THE MINERALOGICAL RECORD

MARCH–APRIL 2010 • VOLUME 41 • NUMBER 2

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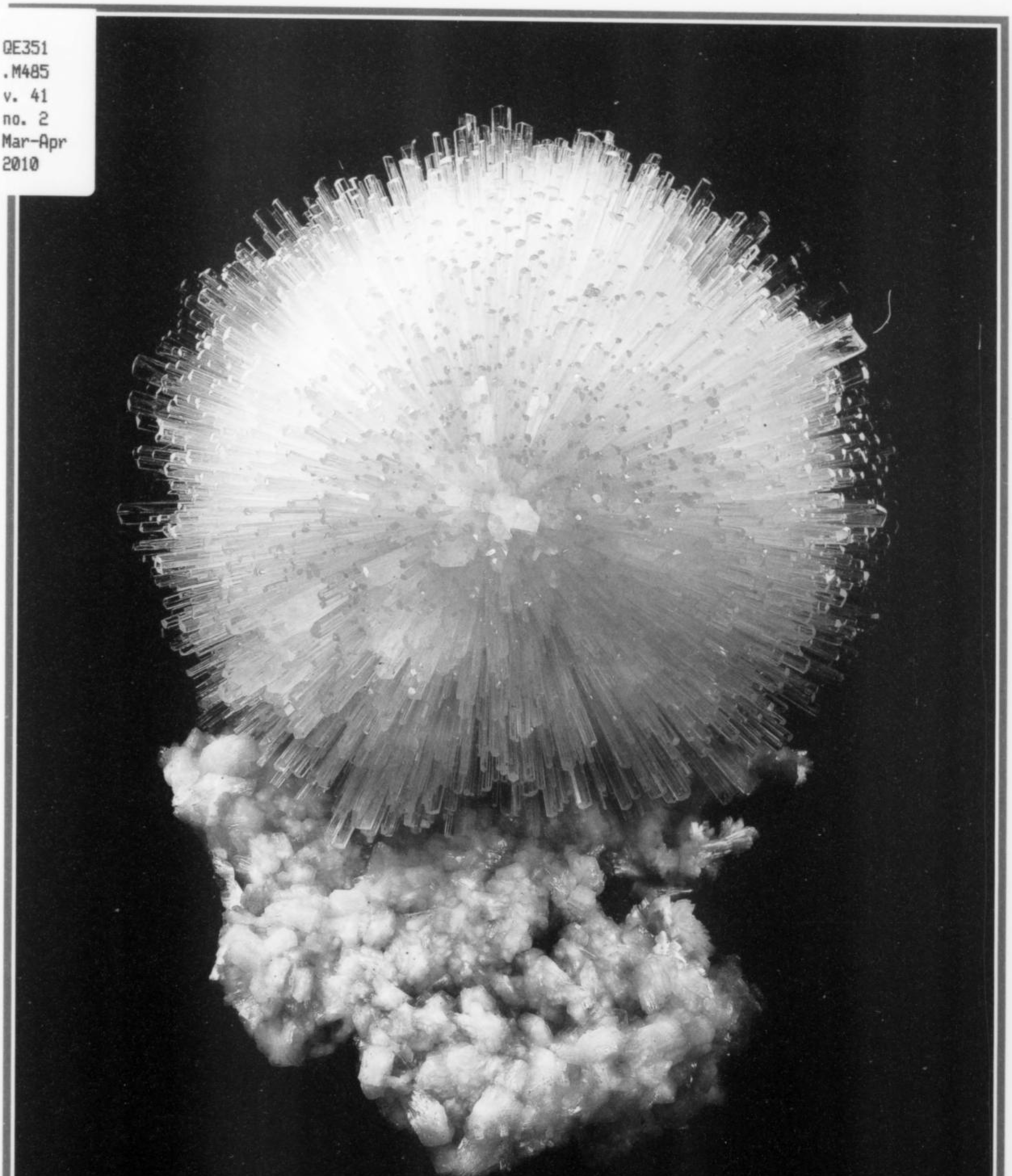

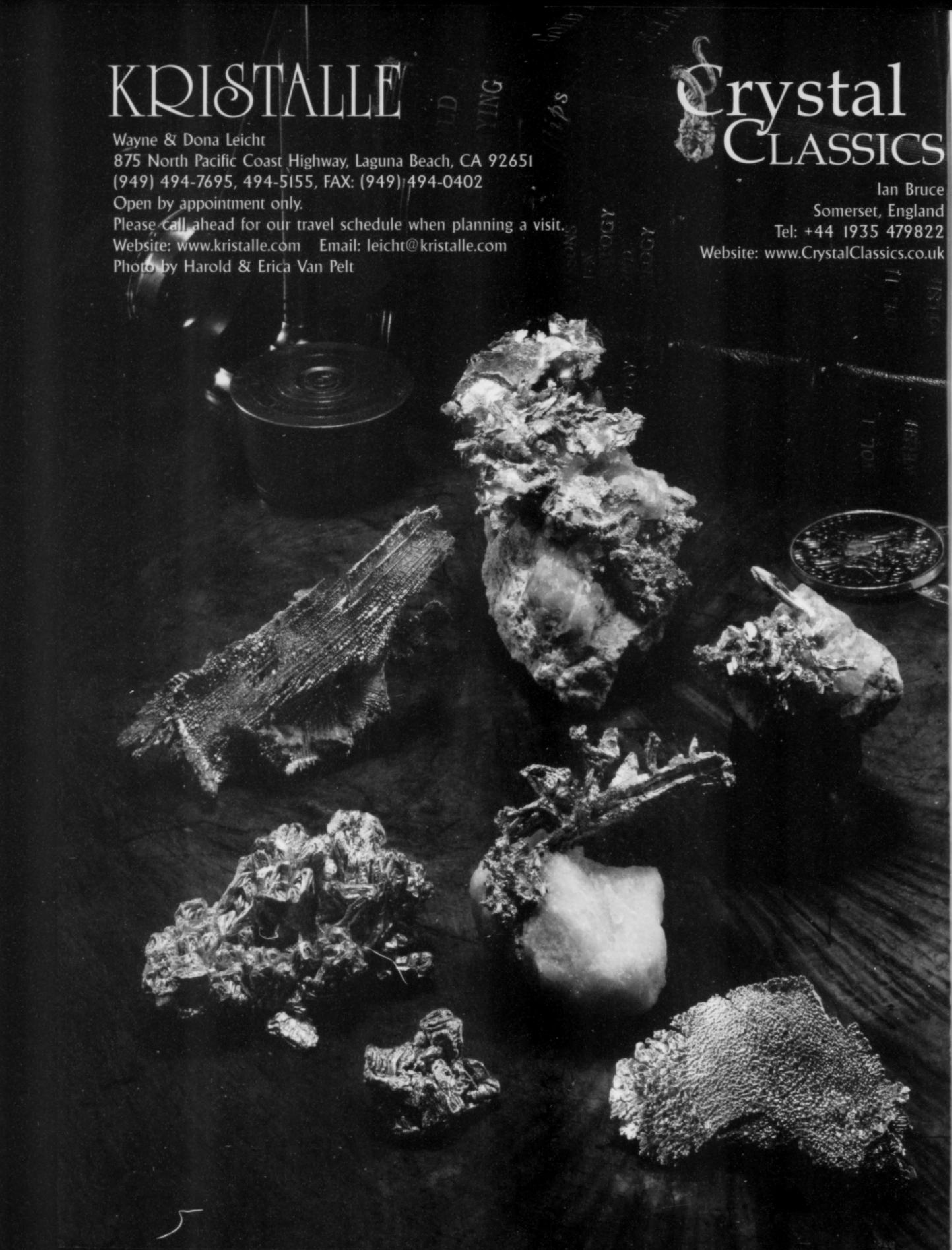
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The

Mineralogical Record

The International Magazine for Mineral Collectors

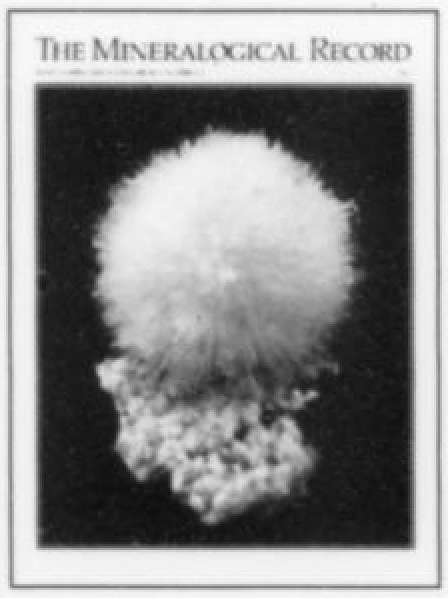
VOLUME 41 • NUMBER 2 MARCH–APRIL 2010

Continued on page facing inside back cover

Articles

Columns

This issue was made possible in part by contributions from Philip G. Rust and the Fellows of the Mineralogical Record



COVER: SCOLECITE, 23 cm, from Jalgaon, Maharashtra, India. Fine Minerals International specimen; James Elliott photo. For more on Indian zeolites see the special issue, "Minerals of the Deccan Traps," by Berthold Ottens, vol. 34, no. 1 (2003).

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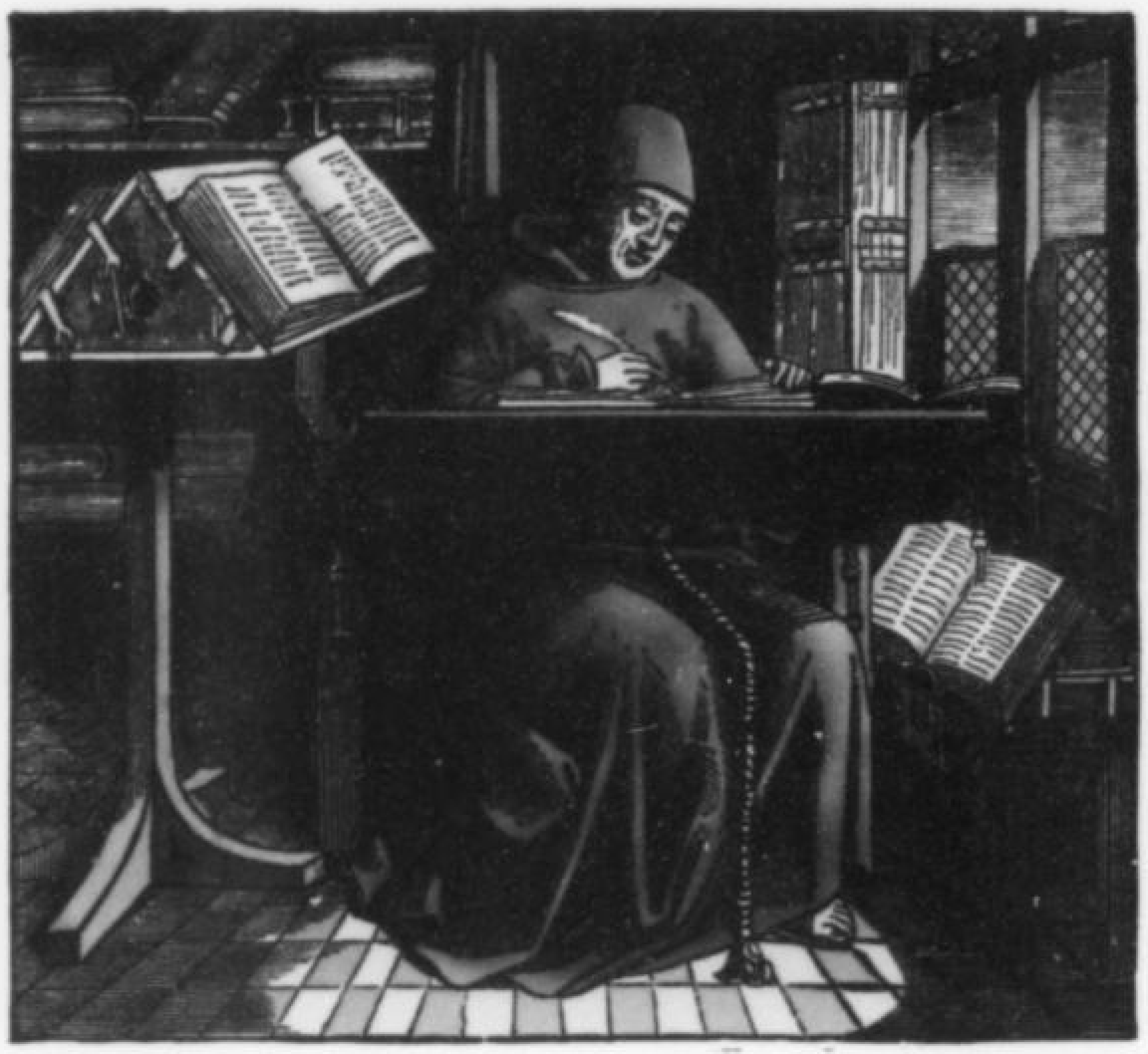
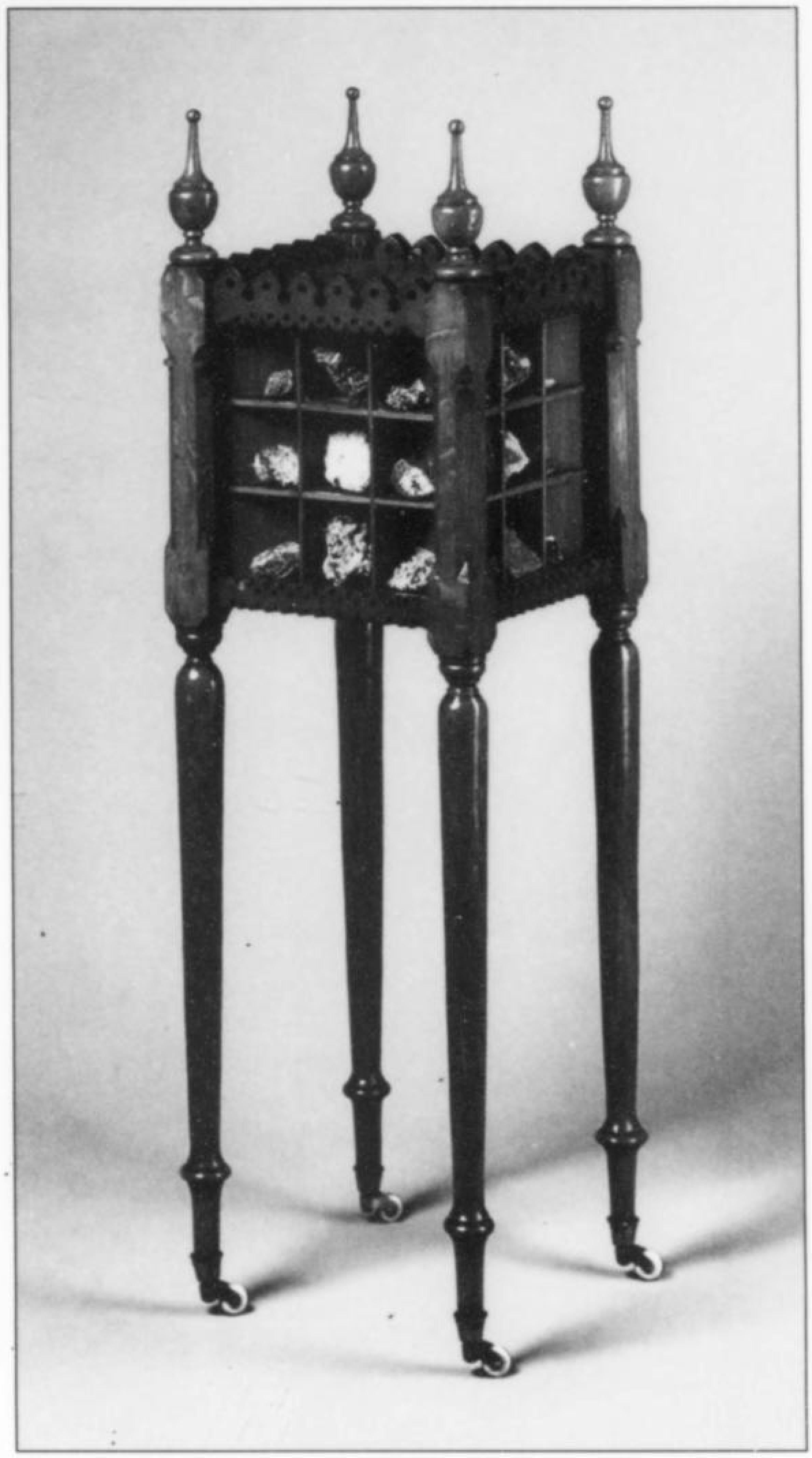


Notes from the Editors



Victorian 4-sided mineral cabinet (ca. 1860–1870)

Victorian 4-sided Mineral Cabinet

Looking for a really different design for a mineral display? Look no further than the four-sided English Victorian mineral cabinet pictured here, dating to around 1860–1870. It is made of mahogany and oak, with original brass and ceramic casters, and stands 114 cm (about 45 inches) tall. Each side has alcoves to hold nine mineral specimens; some of the shelves still retain their original specimen labels. Apparently it was designed so that the owner could relax in his favorite chair in the sitting room and roll the cabinet over beside him for casual inspection and enjoyment, rotating it to show whichever specimens he wanted to study. Is this a one-of-a-kind cabinet, or did some Victorian mineral dealer sell them? This one was sold at auction recently by the London antiques dealership Finch & Co.

Rock & Gem Issues Needed

We need some back issues of *Rock & Gem* magazine to complete the Mineralogical Record Library's run, and we'll be happy to trade credit toward your subscription to the *Mineralogical Record*, on a one-for-one issue basis. The issues we need are listed below. If you have any of these and are willing to trade, email Wendell Wilson at **minrecord@comcast.net.**

1991: Apr., July, Nov., Dec.
1992: Jan., Feb., Mar., Apr., Sept., Oct.
1993: Jan., Feb., Mar., Apr.
1996: Oct.
1997: Mar., Apr., May, June, July, Sept., Oct., Nov.
1998: Jan., Feb., Apr., June, July, Aug., Sept., Oct., Nov.

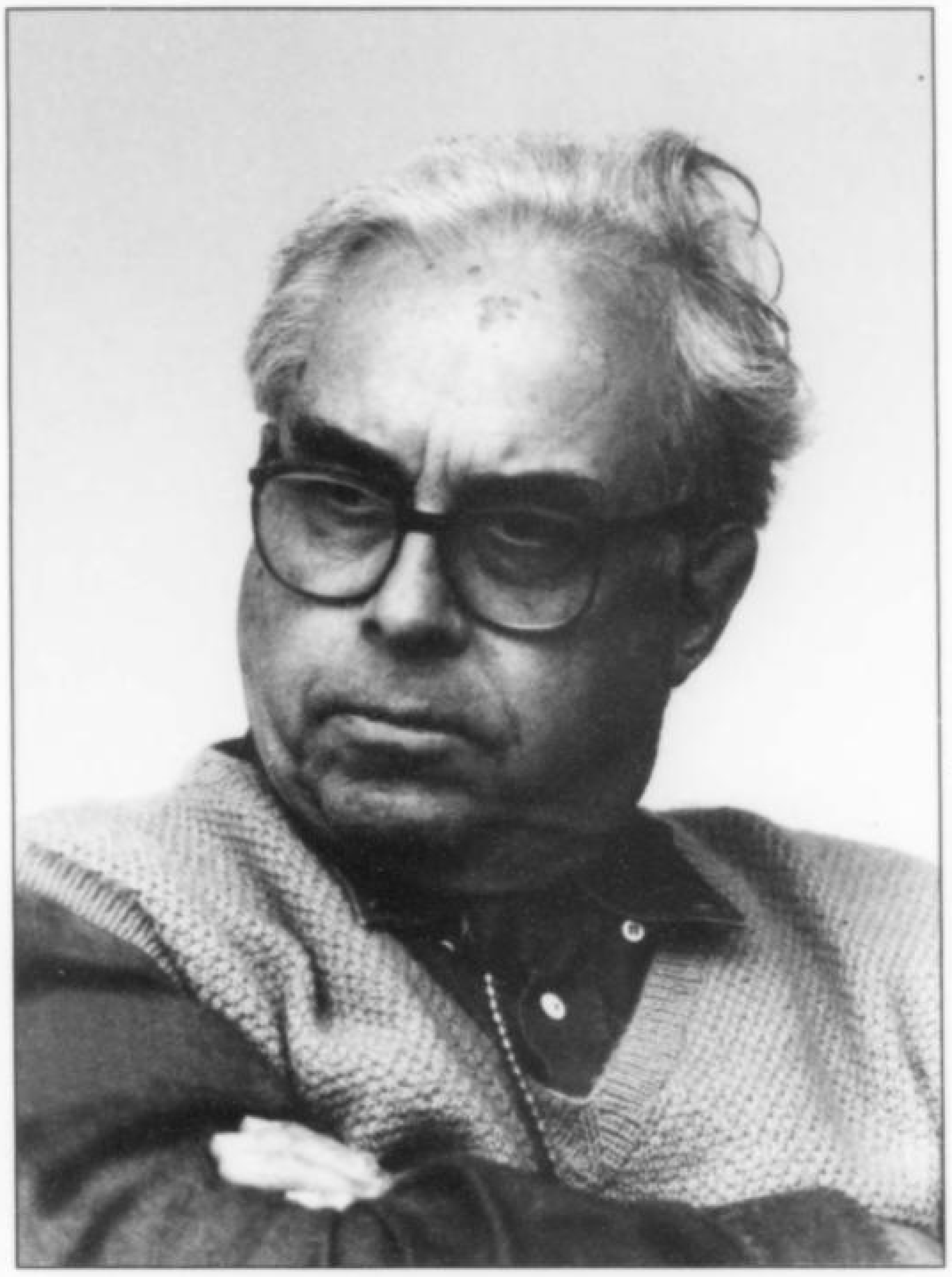
The Neurology of Collecting

Shirley M. Meuller, a board-certified neurologist and psychiatrist, made an interesting statement in a recently published essay, "The neuropsychology of the collector" (in *Collectible Investments for the High Net Worth Collector,* Stephen Satchell editor, Academic Press, 2009). Research conducted at Stanford University has confirmed that the mere *expectation* of receiving a reward, such as acquiring a fine specimen for one's collection, stimulates the pleasure center in the brain (called the *nucleus accumbens*). This was determined using Magnetic Resonance Imaging (MRI) to measure changes in blood flow and oxygenation to different parts of the brain in test subjects. The pleasurable feeling begins the moment we see a desirable specimen and begin to fantasize or visualize about the pleasure of owning it:

> If a functional MRI is performed, it erupts with activity when a reward is anticipated. Once the prize is actually obtained, however, less [activity in the pleasure center] is present. Essentially, *anticipation of the reward is more exciting to our pleasure center than actually getting it.* This might explain, in

part, why collecting often transcends a mere pastime to become a passion. Expectation gives so much joy that the participant wants to continue the pursuit evermore vigorously.

In other words: for many people, at least, it's all about the hunt! I suspect that the pleasure-center experience of simply seeing a fine specimen (e.g. in a magazine such as this one), even when we know that it probably cannot be obtained, is still quite high for the passionate collector.



Erich Offermann (1920–2009)

Died, Erich Offermann, 89

Erich Carl Offermann, longtime mineral photographer and micromounter, was born to an American mother (from San Francisco) and a Swiss father on February 28, 1920 in Zürich, Switzerland. Minerals were in his blood—his great-great grandfather, Carl Alexander Offermann, had been an early Swiss mineral collector. Erich studied law in Zürich, Bern and Geneva before receiving his Doctor of Jurisprudence Degree in 1949, following which he spent most of his professional career on the legal staff of Ciba-Geigy Corporation.

When Erich was eight years old his father, a professional electrical engineer, took him to see the mineral collection at the Technical College in Zürich. Smoky quartz crystals taller than he was greatly impressed him, and soon he began collecting Swiss minerals in the field, and buying Austrian specimens through the mail. By the age of 12 he was studying serious mineralogical textbooks. But sadly, his first fledgling mineral collection was discarded by his mother when World War II broke out.

At the age of 38 Erich experienced a renewed enthusiasm for his childhood interest in minerals and began collecting again. Soon thereafter, around 1959, he began trying to take photographs of mineral specimens using relatively primitive equipment. Werner Lieber's 1972 book *Kristalle unter der Lupe* ("Crystals under magnification") and Alex Kipfer's *Der Micromounter* (1972) provided further inspiration, and Erich eventually concluded that the perfection of microcrystals rendered them the most interesting. He developed an extensive correspondence over the years with other collectors, photographers and micromounters throughout Europe and America, and made many friends.

Over the decades he assembled a collection of over 5,000 micromounts plus many larger specimens, the selection focusing on beauty and morphology. At the same time he worked diligently on his mineral photography, often utilizing bright daylight on a cloudy day as his light source; eventually he accumulated over 10,000 photos (about half of them depicting Swiss minerals), over 1,000 of which have been published. In 1976, my first year as editor, I invited him to join the board of Associate Photographers of the *Mineralogical Record*, and he served happily in that capacity for over 30 years.

In 1980 I began experimenting with mineral stereophotography; wanting to introduce my friend to this exciting twist on mineral photography, I sent him a homemade viewer designed for slides, and a few 35-mm stereopair slides of minerals I had taken. As soon as he took the viewer out of the mailing envelope and unfolded it, before even reading my explanatory letter, he immediately figured out in a flash what I was doing and soon became the leading proponent of mineral stereophotography in Europe. He even donated $8,000 to the *Mineralogical Record* in 1983 so we could send a stereo viewer to each of our subscribers, allowing them to view stereo pairs in the magazine.

In 1990 Erich began experimenting with the SHAPE crystal drawing program and became totally involved, including in the generation of stereopair crystal drawings. Over the years he published over 30 articles illustrated with his photos and crystal drawings, mostly in German and Swiss journals (*Lapis, Mineralien Magazin, Magma, Schweizer Strahler, Mineralienfreund*, and *Der Aufschluss*, and also in the *Mineralogical Record*), but his major contributions were his many photos that were published in articles by other authors.

Erich died December 10, 2009, after a long illness and having gone almost completely blind in his later years. His extensive mineral collection has been donated to the Basel Museum of Natural History, where he had been a Museum Associate since 1989.

WEW

Died, Julius "Julie" Zweibel, 83

Julius Robert "Julie" Zweibel, prominent dealer in Tsumeb minerals in the 1970s and 80s, was born in New York City on February 4, 1925, the son of Austrian immigrants who worked in the poultry business. Julie attended Science High School, and in 1948 married fellow New York native Miriam Koblin (a B.A. graduate of Hunter College, born December 16, 1925). Julie worked for 30 years as a meat wholesaler in New York, before he and Miriam discovered their interest in minerals. They had three children: Ellen (now a Professor of Law), Stuart (now a dermatologist and cancer surgeon), and Ann (now an executive with City Corp)—each of whom has given Miriam and Julie two grandchildren.

How did they get started in minerals? In 1971 they had seen a beautiful amethyst specimen at a friend's house, and then noticed a variety of attractive decorator specimens for sale by Astro Minerals in Bloomingdale's. Their interest piqued, they subscribed to Julio Tanjeloff's short-lived but spectacular magazine called *Mineral Digest*, and in the second issue they came across an eye-opening article about the minerals of Tsumeb, Namibia. The article was discouraging about prospects for actually visiting the mine and buying specimens, but they took a trip to South Africa anyway and were able to buy their first Tsumeb dioptase in Johannesburg. They

Julius Zweibel (1925–2009)

then continued on to Brazil where they bought a ton (literally) of mineral specimens in Rio de Janeiro.

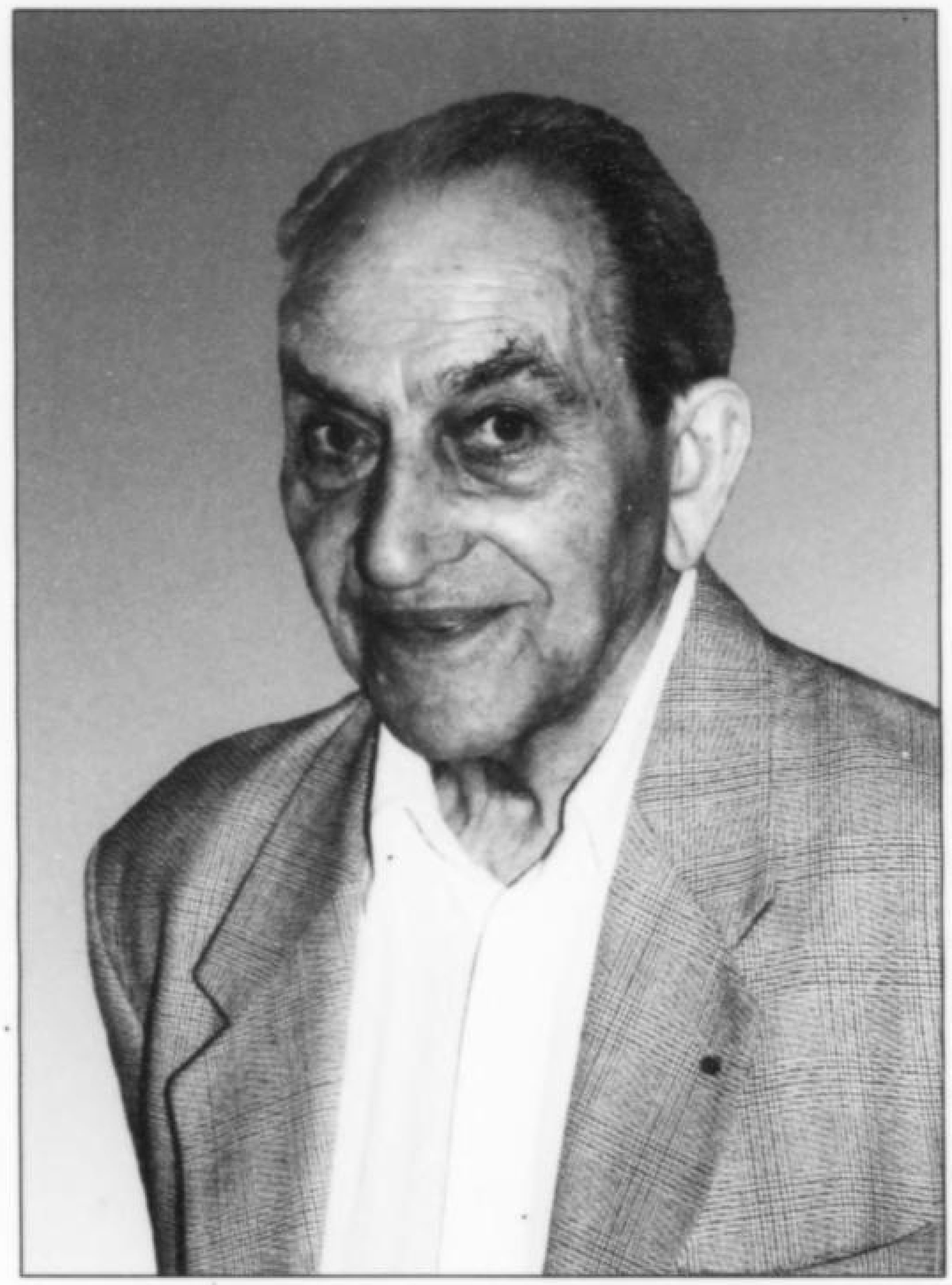
Shortly thereafter they met a mineral dealer named Marty Greifenberger, who sold them a few Tsumeb specimens in his shop. Julie noticed ten unopened boxes of specimens that had just been shipped to Marty from Tsumeb, and he purchased them on the spot, sight-unseen (by either Marty or Julie!). Marty drove the crates to Julie's house at 3 a.m., and after opening them the next day and covering a pool table with sparkling dioptase, the Zweibels were officially hooked on Tsumeb. They opened their new mineral business, called *Mineral Kingdom of Woodmere,* out of their home in Woodmere, New York in 1973.

Greifenberger then took Julie with him on a buying trip to Tsumeb, where Julie purchased the spectacular collection of a Mercedes auto mechanic in Tsumeb named Henckel. With their hoard of fabulous Tsumeb specimens as selling stock they became dealers at their first Tucson Show in Greifenberger's wholesale booth in 1973—where a memorable "feeding frenzy" by excited buyers took place. The Zweibels also met venerable Mexican mineral dealer Manuel Ontiveros at the Tucson Show, and purchased his personal collecton in 1974. With the support of fellow dealer Walt Lidstrom, and the encouragement of Smithsonian curator Paul Desautels, the Zweibels were finally given booth space in the retail section of the Tucson Show.

During their first few years in the mineral business the Zweibels developed an extremely fine personal collection by putting away about 175 of the best Tsumeb and Mexican specimens. In 1977 Julie won the prestigious Ed McDole Trophy for his mineral collection at the Tucson Show. In 1980 they sold the collection; Paul Desautels bought 99 of their specimens for the Perkins Sams collection, and the rest went to Dallas collector Jim Gibbs.

In 1980 the Zweibels moved their business to Houston, Texas (changing the name to *Mineral Kingdom*), and in 1987 they moved again, back to Bank Street in New York City. They retired to Pompano Beach, Florida in 1992 and ended their mineral business shortly thereafter. Julius died, after a long battle with Parkinson's Disease, on November 23 in Boca Raton, Florida.

WEW



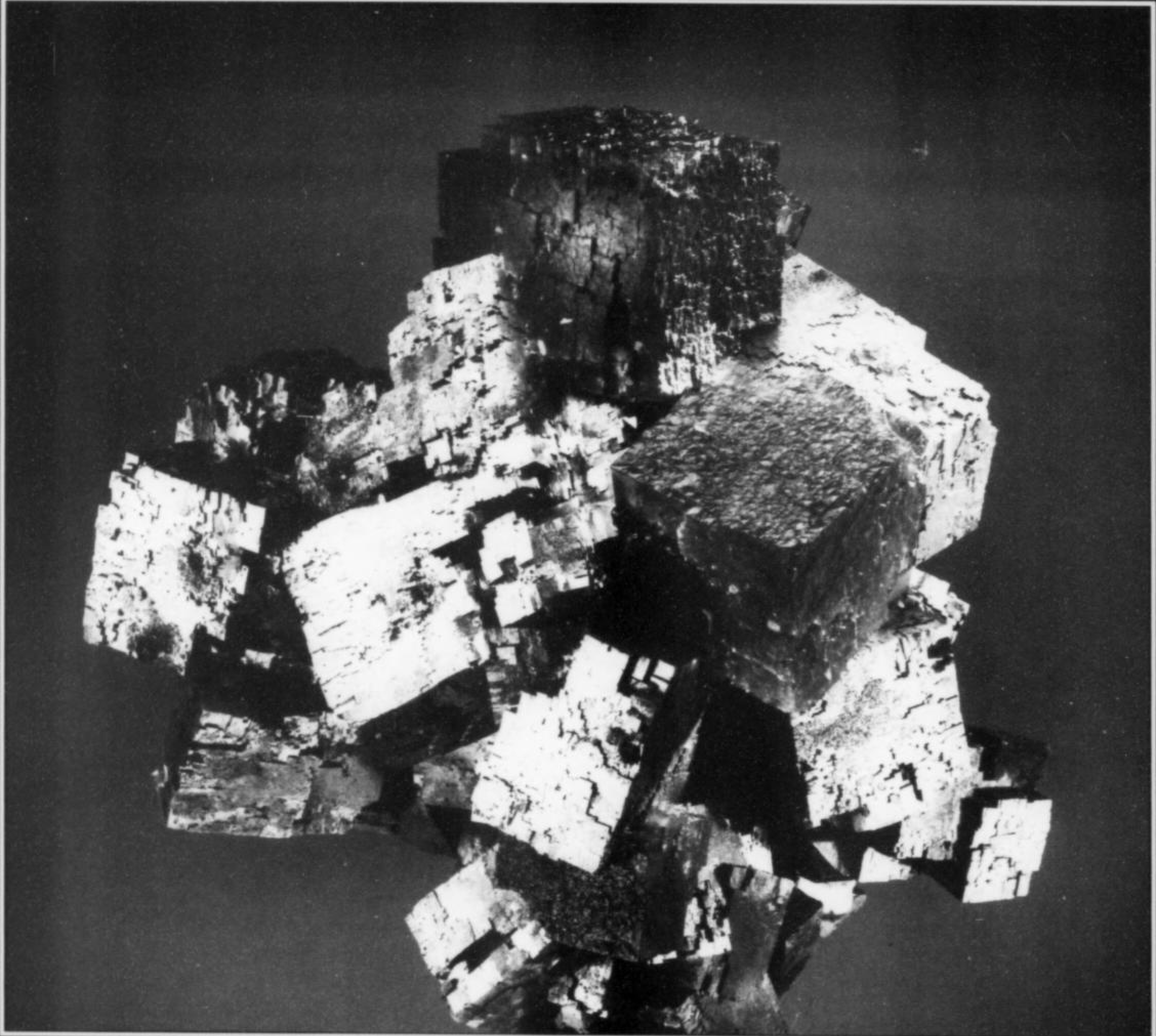
Roger Titeux (1913–2009)

Died, Roger Titeux, 96

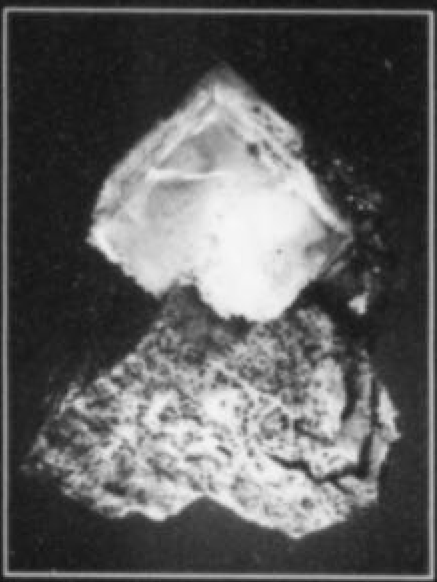
Roger Titeux, long-time French mineral dealer, was born in 1913 and died recently in Vallauris, France on November 2, 2009. He had been a teacher in his first career, then spent some years as a bookseller before developing a passion for mineralogy and mineral collecting. He first became interested in minerals in 1952, when he came across some crystals while hiking in the mountains. Struck with fascination, he decided to learn all he could about them, and used Lacroix's *Minéralogie de la France* (1893–1913) as his "bible." Soon he was teaching himself chemistry and then crystallography, a subject which he found difficult but most appealing. His specialty was the minerals of France, and he field-collected extensively at French localities in the Alps and in Dauphiné. But as a dealer his interests were world-wide; he traveled regularly on buying trips to Brazil and collected in the field there as well. He began selling his extra specimens at shows in the 1960s, and developed an interest in cut stones for collectors.

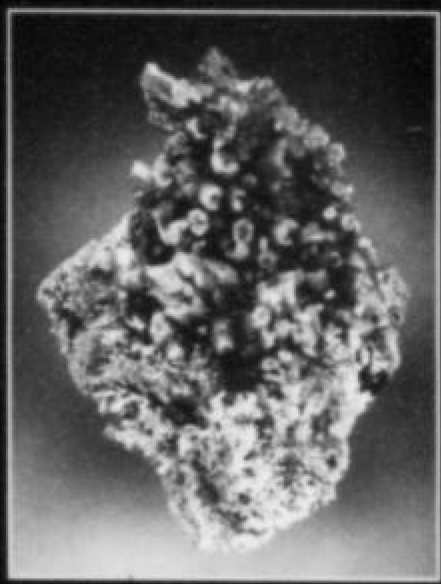
Roger was well-known and respected for his mineralogical and gemological knowledge, his willingness to help collectors (especially beginners and young collectors), and his good business reputation. He was a remarkable man in many ways, able to calculate cube roots in his head faster than a hand-calculator, and famous for his "Titeux quiche" recipe. He was passionate about music as well as mineralogy, and saw a parallelism of harmony and structure between the two subjects—"like the music of Bach and Mozart, solidified," he once said. Though less well known in America, he was a legend in France and helped to enrich the collections of many museums and private collectors there.

WEW



FLUORITE ON GALENA, 7.5 INCHES, ELMWOOD MINE, TENNESSEE




from the Collection of STEVE NEELY

PHOTOS BY JEFF SCOVIL

Kunzite, Corrego Do Urucum, Brazil. 8 1/2" long
wilensky photo

Sperrylite from the Talnakh Orefield, Norilsk Region

Eastern Siberia, Russia

Thomas M. Gressman[1]
Ivo Szegeny[2]
Wendell E. Wilson[3]

One of the most exciting specimens on display at the 1986 Munich Show was a sperrylite from the Talnakh orefield, Norilsk region. In the years since then, additional sperrylite specimens have occasionally been collected in the Oktyabr mine and sold on the Western mineral market, including some that rank among the finest known examples of the species. The Talnakh orefield is also the type locality for 33 species including many platinum-group-element minerals.

INTRODUCTION

The mines of the Talnakh (Талнах)[4] orefield in the Norilsk (Норильск) region of Siberia exploit some of the world's largest deposits of nickel, copper, cobalt and platinum-group elements. Prior to the discovery of the Talnakh sperrylite specimens, the only significant sperrylite crystals known were a very small number collected in the 1920s from a now-exhausted occurrence on the Tweefontein Farm in South Africa (Spencer, 1926; Cairncross and Dixon, 1995; Wilson, this issue), and some lesser crystals from the type locality at Sudbury, Ontario (Wells, 1889; Penfield, 1889; Walker, 1895; Goldschmidt and Nicol, 1903). Consequently it was quite a surprise in 1986 when the Russian collector Vladimir Pelepenko first exhibited a miniature matrix specimen with good crystals of sperrylite from the Norilsk region. His exhibit of Russian minerals at the 1986 Munich Show (Münchner Mineralientage) was the first such showing following the lowering of borders and restrictions under the Soviet Union's new philosophy of *glasnost*—"openness." There followed a flurry of activity in the sales of Russian mineral specimens to the newly accessible Western market, including small numbers of Talnakh sperrylite specimens that appeared regularly during the 1990s. These specimens are highly valued by mineral collectors today, especially in view of the fact that the locality has not produced any new specimens since about 1997.

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[3]The Mineralogical Record, 4631 Paseo Tubutama, Tucson, Arizona 85750 (minrecord@comcast.net)

[4]Transliteration notes: In Russian a suffix (-sky, -ski, -skiy, -skii, etc.) is added at the end of nouns when using them as modifiers (e.g. Oktyabr and Oktyabrsky). Our convention here, for consistency and to avoid confusion, is to leave off the suffixes. We also choose to eliminate the apostrophe that is sometimes used as a direct transliteration of the soft Cyrillic "ь" (e.g. Norilsk vs. Noril'sk).

LOCATION

The Talnakh orefield is located at the foot of the Talnakh hills, approximately 25 km north of the city of Norilsk on the Putoran Plateau, Taymyr Rayon, in the Central-Siberian Krasnoyarsk Kray, Russia (longitude 69°45'N, latitude 88°35'E). The Norilsk settlement was granted city status in 1953, becoming the northernmost

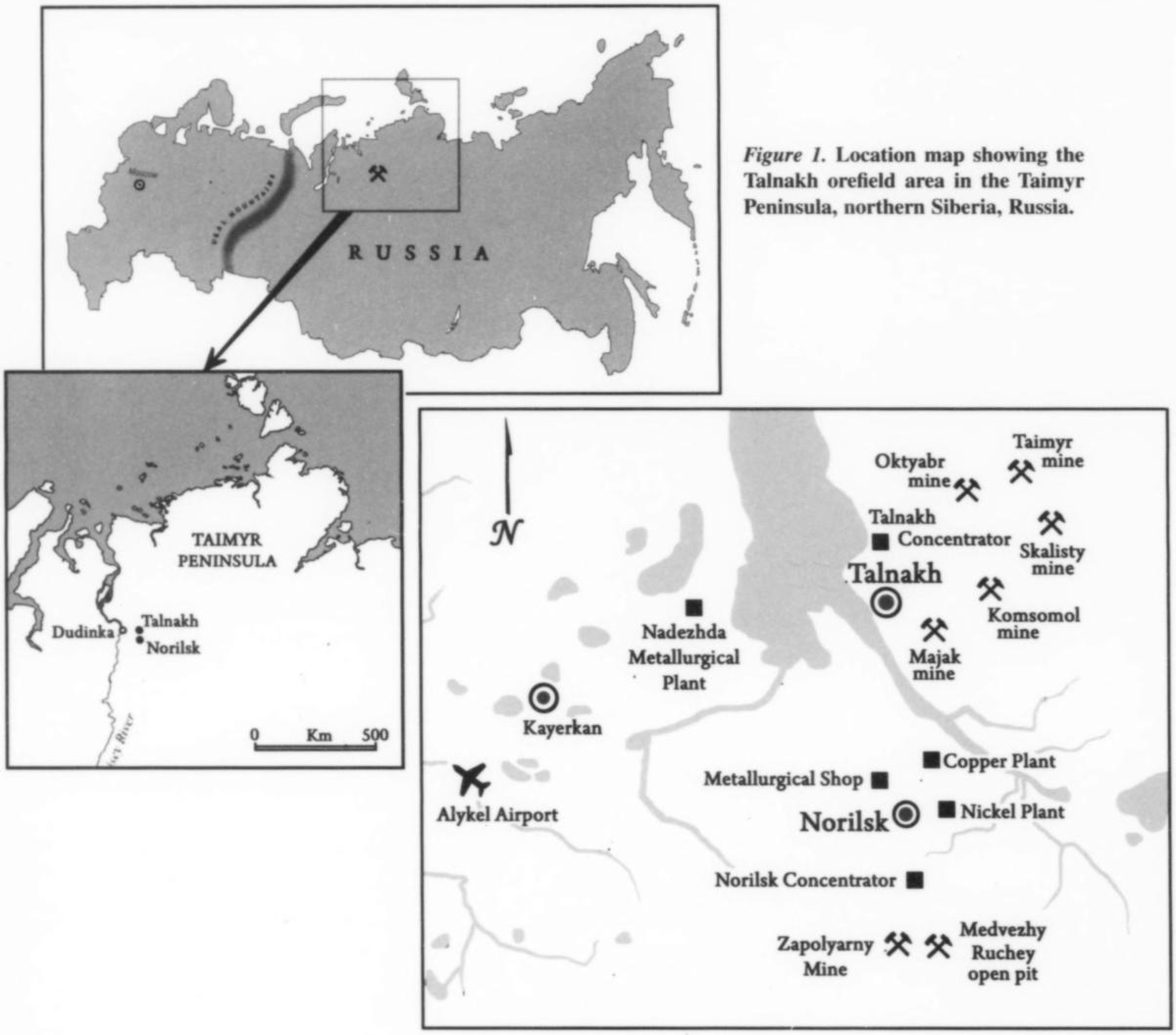


Figure 1. **Location map showing the Talnakh orefield area in the Taimyr Peninsula, northern Siberia, Russia.**

city in Siberia and the second largest city located above the Arctic Circle in the permafrost zone (the largest is Murmansk). Norilsk also has the distinction of being the northernmost city in the world with a population of over 100,000 (estimated population as of 2008 is 230,000). Talnakh, its satellite city about 40 km away, harbors a population of 70,000. There is no overland road or highway leading into the Norilsk/Talnakh area; access is solely by air and sea. A railroad links Norilsk with the Yenisei River port of Dudinka, and from there a fleet of nuclear-powered icebreakers leads interference for ore ships transporting the ore and concentrates via the Northern Sea Route to European Russia.

During the Cold War, Norilsk was designated as a "closed city" by the Soviet government because of the strategic importance of the metalliferous deposits, and because an inter-continental ballistic missile complex was located nearby. Following the collapse of the Soviet Union, the new Russian government was willing to open the city to outsiders; but the residents of Norilsk, wanting to protect their jobs by keeping out foreign laborers, voted in 2001 to keep the city closed.

Because of air pollution from the large smelting and metallurgical facilities located very near the city, Norilsk is considered to be one of the ten most polluted cities in the world. Not a single living tree exists within 50 km of the Nadezhda ("Hope") smelter. Kramer (2007) estimates that 1 percent of the entire global emissions of sulfur dioxide come from this one city. Heavy metal contamination near Norilsk is so severe that it is now economically feasible to mine the soil for the high concentrations of platinum and palladium that have been deposited from pollution. The Blacksmith Institute (2007) estimates that 4 million tons of cadmium, copper, lead, nickel, arsenic, selenium and zinc are released into the air every year by the Norilsk facilities.

HISTORY

A total of six major deposits have been discovered in the Norilsk district; thus far only three (the Norilsk-I, Talnakh and Oktyabr deposits) have been commercially mined. Ore is enriched at the Talnakh and Norilsk Concentrators. The Talnakh Concentrator processes ores mined at the Oktyabr and Talnakh deposits, producing nickel, copper and pyrrhotite concentrates. The Norilsk Concentrator processes all disseminated and cuprous ores from the Oktyabr and Talnakh deposits, as well as reserved pyrrhotite concentrates to produce nickel and copper concentrates (Norilsk Nickel, 2008).

Norilsk Deposit

Copper-nickel deposits were known to exist in the Taimyr Peninsula as far back as the 16th century (Kunilov, 1994); there is

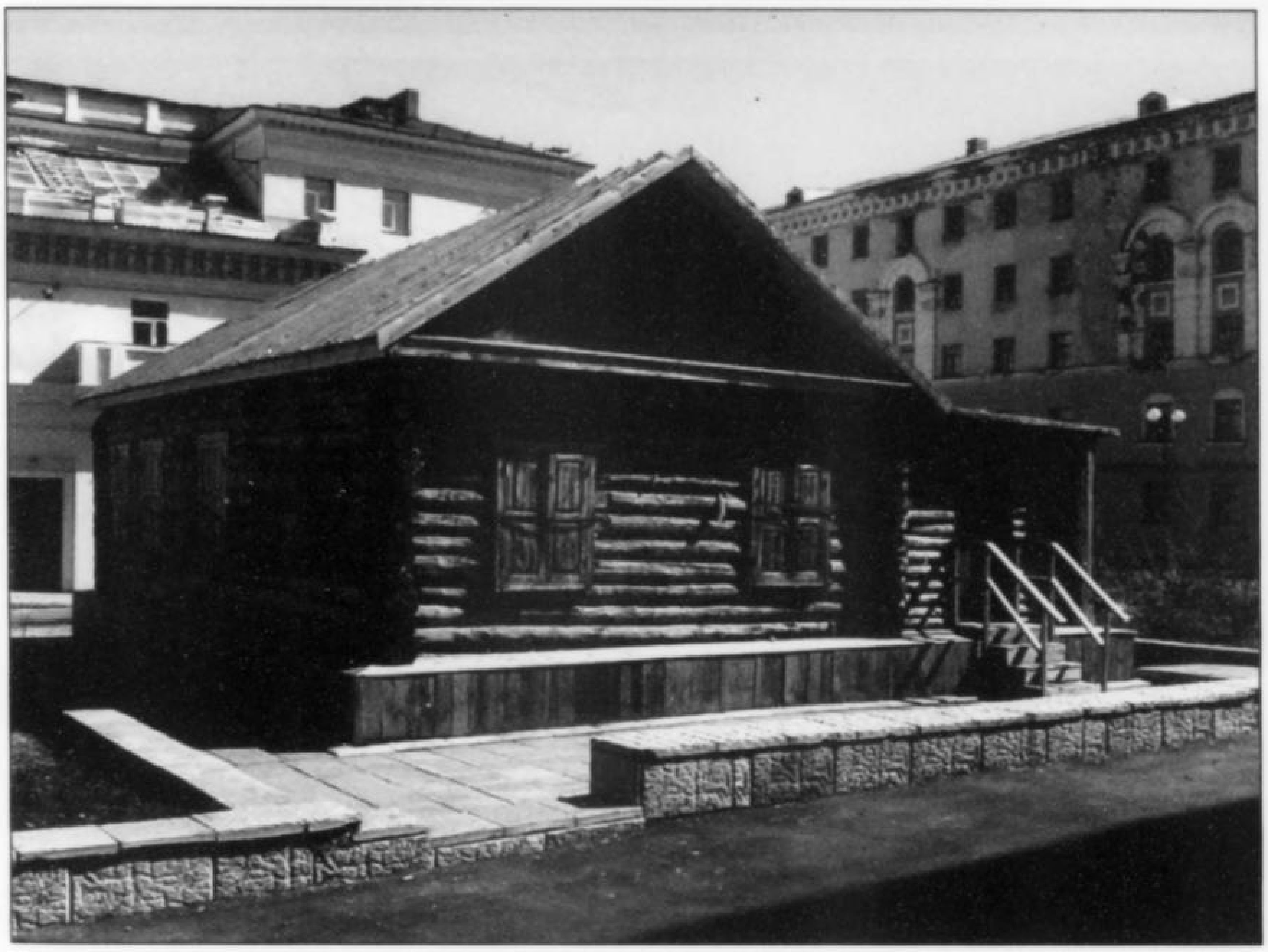


Figure 2. **Aerial view of the Talnakh mining complex on the east bank of the Kharaelakh River. The six square towers are headframe structures over Oktyabr mine shafts.**

Figure 3. **The first house built in Norilsk during the exploration phase in 1921.**

archeological evidence that an active smelting industry based on Norilsk ores existed at a settlement on the Taz River. Nevertheless, the economic potential of the deposit was not appreciated in modern times until 1919, when an expedition led by Nikolai Urvantzev came across the Norilsk-I orebody outcrop; he likened the ore to that found at Sudbury, Ontario. The first adit was opened around 1923, and the settlement of Norilsk was founded as exploration continued (Freidin *et al.*, 2007).

In 1935 the Council of Peoples' Commissars of the USSR passed a resolution "On Building the Norilsk Combine," and charged the Commissariat of Home Affairs (i.e. the Soviet security services, later known as the KGB) with developing the project. To provide the necessary labor force, Norilsk was established as the center of the Norillag system of Gulag labor camps. Thus ground was broken in 1936 for what was to become Russia's largest mining and metallurgical complex, located nearly 2,000 kilometers north of the Siberian city of Krasnoyarsk. According to the archives of Norillag, 16,806 prisoners (mostly political prisoners) died in Norilsk between 1935 and 1956, under conditions of forced labor, starvation and intense cold (Federal State Statistics Service). Fatalities were especially

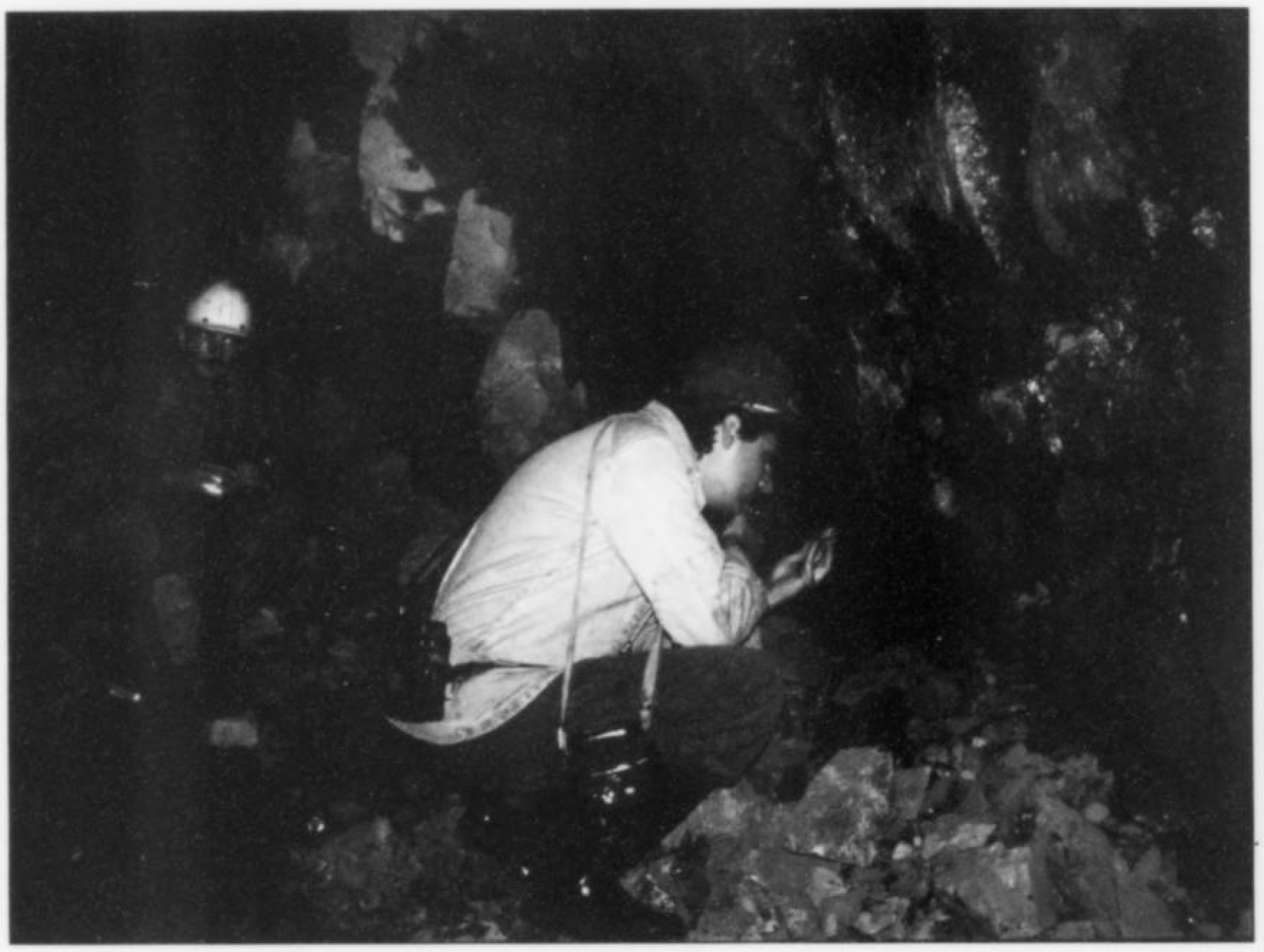


Figure 4. **Jaromir Tvrdy examining sulfide ore underground in the Komsomol mine. P. Kolesar photo.**

Figure 5. **Surface structures at the Oktyabr mine. P. Kolesar photo.**

high during the war years of 1942–1944 when food supplies were particularly scarce. Unknown but significant numbers of prisoners continued to serve and die in the mines until around 1979.

The first copper-nickel matte was produced in Norilsk in 1939. By the beginning of World War II the Norilsk Combine included a small metallurgical works, facilities for producing oxygen and coke, a machine shop, a temporary power station, three open-pit coal mines, three metal mines and others under development, plus sandstone and limestone quarries, a railway, an airport, and a port on the Yenisey River at the old town of Dudinka (founded in 1667). By 1953 the Norilsk Combine was producing 35% of the Soviet Union's total nickel output, 30% of its cobalt, 12% of its copper, and 90% of its platinum-group metals.

The Norilsk Combine operated the mines until 1989 when it was reorganized as Norilsk Nickel, a "State Concern for Non-ferrous Metals Production." In 1994 Norilsk Nickel was privatized to a Russian Joint Stock Company, and shares were sold to over 250,000 private investors. The Russian government, however, held the majority of the shares until they were transferred to Uneximbank in 1997 via a mortgage auction (McGlasson and Moore, 2001).

Today the Norilsk-I deposit is worked by the Medvezhy Ruchey ("Bear Creek") open pit and the adjacent Zapolyarny underground

Figure 6. **The Medvezhy Ruchey ("Bear Creek") open pit at Norilsk.**

mine. The Norilsk-I deposit is the type locality for the following species:

Manganoshadlùnite	$(Mn,Pb,Cd)(Cu,Fe)_8S_8$
Nickelhexahydrite	$(Ni,Mg,Fe)SO_4 \cdot 6H_20$
Stannopalladinite	Pd_5Sn_2Cu
Talnakhite	$Cu_9(Fe,Ni)_8S_{16}$
Vysotskite	$(Pd,Ni,Pt)S$
Zvyagintsevite	$(Pd,Pt,Au)_3(Pb,Sn)$

Talnakh Deposit

The Talnakh Cu-Ni deposit, 27 km north of Norilsk, was discovered in 1960 by the Norilsk geological prospecting expedition. The initial mine, called the Majak or Mayak ("Lighthouse") mine, was constructed by the youth wing of the communist party (the Komsomol). On April 30, 1964 the Central Committee of the Communist Party and the Council of Ministers of the U.S.S.R. created a decree that accelerated the development of the Talnakh Cu-Ni deposit with the stated goal of producing 77,000 tons of rich ore per year from an underground mine. The first three shafts at the Majak mine were completed ahead of schedule, allowing for mining operations to commence on April 22, 1965—Vladimir Lenin's birthday. The Majak 2 mine, the second mine in the Talnakh deposit, was renamed the Komsomol mine in 1965, in commemoration of the successful efforts of the Komsomol youth group.

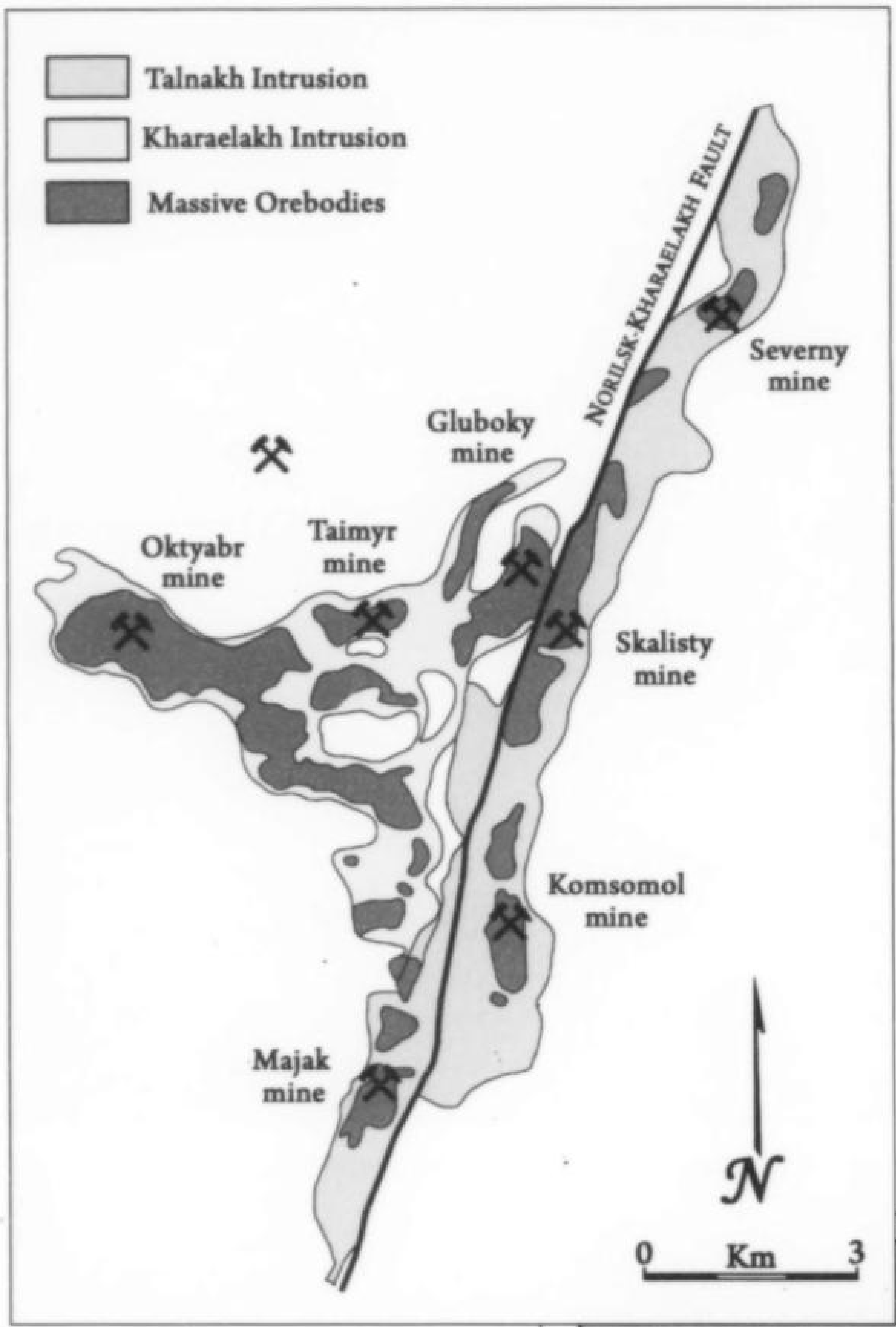
Much of the work at the Majak mine concentrated on prospecting for new ore deposits, whereas the Majak 2, now known as the Komsomol mine, was focused more on the development and utilization of new mining technologies and equipment. The Komsomol mine reached projected production expectations by 1975.

By early 1988 the Majak mine, the Komsomol mine and a third mine named the Skalisty ("Rocky") had been consolidated into a single mining complex. In 2003 this mining complex was designated collectively as the Talnakh Mining Administration. The Talnakh deposit is the type locality for the following species:

Godlevskite	$(Ni,Fe)_9S_8$
Kharaelakhite	$(Pt,Cu,Pb,Fe,Ni)_9S_8$
Majakite	$PdNiAs$
Manganoshadlunite	$(Mn,Pb,Cd)(Cu,Fe)_8S_8$
Nickelboussingaultite	$(NH_4)_2Ni(SO_4)_2 \cdot 6H_20$
Palarstanide	$Pd_8(As,Sn)_3$
Palladoarsenide	Pd_2As
Plumbopalladinite	Pd_3Pb_2
Polarite	Pd_2PbBi
Shadlunite	$(Pd,Cd)(Fe,Cu)_8S_8$
Taimyrite	$(Pd,Cu,Pt)_3Sn$
Talnakhite	$Cu_9(Fe,Ni)_8S_{16}$
Telargpalite	$(Pd,Ag)_3(Ti,Be)$
Thalcusite	$Tl_2Cu_3FeS_4$
Urvantsevite	$Pd(Bi,Pb)_2$
Vyalsovite	$FeS \cdot Ca(OH)_2 \cdot Al(OH)_3$

Oktyabr Deposit

The Oktyabr deposit was discovered in 1965, near the bank of the Kharaelakh River at the foot of Medvezhja ("Bear") Mountain. At first it was called the Kharaelakh deposit, but in 1967 it was renamed in commemoration of the 50th anniversary of the October Revolution (of 1918). Drilling on 50 × 50-meter and 100 × 50-meter grids down to a depth of 3,000 meters was undertaken to delineate the orebody and provide estimates of ore grade (Naldrett, 2004). Construction work began in 1969, and the first section of the mine was opened in 1974. Today the Oktyabr mine is the largest in the Talnakh orefield and accesses the richest ores. The mine has eight underground levels from 500 to 950 meters in depth, and produces 50% of the platinum recovered from all of the Norilsk Nickel



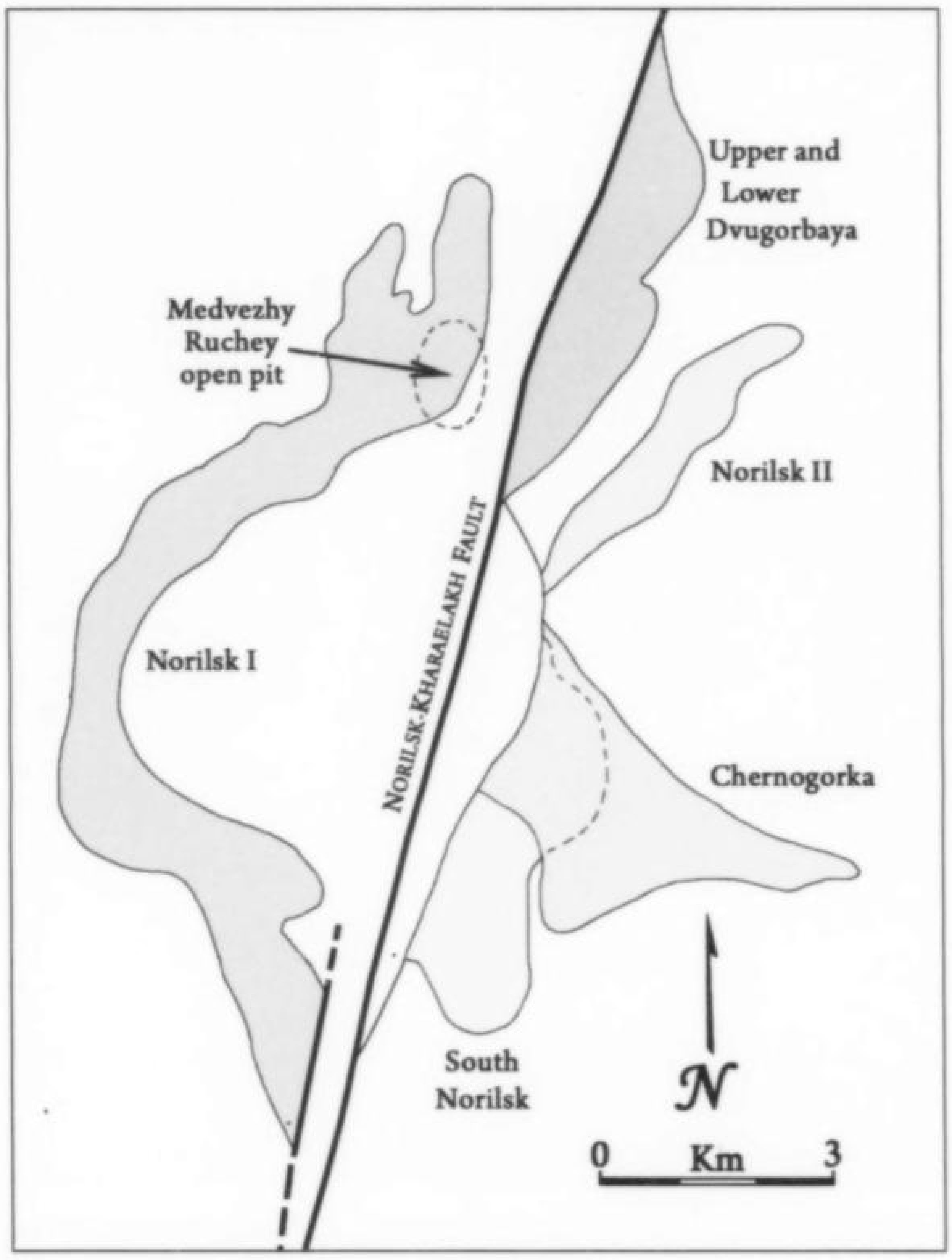


Figure 7 (above). **Simplified geologic map of the "Talnakh ore junction" showing the major clusters of orebodies relative to the two major intrusions and the Norilsk-Kharaelakh Fault. Mine locations shown are approximate, as the underground workings are extensive and often interconnect. After Arndt *et al.* (2003).**

Figure 8 (above right). **Simplified geologic map of the mineralized intrusions in the "Norilsk ore junction." (After Arndt *et al.*, 2003).**

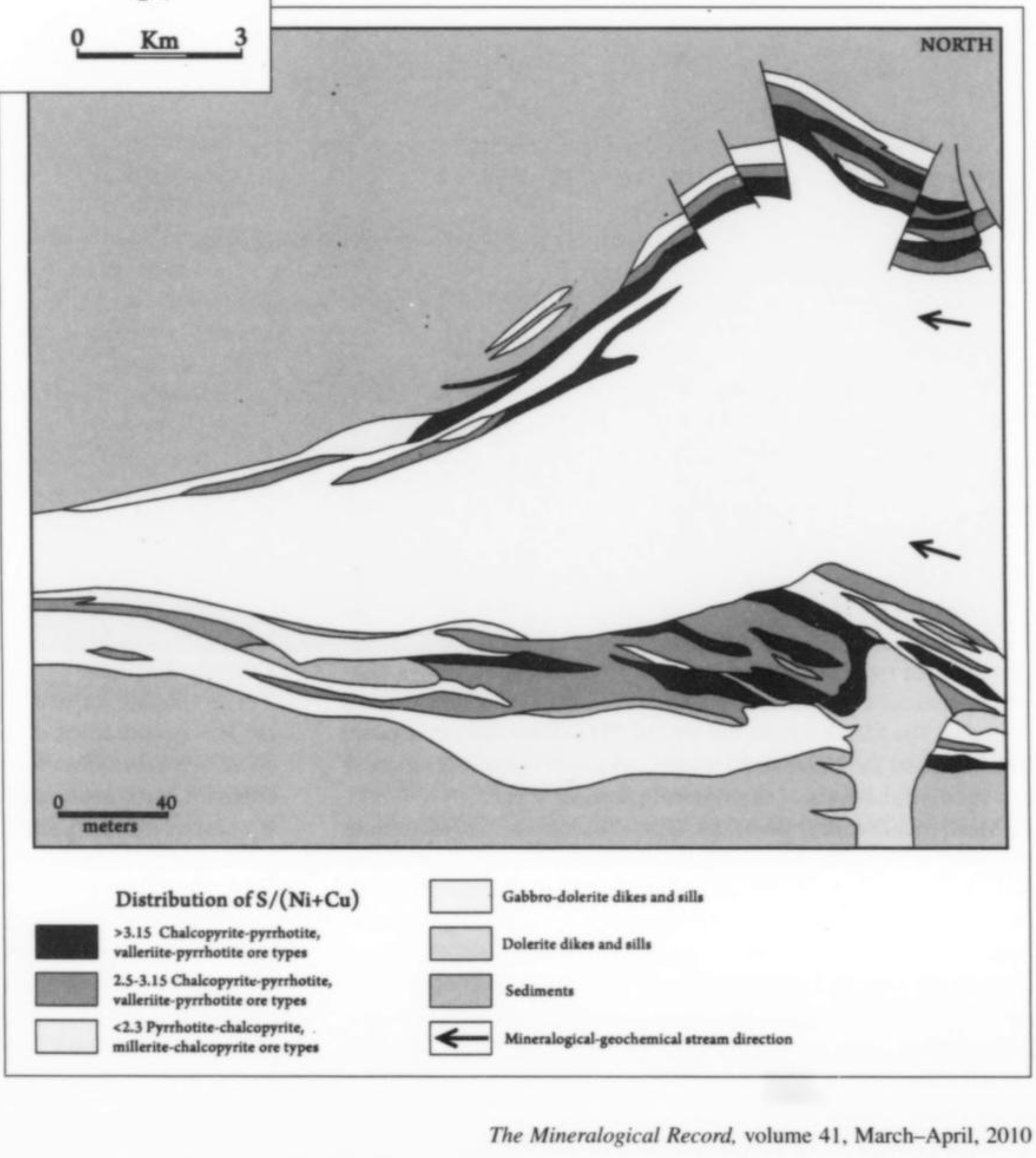


Figure 9 (right). **A vertical cross section through the Oktyabr orebody, about 270 meters thick at this point, showing the direction of movement of the precipitating magma and mineralogical-geochemical zoning of the sulfide ores at the bottom and on the roof of the magma chamber (after Stekhin, 1994).**

mines. Stopes are completely backfilled with concrete produced in an underground mixing plant; a total of 34 million cubic meters of stoping has thus far been backfilled in this way.

The remarkable lenticular orebody proved to be up to 50 meters thick in places. Its zoned structure is characterized by a sequence of ores composed of base-metal sulfides of the pyrrhotite and chalcopyrite groups in varying proportions, with magnetite, a number of rarer sulfides, silver-gold alloys and a surprisingly large array of more than 20 different platinum-group-element minerals (Genkin *et al.*, 1981).

The platinum-group-element mineral assemblages from the Oktyabr deposit are of two general types. The first type is associated with ores in which pyrrhotite-troilite exceeds chalcopyrite which in turn exceeds pentlandite. The minerals occur as metacrystals, veinlets and polymineralic intergrowths of sperrylite $PtAs_2$, the atokite-rustenburgite series $(Pd,Pt)_3Sn$, paolovite Pd_2Sn, and domains of $Pd_2(Sn,As)$, $Pd_2(As,Sn)$, Pd_5As_2 and $(Pd,Ni)_5As_2$. Assemblages of the second type form zoned intergrowths of Pd(Pt)-Sn-Cu minerals with silver-gold alloys in chalcopyrite-cubanite ores. Species found there include sperrylite $PtAs_2$, froodite $PdBi_2$, and majakite PdNiAs. Urvantzevite $Pd(Bi,Pb)_2$ is found primarily in the talnakhite-cubanite ore. Stannopalladinite Pd_5Sn_2Cu, taimyrite $(Pd,Cu,Pt)_3Sn$ and polarite Pd_2PbBi, among others, have also been found in the Oktyabr ores (Genkin *et al.*,1981; Distler *et al.*, 1999; Genkin and Evstigneeva, 1986; Barkov *et al.*, 2000).

Today the Oktyabr deposit is exploited by three mines: (1) the Oktyabr mine, (2) the Komsomol mine, and (3) the Taimyr mine. The Oktyabr deposit is the type locality for the following species:

Argentopentlandite	$Ag(Fe,Ni)_8S_8$
Bismutohauchecornite	$Ni_9Bi_2S_8$
Borishanskiite	$Pd_{1+x}(As,Pb)_2$
Cabriite.	Pd_2SnCu
Ferroskutterudite	$(Fe,Co)As_3$
Maslovite	PtBiTe
Paolovite	Pd_2Sn
Putoranite	$Cu_9(Fe,Ni)_9S_{16}$
Sobolevskite	PdBi
Tatyanaite	$(Pt,Pd,Cu)_9Cu_3Sn_4$
Telargpalite	$(Pd,Ag)_3Te$
Thalfenisite	$Tl_6(Fe,Ni,Cu)_{25}S_{26}Cl$

SPECIMEN RECOVERY

Specimens of sperrylite from the Talnakh orefield have been known at least since 1986, when Vladimir Pelepenko exhibited his specimen at the Munich Show. The 1990s saw sporadic but regular appearances of sperrylite specimens on the Western market. However, since 1997 there have been no new discoveries of sperrylite crystals, and dealer stocks of raw specimen material awaiting preparation have been dwindling. Consequently fewer sperrylite specimens have been available at shows in the U.S. and Europe.

This scarcity is also in part the result of strengthened security around Norilsk; there are now laws in place that make it unlawful to remove or even own specimens of precious metals. Norilsk is like a state within a state, and everything there, including sperrylite, is considered to be the property of Norilsk Nickel. Taking sperrylite specimens out, even to other Russian territories, is therefore regarded as theft by local authorities (i.e. by Norilsk Nickel), and it is furthermore forbidden to export sperrylite specimens outside of Russia. These laws were established to combat the smuggling of platinum and palladium by organized thieves, and unfortunately the comparatively harmless mineral dealers are caught in the same net. In 1998 a Russian mineral dealer was imprisoned and beaten for attempting to leave from the local airport on a flight to Moscow with sperrylite specimens in his possession. Since then there has been a further tightening of security by Russian authorities against anyone attempting to take sperrylite specimens out of the region.

Legal hindrances aside, additional finds are unlikely in the near future because platinum mineralization occurs in the lower areas of the orebody and these lower areas are not scheduled to be mined until 2012 or later.

GEOLOGY

The deposits of the Talnakh orefield are associated with gabbro-dolerite sill complexes interpreted as a sub-volcanic conduit system associated with olivine-bearing differentiated mafic intrusive bodies and an extensive Permo-Triassic flood basalt sequence known as the Siberian Traps (Naldrett and Lightfoot, 1995). This ore zone covers an area of approximately 1 × 3 km, at an average thickness of 20 meters. The deposit typically contains 27.4% copper, 2.5% nickel, 35.2 grams/ton palladium and 8.8 grams/ton platinum in the copper-rich zones (Naldrett and Lightfoot, 1993). Reserves are estimated at 555 million metric tons of ore containing 2.7% nickel, 8.1% copper and 160 million ounces of platinum. In addition, the elements Os, Co, Au, Ag, Te, Bi, Sn, Zn, Fe, Ti, Sb, As and S are recovered in commercial quantities from the ore.

Although it is accepted that the Norilsk deposits are not of meteoritic impact origin like the deposit at Sudbury, Ontario, researchers have been debating and evolving their views of the precise origin of the deposit (see, for example, Czamanske *et al.*, 1995; Diakov *et al.*, 2002; Naldrett, 2004 and 2005), in order to account for its complex geochemical peculiarities. Circulation of magma through the system of sills and chambers over millions of years, complicated by the presence of feeder pipes to surface volcanism and a major fault zone, appears to have permitted the concentration of sulfides and especially of the platinum-group elements. Magma ascending from a deep reservoir circulated through the chambers and sills of the system, enlarging them through thermal erosion, and then plunged back down to the reservoir. Naldrett *et al.* (1992) estimated that the amount of platinum-group metals in the deposit must have been concentrated from a volume of magma 200 times larger than that represented by the mass of the intrusions as they exist today.

The intrusions are surrounded by an intense metasomatic and metamorphic aureole that, in many cases, extends farther into the country rock than the thickness of the intrusions themselves, providing further evidence that the magma was not merely stagnant and cooling, but rather was continuously circulating and bringing renewed heat to bear on the contact rocks over a long period of time. The unusual ore minerals occur disseminated throughout the local volcanic country rock in veinlets and are concentrated especially in the aureoles surrounding the intrusive bodies. These aureoles are the most economically important of the various types of orebodies (Tvrdý and Kolesar, 1995; McGlasson and Moore, 2001; Naldrett, 2004).

MINERALOGY

Platinum-group-element minerals found in the Talnakh orefield (Distler *et al.*, 1999), in addition to those listed above as type species and various as-yet unnamed species, include:

Braggite	(Pt,Pd,Ni)S
Cooperite	(Pt,Pd,Ni)S
Geversite	$Pt(Sb,Bi)_2$
"Guanglinite"	Pd_3As
Hollingworthite	(Rh,Pt,Pd)AsS
Insizwaite	$Pt(Bi,Sb)_2$
Iridium	Ir

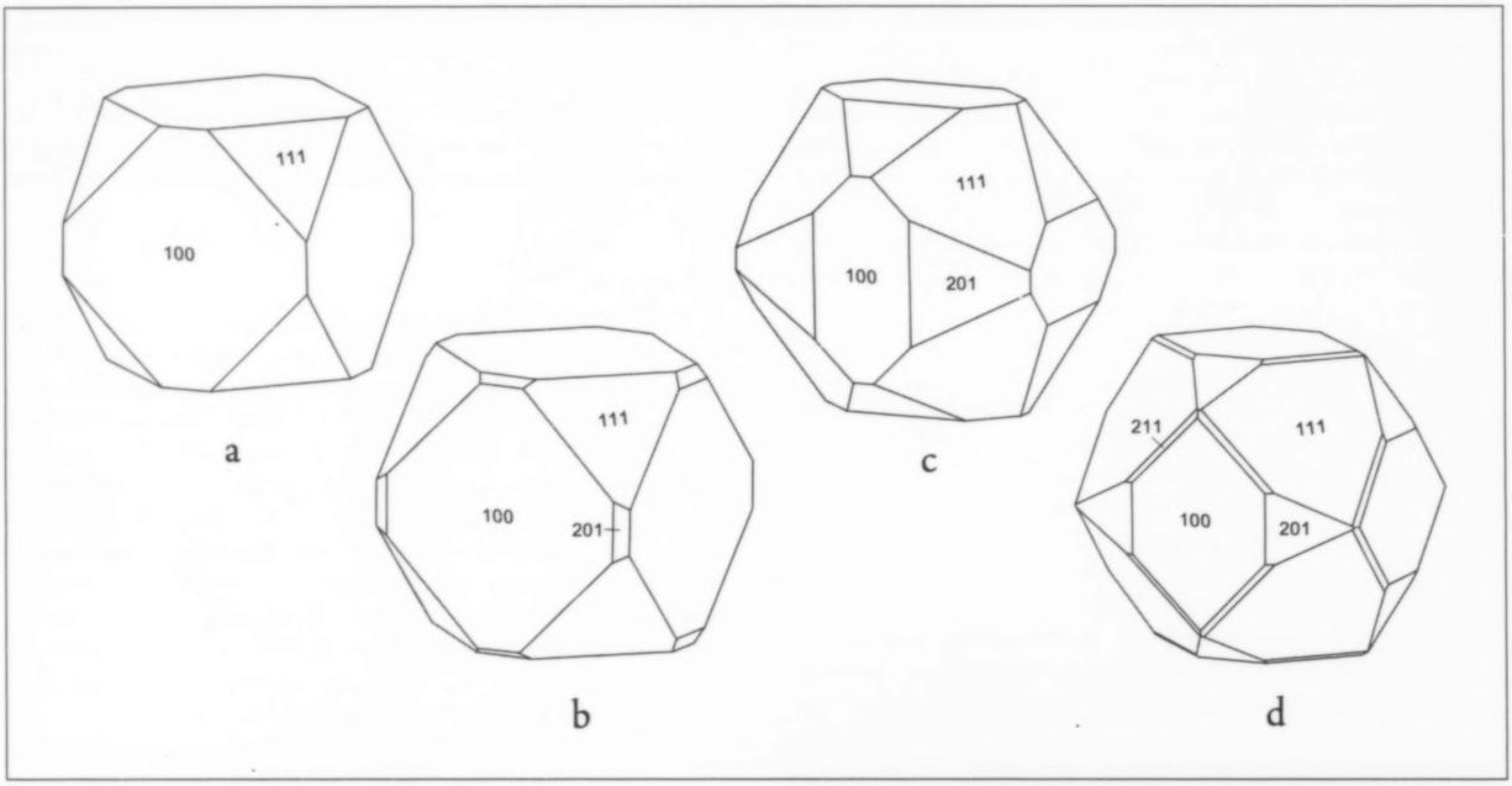


Figure 10. **Sperrylite crystal drawings showing typical habits for crystals from the Oktyabr mine: (a) simple cube {100} and octahedron {111} combination, (b) cuboctahedron modified by small pyritohedron {201} faces, (c) cube, octahedron and pyritohedron combination in equal development, and (d) cube, octahedron and pyritohedron combination modified by small, narrow trapezohedron {211} faces.**

Isoferroplatinum	Pt_3Fe
Isomertieite	$Pd_{11}Sb_2As_2$
Kotulskite	Pd(Te,Bi)
Merenskyite	$PdTe_2$
Mertieite-II	$Pd_8(Sb,As)_3$
Michnerite	PdBiTe
Moncheite	$PtTe_2$
Nigliite	PtSn
Palladium	Pd
Plumbopalladinite	Pd_3Pb_2
Rhodium	Rh
Sopcheite	$Ag_4Pd_3Te_4$
Sudburyite	PdSb
Tetraferroplatinum	PtFe
Tulameenite	Pt_2FeCu
Vincentite	$(Pd,Pt)_3(As,Sb,Te)$
Vysotskite	(Pd,Ni)S

The exotic sulfides which, in massive form, constitute the bulk of the ore include:

Mooihoekite	$Cu_9Fe_9S_{16}$
Putoranite	$Cu_{18}(Fe,Ni)_{18}S_{32}$
Talnakhite	$Cu_9(Fe,Ni)_8S_{16}$
Thalcusite	$Tl_2Cu_3FeS_4$

At least 280 mineral species had been identified from the district by the mid-1990s (Distler *et al.*, 1999; Genkin *et al.*, 1981; Tvrdý and Kolesar, 1995).

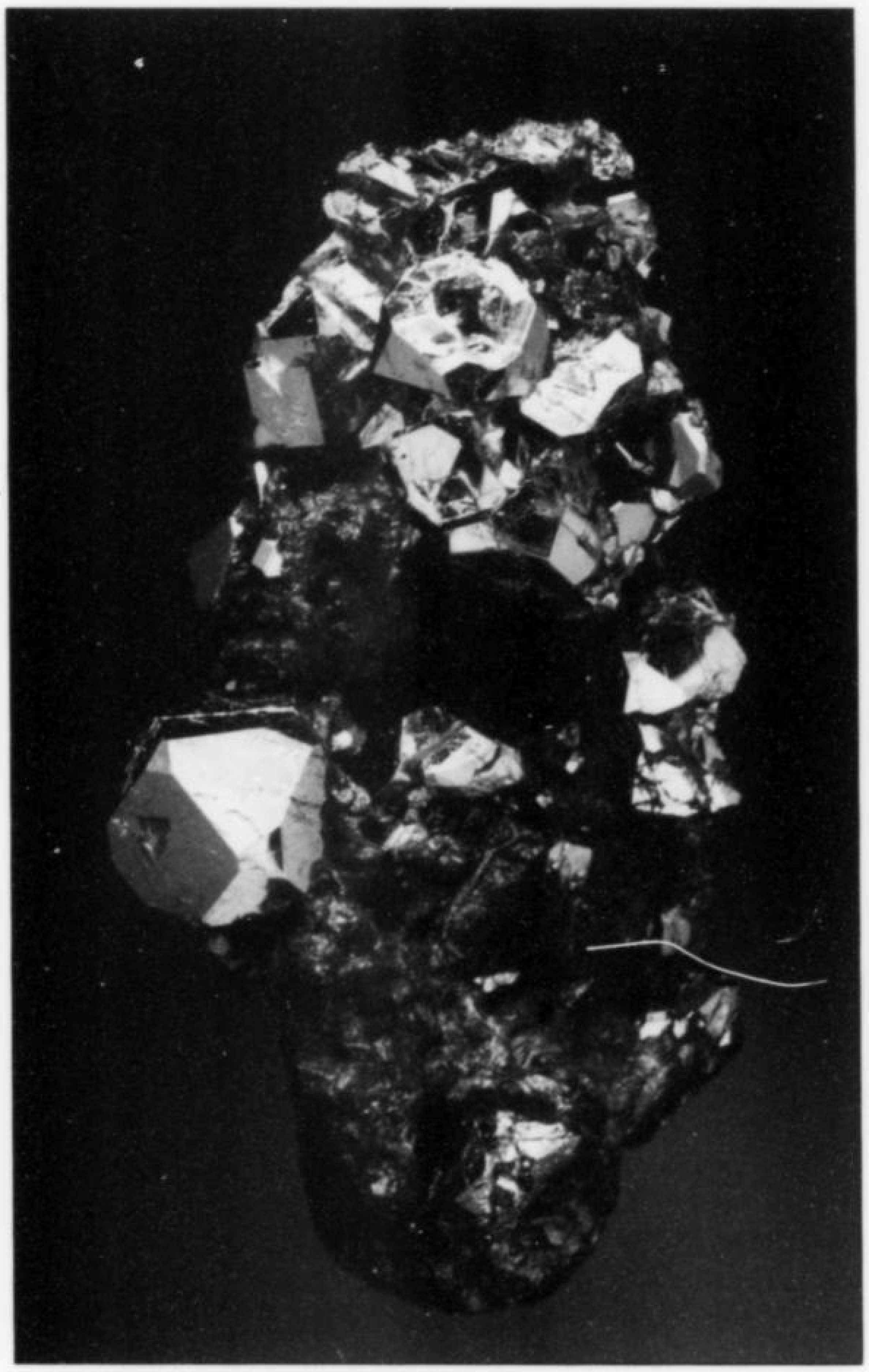


Figure 11. **Sperrylite crystals showing cube, octahedron and pyritohedron faces, 7.2 cm, from the Oktyabr mine. Collector's Edge Minerals specimen; Jeff Scovil photo.**

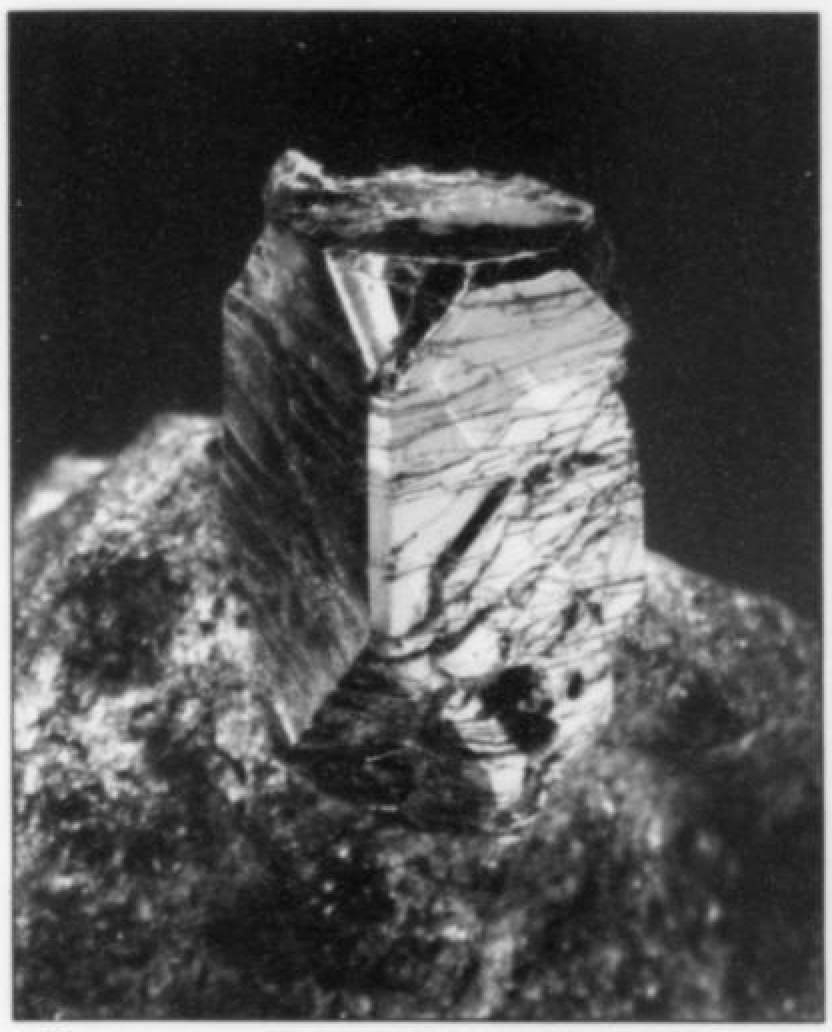


Figure 12 (above). **Elongated sperrylite crystal, 1.3 cm, in sulfide matrix, from the Oktyabr mine. Tom Gressman collection; Wendell Wilson photo.**

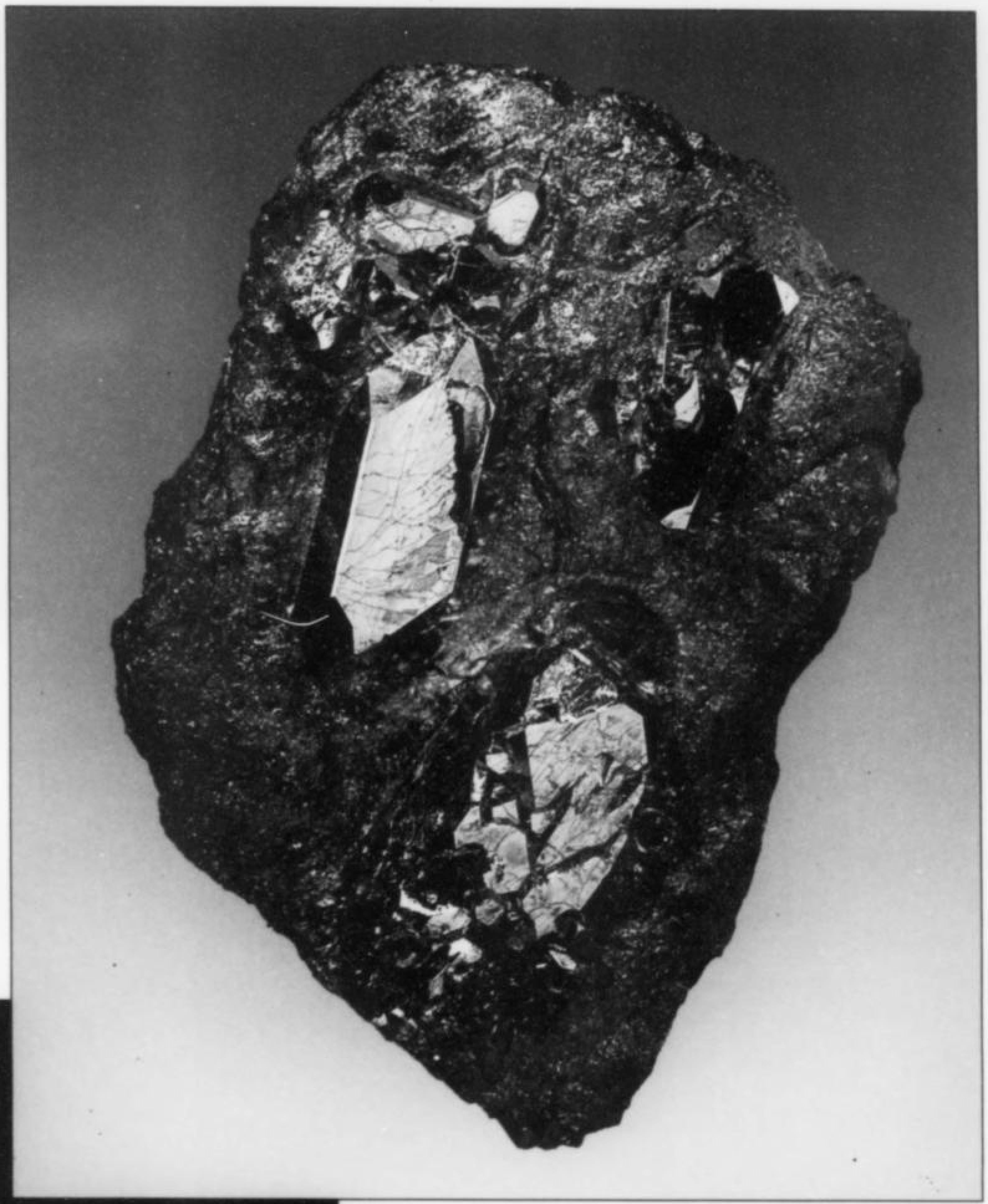


Figure 13 (right). **Elongated sperrylite crystals in sulfide matrix, 6.4 cm, from the Oktyabr mine. Stuart Wilensky specimen and photo.**

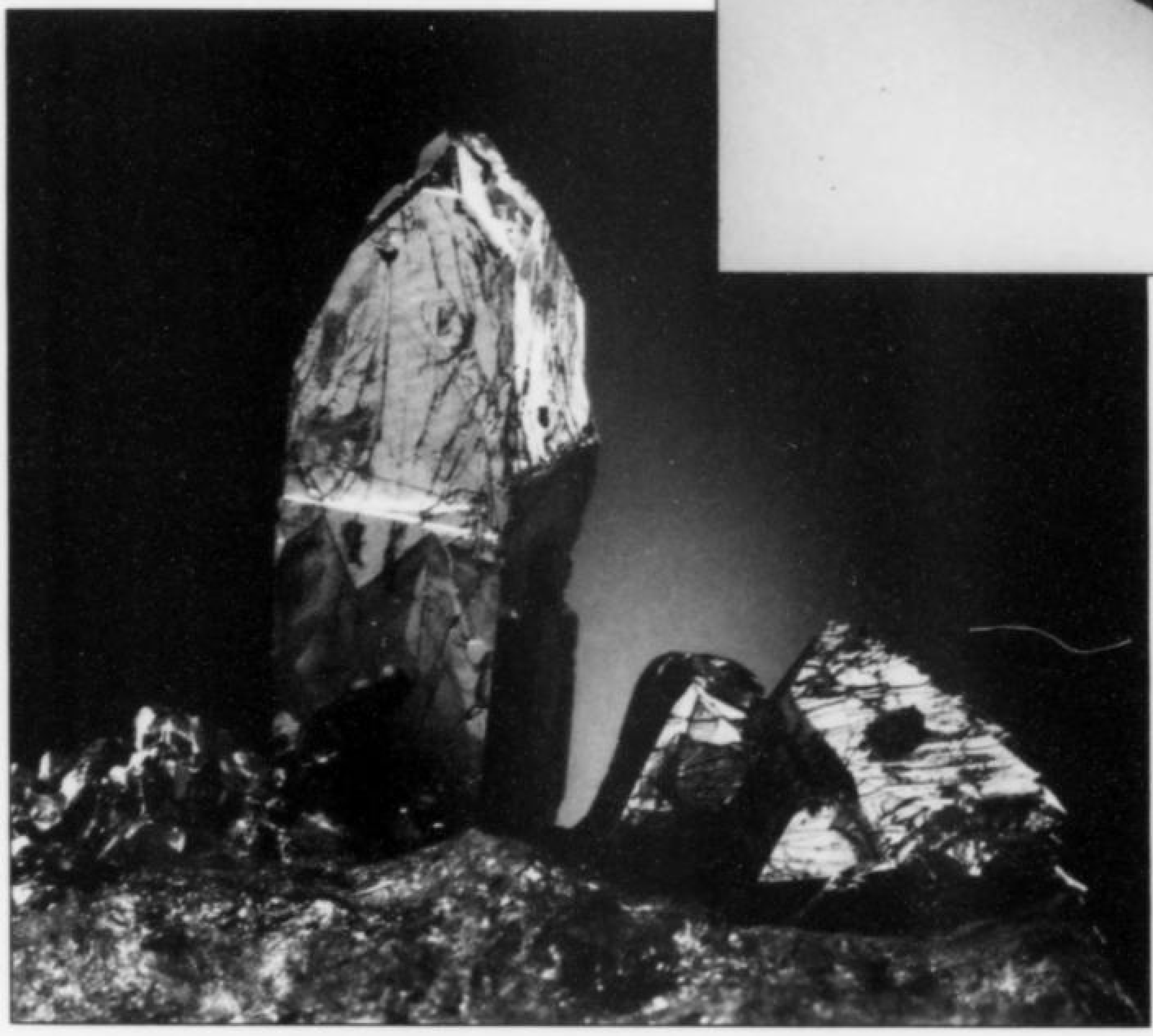


Figure 14. **Elongated sperrylite crystals to 1.6 cm in sulfide matrix, from the Oktyabr mine. Crystal Classics specimen; Jeff Scovil photo.**

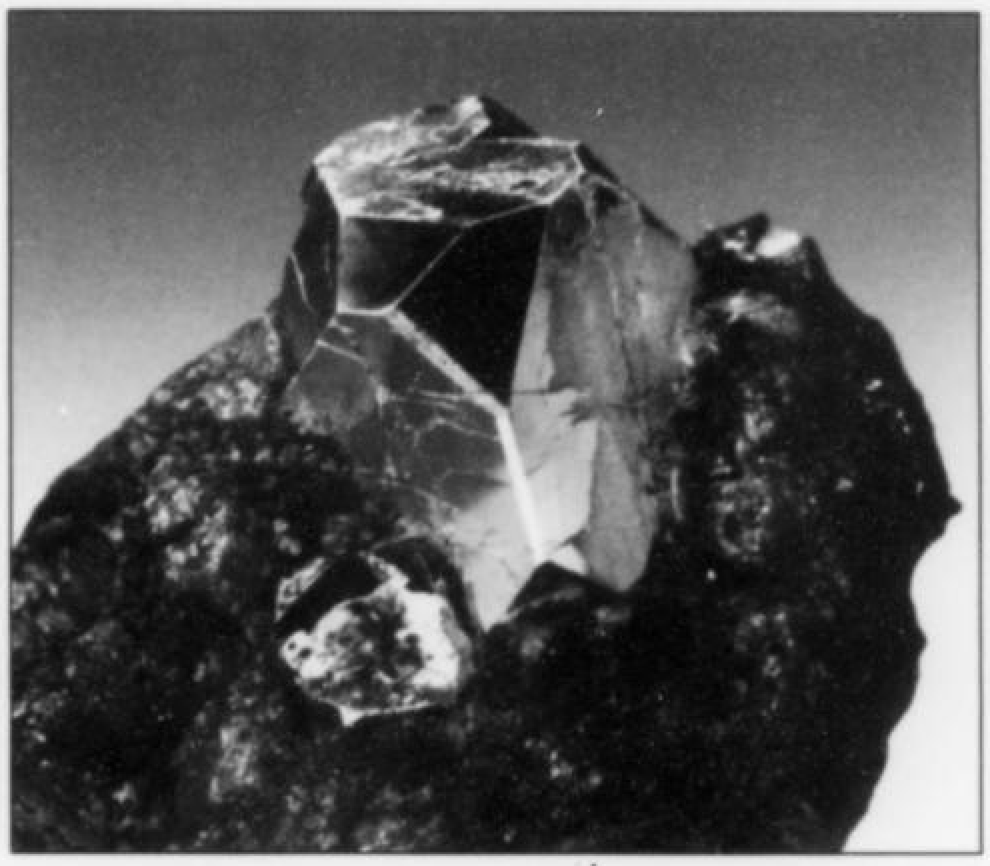


Figure 15. **Sperrylite crystal, 1 cm, showing cube, octahedron, pyritohedron and trapezohedron faces, from the Oktyabr mine. Wendell Wilson collection and photo.**

Overall, about 98% of the platinum occurs as discrete crystals of platinum-group-element minerals, whereas most of the palladium occurs in solid solution in pentlandite, in concentrations up to 1,600 grams per ton. The exceptions are seen in the Oktyabrsky mine, where about 50% of the palladium is incorporated into platinum-group-element minerals, and the Norilsk deposit where the figure is closer to 95%. Other platinum-group elements (rhodium, ruthenium, iridium and osmium) occur exclusively in solid solution in pyrrhotite and pentlandite (Naldrett, 2004).

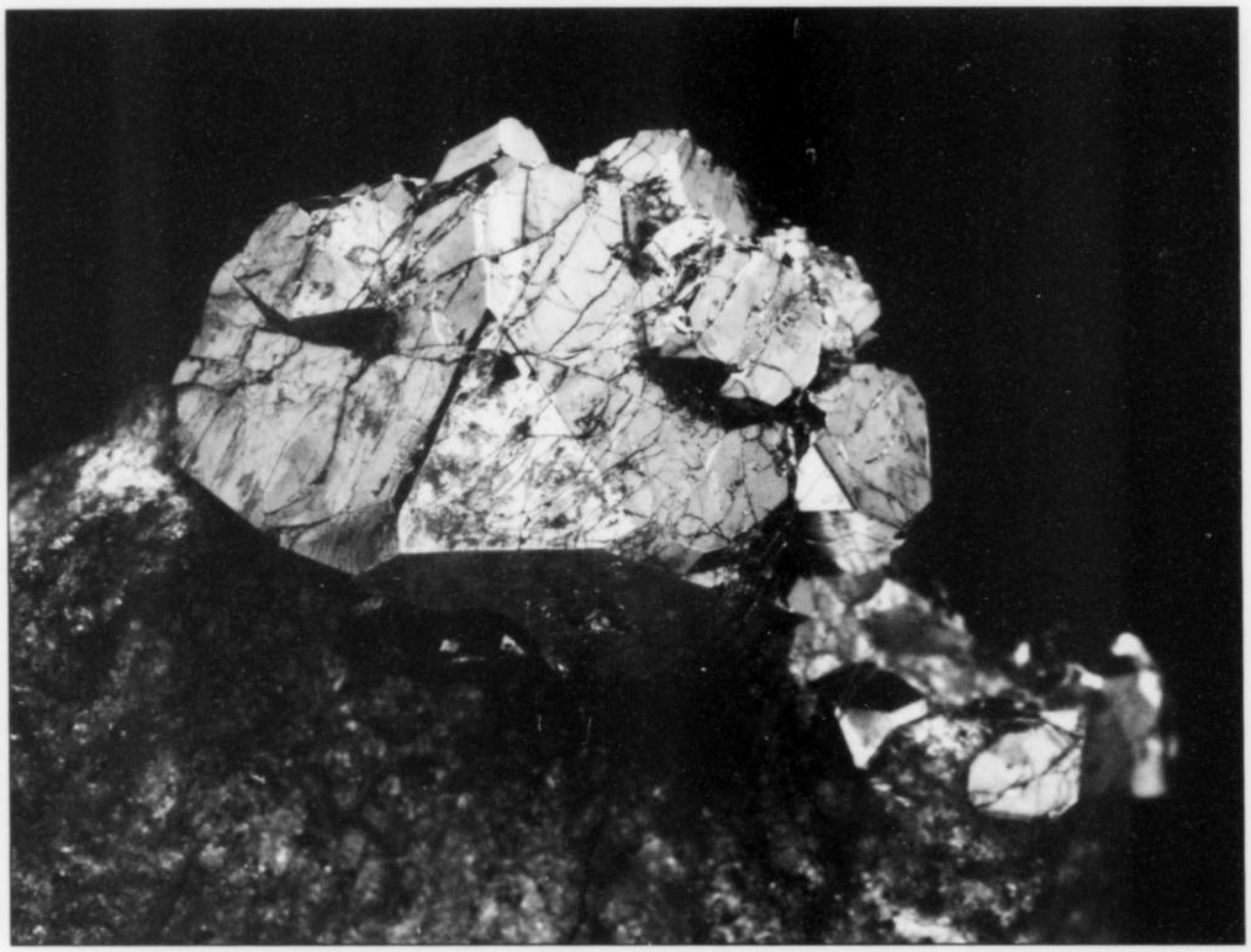


Figure 16. **Sperrylite crystals in chalcopyrite ore, 4.7 cm across, from the Oktyabr mine. Scott Rudolph collection; Jeff Scovil photo.**

Figure 17. **Sperrylite crystals in chalcopyrite ore, with rounded, dark gray crystals of cabriite (Pd_2SnCu), 9.4 cm, from the Oktyabr mine. Steve Smale collection; Jeff Scovil photo.**

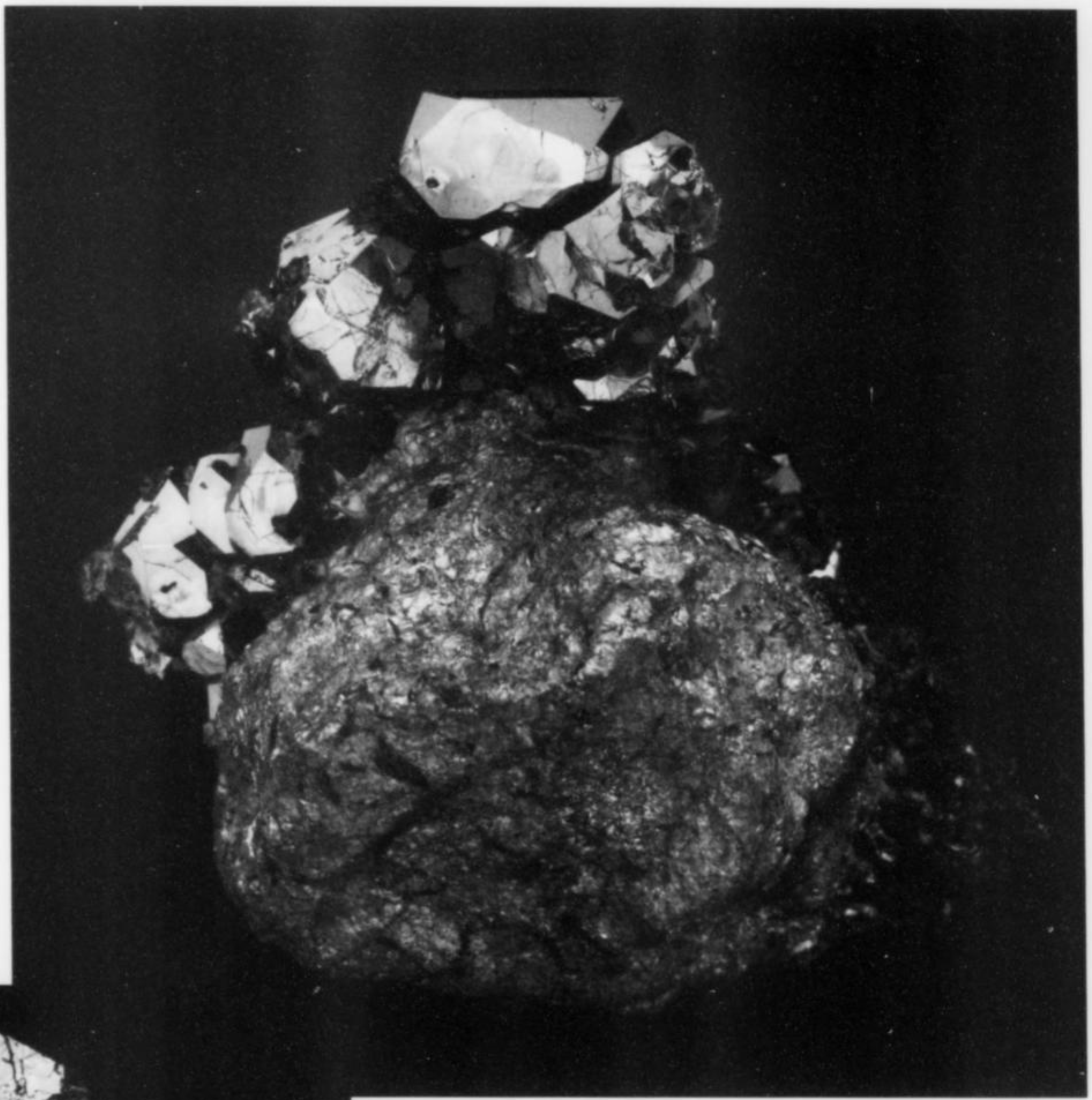


Figure 18. **Sperrylite crystals in chalcopyrite matrix, 5.5 cm, from the Oktyabr mine. Rice Northwest Museum of Rocks and Minerals collection; Jeff Scovil photo.**

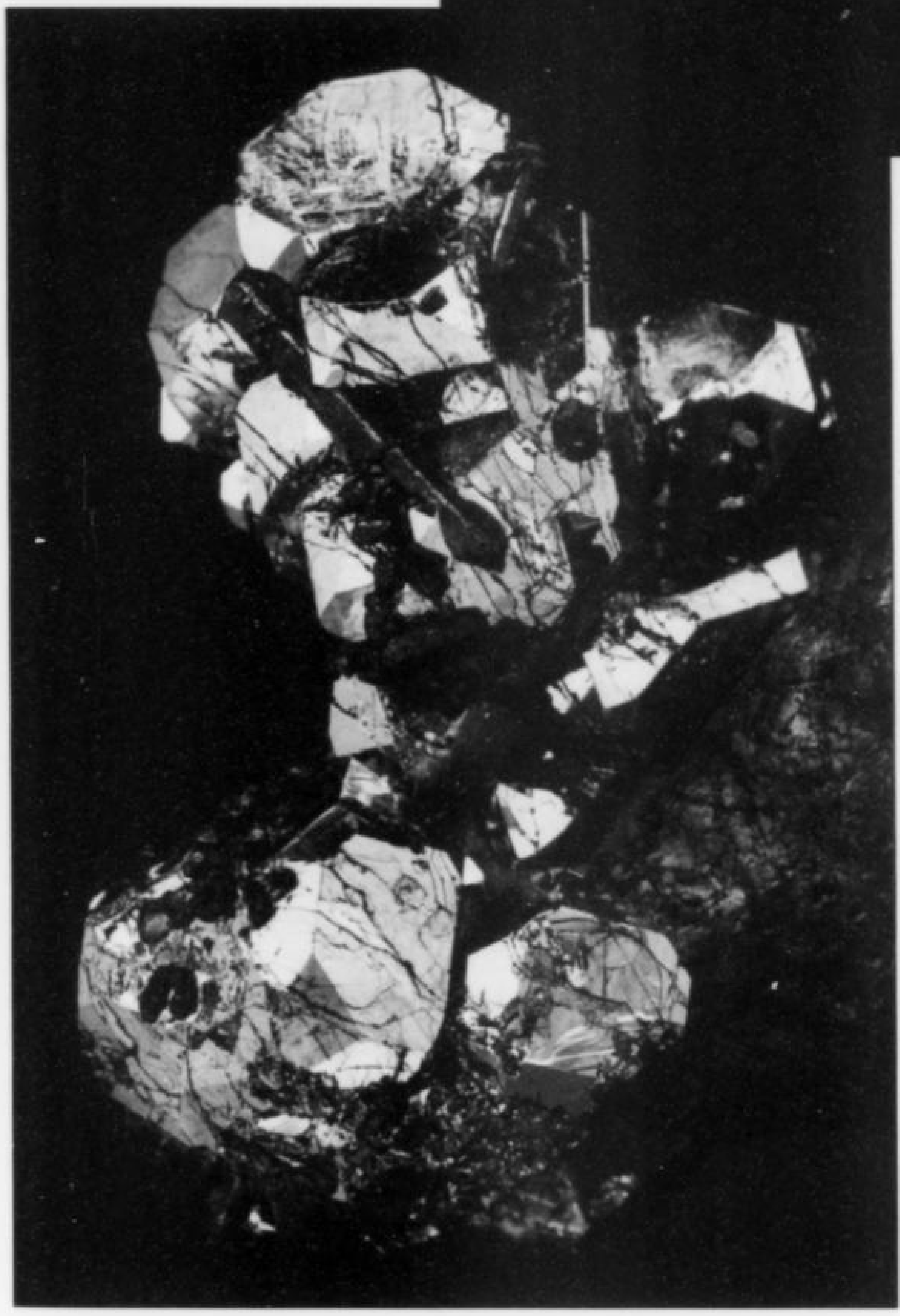


Figure 19. **Sperrylite crystal cluster with black magnetite crystals, on sulfide matrix, 3.2 cm, from the Oktyabr mine. Gail and Jim Spann collection; Jeff Scovil photo.**

Sperrylite $PtAs_2$

Sperrylite was first described by Wells (1889), based on material collected by the American chemist Francis L. Sperry (1861–1906) at the Vermilion mine, Sudbury district, Ontario. Sperry was chief chemist with the Canadian Copper Company of Sudbury at the time, and Wells named the new species in his honor.

The Tweefontein Farm in South Africa produced sperrylite crystals up to 2.6 cm in the 1920s (see Wilson, this issue), but this size record was surpassed in the 1990s by sperrylite discovered at Norilsk in well-crystallized cubes modified by octahedron and pyritohedron faces that reach over 4 cm on edge. Other forms appear to be present as well. Crystals are commonly elongated and may be cavernous on one side. Among the finest specimens is the one currently in the Rice Northwest Museum in Hillsboro, Oregon.

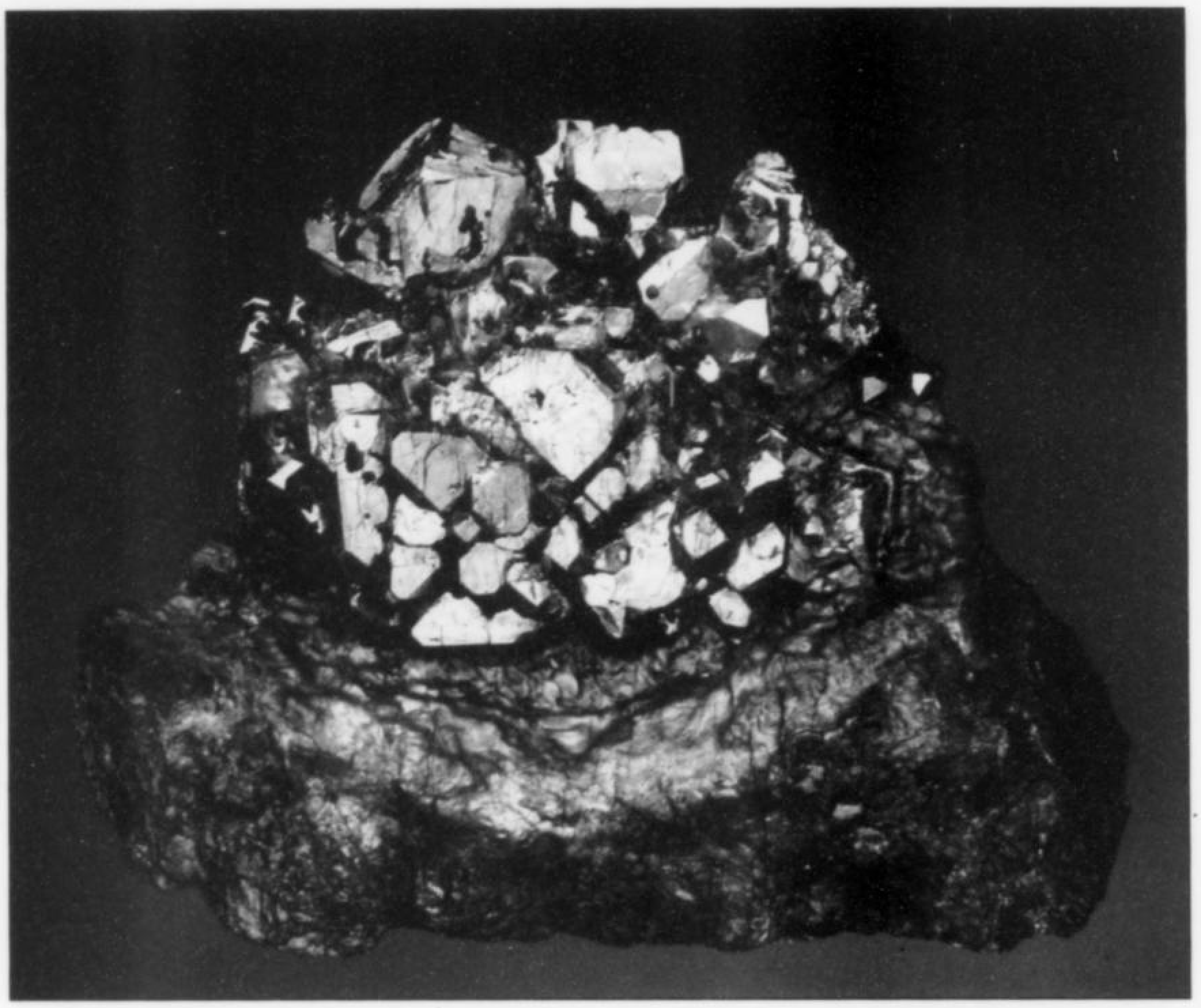


Figure 20. **Sperrylite crystal cluster in sulfide matrix, 7.8 cm wide, from the Oktyabr mine. KARP specimen; Jeff Scovil photo.**

Figure 21 (below). **Bronze-colored paolovite (Pd_2Sn) crystal group, about 5 mm, nestled into a sperrylite crystal, from the Oktyabr mine. This is the only known specimen of paolovite crystals large enough to be visible to the naked eye (identified by X-ray diffraction and microprobe analysis). William Pinch collection; Jeff Scovil photo.**

Another world-class sperrylite specimen shows crystals up to about 4.5 cm (of which 3.5 cm are visible) and a third specimen is known with a crystal cluster measuring 4.5 × 5.5 cm. A 4-cm sperrylite crystal cleavage in matrix has also been seen. But crystals of such dimensions are altogether exceptional; sharp crystals even in the 3 to 7-mm range are quite rare on the specimen market and are highly valued by collectors.

Sperrylite is tin-white to gray in color, and crystals typically have a brilliant luster similar to that of carrollite crystals from the Congo. There is no discernible cleavage, and the fracture is conchoidal. Norilsk sperrylite crystals are brittle and many have microfractures visible along the crystal faces. The fractures render them fragile, and some crystals have been known to fall apart even after the most careful work to free them from matrix.

Sperrylite occurs as fine-grained disseminations in most of the mines, but all of the known collector-quality sperrylite specimens from the Talnakh orefield were apparently collected in the aureole zone in the Oktyabr mine (Tvrdý and Kolesar, 1995; Barlow, 1996; Wilson, 2000; Larson, 2002; Trinchillo, 2008). A few are known to have come from the Majak mine as well, but they are grainy and unaesthetic; all of the good crystal specimens are from the Oktyabr mine.

Other Minerals

Paolovite occurs as disseminated blebs and microcrystals, but crystals to several millimeters are known from a single specimen (Fig. 21). Tvrdy and Kolesar (1995) noted a number of other species that occur in crystallized specimens in the Talnakh orefield, but because of the preeminence of collector interest in sperrylite, none have reached the specimen market. These include acicular **cubanite** crystals a few millimeters long, similar in appearance to millerite, and crude, embedded crystals of native **platinum** to 8 mm. From Talnakh: white **pectolite** "puff balls" on drusy crusts of colorless datolite; and crude, barrel-shaped black **wurtzite** crystals to several centimeters. From the Komsomol mine: clusters of green **ktenasite** microcrystals; acicular tufts of white **thaumasite**; tabular **apophyllite** crystals to 5 cm, some of them water-clear or showing growth zones; transparent, rhombohedral crystals of **calcite** in clusters to 5 cm; white **okenite** "puff balls" to 6 mm; attractive clusters of orange **stilbite** crystals to 6 cm; clusters of attractive pink **laumontite** to 6 mm; and sharp, lustrous **pyrite** crystals on pink apophyllite-encrusted matrix to 8 cm across. From the Oktyabr mine: honey-yellow **apophyllite** in thin, gemmy crystals on pink calcite to 4.5 cm. And from Norilsk: short prismatic **babingtonite** crystals.

Visiting Norilsk

Author Ivo Szegeny visited Norilsk and Talnakh about twice a year from the mid-1990s until 2000, and has never been underground there, but the following excerpts gleaned from his travel diary will give an idea of what such a visit is like:

Even in the dark, Norilsk fulfilled my expectations when I first visited there in 1994—A concerto of wire, concrete, pipelines, frost, wind, ice, snow, smoke and stink. Concrete houses in various stages of deterioration stood surrounded by smoke-belching smelters in a region that can only be called an ecological catastrophe. The smelters and metallurgical plants are located all around the city, so regardless of the wind direction it brings heavy air pollution into the city. It is a kind of broken-down hell on the 69th parallel, made even worse in the summertime by hoards of mosquitoes and heavy-metal-laden dust blowing off the mine dumps.

Everything here is built on permafrost, so even the nine-story apartment buildings have to be built atop concrete pilings like legs. Entrances often look like ice caves, sometimes full of vapor or pouring out waterfalls from broken pipes (or icefalls if the pipes break in winter). Most local residents would like to move away but they can't. They used to come here planning to stay for five or ten years and make some money, but hyperinflation in the early 1990s destroyed the value of their savings, and salary checks always come three to six months late.

The climate here is harsh. Medical research studies have shown that no one can live here in the cold and inescapable pollution for more than seven years without suffering a permanent impact on their health. Locals say that the cold by itself is not as bad as the sudden changes in atmospheric pressure and temperature, sometimes falling as much as 70°F in a few hours. Because of the dry air the cold winter temperatures of −70°F are not as uncomfortable as one might expect, as long as there is no wind; but the slightest wind at that temperature changes everything. And of course it is dark in the winter: the polar night lasts for six weeks with no sunshine at all, and at other times during the winter the sun does not rise very high above the horizon. Summers are short; as the local joke goes, a miner who was asked how the summer had been in Norilsk replied that he'd heard it was nice, but unfortunately he was working his underground shift at the time and missed it.

The severity of the climate, however, tends to bring people closer together. I was invited to a wedding feast; by the third day of the celebration the music and dancing on the seventh floor could still be heard from the entrance down on the ground floor. There was food, vodka and fun that one simply could not refuse.

In December of 1994 a steam plant in Talnakh broke down, and all heat to the apartments in the area was cut off. People switched to their electric heaters, all at the same time, and the local electric transformer burst into flame. No heat, no hot water, no electricity. Many houses froze and their hot water radiators also froze solid and cracked. Temperatures fell below 0°F inside the apartments. It took weeks for everything to be replaced or fixed; the women and children moved into the kindergarten building in an unaffected part of town while the men stayed to guard their property from thieves gathering together drinking vodka in the dark. Even by March I could see 20-meter-high, 5-meter-wide rusty ice flows covering apartment buildings. As a friend of mine told me, "You can exist here, but you can't really live here."

Even for an outsider like myself, *leaving* Norilsk is not so easy. Waiting in line in the cold and wind for limited-capacity buses to the airport can be brutal, and because of the unpredictable weather the airport might close at any time—for a few hours, a few days, or even a week. I was lucky that first time in 1994; my flight was delayed for only 11 hours. But ticket availability was often very limited, and tickets could not be purchased in the Czech Republic where I live, so I had to wait until arriving in Russia to buy tickets for flights onward, which made for good training in improvisation. During some of the flights I have flown on the worst airplanes in my life, but there was no other option at the time.

Since the mid-1990s the situation has definitely improved somewhat in Norilsk and Talnakh, and I could see changes taking place even in 2000 when I visited the area for the last time. The mines were paying good wages again. But I suspect the global financial crisis of the last year may have hurt the local economy.

SPECIMEN PREPARATION

Although mechanically removing matrix from around sperrylite crystals is possible, there is a great danger of damaging the crystals in the process. Where crystals are partially embedded in ultrabasic rock instead of sulfides there is no alternative. But fortunately the high hardness of sperrylite (6–7 on the Mohs scale) makes it possible to expose crystals embedded in softer massive chalcopyrite/talnakhite ore by air-abrasive techniques. It is necessary to select the type of abrasive powder carefully to assure that it does not cause even microscopic damage or fracturing to the sperrylite. A material softer than glass beads is recommended.

Some preparators prefer to begin by X-raying blocks of ore from several directions in order to locate sperrylite crystals inside and determine their orientation. The tedious process of wearing down the enclosing chalcopyrite/talnakhite slowly and carefully with the air-abrasive powder can require many hours of work. But the effort is worth it. Professionally prepared specimens show sharp-edged, brilliant sperrylite crystals and crystal clusters perched on contrasting golden yellow chalcopyrite matrix.

THE NORILSK MUSEUM

The Talnakh Branch of the Norilsk Museum of Settlement and Development of the Norilsk Region has three showcases exhibiting about 70 mineral and ore specimens from the district, but there is no particular classification or emphasis on rarities. Another 400 specimens are exhibited in an "ore genesis" display, sponsored

Figure 22. **Exhibit of mineral and ore specimens in the Talnakh Branch of the Norilsk Museum of Settlement and Development of the Norilsk Region.**

by the former president of Norilsk Nickel, Mr. Prokhorov. Unfortunately the most complete collection of about 3,500 specimens from Talnakh/Norilsk and elsewhere was destroyed in a fire at the company storage facility in Norilsk in 1995.

CONCLUSIONS

Whether more of these brilliant metallic crystals from Siberia will emerge on the collector market remains unknown. There is certainly more of the crystal-rich zone left to be mined, but it is at a depth of 1,600 meters and will probably not be mined for at least five to ten years. The harsh Russian laws being enforced against taking sperrylite out of the area have also discouraged the preservation of additional specimens. This situation seems unlikely to change in the future.

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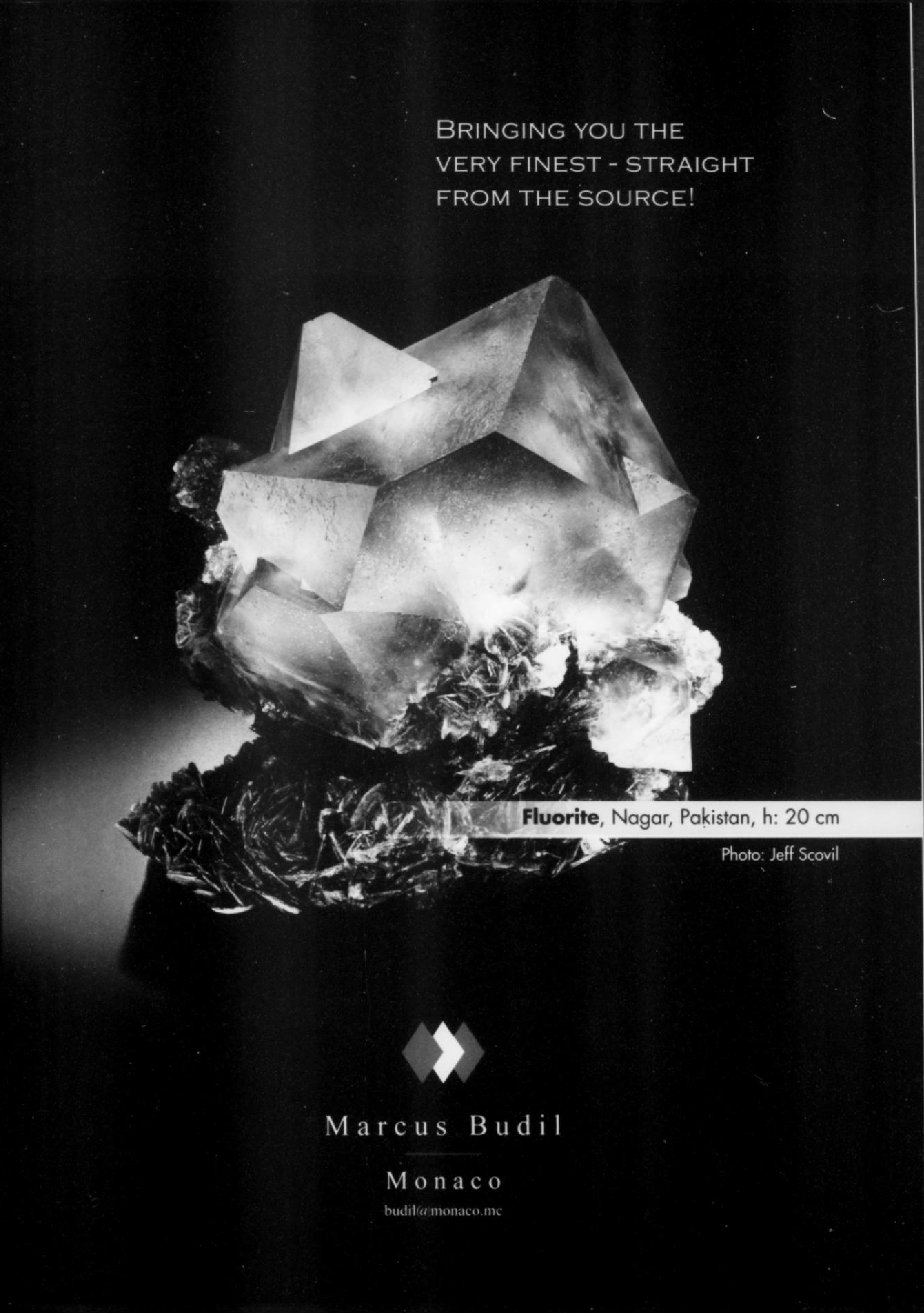
BRINGING YOU THE
VERY FINEST - STRAIGHT
FROM THE SOURCE!
Fluorite, Nagar, Pakistan, h: 20 cm
Photo: Jeff Scovil
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SPERRYLITE FROM THE TWEEFONTEIN FARM

Limpopo Province, South Africa

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For over 80 years the Tweefontein farm in the Transvaal province of South Africa has been famous among mineralogists and mineral collectors for producing some of the world's largest and finest crystals of sperrylite. The Tweefontein farm is also the type locality for stibiopalladinite.

INTRODUCTION

Until the discovery of large, well-formed sperrylite crystals at the Oktyabrsky mine in the Norilsk region of Siberia in the mid-1980s, the Tweefontein farm in the Transvaal, South Africa, was the undisputed premier locality for the species. Unfortunately the occurrence there produced very few specimens, and even most major museums do not own an example. Were it not for the entry in Bancroft's *World's Finest Minerals and Crystals* (1973), most mineral collectors today would probably still be unaware of this extraordinary occurrence.

LOCATION

The abandoned workings of the Tweefontein mine are located on Tweefontein[1] farm plot 238 KR (formerly 1033), about 14 km north-northwest of the town of Mokopane (formerly Potgietersrus[2]) in the southern part of the Tweefontein farm, in the Potgietersrus district of the former Transvaal Province (subdivided in 1994; now called Limpopo Province), South Africa. Access is by highway north from Pretoria to Mokopane, and then by road north-northwest to the mine area. The Tweefontein farm 238 KR workings, in the northern limb of the Bushveld Complex, should not be confused with the Tweefontein Chrome mine located south of Steelpoort in the eastern limb of the Bushveld Complex.

HISTORY

Platinum was first discovered in South Africa in 1923 by Mr. A. Erasmus, a prospector who was panning the ground from termite mounds about 31 km southwest of the town of Potgietersrus. The results led him to the Waterberg lode deposits, which became the first platinum mine in South Africa, worked from 1924–1927. In September 1924, Hans Merensky (1871–1952) and Andries Lombaard discovered an extensive platiniferous orebody (now known as the Merensky Reef[3]) on the Maandagshoek farm near Steelpoort in the Transvaal Province. The orebody runs along the eastern edge of the eastern limb of the mafic Bushveld Complex, an ancient igneous complex over 2 billion years old. Merensky and his colleagues traced the outcrop of the reef for some 80 km. Following the discovery a "platinum rush" to the area took place as miners scrambled for prospecting options in both areas.

In 1925 Merensky identified an even more promising occurrence

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[1]The name *Tweefontein* = "Two springs."

[2]Spelled "Potgietersrust" in earlier literature.

[3]The term *reef*, as used by South African geologists, does not refer to an organic deposit like a coral reef but rather is a provincial term for a linear outcropping of a metalliferous deposit.

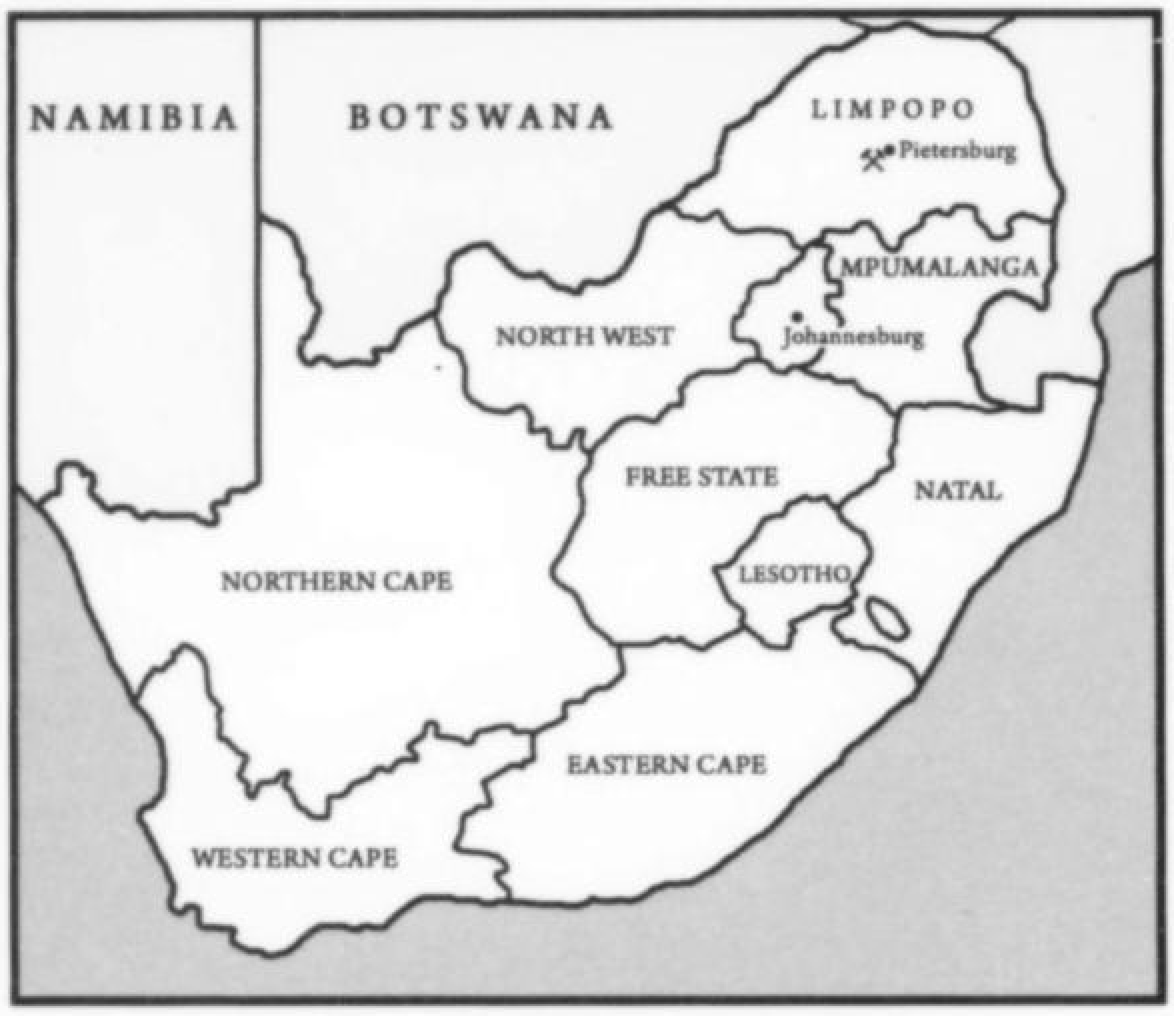


Figure 1. **Location map—South Africa.**

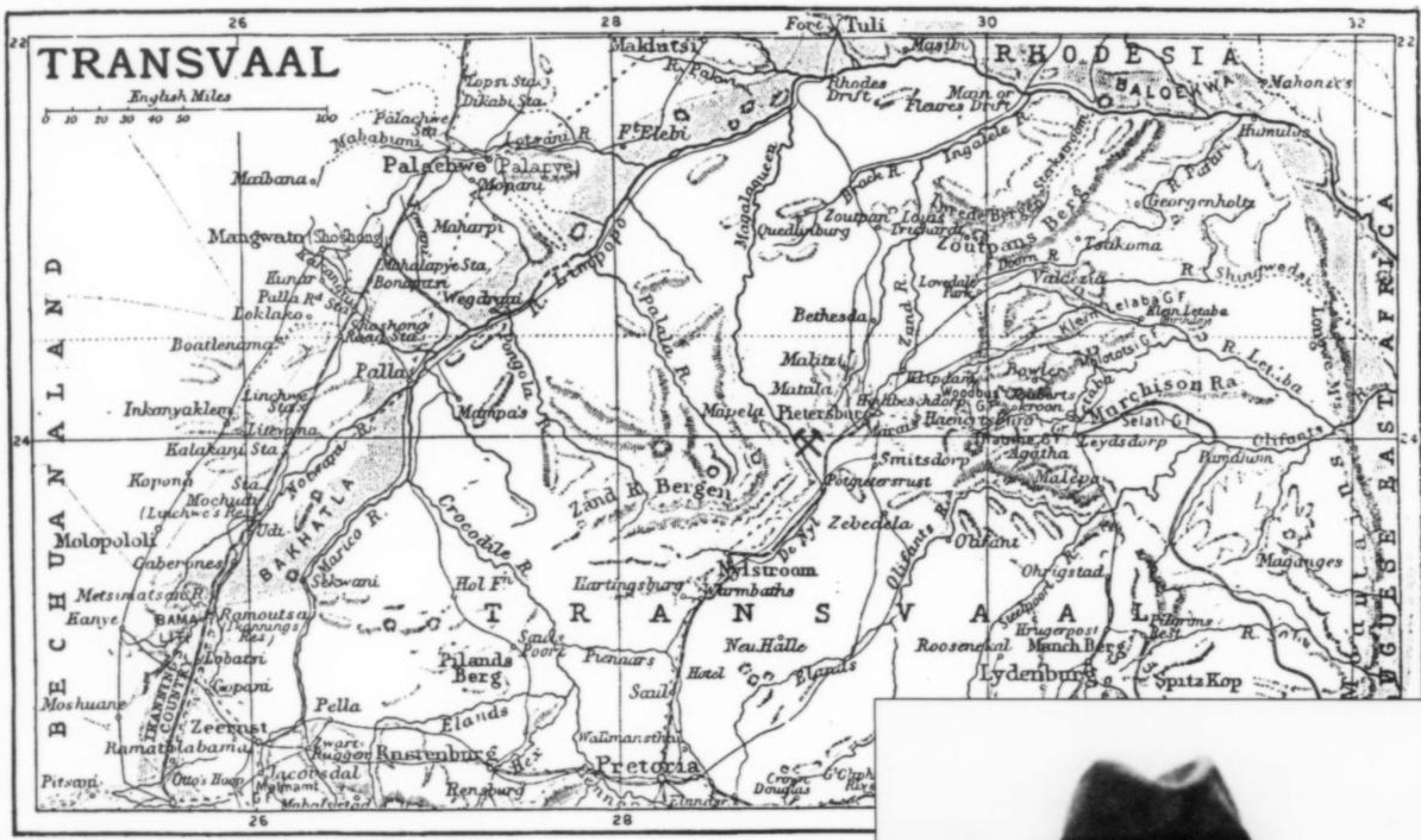


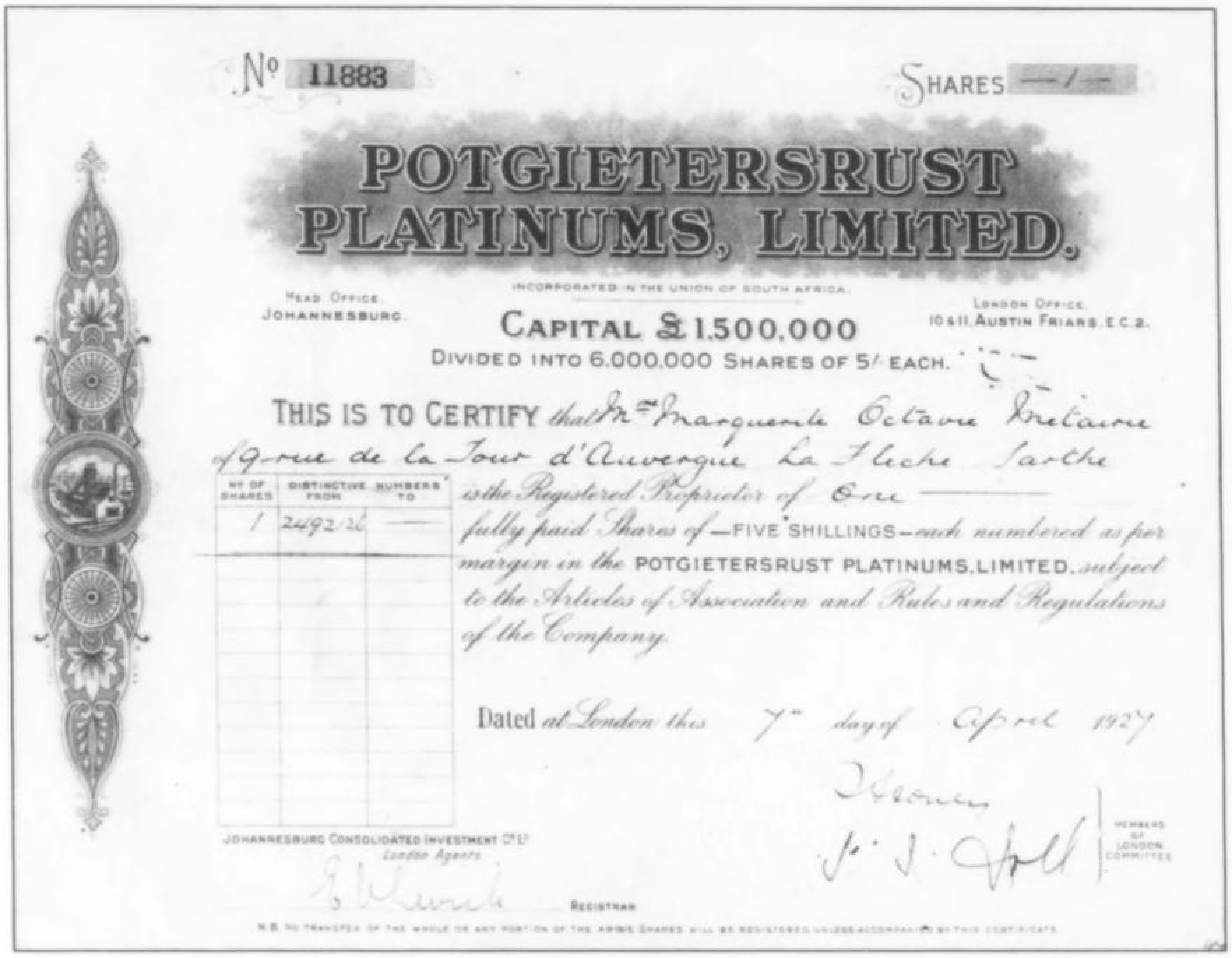
Figure 2. **A 1906 map of the northern part of the Transvaal province showing the location of the Tweefontein farm where platinum was discovered in 1925.**

Figure 3. **Hans Merensky (1871–1952), discoverer of the Platreef and the Tweefontein Hill deposits.**

in the northern limb of the Bushveld Complex, near Potgietersrus, which came to be called the Platreef. Pre-European copper workings were discovered on Tweefontein Hill, a bush-covered prominence rising about 140 meters above the surrounding plain on Tweefontein farm plot 1033, later redesignated 238 KR (Wagner, 1925, 1926a–d), and prospecting was initially directed toward a pyroxenitic zone at the base of the Bushveld rocks which Merensky recognized as being similar to the rocks of the Merensky Reef. The pyroxenite zone was shown to have platinum group values of up to 28 grams/metric ton (28 ppm) (Wagner, 1929). It is known today as the world's third largest deposit of platinum-group elements, and it is here that some of the largest and finest sperrylite crystals ever seen were discovered.

Over 50 mining companies were established in 1925 in the Waterburg district and Bushveld Complex to exploit the platinum deposits. By far the largest claim-holder among these was Potgietersrust Platinums, Ltd. The deposits found in a breccia zone in ironstone on Tweefontein Hill were worked briefly in 1925–1926; 631 meters of underground development in the mineralized shear zones were excavated, plus another 1,012 meters farther down the hill along the contact between the Bushveld Complex rocks and the ironstone. The deposit was ultimately deemed uneconomical, though, and mining there ceased.

The large sperrylite crystals for which the mine is famous were encountered in 1925 or 1926 in the upper part of Tweefontein Hill, where an adit had been opened at a site showing evidence of early copper mining. The crystals were found embedded in limonite in



No 11883 SHARES —/—

POTGIETERSRUST PLATINUMS, LIMITED.

INCORPORATED IN THE UNION OF SOUTH AFRICA.

HEAD OFFICE. JOHANNESBURG.

CAPITAL £1,500,000

LONDON OFFICE. 10 & 11, AUSTIN FRIARS, E.C.2.

DIVIDED INTO 6,000,000 SHARES OF 5/- EACH.

THIS IS TO CERTIFY that Mme Marguerite Octavie Metairie of 9 rue de la Tour d'Auvergne La Fleche Sarthe is the Registered Proprietor of One fully paid Shares of —FIVE SHILLINGS— each numbered as per margin in the POTGIETERSRUST PLATINUMS, LIMITED, subject to the Articles of Association and Rules and Regulations of the Company.

No. OF SHARES	DISTINCTIVE NUMBERS FROM	TO
1	249226	—

Dated at London this 7th day of April 1927

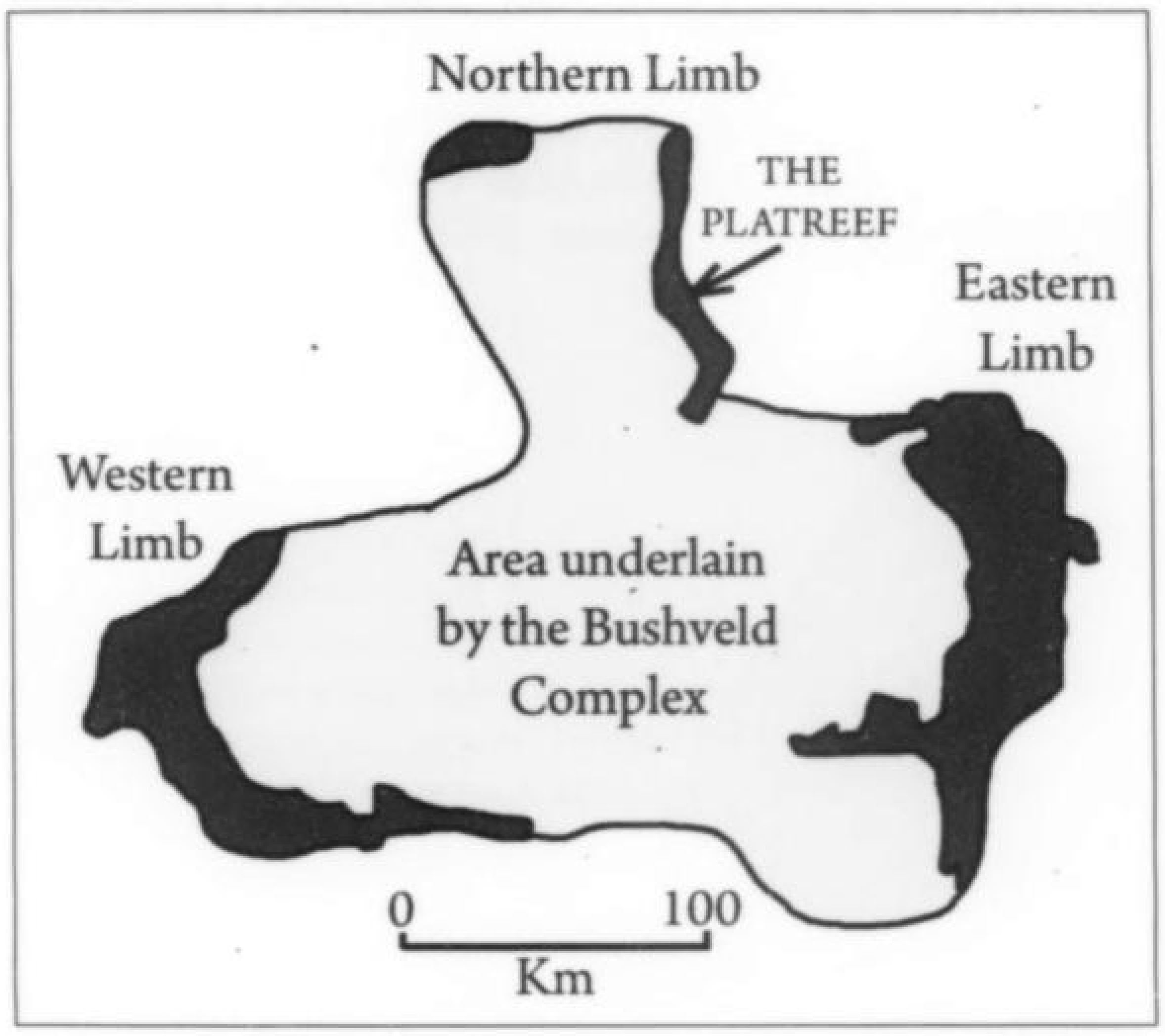
JOHANNESBURG CONSOLIDATED INVESTMENT Co. Ld. London Agents

REGISTRAR

MEMBERS OF LONDON COMMITTEE

Figure 4. **A 1927 stock certificate from the Potgietersrust Platinums, Ltd., company, operators of the Tweefontein Hill mine (Mineralogical Record Library).**

Figure 5. **The Bushveld Complex and the associated "reef" deposits around the margins (after Cawthorn, 1999).**



a winze off of the main inclined shaft. Abandoned adits and the shaft can still be visited there today.

Potgietersrust Platinums Limited, administered by the Johannesburg Consolidated Investment Company Limited, was formed in mid-1926 and commenced production in September 1926 on the nearby Zwartfontein and Vaalkop plots. During the period 1926 to 1930 a total of 111,000 tons of ore was milled to yield 25,000 ounces of platinum-group metals from the mining operations in the area. However, in May 1930 the price of platinum declined, and production in what was called the Potgietersrust district ceased. Mining activity shifted to the more profitable Merensky Reef deposit at Rustenburg, and it wasn't until the price of platinum increased again in the late 1960s and early 1970s that serious interest was again shown in the Potgietersrus area.

The Platreef is still being mined today by Potgietersrust Platinums Ltd., now a wholly owned subsidiary of Anglo American Platinum Corporation, which established the first viable mining operation on the Platreef. The old Tweefontein workings are now considered to be part of the Potgietersrust mine, which exploits the entire Platreef. At some time in the future an open pit mining operation may be initiated there, permanently obliterating the mineralogically historic site.

GEOLOGY

The Platreef is a 10-meter to 400-meter-thick pyroxenitic unit at the base of the northern limb of the Bushveld Complex. This famous (among geologists, at least) complex is an enormous and ancient layered intrusion of lenticular shape that is depressed in the middle—a configuration classifying it as a *lopolith*. Rich in copper, nickel and platinum-group elements, the Platreef strikes north-northwest for about 30 km and dips 40° to 45°W through the Tweefontein farm area. At Tweefontein Hill the Platreef ranges in thickness from 100 to 220 meters. There it is sandwiched between the overlying Main Zone gabbronorites and the 2.2 to 2.6-billion-year-old Transvaal Supergroup Metasedimentary Sequence (Cawthorn, 1999).

Typically, in the Platreef the proportions of platinum and palladium are about 44% and 46%, respectively, with the other platinum-group metals comprising the other 10%. Unlike the Merensky Reef, the Platreef mineralization does not have sharply defined boundaries. Current mining is from open pits, where the orebody dips at about 40°. Once the shallow part of the reef has been exhausted, it will be necessary to develop underground mining operations.

The discontinuous massive sulfide mineralization in the Platreef has been attributed to gravitational settling of a magmatic sulfide liquid within the reef structure, following a major pulse of magma. The amount of contamination by the country rock has been a subject of debate. Gain and Mostert (1982) believe that formation of the sulfide fluid in the magma was triggered by the absorption of dolomitic xenoliths that contributed CO_2, H_2O, and S to the magma; this simultaneously lowered the solubility of sulfur in the magma while adding more sulfur, resulting in the separation of an immiscible sulfide liquid. But the most recent studies (Howell *et al.*,

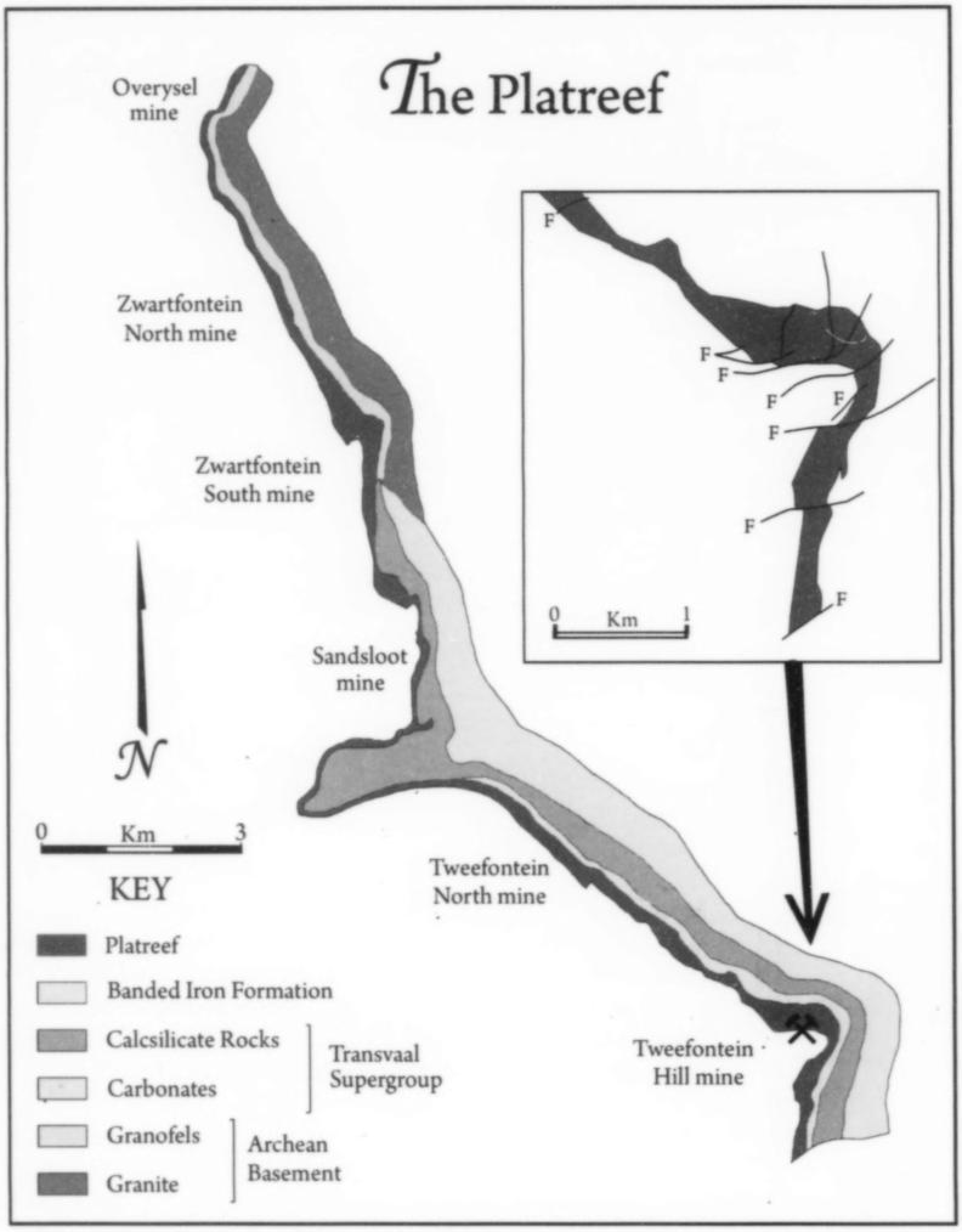


***Figure 6.* The Platreef, showing the locations of the various mines, including the 1925–1926 workings of the Tweefontein Hill mine where the large sperrylite crystals were found (after Appiah-Nimoh, 2004; White, 1994).**

2007) suggest that the effect of contamination was relatively minor, and that the magma pulse carried with it the preformed platinum-group-element-rich sulfide liquid. The Tweefontein breccia deposit is believed (White, 1994) to represent a relatively low-temperature late-stage hydrothermal surge of platinum mineralization.

The distribution of the major sulfide minerals in the Platreef indicates a change from a sulfur-rich to a metal-rich environment during the crystallization. Pyrite, pentlandite, monoclinic pyrrhotite and chalcopyrite are dominant in the lower zone of the Platreef, whereas pentlandite, hexagonal pyrrhotite and chalcopyrite (± cubanite) predominate in the upper zone (Gain and Mostert, 1982). Subsequent deformation can be correlated with regional fault structures which have had the effect of focusing hydrothermal mineralization and remobilization of platinum-group elements along north-south and north-northeast-trending faults (Nex, 2005).

Spencer (1926) described one of the British Museum's sperrylite specimens as embedded in copper-stained limonite from a brecciated shear zone in banded ironstone (Penge Formation of the Pretoria Series; Button, 1976). Included in these zones are "eyes" of a pegmatitic rock (a graphic intergrowth of quartz and grayish brown feldspar). Overlying the banded ironstone is a coarse-grained, black pegmatoid consisting of augite and inverted pigeonite with minor plagioclase and olivine. The rock is very well mineralized with disseminated sulfides, and has intruded into and reacted with the underlying banded ironstone. The limonite is obviously an alteration product of iron and copper sulfides (which, in their unaltered form, comprise the matrix of the Norilsk specimens).

SPERRYLITE

Sperrylite was first discovered in South Africa in 1923, in gossan from the Vlakfontein mine in the Rustenburg district. In 1925 it was reported from the sulfidic platinum ore of the Sandsloot mine in the Potgietersrust district. The third discovery was at the Tweefontein mine, described by Wagner (1926c) as follows:

> The sperrylite crystals are of a bright tin-white colour with splendent luster. Many of them look as though they have been polished, and are objects of great beauty. The crystals are mostly of cubic habit, but the cube and octahedron are sometimes equally developed. Other forms are invariably present, thus the edges of the cube and octahedron are generally beveled by narrow crystal faces, and in consequence reflect the light from numerous brilliant facets. The following forms were identified: the rhombic dodecahedron, the pyritohedron, the trapezohedron, several dyakis dodecahedra, and probably the triakis octahedron [= trisoctahedron].

Wagner stated that the Tweefontein sperrylite crystals are typically 1.3 mm to 1.7 cm in size.

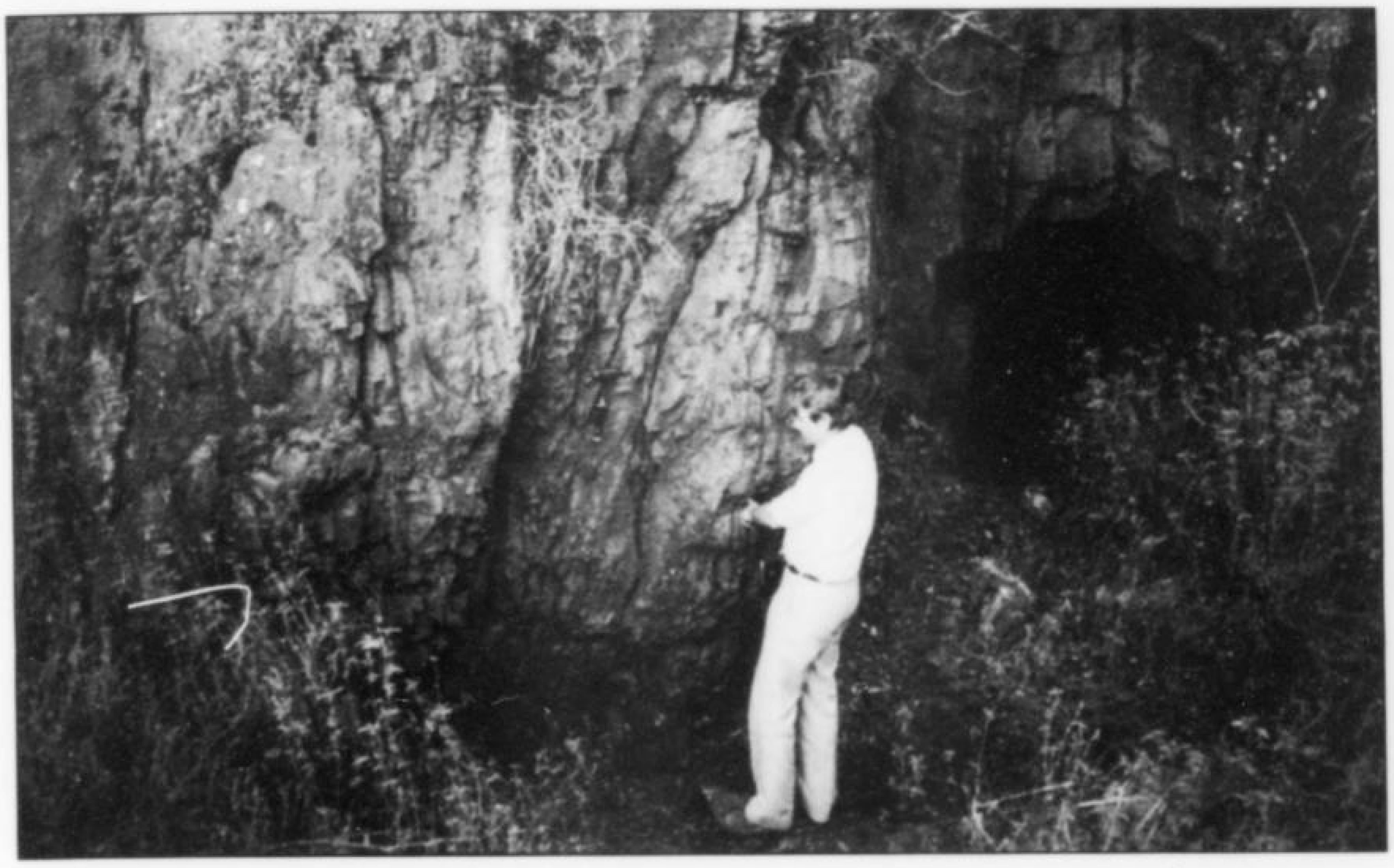


Figure 7. **Ironstone layers by the entrance adit to the Tweefontein Hill mine. Sperrylite crystals up to 1 mm can still be found in the dump from the adit. Morris Viljoen photo.**

Figure 8. **Sperrylite crystals from Tweefontein Hill (Wagner, 1929). The large crystal at lower left, now in the Natural History Museum, London, measures 2.6 cm. The matrix specimen was in the Museum of the Geological Survey of South Africa but was stolen in 1971.**

Specimens first came to the attention of Leonard J. Spencer, Assistant Keeper in the Mineralogy Department of the British Museum (Natural History), in 1926. Spencer read a paper before the British Mineralogical Society on June 15 of that year, and it was published in the society's journal, *The Mineralogical Magazine*. Spencer described several specimens that had recently been acquired by the Museum:

(1) The first crystal was donated to the Museum by George H. Beatty of Johannesburg (at that time employed by the Johannesburg Consolidated Investment Company, Ltd., and acting as a consulting engineer for Potgietersrust Platinums, Ltd., the company operating the Tweefontein mine); it had been collected in "a new adit" on the Tweefontein farm, suggesting that underground mining had been going on there previously via other adits. Beatty had already given a brief preliminary account of Tweefontein sperrylite crystals at a meeting of the Chemical, Metallurgical and Mining Society of South Africa on February 20, 1926. The crystal Spencer described

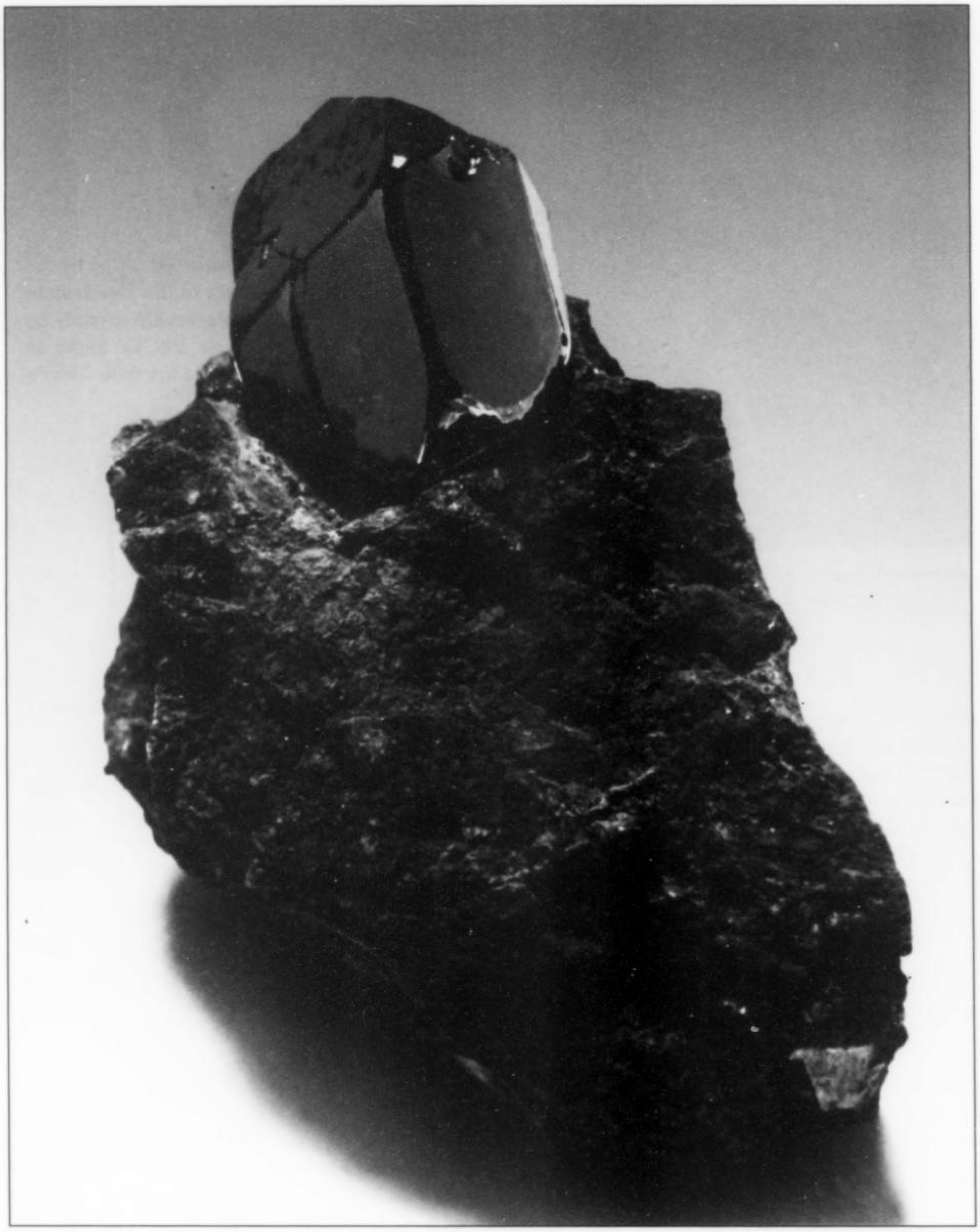


Figure 9. **Sperrylite crystal, 2.6 cm, on a 6.2-cm limonite matrix from the Tweefontein farm. This is the specimen donated to the British Museum (Natural History) in 1926 and pictured in Bancroft (1973). Until the mid-1980s when the Norilsk, Siberia specimens were found, it ranked as the largest and finest sperrylite in the world. Note that the loose crystal has been set up-side-down on its pocket in the matrix, so as to conceal a damaged spot. Photo by Peter Green and Frank Greenaway.**

measures 5.3 × 5.5 mm, which at the time ranked it as larger than any sperrylite crystal ever found at any other locality worldwide. Spencer also mentioned seeing larger but imperfect and broken crystals from Tweefontein up to 1.3 cm.

According to Spencer, the crystal shows "brilliant metallic lustre with silver-white colour, much resembling the crystals of amalgam (silver-amalgam) from the Palatinate (Rhenish Bavaria)"—by which Spencer was probably referring to the mineral moschellandsbergite, which was not named until 1938. The sperrylite crystal is euhedral, without any point of attachment, and is cuboctahedral in habit with rounded edges that give curved outlines to the cuboctahedron faces, similar to the manner in which diamond crystals tend to be rounded. A close examination of the rounded edges reveals minute facets of the dodecahedron, tetrahexahedron and trapezohedron. One of the cube faces reveals terraced growth lines, a feature common to Norilsk sperrylite as well.

It is interesting to note that the Tweefontein sperrylite crystals are pristine and do not show the fine network of cracks that is typical of sperrylite crystals from Norilsk. This is probably because the Tweefontein crystals were found in soft gossan that had gradually altered from the sulfides that had originally encased them, whereas the Norilsk crystals are still embedded in unaltered sulfides. These solid sulfides must surely transmit the shock waves caused by blasting more effectively than would a soft gossan, thus resulting in cracks in the sperrylite.

(2) The second, much larger crystal (the largest that had been found at Tweefontein) was brought to the British Museum by Beatty as well, as a donation from the Chairman and Directors of the Potgietersrust Platinums, Ltd. This crystal measures 2.26 cm (nearly an inch). It is a cuboctahedron with rounded edges, silver-white in color and showing a brilliant metallic luster and mirror-smooth faces that under magnification show minute growth terraces. This

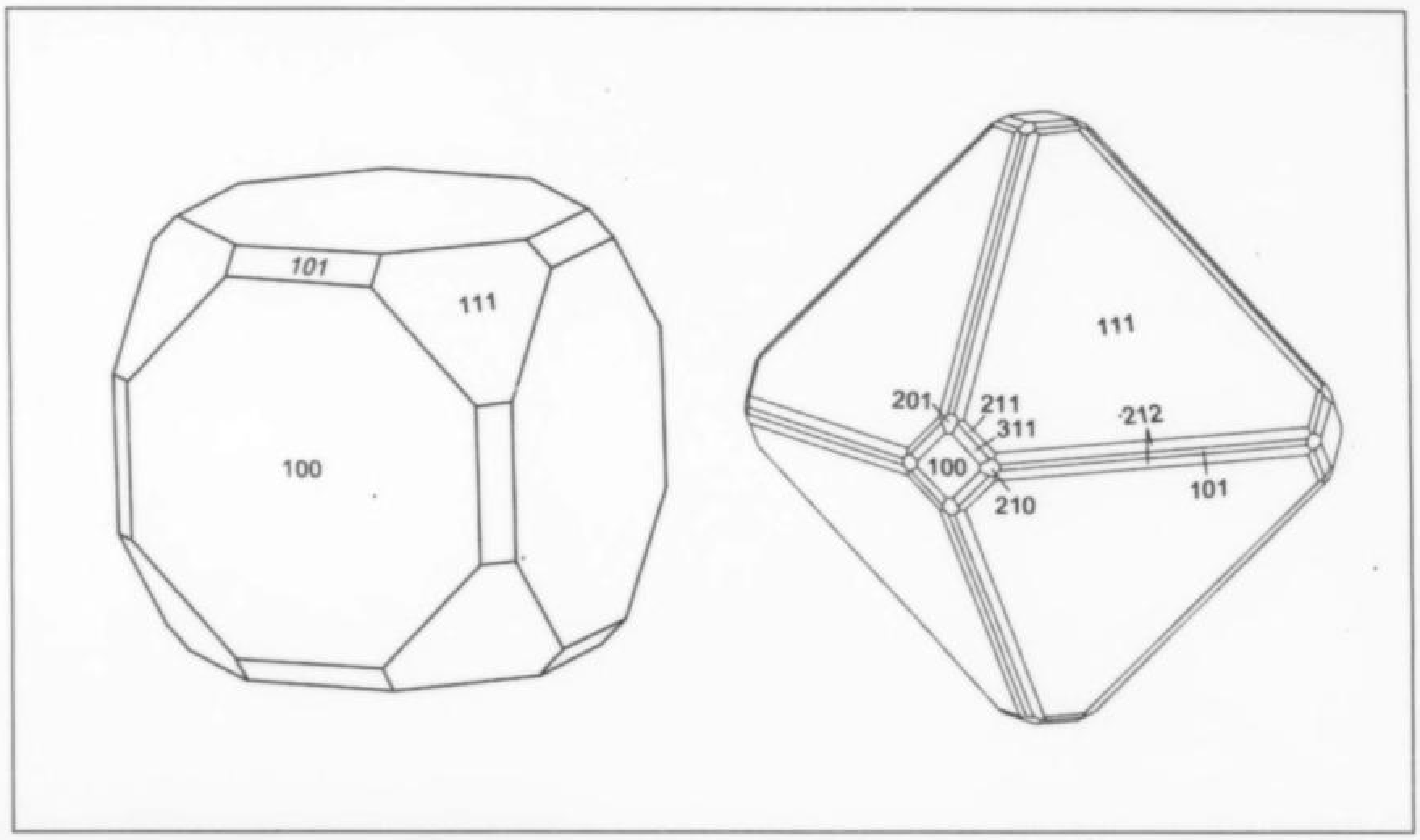


Figure 10. **Crystal drawings of Tweefontein sperrylite, based on photos and on the forms described by Wagner (1926c) and Spencer (1926). Left: cube and octahedron modified by narrow dodecahedron faces; right: predominantly octahedral crystal modified by vicinal faces that make the edges and corners appear rounded; cube {100}, octahedron {111}, dodecahedron {101}, tetrahexahedron {210}, trapezohedron {211} and {311}, pyritohedron {201} and trisoctahedron {212}.**

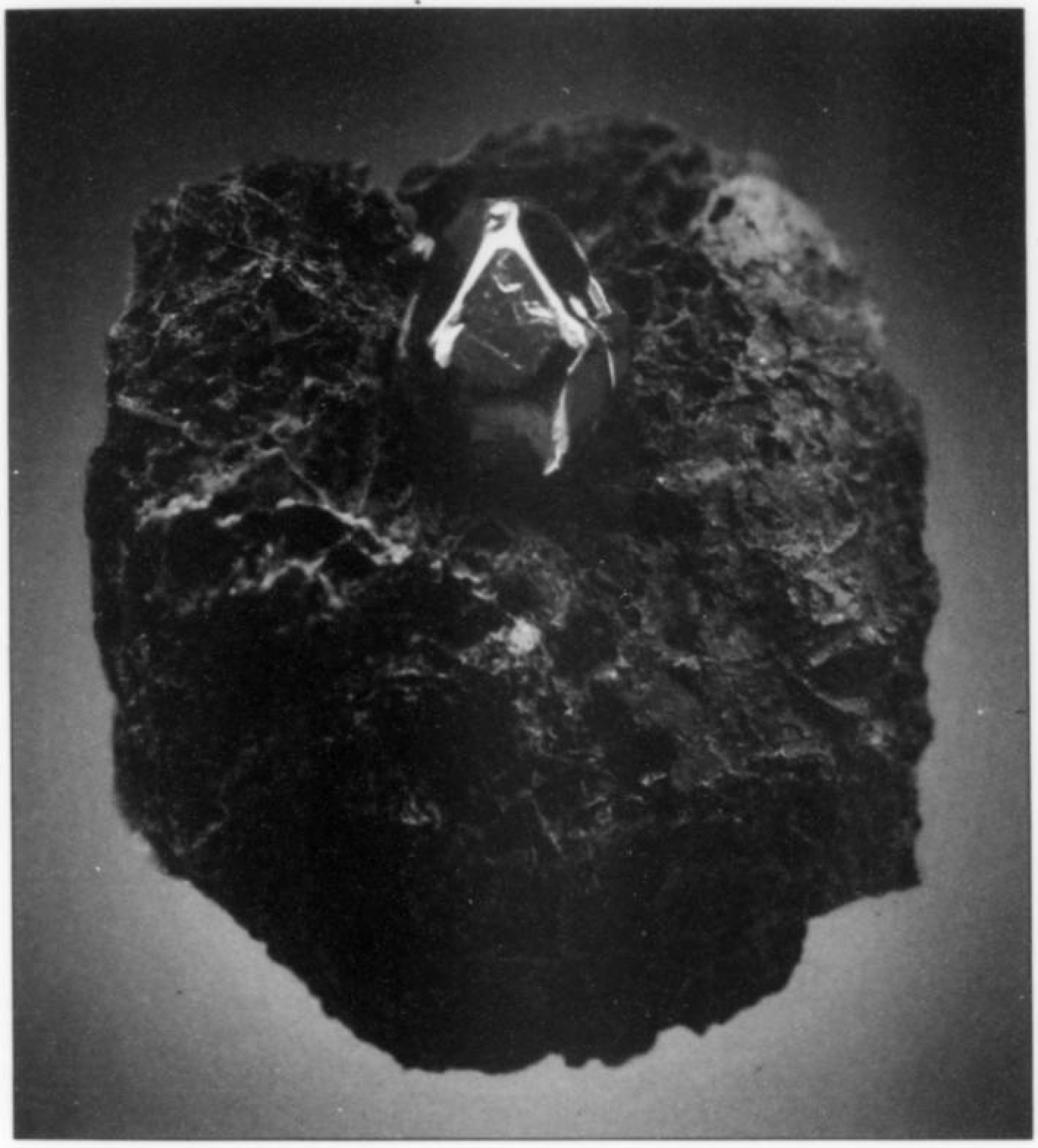


Figure 11. **Small sperrylite crystal in limonitic matrix, 2 cm, from the Tweefontein Hill mine. Anthony Kampf photo; Natural History Museum of Los Angeles County collection.**

crystal is accompanied by (though detached from) a 6-cm limonite matrix which has a sharply marked cavity into which the crystal fits perfectly. The inner surface of the cavity is smooth and glazed. This is the specimen illustrated in Bancroft (1973) and shown here (Fig. 9). Intriguingly, the matrix also shows two other similar cavities from which crystals had obviously been removed, but the ultimate fate of those crystals remains unknown.

Spencer notes that the crystal is "slightly broken" in two places; however, the largest damaged corner is not visible in the photo or on display in the museum. The curators have inserted the loose crystal up-side-down in its matrix socket so as to show instead the undamaged side (this can be detected in the photo because the crystal does not fit snugly down into the socket).

(3) A third specimen received by Spencer shows "minute specks and small splashes of sperrylite in a more compact matrix consisting of a mixture of limonite, malachite, quartz and feldspar . . . no doubt representing a mineralized pegmatite."

(4) Spencer also mentions a "much smaller crystal of sperrylite from this locality, which was sent by Dr. A. W. Rogers for the Cambridge Mineralogical Museum." It shows a more perfect development of many small faces.

The Natural History Museum of Los Angeles County has one of the few Tweefontein sperrylite crystals in the United States; it is a 2.5-cm limonite matrix piece containing a well-formed 8-mm cuboctahedral sperrylite crystal with rounded edges–precisely like the British Museum matrix specimen but smaller.

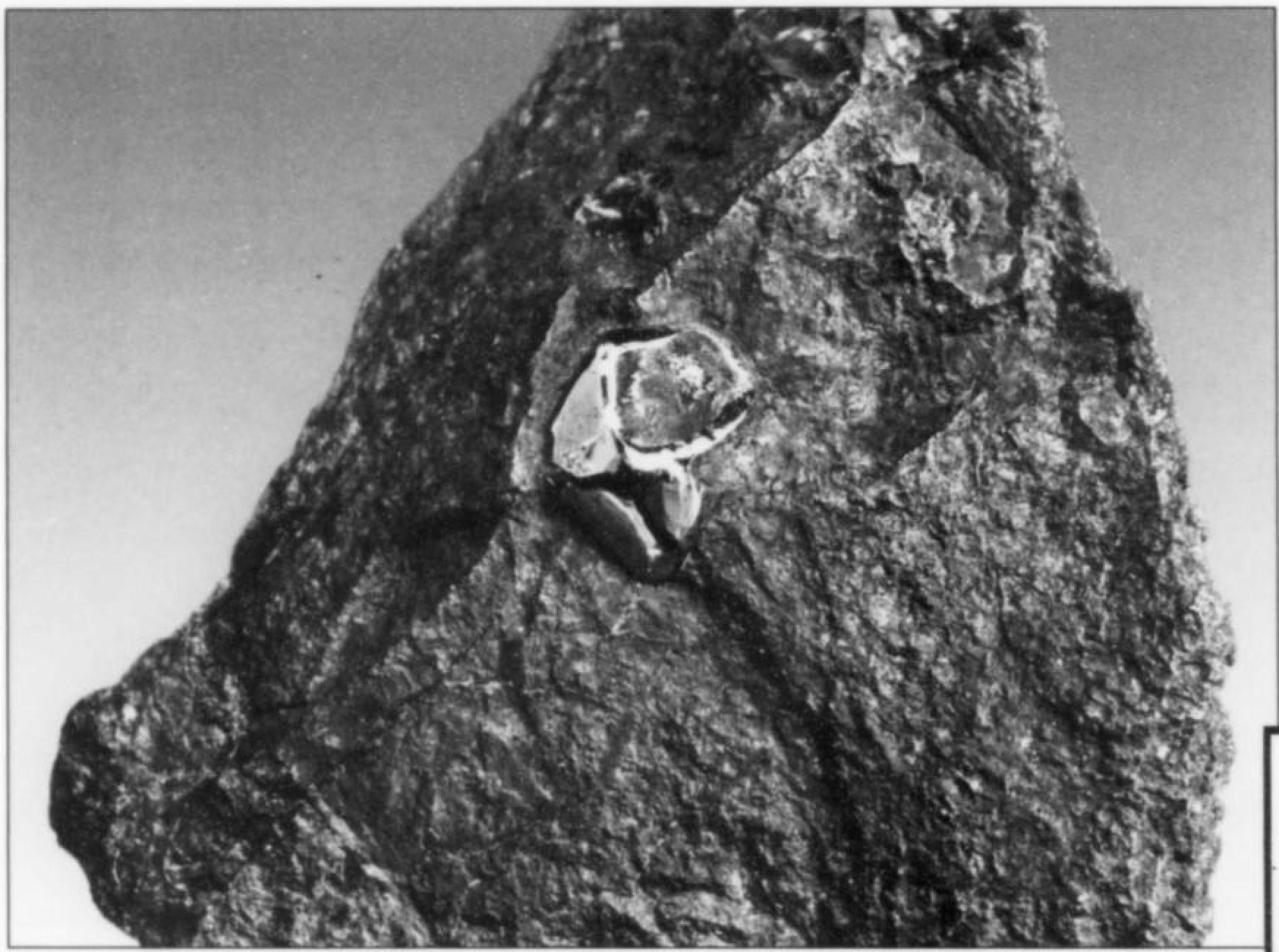


Figure 12. **A sperrylite crystal, 2.6 mm, in limonitic gossan matrix with malachite from the Tweefontein Hill mine. Grant Cawthorn collection; Bruce Cairncross photo.**

Figure 13. **A 1989 100-peso postage stamp from Mexico depicting a Tweefontein sperrylite crystal. Whether the specimen is real or fictitious is not known. Mineralogical Record Library.**

OTHER MINERALS

A number of other rare-earth-element minerals have been found at the Tweefontein farm, mostly as small grains in ore concentrates and in polished sections. These include **braggite** (Pt,Pd,Ni)S, **cooperite** (Pt,Pd,Ni)S, **laurite** RuS_2, **mertieite-II** $Pd_8(Sb,As)_3$ and native **platinum** Pt. Joints cutting the platinum-bearing veins are typically lined by botryoidal crusts of bright peacock-blue **chrysocolla** (Wagner, 1925).

The Tweefontein farm is also the type locality for **stibiopalladinite.** Adam (1927) described a new silver-white to dark steel-gray "Pd_3Sb" mineral from the Tweefontein mine. He cited a description by Mr. E. L. Gay-Roberts, manager of the Tweefontein mine, stating that the new mineral is found as small crystals associated with sperrylite in the pegmatitic "eyes" in the brecciated ironstone. The formula was later refined to Pd_5Sb_2, and refined again to $(Pd,Cu)_{5+x}Sb_{2-x}$ (Cabri and Chen, 1976). It forms hexagonal, thin to thick tabular crystals to about 200 µm.

ACKNOWLEDGMENTS

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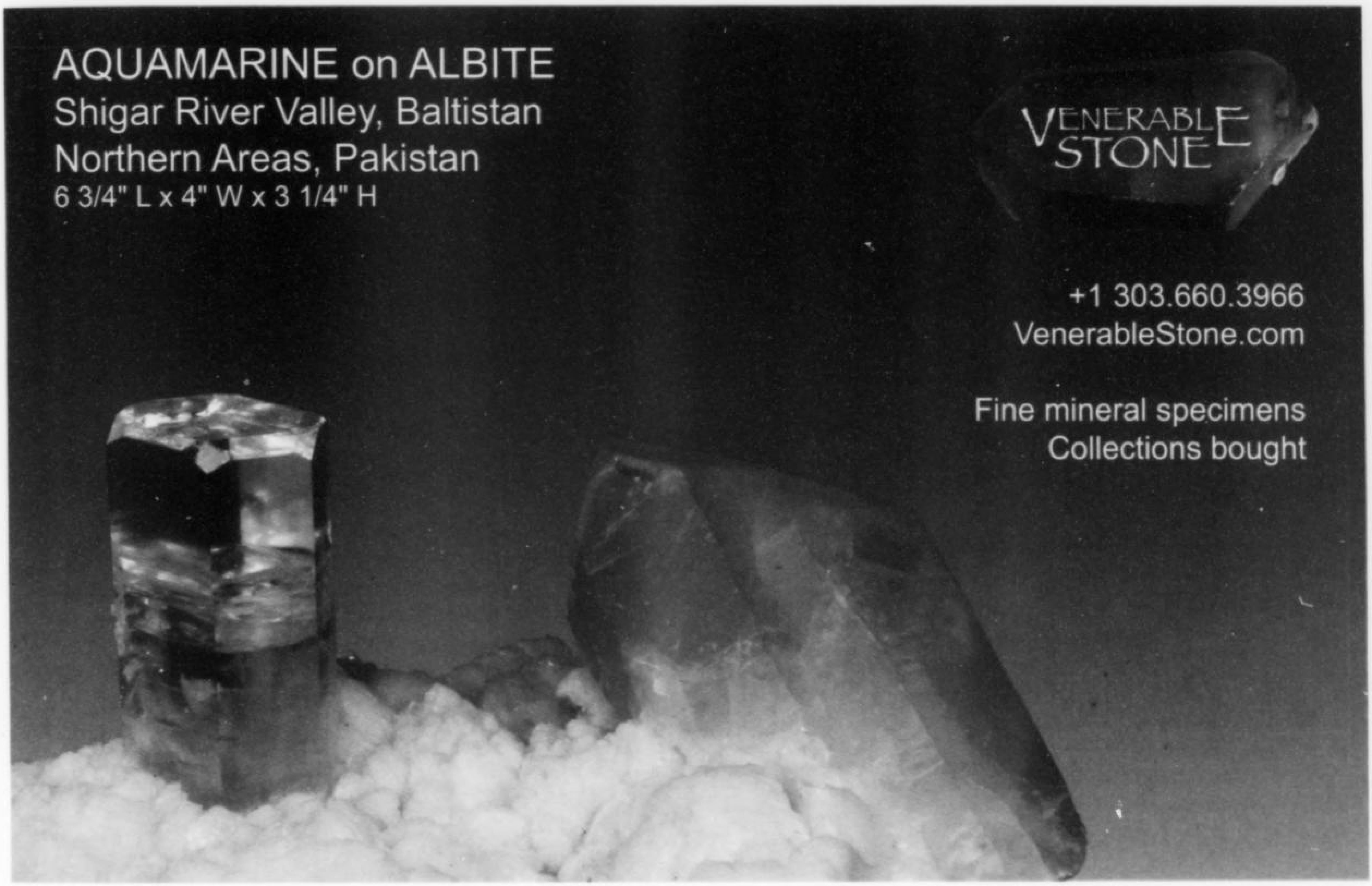

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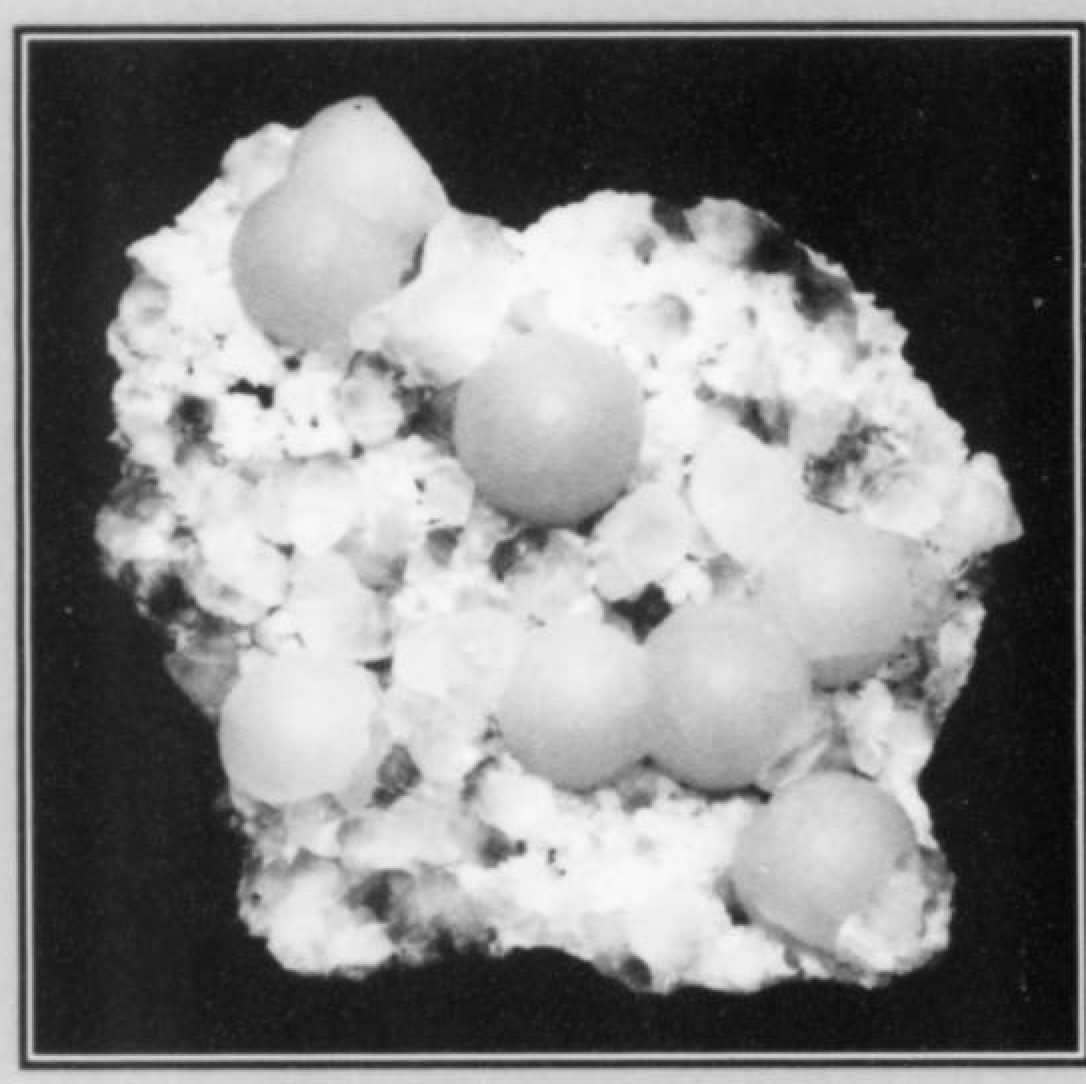
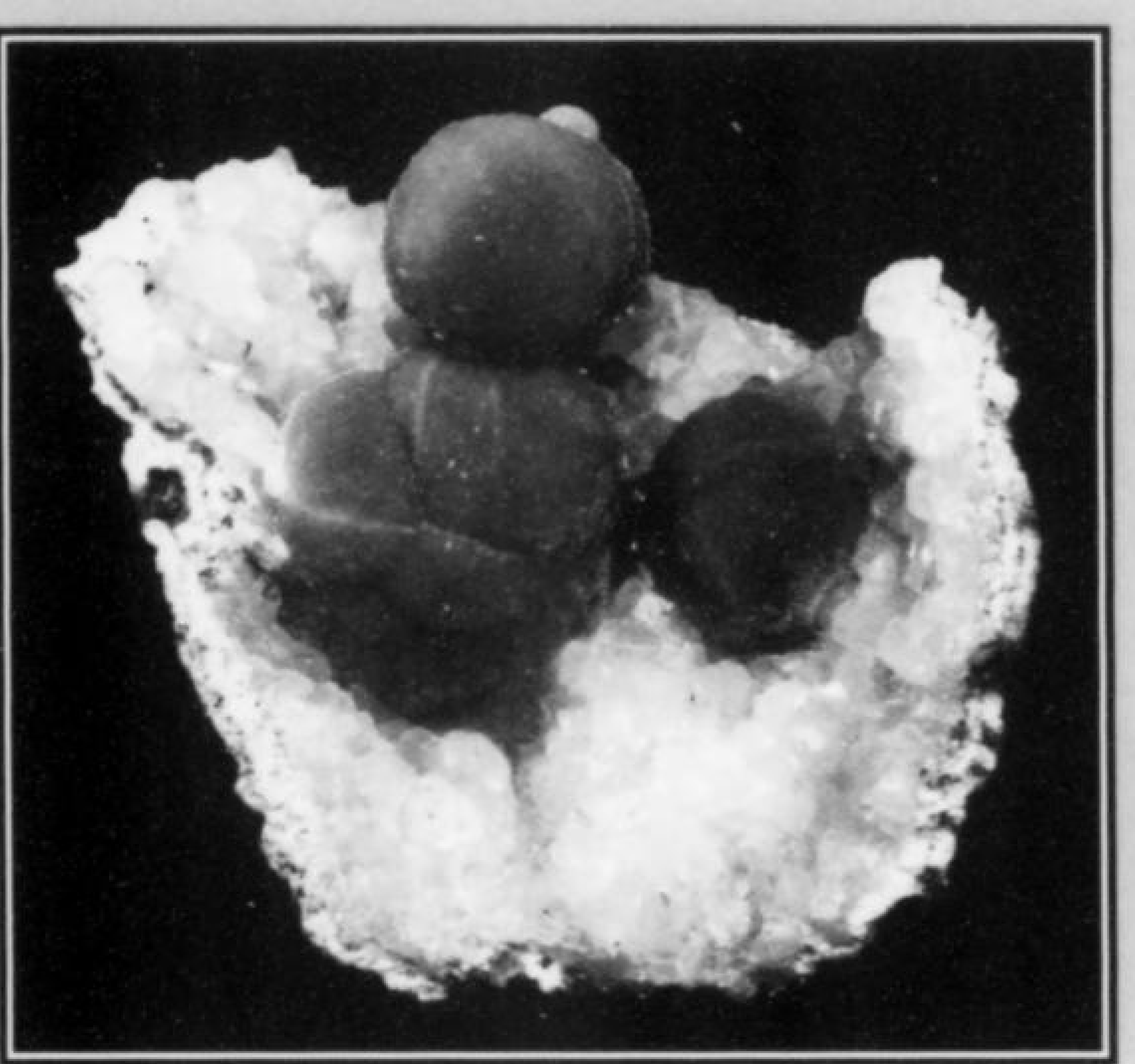
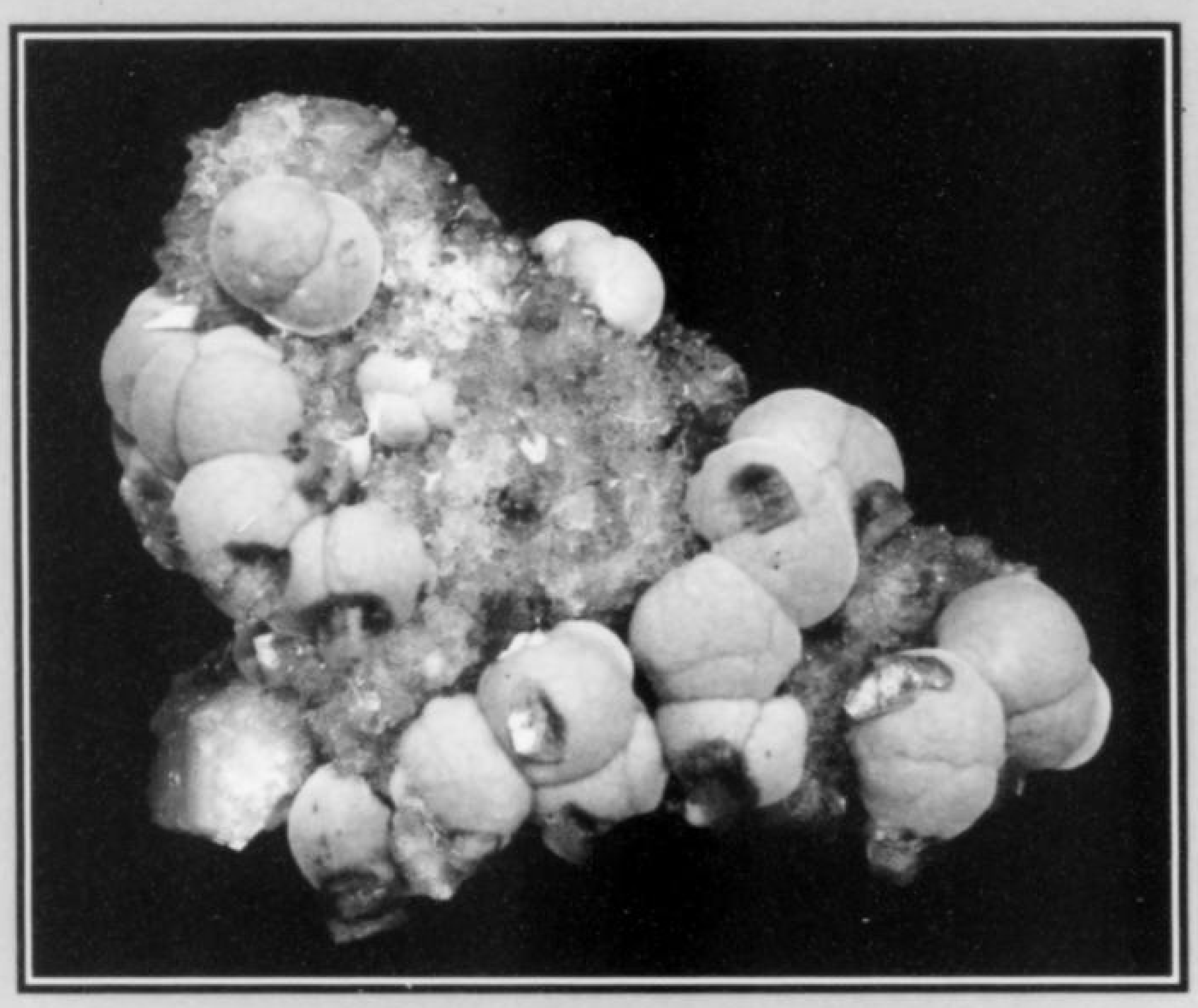


Prehnite with Calcite, 6.5 cm
Upper New Street Quarry, Paterson



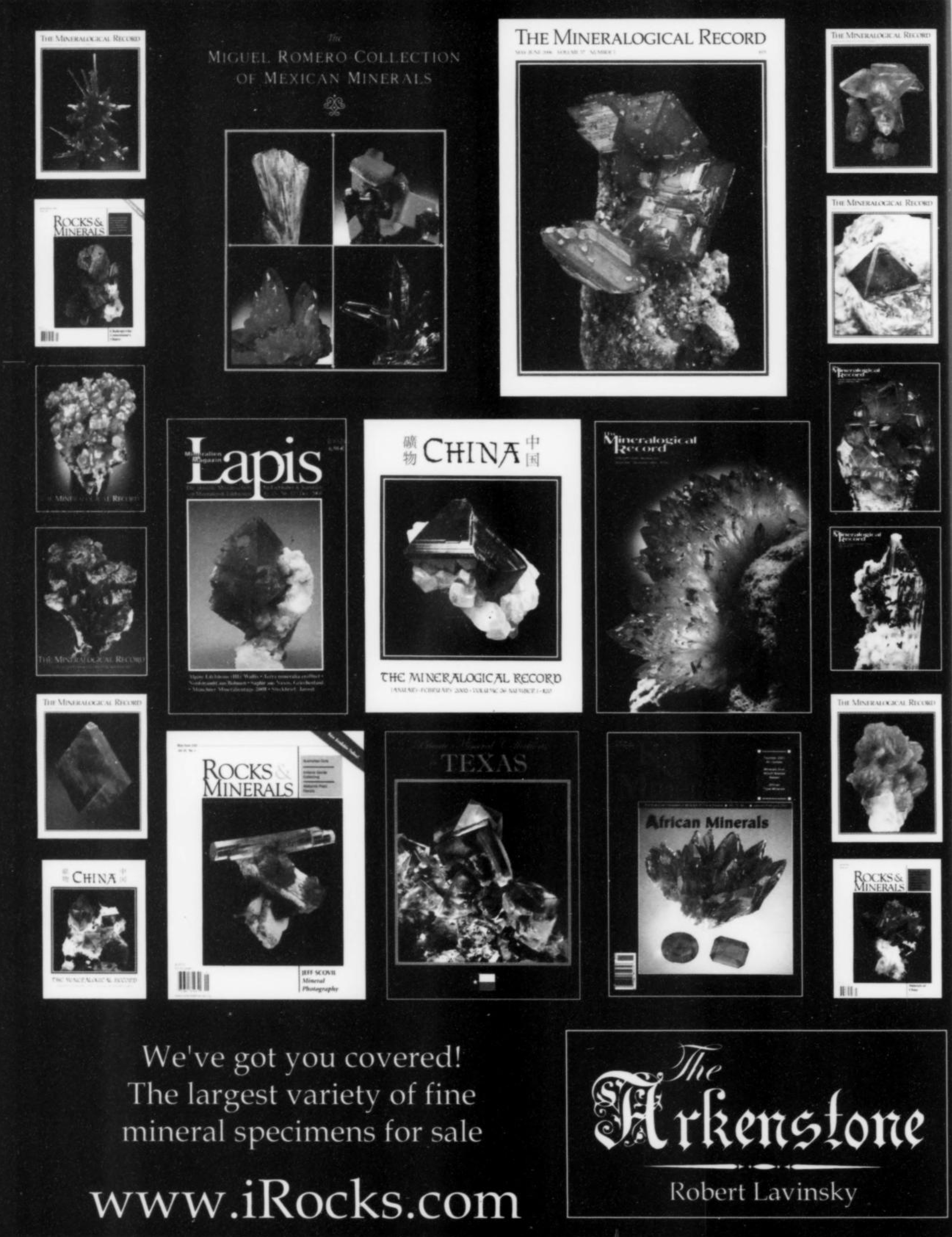
Pectolite on Datolite, 8.6 cm
Millington Quarry, Bernards Township



Pectolite, Heulandite and Babingtonite on Quartz, 9.1 cm
Prospect Park Quarry, Prospect Park

Frank A. Imbriacco III

1 Fox Hill Road
Edison, New Jersey 08820
732-548-1796 • fai122@aol.com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THE FANWOOD QUARRY

Somerset County, New Jersey

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New Jersey's Fanwood quarry has been operating for more than a century. Although not a major producer of collector-quality specimens, it has yielded fine examples of heulandite, stilbite, calcite, chalcedony, datolite and prehnite.

INTRODUCTION

The Fanwood Crushed Stone Company quarry, also known as the Fanwood quarry or the Weldon quarry, is in the Borough of Watchung, Somerset County, New Jersey. Since the late 1890s, the quarry has been owned and operated by the Weldon family. Weldon Materials Inc. produces crushed aggregates, ready-mixed concrete and hot asphalt at the site for the construction industry.

Originally exploiting mostly barren, massive basalt, the operation has greatly expanded over the years, exposing large areas of the quarry's mineralized horizons. Although some interesting and aesthetic specimens of zeolites and associated minerals have been collected there, the Fanwood quarry is not considered to be a major source of high-quality specimens as some of the other New Jersey traprock locations have been. For the most part, the distribution of eye-catching minerals is rather erratic and localized.

GEOLOGY

During the late Triassic and early Jurassic periods, North America split apart from Africa, creating a broad zone of block-faulted uplifts, grabens (down-dropped blocks) and half-grabens (dropped down on one side). The Fanwood quarry is situated in the half-graben known as the Newark Basin, the largest exposed early Mesozoic basin in eastern North America; it extends from southern New York through northeastern and central New Jersey and into southeastern Pennsylvania. The Newark Basin is approximately 190 km long and 50 km wide, and is filled to an estimated depth of 6.8 km with sediments and intrusive and extrusive basaltic rocks (Schlische, 1992; Olsen *et al.*, 1996). In its northern part, the Newark Basin is bounded on the northwest by the Ramapo fault, which separates the late Triassic and early Jurassic deposits within the basin from Precambrian gneiss to the west. The Hudson River borders the graben's eastern flank, while Cretaceous and Tertiary sediments overlap its southeastern and southern margins.

Three basalt flows collectively known as the Watchung Mountains lie within the upper third of the stratigraphic section of the Newark Basin. These formations include, from oldest to youngest, the Orange Mountain Basalt, the Preakness Mountain Basalt and the Hook Mountain Basalt. Each volcanic ridge is separated from the next by an intervening sedimentary unit. The sedimentary beds are composed predominantly of conglomerate, shale, sandstone and mudstone; the majority of these rocks have a reddish brown hue caused by an abundance of iron oxide minerals.

The Fanwood quarry is within the southwestern segment of the Orange Mountain Basalt. Roughly 96 meters of three successive outpourings of lava are exposed in the quarry, all of which dip to the northwest at 10 to 15 degrees, contain numerous high-angle faults, and exhibit the classic colonnade and entablature joint pattern (Laskowich and Puffer, 1990). The term "colonnade" refers to the layer of a flow unit where the basalt fractures into a somewhat uniform series of columns; the term "entablature" refers to a basalt layer which displays a closely spaced columnar joint pattern. The "red beds" of the Passaic Formation underlie the Orange Mountain Basalt; however, the contact between the two has yet to be exposed in the Fanwood quarry.

The principal secondary mineralization is found in the amygdules: gas pockets located in the upper parts of the first, second and third basalt flows and in the adjacent 20 cm of the overlying flows. Secondary mineralization also occurs in fissure veins that transect the massive basalts. These veins are typically filled with calcite,

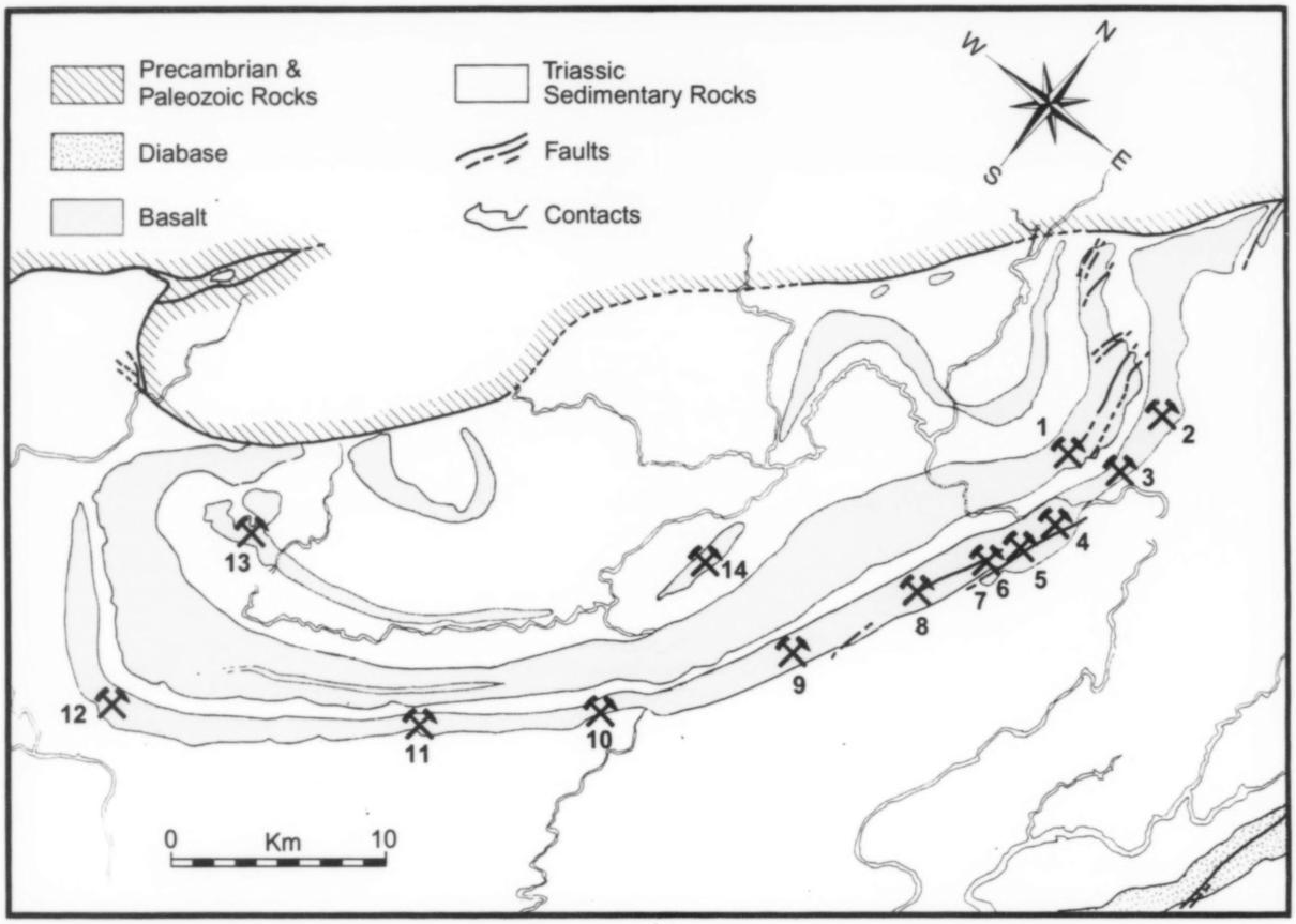


Figure 1. **Location map showing the Fanwood quarry and other important New Jersey trap rock localities in the Watchung Basalts (modified after Mason, 1960).**

(1) Braen quarry (Haledon)
(2) Braen quarry (Hawthorne)
(3) Prospect Park quarry
(4) Union Building and Construction quarry
(5) Upper New Street quarries
(6) Great Notch quarry
(7) Houdaille quarry
(8) McDowell's quarry
(9) Eagle Rock quarry
(10) Summit quarry
(11) Fanwood (Weldon) quarry
(12) Chimney Rock quarry
(13) Millington quarry
(14) Riker Hill

infrequently associated with stilbite or sulfides. The most interesting and exciting mineralized areas encountered in the quarry are in regions where the lower colonnade of the first or second flow arches upward into the overlying entablature. The dome-shaped volcanic structures which form in this event are referred to as diapirs (Laskowich and Puffer, 1990). A diapir is thought to be a cooling feature which reflects the uneven downward movement of the solidification front (Cummings, personal communication, 2009). Locally, in areas where the front proceeds downward more slowly, an upward-oriented dome of lava develops. Gases from adjoining areas, where solidification has already penetrated more deeply, migrate towards the top half of the diapir and are ultimately frozen in place as a cluster of amygdules. The upper interiors of most diapirs contain partially filled vugs of varying shapes and sizes, up to 1.8 meters across, typically mineralized with prehnite and calcite. Since 1985, three diapirs have been identified by field collector Mark Bianchi. The largest was nearly 10 meters wide at its base and 9 meters thick from the bottom of the colonnade to the top of the arch.

The lower amygdaloid is about 20 meters thick—the thickest of the three layers of mineralized gas pockets. Near the top of this unit is a zone of brecciated scoria, slag-like basalt containing numerous amygdules, all less than 2.5 cm in diameter. Between the angular blocks of scoria, irregular breccia cavities up to 30 cm in size are largely filled with red mudstone, precluding the formation of fine crystal specimens. Just below the rubbly basalt, the degree of alteration becomes less apparent until the rock reaches a relatively uniform dark gray at depth. A myriad of irregularly shaped cavities are dispersed throughout this gradually less altered basalt, which encompasses slightly greater than two thirds of the amygdaloid. Although many of these cavities are either small, partially filled with scoria or nearly solid, large open pockets, around 25 cm or more, are occasionally located.

The Fanwood quarry's middle amygdaloid is approximately 15 meters thick. A layer of greatly altered pillow lava and associated breccia averaging 3.2 meters thick is plainly visible at the uppermost level. The pillow structures clearly indicate that portions of the second flow unit erupted into or under water (Puffer, personal communication, 2008). Isolated cavities, up to 1.3 meters across, sporadically occur in the interior of the pillows. Nearly all of the pockets are badly weathered and show little or no mineralization.

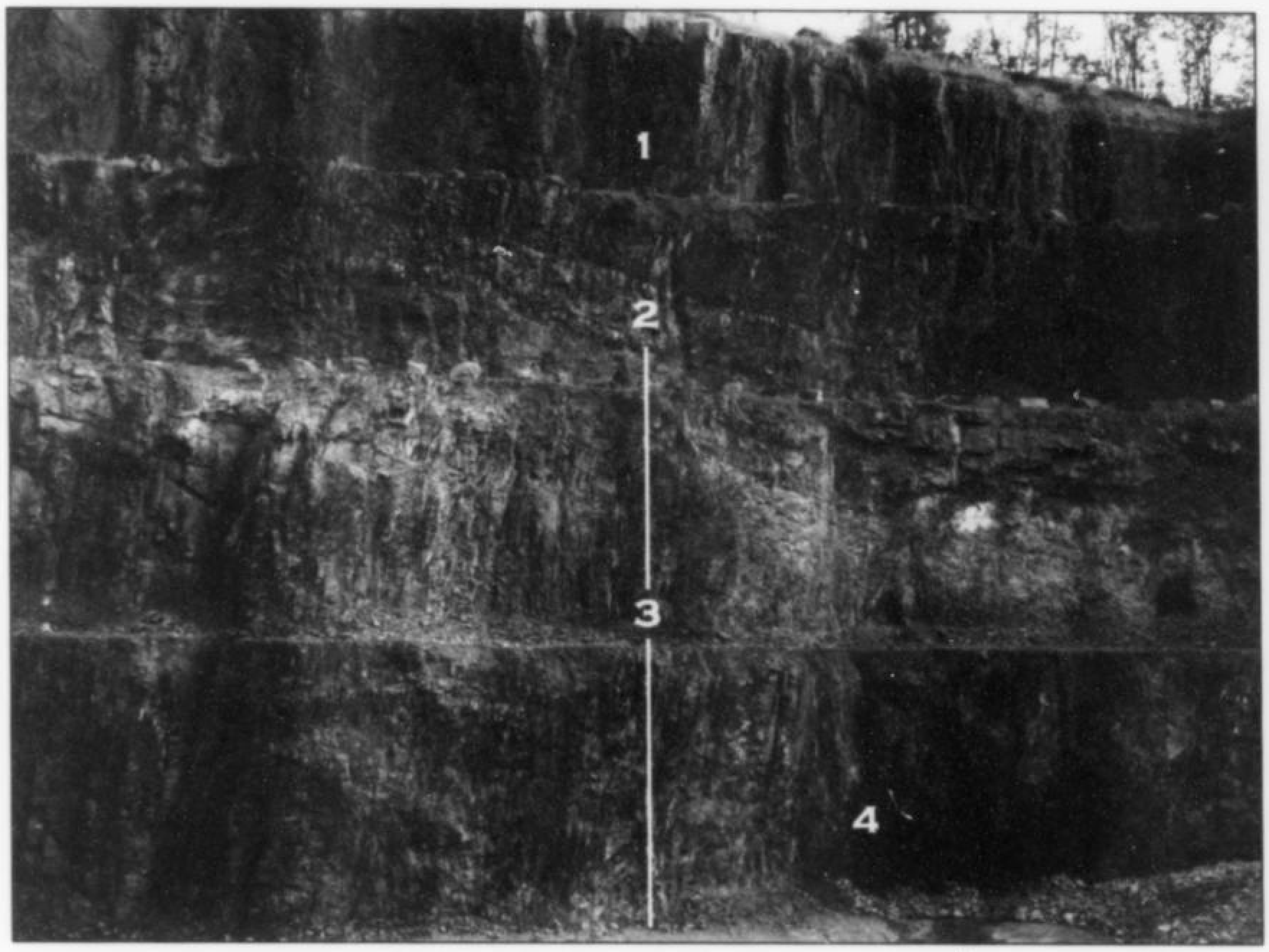


Figure 2. **The entablature (1) and the lower colonnade (2) of the Orange Mountain second flow; the lower amygdaloid of the Orange Mountain first flow (3); and a mudrock and calcite filled vein (4) at the Fanwood quarry. Mark Bianchi photo, 2008.**

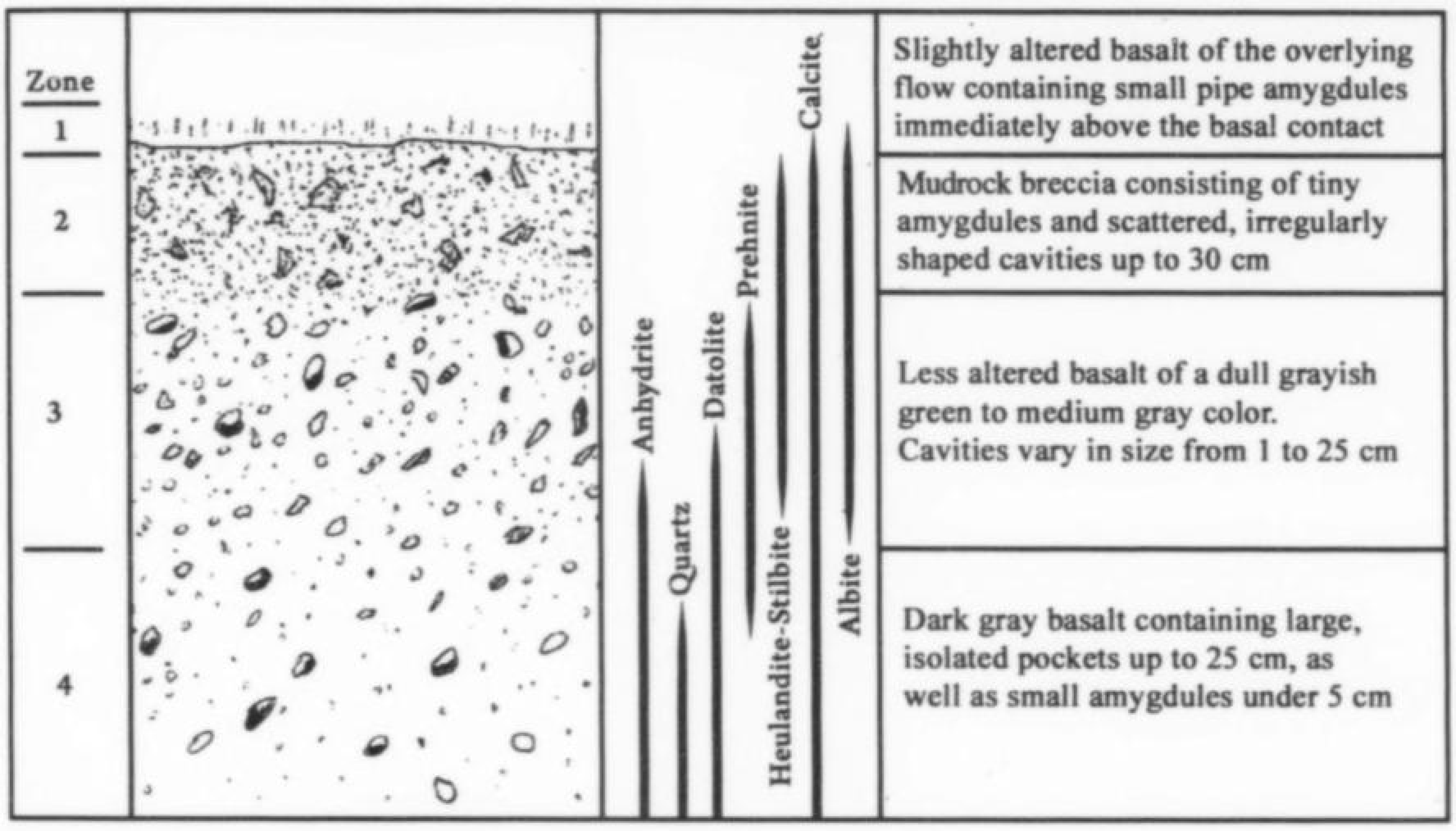


Figure 3. **Zonation and distribution of minerals in the lower amygdaloid at the Fanwood quarry (modified after Cummings, 1987).**

However, a very small number are lined with attractive combinations of stilbite, heulandite, albite and calcite crystals. Immediately below the pillow basalt and continuing downward, the vuggy rock is similar in appearance and mineralization to that seen in the equivalent horizons of the lower amygdaloid—with the noticeable difference that albite is not as common as it is in the middle part of the lower amygdaloid.

In 2005, the upper amygdaloid was unearthed when the quarrying operations reached the rear perimeter of the property. Erosion had stripped away the topmost level, leaving roughly 3 meters of the pocket zone. The cavities there have yielded prehnite and calcite, but the destructive effects of surface water percolating through the basalt have rendered specimen quality poor.

SECONDARY MINERAL PARAGENESIS

The secondary mineralization at the Fanwood quarry was the result of the hydrothermal alteration of the Orange Mountain Basalt, as described by (Cummings, 1987; personal communication, 2009). The hydrothermal fluids were formation brines high in calcium and sodium sulfates which were derived from the underlying Passaic formation. The fluids circulated upward into the amygdaloids and the vuggy areas of the diapiric structures through faults and joints in the basalt. Late in the Newark Basin's history (around 180 million years ago) there was a period of high heat flow and dynamic fluid movement. This appears to have coincided with the final separation of Africa from North America and a shift in tectonic stress from tension to compression. Steckler *et al.* (1993) proposed that fluid circulation was driven by an artesian system which appears to have briefly increased the temperature of the Orange Mountain basalt to around 220° C. As the temperature rose, basin brines in openings in the basalt began to react with the host rock, especially the glassy, poorly crystallized parts, which initiated a progressive fluid/rock interaction. This vigorous and evolving process partially replaced some of the basalt's primary chemical components, while others were released to the fluid stage. These chemical components recombined to produce a secondary mineral assemblage that was

Figure 4. **Excavation in a mineralized diapir of the lower colonnade of the Orange Mountain second flow. Mark Bianchi photo, 2008.**

Figure 5. **Columnar basalt of the Orange Mountain third flow overlying pillow basalt at the top of the middle amygdaloid of the Orange Mountain second flow. Mark Bianchi photo, 2008.**

stable in the hydrothermal environment and that is now seen in the open spaces of the basalt throughout the quarry.

Cummings (1987) has broken down the amygdaloids into four distinct and discernible stratigraphic zones based on the secondary mineralization expected in each. The spatial distribution of the secondary minerals within these zones reflects the physical characteristics of the basalt, most importantly its permeability, porosity and crystallinity. These factors regulated the fluid chemistry, the fluid flux and the rate and degree of change in the host rock (Cummings, 1987). The progressive alteration in the fluid chemistry produced a paragenetic sequence comparable to that illustrated by Schaller (1932): (1) saline period, (2) quartz period, (3) prehnite period, (4) zeolite period and (5) calcite period.

The five stages in the paragenetic sequence can be seen in the four zones within the Fanwood quarry's amygdaloidal horizons. Quartz and datolite, two of the earliest minerals to form, are the main constituents inside cavities at the bottom of zone 4 (the lowermost of the four zones). Calcite first appears near the bottom of zone 4 as crystals on quartz and datolite and as fillings of quartz-lined vugs. In the upper section of zone 4, prehnite becomes plentiful in relation to datolite. Since anhydrite crystallized in the initial period of Schaller's sequence, quartz, datolite and prehnite pseudomorphs

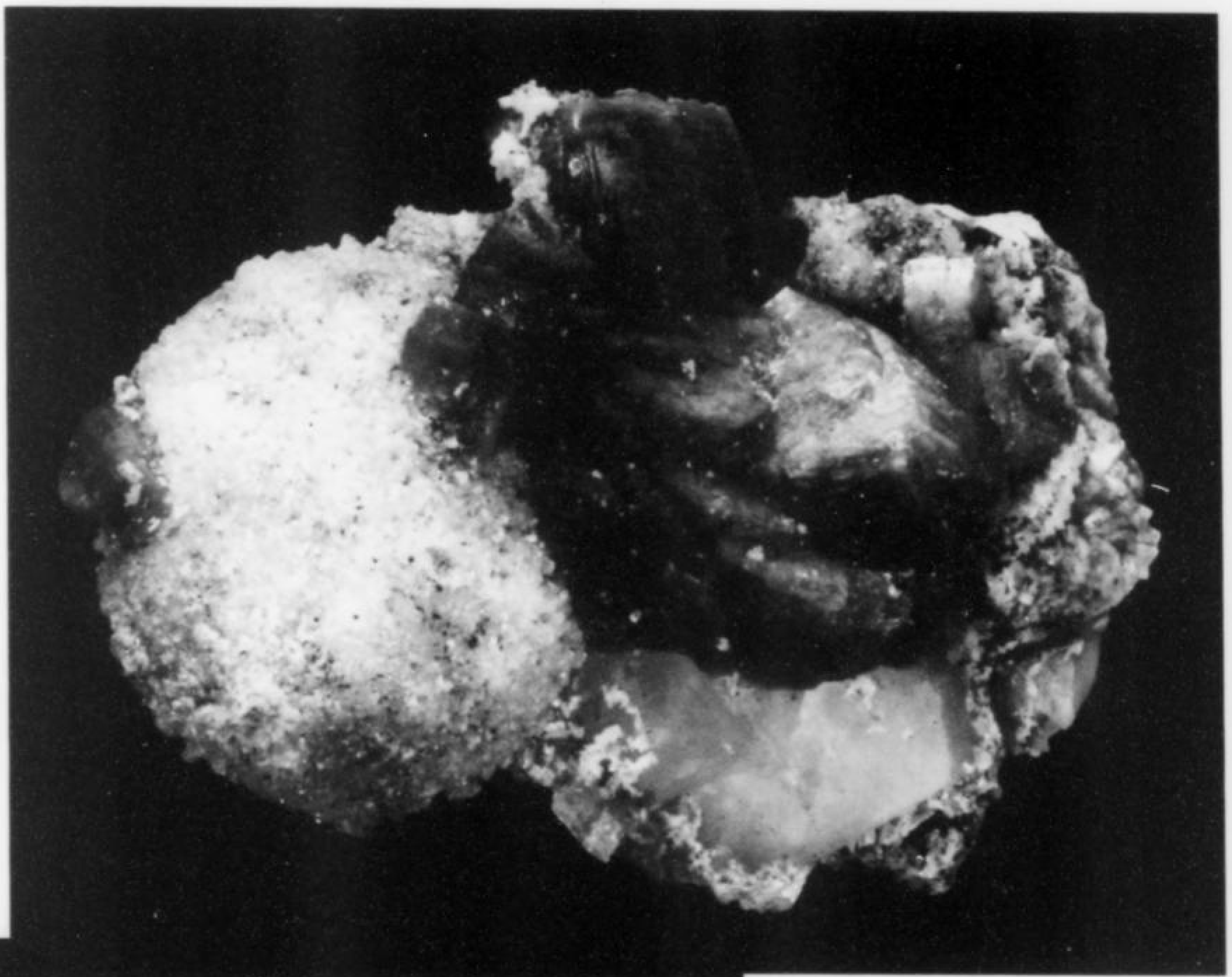


Figure 7. **Albite pseudomorph after analcime, 2.5 cm, with calcite and heulandite, from the Fanwood quarry. Brad Plotkin collection; Frank Imbriacco photo.**

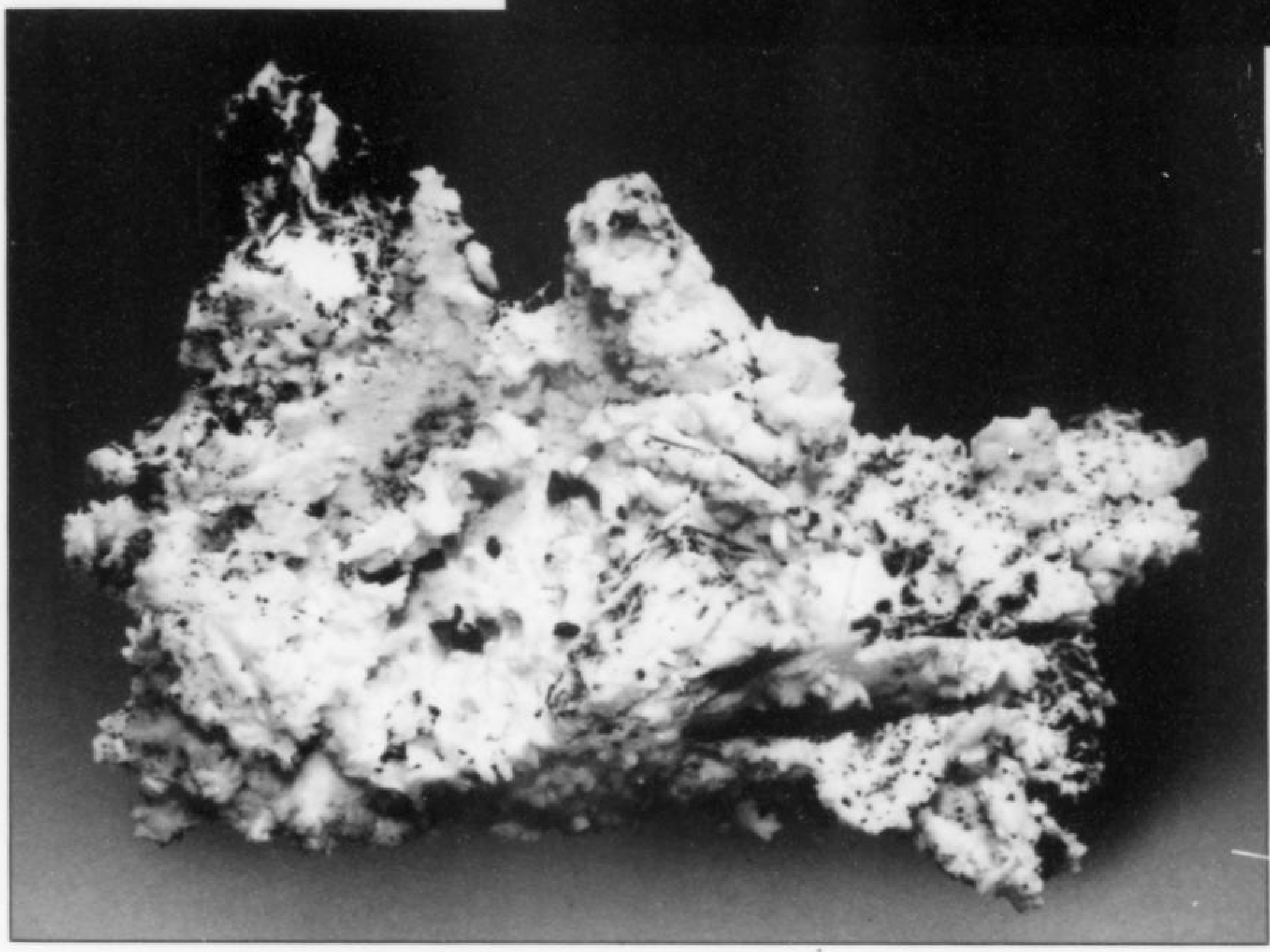


Figure 7. **Albite pseudomorph after anhydrite with chalcopyrite, 6.7 cm, from the Fanwood quarry. Brad Plotkin collection; Frank Imbriacco photo.**

after anhydrite are found throughout zone 4. An undulating sulfide horizon is present between the top of zone 4 and the bottom of zone 3. Gas pockets within the sulfide horizon range in size from 2.5 to 10 cm and are typically lined with prehnite and datolite. Crystals of calcite, chalcopyrite and rarely galena are scattered atop the prehnite and datolite.

Zone 3 marks the transition between the earliest-formed minerals of Schaller's periods and the later-formed minerals. Datolite and prehnite are still present; however, albite and calcite become more common, as do the zeolites heulandite and stilbite.

The minerals of the early paragenetic periods are missing from zone 2 in both the mudstone-filled breccia of the lower amygdaloid and the pillow formation of the middle amygdaloid. Mineralization in these two upper stratigraphic sections is limited to heulandite, stilbite, calcite and albite.

Zone 1 (the uppermost of the four zones) is a 20-cm-thick layer at the basal unit of the overlying second and third flows. It contains numerous small pipe amygdules lined or totally filled with albite and calcite.

MINERALS

Albite $NaAlSi_3O_8$

Albite is ubiquitous in much of the lower amygdaloid and is common in zones 1 through 3 of the middle amygdaloid. While

Figure 8. **Calcite crystal, 2.8 cm, growing over prehnite-after-glauberite epimorphs, from the Fanwood quarry. Frank Imbriacco collection and photo.**

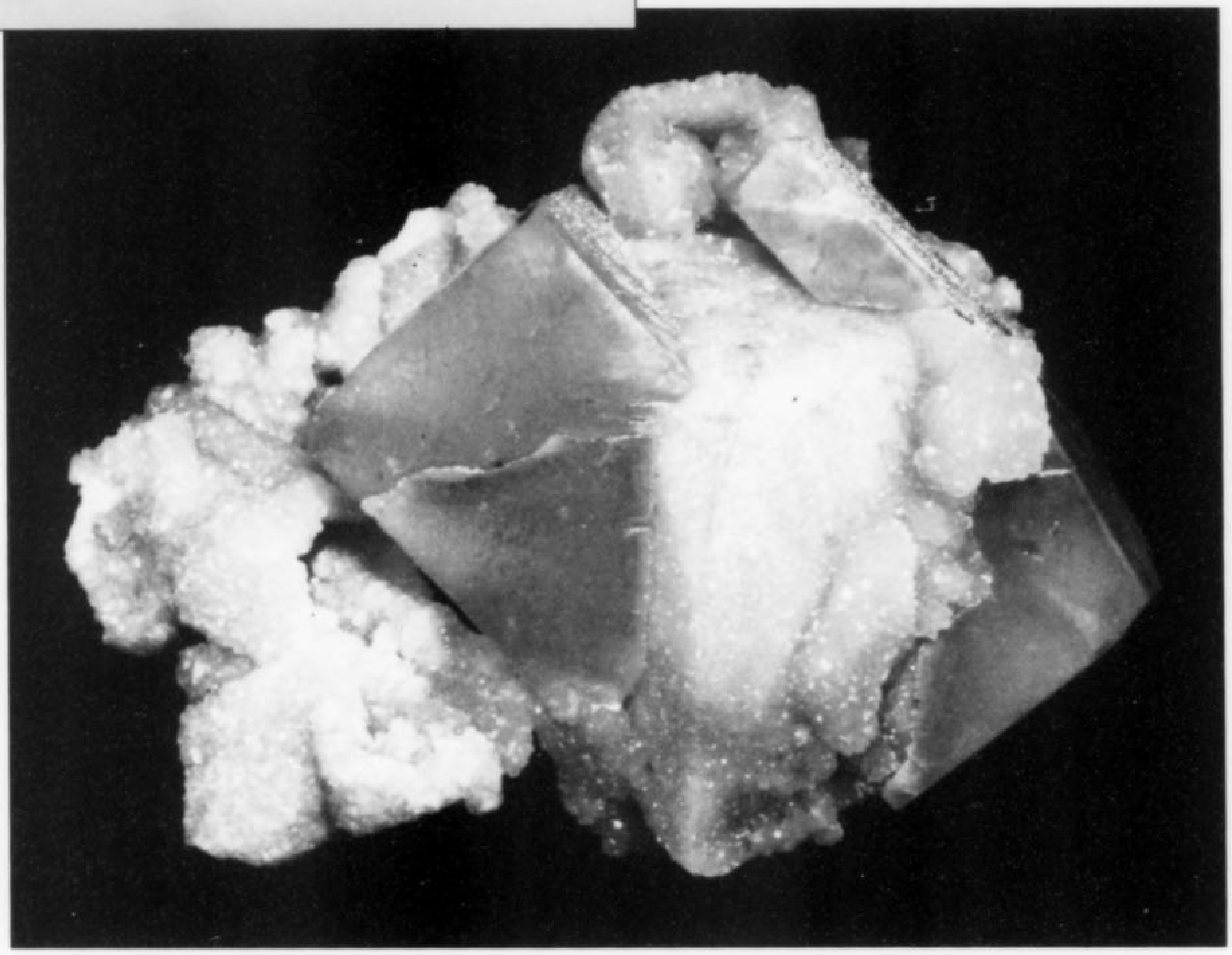


Figure 9. **Calcite on prehnite-coated calcite crystals with prehnite-after-glauberite epimorphs, 8.3 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

albite is primarily an early-formed mineral seen as thin cavity linings, it also formed following the deposition of heulandite, stilbite and calcite. Crystals are typically white to pinkish orange elongated blades, around 1 mm, in spherical and fanlike groups.

Analcime $Na_2(Al_2Si_4O_{12})\cdot 2H_2O$

Unaltered analcime crystals are unknown from the Fanwood quarry. Hollow albite epimorphs after analcime crystals to 2.5 cm, in combination with heulandite and calcite, have been collected from a cavity in zone 3 in the middle amygdaloid.

Anhydrite $CaSO_4$

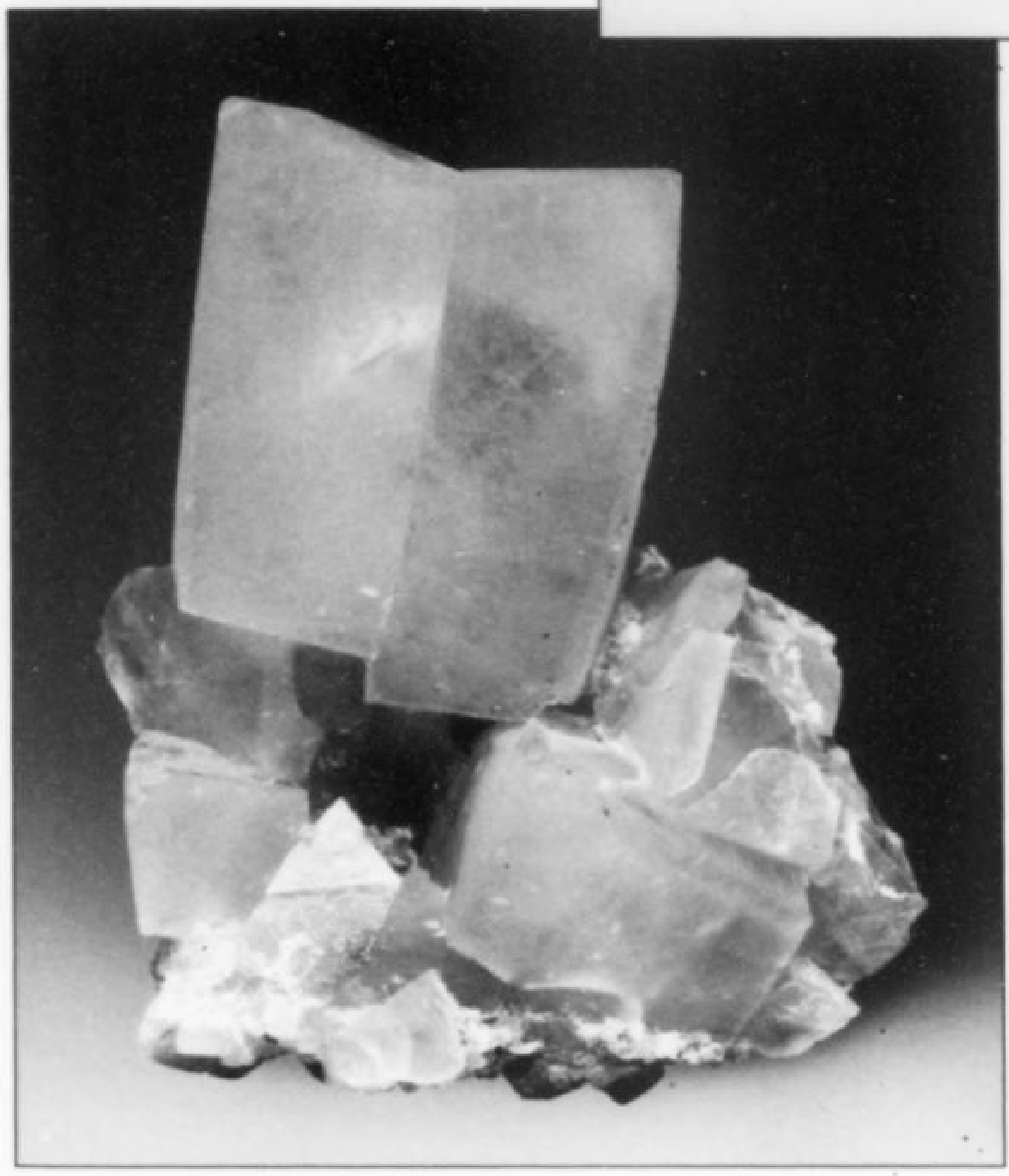
Anhydrite has been noted by Cummings (1987) as rare, but no specimens attributable to the Fanwood quarry have been seen by the author. Quartz, datolite, prehnite and albite are found as pseudomorphs after anhydrite within zones 3 and 4 of the lower and middle amygdaloids.

Apophyllite-(KF) $KCa_4Si_8O_{20}(F,OH)\cdot 8H_2O$

Only a handful of apophyllite specimens from the Fanwood quarry are known to exist. Glassy prismatic crystals up to 1 cm on datolite have been collected in zone 4 of the middle amygdaloid.

Figure 10. **Calcite crystals, 26 cm, from the Fanwood quarry. Bob Batic collection; Frank Imbriacco photo.**

Figure 11. **Calcite twin, 3.3 cm, from the Fanwood quarry. John Geiges collection; Frank Imbriacco photo.**



Bornite Cu_5FeS_4

Bornite is fairly common in zone 3 of the lower amygdaloid, occurring as dodecahedral crystals from 0.5 to 2 mm on albite. Chalcopyrite typically coats bornite, imparting a brassy hue to the crystals.

Calcite $CaCO_3$

Calcite is abundant in all of the quarry's mineralized structures. It is distributed throughout the amygdaloids starting near the bottom of zone 4 and continuing upward into zone 1. Calcite lines a large percentage of the veins which run vertically through the flows. Diapiric cavities commonly contain calcite alone or in combination with prehnite. Calcite crystals occur in a wide variety of habits, the scalenohedron and rhombohedron being the most common forms. The largest known crystal is 14 cm in diameter, but most are in the 1 to 5-cm range. Colors range from colorless or white to gray, golden yellow, orange and occasionally pink or pale red.

Chalcopyrite $CuFeS_2$

Chalcopyrite is found throughout zones 3 and 4 of the lower and middle amygdaloids as brassy sphenoidal crystals up to 1 cm on datolite, prehnite, albite and heulandite. Several specimens showing butterfly-twinned crystals have been collected. Chalcopyrite also occurs as overgrowths on bornite and infrequently as crystals and small masses within calcite veins.

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

Chrysocolla forms as a thin turquoise-colored coating on weathered chalcopyrite inside veins.

Datolite $Ca_2B_2Si_2O_8(OH)_2$

Datolite is plentiful in the amygdaloids from the middle of zone 3 downward through zone 4. Datolite is seen as compact masses of granular microcrystals, aggregates of small crystals and isolated sharp crystals, no more than 3 cm across, in combination with prehnite, calcite, albite and zeolites. Datolite varies in color from colorless to milky white, yellow-green and pale green. Crystal surfaces can be lustrous or dull.

Galena PbS

Galena is the rarest sulfide found in the quarry. Crystals are modified gray cubes and octahedrons measuring less than 2 mm, associated with prehnite, datolite, calcite and chalcopyrite.

Glauberite $Na_2Ca(SO_4)_2$

Glauberite in its original state has not been found at the Fanwood quarry. Prehnite pseudomorphs after glauberite are widespread within the diapiric amygdules of the first and second flows. Glauberite molds are uncommon outside of the cavities in diapirs. Within the pockets of the lower and middle amygdaloidal horizons,

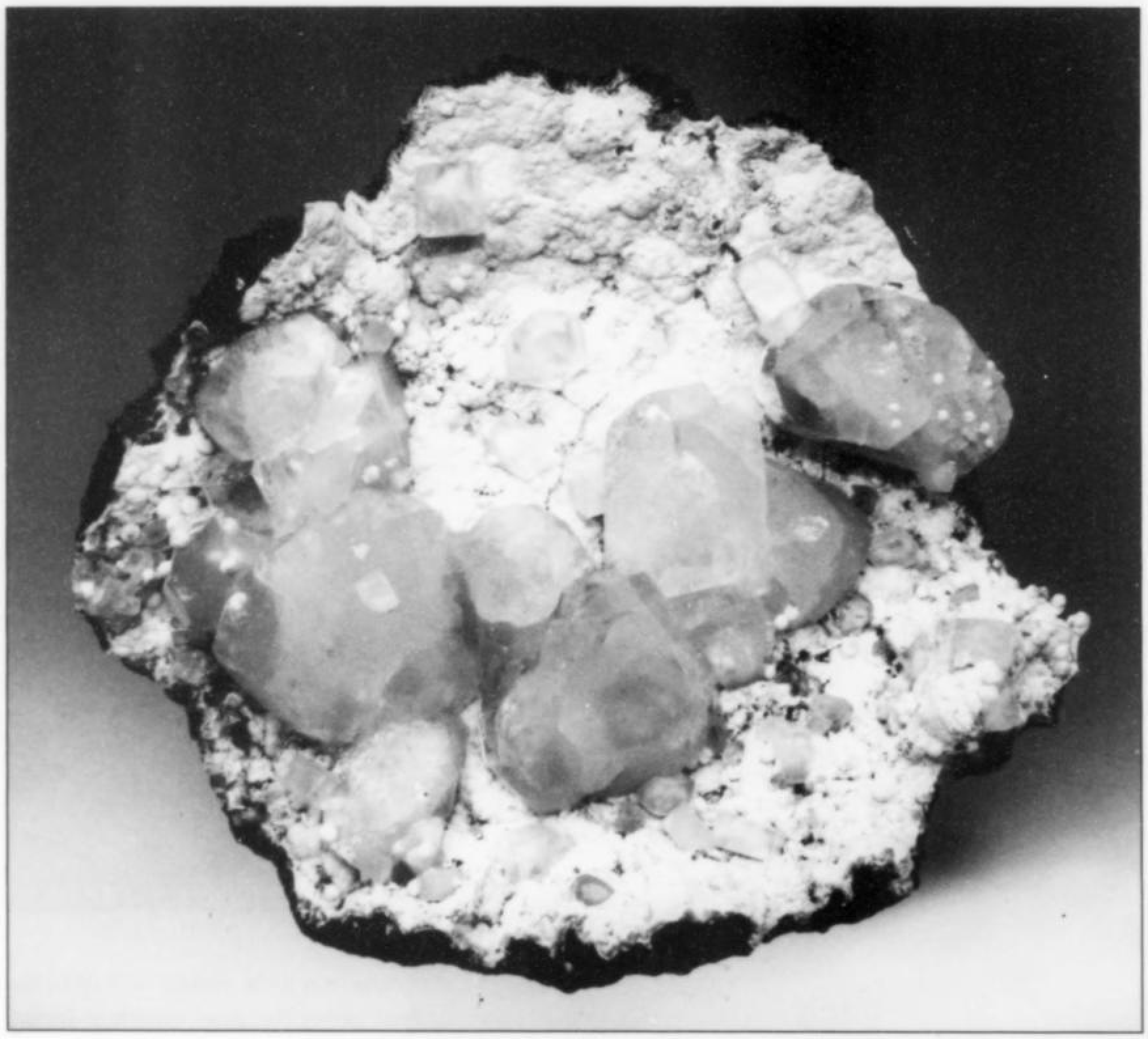


Figure 12. **Datolite crystals with calcite, 9.6 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 13. **Heulandite with stilbite, 7.5 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 14 (right). **Prehnite pseudomorph after glauberite, 10.5 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

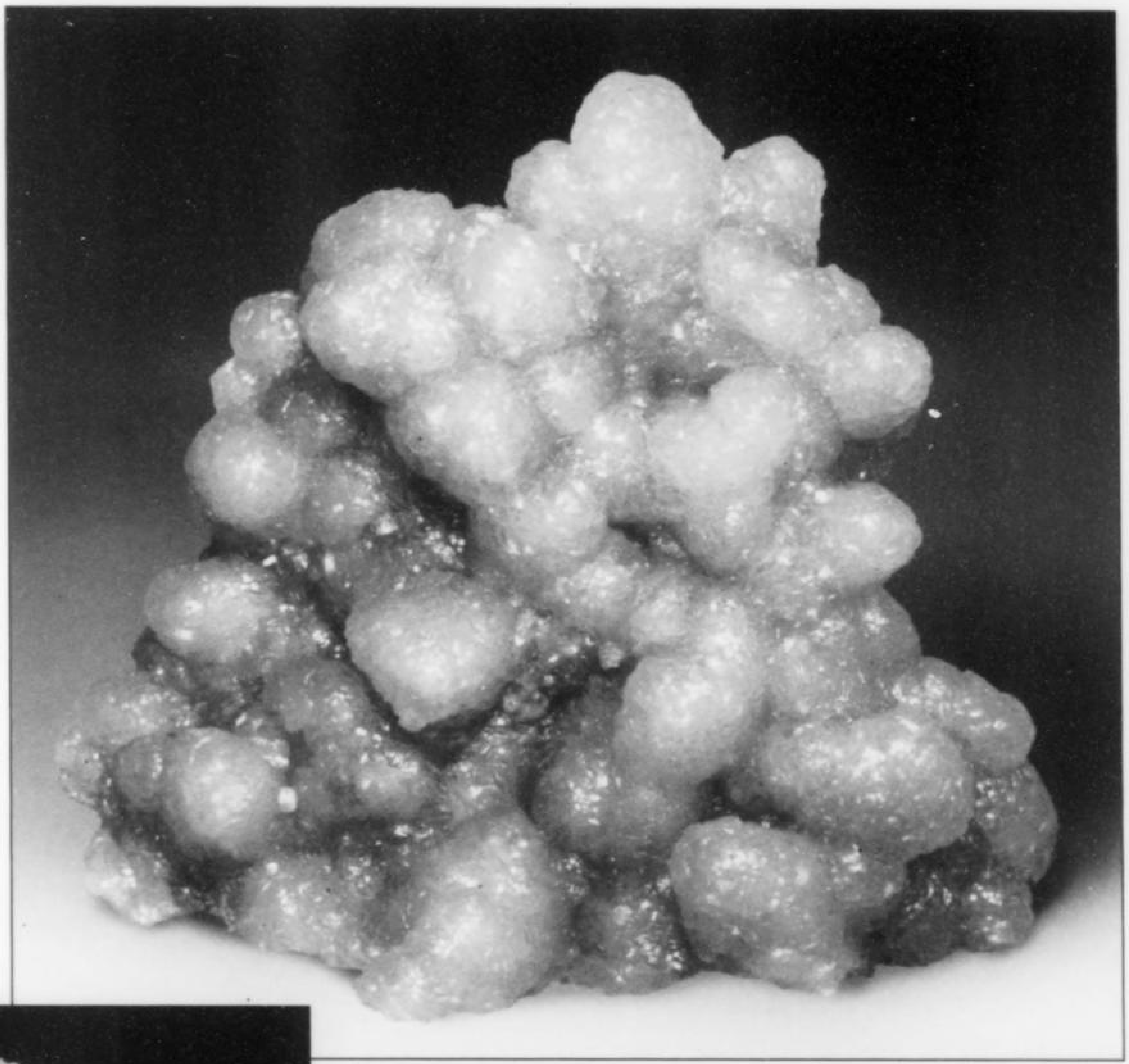
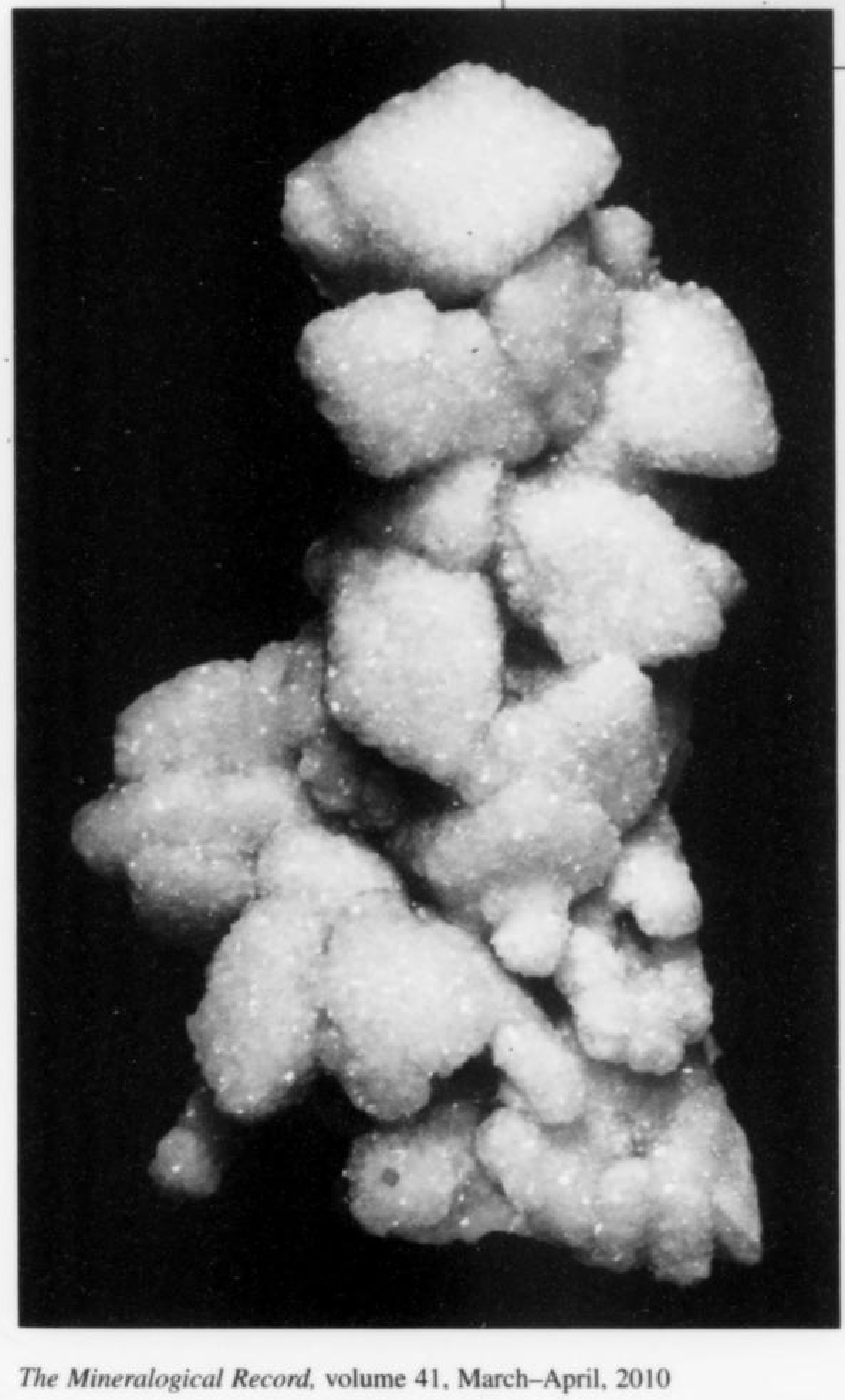
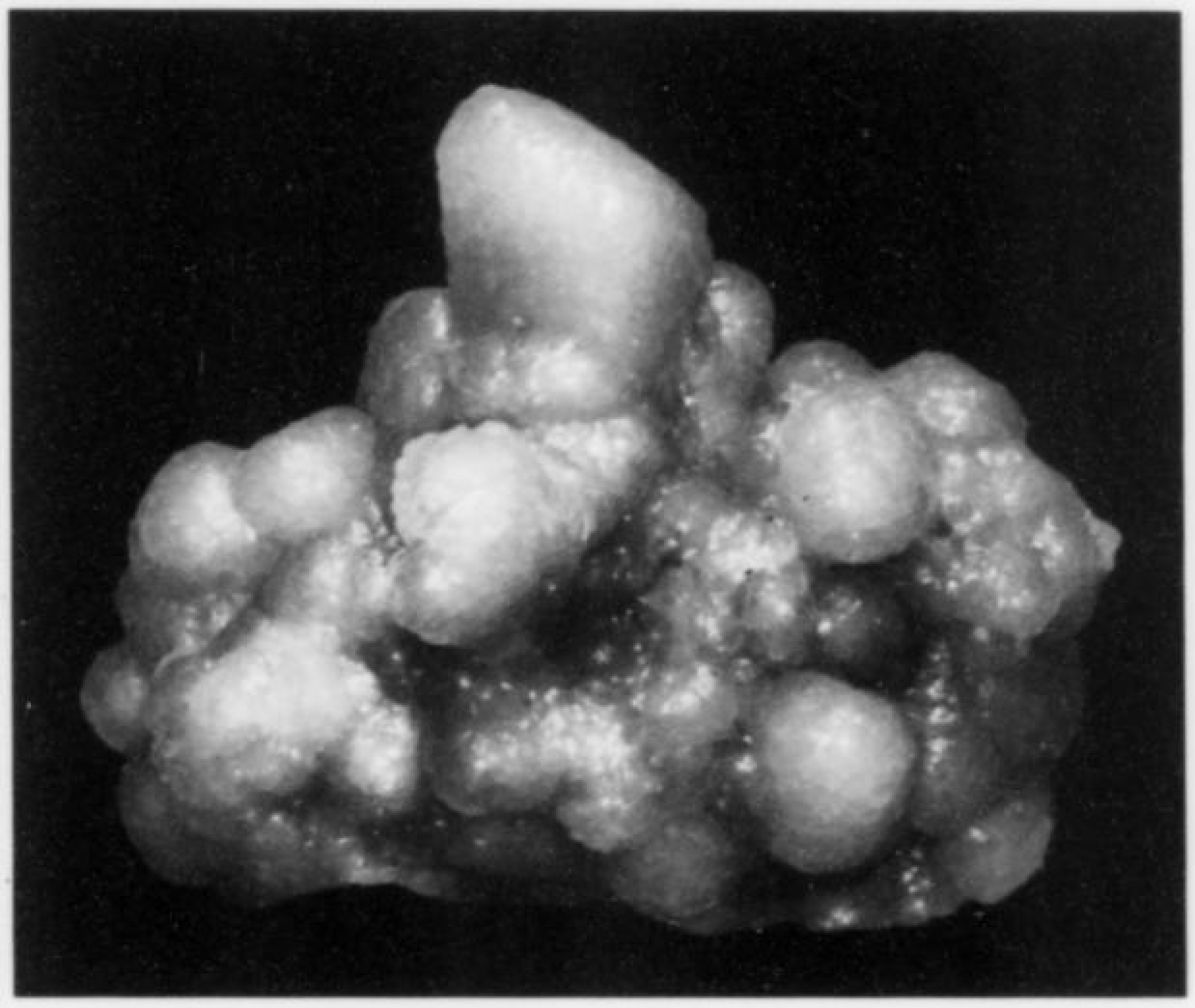


Figure 15 (below right). **Prehnite pseudomorph after glauberite, 8.3 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 16 (below). **Prehnite pseudomorph after glauberite, 10 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**





quartz, datolite and albite have covered glauberite, leaving behind rectangular epimorphs as hollow shells.

Gmelinite $(Na_2,Ca)(Al_2Si_4)O_{12}\cdot 6H_2O$

Gmelinite is a rare zeolite found only as crystals on datolite, in the basal zone of the lower amygdaloid. The striated crystals, ranging from 3 to 8 mm, are pale pink and highly lustrous.

Hematite α-Fe_2O_3

Hematite is found in amygdaloidal cavities as druses of silvery black microscopic crystals on datolite, prehnite, albite, calcite, heulandite and stilbite. It is probable that hematite inclusions are the cause of the very infrequent pink color seen in calcite.

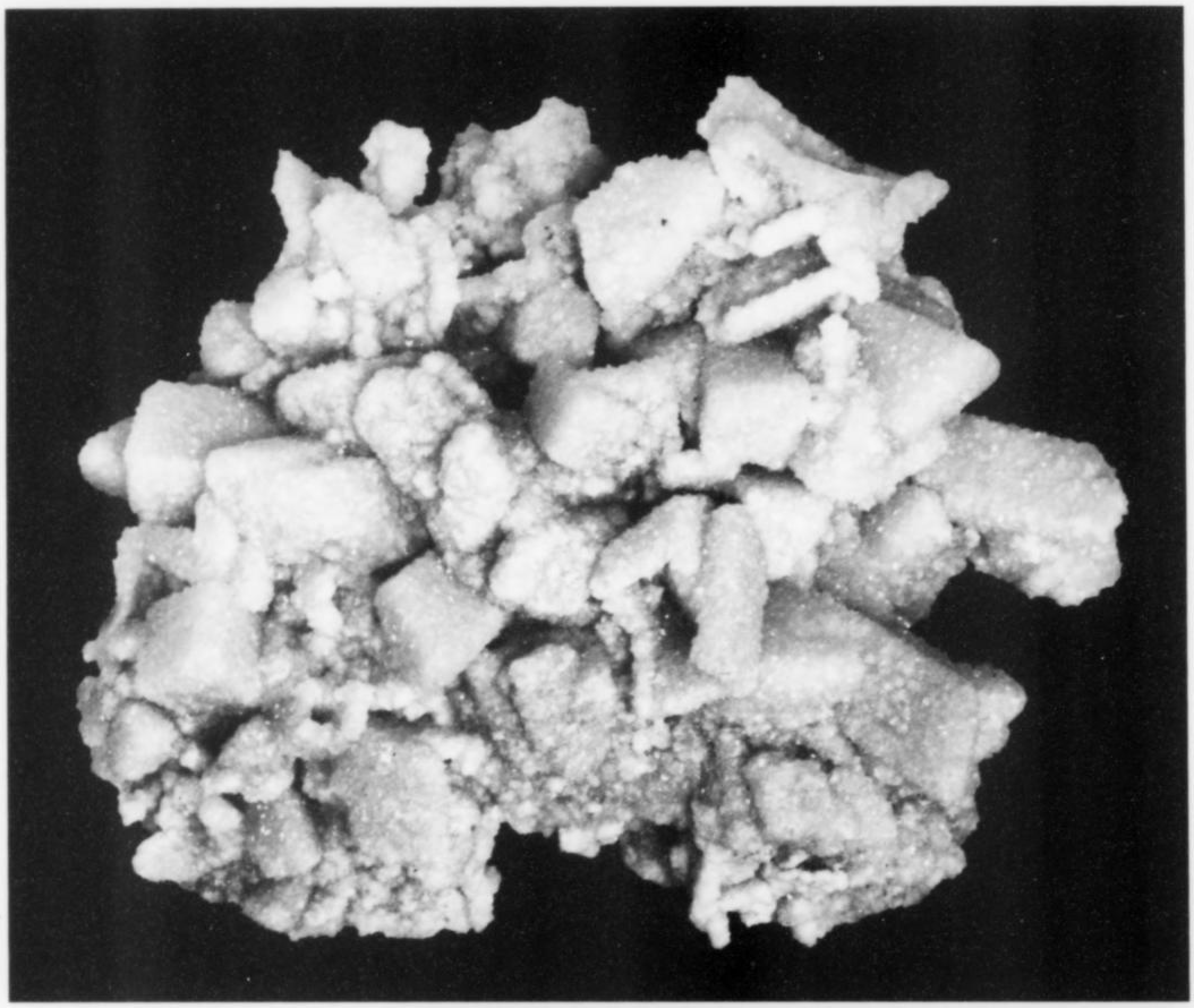


Figure 17. **Prehnite pseudomorph after glauberite, 10.7, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 18. **Prehnite pseudomorph after glauberite with calcite, 12.5 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

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

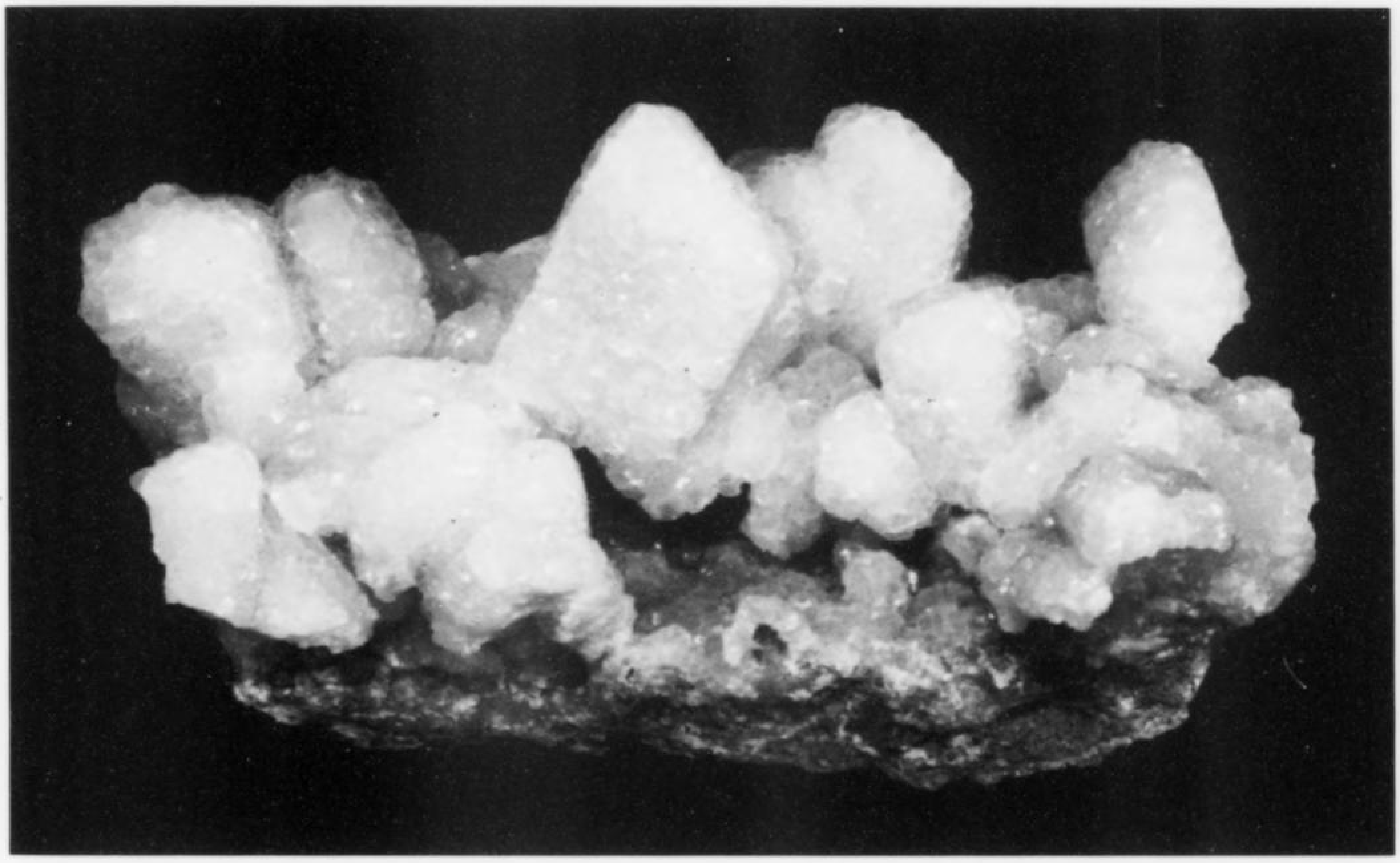
Heulandite is the most common zeolite at the Fanwood quarry, frequently found directly attached to the pocket wall. Crystals are typically coffin-shaped and blocky with varying degrees of luster depending on alteration. Although crystals up to 3.2 cm are known, most are much smaller. Colors include white, gray, greenish gray and shades of brown. Heulandite is commonly associated with stilbite, calcite, albite and (less commonly) prehnite and datolite.

Natrolite $Na_2(Al_2Si_3)O_{10}\cdot 2H_2O$

Natrolite is an extremely rare zeolite at the Fanwood quarry; specimens were discovered on one occasion as jumbles of acicular

Figure 19. **Prehnite pseudomorph after glauberite, 14.2 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 20. **Prehnite pseudomorph after glauberite, 8.9 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**



crystals, no longer than 1 cm, on prehnite in a diapiric amygdule. The crystals are white and exhibit the classic elongated orthorhombic prism with pyramidal terminations.

Prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$

Prehnite occurs in the amygdaloids distributed between the top of zone 4 and the upper part of zone 3. It forms thin botryoidal cavity linings and small spheroids which are orange, green and yellow-green. It is particularly abundant in the sulfide horizon, where it forms the base on which calcite, chalcopyrite and occasionally galena have grown. The quarry's best prehnite comes from the numerous vuggy openings inside diapirs. Within these structures prehnite is found as botryoidal coatings, isolated spheres and thick carpets composed of prehnite pseudomorphs after glauberite and anhydrite. The color, shape and luster of the prehnite can vary greatly between the pockets. Colors range from a bleached whitish green to a vivid green.

Pyrite FeS_2

Pyrite is uncommonly found as lustrous cubic crystals, between 2 and 5 mm, in combination with later-formed minerals such as zeolites and calcite. The crystal faces are typically striated.

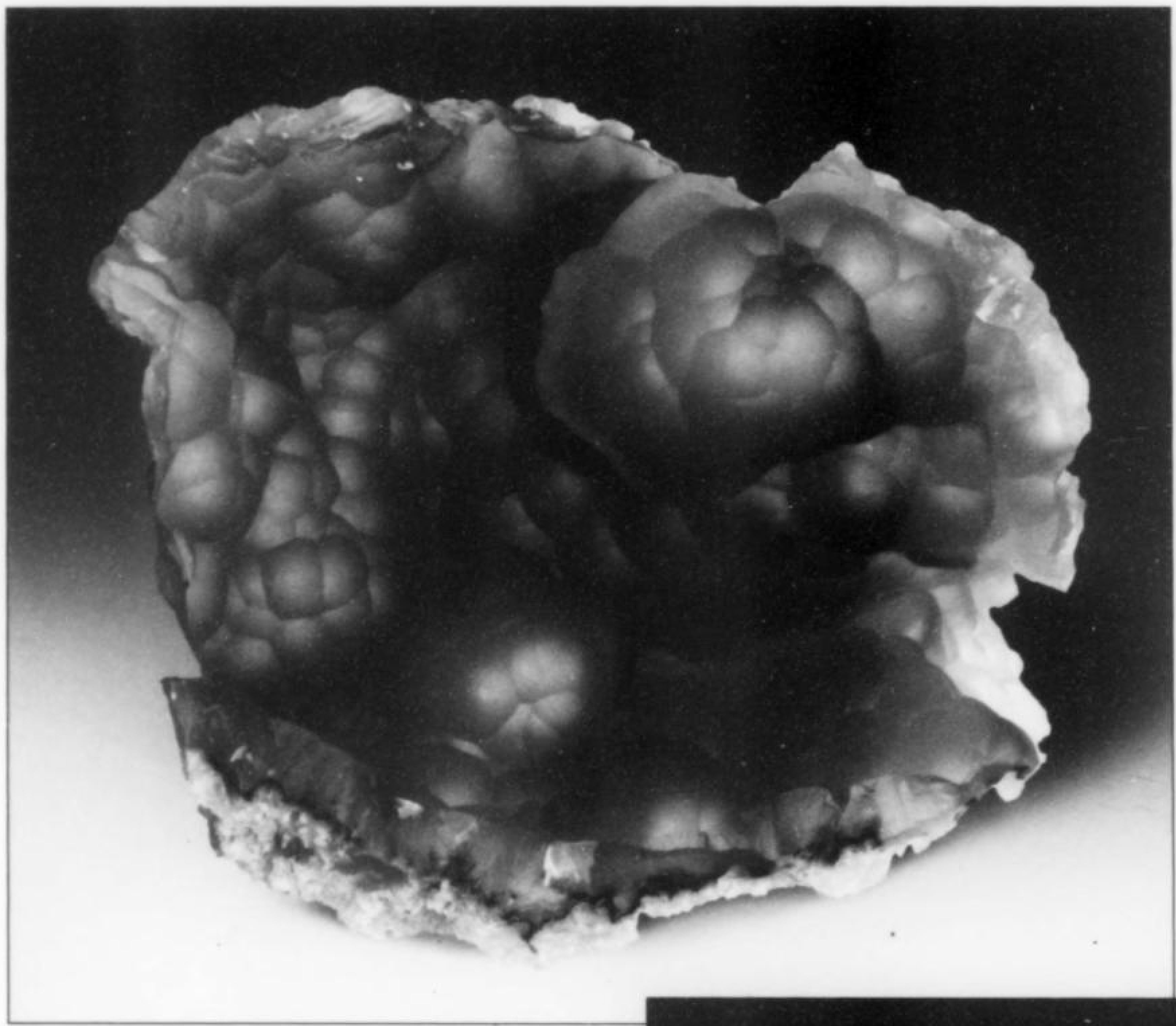


Figure 21. **Botryoidal chalcedony, 9.5 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 22. **Stilbite sphere, 3.4 cm, with heulandite, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Quartz SiO_2

Colorless, amethystine and smoky quartz, as well as chalcedony, occur commonly in the bottom half of zone 4 of the lower and middle amygdaloids. Crystals range in size from microscopic up to 1 cm across, normally tightly configured in pockets with only the terminations being visible. Chalcedony is found as translucent gray and off-white botryoidal cavity linings and massive vein fillings; banded agate is also sometimes found. Many pockets at the base of zone 4 contain a layered sequence beginning with chalcedony and followed by quartz crystals, then calcite.

Stilbite $NaCa_2(Al_5Si_{13})O_{36}\cdot 14H_2O$

After prehnite, stilbite is probably the most interesting of the Fanwood quarry minerals for collectors. Stilbite is readily seen in a variety of habits, including single sheaf-like crystals, half and full bow ties, and globular radiating aggregates. The largest spheres can exceed 7 cm in diameter, but most are much smaller. Stilbite is generally golden brown, gray, orange or tan in color. A large percentage of the spherical groups are quite splintery, readily breaking apart into sharp needles. Stilbite generally occurs in association with calcite, albite and heulandite, but it is occasionally found with prehnite and datolite. Some of what appears to be stilbite has been identified by Francis and Metropolis (1985) as stellerite.

Other Species

Several other mineral species occur at the Fanwood quarry but are of little interest to most collectors. These include pumpellyite and

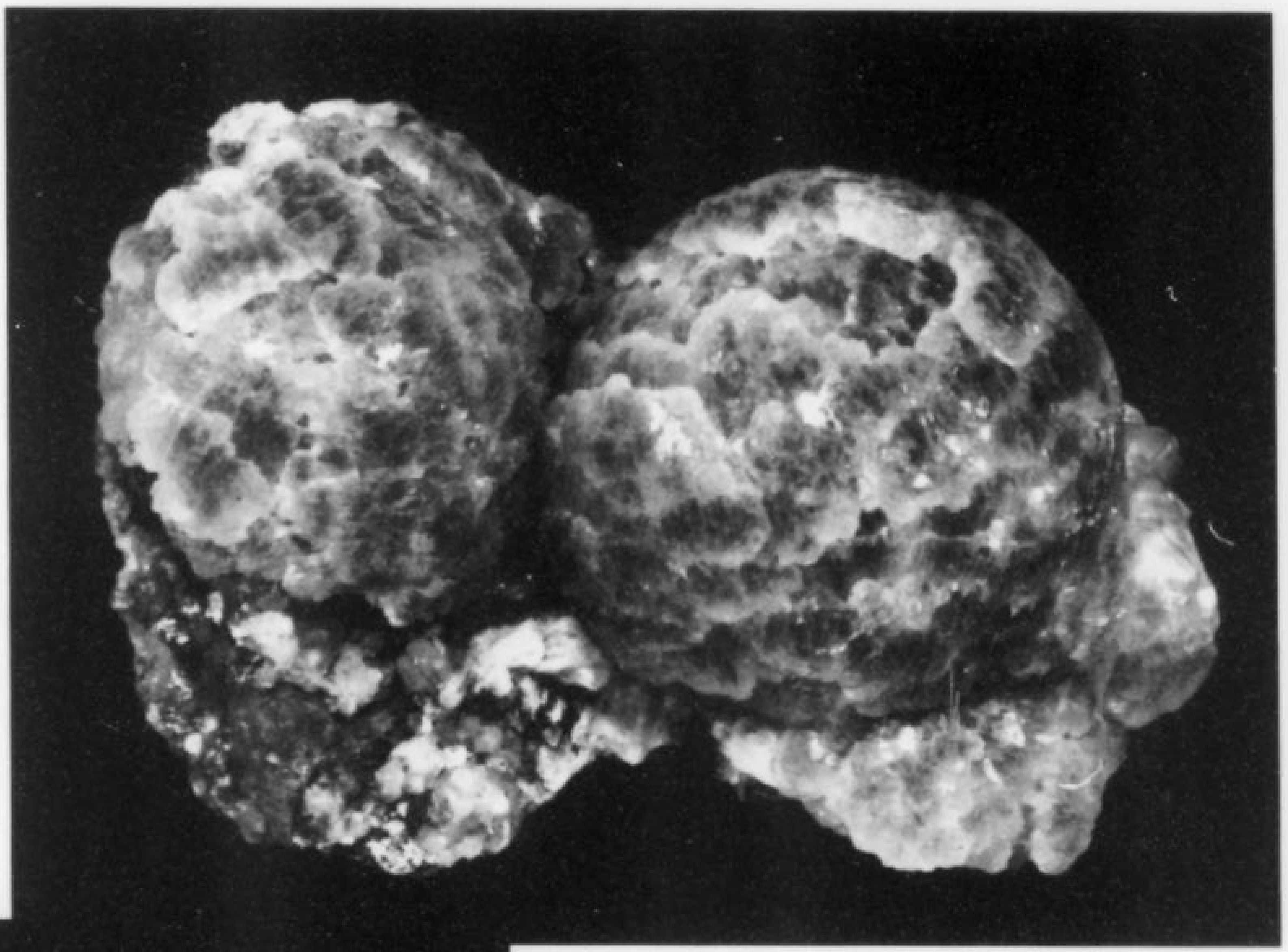


Figure 23. **Stilbite spheres, 2.9 cm, with calcite, from the Fanwood quarry. Frank Imbriacco collection and photo.**

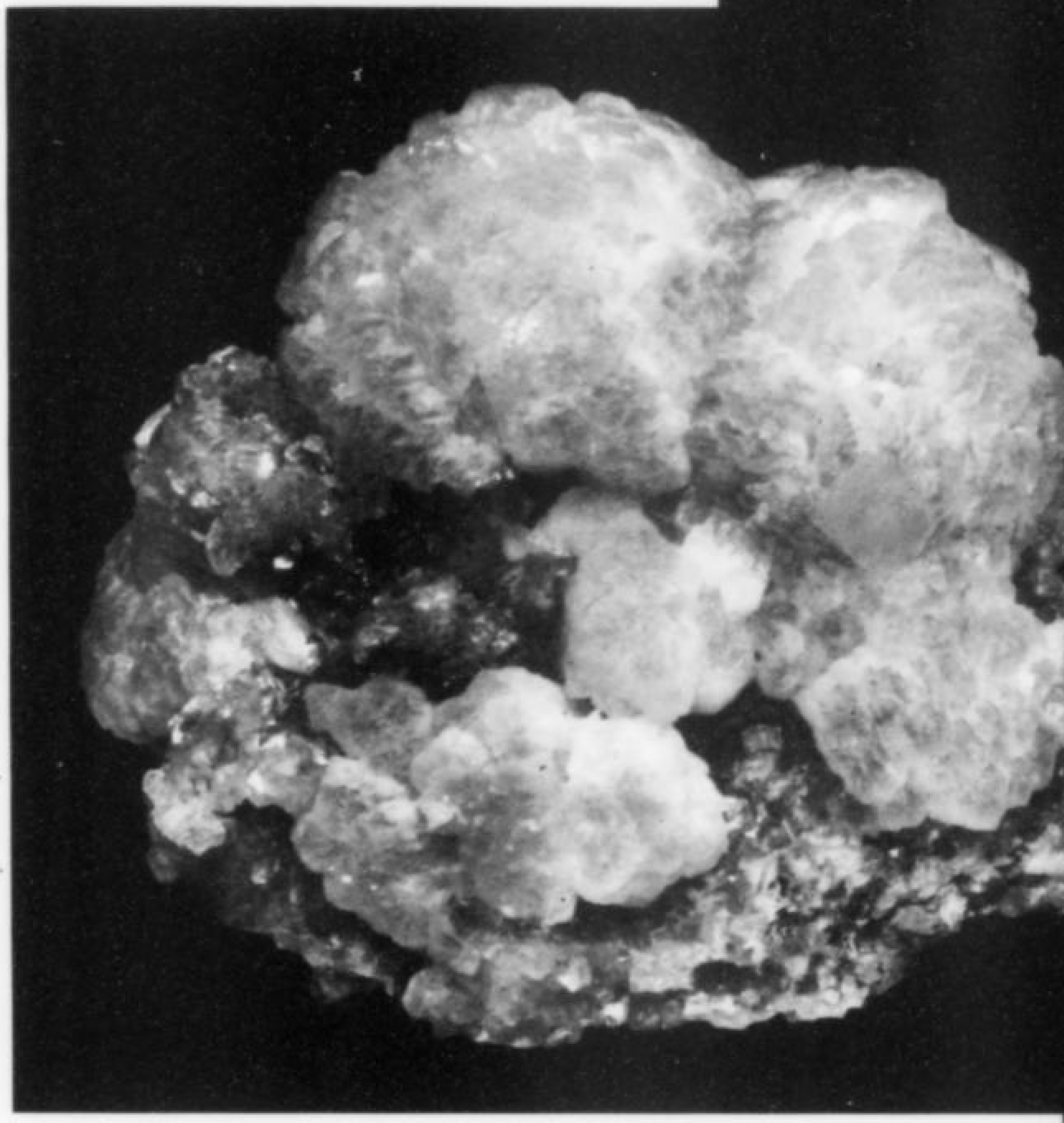
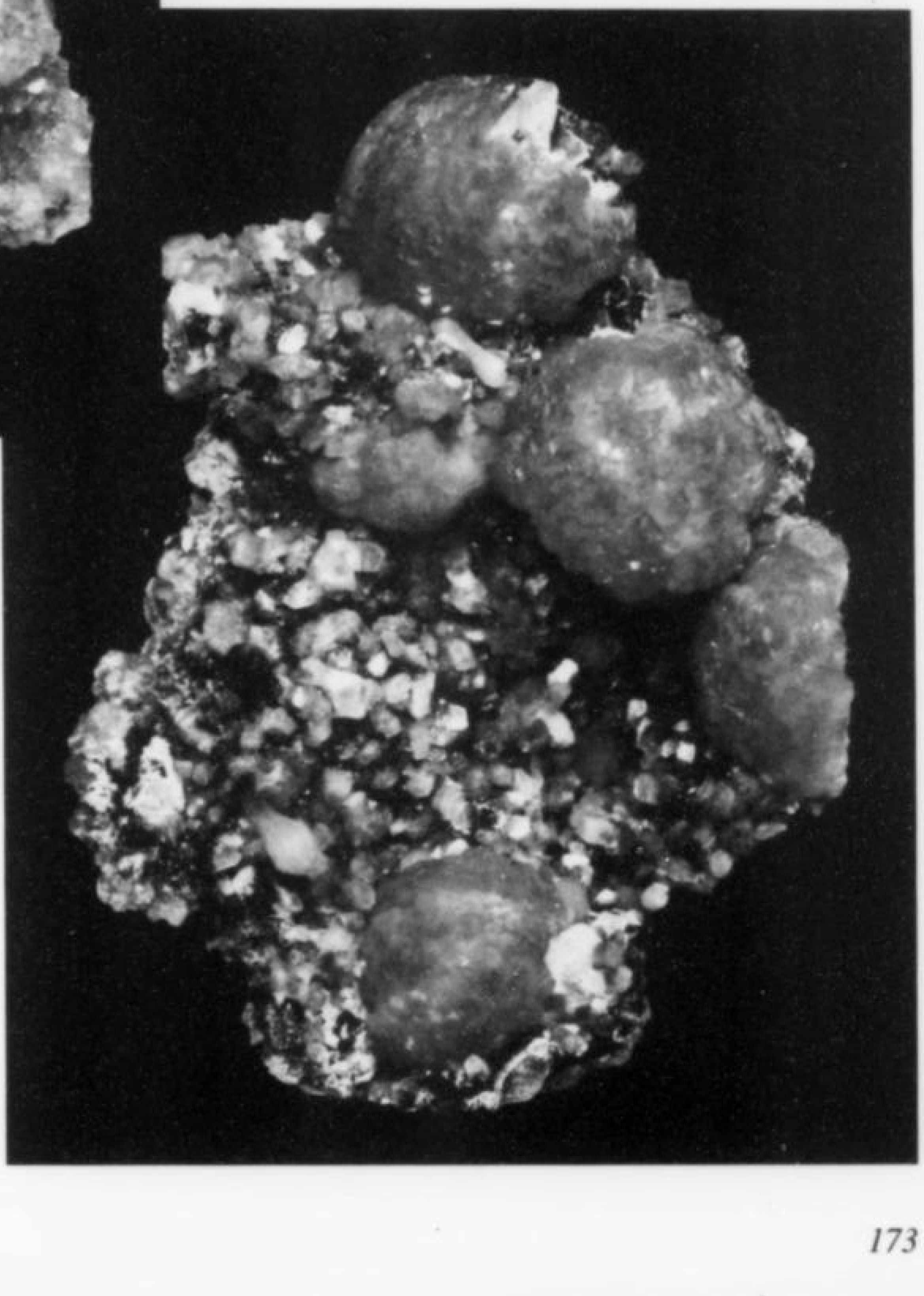


Figure 24. **Stilbite with heulandite, 5.3 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**

Figure 25. **Stilbite spheres with albite, calcite and heulandite, 11.2 cm, from the Fanwood quarry. Frank Imbriacco collection and photo.**



members of the chlorite group, all of which form as tiny clusters of greenish black to black microscopic crystals on other minerals and on cavity walls.

CONCLUSION

During the Fanwood quarry's over-100-year history, the operators have exposed large expanses of mineralized basalt from which scattered collector-quality specimens of stilbite, calcite, heulandite, quartz, datolite and prehnite have been recovered. Several significant discoveries of minerals have been made by collectors. An enormous volume of mineralized rock remains to be uncovered on the property via blasting; thus the potential for finding attractive specimens should continue indefinitely.

Weldon Materials Inc. does not allow general collecting, although occasionally the company will permit state and university geologists to study, photograph and collect inside the quarry. The property is patrolled by security, and management intends to prosecute any and all trespassers.

ACKNOWLEDGEMENTS

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The BROWN MONSTER *and* REWARD MINES

Inyo County, California

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In a historic gold mine in the Owens Valley, California, alteration of sulfide veins has produced a variety of well-crystallized uncommon secondary lead, copper and bismuth minerals. These include arsentsumebite, tsumebite, corkite, fornacite, duftite, caledonite, kettnerite, linarite, leadhillite, brochantite, mimetite, pyromorphite, vanadinite and wulfenite.

INTRODUCTION

The Brown Monster–Reward mines are located in Section 3, T. 14S, R. 36E (M.D.M.) at an elevation of 4,500 feet on the western flank of the Inyo Mountains, about 13 miles northeast of Lone Pine in Inyo County, California. They can be reached by driving 5 miles east from State Route 395 on the unpaved Manzanar-Reward Road, to the base of the mountains where several old mining ore bins are located. The road is to the east of the site of the Manzanar World War II internment camp and crosses concrete runways built during the war and used as part of the Civilian Pilot Training Program. These runways were also part of the Western Region Defense Plan, functioning as contingencies in case the West Coast was invaded during the war.

The mines of the Brown Monster–Reward group were some of the earliest gold mines developed in the Owens Valley; at the turn of the century the small town of Reward was located there. In addition to gold deposits, galena and other sulfide veins were discovered. These mines have produced an interesting suite of uncommon colorful crystallized secondary lead and copper minerals.

HISTORY

The earliest history of the Owens Valley is given by Chalfant (1922). No one knows who the first whites were to enter the Owens Valley. It has been suggested that Jedediah Smith passed through the valley in the mid to late 1820s, and there are reports that he discovered placer gold near the north shore of Mono Lake on his return to Salt Lake City. It has also been suggested that in 1833 the mountain man Joseph R. Walker passed through the valley while on an expedition which he led from Salt Lake City, Utah to Monterey, California. The first well-documented party of whites to enter Owens Valley was a wagon train led by Walker in 1843. The group of about 50 was organized in Independence, Missouri by Joseph Chiles and was met in Fort Laramie, Wyoming by Walker, who guided them to Visalia, California and the Gilroy Rancho after many ordeals. It has been speculated that his route through the Owens Valley at this time was based on his earlier travels in 1832–1833. An expedition led by John C. Fremont which left from Bent's Fort on the Oregon Trail met up with Walker and Richard Owens in 1844, and it was Fremont who named Owens River, Owens Valley and Owens Lake in honor of Owens' abilities. This party passed through Owens Valley in 1845 after having traveled through the San Joaquin Valley and crossing the Sierra Nevada.

Following the discovery of gold at Sutter's mill, near Sacramento in 1849, the gold rush sparked exploration and prospecting for gold throughout much of the Sierra Nevada and beyond. In 1859 Cord Norst discovered placer gold in Mono Gulch, in the northern part of Owens Valley, and this may have been the site where Jedediah Smith discovered gold in the 1820s. This sparked the "Mono diggings" and the formation of the short-lived settlement of Monoville.

Figure 1. **The town of Reward with mill, ca. 1900.**

Figure 2. **Reward mill and other buildings, ca. 1890.**

By 1859–1860 several parties had begun to prospect the southern Owens Valley, including the Hill party, which established temporary headquarters near Lone Pine and which prospected Mazourka Canyon. In 1860 the party of Dr. Darwin French (the Darwin mines and Darwin Falls were named after him), which included Dennis Searles, had discovered silver-lead ores at Old Coso south of the Owens Valley.

On March 4, 1860 the New World Mining and Exploration Company, consisting of about 20 men led by Colonel H. P. Russ, left San Francisco with the purpose of prospecting the Owens Valley and adjacent areas. A second group, headed by Dr. S. G. George, which left from Visalia, met the party at Walker's Pass and the combined group entered Owens Valley, with one party exploring eastward from Owens Lake. A camp was established on the banks of the Owens River, a few miles southeast of the present town of Independence, from which Dr. George spotted the Union vein with his field glasses. Russ and George examined the outcropping, which was encouraging, and they moved camp nearer to the lode and organized the Russ Mining District on April 20, 1860. The claims located at that time included the Union, Ida, and Eclipse, which was later named the Brown Monster. During these early times the local Paiute Indians were curious and generally friendly. The Indians indicated that the mountain to the east of the valley was named "Inyo" which was interpreted to mean "the dwelling place of the great spirit."

By 1861, not only had prospectors begun to enter the Owens Valley but cattlemen also arrived, bringing their herds with them, and decided to winter in the area. The winter of 1861–1862 proved to be the most severe in many years, with 54 straight days of either heavy rain or snow. This created hardships for everyone, and on occasion the Indians would slaughter a steer. This was tolerated for some time but finally the cattlemen murdered several Indians in retaliation. After a brief truce the situation deteriorated rapidly and a full-blown Indian war erupted. Lone prospectors were particularly

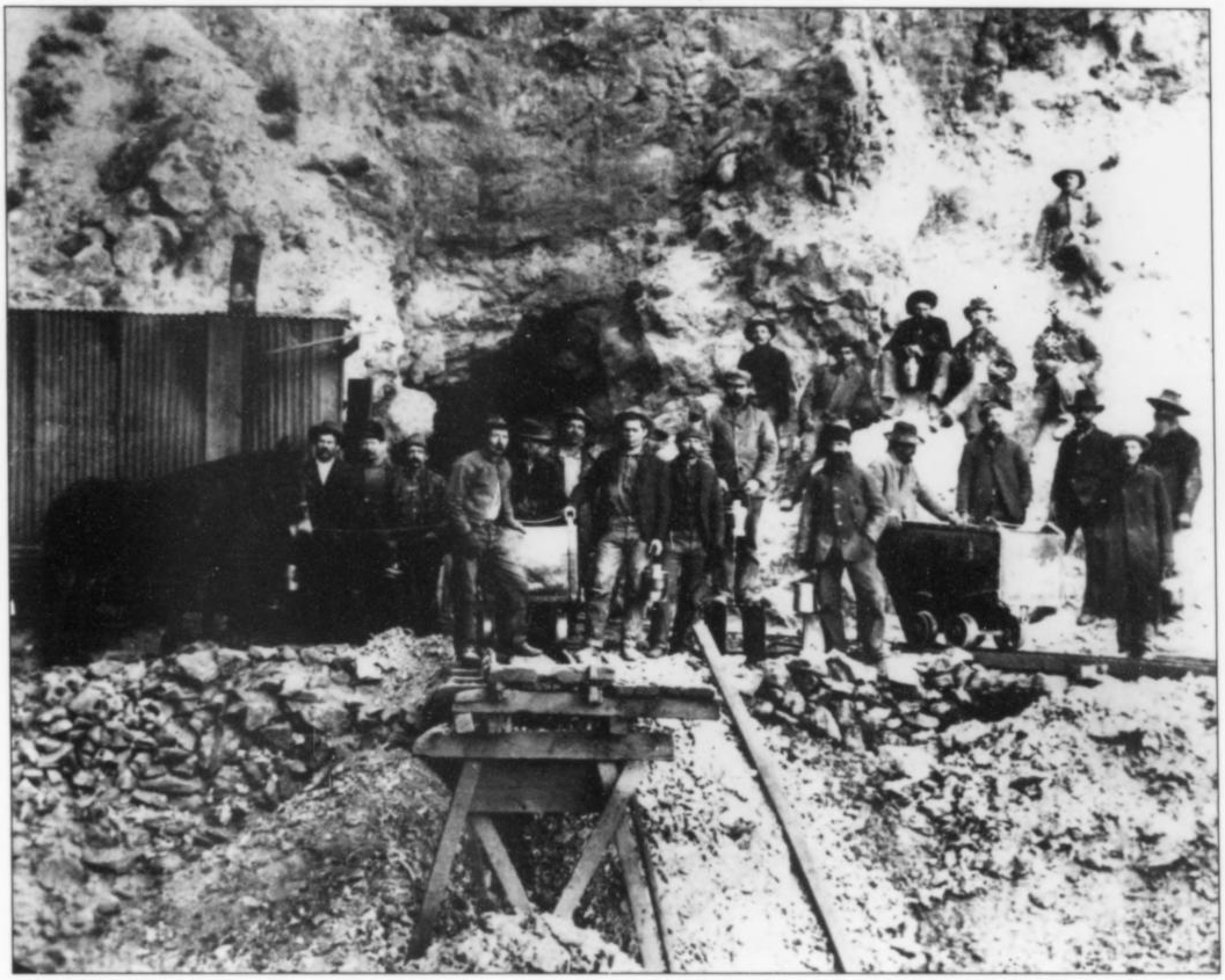

***Figure 3.* Miners at the portal of the Reward mine, ca. 1890.**

at risk of being ambushed, property was destroyed, and parties as large as 13 had been massacred.

By May of 1862 the Indians were in nearly undisputed possession of the Owens Valley. As a result, there was an appeal for military protection, and on June 12, 1862 a Colonel Evans left Fort Latham, near Los Angeles, with 157 men as part of the Mono and Owens River Military Expedition. On July 4, 1862 they settled into a site in the Owens Valley which they named Camp Independence, because of the occasion, and which later became the town of Independence. The soldiers not only attacked the Indians but also destroyed their food caches. A truce and treaty were quickly established, and during the remainder of 1862 work began at the Eclipse mine, with R. S. Whigham as superintendent.

A prospecting soldier discovered gold in the range northeast of the Camp, and when samples sent to San Francisco proved rich, the San Carlos Mining and Exploration Company was organized. On September 24, 1862 Henry G. Hanks (after whom hanksite was later named), who was to become the first state mineralogist in 1880, was sent to investigate, and he became the assayer for the San Carlos mine.

The truce with the Indians was tenuous at best and skirmishes would periodically break out. Henry Hanks, in his correspondence to the President of the San Carlos Company in 1862, noted that he and a Captain Anderson took six rifles and ammunition down to the Union mine to protect the mill, and that several nights earlier Indians had burned the haystack and camp at the mine. In July 1863, after the Kern massacre and persistent destruction of their food caches by the soldiers, 400 Indians surrendered and a total of 900 Indians were relocated to the San Sebastian reservation near Fort Tejon.

During periods when conflicts with the Indians were less frequent, and it was perceived that the warfare had ended, settlers continued to enter the Owens Valley and mine development continued. In a letter from San Carlos to the San Francisco *Alta California* in September 1863 it was noted: "In the Russ district several companies are at work. The Eclipse is turning out rich ore and is of great extent. If it is not the richest mine in all of California we are all mistaken . . ." It is not known how true this statement was, but for the purposes of attracting investors it is assumed one always has "the richest mine in all of . . ."

At this time several small communities, which no longer exist, sprang up. The closest to the Eclipse mine was Bend City, so named because it was situated on a bend in the Owens River. To the north were San Carlos and Chrysopolis. Both Bend City and San Carlos consisted of 60 or more adobe dwellings, including several hotels, dry good stores and saloons, and each had a ferry to provide access across the Owens River to the mines and prospects to the east in the Inyo Mountains. Indian raids resumed during the mid-1860s, and in 1865 the Union mill was burned. While many inhabitants fled the area, some that remained organized a militia and took part in the Owens Lake massacre in January 1865, where dozens of Indian women, children and unarmed men were murdered. With the end of the Indian war around 1867, settlement and development of the Owens Valley resumed. The total loss of life as a result of the war was about 60 whites and 200 Indians.

With the founding of the town of Independence in 1865, at the former site of the camp, the communities of Bend City and San Carlos quickly fell into obscurity. In 1870 Isaac Friedlander applied to patent the Eclipse mine (Chalfant, 1922) and a six-stamp mill had been constructed at the site of the old Union mill on the banks of the

Figure 4. **"Slim Princess" narrow gauge railroad engine at Manzanar station, which serviced the Reward mine. Image from Ferrell (1982).**

Owens River. Much of the following history comes from numerous accounts in the *Inyo Independent*, a local newspaper.

In 1870 the mine was purchased from the Union Company by a group of English investors, the Eclipse Gold Mining Company, for $150,000. Goodyear visited the mine in 1870 and published a description in Irelan (1888). At that time, Captain Eudey, who was superintendent of the works, was awaiting arrival of mill machinery from England. The mine consisted of three levels which followed a quartz vein. "Much of it is very cellular, filled with cavities containing crystals of calcite, etc. . . . Some of it contains beautiful crystals of perfectly transparent quartz . . . fine particles of free gold may be seen quite plentifully scattered through some jaspery rock . . . ." Later in 1871 a 1.5-mile tram was completed, a 20-stamp mill was operational and a ditch to supply water from the Owens River was deepened.

On March 26, 1872 a strong earthquake (around magnitude 7.6) struck near Lone Pine, killing 27 people there, while killing one person and injuring another at the Eclipse mine. Most of the adobe dwellings in Lone Pine, Bend City and San Carlos were destroyed, including those at the Eclipse mine (Chalfant 1922). Fanciful accounts of the quake were reported in the local newspapers. "Immediately following the great shock, men whose judgment and veracity is beyond question, while sitting on the ground near the Eclipse mine, saw sheets of flames on the rocky sides of the Inyo Mountains but a half mile distant. These flames, observed in several places, waved to and fro apparently clear of the ground, like vast torches; they continued for only several minutes." Later that year the mine was beset by claim jumpers, and rumors of mismanagement were circulating in the London *Mining Journal*.

In 1874 Captain Eudey brought eight to ten English miners to work at the Eclipse. By 1875 the mill had been completed along with a 3-mile tramway that connected the mine with the mill. In 1876 the Eclipse mine shipped $18,346 worth of bullion and by 1877 an additional ten stamps were added to the mill, bringing it to a total of 30. By 1877 Captain Eudey had been replaced as manager, and the mine ran into such severe financial difficulties that it had to be sold. This ended the connection of the London Company with the enterprise, since they were forced to sell it in order to pay creditors, primarily local merchants (one of whom was A. W. Eibeshutz), who may have been in league with Captain Eudey. Captain Eudey then became mine manager once again, and made the mine operational. It was renamed the Brown Monster mine, and a 30-stamp mill was constructed 4 miles from the mine, on the banks of the Owens River.

The main Eclipse vein was discovered in 1878 (Knopf, 1914). The mill, which had a crushing capacity of 45 tons of ore a day, was connected to the mine by a railroad and was driven by water carried from the Owens River in a 6-mile ditch (Irelan, 1890). In 1880 the Carson and Colorado narrow gauge railroad was incorporated, and by 1883 the line extended from Carson City, Nevada to the Owens Valley, where it ran along the east side of the valley from Laws to Keeler on the north shore of Owens Lake. The railroad was only a mile from the west flank of the Inyo Mountains, providing easy access to the local mines, including the Brown Monster and Reward. Similarly a series of canals that were constructed ran along the east side of the Owens Valley and provided water to the mines from the Owens River.

In 1882 patent applications were submitted for the Brown Monster mine by A. W. Eibeshutz and for the nearby Hirsch mine (later renamed the Reward) by Nathan Rhine, another local merchant. Rich ore was supposedly being taken out of the Hirsch by Captain Watt and the Furguson brothers. Eibeschutz spent considerable money suing the English mining company and defending himself. As a result, he had little capital to invest in the Brown Monster mine, and by 1885 the mine was being leased to Tom Bastion and the mill had fallen into disrepair.

For the next ten years there is little to no mention in the local newspapers of mining activity at the Brown Monster mine, or anywhere else in Inyo County. By 1896 the Hirsch mine had been renamed the Reward, the shaft was down 115 feet, and 25 men were employed there by the company. In 1902, A. W. Eibeshutz sold the Brown Monster mine to some Los Angeles investors, who probably were also the owners of the Reward mine, for $15,000.

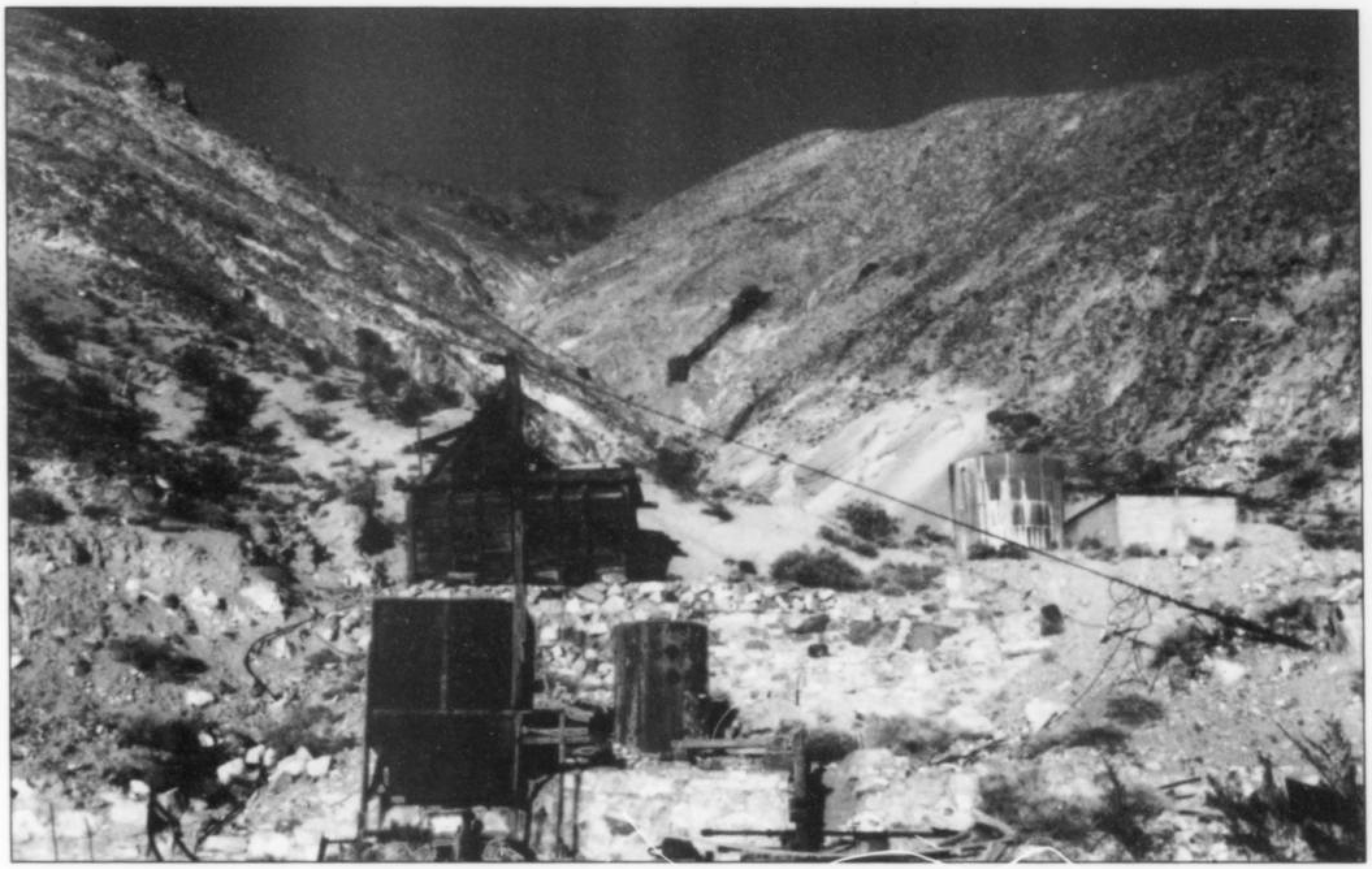

Figure 5. **Mining structures at the base of Reward gulch.**

At this time a 14-foot ledge containing high-grade ore (". . . coarse gold, like wheat grains . . .") was developed.

In 1903 the 30-stamp mill was dismantled and replaced by a 20-stamp mill which was located at the mine site and connected to the upper workings by a gravity tram (Knopf, 1914). This new mill and a 120-kilowatt generator, powered by a small waterfall in the William Penn Colonial Association ditches, cost $80,000 and a small school house was also built at a cost of $2,500. During this time a small town developed which, in addition to the school house, had a U.S. Post Office from 1900–1906.

In 1910 the Carson and Colorado Railroad was taken over by the Southern and Pacific, and the narrow-gauge engines were affectionately nicknamed the "Slim Princess" (Ferrell, 1982). After some neglect, due to lack of adequate power for profitable development, the mine was taken over by A. J. McCone and Associates in 1910. In 1911 the mine facilities and mine were overhauled and an electric transmission line was constructed across Owens Valley in order to supply power. In 1912 the mine was closed in order to install a cyanide plant; however, there was also a pending change of ownership, and evidently the mine remained idle until 1935.

The Brown Monster was leased and worked by T. L. Brite (or Bright) of Independence for most of the period from 1936 to 1951. The owners were Guy Eddie and Charles De Chase of Los Angeles. The property consisted of two patented claims (the Reward and the Brown Monster) and six general claims (including the Eclipse, Hidden Treasure, Hirsh and Telescope groups). The Hirsh is located a little above the Brown Monster mine and consisted of a 100-foot-long tunnel with a 200-foot drift running along on the ledge, from which three winzes were sunk. The gold-bearing quartz vein proved to be 4 to 8 feet thick and also carried argentiferrous galena.

From April 1935 to February 1936, some 2,000 tons of ore averaging $25 per ton of gold was extracted from the Brown Monster (Tucker and Sampson, 1938). From March to August 1936 the Reward was leased by Monte Carlo Mines, Inc. and ore was shipped to the Mount Whitney/Union mill for treatment. However, there was insufficient recovery to justify continued operation. In 1938 ten men were employed at the Brown Monster mine; ore, said to carry $25–40 per ton of gold, was shipped to the Burton Brother's mill at Tropico in Kern County (Tucker and Sampson, 1938).

From 1940 to 1942 the mines, which were owned by Basil Prescottt of Beverly Hills, were subleased to the Golden Queen Mining Company which undertook considerable exploration. Several hundred feet of drifts and crosscuts were driven, and diamond drilling work was done at both the Brown Monster and the Reward. Ore was shipped to the Golden Queen mill in Mojave but results were not encouraging. In 1948 veins carrying lead, silver and gold were discovered in the upper levels of the Reward and for a while 10 tons per day, assaying at $100-150/ton, were shipped to the American Smelter and Refining Company in Selby, California (Norman and Stewart, 1951). As of 1951 a small mill had been constructed to concentrate lower-grade ore and three men were employed there.

In the early 1980s the workings were reactivated by International Recovery of Los Angeles, with Ted Youngquist as mining engineer, and a modern two-compartment mine tunnel was cut into the lower workings of the Brown Monster mine from the north side of the ridge, opposite from the original inclined shaft (*California Mining Journal*, 1983). This tunnel is on an approximately 25° incline and has several side tunnels and horizontal workings at its base. These tunnels appeared to follow and intersect some of the original lower workings but, in general, only penetrated barren ground. Supposedly stoping was performed in the upper levels and ore was transferred by gravity along chutes to the new haulage tunnels. The ore was processed at the Firestone mill east of Independence, but there was little recovery. During this time period there was extensive machinery on the premises, but today it has all been removed and the site is abandoned. The two-compartment 25° incline is a popular attraction for people who enjoy the thrill of actually being able to drive their vehicle underground.

At present, many of the picturesque original ore chutes and bins and the aerial tramway still remain in the gulch, giving the area its historic character, but little remains of the town of Reward, with the exception of a few minor stone building foundations and a

Figure 6. **Ore chute just below the level of the Brown Monster mine entrance.**

Figure 7. **Ore car on the 2nd or 3rd level of the Reward mine. Compare with Figure 3.**

concrete slab. In 1959 the Southern and Pacific (formerly Carson and Colorado) narrow-gauge railroad line, which was the last commercially operated narrow-gauge line in the country, was reclaimed and the Owenyo Road marks the location of the old railroad bed. The remains of the old canals that once brought water to the mines along the east side of the Owens Valley, before the Los Angeles aqueduct was constructed, can still be seen in places as long, shallow, mud-crack-filled depressions.

GEOLOGY AND MINE WORKINGS

The Brown Monster and Reward mines are located at the western base of the Inyo Mountains in a block of metamorphosed limestone of the Early Permian Lone Pine Formation (Stone, *et al.*, 2000). The limestone is adjacent to the Middle Jurassic Pat Keyes Pluton and some minor Jurassic diorite dikes. This report will follow the convention of Knopf (1914), who referred to the workings north of the narrow, steep Reward gulch as the Brown Monster mine, and those on the south side as the Reward mine. The workings of the two mines are separated by a fault or shear zone located in the gulch.

The main Brown Monster inclined shaft is located in Reward gulch, just above an old ore chute. The portal is rather obscure now because debris from the Reward dump has washed down the gulch and partially fills the entrance (you must crawl on your hands and knees to enter or use a side entrance). The shaft, which follows a fault that strikes N 40° E, is gently inclined (25°) near the surface but steepens (to 50°) with depth, with side tunnel levels at 60, 96, 200 and 250 feet (Tucker and Sampson, 1938). The various levels are partially connected by inclined stopes which follow a quartz vein that averages 6 feet in width. At the lower level, a series of ladders connect with the 1980s tunnel/workings that were driven from the north side of the ridge. The gold ore was found in quartz veins that locally contain sulfides and cut across marble. There are also a number of surface workings about 100 feet above the portal which were connected to the base of the gulch by an aerial tramway.

The main Reward and Brown Monster tunnels were supposedly connected by a 50-foot-long tunnel. This connection could not be found recently, but several tunnels in the Brown Monster mine that appeared to extend in the right direction were found to be either caved or silted closed and filled with debris that has cascaded down the steep Reward gulch. The Reward vein striking N 40° W and dipping 40° NE, is about 6 to 8 feet in thickness and consists of milky quartz. The lowest Reward tunnel, which was once connected to the main Brown Monster incline, was driven 1,200 feet N 55° E, for 650 feet to the vein, and then drifted southeastward 800 feet (Tucker and Sampson, 1938). About 50 feet above the lowest tunnel is another, which was driven southeastward for 800 feet. At about 25-foot intervals above the second tunnel are four more tunnels driven from 300 feet to 700 feet. Three of the tunnels are connected by a large, continuous, inclined stope, which can be accessed by a tunnel (4th–5th above the lowest) which opens to the surface. It had been difficult to reach this tunnel because of a small dry waterfall, but in 1998 the collapse of a portion of the Reward dump into the gulch created easier access. This tunnel and the Reward dumps are located about 70 feet above the Brown Monster main inclined tunnel. From the lowest part of the large inclined stope a ladder leads to the lower tunnels, but these were not explored by the author. Above the dumps and access tunnel for the Reward mine are several other small workings which follow the surface outcrop of the vein.

The gold ore in both the Reward and Brown Monster mines occurs in thick (to 6 feet) milky quartz veins that dip 25°–50°. From 1889 to 1951 the Reward mines produced $600,000 (19,370 oz.) of gold, 102,600 oz. of silver, 30,900 lb. of copper and 203,300 lb. of lead (Conrad *et al.*, 1987). Primary sulfide minerals in the quartz veins include pyrite, galena, chalcopyrite and minor sphalerite. More recently covellite has been identified (R. Thomssen, personal communication, 2004).

An interesting suite of secondary lead and copper minerals also occurs in the quartz veins and adjacent marbles and limestones. These, first briefly described by Knopf (1914), included linarite, caledonite, anglesite, wulfenite, hemimorphite and cerussite.

Minerals in this report were identified by X-ray diffraction (XRD) or energy dispersive X-ray spectroscopy (EDXS) in the scanning electron microscope (SEM). All figured specimens, were photographed by, and are in the collection of the author. All of the minerals that will be described have been collected from the underground workings during numerous visits from 1997-2001. At that time there was very little of mineralogical interest exposed on the dumps of the various mines and prospects; however, since then there has been considerable effort to expose buried portions of the Reward dump. It is not known whether this has produced any new material different from what has been collected underground.

On the north-facing slope of the ridge that separates the large drive-in tunnel and the main upper portal of the Brown Monster mine, a skarn containing large (1–3 cm) green diopside crystals and brown vesuvianite crystals in blue calcite was observed. The micromineralogy of the Brown Monster and Reward mines has been documented previously by Adams (1999 and 2000, respectively). The purpose of these earlier reports was to document newly described species from the mines and to present SEM photomicrographs of the more unusual microminerals. The following is a more comprehensive description of the minerals found at the two mines, with particular attention paid to minerals of interest to collectors, and to discoveries made since 2000.

MINERALOGY

Anglesite $PbSO_4$

Colorless, transparent, complex crystals (to 2.5 mm) of anglesite occur with brochantite, caledonite, chlorargyrite and linarite in cavities at the Reward mine. At some locations the anglesite crystals have a frosted appearance, and at others the anglesite encloses remnants of linarite.

Apatite-(CaF) $Ca_5(PO_4)_3F$

Plumbian apatite-(CaF) has been found as overgrowths on mimetite prisms (to 1 mm) in a few specimens from the Reward mine.

Arsentsumebite $Pb_2Cu(AsO_4)(SO_4)(OH)$

At the Reward mine some of what was originally assumed to be tsumebite is more yellow-green in color than is typical for that mineral. These specimens (to 0.2 mm crystalline aggregates), are actually arsentsumebite, since the As:P ratio can be as high as 2:1. They occur in an early assemblage and are usually associated with brochantite, perite and other bismuth minerals, plattnerite and minute wulfenite crystals, which they commonly overgrow.

Austinite $CaZn(AsO_4)(OH)$

Botryoidal gray-green plumbian austinite crystals (to 0.5 mm) have been found coating fracture surfaces with mimetite in the upper stope of the Brown Monster mine.

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

Massive azurite is found with acicular malachite in one of the upper workings (7th level) of the Reward mine.

Bismutite/Bismoclite $(BiO)_2CO_3/BiOCl$

Yellowish, minute (0.1-mm) scaly bismutite and bismoclite crystals occur as an early constituent in some vugs with chlorargyrite, arsentsumebite and wulfenite, at the Reward mine.

Figure 8. **Anglesite (0.5 mm) with brochantite, linarite and caledonite from the Reward mine.**

Figure 10. **Plumbian austinite (1 mm groups) and acicular mimetite from the Brown Monster mine.**

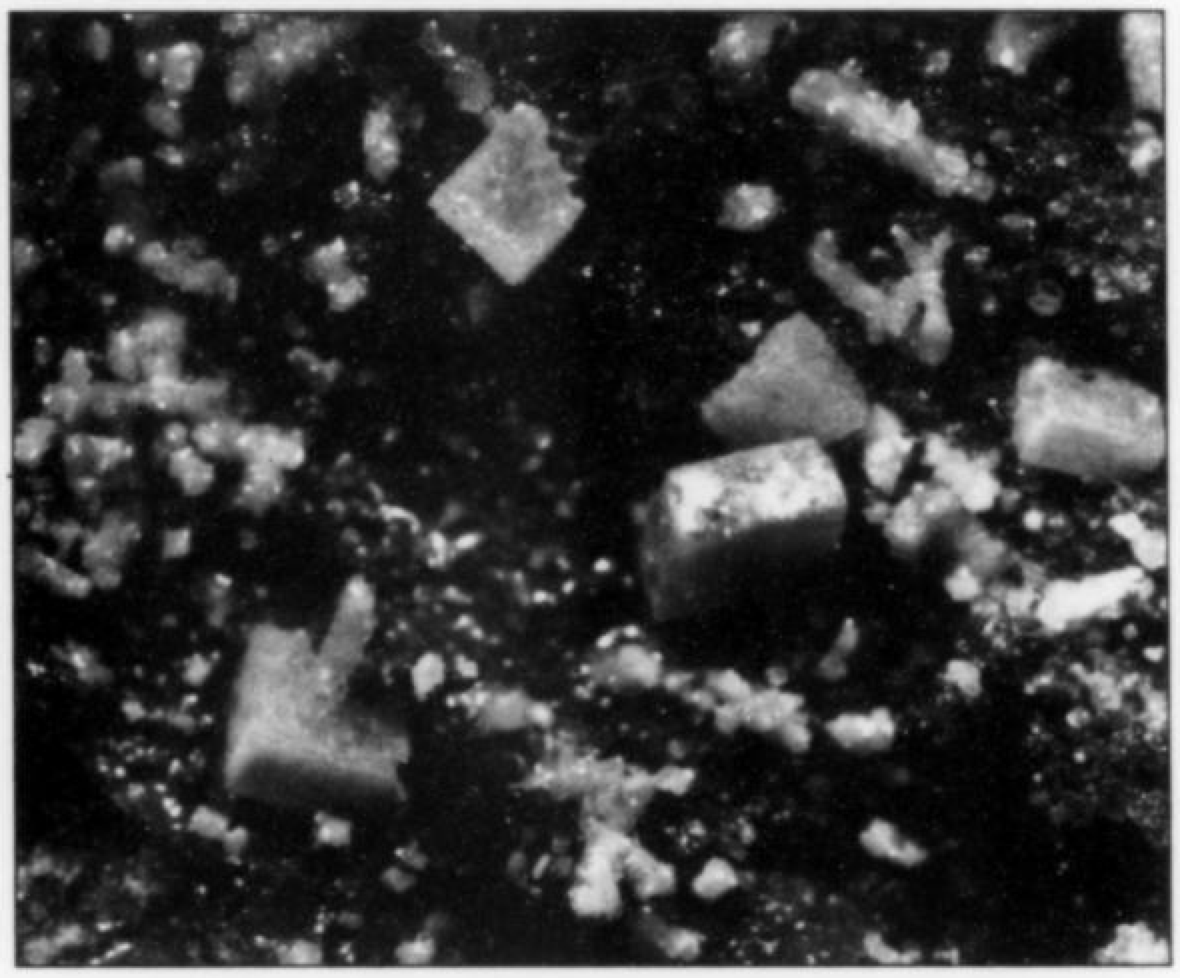

Figure 9. **Arsentsumebite (0.25 mm) and wulfenite from the Reward mine.**

Brochantite $Cu_4(SO_4)(OH)_6$

Brochantite is one of the more common secondary minerals in the Reward mine. It occurs in cavities and on fracture surfaces in a variety of crystal habits ranging from blocky, near equant crystals (to 1 mm), to flat blades or tablets and lustrous, transparent, dark green radiating acicular sprays (to 3 mm). Commonly the brochantite is associated with cerussite, chlorargyrite, linarite, caledonite and leadhillite. Chrysocolla is often found as pseudomorphs after brochantite crystals.

Bromargyrite AgBr

Minute (to 1.5 mm) yellow-green distorted octahedrons and cuboctahedrons of bromargyrite have been found on white microcrystalline drusy quartz, cerussite and plattnerite in a localized area near the portal of the Brown Monster mine. The bromargyrite contains significant amounts of chlorine.

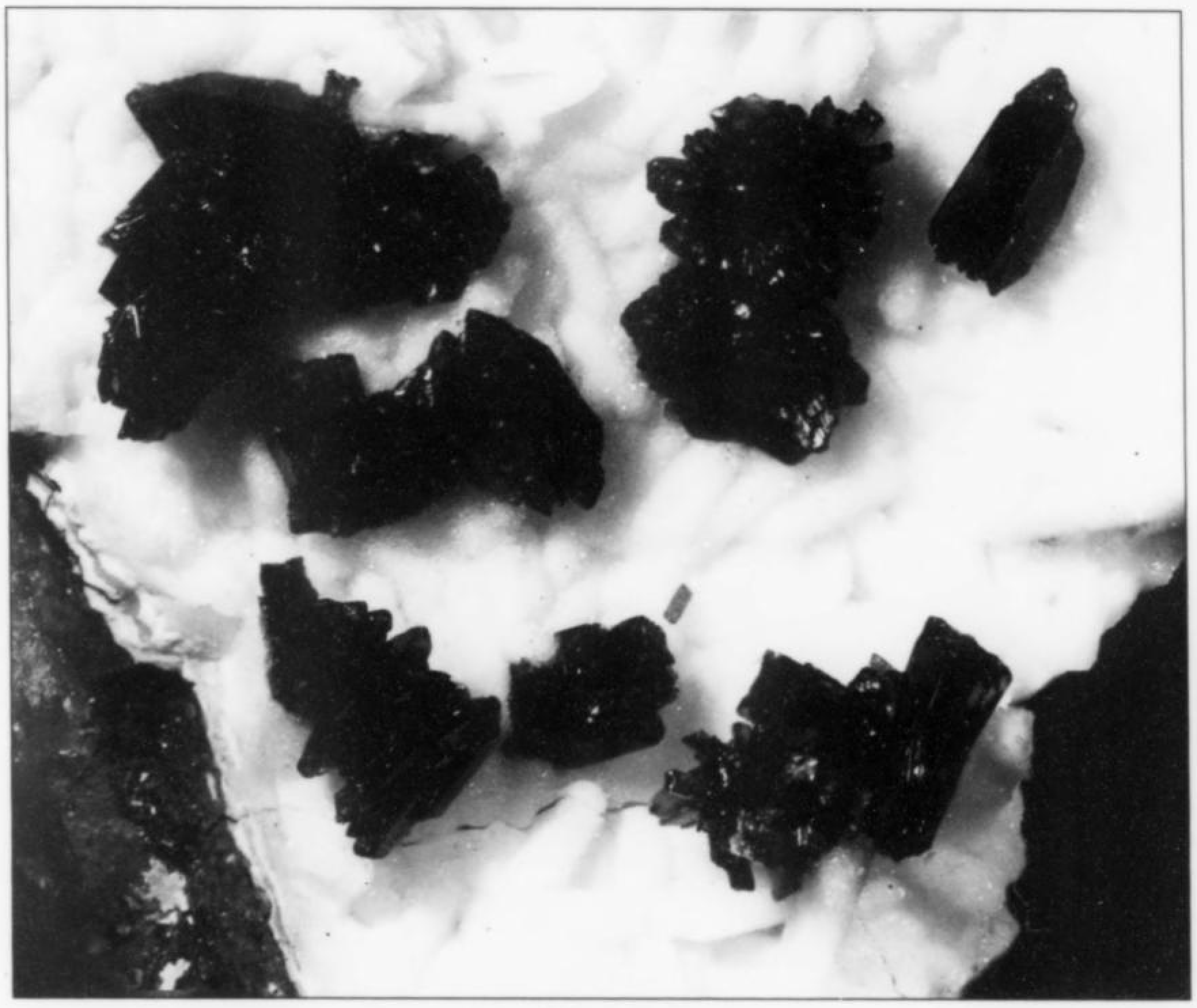

Figure 11. **Equant brochantite (1 mm) on micro drusy quartz after unkown from the Reward mine.**

Figure 12. **Brochantite plates (0.5 mm) from the Reward mine.**

Calcite $CaCO_3$

At the margins of the main quartz vein in the Reward mine the enclosing limestone has been recrystallized to coarse-grained marble, and veins of calcite crystals (to 4 cm), with habits ranging from platy to blocky, are common in several areas. At the Brown Monster mine calcite crystals (to 1.5 cm) lining fractures in marble are also common. From vein to vein there is a wide variety in the habit of the calcite crystals, which range from nearly equant "pseudo-octahedral" crystals, to stacks of subparallel plates, to dogtooth crystals and fish-tail twins. Late-stage colorless, transparent calcite crystals (to 6 mm), as simple rhombs to tapered tablets, can also be found growing in some of the cavities associated with cerussite and other secondary lead minerals.

Caledonite $Pb_5Cu_2(CO_3)(SO_4)_3(OH)_6$

Caledonite occurs at the Reward mine as striated, green-blue, flat bladed crystals (to 1 cm) lying parallel with fracture surfaces in milky quartz and in vugs. Linarite, brochantite, anglesite and leadhillite are commonly associated. Commonly the caledonite has an olive-green appearance as a result of having overgrown chlorargyrite crystals. At the Brown Monster mine small caledonite crystals (0.5 mm) occur with linarite near altered galena pods.

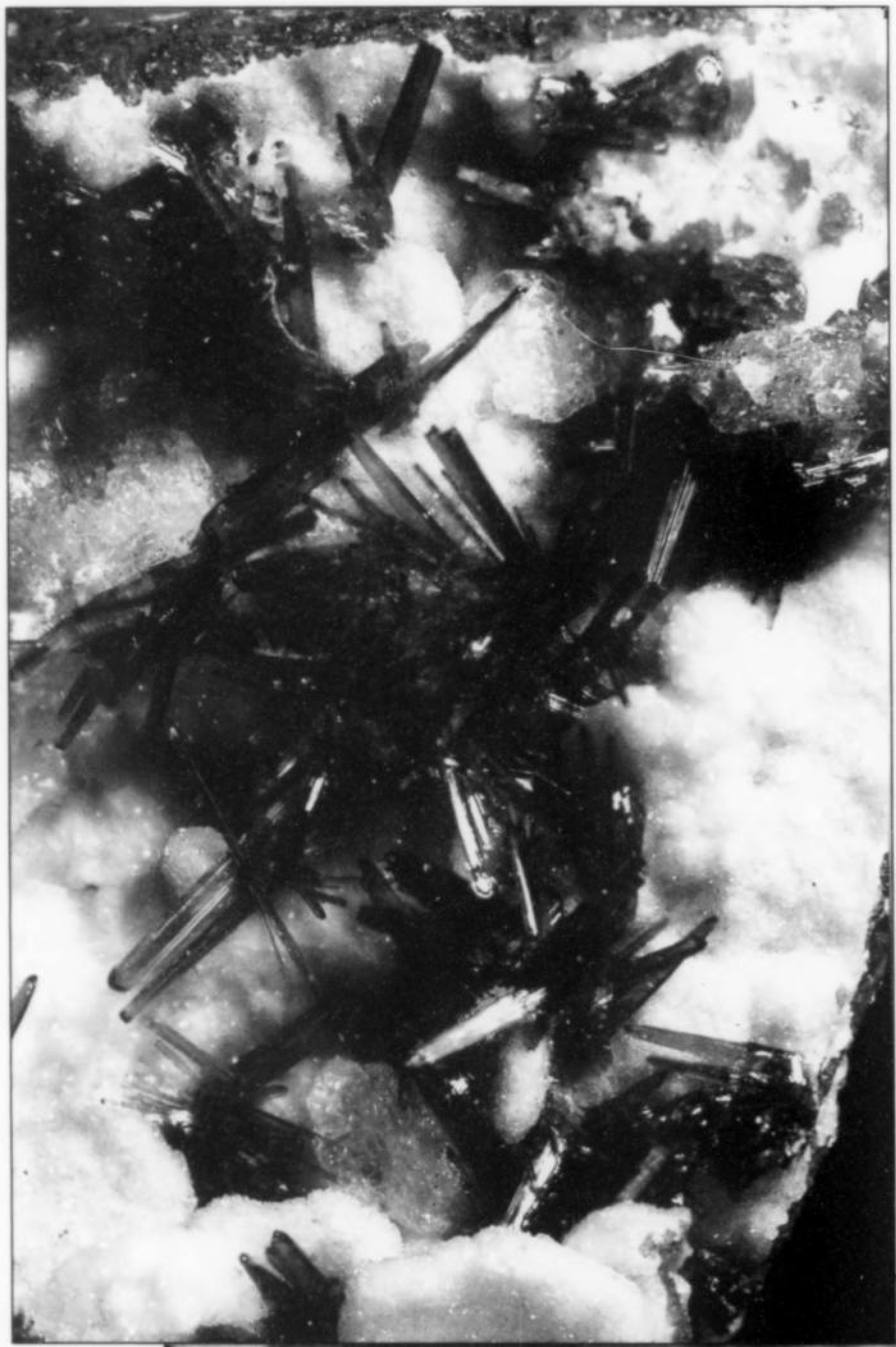

Figure 13. **Acicular brochantite (1 mm) from the Reward mine.**

Figure 14. **Brochantite plates (0.5 mm) on quartz crystals from the Reward mine.**

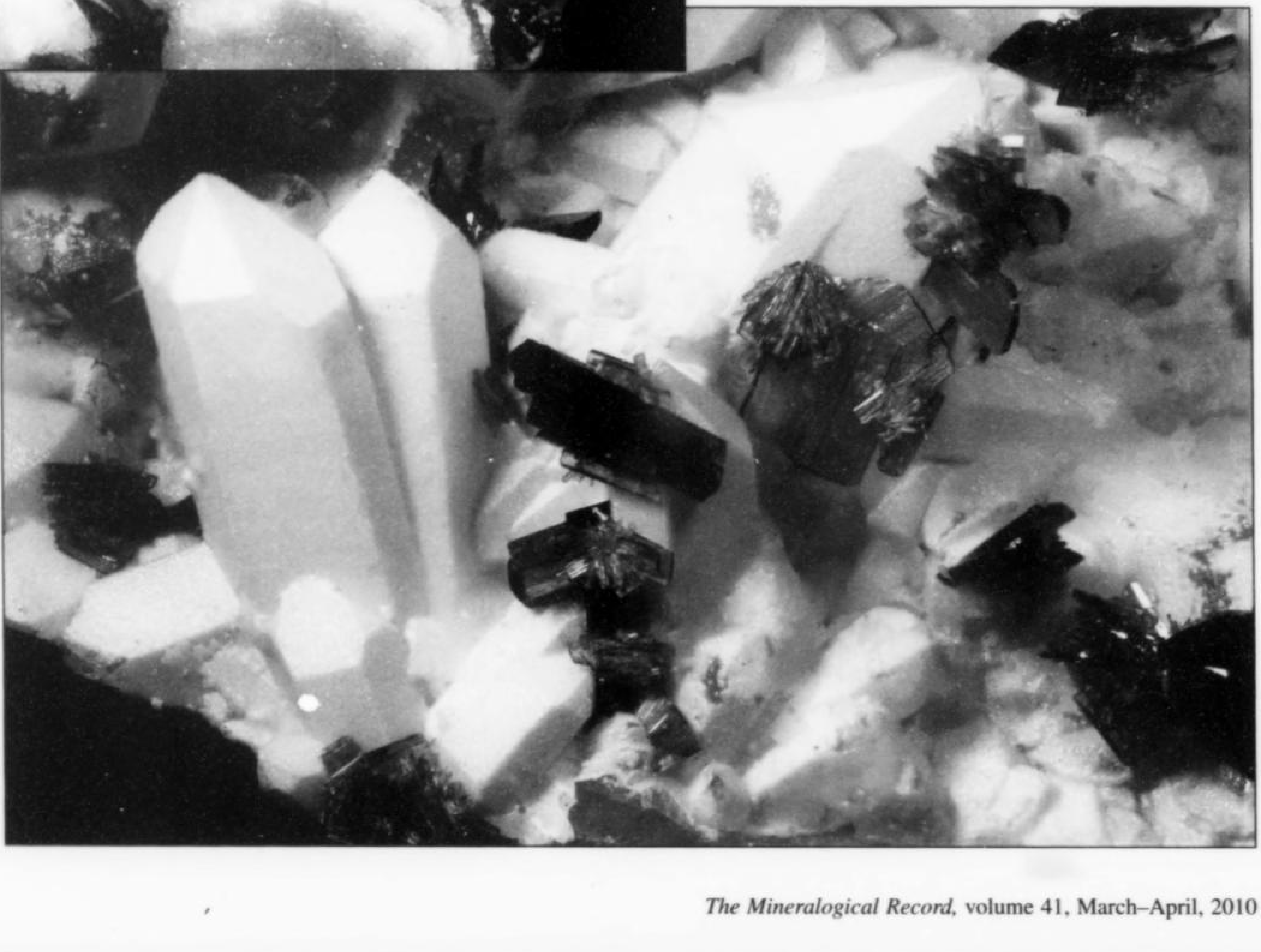

Figure 15. **Caledonite (to 3 mm) with linarite from the Reward mine.**

Figure 16. **Caledonite (to 3 mm) with leadhillite and linarite from the Reward mine.**

Cerussite $PbCO_3$

At the Reward mine cyclic twins of cerussite were one of the earliest secondary minerals. Sometimes crystals can still be found that have a thin coating of chrysocolla but it is more common to find epimorphs of micro-drusy quartz after the cerussite. These typically are hollow shells after either cyclic or V-shaped twins (to 5 mm). A second, relatively late generation of cerussite is also found. These crystals (to 3 mm) usually appear as colorless and transparent to white, flattened, subparallel growths which often overgrow brochantite. They are very difficult to distinguish visually from leadhillite but typically leadhillite is only found when caledonite is present. Cerussite has also been found as large (1 cm) botryoidal coatings

Figure 17. **Twinned cerussite (to 4 mm) overgrown by quartz from the Brown Monster mine.**

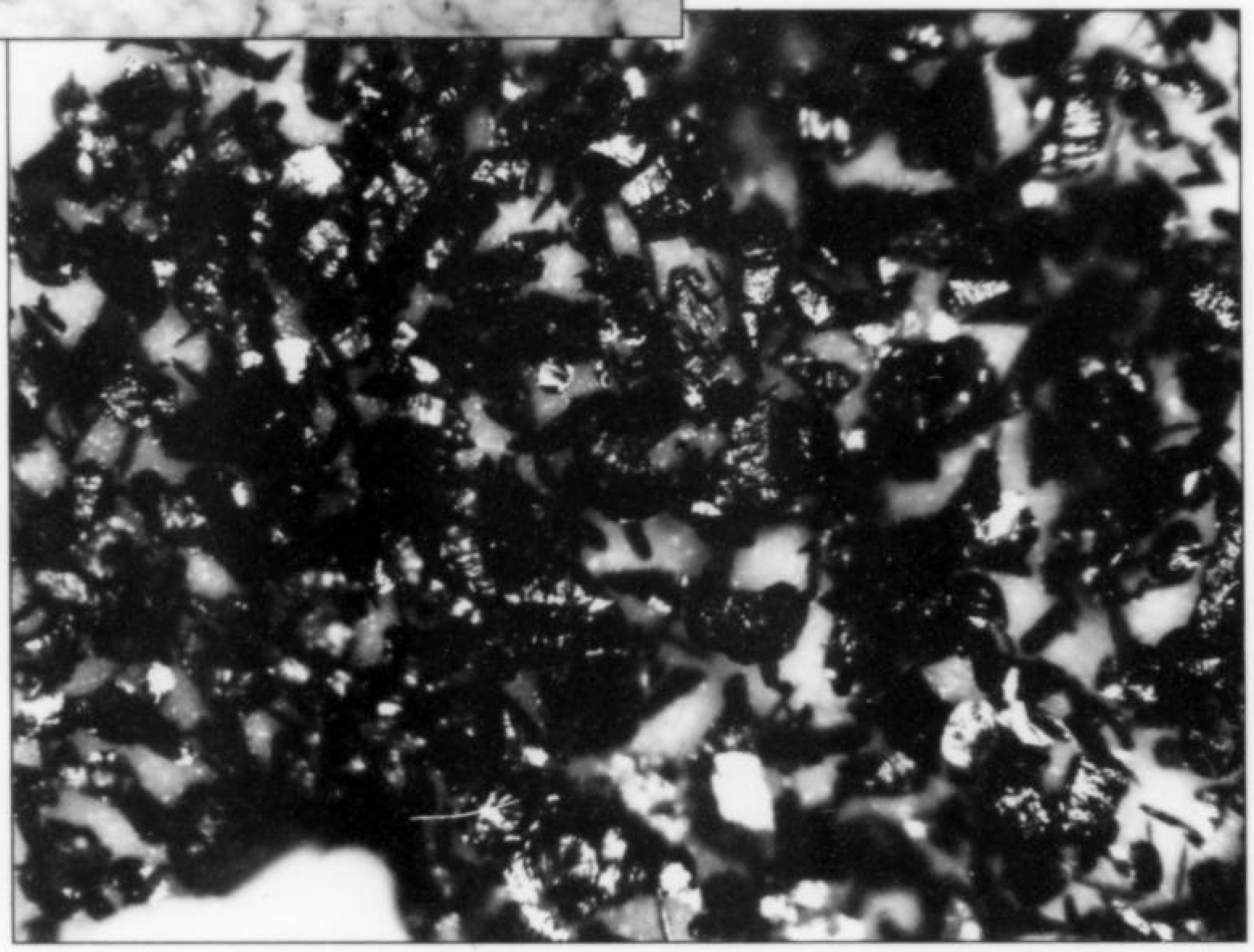

Figure 18. **Plattnerite (to 0.4 mm) on quartz overgrown cerussite crystals from the Brown Monster mine.**

in rubble. At the Brown Monster mine one area near the portal contained resinous masses of cerussite which contained cavities lined with euhedral crystals, many as V-shaped twins (to 8 mm). The cerussite crystals have a thin coating of white, micro-drusy quartz which gives them a frosted appearance; they are usually associated with plattnerite and bromargyrite.

Chalcanthite $CuSO_4 \cdot 5H_2O$

Small (1 mm) masses of pale blue, transparent chalcanthite are rare but have been found in the Reward mine. Identification was made by Raman spectroscopy.

Chlorargyrite AgCl

Olive-brown corroded crystals and distorted octahedrons (to 1 mm) of chlorargyrite occur as an early-stage mineral in vugs at the Reward mine. The chlorargyrite contains significant amounts of bromine, approaching 50 atom percent.

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

Pseudomorphs of chrysocolla after brochantite (to 2 mm) are relatively common at the Reward mine. Chrysocolla also forms thin coatings on quartz pseudomorphs after cerussite. Chrysocolla pseudomorphs (to 5 mm) after a bladed or acicular mineral (malachite?) and a mineral which formed small (to 2 mm) lenticular crystals were also found in an isolated occurrence in a pillar. Chrysocolla pseudomorphs of botryoidal malachite (to 4 mm) with hemimorphite have also been found in float. Pseudomorphs after platy rosettes (to 8 mm) have also been found.

Corkite $PbFe_3(PO_4)(SO_4)(OH)_6$

Minute, golden brown to chocolate-brown corkite crystals (0.25 mm) are uncommon at the Reward mine. Some of the crystals form rounded aggregates. They typically occur with other phosphates, including tsumebite and pyromorphite.

Descloizite $PbZnVO_4(OH)$

Descloizite has been found at the Brown Monster mine, associated with mottramite. It is brown in color and tends to form larger crystals (to 0.25 mm) than the mottramite, which is typically more

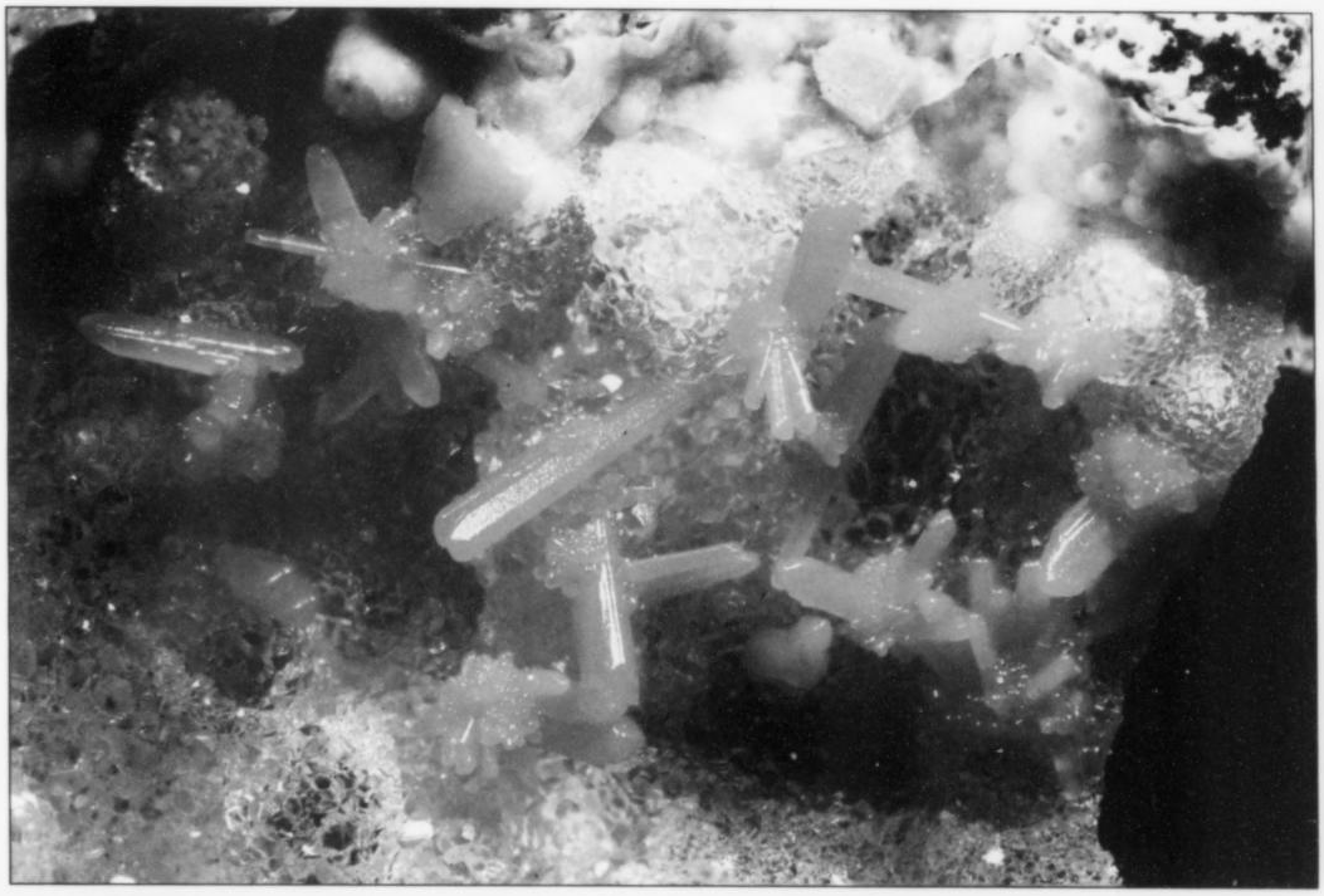

Figure 19. **Chrysocolla after brochantite (to 3 mm) from the Reward mine.**

Figure 20. **Chrysocolla after brochantite and after unknown (to 5 mm) from the Reward mine.**

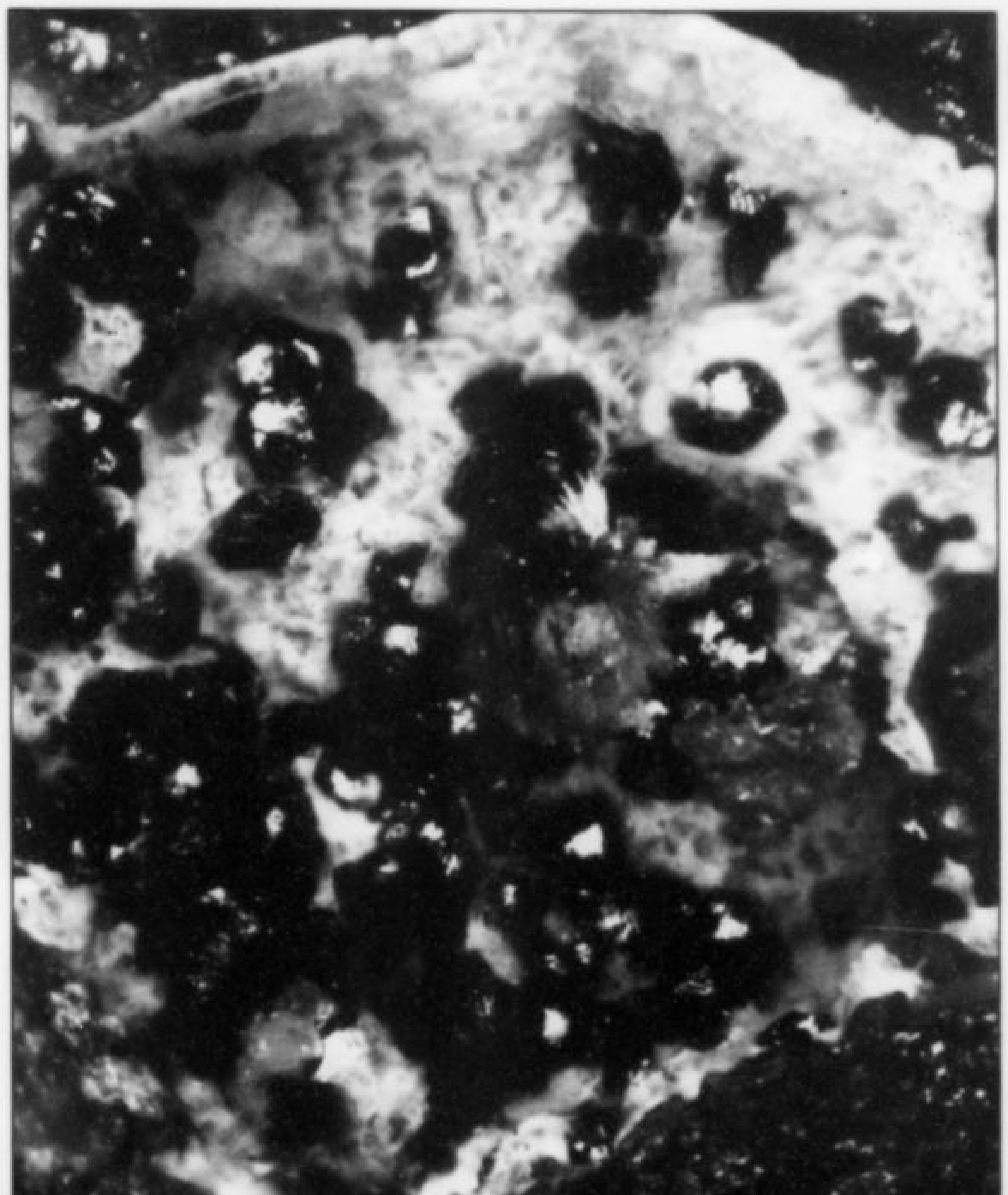

Figure 21. **Corkite (0.25 mm), tsumebite and pyromorphite from the Reward mine.**

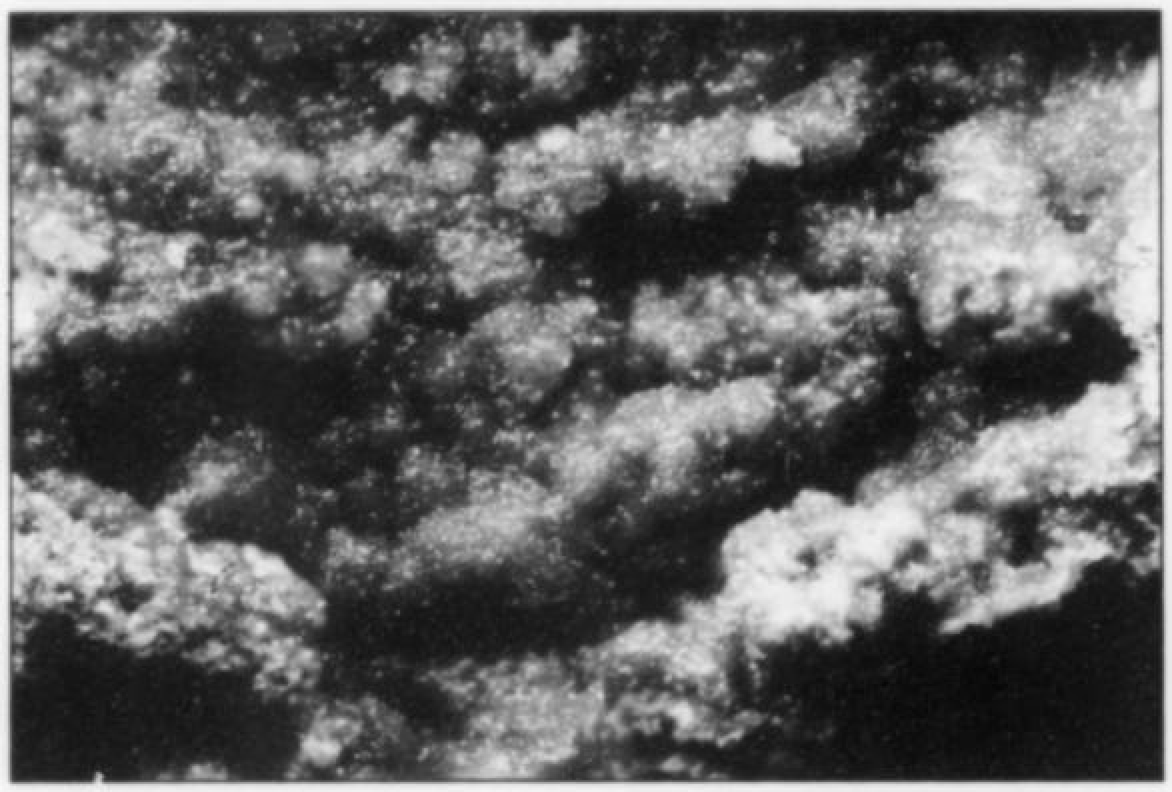

Figure 22. **Calcian duftite from the Brown Monster mine (field of view 3 mm).**

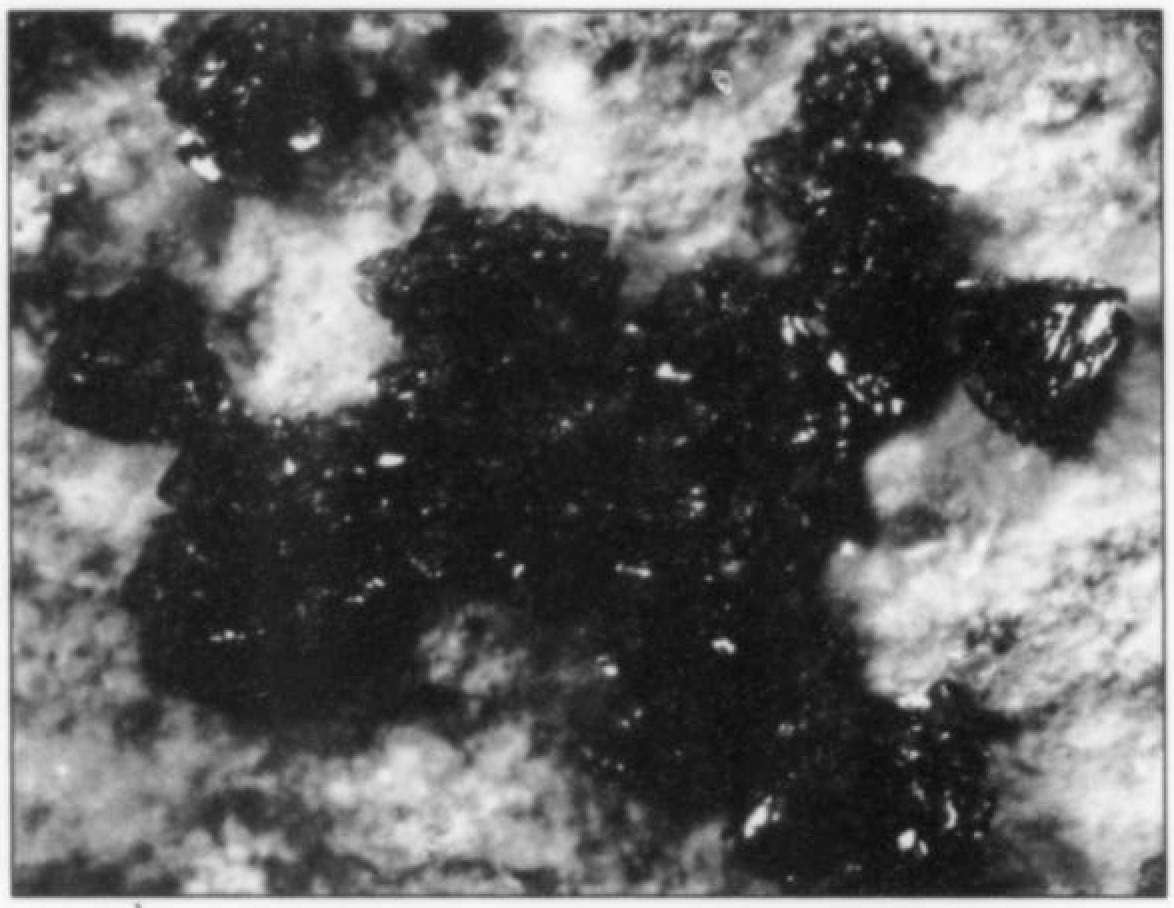

Figure 23. **Fornacite (0.25 mm) from the Reward mine.**

micro-botryoidal. Micro-fibrous cuprian descloizite has also been found covering small quartz crystals.

Duftite (Pb,Ca)Cu(AsO_4)(OH)

An intermediate composition in the duftite-conichalcite series has been found at both the Reward and Brown Monster mines, but is not common. At the Reward mine green botryoids (0.5 mm) of calcian duftite were found associated with uncommon elongate white mimetite prisms (to 1 mm). Green botryoidal duftite-conichalcite (2–3 mm) has also been found associated with mimetite at one location in the Brown Monster mine. It is very similar in appearance to green mottramite found at another location in the mine.

Fornacite $Pb_2Cu(AsO_4)(CrO_4)(OH)$

At the Brown Monster mine, groups of brown bladed fornacite (to 0.4 mm) are relatively uncommon and are found on drusy quartz or lining fractures in marble. At the Reward mine, fornacite occurs with mottramite, mimetite, vanadinite and wulfenite on fractures in marble. It has also been found in float with minute white sprays of pyromorphite, hemimorphite and chrysocolla after malachite.

Goethite α-$Fe^{3+}O(OH)$

Crystallized goethite is relatively uncommon at the Reward mine. It is usually found as minute (0.5 mm) golden radiating sprays. Transparent violet-brown plates (to 0.2 mm) are less common. At the Brown Monster mine goethite and kaolinite form casts after a bladed mineral, most likely hemimorphite.

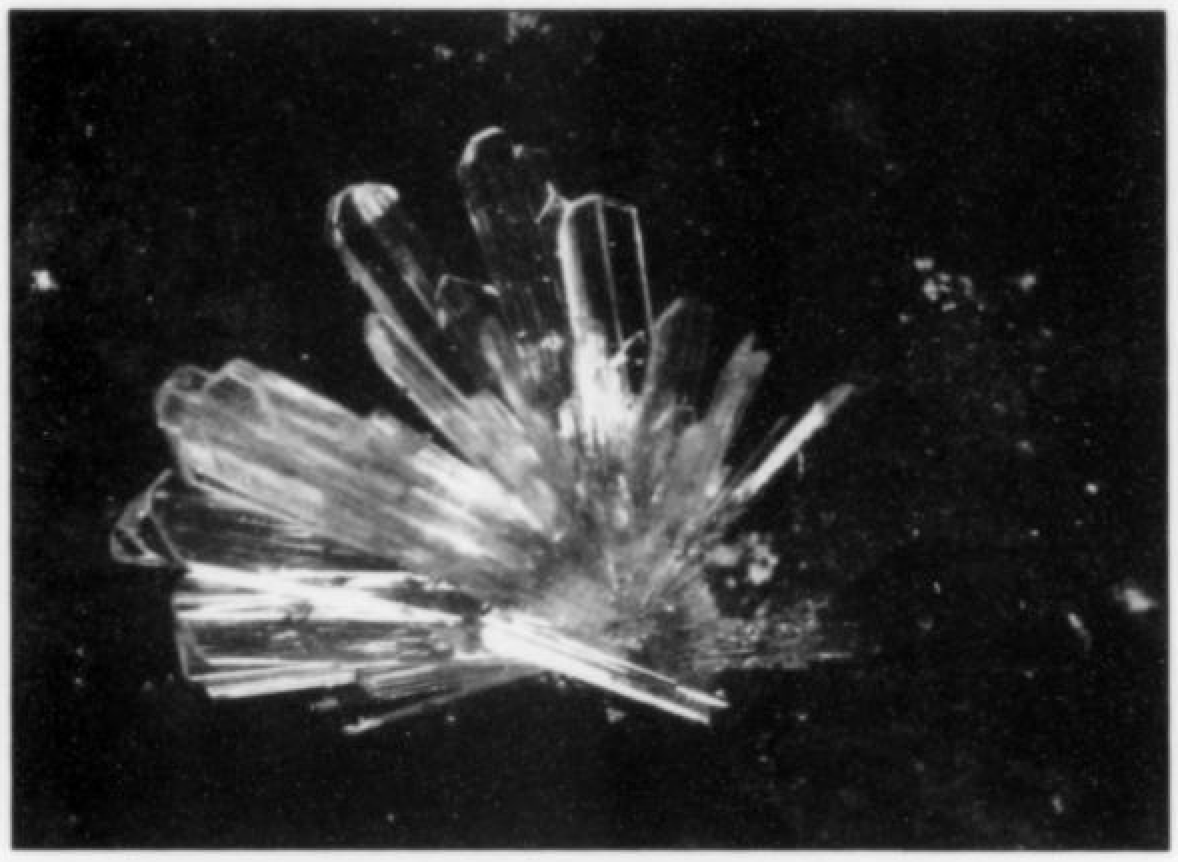

Figure 24. **Bladed hemimorphite spray (to 3 mm) from the Reward mine.**

Gold Au

With all the colorful secondary minerals at the Reward and Brown Monster mines one can easily lose sight of the fact that the mines were gold mines and that gold can still be found there today. A few small flakes (to 1 mm) of gold have been found in milky quartz in the Reward mine, associated with brochantite and linarite. The gold has been described as being most plentiful in the more jasper-like quartz rock (Irelan, 1888).

Gypsum $CaSO_4 \cdot 2H_2O$

Rare curved fibers (to 1 mm) of gypsum have been observed with brochantite at the Reward mine.

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

Bladed hemimorphite crystals (to 2 cm) were found in the Reward mine in one difficult-to-reach occurrence (2.5 meters up the side of a pillar). While some of the crystals were rather large it was difficult to collect undamaged terminated crystals because they tended to bridge the whole width of cavities in hard quartz. Occasionally, radiating sprays (to 7 mm) from this occurrence could be collected intact. These are commonly overgrown by micro-drusy quartz and colorless, transparent discoidal calcite crystals. Smaller sprays of hemimorphite, associated with acicular microcrystals of pyromorphite and chrysocolla after malachite were sometimes found in rubble in the stope. Colorless, transparent bladed hemimorphite crystals (to 3 mm) occur at the Brown Monster mine associated with mimetite and wulfenite. At one locality hemimorphite crystals to 2.5 cm have been found (F. DeVito, personal communication, 1998). Radiating groups of hemimorphite up to 1 cm in diameter have been reported from the fifth level of the Brown Monster mine (Knopf, 1914).

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

At the Brown Monster mine orange to tan crusts of jarosite, some with brown spheres (0.5 mm) of mottramite, are occasionally found with mimetite on fracture surfaces in gray limestone. Plumbojarosite has also been identified in some of this material (R. Housley, personal communication, 2004).

Kettnerite $CaBi(CO_3)OF$

Minute (0.2 mm), pale yellow-green square plates of kettnerite are rare as part of an early bismuth-containing assemblage in the Reward mine.

Leadhillite $Pb_4(SO_4)(CO_3)_2(OH)_2$

At the Reward mine, leadhillite occurs as colorless, transparent, flattened, subparallel crystals (to 7 mm) on quartz associated

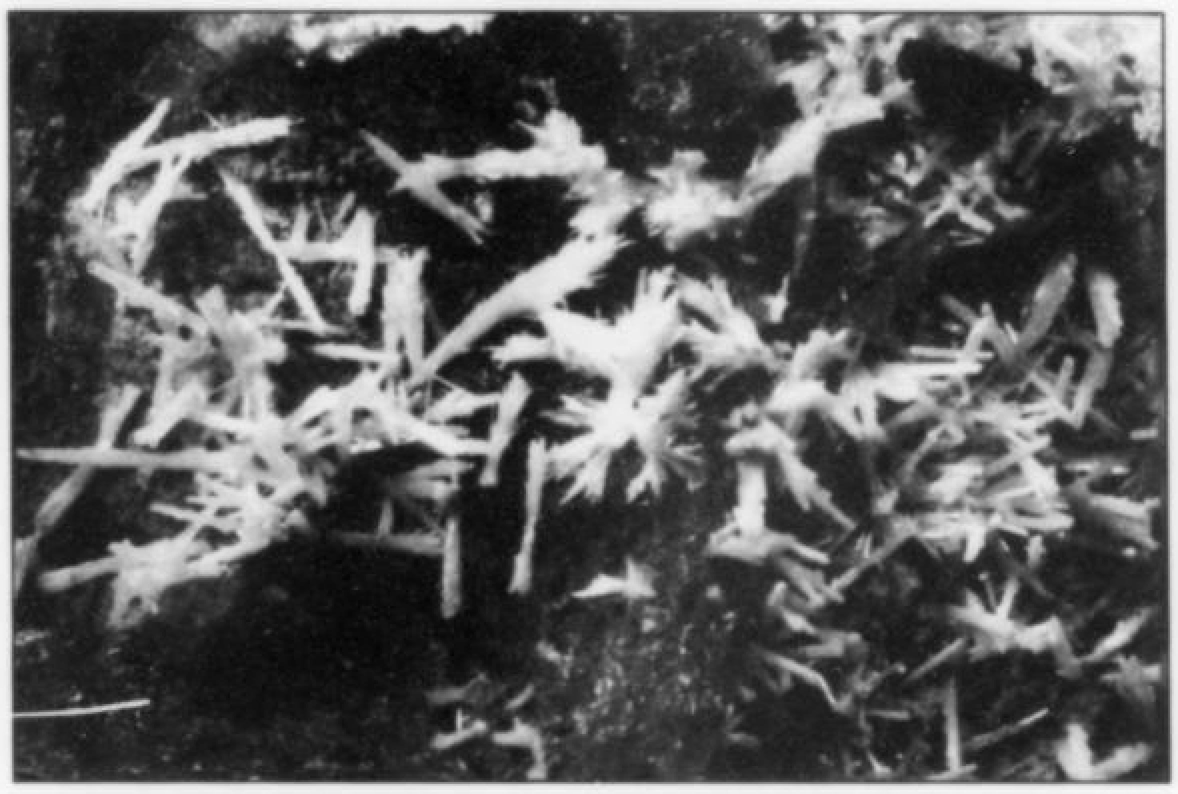

Figure 25. **Mimetite (to 2 mm) from the Reward mine.**

with linarite, brochantite and caledonite. Typically it is only found where caledonite is present. Fourier transform infrared (FTIR) spectroscopy was used to distinguish between leadhillite, anglesite and cerussite. At one location in the Brown Monster mine massive leadhillite cleavages are relatively common (F. DeVito, personal communication, 1998).

Linarite $PbCu(SO_4)(OH)_2$

Dark blue linarite crystals occur locally along fractures in white quartz veins at the Reward mine. The crystals (to 1.2 cm) are usually flattened and lie parallel to the fracture surfaces. Specimens to 8 × 10 cm consisting of groups of crystals covering fracture surfaces have been recovered. Brochantite, cerussite, anglesite, leadhillite and caledonite also occur with linarite in various combinations. In addition to forming on fracture surfaces, a similar assemblage has rarely been found in vugs and cavities. At the Brown Monster mine small linarite crystals (0.5 mm) occur with caledonite near altered galena pods.

Malachite $Cu_2(CO_3)(OH)_2$

At the Reward mine, fibrous to feathery malachite crystals occur as coatings on pseudomorphs of brochantite after chrysocolla, and radiating aggregates to 3 mm; it is a late stage mineral. Acicular malachite also occurs lining cavities in the upper workings (7th level), where it is found with massive azurite.

Mimetite $Pb_5(AsO_4)_3Cl$

Mimetite is relatively common at the Brown Monster mine, in a variety of habits and associations. In quartz veins near the marble contact mimetite occurs as elongated lemon-yellow prisms (to 1.5 mm) which grade into vanadinite. In one area crystalline mimetite forms radiating aggregates of yellow acicular crystals (0.2 × 0.15 mm) that protrude from fracture surfaces in gray limestone in the ceiling of the stope. Wulfenite is commonly associated with the mimetite, and fracture surfaces to 3 × 7 cm have been found covered with microcrystals. On some fracture surfaces the mimetite has a feathery appearance. In one area, where it is associated with mottramite, the mimetite displays a wide variety of habits ranging from colorless, transparent prisms, to very acicular clusters, to nearly equant crystals. One small occurrence of elongated cream-colored mimetite prisms (to 1 mm) with green botryoidal duftite-conichalcite (0.5 mm) was found in the Reward mine. Mimetite crystals, similar in appearance and associations to those at the Brown Monster mine, are also found at one location on fracture surfaces in marble at the Reward mine. At the Reward mine the white mimetite is usually pure, whereas the yellow to orange mimetite typically contains vanadium and can grade into arsenian vanadinite.

Mottramite $PbCuVO_4(OH)$

At the Brown Monster mine, mottramite is relatively common at certain locations. It forms botryoids and crusts that range in color from pale yellow-green to tan, brick-red and chocolate-brown. It is commonly associated with mimetite and wulfenite. Locally it has been found as dark brown botryoidal coatings to 2 mm thick and as individual brown spheres (to 1 mm) associated with dark reddish brown vanadinite. Evidence of multiple episodes of growth is relatively common. Mottramite has been observed overgrowing mimetite, quartz and calcite crystals. A similar occurrence is found in a localized vanadate assemblage in the Reward mine. Small spheres (0.25 mm) of brown calcian mottramite have been found on rubble near the portal to the Reward mine.

Perite $PbBiO_2Cl$

Minute plates (0.2 mm) of pale brown perite occur as an early mineral with elongate pyramidal wulfenite, arsenian tsumebite and plattnerite in the Reward mine.

Phosphohedyphane $Ca_2Pb_3(PO_4)_3Cl$

In one area of the Brown Monster mine, minute (0.5 mm) white prisms of what was originally assumed to be calcian pyromorphite were found associated with rosettes (1 mm) of brown fornacite. The composition of these crystals is consistent with phosphohedyphane (A. Kampf, personal communication, 2007).

Plattnerite PbO_2

Plattnerite has been found at the Brown Monster mine in several habits. Locally it forms dense clusters of thin tablets (0.01 × 0.15 mm) found on white micro-drusy quartz-covered cerussite crystals. Veins in marble lined with micro-drusy quartz casts after a tabular or bladed mineral (calcite) commonly have a sooty appearance as a result of being dusted with very minute (0.02 × 0.10 mm) elongated prisms of plattnerite. At the Reward mine plattnerite crystals (to 0.2 mm) occur with perite, arsentsumebite and wulfenite. Under the scanning electron microscope the plattnerite sprays can be seen to have an unusual conical shape, expanding from a narrow base.

Plumbogummite $PbAl_3(PO_4)_2(OH,H_2O)_6$

Casts (to 3 mm) of goethite and kaolinite after a bladed mineral have been found found at the Brown Monster mine, on fracture surfaces in limestone. Associated with the casts are minute (0.05–0.10 mm) groups of white plumbogummite crystals and occasional brown spheres of mottramite. Some minute plumbogummite crystals were also found with jarosite crusts and mimetite, but these could only be identified by EDXS in the SEM. Overgrowths of brown plumbogummite on spherical corkite groups (to 0.5 mm) have occasionally been found at the Reward mine.

Plumbojarosite $PbFe_6(SO_4)_4(OH)_{12}$

At the Reward mine plumbojarosite occurs as small (to 0.25 mm) brown to golden plates with chlorargyrite in vugs containing an early mineral assemblage. Plumbojarosite has also been reported from the Brown Monster mine (R. Housley, personal communication, 2004).

Pyromorphite $Pb_5(PO_4)_3Cl$

At the Reward mine, white radiating groups of pyromorphite crystals (0.5 mm) were occasionally found with tsumebite and corkite. Gray, rounded, hexagonal prisms of calcian pyromorphite have also been found with corkite, and minute white acicular sprays of pyromorphite have been found with hemimorphite and chrysocolla after malachite in rubble in one of the stopes.

Quartz SiO_2

Cavities lined with quartz crystals (to 9 cm), are relatively common in the veins at the Reward mine but the crystals tend to be

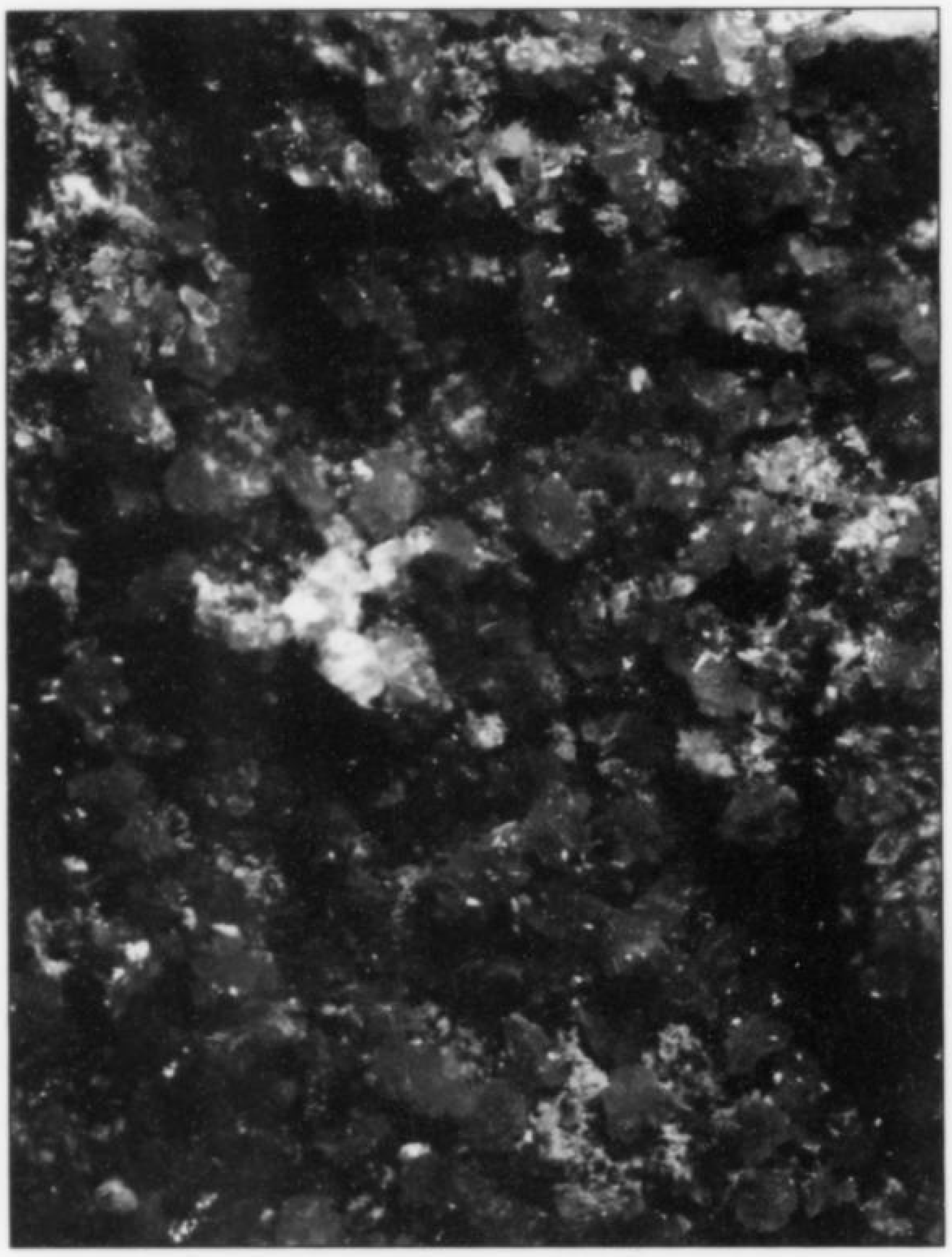

Figure 26. **Tsumebite (to 0.25 mm) from the Reward mine.**

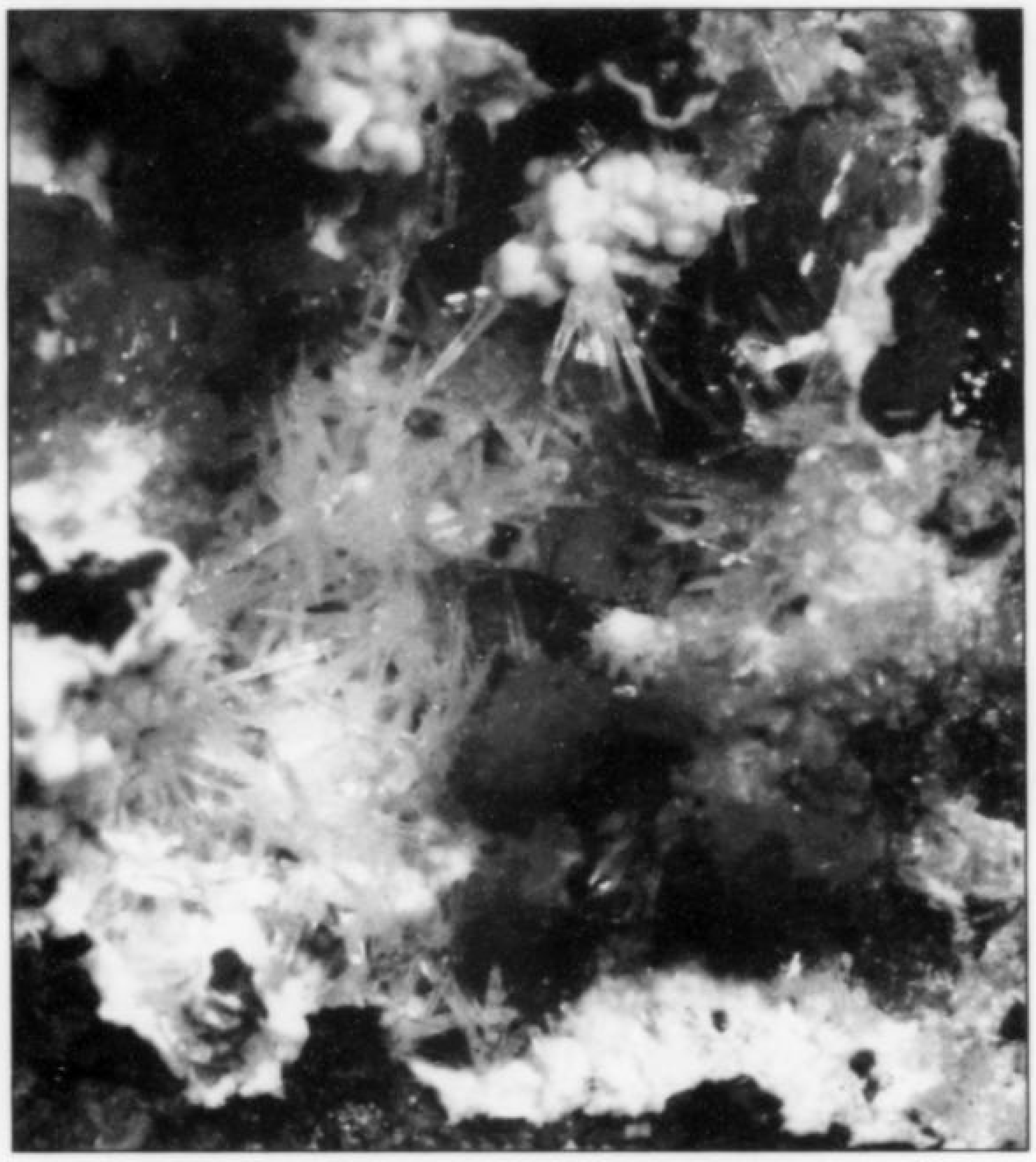

Figure 27. **Tsumebite (to 0.25 mm) and pyromorphite from the Reward mine.**

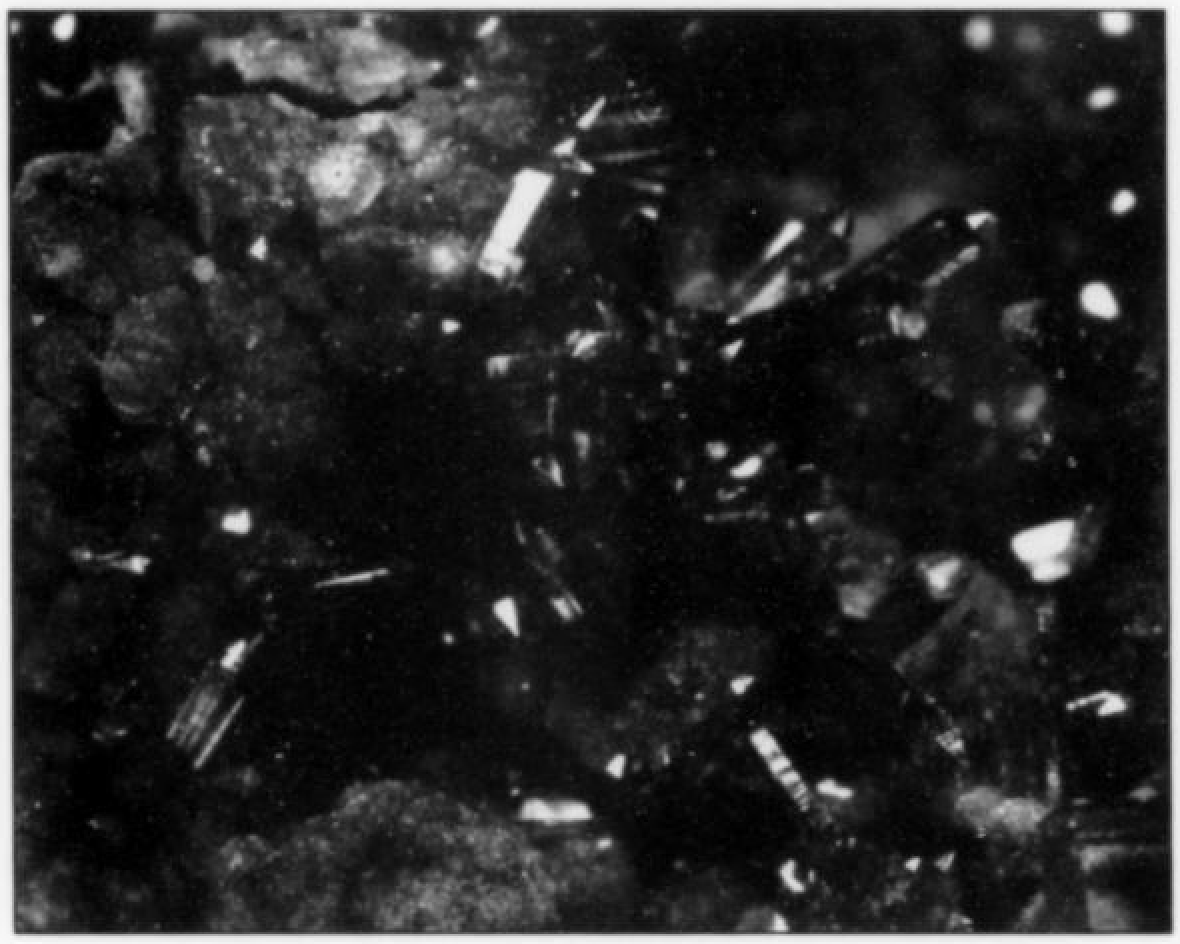

Figure 27. **Vanadinite (to 2 mm) and mottramite from the Brown Monster mine.**

tectonically broken and heavily iron-stained (including fracture surfaces). White to gray calcite crystals (to 5 mm) and gray-blue chalcedony are occasionally found associated with iron-stained quartz crystals. The chalcedony fluoresces bright green in ultraviolet light.

At the Brown Monster mine, late-stage micro-drusy quartz commonly overgrows the secondary minerals; cavities lined with large crystals are rare. As early as 1870 "beautiful crystals of perfectly transparent quartz" were described from the Brown Monster mine (Irelan, 1888).

Tsumebite $Pb_2Cu(PO_4)(SO_4)(OH)$

At the Reward mine, tsumebite, as pale apple-green crystalline aggregates (to 1 mm), is found either by itself or associated with other phosphates such as minute, elongated prisms of white pyromorphite (to 0.5 mm) and small olive-brown crystals of corkite. The tsumebite is usually associated with small gray marble inclusions in the quartz vein. Areas up to 3 × 3 cm covered with tsumebite have been recovered.

Vanadinite $Pb_5(VO_4)_3Cl$

At the Brown Monster mine, vanadinite occurs as transparent reddish brown crystals (to 2 mm) associated with mottramite and wulfenite. The dark red-brown crystals typically have steep pyramidal terminations, many of them with pale yellow tips. These crystals typically have a second generation of oriented acicular vanadinite growing from the tips. In one small area the vanadinite crystals were found perched on micro-bladed deep red mottramite, while in another area the pale orange mottramite forms crusts (molds) that cover vanadinite and calcite crystals. Late-stage microcrystalline drusy quartz also forms molds covering 2 to 3-mm prismatic vanadinite crystals.

Vanadinite crystals with appearances and associations similar to those at the Brown Monster mine are also found at one location near the portal of the Reward mine. At both mines the darker red varieties tend to be arsenian vanadinite while the paler orange to yellow crystals are vanadian mimetite—but exceptions exist.

Wulfenite $PbMoO_4$

Wulfenite is relatively common at the Brown Monster mine where it occurs as bright orange to yellow microcrystals in a variety of habits ranging from thin tablets (to 2 mm), to elongate simple tetragonal prisms (to 2 mm), to equant crystals (to 1 mm). The wulfenite is commonly associated with mimetite and mottramite.

Wulfenite is also common at the Reward mine, where pale orange crystals are occasionally found associated with brochantite and are

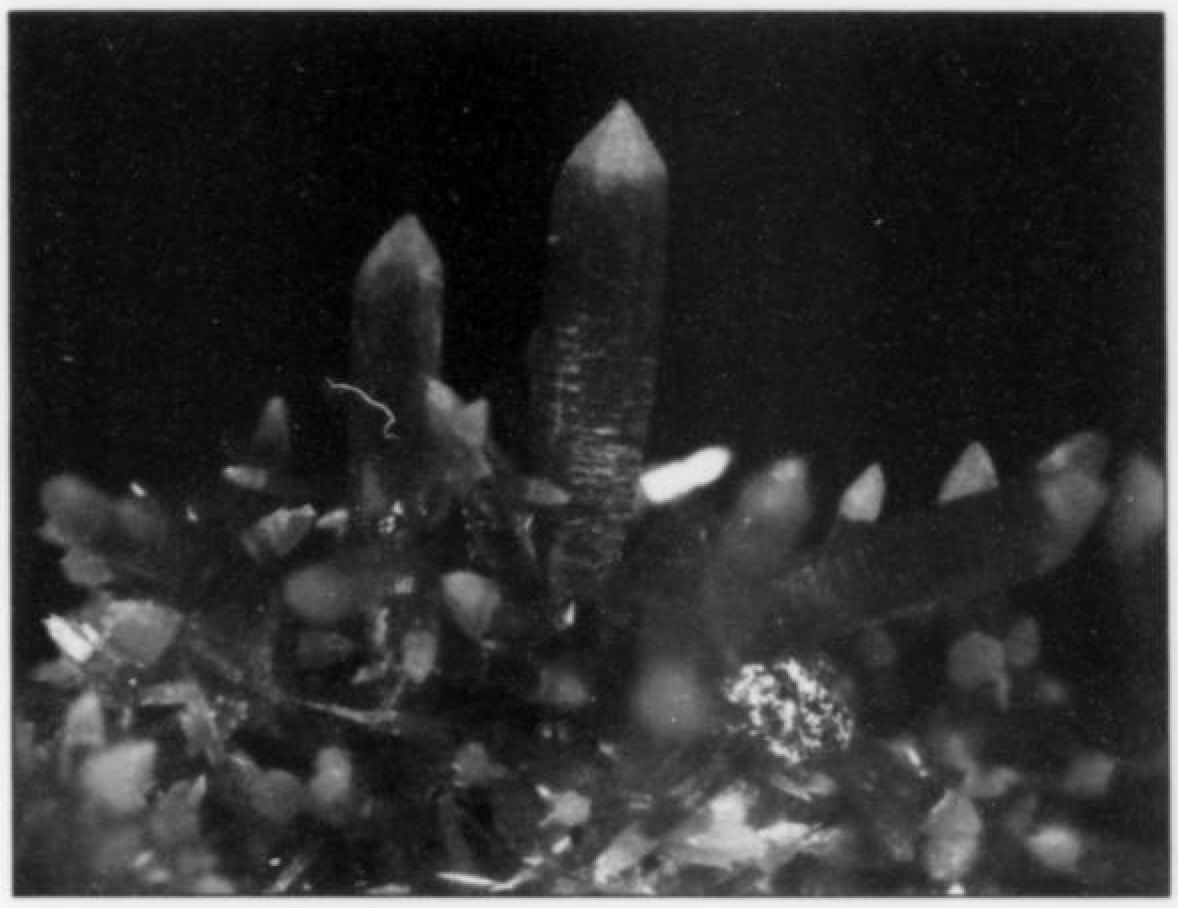

Figure 29. **Pyramidal vanadinite (to 2 mm) from the Brown Monster mine.**

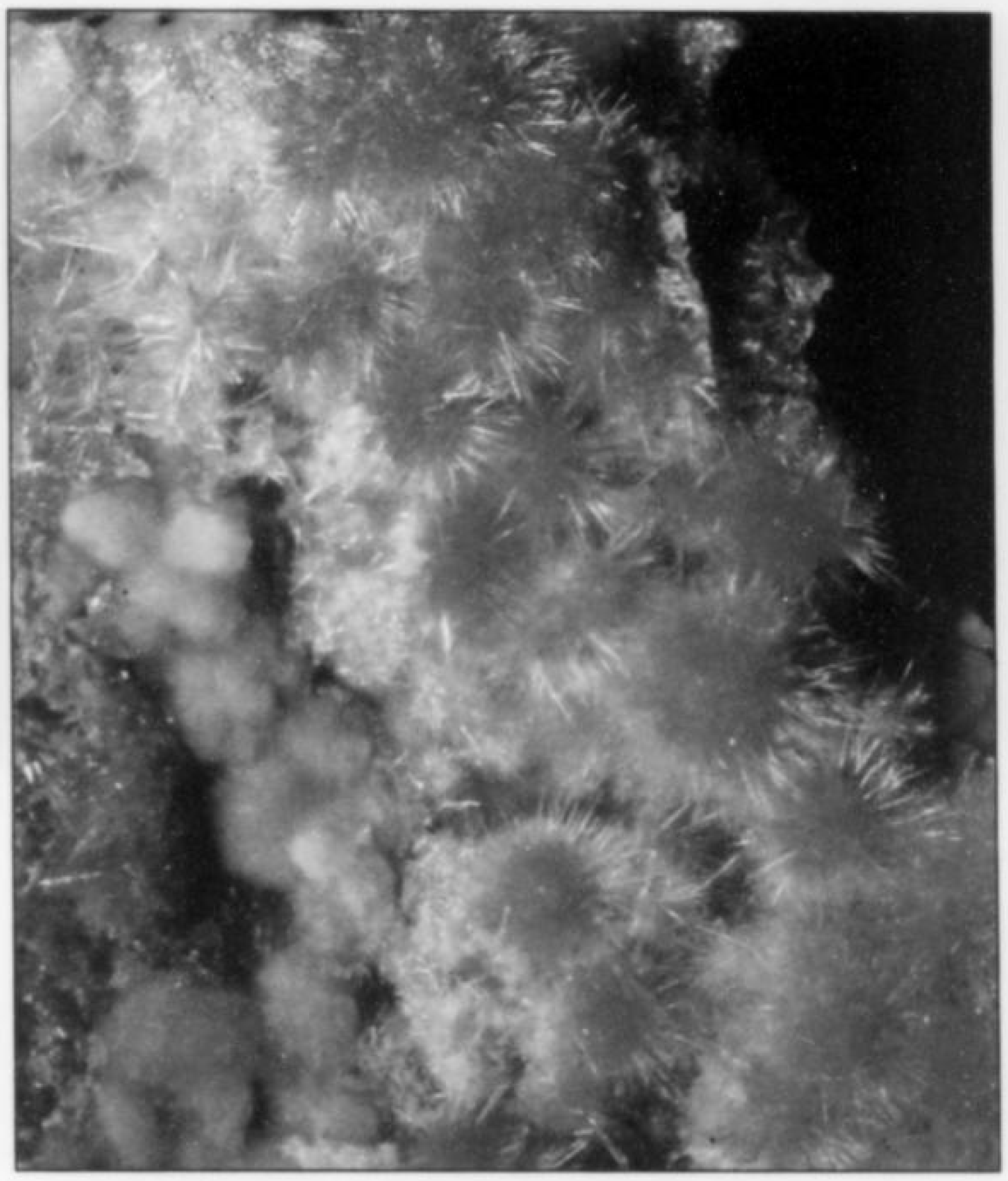

Figure 30. **Acicular vanadinite (sprays to 2 mm) on chrysocolla from the Reward mine.**

often found as overgrowths on arsentsumebite. Most crystals are simple elongate tetragonal prisms (to 3 mm); although elongated pyramidal and equant crystals also occur. More complicated tetragonal prisms were also found associated with brochantite at one location. Pseudomorphs (to 3 mm) of arsentsumebite and chrysocolla after wulfenite have rarely been found. Orange platy wulfenite crystals associated with vanadates (mimetite and mottramite) have been found at one location; the specimens are indistinguishable from those from the Brown Monster mine. Orange wulfenite plates (to 4 mm) partially or totally encased in colorless, transparent discoidal calcite crystals have also been found associated with hemimorphite.

CONCLUSIONS

Both the Brown Monster and Reward mines have produced a nearly indistinguishable assemblage of lead arsenate, molybdate and vanadate minerals including fornacite, mimetite, mottramite, vanadinite and wulfenite. The size and habits of the crystals are nearly identical and it is impossible to identify the source based on appearance. The crystals are mostly associated with fracture sur-

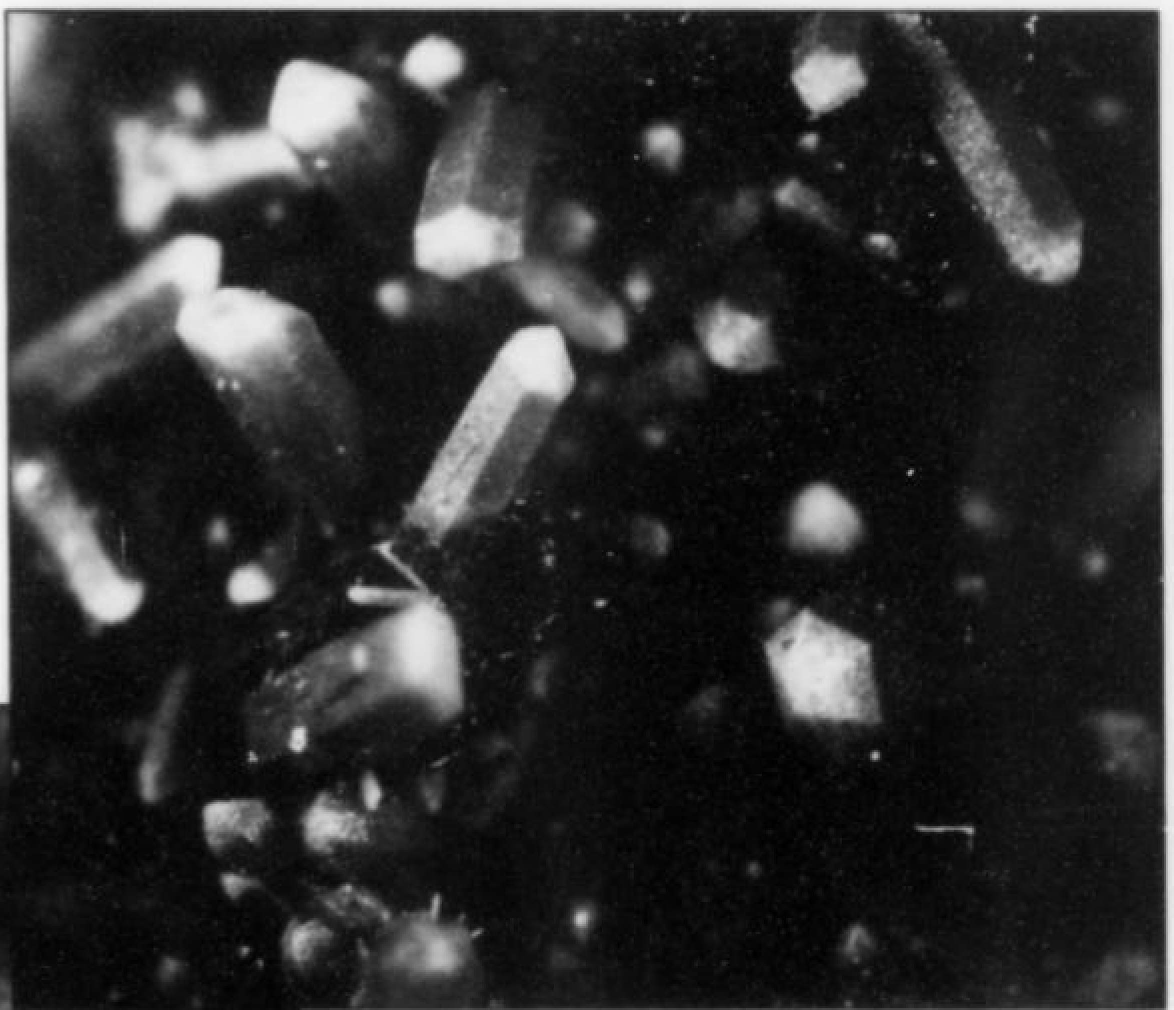

Figure 31. **Prismatic vanadinite with pyramidal terminations (to 3 mm) with yellow terminations from the Brown Monster mine.**

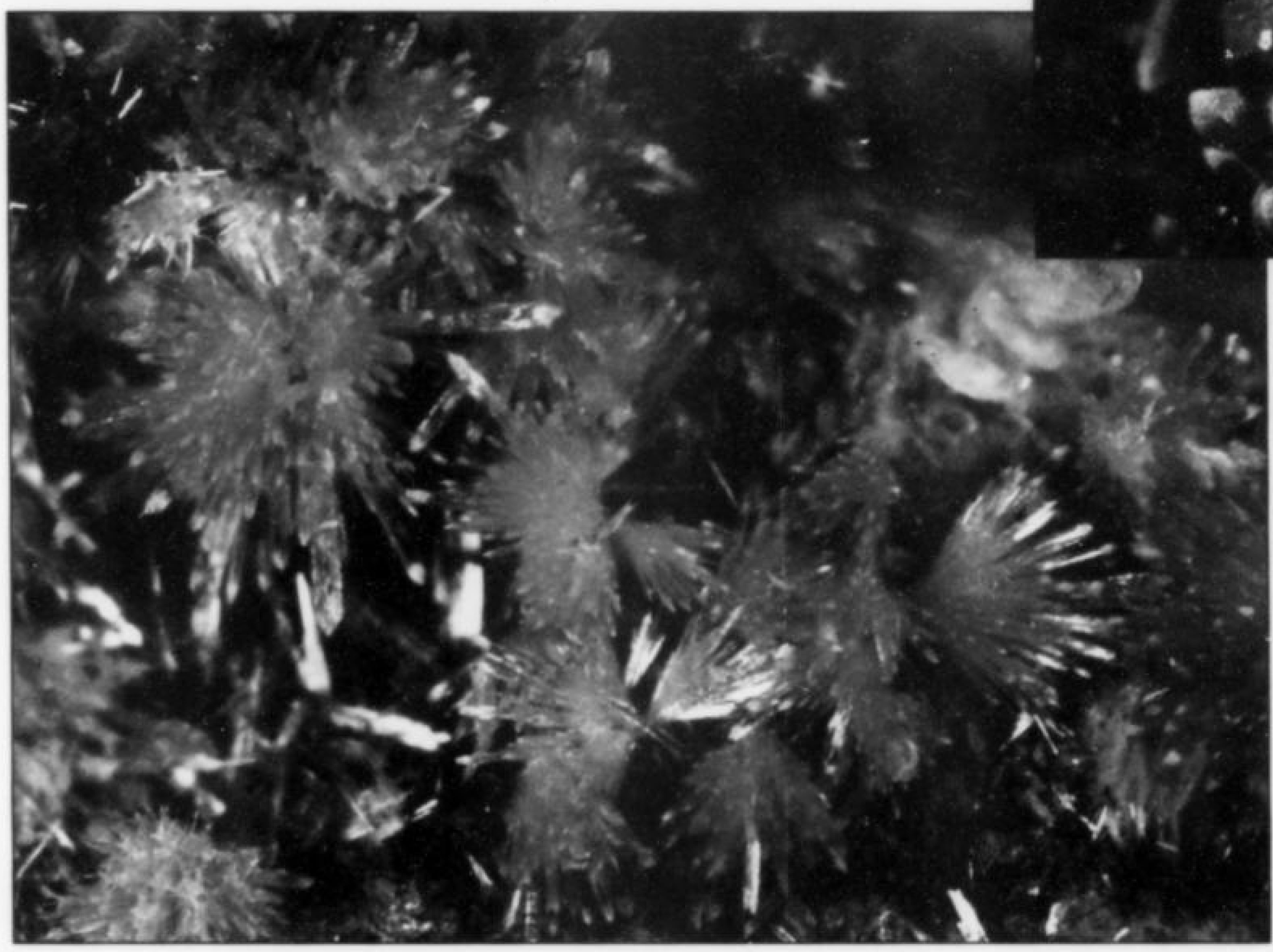

Figure 32 **. Radiating acicular vanadinite (to 2 mm) from the Reward mine.**

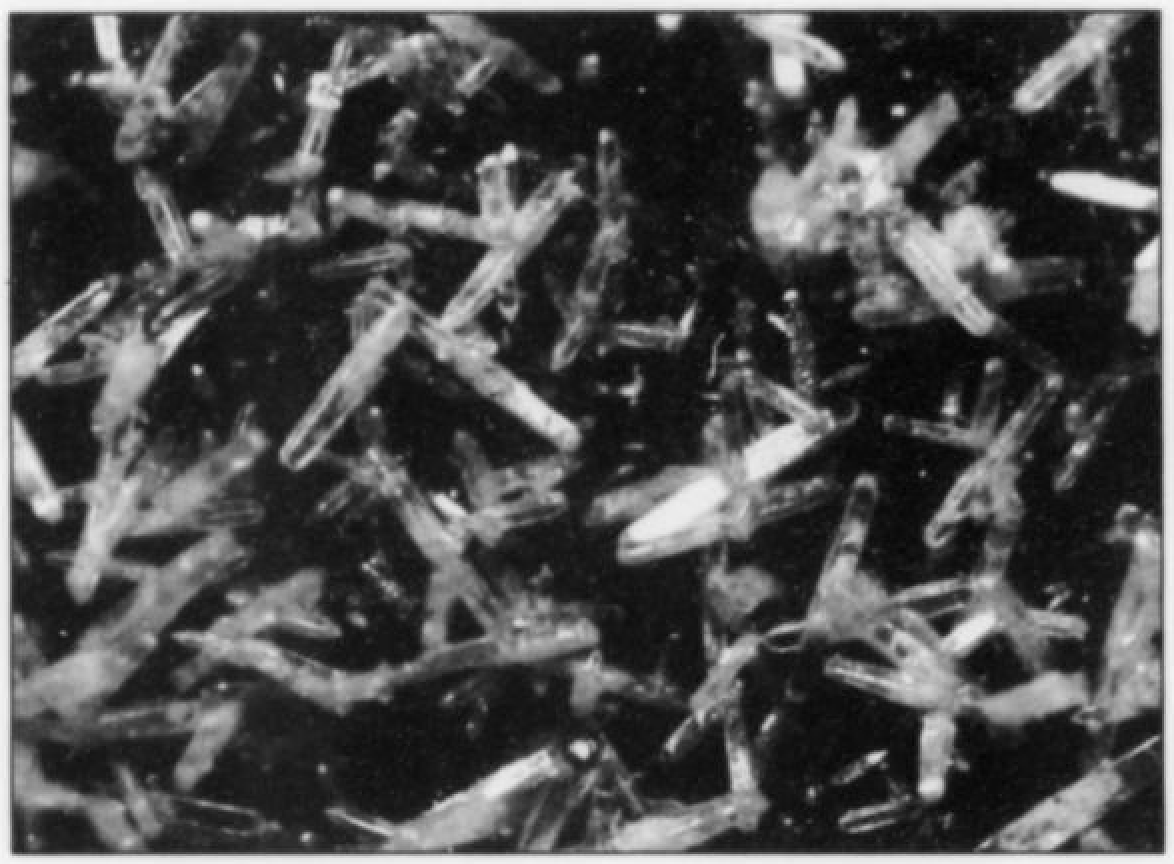

Figure 33. **Prismatic wulfenite (to 2 mm) from the Reward mine.**

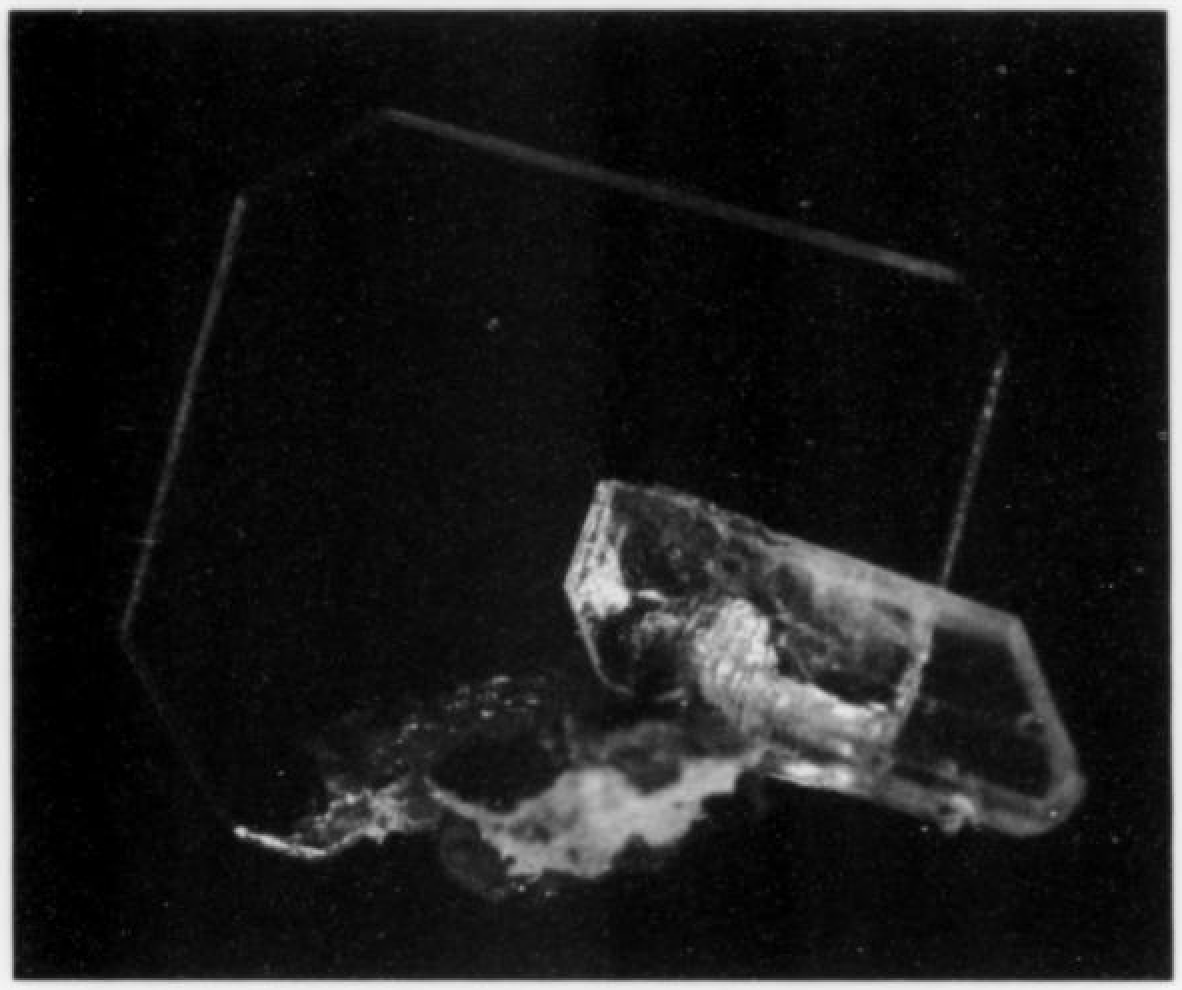

Figure 34. **Tabular wulfenite (3 mm) from the Brown Monster mine.**

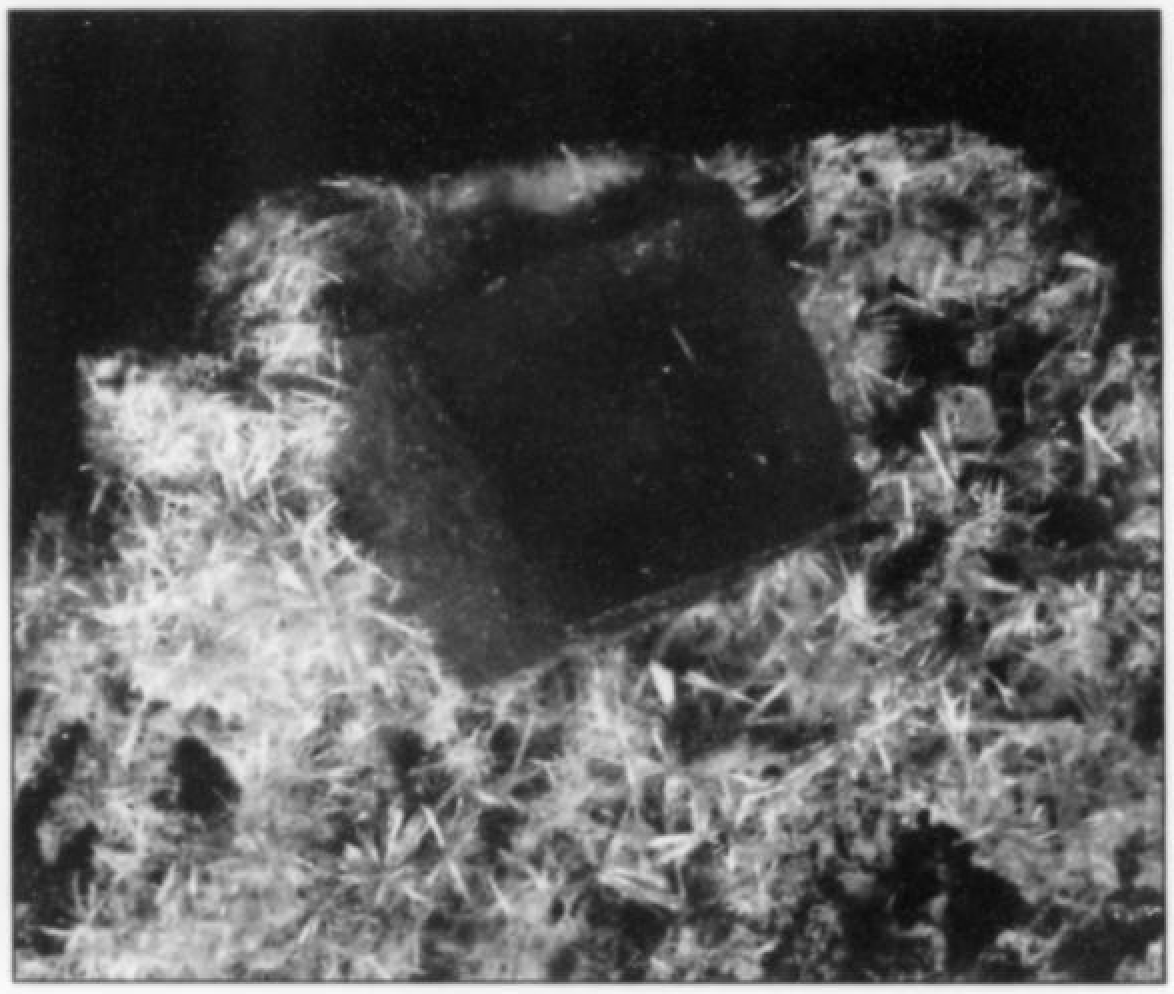

Figure 35. **Equant wulfenite (2 mm) with mimetite from the Brown Monster mine.**

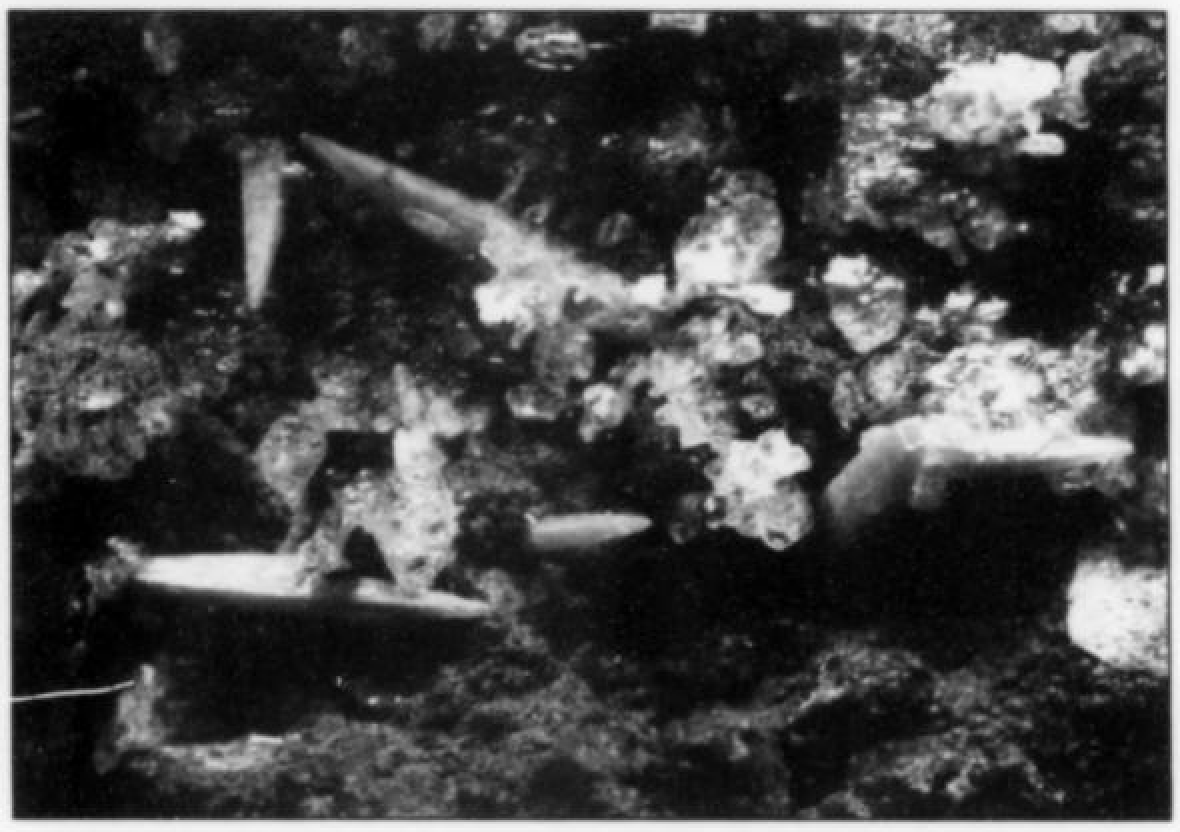

Figure 36. **Arsentsumebite overgrowing chrysocolla pseudomorphs after prismatic wulfenite (to 4 mm).**

faces and thin quartz veins in marble. In both mines zinc minerals (primarily hemimorphite) are present, but are limited in distribution. While the Brown Monster and Reward mines are in close proximity, a fault or shear zone separates them so the exact relationship between the two quartz veins remains uncertain.

The Reward mine has produced a more extensive suite of lead and copper sulfates and phosphates which appears to be more associated with galena in thick quartz veins. These minerals show interesting changes in chemical history. In a localized vuggy zone, cerussite appears to be one of the first secondary minerals to have formed. This was followed by a mixed group of lead and bismuth minerals including chlorargyrite, wulfenite and perite followed by arsentsumebite. This introduction of minor amounts of phosphate minerals was followed by a much more significant deposition of copper and lead sulfate (and minor phosphate) minerals, such as brochantite, linarite, tsumebite, corkite and pyromorphite. This phase also included the introduction of mixed carbonates such as caledonite and leadhillite, leading finally to a simple assemblage of copper carbonates and silicates (malachite and chrysocolla). During these several chemical transitions, earlier minerals frequently became unstable, leading to the formation of interesting pseudomorphs.

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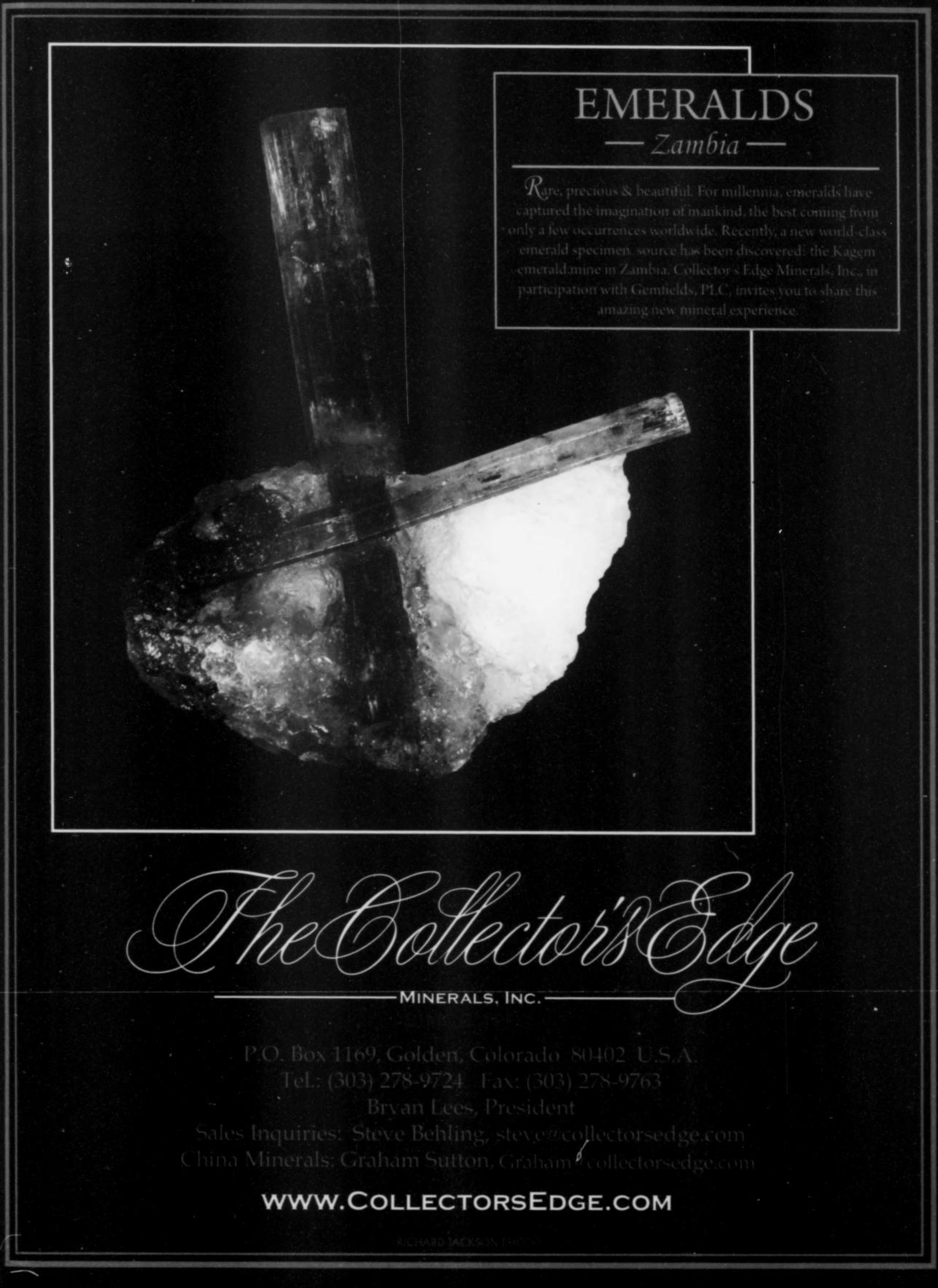
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