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GUEST EDITORIAL

MINERAL FRAUD

Buyer beware is a phrase common in the highly transient and often trendy marketplace of mass-produced goods; the warning is even more important, unfortunately, in today's mineral market. Mineral fakes and frauds are becoming increasingly pervasive within the mineral hobby to some degree, and part of mineral commerce to an alarmingly greater degree. Also of concern is the tacit approval given to such practices by many influential people. The cosmetic alteration of mineral specimens is presently receiving an insidious amount of encouragement at the recovery, wholesale, retail, museum, collection, and exhibition levels. No matter what they are called, the practices are fakery and fraud.

Most of us collect minerals for our appreciation of them as rare and beautiful natural history objects. Honest field collectors know that their specimens are exactly as they were when found, less a little clay, insects, or plant roots. Many mineral collectors who purchase their specimens believe that they are acquiring "natural-from-the-earth" mineral specimens. What they may unknowingly be obtaining, however, are specimens which have been "enhanced" (*i.e.* faked) to make them more esthetic, thereby generating a quicker sale and/or higher price. Instead of purchasing unadulterated mineral specimens, they are obtaining specimens which have been sprayed, dyed, heat-treated or otherwise altered in appearance or condition to make them "look better" than when they came from the earth. In some cases, this problem involves only a few specimens; in other cases thousands of specimens have been processed at one time. In all such cases there is misrepresentation.

The rewards of collecting are as varied as the motives and desires of collectors. To those who really like specimens which have been dyed, sprayed, oiled, heat-treated or faked in some manner, we wish you happy collecting. The paper on mineral fakes in this issue was written for those who prefer natural specimens. Most mineral collectors value the naturalness of their specimens as contrasted with the man-made origin of most collectables in the art and antique worlds.

EXHIBIT FRAUD

The area of the mineral hobby where we found the most prevalent occurrences of faking was exhibitions. This includes all segments of the exhibiting community: the competitive, non-competitive, commercial and museum exhibits. Many collectors involved in competitive exhibiting find that oiling and "touch-ups" are not only prevalent, but are fast becoming a "requirement" to obtain the perfection needed to win the highest Federation awards. There is a greater evil than just the cosmetic alteration of specimens in search of awards, satisfaction, honors and peer-recognition. That greater evil is the outright misrepresentation of what minerals really look like in nature. Presenting specimens to the viewer in an unnatural condition (without honest labeling of the alterations), is misrepresentation.

Because the Federations are the promulgators of the rules for competitive exhibition, we urge that their rules committees consider a detailed re-examination of those sections of the *Uniform Rules* which pertain to both repaired and faked specimens, their labeling, and their status. (Educational exhibits, the topics of which are repaired or faked specimens, should be specifically excluded.) As the sole source of regulations, the Federations alone will decide whether or not they shall enforce some aspects of ethics in these matters.

The competitive exhibitor is not the only participant. Many curators and collectors use falsification techniques. A few excel at it, thinking the ultimate challenge to be the exhibition of a specimen which is more beautiful than when acquired. When misrepresentation of appearance becomes the norm instead of the exception, it is time to re-examine our values. We call for a back-to-basics attitude among those involved in the exhibition of mineral specimens. Minerals should be shown as they are found, with a minimum of cleaning to remove soil and organic debris. There is adequate beauty in the natural condition of specimens and therefore no need to falsify appearances.

COMMERCIAL FRAUD

The broad and unregulated nature of the mineral marketplace puts few constraints on those who might sell, trade or exhibit a specimen which, in reality, is not what appearances might indicate it to be.

Proposed here are some guidelines for commerce in fakes and frauds. Although some purists might argue that no one should sell fake specimens, that viewpoint is perhaps too narrow. To attempt to restrict mineral commerce is futile; the barter of mineral specimens will go on for all time (we hope) and all that can be expected is to influence it slightly with regard to the ethics of selling fakes. Below are two proposals.

a) All repaired specimens should be *prominently* labeled "repaired" on both the label and the specimen itself.

b) All fakes should be labeled both on the label and the specimen itself by affixing a "FAKE" label directly to the back of the specimen.

Such techniques call attention to fakes, thereby stimulating more interest in them. The specimens themselves would likely become educational conversation pieces. Some collectors might begin small sub-collections specifically devoted to fakes simply for their curiosity or educational value, thereby relieving the dealer of the now-unsellable fake acquired by accident.

One cannot predict the criteria which will govern value-systems in the mineral marketplace of tomorrow. In most collecting hobbies and avocations, the "unaltered original" concept is dominant in long-term value setting, and purists usually prevail. The altered specimen of today may become the undesirable specimen of tomorrow. It might be worth serious thought to consider whether or not you want to take a chance on altering a "natural original" specimen to something which might be much less desirable in the future.

Collectors should retain and protect that naturalness by avoiding specimens treated with dyes, acids, sprays, oils, lacquers, and so on. The mineral market is not isolated; it is remarkably responsive to demand. If the collector community demands unfalsified and unaltered specimens, they will be provided.

The alternatives to active discouragement of fakes are all too obvious. Collectors might eventually be offered *only* mineral specimens which have been falsified in some way, and today's unfalsified specimen may become tomorrow's rarity. We make these arguments only because there seems to be no counterforce arguing against such fraud in commerce and exhibition, both of which reward the cosmetic alteration of specimens. Perhaps the collector's triumph of 1990, instead of the successful acquisition of a rare species, will be the acquisition of a natural, undyed, unoiled, unsprayed specimen. Will they become that rare? The choice is largely up to you.

Pete J. Dunn and **Ronald E. Bentley**

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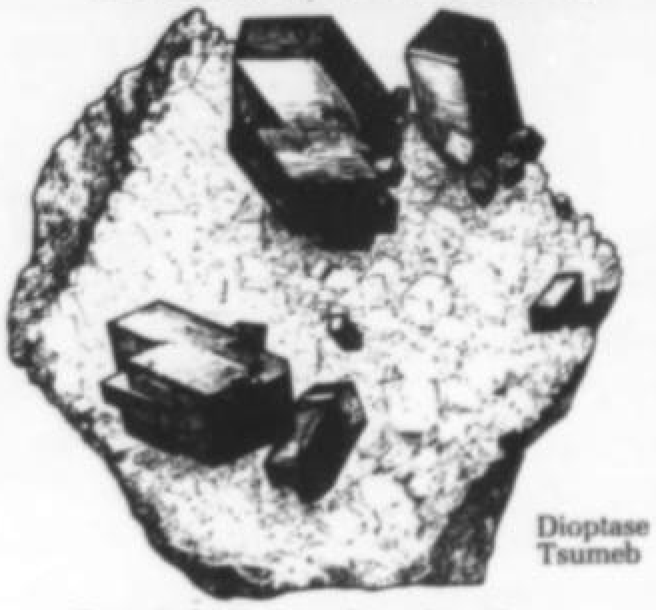

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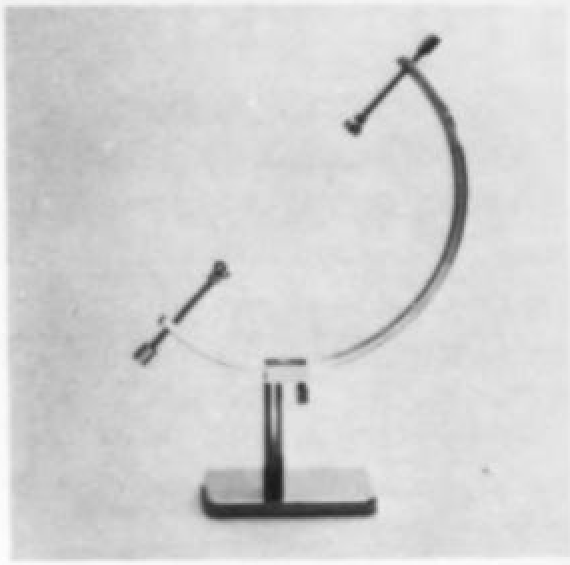

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Mineral Fakes

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The falsification of mineral specimens poses a risk and a challenge to collectors, curators and researchers alike. Most are unaware of the scope of the problem and the care required for the detection of faked specimens.

INTRODUCTION

The physical qualities of mineral specimens can make them interesting, valuable, and sometimes very beautiful objects. Human nature becomes involved when people collect these specimens and attempt to "improve" upon them in some way. Sometimes the "improvement" is as harmless as washing and judicious trimming. Lapidaries and craftsmen use the natural qualities of minerals to produce legitimate arts and crafts. Our focus, however, is on the natural-appearing mineral specimens which have been "improved" to the point of falsification. The value differential between specimens that are damaged and undamaged, colored and uncolored, lustrous and dull, esthetic and unesthetic, is sufficient motivation for some people to attempt a fraudulent upgrading.

DEFINITIONS

Fake: An object represented as a natural mineral specimen but having one or more falsified characteristics or synthesized parts.

Reinforce: To alter, impregnate or coat a specimen to prevent future physical deterioration.

Repair: To secure any separated portion of a specimen in its original position and orientation.

Restore: To replace damaged or missing portions of a specimen with foreign material designed to duplicate the original appearance.

Stabilize: To alter, impregnate or coat a specimen to prevent future chemical deterioration.

EXCLUSIONS

For reasons of limitation we will not discuss the falsification of gems and fossils, but only mineral specimens which are represented as natural.

Not all alterations or improvements that can be made on mineral specimens result in fakes. The following categories are excluded:

Lapidary enhancement

Specimens which have been *non-deceptively* enhanced by grinding, cutting and polishing in order to better show their intrinsic beauty fall outside the scope of this study.

Repair

Specimens which have been repaired and are *clearly marked* as repaired are not deceptive, and are therefore outside the scope of this study, provided that:

(1) The repair has returned the specimen to its original configuration and has not "improved" it.

(2) The glue or cement used is colorless, so as not to alter the apparent color of the specimen.

(3) No missing portions have been replaced by foreign substitutes.

One should bear in mind that a specimen may be both repaired and faked. Furthermore, an attempted repair may unintentionally result in a fake if some mistake is made and the finished specimen is better than the original was. There is no intent to deceive in such a case, but the results are identical. Because the intent of the person may be unknown, the specimen by itself is deceptive and must be considered a fake.

Stabilization and Reinforcement

Legitimate advantages may be obtained by reinforcing and stabilizing weak matrixes and crystals which are prone to decomposition, dehydration or deliquescence. The techniques should be strictly limited to use on specimens actually in danger, however, because a contamination of the specimen does result. Any such treatment should be described fully on the label.

Techniques used include soaking specimens in thinned lacquer, concrete sealer, or water-soluble glues. Such treatments have the advantage of being largely reversible with solvents.

Restoration

A matter which can lead to hours of discussion and the exposition of some really divergent viewpoints is the practice known as *restoration.* For instance, where does one draw the line between restoration and replication? Restoration can only be honestly attempted with accurate knowledge of how the specimen looked before it was damaged. Only highly accurate photographs, castings, or other firm evidence might form an acceptable basis for restoration. Lacking these, the restorer is only guessing about what the specimen looked like prior to damage, and the "restoration," if incorrect, may actually be a fake.

Consider the example of a hypothetical tourmaline crystal on matrix which has been photographed carefully and which subsequently becomes damaged. The damaged portion of the crystal is then replaced by colored plastic identical in appearance. If the restoration is a microscopic chip on the back of the crystal, almost all would agree that this specimen is not a fake. However, imagine the continuous spectrum of possible cases here, the amount of restoration becoming larger and larger in each case until the entire crystal has been restored (*i.e.* replicated) in plastic. One and all would agree that this is a replica and a fake. The two extreme cases are thus defined, but what about all the cases in between? There is no point in the continuum where a logical distinction may be nonarbitrarily drawn. Consequently, it is not possible to *precisely* define the distinction between restoration and fake. In individual cases, this must be left to the judgment of the individual collector or, in disputes, an esteemed arbiter agreeable to both sides. A specimen should probably be considered a fake when an "important part" of the specimen has been replaced.

Replication

Though replicas may be produced to deceive (and in such cases would be fakes), they do have some legitimate uses:

Education: The use of replicas as an aid to students is primarily found in the area of fossil studies through the use of plaster casts and models of rare species. Although the educational use of replicas of minerals has rarely advanced beyond the crystal-model stage, it should not be ruled out as a teaching aid, and such aids needs not be considered fakes.

Security: With the ever increasing risk of museum thefts, curators are becoming more and more hesitant about displaying items with high intrinsic value. More and more replicas of gold nuggets are on display while the originals repose in vaults.

Replacement: There have been instances in the past wherein well-documented specimens have somehow been lost or stolen. In these instances, with enough documentation, replicas may be fabricated which are very similar to the original.

HISTORY

Very little has been mentioned in the mineralogical literature regarding fakes, but the earliest reference is very old: Pliny's *Natural History,* written around 70 A.D. According to Pliny, certain stones could be improved by the use of oil. About the carbuncle (red garnet) he wrote: "it is possible, they say, to heighten the brilliancy of dull stones, by steeping them for fourteen days in vinegar, this adventitious luster being retained by them as many months." Furthermore, he added, "all precious stones in general are improved in brilliancy by being boiled in honey."

The oldest fake we have been able to find is a specimen which is part of an artwork entitled "Moor with tray of emeralds" (Fig. 1) which was constructed about 1724 by Dinglinger and Permoser. The emerald matrix specimen in the statue is much older than the artwork itself. In 1581, when Elector Augustus of Saxony paid a visit to the Holy Roman Emperor Rudolf II in Prague, he was presented with a specimen of emerald crystals in matrix. The specimen had been found in Colombia, and presumably it had been presented to Emperor Charles V (who reigned from 1519 to 1556) as an indication of the riches of the New World (Heres and Kiontke, 1978). The sixteen emerald crystals and the matrix all appear to be Colombian; nearly all of the crystals have been manually implanted into crude holes carved in the matrix. The original piece of matrix had very few crystals *in situ,* and the donors apparently wanted to be certain the Emperor was duly impressed.* It is quite probable, therefore, that this early fake was fabricated for political and/or economic reasons.

Figure 1. **"Moor with tray of emeralds" by Dinglinger and Permoser, ca. 1724. Nearly all of the large Colombian emerald crystals have been manually implanted in crude holes dug in the matrix. Green Vaults collection, Dresden, East Germany. The specimen is about 10 cm across.**

Another very old mineral specimen fake found during the course of this study is a pre-1812 specimen of "yenite" (= ilvaite) which was part of the Seybert collection at the Academy of Natural Sciences of Philadelphia (Fig. 2).

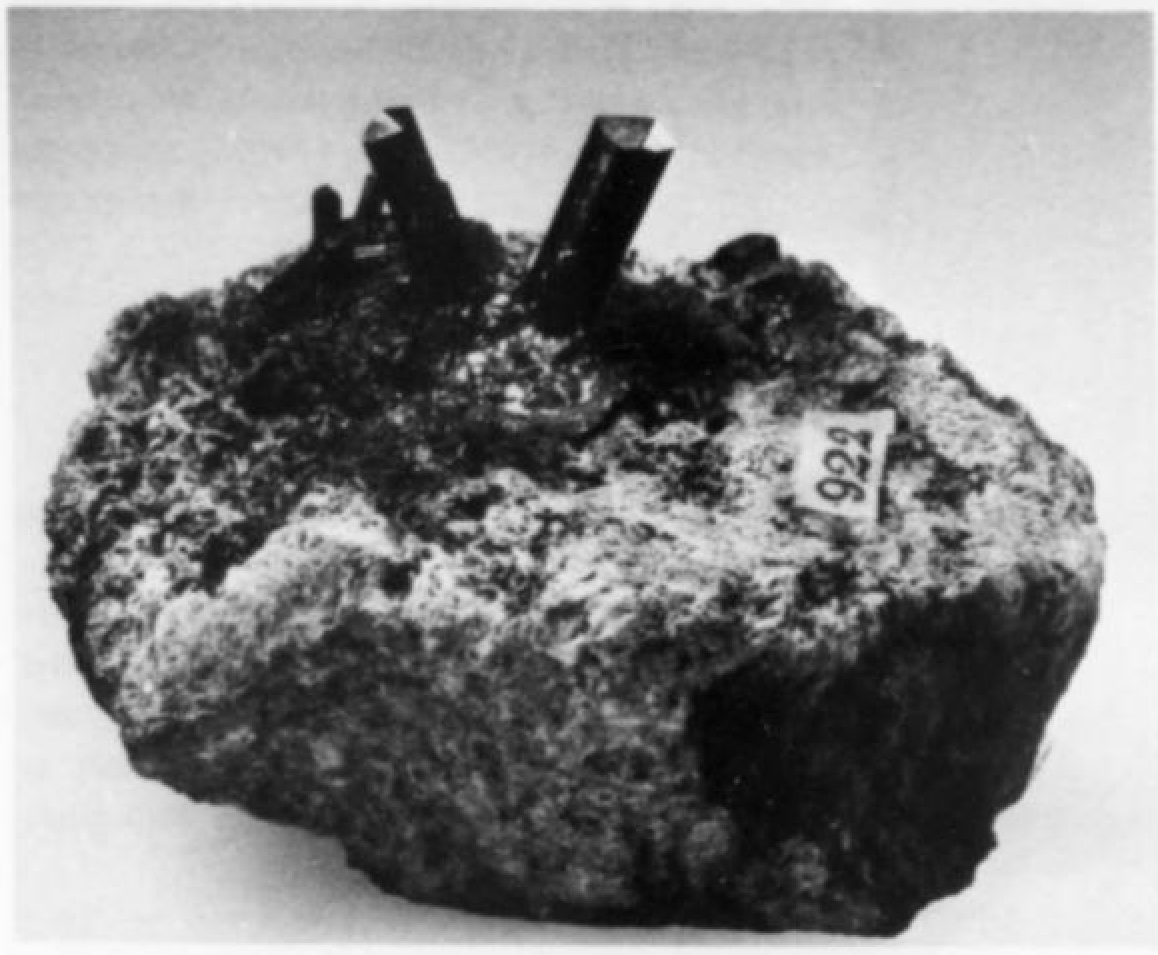

Figure 2. **Black ilvaite crystals glued on matrix. Purported locality: Elba, Toscana, Italy. The large crystal is 1.2 mm. From the Seybert collection in the Academy of Natural Sciences, Philadelphia (ANSP). This specimen, made before 1812, is the oldest known fake in an American collection.**

In 1894, Arthur Chamberlain and some friends began publication of *The Mineral Collector,* a monthly periodical for the mineral enthusiast. It was not until the February 1895 issue of *The Mineral Collector* that the first mention of fakes was made there, and then only as a small editorial comment.

> "Mending specimens is legitimate, of course, but not with intention to deceive. It is, therefore, advisable to write on the label that the specimen is a mended one, even though one means to keep it for himself, because it will sometime come under the notice of careful observers."
>
> *The Mineral Collector,* **1**, 192. (1895)

In March, 1897, two articles were published; the first was scientific in nature, the second had definite overtones with regard to fakes.

Artificial Hematite Crystals

> "A method of preparing hematite artificially is the work of Mr. H. Arctowski . . . The crystals are of the same form as the hematite crystals from Elba."
>
> *The Mineral Collector,* **4**, 10. (1897)

Artificial Auriferous Quartz

> "The Imperial Institute, Edinburgh, has had brought to its attention some interesting phenomena relating to the method by which gold was originally deposited in auriferous quartz. On this occasion Mr. J. C. Johnson of Adelaide, Australia, who has given great attention to the subject, exhibited specimens of non-gold-bearing stones in which he had artificially introduced gold in interstices and on the face in such a manner as to defy detection, even by skilled experts. Some of these specimens were shown privately to several distinguished geologists, who expressed great surprise at the remarkable character of the same. It seems that the discovery, some years ago, that gold could be induced to deposit from its mineral salt to the metallic state on any suitable base, such as iron sulphide, led Mr. Johnson to experiment with various salts of gold, and by which he found himself able to produce the most natural-looking specimens of auriferous quartz from stone which, from previous assay, contained no trace of gold; moreover, the gold, which penetrates the stone so thoroughly, assumes some of the more natural forms."
>
> *The Mineral Collector,* **4**, 13. (1897)

The first really public admittance of the problem of fakes had to wait until January of 1900 for an article by W. S. Valiant, then Curator of the Rutgers College collection. We excerpt the following from his paper entitled "A Stony Sermon."

> "All collections contain more or less of fake specimens—crystals from one locality stuck on to a matrix from another; a fine quartz geode with one amethyst crystal cemented in just right; artificial crystals put into natural rock cavities; massive minerals cut and polished in the shape of crystals; meteorites made in a blacksmith shop; crystals cast in a mold and finished to imitate the real; glass models tumbled in a sand box to imitate water-worn gem pebbles; fossils carved from slate or limestone; rocks made with cement and stones; and fancy marble made by painting a slate surface.
>
> "Such specimens are not rare, and many know that they have them, but the counterfeit is usually of a rare species, and they cannot spare it. But we do not do it all; the Japanese, Chinese, Turks, German, French, and many others are not slow at it, and some call it art. Art is an imitation of nature, and often artists produce work of great value, but art is never nature, and has no place in a collection of natural objects—except, occasionally, to show the use of certain natural substances, as precious and semi-precious stones cut and polished."
>
> *The Mineral Collector,* **6**, 173–177. (1900)

The Mineral Collector ceased publication in 1909. It was not until Peter Zodac started *Rocks and Minerals* in 1926, that another mineral magazine became available to the mineral public. In 1927, Charles Hoadley offered what, for the time, must have been a blistering exposé of fakes.

> "Occasionally the collector is offered small loose crystals by the dealer, these may be kept in small vials or mounted on stands, made for this purpose. But I have known of unscrupulous dealers mounting or cementing a crystal in a matrix which is foreign to the species offered.
>
> "Recently I had occasion to examine a specimen labelled *topaz, Thomas Mt., Utah,* on the matrix were three crystals of topaz and two were from Japan, one from Thomas Mt., but all three were cemented in place.
>
> "On another occasion, in looking through the stock of a dealer, I found two specimens, both black crystallized tourmaline, which had originally been one specimen, broken in half by the dealer to sell as two. One half was labeled *tourmaline, Acworth, N.H.,* the other half was labeled *Pierrepont, N.Y.* Both were from Haddam, Conn.
>
> "I have seen specimens of tourmaline, cemented in the gangue, which projected like quills on a porcupine and I have seen emerald crystals from the Ural Mts. affixed to a piece of New York building stone."
>
> *Rocks and Minerals,* **2**, 28–29. (1927)

Another article on fakes dealt with perhaps the first use of fluorescence to detect glued areas. The paper, by Paul Zimmer, was entitled "Notes on the separation of two rock crystals."

> "One evening, while going over my microscope slides, I accidently put one under the argon bulb. To my surprise it fluoresced a light green. I then went over all of the slides and found that they also fluoresced. As these slides were made by me, I started

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*The authors had the opportunity to examine this specimen when it was displayed in Washington, D.C., as part of "The Splendors of Dresden" exhibit loaned by the government of the German Democratic Republic (East Germany).

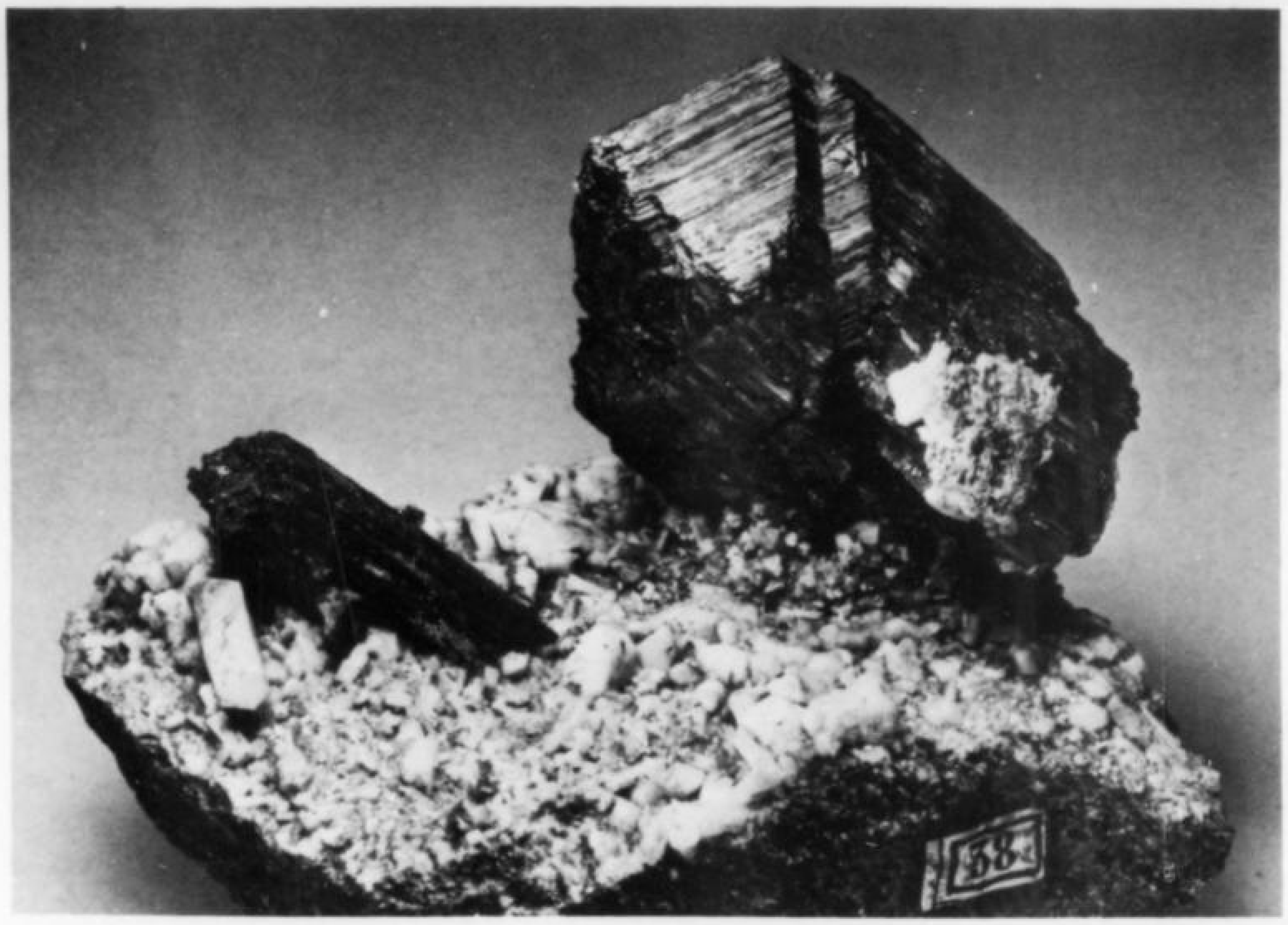

Figure 3. **Dark brownish-red rutile crystals, the right one glued onto matrix. Purported locality: Pfitsch, Tirol, Austria. Notice the fragments of white feldspar used to disguise the glued contact. The large crystal is 4.6 cm. (ANSP #11116.)**

going over the various substances that were used to make them in order to find out what caused the fluorescence. I found that the Balsam used to join the cover slip to the slide was the substance that fluoresced. I made a note of this, little realizing that some day it would prove of value.

"Some few months later, I was reading the Readers' Section of the Dec. 1934 issue of *Rocks and Minerals.* There I came upon Mr. A. J. Harstad's note concerning two rock crystals that were joined together in the form of a T. The junction between the two crystals fluoresced a light green which made him suspect that the crystals had parted and had been glued together again. Mr. Harstad wanted some information on separating them. I immediately thought of my microscopic slides and wrote him stating that Balsam which is used as an adhesive is soluble in Xylene. He in return sent me the crystals to separate if possible. After soaking them in Xylene for four days, I began to get discouraged, but on the fifth day they came apart. I tested both crystals under the argon bulb but found that neither would fluoresce so decided that the Xylene had dissolved the adhesive material whether it was Balsam or not."

Rocks and Minerals, **11**, 55. (1936)

Later references to fakes were found in Neal Yedlin's column, the Micro-mounter, which he wrote for *Rocks and Minerals.*

"One thing the microscope shows up is a mineral fraud. Normally these are easily spotted, but sometimes a rare bit of workmanship gets by until suspicion is aroused and careful examination is made.

"We obtained just the other day a small specimen of silver in cerussite, from Wardner, Idaho. The "mike" showed a peculiar thing. The cerussite surrounding the silver was botryoidal instead of crystalline. We probed with a needle (Who are these Swiss watchmakers, anyhow?) and found that the blebs were cement, and that each bit of silver had been implanted in the cerussite, very expertly, for it did not show except under high power. Under U.V. light the glue fluoresced. We happened to know that the dealer had obtained the specimen as part of a large collection. The silver is good, and well crystallized. So is the cerussite. We bought it because of the association of minerals. The manufacturer of that fraud must have surmised that someone would. We suggest, then, that when buying minerals, where a thing is very unusual, unique, out of place, illogical, etc., you doubt its authenticity, at least to the extent of most careful examination and U.V. test."

Rocks and Minerals, **23**, 929. (1948)

Figure 4. **Pink and green elbaite crystals (left crystal is 1.5 cm) imbedded in reconstituted matrix. Purported locality: Minas Gerais, Brazil. The "matrix" around the crystals is crushed lepidolite made into a paste with glue. (Bentley collection.)**

An additional observation on fakes was made by Lou Perloff in 1949 and was printed in Neal Yedlin's column, The Micromounter.

"Once I got a jordanite in Binnenthal limestone. The first glance under the 'scope showed it to be a fake. Someone had plugged a bruised twin into a cavity in exactly the way it would occur in that material. A neat job, but still a fake. As a cabinet piece it was worthless. Out came the hammer, and here you have a paradoxical illustration of the fact that a micromounter can sometimes be a good samaritan in smashing up supposedly good cabinet material. I wonder through how many trusting hands that lemon passed until it came to its final resting place under my hammer. Well, inside that limestone were some jordanites that really belonged there, as well as blood-red rutile, a transparent yellow tetrahedron of sphalerite showing the combination of positive and negative tetrahedra, and yellow tourmaline in well-terminated xls."

Rocks and Minerals, **24**, 504. (1949)

Sinkankas, in his *Gemstone and Mineral Data Book* (1972), devoted nine pages to fakes and repairs. He lists and describes well over 100 species which are likely to be found on the mineral market as repaired or faked specimens. This list affords a large number of additional examples beyond those mentioned in this paper, and should be consulted.

Bideaux (1972) wrote a discussion of the topic of fakes for his column, *The Collector.* Bideaux not only described some of the techniques used in identifying and making fakes, but also was the

Figure 5. **Fake gold specimens: the tiny nuggets in the foreground are gold-plated copper. Purported locality: California. (Harvard specimen #100106.) The white quartz in the background has had tiny pieces of gold manually pressed into cracks. Purported locality: the Dome Rock Mountains, Yuma County, Arizona. (Harvard specimens #106489 and #106070.) The specimen on the left measures 7 cm tall.**

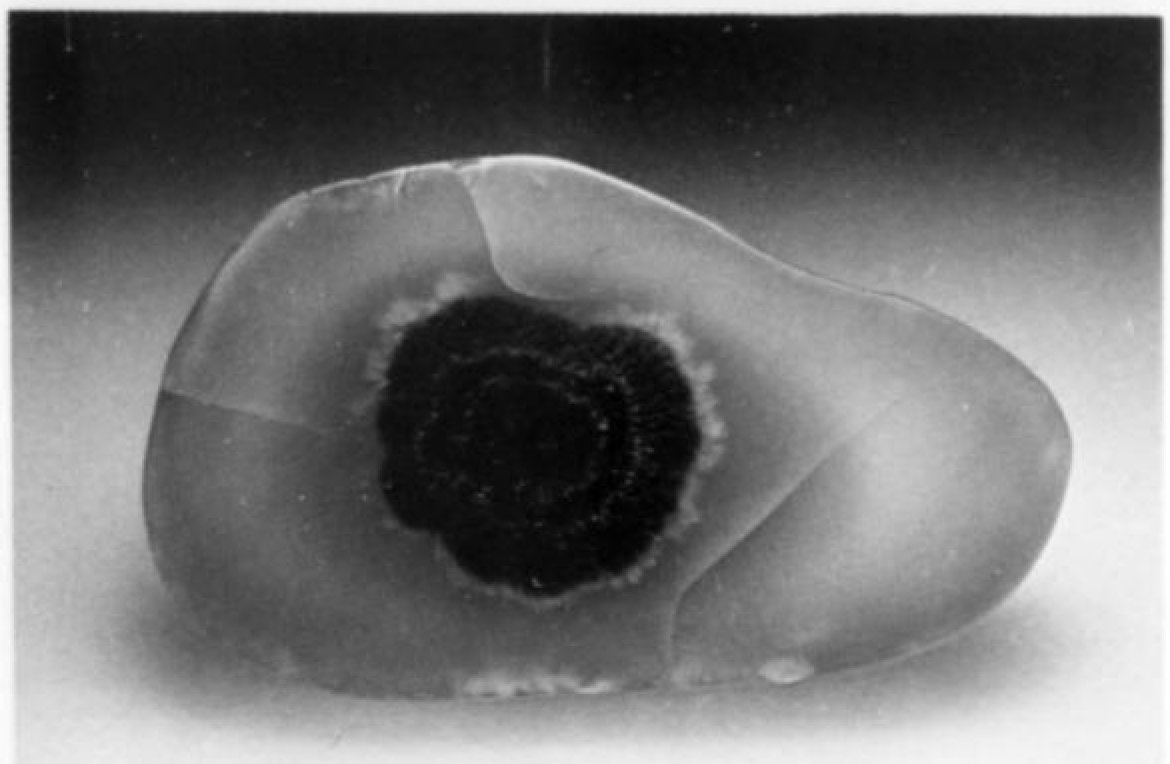

Figure 6. **Synthetic copper "bloom" grown in chalcedony by exposure to laser light; sold as a natural specimen from Tsumeb, Southwest Africa. (Harvard specimen #114701.) The specimen is about 7 cm across.**

first writer to address the problems of specimen enhancement. His paper, readily available in the *Mineralogical Record,* is highly recommended.

Thompson and Richards (1976) discussed fakes and repair in an editorial in the *Mineralogical Record.* Their comments should be read as well, to ensure an overview of previous statements on this topic. Recent observations by other authors are cited in the text.

In summary, the historical record of the efforts of mineralogists, collectors and writers to educate collectors and the mineral world about fakes and fraud is rather limited. It is interesting to see how many of the admonitions of the older collectors are still valid today.

ALPINE MINERALS

During the course of this study, more fake Alpine specimens were encountered than from any other specimen-producing region. Although we are not bound in any way to discuss this particular geographical concentration of mineral specimen fakes, to ignore the leading source would do an injustice to history. With few exceptions, most of the knowledgeable collectors, dealers and curators with whom we discussed this project agreed that Alpine minerals were the most commonly encountered "old" fakes. The most frequently faked species include hematite, rutile, adularia, anatase, brookite, epidote and, in fact, all of the typical Alpine minerals. One could speculate endlessly about why Alpine minerals were so frequently faked. Some of the logical reasons that come to mind include the euhedral quality of the species found in the Alpine clefts, the long winters when the *strahlers* could not collect, the fact that many Alpine mineral specimens do come in "ideal" configuration, with simple euhedral crystals perched neatly on matrix, and the tendency of brittle crystals on rocks to break off during recovery attempts.

An interview with associate editor Eric Offermann (of Arlesheim, Switzerland) provided some insights into the matter. Offermann pointed out that the majority of Alpine fakes known today are *older specimens.* In the olden days it was apparently not considered unethical to glue crystals onto mineral specimens. The specimens were collected for beauty rather than the yet still developing science of mineralogy, and it was common to add on a few pretty crystals here and there, as a way of upgrading the specimen. Offermann told us that this was particularly common with the pink fluorite octahedra glued on quartz. The fluorite crystals often became detached during even the most careful collecting and had to be glued back on. Inasmuch as the interfacial angles of quartz (represented on the contact surfaces of the detached fluorites) are always the same, it was easy to put the crystals back on in an "ideal" position, or to add a few crystals. Only in recent times (the last 20–25 years), according to Offermann, has such "upgrading" generally been considered unethical. Although the innocence of their motives might exonerate the ancient *strahler* from criticism, the attitudes of collectors are different today.

We asked Offermann about the Altdorf show, which we understood has a rather admirable and stringent policy regarding the selling of fakes. According to Offermann:

> "Fakes are not only fought at the Altdorf show but, to my knowledge, at every Swiss mineral show. Most *bourse* officers are concerned about maintaining a good reputation for their *bourse,* which necessitates sufficient protection of the non-expert

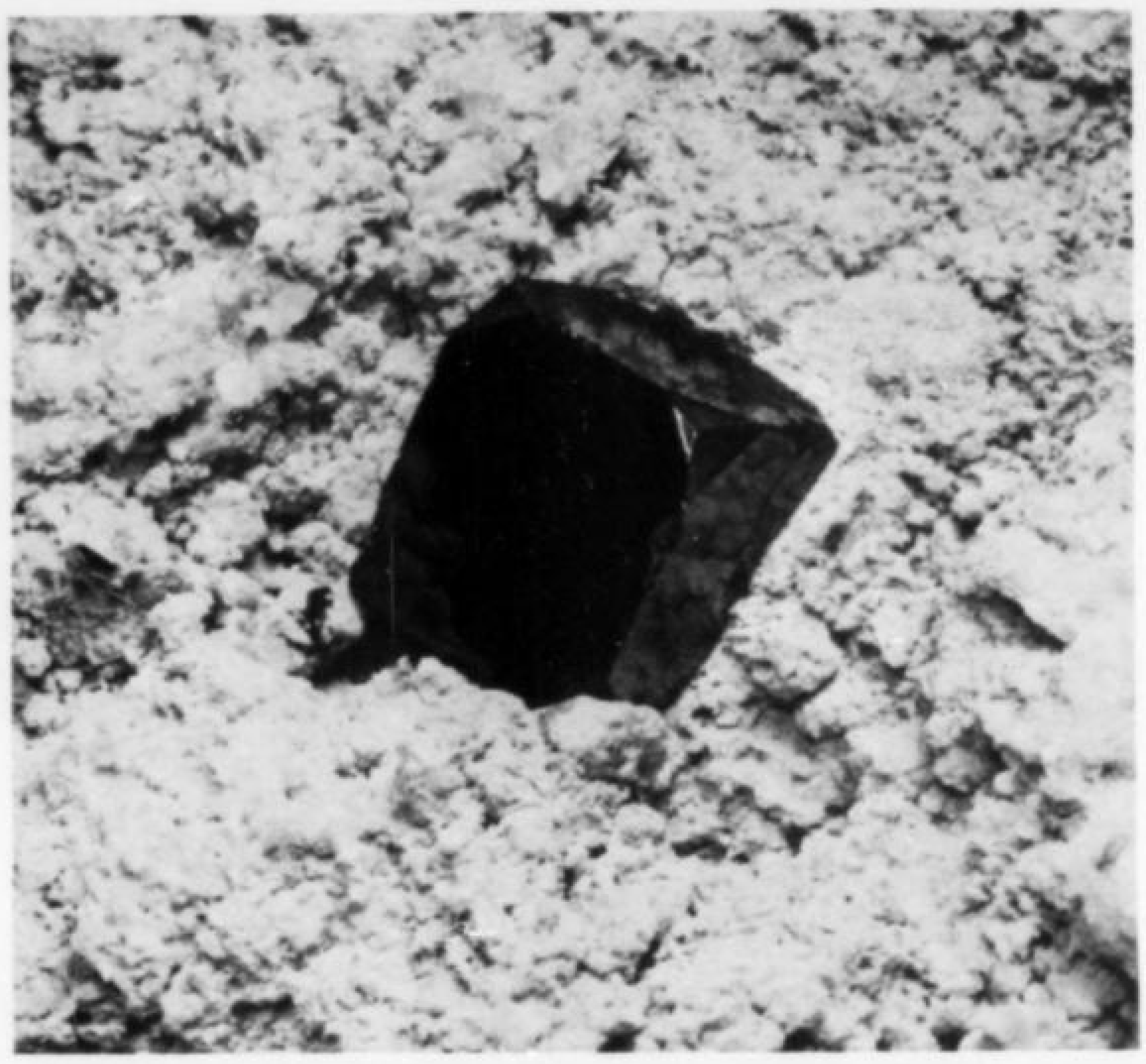

Figure 7. **Bixbyite crystal manually implanted in rhyolite, from the Thomas Range, Utah. Only after being soaked in water for several hours did the white composite material (glue of some type, mixed with powdered rhyolite) surrounding the crystal begin to soften and reveal itself. (National Museum of Natural History (NMNH), Smithsonian Institution, specimen #136165.) The crystal is about 1.8 cm across.**

consumer. Therefore, practically all show organizations maintain an internal "police force" *(Börsenaufsicht)* composed of advanced club members and specialists who examine the dealers' booths for frauds and fakes. In some *bourses,* the "police" wear a special badge and have the authority to demand (in borderline cases) correct label designations for synthetics and replicas. If there is doubt about a fake, they will demand removal of the fake from the table. In case of a dispute, the "police" report to the *Börsenleitung* (show committee) who decide. In most cases, the committee's orders are followed without further argument since disobedience means disqualification from that particular *bourse* and the risk of not being invited again to that or other local or national *bourses.*"

Figure 8. **Cassiterite crystal 2.9 cm wide and very dark brown, glued onto matrix. Purported locality: France. Note rock fragments mixed with glue. (ANSP specimen #20001.)**

Offermann emphasized that the abundance of Alpine fakes should not be construed as indicative of present attitudes toward fakes in Switzerland. On the contrary, perhaps due to this abundance of early "strahler fakes," the Swiss are very keen today on discouraging and preventing such practices.

FAKE TYPES

The concept of fake

While everyone would agree that a plastic tourmaline crystal is a fake, perhaps not everyone would so judge the more subtle techniques of falsification (referred to by some as "enhancement"). But consider: the spectrum of fakes runs from the totally false (such as the plastic crystal) to cases in which only one particular characteristic has been faked. Amethyst, baked in an oven until it turns yellow and then sold as natural citrine, certainly amounts to *fake* citrine even though only its color has been altered. A fracture-filled crystal, heavily oiled and presented as gemmy and near flawless has had only its clarity altered. A dull crystal, polished on a buffing wheel, has had only its luster altered. But the fact remains that an important characteristic has been changed in each case, and the specimens no longer represent the true craftsmanship of nature. A mineral specimen must be considered fake when any inherent characteristic has been falsified or synthesized.

Attempting to decide *which* types of fakes are more or less objectionable than others leads to hopelessly emotional debates. Hence, no such relative judgments should be attempted. Below are noted most of the various faking techniques found during this study, together with specific examples. Admittedly, some information is given which the unethical person could use to fraudulently alter mineral specimens. However, only by being made aware of these techniques can the collector learn to recognize them.

Mineral fakes are extremely varied; identified here are eight different types. Types other than these are certain to be discovered or

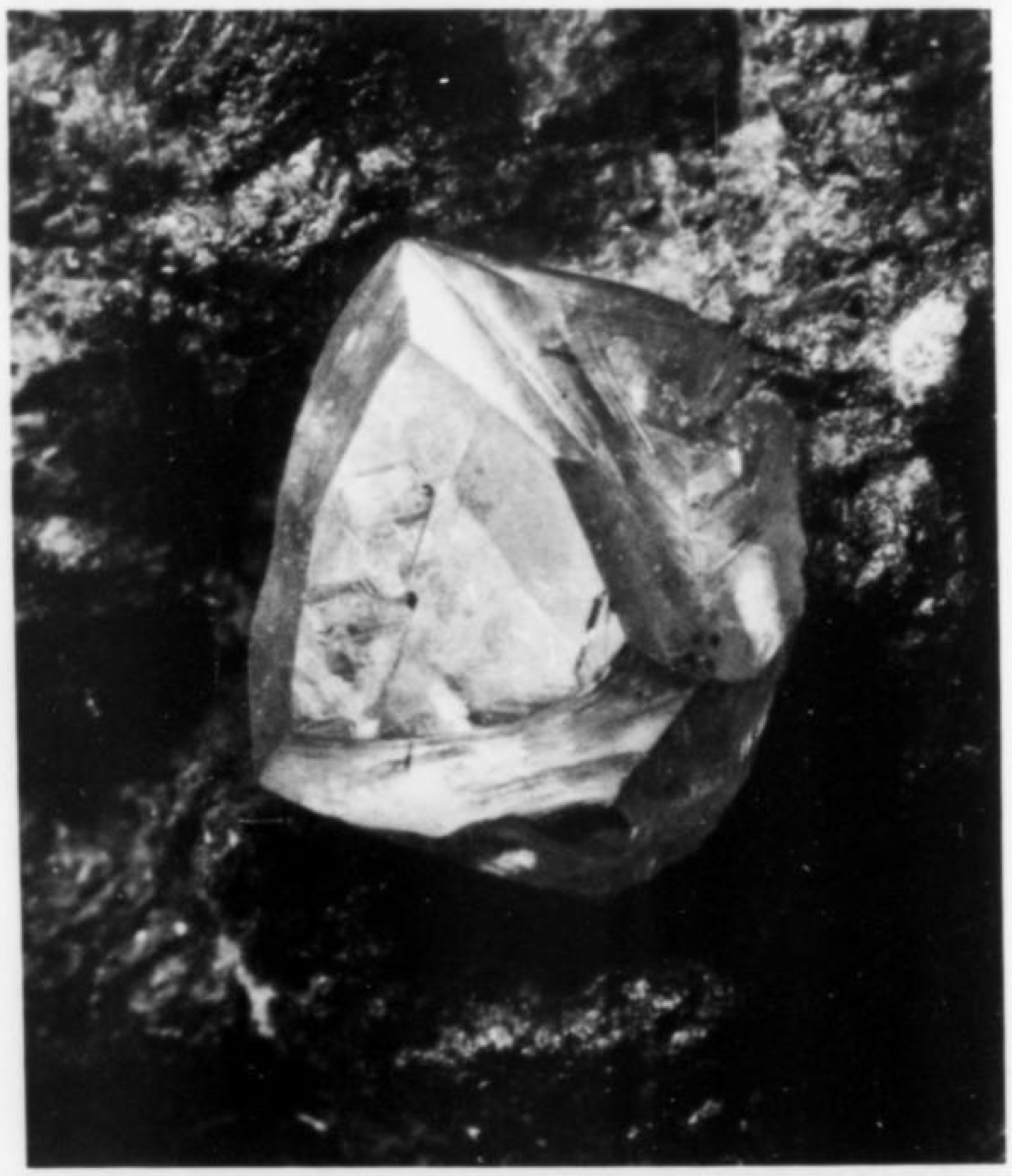

Figure 9. **Colorless diamond crystal about 4 mm across, manually implanted in kimberlite matrix. Purported locality: Kimberley, South Africa. (NMNH specimen #C61.)**

Figure 10. **Pale blue topaz crystals with lepidolite from Virgem da Lapa, Minas Gerais, Brazil. Two different fragments of topaz crystals have been brought together to simulate a single crystal, the join camouflaged by addition of lepidolite. Differing luster on the main topaz face on each side of the lepidolite is a clue that the two sides are not part of the same crystal. Jack Lowell specimen, 8.7 cm across.**

Figure 11. **White apatite crystal 4 cm across, glued on matrix. Purported locality: Schwartzenstein, Austria. Note rock powder mixed with glue at crystal base. (NMNH specimen #C6462.)**

invented in the future, so this list should not be considered exhaustive. It should also be remembered that a given specimen may be falsified in more than one way. The types are:

A. **Falsified attachment (malattachment)***
B. **Falsified color**
C. **Falsified luster**
D. **Falsified clarity**
E. **Falsified shape** (by bending)
F. **Falsified faces**
G. **Replication and synthesis**
H. **Falsified surface composition**

The examples cited in this paper are based on specimens actually examined by the authors or learned of through presumably reliable reports from others. Unless specifically stated, these examples are not meant to imply that all specimens of that species from the same locality are fakes.

TYPE A: Malattachment

Malattachment is defined here as the unnatural or misaligned assembly of a specimen. Adjusting the orientation of a crystal to a more esthetic position on its own matrix is one example. Building up a specimen with pieces from unrelated specimens or materials is the extreme case. These have also been called "assembled specimen," or "manufactured specimens."

The attachment may be accomplished with glue, welding, soldering, or simple pressure. The time-honored (dishonored) "glue-job" remains the most common of fakes. Typically the glue has been mixed with powdered minerals to simulate the color and texture of matrix. Specific examples are abundant; only a few are mentioned here.

Diamonds

Diamond specimens are far more desirable in matrix, though in the vast majority of all known specimens the diamonds have been manually implanted in kimberlite. Some are poorly done, others show a high degree of skill. Present day mechanized crushing and separating techniques in South America and elsewhere practically rule out the preservation of crystals in matrix.

Boulangerite

Boulangerite from Mexico is frequently faked. The miners can take an appropriate piece of matrix, coat it with spray glue, and press the wet matrix into a boulangerite-filled pocket. The matrix is withdrawn from the pocket, covered with acicular boulangerite, which is then trimmed with scissors (given a haircut) before being packed in beer-flats for sale. The whole operation can take place right at the mine. The glues used, to date, have been water-soluble and the fake easily detected by immersion in water.

Silver

Silver specimens from Guanajuato, Mexico, are frequently glued onto matrix. However, most of the glues have been water-soluble and these fakes are easily detected.

Hematite

Hematite crystals from Casa de Pedras, Congonhas, Minas Gerais, Brazil have been glued onto matrix. The easiest clue to find on these assembled specimens is the differing habit of the crystals on the same specimen, where on a natural specimen, one similar habit will usually predominate, assuming only one generation of growth.

Gold

Gold is frequently attached to matrixes on which it does not belong. The gold may be glued on the matrix or may be impressed into cavities or fractures in other minerals. Since gold is malleable, this is a rather simple procedure.

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*(We have coined a word, *malattachment,* for this pervasive type of fake; from the Latin *malus,* meaning bad, wrong or evil.)

Figure 12. **Beryl (aquamarine) crystal glued on matrix. Purported locality: Klein Spitzkopje, Southwest Africa. The crystal is about 2.5 cm tall. Note rock powder paste used as glue. (Harvard specimen #98382.)**

Beryl (Emerald)

Emerald is frequently faked by malattachment. Interestingly, the attached crystals are usually implanted in the correct matrix, and not just in a random piece of rock. The crystals may be surrounded by powdered matrix, other faked crystals, or other natural emerald crystals.

Brazilianite

Brazilianite crystals from Conselheira Pena, Minas Gerais, Brazil, have been glued on matrix. In some cases, the glue was water soluble and the fakes easily detected by washing.

Micromounts

The faking of a micromount is a very difficult procedure. It requires a significant amount of manual dexterity to construct, and the very nature of the specimen requires that it be appreciated under magnification where glues are more easily seen. Hence, micromount fakes are rare. We did see one fine micromount fake consisting of three 1.5-mm anatase crystals glued on adularia. The purported locality was Oberwald, Wallis, Switzerland. Although a very uncommon size of fake, we mention it here simply to point out that it is possible to fake a micromount and that micromounters must be as wary as the collectors of larger specimens. Incidentally, it is conceivable that micromounts could be faked by methods other than malattachment.

TYPE B: Falsified color

Because color is one of the dominant factors in the selection of minerals by some collectors, the demand for beautifully-colored specimens has exceeded the supply. Fakery has, in part, filled the gap with an abundance of artificially-colored mineral specimens. Some examples are noted below, though the list is not at all comprehensive. The techniques of color-alteration are not all known; many remain secret. The color-alteration techniques in the forefront today require advanced technology and are the types of

Figure 13. **Elbaite crystals glued onto matrix. Purported locality: Elba, Toscana, Italy. The large crystal is about 3.5 cm tall. Note crystal fragments used to camouflage join at crystal bases. (AMNH specimen #12226.)**

Figure 14. **Brazilianite crystals (the largest is about 2.7 cm) glued together with muscovite crystals, from Corrego Frio, Minas Gerais, Brazil. (Harvard specimen #107988.)**

Figure 15. **Beryl (emerald?) crystal glued onto matrix using a rock paste with emeralds and pyrite fragments included. Purported locality: Colombia. The large crystal, about 2.5 cm, fluoresces under ultraviolet light, whereas the small emerald crystals do not. Miriam and Julius Zweibel specimen.**

fakery likely to proliferate with further technological advances.

Changes in the color of minerals may be produced by the application of dyes, paint, heat, sunlight, ultraviolet light, X-rays, gamma rays, and particle fluxes consisting of protons, neutrons, deuterons, alpha-particles or beta-particles (Sinkankas, 1972). Most of the latter treatments are generated by expensive and dangerous radiation tubes, accelerators, or radioactive isotopes which are available only rarely to the mineral faker. The usual effect of sunlight, if it has any effect at all, is to lighten or darken (rather than intensify) the color of minerals, and so it is generally not used to enhance value or appearance. Dye and heat treatments are the most common methods used to alter the color of minerals. All of the above techniques may be applied to the color-alteration of gemstones, and the literature pertaining to such techniques is extensive. A fairly large number of mineral specimen fakes has resulted from these color alteration techniques, and some specific examples deserve mention.

Dyes and coloring agents

Dyes, in a wide variety of colors and viscosities, are sometimes used to enhance specimen or crystal color. They are usually transported into the interior of the specimens or crystals by the use of carriers such as glycerine and solvents. The dyes penetrate cracks, fissures, cleavage traces and intergranular boundaries. Most dyes are rather easily detected because they are soluble and will color the solvent in which they are immersed. The dying of mineral crystals is still in its infancy; we do not know yet of any sophisticated mordants (substances that fix color) which could make the dying process more permanent.

Chalcedony in its many forms is among the substances most amenable to dying because of its porous, cryptocrystalline texture. Dreher (1913) described recipes for dying agates and other chalcedony red, black, blue, green and yellow. Some industrious fakers have attempted to dye macrocrystalline quartz, for example, to intensify the hue of amethyst, but the dye rests only on surfaces and in cracks, and is readily detectable. Microcline, according to Sinkankas (1972), is susceptible to organic dyes dissolved in acetone or alcohol; the depth of penetration into crystals is about 3/8 inch. Turquoise, jadeite, opal, magnesite, howlite, calcite and alabaster have also commonly been dyed. Some aragonite absorbs copper-sulfate solution quite readily and is therefore easily dyed. Gypsum in the selenite variety does not absorb it as readily and faked specimens of blue aragonite on colorless gypsum have been sold in recent years. Felt-tipped pens and tinted varnish have been used to dye small blemishes on the outside of crystals. Because the process makes the blemishes less noticeable, one must look very carefully to detect this technique.

The simple technique of painting a crystal or a specimen to enhance its appeal is still used. Although the knowledgeable collector is not fooled by such an obvious device, some of the older emeralds were painted with green lacquer and, in at least one case, a green-painted quartz crystal was sold as an emerald. Interior decorators have been purchasing specimens for esthetics only, including some rather garishly painted; among those seen are a purple pyrite and a vivid blue quartz crystal.

Heat treatments

Heat treatment of mineral and gem specimens is widespread, and

Figure 16. **Red zircon crystal 1.6 cm tall glued onto matrix. Purported locality: near Perth, Ontario. The glue and crushed rock mixture to the left of the crystal is fluorescent, but only in longwave ultraviolet light. (AMNH specimen #11321.)**

Figure 17. **Pale green tourmaline crystal, about 1.6 cm, glued on matrix. Purported locality: Campolungo, St. Gotthard, Ticino, Switzerland. Note tiny bubble of glue carelessly left showing at crystal base. (AMNH specimen #12271.)**

commonly done right at the mine.

"Burnt amethyst" is the name given to amethyst from Brazil which turns a pleasant yellow color when heated to 430°C; the material is commonly sold as "Brazilian citrine." As recently as the 1979 shows, dealers were offering Brazilian amethyst side-by-side with burnt amethyst labeled "citrine, Brazil."

Beryl is another mineral commonly subjected to heat treatment. One method used in Brazil (Frondel, 1952) consists of wrapping green beryl crystals in bread dough and baking them. When the baked bread has cooled and is broken open, the crystals have turned a more valuable blue. The dough acts as insulation to prevent too rapid heating and cooling which might cause the crystals to crack. According to Sinkankas (1972) crystals of quartz larger than 1 inch, and beryl larger than 2 inches, can seldom be heat treated without cracking. All authorities agree that emerald cannot be affected by heat treatment, and Frondel (1952) reports treatment of Utah red beryl to 1,025°C without change. Many other changes in beryl have been noted, depending upon the original color and the locality.

Another commonly seen example is red tiger-eye (quartz after riebeckite) which is produced by the heat treatment of yellow tiger-eye. Yellow, yellow-orange and orange-brown crystals of Brazilian topaz may be turned pink by heat treatment in the 300° to 450°C range, the intensity of the pink being directly proportional to the intensity of the original hue. Tanzanite, the recently discovered gem variety of blue zoisite, is routinely heat treated to remove brownish-purple, reddish and greenish tinges. This latter treatment is done in an ordinary kitchen stove.

One additional type of color alteration is interesting in that its objective is to *decrease* clarity while inducing a color change. Some gypsum clusters are flame treated to give the crystal edges a white "frosted" appearance. Unlike oven heating, the gypsum clusters are usually done by the thousands by "toasting" in the open air with a propane torch.

Radiation treatments

For several years now, large quantities of smoky quartz from Arkansas have been offered for sale at major mineral shows in the United States and Europe. The first appearance of this material was startling because smoky quartz had been rare in Arkansas, and now it was arriving literally by the truck-load. The specimens are identical in form to the well-known clear and colorless quartz from Arkansas. The smoky portions are very dark and taper internally toward the base of some crystals.

Inquiries into the source of this material eventually led to a gem and mineral dealer familiar with the treatment of quartz by irradiation. According to him, large quantities of quartz are placed in steel baskets and lowered into a gamma-ray sterilization facility. One such facility is used for the sterilization of supplies for hospitals. The facility uses large amounts of radioactive cobalt-60 as the gamma-ray source. After an exposure of 1–6 hours the quartz is removed, carrying no residual radioactivity but it has changed from colorless to a dark smoky hue.

The quantity of irradiated smoky quartz produced in recent years

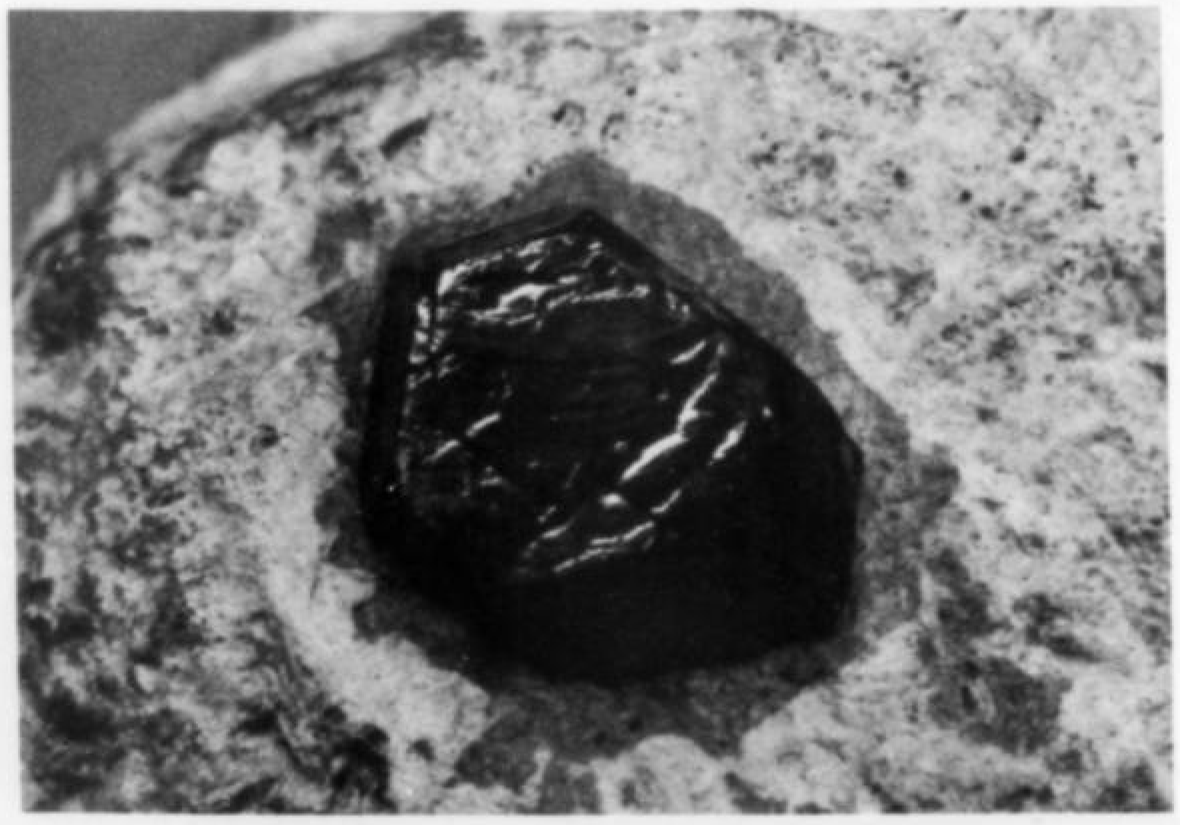


Figure 18. **Dark orange-brown zircon crystal (about 7 mm) glued into matrix. Purported locality: Niedermendig, Eifel district, Rheinland-Pfalz, West Germany. The glue-matrix mixture has apparently discolored with time and is now clearly visible. (AMNH specimen #20704.)**

Figure 19. **Large and fine hematite crystal (4.4 cm across) with epitaxial rutile, glued onto matrix. Purported locality: Tavetsch, Graubünden, Switzerland. Note mixture of glue and crushed matrix at crystal base. (Originally from the Mining Academy of Freiberg collection, currently in the Carnegie Museum collection, #3200.)**

Figure 20. **Pyrite crystals implanted in white marble matrix. Purported locality: Franklin, New Jersey. Note mixture of glue and crushed marble around crystal bases. The largest crystal is about 3 cm. (NMNH specimens #C615, C615, and R788.)**

is staggering. One dealer claims to have produced 250,000 pounds during one year alone, and that such treatment of quartz by himself and others has gone on over a period of several years. Fake smoky quartz from Arkansas probably holds the record for sheer number of specimens for any kind of fake.

Doelter (1910, 1915) reported cathode-ray-induced fluorite color changes of pale green → pale violet, and pink → darker pink. Doelter also reported "radium ray" (alpha particle)-induced fluorite color changes, including a dark blue-green, but most are impermanent and some may be restored to their original hue by exposure to ultraviolet radiation.

Yellow and orange topaz from Brazil can be intensified in color by treatment with X-radiation or alpha particles. Ultraviolet radiation sometimes causes yellow topaz to turn lilac-colored. Pale-brown topaz from Utah will change to smoky-brown under X-radiation, and amethyst will darken.

An interesting report by Möhler (1973) discussed the irradiation of colorless barite crystals from Romania which turns the crystals a blue color, which may later fade.

This is by no means a complete list of possible radiation-induced changes. The reader should be aware that such radiation effects can happen naturally in the earth and that radioactive minerals in pegmatites can sometimes cause natural changes such as the darkening of quartz. The above observations were obtained by us from various sources but we have not conducted any experiments to validate these reports.

Radiation-induced color changes are the area of fakery and fraud likely to become most active in the future. The potential financial return for heavy investment and the ease of mass-production combined with public ignorance of the techniques may ensure a ready market for such fakes. The investment-minded or serious collector would be well-advised to try to keep abreast of the gemological literature; such treatments are likely to be reported in those journals first. It is important to keep in mind that gems are but minerals and what a fraud-artist may do to a gem, he may also do to the uncut crystal.

TYPE C: Falsified luster

Most collectors who own dull specimens wish their specimens had a higher luster. Fortunately, most collectors tolerate the natural dullness of some crystals and have not tried to alter them.

Increasing the luster or surface reflectivity of a crystal by abrading, dissolving or coating microscopic growth features on that crystal results in a fake. This is because the surface thus produced is unnatural in that it never existed as a free face at any time during the crystal's growth.

Polishing

Abrading away microscopic growth features which may give a frosty luster to crystals is a particularly destructive type of fakery.

Figure 21. **Plastic imitation of a tourmaline crystal, about 6.7 cm, on matrix. Purported locality: Pala, California. Pala Properties specimen.**

Figure 22. **Large beryl (aquamarine) crystal about 4 cm across on smoky quartz. Purported locality: Brazil. The aquamarine has had all of the terminal faces added by grinding and polishing . . . it was probably formerly broken and missing its termination. (AMNH specimen #42385.)**

The treatment is irreversible and destroys crystallographic information. Collectors of yesteryear, while polishing their crystals, never dreamed that today's mineralogists could have studied those surfaces at 40,000 magnifications and learned something. Collectors today cannot claim that excuse.

Acid-dipping of acid-soluble minerals

Carbonate minerals in particular have often been dipped in acid to dissolve the microscopic surface features which cause the crystals to be less than bright in luster. This treatment is as destructive as polishing. Scratches and bruises have also been camouflaged in this manner.

Surface oiling or lacquering

The application of a high-luster oil, such as silicone oil, or lacquer tends to fill in the areas around microscopic surface features and bruises with an optically continuous substance, thereby making the surface appear smoother and more lustrous. This technique is extremely common today, especially among exhibitors, though fairly easy to detect when a specimen may be handled.

TYPE D: Falsified clarity

Flawless, gemmy crystals are as desirable as brilliantly lustrous ones, though nature is remarkably disinclined to yield them in that condition. The disguising of internal fractures and surface bruises by filling the spaces with an optically continuous fluid is therefore a common and easily accomplished type of fakery. Many commercial products lend themselves to this use. The coaters supplied with black and white Polaroid film have commonly been used to touch up bruises. *Liquid Wrench,* ethylene glycol, *WD-40* and various silicone oil preparations are in widespread use among some dealers and collectors because they will penetrate into the cracks in crystals and cause the cracks to disappear. Yellow fluorite crystals from the

May Stone Company quarry in Ft. Wayne, Indiana, were often soaked in some penetrating oil to disguise internal fractures.

TYPE E: Falsified shape

Shape distortion is an uncommon type of fakery limited to minerals which can be easily deformed without apparent evidence of such deformation. For example, stibnite is sometimes bent into a deformed crystal, which some collectors find desirable. Stibnite crystals from Ichinokawa, Iyo, Shikoku, Japan are supposedly naturally deformed and desirable because of this oddity. However, other stibnite crystals are sometimes bent in a similar manner and the collector should be aware of the possibility of faked bending. Unlike malleable metals, stibnite "bends" by translation-gliding of planes of atoms and cannot be re-bent to the original position without breakage. Any deliberate distortion of the shape of a crystal is fraudulent . . . it is actually "fake damage."

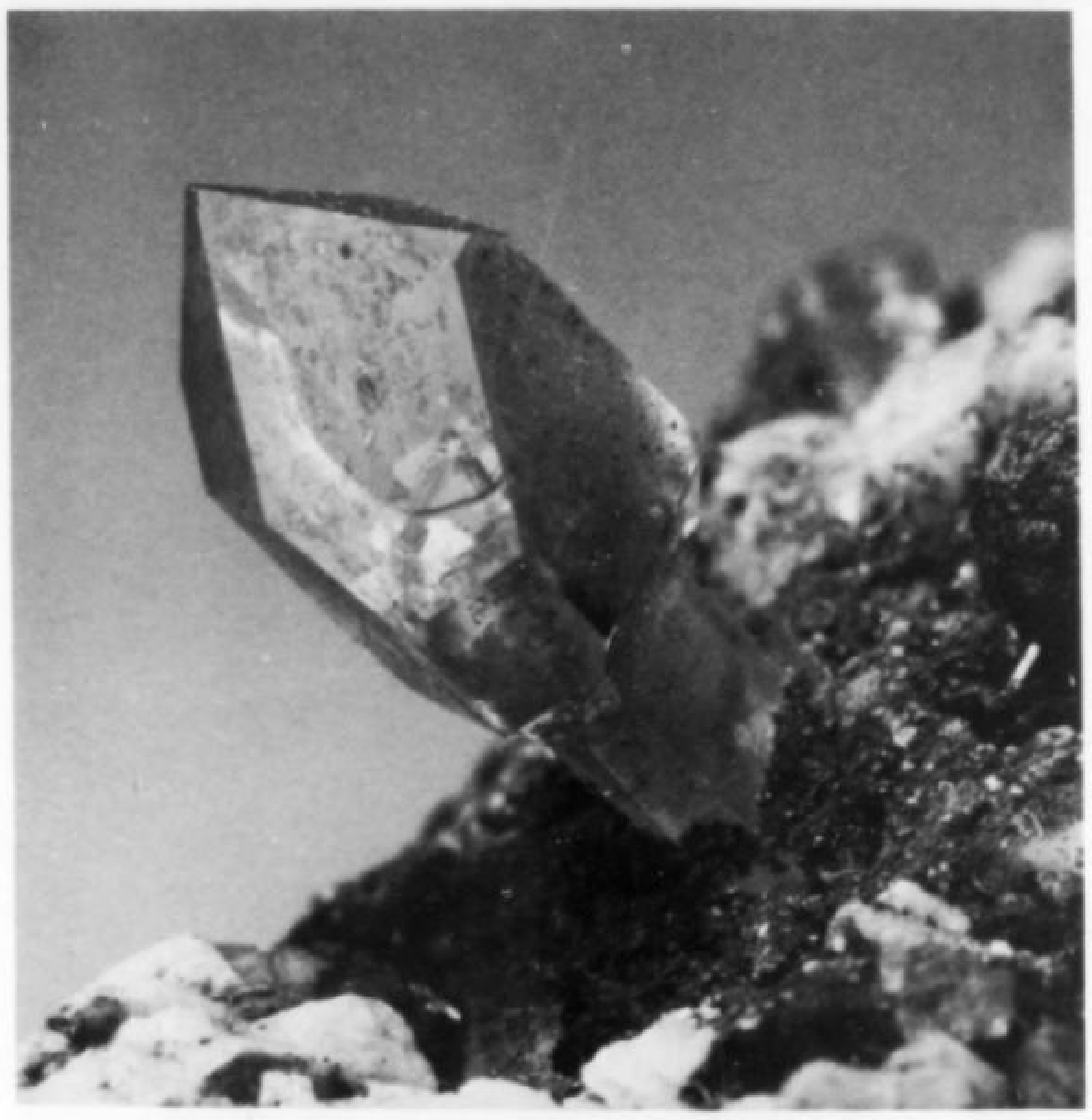


Figure 23. **Quartz scepter crystals (the largest is 1.4 cm) glued on matrix. Purported locality: Zillertal, Tirol, Austria. Note glue and crushed matrix mixture at crystal bases. Bentley collection.**

Gold and silver wires and plates are frequently bent into esthetic positions, relative to each other or to the matrix. Sometimes the wire-crystals of silver are curled into "ram's horn" shapes and other "desirable" forms so as to make the specimen more appealing to a consumer looking for something unusual.

TYPE F: Falsified faces

Although not frequently recognized, the intentional grinding and polishing of "crystal faces" in place of a bruised or broken crystal face is more common than one might suspect. Many of the older "artful terminations" were crudely done and are easily recognized by experienced collectors. However, the modern skilled artisan, armed with a precision faceting machine, a crystallographic angle-table for the species being adjusted, some basic knowledge of crystal symmetry, and patience, can readily add faces to broken or bruised crystals and do so convincingly.

Beryl crystals which have been broken can be "terminated" again by sawing off the broken termination at 90° to the prism and polishing the surface.

Cuprite has been cut in crystal form from massive material and then treated on the surface to generate a malachite coating. Although only one example was found, others may exist.

Scheelite crystals from the Friendship mine, Devon, England, have been frequently faked in this way. Damaged or anhedral crystals were given new faces by grinding, without much regard for angular accuracy. The crystals are typically loose singles but in some examples a little matrix is attached.

TYPE G: Replication and synthesis

The physical reproduction or simulation of a mineral specimen may be complete or only partial, but the result is a fake unless the restored portion of the specimen is insignificant. Replication and synthesis are characterized by the use of foreign or synthetic compounds to duplicate the appearance of a natural mineral. The substance used may be the chemical and crystallographic mineral-equivalent, electrolytic copper to imitate natural copper crystals for example, or a totally foreign material such as plastic or plaster. Figure 43 shows a franklinite crystal partially restored with carved and blackened plaster.

Matrix has also been faked by replication, principally by two ap-

Figure 24. **Large, metallic gray jordanite crystal (2.3 cm) glued on matrix. Purported locality: the Lengenbach quarry, Binntal, Valais, Switzerland. Note gap at base where crystal does not perfectly meet matrix. (NMNH specimen #B19708.)**

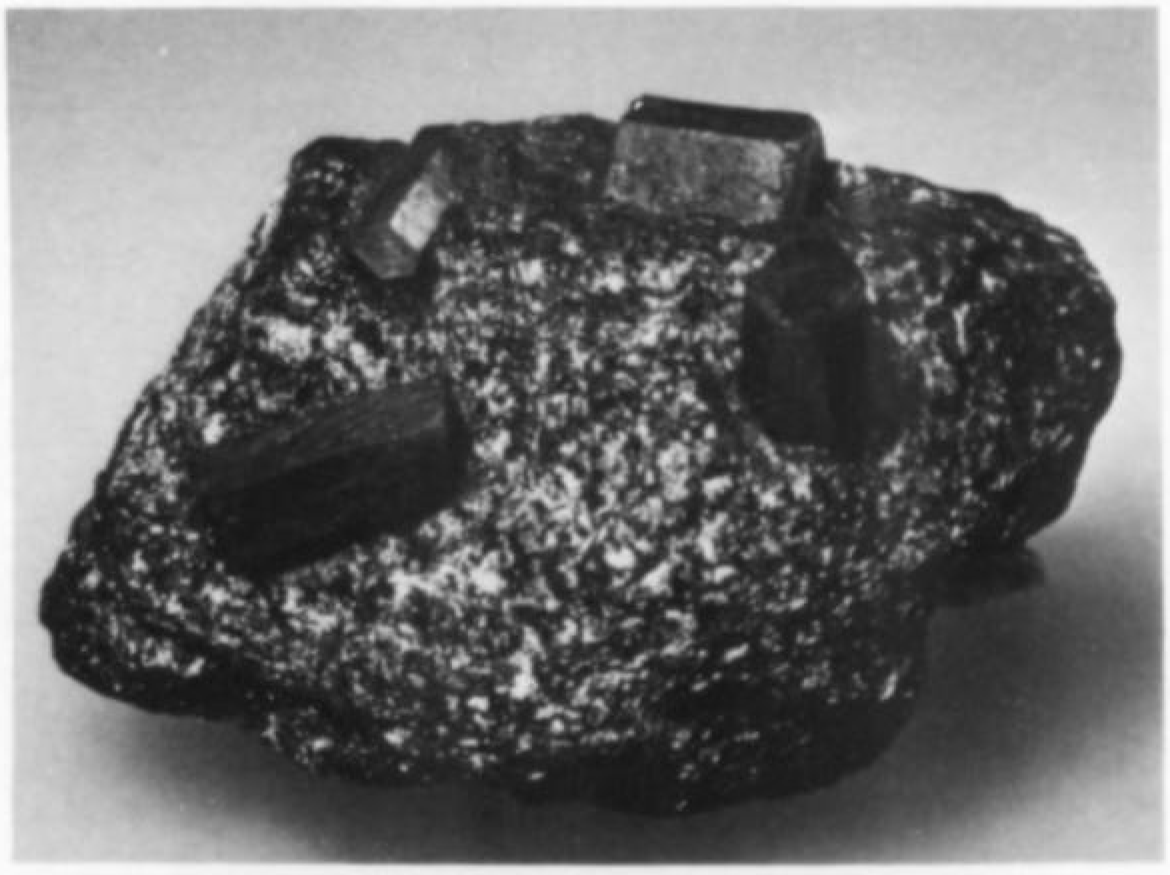
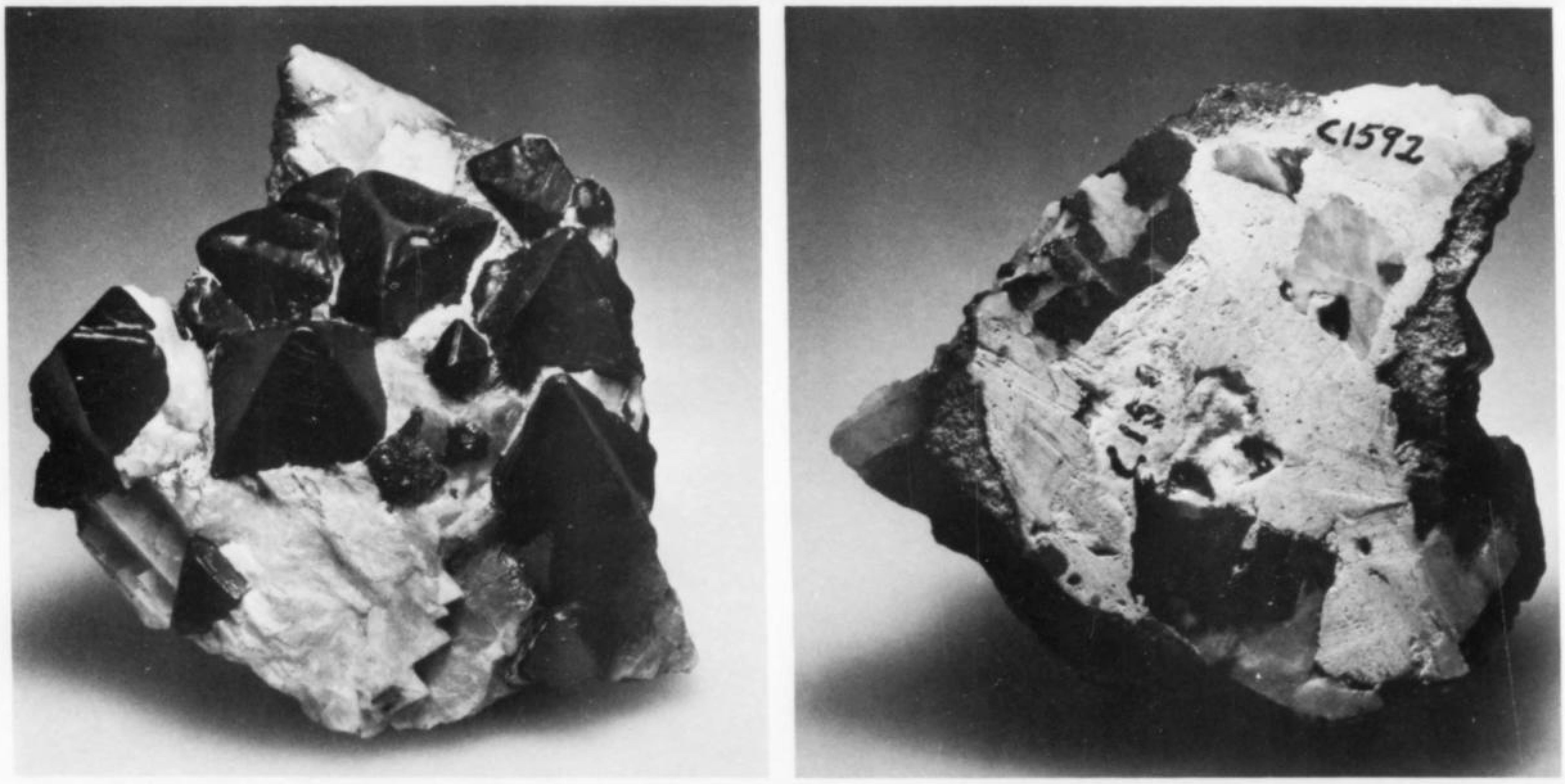


Figure 25. **Beryl (emerald) crystals glued into schist matrix. Purported locality: Salzburg, Austria. The largest crystal is 4.8 cm. Only the small crystal at upper left belongs to this matrix. (NMNH specimen #R14501.)**

Figure 26. **Black spinel specimen about 10 cm tall. Purported locality: Franklin, New Jersey. The broken corner reveals plaster core onto which spinel crystals were attached; the plaster showing at the specimen surface was darkened with lampblack. (NMNH specimen #C1554.)**

Figure 27. **Franklinite and calcite from Franklin, New Jersey. Left: front view. Right: the back of the specimen has been sawed off, revealing the plaster core into which the calcite and franklinite crystals were imbedded. The specimen is about 9 cm tall. (NMNH specimen #C1592.)**



proaches. In some cases crystals have been implanted in a "matrix" of plaster, epoxy, asphalt or other substances which are then given surface treatments to disguise their composition. Spinel crystals and also calcite and franklinite, all from Franklin, New Jersey, have been found implanted in plaster; and Austrian epidote crystals have been implanted in asphalt which is then covered by a mat of hairy byssolite for camouflage.

The second method of faking matrix is far more difficult to detect, requiring very careful observations of texture, grain-orientation, density, and coloration of matrix in order to be recognized. In this technique, the matrix is crumbled, even mixed with broken bits of crystals or very small euhedral crystals, and then mixed very carefully with epoxy or other chemicals to yield a "rock" which will hold the implanted crystals-of-interest in esthetic positions. This technique is ideally suited to imitate matrixes which are friable in nature or which have a naturally brecciated texture.

Today, synthetic crystals of a wide variety are grown, as explained in a broad fashion by Arem (1973). However, only those synthetic materials and mineral-equivalents which the collector is likely to encounter on the marketplace are mentioned here. Aside from water soluble compounds (discussed below) the dominant synthetic materials used for fakes on today's market are the byproducts of industrial processes or are crystals grown by industrial producers for scientific or technical applications.

In particular, synthetic quartz has recently become available in quantity, the latest products grown in shapes which resemble natural amethyst crystals of a squat habit. The next most frequently encountered mineral-equivalents are copper, bismuth, gold, and silicon carbide (the synthetic equivalent of moissanite). Silicon carbide was reported in Germany as fake moissanite by Metz (1972), and has been sold in some mineral shops for decades. Less common, but still encountered with disquieting frequency are silver, antimony, nickel, corundum, and zincite.

Water-soluble mineral equivalents

Among the easiest fakes to manufacture are water soluble compounds grown as crystals on some sort of matrix. The procedure is almost childlike in its simplicity: one simply dissolves the compound in water to make a saturated solution, immerses the matrix

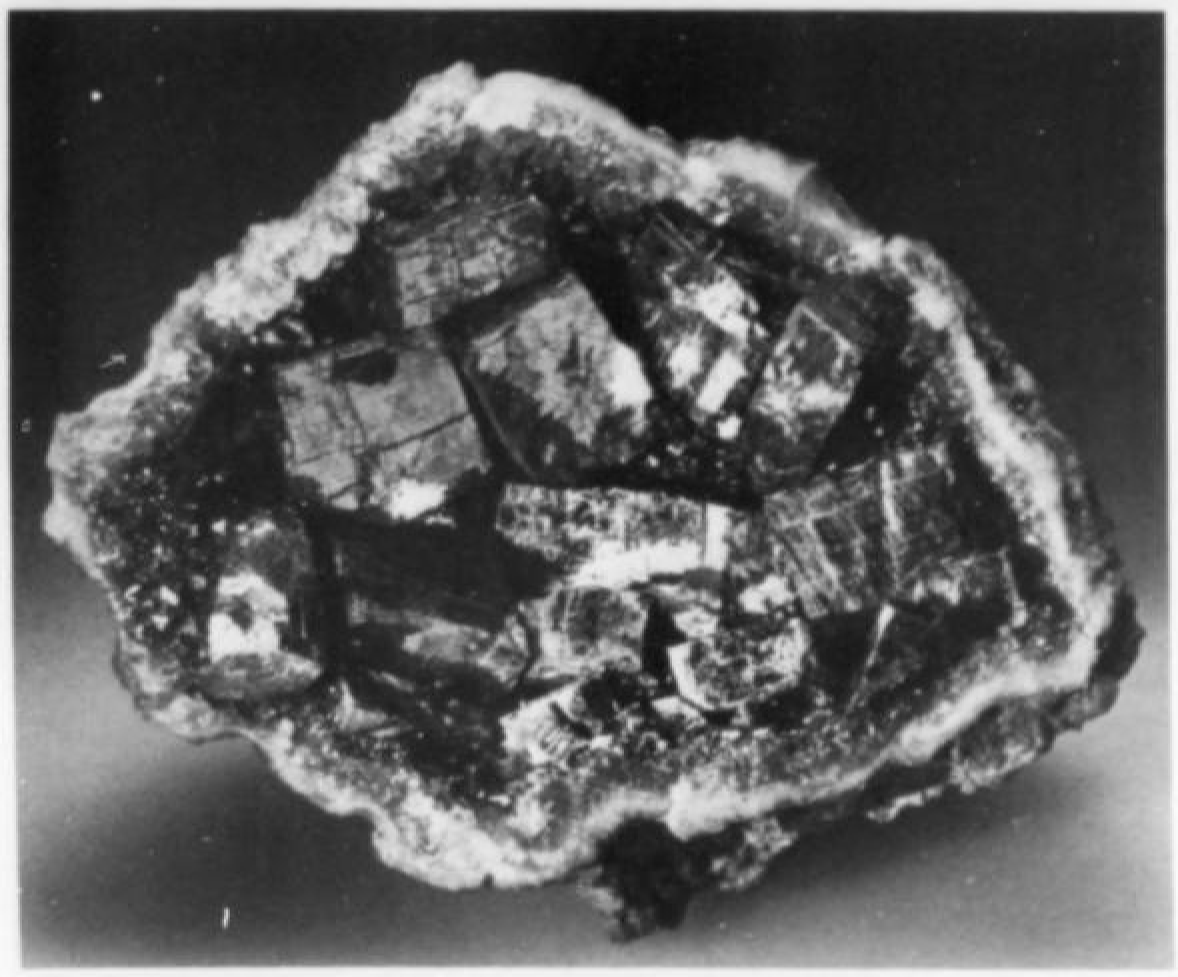


Figure 28. **Galena cleavages glued into an 8-cm quartz geode; purchased from a street vendor in Morocco. Sylvia Churgin specimen.**

in the solution, and leaves the container holding the solution and matrix uncovered or partially uncovered. As the water evaporates, the dissolved salt precipitates as crystals on the matrix, and a new fake is generated. The most abundant fake of this sort by far is copper sulfate hydrate, $CuSO_4 \cdot 5H_2O$, known in the mineral world as chalcanthite. Its abundance is probably due to the easy availability of the compound, its high solubility, easy nucleation, and rapid growth as beautiful, bright blue, triclinic crystals which are very esthetic. Sir Arthur Russell was of the opinion that nearly all specimens of Cornish chalcanthite, particularly those from the Phoenix mine, Linkinhorne, are synthetic. Synthetic halite is likely second in abundance.

Figure 29. **Sperrylite crystal from the Transvaal, South Africa (the world's largest and best formed crystal, measuring about 2.4 cm). Because the side of the crystal originally facing outward was damaged, the crystal was removed from its matrix and inverted to show the undamaged inner side. The crystal is sitting *loose* on its matrix and has not been re-attached with glues or adhesives. British Museum (Natural History) specimen. Photo by Peter Green and Frank Greenaway.**

In addition to chalcanthite, one can also easily synthesize morenosite, $NiSO_4 \cdot 7H_2O$; lopezite, $K_2Cr_2O_7$; potash alum, $KAl(SO_4)_2 \cdot 12H_2O$; and an abundance of others. Although frequently sold as mineral specimens and sometimes as collectable "decorator pieces," these compounds, when grown on rock, clearly are fakes.

Growing crystals can be a delightful and stimulating activity, and one from which the collector can learn much about the nature of crystal growth and deposition. For the reader who wishes to pursue this activity, we recommend the Doubleday paperback entitled *Crystals and Crystal Growing* by Holden and Singer. However, it would be best if all potential crystal growers refrained from growing crystals on rock matrix, for the sample can easily pass into unwary hands.

Another interesting example was noted by Dietrich and Dietrich (1966) and translated into English by Kay Robertson (Dietrich and Dietrich, 1967). In this case, someone had grown crystals of synthetic urea, $CO(NH_2)_2$, on a rock matrix and sold and traded them as aragonite. A soaking in water dissolves them completely.

Metalworking

In recent years, the use of man-made metals to fake natural specimens of gold, silver and other precious metals has increased. In addition to use as crystals, metallic elements have been dripped or sprayed onto natural specimens. Rhodochrosite from Colorado

Figure 30. **Greenish brown pyrosmalite crystals to 2.8 cm on matrix. Purported locality: Nordmark, Varmland, Sweden. The main crystal does not belong where it is presently attached, though it may simply have been inverted to conceal damage and re-attached in the wrong orientation. (NMNH specimen #138658.)**

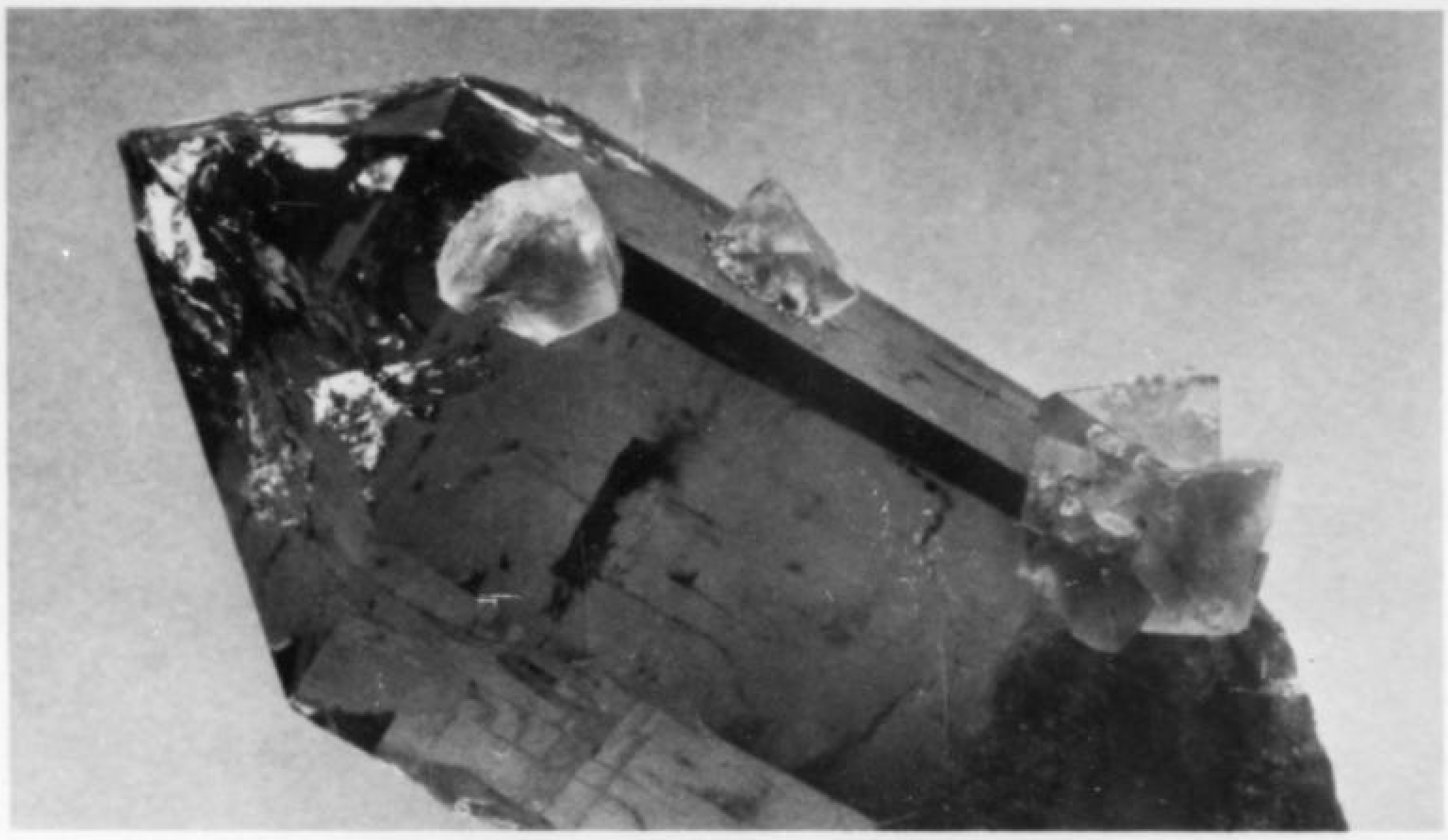


Figure 31. **Pink fluorite crystals to about 1 cm, glued onto a quartz crystal. Purported locality: Göschenen, Uri, Switzerland. Eric Offermann photo.**

Figure 32. **Two specimens of epidote crystals with byssolite. Purported locality: Austria. The epidote crystals have been pressed into balls of asphalt (which fluoresces yellow under ultraviolet light) and the asphalt has been covered by the addition of byssolite. A lump of serpentine was added to the 6-cm specimen at right. (Yale collection, #1104 and #3500.)**

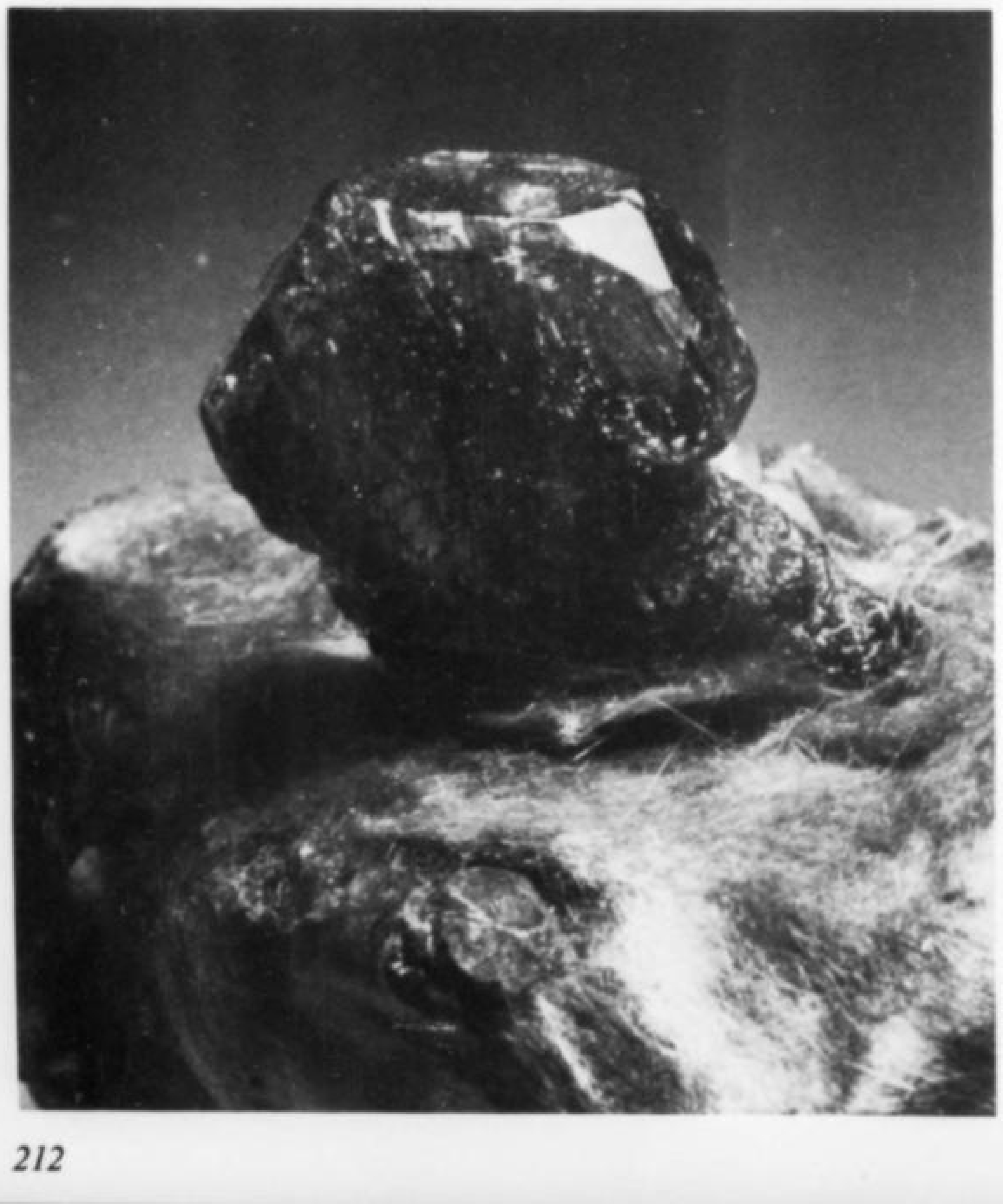


Figure 33. **Colorless apatite with byssolite inclusions implanted on matrix. The addition of more byssolite to the matrix has concealed the glued join at the base of the 2.7 cm apatite crystal. Purported locality: Untersuzbachtal, Salzburg, Austria. (NMNH specimen #R5229.)**

and dolomite from the Morro Velho mine, near Nova Lima, Minas Gerais, Brazil, have both had molten gold applied to otherwise unfaked specimens in this manner. The misuse of gold was also noted in Germany by Lieber (1966).

A British dealer of the 1850's produced many fakes, the most interesting of which imitate the well-known pseudomorphs of granular cassiterite after orthoclase from the Coates mine, Cornwall. The cores are made of lead cut to approximate the shape of a Carlsbad twin and covered with small cassiterite grains set in glue.

Laser-induced crystallization

Some interesting specimens have been produced through the use of high-powered laser beams. According to one mineral dealer, a lump of chalcedony or chrysoprase is cut into ¼ inch slabs and arrayed in a rack so that each slab is separated from the next by ¼ to ½ inch. The rack is lowered into an aqueous copper solution, and an intense laser beam is shot through the array of slabs, passing

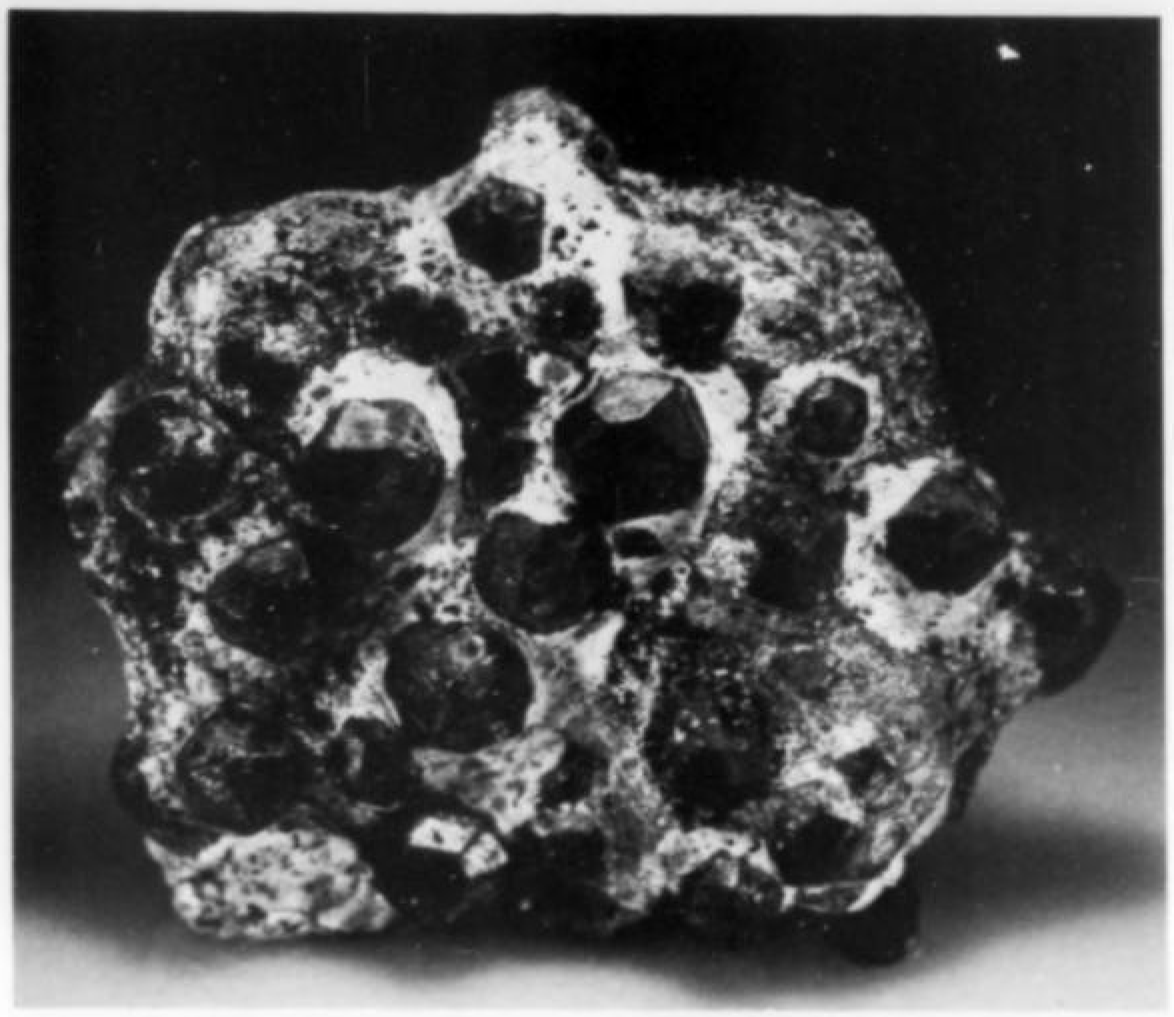
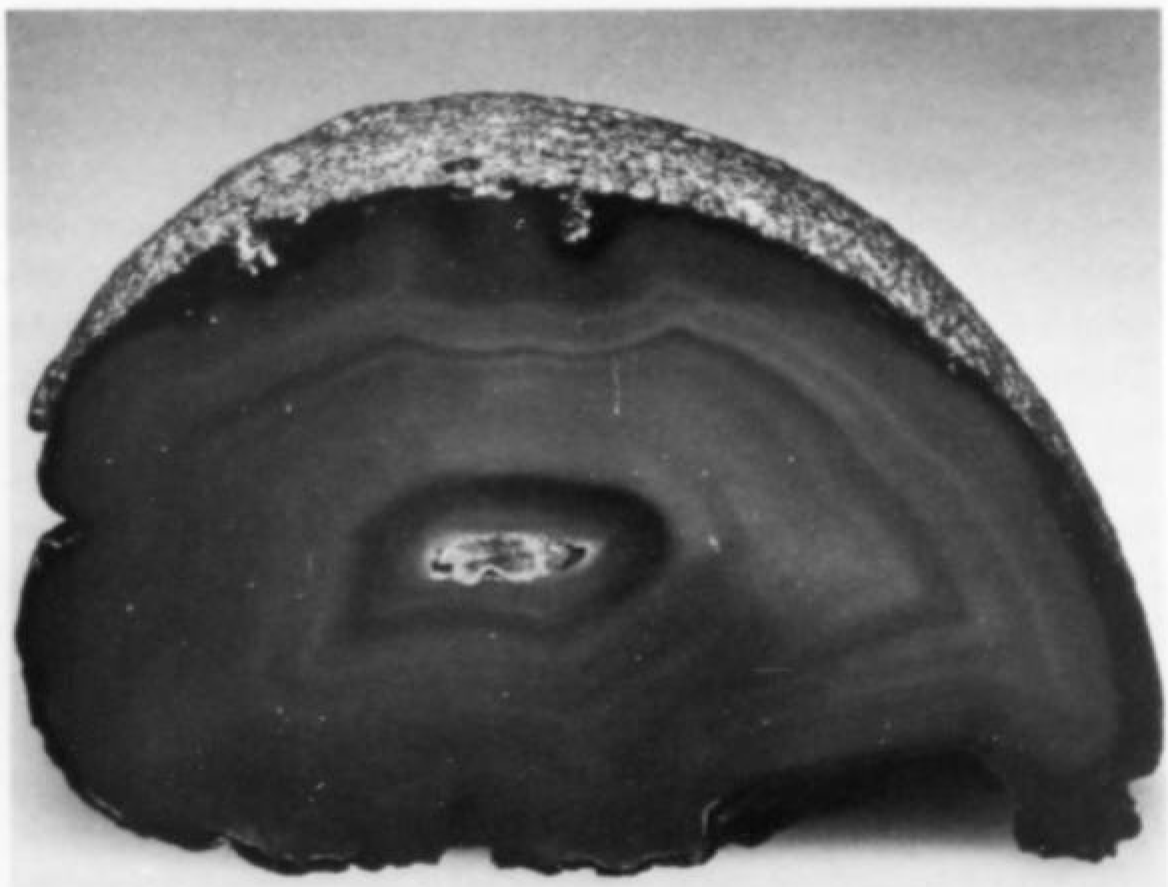


Figure 34. **Reddish black garnet crystals to 1.5 cm glued onto matrix. Purported locality: Roxbury, Connecticut. Crude rings of white glue and powdered rock encircle the crystals and fluoresce strongly under ultraviolet light. (Harvard specimen #89047.)**

Figure 35. **Silver. Purported locality: the Quincy mine, Calumet, Michigan. Arrows mark where four different silver specimens have been welded together. The specimen is 5.5 cm across. (Los Angeles County Museum of Natural History specimen #17913a.)**

Figure 36. **Banded agate with small central geode space into which has been hammered a copper-silver "half-breed." Sold originally as a Lake Superior agate, 9.7 cm across. Bentley collection.**



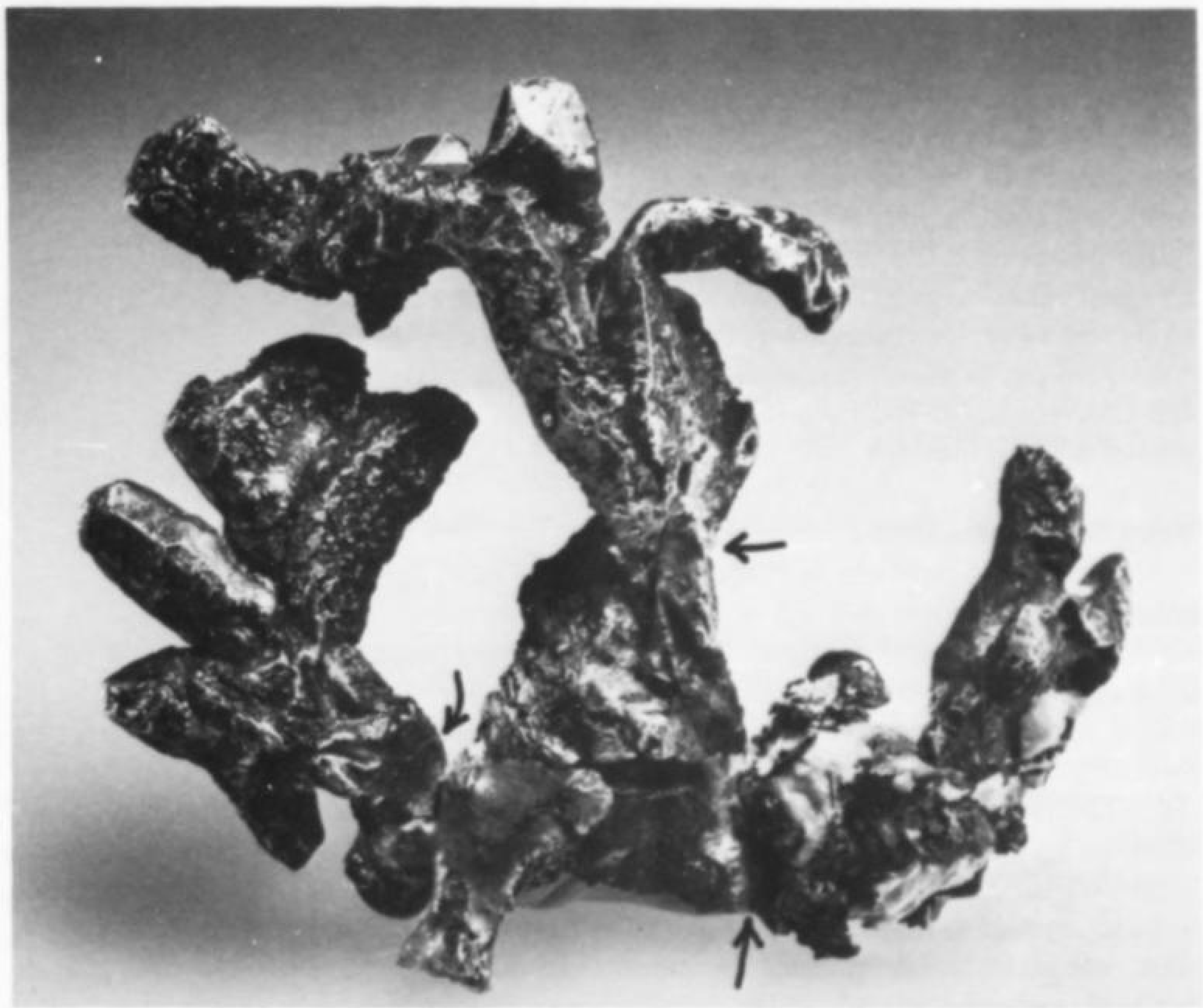
through the center of each slab in succession. The beam causes elemental copper to crystallize out of the solution and into the microscopic voids and grain boundaries of the cryptocrystalline quartz. The result is a sort of "bloom" or flower of elemental copper enclosed within the chalcedony slab. The slab closest to the laser generator exfoliates or bursts; the slab at the tail-end of the array may show little effect; but the center slabs show a satisfactory growth of copper. Such *copper blooms* in chrysoprase have, in the past, been offered as natural specimens from Tsumeb, Namibia. (Note: the authors have not confirmed this report through any other sources.)

TYPE H: Falsified surface composition

This type includes all treatments with products other than oils which might be applied to the surface of a mineral specimen. The use of paint, chemicals, electroplated metals and induced tarnishes is all fakery.

Gold has been faked in many ways, most commonly by electroplating of copper or base-metal nuggets with gold.

Bornite is frequently faked by boiling chalcopyrite in liquid bleach (sodium hypochlorite). This generates a very thin film on the surface of the chalcopyrite which has the appearance of bornite. Defended by its perpetrators as being done for other than mineral collectors, it nonetheless is seen in almost all mineral shows with the label bornite. The technique is not new and not American in origin; it was noted 19 years ago by Lieber (1961) as being practiced in Germany. At that time, the mineral was cooked in *Persil,* a laundry product.



DETECTION

It is a sad commentary on the mineral market that one must look at specimens as possible fakes and then go about disproving this suspicion. However, this attitude frequently prevents one from being deceived. This warning is not necessarily a reflection on today's mineral dealers. As active sources dry up, and more and more older collections are recycled, the chances of a dealer unwittingly recycling an old fake increase. Bear in mind that one of the most difficult tasks for the faker is to make a specimen look natural. Have you ever tried to arrange rocks in a rock garden in

Figure 37. **Quartz crystal, 10.2 cm long, with metallic lead manually pressed into crystal voids. This technique has also been used to implant gold in quartz. Bentley collection.**

search of a natural placement? It takes several tries to get the appearance even close to natural. Faking a mineral specimen sometimes involves the same problem; something about the arrangement of crystals and matrix commonly doesn't ring true to the experienced eye.

Although there are many detection methods, there is no effective substitute for a very careful visual inspection of the specimen, aided by a hand lens of moderate magnification (5–15x) where necessary. Examination of the specimen, both at arm's length and with magnification, remains your best insurance against fakery. Finally, you might just develop the "sixth sense" that some experienced collectors and curators have. Some persons can spot a good fake from many feet away, just by the "way it looks." This is a very difficult concept to put in words. It is almost uncanny, but it is a talent well worth developing if you have the potential. Following is a discussion of what to look for.

TYPE A: Malattachment

Malattached crystals are not only the oldest and most prevalent type of fake, they are also the easiest to detect. Most malattachments are accomplished with glue and one must be very much concerned with proving the absence or presence of the glue. The following steps are recommended in examining any possible fake, but especially for malattachments.

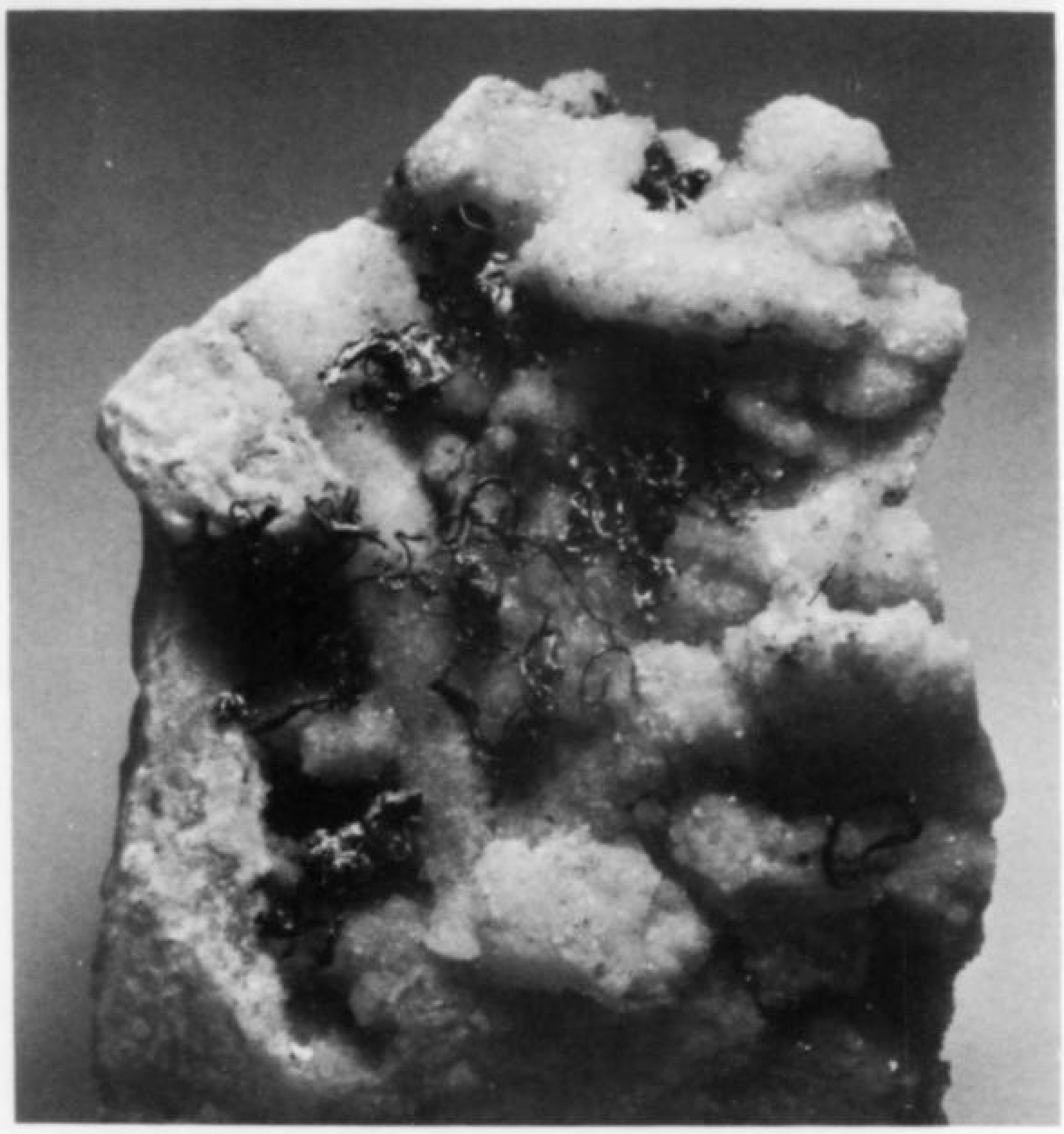
1. Examine the contacts between the crystals and the matrix very carefully for evidence of:

(a) Powdered matrix or related mineral matter, mixed with glues to bond crystals to matrix. Some older fakes have cements mixed with several different minerals in proportions and grain-sizes designed to give the best match with the matrix. Among the favorite glue-disguising components are quartz, albite, micas, chlorite, byssolite and clays.

(b) A different luster or orientation of surface markings (etch pits, striations, etc.) on the featured crystals. For example, on a Swiss magnetite, one might find that all the crystals look alike except the one largest and most important crystal. If the featured crystal has significantly different markings, this suggests it was implanted.

2. Look for "rings" of associated minerals around the base of the crystal. Many Alpine fakes have small girdles of chlorite or powdered material around the bases of faked crystals. The components of such "rings" may have been removed from the back of the matrix and may therefore be "true" associated species. Also suspect are areas of slightly discolored matrix or of differing particle size. Any hair-like mineral obscuring the crystal-matrix contact areas should be very carefully examined because it may conceal glue. Byssolite (actinolite) and chlorite are most commonly used this way. Wire silver has been used to hid the contact where a large clump of wire silver "emerges" from a matrix.

Figure 38. **Silver wires glued onto drusy quartz. Purported locality: Guanajuato, Mexico. The specimen is 5.7 cm tall. C. C. Rich collection.**



3. Look for uncommon coatings or lusters on the specimen as a whole which may be the result of sprays or glues. Soak the specimen in water or alcohol to see if anything interesting falls off. Immersion is a useful test for all sorts of faked specimens and should routinely be done whenever there is some doubt. In addition to dissolving some glues, alcohol also dissolves certain dyes used in color-enhancement of the specimen. While the specimen is immersed, check it carefully for evenness of wetting. Uneven wetting suggests the specimen is deserving of more detailed examination.

4. Check for crystal position. Some specimens with just one notable crystal "ideally" oriented are particularly suspect if you cannot see the point of attachment. Some topaz crystals from the Thomas Mountains have been faked in this manner in recent years, and many have gone undetected.

5. When a single crystal on matrix is involved, check the surfaces facing the matrix. You would expect to see natural smooth faces facing the matrix and not uneven contact faces which would suggest that the crystal came from a group on some other specimen.

6. Be suspicious of specimens which show damage to one or more crystals which are in places on the specimen which are protected by larger *un*bruised crystals, indicating that the *un*bruised ones might be implanted.

7. Try ultrasonic cleaning. It may shake loose some crystals implanted by someone other than Father Nature and, in addition, will certainly supply you with a cleaner surface for other observations. Caution: some legitimate specimens may come apart.

8. Use ultraviolet radiation to test for fluorescent glues. Both Elmer's glue, Duco cement and similar products fluoresce well enough to be easily visible under strong ultraviolet light. Elmer's glue is most strongly fluorescent and both glues fluoresce more strongly in longwave ultraviolet than in shortwave. The fluorescence is bluish gray, but one should first test each glue for a personal impression because fluorescence observations are subjective and glues may vary in response. Be sure to allow the eyes time to adjust to darkness and keep outside light sources to a minimum. Fluorescent response of some glues may be quite weak if acetone or some other solvent has been used to spread the glue over a larger surface and make it less detectable. A fluorescence test will not detect egg albumen, mucilage, pitch, plaster or water glass (sodium silicate). As an extra precaution, it may be advisable to remove the filter from the ultraviolet source to intensify the ultraviolet radiation.

9. Look closely for malleable metals, particularly gold or silver which are easily forced into crevices in the matrix to give the impression that they formed there. These may sometimes be detected by microscopic or hand-lens examination which reveals tooling-marks on the metal surfaces left by the tools used for emplacement. The careful faker, however, will leave no such clues to be found.

Figure 39. **Colorless quartz turned smoky gray by exposure to gamma radiation from Cobalt-60. The crystal, from Arkansas, is 5.2 cm tall. Bentley collection.**

10. Look closely for the attachment of small crystals of valid associated minerals over bruises and dings on larger crystals. Such disguised damage can be convincing if very small crystals are used and attached with minute drops of glue in a well-protected area on the specimen.

11. Check metallic specimens for evidence of welding or soldering of minerals to each other or to an appropriate matrix.

TYPE B: Falsified color

Although color falsification is common, detection methods are limited to use on dyed or painted specimens, because there are few published reliable methods for detecting specimens which have been altered by heat, or irradiation. However, many dyed or painted specimens are relatively easy to detect because the coloring agents are soluble in water or alcohol, and even more so in acetone and other organic solvents. In some cases, immersion in solvent for several hours (preferably a warm solution) will reveal dye by a coloring of the previous colorless solvent. Conducting the test in colorless containers on white paper assures the maximum degree of sensitivity possible for this visual examination. The procedure might also dissolve some glues on a possible malattached fake, as noted before. Examine the specimen very carefully for evidence of uneven dying or coating; dyes frequently permeate microcrystalline areas more evenly than macrocrystalline areas, and can frequently be seen concentrated along grain boundaries under magnification. Although most dyed specimens are neatly done, one should still look for drip-marks on the outside of the specimen.

The use of colored felt-tip pens as dyes is easily detected inasmuch as most of them are water or alcohol soluble.

TYPE C: Falsified luster

Acid dipping of soluble minerals can result in a luster change easy to recognize. If the dipping is done very quickly, it may be almost impossible to detect. However, if the dipping is continued for too long, small etch pits may form, as well as slight rounding of crystal edges. In addition, acid may enlarge the spaces where crystals meet each other. Unfortunately, the presence of etch-pits and enlarged spaces is not, in itself, proof of acid treatment. (Incidentally, corrosive bases have also been used.)

The polishing of crystal faces is more easily detected. What to look for depends on the process used. If the crystal was polished with a light abrasive on a cloth or buffing wheel, scratches may be visible under magnification which are different in orientation from natural growth striations controlled by crystal symmetry. If the crystal was polished using an abrasive propellant machine, differences in luster may be visible where the abrasive did not reach. Such abrasion polishing can be very difficult to detect if done properly. One might find a specimen with a perfectly glossy pinacoid on one crystal and a frosty pinacoid on a very small one immediately adja-

Figure 40. **Purple fluorite, purportedly from Illinois, which has been varnished to "improve" its luster; 9.5 cm across. Bentley collection.**

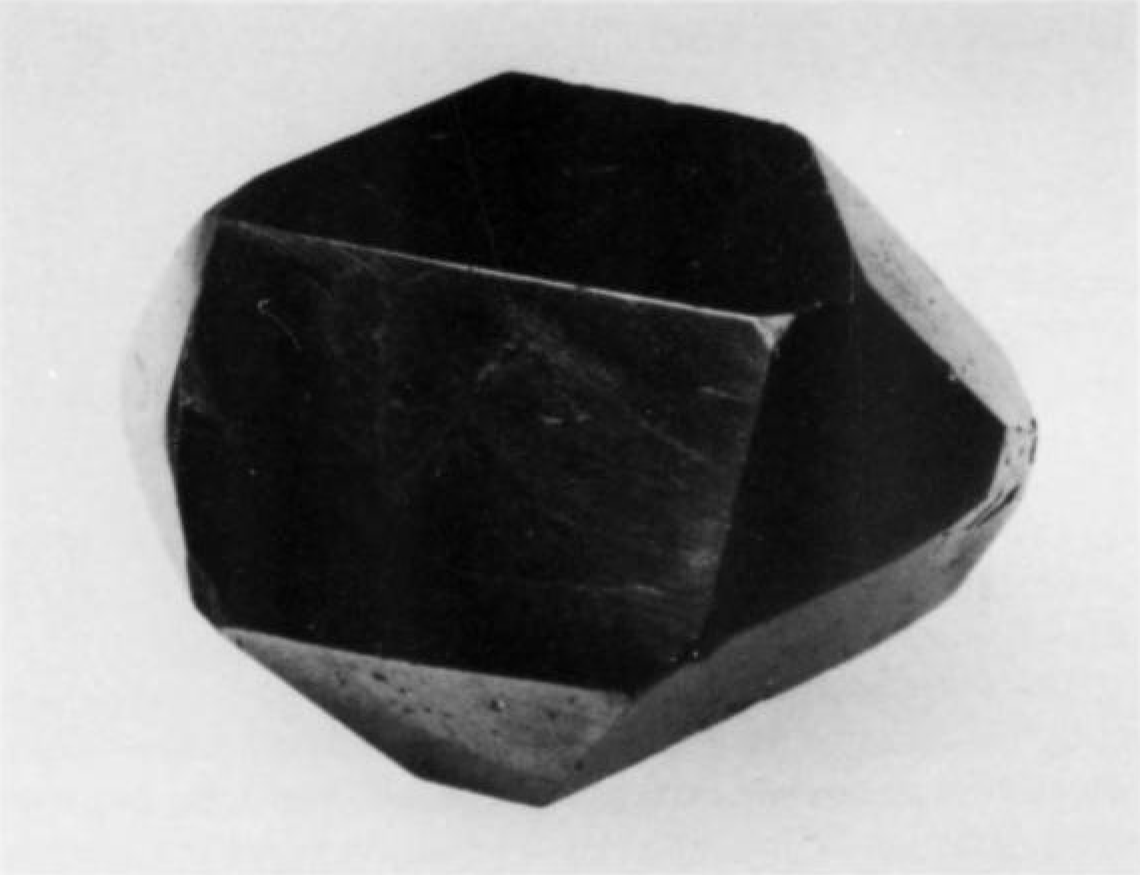


Figure 41. **Completely faceted hematite 1.8 cm across, designed to appear as a natural crystal. Purported locality: Minas Gerais, Brazil. These have been made and sold by the hundreds. Bentley collection.**

cent to it. The observation of minute detail can be very helpful.

Falsification of luster by use of sprays, lacquers and oils is readily detected by scratching with a needle or the use of solvents. Surface oil, if applied at all generously, can be felt or rubbed off on a fingertip and easily detected.

TYPE D: Falsified clarity

Clarity falsifications which are external (a penetrating liquid applied to the outside of a crystal) are detected easily. Bruises, scratches or blemishes are still present, merely less visible. By looking carefully for blemishes, one will note, in most cases, a different reflectivity of the crystal near the imperfection. The easiest way to train your eye for this observation is to practice with broken study specimens which you have treated yourself (and then clean off the coatings from the study specimens).

Internal clarity falsifications are much more difficult to detect. The oils and other liquids which have penetrated into the crystal are not obvious. In some cases, gentle warming expands and thins the oils which then seep out to stain the material under the specimen. However, if the specimen was oven-dried after oil treatment, detection may be impossible because further heating causes the crystal to expand and the oil may penetrate deeper. In addition, oven-heating could drive off all vapors and excess oils.

Comparison with other specimens from the same locality may be useful; many of the oilings affect the color of the matrixes and comparing matrixes may offer some guidance.

Exposure to ultraviolet light may cause some oils and coatings to fluoresce.

TYPE E: Falsified shape

The detection of shape falsification is very difficult because it is used only on minerals which are found naturally deformed. Manipulations by the faker produce the same type of distortions. In the case of stibnite which has been bent, one might examine the naturally bent stibnite crystals in museums and make comparisons as to whether or not the purported "bent" crystals appear to be similar to the natural ones.

In the case of the "curling" of wire crystals of silver and gold, one can look for tweezer and instrument marks on the inside of the "curl" as possible evidence of unnatural distortion. Little more can be observed.

TYPE F: Falsified faces

False faces on crystals are among the easier types of fakes to detect. The primary thing one must keep in mind is to check all faces on the termination of every crystal. This might seem elementary, but it is often overlooked in the excitement of acquisition. With few exceptions, false faces on crystals were only discovered at some time following the purchase. The detection of false faces requires careful observation of detail and a familiarity with natural surface markings of crystals. Both of these skills are within the abilities of any collector who attempts to sensitize himself to the need for careful observation.

False faces are usually well-polished and the presence of polishing-marks on the surfaces is an obvious indicator. (Spend some time examining polished surfaces to learn what these look like.) Polishing marks are usually quite fine and require careful examination, preferably with magnification. They are distinguished from natural crystal markings by (a) possibly being curved, (b) lack of crystallographic orientation relative to the crystal symmetry.

Unlike natural crystals on which all faces of a form usually have the same luster and markings, "faces" of the polished fake may not. This is certainly the case on the older fakes whereon the faker simply polished the face that needed the repair, ignoring the other symmetry-equivalent faces which needed no attention. For example, one may find one face of a pyramid on a tourmaline crystal lustrous, while others are dull. Awareness of symmetry is growing, however, and the fakes composed of false faces will certainly be more correctly done in the future.

When the quality of a faked crystal is very high (a gemmy flawless crystal, for example) the financial incentive for disguising false faces justifies increased time and expense. Acid-etching newly polished faces to yield a natural-appearing luster is one method. Species such as spodumene and beryl are commonly severely etched when taken from the earth and false etching, if done properly, can make a very fine and almost undetectable fake.

Polishing marks can also be removed by using air-abrasive units. Detection of this type of treatment may be very difficult.

TYPE G: Replication and synthesis

The detection of replicas and synthetics is markedly simpler than the detection of some other kinds of fakes. There are two possible subjects: the crystal and the matrix.

The detection of replication of a crystal requires observations of heft (density), luster, and even feel. In the case of a crystal

Figure 42. **Pale green beryl crystal 2.3 cm in size. Purported locality: Bahia, Brazil, which has a termination added by grinding and polishing, and which has also been glued into matrix. (AMNH specimen #42384.)**

Figure 43. **Franklinite crystal, 4.9 cm across, with calcite and zincite, from Franklin, New Jersey. Much of the upper portion of the crystal, including the termination, is actually carved plaster darkened with lampblack. The granular zincite patch (upper left) is composed of crushed zincite made into a paste with glue. (ANSP specimen #11490.)**

Figure 44. **Yellow chondrodite crystal about 7 cm across on calcite matrix. Purported locality: Orange County, New York. Three-quarters of the chondrodite crystal is carved plaster colored with brownish-yellow lacquer. (Harvard specimen #89095.)**

being partially restored, the replaced portion may be covered with paint, lampblack, or dye, which usually has a different luster than the natural parts of the crystal. Simple comparisons of luster usually reveal this type of fake, and a hardness test will as well (hardness testing on euhedral crystals is not recommended!)

The detection of replicas of whole specimens such as gold nuggets usually depends on heft and some familiarity with the density of gold, *unless* the replica itself is cast in real gold. Tiny clues such as bubbles, casting marks and traces of plaster might be seen under magnification.

The detection of replicas of whole crystals is a relatively easy procedure. In the case of the plastic tourmaline, shown in Figure 21, the crystal has several odd points. Among these are (a) strong, pure, abnormal coloration, (b) extremely low density, (c) rounded edges, molded faces and forms, (d) admittedly subjective, a decidedly strange appearance, and (e) an unnaturally warm feeling when touched.

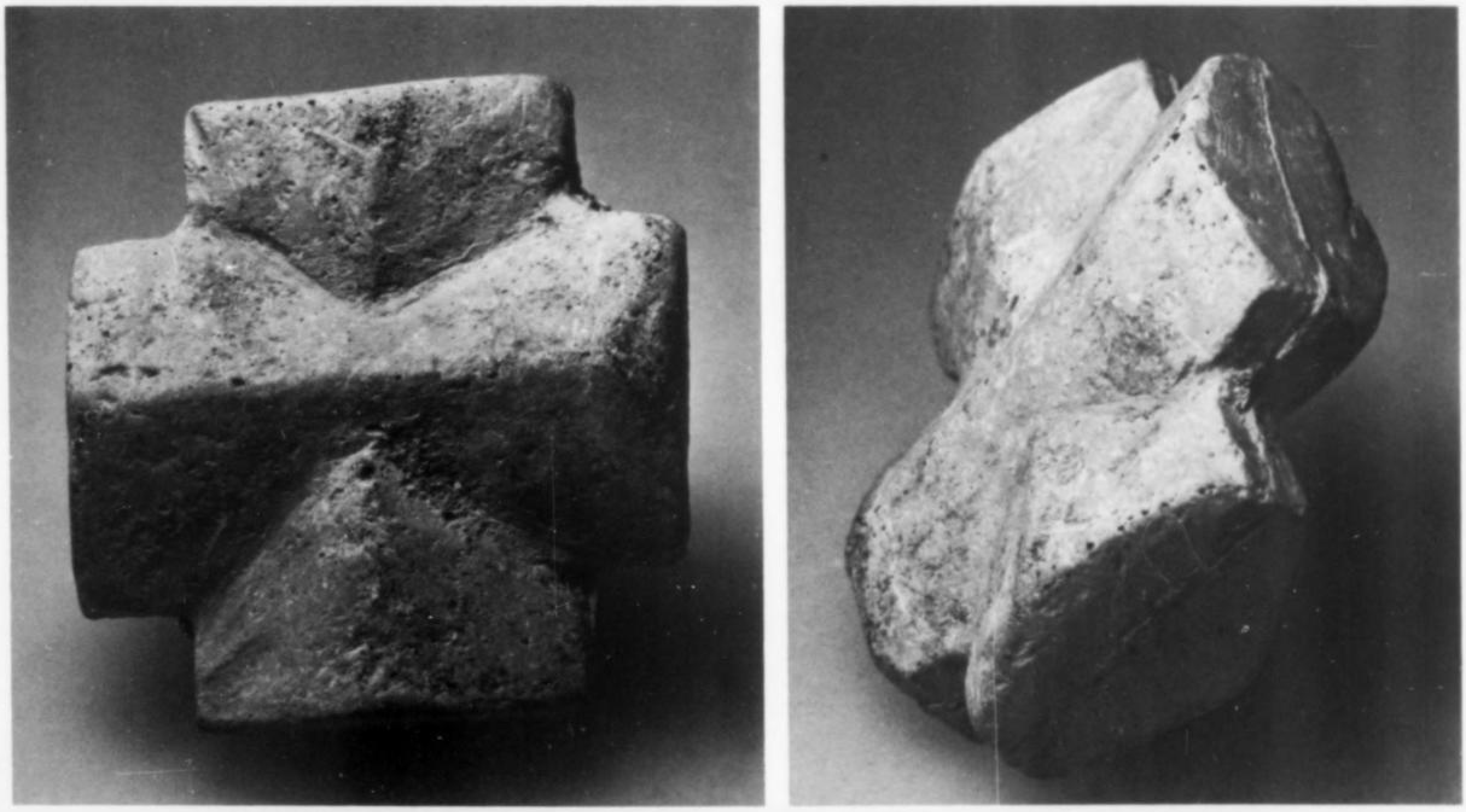


Figure 45. **Fake staurolite pseudomorph, 4.7 cm across, composed entirely of cast, pale pink plaster. The maker neglected to remove mold marks (right). Tiny bubbles are also visible. Flakes of mica have been pressed into the surface. Michael Corrigan specimen.**

Figure 46. **Synthetic crystals of chalcanthite (copper sulfate) grown on a 16-cm piece of matrix. Purported locality: Pennsylvania. (NMNH specimen #C4686.)**

Figure 47. **Copper crystals 5.4 cm long, plated with silver. Purported locality: Houghton, Michigan. Bentley collection.**

Matrix replicas are detectable, in most cases, by heft or by immersion in solvents. In the case of the franklinite or scapolite crystals held in a plaster "matrix," the specimens have a lighter heft than comparable natural specimens and one can usually detect the plaster by chipping away a part of the matrix to expose it.

Crystals that have been implanted in a "matrix" which is a mixture of powdered natural matrix, glues and epoxy, are more difficult to detect. Two actions are recommended. One is to compare its texture and cohesion with other specimens from the locality which have been obtained from other sources, or which are much older, perhaps residing in museum collections. The second is to soak the sample in *organic* solvents such as acetone, toluene, benzene or ethyl acetate. A thin-section examination of a small piece of "matrix" would be conclusive.

Synthetics can usually be detected or, at least, suspected by careful observation. Man-made crystals typically have an unnatural appearance and a complete absence of associated species. If foreign matter is attached it is frequently of a porous slag-like nature. The crystals are usually small, due to rather rapid cooling, and arborescent groupings are common.

Water-soluble mineral-equivalents which have been grown on rock-matrixes are much harder to detect because the faker has simply duplicated the very processes that occur in nature. However, the most common of these is synthetic chalcanthite. Once one has seen the poor quality and scarcity of natural chalcanthite, the very fine quality synthetic specimens become obvious by comparison. When the collector is not sure of the natural appearance of a specimen, he should seek the advice of a more knowledgeable and experienced collector.

Faked crystal specimens of the native precious metals can sometimes be detected by their low density. But clever fakers may put the specimen in a sealed box where it cannot be carefully examined, and may line the box with concealed heavy lead foil to add weight, thus disguising the low density of the fake. (One is reminded of the folk-lore precaution against buying a "pig-in-a-poke.") One should never purchase a mineral specimen which cannot be examined carefully.

TYPE H: Falsified surface composition

The simple plating of a mineral or crystal by painting is easily detected by scratching an unobtrusive portion with a needle. Most platings do not adhere well to crystals. Metal nuggets electroplated with gold or other precious metals are easily detected by their low density.

Chemical tarnishing by boiling the mineral (usually oxides or sulfides) in chlorine bleaches and other compounds is very difficult to detect if done carefully. More research is needed on this problem.

CLOSING REMARKS

The advice of Gottlieb Tobias Wilhelm, written in Vienna in 1827, is still valid today:

> "If one must rely on purchases to build one's collection, then a few words of caution must be given. At least for beginners, because of the lack of knowledge of the objects, and of the character of the mineral dealer, which often leads to deception. Such unscrupulous spectators often switch identities of minerals, ask unrealistic prices and not rarely invent localities, often far removed from the actual source. The beginner must not fall into the grips of such peddlers lest he obtain misidentified specimens, poor examples, overly expensive pieces or such pieces with false localities. The advice of experienced men, and in the case of pre-

cious stone purchases, the advice of a reliable jeweler or stone cutter would be indicated to prevent a poor purchase by those with little experience." (Translation by Herbert Obodda)

In other words, Let The Buyer Beware. Experienced collectors and dealers have many times observed, in themselves and others, the "want-to-believe" syndrome, a subconscious desire for a beautiful specimen to be legitimate and not fake. We all dream of the once-in-a-lifetime opportunity to acquire a really superb specimen at a low price, whether in cash or trade. When the opportunity comes at last, in some dimly lit, out-of-the-way place or at a bustling mineral show, offered by some apparently trustworthy and guileless person, we abandon suspicion and *bite* with vigor, only to find out much later, if at all, that we were bitten instead.

Dispassionate caution is the best defense against the purchasing of fakes. And fakes are indeed abundant today. Heightened awareness (due to researching this paper) caused the authors to recognize a huge number of fakes at several major mineral shows, some being carried around by the satchel-full, ready for unsuspecting buyers. It is likely that the increasing prices commanded by fine mineral specimens, combined with the availability of new technologies and an increasing demand for quality and perfection, have greatly stimulated the production of fakes in recent years. The consumer of today must be aware and cautious, or risk being repeatedly victimized.

NOTE:

The authors request that readers *not* send them suspected fakes for verification. However, information and photos regarding fakes will be much appreciated.

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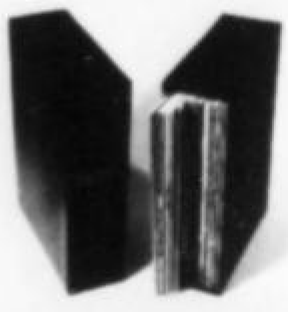

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Edingtonite and Natrolite
from Ice River, British Columbia

by **J. D. Grice** and **R. A. Gault**
National Museum of Natural Sciences
National Museums of Canada
Ottawa, Ontario. K1A 0M8

Edingtonite and natrolite crystals of exceptional quality have been found in the Ice River complex, British Columbia, Canada. This complex is an alkaline intrusion, an assemblage of rocks which is often the source of interesting minerals and sometimes of economic ore deposits. The Ice River has been known as a source of sodalite for almost 100 years but not until recently has it become a noteworthy zeolite locality.

LOCATION AND ACCESS

The Ice River alkaline complex lies within the western part of the Rocky Mountains, primarily within the Ottertail Range. It is centered approximately 25 kilometers south of Field, British Columbia, and most of the complex is contained within the Yoho and Kootenay National Park boundaries (Fig. 1). Collecting within a national park is prohibited without permission from Parks Canada.

Access to the Ice River complex is difficult. There is a restricted-access fire road leaving the Trans-Canada Highway near Hoodoo Creek which is traversable for 18 km to the south end of the Ice River Valley. All portions of the complex must be accessed by backpacking up valleys and by tedious climbs.

The topography is very rugged and alpine in nature (Fig. 2). There are two main streams flowing from north to south which cut the complex: Ice River and Moose Creek (Fig. 3). The valleys are deep (1500 m) and glaciers have modified them to U-shapes (Fig. 3). There is very little rock outcrop below the timberline, which is at a level about 2200 m above sea level. Dense undergrowth makes walking over the lower slopes difficult. Above the treeline one encounters large talus slopes which all too often end in sheer cliffs. In addition to the sample collecting difficulties imposed by the physiography, there are unexpected squalls and snow storms which impede progress.

HISTORY

The portion of the Rocky Mountains in which the Ice River complex lies was originally inhabited by the Stoney and Kootenay Indians who used the trails which are now maintained by the staff of Yoho and Kootenay National Parks. The area was initially described in a report by Sir George Simpson of his travels to the area in 1841, in which he described, in addition to the spectacular scenery, "a troublesome and venomous species of winged insect, which, in size and appearance, might have been taken for a cross between the bull-dog and the house-fly," (Simpson, 1847). In 1885 the Canadian Pacific Railway was completed, linking east to west and opening the area to further exploration. Yoho and Kootenay National Parks were established the following year in an effort to preserve the natural environment of this magnificent section of the Rocky Mountains.

The first geological investigation of the Ice River complex was made by G. M. Dawson in 1885, when he traced sodalite and syenite pebbles to their source in the Ice River Valley. The first intensive investigation was carried out by J. A. Allan during the 1910 and 1911 field seasons. In his report, published in 1914, he noted the occurrence of large crystals of acmite, natrolite and other zeolites and thick seams of fine-quality blue sodalite. A complete reinvestigation and mapping of the complex was recently undertaken by K. L. Currie of the Geological Survey of Canada and published in 1975.

Several mines, all located in the sedimentary rocks surrounding the complex, produced lead, zinc and copper during brief periods in the early 1900's but were soon abandoned due to low ore grades and difficult access. Several adits, such as those which can be viewed from the Trans-Canada Highway in the Kicking Horse Pass (Fig. 4), were driven into vertical cliffs in seemingly impossible positions, attesting to the tenacity of the miners of the day. Interest in the Waterloo Mining claim, which is situated in Moose Creek Valley outside Yoho National Park, was renewed in 1969 for radioactives and further exploration work was carried out. Sodalite, which is common throughout the complex, has been "mined" from various places and used locally for jewelry and ornamental items. The only source outside the park is in Moose Creek Valley but access is very difficult and the talus slope, rich in sodalite, is held by claims.

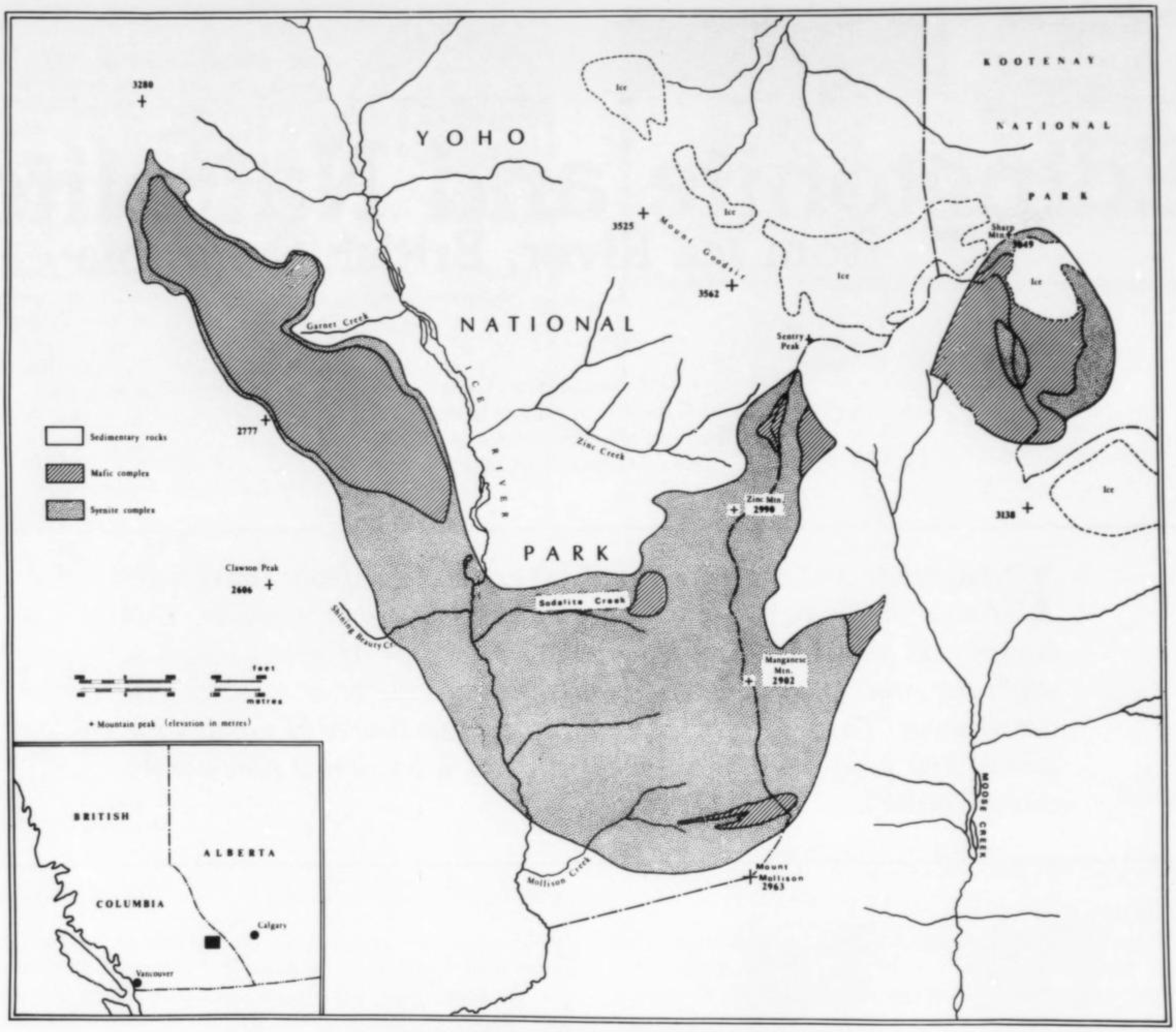

Figure 1. **Location map and general geology of the Ice River complex, British Columbia (modified after Currie, 1975).**

GENERAL GEOLOGY

The Ice River complex lies within sedimentary rocks of Cambrian and Lower Ordovician age (450 to 550 million years old). The exposed portion of the complex is trough-shaped and is approximately 18 km in length and 6 km in width at its maximum (Fig. 1). The age of emplacement is roughly 245 million years (Currie, 1975).

The Ice River complex is described as an alkaline intrusion. The initial magma, rich in alkalis (sodium and potassium), mafics (iron and magnesium) and calcium, separated into two liquid phases (Currie, 1975). The first fraction intruded was rich in mafics and calcium, crystallizing into a series of rhythmically layered rocks rich in pyroxenes, magnetite, nepheline, micas and, later, calcite (carbonatite rock type). Shortly after the emplacement of the first fluid, a second magma rich in alkalis intruded, crystallizing into a series of syenite rocks containing feldspars, feldspathoids (nepheline, sodalite), zeolites and pyroxenes. In Currie's detailed mapping and discussion of this area he has subdivided these two major units into several rock types but, for simplicity, we have shown only the two units (Fig. 1).

The major mountain building orogeny of this belt is believed to have begun in the mid-Mesozoic, approximately 180 million years ago (Price and Mountjoy, 1970). During this period of deformation the sedimentary rocks were severely folded and faulted but the block of dense rocks of the Ice River alkaline complex remained relatively unaltered.

MINERALOGY

In exploring the complex a series of traverses were set up, based on the geological map (Currie, 1975) and aerial photographs. Careful inspection of talus slopes gave an indication of areas of mineralogical interest which, in some cases, could be traced to the outcrop. The syenite rocks afforded the most rewarding specimens. In general the rocks of the Ice River complex are composed of medium to coarse, interlocking grains. This type of rock does not lend itself to the development of good crystal specimens and one must pursue rare pockets or veins. These are probably quite late in the crystallization sequence of the syenite complex and are rich in the rarer species edingtonite, natrolite and ancylite. The minerals listed in Table 1 are those collected by the authors in 1979 and subsequently identified. A few of the more interesting species are described in detail below. Minerals other than those listed have been reported by Allan (1914) and Currie (1975) and include corundum, hercynite, leucoxene, perovskite and scapolite.

Figure 2. Camp at 2400 m elevation with Sentry Peak in the background. A July storm precipitated almost a meter of snow, causing frequent avalanches. A superb natrolite pocket was found just below the ridge on the left.

Figure 4. Several mine adits in the lower cliffs of Mount Field, Kicking Horse Valley.

Figure 3. Glaciated valley of Moose Creek looking south to the Columbia River Valley. Note the layered sedimentary rocks across the valley in contrast to the massive alkaline intrusive rocks to the right.

Table 1. A list of minerals from the Ice River complex, British Columbia.

Acmite*	$NaFeSi_2O_6$	Emerald-green, elongate crystals to 10 cm — common in sodalite-syenite.
Analcime	$NaAlSi_2O_6\cdot H_2O$	White, opaque masses to 8 x 7 cm — lamellar twin striations often evident — found in late syenites.
Ancylite*	$SrCe(CO_3)_2(OH)\cdot H_2O$	Pinkish grey, euhedral prismatic crystals to 2.5 mm — associated with natrolite.
Andradite	$Ca_3(Fe,Ti)_2(SiO_4)_3$	Black, opaque, anhedral grains < 1 mm to subhedral crystals of 1 cm — melanite variety sometimes schorlomite in composition (Currie, 1975) — major constituent of some mafic rocks.
Apatite	$Ca_5(PO_4)_3(F,OH)$	Red-brown, prismatic crystals to 5 mm — common constituent in some mafic rocks.
Augite	$Ca(Fe,Mg,Ti)(Si,Al)_2O_6$	Very dark green prismatic crystals to 1 cm — Ti-rich — essential constituent of mafic rocks.
Calcite	$CaCO_3$	Turbid-brown, coarse cleavable masses as main carbonatite constituent — also pale yellow crystals or white cleavage blocks associated with zeolite pockets in syenite rocks.
Cancrinite	$(Na,K,Ca)_{6-8}(Al,Si)_{12}O_{24}(SO_4,CO_3,Cl)\cdot nH_2O$	White, massive — occurs as veins in nepheline syenite or as replacement of sodalite, nepheline and microcline.
Cerussite	$PbCO_3$	White, powdery coating on galena.
Edingtonite*	$BaAl_2Si_3O_{10}\cdot 4H_2O$	Colorless to white, transparent to translucent, prismatic crystals to 7 x 2 x 2 mm — associated with natrolite and calcite pockets in nepheline syenite.
Fluorite	CaF_2	Purple cleavable masses to 7 mm — rare constituent of the carbonatite.
Feldspar group	$(K,Na)AlSi_3O_8$	Usually a micro-perthitic intergrowth of microcline and albite — main constituent of syenites.
Galena	PbS	Anhedral grains, up to 1 cm — rare in sodalite syenite and zeolite-rich pockets.
Kaersutite	$(Ca,Na,K)_3(Fe,Mg)_4Ti(Si,Al)_8O_{22}(OH)_2$	Dark green masses to a few mm — major constituent of nepheline syenite.
Ilmenite	$FeTiO_3$	Lustrous, tabular crystals to 15 x 15 x 2 mm — associated with mafic complex.
Magnetite	Fe_3O_4	Octahedra to 2 mm — major constituent of some mafic rocks.
Mica group	$K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$	Phlogopite — biotite is a common constituent of mafic rocks — flakes to several cm — also found replacing acmite.
Natrolite*	$Na_2Al_2Si_3O_{10}\cdot 2H_2O$	Colorless to white, transparent to translucent prismatic crystals to 16 x 3 x 3 cm — in calcite pockets in nepheline syenite.
Nepheline	$(Na,K)AlSiO_4$	Gray, subhedral prismatic crystals to approximately 1 cm — common and widely distributed throughout complex.
Pyrite	FeS_2	Cubes to several mm — uncommon in syenites.
Sodalite*	$Na_4Al_3(SiO_4)_3Cl$	Dark to light blue, white or pink rarely — veins to 5 cm — essential constituent of sodalite-syenite.
Sphalerite	$(Zn,Fe)S$	Light brown cleavage sections to a few mm — rare in sodalite syenite.
Titanite	$CaTiSiO_5$	Brilliant yellow — crystals to 1 mm — accessory mineral in several rock types.
Tremolite-actinolite		Dark green fibrous mass to several cm — in skarn.
Vesuvianite	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$	Light brown cleavage fragments to 8 x 5 cm — associated with wollastonite in skarn rock.
Wollastonite	$CaSiO_3$	White, compact fibers to a few cm — in skarn and some mafic rocks.
Zircon	$ZrSiO_4$	Lavendar-grey, highly lustrous, euhedral, dipyramidal crystals to 1 mm — in sodalite syenite.

*Further details are given in the text.

Where a visual identification was not sufficient, optical and X-ray techniques were employed. The major chemical elements of acmite, ancylite, andradite, edingtonite, natrolite and phlogopite were determined on an energy dispersive spectrometer (EDS) by D. G. W. Smith, University of Alberta. Chemical analyses of the major groups (amphibole, feldspar, garnet, mica and pyroxene) are given by Currie (1975).

Edingtonite from the Ice River was first identified in May, 1978 (NMNS #40378), and subsequently loaned to the Geological Survey of Canada (Ansell *et al.*, in press) for chemical analysis (Table 2). This very rare zeolite occurs in pockets and seams in nepheline syenite associated with natrolite and calcite. The crystals are transparent to translucent, colorless to white, with prisms measuring up to 7 by 2 by 2 mm. The better specimens are rich in edingtonite, with crystals almost completely covering pale yellow calcite rhombohedra.

This edingtonite is almost a pure end-member (Table 2). Three different crystals were analyzed by M. Bonardi, Geological Survey of Canada, on an electron microprobe using the wavelength dispersive technique. A subsequent EDS analysis gave slightly higher K_2O (0.9 wt. percent) and in addition 0.2 wt. percent ZnO. Density and optical measurements were made on clear, colorless fragments; crystals most commonly have cloudy cores: D(observed) = 2.72(1) gm/cm^3; $\alpha = 1.535(2)$, $\beta = 1.542(2)$, $\gamma = 1.545(2)$, $2V = 62°$. The 2V in the cloudy cores was much smaller, being as little as 10° in some crystals. Some fragments appeared to have lamellar twinning on {110}.

Edingtonite is orthorhombic (pseudo-tetragonal) and belongs to the non-centrosymmetric crystal class 222. The morphology of the Ice River crystals is very simple. Crystals have good terminations (Fig. 5) and some specimens are doubly terminated. Forms present include the prism *m*{110}, two sets of disphenoids *o*{111} and

Table 2. Chemical analyses of minerals from the Ice River complex, British Columbia.

	Edingtonite[1]	Natrolite[2]	Sodalite[3]	Acmite[4]
SiO_2	36.3	47.17	36.2	52.
Al_2O_3	20.6	26.84	32.6	1.2
Fe_2O_3		0.07		35.
MgO		0.05		.0
CaO		0.12		.1
BaO	28.6			
Na_2O		15.89	25.5	15.
K_2O	0.32	0.02		.0
H_2O	12.8	9.58		
Cl			5.8	
SO_3			0.25	
Total	98.62	99.74	100.35	103.3

1. Analyst: M. Bonardi, GSC; see Ansell *et al.*, 1980. Water analysis by R. Ramik, Royal Ontario Museum, Toronto.
2. See Phillips, 1916.
3. See Annerstein *et al.*, 1979.
4. Analyst: D. G. W. Smith, see text, semi-quantitative EDS.

Figure 5. **White edingtonite crystal 2.5 mm long (NMNS#41267).**

$p\{1\bar{1}1\}$, and the basal pinacoid $c\{001\}$ (Fig. 6a, b). On most crystals the disphenoids are almost equally developed giving the morphology a tetragonal appearance (Fig. 6b). Careful inspection of rare, doubly-terminated crystals gives the true symmetry (Fig. 6a). The cell dimensions of the Ice River edingtonite, as measured by G. Ansell of the Geological Survey of Canada, indicate this mineral's pseudo-tetragonal nature: a = 9.583(7), b = 9.624(7), c = 6.527(6).

Natrolite, like edingtonite, occurs in pockets in the nepheline syenite. Coarse, cleavable calcite is the only other major constituent of these pockets, although edingtonite is sometimes present. Very minor associated species include pyrite, galena, acmite, zircon, ancylite, magnetite and phlogopite. Where the pockets are open, excellent prismatic crystals with complex terminations are found (Fig. 7). Crystals are transparent, colorless to white; the largest observed measured 16 by 3 by 3 cm. Gemmy crystals with bright faces make these natrolites some of the finest we have seen.

An early chemical analysis (Table 2) of the Ice River natrolite is given by Phillips (1916). An EDS check on gemmy material confirmed it to be a very pure end-member with no detectable calcium or potassium.

The forms on nine crystals were measured and a compilation of these is given in the idealized drawing of Figure 8. Natrolite is orthorhombic (pseudo-tetragonal) and belongs to the non-centrosymmetric crystal class *mm*2. The lack of a center of symmetry is evident on doubly-terminated crystals, which are unequally developed on either end; the end with frosted crystal faces invariably having much fewer forms than the end with bright faces. The 19 forms observed are: prisms $m\{110\}$ and $n\{120\}$, pinacoids $a\{100\}$ and $b\{010\}$, domes $D\{101\}$, $u\{301\}$ and $e\{011\}$, and pyramids $o\{111\}$, $o'\{11\bar{1}\}$, $s\{311\}$, $s'\{31\bar{1}\}$, $y\{131\}$, $t\{511\}$, $t'\{51\bar{1}\}$, $\tau\{151\}$, $z\{331\}$, $\pi\{551\}$, $p\{531\}$ and $r\{351\}$. No single crystal was found with all of these forms but each crystal contained several, the most common being {110}, {100}, {010}, {111}, {311} and {331}.

In one natrolite pocket a few crystals of **ancylite** were found. It occurs as euhedral, pale-pink, prismatic crystals with a pyramidal termination. The largest crystal is 2.5 mm in length and 1 mm wide. An EDS analysis on this material confirmed its identification and indicated a significant but undetermined amount of neodymium.

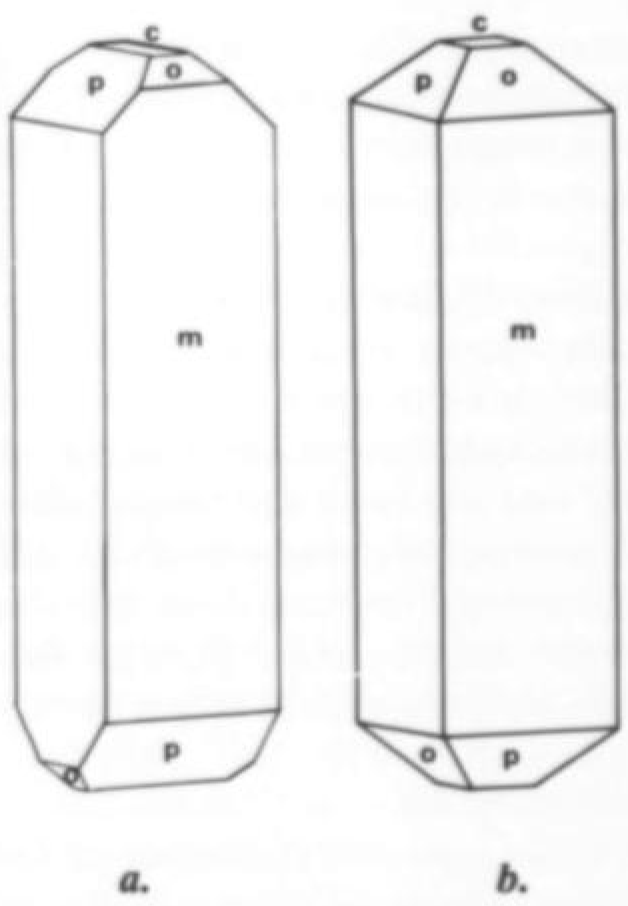

Figure 6a. **Idealized drawing of an edingtonite crystal showing its true orthorhombic symmetry 222. Crystal forms are prism $m\{110\}$, disphenoids $o\{111\}$ and $p\{1\bar{1}1\}$, and basal pinacoid $c\{001\}$.** *6b.* **Sketch of an edingtonite crystal with the crystal forms given in Figure 6a but displaying a pseudo-tetragonal habit.**

Sodalite was the first mineral to attract attention in the Ice River. It is widely distributed throughout the complex as an essential constituent of the sodalite-syenite and as a minor constituent of other rock types in the syenitic complex. It occurs as primary veins up to 5 cm in width and also as a secondary alteration of nepheline. Commonly the color is deep blue but grades through sky-blue to white (rare). Green sodalite has been reported as well (Currie, 1975). Chemical analyses (Table 2) of this material show it to be an almost pure sodalite end-member.

Often associated with sodalite is a very pure **acmite** (semi-

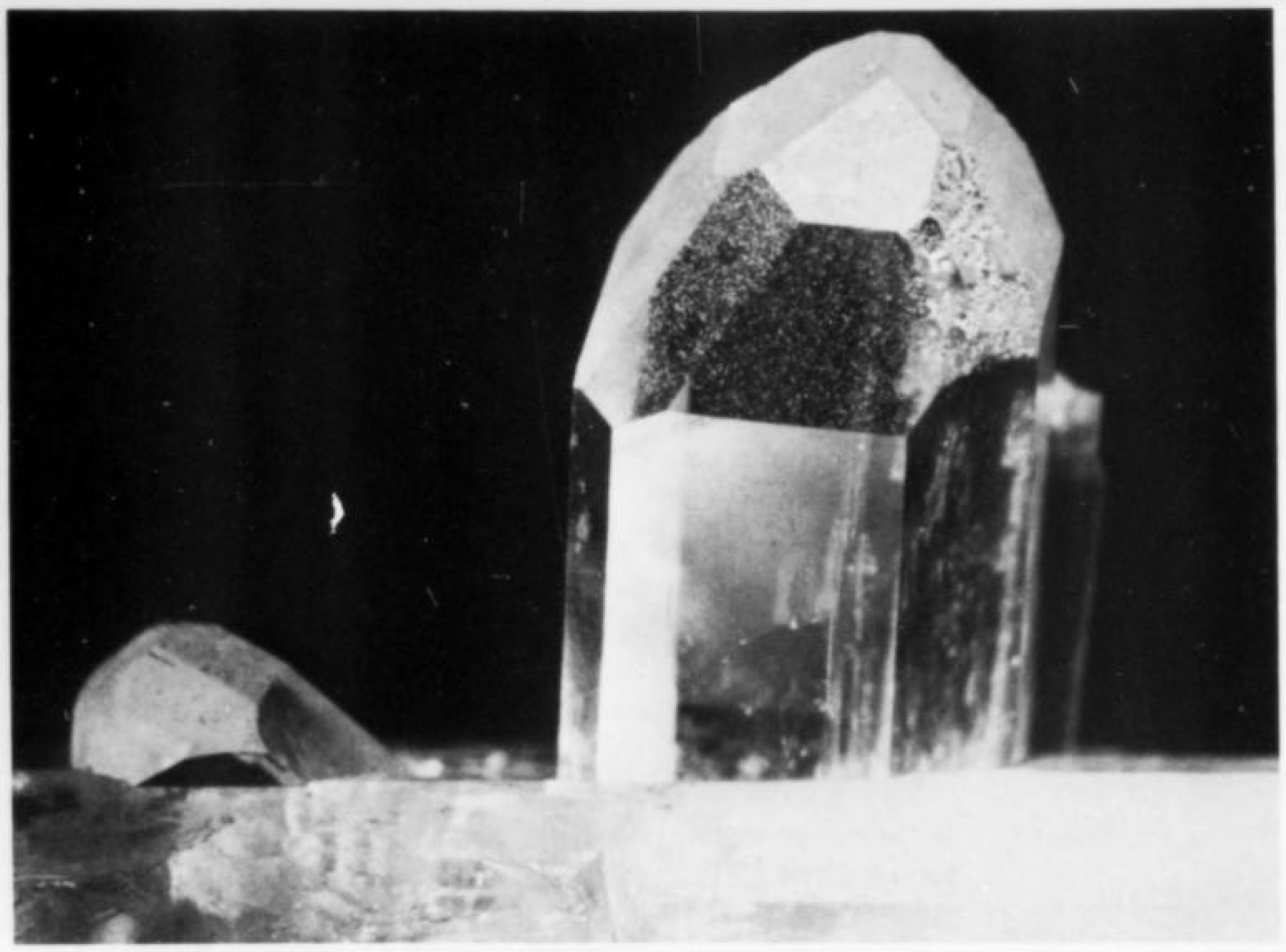

Figure 7. **Clear, colorless natrolite (1.5 cm long) on larger, white prismatic natrolite (NMNS #43218).**

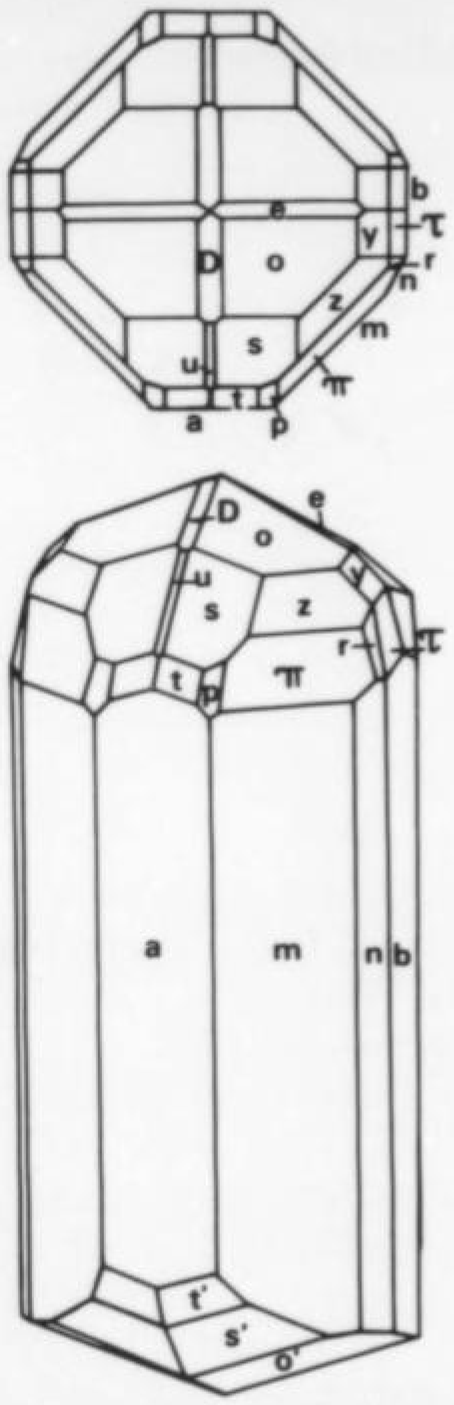

Figure 8. **Idealized drawing of a natrolite crystal showing a compilation of all the observed forms: pinacoids** *a*{**100**}, *b*{**010**}, **prisms** *m*{**110**}, *n*{**120**}, **domes** *D*{**101**}, *u*{**301**}, *e*{**011**}, **pyramids** *o*{**111**}, *o*'$\{11\bar{1}\}$. *s*{**311**}, *s*'$\{31\bar{1}\}$, *y*{**131**}, *t*{**511**}, *t*'$\{51\bar{1}\}$, *τ*{**151**}, *z*{**331**}, *π*{**551**}, *p*{**531**} **and** *r*{**351**}.

quantitative EDS analysis in Table 2). Prismatic crystals are bright emerald-green in color and in pegmatitic phases crystals up to 10 cm in length have been observed. The coarse intergrowths of sodalite, acmite and nepheline make a stunning decorative stone.

ACKNOWLEDGMENTS

The authors would like to thank Parks Canada for permission to collect in Yoho and Kootenay National Parks. We are especially grateful to F. Stevens and D. Mickle of the Yoho National Park for their kind assistance and helpful advice in the field. We gratefully acknowledge the assistance of the following staff of the National Museums of Canada: R. Dinn for her typing of the manuscript, C. Douglas and G. Van Velthuizen for drafting assistance and R. Williams for his critical review of the manuscript.

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Boehmite

from syenite pegmatites in the Oslo region, Norway

by **Alf Olav Larsen**
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INTRODUCTION

Boehmite is found in most bauxite deposits, sometimes as a major constituent, formed by weathering and desilication of aluminum silicate minerals under tropical conditions. Boehmite from bauxite deposits is usually submicroscopic and the crystallinity is variable. Because of this, little is known about the morphology of natural boehmite crystals. Larger crystals up to fractions of a millimeter in size are very rare and few occurrences are reported, notably from peralkaline rocks (Bohnstedt-Kupletskaya and Vlodavetz, 1945; Shelley *et al.*, 1977). Boehmite crystals up to 0.1 mm in size are reported in vugs in corundum (Sahama *et al.*, 1973). The present article describes boehmite occurring as millimeter-size crystals, the largest ones hitherto reported, from vugs in natrolite formed as a result of hydrothermal alteration of nepheline in syenite pegmatite. Boehmite is found to be a common constituent of such alteration products, known as *spreustein*.

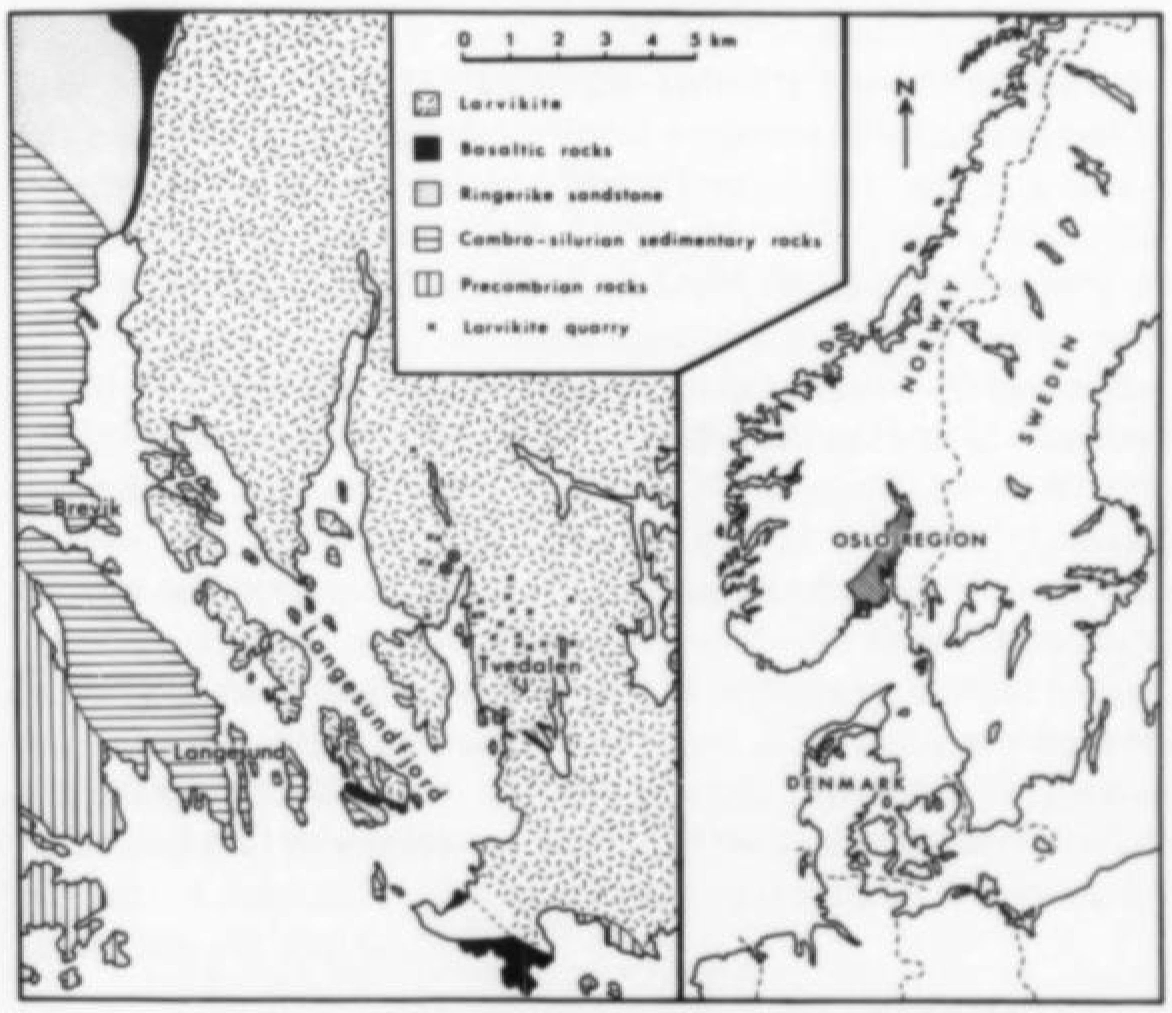


Figure 1. **Geological map of the Langesundfjord area. The Saga quarries are marked with circles (I lower, II upper). Geology mainly after Oftedal *et al.* (1960).**

OCCURRENCE AND PARAGENESES

Syenite pegmatites in the monzonitic rock larvikite in the southwestern part of the Oslo Region, southern Norway, are known to contain a large suite of rare and unusual minerals. Of the about 120 minerals found in these pegmatites, 20 have originally been described from there (Brøgger, 1890). The pegmatites consist of white to gray microcline, either aegirine or a barkevikitic hornblende and biotite (lepidomelane). Nepheline, sodalite, magnetite, analcime and zeolites are typically abundant, but may be absent in some areas. Accessory minerals such as zircon, eudialyte (variety *eucolite*), wöhlerite, astrophyllite, catapleiite and pyrochlore are often found, but have an uneven distribution.

Hydrothermal alteration of nepheline and sodalite results in either micaceous (illite, smectite) or zeolitic material. In the Langesundfjord area the latter has been called *spreustein* because of its fibrous appearance. The main mineral in *spreustein* is natrolite which occurs as white to reddish, finely fibrous, dense aggregates as well as coarsely crystalline masses. The presence of alumina minerals in *spreustein* was already known 120 years ago, and Brøgger (1890) found 3 percent acid-insoluble material in *spreustein*, in-

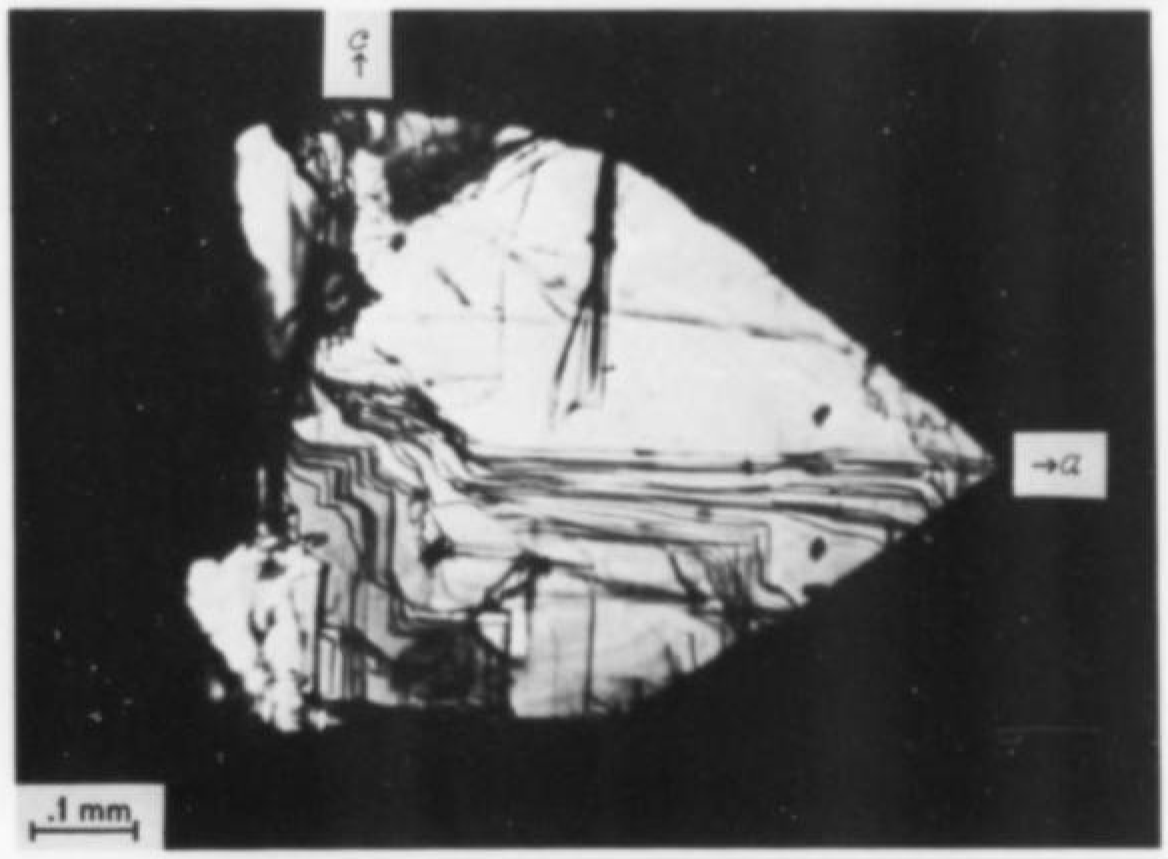
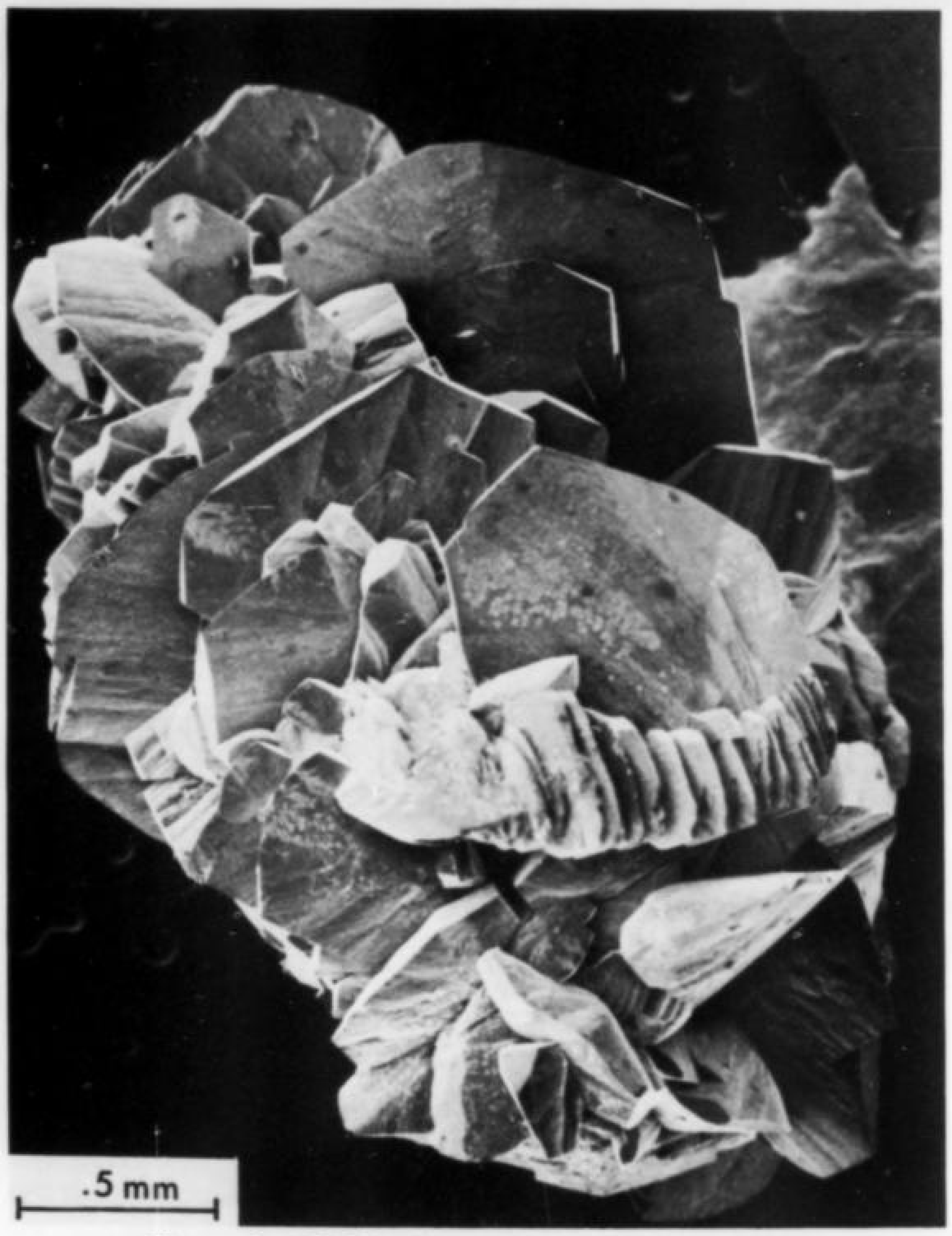
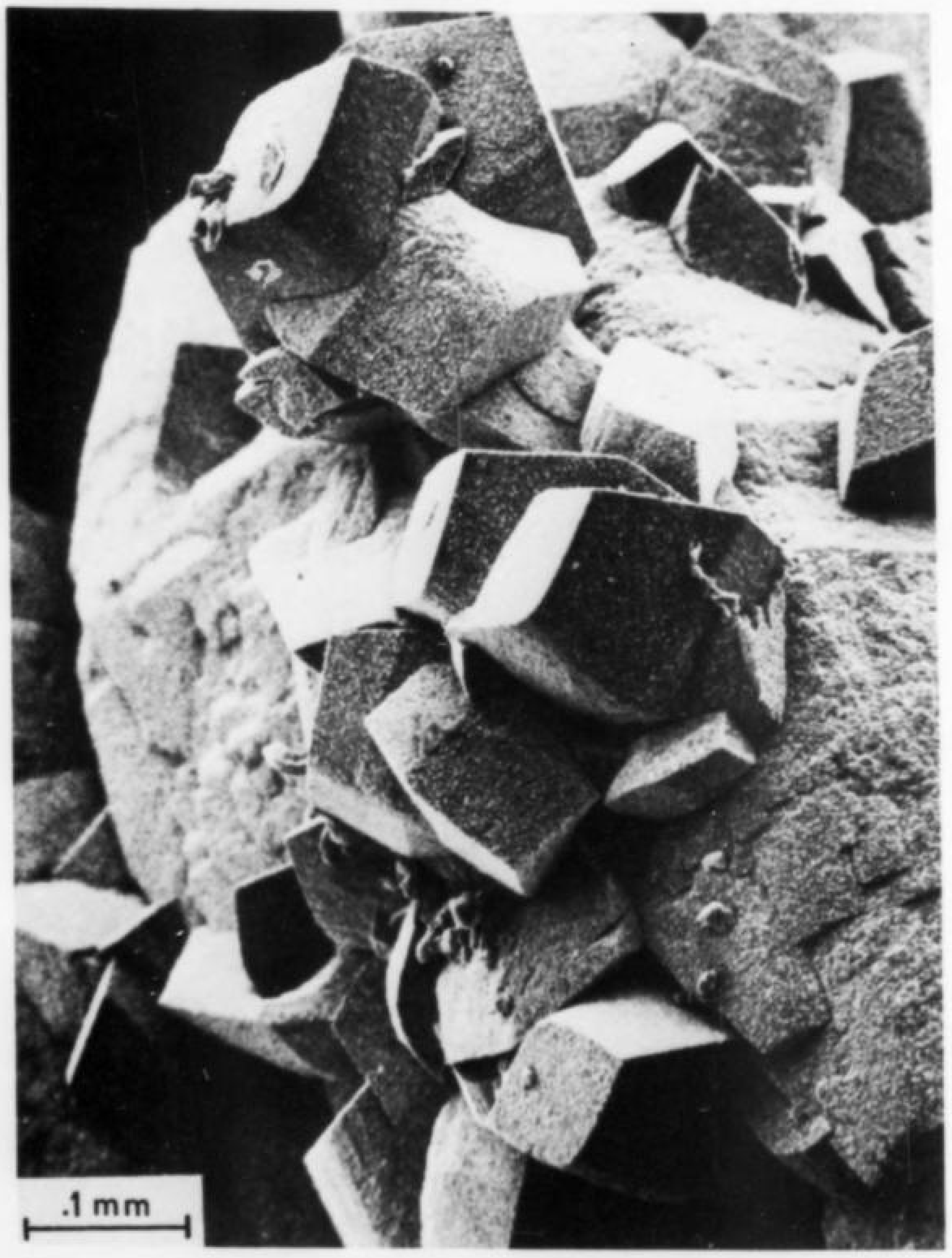


Figure 2. **Cleavage fragment of a boehmite crystal lying on (010) showing the {100} and {001} cleavages. Crossed nicols.**



Figue 3. **SEM photograph of intergrown boehmite crystals from the Saga I quarry.**

Figure 4. **SEM photograph of boehmite crystals from the Saga II quarry.**



terpreted by him as being diaspore. In the Langesundfjord area diaspore is not uncommon as small violet specks in white *spreustein* and it was described as small crystals in vugs in natrolite by Flink (1899) and Sjögren (1899). Gibbsite has also been found in vugs in natrolite as a decomposition product of nepheline or sodalite. Edgar (1965) investigated the mineralogical composition of hydrothermal alteration products of nepheline from various localities throughout the world. He stated that, "in none of the samples studied . . . is there any evidence of diaspore or other alumina-bearing minerals." In his listings of *d*-values he let the 6.1 Å peak, the most intense *d*-value for boehmite, remain unidentified in three samples, two of them from the Langesundfjord area. To ascertain whether boehmite is present or not in *spreustein* from this area, eight samples of different colors and appearances were analyzed on an X-ray diffractometer, both as bulk samples and as insoluble residues following hydrochloric acid treatment. Diffractograms of the bulk samples showed the main mineral in all samples to be natrolite with a rather strong 6.1 Å boehmite peak. The acid-resistant material proved in all cases to be boehmite with more or less diaspore in five of the samples. The diaspore peaks, however, did not show up on the bulk sample diffractograms, probably because of the small amount of the material present. Thus, boehmite and diaspore are widespread constituents of Norwegian *spreusteins* although usually in a very fine grained state. Boehmite from a similar occurrence was briefly mentioned by Sæbø (1966) from Brathagen, 17 km northeast of the Langesundfjord.

Recently relatively large crystals of boehmite have been found in the Saga quarries (I and II) on the mainland on the east side of the Langesundfjord (Fig. 1). Here in the Tvedalen area numerous quarries are worked for larvikite rock which, because of its labradorescent feldspar, is used for ornamental purposes. During quarrying of the larvikite, syenite pegmatites are commonly encountered; they produce many mineral specimens. The Saga I quarry has been especially fruitful in recent years and many rare minerals such as eudidymite, epididymite, berborite, hambergite and tadzhikite have been found. Natrolite as an alteration product of nepheline or, in part, sodalite is very common in the Saga quarries. In centimeter-size vugs in the fibrous natrolite, crystals of boehmite are sometimes found lining the walls or almost completely filling smaller vugs. Only rarely are other minerals found with boehmite, but in the Saga II quarry berborite, fluorite, calcite and hematite occur in small amounts with boehmite.

PHYSICAL AND OPTICAL PROPERTIES

The boehmite is colorless to very pale grayish brown and the streak is white. The luster is pearly on (010), otherwise vitreous. Hardness = 3½. The density of the boehmite is 3.05(2) g/cm^3 determined by the sink/float method in Clerici solution diluted with water.

Boehmite possesses a perfect {010} cleavage; {100} and {001} are also visible (Fig. 2). All three cleavages have only once before been observed (Bohnstedt-Kupletskaya and Vlodavetz, 1945). Lapparent (1930) and Shelley *et al.* (1977) observed two of the cleavages, while Sahama *et al.* (1973) only reported the perfect {010} cleavage.

The Saga I boehmite is biaxial (+). Orthoscopic U-stage measurements gave $2V_z = 74(3)°$. The refractive indices $\alpha = 1.644(2)$, $\beta = 1.654(2)$ and $\gamma = 1.664(2)$ were measured by the immersion method in sodium light. The optical orientation is $\alpha \parallel c$, $\beta \parallel b$ and $\gamma \parallel a$.

MORPHOLOGY

Boehmite from the Saga quarries occurs as flattened dipyramidal crystals up to 1 mm in length, usually in intergrown aggregates (Fig. 3). The crystals were unsuitable for optical goniometry. Therefore the interfacial angles were measured under the microscope and from SEM photos. The angles obtained were compared with those calculated from the unit cell dimensions, and in this way the appropriate indices were fitted to the various faces.

Boehmite crystals from the Saga II quarry are very simple in habit, showing only the *p*{111} dipyramid and *b*{010} pinacoid (Figs. 4 and 6a). The edges between the {111} faces on each side of the crystals are rounded and all faces are dull. The Saga I boehmite crystals are dominated by the *p*{111} dipyramid and *k*{011} dome (Fig. 6b) whose faces are dull, slightly curved and roughly striated. The majority of the crystals also show small *b*{010} and *l*{210} prism faces which, however, are smooth and shiny (Figs. 5 and 6c).

X-RAY CRYSTALLOGRAPHY

Unit cell dimensions for the Saga I boehmite are a = 3.687(9) Å, b = 12.226(9) Å, c = 2.866(2) Å and V = 129.2 Å^3. The data were obtained by least square refinement from an X-ray diffractogram using CuKα_1 radiation (λ = 1.5418 Å), graphite monochromator and NaCl as internal standard. Recent investigation of synthetic boehmite confirmed the space group to be *Amam* (Christoph *et al.*, 1979).

Table 1. Chemical composition (weight percent oxides) of boehmite.

	Saga I	AlO(OH)
SiO_2	0.09	
TiO_2	0.05	
Al_2O_3	84.86	84.99
Fe_2O_3	0.06	
Ga_2O_3	0.02	
Mn_2O_3	0.01	
CaO	0.02	
H_2O	14.97	15.01
Total	100.08	100.00

CHEMISTRY AND THERMAL PROPERTIES

Boehmite from the Saga I quarry was handpicked under the binocular microscope and small amounts of natrolite removed by the use of heavy liquids. Finely ground boehmite dried at 110° C was used for the analysis. The elements were analyzed by X-ray fluorescence spectrometry using synthetic standards. Water was determined as loss on ignition at 900° C. The results are shown in Table 1. The Tvedalen boehmite is very close to pure AlO(OH) with only minor substitution for Al. The very pale brown color is probably due to the small amount of ferric iron.

A differential thermal curve obtained for the same boehmite shows a single, large endothermal peak with its maximum at 560° C due to dehydration and concommitant transition to γ-Al_2O_3. According to MacKenzie (1957) the dehydration peak of boehmites occurs in the region 450°-580° C, depending on the particle size and crystallinity.

CONCLUSION

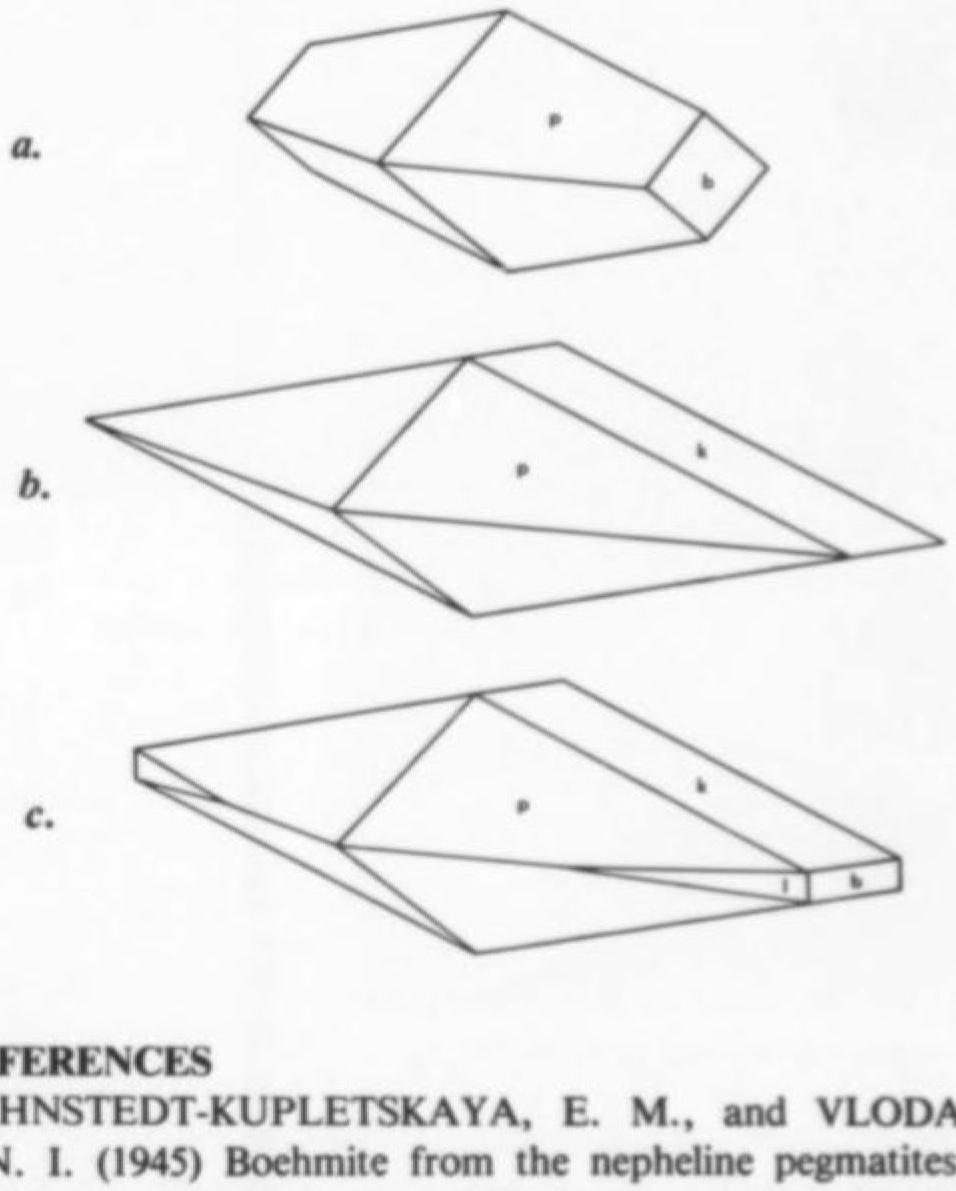
Boehmite, diaspore and gibbsite represent the final products of decomposition of nepheline during a late, low temperature hydrothermal stage in the pegmatite formation. This corresponds with experiments carried out by Morey and Fournier (1961) and Wirsching (1979) who found boehmite to be the final alteration product of nepheline which has been acted upon by solutions having low pH and no Na^+, K^+, Ca^{2+} or SiO_3^{2-}.

ACKNOWLEDGMENTS

I thank J. Naterstad for the U-stage measurements and T. Mellem for making the SEM photographs. W. L. Griffin and G. Raade critically read the manuscript and corrected the English text.

Figure 5. **SEM photograph of boehmite crystals from the Saga I quarry.**

Figure 6. **Somewhat idealized crystals of boehmite from the Saga II quarry (a) and Saga I quarry (b and c). Observed forms: *b*{010}, *k*{011}, *l*{210}, *p*{111}.**



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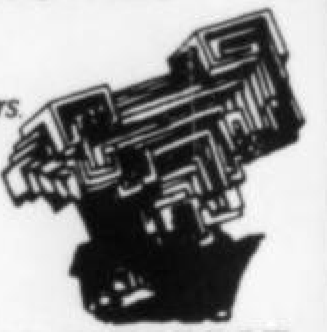

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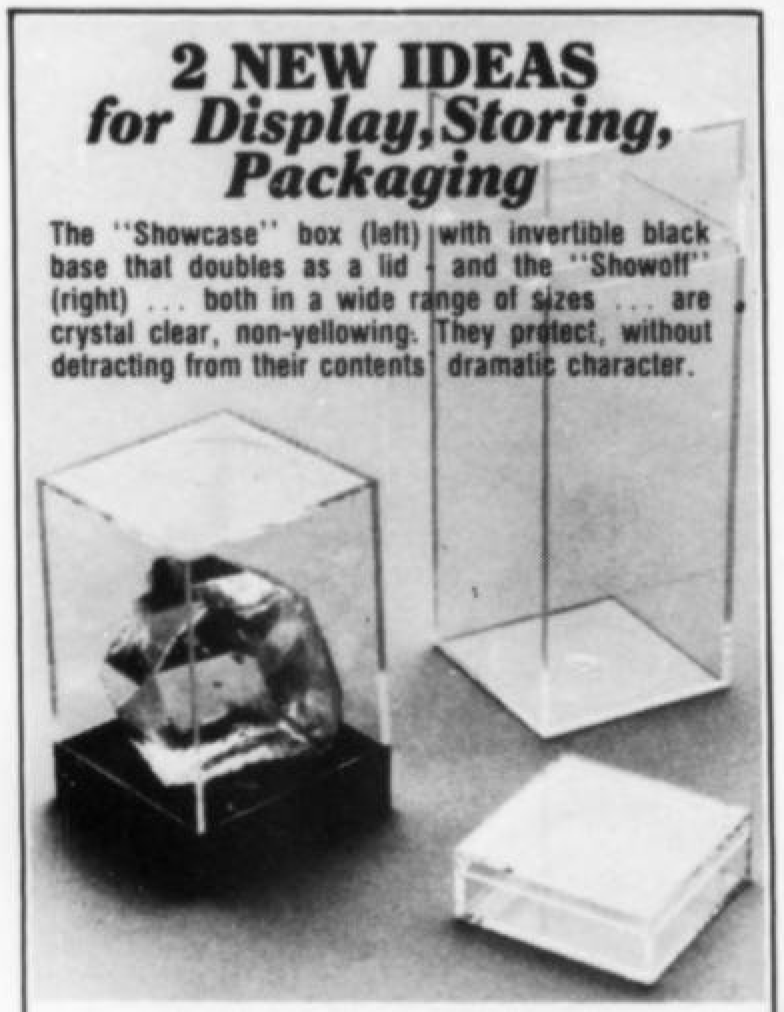

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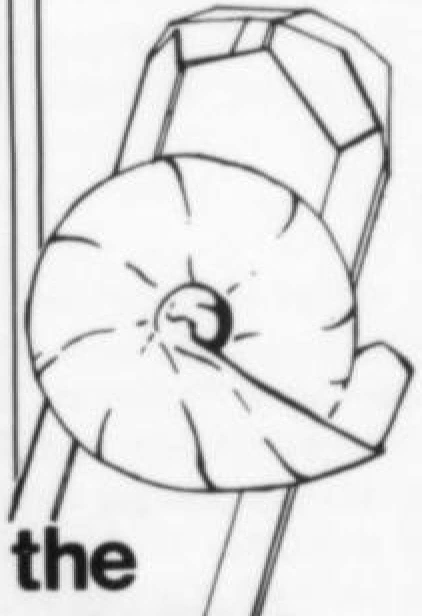

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Morphology and Twinning of Sellaite from Gjerdingen, Norway

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Universitetet i Oslo
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INTRODUCTION

A survey of the rare fluorides from a soda granite (ekerite) at Gjerdingen, Oslo Region, Norway, was recently published in this journal (Raade and Haug, 1980). At that time we were unable to present a good scanning electron micrograph of the rare mineral sellaite (MgF_2). The few specimens available to us only showed the mineral as very rough, flattened bipyramids or as irregular aggregates. In the meantime, we have found some specimens with excellent micro crystals of sellaite, both single and twinned. The unique habit shown by these crystals is considered to justify a short description, as an addendum to our previous paper. The identification of sellaite was made by X-ray powder diffraction.

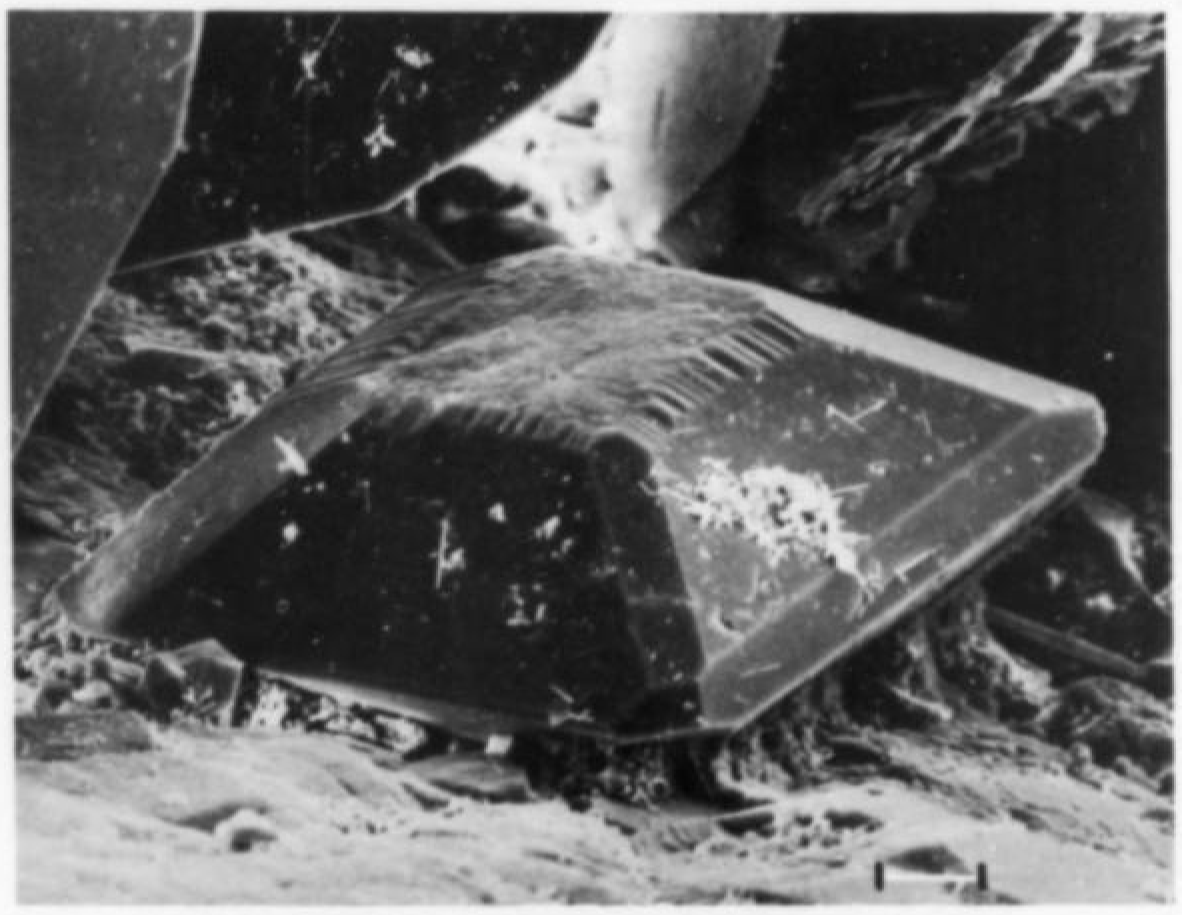

Figure 1. **Bipyramidal crystal of sellaite from Gjerdingen, Norway, showing tetragonal bipyramids *s*{111} and *e*{101}, tetragonal prisms *m*{110} and *a*{100}, and a very irregular basal pinacoid *c*{001}. Scale bar is 10 μm. Compare Figure 2.**

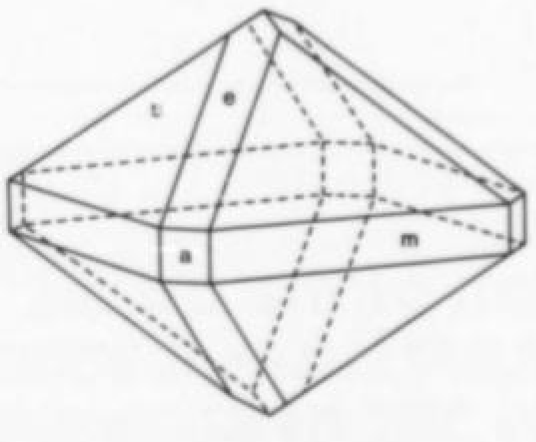

Figure 2. **Clinographic projection of a sellaite crystal showing *s*{111}, *e*{101}, *m*{110}, and *a*{100}.**

STRUCTURE AND CRYSTAL HABIT

Sellaite is tetragonal, space group $P4_2/mnm$, $a = 4.65$, $c = 3.07$ Å. It is isotypic with six other minerals: rutile (TiO_2), paratellurite (TeO_2), cassiterite (SnO_2), plattnerite (PbO_2), pyrolusite (β-MnO_2), and stishovite (high-pressure polymorph of SiO_2). In the crystal structure of these compounds, the cation is surrounded by six oxygens in an octahedral arrangement. The octahedrons form infinite, strongly bonded chains along the *c*-axis by edge-sharing. Neighboring chains are connected by weaker bonds through the sharing of common corners. These structural features explain some of the typical properties of these minerals: crystal elongation along *c*[001] and the more or less pronounced prismatic cleavages {110} and {100}. More specifically, the normal habit of sellaite crystals is described as stubby prismatic to acicular, often as fibrous aggregates (Roberts *et al.*, 1974).

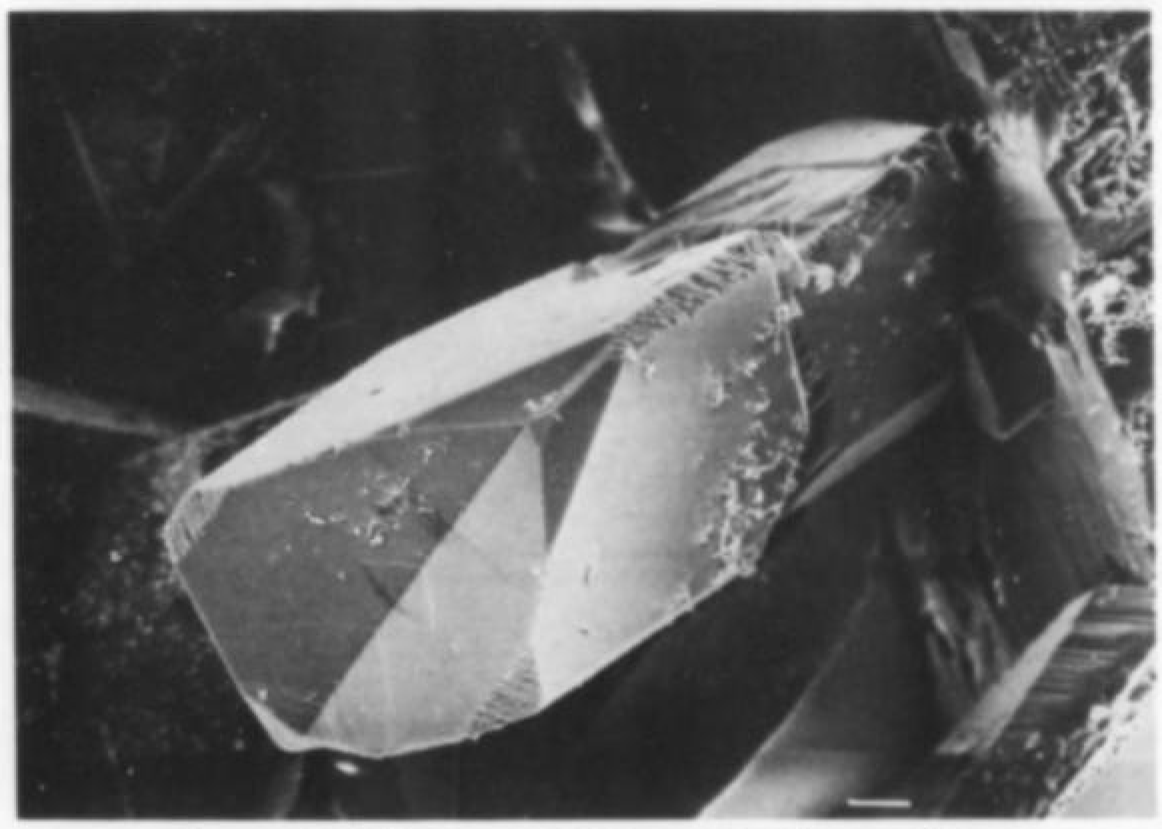

Figure 3. **Sellaite crystal from Gjerdingen, Norway, twinned on *e*{101}. Scale bar is 10 μm. Forms are labeled in Figure 4.**

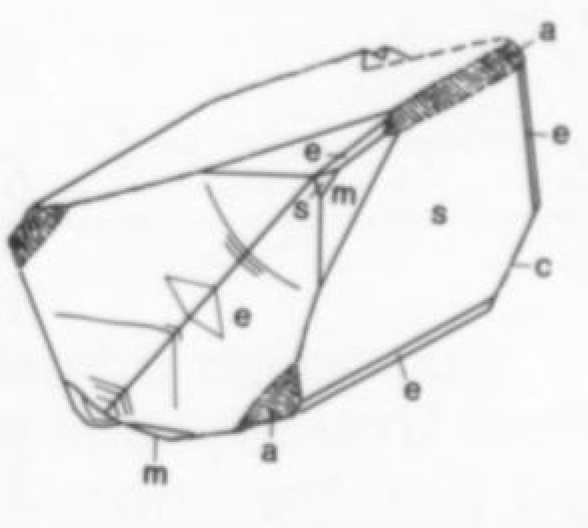

Figure 4. **Drawing of the twin crystal in Figure 3 with forms identified: *s*{111}, *e*{101}, *m*{110}, and *a*{100}.**

SINGLE CRYSTALS

The unusual habit of the single sellaite crystals from Gjerdingen is seen in Figures 1 and 2. They occur in the form of flat tetragonal bipyramids with *s*{111} dominating and *e*{101} less prominent. A very narrow prism zone is always present: *m*{110} and *a*{100}. The faces of the form {110} may be rather irregular, and this is the rule for the small faces of {100} (the crystal shown in Fig. 1 is atypical in this respect). The crystals are always very irregularly terminated, and the basal pinacoid *c*{001} is never developed as smooth faces. This form has, to the best of our knowledge, not been reported for sellaite before. Such uneven faces are rather common for substances crystallizing rapidly from a vapor phase. In general, the development of different crystal habits for the same substance is influenced by the peculiar conditions prevailing during crystallization (the presence of various other components, temperature and pressure).

TWINNED CRYSTALS

Twinning on {101} was originally observed on synthetic crystals of MgF_2 and was subsequently described for natural sellaite from Bleicherode, Germany (Heidorn, 1932). In Dana's *System of Mineralogy* (Palache *et al.*, 1951), the twinning plane of sellaite is erroneously given as {110}, which can apparently be traced back to a printing error in the paper by Heidorn. An example of a twinned sellaite crystal from Gjerdingen is shown in Figure 3. The crystals are contact twins on *e*{101}. The forms present are the same as for the single crystals, which may be difficult to recognize in the first instance, because of a high degree of distortion and a very uneven size development of faces belonging to the same form. In Figure 4 we have therefore drawn a sketch with labeled faces of the twinned crystal shown in the SEM picture (Fig. 3). Stereo pairs of SEM pictures and the study of solid models were valuable aids in the interpretation of the twinning relations. Sellaite twins like these may strongly resemble some cassiterite twins (in German called *Visiergraupen,* which means "sight" or "aim" in English). Twinning on {101} is also very common for rutile, whereas twinning on {301} is very rare ("arrowhead twins"). A structural-geometric explanation of the twin laws for rutile was given by Gliszczynski (1940), and is of course applicable to the other isotypic minerals as well.

RARITY OF SELLAITE

Sellaite has been found in a number of different environments, e.g. with anhydrite in bituminous dolomite, in cavities of marble, in lava and inclusions in lava, in hydrothermal fluorite deposits, in skarn, and in cavities of soda granite. Nevertheless, sellaite must be considered a very rare mineral; it has been reported only from about a dozen occurrences and always in insignificant amounts. The reason for the rarity of sellaite compared to calcium fluoride (fluorite) is an interesting topic, which, however, is outside the scope of the present note; but the reader is referred to the papers by Heidorn (1932) and Sahama (1945).

ACKNOWLEDGMENTS

The SEM pictures were taken by Tor Mellem of Elektronmikroskopisk laboratorium for biologiske fag (University of Oslo) on a JEOL JSM-35C instrument. We thank John Brommeland for enlightening discussions.

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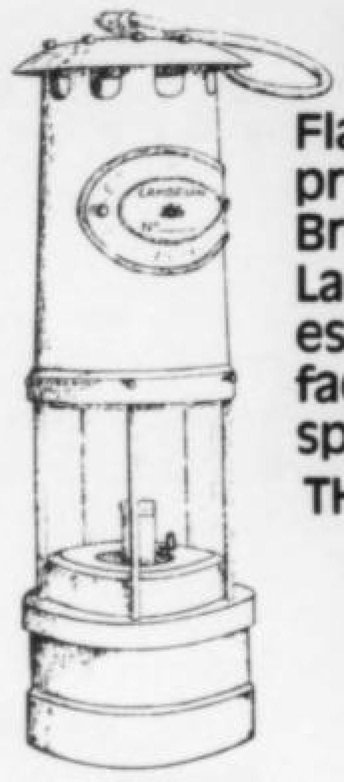

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"Nothing can equal the barren and gloomy appearance of the country round; neither tree, nor shrub, nor verdure, nor picturesque rock, appear to amuse the eye; the spectator must plunge into the bowels of these mountains for entertainment."

Thomas Pennant, 1772

INTRODUCTION

Although mining at Leadhills and Wanlockhead ceased in the 1930's after over 400 years of continuous exploitation, the district still attracts the interest of mineral collectors. Leadhillite, susannite, lanarkite and caledonite, mineral species first discovered in the district, have established the worldwide reputation of the Leadhills and Wanlockhead mines. In Scotland, however, the district is the most important lead-zinc deposit and has produced a far greater number of mineral species than any other Scottish locality.

About 70 veins have been worked in an area of about 8 square kilometers around the villages of Leadhills and Wanlockhead, situated about 1.5 km apart in the Lowther Hills of the Southern Uplands of Scotland. These villages, the highest in Scotland, lie at a height of around 400 m above sea level and experience a rainfall of over 150 cm a year, with significant falls of snow in winter. The surrounding heather-clad hills constitute a valuable grouse moor and also support Blackface sheep.

Leadhills lies in Lanark district of Strathclyde region, and Wanlockhead lies in Nithsdale district of Dumfries and Galloway region; their common boundary divides the mining district. Leadhills is the property of the Hopetoun estate, and Wanlockhead is the property of the Buccleuch estate. Although the veins are continuous across the boundary, the deposit has, from early times, been exploited as two separate mining districts. No underground workings were ever driven beneath this boundary and the mining companies on each property maintained their own drainage adits, concentrating plants and smelters.

HISTORY

The earliest documentary evidence of mining in the district relates to a mine at Leadhills granted to the monks of Newbattle Abbey in 1293. From that time mining was probably intermittent until 1592 when Thomas Foullis bought land at Leadhills and operated a lead mine on a scale hitherto unknown in Scotland. In 1638 the mines passed by marriage to James Hope of Hopetoun, whose descendants own the property to the present day. The mines at Wanlockhead were said to have been rediscovered by a German, Cornelius Hardskins, towards the end of the 16th century.

During the 16th century it was the mining of gold that made the district famous. Commercial exploitation of the alluvial gravels of the Shortcleuch, Glengonnar, and Wanlock Waters (streams) appears to have been carried out on a large scale, for at one time 300 men were employed and during three summers' work obtained £100,000 worth of gold. Between 1538 and 1542, the district produced 1163 grams of gold for a crown for King James V of Scotland, and 992 grams for a crown for his queen. Much of the gold coinage of James V and Mary Queen of Scots was minted from Leadhills gold.

About 1576, Thomas Foullis brought a renowned English mining expert, Bevis Bulmer, to Leadhills to work his lead mine. However, Bulmer turned his attention to the search for gold and he is reputed to have discovered a gold quartz vein and built a stamping mill. Tradition attributes the mounds of debris along the valley floors and the scars down the hillsides to his operations.

In the early years of the 17th century, a search for the quartz

Figure 1. **The village of Leadhills, looking south toward the regional and district boundary.**

veins from which the gold was thought to have been derived met with little success. Lack of bedrock exposures led another English adventurer, George Bowes, to use the method of hushing (hydraulic prospecting) to tear up the ground along the Wanlock Water. No gold veins were discovered, but the lead veins he found were later to give considerable impetus to the infant lead mining industry. No commercial gold mining appears to have taken place after 1620, but gold washing with a sluice box or pan was later to become a sometimes lucrative pastime of the lead miners.

It was not until the second half of the 18th century that rapid expansion in lead mining took place. Output was increased largely by the application of steam power in place of water power to the problem of drainage and thus permitting the mines to be worked to a greater depth. For example, Ronald Crawford of Meason and Company, who were the sole operators at Wanlockhead between 1755 and 1842, erected the second Watt engine in Scotland in 1788 and subsequently had further engines built and improved by their own engineer, William Symington, the pioneer of steam navigation. Activity at Leadhills was divided between several companies, the most important being the Scots Mining Company founded in 1715 and dominating the field until 1860. Between 1734 and 1770 the mines at Leadhills were reorganized and made profitable by the company's manager, James Stirling, a mathematician.

Throughout the 18th century the most prolific mine worked by the Scots Mining Company was the Susanna which by the 1790's was being worked to a depth of about 150 m below adit. Widths of solid galena of about 4.3 m were reported at the time. Between 1770 and 1794 the company drove the Gripps drainage level a distance of 1.5 km to facilitate the drainage of the Susanna mine. At Wanlockhead during this period operations were largely in the Belton Grain, Old Glencrieff, Lochnell, Cove, Straitstep and Margaret's veins. The Belton Grain vein was for a long time reputed to be one of the richest in Scotland and was worked to a depth of about 115 m below adit. During the 18th century the vein pattern as known at present was established, with many new discoveries of ore made. At Wanlockhead, for example, the Smelting Company discovered the famous New Glencrieff vein between 1710 and 1721, and in 1740 the West Branch was discovered during the driving of the Glenglass drainage adit.

By the middle of the 18th century the mines were becoming well known throughout Britain not only as a great industrial and technological showpiece, but also for their mineralogical features. In particular, it was the discovery of several new mineral species which attracted the interest of the mineralogists of the day. Leadhillite, lanarkite and caledonite were the names eventually attached to these minerals by the French mineralogist Beudant in 1832.

The Reverend Dr. John Walker, subsequently Professor of Natural History at Edinburgh University, appears to have been the first to study and collect the minerals of the district, particularly while Minister of Moffat between 1761 and 1764.

> "Leadhills and Wanlockhead being within a forenoon's ride, I frequently visited the mines at these places, and went down in them to the greatest depth. . . . Though I may have been at these mines about thirty times, I never paid one visit in which I did not find something new."

Many of the species of lead ores found by Dr. Walker had never previously been found in Britain, including "plumbum cyaneum" or linarite. In 1772, Thomas Pennant, an eminent naturalist and mineral collector, visited Leadhills and also observed these ores of lead including "the curious white ores, lamellated and fibrous, so much searched after for the cabinets of the curious."

During the first quarter of the 19th century, the Leadhills and Wanlockhead mines were making a significant contribution to the early development of mineralogy. Prolific mines in the oxidized zone like the Susanna and Belton Grain, helped by the favorably high price of lead during the Napoleonic War, ensured that good

Figure 2. **The Wanlock valley, Wanlockhead; the large dump of the Glencrieff mine is in the distance at left. Much early mining took place under the Wanlock Dod, the hill to the right.**

specimens were available. The managers of the two main mining companies, Alexander Irving at Leadhills (later a Scottish judge with the title of Lord Newton), and Gilbert Laing Meason at Wanlockhead, both men with an interest in science, acquired these rare mineral specimens from their mines and passed them to the growing number of mineralogists like James Sowerby, Henry Brooke and David Brewster, who were applying new techniques of chemical analysis and using the new reflecting goniometer. Alexander Irving was sufficiently interested in mineralogy to undertake one of the earliest analyses of leadhillite in the 1820's.

Many of these new minerals from the district were first figured by Sowerby between 1804 and 1817. Sowerby's illustration of leadhillite, a specimen from Wanlockhead, is dated 1809 and published in 1811. However, he considered this mineral to be merely a variety of lead carbonate crystallized in "hexahedral laminae" and later remarked on: "not having information enough at the time to consider it as a distinct species." Sowerby also published illustrations of caledonite and linarite from Wanlockhead in 1809 but described these minerals as green and blue carbonates of copper.

It was Compte de Bournon who, in 1817, first recognized leadhillite as a separate species, naming it rhomboidal carbonate of lead. He also described lanarkite as a variety of carbonate of lead.

Dissatisfied with these previous determinations, Henry Brooke of London, during 1819, analyzed three of the Leadhills minerals and his results appeared in the *Edinburgh Philosophical Journal* in 1820. Brooke named these three species of lead ore as sulphato-carbonate of lead, sulphato-tri-carbonate of lead, and cupreous sulphato-carbonate of lead, which Beudant later renamed lanarkite, leadhillite and caledonite respectively. In 1822, Brooke determined Sowerby's blue carbonate of copper to be cupreous sulphate of lead.

Crystallographic determinations of leadhillite were done by Brooke and Haidinger while Sir David Brewster of Edinburgh used the mineral in his pioneer work on the optical properties of crystals.

So well known had the minerals of Leadhills become during the 1820's that the Scots Mining Company had to make a regulation preventing the miners from disposing of specimens to the growing number of collectors.

From the 1830's onward, lead mining in the district went into decline and with it came a corresponding downturn of interest in the minerals. The price of lead fell with the introduction of Free Trade and the mining companies changed back from steam to water power as an economy measure. Few new discoveries of ore were made and most of the ore raised was obtained from the reworking of the waste of the old workings. Depression at Leadhills was aggravated by a lengthy litigation over water rights between the Scots Mining Company and the Leadhills Mining Company. This dispute lasted for over 20 years and was resolved in 1861 with the main company giving up its lease and the Leadhills Mining Company taking over the entire field.

From the 1860's modernization and large-scale capital investment appears to have brought about a revival. The Leadhills Mining Company reopened the Susanna mine in 1869 and made new discoveries of lead, but soon abandoned the mine because of water pumping difficulties and lack of ore. By the end of the 19th century workings at Leadhills were confined to the Brow, Brown's and Raik veins. The Duke of Buccleuch took over the working of the mines at Wanlockhead in 1842. His manager, James Stewart, reopened the New Glencrieff mine between 1842 and 1850 after it had lain abandoned for about 70 years, and discovered the ore shoot at the south end of the mine which subsequently proved the richest in Scotland.

It was during the latter half of the 19th century that Dr. Matthew Forster Heddle (1828–1897), Professor of Chemistry at St. Andrew's University from 1862, amassed the finest collection of Scottish minerals ever made. Heddle was, to some extent, responsible

Figure 3. **Lady Manner's Scar, Leadhills, where the Susanna vein was formerly worked. The vein outcropped along the left side of the scar.**

for the revival of interest in Leadhills and Wanlockhead minerals and his descriptions of them appeared in his posthumously published *Mineralogy of Scotland* in 1901. However, with the abandonment of many of the old productive mines, the rarer secondary minerals easily available at the start of the century were by this time becoming scarce. Heddle (1901) states that lanarkite "has not been met with in the workings since the last flooding of the Susanna Mine," and Collie (1889) states that leadhillite is not often found, and that "for several years past, few specimens have been obtained." Robert Brown, a native of Wanlockhead, writing in 1919, says that "it is quite evident that the mines are now getting too deep to find any of the older and rarer minerals such as caledonite, linarite, leadhillite, susannite etc. . . . they are not to be found in any of the veins that are being worked at the present time." However, in the 1920's Robert Brown and two Leadhills miners, John Weir and John Blackwood, spent their leisure time digging into the old dumps and rediscovered many of these rare minerals "after a lapse of 50 years." Robert Brown's collection of a few thousand specimens was perhaps the finest of a number of collections which at one time existed in the district.

By the 1920's, mining in the district had become restricted to two mines. The Leadhills Mining Company worked Brow and Brown's veins from the Glengonnar shaft and the Wanlockhead Mining Company worked the New Glencrieff vein and its West Branch from the Glencrieff shaft. Both mines were worked to a depth of over 425 m below the surface.

Brow vein averaged 2.4 meters in thickness and consisted mainly of brecciated country rock cemented by ore-bearing calcite and ankerite, and often strung through with ribs of galena varying from 1.25 to 30.5 centimeters thick. The primary ores were galena, sphalerite, pyrite and chalcopyrite, and the secondary ores were limonite, hematite and small quantities of malachite and chrysocolla. The gangue was mainly calcite and ankerite, together with a little siderite, quartz and barite (Wilson, 1921).

The New Glencrieff was a strong, cavernous and well defined vein. At the south end, the top levels were very rich in galena and the main shoot of ore continued for a distance of 365 m. At the 80-fathom level large quantities of hemimorphite were found, and at the 120-fathom level this gave place to sphalerite. From that level downward the galena gradually gave out until at the 200-fathom level the vein consisted almost entirely of sphalerite. The secondary minerals were pyromorphite, cerussite, and hemimorphite, and the gangue minerals were calcite, ankerite, quartz, barite and small quantities of witherite. The New Glencrieff mine was favored with a deep oxidized zone which extended to a depth of 365 m at the south end (Wilson, 1921).

Brown (1919) commented about the lack of mineral specimens from the Glengonnar mine: "although the miners come across a cavity occasionally it is seldom that a crystal is to be seen, while at Wanlockhead within the last twelve years hundreds of fine specimens have been found."

According to Brown (1919), the richest working in the New Glencrieff for specimens was between the 80-fathom and 120-fathom levels where many fine specimens of hemimorphite, aragonite, cerussite and pyromorphite were obtained. However, the use of dynamite in place of gunpowder was particularly unfavorable to the collector as many hundreds of valuable specimens that might have been saved were blown to pieces. In the same part of the mine, a vug was opened up about 1.8 m long by 1.8 m deep and 0.6 m wide in the center with the walls covered with aragonite and cerussite. "All that the miners did was simply to pick up a few specimens that were lying loose, and then fire their remaining shots, thus destroying the whole lot."

It was in the early months of 1919 that the first authenticated

Figure 4. **The Glencrieff mine, Wanlockhead. During the first quarter of this century, the New Glencrieff vein produced many impressive crystallized specimens of primary minerals.**

Scottish specimens of witherite were found in the West Branch of the New Glencrieff mine. They were found at the 200-fathom level, along with calcite, barite and galena, in a cavity 7.3 m deep, 4.6 m long and 0.9 m wide in the center. The witherite occurred in two globular masses 17.8 cm and 12.7 cm in diameter, pseudomorphous after barite, "hanging in the cavity like two large fungi." Many specimens were damaged when the first shots were fired: "the miners said that when they were removing the debris after the blast it sounded as if they were shovelling china or bell metal" (Brown, 1919).

During the 1920's the mining companies undertook exploratory work. The Borlase shaft (or Wembley, as the miners called it) was sunk at Leadhills in 1925–1928 on Mill vein and a crosscut was started at 137 m from the surface and cut Glasgow, Carse's, Meadowhead and Labour in Vain veins but did not find any paying quantities of ore. At Wanlockhead, the 160-fathom crosscut was driven 1158 meters eastwards from the New Glencrieff mine between 1919 and 1929 and encountered nearly all the old productive veins. Leadhills mine closed in 1929 due to impoverishment of the main ore shoot. Wanlockhead mine closed in 1931 and after a partial resumption was finally abandoned in 1934. Shortly before abandonment the bulk of the output was from the Straitstep vein intersected by the 160-fathom crosscut.

Re-examination of the whole district was undertaken between 1951 and 1958 by Lowland Lead Mines Ltd. involving surface and underground geological mapping. During that investigation, A. K. Temple made a study of the mineralization of the district and, by applying X-ray diffraction techniques, discovered minerals not previously recorded from the district, including a "new chromian mineral"; a new variety of leadhillite ("chromian leadhillite"); a "mineral previously recorded only as an artificial product (lead hydroxyapatite)" and "phoenicochroite, not previously confirmed in the British Isles" (Temple, 1956). However, Williams (1974) states that Temple's new chromian mineral is phoenicochroite and that his "phoenicochroite" is an impure form of that mineral.

Wanlockhead mine was pumped out in 1954 and, up to 1957, in conjunction with Rio Tinto Company Ltd., about 1828 m of drifting was carried out, of which 57 percent was general exploration. Lead prices caused the mine to be put on care and maintenance in May, 1958 (Mackay, 1959).

Closure of the mines in the 1930's, with only a brief revival in the 1950's, brought about a general decline in the villages. Lack of employment, together with remoteness, made it increasingly difficult for the villages to exist. In the last 15 years the district has experienced an unprecedented change, for many of the cottages have been bought as holiday residences for use during the summer. The revival of interest in the district has brought about the establishment of the Wanlockhead Museum Trust with the object of preserving the remnants of the lead mining industry while, at Leadhills, the Allan Ramsay Library (the first circulating library in Britain, founded in 1741) has been restored. Interest in geology generally, and in minerals in particular, attracts many collectors to the district during the summer months. But good specimens are not easily found and quality specimens of the rare lead minerals are virtually unobtainable, particularly since all the veins at Leadhills are inaccessible. What the future holds for the mineral collecting possibilities of the district is uncertain. It is unlikely that mining will ever resume in the upper oxidized portion of the veins but reserves of lead ore do exist and, assuming a favorable price for lead, good specimens may once again be available.

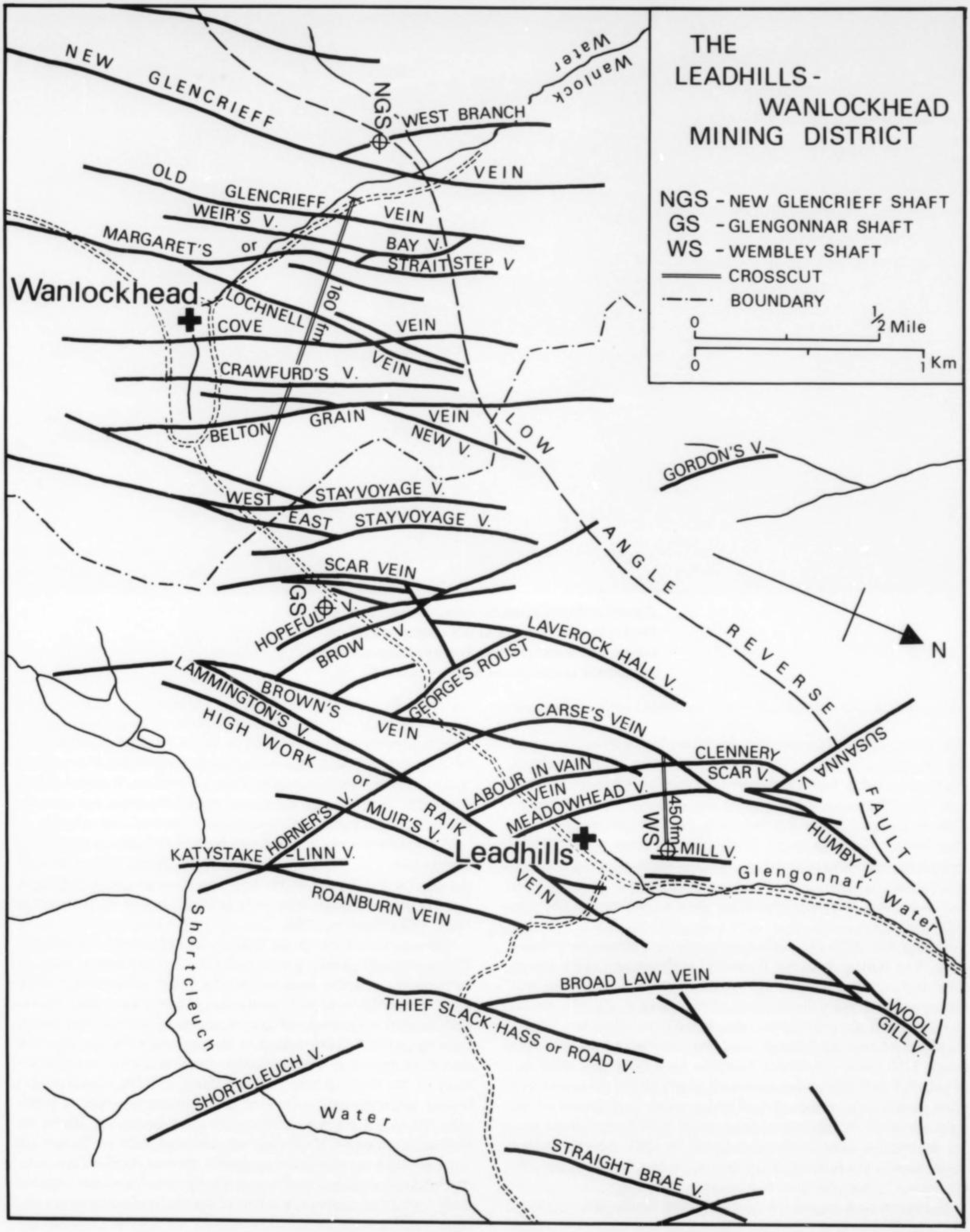


Figure 5. **Location of the principal veins in the Leadhills-Wanlockhead district.**

Figure 6. **Cerussite on malachite, Wanlockhead. The large crystal is 2 mm in size. (Royal Scottish Museum, Dudgeon collection, #1878.49.535.)**

Figure 7. **Caledonite crystals to 2 mm, Leadhills. (Photo by Eric Offermann.)**

GEOLOGY

The country rock of the district is a series of greywackes, mudstones, shales and cherts of Ordovician age intensely folded and faulted during the Caledonian orogeny and striking northeast and northwest.

The veins cut these rocks in two dominant directions. One set trends approximately northwest-southeast, and the other set approximately north-south. The veins at Wanlockhead are subparallel and strike in a northwesterly direction and nearly all dip to the east. At Leadhills the two main strike directions are more apparent; generally the northwest-southeast set dips to the southwest, while the north-south set dips to the east.

The mineralized portions of the veins are confined to the greywackes and mudstones and the veins generally cease to be ore-bearing to the northwest where they cut the black shales and cherts (Wilson, 1921).

In the 1920's, Mitchell, then manager of the New Glencrieff mine, recognized a zone of movement dipping 30–40° to the northwest in all the levels driven into the barren black shales. Geological mapping in the 1950's confirmed a low angle reverse fault to be the major structural control to the mineralization in the district. This fault had the effect of bringing the shales and cherts on top of the greywackes to form an impervious ceilings resulting in the "im pounding" of the mineralization in the fissures below the fault zone. Much of the exploration in the 1950's took place on the assumption that "blind" veins may exist below the shales (Mackay, 1959).

The veins vary in width from stringers up to 4.3 m, but a width of about 1 m appears to be average. They are generally filled with brecciated greywacke cemented with gangue minerals, usually ankerite and calcite. Galena occurs in the filling and may be concentrated on either the footwall or the hangingwall of the vein. A zig-zag pattern to the veins is common, with the ore shoots alternating with "checks" where the walls of the vein may come into contact. The ore shoots vary in size. The main shoot at the south end of the New Glencrieff vein extended almost from the surface to a depth of 365 m and had a pitch length of about 488 m and a breadth of 366 m. Generally the shoots of ore are smaller: about 110 m vertically and 36.6 m horizontally (Mackay, 1959).

MINERALS

Over 60 mineral species have been identified from the district. Of these, galena, sphalerite, chalcopyrite, and pyrite, with a gangue of ankerite, calcite, barite and quartz are the minerals common to nearly all the veins; the finest specimens of these minerals came from large cavities in the New Glencrieff vein.

It is the occurrence of the secondary minerals of lead, copper and zinc which is of particular interest to collectors. Nearly all the veins that have produced galena in any quantity have furnished secondary lead minerals. However, since no significant mining has taken place in the upper oxidized zone of the veins since at least the 1860's, rare secondary minerals have only been obtained sparingly from the mine dumps. Many of these old dumps were extensively dug over by the miners in the 1920's, and unfortunately many of the rare specimens that were found are now lost. More recently, A. K. Temple made an examination of all the dumps and all available mineral collections and, with the aid of X-ray diffraction, con-

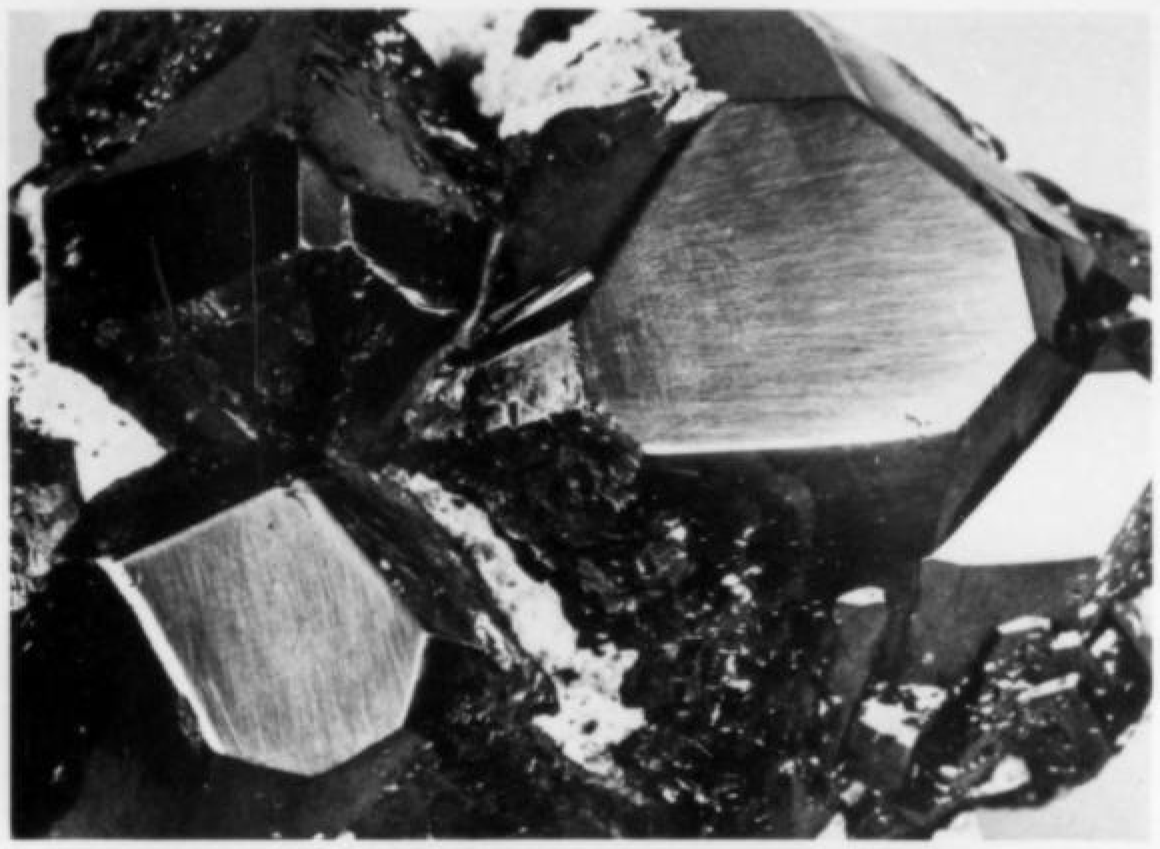


Figure 8. **Galena crystals to 4 cm from Brown's vein, Glengonnar mine, Leadhills. (Royal Scottish Museum collection, #1878.49.14.)**

firmed most of the mineral species occurring in the district including 15 species new to the district.

Galena is the only primary lead mineral and usually the only ore of lead worked. Silver was extracted from the galena and at Wanlockhead, 198 to 312 grams of silver to the ton of galena was obtained. Temple recorded 19 secondary lead minerals, of which cerussite and pyromorphite are by far the most common.

Sphalerite is the only primary zinc mineral and was unworked until 1880. Hemimorphite is the only abundant secondary and is found in all the veins that contain sphalerite. Smithsonite has not yet been confirmed from the district although Heddle (1901) mentions its occurrence "on the authority of Dr. Wilson of Wanlockhead."

Copper minerals are not as common as lead or zinc. Chalcopyrite is the only primary copper mineral, and six secondary copper minerals occur (excluding those which contain lead). Chalcopyrite, along with a little malachite was worked at the Longcleuch and Katystakelinn veins during the 18th century.

The following species are the secondary minerals which are of greatest interest to collectors and have established the reputation of Leadhills and Wanlockhead as a mineral locality of note.

Cerussite, ($PbCO_3$). The crystals are generally small and occur in a great variety of forms with twinning common. According to Allan (1834), the "stalactitic and stellated" crystallizations were of particular note. It is usually white or colorless but can be gray, yellow, brown, black, and rarely green, blue or red.

Cerussite occurs throughout the district and was formerly abundant in the upper levels of the Susanna mine where it was once worked as "white lead ore." Cerussite is associated with most of the other rare secondary lead minerals.

Anglesite, ($PbSO_4$), occurs in many forms and combinations: prismatic, pyramidal, tabular, bladed or "dagger-shaped" crystals, and occasionally stalactitic. It commonly occurs as nodules enclosing an unaltered core of galena or occupying cavities left by cubical crystals of galena. Anglesite is commonly colorless or white, but in some cases yellow, gray or brown. Black specimens occur due to finely disseminated galena.

Anglesite is not a common mineral but was formerly plentiful in the Susanna and Belton Grain veins associated with all the secondary lead minerals.

Leadhillite, $Pb_4(SO_4)(CO_3)_2(OH)_2$, occurs usually as hexagonal platy crystals with a characteristic pearly luster on the cleavage planes. According to Allan (1834), the crystals seldom exceeded 2.5 cm in diameter. The color is generally yellowish-white to gray, yellowish-green, yellow or brown.

Leadhillite sometimes occurs alone, but more commonly occurs with cerussite or with other rare secondary lead minerals. Heddle (1901) states that leadhillite was found in all the veins of the district except the Belton Grain.

Temple (1956) discovered a chromian variety of leadhillite.

Susannite, $Pb_4(SO_4)(CO_3)_2(OH)_2$, is the trigonal polymorph of leadhillite first distinguished by Haidinger (1845). It occurs as white, green, yellow, or brownish crystals with a resinous to adamantine luster, and pearly on the cleavage faces. Mrose and Christian (1969) established that leadhillite and susannite are the monoclinic and trigonal dimorphs respectively of $Pb_4(SO)_4(CO_3)_2(OH)_2$ and that leadhillite is a low temperature polymorph of susannite.

Lanarkite, $Pb_2(SO_4)O$, occurs as small monoclinic prisms and in diverging aggregates of long slender crystals 2.45 to 5 cm in length. The luster is resinous to adamantine, but pearly on the cleavage faces. The color is greenish white to yellow-white and sometimes gray. According to Heddle (1901), lanarkite was the rarest mineral occurring in the district and had been found only in the Susanna mine associated with susannite, caledonite, and in some cases cerussite. Brown (1919) found lanarkite on mine dumps from other veins in the district.

Caledonite, $Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$, occurs as small prismatic crystals of a verdigris-green to bluish green color in oxidized chalcopyrite-galena ores associated with most of the rarer secondary lead minerals.

Linarite, $PbCu(SO_4)(OH)_2$, occurs generally as small bladed crystals of an azure to dark blue color and is common on many of the old dumps. It is usually found in oxidized chalcopyrite-galena ores associated with caledonite, malachite, brochantite, anglesite and cerussite.

Pyromorphite, $Pb_5(PO_4)_3Cl$. The district has long been famous for its specimens of pyromorphite. Nearly every shade of green, brown, yellow, orange and red has been found. Pyromorphite occurs as barrel-shaped or acicular crystals and as botryoidal masses. Collie (1889) considered the green botryoidal variety with a conchoidal fracture as peculiar to Leadhills. The orange and red varieties were considered by Temple and Collie to be chromium-bearing and according to Heddle were only found in the Susanna mine. Pyromorphite occurs on nearly all the dumps of the district.

PARAGENESIS AND ORIGIN OF THE DEPOSIT

Nearly all the work on the paragenetical mineralogy in relation to the origin of the Leadhills-Wanlockhead deposit was carried out by A. K. Temple in the early 1950's (Temple, 1956).

Temple recognized two periods of mineralization. The first consisted of quartz veins with which are associated small amounts of gold, pyrite and muscovite which he tentatively assigned to the Caledonian orogeny; the second comprised the lead-zinc mineralization associated with the Hercynian orogeny.

The most distinguishing feature of the paragenesis is the occurrence of two generations of sulfides. Temple attributed this second generation to the reprecipitation of elements derived from the replacement of the first generation by late stage quartz. Material on the dump from the New Glencrieff vein, presumably from depth, was found to be first-generation sulfide, but in veins near the surface galena and chalcopyrite were later than the calcite filling of the veins.

The only primary lead mineral is galena and the general oxidation sequence of galena → anglesite → cerussite was confirmed by Temple. A great variation in the copper-lead minerals oxidation sequence was found to occur, e.g. anglesite replaced by caledonite and linarite; and cerussite → leadhillite → caledonite. The sequence anglesite → cerussite, followed either by pyromorphite or leadhillite or by leadhillite-lanarkite, was found to be widespread throughout

Figure 9. **Brilliant white crystals of cerussite to 1 cm, from the Belton Grain vein, Wanlockhead. (Royal Scottish Museum collection, #1951.8.35.)**

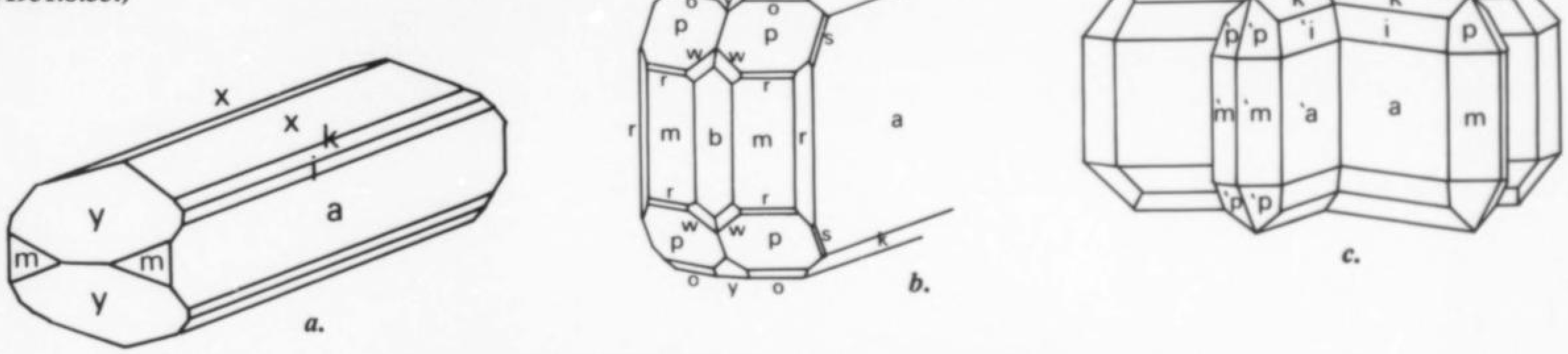
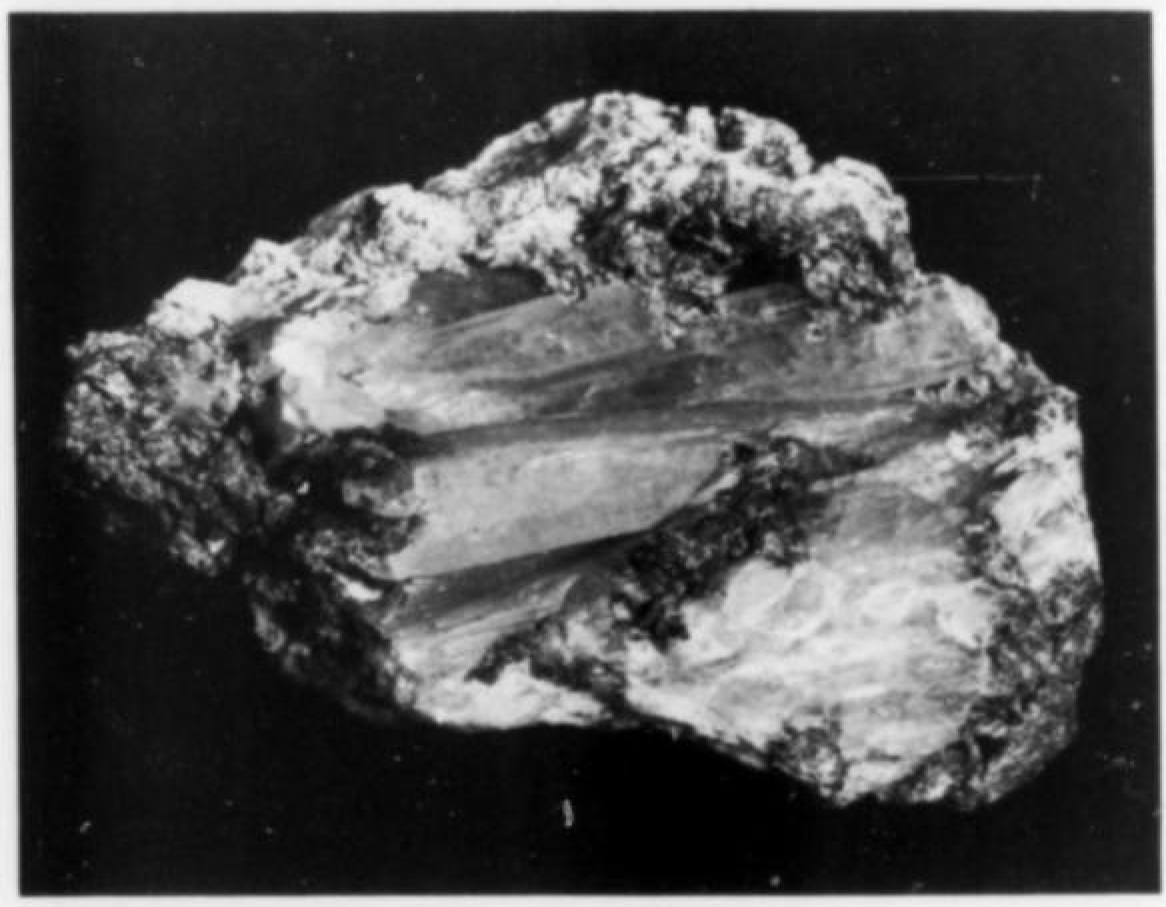


Figure 10. **Crystal forms of cerussite: (A) Susanna mine, (B) Glengonnar mine, (C) Leadhills. From Heddle (1901).**

Figure 11. **Bladed, honey-yellow anglesite from the Susanna mine, Leadhills. The specimen is about 7.5 cm long. (Royal Scottish Museum, Heddle collection, #721.16.)**



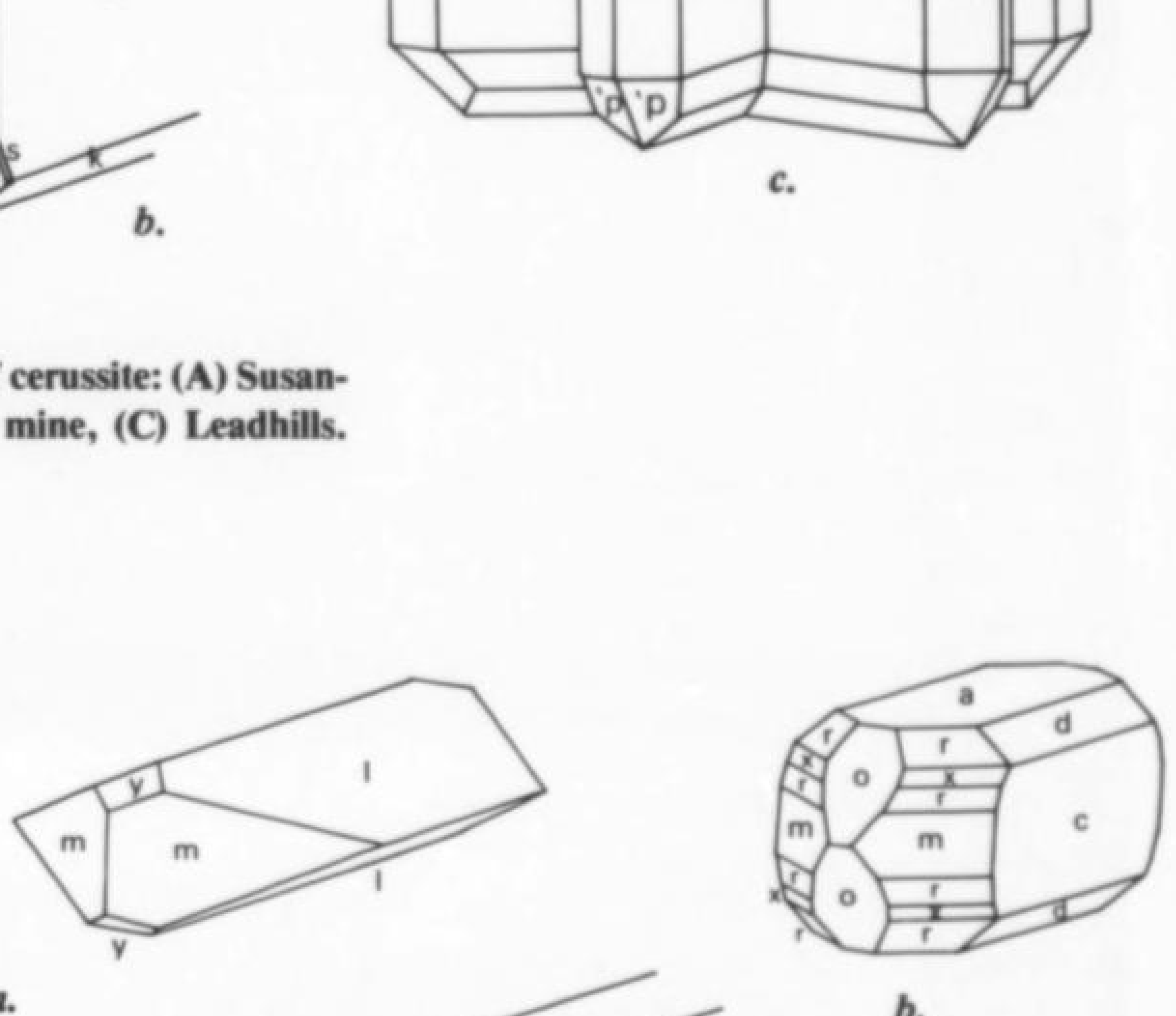


Figure 12. **Crystal forms of anglesite: (A) Susanna mine, (B) and (C) Leadhills. From Heddle (1901).**

(continued on page 246)

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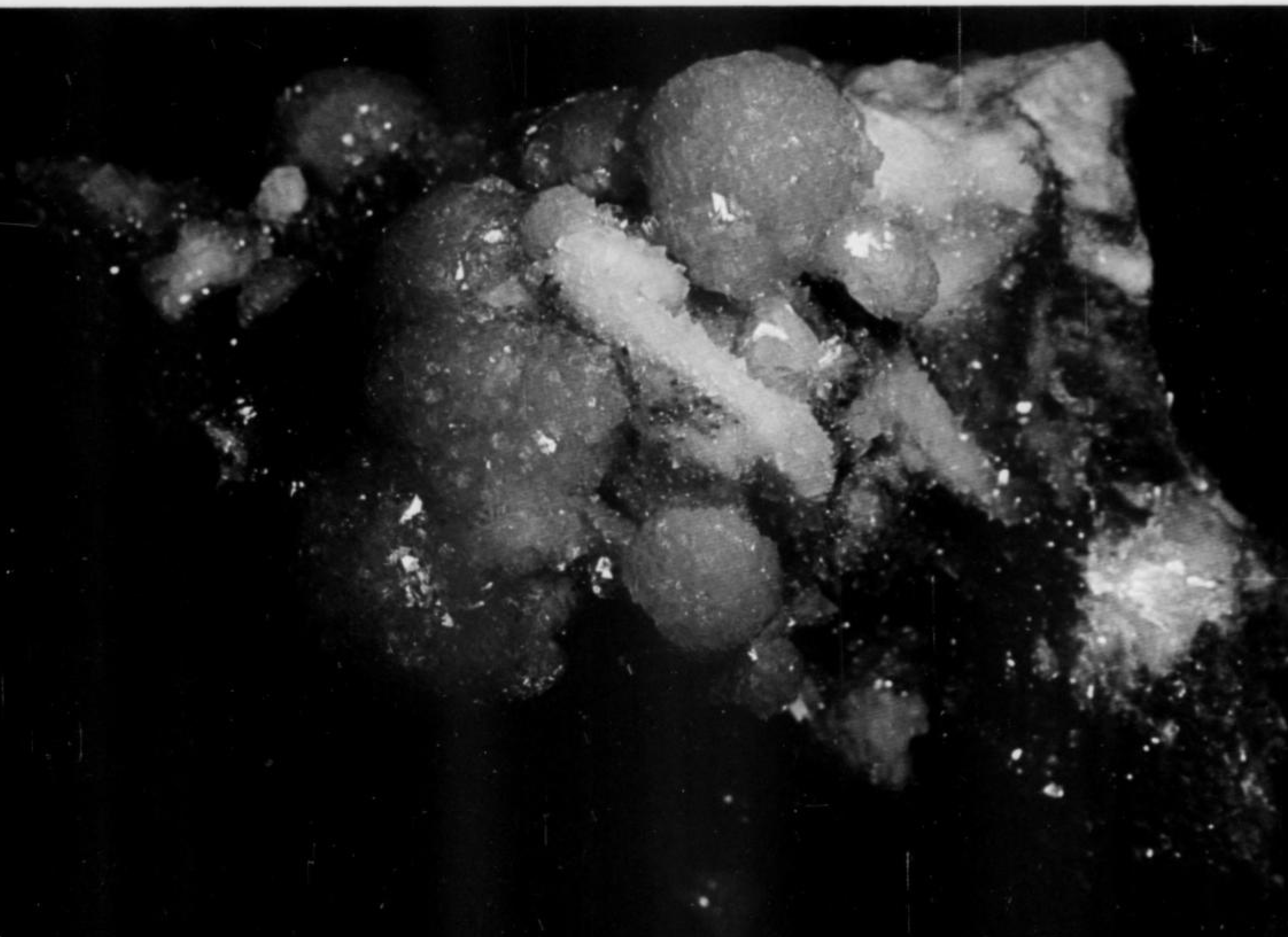

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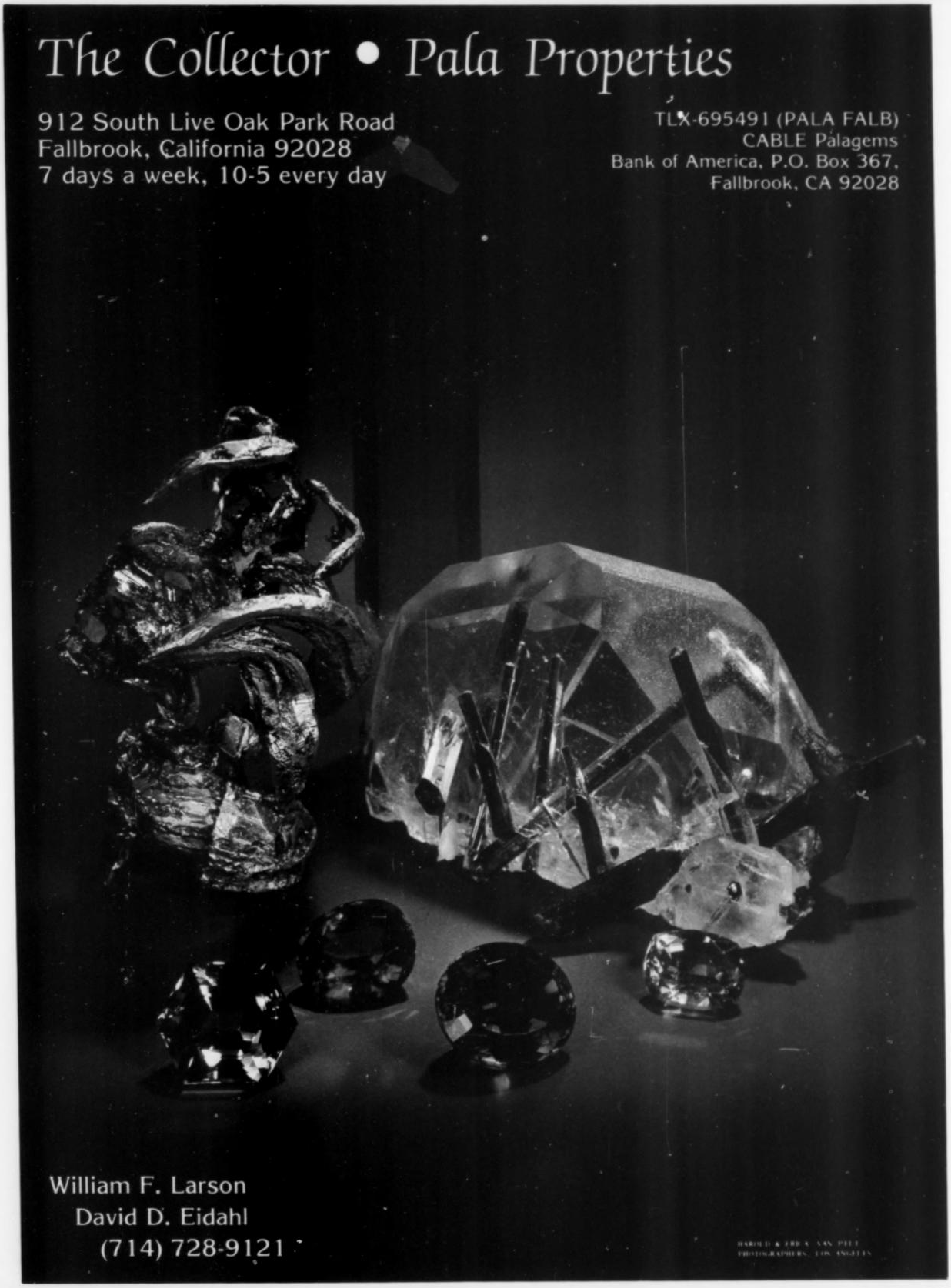

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Figure 13. **White leadhillite crystal 1.6 cm in size, Leadhills. (Royal Scottish Museum, Heddle collection, #734.22.)**

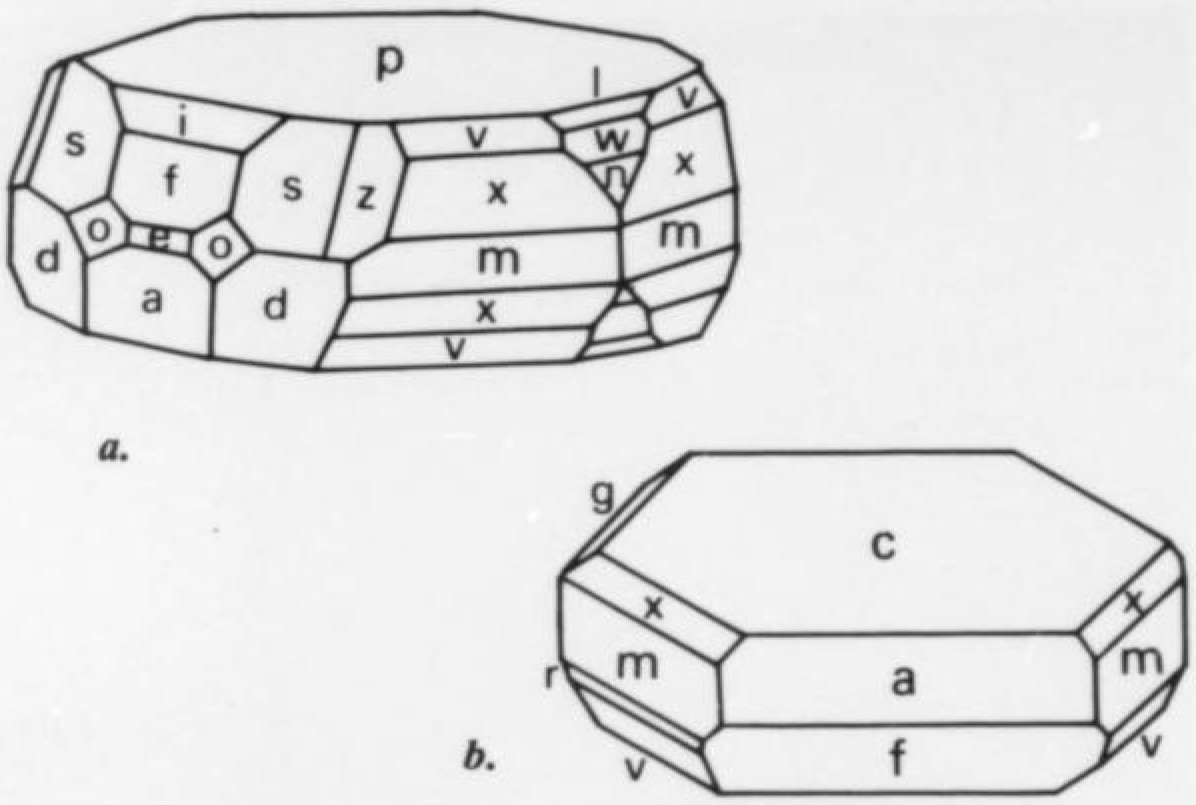

Figure 15. **Crystal forms of leadhillite: (A) Leadhills; from Greg and Lettsom (1858), (B) Leadhills; from Heddle (1901).**

Figure 14. **Illustration of Wanlockhead leadhillite, dated 1809, from Sowerby's *British Mineralogy,* volume 4.**

Figure 16. **Apple-green susannite crystals to about 1 cm, Glengonnar mine, Leadhills. (Royal Scottish Museum, Heddle collection, #734.A.9.)**

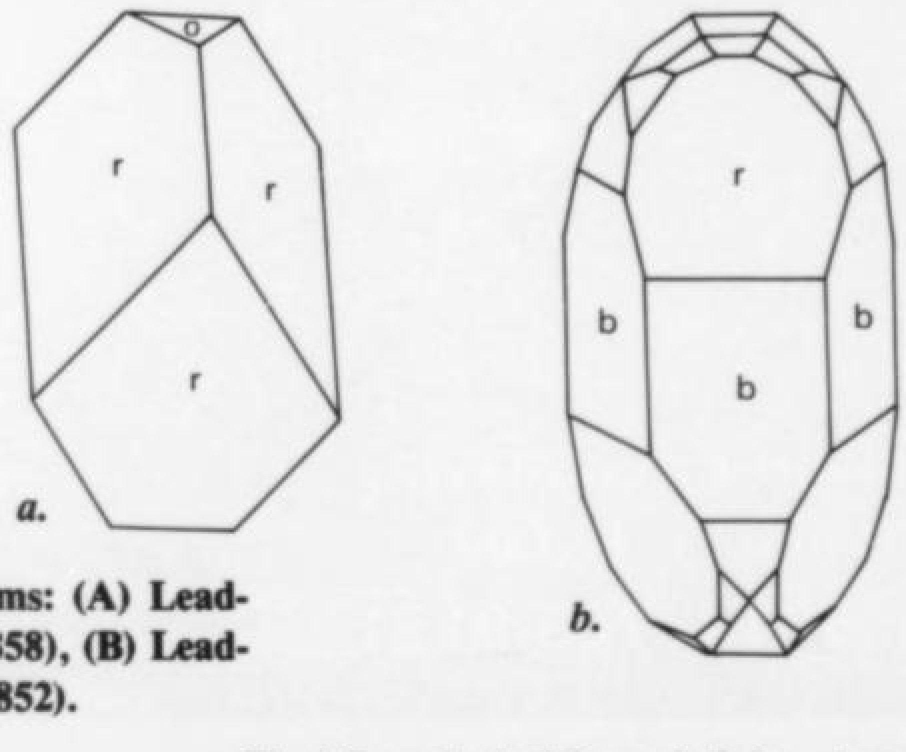

Figure 17. **Susannite crystal forms: (A) Leadhills; from Greg and Lettsom (1858), (B) Leadhills; from Brooke and Miller (1852).**

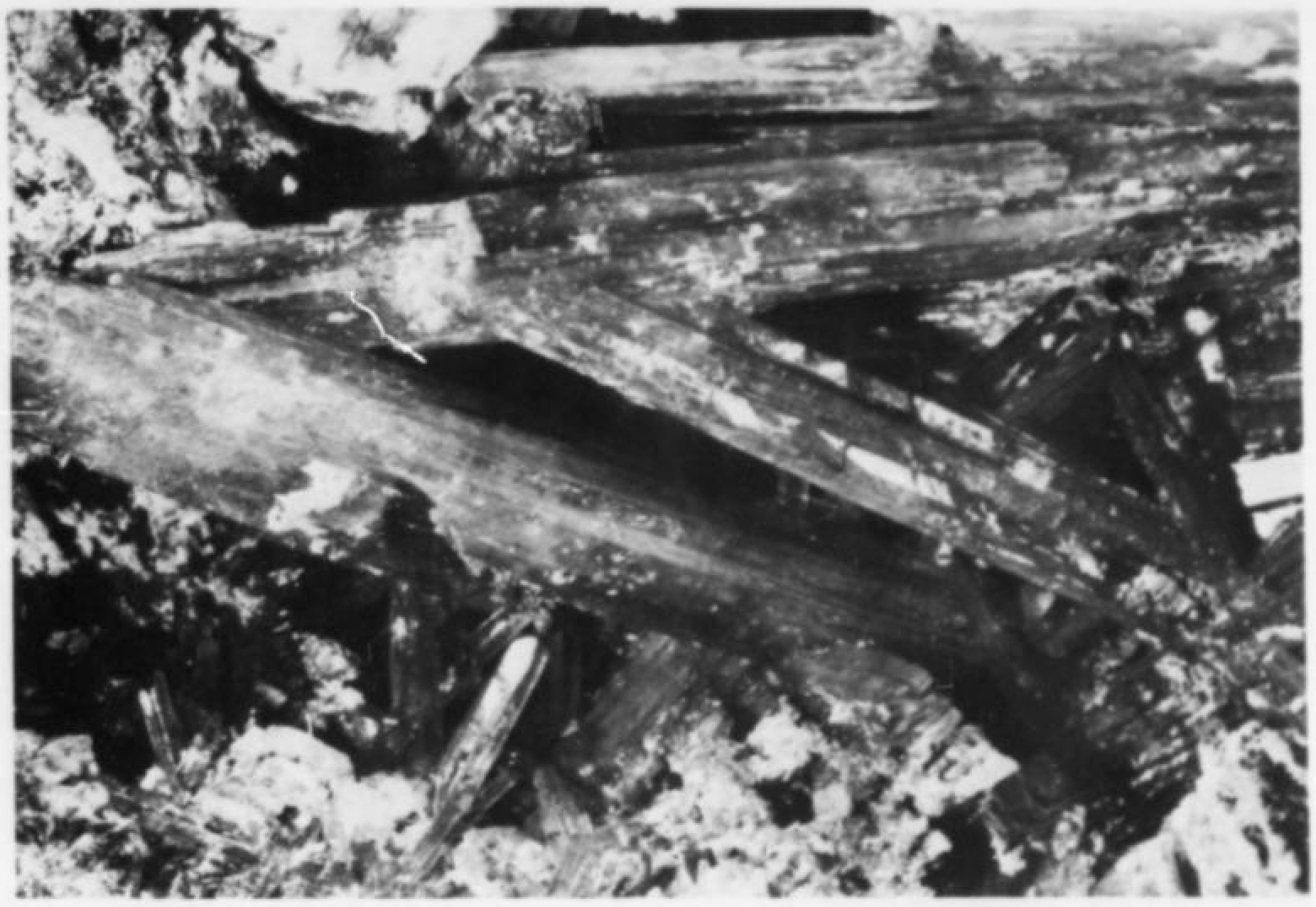

Figure 18. **Bladed crystals of white to siskin-green lanarkite about 2.5 cm long, from the Susanna vein, Leadhills. (Royal Scottish Museum collection.)**

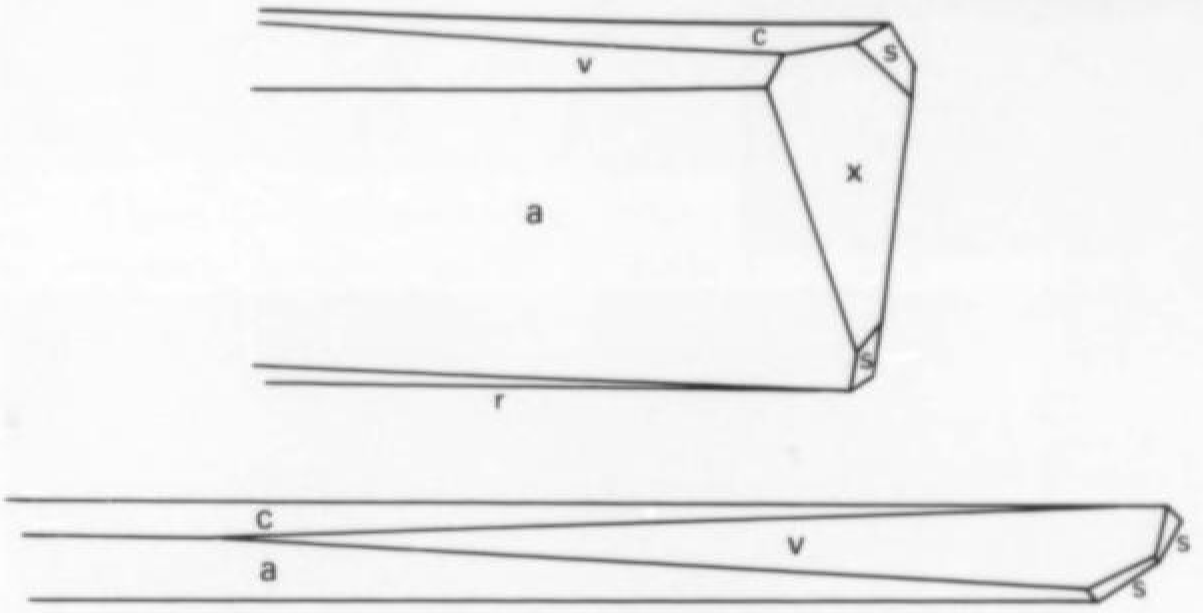

Figure 19. **Crystal forms of lanarkite from the Susanna mine. From Heddle (1901).**

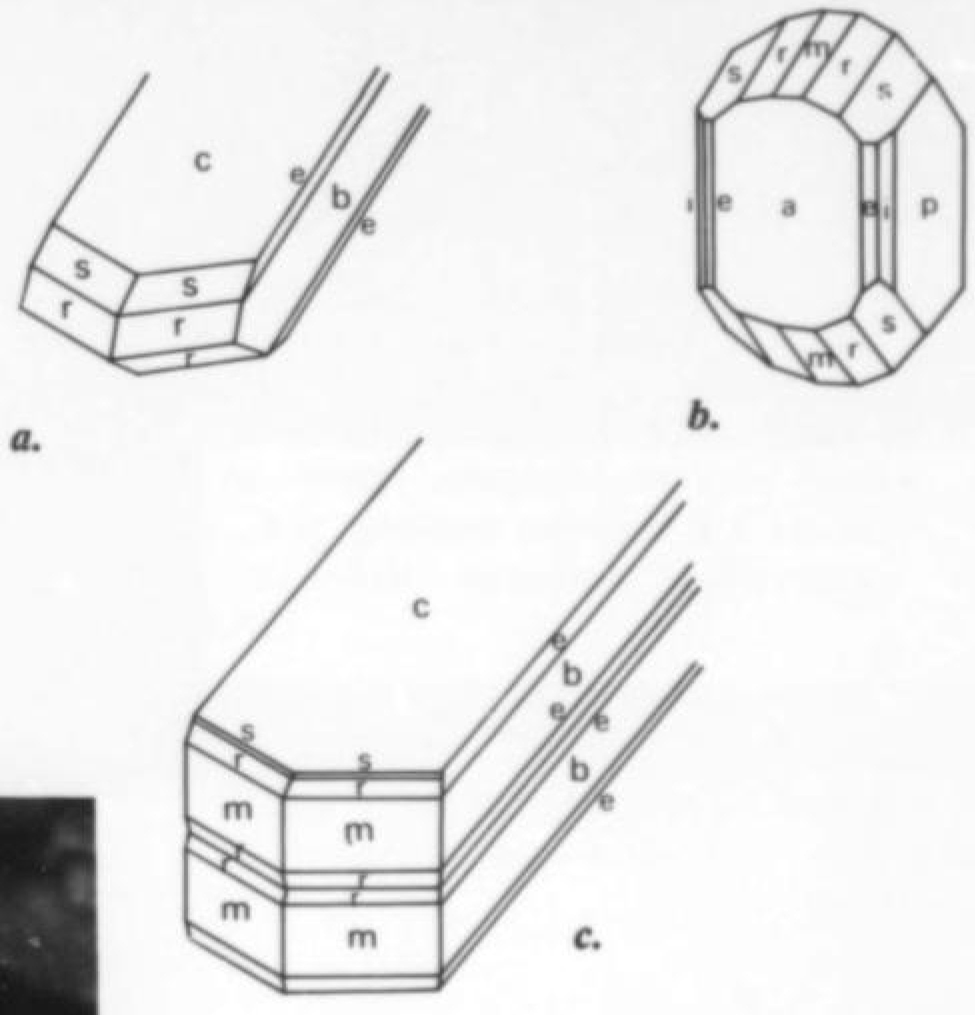

Figure 20. **Crystal forms of caledonite (see also Fig. 7): (A) and (C) Susanna mine; from Heddle (1901), (B) Leadhills; from Greg and Lettsom (1858).**

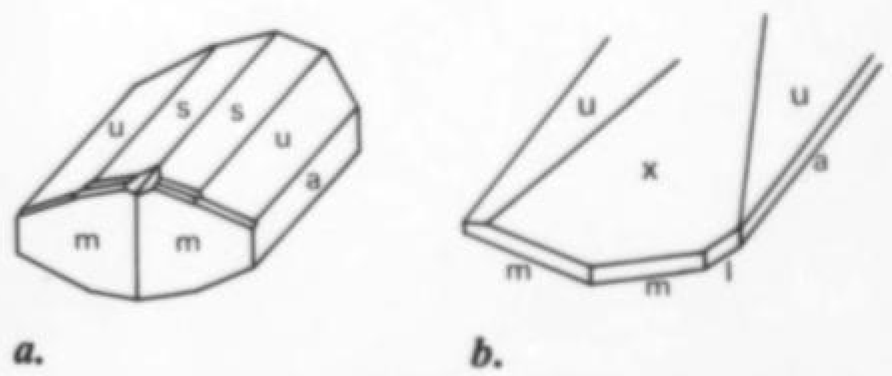

Figure 21. **Crystal forms of linarite (see also Fig. 18): (A) Susanna mine, (B) Leadhills; both from Heddle (1901).**

Figure 22. **Light brown vanadinite crystals to 3 mm, Belton Grain vein, Wanlockhead. (Royal Scottish Museum collection, #552.9.)**

Figure 23. **Linarite crystals to about 1 cm, Susanna mine, Leadhills. (Royal Scottish Museum, Heddle collection, #741.18.)**

Figure 24. **Pyromorphite crystals to 2 mm, Leadhills. (Royal Scottish Museum, Heddle collection, #550.19.)**

Figure 25. **Variegated white, yellow, orange and brown hemimorphite in stalactitic and botryoidal masses, New Glencrieff mine, Wanlockhead. The view is 8 x 9 cm. (Royal Scottish Museum collection, #1951.8.21.)**

Figure 26. **White aragonite crystals from Leadhills. The specimen measures 9 x 14 cm. (Royal Scottish Museum collection, #1881.38.11.)**

the district (Temple, 1956).

Emplacement of the primary minerals took place at a temperature of about 143° to 281° and the mineralizing solutions were acid in the early stages, changing fairly rapidly to alkaline (Temple, 1956). Potassium-argon isotopic age determinations suggest that emplacement of the minerals took place 218 to 343 million years ago (Ineson and Mitchell, 1974).

On the basis of the mineral assemblage and the relationship to igneous activity, Temple concluded that the deposit was probably derived from the top of the tholeiitic crustal layer and the base of the granitic crustal layer. The mineralization was thought to have been concentrated in local updomings of the granitic crust, and the passage upward effected by deep fissures. Deposition of the minerals from these "feeder" fissures was considered to be due to the presence of the barrier of the northwest-dipping thrust fault.

Conclusive evidence of zoning of the primary minerals has not been obtained. Vertical zoning was suggested by Brown (1919) who pointed out that the upper levels of the New Glencrieff vein were rich in barite, but in the lower workings it was "seldom if ever seen." Wilson (1921) stated that the top levels of the New Glencrieff vein at the south end were rich in galena but decreased in quantity from the 120-fathom level downward to the 200-fathom level where the vein consisted entirely of sphalerite. Wilson observed a similar sequence in the Brow vein at Leadhills. Temple noticed evidence of lateral zoning, in as far as no sphalerite or barite is to be found on the dumps towards the eastern edge of the district.

In general the veins have a deep oxidized zone which bears no relationship to the present water table. Wilson (1921) and Brown (1919) noted the oxidized zone extending to 365 m below the surface at the south end of the New Glencrieff vein. Temple concluded that the district had undergone a period of low water table at some time in the past.

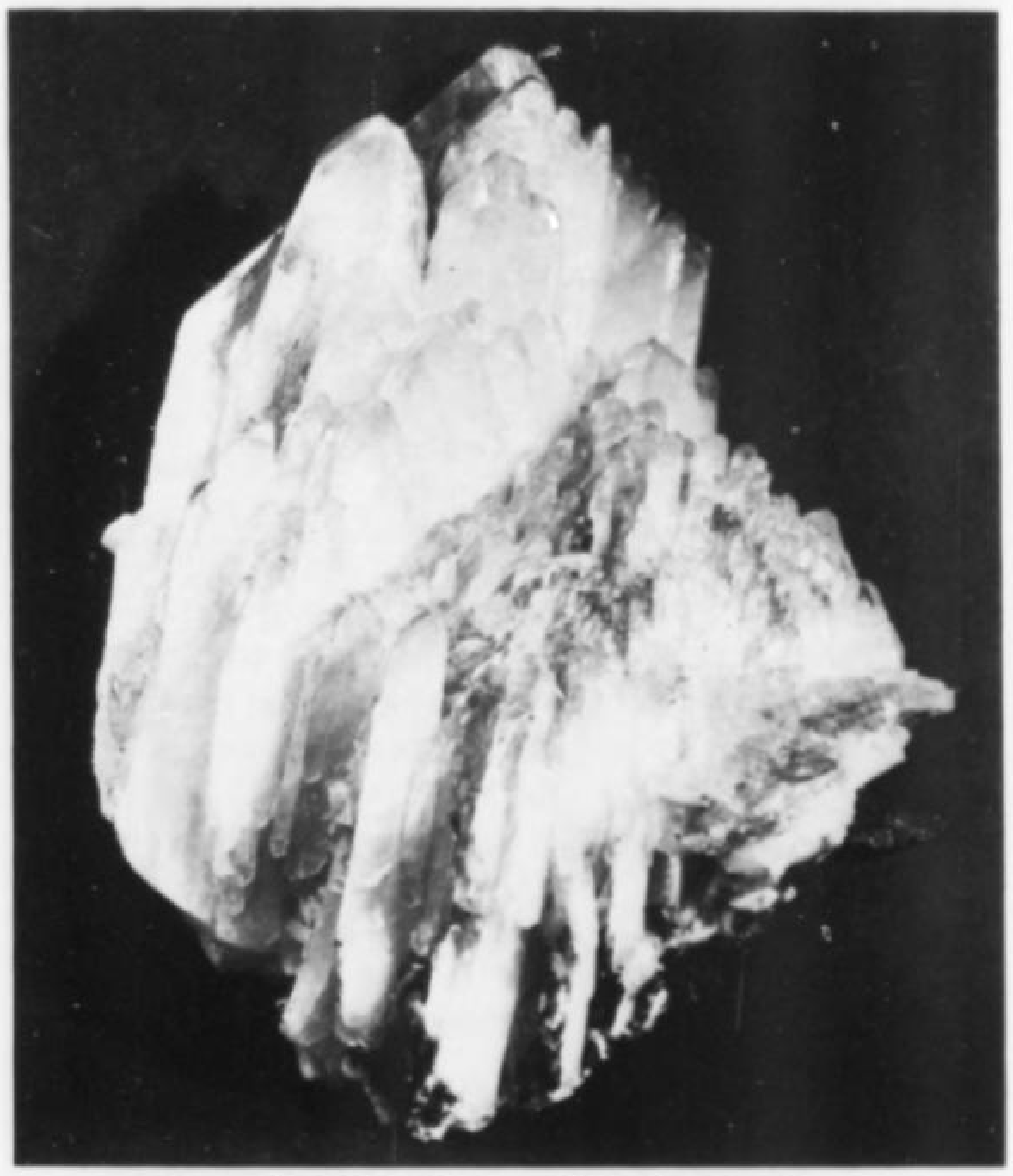

Figure 27. **White barite with yellow terminations, on sphalerite, New Glencrieff mine, Wanlockhead. The specimen is 13 x 19 cm. (Royal Scottish Museum collection, #1927.2.7.)**

Minerals occurring in the Leadhills-Wanlockhead District

PRIMARY MINERALS

Ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$	Marcasite	FeS_2
		Nickeline	$NiAs$
Aragonite	$CaCO_3$	Pyrite	FeS_2
Barite	$BaSO_4$	Quartz	SiO_2
Calcite	$CaCO_3$	Rammelsbergite	$NiAs_2$
Chalcopyrite	$CuFeS_2$		
Cobaltite	$CoAsS$	Sphalerite	ZnS
Galena	PbS	Witherite	$BaCO_3$

SECONDARY MINERALS

Lead

Anglesite	$PbSO_4$	Linarite	$PbCu(SO_4)(OH)_2$
Beudantite	$PbFe_3(AsO_4)(SO_4)(OH)_6$	Mimetite	$Pb_5(AsO_4)_3Cl$
		Minium	Pb_3O_4
Caledonite	$Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$	Phoenicochroite	$Pb_2(CrO_4)O$
Cerussite	$PbCO_3$	Plattnerite	PbO_2
Cotunnite	$PbCl_2$	Plumbogummite	$PbAl_3(PO_4)_2(OH)_5 \cdot H_2O$
Crocoite	$PbCrO_4$		
Descloizite	$PbZn(VO_4)(OH)$		
Hydrocerussite	$Pb_3(CO_3)_2(OH)_2$	Pyromorphite	$Pb_5(PO_4)_3Cl$
Lanarkite	$Pb_2(SO_4)O$	Susannite	$Pb_4(SO_4)(CO_3)_2(OH)_2$
Leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$	Vanadinite	$Pb_5(VO_4)_3Cl$
Lead hydroxyapatite	$2(Pb_5(PO_4)_3OH))$	Vaquelinite	$Pb_2Cu(CrO_4)(PO_4)(OH)$

Zinc

Aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	Hemimorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$
Goslarite	$ZnSO_4 \cdot 7H_2O$	Hydrozincite	$Zn_5(CO_3)_2(OH)_6$

Copper

Azurite	$Cu_3(CO_3)_2(OH)_2$	Copper	Cu
Brochantite	$Cu_4(SO_4)(OH)_6$	Covellite	CuS
Chalcocite	Cu_2S	Malachite	$Cu_2(CO_3)(OH)_2$
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$	Olivenite	$Cu_2(AsO_4)(OH)$
		Tenorite	CuO

Others

Annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$	Greenockite	CdS
		Gypsum	$CaSO_4 \cdot 2H_2O$
Apatite	$A_5(XO_4)_3(F,OH,Cl)$	Hematite	alpha-Fe_2O_3
		Magnesite	$MgCO_3$
Chlorite	$M_{5-6}(Al,Si)_4O_{10}(OH)_8$	Palygorskite	$(Mg,Al)_2Si_4O_{10}(OH) \cdot 4H_2O$
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$	Psilomelane	$2((Ba,H_2O)_2Mn_5O_{10})$
Fluorite	CaF_2	Pyrolusite	MnO_2
Goethite	alpha-$FeO(OH)$	Siderite	$FeCO_3$
		Strontianite	$SrCO_3$
Gold	Au	Titanite	$CaTiSiO_5$

ACKNOWLEDGMENTS

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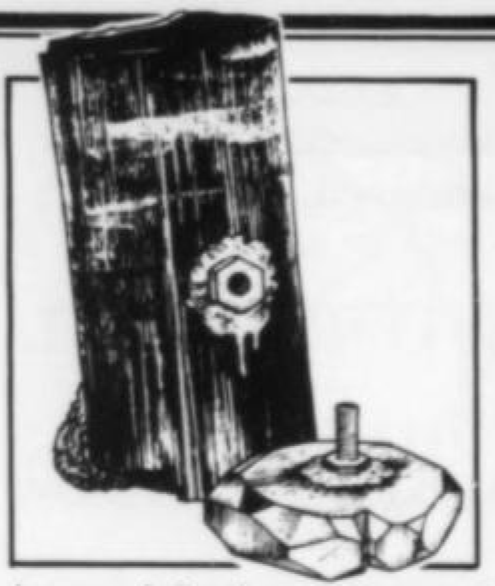

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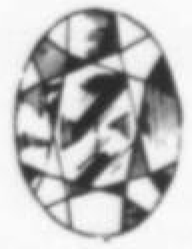

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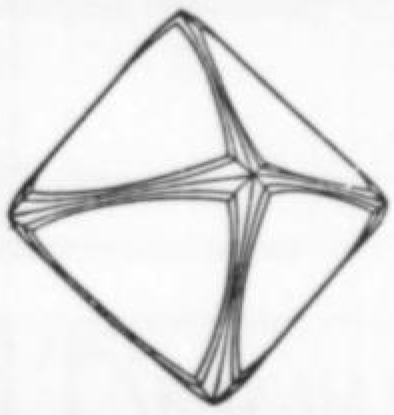

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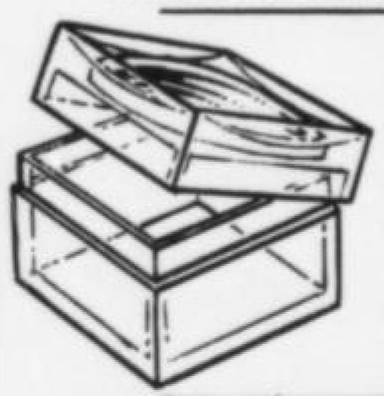

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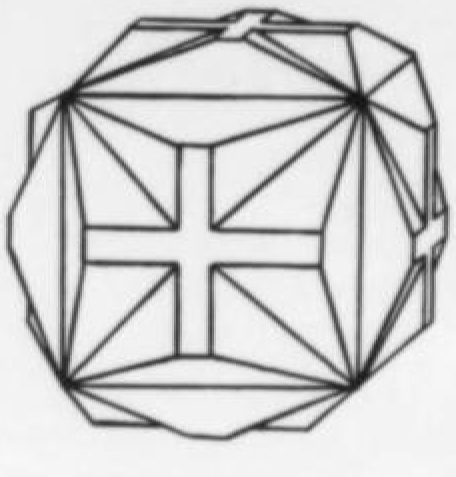

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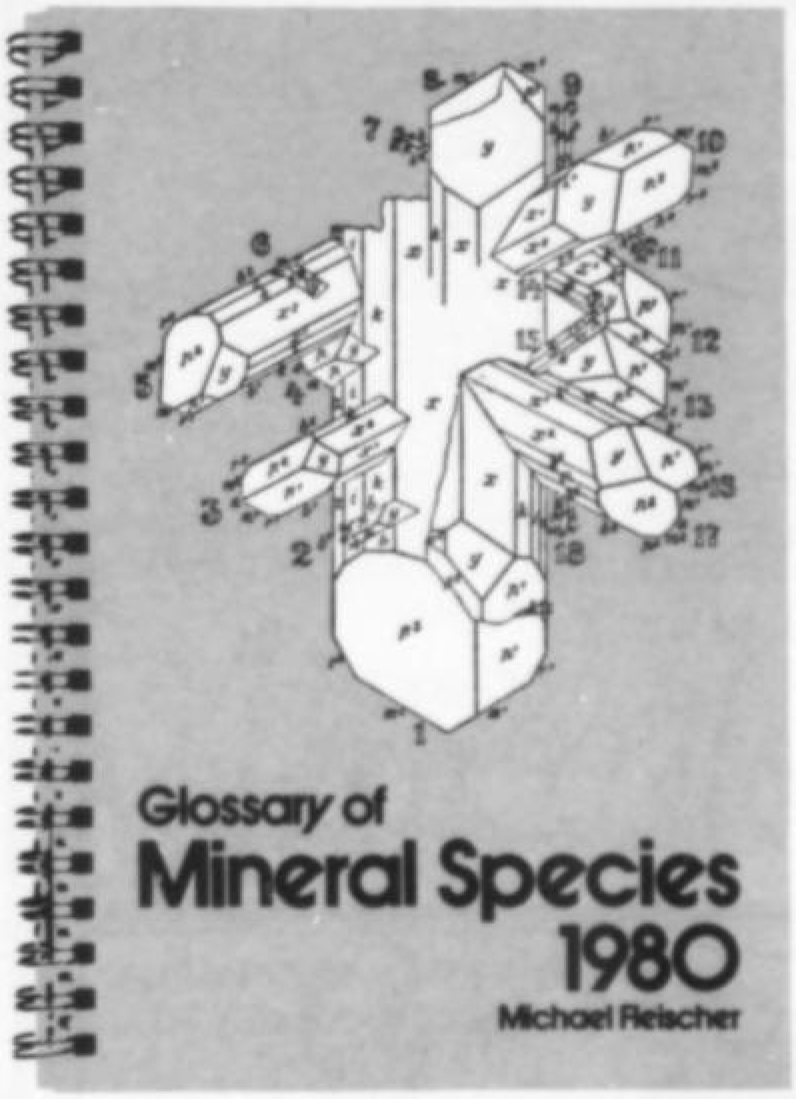

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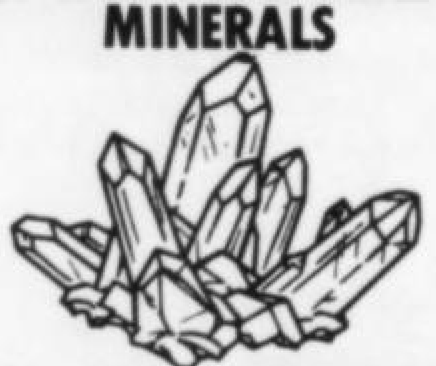

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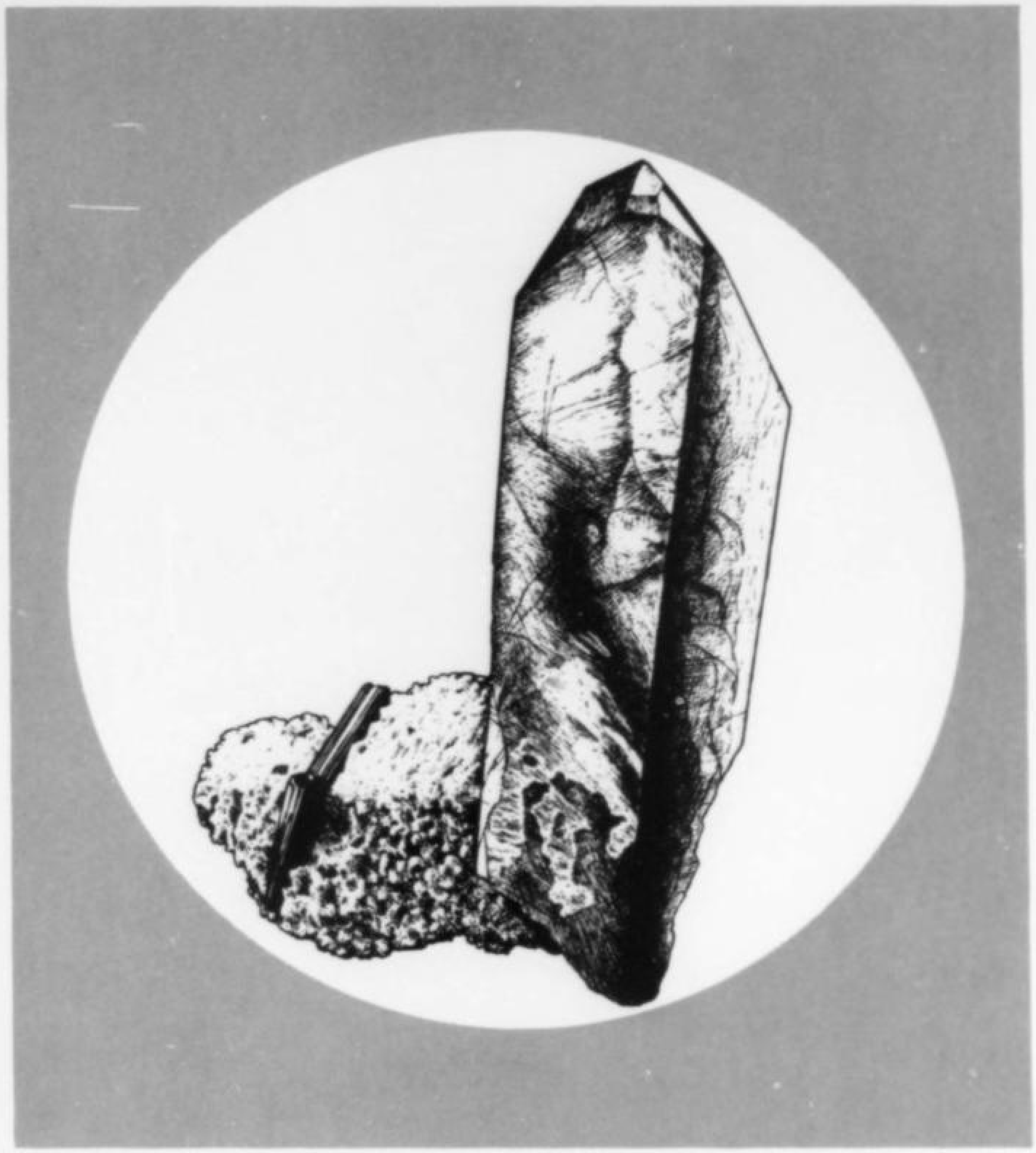

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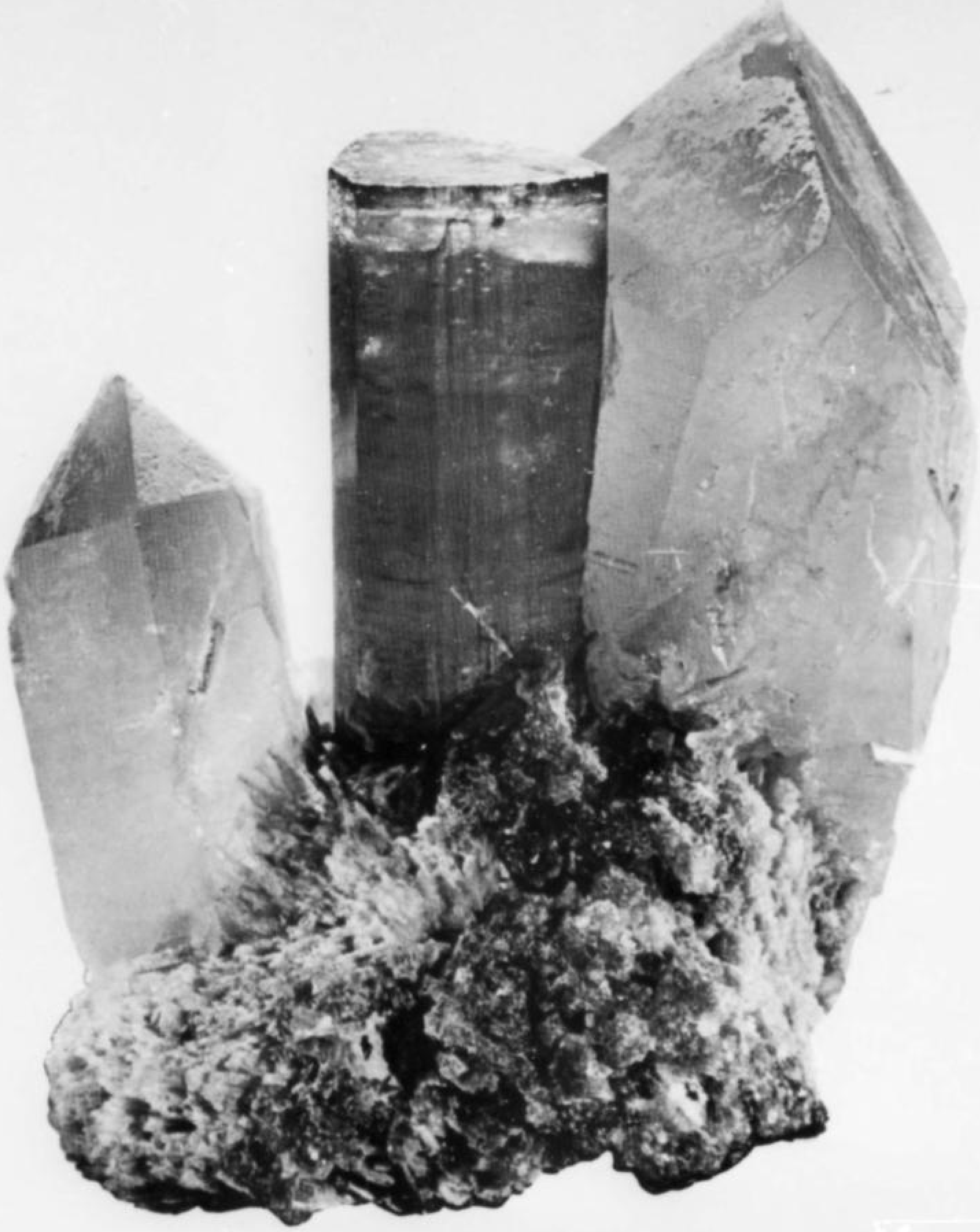

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