seen this happen on exposed specimens from the dumps, on specimens accidentally kept in a moist enclosed space and which have been attacked by fungi, and specimens kept at the coast. In this regard specimens from some pockets are more prone to this alteration than others, and small crystals and fracture surfaces are the most strongly

affected. The color change has been ascribed to the replacement of sturmanite by gypsum.

There has been discussion in the literature (Hochleitner, 1986) as to whether all sturmanite is actually sturmanite, and Hochleitner classified a large proportion of the sturmanite as ettringite. There has been no detailed study on the compositional variables, and from our preliminary results there appears to be a solid-solution series with crystals from each pocket having a slightly different composition. Typical analyses are presented in Table 3; according to these analyses, none of the material is sturmanite, since ideally sturmanite does not contain Si. This presents problems because according to Peacor *et al.* (1983), Si was detected in a qualitative spectrographic analysis, although not analyzed quantitatively. It is doubtful if material with Si > Al would qualify as sturmanite. At present we are lumping all the crystals under "sturmanite," but absolute identification in each case will depend on analysis. We are fully aware that a large proportion of the crystals are either ettringite or charlesite, or a solid-solution towards thaumasite (some contain significant carbonate), and are working towards the redefinition of the minerals in the group.

Many minerals are associated with "sturmanite": calcite, hausmannite, hematite, gypsum, sphenoidal manganite, barite, henritermierite, andradite, grossular, brucite, rhodochrosite, kutnohorite, galena, celestine, bultfonteinite, vesuvianite and gaudefroyite. Several more as yet unidentified associated minerals include small white balls, orange powdery balls with a pearly sheen, an azure-blue copper sulfate, and others. Sturmanite growing on an earlier generation of sturmanite was noted on two occasions. Paragenetically sturmanite is one of the last minerals to form, with some gypsum forming even later.

Sugilite $(K,Na)(Na,Fe^{+3},Mn)_2(Li,Fe,Mn,Al)_3Si_{12}O_{30}$

The description by Dunn *et al.* (1980) of sugilite from Wessels was based on massive material interlayered with fine-grained aegirine and manganese oxides, chiefly braunite. Dixon (1985) described further occurrences of the mineral and its paragenesis. Since these publications, however, superb crystals of sugilite have been recovered from Wessels, albeit in limited amounts. The best specimens consist of a white base of fibrous pectolite on top of which are perched transparent, pale purple prisms of sugilite up to 6 mm long. These prisms are terminated with the pinacoid at both ends. Other specimens include intergrown masses of dark purple crystals up to 3 mm in size, and beautiful floaters of doubly terminated clear quartz, tabular hydroxyapophyllite and small reddish purple acicular sugilite, some included in the hydroxyapophyllite. The largest sugilite crystals we have seen grew in narrow cracks with pectolite. They are dark purple, elongated prisms terminated by the pyramid, and are up to 2 cm long, although much cruder than the smaller crystals. Only a few occurrences of sugilite crystals have been found so far, and good specimens are rare. Massive sugilite has also been found at N'Chwaning II as isolated occurrences.

Sussexite $MnBO_2(OH)$

A few specimens that were nearly discarded into the "kutnohorite basket" but somehow managed to attract attention, have come from Hotazel. These consist of a cream velvety base of sussexite microcrystals covered with small orange rhodochrosite balls. One specimen from another pocket has small 3–4 mm balls of sussexite microcrystals on manganite. The identity has been confirmed by XRD.

Tephroite Mn_2SiO_4

Two specimens with short, prismatic, resinous looking crystals of a semi-translucent, pale purple mineral were brought to our attention by a Cape Town mineral dealer, and identified as tephroite (XRD). The crystals are up to 2 cm and are associated with small red andradite crystals and manganoan calcite. The base of the specimens is a layer of tephroite on manganese ore. Since then, we have been several more similar specimens from Wessels, some associated with hausmannite crystals. Magnesian tephroite associated with braunite II and hausmannite was described from Wessels ore by Kleyenstuber (1984), as well as from Leinster with jacobsite and andradite.

Figure 36. **Pale purple tephroite crystals on matrix, 9 cm across, from the Wessels mine.**

Thaumasite $Ca_3Si(CO_3)(SO_4)(OH)_6 \cdot 12H_2O$

Thaumasite is present in limited quantities at both Wessels and N'Chwaning II. At Wessels it forms a sugary white layer at the base of clear calcite crystals, and at N'Chwaning II it forms pale yellow, sugary masses several centimeters thick filling fissures. An isolated occurrence at N'Chwaning II was of water-clear colorless crystals on pale brown calcite and hydroxyapophyllite. These thaumasite crystals are squat hexagonal prisms capped by a pinacoid up to 1 cm across.

Figure 37. **Colorless, water-clear thaumasite crystal, 1.1 cm, from the N'Chwaning II mine. W. Henderson specimen and photo.**

Recently (1987) a fissure was found which yielded clear thaumasite crystals with a slight yellow tinge which reached 5 cm in size, some doubly terminated. Thaumasite has also been found associated with xonotlite, sturmanite and brucite.

Todorokite $(Mn^{+2},Ca,Mg)Mn_3^{+4}O_7 \cdot H_2O$

Asbestiform todorokite fibers up to 15 cm long, in layers parallel to bedding, has been found at the Smartt mine, in solution cavities lined with clear calcite rhombs. At Langdon-Devon this mineral has

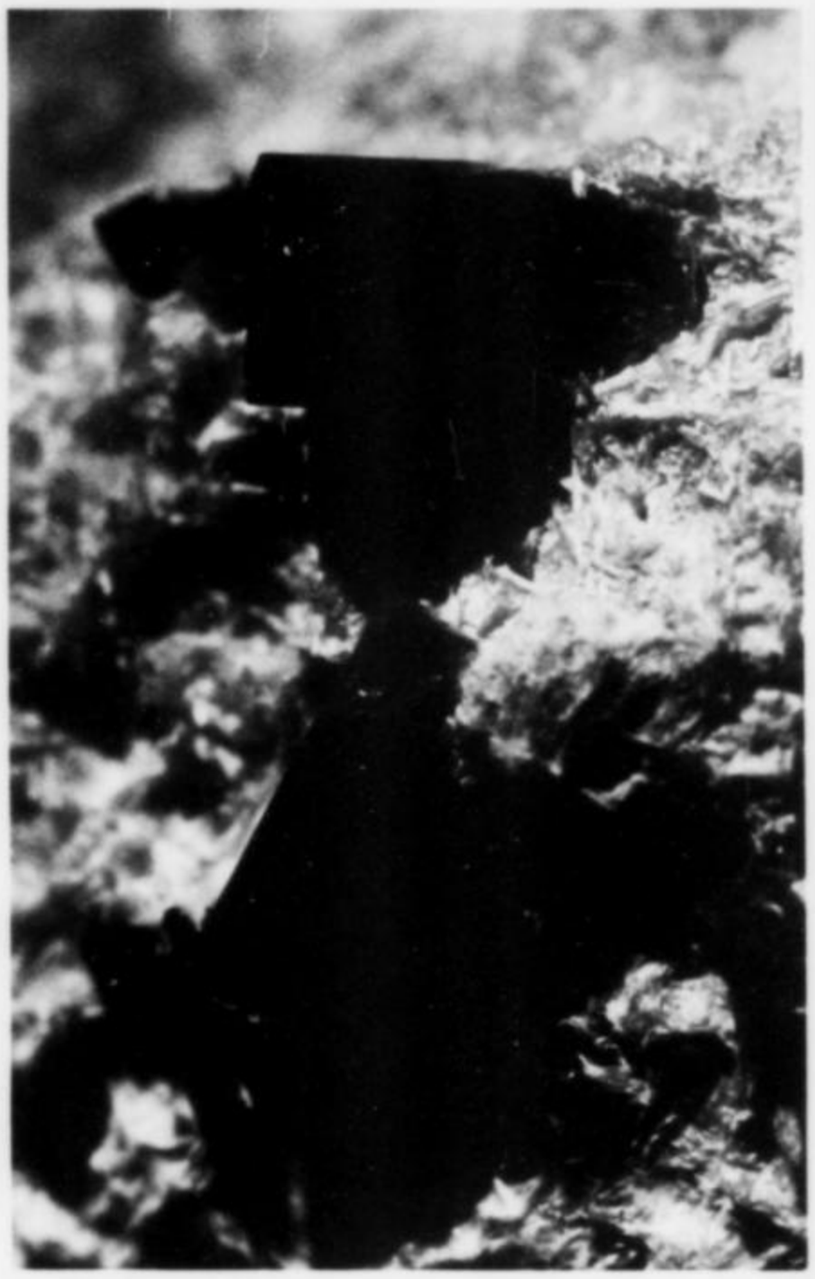

Figure 38. **Prismatic, 3-mm crystals of sugilite on pectolite from the Wessels mine. Note the color zoning.**

Figure 39. **Sugilite crystals to 4 mm in diameter from the Wessels mine. Note the prism, pyramid and pinacoid faces.**

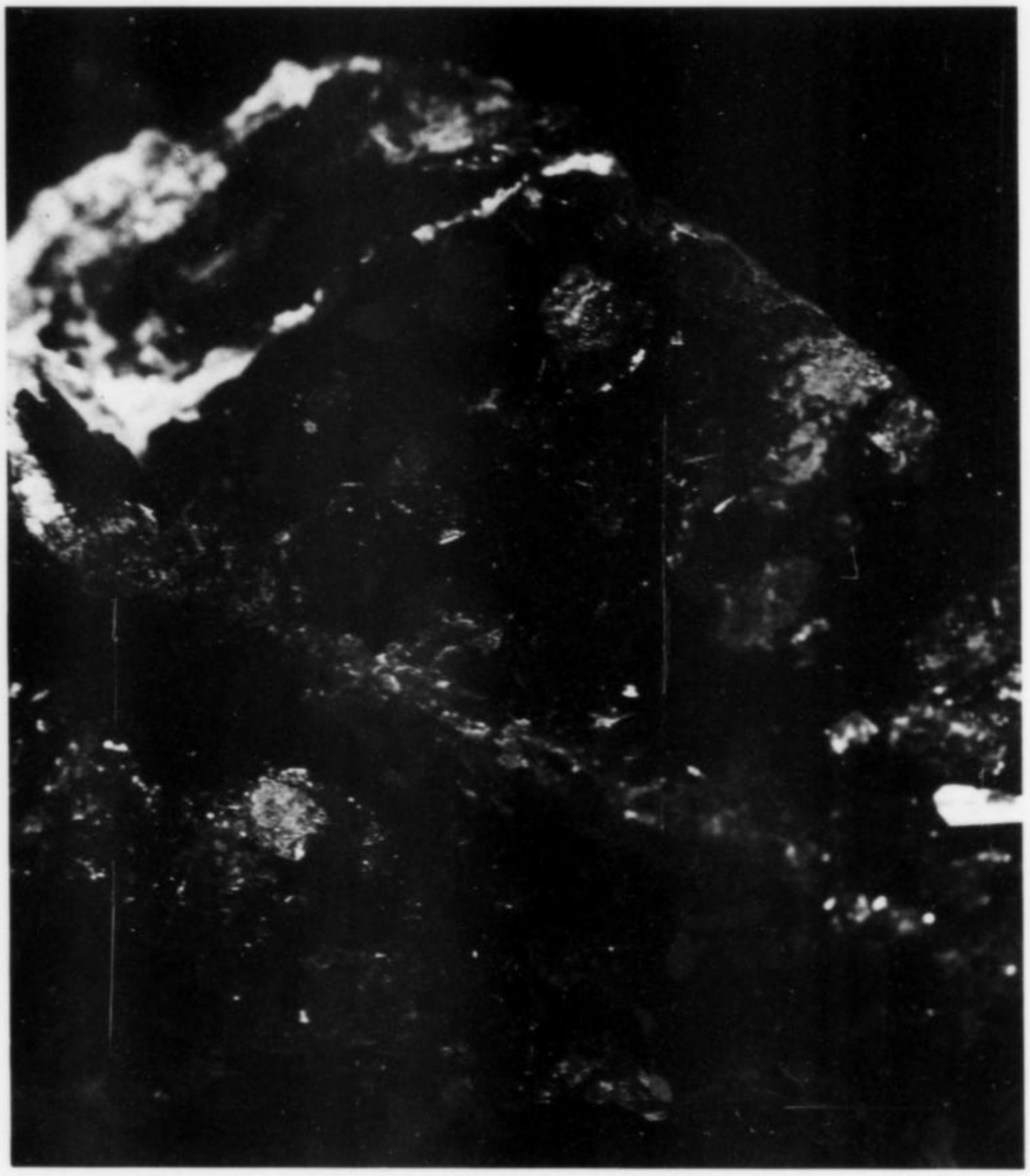

Figure 40. **Sugilite crystals to 4 mm, from the Wessels mine.**

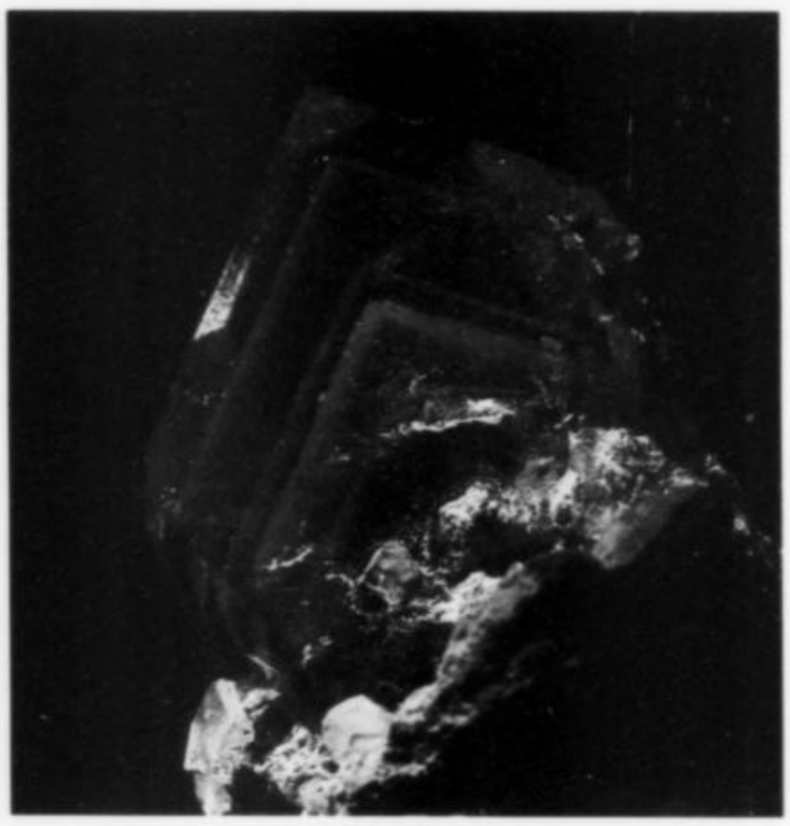

Figure 41. **Multiple sugilite phantoms in a 2.5-cm quartz crystal from the Wessels mine.**

a matted hairy appearance, and at Hotazel spectacular pink rhodochrosite takes the place of the clear calcite as found at Smartt. Exceptional specimens of asbestiform todorokite with calcite have also come from the Adams mine. Todorokite tufts have also been found enclosed on gypsum at N'Chwaning II.

Tridymite SiO_2

Massive greenish brown tridymite was found on a fault-plane in the open-pit at Mamatwan.

Vesuvianite $Ca_{10}Mg_2(Al,Mn,Fe)_4(SiO_4)_5(Si_2O_7)_2(OH)_4$

Euhedral, dark green, 3-mm crystals of vesuvianite with calcite and friedelite have been found at N'Chwaning II, and purple manganese-rich crystals up to 8 mm in calcite with andradite have come from Wessels. Also from Wessels are small (1 mm) red-brown crystals in and on brucite, with sturmanite, calcite, barite and an unidentified blue copper sulfate.

Table 1. **Minerals of the Kalahari Manganese Field.**
(The *Mn* symbol is shown in bold to emphasize the large number of manganese-containing species.)
***Ore minerals seen only in thin sections.**

Native Elements	
Copper	Cu
Sulfides and Sulfosalts	
Chalcopyrite	$CuFeS_2$
Friedelite	$Pb_5Cu_5Bi_7S_{18}$
Galena	PbS
Marcasite	FeS_2
Pyrite	FeS_2
Oxides and Hydroxides	
Birnessite	$Na_4\mathbf{Mn}_{14}O_{27}\cdot 9H_2O$
Bixbyite	$(\mathbf{Mn}^{+3},Fe^{+3})_2O_3$
Brucite	$Mg(OH)_2$
Chalcophanite	$(Zn,Fe^{+2},\mathbf{Mn}^{+2})\mathbf{Mn}_4^{+3}O_7\cdot 3H_2O$
Cryptomelane*	$K(\mathbf{Mn}^{+4},\mathbf{Mn}^{+2})_8O_{16}$
Diaspore	AlO(OH)
Feitknechtite	β-$\mathbf{Mn}^{+3}O(OH)$
Goethite	α-$Fe^{+3}O(OH)$
Groutite	$\mathbf{Mn}^{+3}O(OH)$
Hausmannite	$\mathbf{Mn}^{+2}\mathbf{Mn}_2^{+3}O_4$
Hematite	α-Fe_2O_3
Hollandite	$Ba(\mathbf{Mn}^{+4},\mathbf{Mn}^{+2})_8O_{16}$
Jacobsite*	$(\mathbf{Mn}^{+2},Fe^{+2},Mg)(Fe^{+3},\mathbf{Mn}^{+3})_2O_4$
Lepidocrocite	γ-$Fe^{+3}O(OH)$
Lithiophorite	$(Al,Li)\mathbf{Mn}^{+4}O_2(OH)_2$
Magnetite	$Fe^{+2}Fe_2^{+3}O_4$
Manganite	$\mathbf{Mn}^{+3}O(OH)$
Manjiroite	$(Na,K)(\mathbf{Mn}^{+4},\mathbf{Mn}^{+2})_8O_{16}\cdot nH_2O$
Marokite	$Ca\mathbf{Mn}_2^{+3}O_4$
Nsutite	$(\gamma\text{-}\mathbf{MnO}_2),\mathbf{Mn}_x^{+3}\mathbf{Mn}_{1-x}^{+4}O_{2-2x}(OH)_{2x}$
Portlandite	$Ca(OH)_2$
Pyrochroite	$\mathbf{Mn}^{+2}(OH)_2$
Pyrolusite	$\mathbf{Mn}^{+4}O_2$
Ramsdellite	$\mathbf{Mn}^{+4}O_2$
Todorokite	$(\mathbf{Mn}^{+2},Ca,Mg)\mathbf{Mn}_3^{+4}O_7\cdot H_2O$
Fluorine-containing Minerals	
Bultfonteinite	$Ca_2SiO_2(OH,F)_4$
Creedite	$Ca_3Al_2(SO_4(F,OH)_{10}\cdot 2H_2O$
Hydroxyapophyllite	$KCa_4Si_8O_{20}(OH,F)\cdot 8H_2O$
Carbonates	
Ankerite	$Ca(Fe^{+2},Mg,\mathbf{Mn})(CO_3)_2$
Aragonite	$CaCO_3$
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Gaudefroyite	$Ca_4\mathbf{Mn}_{3-x}^{+3}(BO_3)_3(CO_3)(O,OH)_3$
Jouravskite	$Ca_6\mathbf{Mn}_2^{+4}(SO_4,CO_3)_4(OH)_{12}\cdot 26H_2O$
Kutnohorite	$Ca(\mathbf{Mn}^{+2},Mg,Fe^{+2})(CO_3)_2$
Malachite	$Cu_2^{+2}(CO_3)OH)_2$
Rhodochrosite	$\mathbf{Mn}^{+2}CO_3$
Siderite	$Fe^{+2}CO_3$
Thaumasite	$Ca_6Si_2(CO_3)_2(SO_4)_2(OH)_{12}\cdot 24H_2O$
Boron-containing Minerals	
Charlesite	$Ca_6(Al,Si)_2(SO_4)_2B(OH)_4(OH,O)_{12}\cdot 26H_2O$
Datolite	$CaBSiO_4(OH)$
Gaudefroyite	$Ca_4\mathbf{Mn}_{3-x}^{+3}(BO_3)_3(CO_3)(O,OH)_3$
Gowerite	$CaB_6O_{10}\cdot 5H_2O$
Oyelite	$Ca_{10}Si_8B_2O_{29}\cdot 12.5H_2O$
Sturmanite	$Ca_6(Fe^{+3},Al,\mathbf{Mn}^{+2})_2(SO_4)_2[B(OH)_4](OH)_{12}\cdot 25H_2O$
Sussexite	$\mathbf{Mn}^{+2}BO_2(OH)$
Sulfates	
Barite	$BaSO_4$
Celestine	$SrSO_4$
Charlesite	$Ca_6(Al,Si)_2(SO_4)_2B(OH)_4(OH,O)_{12}\cdot 26H_2O$
Creedite	$Ca_3Al_2(SO_4)(F,OH)_{10}\cdot 2H_2O$
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$
Gypsum	$CaSO_4\cdot 2H_2O$
Jouravskite	$Ca_6\mathbf{Mn}_3^{+3}(SO_4,CO_3)_4(OH)_{12}\cdot 26H_2O$
Sturmanite	$Ca_6(Fe^{+3},Al,\mathbf{Mn}^{+2})_2(SO_4)_2[B(OH)_4](OH)_{12}\cdot 25H_2O$
Thaumasite	$Ca_6Si_2(CO_3)_2(SO_4)_2(OH)_{12}\cdot 24H_2O$
Phosphates	
Fluorapatite	$Ca_5(PO_4)_3F$
Silicates	
Aegirine	$NaFe^{+3}Si_2O_6$
Afwillite	$Ca_3Si_2O_4(OH)_6$
Akermanite	$Ca_2MgSi_2O_7$
Albite	$NaAlSi_3O_8$
Andradite	$Ca_3Fe_2^{+3}(SiO_4)_3$
Banalsite	$BaNa_2Al_4Si_4O_{16}$
Bementite	$\mathbf{Mn}_8^{+2}Si_6O_{15}(OH)_{10}$
Braunite*	$\mathbf{Mn}^{+2}\mathbf{Mn}_6^{+3}SiO_{12}$
Braunite II	$Ca(\mathbf{Mn},Fe)_{14}SiO_{24}$
Bultfonteinite	$Ca_2SiO_2(OH,F)_4$
Bustamite	$(\mathbf{Mn}^{+2},Ca)_3Si_3O_9$
Caryopilite	$(\mathbf{Mn}^{+2},Mg)_3Si_2O_5(OH)_4$
Chamosite	$(Fe^{+2},Mg,Fe^{+3})_5Al(Si_3Al)O_{10}(OH,O)_8$
Charlesite	$Ca_6(Al,Si)_2(SO_4)_2B(OH)_4(OH,O)_{12}\cdot 26H_2O$
Chrysocolla	$(Cu^{+2},Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$
Clinochlore	$(Mg,Fe^{+2})_5Al(Si_3Al)O_{10}(OH)_8$
Clinochrysotile	$Mg_3Si_2O_5(OH)_4$
Cymrite	$BaAl_2Si_2(O,OH)_8\cdot H_2O$
Datolite	$CaBSiO_4(OH)$
Diopside	$CaMgSi_2O_6$
Ephesite	$NaLiAl_2(Al_2Si_2)O_{10}(OH)_2$
Epidote	$Ca_2(Fe^{+3},Al)_3(SiO_4)_3(OH)$
Ferri-annite	$K(Fe^{+2},Mg)_3(Fe^{+3},Al)Si_3O_{10}(OH)_2$
Ferrobustamite	$Ca(Fe^{+2},Ca,\mathbf{Mn}^{+2})Si_2O_6$
Foshagite	$Ca_4Si_3O_9(OH)_2$
Gageite	$(\mathbf{Mn}^{+2},Mg,Zn)_{42}Si_{16}O_{54}(OH)_{40}$
Glaucochroite	$Ca\mathbf{Mn}^{+2}SiO_4$
Glauconite	$(K,Na)(Fe^{+3},Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$
Gonyerite	$(\mathbf{Mn}^{+2},Mg)_5Fe^{+3}(Si_3Fe^{+3})O_{10}(OH)_8$
Grossular	$Ca_3Al_2(SiO_4)_3$
Henritermierite	$Ca_3(\mathbf{Mn},Al)_2(SiO_4)_2(OH)_4$
Hydrogrossular	$Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$
Hydroxyapophyllite	$KCa_4Si_8O_{20}(OH,F)\cdot 8H_2O$
Inesite	$Ca_2\mathbf{Mn}_7^{+2}Si_{10}O_{28}(OH)_2\cdot 5H_2O$
Jennite	$Ca_9H_2Si_6O_{18}(OH)_6\cdot 6H_2O$
Johannsenite	$Ca\mathbf{Mn}^{+2}Si_2O_6$
Kaolinite	$Al_2Si_2O_5(OH)_4$
Kentrolite	$Pb_2\mathbf{Mn}_2^{+3}Si_2O_9$
Kirschsteinite	$CaFe^{+2}SiO_4$

Leucophoenicite	$\mathbf{Mn}_7^{+2}(SiO_4)_3(OH)_2$
Magnesio-arfvedsonite	$Na_3(Mg,Fe^{+2})_4Fe^{+3}Si_8O_{22}(OH)_2$
Minnesotaite	$(Fe^{+2},Mg)_3Si_4O_{10}(OH)_2$
Nontronite	$(Fe^{+2},Mg)_3Si_4O_{10}(OH)_2$
Opal	$SiO_2 \cdot nH_2O$
Orientite	$Ca_2\mathbf{Mn}^{+2}\mathbf{Mn}_2^{+3}Si_3O_{10}(OH)_4$
Orlymanite	$Ca_4\mathbf{Mn}_3^{+2}Si_8O_{20}(OH)_6 \cdot 2H_2O$
Oyelite	$Ca_{10}Si_8B_2O_{29} \cdot 12.5H_2O$
Pargasite	$NaCa_2(Mg,Fe^{+2})_4Al(Si_6Al_2)O_{22}(OH)_2$
Parsettensite	$(K,Na,Ca)(\mathbf{Mn},Al)_7Si_8O_{20}(OH)_8 \cdot 2H_2O$ (?)
Pectolite	$NaCa_2Si_3O_8(OH)$
Phlogopite	$KMg_3Si_3AlO_{10}(F,OH)_2$
Piemontite	$Ca_2(Al,\mathbf{Mn}^{+3},Fe^{+3})_3(SiO_4)_3(OH)$
Quartz	SiO_2
Rhodonite	$(\mathbf{Mn}^{+2},Fe^{+2},Mg,Ca)SiO_3$
Richterite	$Na_2Ca(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$
Riebeckite	$Na_2(Fe^{+2},Mg)_3Fe_2^{+3}Si_8O_{22}(OH)_2$
Ruizite	$Ca\mathbf{Mn}^{+3}Si_2O_6(OH) \cdot 2H_2O$
Saponite	$(Ca,Na)_{0.3}(Mg,Fe^{+2})_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$
Serandite	$Na(\mathbf{Mn}^{+2},Ca)_2Si_3O_8(OH)$
Stilpnomelane*	$K(Fe^{+2},Mg,Fe^{+3})_8(Si,Al)_{12}(O,OH)_{27}$
Sugilite	$KNa_2(Fe^{+2},\mathbf{Mn}^{+2},Al)_2Li_3Si_{12}O_{30}$
Talc	$Mg_3Si_4O_{10}(OH)_2$
Tephroite	$\mathbf{Mn}_2^{+2}SiO_4$
Thaumasite	$Ca_6Si_2(CO_3)_2(SO_4)_2(OH)_{12} \cdot 24H_2O$
Titanite	$CaTiSiO_5$
Tremolite	$Ca_2(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$
Tridymite	SiO_2
Vesuvianite	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
Wollastonite	$CaSiO_3$
Xonotlite	$Ca_6Si_6O_{17}(OH)_2$

***Table 2.* Microprobe analyses of some minerals from the Kalahari Manganese Field.**

	Glaucochroite	*Kirschsteinite*	*Akermanite*	*Akermanite*	*Akermanite*	*Hydroandradite*	*Henritermierite*	*Andradite*	*Magnesio-arfvedsonite*
SiO_2	31.89	33.71	43.65	39.82	35.26	28.62	28.00	35.95	56.95
Al_2O_3	0.93	1.41	5.71	0.81	2.20	1.78	4.48	0.32	0.37
FeO	0.66	18.08	6.60	9.57	22.52	—	—	—	—
Fe_2O_3	—	—	—	—	—	23.78	0.79	24.53	7.69
MnO	37.34	14.64	2.76	11.86	3.60	—	—	—	5.07
Mn_2O_3	—	—	—	—	—	3.49	25.17	5.99	—
MgO	1.07	0.15	9.06	5.37	0.14	1.12	0.16	0.28	16.26
CaO	27.61	31.44	31.94	32.47	35.56	36.52	36.46	33.81	1.44
Na_2O	—	—	0.06	—	0.18	—	—	—	7.13
K_2O	—	—	0.12	—	0.09	—	—	—	4.17
H_2O	—	—	—	—	—	4.69	4.94	—	—
Total	99.50	99.43	100.00	99.90	99.68	100.00	100.00	100.88	99.08

Table 3.* Variations in "sturmanite"-ettringite-charlesite

Color	Composition	Probable Identity
1. Transparent, colorless core from a large crystal	Low Si; no Fe, no Mn	Ettringite
2. Canary-yellow outer rind on a crystal	Significant Si; Al exceeds Si; very minor Fe, Mn	Charlesite (ferroan and manganoan)
3. Pale orange-brown to colorless zoned crystal	Al greatly exceeds Si; very low Fe and Mn	Ettringite (ferroan)
4. Medium brown, strongly zoned crystal	Si exceeds Al; high Fe; low Mn	Charlesite (ferroan)

*Analyses conducted at the American Museum of Natural History. In all cases, a flame test for boron was positive in the outer rind of crystals and faintly positive in the cores.

Wollastonite $CaSiO_3$

Wollastonite occurs with pectolite in a sugilite assemblage at Wessels (Dixon, 1985), and also as pinkish, manganese-rich acicular masses with clove-brown johannsenite from the same mine.

Xonotlite $Ca_6Si_6O_{17}(OH)_2$

Masses of crossed bundles of white crystal fibers of xonotlite have come from N'Chwaning II. Fibers reach 2 cm and more in length. Associated minerals are thaumasite and pink apophyllite pseudo-octahedra to 4 cm.

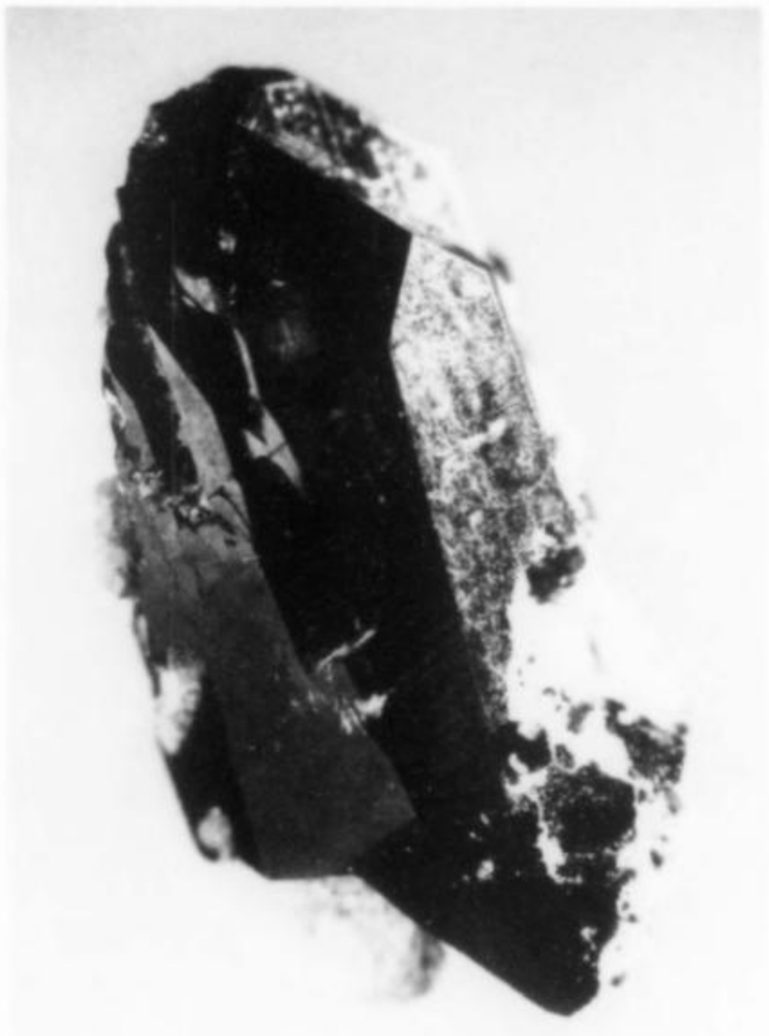

***Figure 42.* Unknown copper sulfate-carbonate crystal, 1.5 cm. The mineral is dark azure blue, and came from an isolated pocket containing primarily sturmanite at the Wessels mine.**

Unidentified Minerals

Numerous unidentified minerals await characterization, and we want to highlight two of these. The first is an azure-blue copper sulfate from a single pocket at Wessels, with a few crystals up to 3 cm intimately associated with two generations of sturmanite. Other minerals in this pocket include bultfonteinite, brucite, vesuvianite, calcite and barite.

The second mineral is a sepia-brown manganese silicate occurring

in spheres of radiating acicular crystals up to 8 mm in diameter on calcite. It was found in a single fissure in a highly faulted area in the N'Chwaning II mine.

CONCLUSIONS

Due to the variety of factors controlling the formation of this ore deposit and its subsequent metamorphism, many unusual minerals have been, and will continue to be, found here. The Kalahari district has features that resemble in some ways those of Franklin, Crestmore, Långban, Tachgagalt and the Japanese manganese deposits, but it also has features that are at present unique. Much work remains to be done, before the genesis of the minerals found in the Kalahari Manganese Field is fully understood.

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In 1988 a large quantity of very distinctive quartz specimens appeared on the market; most are densely filled with green hedenbergite inclusions, and some are partially amethystine. The locality, on the Greek island of Seriphos, has produced other species as well, including excellent ilvaite crystals to 20 cm.

INTRODUCTION

A skarn is defined as a zone of calcium silicates derived from nearly pure limestone or dolomite with the introduction of large amounts of Si, Al, Fe and Mg (*Glossary of Geology*, third edition, 1987). In Greece there are many skarns which have produced—or have the potential to produce—attractive mineral specimens. Examples include Xanthi in Thrace, Vrodou in central Macedonia, and the Aegean islands of Tinos, Naxos, Mykonos, Paros and Seriphos. A skarn may constitute an economic ore deposit, or simply a source of collectible specimens. The Seriphos skarn is both of these.

The island of Seriphos is part of the Cycladic Archipelago in the Aegean sea, about 100 km south-southeast of Athens. It is relatively small, not exceeding 13 km in longest dimension. Topographically it consists of a high central plateau rising to about 600 meters elevation, surrounded by a system of ridges and valleys ending in a crenulated coastline.

Iron mining was the principal industry of the island, at least since Roman times. From 1869 to 1940 the iron ores were exploited by open pits and also underground mining.

Seriphos has long been known for producing superb crystals of ilvaite. But it was not until recent years that one of the authors (NA) brought quantities of beautifully crystallized quartz and garnet specimens to the international specimen market, making it famous for those minerals as well.

GEOLOGY

The geology and metallogeny of Seriphos have been described by Ktenas (1914), Marinos (1951) and, more recently, by Salemink (1985). Like its neighboring islands, Seriphos is primarily an outcrop of the Attic-Cycladic crystalline massif, associated with the Tertiary Alpine Orogeny. A local peculiarity, however, is the intrusion of a granodiorite into a series of metamorphosed sediments. The sequence of these metasediments, from bottom to top, is as follows:

(1) A lower unit of banded gneiss (quartz with biotite and minor albite-oligoclase). Several intercalated quartzitic lenses and marble beds are also present. Maximum thickness: 150 meters.

(2) A middle unit of marble, consisting of an upper calcitic member and a lower dolomitic member. Maximum thickness: 70 meters.

(3) An upper unit of schist, locally calcium-enriched, with marble intercalations. Maximum thickness is unknown, but it accounts for roughly half the surface of the island.

The granodiorite intrusion produced a doming of the metasedimentary units, with localized folding and faulting. Any of the three units may be in direct contact with the intrusion, due to their rather irregular and discontinuous configurations. Late-stage granitic and dioritic dikes were then emplaced in the metasediments in a radiating pattern about the granodiorite intrusion. The extreme southwestern peninsula of the island is faulted, with development of serpentine containing grains of magnetite and olivine. Erosion has resulted in a broad, low plateau of granodiorite as the surface expression of the dome.

Mineralized areas include virtually the entire marble unit, and a carbonate-rich zone of the schist, as well as voids that developed inside the schist and at the granodiorite contact. Contact metamorphism out to a distance of several hundred meters, combined with metasomatism, have produced the present mineral assemblages. The metasomatic effects were derived from hydrothermal leaching, the extraction by dissolution (in hot, high-pressure water) of Fe, Mg and

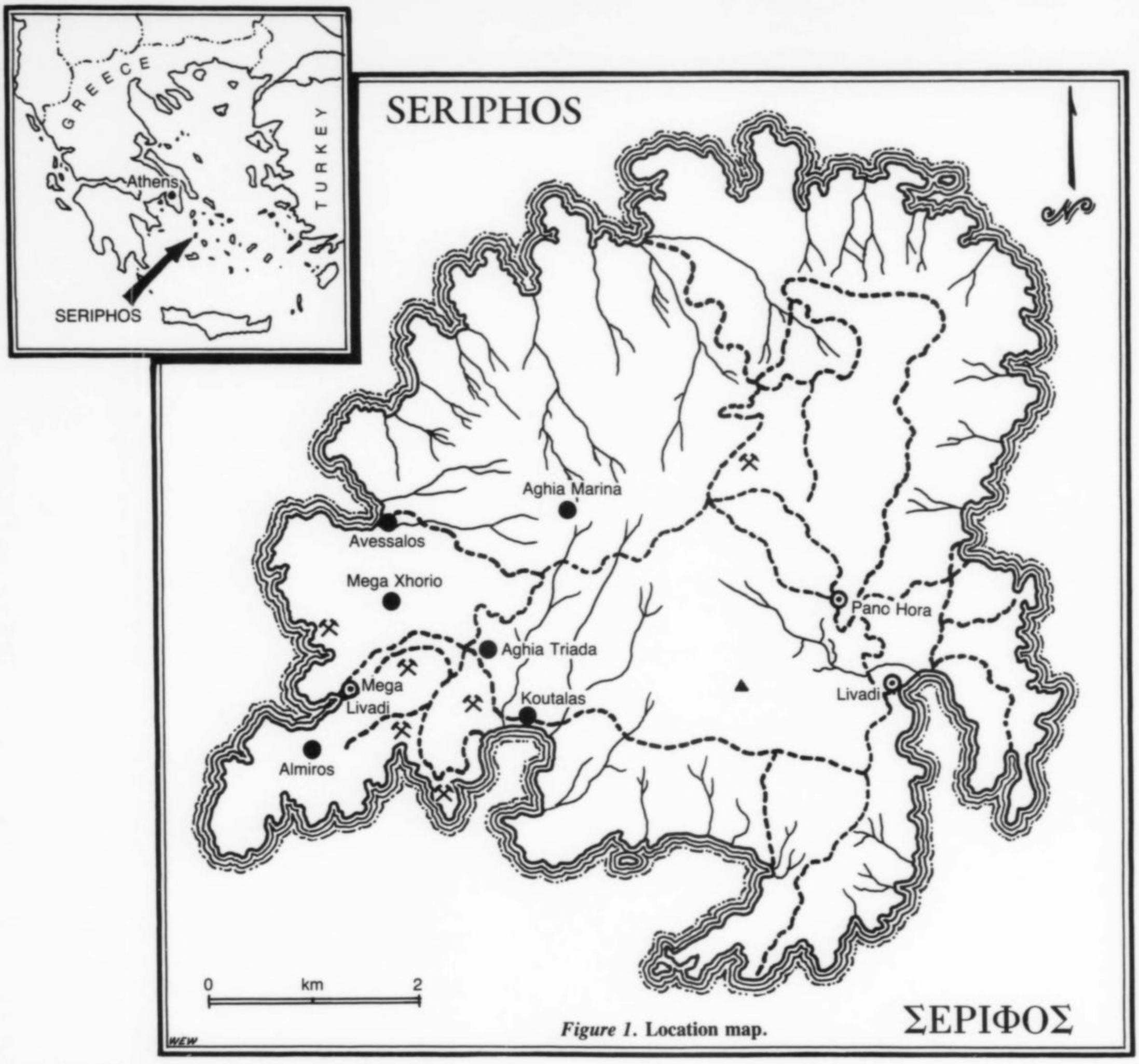

Figure 1. **Location map.**

Mn, and their subsequent reaction with calc-silicates over a range of temperatures and durations.

In the marble unit these processes created a calcium contact skarn containing a wealth of well-crystallized minerals in vugs and fissures, and also massive accumulations of ores. The ores are of two general types: (1) iron ore, either hematite-limonite or magnetite-pyrite, and (2) zinc-lead-copper ore consisting of sphalerite, galena and chalcopyrite (reported only from the schist). Several deposits on Seriphos have been profitably mined for these ores, but noteworthy specimen material has not been reported from the orebodies.

The age of mineralization on Seriphos has been placed at 8 to 9 million years (Wendt *et al.*, 1977), similar to the age of mineralization at Laurium 80 km to the northwest.

MINERALOGY

Andradite $Ca_3Fe_2(SiO_4)_3$

Beautifully crystallized, black or brown to amber-yellow andradite occurs on hedenbergite lining cavities and fissures in the skarn. The crystals are typical dodecahedrons and trapezohedrons, generally 5 to 10 mm in size but rarely as large as 3 cm. Quartz is commonly associated. The best specimens have come from the Aghia Marina area.

Barite $BaSO_4$

Tabular, colorless and transparent crystals of barite showing a slightly curved habit have been found near the villages of Almiros, Koutalas and Aghia Trias.

Hedenbergite $CaFeSi_2O_6$

Fibrous, gray hedenbergite (Salemink, 1985a) occurs lining cavities in marble. Blocky dark green crystals and black, elongated, narrow prisms to 5 cm with flat terminations have recently been found associated with andradite; the luster varies from dull to bright. Parallel to subparallel aggregates are common. The best locations are Aghia Marina, Avessalos and Mega Xhorio ("Xhorio" is pronounced "Korio").

Hematite Fe_2O_3

"Iron rose" groups of hematite crystals on quartz crystals occur throughout the skarn, especially at Aghia Marina, Avessalos and Mega Xhorio.

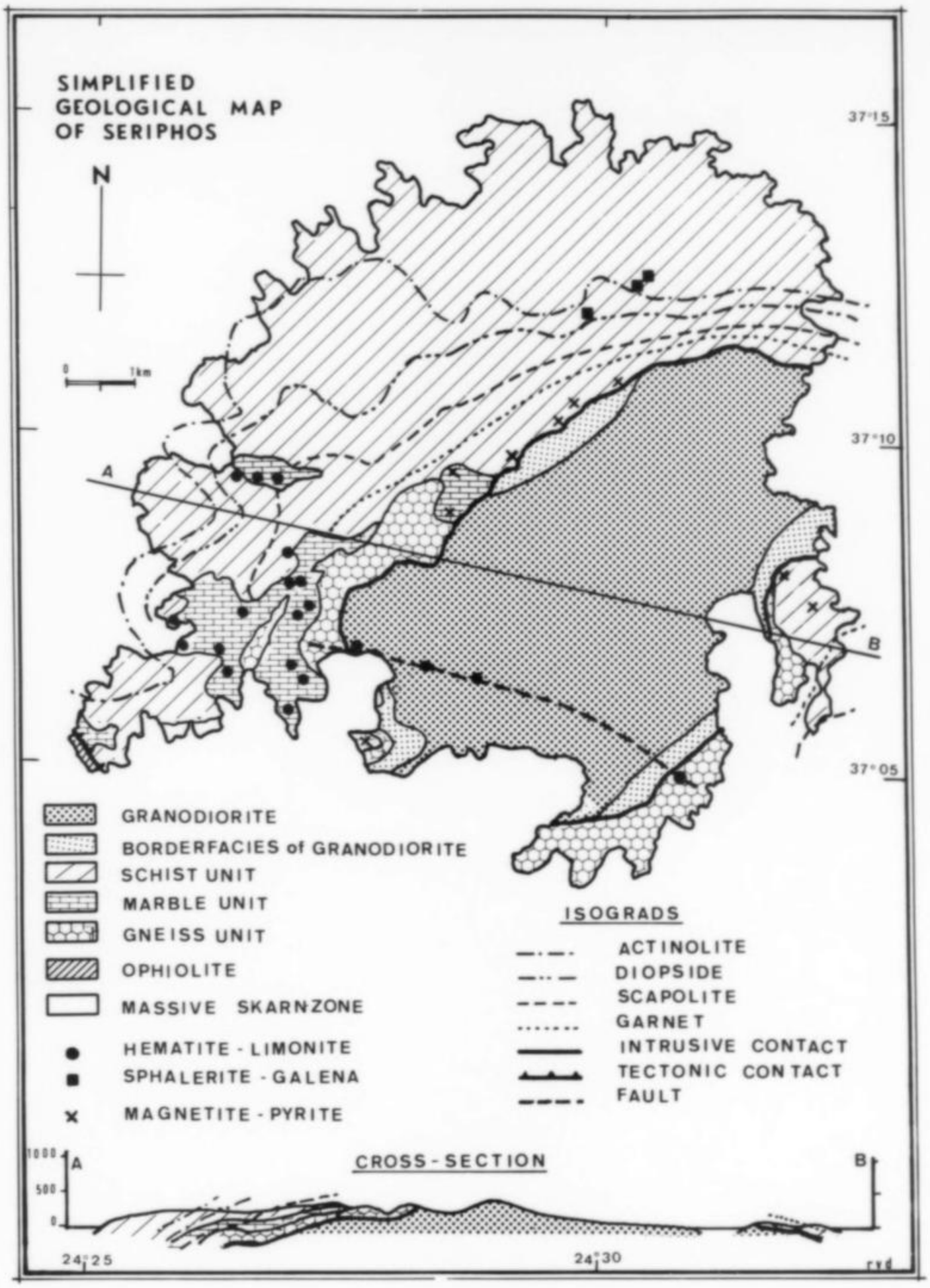

Figure 2. **Simplified geological map of Seriphos, with cross-section (after Salemink, 1985b).**

Ilvaite $CaFe^{+2}_2Fe^{+3}Si_2O_7O(OH)$

Superb, well-formed crystals of black ilvaite up to 30 cm long have been found in a mine north of Mega Livadi, in an outcrop nearby at Koundouro Bay, and to the northeast near Aghia Marina. The coastal outcrop is in a sheer cliff face overlooking the northern side of the bay, at a greenschist/marble contact zone which extends inland (Vogt, 1991). The first and best specimens were apparently collected shortly after the turn of the century. William E. Ford does not mention them in the third appendix (1915) to *Dana's System of Mineralogy*, nor does the occurrence appear earlier in the Dana series, but he does refer to "fine specimens from the island of Seriphos" in the 1932 edition of *Dana's Textbook of Mineralogy*.

The crystals are short to elongated four-sided prisms terminated by two triangular faces forming a chisel-like aspect. Groups, especially in parallel growth, are typical, and isolated individuals on matrix are rare. The crystals are usually rather dull, and only rarely lustrous. A white to brown clayey crust commonly covers the crystals. Associations include green quartz scepters, hematite *eisenrosen*, small garnet crystals, and pyrite. These days only ilvaite fragments and small crystals can be found at the site.

Quartz SiO_2

Large quantities of quartz crystals were deposited in irregular cavities in marble. The sides of the cavities bulge inward to form concave polygons (usually triangular) in cross section. Apparently these cavities were already mostly filled with fibrous hedenbergite which had formed earlier and was then encompassed by the growing quartz crystals. Consequently most Seriphos quartz is pale to dark green due to the extremely dense inclusions of hedenbergite.

The crystal habit is generally spindle-shaped, with hexagonal prism faces curving gently to a somewhat frosty, jagged, terminal point megascopically lacking obvious rhombohedron faces. Other crystals, especially those having terminations free of inclusions, are more sharply terminated with small rhombohedron faces.

Some crystals are colored limonite-yellow or hematite-red due to inclusions of iron oxides, and some show areas of pale amethystine color. A few rare examples are tri-colored. Colorless quartz lacking any inclusions is uncommon. Crystals to 20 cm have been recovered (5 to 10 cm being the most common).

Curved crystals, scepters and "bow tie" habits have all been observed, but the most common habit is the hexagonal "spindle," in singles, divergent groups and randomly oriented groups from thumbnail to large cabinet size. Most of these have grown on a base of hedenbergite, although numerous unattached "floaters" have also been found. Specimens with ilvaite or andradite are rare.

Quartz-lined cavities vary in size from 1 cm to about a meter in width and several meters in the long direction. Some vugs lined with crystals have reportedly been filled in with compact sepiolite.

The best specimens have been found at Mega Xhorio, Avessalos, Aghia Marina and Aghia Triada (small villages on the west side of the island, in the marble outcrop).

It is interesting to note that very similar green quartz has been found at a skarn, with hedenbergite and ilvaite, at Portocciolo on the island of Elba, Italy.

Table 1. **Minerals of Seriphos, Greece.**

Actinolite	Chlorite	Hedenbergite	Scapolite
Albite	Chrysocolla	Hematite	Sepiolite
Allanite-(Ce)	Copper	Ilvaite	Sericite
Andradite	Cuprite	"Limonite"	Siderite
Ankerite	Diopside	Magnetite	Sphalerite
Apatite	Dolomite	Malachite	Szaibelyite
Aragonite	Epidote	Orthoclase	Talc
Barite	Fluorite	Phlogopite	Titanite
Biotite	Galena	Pyrite	Tourmaline
Calcite	Glaucophane	Quartz	Wollastonite
Chalcopyrite	Graphite		

Figure 3. **The authors by a large pocket. Photo by A. S. Vafidis.**

Figure 4. **Group of dark green, hedenbergite-filled quartz crystals, 8.8 cm. A. S. Vafidis collection and photo.**

Figure 5. **Spindle-shaped quartz crystals with pale amethystine terminations, 6.2 cm.**

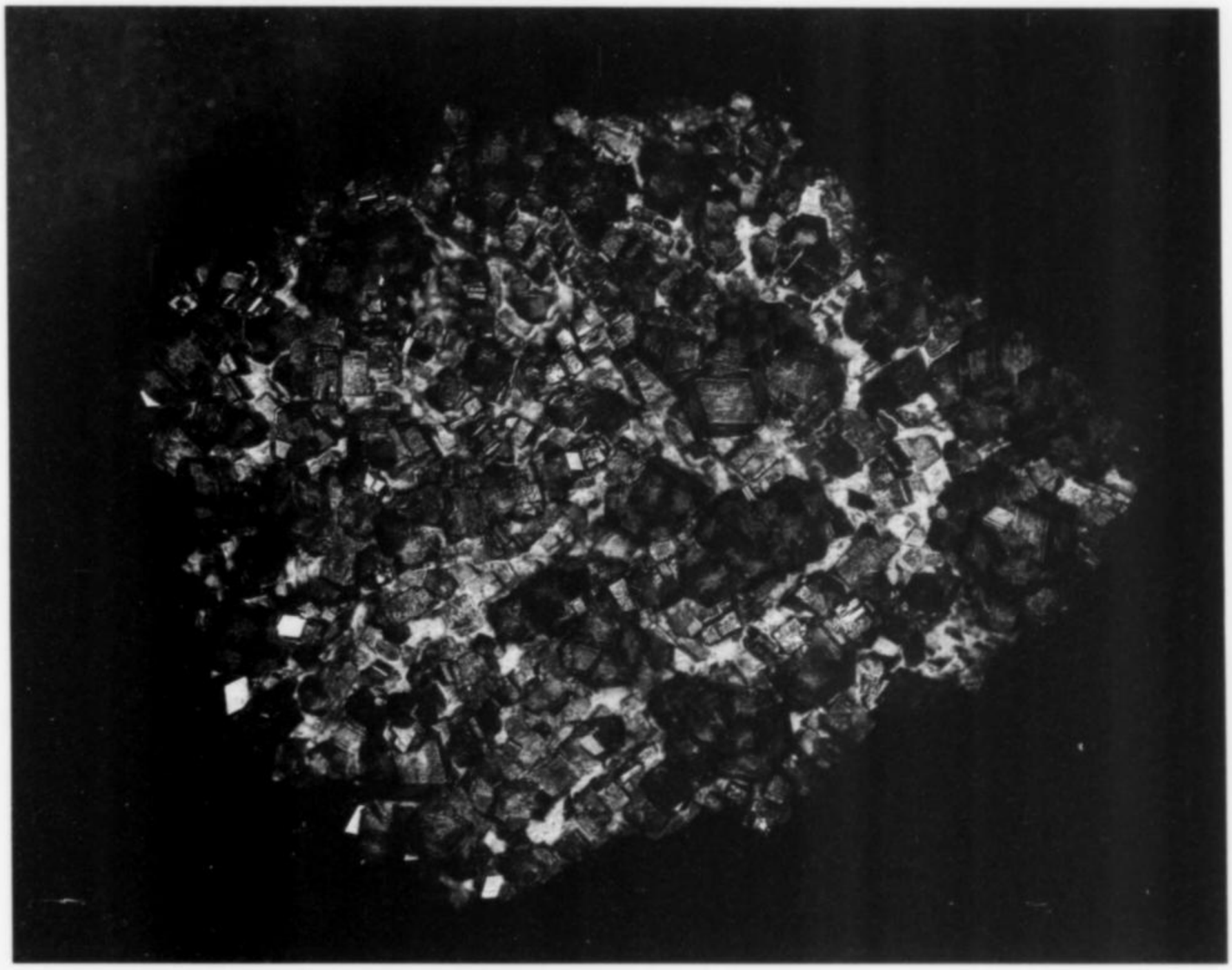

Figure 6. **Andradite and blocky green hedenbergite, 33 cm across, from Mega Xhorio, Seriphos. M. M. Groben collection and photo.**

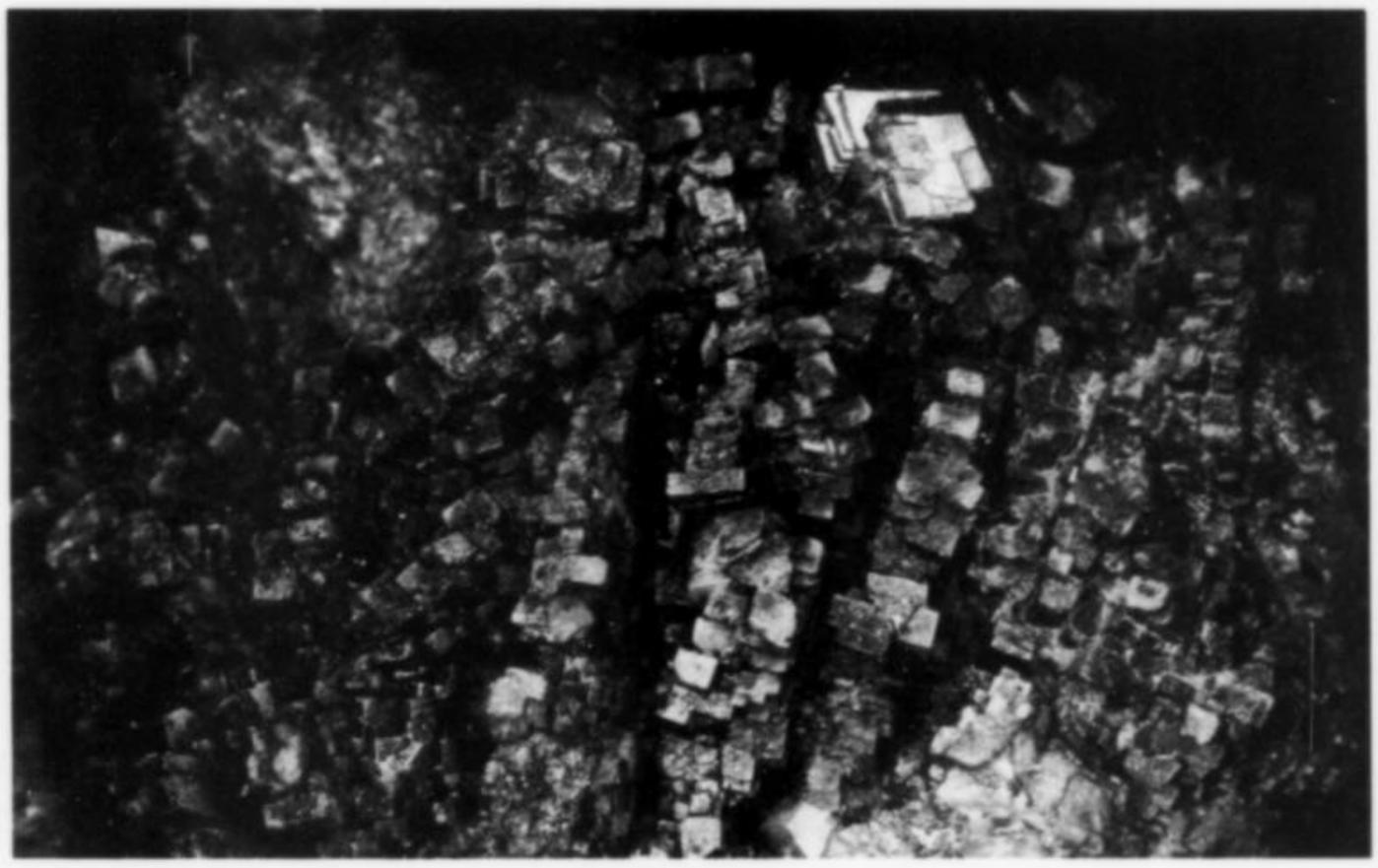

Figure 7. **Blocky green hedenbergite in parallel columnar aggregates, with andradite, 25 cm across, from Mega Xhorio, Seriphos. M. M. Groben collection and photo.**

Figure 8. **Spindle-shaped quartz crystals, 10.4 cm, with yellow limonitic inclusions. A. S. Vafidis collection and photo.**

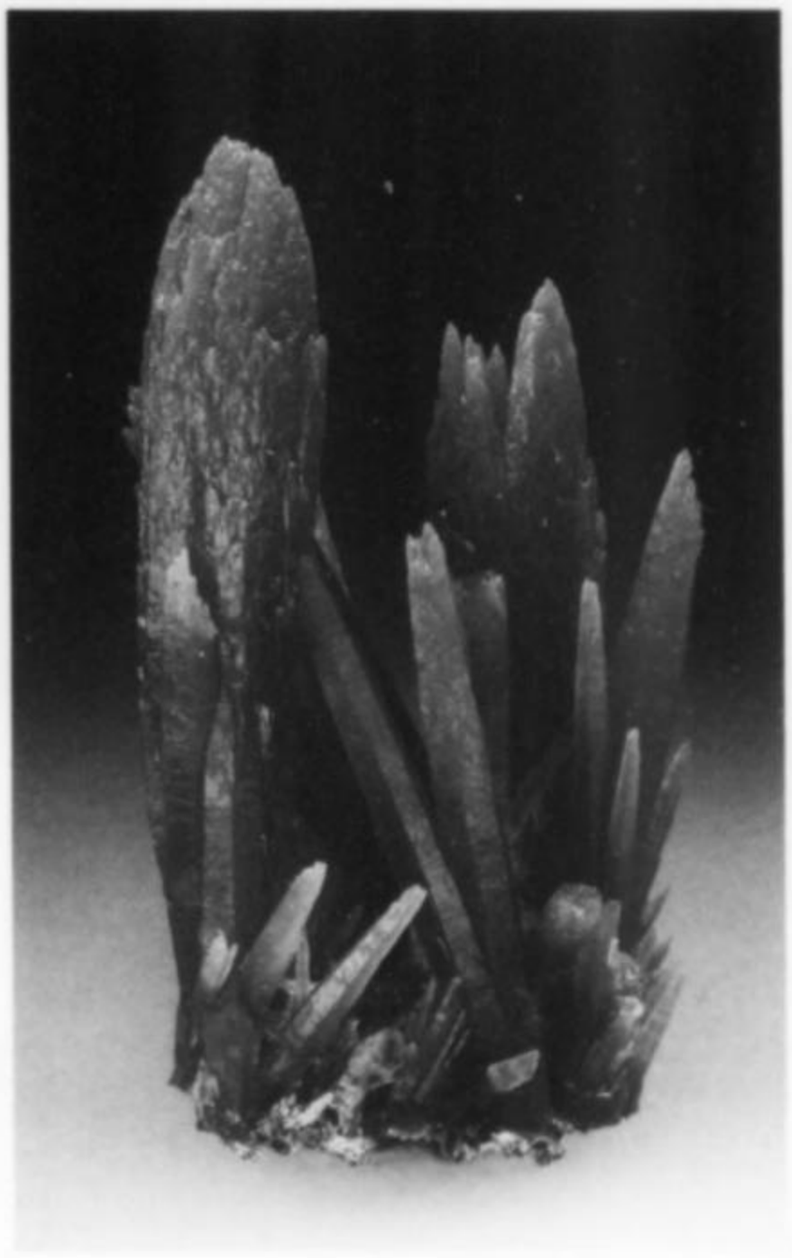

Figure 9. **Spindle-shaped hexagonal quartz crystal group with green hedenbergite inclusions, 4.5 cm.**

Specimens of green quartz collected at Seriphos in the 19th century are on exhibit in the Mineralogical Museum of Athens University and in the Mineralogical Museum of the Paris School of Mines. Large-scale collecting, however, is a relatively recent activity at the occurrences. It was not until the 1988 Tucson Gem and Mineral Show that large quantities (over 50 flats) of Seriphos quartz came on the collector market.

OTHER MINERALS

Fluorite has been found in association with iron mineralization at Seriphos. Allanite-(Ce) occurs locally at the granodiorite contact. Epidote, albite, diopside and glaucophane are all common in the skarn zone, although not in collector-quality specimens. Table 1 gives a complete list of Seriphos minerals.

ACKNOWLEDGMENTS

We wish to thank Sotiris Vafidis of Athens, Greece, and Mike Groben of Coos Bay, Oregon, for kindly supplying photography; Roger Van Dooren of Brussels for drafting the geological map; and Dr. Wendell Wilson for supplying photos and refining the English translation.

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Book Reviews

Crystal Quest 1

by Marcel Vanek. Published (1991) by Geoscience Press, 1040 Hyland Circle, Prescott, Arizona 86303. Softcover, 14 x 22 cm, 96 pages, ISBN: 0-945005-05-9, price: $9.95 plus $2 postage and handling.

Czechoslovakian artist Marcel Vanek has been creating cartoons about the mineral hobby for several years. His work has appeared mostly in *Lapis* and in the annual Munich Show catalog, but also in *Rocks & Minerals* and elsewhere. Creating mineral-oriented humor is not easy, but Vanek accomplishes it with verve. Many, if not most, of his cartoons are designed without requiring captions or wording, and so they require no translation. This new collection of his cartoons, the first in a projected series, contains 87 examples, half of them in full color. The book provides many pleasant chuckles; that makes it well worth the price.

W.E.W.

Die Mineralien der Schweiz

["The Minerals of Switzerland"] by Max Weibel, Stefan Graeser, W. F. Oberholzer and H.-A. Stalder. Published (1990) by Birkhauser Verlag, Klosterburg 23, P.O. Box 133, CH-4010 Basel, Switzerland. Hardcover, 13 x 20 cm, 222 pages, ISBN: 3-7643-2465-1, price: DM 48.

Max Weibel's first guide to the minerals of Switzerland appeared in English in 1966. The publisher, John Wiley and Sons, hoped that the book would form the first of a series which would, in time, cover all the countries of Europe. This hope was never realized; but the Weibel book has now triumphantly reached its fifth edition. It is a conveniently pocket-size guide with many full-color and black-and-white illustrations. The minerals are arranged in chemical order, the main section being preceded by notes on geology, mineral associations, rock types, meteorite falls, historical geology and mineralogy, and notes on the most important Swiss occurrences. Well drawn maps follow the descriptive section. Finally, there are sections devoted to a glossary of terminology, addresses of Swiss mineralogical organizations, a mineral index and a locality index. The quality of printing and illustrations is high. This book is essential for anyone with an interest in Alpine mineralogy.

Michael O'Donoghue

Der Grosse Lapis Mineralienverzeichnis

*["The Great **Lapis** Mineral List"] by Stefan Weiss. Published (1990) by Christian Weise Verlag, Oberanger 6, D-8000 München, Germany. Softcover, wire-O binding that lays flat, 15 x 23 cm, 303 pages, ISBN: 3-921656-17-6, price: DM 29.80.*

This is a handy reference list of "Alle Mineralien von A-Z," arranged alphabetically by species, and providing chemical composition, crystal system, hardness, color, streak, cleavage, form and size of crystals (where appropriate), along with comparative rarity.

Each species is assigned a unique number, the first component of which signifies its mineral group; a detailed explanation of this numbering system is given at the back. The list is well up-to-date, well printed and easy to handle. Comparisons with the *Glossary of Mineral Species* are inevitable; the *Glossary* contains fewer data categories per species, but lists the members of the various mineral groups.

M. O'D.

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Letters

BRITISH MUSEUM PLANS

Readers of the Jan.-Feb. Letters column saw a statement from Neil Chalmers, Director of the British Museum (Natural History) (now called the "Natural History Museum, London"). There he explained the museum administration's rationale for dismantling the famous old systematic exhibit of minerals in favor of a more modern, more general-interest-oriented exhibit. The British mineralogical community is staunchly opposed, but that opposition appears to be unavailing. In Chalmer's statement, the word "inevitably" is applied to the reduction in final exhibit space. We wonder which other branches of natural science exhibits will "inevitably" benefit at mineralogy's expense. Ed.

Regarding the impending fate of our national systematic displayed mineral collection (vol. 21, no. 5, p. XX; vol. 22, no. 1, p. XX):

The purpose of this letter is to point out that Neil Chalmer's reply to you is 100% stock material which has been dished out by him and by Giles Clarke (Dept. of Public Services) to other enquirers and does absolutely nothing to allay the fears of professional and lay mineralogists regarding the fate of the collection—indeed it only heightens those fears. The advisory panel on whose recommendations the fate of the collection rests did not contain a single mineralogist. The museum's public services man normally responsible for replying to enquiries (Giles Clarke) happens to be a botanist who considers the systematic collection to be "relentless"—he has said exactly that in a letter to myself.

There is now little doubt that this fine display will be seriously decimated and that a very large part of it will be relegated to the "reserve collections." Their statement to the effect that it will be available for reference by those with special interests is just not believed—staffing levels would preclude it, excepting perhaps to a carefully selected few and by prior arrangement. All this calls into question the true purpose of a natural history museum; ideas seem to have changed. I am afraid most of us over here are resigned to the fact that the interests of the mineralogical fraternity are to be inevitably sacrificed in attempts to pander to the vast majority of museum visitors whose interests in such things as uncommon sulfosalts are and likely to evermore remain, absolutely "zilch."

J. R. Knight
Manchester, England

MINERAL RESEARCH IN MUSEUMS

Pete Dunn and Joel Grice's admirable article (vol. 22, p. 7–10) is a salutary reminder of the variety of mineralogical research carried out in museums. Unfortunately not every museum can match the resources available in their renowned institutions, nor can all curators devote as much time to research as they themselves might wish.

It is worth pointing out, therefore, that a museum's main contribution to research will often be the result of making its collections available to outside research workers. In the past, lack of adequate documentation may have deterred research workers from making full use of the resources available, but with the advent of microcomputers, catalogs of a museum's mineral holdings are no longer an unattainable ideal.

For the past half century, Liverpool Museum has been rebuilding the geological collections which were destroyed during the Second World War. The recent transfer, on long-term loan, of the reserve collections from the Earth Sciences Department of Liverpool University has boosted our holdings to 11,000 specimens, all of which are now computer-recorded. The collections are world-wide in origin, with minerals from northern England localities forming our particular field of interest. Enquiries from mineralogists, professional or amateur, are always welcome and printouts of our holdings, whether of particular minerals or of minerals from specified localities, can be provided on request.

Nor are we alone in this respect. "Support your local museum" may sound like an appeal for funds, but valuable support can also be provided by making use of the collections housed therein. Such support has the added advantage of being to the benefit of researcher and institution alike.

Geoffrey Tresise
Curator of Earth and Physical Sciences
Liverpool Museum
Liverpool, England

SEM

Brian England's excellent article, "Scanning Electron Microscopy" (vol. 22, p. 123–132) is certainly a good review of an important aspect of modern mineralogy. Anyone interested in microminerals can certainly appreciate the details and depth of field of good SEMs.

Your readers who appreciate and enjoy SEMs may not be aware of a volume entitled, *The SEM Petrology Atlas* (1984) by Joann E. Welton, published by the American Association of Petroleum Geologists. The book contains 237 pages and covers about 60 minerals with several SEMs of each, plus possibly a thin section color photo and the EDX spectrum of each mineral. The emphasis is on minerals occurring in sedimentary rocks, so 13 clay minerals are illustrated, but it also covers 13 zeolites. The book can be ordered from the AAPG Book Store, P.O. Box 979, Tulsa, OK 73101. It is catalog number 609, and sells to nonmembers for $33 plus $5.75 postage and handling.

I enjoyed Larry Conklin's new column and hope it continues. There should be a lot of other good stories that can be written up. It makes a nice break from the more formal articles.

Art Smith
Houston, Texas

SOWERBY CENSUS

As part of a comprehensive article in preparation for the *Mineralogical Record* on the life and mineralogical works of James Sowerby (1757–1822), I wish to take a census of known copies of his *British Mineralogy* (5 vols., 1804–1817) and his *Exotic Mineralogy* (2 vols., 1811–1817). I would appreciate hearing from anyone who owns or knows of the location of sets or partial sets of these works.

Lawrence H. Conklin
2 West 46th Street
New York, NY 10036

BREISGAU PYROMORPHITE

Regarding the reader who purchased a pyromorphite labeled "Brisgaw," and concluded this was "Breisgau" (vol. 22, no. 1, p. 72), the full locality designation is most probably "Schauinsland, near Freiberg/Breisgau, southern Schwarzwald, Baden, Germany."

Werner Lieber
Heidelberg, Germany

STEREOPHILE

Thank you for the back issue of the *Mineralogical Record* containing the free stereo viewer (vol. 18, no. 6). I was extremely pleased; the effect is truly amazing. I was surprised at the quality of the three-dimensional effect, and its value in examining crystal forms. I sincerely hope that future issues of the magazine will continue to include stereo pairs as frequently as possible, and that you will encourage authors to use this technique.

Bruce S. Vick
Belleville, IL

They will indeed, and we certainly do. It bears repeating that the stereo viewers issued with vol. 18, no. 6, were paid for by a generous donation from Associate Photographer Eric Offermann. Ed.

AUTHOR COMMENTS

My recent review paper on amethyst in your journal (vol. 20, p. 365) evinced more response than any of my papers on this subject in the so-called "more professional" journals.

All mineralogists in this area are proud of and impressed by your September-October issue containing the Carnegie Museum supplement. The letters between my friends John S. White and Paul B. Moore are alone worth the subscription price.

Alvin J. Cohen
University of Pittsburgh and
Carnegie Institute of Natural History

ERRATUM

The names "Kongsberg" and "Kopparberg" were inadvertently switched on the map accompanying Thomas Moore's article on touring Scandinavia (vol. 22, no. 1, p. 44).

Ed.

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The 1991 Board of Directors breakfast meeting was held on February 15 at the Santa Rita Days Inn in Tucson, Arizona. Newly elected Directors are Bernard L. Murowchick (Lakeland, Florida), Chief Mineralogist for International Minerals and Chemical Corporation prior to retirement; and Karen J. Wenrich (Golden, Colorado), U.S. Geological Survey in Denver. Re-elected Directors are Mike Groben (Coos Bay, Oregon), mineral collector for 45 years and Past President; Robert W. Jones (Scottsdale, Arizona), collector, photographer, speaker, author; Betty Tlush (Belen, New Mexico), interested in minerals over 25 years and co-owner of a mineral dealership; and Marcelle Weber, Charter member and long-time collector. The current officers were re-elected for 1991: President, Al Kidwell; Vice President, Arlene Handley; Secretary, Art Smith; and Treasurer, Richard Thomssen (P.O. Box 1656, Carson City, NV 89702). Retiring Directors were Russell Boggs and Gene Foord.

Other members of the Board are Richard Hauck (Bloomfield, New Jersey); Jay Lininger (Dillsburg, Pennsylvania); Peter J. Modreski (Littleton, Colorado); Anthony Kampf (Los Angeles, California); Marie Huizing (Cincinnati, Ohio); Raymond Lasmanis (Olympia, Washington); Dan Behnke (Northbrook, Illinois); Kay Robertson (Los Angeles, California); Arlene Handley (Vancouver, Washington); and Art Smith (Houston, Texas).

The Mineral Locality Index project creeps ahead. Nine state localities have been published or soon will be; nine are under way and there are tentative plans for 18 more. Individuals interested in contributing time to this project may contact Pete Modreski (8075 W. Fremont Dr., Littleton, CO 80123).

The 12th Annual Symposium sponsored by the Friends of Mineralogy, the Tucson Gem & Mineral Society and the Mineralogical Society of America was held on Saturday morning, February 16, with azurite as the topic. The Chairman was Dr. Karen Wenrich. The abstracts were printed in the *Mineralogical Record,* January-February issue. The 1992 symposium topic will be pyromorphite, but papers will not be restricted to this mineral. Dr. Carl A. Francis, Harvard Mineralogical Museum, will be the Chairman.

It was suggested and unanimously approved that FM establish a yearly best paper award for *Rocks and Minerals* magazine, similar to the one for *Mineralogical Record,* the article to be selected in the same manner with the same recognition and award to be presented at the annual Rochester Mineralogical Symposium. The first award will be presented in 1992 for the best article in 1991.

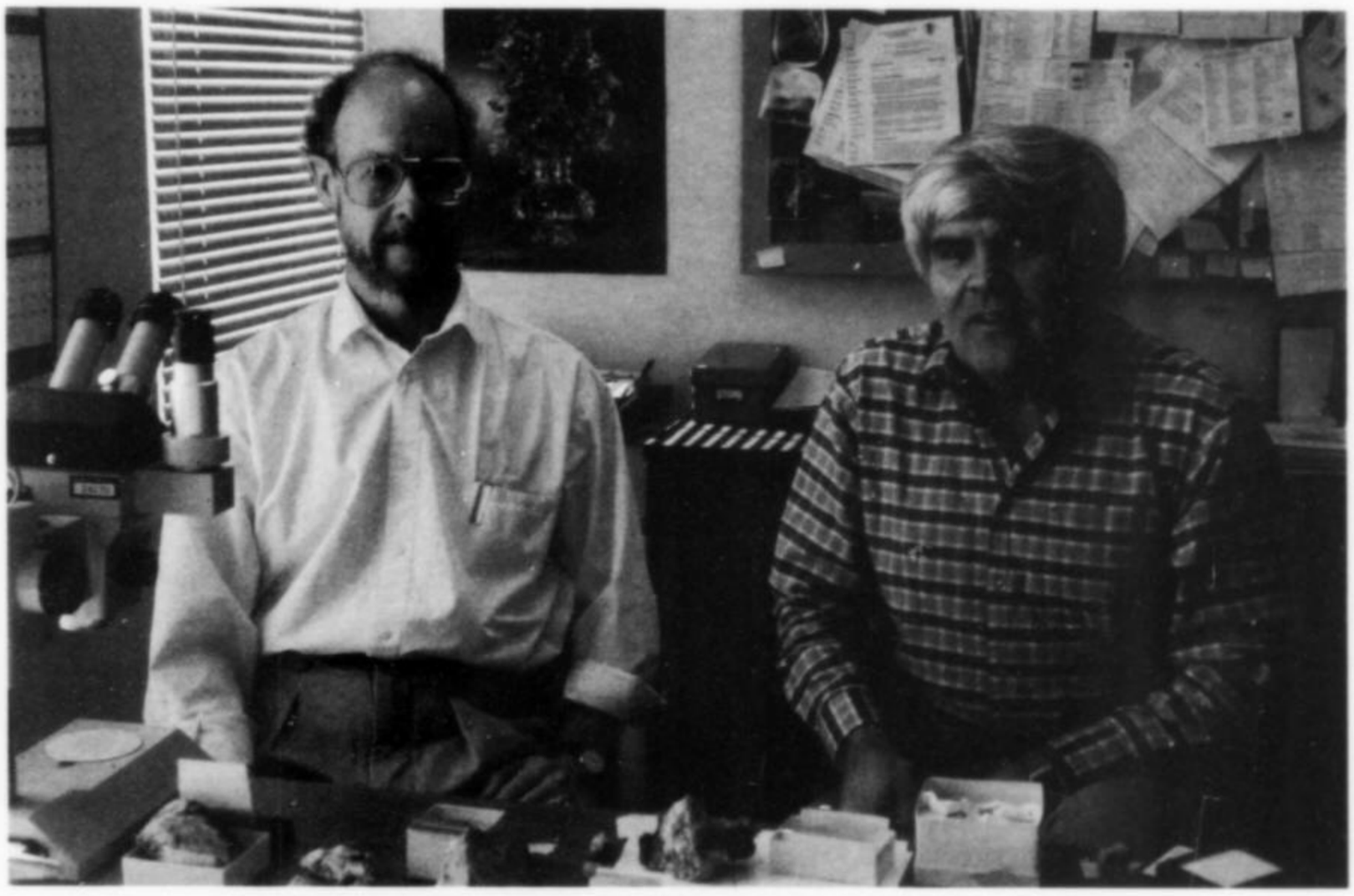
The National dues were increased to $10.00 per year; $5.00 per member through Chapters.

The annual membership meeting was held on Saturday, February 16 at 4:30 p.m.

The panel of judges unanimously selected "The Mineralogy of Mont Saint-Hilaire, Quebec" as the best 1990 article in the *Mineralogical Record*. As neither László Horváth nor Robert A. Gault were to be in Tucson, they requested that their certificates, presented on Saturday night, be accepted by Frank Melanson who is recognized as having first brought attention to the locality in 1963. A contribution of $200.00 was made to the *Mineralogical Record* in the authors' names.

The Mineralogy of Mont Saint-Hilaire, Quebec
(Mont Saint-Hilaire issue, vol. 21, p. 284–359)

In its relatively short time as a mineral locality, Mont Saint-Hilaire has become a contemporary classic, notable for unusual and abundant mineral species. When this article was written, 250 species had been identified (including polytypes), 16 of them new to science. To its dedicated collectors, the locality is known as "The Magic Mountain."



Robert A. Gault (left) and László Horváth.

László (Les) Horváth was born in Hungary, emigrated to Canada in 1957, and became a Canadian citizen in 1963.

Les was graduated from a Metallurgical Technical College in Miskolc, Hungary, and continued his education in Canada. He has been employed in the manufacturing industry as a metallurgist, and has held various Quality Assurance-related and management positions for a large public utility during the last 27 years. He has been connected with the procurement and Quality Assurance of critical equipment, such as nuclear reactors and heat transfer equipment.

Les has been, from early childhood, "an avid collector of everything from stamps to insects (including a systematic collection of bird feathers)," but he started collecting minerals seriously in 1971. His childhood collecting involved fossils but not minerals, even though he recalls a Peruvian stibnite, a malachite and a pyrite specimen of unknown origin at the age of 10.

Les describes his collecting and collection thusly: since 1971, he has intensely collected at the two prime localities in the Montréal area: Mont Saint-Hilaire and Francon Quarry. With his talented and dedicated field collecting companion, his Swiss-born wife Elsa, they have assembled an extensive mineral collection, including one of the largest systematic collections of Mont Saint-Hilaire minerals. Undoubtedly, the main focus of the Horváth's field collecting was and is Mont Saint-Hilaire, and they were the first to find 35–40 of the approximately 290 (including UK's) mineral species reported from that locality. Their collecting interests include the minerals of other nepheline syenite intrusives which have mineralogies similar to that of Mont Saint-Hilaire, such as the Langesundfjord area in Norway, Ilímaussaq and Narssârssuk in Greenland, and the Khibina and Lovozero complexes in the Kola Peninsula, USSR. The Horváth collection also includes a very large sub-collection of Francon minerals, and extensive sub-collections from Canadian, Swiss, German and Hungarian localities, as well as a sprinkling of specimens from around the world. More than 80% of the collection is self-collected, and consists of micromounts, thumbnails, and small and large cabinet specimens. About 50% of the specimens and many of the very rare species are micromounts; however, the preferred size is thumbnail to small cabinet. Many people know the Horváths as "micromounters," which appellation is not one that Les likes; he prefers to be called a mineral collector or minerophile, and considers "micromounting" strictly a technique to preserve and protect delicate specimens rather than a raison d'être.

In his spare time Les does engage in occasional mineral photography (mostly photomacrography), collects miniature books and recordings of rare and obscure operas, enjoys traveling, classical music, gourmet food and good wine.

Robert Allan Gault was born June 19, 1943 in Ottawa, Ontario, Canada. He was graduated from Lesgar Collegiate, Ottawa, in 1961 and from Carleton University which he attended full time 1961–1963 and part time 1965–1969.

Bob became interested in minerals at about the age of 10, and a few years later joined the Ottawa Valley Mineral Association. He became an active member of the club, serving as program and field trip directors and as president for a number of years. He thus enjoyed field collecting for many years before becoming a professional curator.

Bob became a member of the staff of the Canadian Museum of Nature (then National Museum of Natural Sciences) in 1970. He is presently Collection Manager, responsible for acquisition and accessioning of new specimens and loans of specimens for research and exhibits.

Bob's research interests encompass the minerals of Mont Saint-Hilaire and other alkaline intrusives, descriptions of new species, and microprobe studies of various mineral groups. Between 1977 and 1991, he co-authored at least 13 papers or articles which have appeared in *Mineralogical Record*, *GAC/MAC Programs and Abstracts*, *GAC/MAC Guidebook*, *Rocks and Minerals*, *Canadian Mineralogist* and *American Mineralogist*. The latest, in press (*Canadian Mineralogist*) is "Silinaite, a new sodium lithium silicate hydrate mineral from Mont Saint-Hilaire, Quebec," by Chao, Grice and Gault.

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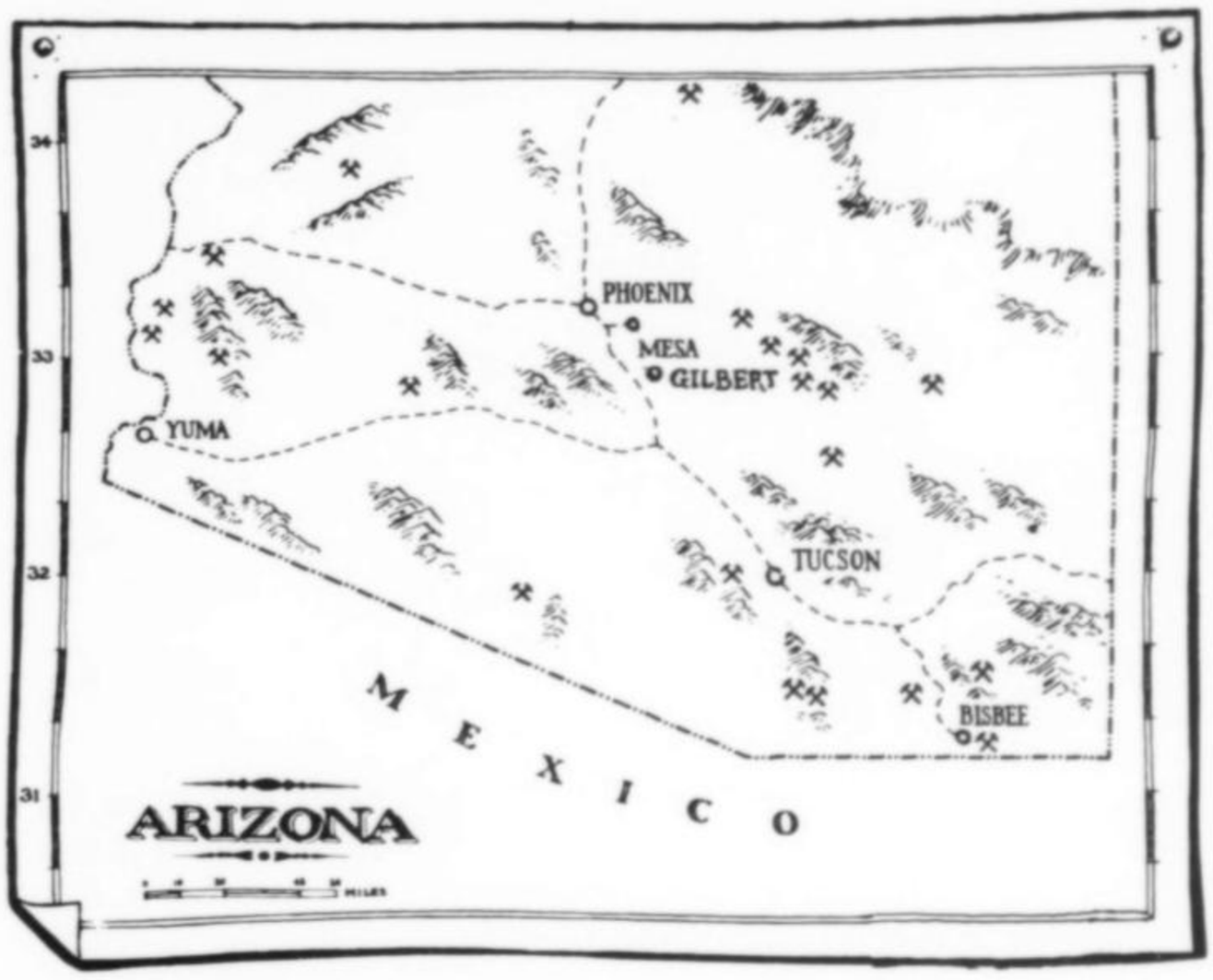

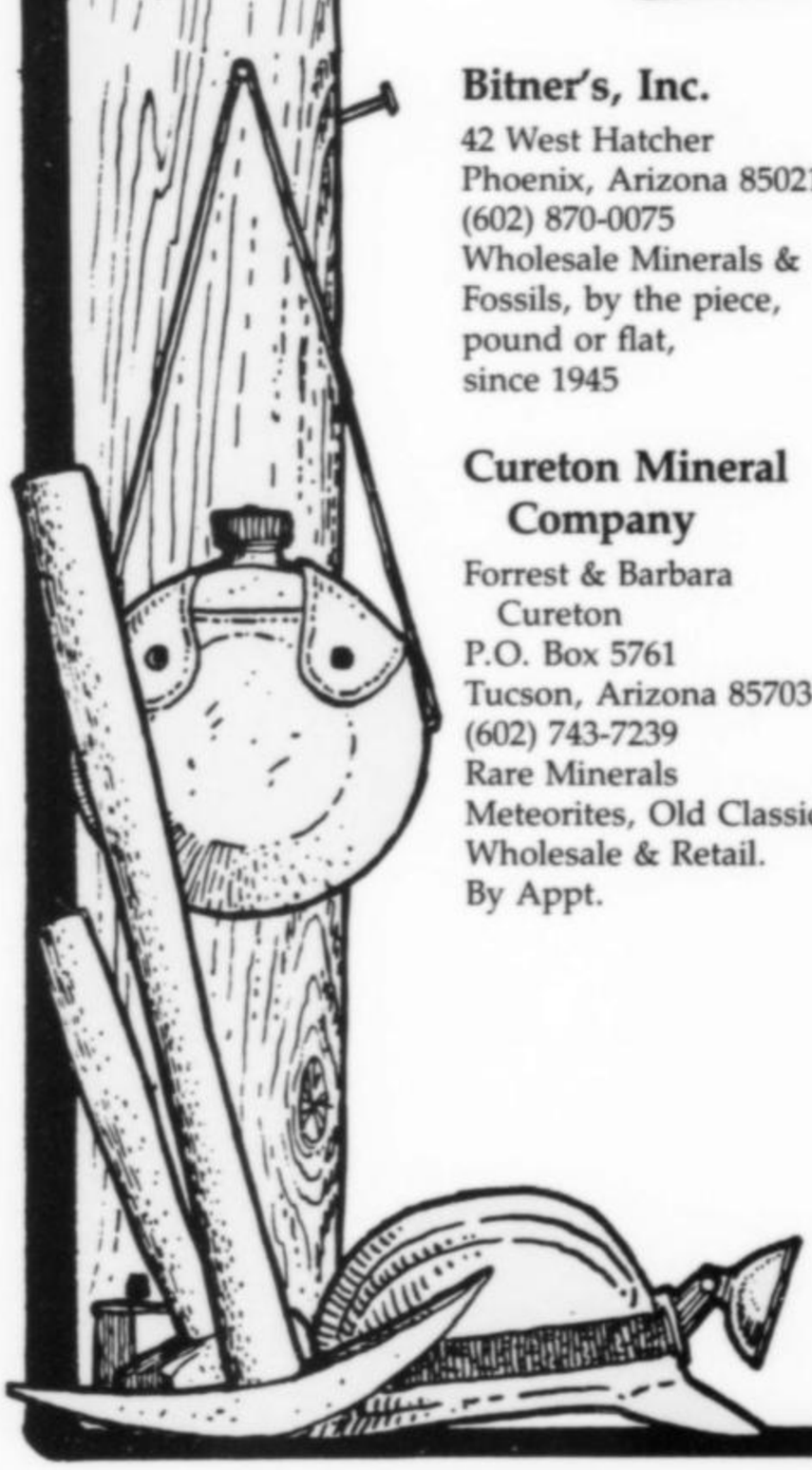

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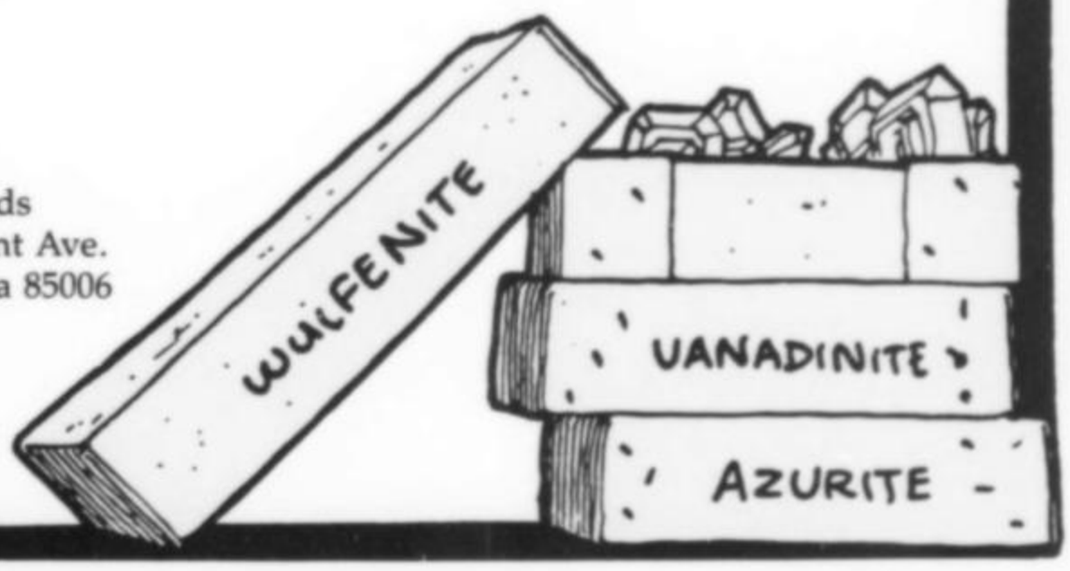

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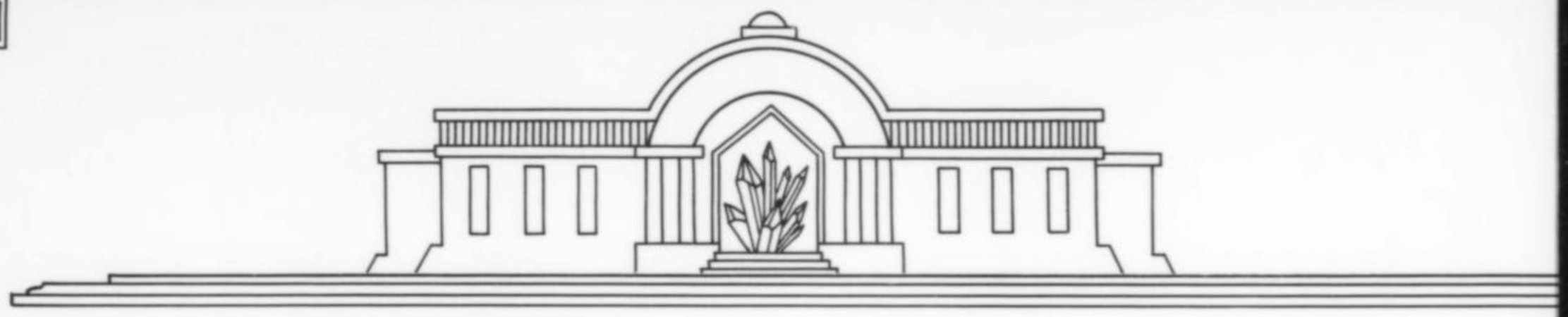

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Blacksburg, VA 24061-0420
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Curator:
Richard Berg
Adjunct Curator:
Lester G. Zeihen
Tel: (406) 496-4414
c/o Montana Tech
Butte, MT 59701-9981
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Specialties: Montana & Idaho minerals; systematics

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Curator (mineralogy):
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Glenbow Alberta Institute
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Specialties: W. Canadian and worldwide minerals & gems

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Curators:
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William Metropolis
Tel: (617) 495-4758
24 Oxford Street
Cambridge, Mass. 02138
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Specialties: Systematic Mineral Collection

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Kim B. Cochran
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Tel: (719) 486-1229
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Leadville, Colorado 80461
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Natural History Museum of Los Angeles County

Curator (mineralogy):
Dr. Anthony R. Kampf
Tel: (213) 744-3328
900 Exposition Blvd.
Los Angeles, CA 90007
Hours: 10–4:45 Tu–Sun.
Specialties: Calif. & worldwide minerals, gold, gem crystals, colored gemstones
Support organization:
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Sterling Hill Mining Museum

Curators:
Robert Hauck
Richard Hauck
Tel: (201) 209-7212
30 Plant Street
Ogdensburg, NJ 07439
Hours: 10–5 M–Sun, Mar.–Dec.
Specialty: Local mining & minerals

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Tel: (412) 622-3391
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Pittsburgh, PA 15213
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10–9 F, 1–5 Sun,
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New Mexico Bureau of Mines & Mineral Resources Mineral Museum
Mineralogist/Curator:
Marc L. Wilson
Tel: (505) 835-5246
Campus Station
Socorro, NM 87801
Hours: 8–5 M–F & by Appt.
Specialty: New Mexico minerals

M.Y. Williams Geological Museum
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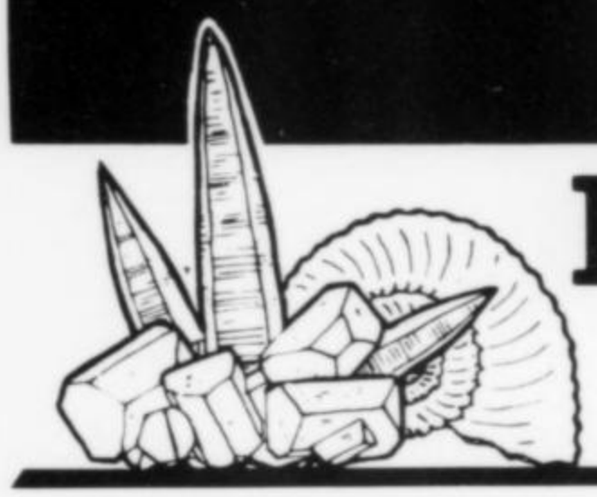

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