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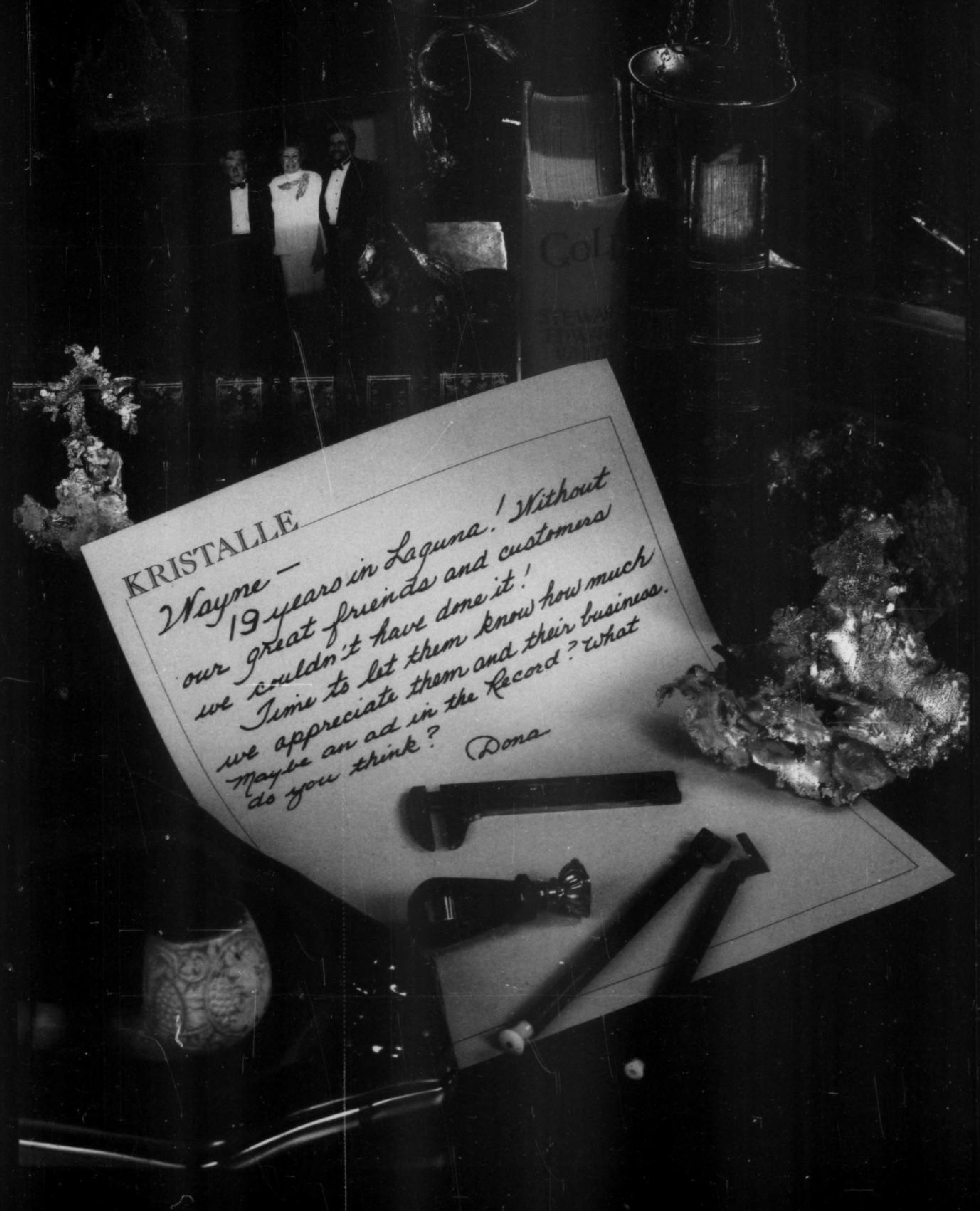

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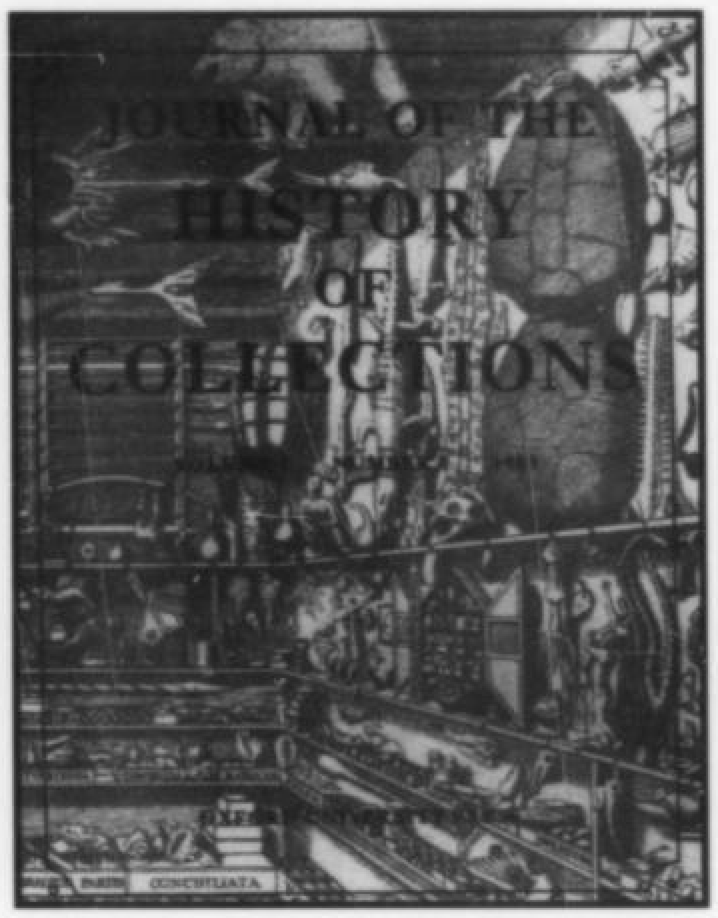
Articles

Columns

COVER: BROOKITE crystal, doubly terminated, 2.5 cm (1 inch) long, from Grieserntal, Canton Uri, Switzerland. Photo by Werner Lieber.

notes from the EDITOR



NEW GERMAN MAGAZINE

Rainer Bode, publisher of *Emser Hefte* and the defunct *Magma,* and one of the world's top mineral photographers, has recently launched a new mineral magazine entitled *Mineralien-Welt* ("Mineral World"). The first issue, apparently released as a market test, is labeled *Sondernummer* ("special issue") *1, 1990*. The second issue is labeled *1. Jg, Heft 1* (vol. 1, no. 1), July-August 1990.

Subtitled "the magazine for the collector of beautiful stones," it features Bode's fine mineral photography, news items, show reports, a calendar of European shows, classified ads, and articles on European mineral localities.

A one-year subscription, six bimonthly issues, is 60 DM in Germany and 66 DM elsewhere, plus an additional 6 DM for the *Sondernummer*. Order from Mineralien-Welt, Postfach 405, D-4358 Haltern 4, West Germany.

NEW HISTORY JOURNAL

For serious scholars and hardcore history buffs there is a new journal of interest entitled *Journal of the History of Collections*. The publication traces its parentage to a week-long symposium at Oxford in 1983, focusing on 16th and 17th century "cabinets of curiosities," proceedings of which were later published in hardcover under the title of *The Origins of Museums* (1985) (Oliver Impey and Arthur MacGregor, eds.). The popularity of that book encouraged Oxford University Press to launch the new venture as a regular forum for investigations into the history of collecting, under the guidance of the same two editors. Because of the universal scope encompassed by Renaissance and Baroque collections, it has proven easy for all manner of natural history specialists, including mineralogists, to recognize the beginnings of their various disciplines in those early cabinets.

Three issues have thus far been published. Articles include advice written in 1587 on "How a Kunstkammer should be formed"; a discussion of the classical etymology and Renaissance genealogy of the museum; a description of the early 18th century geological and mineralogical collection of John Woodward (which has survived intact, in its original cabinets); a look at the Royal Microscopical Society's collection of antique microscopes; gems from the collection of Russian Princess Catherine Dashkov (1743–1810); and an attempted reconstruction of the Museum Wormianium (1655).

The subscription price for private individuals is $36 per year for two issues (vol. 1 ran to 230 pages). Order from Journals Subscriptions Dept., Oxford University Press, Pinkhill House, Southfield Road, Eynsham OX8 1JJ, England.

BRITISH JOURNAL

Readers are no doubt already aware of one British journal of minerals and mineral collecting: *UK Journal of Mines and Minerals* (see their ads in recent issues of the *Mineralogical Record*). It is not, however, the only one. *Journal of the Russell Society* is devoted to the mineralogy of the British Isles as well, and most of the back issues (vols. 1 and 2) are still available. A one-year subscription (two issues) costs £10, and back issues are £2.50 to £3.50. Write to J. Wooldridge, 20 Fir Tree Road, Fern Hill Heath, Worcester, WR3 8RE England.

SLAG COLLECTORS

For people interested in slag minerals and occurrences (such as the famous Laurium, Greece, locality) there is a new organization: *The International Association of Collectors of Slag Minerals*. A quarterly newsletter for members will be published by *Oryktologika Nea—News on Minerals* in collaboration with the South African Micromount Society. Membership fee will be $5 to cover printing and postage costs. To obtain an application form write to D. G. Minatidis (70 Queen Sophia Avenue, 185-32 Piraeus, Greece) or Horst Windisch (P.O. Box 17273, Groenkloof, South Africa 0027).

NOTICE

Died, John ("Jack") Parnau, 84, of Campbell, California. He was born in Stockton, California, where he worked as an electrician until his retirement. He was a man of many hobbies: ham radio, photography, semi-pro tennis and (in his later years) primarily mineral collecting. Parnau was instrumental in encouraging many young people to take up mineralogy as a hobby. The mineral *parnauite* was named in his honor. He died on July 16, 1990.

Edward H. Oyler

SPECIALIZATION IN MINERAL COLLECTING

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For those who have wondered, "Can my collection ever be important to others? Will it be of benefit to the science of mineralogy? Which directions can I pursue to help assure that it is?", specialization may well be the answer.

The views of museum mineralogists regarding mineral collecting are not always wholly congruent with those of many collectors. Most people collect minerals as their own property, whereas museum personnel collect minerals for their institution's collections, not only to serve such immediate needs as exhibits and research programs but also to serve the needs of those as yet unborn, for posterity in the greatest and grandest sense of the word. This requires museum perspectives to be longer and museum interests to be broader than those of most people who collect only for themselves. Because mineralogical science and mineral museums will inevitably be as dependent on collectors for specimens and collections in the future as they have been in the past, it is in the interest of museums that mineral collecting remains both a challenging and a rewarding hobby for private individuals.

Collectors who are serious about mineral collecting must sooner or later ponder the choice of directions in which to proceed, and may eventually seek to change directions and develop new strengths. Some, sharing the curator's concern for the long term, wonder if and how their collecting activities might ultimately benefit mineralogy. This essay on the benefits of specialization is a response to such questions. Not all specialized collections address the questions of usefulness to others and to the science, or have truly *transcendant value* which might argue for their always being kept intact for their scientific importance, so the discussion goes beyond these considerations. Rather, some general ideas are set out. Thematic collections are not for everyone, and fortunately so. An increase in the diversity of collecting is always desirable, and specialized collections do offer a really significant opportunity to diversify.

Specialization does not mean limiting a collection to a Uniform Rules size-class or some other *arbitrary* standardization. Rather, it means the development of collections around interesting *themes*. A thematic approach can help guide the growth of scientifically meaningful collections. It instills a discipline which constructively constrains an individual's collecting energies and resources. Thematic collections are not random assortments of specimens united only by size or aesthetics. They are meaningfully focused and they have broad-based and well-recognized value to collectors and scientists alike. The following sections examine several possible themes, not all of which have a scientific basis.

SINGLE-LOCALITY COLLECTIONS

Collections devoted to minerals of a specific locality are among the greatest scientific resources a mineral collector can amass and contribute. The preponderance of existing collections of this kind has been assembled by dedicated collectors, not the scientific or business communities, and is an enormous legacy to mineralogy. This type of collection is an important and noble pursuit for the dedicated collector and the challenge is a continuing one. Old localities (Andreasburg, Chañarcillo, and others), well-known producers of the recent past (Crestmore, Butte, Joplin, Mapimi . . .) and new localities (Gilgit, Kuruman, Nasik, St. Hilaire . . .), and hundreds of other localities, all merit the same level of attention that has been lavished by collectors on Franklin, Långban and Tsumeb. There is much more to do, and the sooner the better; it must be done right away. Far too few are involved in this important task.

There are great personal satisfactions in single-locality collections. At localities with a moderate or small number of species, the collector's natural but usually unsatisfied goal of attaining completeness can actually be realized. Typically there is an initial period of intense collecting and learning about the locality's minerals, its geology and its history. This intensity level usually diminishes somewhat by the time a representative collection has been assembled. However, filling out and upgrading the collection until it becomes truly important and probably unique because of its comprehensiveness and quality may require a lifetime.

The process of building an important single-locality collection requires the collector to become broad-minded about other aspects of what he collects. The collection might contain micromounts as well as cabinet specimens, and massive specimens as well as fine crystals. Scientifically prepared specimens, including ore concentrates, drill cores, microprobe mounts, powders and thin-sections might all have a place in such a collection (categories and size-tidiness be damned!). It also requires the collector to be a careful documentor of his holdings; otherwise **all** is for naught.

The significance of such a reference collection to the local *mineralculture* is rewarding in several respects. At complex localities, the challenges are really daunting (try Långban or Franklin if you are truly brave; St. Hilaire or Tsumeb likewise require courage), the subject matter may be quite difficult, and the learning-curve is a long one. However, the rewards are surely proportionate, and you join a select group of persons who really know all about the minerals from these localities and are greatly respected for their expertise. It is at this time that one could write or coauthor or serve as a resource for the definitive mineral locality-description paper for the deposit and publish it. When you are an elder in your years, you are also a respected "elder" in your specialty, and in a position to help others . . . continuously. It's a fine pursuit!

REGIONAL COLLECTIONS

Regional collections are commonly limited to the minerals from a particular area or political region, and occasionally (and laudably) from a geologic region irrespective of political boundaries, but the theme can be broader or narrower in scope. When such collections are organized around geologic principles, they become invaluable. This type of collection may be ideal for collectors who do not live near famous localities, have a limited ability to travel, or a limited budget. If it has the virtues of reliable documentation and comprehensiveness, a regional collection can become the basis for a regional mineralogy, a staple of the mineralogical literature. It can also serve as the highlight of a local museum exhibit or mineral-show exhibit. Such collections become attractions for visiting mineralogists and collectors, with all the attendant social benefits.

FIELD-COLLECTED COLLECTIONS

Such collections result from great personal efforts. Among all the specimens removed from specific locations, field-collected specimens have the greatest archival value, assuming the collector has taken great pains to document the *mineralogy and geology* of his collection, assuredly in personal catalogs, and ideally, partly in the formal literature as well. This type of collection, usually broad in its scope, is assembled by visits to many localities, and by collecting with local experts; it thus has much material of value to posterity, the mineralogists and collectors of tomorrow. Such collections have no second-hand locality information; they are priceless in that regard. These collections are fun to develop, can sometimes be built with limited financial resources, and can often be donated to science with but little loss to estate heirs. Additional benefits are that the overall total specimen base is constantly increased and enriched, and new and unique material is recovered and retained. Such collections are unique. There is a great advantage to the collector who lives nearby; he can preserve parts of nearly every find because he is right there "on the spot." One of the satisfactions is having and being able to share things which others don't have. The collector, however, has to want to build such a collection for its own sake and no other. Unlike some other collecting specialties, peer recognition comes slowly and cannot be purchased. Additionally, such collections are very personal, providing enormous pride to the collector. As time goes on, some of these specimens may be described in articles in the *Mineralogical Record, Rocks & Minerals,* the *American Mineralogist,* and other journals. The satisfactions of this specialty are great, and the collection as a whole is **much greater** than the sum of its parts.

COMPREHENSIVE SPECIES COLLECTIONS

Species collections have the idealized goal of including specimens of all the ≈3500 mineral species. This objective is doomed from the start because some species are not now attainable. Even the oldest, largest, best institutional collections can only *approximate* this goal. However, the attempt can be very rewarding to those willing to endure its inherent frustrations. It is especially important to keep an eye on the real significance of what is collected (see our comments on mineral specimen fragmentation in the *Mineralogical Record,* **17**, 226; **18**, 167–168). Nevertheless, some of the greatest mineral collections ever formed were built with this objective. The mineralogical education one obtains is the ultimate reward of building such a collection.

SINGLE-SPECIES COLLECTIONS

These collections are composed of a wide variety of habits and occurrences of but a single mineral species. One may collect calcite, or wulfenite, or quartz, or barite, or any of the relatively common minerals for which sufficient variations exist to make the quest stimulating and worthwhile. Such collections are almost always very interesting, have educational and archival value, and make really fine exhibits. They also serve the science, as do some other specializations, by pulling together much material that would be otherwise greatly dispersed. Moreover, collectors are not limited to collecting *one* mineral; some collectors have chosen to have a number of species specialties. Collecting associations moves this specialty in the direction of paragenetic collections.

CHEMICALLY-SPECIALIZED COLLECTIONS

Chemically-specialized collections are composed of mineral specimens which fit a specific chemical characteristic . . . usually either an anion group (phosphates, carbonates, etc.) or a cation (zinc minerals, beryllium minerals, etc.). As it grows, this collection becomes a specialized species collection, with its attendant challenges and frustrations. Such chemically specialized collections have even greater educational and scientific value than single-species collections.

PARAGENETIC COLLECTIONS

An interesting and insightful way to collect and study minerals is to compare and contrast minerals from various localities, all of which represent a single geologic mode of occurrence. Paragenetic themes can easily be built around the minerals from alpine clefts, evaporite deposits, pegmatites, or oxidation zones of base-metal deposits. The possibilities are numerous and, when combined with other niches listed above, are nearly unlimited. For example, one might collect rare-earth minerals from carbonatites, zirconium minerals from nepheline-syenite occurrences, or phosphates from ironstone formations, and so on.

HISTORICAL COLLECTIONS

Historical collections specialize in mineral specimens with historical significance. They are, with exceptions, of limited scientific utility, but are of great importance to the history of the *mineralculture*.

PHENOMENOLOGICAL COLLECTIONS

Many minerals exhibit properties and features which can serve as the focus for a specialization. One such type of collection is that of minerals which fluoresce in response to ultraviolet radiation. Others might be pseudomorphs, selective encrustations, epitaxies, rehealed crystals, and on and on. These specializations can provide the collector with a very interesting pursuit, and a collateral depth of skill in mineral recognition. Such collections can have educational significance if carefully assembled. It's also a lot of fun.

HABIT COLLECTIONS

Mineral habit collections are those which have as their focus some physical aspect which numerous minerals have in common, usually employing a textural or crystal-habit discriminant. The usefulness of such collections depends on how they are assembled. Among the varied possibilities are: crystal collections, ore-texture collections, and a great many more. One can also choose little-studied but important aggregate habits, such as banded minerals, druses, and the like. Too little attention has been given to this specialty in modern times.

SUMMARY

For those interested in developing new dimensions in their collecting, and simultaneously helping to preserve aspects of our mineral heritage in an organized manner, specialization offers much pleasure and satisfaction. For those not already consciously specializing, a reexamination of one's collection might reveal a subconscious predisposition for one kind of specimen or another, suggesting a latent specialty that can be further developed. A speciality need not be the sole focus of a collection. Indeed, many collectors have adopted several different specialties and it is more than just doubly pleasurable when two specialties are satisfied with a single acquisition. One might specialize in a species or two, or three, a favorite locality or two, and some narrower peculiar niche just to keep the need and urge always present and unsatisfied!

ACKNOWLEDGMENTS

We are indebted to the many collectors with whom we have discussed these ideas and, in particular, to those whose pointed inquiries stimulated this effort. We thank Dr. Steven Chamberlain, Richard C. Erd, Marie and Terry Huizing and Dr. Wendell Wilson for critical readings. ▨

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Karen Bailey and **Doug Dumka**
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Canada

The Nanisivik mine on Baffin Island has been in operation for only 14 years. But in that time it has yielded fine specimens of pyrite which qualify the occurrence as among the world's best and most interesting for the species.

INTRODUCTION

The Nanisivik mine is situated on Strathcona Sound at the northwest end of Baffin Island near latitude 73°N and longitude 85°W, about 700 kilometers north of the Arctic Circle (Fig. 1). The mine has been operating since 1976, and produces mainly zinc, with lead and silver as by-products. In recent years spectacular mineral specimens, especially pyrite, have been found.

The mine operates all year round, the ore being concentrated and stockpiled during the winter for shipment. In the summer, five shiploads, each containing 25,000 metric tons of concentrate, are transported to Belgium for distribution to smelters throughout Europe. An icebreaker brings in the first ore ship of the season in July and the last ship, escorted out by an icebreaker, leaves in November (Fig. 2).

In winter, the nights get longer and longer until there is total darkness for all of December and the first two weeks in January when the temperature may fall to −50° C (−58° F). The Arctic summers are the opposite with the days lengthening to 24 hours for a few weeks in June and July.

The only accommodations and other facilities at Nanisivik are the property of the mine, so it is impossible for someone not connected with the company to plan a trip to this remote locality. There is a regularly scheduled jet service to the Nanisivik airport two days a week, but rapid and unpredictable changes in the weather can close the airport without warning. Many a 737 has had to return to Iqaluit (formerly Frobisher Bay) or Montreal, because of a sudden white-out or low ceiling causing zero visibility. An account of life at Nanisivik may be found in a two-part article by Judy Steed in Toronto's *Globe and Mail* (Steed, 1986). An excellent overview of the Nanisivik mine, its history and operation may be found in Loree (1989).

Even though the temperature may be +10° C in the summer, the underground temperature is closer to −15° C, because the mine is in the 500-meter-deep permafrost. This, of course, dictates some unusual collecting strategies and techniques. Protective clothing consisting of insulated coveralls, boots and mittens are worn to prevent frostbite and hypothermia. An ice pick, instead of a geological hammer, becomes an important collecting tool because nearly all the vugs are completely filled with ice (Figs. 5 and 6). Though initially frustrating, the ice protects the crystals in the vugs and makes collecting easier than one might think. The ice is chopped from the center of the vug with an ice pick, to create an open space. Then, leaving a few centimeters of ice as a protective covering over the crystals, portions of

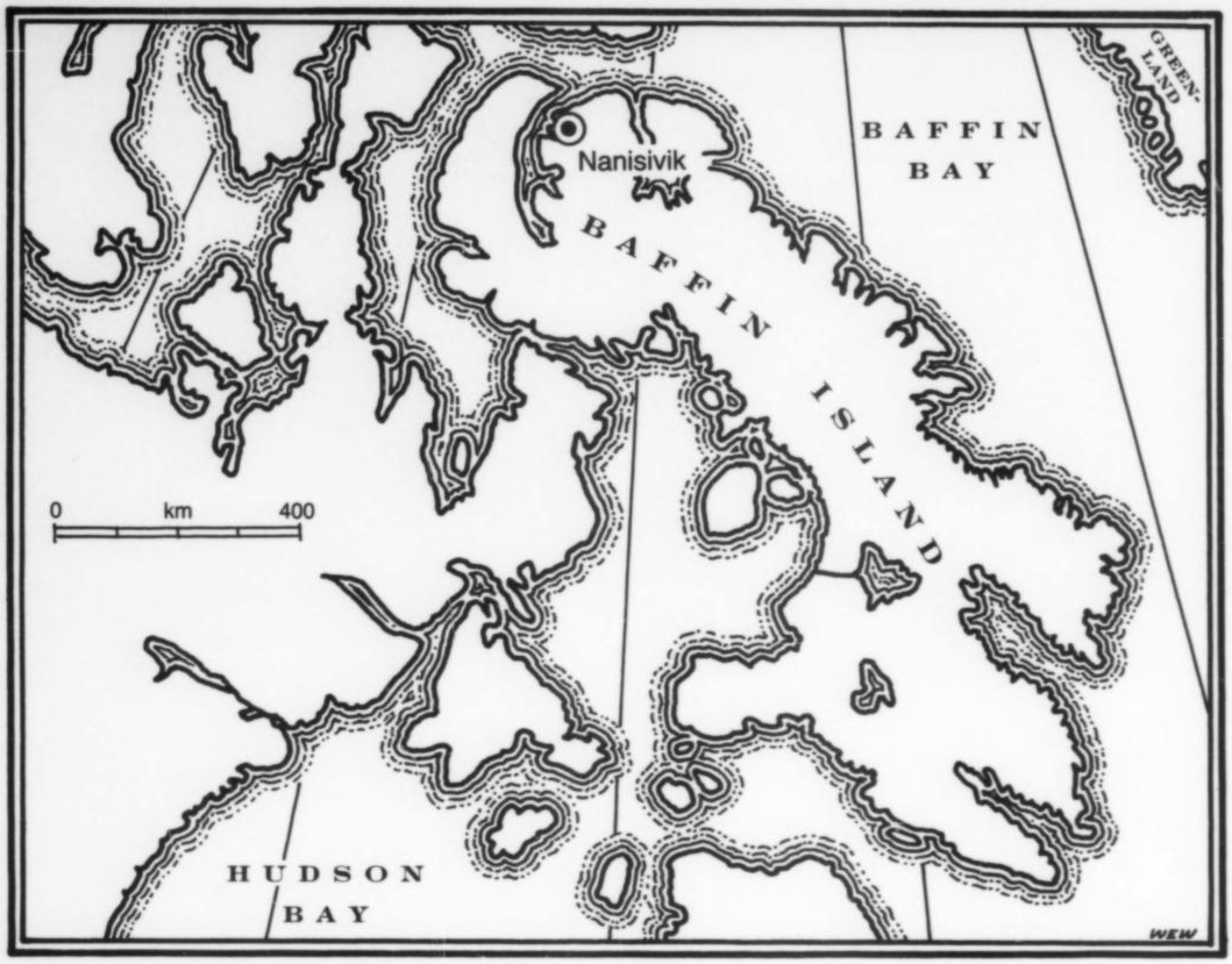


Figure 1. **Location map.**

the vug are dislodged into the opening with a hammer and chisel. This has to be done carefully, because a fracture in the ice can break off the tops of the crystals. The ice-covered specimens are then taken to the surface where the ice is slowly melted to expose the crystals to avoid a sudden change in temperature that may cause the crystals to shatter. Most of the specimens collected by this technique have minimum damage and need little cleaning, as the vugs contain little dust and no oil or clay.

An advantage of the permafrost is that it holds rocks in place that would otherwise fall, and so reduces a major hazard of underground collecting. A disadvantage becomes evident in the summer when the mine acts like a giant freezer, and up to half a meter of frost and ice crystals cover the walls, obliterating everything. Defrosting it is impossible. The frost forms by condensation of water vapor from the warm, humid outside air used to ventilate the underground workings. Collecting is therefore best during the winter months, when the air is cold and dry and the walls of the mine are frost free.

In spite of the hardships of the cold and the long winter nights, the collecting is nothing less than incredible, for crystal-lined pockets are everywhere and even pieces of ice lying about on the freshly blasted muck piles usually contain good specimens. Confronting a 5-meter-high wall of solid pyrite over 100 meters in length is an awesome sight and would thrill any collector.

Most of the vugs at Nanisivik fall into two general categories: (1) The sulfide pockets, containing mainly pyrite and sphalerite, are usually irregular in shape, ranging from a few centimeters up to about a meter in diameter. They occur in the massive pyrite-sphalerite orebody. (2) The carbonate vugs, containing mostly calcite and dolomite and usually concentrated near the upper contact of the orebody in the overlying dolostone, are more lenticular in shape than the sulfide pockets, and may be over 2 meters across. (More details on the occurrence of the different kinds of vugs are given in the geology section.) These carbonate vugs are reminiscent of those encountered in the Mississippi Valley lead-zinc deposits, and may have formed, at least in part, by karst development caused by slightly acidic water dissolving the limestone to make cavities. It is now thought that the cave system at Nanisivik was much smaller than first theories postulated, and that much of the orebody was formed by dissolution and replacement.

HISTORY

Probably the first recorded investigation of the geology of the Strathcona Sound region was by Arthur English, a prospector on a Government-sponsored expedition led by Captain J. E. Bernier aboard the steamship *Arctic* in 1910. After spending the winter of 1910–11 in Arctic Bay, English issued the following report, quoted here verbatim from Johnston (1911):

> C.G.S. "Arctic,"
> Arctic Bay, July 18th, 1911.
>
> Captain J. E. Bernier,
> Commander C. G. S. Arctic.
>
> Dear Sir,
>
> I have the honor to lay before you the following additional information in regard to my discovery in Strathcona Sound. I regret that I am unable to afford any valuable data from which reliable figures may be taken as to expenses of mining, shipping etc.
>
> As a prospector I can, however, assert with some authority, that a very large body of ore exists in that locality, and under ordinary conditions, or were the deposit located in more favorable latitudes, mining operations could be carried on with a certain profit to investors. Of course, this is assuming that the mineral is valuable; an assay can determine this.
>
> A. English.

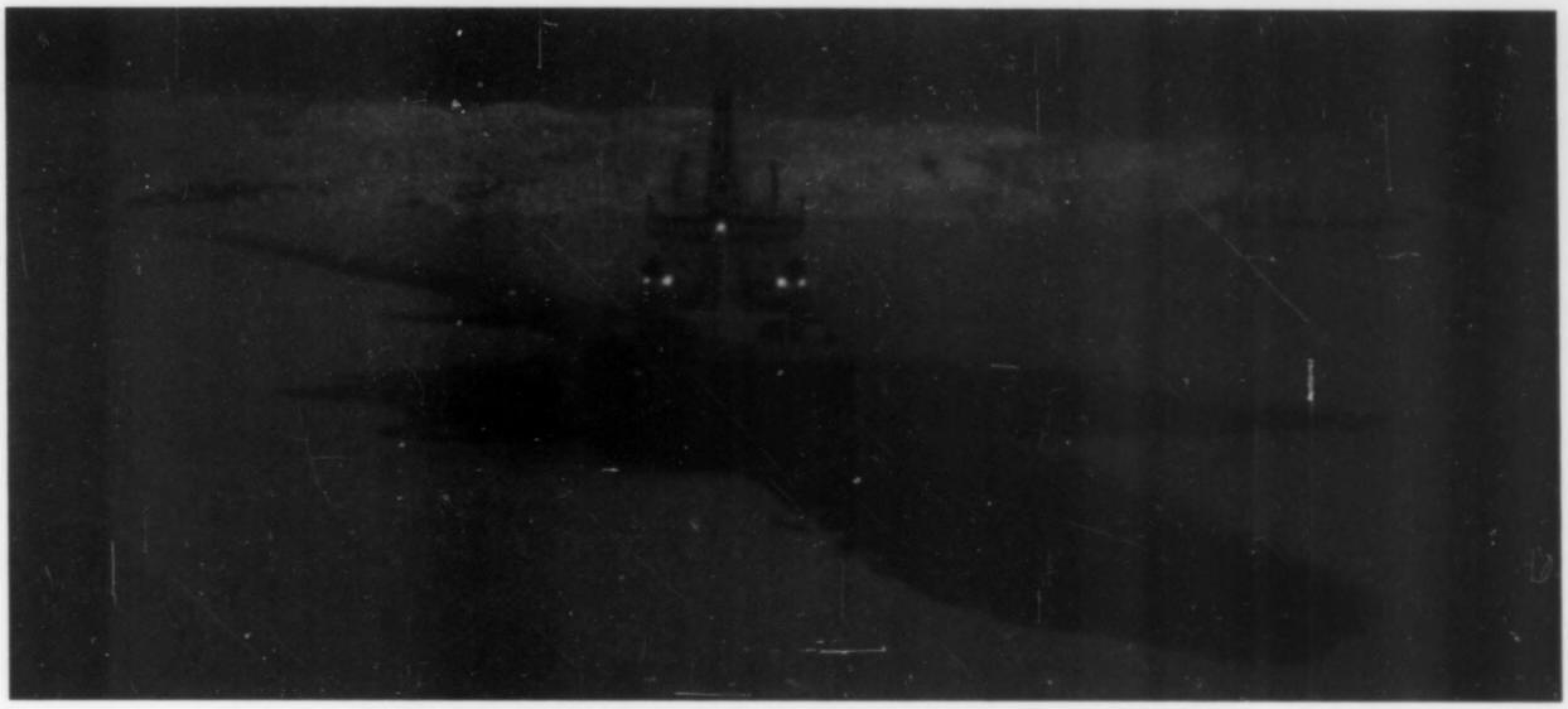


Figure 2. **An icebreaker in Strathcona Sound. Doug Dumka photograph.**

Over a quarter of a century passed before anyone attempted to follow up on this report. In 1937, two brave souls, J. F. Tibbitt and F. McInnes, made a 3,300-kilometer journey by dog sled from Churchill, Manitoba, to stake claims. Time, however, did not permit any significant work to be done in these barren lands, and the claims lapsed. Once again the area lay untouched for a period of years, until 1954 when R. G. Blackadar and R. R. H. Lemon were engaged in regional mapping for the Geological Survey of Canada (Blackadar, 1956).

Soon after the publication of Blackadar's report, Texas Gulf Sulfur (now Texasgulf, Inc.) sent geologists R. D. Mollison and W. Holyk to evaluate the deposit. The results of their efforts are summarized in an unpublished report by the consulting firm of Watts, Griffis and McQuat, Limited (1973):

> A total of fifteen claims were staked by them, covering the Ocean View area north of Lake Kuhulu and the eastern outcrop of the main orebody. In discussions with Mr. Mollison, he related how it was decided to check one last outcrop before leaving the area. This one last outcrop was the one on the eastern extremity of the main orebody. Had this outcrop not been discovered, it is doubtful if Texas Gulf Sulfur would have continued with their exploration efforts in the area and the Strathcona Sound project would not today be on the verge of commercial production.

The following year, additional exploration was carried out, but not without considerable hardship, as the 1973 Watts, Griffis and McQuat report continues:

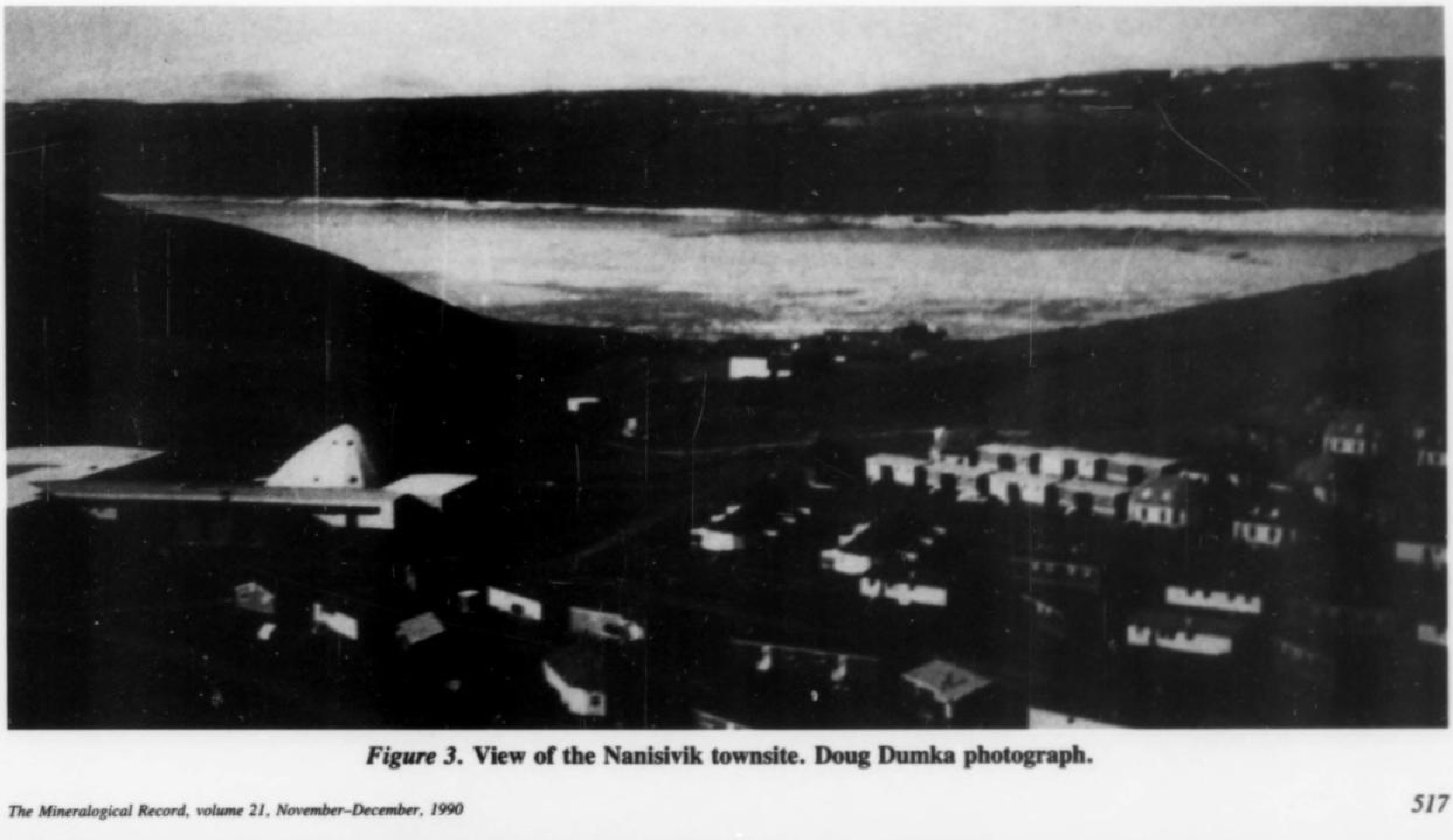


Figure 3. **View of the Nanisivik townsite. Doug Dumka photograph.**

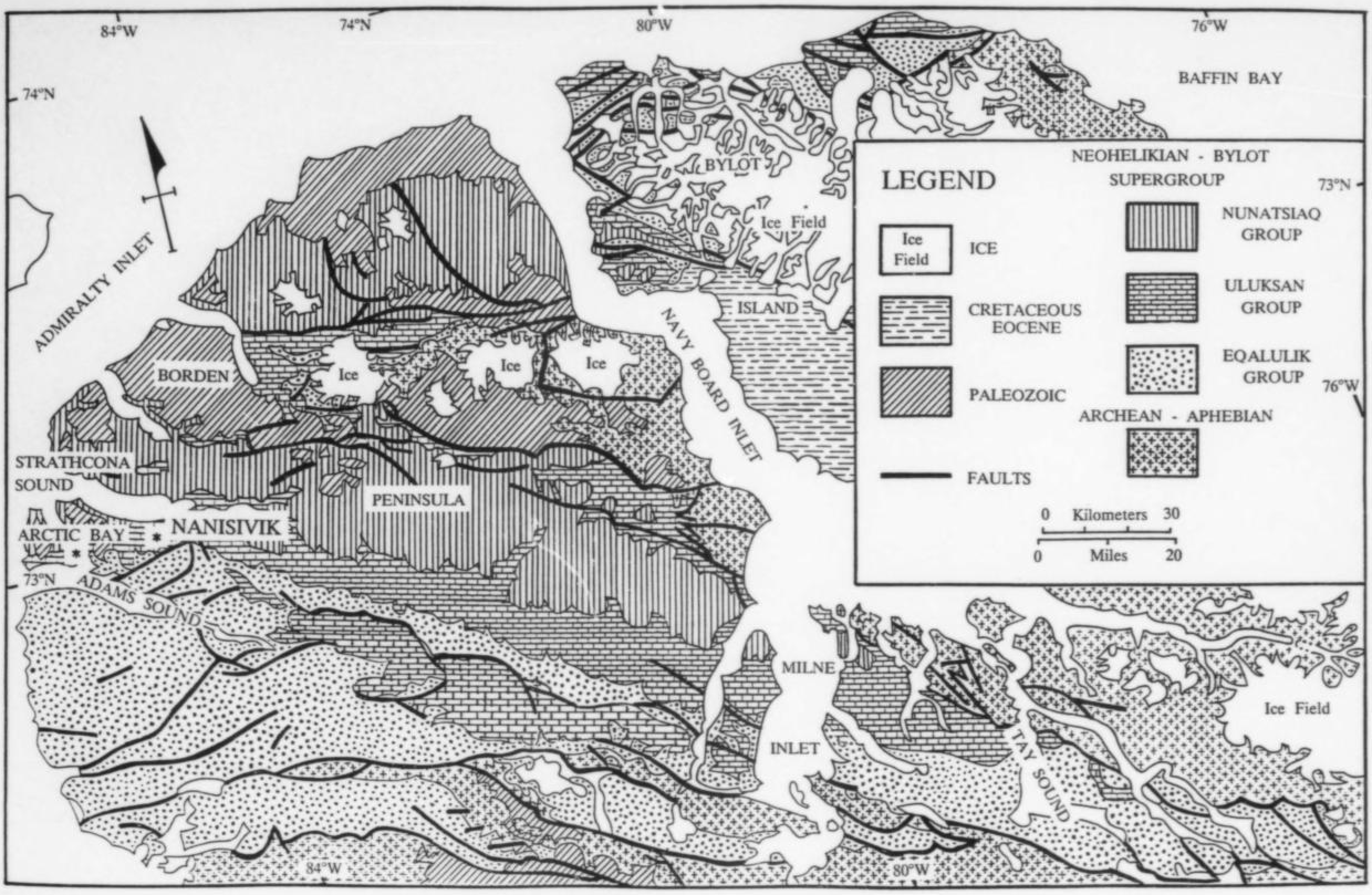


Figure 4. **Geological map of the area around the Nanisivik mine. (Simplified from Olson, 1977.)**

In 1958, Texas Gulf Sulfur sent a party of seven men and two helicopters to further investigate the area. The men and their equipment were flown by DC-4 to Hall Beach, and then ferried into the property by a DC-3 on skis, which landed at Kuhulu Lake. On one of these trips the DC-3, descending through cloud, south of Adams Sound, flew into an ice field on a mountainside at cruising speed. The cockpit, with three men inside, was bent under the fuselage and buried in the snow. The aircraft immediately caught fire, but the remaining passenger, G. Podolsky, a geophysicist, although he had two broken ankles, was able to dig the three men out of the cockpit with a shovel that had been thrown clear of the aircraft. He later fortuitously found four sleeping bags ejected from the aircraft and was thus able to sustain the three men, seriously injured, for three days until the weather cleared sufficiently for rescuers to find the wreck. The site of the crash is now named Mount Podolsky.

Over the next ten years Texas Gulf Sulfur conducted extensive diamond drilling and geophysical programs, exploring several anomalies and delineating the main orebody. The exploration program was slowed down throughout the mid 1960's because the company was bringing the newly-discovered Kidd Creek mine, near Timmins, Ontario, into production.

Once the Kidd Creek project was sufficiently advanced, attention was again focused on the Strathcona Sound area, and in 1969 an exploration adit was driven 650 meters into the east end of the main orebody. The arrival of heavy equipment by sea facilitated operations, and in 1970 a 50-ton bulk sample was shipped to Timmins, Ontario, for metallurgical testing.

In 1972, Texas Gulf was approached by Mineral Resources International of Calgary, Alberta, with a proposal to assume a long-term option on the Strathcona Sound property in exchange for the rights to a sulfur deposit in Mexico. An agreement was reached, and a feasibility study was initiated involving additional drilling, bulk sampling and detailed mapping. The deposit proved to be economically mineable.

The next stage was the formation of Nanisivik Mines Limited, the company that was assigned 100% interest in the mineral claims. This new company consisted of five contributors, each of which were assigned equity: Mineral Resources International held 54%, the Government of Canada 18%, Metallgesellschaft AG 11%, Billiton BV 11% and Texasgulf Incorporated held the remaining 6%. With such diverse interests, the need to bring in a separate managing team became apparent, so in 1974 Strathcona Mineral Services Limited took over and began construction for the project. Only two and a half years later the production of zinc and lead concentrate was started and by 1978 the townsite, dock, airport and mine facilities were completed. Today Nanisivik Mines Limited is owned entirely by Conwest Exploration Company Ltd. and is still being managed by Strathcona Mineral Services Ltd.

GEOLOGY

The deposit at Nanisivik has been dated in the upper part of the Middle Proterozoic, about 1000 million years old, a time period known also as the Neohelikian. The mineralization of the main and lower lenses is in the dolostones of the Society Cliffs Formation, which are overlain by dolomitic shales of the Victor Bay Formation. These two Formations make up the Uluksan Group. Below the dolostones are silty shales of the older Arctic Bay Formation, part of the Eqalulik Group. The Uluksan and Eqalulik Groups are Middle to Late Pro-

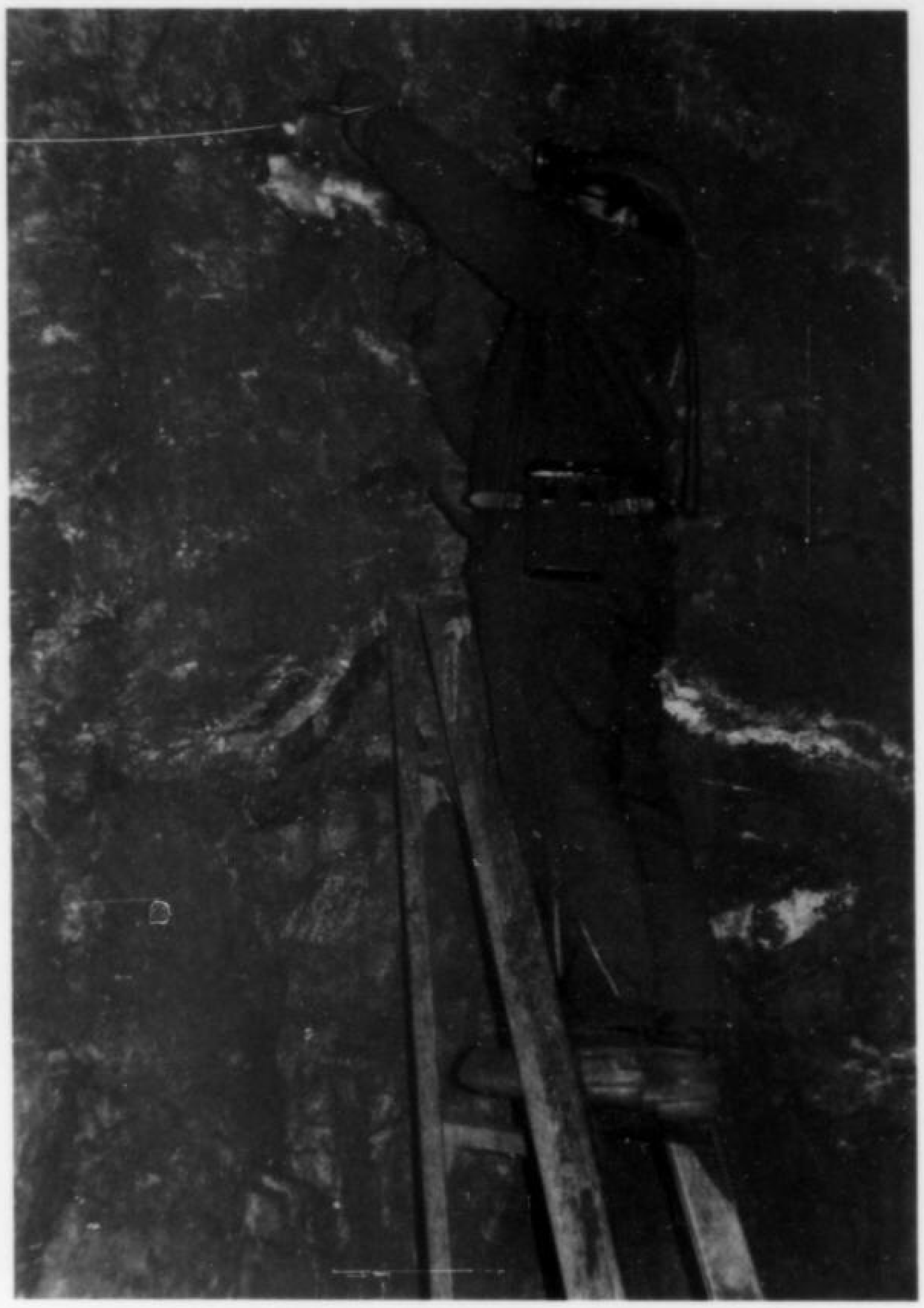


Figure 5. **George Robinson collecting underground at Nanisivik. M. Picard photograph.**

Figure 6. **An ice-filled pocket, about 30 x 40 cm, in Block 27 of the main mine. M. Picard photograph.**

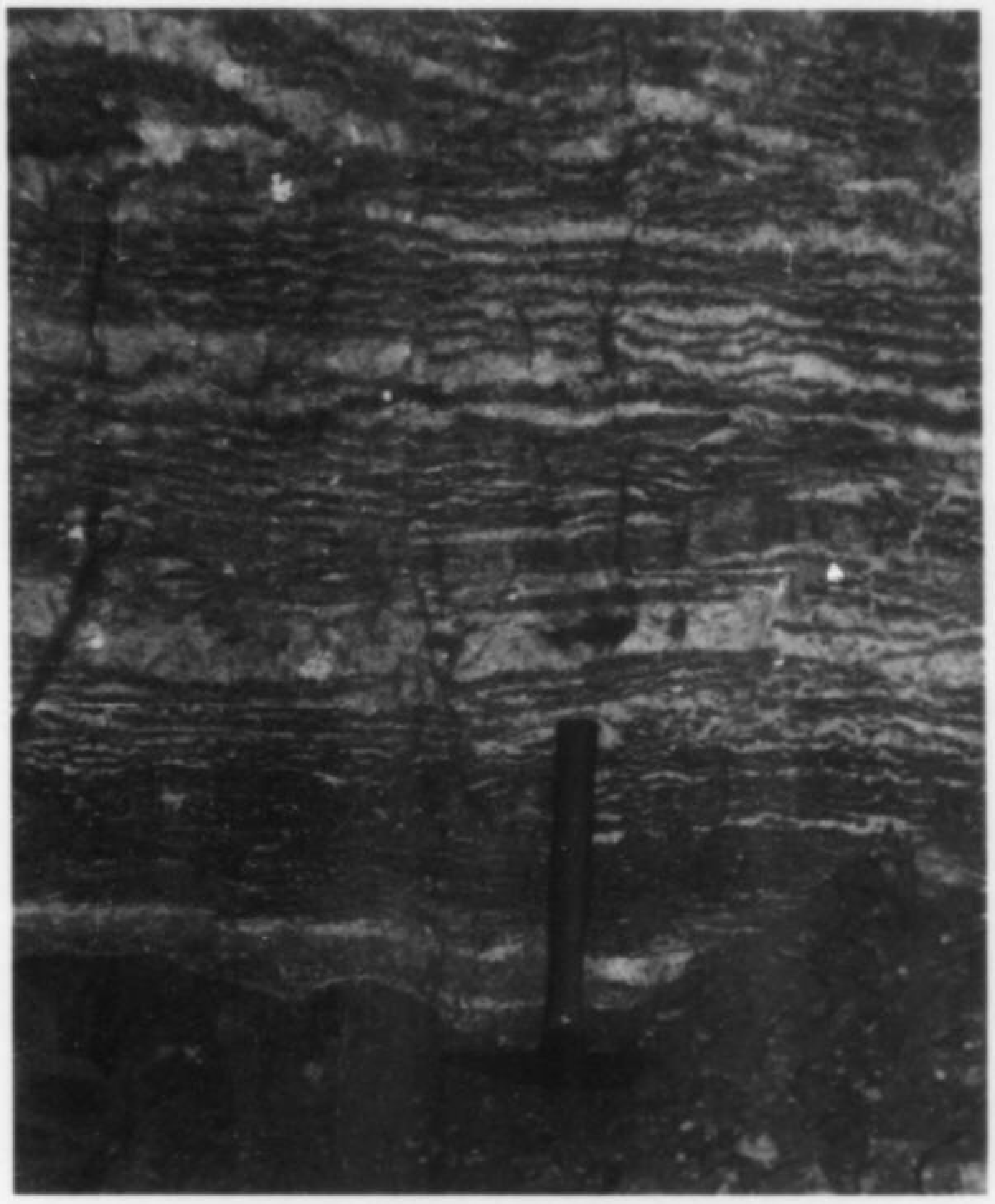


Figure 7. **Banded ore underground in Block 29, Nanisivik mine. G. W. Robinson photograph.**

terozoic in age and are underlain by Early Proterozoic (Aphebian) basement granitic rocks in the Borden Basin (Fig. 4).

In some areas such as Shale Hill and the 04-06 Shale Zones, the Victor Bay shales acted as a cap, sealing in the sulfides. The formations are separated by disconformities and shifted by localized and regional horst and graben faulting.

The basin structure formed as a result of graben faulting in the Borden Rift Zone (Jackson and Ianelli, 1981). It is possible that the tectonic action caused a higher heat flow in the parts of the basin that were affected by the rifting episodes (Curtis, 1984). The Nanisivik area is in the Milne Inlet Trough, a west-northwest trending graben structure. The area has been cut by gabbro and diabase dike swarms of Late Proterozoic (Hadrynian) age. One of these dikes cuts the main orebody, thus defining the age of the mineralization as older than upper Middle Proterozoic (Neohelikian), that is to say older than 1000 million years.

Based on fluid inclusion data (Olson, 1977; McNaughton and Smith, 1986; Arne, 1986) the ore-forming temperatures for the main zone averaged 180° C and varied from 80° C to 230° C. The most likely theory that describes how the ore was formed is as follows: Hot, saline solutions rich in metals, sodium, calcium, chlorine and sulfate ions mixed with cooler, carbonate-rich brines in the presence of a natural gas (probably methane, which produced hydrogen sulfide by sulfate reduction) causing the precipitation of the metallic sulfides marcasite, pyrite, sphalerite and galena.

These sulfides were deposited as epigenetic, secondary cavity fill (Olson, 1977) in a small karst system, which was significantly enlarged by the replacement and dissolution of the dolostones (Curtis, 1984; and Ford, 1986). On the north and south limits of the main orebody are large dolostone fins, proof that the dolostone has been replaced by sulfides. There is an abundance of sparry dolomite, and the banded sulfides are parallel to the dolostone contact of the fins. In other areas sphalerite-dolomite markers can be seen to have partially mineralized the dolostone.

The area around Nanisivik once contained about 60 million metric

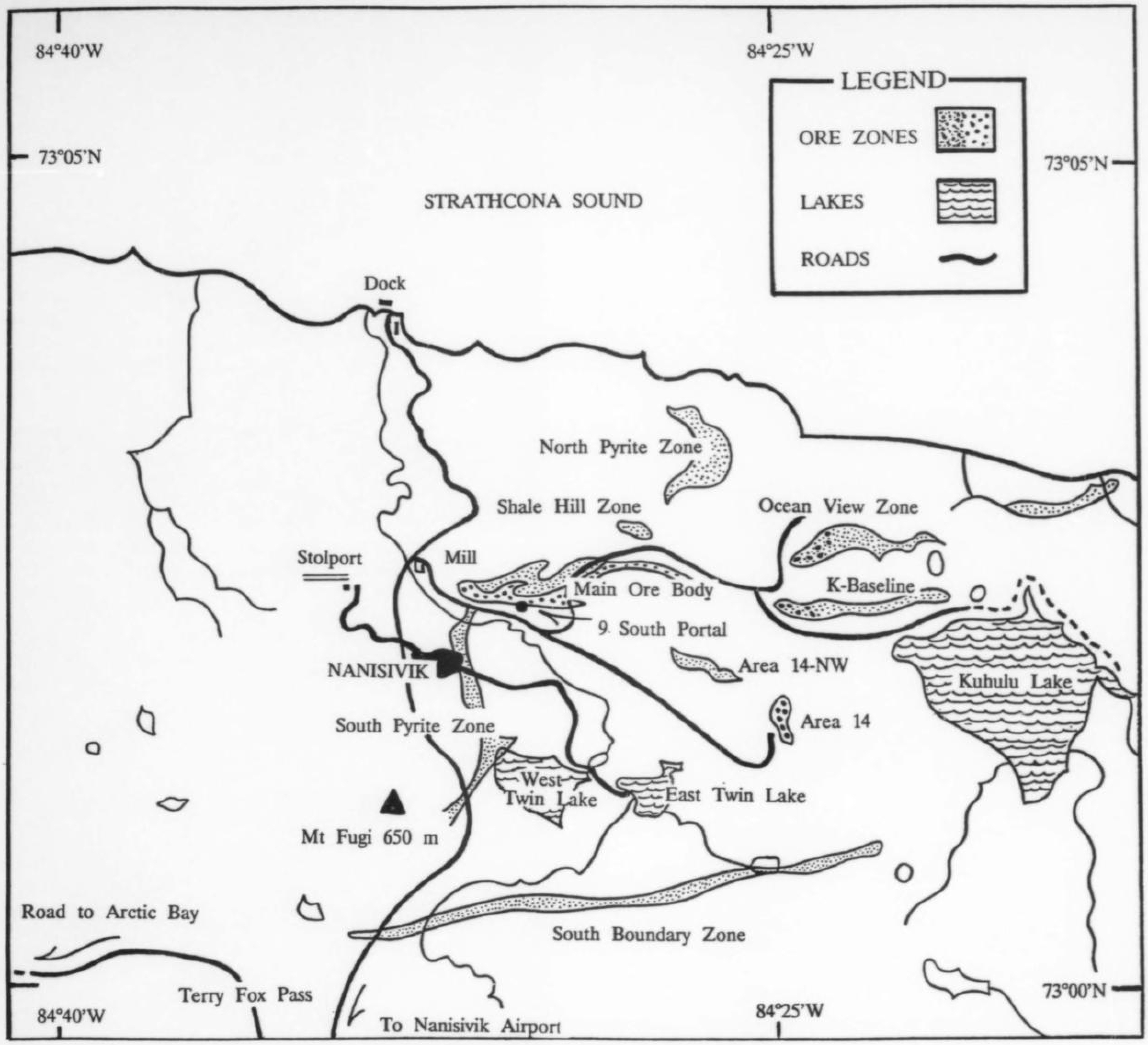


***Figure 8*. Map of the mining areas mentioned in the text. Adapted from a map provided by Nanisivik Mines Ltd.**

tons of pyrite and 12 million tons of ore. Most of the zinc is found in the main orebody, with the rest found in smaller satellite zones. The main mine is made up of a sub-horizontal, lenticular main ore zone with irregular lower lenses connected vertically by a discontinuous keel zone.

The main ore lens is a flat-lying, sinuous body 3 kilometers long. It averages 80 meters wide and may be anywhere from 2 to 30 meters thick. The roof is slightly convex and the hanging wall contact is usually between barren pyrite and dolostone. The sulfide zone is complex and is broken up into several sub-divisions. The main stratigraphic unit is a banded ore found throughout the upper lens. It is made up of variable bands of pyrite, sphalerite and dolomite, as well as galena in some parts of the mine (Fig. 7). The keel zone is centered under the upper lens and the ore closest to it is selvaged and disseminated, seemingly pushed up by the intrusion of the keel. Moving deeper along the keel the zone becomes more pyritic with a finer dissemination of brown sphalerite. There is a lack of galena in the keel that carries down into the lower lenses, except in the east end of the mine where some galena has been observed. Where the lead content of the ore increases in this area the zinc content seems to decrease.

The structure of the smaller zones is similar to that found in the lower lenses of the main mine; some zones such as Shale Hill and K-Baseline, are fault-controlled. Dissolution of the dolostones has created openings in the sulfides that have been filled by a variety of crystals. Many of the vugs were also formed during precipitation of the sulfides. The best crystal specimens are found in these cavities. Pocket areas can be arranged by elevation, starting at the hanging wall, continuing through the keel zone to the lower lenses. The openings along the hanging wall are usually large, lenticular vugs reaching over a meter across and up to half a meter deep, containing predominantly dolomite with some pyrite cubes and blades (pyrite pseudomorphs after marcasite). Other crystals found in these vugs are, in decreasing order of abundance: calcite, doubly-terminated quartz, sphalerite, galena (partly dissolved) and fine needles of gypsum.

In the intermediate elevations the vugs are sometimes up to one meter across, but smaller vugs up to 25 cm across are more characteristic. The shape of the openings varies from round to lenticular with some pockets interconnected to form an open network. The larger vugs contain dolomite and calcite with some pyrite and sphalerite. The smaller vugs contain mainly pyrite found in virtually all the habits and forms common to Nanisivik, with occasional sphalerite. Also present are crystals of calcite, dolomite, quartz and galena. Gypsum is rarely found.

The lower elevations of the main lens host small vugs up to 10 cm across containing mainly pyrite cubes, sphalerite and some calcite. Crystal pockets are uncommon throughout the lower elevations to the keel zone. The keel itself is extremely vuggy but the cavities are small, less than 3 cm across, and lack good crystals.

Pockets in the lower lens can reach up to a meter wide, but smaller cavities up to 5 cm are the most common. As in the main lens, the larger vugs contain mainly carbonates, whereas pyrite cubes (sometimes modified) and sphalerite crystals are found in the smaller ones. Sprays of gypsum crystals were discovered in January 1989. No galena crystals have been found in the lower lens to date.

The two open pits at the ends of the main ore zone uncovered large vugs with pyrite cubes and large dolomite rhombs. Some calcite has been collected with discoidal pink inclusions that are a mixture of gypsum, iron oxides and clay. The East Pit has a high lead content; however, the galena is massive and few crystals are found.

The satellite zones vary extensively in the size and content of vugs. All the high-grade areas (Shale Hill and parts of Area-14) lack crystals completely. Zones similar to the lower lens (K-Baseline) have proven to contain some vugs, with assorted crystals.

Area-14 consists primarily of high-grade sphalerite with a massive pyrite cap. The outer limit closest to the surface is highly oxidized, and it was in this area that the best crystals of gypsum and pseudomorphs of pyrite after pyrrhotite were found. Further details of the regional and local geology as well as the mineralogy of the deposit itself are given in Clayton and Thorpe (1982).

As work in the main mine progresses and new satellite zones are opened, a better understanding of the geology and origin of the sulfide bodies will evolve. New crystal pockets will be uncovered and mineral specimens will be collected and preserved. Figure 8 shows the location of the areas mentioned in the text.

MINERALOGY

The origin of the ore and detailed descriptions of the minerals may be found in Olson's Ph.D. Thesis (1977) and in his paper in *Economic Geology* (1984). Zinc, lead and silver are the main metals mined at Nanisivik, where they are contained in the sphalerite and galena, the principal ore minerals.

The spectacular banded ores shown underground in Figure 7 consist of white, sparry dolomite interlayered with darker zones composed of a mixture of pyrite, galena and sphalerite. The bands vary in width from a few millimeters to a few centimeters and make handsomely textured specimens. There is also a massive type of ore consisting mainly of pyrite, galena and sphalerite.

Besides the massive and banded ore specimens, crystals of calcite, dolomite, galena, marcasite, pyrite, quartz and sphalerite have been recovered in abundance. The following descriptions are based on the specimens that have come to the attention of the authors.

Barite $BaSO_4$

Olson (1977) reports that barite has been identified by X-ray powder diffraction as minute crystals embedded in dolomite from the Ocean View deposit. More recently, however, translucent, white blocky crystals of barite up to 3 cm across have been found occupying small vugs and rectangular molds in dolomite near the hanging wall at both 39 North Portal and the Ocean View Deposit. The crystals are tabular on (001) and often elongated on [100] with large {001} pinacoids and {102} and {011} prisms. Smaller {101}, {201} and {210} prisms are less frequently developed. While high-quality specimens have not been found, the Ocean View property is in its early stages of development, and better specimens may be forthcoming.

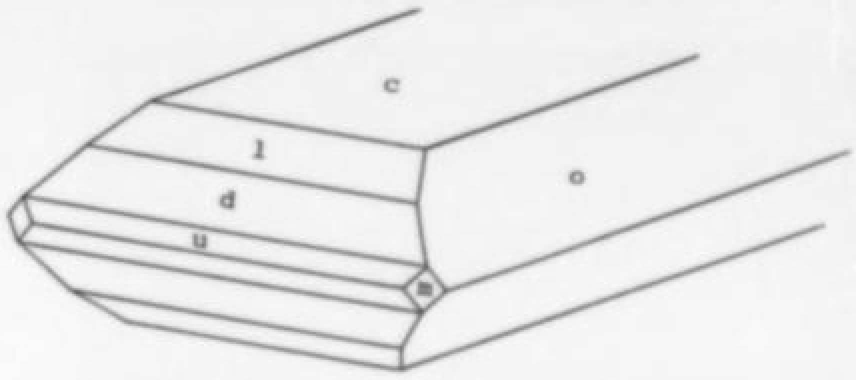


***Figure 9*. Crystal drawing of barite showing the forms *c*{001}, *o*{011}, *l*{102}, *d*{101}, *u*{201} and *m*{210}.**

***Figure 10*. Calcite scalenohedron from "K" Baseline about 1.5 km east of the main orebody. CMN #53750, G. W. Robinson photograph.**

Calcite $CaCO_3$

Calcite crystals occur in vugs in the sulfide body and in the carbonate-rich horizons above the sulfide zone. The crystals are colorless, yellow or honey-colored scalenohedra $\{21\bar{3}1\}$, modified by the positive rhombohedra $\{40\bar{4}1\}$, $\{10\bar{1}1\}$ and $\{10\bar{1}2\}$; minor forms are the negative rhombohedra $\{02\bar{2}1\}$ and $\{08\bar{8}1\}$. Crystals range from minute druses to doubly terminated crystals several centimeters long. In some instances tiny calcite crystals are found oriented on dolomite. One example exists of drusy calcite forming what appears to be an incrustation pseudomorph after a tabular, orthogonal crystal, perhaps anhydrite.

K-Baseline has just recently been opened up (mid-1988), and large pockets of collapsed dolostone containing calcite have been found. They often form clusters of five or six crystals on a brecciated block.

In his Ph.D. Thesis, Olson (1977) notes some fascinating little structures on a few calcite crystals. These are ring-shaped grooves up

Figure 11. **Photograph showing the circular pits on calcite from Block 16 South, main mine. CMN #MOC3202, G. W. Robinson photograph.**

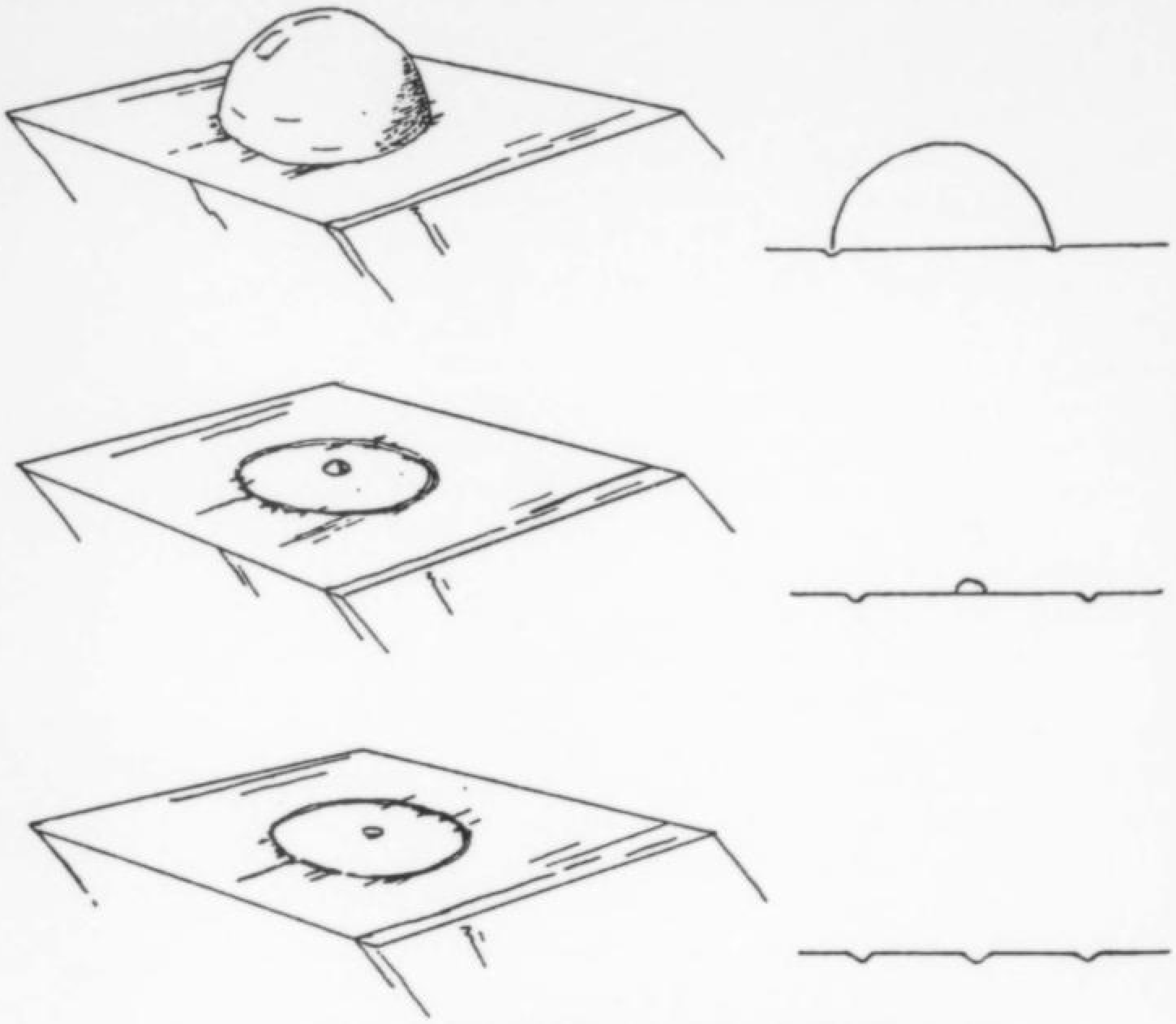


Figure 12. **Sketch showing how the circular pits on the calcite might form. Sketch by Susan Robinson.**

to 2 mm across, commonly accompanied by a small pit in the very center (Fig. 11). Olson speculates that they may be caused by a bubble of corrosive fluid that etched the ring where it touched the crystal and when the bubble collapsed, the resulting minute droplet of corrosive fluid etched the tiny central pit (Fig. 12).

Chalcopyrite $CuFeS_2$

Small, iridescent, tetragonal disphenoids of chalcopyrite occur rarely in some of the vugs, but probably the best specimens have come from the 14-08 bench where crystals up to 8 mm occur with calcite and pyrite.

Dolomite $CaMg(CO_3)_2$

Dolomite is a common mineral throughout the deposit, occurring intimately with the ore minerals as white, coarsely crystalline masses and superb rhombohedral crystals up to 10 cm on an edge. The rhombs are typically pearly white to gray, with curved surfaces composed of a mosaic of smaller crystals. The white, sparry dolomite crystals are triboluminescent, giving off red flashes when crushed (Olson, 1977). Some of the dolomite occurs as drusy crusts that once coated long-gone cube-shaped crystals (Fig. 14), possibly fluorite or galena. Fluorite crystals up to 1 cm were found in a drill core from an area east of the main mine, and smaller crystals have been found north of Ocean View.

Galena PbS

Crystals of galena are scarce and usually appear to have been partly dissolved, resulting in rounded remains of what once were octahedra and cuboctahedrons, but a few sharper crystals up to 4 cm have been found. Deeply etched triangular pits are characteristic of the octahedral faces on some of these crystals. Most of the galena crystals are either cubes or cuboctahedrons, often with a "melted" appearance; some are skeletal.

Gypsum $CaSO_4 \cdot 2H_2O$

Gypsum, although not common, occurs mainly as sprays of small, transparent, prismatic crystals in some of the vugs in the main orebody where it is often the last-formed mineral. Larger, more spectacular individual crystals and "fishtail" twins were found on blocks of dolostone in a collapsed, oxidized zone of the Area 14 mine, 4 km east of the main workings. Because of their transparency and low refractive indices, the crystals are almost invisible when encased in the ice that surrounds the dolostone blocks and are consequently easily overlooked.

Ice H_2O

Although difficult to preserve, this beautiful mineral occurs in a myriad of habits, both inside and outside the Nanisivik mine. While the best-formed crystals and stalactites (icicles) are of post-mining origin, some of the massive ice that fills the vugs shows a crude cleavage indicating that it is probably old ice that has been there long before mining started.

Hollow, hexagonal prisms, sometimes with hopper-growth basal pinacoids up to 5 cm in length, are seen frequently lining open vugs and mine walls. Some of these crystals resemble clusters of vanadinite or pyromorphite and form flower-like clusters several meters across. Fern-like growths of reticulated twinned crystals are also common.

Marcasite FeS_2

Marcasite was once a common mineral in the vugs, and evidence of large, spectacular specimens of "fiveling" twins up to 12.5 cm across occurs, but they have all been altered to pyrite. In our work on these minerals no original marcasite was found in any of these pseudomorphs. These tabular twins are composed of between two and five individual crystals related to each other by the twin plane {101}, and each crystal may be as large as 6 cm on an edge, sometimes found in superb groups. An example of one of these twins is shown in Figure 18.

Unaltered marcasite occurs, however, as a later phase, usually as microcrystals of various habits on dolomite crystals and as oriented overgrowths on pyrite. Some of the habits that have been observed are: oscillatory prisms showing {120}, {110} and {010} terminated by {101} and {001} faces; prismatic crystals showing {110} terminated by

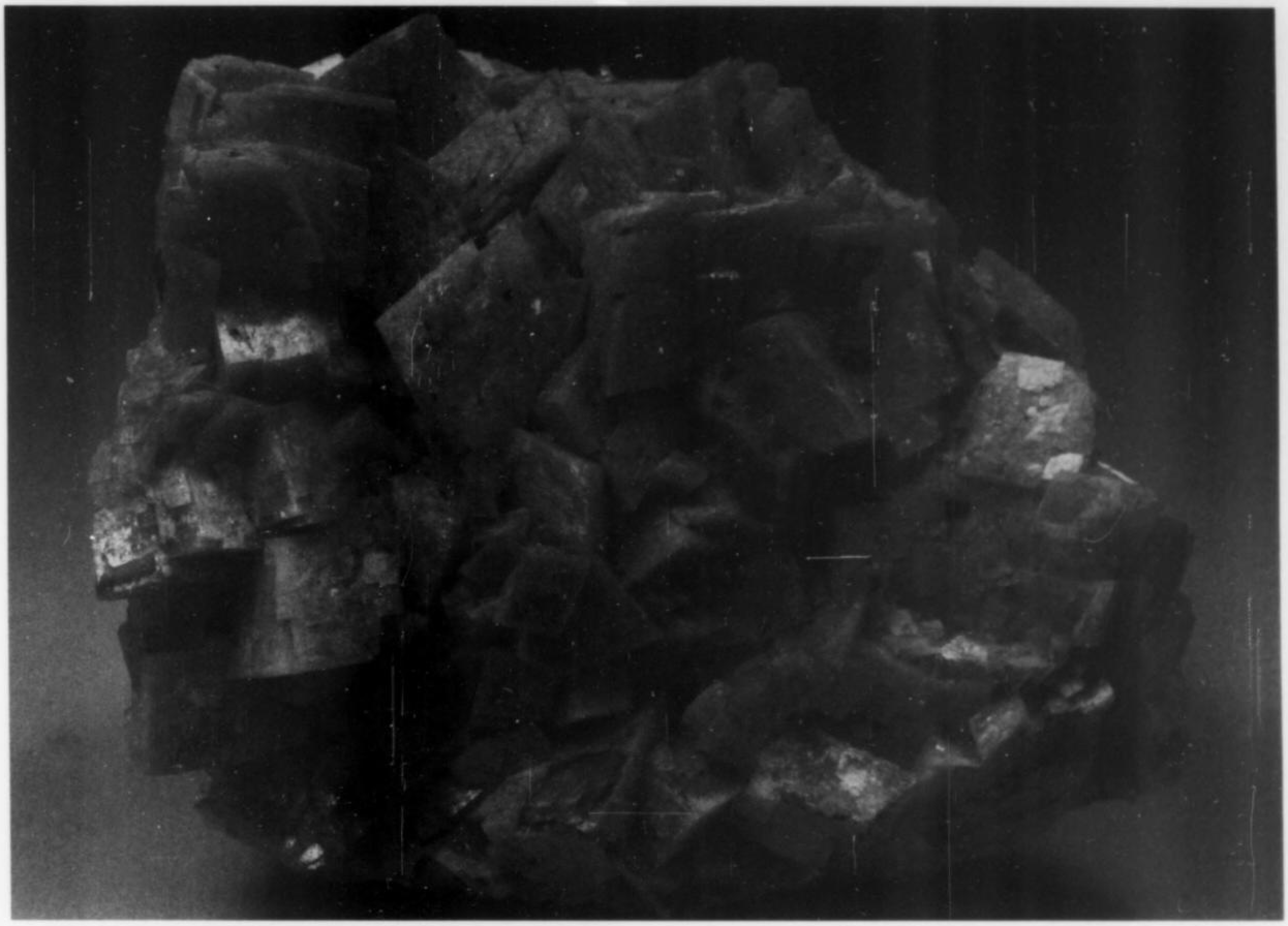


Figure 13. **Dolomite crystals, 2 cm on an edge, with pyrite and sphalerite from Block 20 North in the main mine (overall size 8 x 11 cm). CMN #51867, G. W. Robinson photograph.**

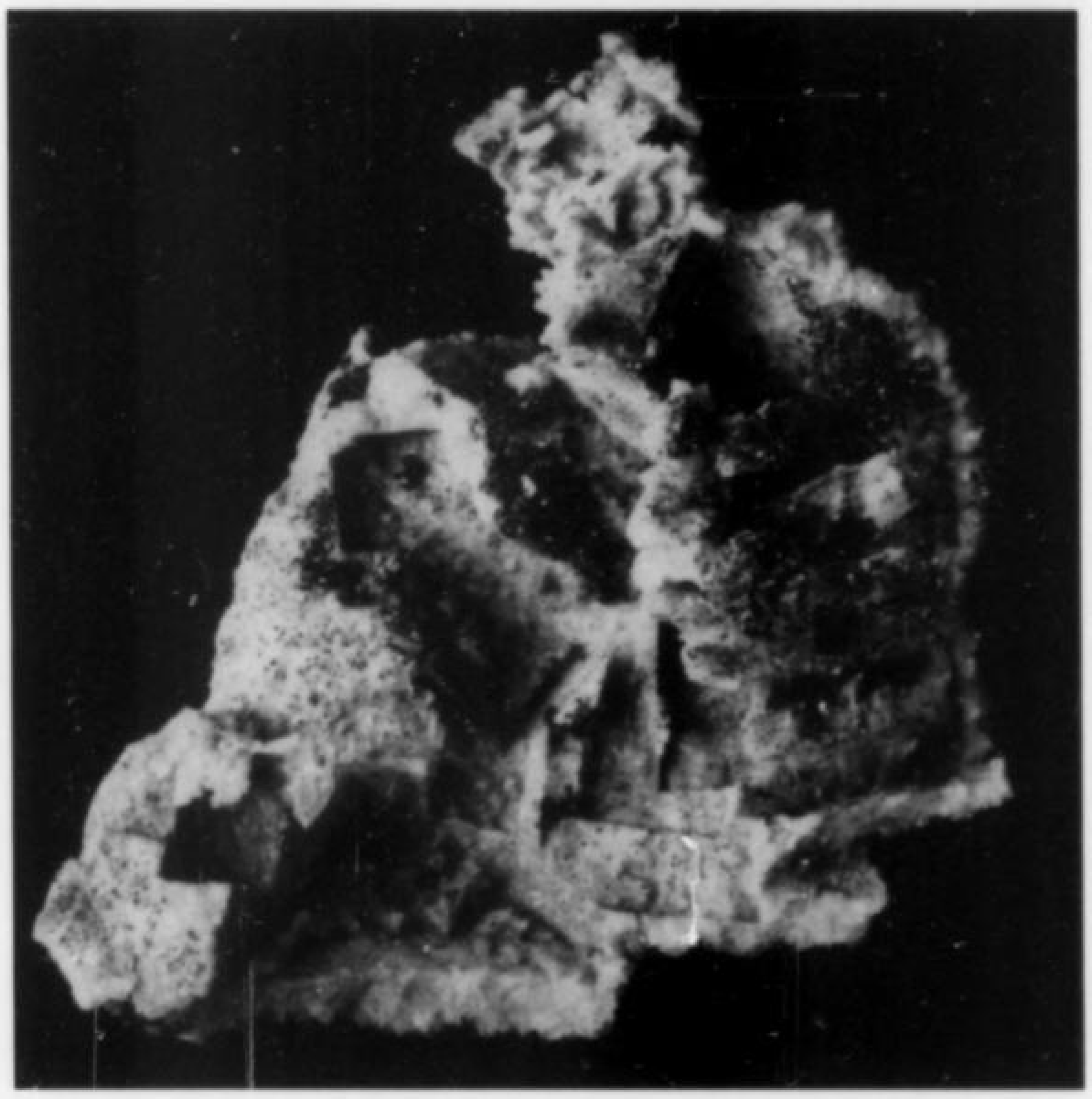


Figure 14. **Dolomite druses forming casts of a cubic mineral, up to 2 cm on an edge. ROM #M41368, ROM photograph.**

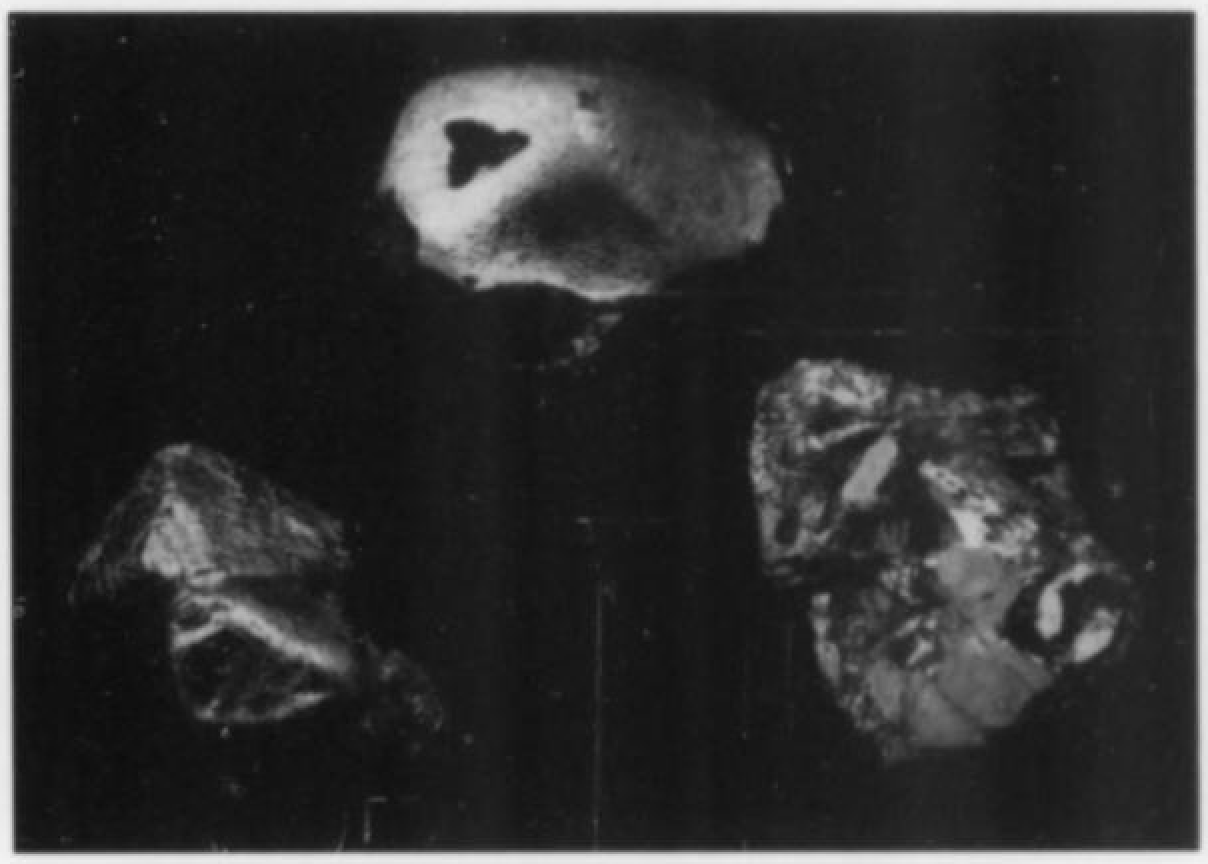


Figure 15. **Rounded crystals of galena about 2 cm across. ROM #M36067, ROM photograph.**

Figure 16. Gypsum crystals on dolostone, longest crystal is 7 cm, from Area 14. CMN #52992, G. W. Robinson photograph.

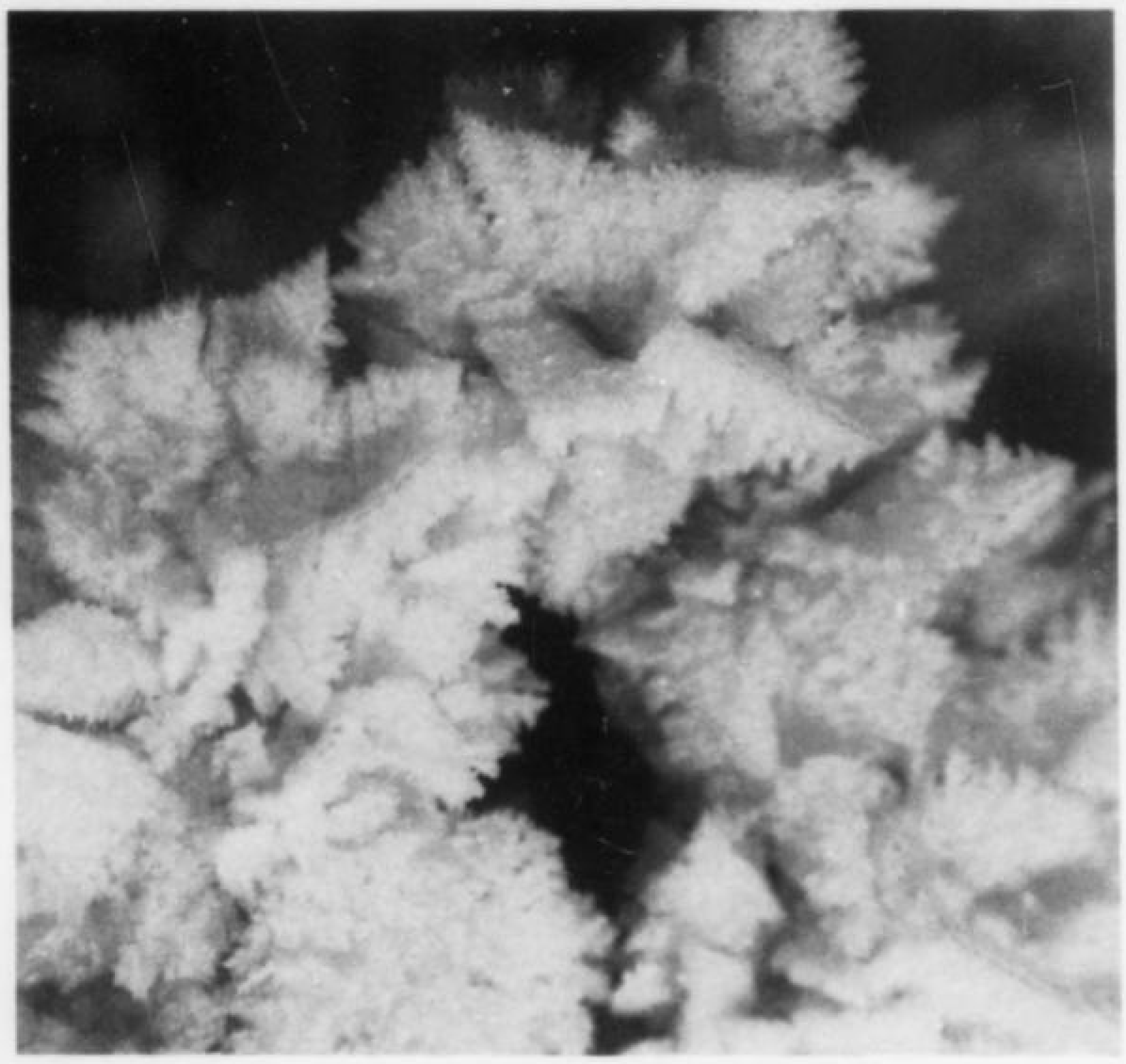


Figure 17. Ice crystals up to 1 cm, sublimated onto the walls of the mine. Fred Bailey photograph.

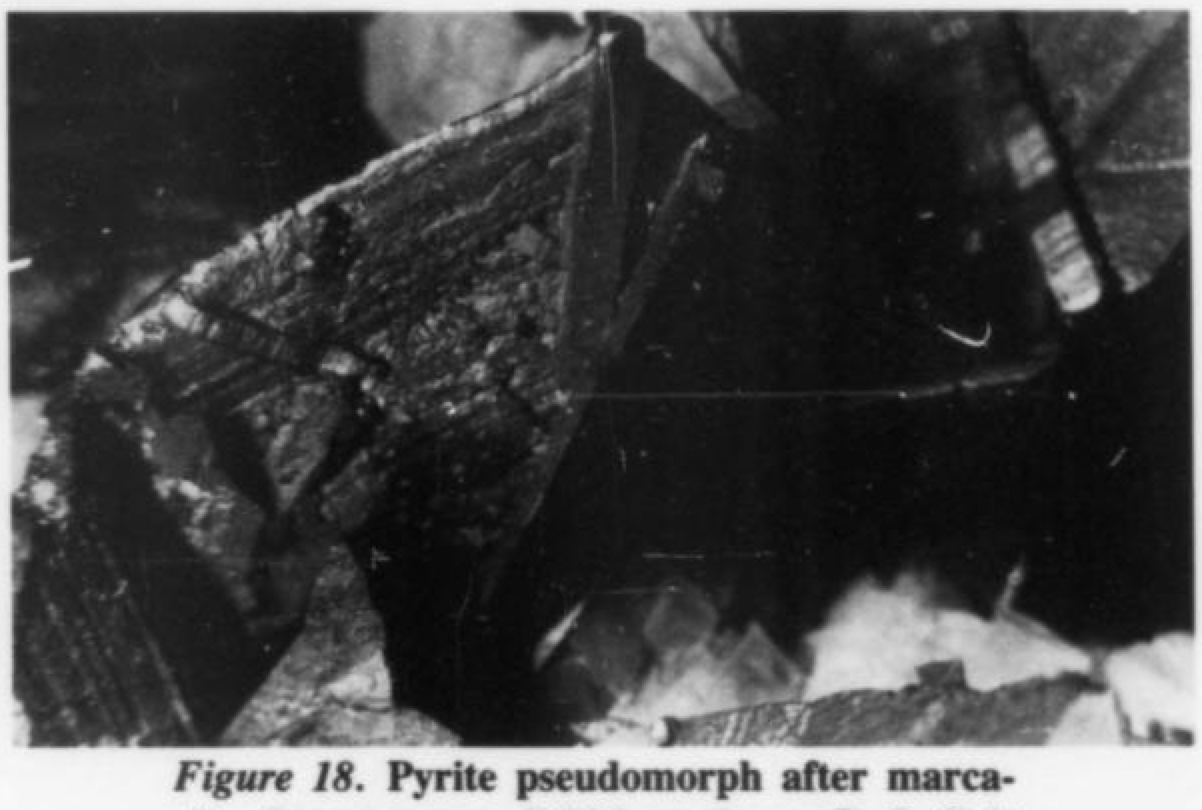


Figure 18. Pyrite pseudomorph after marcasite, 7 mm across. ROM specimen, R. I. Gait photograph.

Figure 19. Photomicrograph of a marcasite crystal 1 mm long. CMN specimen and photograph.

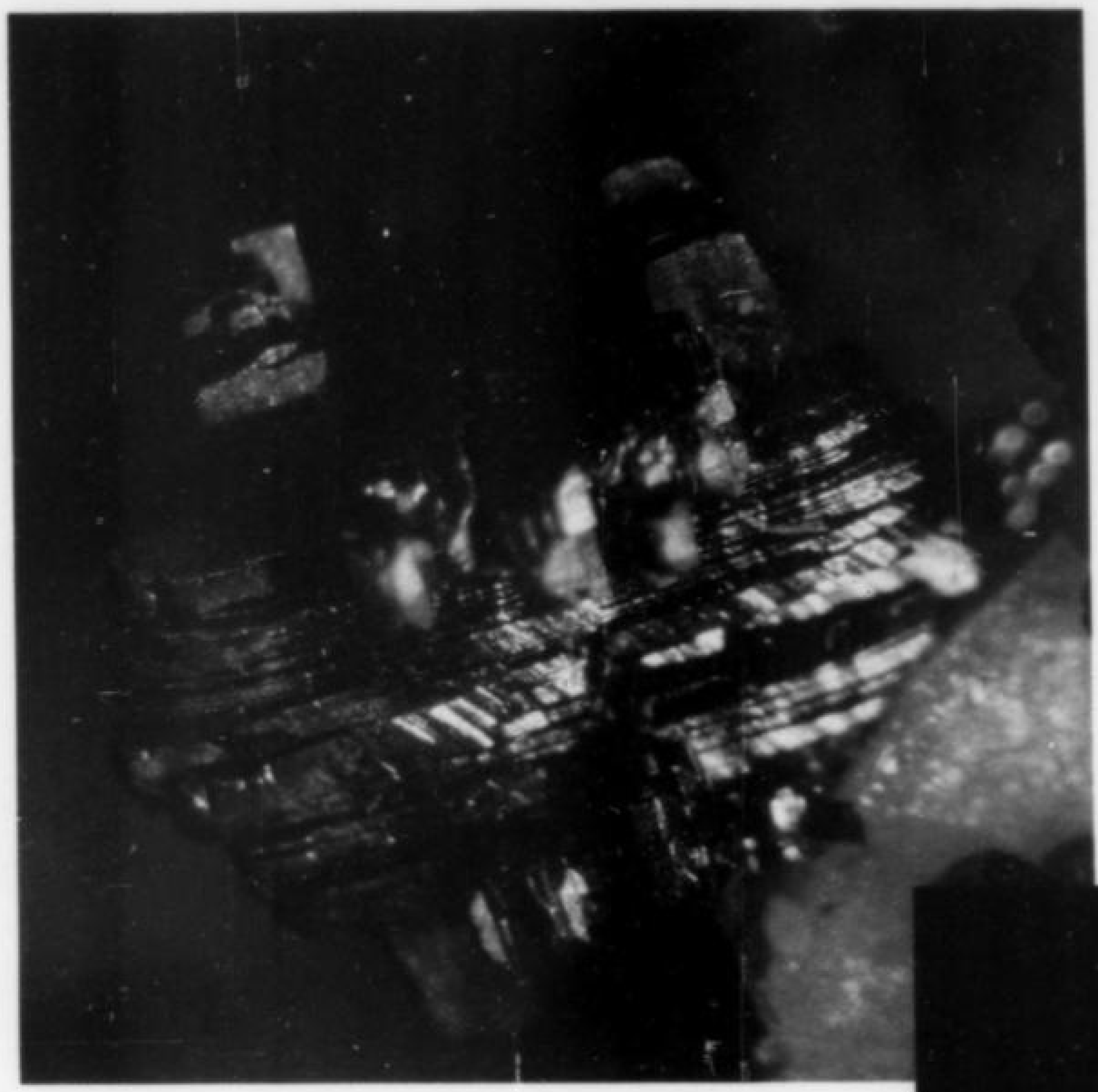


Figure 20. Marcasite "log-cabin," 2 mm across, covering a pyrite pyritohedron. ROM #M41367, R. I. Gait photograph.

Figure 21. Pyrite epitactic on pyritized marcasite, 1.5 x 2 cm. Fred Bailey specimen, G. W. Robinson photograph.

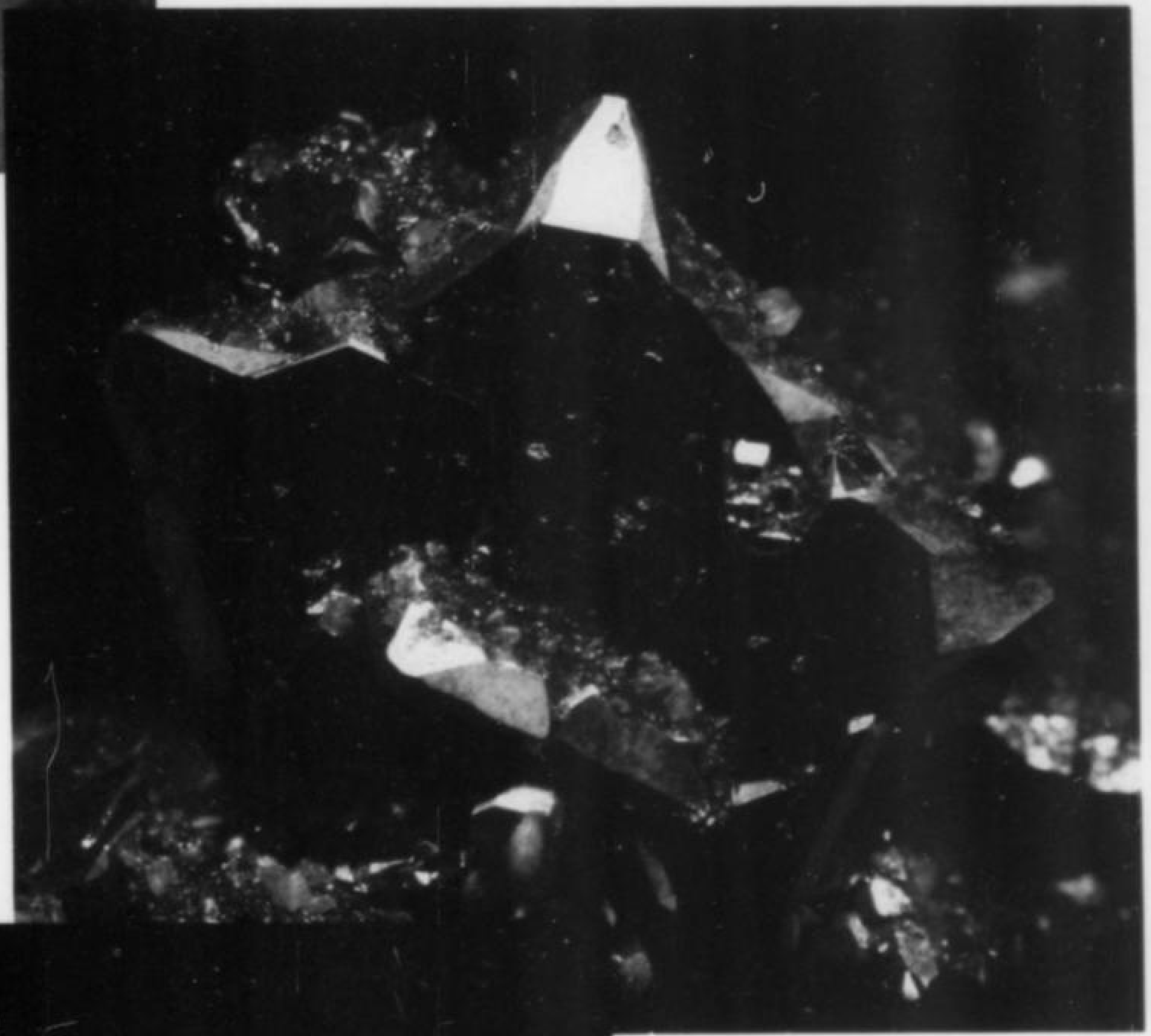
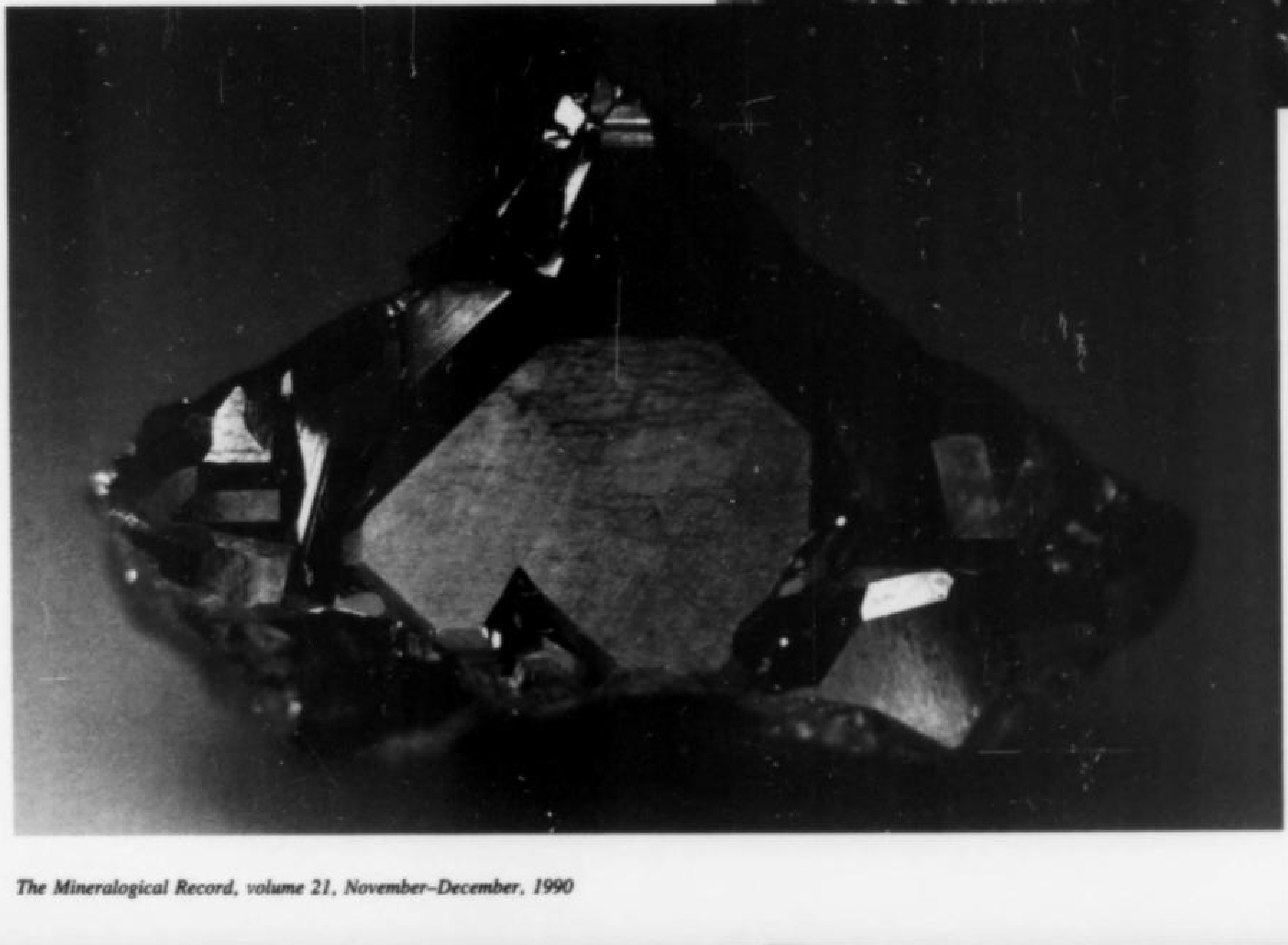


Figure 22. Pyrite epitactic on pyritized marcasite, 3.5 x 5 cm. CMN specimen, G. W. Robinson photograph.



{001}; tabular prisms flattened on {010}, modified by {100}, {140} and {001}; and the various types of twins on (101). A typical crystal is shown in Figure 19.

A particularly fascinating example of marcasite crystals oriented on pyrite occurs on a micro-scale and consists of a tiny pyrite pyritohedron completely covered by three sets of elongated marcasite crystals. Each of the three sets is elongated parallel to the three principal axes of the pyrite, and where the elongated marcasite crystals meet, they interfinger like logs at the corners of a log cabin (Fig. 20). Unfortunately, the largest of these is only a few millimeters in diameter, but even so they are a spectacular example of epitactic overgrowths, where the orientation of the later mineral is controlled by the crystallography of the former.

Pyrite FeS_2

Pyrite crystals occur at Nanisivik in a wide variety of habits and forms. Commonly encountered are the tabular stacks of brilliant crystals that have been described in detail by Gait and Dumka (1986). These tabular stacks are the result of oriented overgrowths of a second generation of pyrite crystals growing on a "template" of pyritized marcasite twins (Fig. 23). The sequence of events in their formation was as follows: tabular marcasite twins crystallized, and were subsequently transformed into pyrite. Then a new period of pyrite crystallization occurred, and small, nearly equant crystals formed, oriented on the underlying pyritized marcasite conforming to the epitactic relationship, pyrite {001}[100] parallel to marcasite {010}[101]. This is illustrated in the drawing in Figure 24. The photographs of the specimens in Figures 21, 22, 32, 33 and 38 show the pyritized marcasite completely overgrown by tabular pyrite crystals.

The pyritized marcasite twins are impressive in themselves, but even more so are the ones not completely covered by the second generation of pyrite, that are characterized by narrow bars of pyrite running parallel to, and straddling the twin planes (Figs. 18 and 24). These pyrite bars frequently extend beyond the edge of the twins and are divided by a fine line marking the underlying twin plane and indicating that the pyrite overgrowth on either side of the bars is matched to the orientation of the underlying original crystals of marcasite.

The crystal forms on pyrite from Nanisivik are not easy to identify, usually because the crystals are flattened parallel to a cube face. The combinations of forms are also unusual. Figure 25 shows the five forms—cube, octahedron, dodecahedron, pyritohedron {210} and trapezohedron {211}, and Figure 26 shows some possible combinations of these forms. The photographs in Figures 27, 34 and 35 are of some real crystals showing these forms.

One specimen in the Canadian Museum of Nature collection shows filiform pyrite in the form of needles and blades, many growing at right angles to each other. Some spectacular examples can be seen with the scanning electron microscope and an example is shown in Figure 39. This has been christened "the hockey goalie's stick."

The more familiar, striated cubes are also found at Nanisivik (Fig. 29), and some show examples of interrupted growth where a cube crystallized and then a druse of tiny dolomite crystals formed on the face. When pyrite crystallization resumed, pyrite was added only at the edges of the cubes because the dolomite inhibited crystal growth in the middle of the faces, thus producing hopper-like crystals. Some crystals show the opposite effect, and the cubes have stepped, pyramid-like growths protruding from the faces.

A few specimens of the classic "iron cross twins" up to a centimeter across have been found recently in the 60 block in the central lower lens. These are interpenetrating pyritohedra, some of them modified by minor cube faces that serve to enhance the appearance of the twins (Fig. 36). An idealized sketch is shown in Figure 37 for comparison.

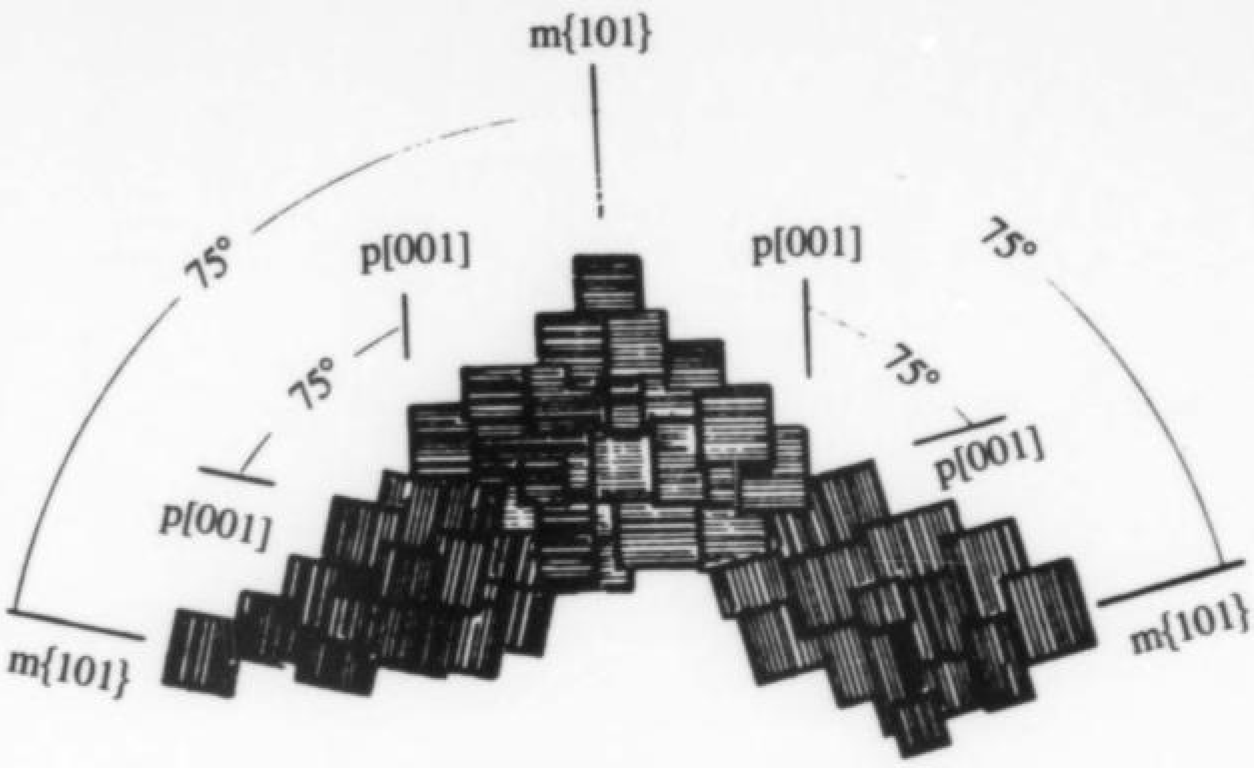


Figure 23. **Sketch of pyrite cubes overgrown on a pyritized marcasite twin.**

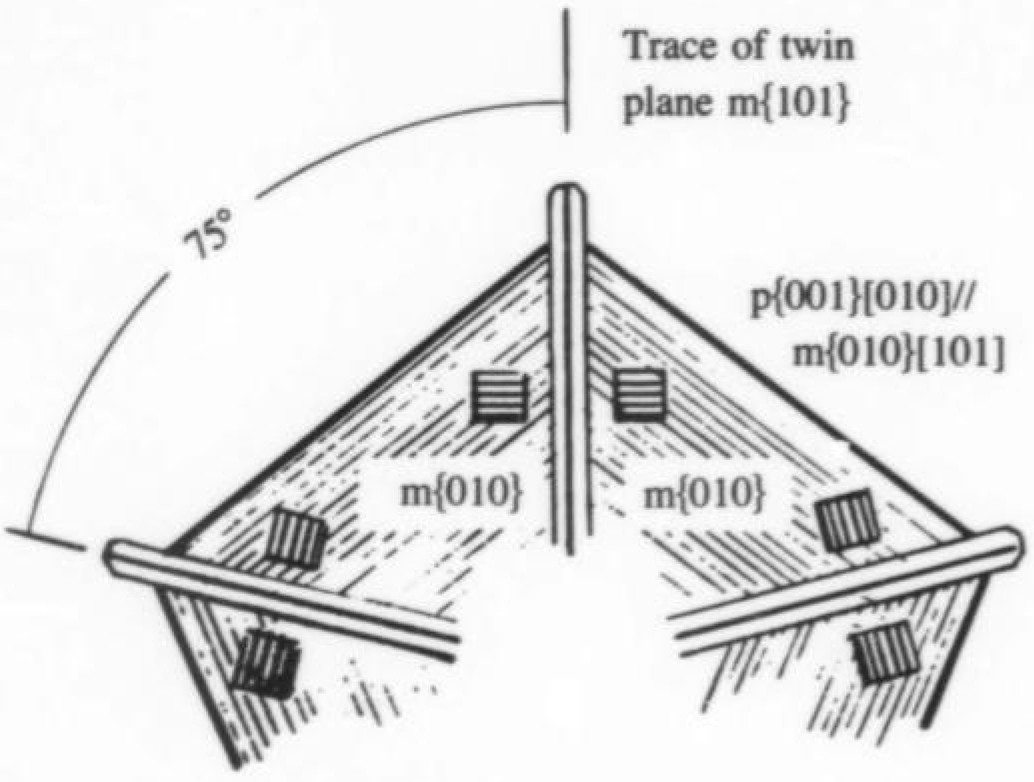


Figure 24. **Sketch of the pyrite-marcasite epitactic relationship.**

One pyrite specimen caused considerable discussion because many of its cube faces have perfectly circular depressions on them, usually a few millimeters in diameter but only about 1 mm deep (Fig. 41). These depressions can be explained if we postulate the presence of a sticky, viscous liquid that settled on the growing pyrite crystals. The presence of the globule would inhibit crystal growth beneath it, and only the uncovered parts of the faces would continue to grow. Removal of the globule would leave a circular, flat-bottomed depression like those we have observed. Hydrocarbons are known at Nanisivik, as in many other carbonate-hosted sulfide deposits. Thus we suggest that a tar-like material, a forerunner of the pyrobitumen (q.v.) before it hardened to the hard, brittle substance, is probably responsible for these interesting features. The depressions, found perpendicular to one another on adjacent crystal faces, are evidence that the liquid must have had high viscosity and, because the pyrite continued to grow around them, it must have had a low solubility in the crystallizing solution. A hydrocarbon would likely behave like this.

Figure 40 shows a massive pyrite specimen with a most peculiar, as yet unexplained texture of beautifully-curved sprays of crystals up to 3 cm long on a smooth, slightly convex surface.

Some of the dolomite crystals were encrusted with a thin layer of minute, equidimensional pyrite crystals during their growth and were subsequently overgrown by more dolomite, thus making a "phantom" within the dolomite. One of these was obtained by dissolving away a large dolomite crystal to reveal a pyrite cast of the dolomite crystal (Fig. 42.

Pyrite "stalactites" have been found at Nanisivik up to 25 cm in length and 1 cm in diameter. When in place, they hang vertically from

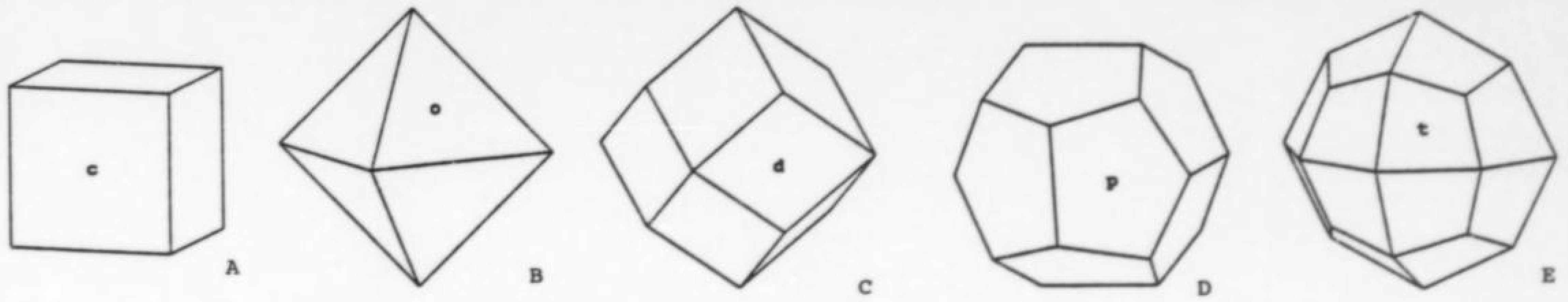


Figure 25. Crystal drawings of A. cube (*c*), B. octahedron (*o*), C. dodecahedron (*d*), D. pyritohedron {210} (*p*) and E. trapezohedron {211} (*t*).

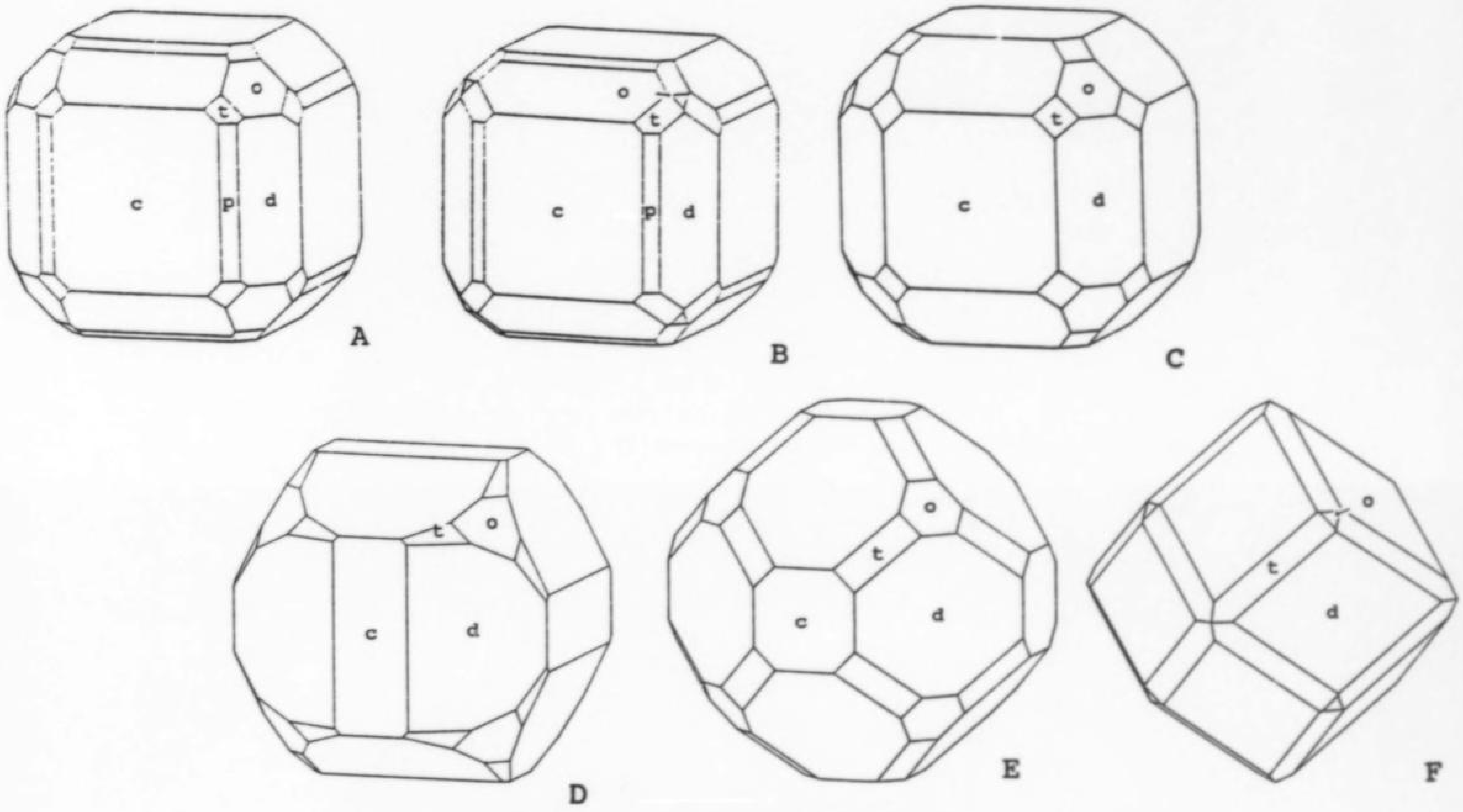
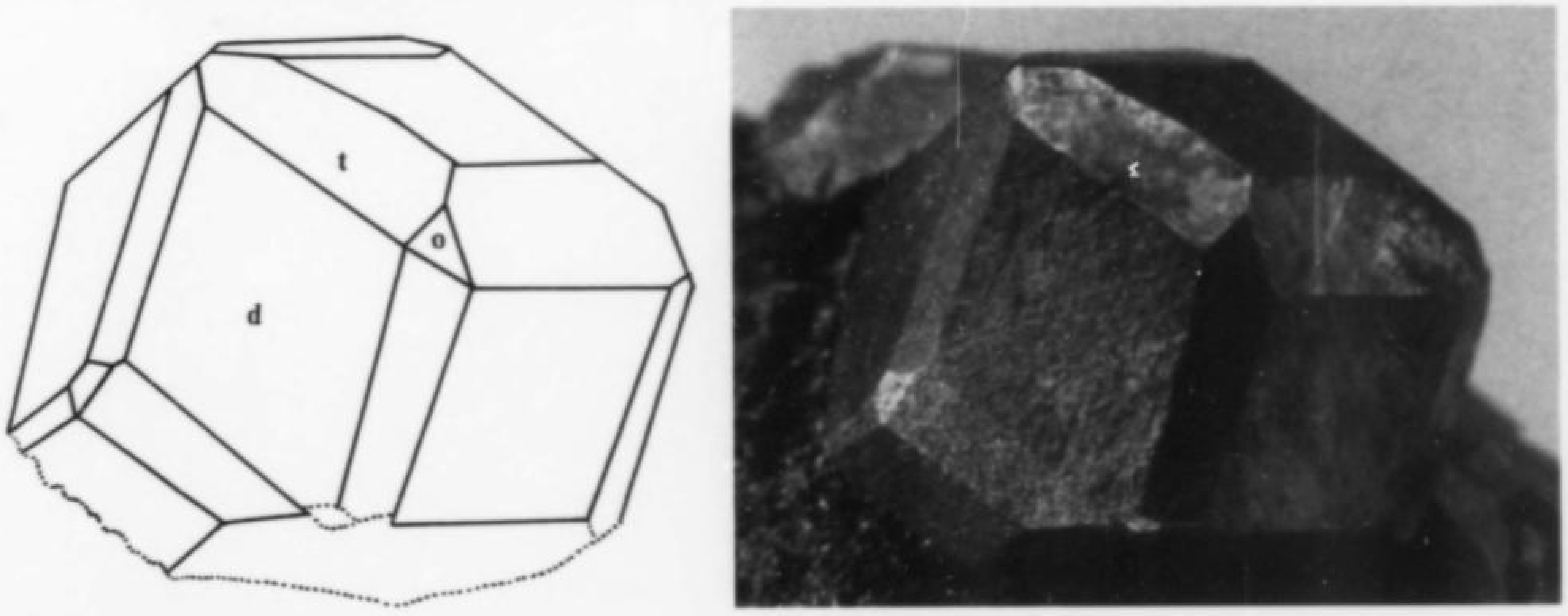


Figure 26. Crystal drawings of combinations of forms shown in Figure 28. A and B. Dominant cube with *d, p, o* and *t*. C. Dominant cube with *d, t* and *o*. D. Dominant pyritohedron with *c, o* and *t*. E. Dominant dodecahedron with *c, o* and *t*. F. Dominant dodecahedron with *t* and *o*.

Figure 27. Dodecahedron of pyrite, 5 mm across, modified by the trapezohedron {211} from Block 29 North in the main mine. CMN #MOC3201, G. W. Robinson photograph.



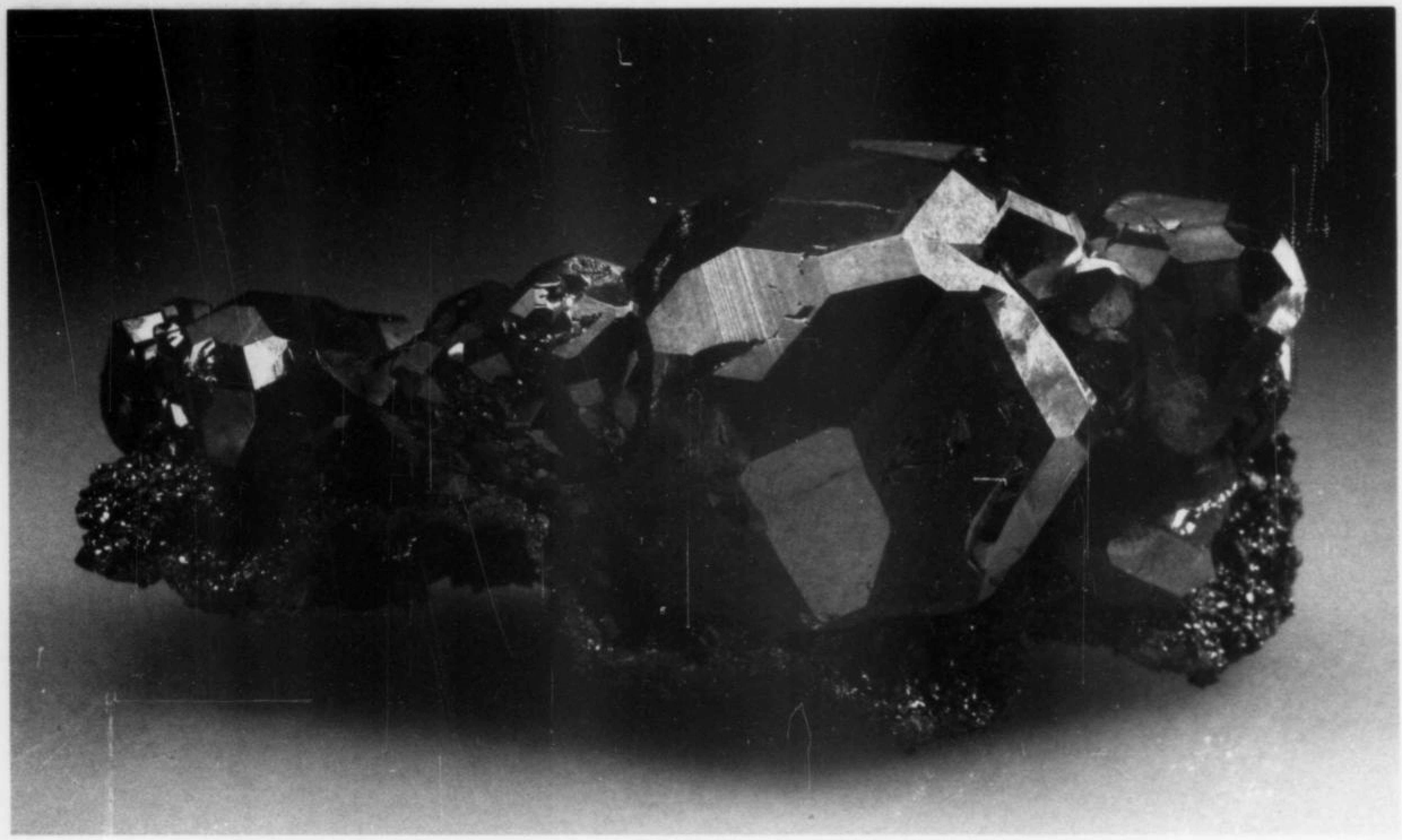


Figure 28. **Pyrite crystal group, 6.5 cm, showing cube, octahedron, dodecahedron, trapezohedron and pyritohedron faces. Fred Bailey collection.**

WEW

WEW

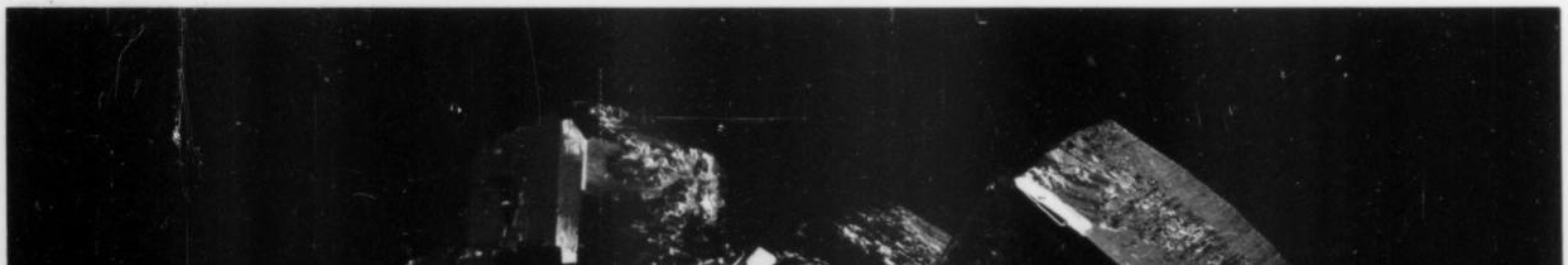


Figure 29. **Group of cubic pyrite crystals, 8.6 cm. Fred Bailey collection.**

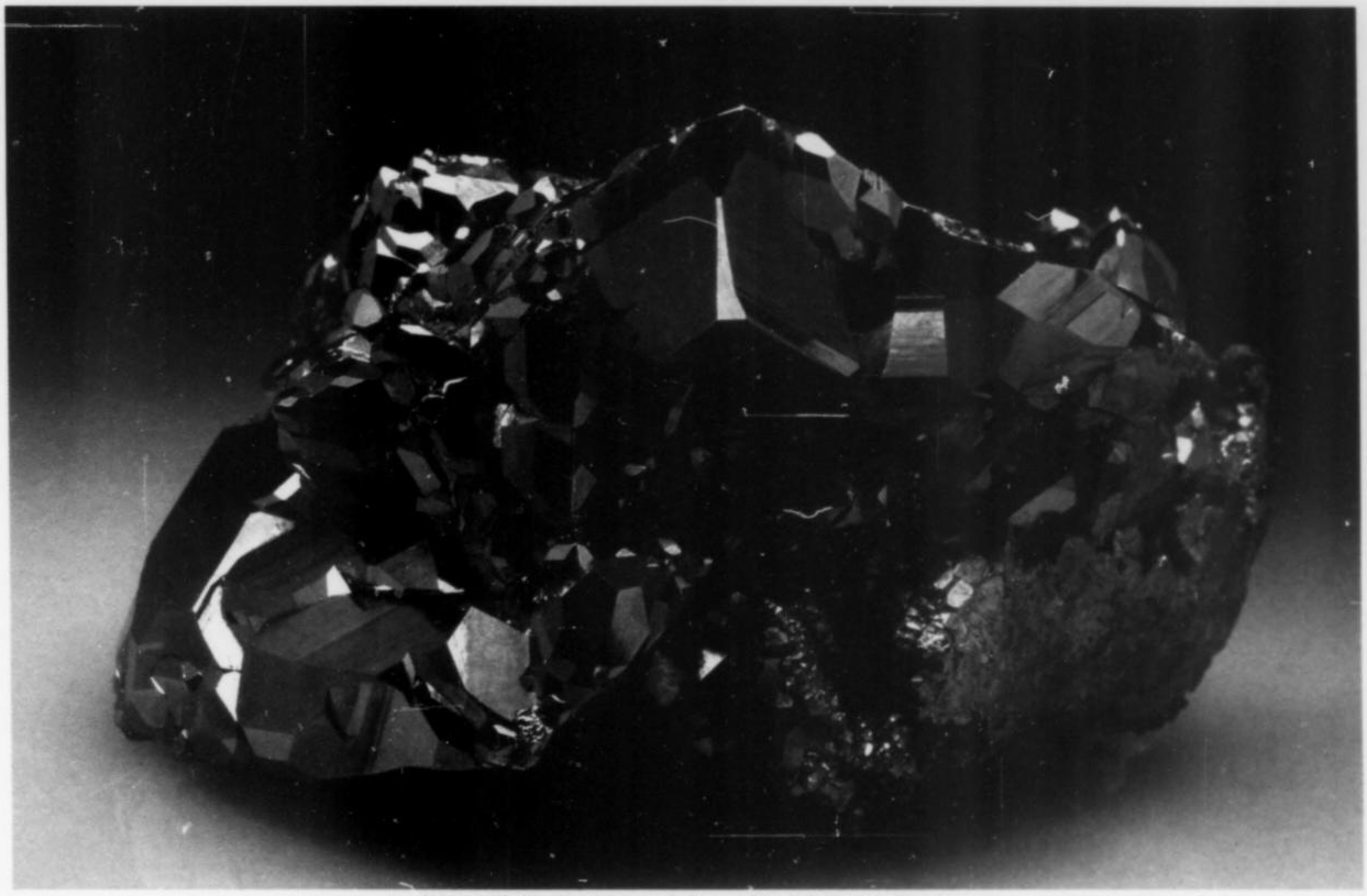


Figure 30. **Pyrite group, 8.5 cm. Fred Bailey collection.**

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Figure 31. **Pyrite after marcasite, 10.5 cm. Fred Bailey collection.**

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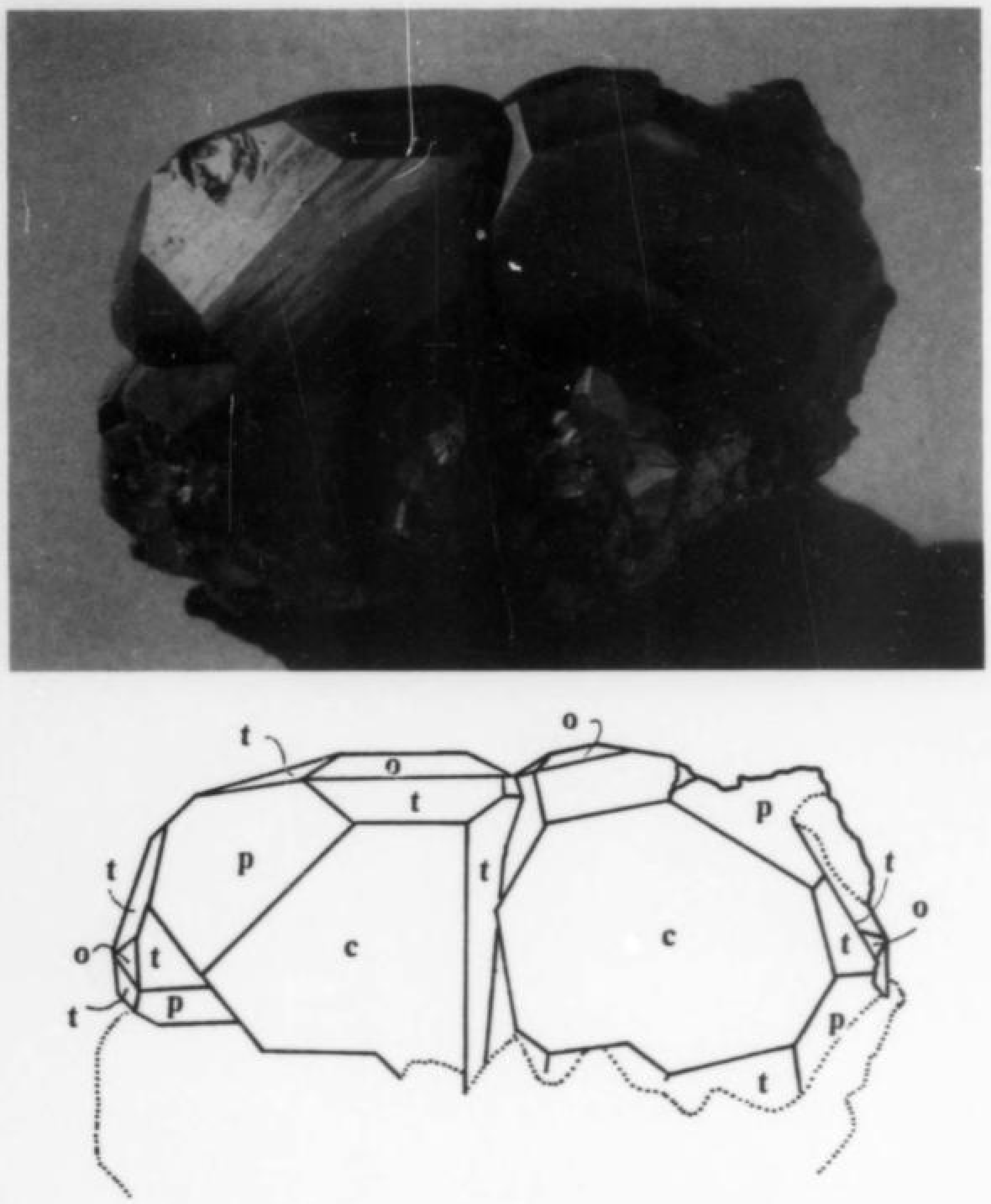


Figure 32. Pyrite epitactic on pyritized marcasite, 4 x 4.5 cm. ROM #M43013 (gift of Dr. J. Satterly), ROM photograph (B. Boyle).

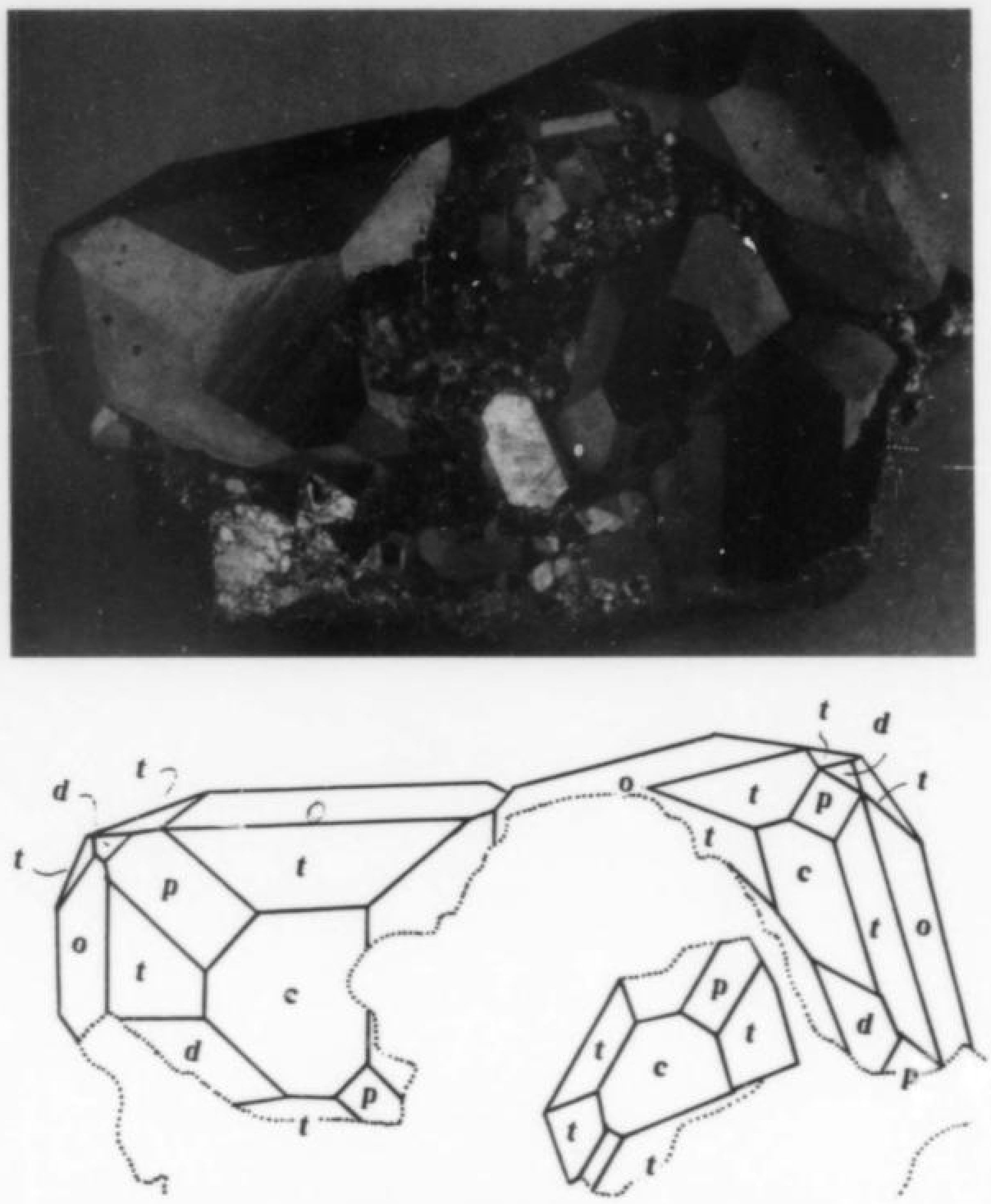
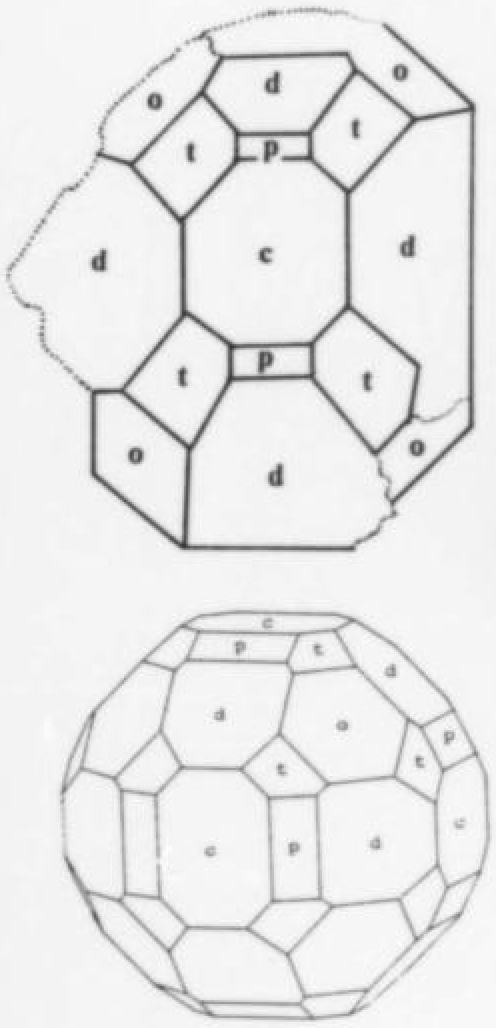


Figure 33. Pyrite epitactic on pyritized marcasite, 2.5 x 3.5 cm. ROM specimen, ROM photograph (B. Boyle).



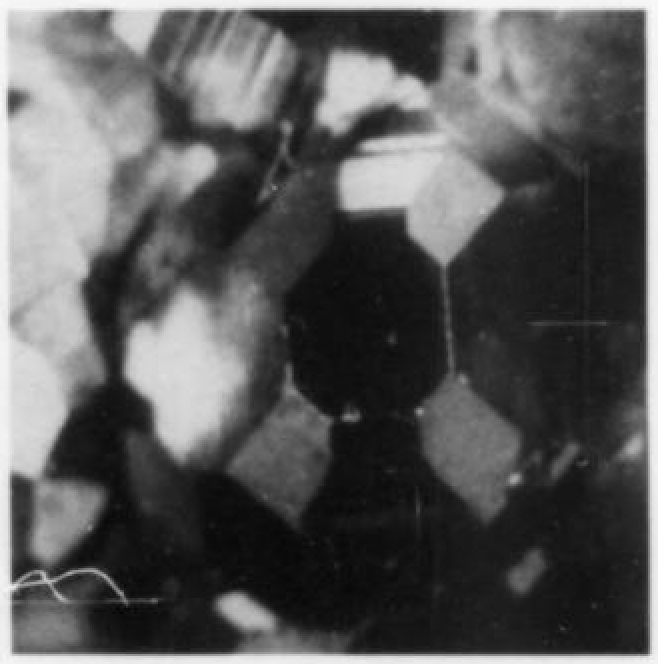


Figure 34. Pyrite crystal 1.5 mm across, showing *c*{100}, *o*{111}, *p*{210} and *t*{211}. ROM # NAN 84-13A, R. I. Gait photograph.

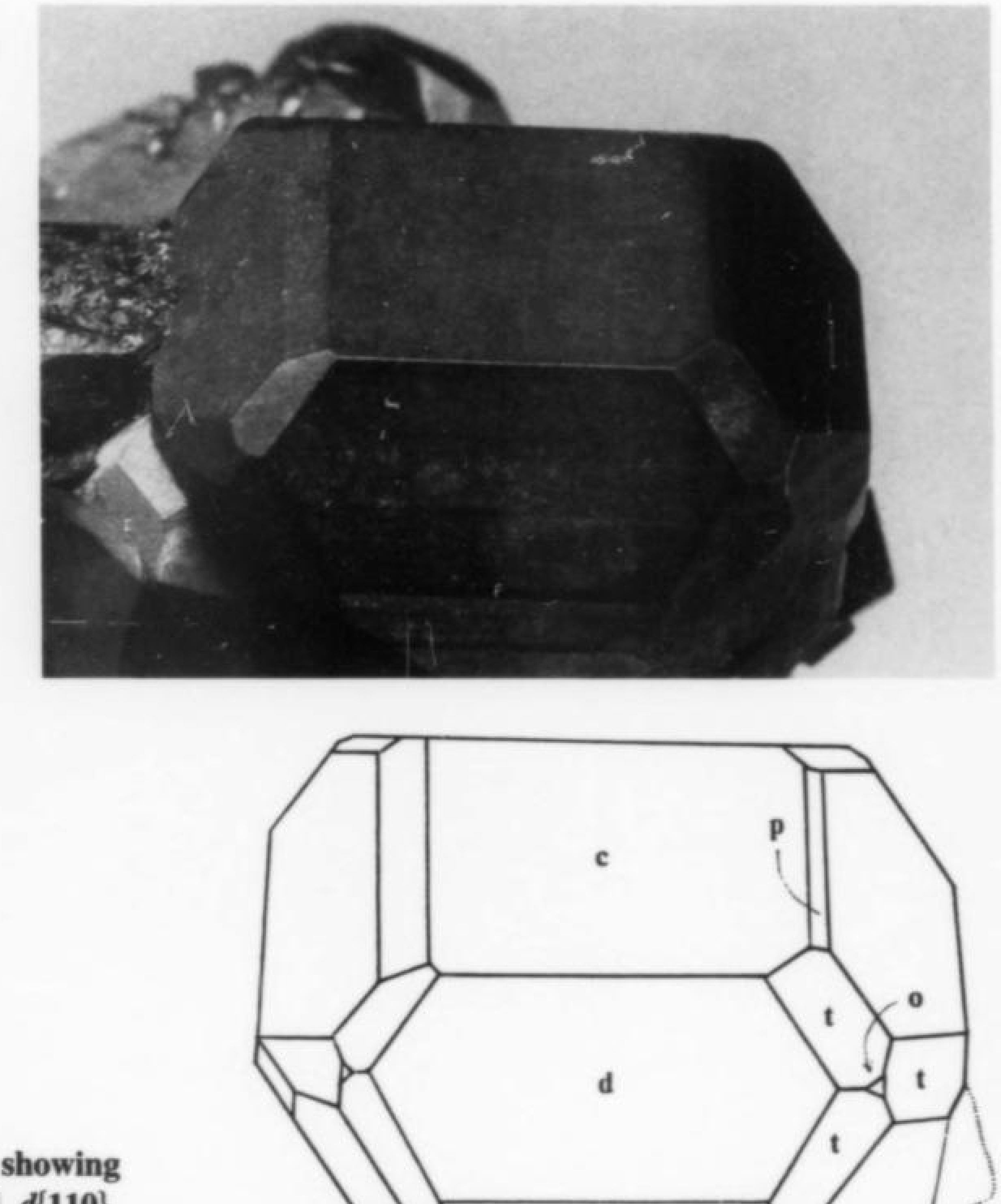


Figure 35. Pyrite crystal 13 x 14 cm, showing the forms *c*{100}, *o*{111}, *p*{120},and *d*{110}, from Block 29 in the main mine. CMN #MOC3205, G. W. Robinson photograph.

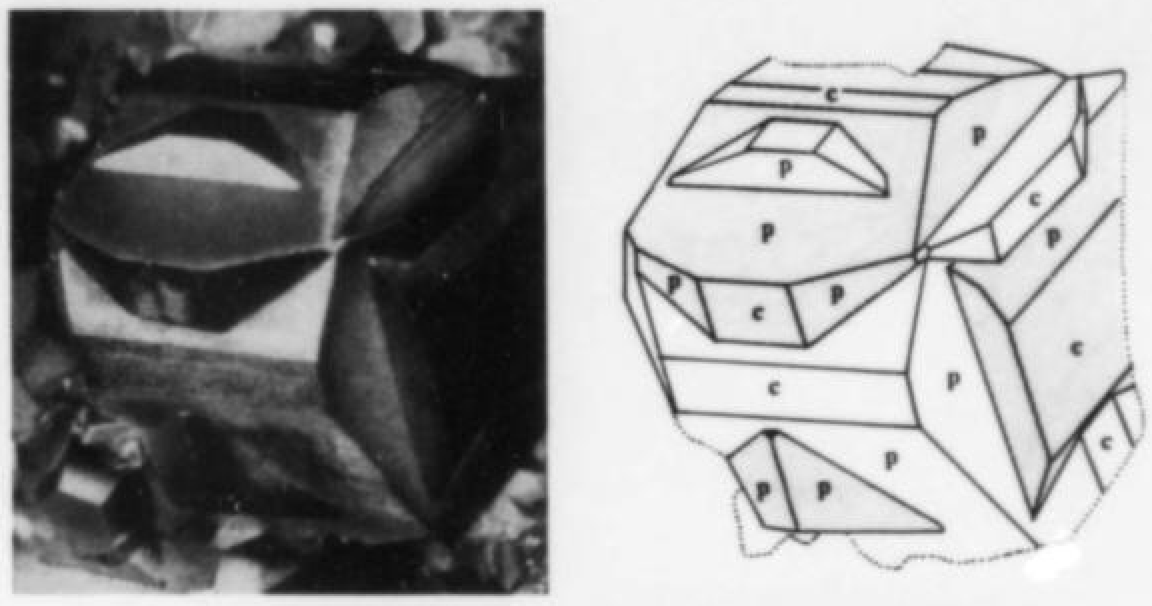


Figure 36. **"Iron cross twin" of pyrite, 6 mm in diameter. Forms present are the cube and pyritohedron. ROM #M43732 (gift of Mr. D. K. Joyce) R. I. Gait photograph.**

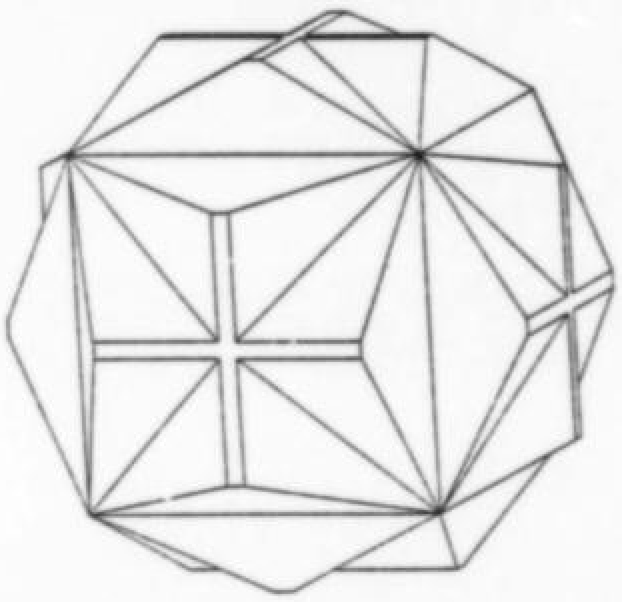


Figure 37. **Idealized drawing of the iron cross twin. Forms present are the cube and pyritohedron.**

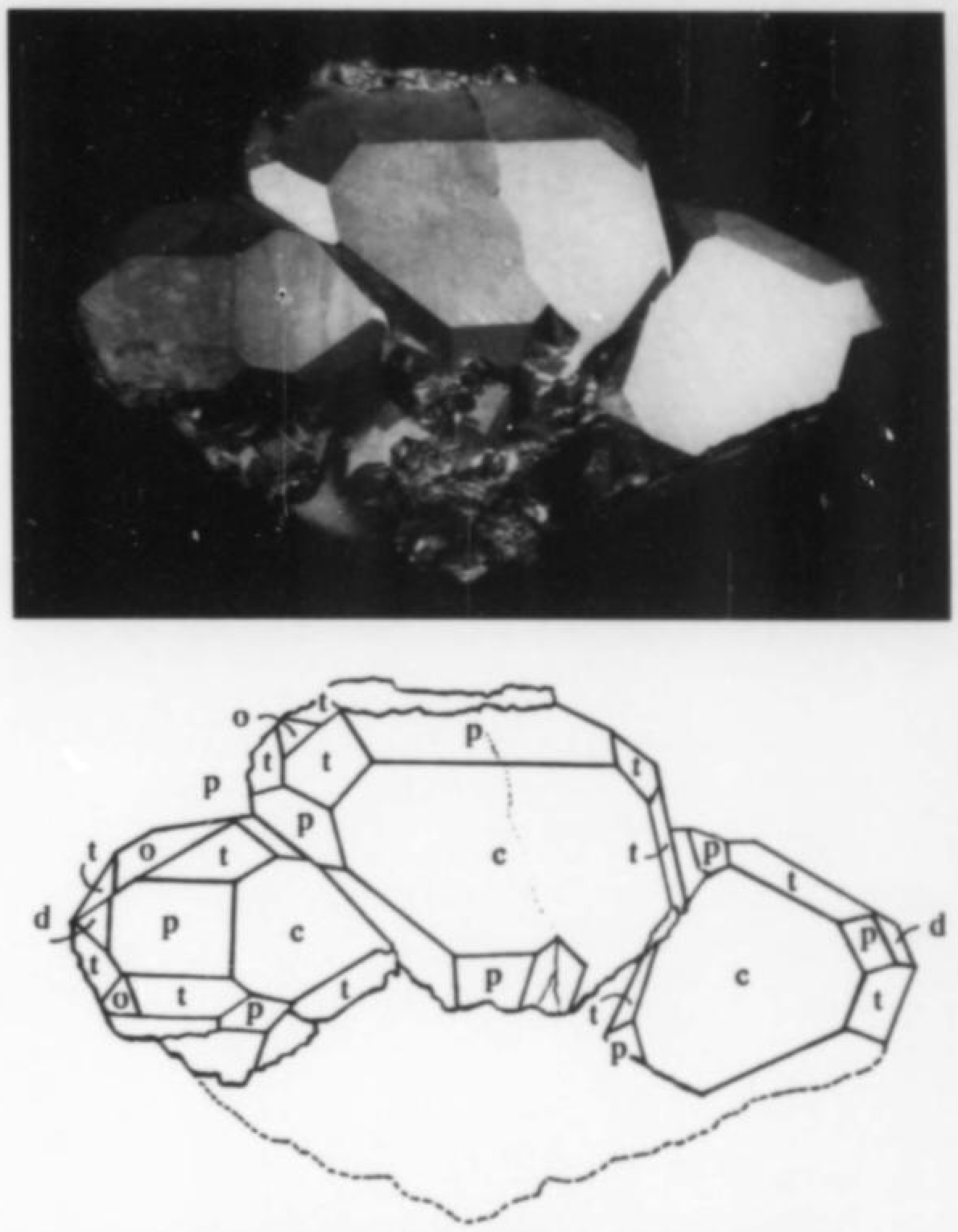


Figure 38. **Pyrite group, 5 cm, an oriented overgrowth on a pyritized marcasite twin. ROM specimen #M44328; ROM photograph by Brian Boyle.**

Figure 39. **Filiform pyrite showing elongated crystals in a three-dimensional orthogonal reticulation, with "goalie sticks." Scale bar 50 microns long. CMN #MOC3323. SEM by G. W. Robinson.**

Figure 40. **"Feather-like" texture on massive pyrite, 1.2 cm long. ROM #M35372, R. I. Gait photograph.**

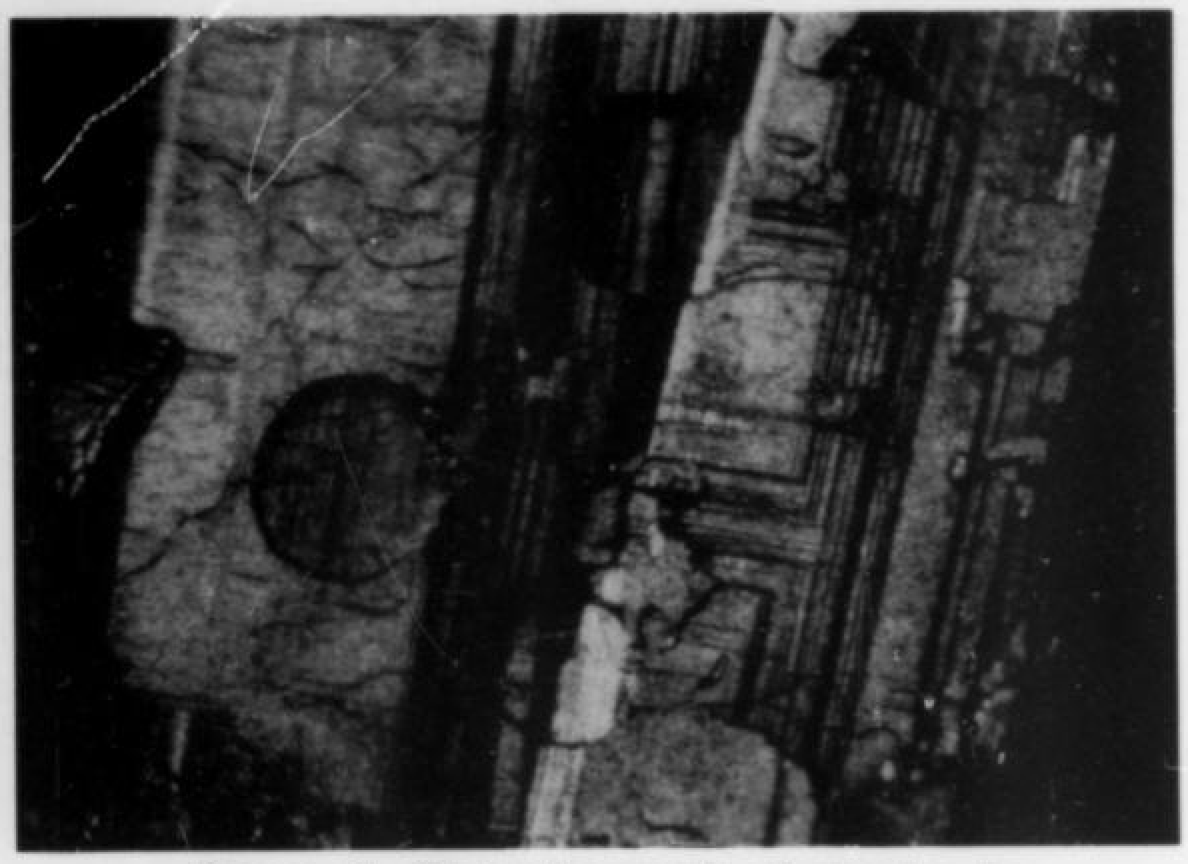


***Figure 41.* Photomicrograph of circular depressions about 1 mm across on pyrite crystals. ROM #M353761 (gift of Dr. W. A. Gibbins), R. I. Gait photograph.**

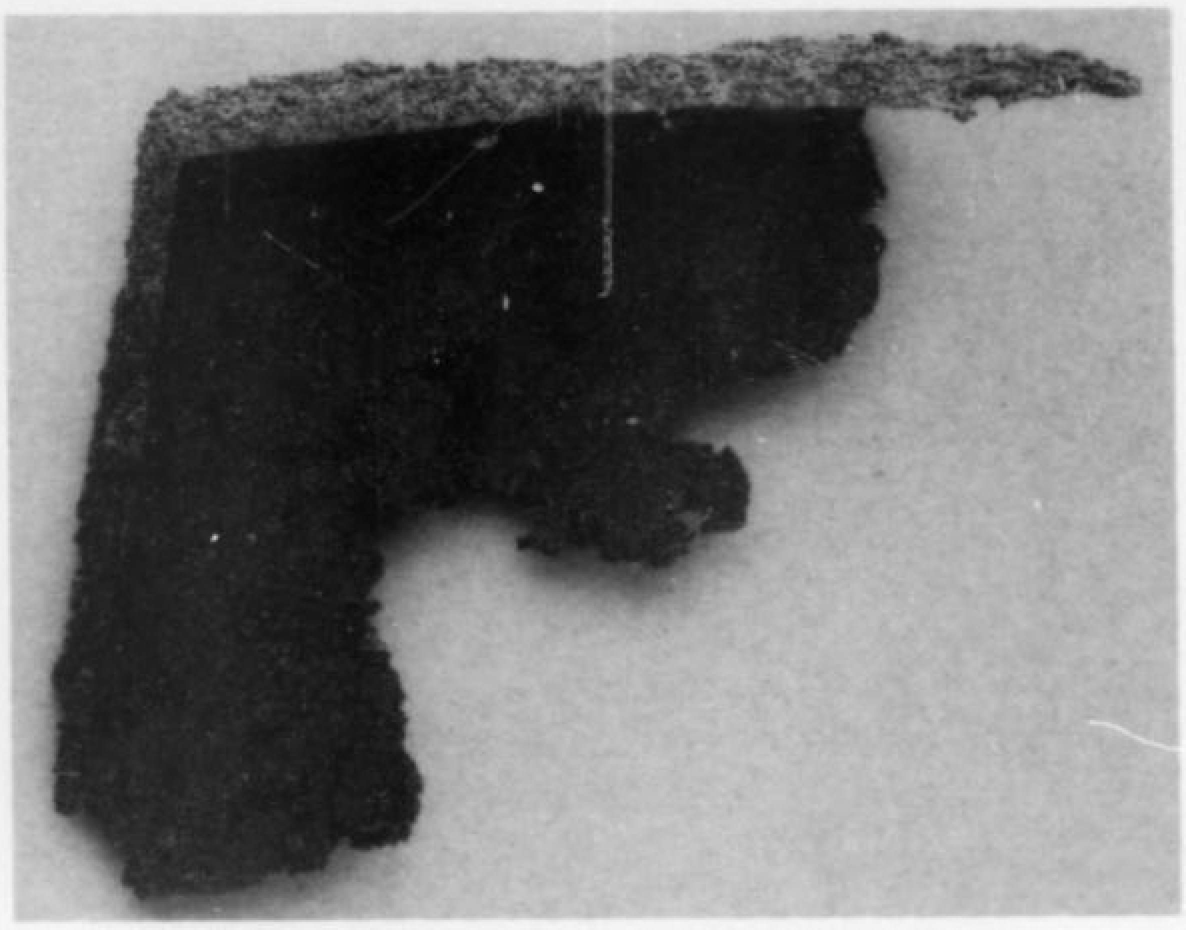


***Figure 42.* Pyrite cast of a dolomite crystal, obtained by dissolving the dolomite, 1 x 4 x 8 cm. ROM #M44226 (gift of Mr. Ian Nicklin), ROM photograph.**

***Figure 43.* Pyrite stalactite, 2.5 cm long, from 26 crosscut in the main mine. CMN #51330, G. W. Robinson photograph.**

***Figure 44.* Pyrite pseudomorph after pyrrhotite, 2.5 x 4 cm. CMN #MOC3208, G. W. Robinson photograph.**

the ceilings of some cavities and the space between them is sometimes partly filled with pyrite. Stalagmites have not been found. Most of these sulfide stalactites are composed of fine-grained, loosely interlocking pyrite crystals surrounded by an intergrown mass of crystals of pyrite pseudomorphs after marcasite (Olson, 1977 and 1984). Other stalactites are hollow and may contain tiny rhombs of dolomite inside them, with their outer surfaces coated with curved, elongated pyrite crystals that gives them a twisted appearance (Fig. 43).

Pyrobitumen Hydrocarbon

Pyrobitumen is a black, solid substance with a conchoidal fracture, most likely "albertite" or "impsonite." Although it is common, it occurs only in small amounts. Fragments are found included in some of the quartz crystals and a petroleum-like liquid is found as inclusions in some of the dolomite crystals (Olson, 1977). These hydrocarbons are used as evidence for the existence of methane, a gas that may have played an important role in the deposition of the metallic sulfides.

Pyrrhotite $Fe_{1-x}S$

Pyrrhotite has been identified which may have formed by the alteration of pyrite near diabase dikes (Olsen, 1984), but recently some large pyrite pseudomorphs after well-formed pyrrhotite crystals have been collected in blocks 10-09 and 10-10 and in blocks 20-25 in Area 14. Most of these crystals are small, but some reach 10 cm in diameter

Figure 45. **Sphalerite crystals, 6 x 7.5 cm, from Block 20 North in the main mine. CMN #51992, G. W. Robinson photograph.**

Figure 46. **Covellite crystals up to 0.5 mm across. CMN #MOC3204, SEM by G. W. Robinson.**

and show the tabular, hexagonal prisms of the original pyrrhotite (Fig. 44).

Quartz SiO_2

Quartz is found as colorless to smoky, doubly terminated crystals up to 15 cm long (Fig. 47), sometimes with fluid inclusions, or inclusions of pyrite and hydrocarbon. They are usually found associated with dolomite and less commonly with pyrite in the large carbonate vugs bordering the hanging wall contact of the sulfide body. Small, clear, doubly terminated crystals resembling "Herkimer diamonds" are found with hydrocarbon in the dolostone above the Area 14 mine.

Sphalerite ZnS

Crystals of sphalerite are dark reddish brown in color and have been found up to 3 cm across. They usually exhibit the typical curved forms involving the {111} faces; Olson (1977) identified the tristetrahedral {211} form on some crystals. The finer specimens consist of clusters of sharp, pseudo-octahedral crystals (combinations of the positive and negative tetrahedra); others are twinned on {111} to produce complex crystals that look like spinel twins. Microcrystals of yellow sphalerite occur as druses on pyrite. The iron content ranges from 1.50 to 6.40 weight % (Olson, 1977). It is interesting to note that the 60 grams of silver per metric ton come from the zinc concentrate and not the lead. Both electron and proton microprobe analyses have shown that most of the silver is present in the sphalerite and only minor amounts in the galena (Cabri *et al.*, 1985). Microscopic inclusions of canfieldite (Ag_8SnS_6) have recently been identified.

Figure 47. **Smoky quartz crystal group on matrix, 11 cm. Fred Bailey specimen, G. Robinson photograph.**

A peculiar, extremely fine-grained, blue-gray coating on pyrite crystals has been studied both at the Royal Ontario Museum and at the Canadian Museum of Nature and has been identified as sphalerite.

Wurtzite (Zn,Fe)S

Wurtzite is occasionally found in association with some of the sphalerite ore, where it occurs as light yellow, platy aggregates 2 to 3 mm thick, or as rims around sphalerite grains enclosed in massive, sparry dolomite. Wurtzite has also been identified as a major constituent in a soft, black, slickensided fracture-filling in pyrite from the 15-09 backslash. Only a few wurtzite specimens are known, and no crystals have been found to date.

Other Minerals

Greenockite has been identified on a single specimen from the 33-10 backslash by both X-ray powder diffraction and qualitative SEM energy dispersive X-ray analysis. It is mixed with sphalerite and appears as a thin, pale green coating on pyrite pseudomorphs after marcasite.

Covellite occurs as rare, millimeter-sized, bipyramidal crystals occupying cavities in a few chalcopyrite specimens collected from the dump at 9 South Portal. Associated species include calcite, **brochantite, chalcanthite** and a **linnaeite group** mineral found as silvery gray cuboctahedral crystals coating some of the chalcopyrite crystals. This mineral has also been observed as metallic, acicular sprays of crystals up to 7 mm on a few of these specimens. Electron microprobe analyses of both habits give similar results, and yield a composition of $(Co_{2.00}Ni_{0.95}Fe_{0.06})_{\Sigma 3.01}S_{3.99}$. Linnaeite group minerals have a general formula $A^{+2}B_2^{+3}S_4$, consistent with their spinel structure type. Intermediate Co-Ni compositions are common, and the mineral siegenite, $(Ni,Co)_3S_4$, is known. However, as its formula implies, siegenite is Ni-dominant, whereas the specimens from Nanisivik are Co-dominant; $CoCo_2S_4$ is linnaeite, and $NiCo_2S_4$ is not known as a natural phase. While it is tempting to rewrite the formula of the Nanisivik material as $(Ni_{0.95}Fe_{0.06})_{\Sigma 1.01}Co_{2.00}S_{3.99}$ (ideally $NiCo_2S_4$), or as $Co_{1.00}(Co_{1.00}Ni_{0.95}Fe_{0.06})_{\Sigma 2.01}S_{3.99}$ (Ni-rich linnaeite), we have no structural evidence for doing so. Co, Ni and Fe are completely isomorphous within the

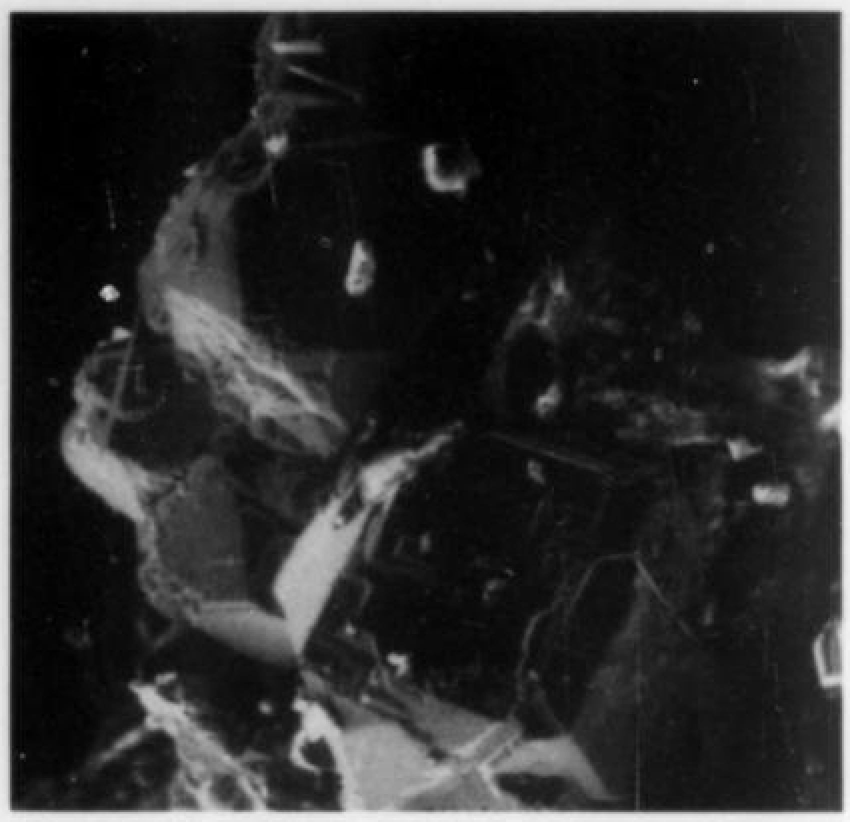


Figure 48. **Cuboctahedral crystals, 0.8 mm across, of a linnaeite group mineral. CMN #MOC3206, SEM by G. W. Robinson.**

group, and similarity in ionic radii and atomic scattering factors for these elements preclude resolution of the problem by normal X-ray means. Neutron diffraction techniques may be of some help, but are not available to the authors.

Occasionally, various secondary iron, zinc and magnesium sulfate minerals are encountered as secondary white, powdery coatings on fracture surfaces in the ore. Because these minerals are never well-crystallized, and most occur as intimate mixtures of several species, the only way they may be properly identified is by X-ray and chemical means. These species are also found locally in oxidized areas of the mine where they occur in black, carbonaceous, earthy masses mixed with dolomite, gypsum, **goethite** and **sulfur.** It is possible that the sulfur may have formed by bacterial reduction of the sulfates, but the isotopic studies needed to confirm this have not been done. To date the following minerals have been identified: **anglesite, bianchite, boyleite, copiapite** (or zincocopiapite), **gunningite, hexahydrite, jarosite, melanterite,** zincian melanterite and zincian **rozenite.** A material similar to laurionite has also been found but its identity needs confirmation.

Since the presence of sulfate causes problems in the flotation process used to concentrate the ore minerals, areas rich in these minerals are avoided during mining, and it is unlikely that many of these specimens will be collected in the future.

SUMMARY

The Nanisivik deposit, despite its seemingly simple mineralogy, is extremely complex and fascinating especially for the habits and forms of pyrite, and the pyrite pseudomorphs after marcasite. Exceptional specimens of pyrite, dolomite, sphalerite and calcite have been recovered, as well as some magnificent pyrite pseudomorphs after pyrrhotite and twinned marcasite crystals. Excellent specimens are on the market and available to collectors and we hope that the supply will continue. Most likely there will be even more enigmatic crystals to test our interpretive skills in the future.

ACKNOWLEDGMENTS

We are indebted to Nanisivik Mines Ltd. for permission to publish this article and for their cooperation in making a suite of specimens available to RIG for study. Nanisivik also granted permission to GWR to collect specimens for the Canadian Museum of Nature. Other specimens used in this study were donated to the Royal Ontario Museum by Mr. David Bending, Dr. Walter Gibbins, Dr. Donald H. Gorman, Mr. Dave Joyce, Dr. Jack Satterly and the late Mr. Rod C. Staveley and we thank them for their generosity. We thank Dr. R. A. Olson for making available the mineral description sections of his Ph.D. Thesis. Susan Robinson did the sketches for Figure 12. Frances Brittain designed and drafted the maps for Figs. 4 and 8. Malcolm Back produced most of the crystal drawings using the SHAPE computer program (Dowty, 1986). Critical reading of the manuscript by Richard C. Erd, Fred Bailey and Dr. Donald Peacor is acknowledged and their comments and helpful suggestions are much appreciated. The manuscript has benefited from many informal discussions with friends and colleagues. Nanisivik Mines Ltd. should be congratulated on their progressive policy of permitting specimens to enter the market, thus allowing many wonderful crystals and crystal groups to be preserved in private and public collections.

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FAMOUS MINERAL LOCALITIES: DE KALB, NEW YORK

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Transparent green crystals of diopside from De Kalb, New York, have been known since the late 1800's, and may be seen today in most of the world's major mineral museums. Their color, transparency and overall high quality place them among the world's best examples of the species. For nearly half a century specimens were generally unavailable to collectors, and little was known about the occurrence. However, small scale mining in the late 1960's and 1970's once again produced a number of fine specimens.

LOCATION and ACCESS

The De Kalb diopside locality consists of a series of small pits located on the west side of a northeast-trending ridge approximately 6 km northeast of the village of Richville, De Kalb Township, St. Lawrence County, New York. The principal occurrence is situated at approximately 44° 26.93′ N. Latitude, 75° 19.62′ E. Longitude. Access is normally by foot, proceeding southeast from St. Lawrence County Highway 33 at a point 1.8 km southwest of its intersection with County Highway 112. County Highway 33 parallels U.S. Route 11 approximately 2 km to the southeast.

HISTORY

Perhaps the first person to have collected any specimens from this famous locality was Calvin Mitchell, a farmer who owned the land in the mid to late 1800's. No one knows how long it took before the curious green crystals left the hands of Mr. Mitchell and were recognized as among the finest specimens of diopside the world had yet seen. Kunz (1892) states, "some very large crystals were found in 1884, several of which were over 3 inches long and 1 inch thick, with clear spots of gem material giving promise of cut gems weighing 20 to 30 carats each." Vom Rath described crystals of diopside from De Kalb in 1886, and published a second paper on them in 1888 (vom Rath, 1886, 1888). Specimens are also referenced in Dana's *System of Mineralogy* (1892), Hintze's *Handbuch der Mineralogie* (1896), and Ries' monograph on *The Monoclinic Pyroxenes of New York State* (1896).

In the late 1800's the Mitchell farm was subdivided and changed hands several times, and in 1899 the right to mine diopside was secured by the famous mineral dealer, George L. English. Whether due to the lack of good transportation facilities, the expense and difficulty of mining, a limited market or other factors, little work was actually done, and relatively few specimens were produced. Most of these probably went to New York, where English was located, and were dispersed into the prominent collections of the day. The locality remained unworked for more than 50 years thereafter until 1967, when the first serious attempt at recovering more of these "old time" specimens was undertaken by Terry Szenics. After several weeks of hard work Szenics was rewarded with a pocket which yielded several large crystals and a number of smaller ones (Szenics, 1968). Because the locality was on private land, it was generally not visited by collectors, but in 1968 the New York State Museum was granted permission to mine more specimens. A small field party consisting of M. Raymond Buyce, Ray Morenski, Schuyler Alverson and the author recovered a few more specimens, though no major discovery was made.

Early in 1971 the property was acquired by local collectors Schuyler Alverson, Robert Dow and the author. Some preparatory work and surface prospecting was done that summer, and a number of good specimens were collected. Particularly memorable was one large pocket which was accidentally encountered just before dark on June 6 that year. Having previously found no large pockets at all it was indeed a thrill to watch a 25-cm screwdriver disappear, handle and all, into the narrow clay-filled crevice. Though the sun soon vanished, work continued well past midnight with the aid of a Coleman lantern and truck headlights. The large crystal shown in Figure 4 was the last one removed that night. Over the next two days this pocket and several smaller adjoining ones were completely excavated. Several hundred crystals ranging from 1 to 8 cm were recovered and displayed shortly thereafter at the Eastern Federation show in Lake Placid (Robinson, 1973).

Figure 1. **Southeast view of the main collecting area as it appeared in the summer of 1973. G. Robinson photo.**

Figure 2. **A 4.8 x 6.5-cm diopside crystal from the June 6, 1971 pocket. Canadian Museum of Nature specimen, catalog no. 50606. G. Robinson photo.**

The property was worked intermittently over the next decade, but progress was slow and the work tedious, as numerous complications arose. Cattle in nearby fields had to be evacuated before every blast, and any stray rocks had to be recovered by hand. Approximately half the outcrop was covered by glacial overburden that had to be removed. The hardness and fabric of the rock, compounded with its intersecting joints, foliation and abundance of small tremolite pockets, presented ever-challenging problems to drilling and blasting: light blasting did not fracture the rock and heavy blasting could not be employed due to overhead electrical lines and the obvious risk of losing too many crystals. Only about 20% of the pockets encountered actually contained diopside, and those were filled with a compact mixture of talc and needle-like fibers of tremolite that easily pierced the skin, hindering removal of specimens. Lastly, the deposit was found to be mineable only about four months of the year due to a shallow water table and harsh winter conditions. Nevertheless, in spite of these difficulties a number of good specimens were collected and placed on the market during this period.

Today the property is jointly owned and operated by Schuyler Alverson (Rensselaer Falls, New York) and Robert Dow (Canton, New York). Collecting by the public is not permitted.

Figure 3. **Three specimens of diopside illustrating the most common crystal habits. Canadian Museum of Nature specimens, left to right: no. 51110, 2.3 x 2.8 cm, collected summer, 1973; no. 50896, 1.5 x 2.6 cm, collected August, 1973; no. 51111, 1.8 x 3.2 cm, collected pre-1900. G. Robinson photo.**

Figure 4. **Diopside with quartz from the June 6, 1971 pocket. Canadian Museum of Nature specimen, catalog no. 51107, 3 x 4 cm area. G. Robinson photo.**

GEOLOGY

Much of the bedrock throughout St. Lawrence County, New York, consists of Precambrian metasedimentary rocks of the Grenville series. The regional geology has been summarized by Cushing and Newland (1925) and will not be discussed here. The diopside occurrence is located on a northeast-trending ridge of interbedded quartzite and calc-silicate rock that dips approximately 45° to the northwest. The crystal pockets are confined to the calc-silicate unit, which ranges in composition from a quartz tremolite schist to nearly pure, white, massive diopside, and is probably a metamorphic equivalent of a sandy dolomite.

A series of parallel joints and tremolite veinlets transect the ridge roughly perpendicular to its strike. The majority of the crystal-bearing pockets occur along these veinlets and joints, but a few are occasionally found isolated within the massive diopside rock. The pockets range in size from a few centimeters to nearly half a meter in maximum dimension. Coarsely crystallized diopside or tremolite usually indicate the proximity of a pocket. Both the pockets and tremolite veins probably resulted from fluids (saturated in Ca, Mg and Si) migrating to and accumulating in tensional fractures during regional metamorphism in a manner somewhat analogous to the genesis of alpine clefts.

In many of the pockets diopside is partially altered to tremolite, which is observed as epitactic overgrowths on the diopside with $[001][010]_{trem} = [001][010]_{diop}$. Complete pseudomorphs of tremolite after diopside are relatively common. Some of the tremolite, in turn, is altered to talc, and nearly all the pockets are filled with a mixture of talc and quartz with or without calcite. X-ray diffraction and qualitative EDS microprobe analyses show that at least some of this "talc" is actually a mixture of talc, montmorillonite and palygorskite. The

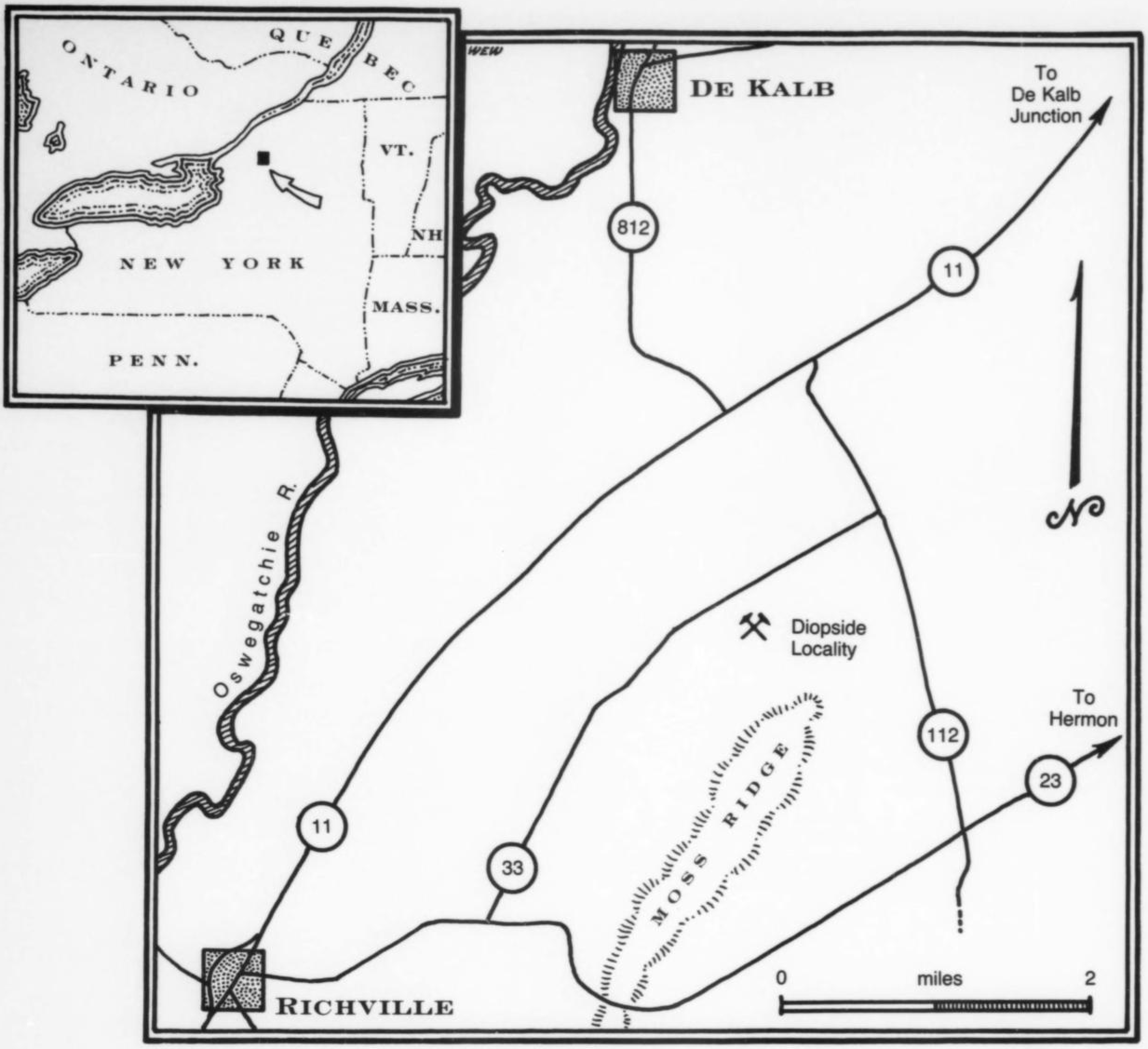

Figure 5. **Location map.**

paragenetic sequence diopside → tremolite → talc + quartz + calcite is clear, and suggests a retrograde reaction that accompanied a probable decrease in temperature and pressure and relative increase in H_2O and CO_2 activities.

MINERALOGY

Of all the species found or reported, probably only the diopside and tremolite are of interest to collectors. As mentioned earlier, calcite, quartz and talc occur principally as vug-filling masses, though a few specimens of crystallized quartz are known. These typically consist of colorless, centimeter-sized, transparent to milky crystals encrusting diopside. A few contain small cauliflower-like inclusions of talc, indicating a genesis contemporaneous with that mineral, but later than the diopside. Pyrite occurs infrequently as small pyritohedrons in the diopside rock, but these seldom exceed a centimeter in size and are typically altered to iron oxide. Albite occurs very sparingly as tabular, white, etched crystals to 2.5 cm. Datolite was reported by Cushing and Newland (1925), but has not been confirmed.

Diopside $CaMgSi_2O_6$

Some of the lustrous, transparent grass-green crystals of diopside that have been found at De Kalb are among the world's best for the species. Unlike most other crystals of diopside from numerous localities in the Grenville Province, those from De Kalb seldom show basal parting and nearly always exhibit good prismatic {110} cleavage. They are pale in color rather than dark, but above all they are transparent and of gem quality. Like many gem crystals, the region near the termination is usually more transparent and of richer color than elsewhere within the crystal. The average size of the crystals ranges from 1.5 to 2 cm, with individuals up to about 7 cm occurring far less commonly. To the author's knowledge the largest on record is the 5 x 10-cm crystal from the Bement collection at the American Museum of Natural History (Seaman, 1968). In most of the pockets the crystals are found detached from the walls so that good matrix specimens are relatively scarce. Similarly, singly terminated crystals far outnumber doubly terminated ones.

Crystal habits range from relatively simple to moderately complex.

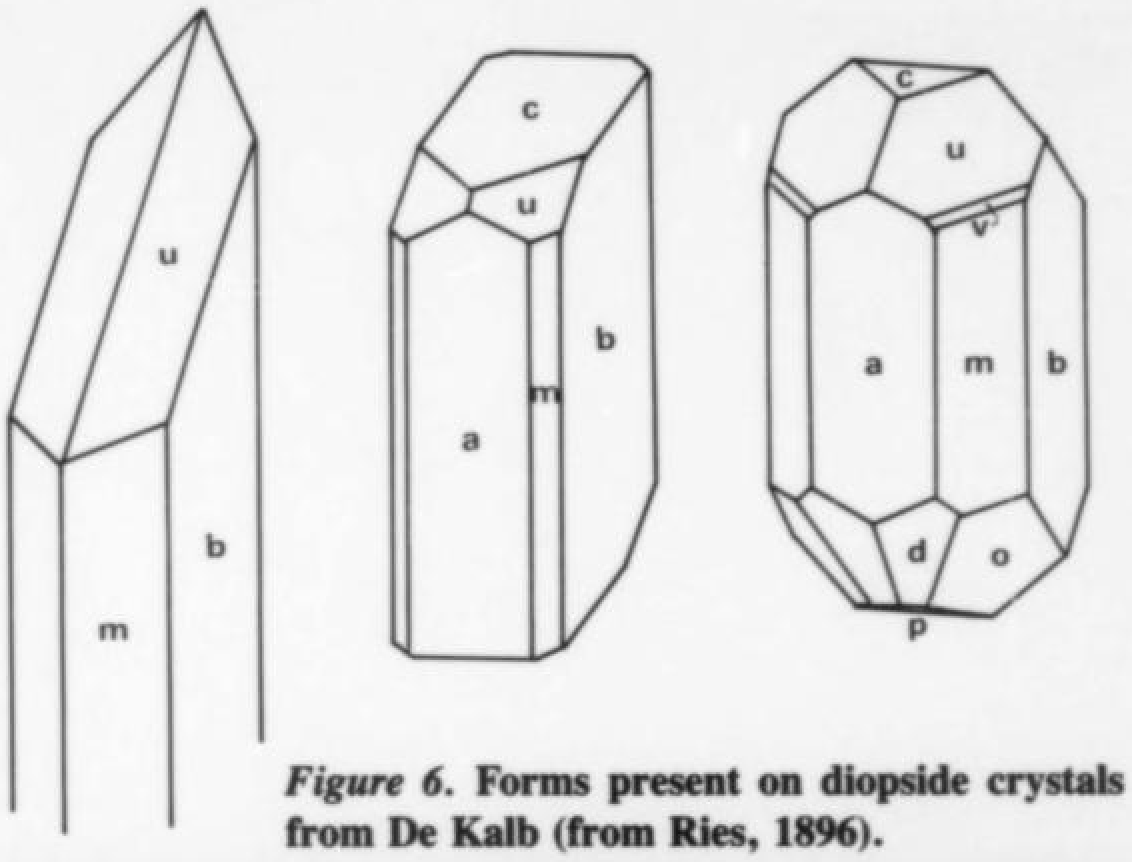

Figure 6. Forms present on diopside crystals from De Kalb (from Ries, 1896).

Figure 7. A 9 x 11-cm group of diopside crystals partially replaced by tremolite and talc from the June 6, 1971 pocket. Canadian Museum of Nature specimen, catalog no. 43859. G. Robinson photo.

Figure 8. Acicular tremolite on tremolite pseudomorphs after diopside, collected 1975. Canadian Museum of Nature specimen, catalog no. 45301, field of view 5 x 7 cm. G. Robinson photo.

Figure 9. A 2 x 3 cm crystal of diopside showing progressive replacement by tremolite and talc. Canadian Museum of Nature specimen, catalog no. MOC3466, collected circa 1980. G. Robinson photo.

Figure 10. A 9 x 13-cm group of tremolite pseudomorphs after diopside, collected June, 1971. Canadian Museum of Nature specimen, catalog no. 51204. G. Robinson photo.

Figure 11. **A large talc-filled pocket of diopside and tremolite *in situ,* September, 1971. G. Robinson photo.**

Figure 12. **Gem quality diopside. Canadian Museum of Nature specimens, left to right: no. 22274, 11.4 carat stone collected and cut by the author, 1969; no. 50896, 1.5 x 2.6 cm, collected August, 1973; no. 51109, 0.8 x 3.4 cm, collected autumn, 1972. G. Robinson photo.**

Most are prismatic parallel to [001], somewhat tabular on (010) and show well-developed $a\{100\}$, $b\{010\}$, $c\{001\}$, $m\{110\}$ and $u\{111\}$ faces. The pinacoids and {110} prism faces tend to be smooth and lustrous, whereas the {111} prisms are typically pitted and often show unequal development. Less commonly observed forms include $p\{\bar{1}01\}$, $e\{011\}$, $s\{\bar{1}11\}$, $o\{\bar{2}21\}$, $v\{221\}$ and $d\{\bar{3}11\}$ (Ries, 1896).

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

Tremolite occurs commonly in four different habits at De Kalb: as euhedral, gray-white prismatic crystals, as individual acicular fibers, in reticulated masses of acicular crystals and as pseudomorphs after diopside crystals. Individual prismatic crystals up to 10 cm long have been found, but are seldom terminated, since they tend to bridge pocket walls. The reticulated masses are unfortunately difficult to collect due to their extremely fragile nature, and few if any specimens have been preserved in collections. These probably formed as a result of mats of crystals becoming attached to the rhombohedron faces of growing calcite crystals; the calcite was later leached away by groundwater, exposing the boxwork of tremolite.

Perhaps the best known tremolite specimens from this locality, however, are the pseudomorphs after diopside. These illustrate all stages of replacement from relatively slight to nearly complete. Most still have diopside cores showing progressive uralitization toward the outside edges, and retain a distinct pyroxene morphology.

FUTURE OUTLOOK

There is no reason to believe this locality is exhausted. On the contrary, there is still a good deal of pocket-bearing calc-silicate rock to be explored down-dip and along strike. As noted, however, this will not be a particularly easy task. While the present owners cannot permit collecting by the public, their own operation may continue to supply fine quality specimens from this classic locality for years to come.

ACKNOWLEDGMENTS

Thanks are given to Gerry Van Velthuizen for drafting the crystal drawings, and to Dr. Wendell Wilson for drafting the map.

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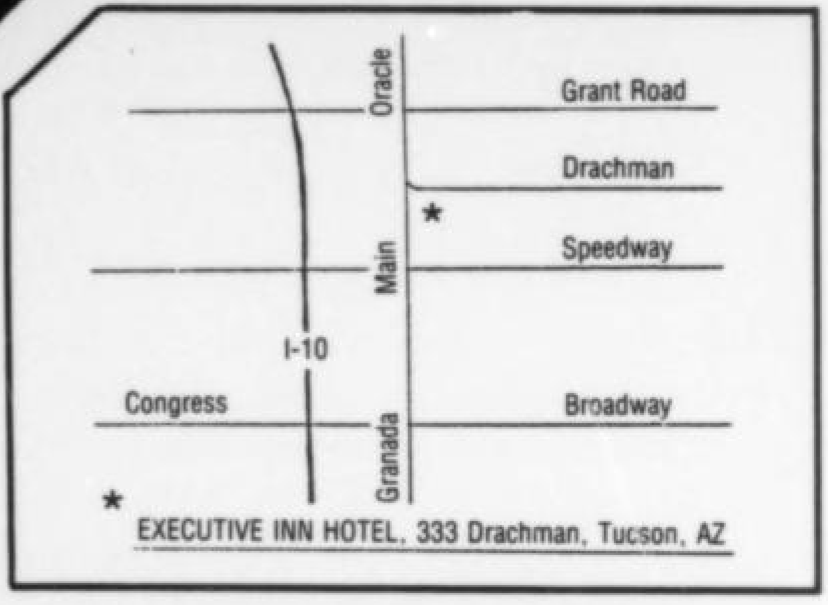

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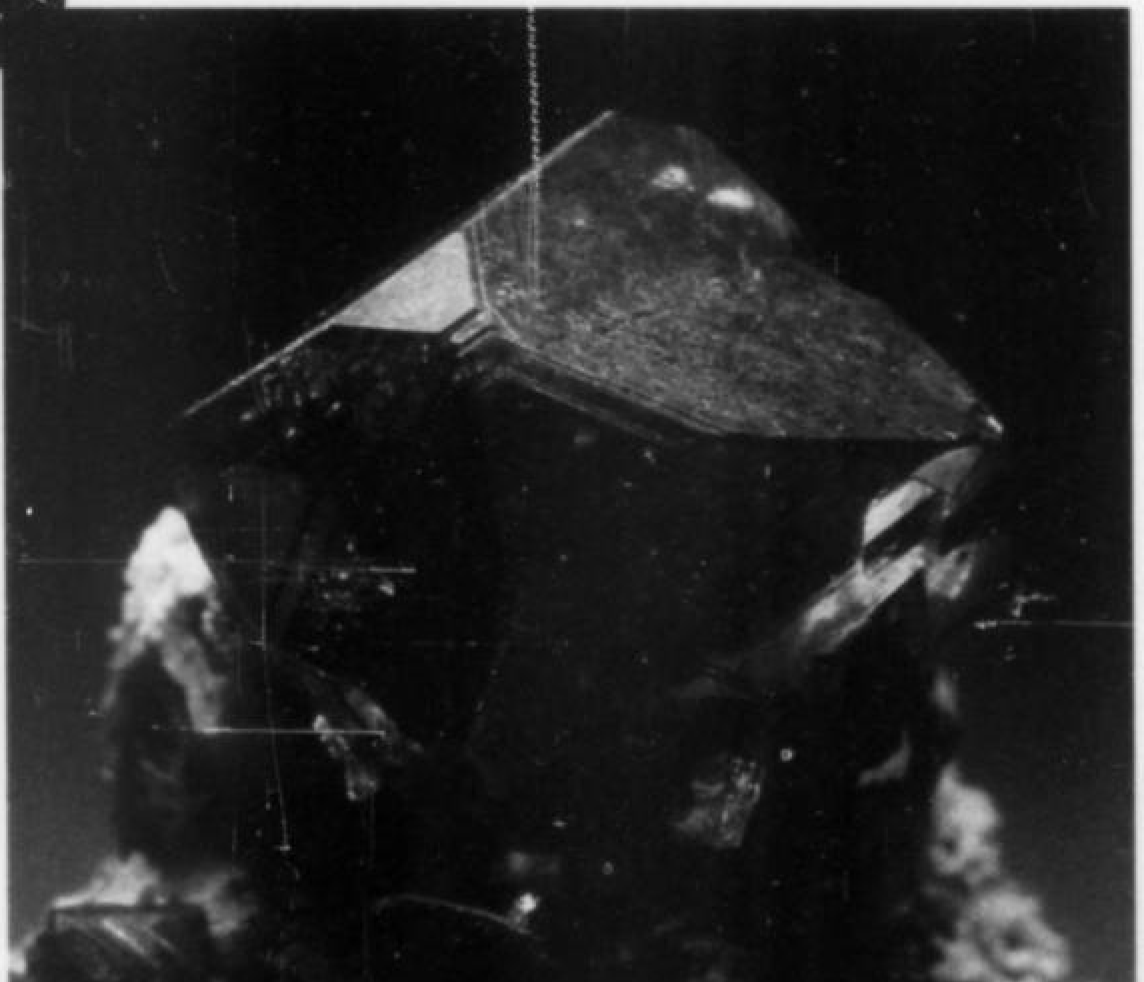

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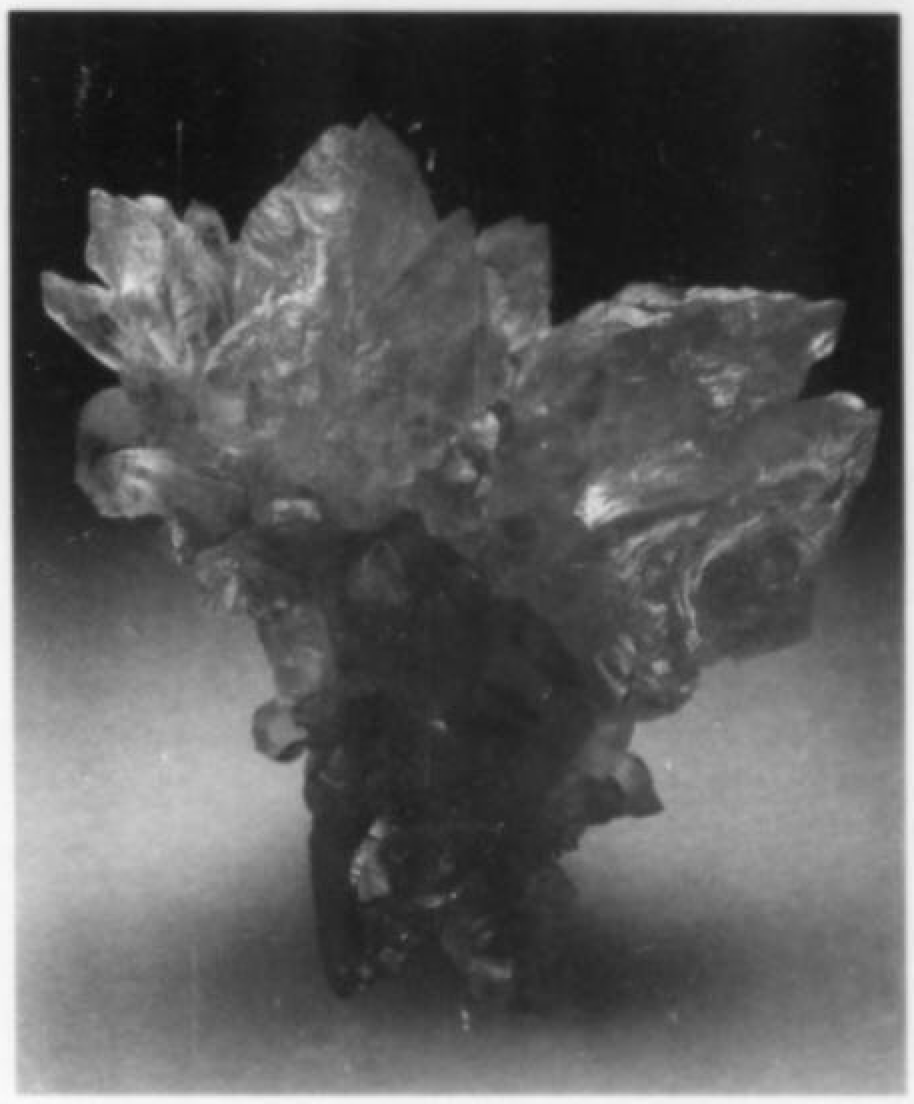

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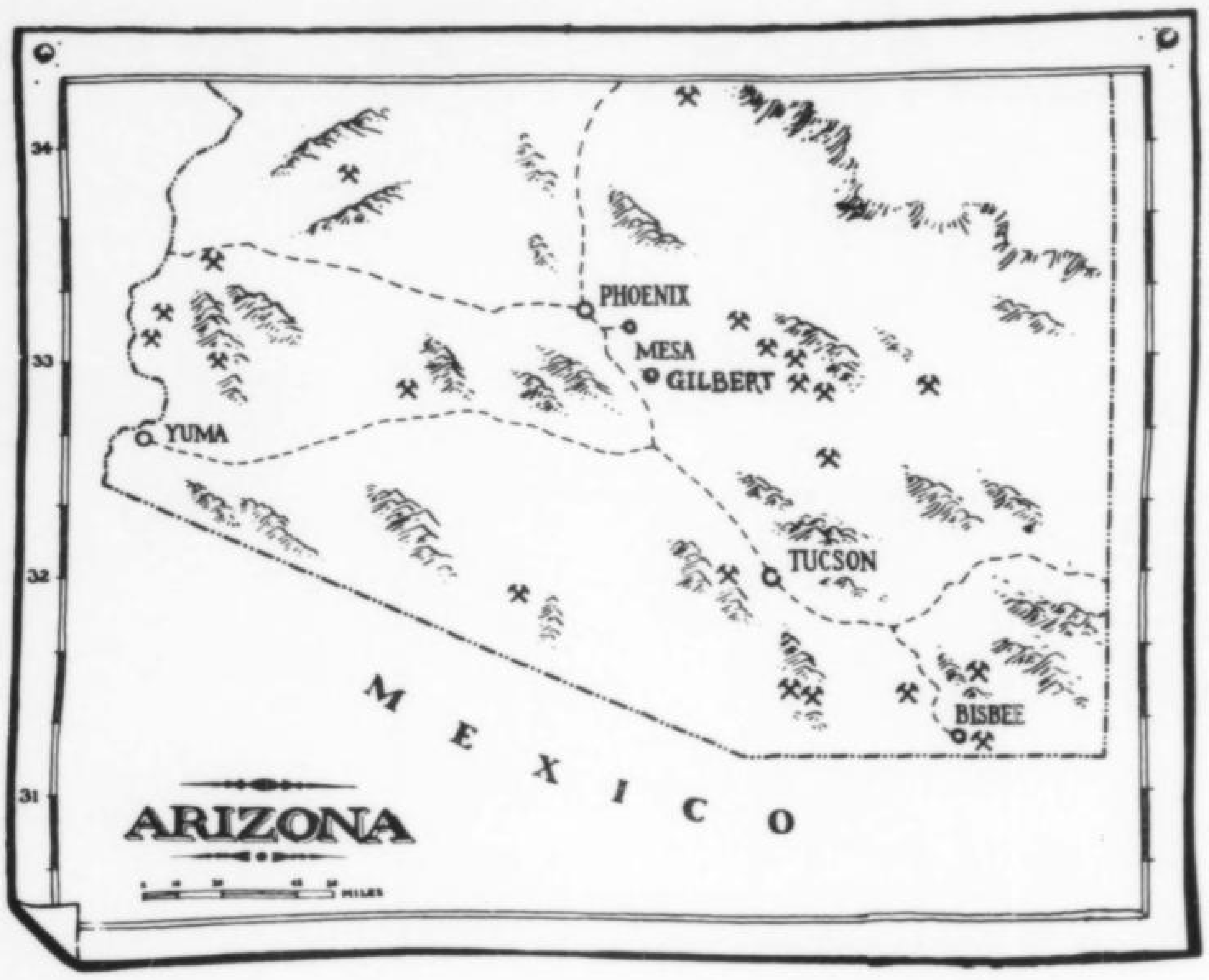

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The story of Arkansas diamonds has intrigued many people. To geologists it has posed questions of origin and relationships of the deposits to other geological features. To collectors it has meant the challenge of finding one's own diamonds in a world-famous deposit. To speculators and legitimate operators it has been a struggle to either make a quick profit or to mine the deposit as a carefully planned business venture.

LOCATION

The largest and best known diamond-bearing location in Arkansas is the Prairie Creek intrusive, located about 3.5 kilometers southeast of Murfreesboro in Pike County, southwestern Arkansas. The topography of the region is gently rolling but includes three small hills formed by the more resistant parts of the igneous intrusion. The overall igneous complex is oval in shape and crops out over about 0.3 square kilometers (73 acres). At least six other small igneous bodies are known in the general area but they are all of small areal extent and have produced relatively few diamonds. They will not be discussed further.

HISTORY

The presence of peridotite in Pike County, Arkansas, was first recognized in 1842 by geologist W. B. Powell, but diamonds were not known to occur in this type of rock at that time. Later in the century the South African diamonds were discovered, and the source rock was found to be a variety of peridotite which was named kimberlite after the important occurrence near Kimberly, South Africa. John C. Branner, then State Geologist of Arkansas, recognized the similarity between the published description of kimberlite and the occurrence of igneous rock in Pike County, but a detailed surface examination by Branner failed to reveal any diamonds (Branner and Brackett, 1889).

On August 8, 1906, an Arkansas farmer, John Wesley Huddleston, discovered the first diamonds on his 160-acre farm which he had recently purchased for $1000. The most credible explanation of the discovery is the one he gave to Howard Millar several years later (Millar, 1976). Huddleston had observed yellow flakes in the soil and washed some of the material to see it if was gold. The yellow flakes were phlogopite mica from the peridotite and since they floated were obviously not gold. However, investigation of the gravel in the bottom of the pan showed two unusual crystals, one yellow and one white, which were different from the common quartz crystals he was accustomed to seeing. At his house was a grinding wheel used for sharpening butcher knives. Using this he was not able to grind a spot on either of the crystals; this made him suspect that they were "dee-mints." It is quite possible that he had talked to Dr. Branner during his earlier reconnaissance and was familiar with what could occur here.

The next day Huddleston rode into Murfreesboro on his mule and showed the crystals first to the bank cashier, who offered him fifty cents each, and then to J. C. Pinnix, president of the bank. Pinnix agreed to send them to Charles Stifft, a Little Rock jeweler. Stifft thought they were diamonds but mailed them to George F. Kunz, vice president of Tiffany's in New York, for confirmation. Kunz replied that they were gem-quality diamonds, one a 3.0-carat white and the other a 1.5-carat yellow. Soon after that Kunz and Dr. H. S. Washington of the Smithsonian Institution visited the discovery site and, although they found no diamonds themselves, witnessed the discovery of a diamond crystal in a chunk of weathered kimberlite. Prior to this time there had been some skepticism, because the great "Arizona Diamond Swindle" a few years earlier had fooled several mineral experts.

Shortly after the discovery became known, the property was purchased from John Huddleston for $36,000 by three Little Rock men, Charles Stifft the jeweler, his son-in-law Albert D. Cohen, and Samuel W. Reyburn, president of the Union Trust Company; and thus the Arkansas Diamond Company was organized.

In arriving at the sale price, Huddleston had reasoned that his family consisted of him, his wife and four daughters, and that $6000 each should be sufficient to last them the rest of their lives. Soon after this Mrs. Huddleston died, and John moved with his daughters to Arkadelphia, a refined college town, so his daughters could receive an education. While there he met and married a "blonde carnival girl" and took her back to Murfreesboro with him in the first Model T Ford that had come to town. Legend has it that his new wife would drive

Figure 1. **John W. Huddleston, the "Diamond King." Photo from Crater of Diamonds State Park.**

for hours around the court house square with John smiling proudly at her side. One day he asked her to stop while he went into a store for a cigar. When he came out the car and the girl were gone for good. Huddleston also let it be known that a $1000 dowry went with the hand of each of his four daughters. Three of them were able to take advantage of it, but by the time the youngest was married, the money was all gone. John Huddleston died a pauper, but he reportedly said that he had no regrets. After all, he was the Diamond King.

When the word got out that this was not a hoax, a diamond rush developed which rivaled some of the western gold rushes. In one year the Conway Hotel of Murfreesboro turned away more than 10,000 people who could not be accommodated. The overflow of prospectors and camp followers was concentrated in the area between Murfreesboro and the Prairie Creek pipe, where the town of Kimberly sprang up (consisting mostly of tents). Today, old Kimberly is a peaceful cow pasture through which State Highway 301 wends its way to Crater of Diamonds State Park. The old Mauney house, which still stands, is the only relic of Kimberly.

At the time of the diamond discovery a geologist–mining engineer, Austin Q. Millar and his son Howard were attempting to recover diamonds from a peridotite occurrence in eastern Kentucky, using state-of-the-art techniques from South Africa, but had found no diamonds. When they heard about the Arkansas discovery they went immediately to investigate and arrived at a very critical time.

In addition to the old Huddleston farm, now owned by the Arkansas Diamond Company, there was an adjacent 40 acres, owned by M. M. Mauney, which was also located over part of the diamond deposit and which the newly formed company had tried unsuccessfully to buy. Mauney first attempted to mine his property, and for a while even allowed visitors to search for diamonds for a fee. Finally, he sold a three-quarters interest in the property to Horace Bemis, who organized the Ozark Diamond Corporation. A dispute developed over ownership of the capital stock, and Austin Millar, who had already become respected in the community, suggested that the Mauney property be divided into four ten-acre portions. Mauney would get first pick of one of the portions and Bemis would accept the other three for his company. The plan was accepted and the new company began operations. However, Bemis soon died and since his heirs were not interested in mining diamonds, the three-fourths of the old Mauney tract was purchased by the Millars. The remaining 10-acre tract of the Mauneys was leased by the Millars, with a 25% royalty on all diamonds produced. The Millars also attempted to purchase the other part of the diamond pipe but failed. There were destined to be two separate and competing series of ownerships until 1969.

The Millars built and operated a small commercial plant which proved to be a successful operation. They were preparing to substantially enlarge it when, on January 14, 1919, the entire installation was destroyed by a series of fires which broke out simultaneously and were proved to be the result of arson. They were never able to obtain financial backing to rebuild the plant.

Soon after the burning of the Millar plant, Stanley Zimmerman arrived in town as manager of the reorganized Arkansas Diamond Mining Corporation, which still owned the Huddleston property. According to Millar (1976) they did not intend to sell stock but instead had been promised cash as needed from J. P. Morgan and Company. Construction of the mining, washing and recovery operations lagged and finally Zimmerman left the area for three months. Upon his return, he told of touring the diamond mines of South Africa and meeting Sir Ernest Oppenheimer, head of DeBeers. Soon after this he and Sam Reyburn wrote an article for *Engineering and Mining Journal* condemning the Arkansas deposits as unprofitable. Some said that he had been paid to "prove" that the deposits were uneconomical.

***Figure 2.* Sunday diamond search party, circa 1910. Photo from Crater of Diamonds State Park.**

Several people tried to produce diamonds commercially over the next few years. The Ford Motor Company in 1923 tested Arkansas diamonds for industrial use and made an offer of $1,150,000 for the entire deposit. However, one of the owners refused to sell and the deal fell through.

In 1927 the stockholders of the Arkansas Diamond Mining Corporation were advised by Tom Cochran, a vice president of J. P. Morgan Company, that the company would be sold to satisfy a $125,000 mortgage held by him. The stockholders raised the money and paid it off, only to find that all of the diamonds mined over the years had been "auctioned off" by Cochran: the previous week he had stood on the steps of the Garland County courthouse in Hot Springs and auctioned them off to himself, as the only bidder, for $19,000. These were later purchased from his estate for $28,000 by Schenck & Van Haelen, a New York diamond-cutting firm who have handled most of the gemstones from the Arkansas deposit. The lot included the largest diamond found in Arkansas, the Uncle Sam, which was cut and sold for $75,000 (Millar, 1976).

The Arkansas Diamond Mining Corporation was acquired in 1941 by Chicago promoter Ray C. Blick and Charles H. Wilkinson (owner of a machine tool company in Logansport, Indiana). The new company, financed by Wilkinson, was called the North American Diamond Corporation. This was during World War II when there was a great need for industrial diamonds. However, the War Production Board refused to grant priority for machinery necessary to work the deposit, even though an Arkansas delegation visited President Roosevelt and tried to impress him with its potential.

After the death of Wilkinson in 1946, his widow Ethel took over the property and in 1948 leased it to Glenn L. Martin, the aircraft magnate. Martin reportedly never saw the property, and his manager was an ex-tavern keeper and earth-moving contractor. The venture cost at least $750,000 and produced only 246 carats of stones over eight months. Probably more stones were stolen than were produced. Mrs. Wilkinson was an ardent believer in astrology, and all of her decisions were based on the position of the stars. Her ex-attorney was quoted as saying that she was more interested in a man's birthday than in his ability.

The first real attempt to open the diamond deposit as a tourist attraction was in 1949 when the Ozark mine was leased for that purpose from the Millars and was opened as the Diamond Preserve of America. The name was later changed to Crater of Diamonds and was successfully operated as a tourist attraction by Mr. and Mrs. Howard Millar. The adjacent property, owned by Mrs. Wilkinson, was opened in competition as the Big Mine, and a war of the billboards ensued between the two properties. In 1969 both properties were purchased by General Earth Minerals of Dallas. Although they announced plans to operate the property as a diamond mine, this was never done. It continued as a private tourist attraction until 1972, when it was purchased for $750,000 by the Arkansas Department of Parks and Tourism. It has been operated as Crater of Diamonds State Park up to the present time.

During the past two decades there has been intermittent exploration and evaluation of the diamond mining potential for the Murfreesboro area by several mining companies. At least two of these companies submitted serious proposals to the state. An early one, by Anaconda Mining Company, was turned down for environmental impact reasons. A recent one was submitted by Hanvey-Boulle Ltd., a diamond mining and development corporation formed by Jean Boulle (formerly with DeBeers Consolidated Mines, Ltd.) and Don Hanvey (a Texas oil businessman). This was given careful consideration and considerable debate, as well as extensive publicity. The result has been passage of a bill and its signature by the Governor of Arkansas to "authorize the

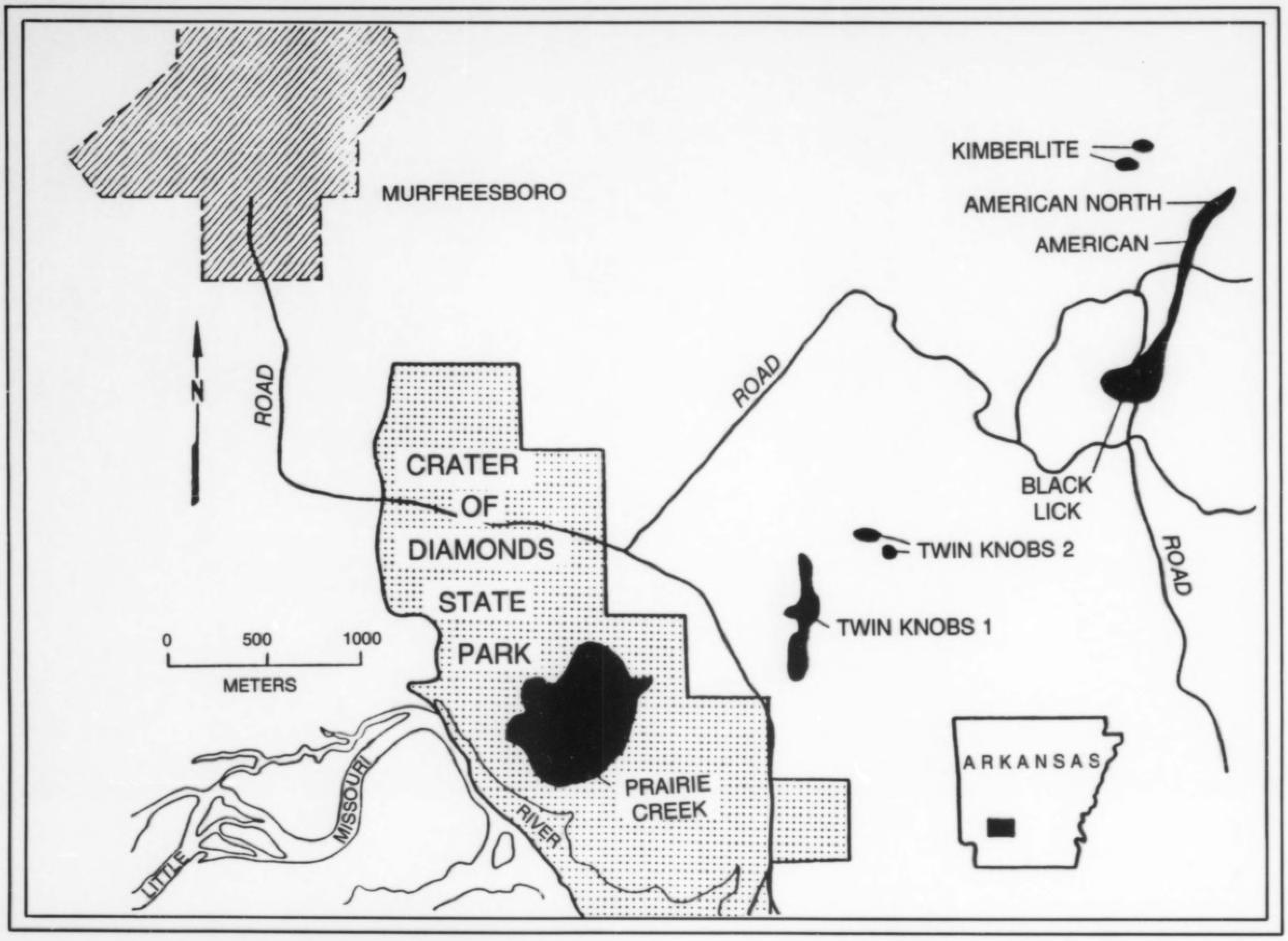


Figure 3. **Location of peridotite bodies in Pike County, Arkansas. (Modified from Michael A. Waldman, *et al.*, 1985.)**

State Parks, Recreation and Travel Commission to execute a lease for the exploration and mining of diamonds at the Crater of Diamonds State Park."

The issue is controversial between those dedicated to keeping the park in its present condition and those who feel that commercial development would be more beneficial to the State of Arkansas.

In early 1990 the State of Arkansas approved an exploratory drilling program to determine whether the kimberlite can be economically mined. The four companies involved in the $350,000 program are Capricorn Diamonds Party Ltd. (West Perth, Australia), Continental Diamonds Inc. (Little Rock), Kennecott Exploration Company (Camden, South Carolina), and Arkansas Development Corporation (Dallas, Texas). The consortium is giving a preliminary estimate of $900 million in diamond ore reserves, and possibly much more. Environmental groups plan to challenge the ruling on the grounds that mining will cause extensive damage to the area around Murfreesboro (Hiss and Shor, 1990).

Figure 4. **Austin Q. Millar, pioneer geologist and mining engineer. Photo from Crater of Diamonds State Park.**

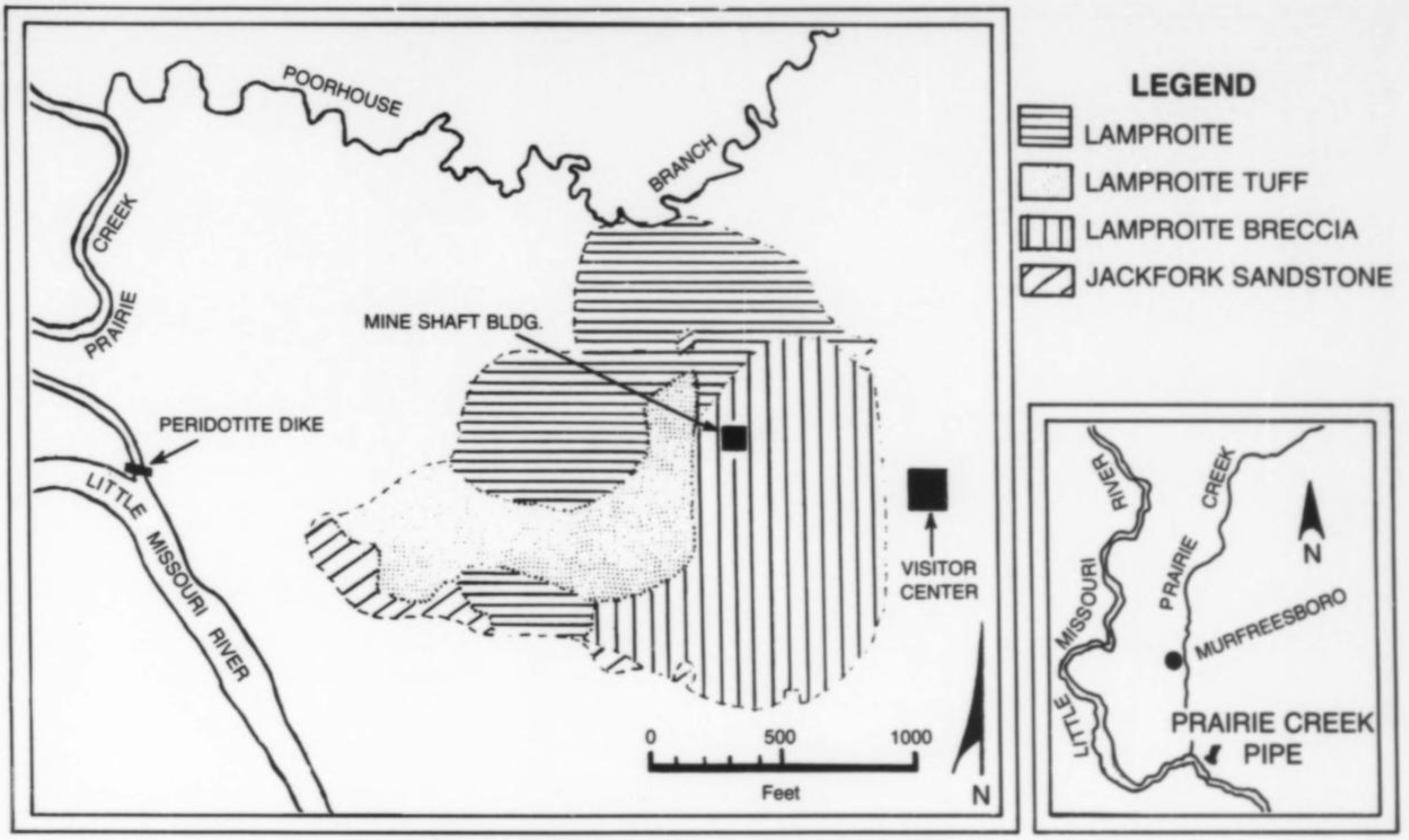


Figure 5. **Geologic map of Prairie Creek lamproite area.**

GEOLOGY

The diamondiferous intrusives are located in the northern edge of the Gulf Coastal Plain, just south of the folded and faulted Ouachita Mountains, which are composed primarily of Paleozoic sandstone, shale and novaculite. These older beds are overlapped from the south by Cretaceous shales, marls and evaporites. The intrusives cut the Lower Cretaceous Trinity Formation and are partially overlain by the Upper Cretaceous Tokio Formation. Thus, the time of the intrusion was pre–Upper Cretaceous, approximately 97–100 million years ago as determined by radiometric dating, which is essentially the same time the igneous activity took place at Magnet Cove and Little Rock to the northeast.

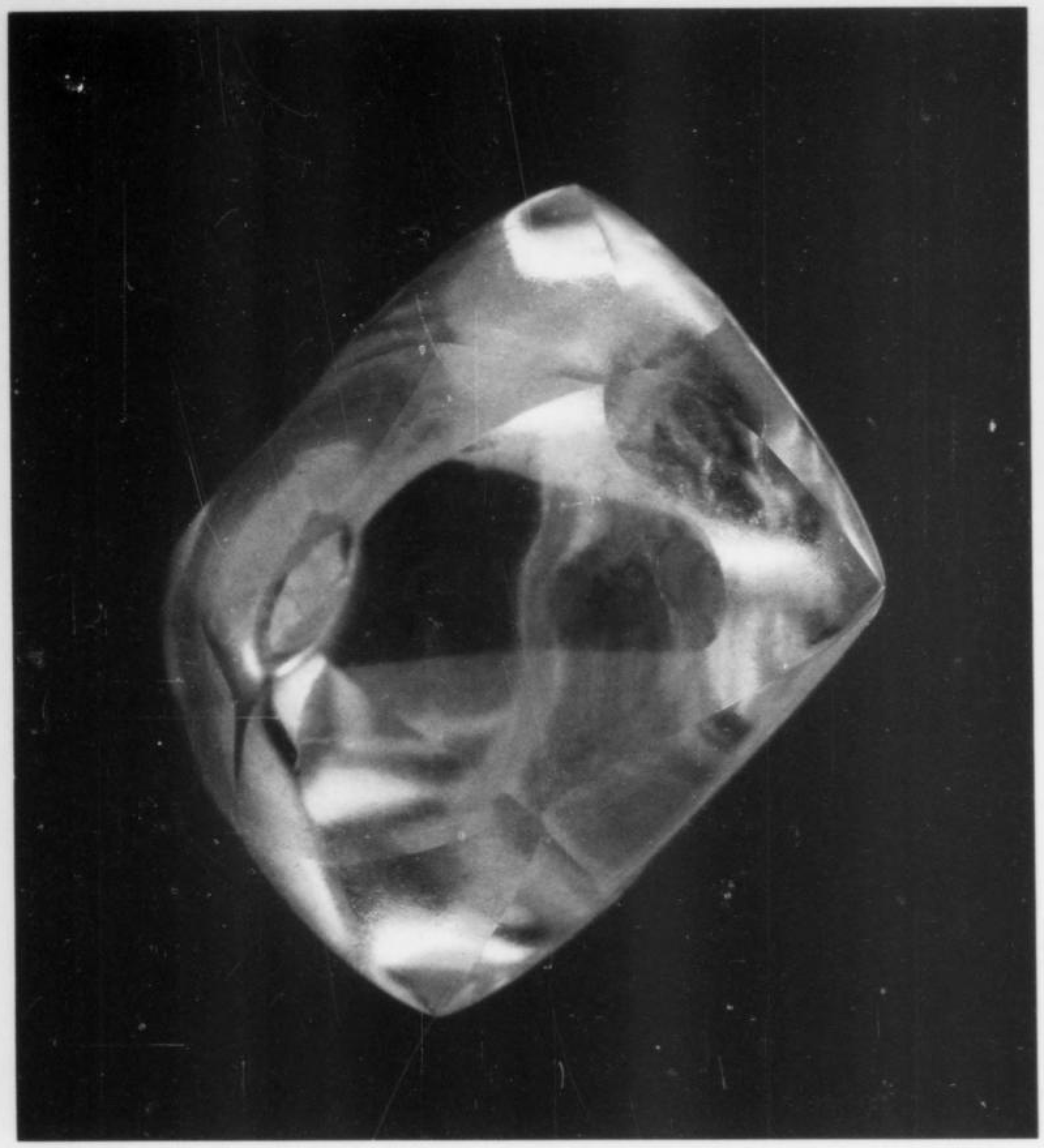
The Prairie Creek intrusive was first called a micaceous peridotite and then a kimberlite, based upon the presence of diamonds and certain similarities to the type kimberlites of South Africa. Three volcanic lithologic units were recognized by Miser and Ross (1923) and have been modified relatively little by later workers. These are intrusive peridotite, peridotite breccia and peridotite tuff. Within the past ten years the rock has been restudied and shown to have closer chemical and mineralogical affinities to the diamond-bearing lamproites of Western Australia than to the true kimberlites of South Africa (Scott-Smith and Skinner, 1984). This distinction is based upon such things as the lack of ilmenite and orthopyroxene, the scarcity of garnet, and the presence of amphibole and priderite, minerals unknown in true kimberlites (Morris, 1986).

The most abundant rock type is greenish black to black intrusive peridotite (lamproite), with a glassy groundmass largely altered to serpentine and chlorite, phenocrysts of altered olivine and phlogopite, and microscopic crystals of diopside, chrome spinel, perovskite, fluorapatite, priderite and amphibole. The principal exposure is in the northern part of the complex. This unit has not yielded any documented diamonds.

A volcanic (lamproite) breccia unit makes up about 40% (30 acres) of the complex. The breccia contains a variable combination of lapilli, igneous rock fragments from below, and sedimentary sandstone and shale from the section penetrated, all set in an altered matrix of serpentine and chlorite and traces of the other original igneous minerals. The rock shows various shades of yellow or green, depending upon the degree of weathering. This rock type constitutes the southern and particularly the southeastern part of the complex. It has been the source for all of the documented diamonds found over the years.

The third rock type is a generally fine-grained, blue-gray tuff containing fragments of the igneous rock, flakes of phlogopite and abundant quartz grains from the underlying sandstones. Part of the tuff shows bedding, which suggests that it was deposited in water occupying an open volcanic vent. There is no record of any diamonds having been found in this material.

Ideas concerning the origin of diamonds in general and Arkansas diamonds in particular have changed through the years as more information has become available, and will no doubt continue to change in the future. Current wisdom suggests that significant numbers of relatively large diamonds can form only at very high temperature and pressure and that they form in ultramafic (silica-deficient) rocks within the upper mantle some 160 km below the earth's surface. Within this zone temperatures exceed 800°C and pressures are in excess of 70,000 kg per square centimeter. The fact that Arkansas diamonds are restricted to a breccia (fragmental) phase suggests that the diamonds formed very slowly during the normal cooling of the earth's mantle and that as this semi-solid rock moved upward toward the surface along zones of weakness it reached a place where explosive eruptions could occur. The early-formed diamond-bearing lamproite was then broken up and emplaced rapidly as a breccia in funnel-shaped vents. On the other hand, the still-molten material did not contain already-formed diamonds, and conditions were not right for their formation during the relatively rapid emplacement which followed. This agrees with the suggestion by Bolivar (1982) that, on the basis of geophysical evaluations, the sequence of intrusion was breccia, peridotite and tuff.



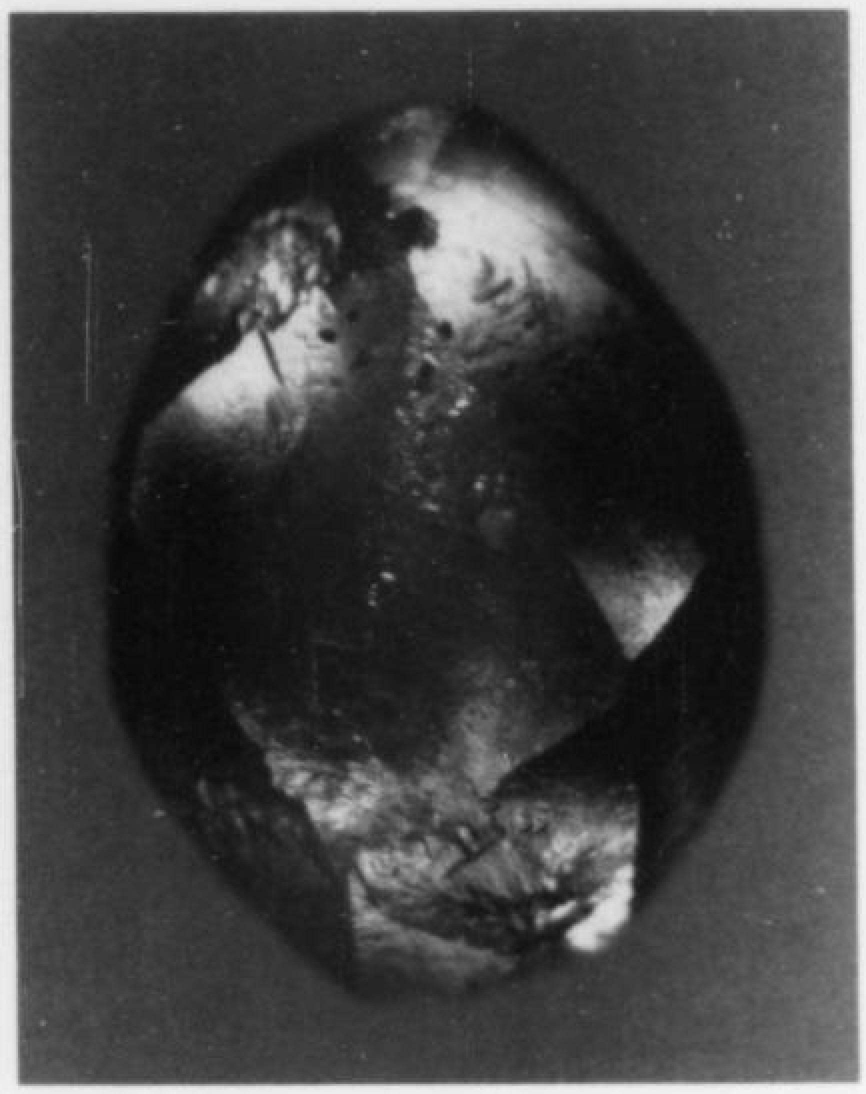
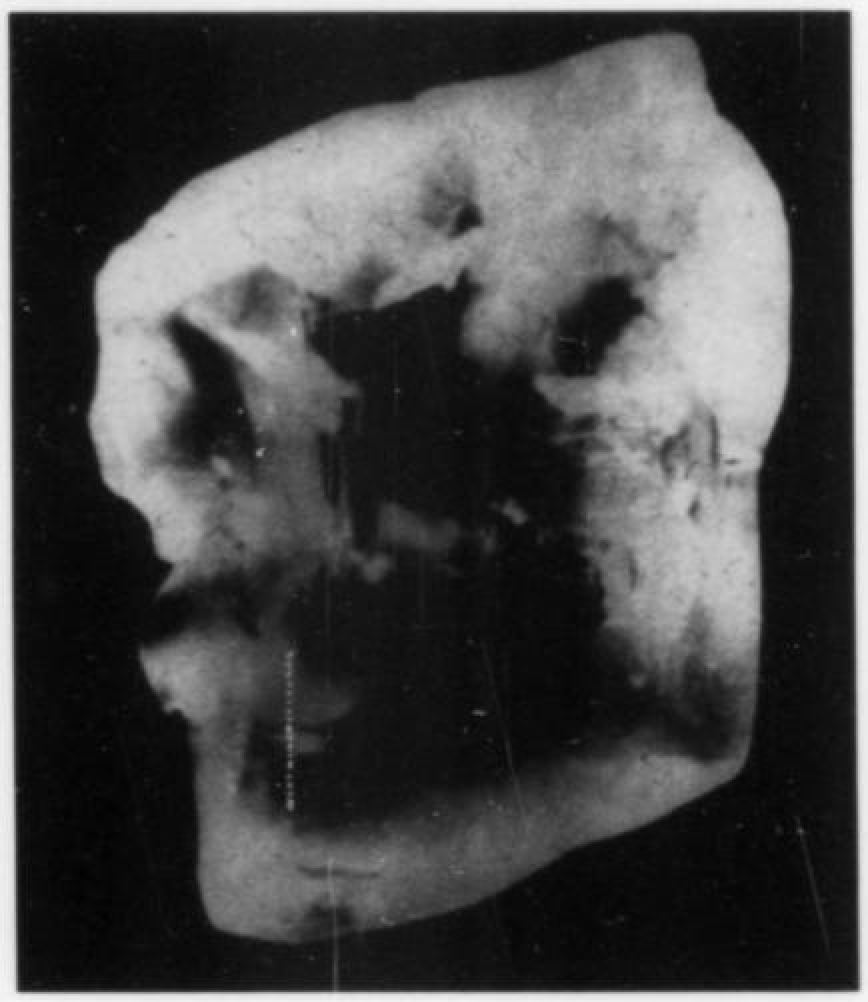


Figure 6. (above) **Typical Arkansas diamond crystal, 2 mm long (9 points). A. L. Kidwell specimen. Dan Behnke photo.**

Figure 7. (left) **Yellow Arkansas diamond crystal in Smithsonian collection (17.86 carats). Smithsonian photo.**

Figure 8. (below) **The Uncle Sam diamond before cutting (40.23 carats). Photo from Crater of Diamonds State Park.**



DIAMONDS

The nature of the diamonds found is well summarized in the following account by Austin Millar in Miser and Purdue (1929).

> From a careful examination of several thousand diamonds, the percentages of yield of the various grades of the mine run are: white stones, 40; yellow, 22; brown, 37; true bort, 1. The gem material of the yellow, the deep canary, is most magnificent, and the mahogany shade of the brown is equally desirable. The white gem material is matchless for purity, and about 10% of the stones classed as white are of this grade.
>
> Their crystallographic characteristics are distinct. As the large proportion of the recoveries belong to the more complex forms of the isometric system, the trisoctahedron and hexoctahedron predominate more than the octahedron or dodecahedron. Rarely are crystals recovered that present sharp angular faces, the characteristic rounded (convexed) surfaces predominating. The true bort is translucent with a radial structure and occurs in rounded forms. Stones have been found with a blue or pink tinge and occasionally a "frosted" or etched white is noticeable in the recoveries.
>
> Fragments and fractures were much more noticeable when mining was being done in surface material; but at slight depth in the undisturbed volcanic ground these features were almost entirely absent.

The above description, based upon the examination of thousands of crystals is difficult to improve upon. No cubes have been reported and simple octahedrons are rare. The actual crystal faces are generally somewhat curved, giving the crystal the appearance of a partially flattened tablet or elongate forms that superficially resemble an almond or a grain of rice.

Crystals may also be in the form of relatively thin triangular twins (macles). The crystal surfaces have the typical adamantine luster grading into a frosty or greasy appearance. It is common to see microscopic triangular growth structures on crystal faces. Black diamonds and bort are extremely rare.

In the years from 1972 through 1988, 12,958 diamonds were found by visitors and certified at the Crater of Diamonds State Park (James Cannon, personal communication). Of these, 60% were classified as white, 21% brown, 17% yellow, and 2% other colors. About 10% of these were considered to be of fine gem quality, based on size, color and clarity.

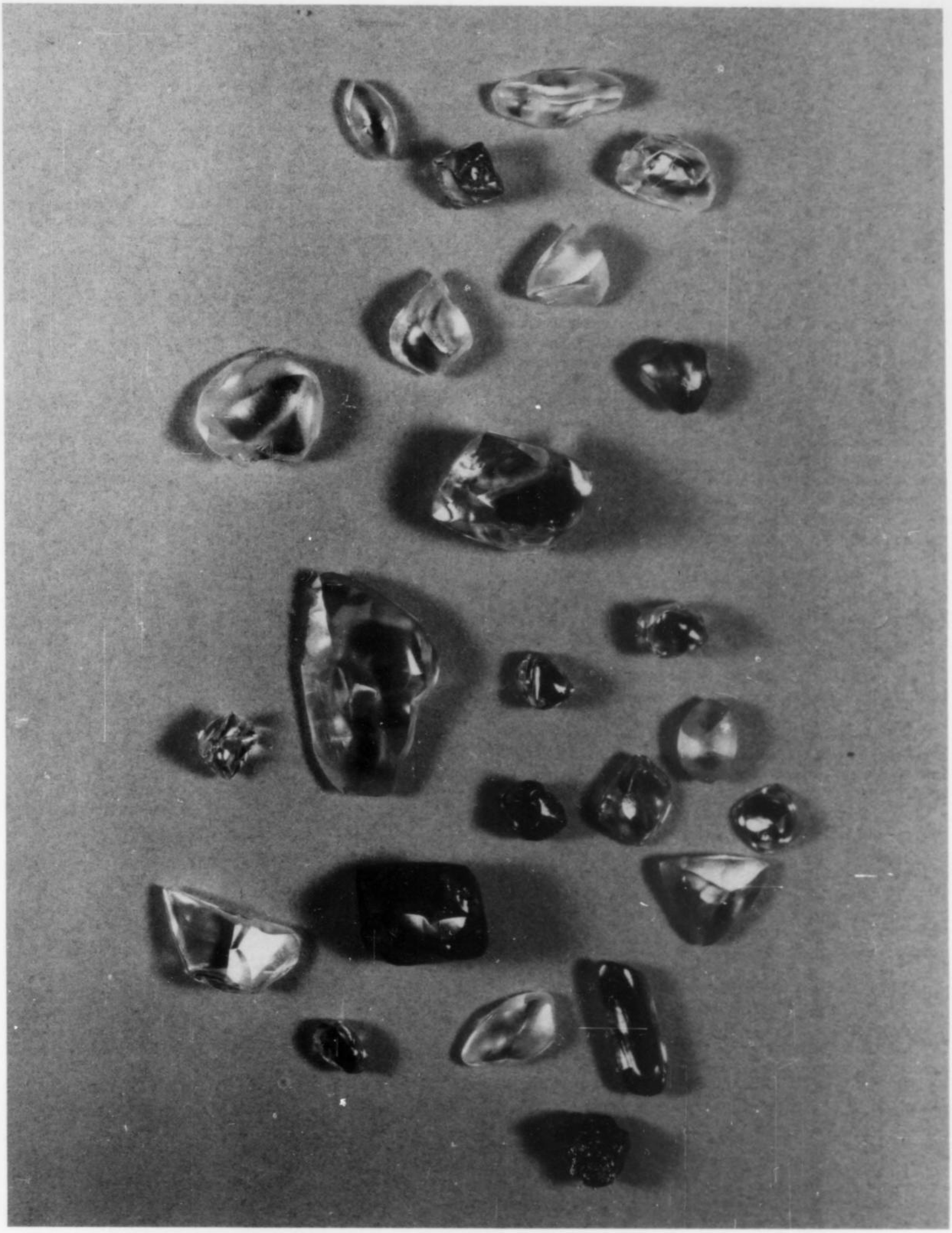


Figure 9. **Arkansas diamond crystals in the Smithsonian collection, ranging up to 17.86 carats for the octahedron (ninth from the top). This is the yellow stone pictured in Fig. 7. Smithsonian photo.**

Figure 10. **The Uncle Sam diamond after cutting (12.42 carats). Photo from Crater of Diamonds State Park.**

Some very detailed analyses of Arkansas diamonds have been reported by Giardini and Melton (1975) on gaseous inclusions in seven Arkansas diamonds. The work was done by crushing the diamonds in a high vacuum and passing the gas released through a mass spectrometer. The actual gases, in order of decreasing abundance, were water, hydrogen, nitrogen, carbon dioxide, methyl and ethyl alcohol, and argon. Two of the crystals crushed for gas content also contained internal cloudy regions which examination under a scanning electron microscope showed to be due to a multitude of very tiny angular cavities containing no extraneous mineral matter. Presumably the gases noted above had been trapped in these cavities.

The diamonds reported found since 1906 range in weight from the 40.23-carat Uncle Sam down to less than one point. Of the diamonds registered since 1972, 18 have weighed from 5 to 17.1 carats, and 443 have weighed one carat or more.

All the Arkansas diamonds of record weighing 5 carats or more are listed in Table 1. Many of the larger ones were given names, i.e., Uncle Sam, Star of Murfreesboro, and Amarillo Starlight. However, the majority of the stones were not named, and for these the name of the finder is indicated. Three of the earlier stones are part of the Roebling collection which is now in the Smithsonian Institution. Several of the larger diamonds are known to have been cut, including the Uncle Sam, Star of Arkansas and Amarillo Starlight.

The Uncle Sam was found in a sluice box by three miners in 1924 and was cut down from an original 40.23 to 12.42 carats. It is owned by Peiken of Fifth Avenue, New York, and was on display at the American Museum of Natural History for several years.

The Star of Arkansas, perhaps the most famous Arkansas diamond, was found at the original Crater of Diamonds in 1956 by a Dallas housewife, Mrs. A. L. Parker. The discovery and subsequent cutting of the stone from 15.33 carats to a magnificent 8.27 carat marquise were highly publicized. Several years later the stone reportedly disappeared under mysterious circumstances (J. Cannon, 1987, personal communication).

Perhaps the most beautiful of the large Arkansas diamonds, which fortunately was not cut, is the 17.86-carat flawless yellow stone found in 1917 by a watchman. The specimen is now part of the Roebling collection at the Smithsonian.

Another highly publicized stone is the Gary Moore diamond, a 6.42-carat flawless yellow stone found in 1960 by Neils Bach. Bach was a newly returned serviceman who happened to watch on TV the appearance of Howard Millar on Gary Moore's program, "I've Got a Secret." Millar's "secret" was that he owned the only active diamond mine in the U.S. Bach vowed to visit the mine, which he did soon thereafter and found the diamond which he named the Gary Moore.

The most amazing story concerns the Cotton Belt Star, an 11.92-carat white cleavage fragment found in 1963 in the mouth of 14-month-old Mary Rogers by her father, who had put her on a blanket while he looked for diamonds and suddenly noticed that she had put something in her mouth. This was the largest of 24 diamonds found by the family in four years of hunting.

One other diamond discovery in Arkansas should be mentioned, although it has no known relation to the Murfreesboro deposits. This 27.31-carat perfect hexoctahedral crystal was picked up in a field near Searcy, Arkansas, located about 80 km northeast of Little Rock and at least 200 km northeast of Murfreesboro. The discovery was made by Mrs. Pellie Howell about 1925, and the crystal is now owned by Tiffany and Company, New York (Sinkankas, 1959). One of several theories is that it was picked up at Murfreesboro by an Indian and dropped at Searcy.

Table 1. **Large Arkansas diamonds of record.**

Name of stone (or finder)	Year	Weight (ct)	Color
Uncle Sam	1924	40.25	White
Star of Murfreesboro			Industrial
(John L. Pollock)	1964	34.25	(Bluish)
Smithsonian Collection	1917	17.86	Yellow
Amarillo Starlight			
(W. V. Johnson)	1975	16.37	White
Star of Arkansas			
(Mrs. A. L. Parker)	1956	15.33	White
Chief of Carlisle			
(Jim Beggs)	1966	13.50	White
Smithsonian Collection	?	12.86	Brown
Cotton Belt Star			
(Mary Rogers)	1963	11.92	Brown
Phillips 66			
(Jack Floyd)	1963	11.23	?
Smithsonian Collection	?	11.21	White
(Fred Woods)	1963	10.40	?
(C. O. Basham)	1964	10.38	?
(C. Blankenship)	1981	8.82	White
(Walter Blunk)	?	8.71	White
(B. Lamie)	1978	8.61	Brown
(Connell Bros.)	1986	7.95	White
(Mrs. Marge Chrisman)	1956	7.00	Yellow
Smithsonian Collection	?	6.83	White
(T. Dunn)	1975	6.75	Brown
Smithsonian Collection	?	6.57	Yellow
Gary Moore (Neils Bach)	1960	6.42	Yellow
(Mrs. Lloyd Turner)	?	6.36	White
(S. Lee)	1980	6.30	White
(C. Newman)	1981	6.25	White
(W. Stockton)	1983	6.20	White
(R. Schall)	1981	6.07	White
(Mrs. Bill Smith)	?	6.00	White
(M. Griffin)	1981	5.90	Brown
(L. C. Hawkins)	1978	5.76	White
(G. Snearly)	1983	5.63	White
(J. Palermo)	1984	5.58	Brown
(T. Moore)	1986	5.19	White
(S. Barkley)	1980	5.15	White
(J. Williamson)	1979	5.05	Brown
(Mrs. Irene Beggs)	1964	5.02	Yellow
(J. Macy)	1978	5.00	Yellow
(D. Mayes)	1979	5.00	White

ASSOCIATED MINERALS

Minerals other than diamonds concentrated during diamond recovery were reported by Miser and Purdue (1929) as follows: hematite, limonite, barite, colorless and amethystine quartz, magnetite, pyrope, almandine, schorlomite, chromite, pyrite, diopside, and epidote. Calcite, kaolinite and hyalite opal also occur as veins or incrustations

Figure 11. **Diamond hunter at work near location where Uncle Sam diamond was found.**

Table 2. **Crater of Diamonds statistics, 1972–1988.***

Year	Visitors	Diamonds (Total)	Diamonds (> 1 Ct.)	Diamonds (> 5 Ct.)	Carats (Total)	Year	Average Wt. (carats)	Visitors per diamond	Visitors per one-ct. stone	Visitors per carat
1972	34,644	135	12	0	55.64	1972	.41	256	2888	625
1973	35,699	151	19	0	71.20	1973	.47	236	1877	501
1974	54,336	241	21	0	90.92	1974	.38	225	2587	598
1975	96,452	663	34	2	88.05	1975	.13	145	2836	1095
1976	93,870	395	18	0	98.95	1976	.25	237	5215	949
1977	91,849	366	41	0	141.06	1977	.38	250	2240	651
1978	119,844	611	40	3	232.30	1978	.38	196	2996	516
1979	93,793	402	24	2	149.87	1979	.37	233	3908	626
1980	80,303	579	26	0	190.97	1980	.33	138	3088	420
1981	97,490	1,324	26	4	238.58	1981	.18	74	2749	409
1982	71,413	1,383	37	0	264.38	1982	.19	52	1930	270
1983	82,271	1,501	44	2	312.57	1983	.20	55	1869	263
1984	75,838	1,339	18	1	202.26	1984	.15	57	4213	375
1985	65,112	699	24	0	148.54	1985	.21	93	2713	438
1986	73,447	930	23	2	154.21	1986	.17	79	3193	476
1987	71,107	959	20	0	160.38	1987	.17	74	3555	443
1988	75,491	1,280	17	1	184.14	1988	.14	59	4441	408
Total	1,312,979	12,958	443	17	2784.82	Average	.27	145	3135	533

*Based on information provided by the staff of Crater of Diamonds State Park, 1988.

associated with the lamproite and breccia. White barite grains are a common constituent of the heavy concentrates produced during panning operations.

Amethystine quartz is the only one of the above-mentioned minerals which has been found in fine specimens at the locality; it occurs in crystal-lined cavities within the breccia unit. Stories are told of veins of massive amethyst and crystal-lined cavities up to 15 meters across which were encountered during the mining operations. Small pockets are occasionally still found after deep plowing, but none of the spectacular crystals have been found since the end of commercial mining.

Various types of agates, jasper and colored novaculite can also be collected from stream gravels and patches of conglomerate on the property.

Figure 12. **Entrance to digging area.**

PRESENT OPERATIONS

The Crater of Diamonds State Park is operated in a very efficient and businesslike manner by the Arkansas Department of Parks and Tourism. The principal difference between this park and most other state and federal parks is that here visitors must pay a $3.00 per day fee and are encouraged to find something of value to take away with them.

Rules for collecting are very simple and considerate, in that any tools or methods of concentration can be used as long as they do not incorporate wheels or motors. There are also common-sense safety regulations concerning the digging of excessively large or deep holes and tunnelling into unconsolidated material.

The surface within the diamond-producing area of the park is plowed occasionally to expose new material in the form of long parallel rows. (This might be described as "cultivating" the diamond crop.)

Statistics regarding numbers of visitors, diamonds found, and sizes of the stones found from the time the property became a state park through 1988 are summarized in Table 2. The park staff keep records on each diamond reported. They feel that most diamonds are reported, because there is no extra charge for diamonds found, and a certificate is issued with each diamond. This certificate constitutes proof that the stone was really found here. This is important when buying stones from local people and shops, because there have been instances of less expensive South African industrial diamonds having been sold as Arkansas stones.

The number of diamonds found each year has held up remarkably since 1972, despite the fact that there have been 1,390,000 paid visitors through 1989. The ratio of number of visitors to diamonds found changed dramatically between 1979 and 1982, from one stone per 235 visitors to one stone per 74 visitors. According to Park Superintendent James Cannon, this change in productivity coincided with the introduction of the Saruca technique for washing the coarse concentrate and also the increase in numbers of "professional" miners. Thus, the number of stones found by casual visitors has probably not increased.

The Saruca (introduced from South America) is a durable circular screen attached to a sturdy plastic or metal ring about 30–40 cm in diameter in such a manner that the screen is bowed down as much as 2 cm in the center. It is used in much the same manner as a gold pan to work the heavier material to the center of the screen. When the screen and its load are flipped over onto a level surface, the diamonds and other heavy minerals, such as barite, will be in the center of the pile, if everything has been done properly. Using this technique, the processing is quicker and fewer stones are overlooked, especially the smaller ones, then by previously used methods. Since about 1980 the area underlain by the old tailings material has also been extensively reworked. Many smaller stones which were not recovered in the earlier operations have been found by careful working of the old tailings.

An estimated 75% of the diamonds are presently being found by diggers referred to as professional miners. These people spend relatively large amounts of time at the property and dig extensive holes, particularly in the southern part of the area where most of the tailings were dumped and also where the natural drainage has cut channels through the alluvial material. Several of the professionals are known to have found more than 100 diamonds each. Estimated recovery for one of the presently active miners who "stopped counting" is more than 4000 stones.

Over the years the professional miners have developed their own techniques by trial and error for locating favorable areas to dig and for processing the loose material for diamonds. These are explained in great detail in a brochure entitled *Visitors Guide to Crater of Diamonds State Park,* which can be purchased at the gift shop and is a good investment.

TOTAL PRODUCTION

One of the first questions asked about the diamond deposit is how many diamonds have been produced here since the discovery in 1906. It should be obvious that no exact answer can be given. Only partial records are available for the output of stones from the various mining ventures.

The greatest unknown is how many stones were highgraded from

***Figure 13.* Mine shack built over old shaft (now filled).**

the mining operations and how many have been picked up illegally by local people. It is rumored that during the depression years many of the local people dug and sold diamonds to survive.

Miser and Purdue (1929) state that the production known to them was at least 10,000 diamonds up to the end of 1923. As already noted in this paper, 12,958 diamonds were picked up at the Crater of Diamonds from 1972 through 1988, and 1,400 were found in 1989.

One diamond-cutting firm in New York, Schenck & Van Haelen, handled approximately 100,000 Arkansas diamonds (Millar, 1976). Howard Millar (1976) estimates that approximately 400,000 diamonds have been recovered by legitimate and other means. Since Millar was a technically trained geologist and engineer and was associated with the deposit until his retirement in 1969, his estimate is probably in the right order of magnitude.

ACKNOWLEDGMENTS

Several people and organizations have been extremely helpful in providing information, illustrative material and advice for this paper. James Cannon and his staff at Crater of Diamonds State Park gave complete cooperation, including copies of 35 mm slides from their photo library. Both the Arkansas Geological Commission and the Arkansas History Commission provided access to little-known information and photographs. John S. White and staff at the Smithsonian Institution furnished valuable information and slides concerning their collection of Arkansas diamonds. Dan Behnke of Northbrook, Illinois, took the photomicrograph of the author's diamond crystal and produced black and white prints from slides which were the only photographic sources available. Literature and editing assistance from Dr. Henry S. Barwood, Henry E. deLinde, J. Michael Howard and Arthur E. Smith are also gratefully acknowledged.

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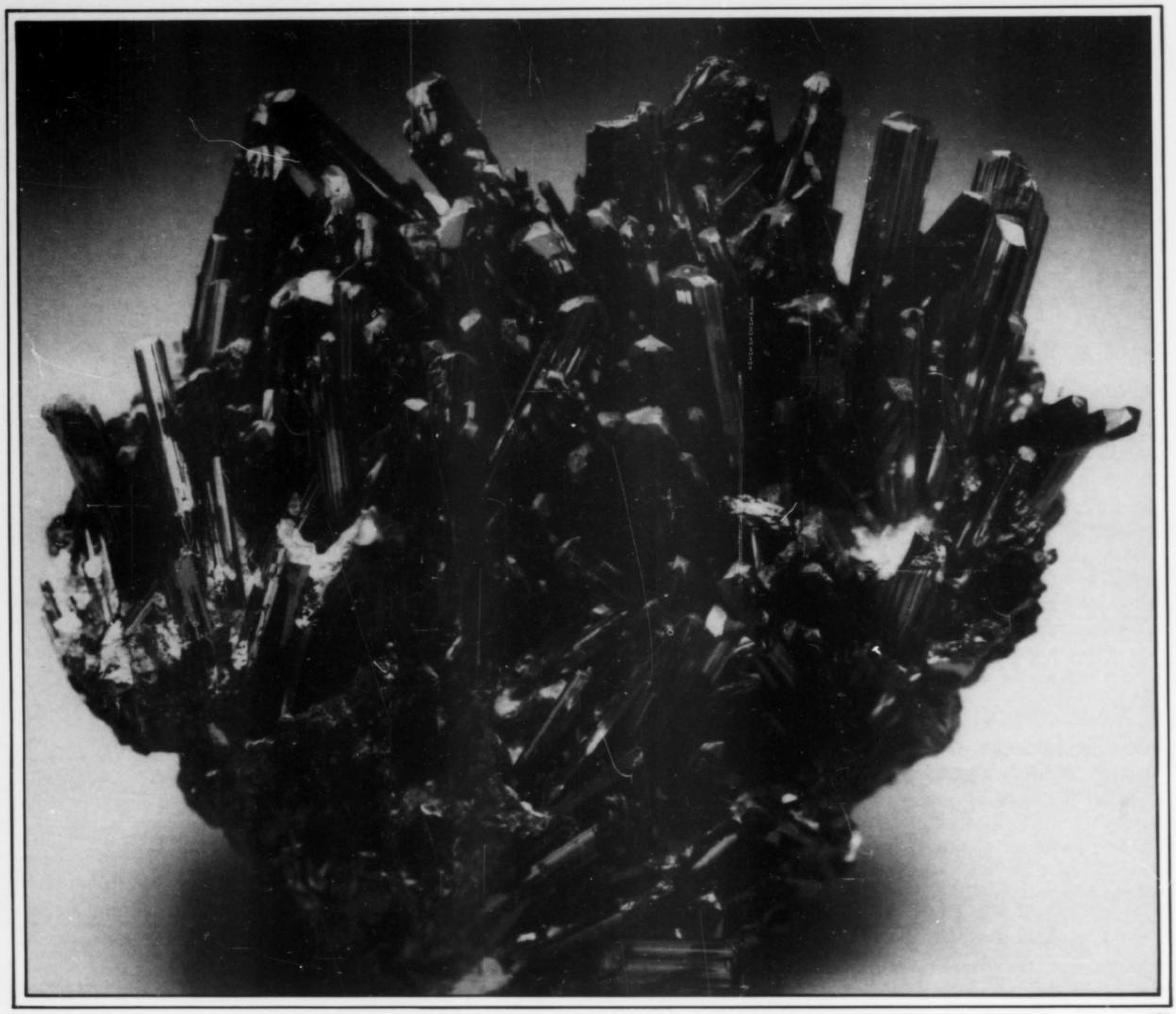

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The Argyle AK1 mine is currently the largest producer of diamonds in the world. The great significance of the gems from this locality is the range and quantity of colored stones, notably brown "cognac," yellow "champagne," apricot, occasionally green or blue, and rarely, the highly desirable pinks.

INTRODUCTION

During 1987 just over 30 million carats of diamond were recovered from the Argyle AK1 mine: this represents a third of the total world's diamond production. For comparison, Argyle produces six times that of the Finsch mine, South Africa's highest yielding diamond mine. Although the deposit has a very high ore grade of 6.8 carats of diamond per metric ton of ore, only 5% of the Argyle diamonds are of gem quality.

The Argyle open pit mine (Fig. 1) is located in the northeastern part of the state of Western Australia (Fig. 2). The nearest town, Kununurra, 200 kilometers to the north, is accessible by road in the dry season, from March until November, but during the monsoons, airplane remains the only reliable form of transport. The only possibility for tourists to visit the mine is through a tour company which has been granted access to the mine site.

HISTORY

Alexander Forrest, a surveyor and explorer, was the first white man to venture into the northern part of Western Australia. For perhaps as long as 50,000 years this had been the domain of nomadic Aborigines who traversed the region in search of food and water. Following Forrest's explorations in 1879, the Governor, Sir William Robinson, sent copies of his report on the area to the Earl of Kimberley, British Secretary of State for the Colonies. He proposed that the region be known as Kimberley, and this was approved by the Earl on August 26, 1880. It is interesting to note that a few years prior to this (on June 5, 1873) the same name, Kimberley, honoring the same individual, was proclaimed to be the new name of what had previously been known as De Beers New Rush, the Colesberg Kopje No. 2, or Vooruitzigt. This, of course, was the site of the great Kimberley diamond mine in South Africa, but it would be another 100 years before a commercial deposit of diamonds was found in Kimberley, Australia.

Forrest's enthusiastic reports on the area encouraged sheep farmers and cattlemen to move into the region. Today there are a few enormous ranches or "stations" but the magnificent plains (Fig. 5) and rough ranges of exposed rock are still largely uninhabited and difficult to reach.

The first geologist to visit the area was Edward T. Hardman, whose sketches and rock descriptions provide the earliest records of Kimberley. Hardman (1884) traveled up the Fitzroy River, visiting several of the lamproite intrusions, which he mistook as ironstone. He described the ultrabasic plug, Machell's Pyramid, as "a curious pyramidal mass of reddish sandstone, rising rather abruptly from the surrounding plain."

The exciting discovery of diamonds in the Kimberley region is relatively recent. Although gold prospectors found the first diamonds in Western Australia in 1905 at Nullagine (Groom, 1896), no systematic exploration for alluvial diamonds, or their source rock, took place until 1965. Nullagine is in an area known as the Pilbara Block, where sufficiently rich deposits of diamonds have yet to be found. Reconnaissance here was discontinued in 1967 and started in the West Kimberley area some 800 km northeast. Here, basic and ultrabasic intrusions had been recognized as early as 1920 by Farquharson (1920).

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Figure 1. **The Argyle (AK1) diamond mine, Kimberley district, Western Australia. Photograph taken looking north, with the main hill being East Ridge. (Photo: Brian Stevenson)**

Much more detailed work on the intrusions was presented by Wade and Prider (1940) following extensive regional oil exploration.

The early search by several companies southwest of the Kimberley basin in both the Ellendale and Noonkanbah areas yielded no diamonds and very little indication of kimberlite's heavy minerals (pyrope, ilmenite, chromite). It was not until Kalumburu Joint Venture (later to be renamed Ashton Joint Venture) carried out an extensive sampling program beginning in 1972, that diamonds were found. In 1976 CRA Exploration became the major shareholder in the Ashton Joint Venture, and during 1978 they announced their finds of diamonds and kimberlite-like material. This initiated a rush to stake mineral claims, primarily in the West Kimberley Province.

During the late 1970's, although most attention was directed to the West Kimberley, the Ashton Joint Venture continued stream gravel sampling in the East Kimberley, east of the Great Northern Highway. This road had been designated as an arbitrary boundary since 1972 when budget constraints prevented exploration to the east. On August 28, 1979, the mineral processing laboratory for the Ashton Joint Venture in Perth recovered diamonds from the Smoke Creek samples. A frenzy of follow-up sampling indicated that the upper Smoke Creek was a viable alluvial diamond deposit. Furthermore, the diamonds formed a clear trail for 20 km upstream to the source, and on October 2, 1979 the Argyle (AK1) pipe was discovered. In the following year the Limestone Creek alluvial deposit was found. This creek drained the southern side of the Argyle pipe area and flowed northeast towards Lake Argyle. The Bow River project, a joint venture between Freeport-McMoran and Gem Exploration and Minerals, commenced commer-

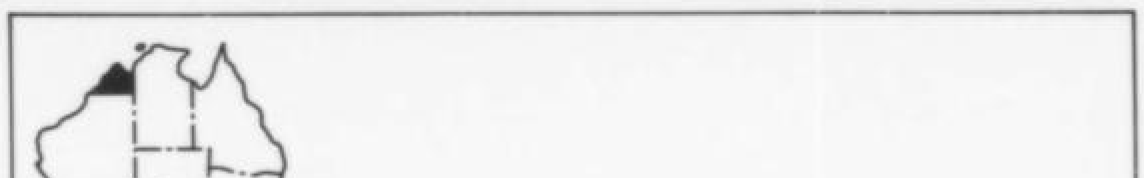


Figure 2. **Map of the Kimberley region showing the two main geological provinces and the location of lamproite and kimberlite provinces.**

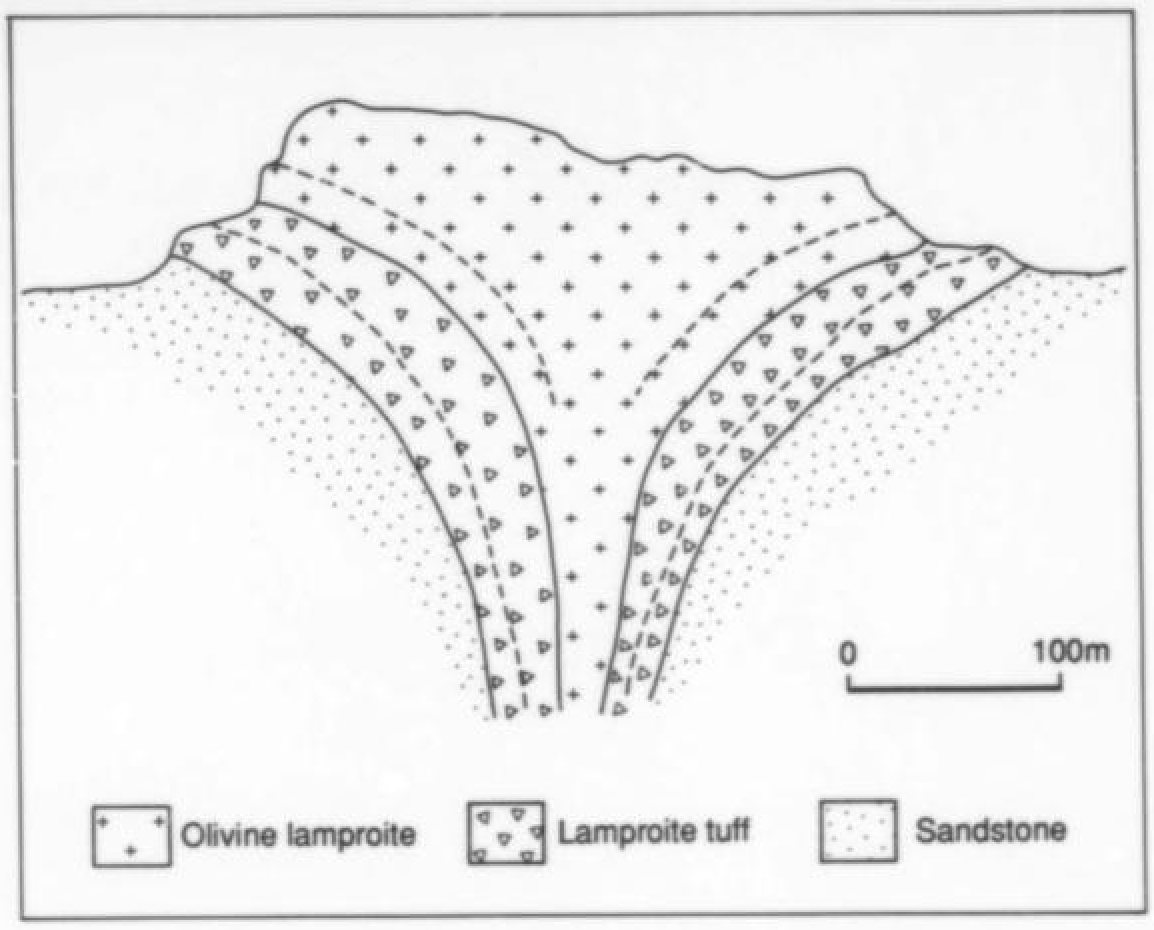
***Figure 3.* Argyle gem-quality diamonds. The largest stone is a pink crystal weighing 6.5 carats. (Photo: Brian Stevenson)**

cial production in 1988 from the diamond-bearing alluvia in the lower reaches of Limestone Creek, some 25 km from the AKI pipe area.

GEOLOGY AND PARAGENESIS

The Kimberley region has two main geological elements (Fig. 2). The central Kimberley Basin consists of a flat-lying sequence of sedimentary and volcanic rocks which were laid down approximately 1,900 to 1,650 million years ago. The Basin is flanked on the east and southwest by older metamorphic and volcanic rocks known as the Halls Creek Province. Within this large area (240,000 square kilometers) there are three provinces containing diamond-bearing intrusive rocks: West Kimberley, North Kimberley and East Kimberley (Fig. 2). At present, East Kimberley contains the only economic diamond deposits. The intrusions are concentrated along major fault

***Figure 4*. The Mount North lamproite intrusion lies in the Ellendale Field. *(above)* The plug, viewed to the north, rises 90 meters above the savannah plain. Not all lamproite intrusions are this prominent in the Kimberley area. *(right)* If seen in cross-section it forms a layered, deep-seated pipe (after Jaques *et al.*, 1986).**



zones. The ages of emplacement of the pipes and dikes vary considerably from 20 to 1,150 million years ago (Jaques *et al.*, 1986).

Until the discovery of the Australian deposits in situ, diamonds everywhere else in the world had always been found associated with kimberlite rocks (as in South Africa, Soviet Union, Brazil, Zaire and Botswana). Kimberlite is an igneous rock originating deep in the mantle (approximately 150 km below the earth's surface); it occurs as small volcanic pipes (Fig. 4), dikes and sills. Common mineral constituents include olivine, phlogopite, calcite, pyrite, diopside, enstatite, ilmenite, spinel, serpentine, monticellite, apatite and perovskite. Kimberlite may contain diamond, but only as a very rare accessory mineral. In the field, weathered kimberlite has a characteristic pale yellow coloration ("yellow ground") and crumbly texture.

The extraordinary aspect of the Australian discovery was the association of diamonds with a different rock type, lamproite. This rock also comes from deep in the mantle, but the bulk chemistry is distinctly different from that of a kimberlite: it is richer in silicon, titanium, potassium and phosphorus, and poorer in aluminum, iron, calcium and carbon. Mineralogical differences are evident in that lamproites commonly contain leucite, richterite, sanidine and sometimes nepheline, priderite and wadeite, whereas kimberlites do not. The lamproites occur as pipes, similar to those of a kimberlite, and have formed by interaction with the groundwater as intrusive material approached the surface. These lamproite pipes, or diatremes, appear to have formed in a similar fashion to the basaltic diatremes and maars of the West Eifel, Germany, and basaltic diatremes elsewhere in the world (Boxer *et al.*, 1989). The discovery of diamonds in lamproites in Kimberley, Western Australia, has prompted a revision of diamond exploration around the world.

MINERALOGY

The recognition of lamproite and kimberlite rocks and their potential as diamond producers requires careful, detailed mineralogical study. Although there is not a large number of actual mineral species in these rock types, their identification is hampered by small grain size and extensive alteration. Jacques *et al.* (1986) give detailed petrographic descriptions, with chemical analyses, for each mineral in the various intrusions within the Kimberley region. Here the authors give only brief descriptions of the minerals that can be observed in hand specimens.

The lamproite rocks have a characteristic gray to green-gray mottled appearance. The matrix generally consists of a very fine-grained pale-colored alteration product after lamproite ash. Within this matrix, typical minerals around a millimeter in size which might be visible include the following: **forsterite** occurs as rounded grains, usually altered to a soft, pale green-brown aggregate; **phlogopite** is fresh, hence more easily recognized as dark red-brown masses, often with a golden shiller on the cleavage; pale green, glassy **diopside** does not alter, so it shouldn't be confused with forsterite; **richterite** (titanian potassic richterite) occurs as red-brown grains to larger cleavable plates; **chromite** and **pyrope** are not visible in hand specimens.

A few of the rarer minerals, which are actually visible in the coarser grained lamproites of the Walgidee Hills intrusion in the Noonkanbah Field, are worth mentioning here because this is the type locality. Birch (1985) gives an overall description of these minerals, with new chemical data. **Priderite,** first described by Norrish (1951) as $(K,Ba)_{1.33}(Ti,Fe^{+3})_8O_{16}$, occurs as brown-black prisms up to a few millimeters in length with a prominent cleavage. The crystals resemble rutile. It is widespread in the lamproites of Kimberley, and is associated with the much rarer **jeppeite** (Pryce *et al.*, 1984), which is similar in chemistry, $(K,Ba)_2(Ti,Fe^{+3})_6O_{13}$, and appearance. Jeppeite resembles schorl, with black, striated prisms, commonly in radial habit. In contrast, **wadeite** (Prider, 1939), $Zr_2K_4Si_6O_{18}$, is quite distinct from the above two minerals. It resembles clear, colorless, fractured quartz, sometimes having a roughly rectangular habit. These new titanium-bearing minerals are often associated with other titanium minerals (including titanite, perovskite, ilmenite and rutile).

Figure 5. **Baobab trees and spinifex grass can survive on the hot, dry plains of the Noonkanbah Field.**

Diamonds

The discovery of diamonds in lamproite rocks was so revolutionary that researchers were anxious to know whether there would be differences between the Australian diamonds and those found in other parts of the world in kimberlites. From the observations given by Hall and Smith (1984), they concluded that there are no differences between diamonds of these two rock types, based on statistical studies of crystal size, distribution, morphology, colors, inclusions and surface characteristics.

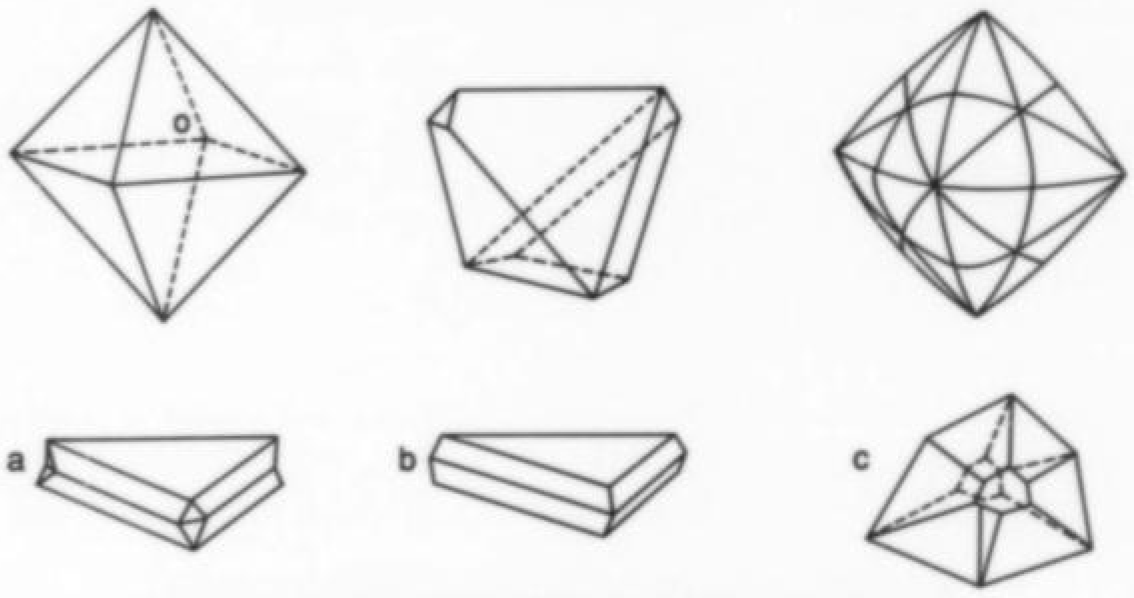


Figure 6. **Triangular diamond twins or macles. In each case the individuals are related by reflection across the (111) plane. (a) Octahedron and twin. (b) Tetrahedron showing the derivation of the macle. (c) Hexoctahedron and twin.**

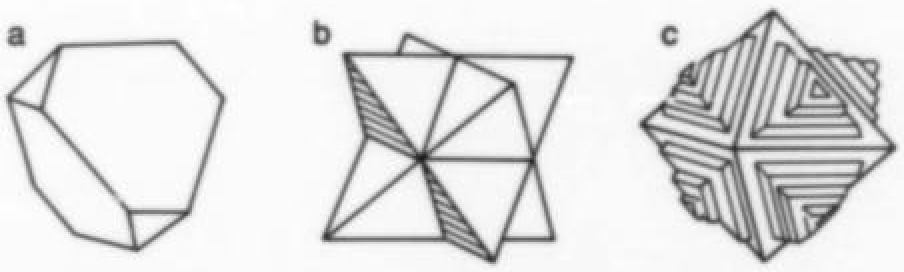


Figure 7. **Twinning of tetrahedra about [001] resulting in a pseudo-octahedron with stepped, triangular plates on {111}. (a) A positive and negative tetrahedron. (b) A twinned positive tetrahedron. (c) Twinned positive and negative tetrahedra.**

The statistics quoted in the following descriptions are from Hall and Smith (1984), who were able to collect data on diamonds from the Argyle mine and Ellendale Field (West Kimberley Province).

In general, the diamonds are not large, averaging 0.1 carat per crystal, with the largest weighing 16.35 ct. Crystals are strongly modified by dissolution, having become rounded with luster ranging from shiny to frosted to deeply etched. In the Argyle pipe only 5% of the crystals are gem quality, but diamonds from the nearby alluvials are approximately 10% gem. In contrast, Ellendale grades are much lower but the proportion of gem-quality stones ranges from 60 to 90%.

A subhedral, rounded habit is most common for Argyle diamonds (Fig. 8b). Complex aggregates composed of several intergrown and/or twinned individuals (Fig. 8a) are also common. Considering only anhedral crystals, the dodecahedron (Fig. 8b) predominates over the octahedron (Figs. 8c, e, f). The cube form was not observed, but tetrahedrons and hexoctahedrons are evident in twinned crystals.

Twinning in Argyle diamonds is common, and it is likely that most crystals are twinned. There are excellent examples of flattened triangular twins (Fig. 8d), or *macles,* as they are often called. Figure 6 shows sketches of the three twin types for Argyle diamonds:

(a) The Spinel Law with twin plane (111), twin axis [111]; a contact twin with reentrant angles, each of the two individuals being a flattened octahedron;

(b) A contact twin with twin plane (111) and twin axis [111] but with no reentrant angle; each of the two individuals consists of a tetrahedron but shortened along the [111] axis;

(c) A contact twin, Spinel Law, with each individual consisting only of hexoctahedral faces. Twins of type (b), above, are evidence of diamonds with lower symmetry class $\bar{4}3m$.

In the early, comprehensive work of Fersmann and Goldschmidt (1911), several examples of tetrahedral diamond crystals were drawn. The subsequent determination of the crystal structure of diamond in the higher symmetry space group $F4^1/d\bar{3}2/m$ in the hexoctahedral crystal class $4/m\bar{3}2/m$ seems to preempt the possibility of tetrahedrons. Yet twinned crystals of the type shown in Figure 6b are best described as tetrahedral. Similarly, "octahedra" with stacked plates are most likely pseudo-octahedrons consisting of tetrahedrons twinned about [001] with twin plane (001) (Fig. 7). Another indication of such "twinning" is striations along "octahedral" edges (Fig. 7c). A possible explanation of the lower tetrahedral symmetry would be a polymorph (perhaps metastable) of carbon with $\bar{4}3m$ symmetry. This might be attained if the structure consisted of the two carbon ions C^{+4} and C^{-4}. If they were arranged like Zn and S in sphalerite, the structure would have $\bar{4}3m$ symmetry (Orlov, 1977). A hexagonal polymorph, lonsdaleite, resembling diamond in many of its physical properties, has been discovered in meteorites and impactites.

The crystal surfaces of Ellendale diamonds are usually shiny, while Argyle stones are typically heavily frosted and many have hexagonal etch pits in the octahedral faces (Fig. 8c) or etch channels. The resorption (Fig. 8e) and etching of diamonds has been attributed to their reaction with the silicate melt which oxidizes the surface to CO_2 (Orlov, 1977).

Another interesting feature of Argyle diamonds is their variation in color (Fig. 3). Approximately 80% of the stones are brown, with most of the rest yellow. A few percent are colorless and very rarely a green or pink crystal is found. About 75% of the stones have dark inclusions, and larger stones commonly have a steel-gray color (bort).

It will be evident from the above description of Western Australian diamonds that their crystal growth has been fraught with complexity, giving rise to aggregate, twinned and resorbed crystals. This, no doubt, has led to defects in the crystal structure which give rise to color centers and consequently a high proportion of colored stones. It is the fancy pinks, first described by Hofer (1985), that excite the gem market, and some truly superb jewelry pieces have been manufactured using these stones. Also, there are attractive settings being produced for the other colors, brown and yellow, which are affordable on a much wider scale.

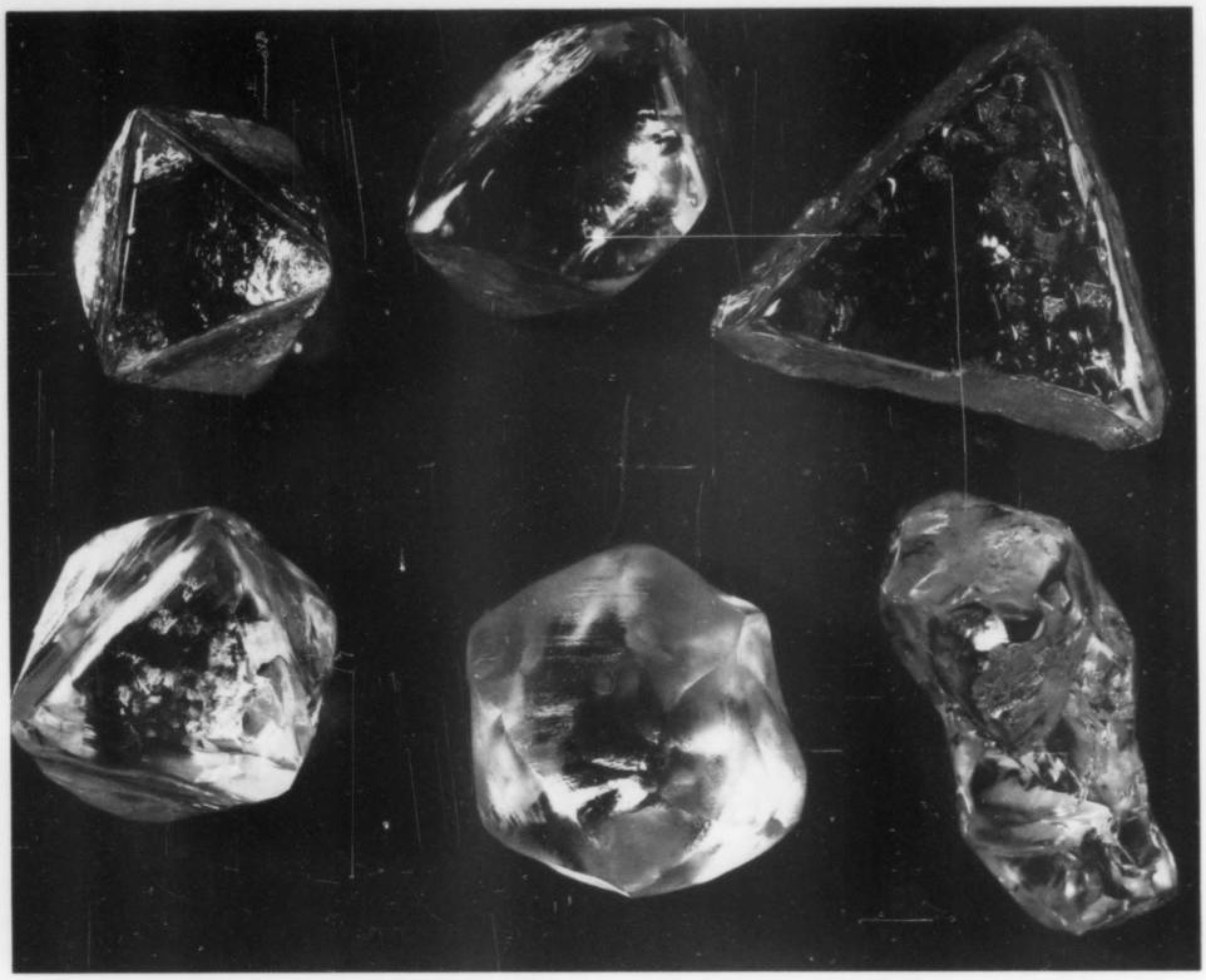


Figure 8. **Argyle diamonds. Left to right, top then bottom row: (a) Sharp octahedron. (b) Distorted octahedron showing the surface effects of resorption. (c) Twinned crystal or macle. (d) Octahedron with hexagonal-shaped etch pits and striated edges. (e) Rounded, dodecahedral habit with frosted faces. (f) Complex, aggregate crystal. Each crystal is approximately 1 cm in size. (Photo: Brian Stevenson)**

ACKNOWLEDGMENTS

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A BRIEF LOOK AT THE SAXON ERZGEBIRGE

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Photography by **Juergen Karpinski**

Silver mining in the Erzgebirge ("Ore Mountains") can be traced back as far as 1168. During more than eight centuries of mining a great number of minerals, both rare and common, have been collected there. Apart from silver ore, the ores of tin and iron were of great importance. Collections of ores and minerals have been in existence in Dresden since the sixteenth century in what is today known as the State Museum of Mineralogy and Geology, and since 1765 in Freiberg at the Mining Academy. These collections have become world-famous.

The Erzgebirge highlands, with a maximum height of 1243 meters and an area of approximately 4600 square kilometers, are located at the border between Germany and Czechoslovakia. The area is a classical region for the mineralogist. It is rich in mining traditions and beautiful, rare minerals, which are now found in many collections worldwide. The Saxon Erzgebirge was once also a center for the development of mining techniques and mineralogical research.

The elements indium and germanium were discovered at Freiberg, and a number of elements were named from old Saxon mining expressions: cobalt and nickel translated, mean "mine goblin," and "deceptive little spirit." Numerous other minerals were named after the places in the Erzgebirge where they were discovered. Today, after eight centuries of mining silver, tin, iron, lead, zinc, copper, cobalt, nickel, bismuth and uranium, as well as non-metallic minerals such as fluorite, barite, marble and gemstones, there is little surviving evidence of mining. The only mines of importance today are the tin mines of Altenberg and Ehrenfriedersdorf, and the fluorite mine near Oelsnitz in the Vogtland region, but production there is coming to an end.

The most common rocks of the Saxon Erzgebirge are metamorphic; these include gneiss, mica schists and phyllitic rocks. These Varistic

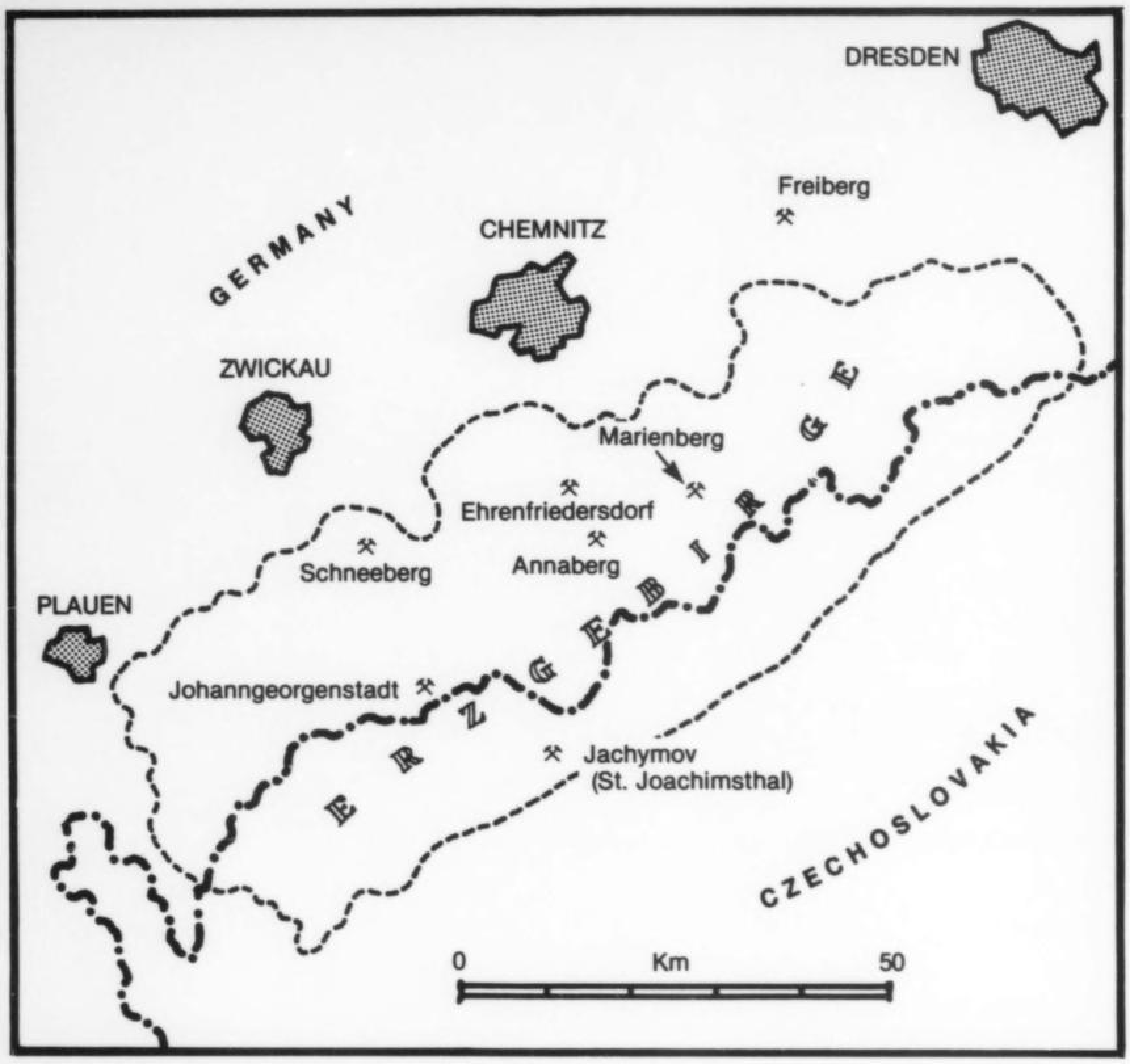

Figure 1. **Important mining districts in the Erzgebirge.**

rock complexes are interspersed with magmatic intrusions which include granites, rhyolites and basalts. Mesozoic and Cenozoic sediments are mostly eroded. The reason for this is the tectonic uplift and tilting of the Erzgebirge in Tertiary times. Through this process the crystalline rocks, ore veins, orebodies and ore layers became accessible for mining purposes. Hydrothermal, polymetallic ore veins are most widespread in the Erzgebirge. The tin orebodies belong to the pegmatitic-pneumatolytic phase in an area of higher temperatures. The Freiberg school divides (with variations) the multitude of magmatic ore deposits into formations and successions as follows:

1. Tungsten-Molybdenum formation
2. Tin-Tungsten formation
3. Quartz-Polymetal formation
    - Pyrite succession
    - Zinc-Tin-Copper succession
    - Lead succession
4. Uranium-Quartz-Carbonate formation
5. Carbonate-Polymetal formation
    - Sulfide succession
    - Silver-Antimony succession
6. Quartz-Iron-Barite formation
7. Fluorite-Barite formation
    - Barite-Quartz succession
    - Fluorite-Barite succession
    - Barite-Fluorite succession
8. Bismuth-Cobalt-Nickel-Silver-Uranium formation
    - Arsenic-Cobalt-Nickel succession
    - Silver/Sulfide succession
9. Quartz-Iron-Manganese formation

Not all formations are of equal importance. Their metal contents vary considerably, along with their regional distribution. There are differences in the depths and lengths as well as the thickness of the veins and their horizontal extensions. Nevertheless, we shall pick out of the numerous examples a few typical ore deposits containing the most important ore minerals.

The tin ore occurrences at Zinnwald, Altenberg and Geyer-Ehrenfriedersdorf (the latter two mines currently in the process of closing) are characteristic deposits of the Tin-Tungsten formation. Of these, Zinnwald represents the vein type of deposit and Altenberg the orebody type, whereas Geyer-Ehrenfriedersdorf is a mixed type. The minerals cassiterite, wolframite, molybdenite and native bismuth, along with the associated minerals topaz, apatite and tourmaline, are widespread.

The large ore district of Freiberg, especially the central part, is the best example of the mineralization of Quartz-Polymetallic formations with their successions. Important ore minerals are galena with varying silver contents, sphalerite, chalcopyrite and tetrahedrite with quartz.

Schneeberg is the main area of the Uranium-Quartz-Carbonate formation, which has only recently become known. Uraninite is here the main ore mineral, accompanied by hematite, quartz and calcite. This vein formation was also found at Johanngeorgenstadt, Annaberg and Marienberg but was of less importance there.

The most recent formation (the list representing at the same time a chronological order, from the oldest to the youngest mineralization) of the Varistic mineralization periods is the development of the Carbonate-Polymetal formation, especially in the area of Brand-Erbisdorf in the southern part of the Freiberg district. It is distinguished by a wealth of argentiferous minerals as well as species containing essential silver. The former include galena, sphalerite and tetrahedrite, all rich in silver. Among the latter we find native silver, argentite, proustite and pyrargyrite as well as many others. Associated vein minerals include rhodochrosite and other carbonates.

A second hydrothermal mineralization cycle, the Synalpidic epoch, starts with the Quartz-Iron-Barite formation. In the upper eastern Erzgebirge (Schellerhau) as well as in the upper western Erzgebirge

***Figure 2.* A view of Schneeberg, Saxony, in 1630.**

(Johanngeorgenstadt) we find very large veins with enormous, far-reaching extensions of this formation, which were once mined for iron ore. Hematite in the form of "kidney ore" constituted the most important ore mineral. At other locations quartz is dominant in the form of amethyst or agate and was mined for the purpose of jewelry. Good examples are Halsbach near Freiberg, Schlottwitz near Glashütte, and Warmbad and Wiesenbad near Wolkenstein.

The Fluorite-Barite formation is best developed in the northern part of the Freiberg district, especially near Halsbrücke. Magnificent crystals of fluorite and barite originated from this area. The object of mining here was, of course, the argentiferous ore minerals such as galena, chalcopyrite, tetrahedrite and sphalerite, which appear in the various successions in different quantities. This kind of vein formation was also found in the districts of Marienberg and Annaberg. The same mountain districts, and especially the ones at Schneeberg and Johanngeorgenstadt, provide the most important deposits of the Bismuth-Cobalt-Nickel-Silver-Uranium formation.

In both successions of this formation an abundance of minerals are to be found, such as native bismuth; the cobalt minerals skutterudite, safflorite and cobaltite; the nickel minerals nickeline, gersdorffite and chloanthite; and also the silver minerals including native silver, chlorargyrite and argentite as well as proustite, pyrargyrite and many others. Finally we must mention uraninite in the form of "pitchblende," which was mined in the Erzgebirge during recent decades.

Due to the flowering of mining in the Erzgebirge, splendid specimens are today preserved in many museums all over the world. In the first place there are of course the silver ores, and such famous mines as Himmelfahrt in Freiberg and Himmelsfürst (which means "Godfather") in Brand-Erbisdorf. Records have been kept for silver production in the Freiberg district since 1524 (1360 kg in that particular year). In the middle of the sixteenth century the annual production was more than 6800 kg. From 1168, the beginning of silver mining in Freiberg, to 1523 it is estimated that the production of silver was almost 2 million kg, averaging about 5400 kg per year. However, one has to realize that around 1580 the world production, with a large Central and South American share, amounted to more than 200,000 kg, almost 40 times more than the quantity produced at Freiberg.

During the following three centuries silver production was more or less constant. From 1524 until 1835 the quantity of silver amounted to 1.8 million kg, approximately 5500 kg per year. In the second half of the nineteenth century the total amount of silver mined rose considerably. In 1840 and 1870, respectively, 13,600 kg and 27,000 kg were mined. In 1885 the production reached 34,000 kg, the largest quantity of silver ever mined in the richest district of the Erzgebirge.

However, other areas also brought high profits for short periods. It is estimated that between 1470 and 1500 more than 114,000 kg of silver were mined in the Schneeberg area (approximately 4000 kg per year). On top of this, large profits have been realized in Schneeberg since 1520 from cobalt mining, which considerably surpassed the value of silver mined.

At the beginning of our century, mining of silver and accompanying metals came to an end in Freiberg, as was the case all over the

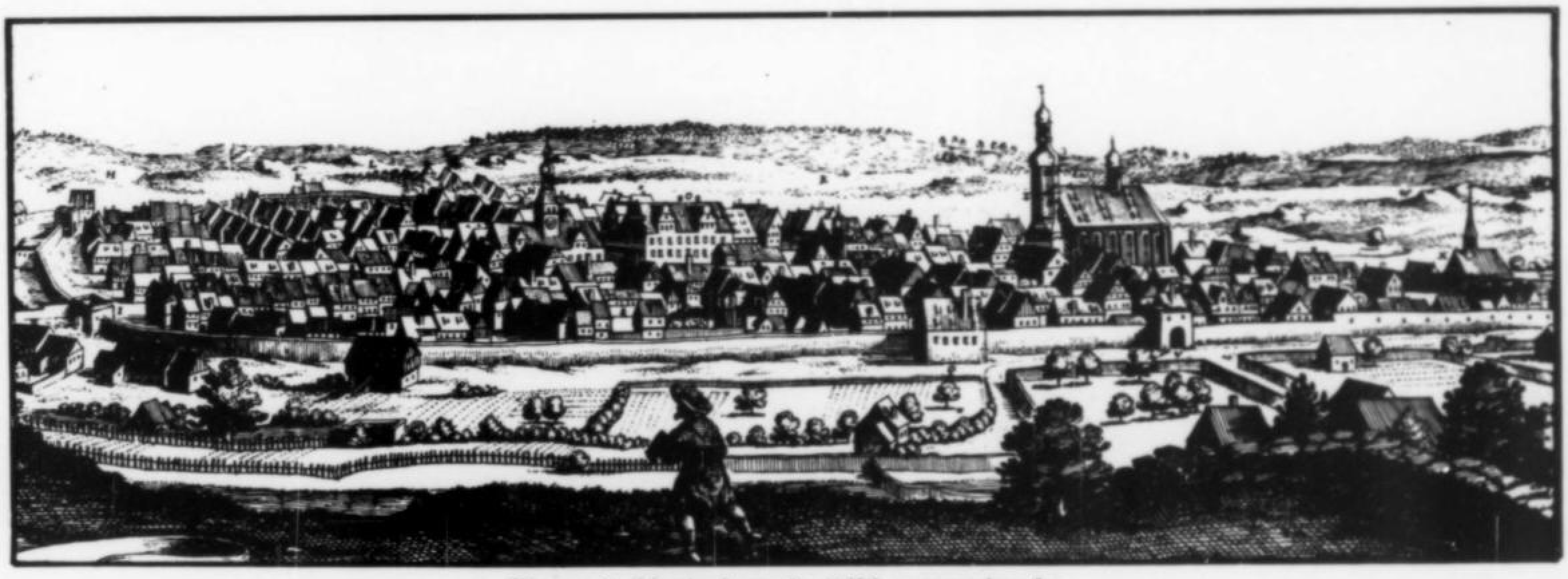

***Figure 3.* Marienberg in 1600; engraving by Mathias Merian. Deutsches Fotothek Dresden.**

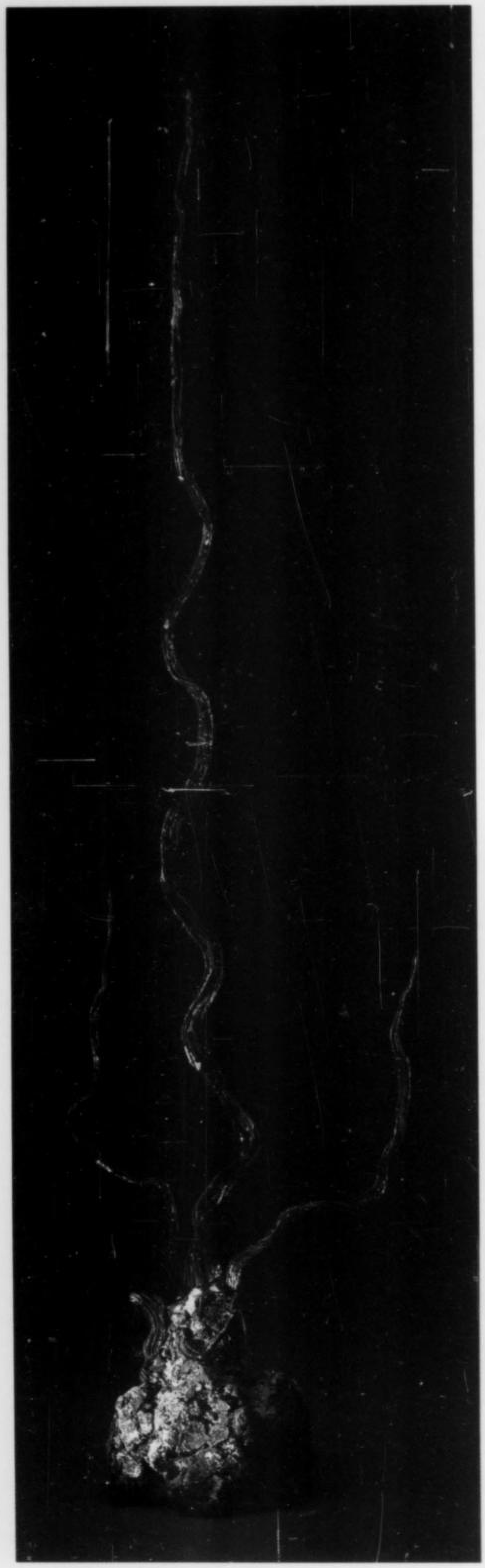

Figure 4. **Native silver known as the "corkscrew," nineteenth century, from Freiberg. (Height 33 cm.)**

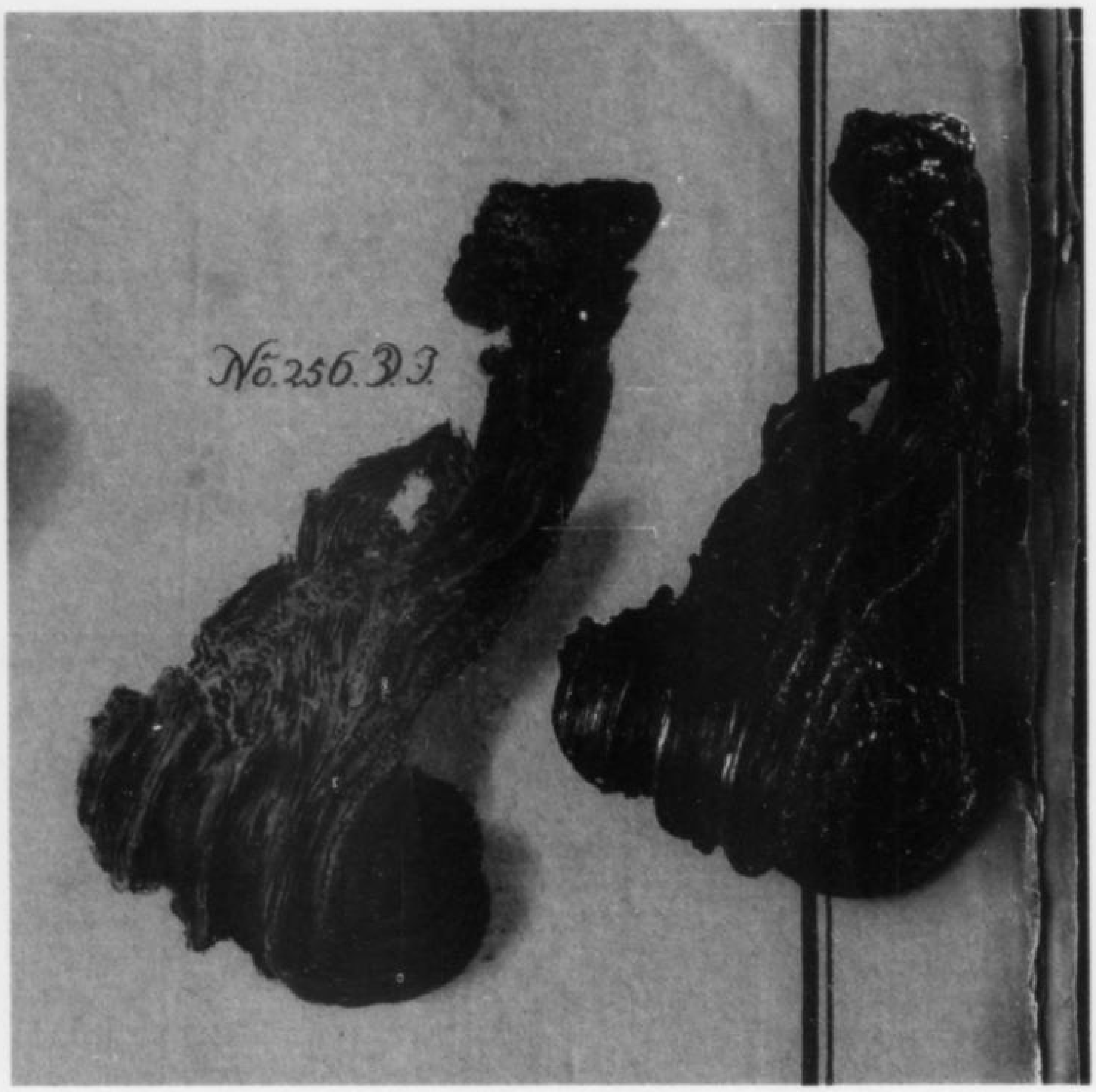

Figure 5. **Native silver, original specimen and painting of same in a catalog of the Dresden silver collection, 1763. (Height 7.6 cm.)**

Figure 6. **Barite, a group of honey yellow crystals from Poehla near Schwarzenberg; found 1985. (Length of largest crystal is 7.6 cm.)**

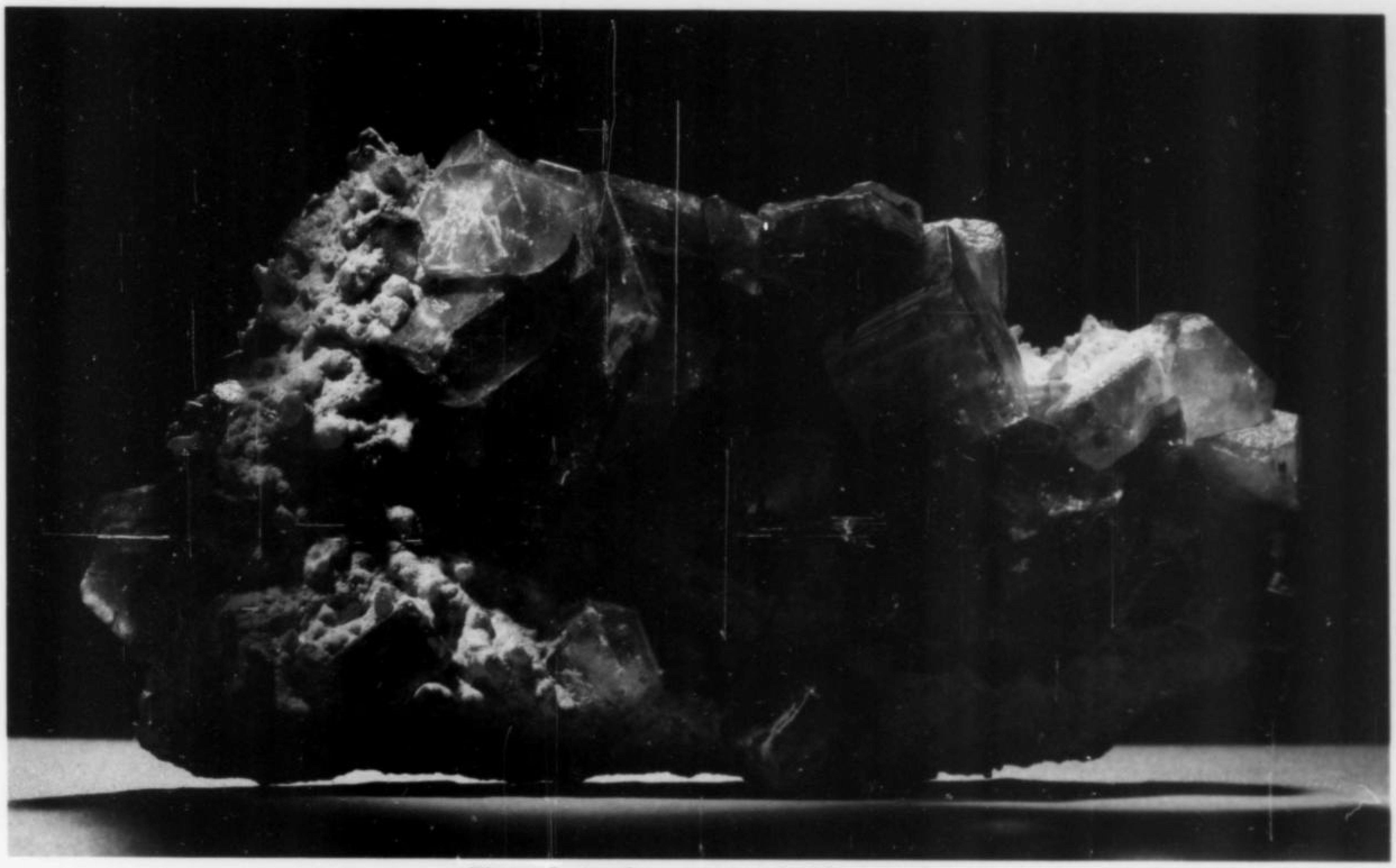

Figure 7. **Apatite, a group of violet crystals from Greifenstein near Ehrenfriedersdorf; nineteenth century. (Length of specimen 10.1 cm.)**

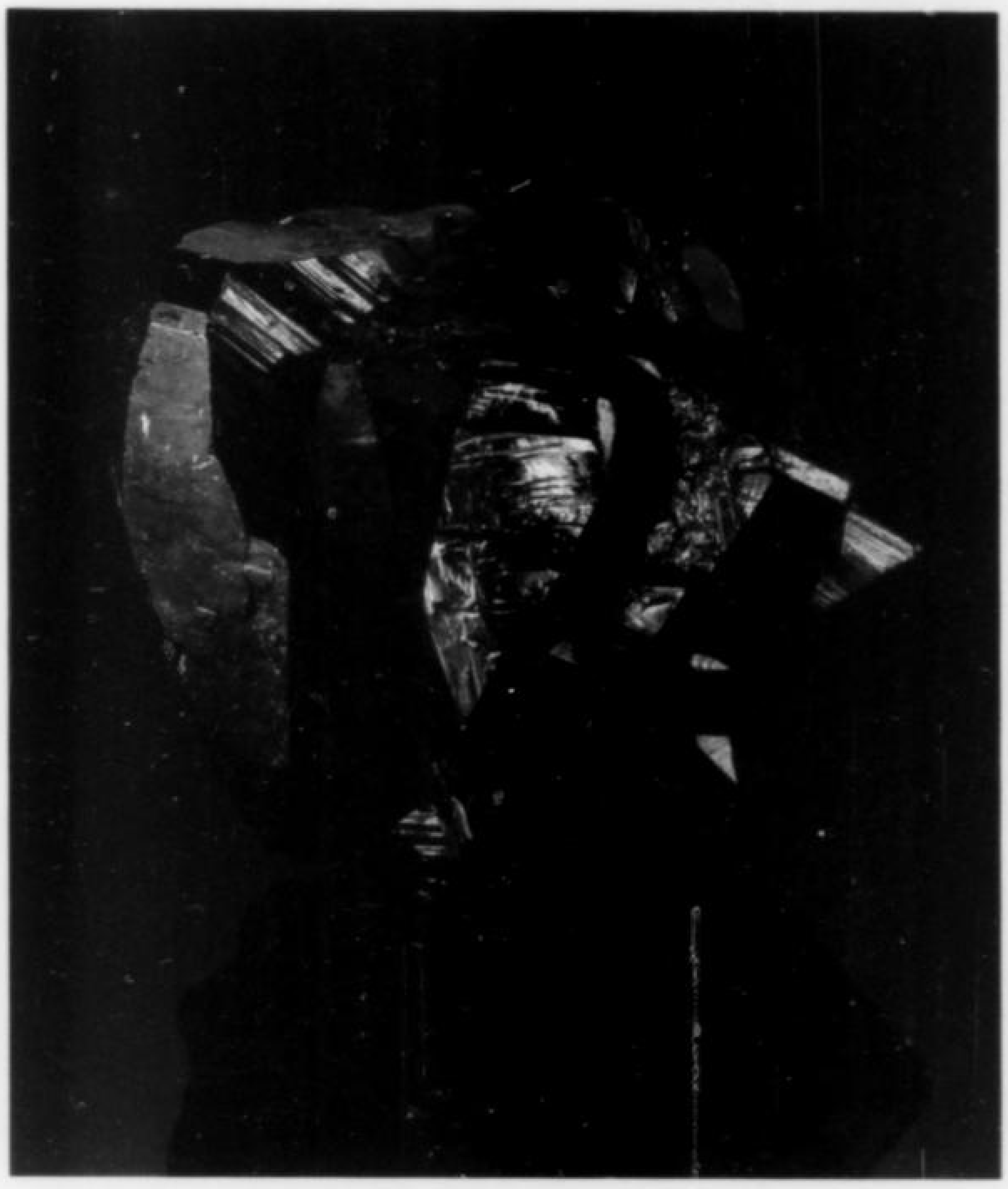

Figure 8. **Cassiterite, multiple twinned crystal (8.1 cm), from Zinnwald; Baldauf Collection.**

Figure 9. **Native silver, massive (1.1 kg), from the Himmelsfürst mine, Brand-Erbisdorf near Freiberg.**

Erzgebirge, due to less expensive imports from abroad. Only after World War II did a short period of prosperity take place in the Freiberg district and different places all over the Erzgebirge, such as Annaberg, Schneeberg, Johanngeorgenstadt and many others.

The metals mined were lead, zinc, silver, tin, tungsten and uranium. From 1950 to 1960 approximately 250,000 kg of silver and 100 million kg of lead were mined in Freiberg.

The magnificent barites and fluorites from Halsbrücke near Freiberg originated during this period; particularly rich silver ore came from veins at Schneeberg-Schlema and other mining areas. The number of such ore veins was quite surprising. The more important veins of different formations in the Freiberg area alone number almost 1000! Many of them are more than 300 meters deep and many kilometers long.

Besides the important ore minerals which were of economic value, the Erzgebirge is also a classical region for the occurrence of rare minerals. Especially the secondary minerals in the uranium-bearing veins of Schneeberg, like uranospherite, uranospinite, zeunerite, walpurgite and pucherite, among many others, deserve to be mentioned. Also important are the beautiful crystals of erythrite, which came from Schneeberg and are known by collectors all over the world.

Furthermore, veins containing gemstones were quite frequently found in the Erzgebirge. The most prominent is topaz from the Schneckenstein locality, followed by a number of splendid quartzes in gem quality, such as rock crystal from Ehrenfriedersdorf, smoky quartz from Zinnwald and amethyst from Wiesenbad near Annaberg. Many excellent specimens of all these minerals can be seen in the large mineralogical Museums in Dresden, Freiberg and Berlin.

The collections of the famous Green Vault, the treasures of the former Saxon Kings, are part of the State Art Collections in Dresden. They contain many works of art made of Saxon gemstones. These form an interesting contrast to the many precious objects made by the most famous artists of Europe during the last five centuries.

ACKNOWLEDGMENT

Our thanks to Karen Pogonowska, London, England, for preparing the English translation of this article, and to Brad Van Scriver for further assistance with the manuscript.

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TITANITE CRYSTALS FROM THE HARTS RANGE, CENTRAL AUSTRALIA

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Well-formed gemmy crystals of titanite showing up to eight crystal forms have been discovered in a feldspathic vein in the Harts Range, 200 km northeast of Alice Springs in Central Australia.

INTRODUCTION

The Arunta Block is an inlier of Archaean rocks forming the basement of the stratigraphy of Central Australia. It crops out extensively in the rugged Harts Range, approximately 200 km northeast of the town of Alice Springs, Northern Territory. The block has been extensively recrystallized and is host to an array of metamorphic and pegmatitic minerals. Ruby (McColl and Warren, 1980), kornerupine and sapphirine (McColl and Warren, 1984), along with an assortment of more common minerals including garnet, kyanite, epidote, beryl, cordierite, mica and corundum, have been found there in formations which are often well-crystallized and spectacular.

The Harts Range rocks are a mixture of volcanics and sediments more than 1.5 billion years old. They were initially subjected to high-grade metamorphism which produced a variety of migmatites, granite gneisses, amphibolites and granulites. During an orogeny about 700 million years ago, milder metamorphism and tectonism produced retrogressive changes and introduced many pegmatites and hydrothermal veins. Tourmaline and muscovite mineralization became widespread in the granitoid pegmatites, while veins with epidote, calcite, rutile and titanite developed in the amphibolitic facies. The new discovery of titanite occurs in one of these veins, within a subgroup known as the Irindina Gneiss.

DISCOVERY

About 50 years ago the only persistent prospecting and mining seen in the rugged core of the Harts Range took place in a search for mica. Much of this was centered on and around Mount Palmer, a prominent massif in the north-central part of the range. Spasmodic regional exploration by mining companies has continued during the last 25 years, but the aridity, ruggedness, inaccessibility and vastness of the terrain, coupled with the sub-economic size of most mineral discoveries, has led only to brief spasms of mining.

Today the largest group of permanent residents in the Harts Range are the native Aboriginal people of the Eastern Arrente tribal group. A population of just over a hundred lives in the community known as Atitjere, on the plains immediately north of Mount Palmer. They have lived a semi-nomadic lifestyle in this region all their lives, and consequently have an exceptionally detailed knowledge of it, often to the extent of knowing literally every hill and valley in what is to us a confusing, repetitious and almost trackless region.

The vein containing the titanite was found by Alex Pedersen among the steep gullies and ridges on the northern flank of Mount Palmer. He and the other Arrente people call the titanite, rather quaintly, "bean crystals" (a corruption of "sphene"—English is a second language for them). Alex discovered the vein while searching for rutilated quartz. Although lacking formal training, his prospecting is surprisingly skilled. He looks in the amphibolites, knowing titanium minerals tend to be more prolific there. He searches for veins where the amphibolite wallrock has formed a margin of chloritized schist, enclosing those hydrothermal veins likely to have produced better and more varied crystallization. In this region, with its thousands of quartz and pegmatite veins, such factors are significant.

The titanite vein, like most mineral deposits they find, was shared among several of the Arrente people who mined it with basic hand tools, offering the product for sale to visiting tourists and mineral and gem collectors. The crystals are not always extracted as carefully as possible, nor are even the best specimens ideally cared for, but their skills in these regards are constantly improving.

GEOLOGY

The mineral-bearing vein had been totally broken up by the time of our visit, but it seems to have been a lens about 5 meters long and perhaps a meter thick, dipping at a shallow angle into a steep hillside. It consisted essentially of drusy plagioclase of albite composition, in which frequent vugs up to 20 cm diameter occasionally contained titanite crystals. Some of the vugs are lined with clusters of euhedral feldspar terminations, with individuals up to 1 cm in diameter. Chlorite

Figure 1. The Mount Palmer massif photographed behind the gully in which the titanite bearing vein was discovered.

Figure 2. The excavated titanite vein, after most of the contents had been removed. Only the general dimensions are still discernible.

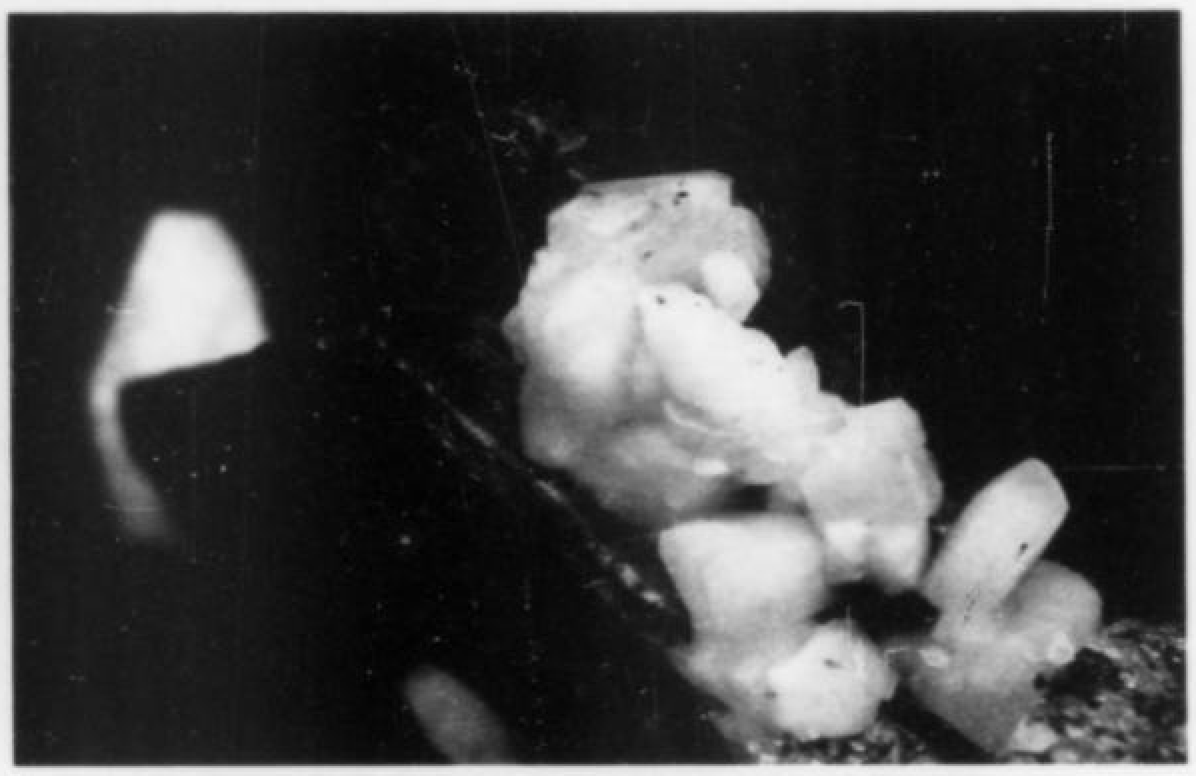

Figure 3. Prismatic crystals of sodic plagioclase clustered between two tabular titanite crystals. The feldspars are from 3 to 7 mm.

Figure 4. One of the rare intergrowths of titanite. The larger crystal is 3.5 cm long.

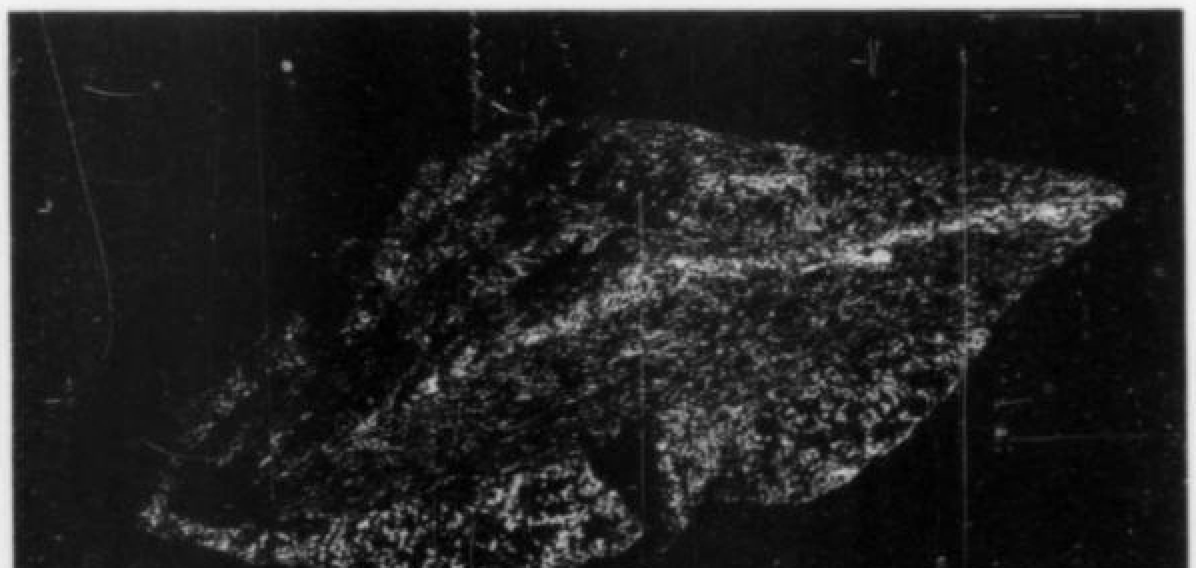

Figure 5. Titanite crystal, twinned on (100), 6.5 cm, from an eastern Harts Range locality.

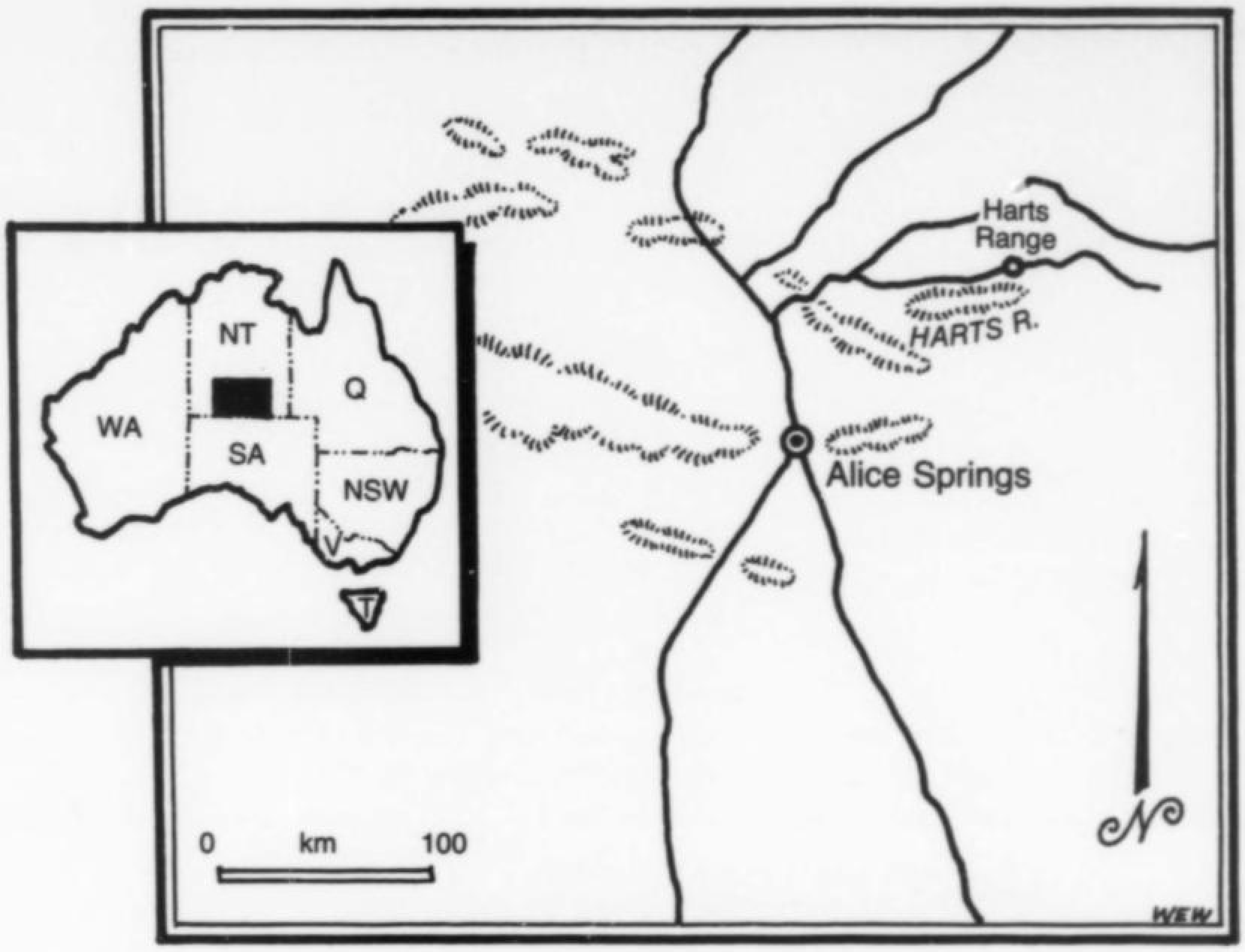

Figure 6. **Location map.**

is present in much of the soft clay fillings of these vugs and coats some of the feldspar crystal surfaces.

Despite the hundreds of titanite crystals which came from this relatively small deposit, it is surprising how few of even the larger crystals were attached to feldspathic matrix. Rather it seems as if they developed preferentially in the more open drusy vugs, suspended precariously on random corners of the feldspar. Consequently clusters or intergrowths of titanite crystals are rare, and detached doubly terminated crystals are the general rule. Titanites with occasional small feldspars embedded in the faces or edges are also prevalent.

The lens is cut off at its southern end by a near-vertical vein of white glassy quartz. This transgresses the titanite-bearing vein, but is itself barren of mineralization. The titanite seems to have formed free of mineral associates except for the albite and a generally sparse sprinkling of chlorite. A few quartz crystals up to 2 cm were found in the excavation detritus, but their source is uncertain. Along the chloritized wallrock, occasional pods and blocks of milky calcite up to 10 cm in diameter occur, and some of this shows thin lamellar intercalations of titanian hematite (?) within the carbonate cleavages.

TITANITE

The titanite crystals ($CaTiSiO_5$) have predominantly tabular form, with diamond-shaped outlines, generally similar to the Pakistani material reported in recent years (see Kazmi *et al.*, 1985). The largest Harts Range crystals are up to 4 x 5 cm, but these are almost invariably distorted by development under confined conditions, so that the more perfect crystals are usually no more than 3 to 4 cm long. Most of the well-formed crystals are a uniform yellowish brown color with variously sized golden gemmy sections along the margins and toward the narrow terminations.

Examination of about 200 of the more completely developed crystals has led to the identification of up to eight crystallographic forms on a single crystal. The indices given here are derived from the unit cell constants $a = 6.56$, $b = 8.72$, $c = 7.44$Å and $\beta = 119°43'$. The pinacoid *x*{102} is invariably predominant in all crystals of appreciable size and imparts the tabular form. This is bounded by the diamond-shaped outline of the prism $l\{\bar{1}12\}$. The other forms produce quite small faces, although some of these are still very persistent, such as the pinacoid *c*{001} which appears on almost every crystal. Surprisingly, the {100} pinacoid, which is so common on the Pakistani titanite, has not been seen on any Harts Range crystals.

On the better crystals, the greatest plethora of crystal faces occurs around the clinopinacoid termination. The prisms *m*{110} and *r*{130} are present on most crystals over 5 mm thick, and on many smaller ones too. The clinopinacoid *b*{010} is a very rare form, but was seen a surprising number of times, considering that we have never seen it before on titanites from any Australian locality, nor on any of the Pakistani material. The prisms *e*{113} and *s*{181} are very rare forms, observed only on a few of the larger and more perfect crystals.

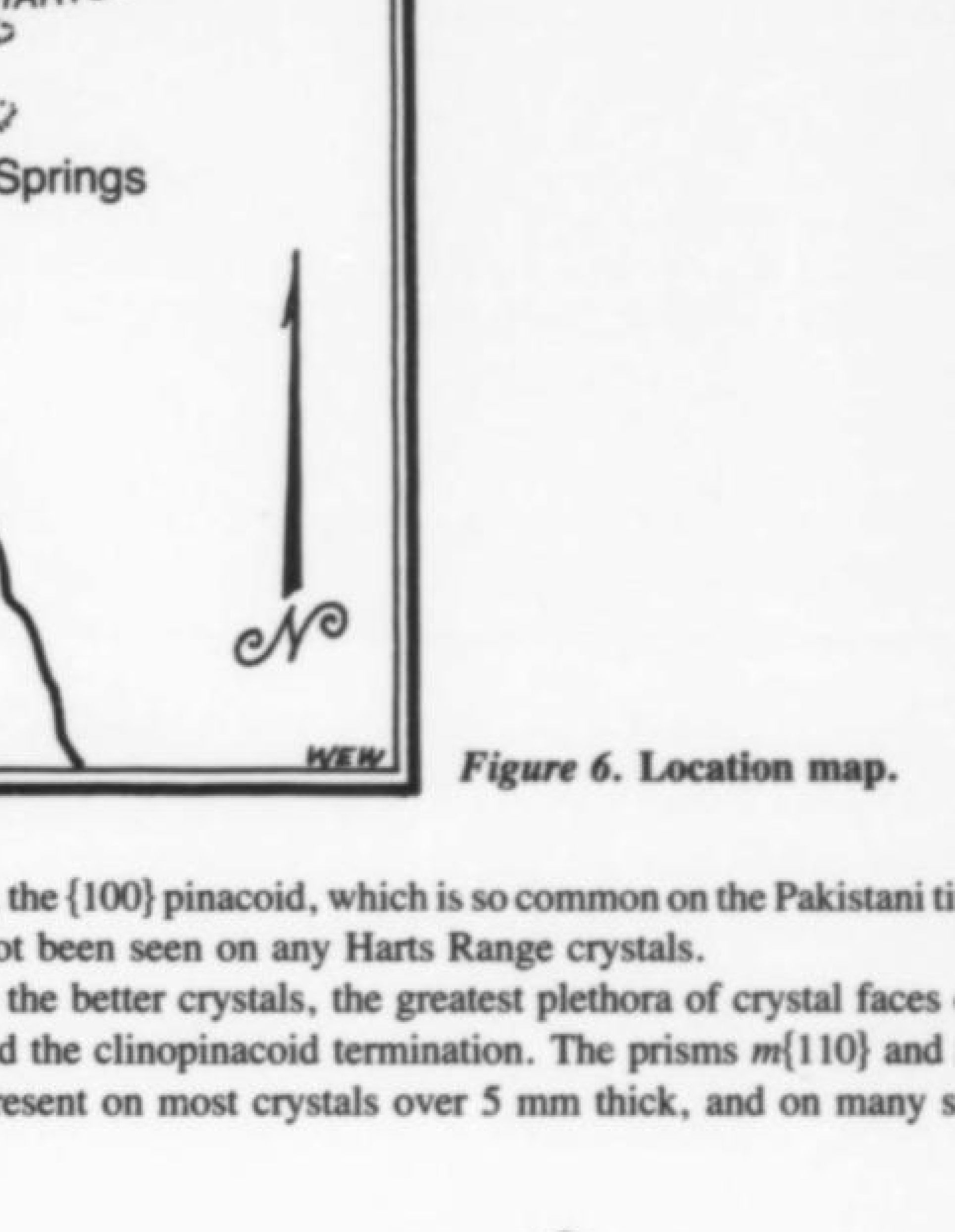

Figure 7. **Computer-generated drawing of an idealized titanite crystal, ordinary clinographic projection, showing the forms and general proportions of the new Harts Range material.**

Figure 7 shows a drawing of an idealized crystal with all the forms so far observed on crystals from this locality. It was generated on the basis of meticulously drawn sketches, supplemented by goniometric measurements of a few selected interfacial angles, by means of the computer program DISTCALC. DISTCALC is a program essentially based on the program SHAPE by Dowty (1980), but further developed by a team at the Geological Museum in Copenhagen to considerably facilitate the drawing of complicated crystals.

Twinning of the titanite crystals is quite uncommon from this new deposit, and only two or three poorly developed examples were seen.

Table 1. **Electron microprobe analysis of Harts Range titanite.**

Elemental Oxide[1]	Weight %[2]	Atomic Proportion
SiO_2	30.20	3.95
TiO_2	39.08	3.83
CaO	29.26	4.10
Al_2O_3	1.29	0.20
FeO	0.22	0.02
MnO	Trace	–
Y_2O_3	Trace	–
F	0.25	0.10
	Total 100.30	

[1] Other rare-earth elements sought were La, Ce, Sm and Yb, but none of these were identified within the detection limits of the instrument.

[2] Average of five analyses.

By comparison, other deposits of titanite in the Harts Range have notably developed the (100) twin, although the form of these crystals is much less perfect than it is on those from the new discovery.

Electron microprobe analysis of the titanite crystals are given in Table 1.

ACKNOWLEDGMENT

Chemical analyses were kindly provided by Dr. Morrie Duggan of the Bureau of Mineral Resources, Geology and Geophysics using the electron microprobe of the Australian National University in Canberra.

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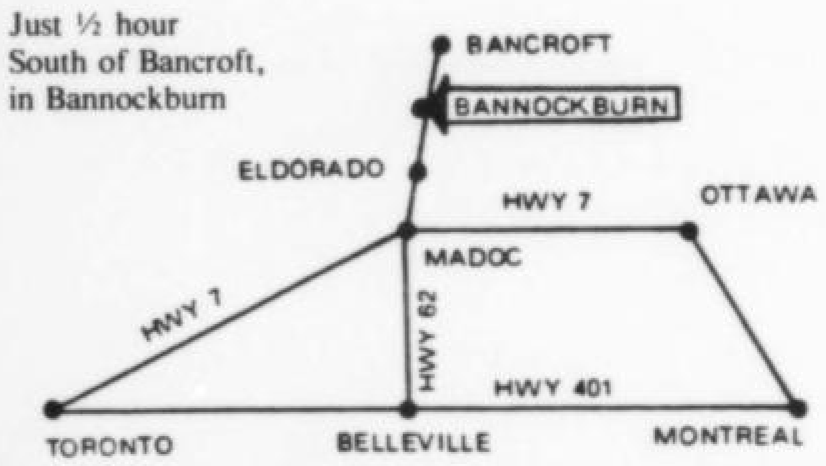

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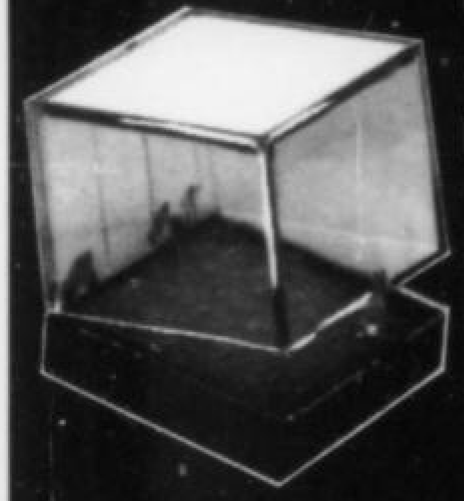

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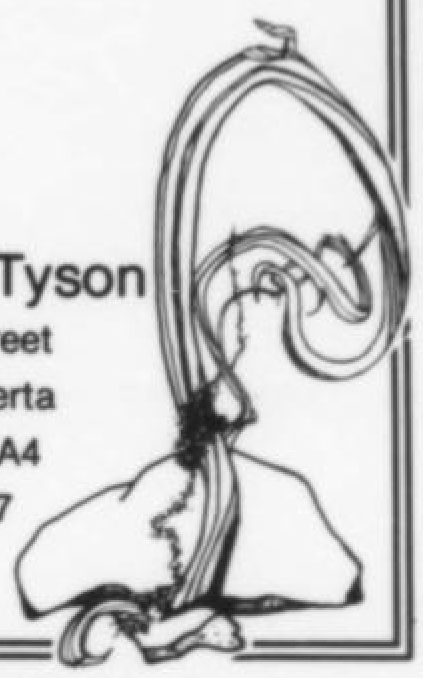

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MUSEUM NOTES

by **Stan Dyl**

THE PHILADELPHIA ACADEMY OF NATURAL SCIENCES

Robert Middleton wrote to tell us that he will be working at the Philadelphia Academy of Natural Sciences through August of 1991 under a grant awarded by the William Penn Foundation. The grant has been awarded to the Academy for conservation of their mineral collection. While in the Philadelphia area, Bob will be serving as curator of the collection assembled by Dr. Arthur Montgomery at Lafayette College and also as a curatorial consultant to the Wagner Free Institute of Science.

HAMPEL MINERALOGICAL MUSEUM

A new star joined the constellation of museums in the mineralogical firmament at the 1990 Cincinnati Gem and Mineral Show. The Hampel Mineralogical Museum, exhibiting publicly for the first time, presented a spectacular display of classic American Midwest minerals, that won the Best-of-Show Award.

The Hampel Mineralogical Museum holds the private collection of Lance T. Hampel, a Milwaukee-area industrialist. Lance is a passionate proponent of Midwest minerals, and strongly believes that fine specimens from the Midwest are every bit as worthy of "world-class" status as a California gold or a Brazilian tourmaline. Correspondingly, his 3500-piece collection consists of suites from the Lake Superior copper and iron districts, the Tri-state and Viburnum Trend lead districts, the Illinois-Kentucky fluorspar district, the Elmwood, Tennessee district, and Midwest quarries. Not to be narrow, Hampel has also assembled ancillary suites of fine specimens from classic North American and world-wide localities. To sum up the Hampel Mineralogical Museum collection: 1,300 pieces are aesthetic display specimens, 1,300 more are reference specimens, and the remaining 1,110 are available for exchange.

A serious collector of fine specimens for over a decade, Lance Hampel has some definite opinions about exhibiting minerals. Lance states that: "We (museum exhibitors) must first appeal to the simple aesthetic senses, so they (the non-specialist) can be moved to more academic or scientific curiosity." On institutional exhibiting at shows, he stresses that: "the duty of curators and collectors is to do the very best job possible . . . displays should have a balance of items to please the general public, the average collector, and academician/scientist, in that order. The last criteria for selection of display material should be ease of transportation, and the pleasing (solely) of the academic type of viewer." Lance goes on to say that: "There should be more emphasis on showmanship, which involves seriously considering specimen types and sizes, lighting, arrangement, color balance and educational impact. Each display is competing for attention and recognition against all others in a given show.

Regarding the role of show committees: "Show committees should encourage and expect 'show-stopper' cases from major institutions. In turn, they should be willing to assist with [support for] large cases and specimens, arranging transportation and helping museum people with all aspects of their displays."

Anyone viewing the Hampel Mineralogical Museum's award-winning Cincinnati Show exhibit would have to agree that Lance seriously attempts to lead by example (or ex-Hampel?). Lance would probably want to leave all of us curators with these thoughts: "A considerable portion of mineral collections are more of an art-type [collection] than a true scientific collection. They are competing for recognition *and funding* [my italics] against other art types. They need to be presented to the public—the ultimate provider of funds—in the best, most appealing way."

NATIONAL MUSEUM OF NATURAL HISTORY, PARIS

Just days ago, a letter arrived in Houghton from Paris, France, from Prof. H. J. Schubnel and Prof. P. J. Chiappero of the French National Museum of Natural History, announcing the opening of a new exhibition entitled "Precious Crystals." The exhibition, accompanied by a stunning full-color brochure, runs from April 11 to December 31, 1990 and is installed in a specially designed gallery in the lower level of the museum.

The entire exhibit contains 1,200 of the best specimens from the National Museum collection. Included are 60 choice pieces from the National School of Mines collection, and Harvard has loaned some of their fantastic gold specimens. One of the latter is the "Avols nugget," 537 g, the largest such specimen from France. Among the most striking specimens are:

—a 14.8 x 15-cm doubly terminated rubellite crystal from Anjanabonoina, Madagascar

—a 14 x 16-cm blue, gem-quality, topaz from Virgem Da Lapa, Minas Gerais, Brazil

—an 8 x 8-cm becquerelite with 1.5-cm crystals from Shinkolobwe, Zaire

History is not left in the dust at the National Museum's "Precious Crystals" exhibition. Two mineral cabinets have been reconstructed in large showcases: one from the eighteenth century, containing crystal models, minerals and a goniometer which belonged to Abbé René Just Haüy, and a second representing nineteenth-century collecting. A third exhibit displays rare books including a volume by D'Agoty, and a fourth consists of case furniture that housed famous collections like those of Rome Delisle and Descloizeau, and a cabinet the Duke of Buckingham had made to house gemstones from Haüy's collection. Lastly, a special showcase is devoted to new acquisitions.

VPI MUSEUM OF NATURAL HISTORY

The newly formed Museum of Natural History at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, located at 428 N. Main Street in Blacksburg, opened in April with an exhibit entitled "Diversity Endangered." The exhibit draws upon extensive collections of mammals, birds and insects to expand the SITES poster series. The new museum is a branch of the Virginia Museum of Natural History, and includes the mineral collections in the Museum of the Geological Sciences, that remain on permanent display at 2062 Derring Hall on the VPI and SU campus. Those planning a visit should call (703) 231-6773 for information concerning hours.

SEAMAN MINERAL MUSEUM

The Seaman Mineral Museum, at Michigan Technological University in Houghton, was recently designated "The Mineralogical

Museum of Michigan" as a result of action taken by the Michigan Legislature. The action commemorates the Seaman Mineral Museum's 88 years of operation and its "valuable service in educating people about the value of mineralogy and geology, in general and specifically about Michigan." The Museum displays more than 20,000 specimens in a modern 5000-square-foot exhibit area, and conserves another 40,000 for reference and research.

The legislative action was encouraged by the Midwest Mineral and Lapidary Society of Dearborn, which recently established the Seaman Mineral Museum Endowment with a gift of $5,000. The resolution was presented to Seaman Museum Curator Stanley Dyl II at an MMLSD reception at the Dearborn Civic Center, during the annual Dearborn Gem and Mineral Show in May. The new endowment provides unrestricted support for the Museum and has since attracted several major gifts, including $10,000 from the Michigan Tech class of 1939, $1,000 from Lucille Lamey, the daughter of the Museum's founder (A. E. Seaman), and an anonymous gift of $25,000. The Seaman Museum Endowment currently totals $43,000.

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    - · indices of refraction · optical class: i., u., b., +/–, 2V · colour · streak colour ·

3. References (approx. 35.000), arranged according to minerals systematics.

The next three chapters are abstracts of the above–mentioned data, i.e. they constitute selections and groupings effected according to special criteria.

4. Crystallography: Selection according to crystal system, grouping in compliance with the space groups, and subgrouping in conformity with the systematics of minerals.

5. Elements: All minerals are listed for each element, and are arranged in line with the systematics of minerals.

6. Petrography: The 318 rock–forming minerals are classified here once more, they are sorted in conformity with different criteria, and listed as follows
    a. Grouping according to optical data, classified according to refraction value;
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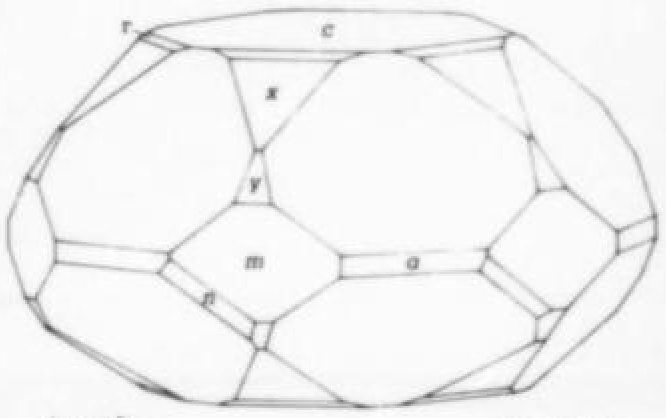
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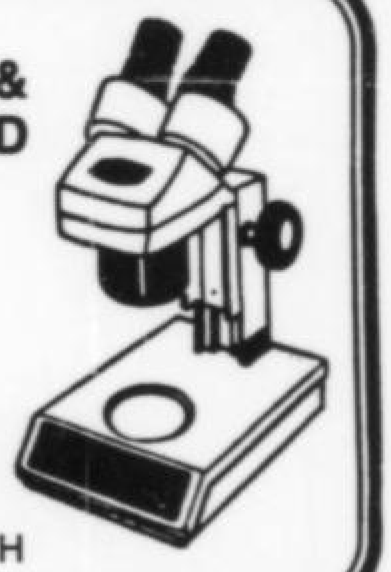

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