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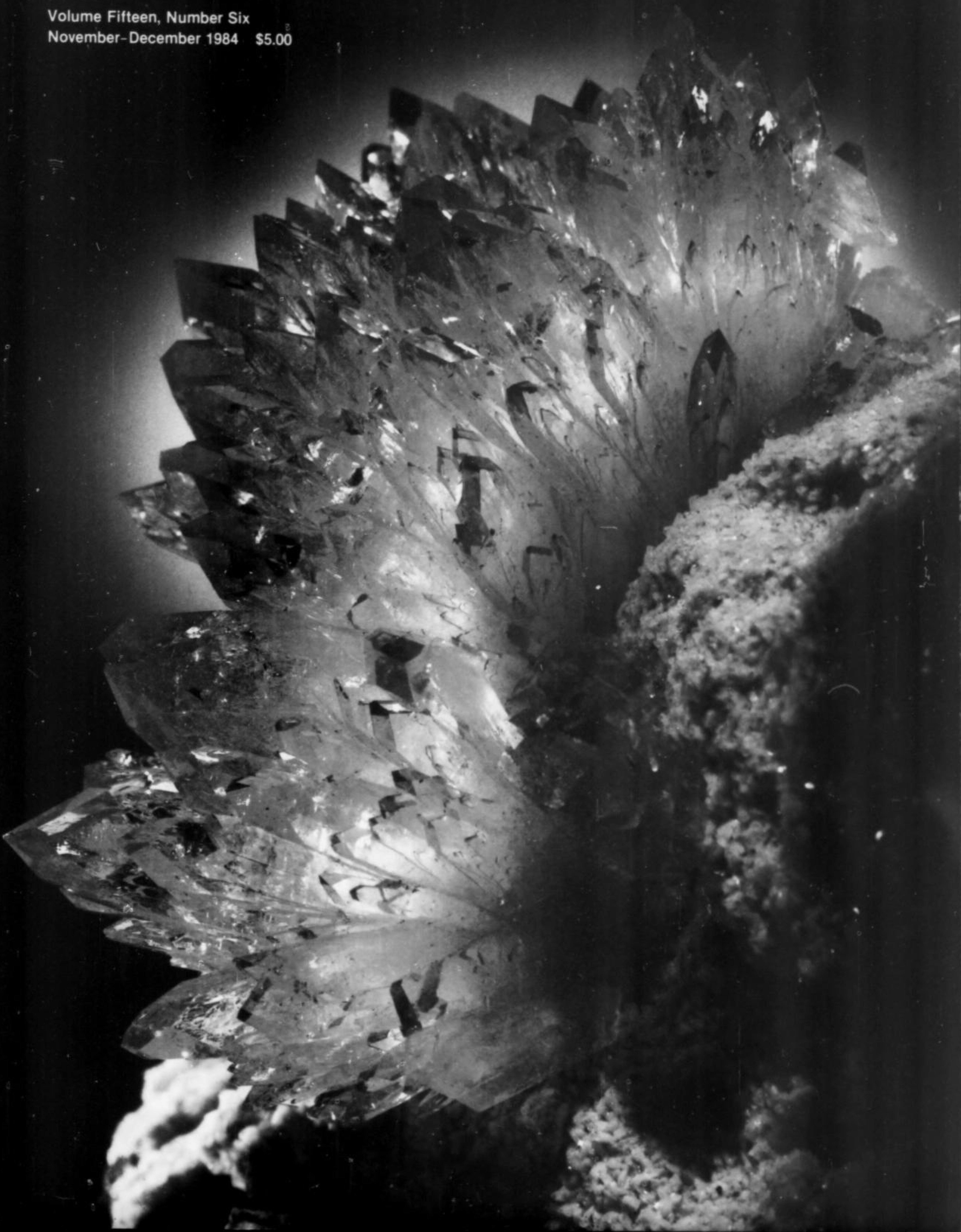


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COVER: APOPHYLLITE recently collected at the Pashan quarry, Poona, India. The crystal cluster is 6 cm from top to bottom. Keith Proctor collection; photo © 1984 by Harold and Erica Van Pelt, Los Angeles.

Famous mineral localities: the mines and minerals of

Bad Ems

Roland Dietrich
Weinfeldstrasse 17
D-6200 Wiesbaden
West Germany

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West Germany

Mined for lead and silver since Roman times, the vein deposits of the Ems district in West Germany have yielded over 50 mineral species. By far the most attractive of these, and the one which has made Bad Ems world-famous, is pyromorphite.

INTRODUCTION

The town of Ems has been well known for centuries, not only for its mineral wealth but also for its mineral waters. In fact, the name Bad Ems or Emser Bad means "Ems Bath," a reference to the natural artesian springs in the area which have supplied heated, carbonated water for countless health-seekers and vacationers. The early Romans, who had a fondness for spas, may well have been initially attracted to Ems by these springs, and perhaps only later discovered the valuable mineralized veins nearby.

The ore-carrying system which comprises the Ems district is known as the Ems-Braubach belt. It consists of several related vein systems and deposits arranged more or less along a line from Arzbach on the east, through Bad Ems near the center, to Braubach on the west, a total distance of about 16 km. These small towns are located just a few kilometers south and east of Koblenz and about 70 km west-northwest of Frankfurt, Hesse, West Germany.

Veins at the Schöne Aussicht mine near Dernbach could be considered a part of the Ems vein system. They lie on the same line, northeast of Arzbach.

A total of 34 major stoped areas and 21 shafts have been developed in the Ems district. The most important of these are the Silberkaute mine near Arzbach; the Pfingstwiese mine near Ems, combined later into the Mercur mine; the Fahnenberg vein; the Neuhoffnung vein; the Bergmannstrost mine; the Friedrichssegen mine, and the Rosenberg mine at Braubach.

Editor's note: This article is a revised, translated composite of articles by the above authors which appeared separately in the April-June 1983 issue of *Emser Hefte* magazine. Our thanks to *Emser Hefte* editor Rainer Bode for permission to rework and republish the articles.

Figure 1. **Location of the Ems district in Germany.**

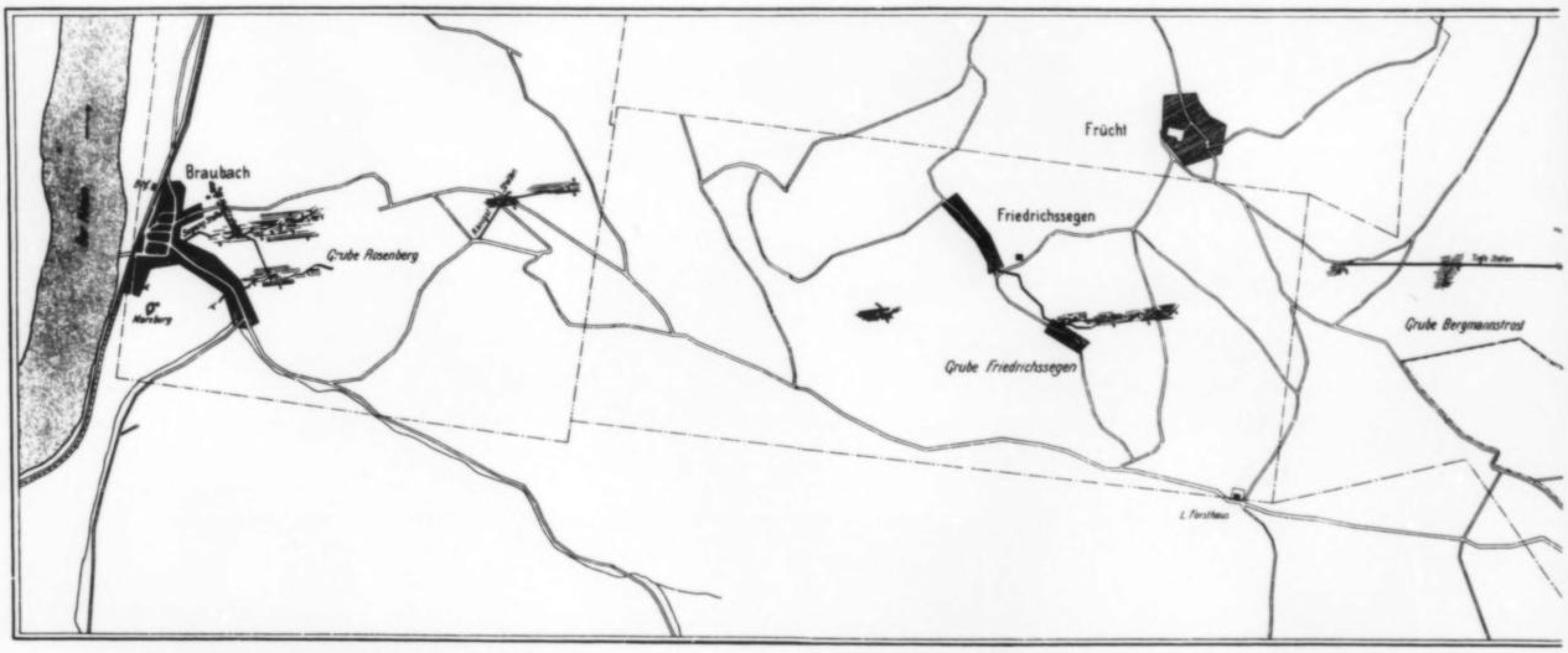


Figure 2. **The Ems district, Rheinland-Pfalz, West Germany (Linkenbach, 1908).**

Although over 50 different mineral species have been identified from the Bad Ems area, the district's fame rests largely on a single species: pyromorphite. Only a handful of occurrences worldwide are recognized as classic localities for fine, display-quality specimens of pyromorphite. These include the Couer d'Alene district in Idaho (Crowley and Radford, 1982) and the Les Farges mine, Ussel district, in France (Brousse, 1982). Bad Ems easily predates both of these and was for many years the world's unrivaled, premier source. Superb specimens are a hallmark of many of the earliest mineral collections, and are diligently sought after by European collectors in particular.

HISTORY

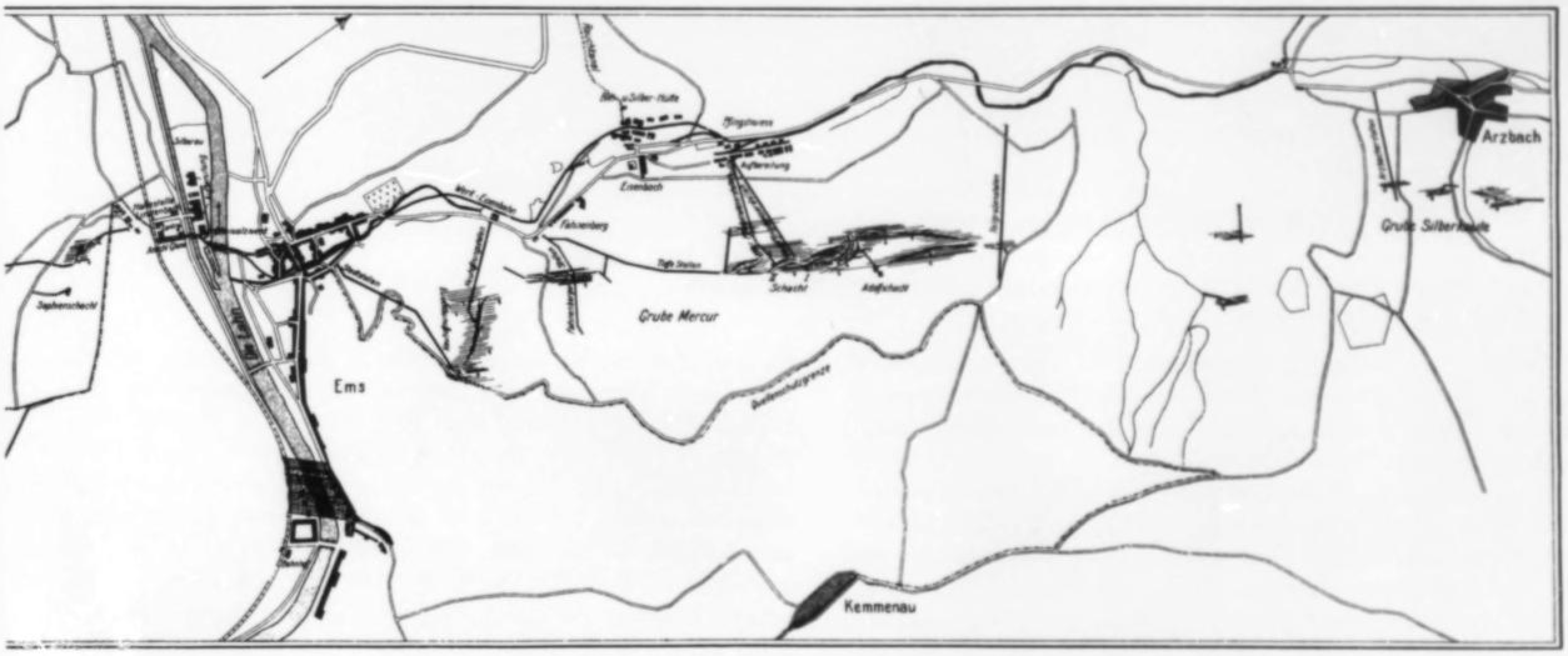
Mining in the Ems region began very early. The Romans first worked the deposits, and a Roman settlement from the second or third century B.C. has been found in excavations near Braubach. In ruins near Pingen, mining tools including a miner's pick axe were found. Between Arzbach and Ems an old metallurgical plant was discovered near a vein, situated in a Roman fort and including two smelting furnaces under which large amounts of lead ore in all stages of smelting were found. Roman coins and remnants of mining tools have been found in a number of the old workings.

Mining in and around Ems continued into the Middle Ages, as attested to by many old documents still on file. For example, in 1158 the diocese of Trier received mining rights from Kaiser Barbarossa to mine silver at Ems. In 1209 Friedrich II leased the Friedrichssegen mine near Lahnstein. A 1301 record of enfeoffment from Albrecht I mentions the mining of silver at Braubach. A mining order from Nassau Catzenellnbogen is known dated 1559. In 1681 the town of Braubach granted permission for prospecting, and in 1723 enfeoffments for the Ickerstiel and the St. Eckardsberg mines (later renamed the Rosenberg mine) were granted. Many other official documents bear evidence of active mining throughout the centuries.

In 1854 a consolidation of the Rosenberg mine took place and from 1891 to 1928 the mine was exploited without interruption. Between 1854 and 1927 1.25 million tons of ore were removed. The Rosenberg mine exploited the Segen-Gottes veins and the Viktor veins, each consisting of two parallel veins dissected by fan-shaped offsets. Three of the early portals were named the Viktor, Segen-Gottes and Gustav shafts, serving eight underground levels. In 1891 the Moritz and the Maschinen shafts were added. The veins measured between 140 and 270 m in length and up to 10 m in thickness. In the North Field four veins were found through the Hohler shaft and the Königstieler tunnel. These eventually communicated with the four shafts in the Rosenberg mine. In the following years imported ore reached the market and a world economic crisis broke out. In addition to that, a general decrease in ore grade was noticed below the sixth level; this in itself is not surprising, as a progressive diminution of the veins in the deeper levels is characteristic throughout the Ems district. In 1906 the Rosenberg mine was electrified and in 1911 a wet-magnetic separator was built. Finally, in 1926, Europe's first flotation plant was constructed there.

To further explore the Rosenberg mine's North Field, a tunnel was driven from the Segen-Gottes veins through the third level in the direction of the Königstiel workings. This pilot tunnel passed through the North Field in such an unfortunate manner that it missed every vein. The North Field was therefore considered to be unprofitable and, in consideration of the total situation, the Rosenberg mine was closed in 1928.

Figure 3. **An early view of mine buildings near Ems.**



In 1853 the "Bergwerk im Köllnischen Loch," the Friedrichssegen mine, was taken over by the *Anonymen A.G. des Silber- und Bleiwerkes Friedrichssegen;* the land was later transferred to *A.G. des Altenbergs.* The mine was active until 1912. After World War II a flotation plant was built in the valley of Friedrichssegen and, up until 1956, ore from various old dumps was reworked.

In 1766 Johann Remy from Bendorf was awarded the Bergmannstrost mine. In 1780 he acquired the Mercur mine near Ems and formed the mining company *Remy, Hoffmann und Co.* In 1860 this company built a processing plant on Silberau Island near Ems. In 1871 the company name was changed to the *A.G. des Emser Blei- und Silberwerkes.* Mining on a large scale began, and steam generating equipment for underground mining was installed. Railroad connections, the building of bridges, a hydroelectric generating station owned by the company, and an inter-plant railway were soon constructed. Electrification followed in the beginning of this century, and modern magnetic separation became part of the ore preparation process.

The Neuhoffnung mine reached its greatest depth of 782 m near Ems. The Friedrichssegen mine reached 484 m and the Rosenberg mine 440 m in the first period of mining. During the total mining period over 200 km of workings were opened. The total amount of raw ore mined came to 10.5 million tons. Depending on the thicknes of the veins, the metal contents were 1–3.5% lead, 3–6% zinc, and up to 0.5% copper. Overall, the silver content amounted to 25–30 grams per ton of raw ore. Silver was bound mainly in galena. Thus, in the time of modern mining, in our century and in the one before, the vein produced a total of 200,000 kg of silver and 15,000 tons of copper. The highest annual yield from the mines was recorded in 1875, 1.6 million marks; the largest amount of ore was mined in 1880.

The mines had to fight extraordinarily heavy water flow. In the Rosenberg mine approximately 2 cubic meters had to be pumped per minute; in Friedrichssegen 5 cubic meters per minute, and 6 cubic meters per minute in the Pfingstwiese mine. Carbon dioxide-containing springs were encountered in the entire area of the vein, especially at greater depths, as in the Rosenberg mine, the Friedrichssegen mine and the Neuhoffnung vein. The Neuhoffnung thermal spring carried a temperature of 48° C (118° F). The cutting of these thermal springs at depth raised concerns about protection

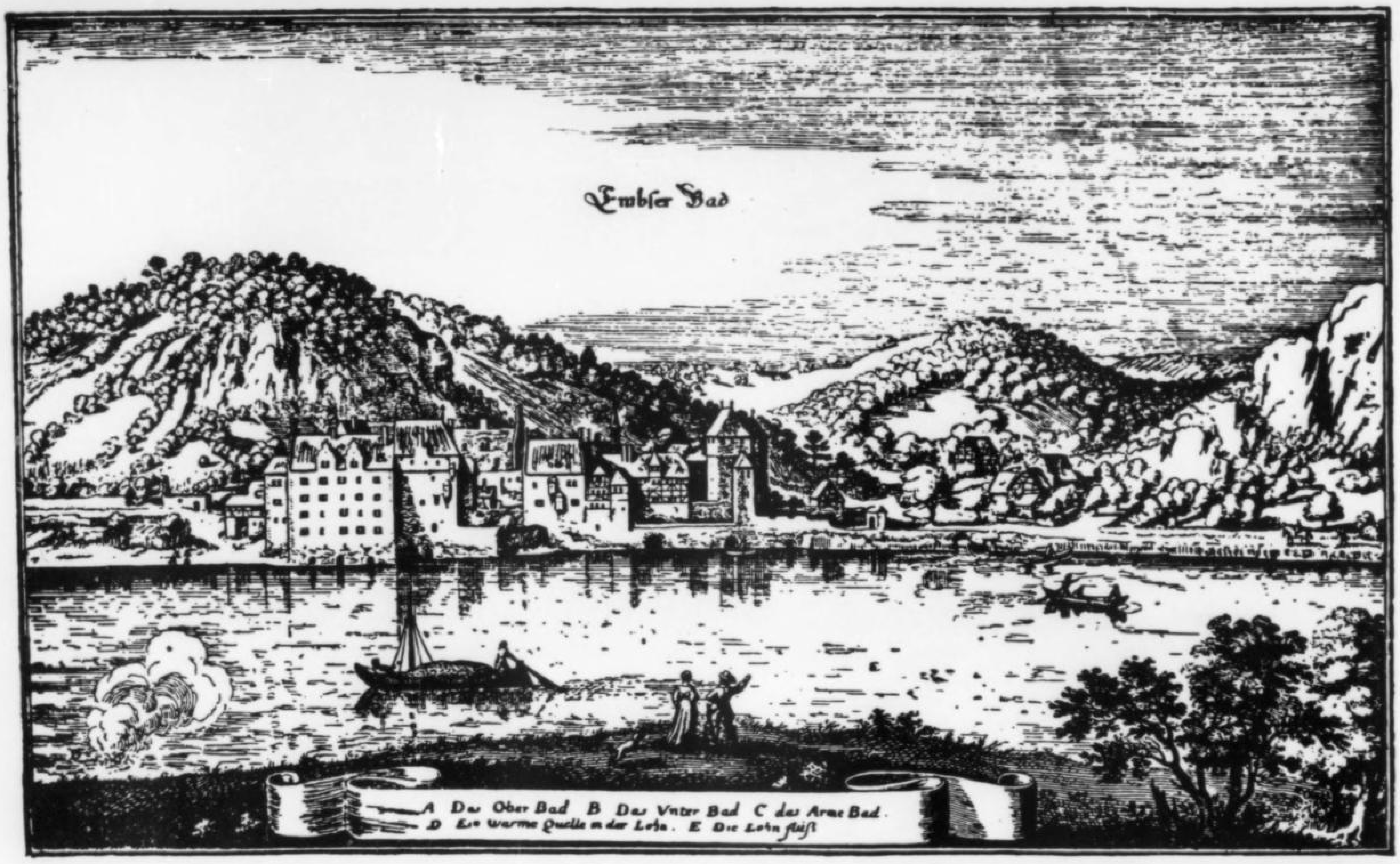


Figure 4. **A view of the Ems spa published by Merian in 1655. The Lahn River passes by in the foreground; note the steaming hot spring emerging from the river bank at left.**

of the spa at Ems and lead to disagreements between spa authorities and the Mercur labor union. Therefore, even though it was one of the richest veins, mining at Neuhoffnung was intermittently interrupted, sometimes for more than a decade.

In prosperous times the mining areas around Ems employed about 1900 people. Production amounted to approximately 10% of the German metal mining industry. But, around 1880, mining in the Ems area began a slow decline. The causes included rising costs, competition in the world market, economic crises, and disagreements with the spa management and other authorities. In 1909 the lead and silver plant at Ems merged with *Stollberger Zinc AG.* The Mercur Mining Company, from then on responsible for all activities in the veins, was formed in Ems. The Friedrichssegen mine was abandoned in 1912, the Bergmannstrost mine in 1922 and, finally, in 1925 the lead smelter at Ems was closed.

During the years immediately preceding World War II the mines at Ems, especially the Neuhoffnung vein, were worked extensively. At the end of the war, because of the electricity shortage, pumping ceased and all mines went completely under water; the mining industry at Ems had come to a more or less final halt. After the war, portions of the old dumps were reworked and considerable amounts of ore were recovered. The Ems milling facilities were used to process ores brought in from elsewhere. In 1971 the city of Ems purchased the Mercur mine; since then the galleries have been used to store the city's water supply.

Following World War II interest was directed toward the Braubach end of the vein system, where untouched ore was suspected. Beginning in 1950 the veins in the Königstiel mine near Braubach were systematically explored. Of the four veins, vein III proved to be the most important. Neighboring veins gather around, and some connect with this vein. But the Königstiel veins are repeatedly offset by fault clusters. On the other side of the disturbance, with its many short veins, the vein continues as the Hohler vein. The Hohler vein was exploited gradually, first on the 50-meter level, then the 190, and finally the 225. A total vein length of about 110 m has been mined out. The vein thicknesses varied greatly and usually measured between 2.5 and 4 m. In 1963, however, shortly before abandonment of the mine, a vein thickness of 11 m was encountered on the 225-meter level. This vein, containing massive sphalerite almost exclusively, was at that time the thickest vein being worked in Germany.

Extraordinarily large amounts of water draining in from the flooded workings of the old Rosenberg mine through cracks and faults caused great difficulties at the Königstiel mine. On the 150-m level the distance to the old workings was only 10 meters. It was decided to unwater them completely and regain access to the old ground but, before any action could be taken, modern developments in world industry and lower priced offers of foreign ore put an end to these considerations. In 1963 the Königstiel mine, after being in operation for ten years, was abandoned as the last mining enterprise of the Ems district. During this period it had produced approximately 132,000 tons of ore.

REGIONAL GEOLOGY and ORE GENESIS

The Schiefergebirge of the Rhineland, a part of the Variscan chain, consists mainly of deeply folded Devonian sediments of a few thousand meters thickness striking northeast-southwest. In it lie a few important deposits, the most significant being the siderite veins in Siegerland, the hematite deposits of the Dill-Lahn region, and the lead-zinc ore veins in the Lahn-Mosel area.

Attempts have been made to find the magma body responsible for the formation of these veins, but Variscan plutonic rocks ap-

***Figure 5.* Friedrichssegen mine around 1910. Bode collection.**

pear to be absent throughout the whole Schiefergebirge area of the Rhineland. According to Bubnoff, the Schiefergebirge lies high above the Variscan intrusion plane, and it has been assumed that the synorogenous intrusions lie in discordant areas between gneissic Precambrian and sedimentary Paleozoic formations.

Hydrothermal lead-zinc veins, as can be seen in many deposits throughout the world, are commonly formed at a significant distance from the parent magma. The problem in the Schiefergebirge of the Rhineland is that only basaltic intrusions are known in the area, whereas lead-zinc veins are thought to be the product of granitic magmas only. A number of theories have been proposed to explain this contradiction. One of these, for example, is the theory of "prolonged initial magmatism." It proposes that very large amounts of intruded magma from subcrustal zones of basaltic composition (but possibly including felsic components) differentiated over a very long time. A range of compositionally different magmas developed, solidified, and produced mineralizations. Thus, the same parent magma, at different times, would have produced the keratophyre rocks of the Sauerland as well as the siderite veins of the Siegerland, the zinc ores, diabase and hematite veins of the Lahn-Dill area, and also the lead-zinc ores near the Lahn and Mosel rivers.

Another view suggests that huge sediment and country rock masses are responsible for the total metal content and that the metals have been mobilized and leached out by thermal waters, sometimes with the assistance of surface waters.

An example of geochemical zoning is the Siegen-Soest N-S-zone, which strikes diagonally through the folded chains of the Schiefergebirge. In this zone the various hydrothermal veins follow

***Figure 6.* Two miners from Ems, 1895.**

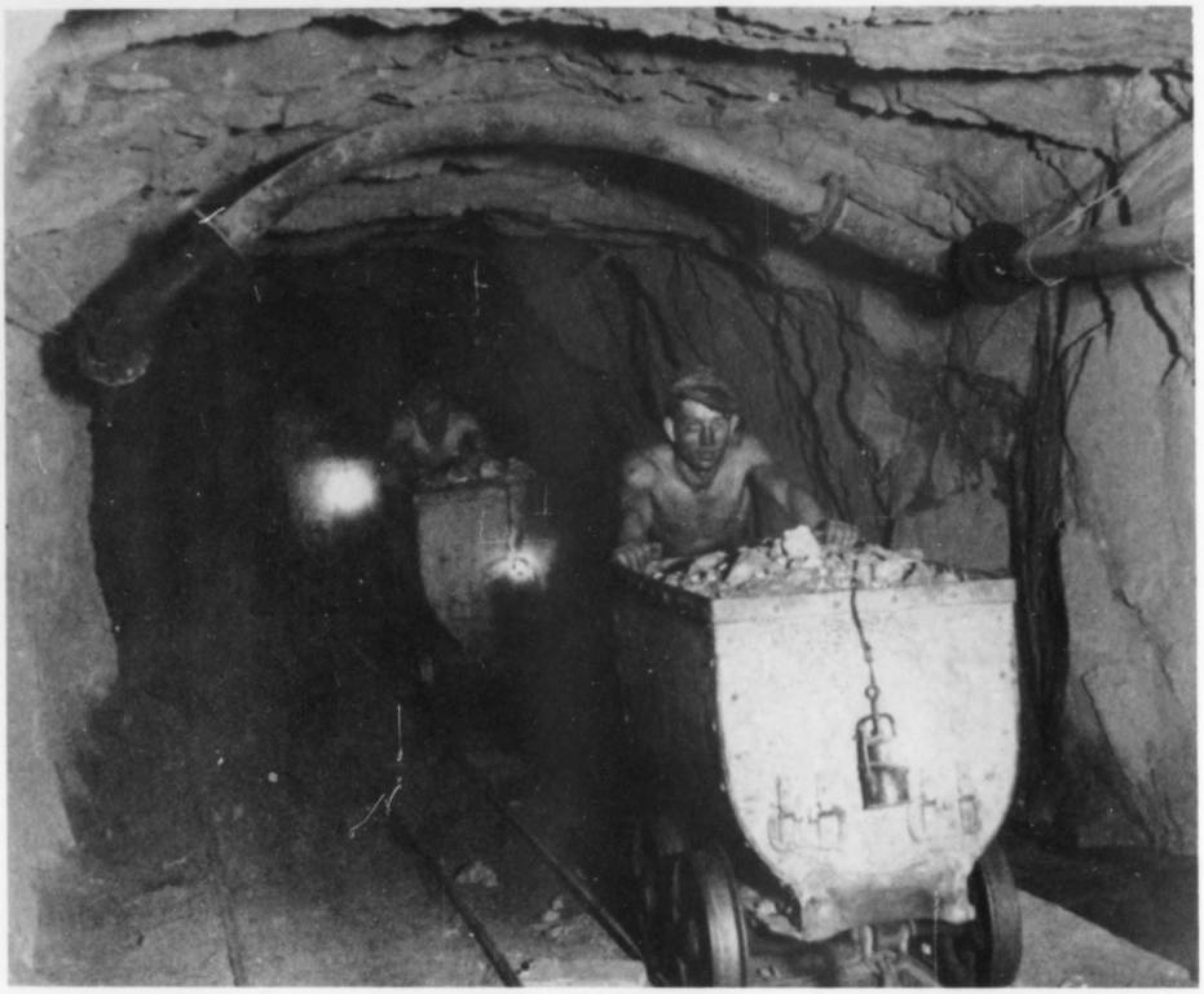


Figure 7. **Miners tramming ore on the 16th level of the Neuhoffnung mine. Bode collection.**

each other in sequence. They range from the galena-sphalerite-chalcopyrite veins near Müsen to the pyrite-sphalerite-chalcopyrite vein near Meggen, to the siderite veins of the Siegerland and from there through a number of smaller deposits to the southern veins of the Ems district.

At Westerwald the existence of fractured zones along the strike and the thermal springs could support the theory of mobilization from substrata and ascent along these fractured zones. But these are all just theories; a definite statement about the origin of mineralization cannot be made at present.

For the time being it is supposed that an intrusion during the middle Devonian era was the source of ore-forming solutions, but the location and extent of the pluton are not known. Its highest upwarping is assumed to be in the nucleus of the main arch of the Siegerland, at a depth of 2000–3000 meters. It is believed that the land surface at the time of the lead-zinc vein formations in the southern part of the Schiefergebirge was 1500–2000 m higher than today. Thus, the intrusion occurred at an approximate depth of 5 km. According to studies made in the Oberharz, the boundaries of the batholith lie 1200 m under the limit of a workable vein.

The lead-zinc veins therefore appear to be telethermal deposits. Hydrothermal solutions traveled long distances and, during the slow decrease in temperature along relatively large areas, formed uniform segregations or paragenetic zones. In the southern part of the Schiefergebirge the height of the workable zones, including parts lost by erosion, ranges from 1500 m at Holzappel to about 1000 m at Werlau-Wellmich, and to a few hundred meters at Hunsrück in the southern part of the Eifel district. A zone pattern of the veins is barely discernible; only a quartz-siderite zone and a higher lead-zinc zone is identifiable. In some cases quartzose formations can be found running upwards and downwards as well as along the trend. Often the quartz root can be compared to the quartz crown, which is ore-deficient as well, even though, in most cases, the crown

Figure 8. **Miners at the Pfingstwiese mine (a part of the Mercur mine), 1937.**

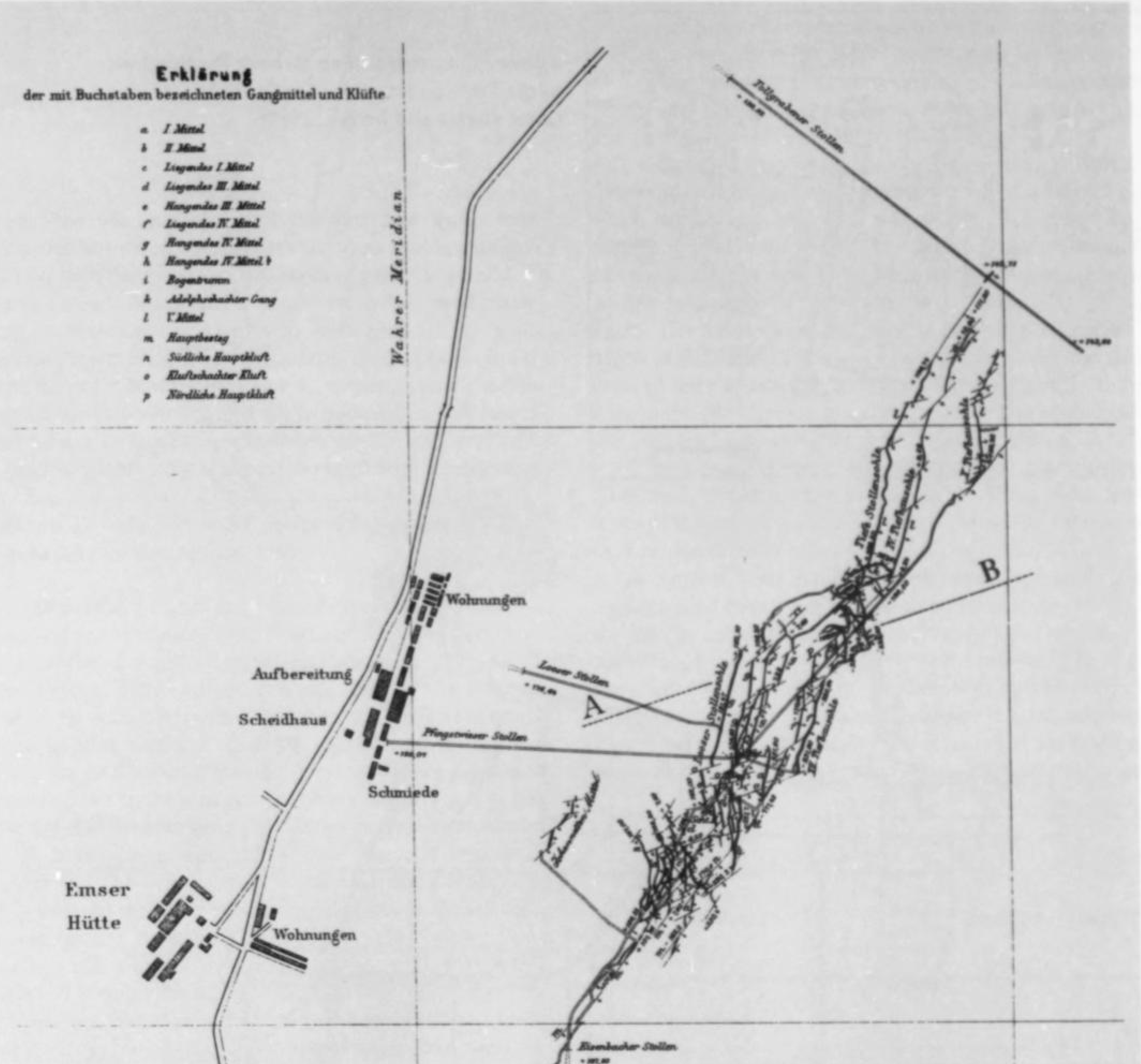


Figure 9. **Map of the complex vein system at the Mercur mine (Pfingstwiese and Neuhoffnung mines).**

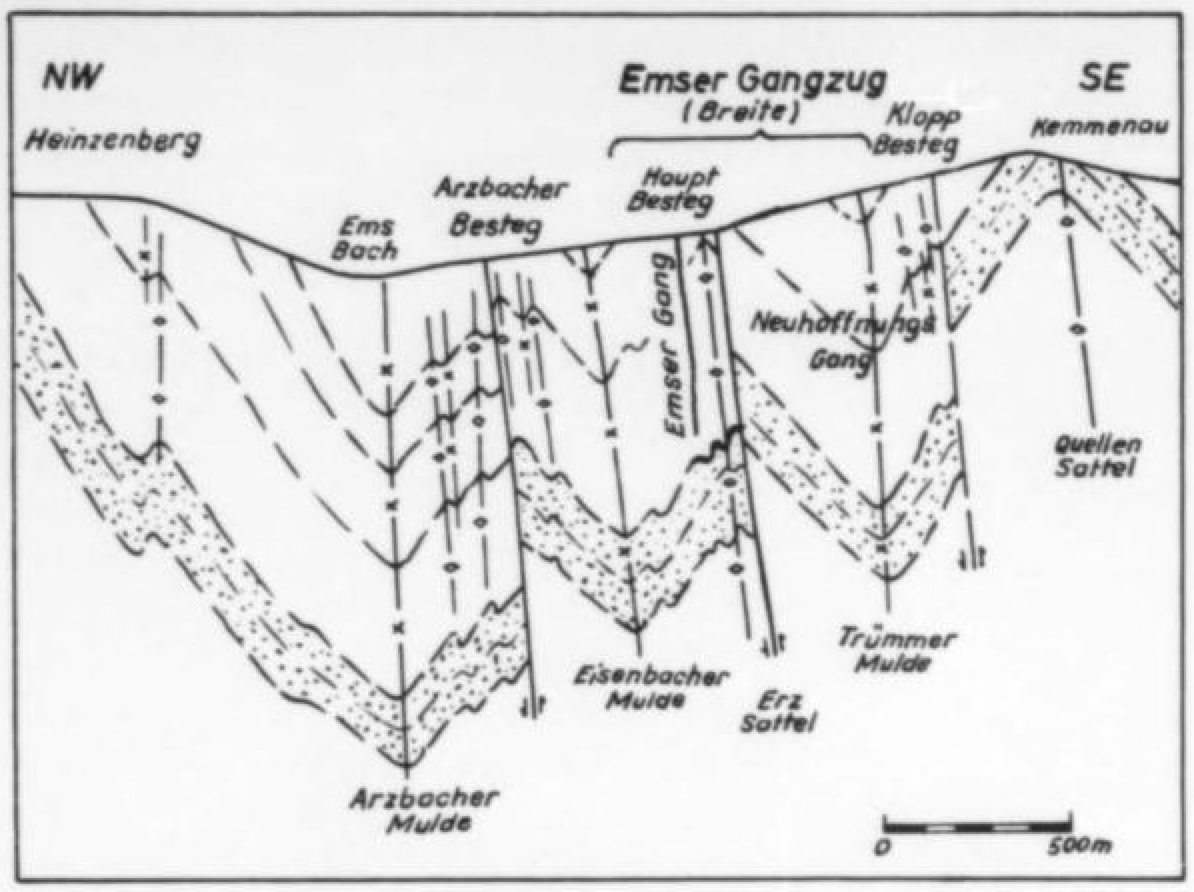


Figure 10. **A cross-section through the structure of the Ems district perpendicular to the fold axis (after Herbst and Müller, 1969).**

that rising heat and solutions following the anticline from the volcanic source at depth are responsible for the springs.

Mining at Ems was made difficult by a multitude of offsets in the veins. Every few dozen meters a vein would appear to end at a fault face. In the early days of mining, when structural geology was poorly understood, productive veins were abandoned at the first offset. Later, however, it was realized that a careful search might reveal the continuation of the vein at some distance along the fault. The Ems district was practically exhausted of ore by the time the complicated structural relationships were finally worked out.

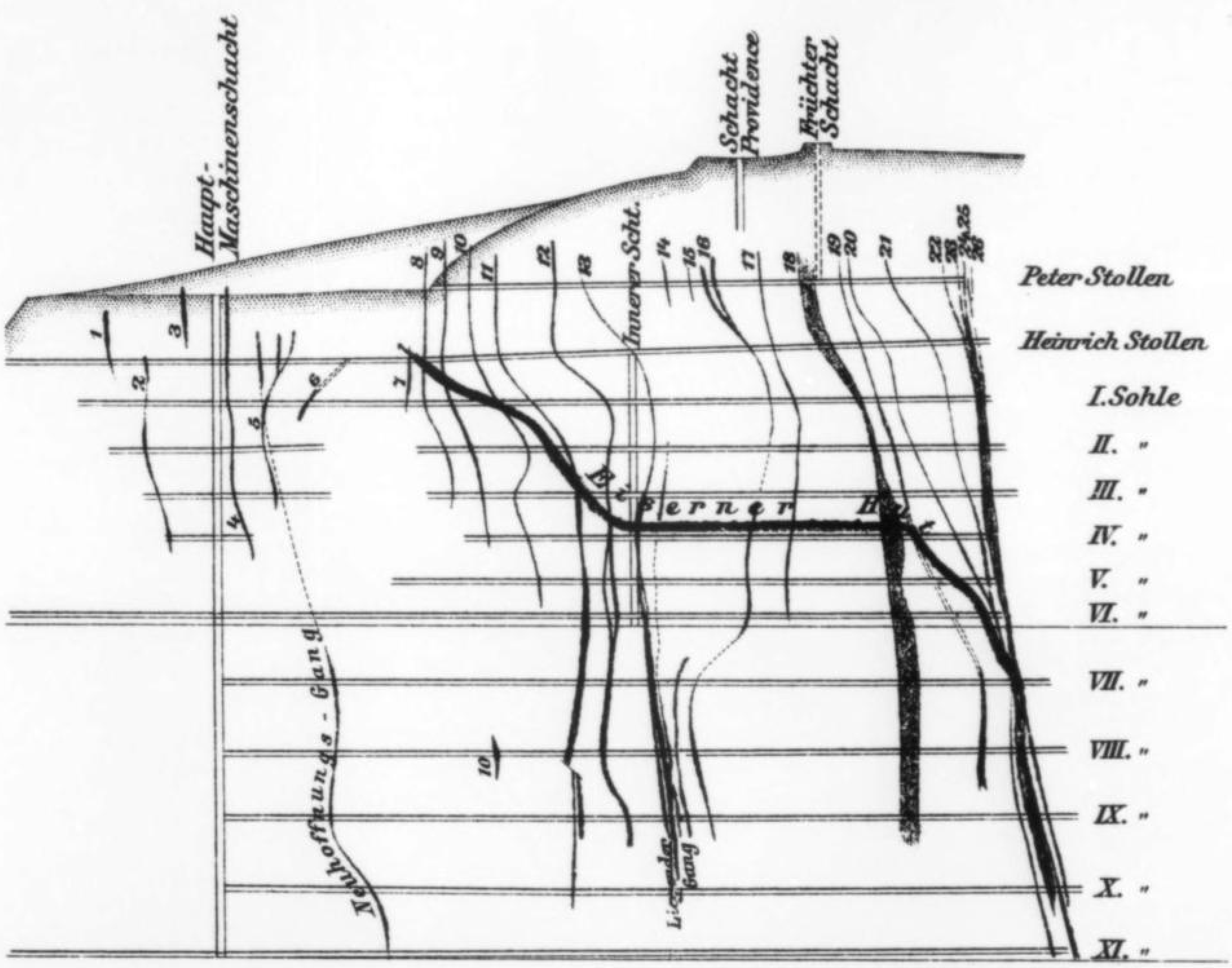


Figure 11. **A cross-section through the Friedrichssegen mine.**

is partially eroded. These conditions were especially visible in the Theodor mine near Tellig on the Mosel. There the mineralization consisted of single ore pockets arranged *en echelon,* deepening toward the south. At a height of 250 m the roots and crowns became more and more quartzose, until at last quartz tails pinched out in the slate of the Hunsrück mountains.

STRUCTURE

Lead-zinc veins of the Ems system occur within a series of lower Devonian shales, graywackies and quartzites totaling nearly 1000 m in thickness. The dominant structural feature of the mineralized area is a major anticline formed during the Variscan orogeny, running between Arzbach and Braubach; most of the Ems veins are located in its flanks or core. Thermal springs rich in CO_2 surface at Bad Ems, rising from this structure. The anticline plunges under two Tertiary trachyte cones northeast of Arzbach, and it is assumed

Current interpretation suggests that the ore-carrying veins were emplaced along a series of fractures belonging to a shear system. With very little variation they intersect the fold axis of the anticline at an angle of 48°. In a balanced shear system, where rocks are compressed in one direction and allowed to expand in perpendicular directions, two sets of fractures which cross each other and which are diagonal to the direction of compression normally result. However, as at Ems, one set can be suppressed to a large extent, under certain conditions. The mineralized fractures at Ems run mainly north-south. The veins appear to have been reopened and remineralized several times, in some cases causing such a disintegration of the adjacent country rock that sharp vein boundaries no longer exist. A few veins follow cleavage planes in the countryrock running parallel to the fold axis (northeast-southwest). A few other

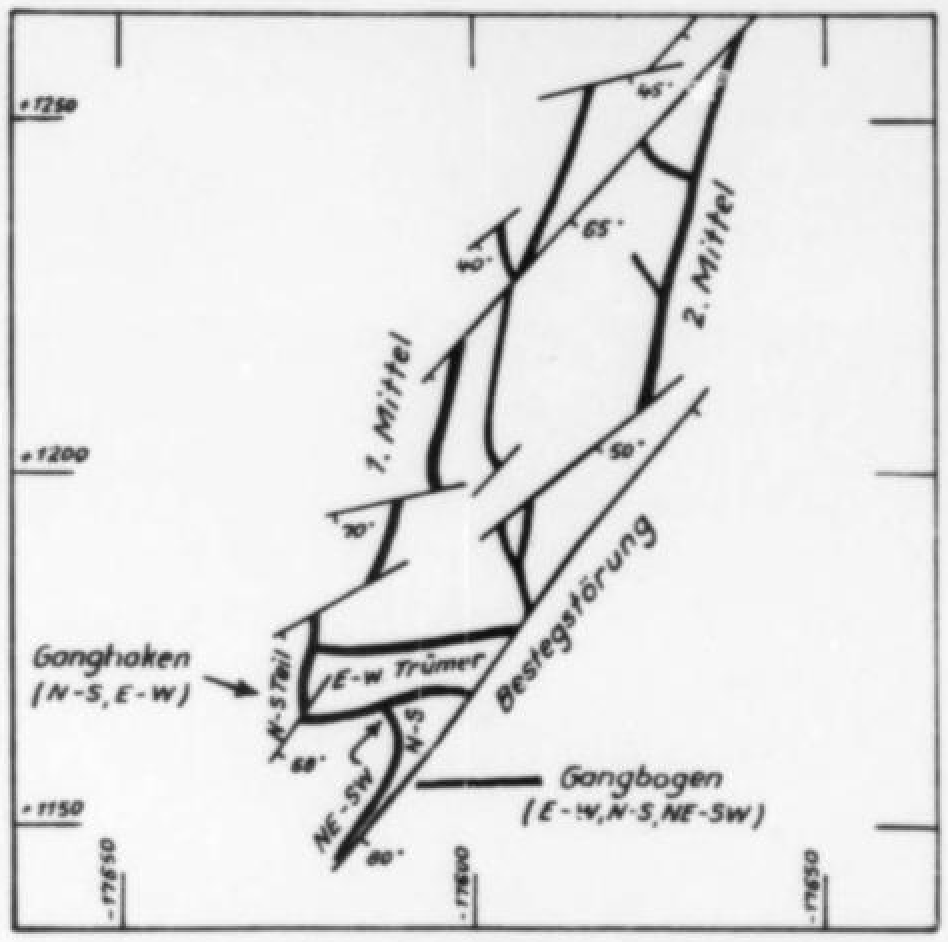


Figure 12. **Map of veins in the Pfingstwiese mine (Herbst and Müller, 1969).**

veins, as in the southern end of the Pfingstwiese mine, follow rare fractures belonging to the suppressed system of the shear structure, and so run east-west. Complicating matters further are a number of veins in the shape of arches which formed through the interaction of both shear sets with the southwest-northeast cleavage pattern.

Post-mineralization faulting dissected the complex system of mineralized veins in a peculiar manner. Upthrust faults known as *bestege* penetrate the entire vein system, always occurring near the core of the anticline and striking parallel to the fold axis. In the proximity of mineralized veins the *bestege* fan out into fault clusters which cut the vein at right angles and then recombine into a single fault on the other side. Displacements of the vein can be significant; at the Rosenberg mine, for instance, the Segen-Gottes vein was offset by 270 meters in a slanting upthrust toward the southeast. A younger set of displacements took place in north-south and east-west directions, resulting in deposition of quartz with minor chalcopyrite, pyrite, calcite and nickel, cobalt and antimony minerals. These young displacements are commonly channels for thermal springs.

PARAGENESIS

Many of the workings in the Ems district are exhausted or have been inaccessible for a great many years. This makes paragenetic study difficult. The Königstiel veins, however, have been mined relatively recently and are more easily studied. Four phases of mineral deposition have been noted at the Königstiel mine:

1. Siderite
2. Dark-brown
3. Yellow sphalerite, galena, chalcopyrite, pyrite, calcite, dolomite
4. Quartz (III)

Siderite, partially banded, together with dark gray, glassy, opaque quartz, is found as the earliest crystallization. Dark-brown sphalerite and the main deposition of quartz as milky white quartz (II), as well as second generation galena are younger than siderite. Often it can be seen that sphalerite and quartz (II) replace siderite, whereby part of the siderite iron migrates, and the remainder combines with sphalerite. Included within sphalerite and quartz is relict siderite in the form of thin stringers and blebs. Also found are country rock breccias and siderite bonded by quartz (II) and sphalerite. Quartz and sphalerite are often intimately bound and form a kind of zebra pattern caused by the healing of fractured sphalerite with quartz, or by alternating succession. Dark brown sphalerite is the most important massive ore in the Königstiel veins. Locally, sphalerite even displaces idiomorphic quartz (II).

Some of the massive galena was formed contemporaneously with sphalerite, but most is younger. In the upper levels it can cover the entire vein thickness, measuring up to 2 m. Galena occurrences are mostly very fine-grained and commonly contain quartz included as fine particles.

It is assumed that small, mainly idiomorphic crystals of yellow sphalerite, galena and chalcopyrite belong to a second generation which can be found together with pyrite, calcite, and dolomite in small fractures in the veins. They probably are the result of recent recrystallizations formed long after the primary ore mineralization. As the last phase of mineralization, quartz (III) was deposited again. The amounts of chalcopyrite and siderite increase with the depth of the veins. The same observations have been made in the veins of the Pfingstwiese and Neuhoffnung mines. In the Neuhoffnung mine the increase in quartz, siderite and chalcopyrite below the 13th level indicates that the root of the veins are not far away.

In the Königstiel veins the oxidation zone extends down to the 50-m level, in places even as deep as the 100-m level. Between the levels of the gallery and the 50-m level the primary ores were present only as deteriorated relics.

Outcrops of veins in the Ems district are thoroughly leached and only the hard quartz has resisted weathering to any extent. Beneath the leached capping is the "iron hat" of the veins, characterized by a network of quartz and relatively soft limonite. The upper zones were much higher before the land erosion, therefore the veins carried the iron mainly in sphalerite and also in small siderite stringers. Zinc is geochemically mobile, and is therefore easily dissolved and carried away. Iron in its oxidized form remains mainly as the oxy-

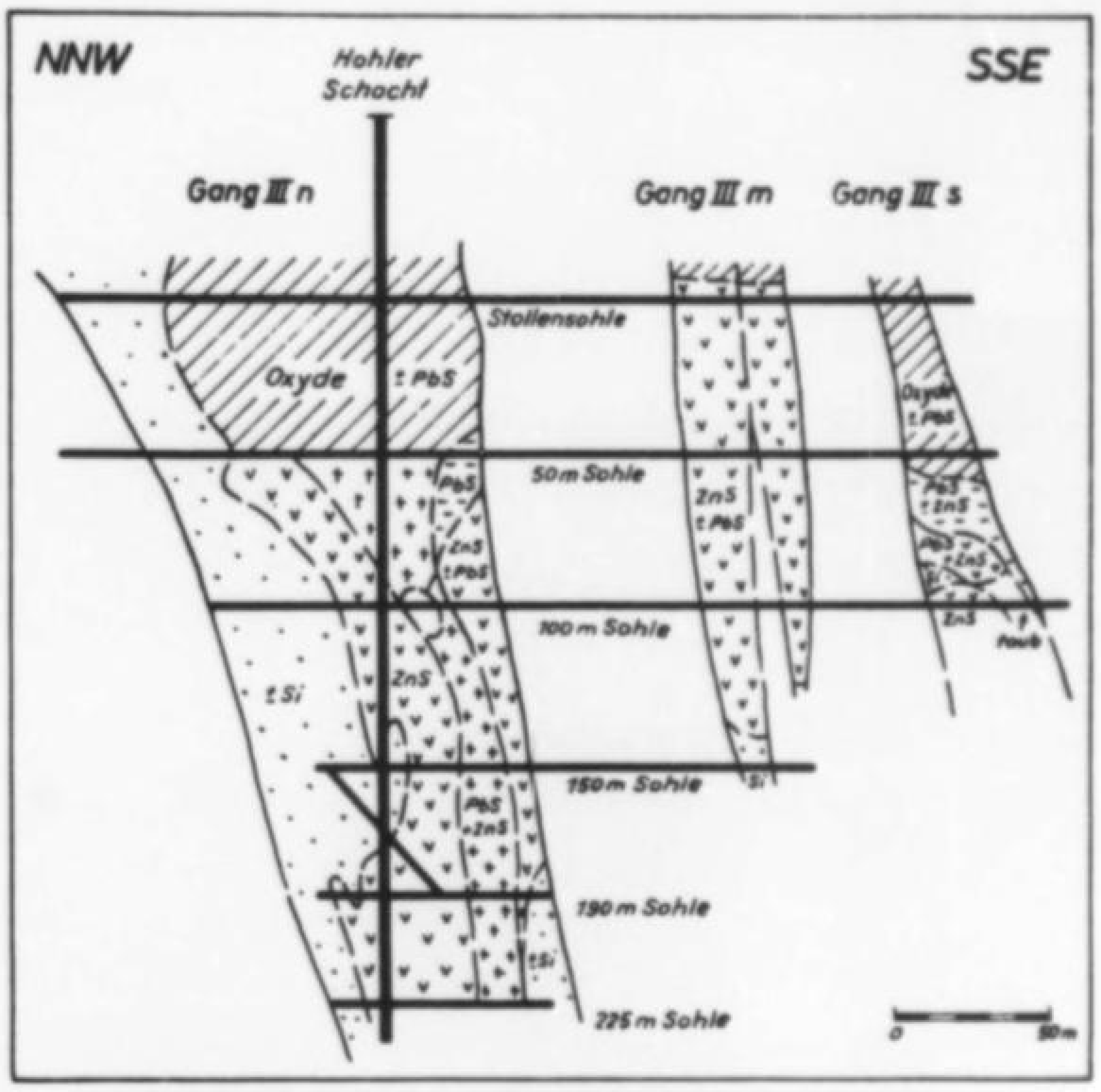


Figure 13. **Structure of the Königstieler III veins at the Rosenberg mine shown in cross-section (Herbst and Müller, 1969).**

hydrate. Lead and copper bind with phosphate, carbonate and sulfate ions and crystallize out in cavities and fissures.

The thickness of the oxidation zone varies. In general, as in the Rosenberg mine, it extends downward for 50–100 m, but along breccia zones and faults it can reach deeper.

In the Friedrichssegen mine the oxidation zone reaches uncommonly far down; in the middle part of the veins it extends to over 400 m. Because of the corresponding multitude of secondary minerals, especially pyromorphite, the mine has become known throughout the world.

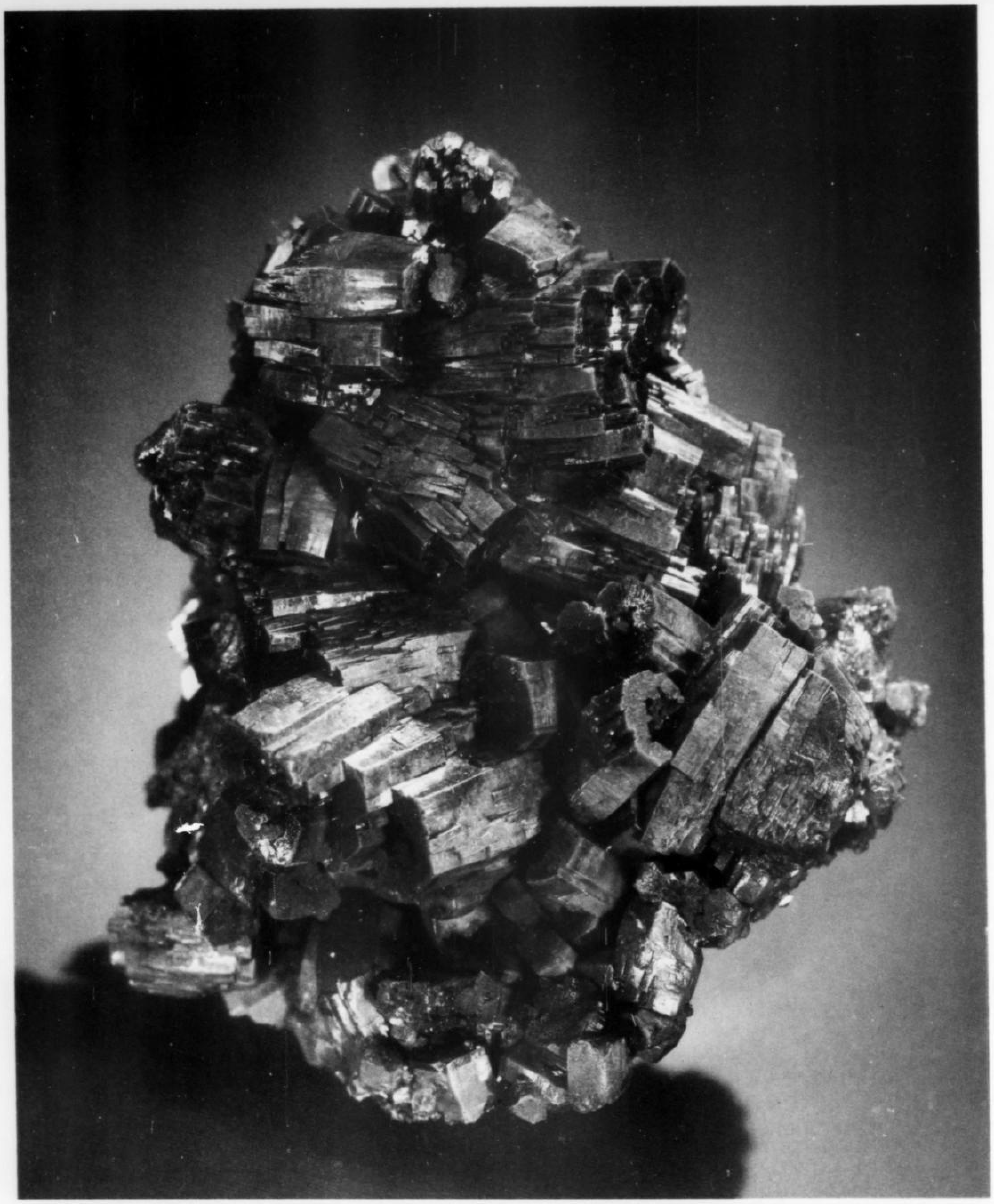


Figure 14. **Pyromorphite, 6 cm tall, from the Friedrichssegen mine. Wayne and Dona Leicht collection; photo by Harold and Erica Van Pelt.**

The Königstiel mine also became famous for exceptional occurrences of pyromorphite. Considering the amount involved, the question of the origin of the considerable quantity of phosphate arises. In the Oberharz the phosphates from animal excretions have been held responsible. In the Ems district, though, horizons of the Laubach and Hohenrhein formations, which are extremely rich in fossils, seem more plausible origins. In the Königstiel veins pyromorphite was also found at greater depths, in some cases greatly enriched. At these depths it was found to be completely colorless. The smoky brown color developed only after exposure to light. In the upper levels pyromorphite exhibited a green color caused by the presence of trace elements.

Intersections of veins with recent fractures carrying carbon dioxide-rich water in some cases also contain abundant pyromorphite, suggesting a possible genetic relationship. On the other hand, in the uppermost levels of the Königstiel veins large amounts of pyromorphite were found. In the completely dry and dusty limonite filling in the loose quartz residuum, pyromorphite was found as aggregate prisms to several centimeters in length.

Figure 15. **This remarkable specimen was collected in 1852 at the Friedrichssegen mine. It shows blue-gray hexagonal pseudomorphs of galena after pyromorphite (*blaubleierz*, "blue-lead-ore"), partially coated by a fresh growth of green pyromorphite. It measures 2 x 3 cm. G. Gebhard collection; photo by Olaf Medenbach.**

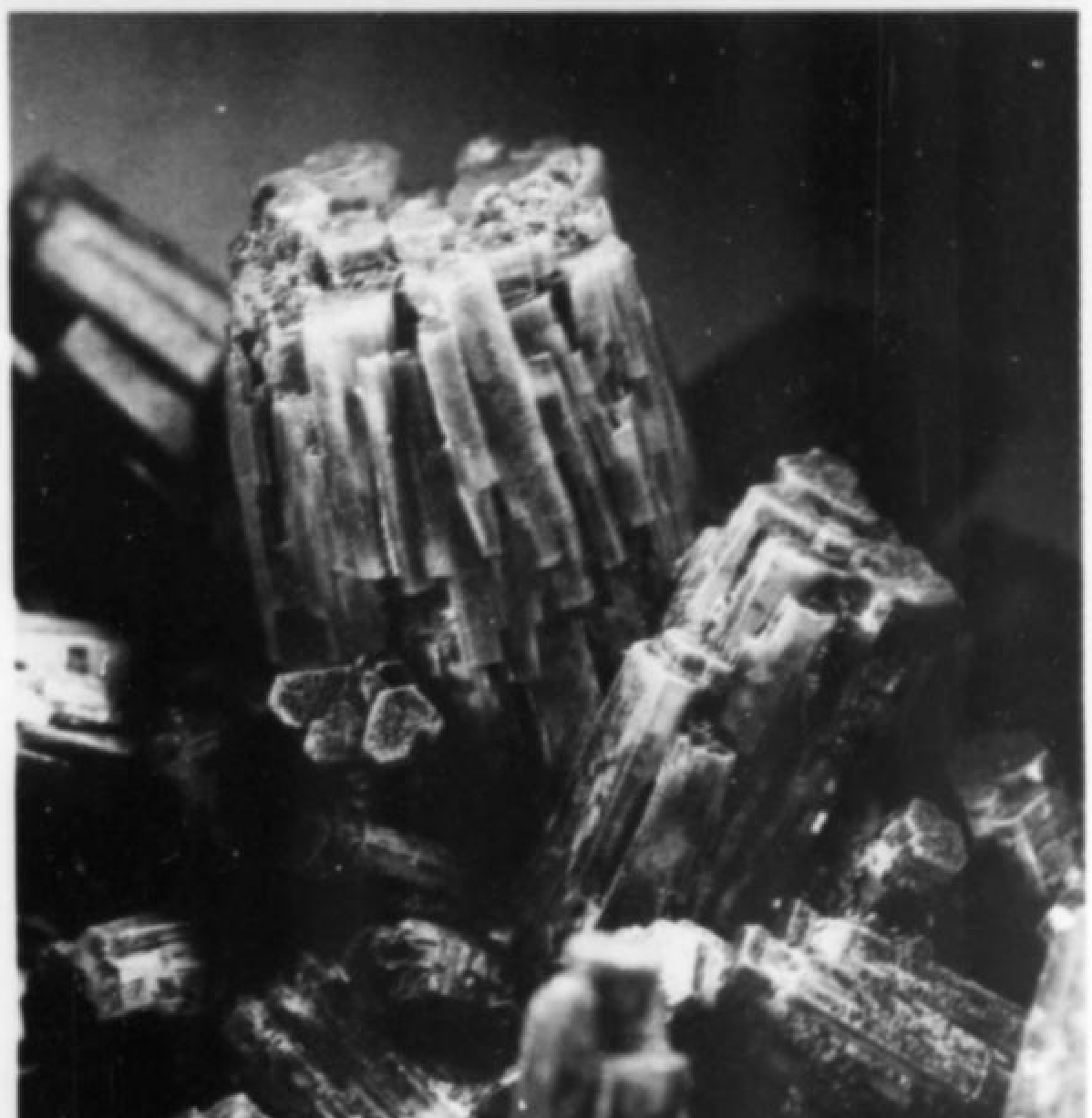


Figure 16. **Green and yellow pyromorphite crystals to 1 cm in parallel growth, Rosenberg mine. Photo by Werner Lieber.**

MINERALS

The Ems district has long been famous for spectacular crystallizations of pyromorphite, but in recent years many other minerals have been found by intensive search on the Friedrichssegen dumps. The proliferation of excellent and moderately priced microscopes among collectors has resulted in many finds which otherwise would have gone unnoticed. Consequently a surprisingly large number of species (though not all of them spectacular) now comprise the Ems list.

Identifications for this study were made by X-ray diffraction and by chemical testing as well as by microprobe where necessary. The analyses were carried out by Werner Krause. Only the better crystallized species are described in the following section; a complete list of all species found in the Ems district is given in Table 1.

Argentite Ag_2S

Wenckenbach (1861) described this silver sulfide, formerly also known as *glaserz*, from the Friedrichssegen mine. It occurred on cerussite as a lead-gray to silver-gray covering.

Brochantite $Cu_4(SO_4)(OH)_6$

Brochantite occurs in 1-mm, tabular, emerald-green, single crystals. Occasionally, spherical aggregates are found.

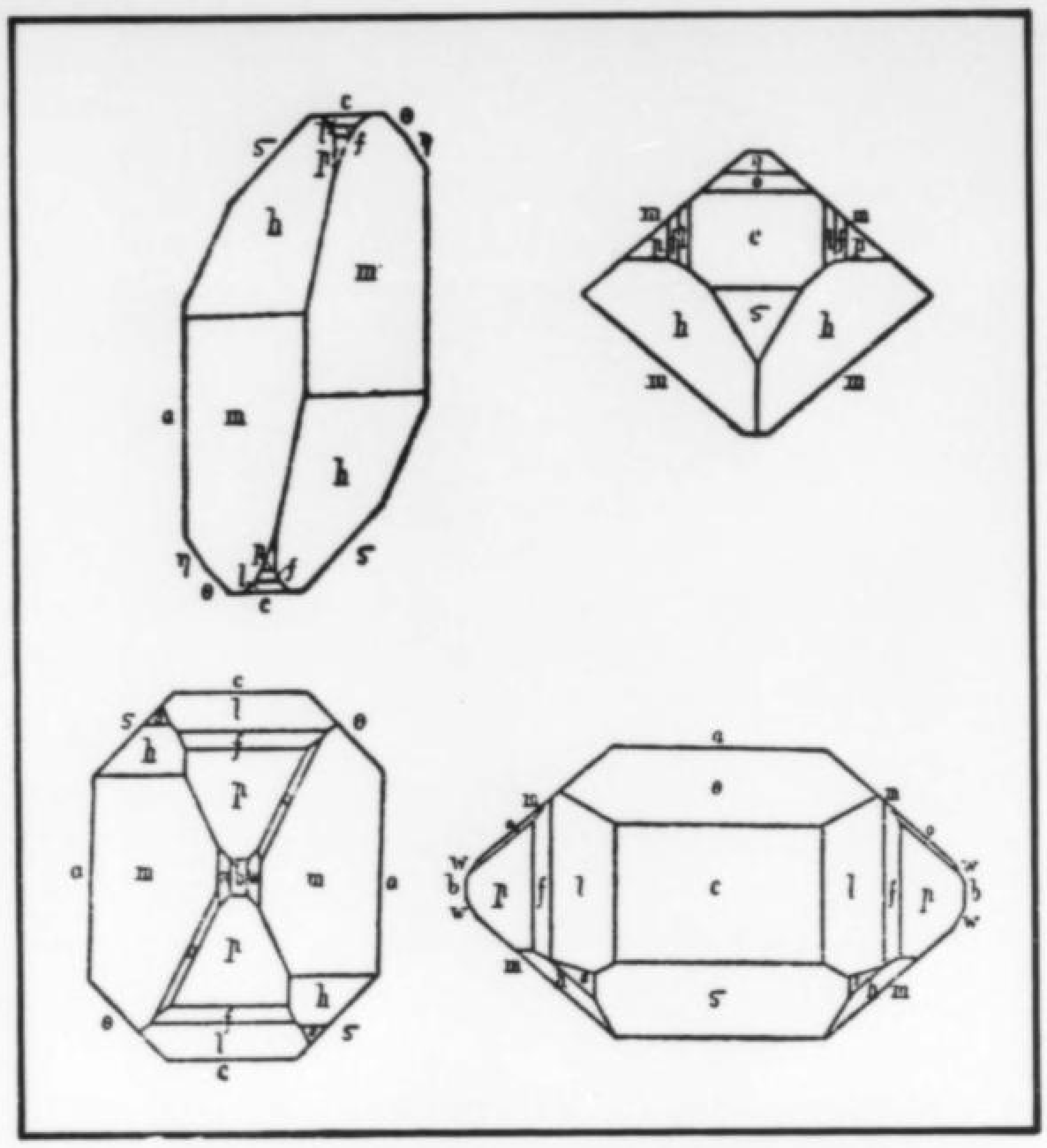


Figure 17. **Azurite crystals, Friedrichssegen mine (Goldschmidt, 1918).**

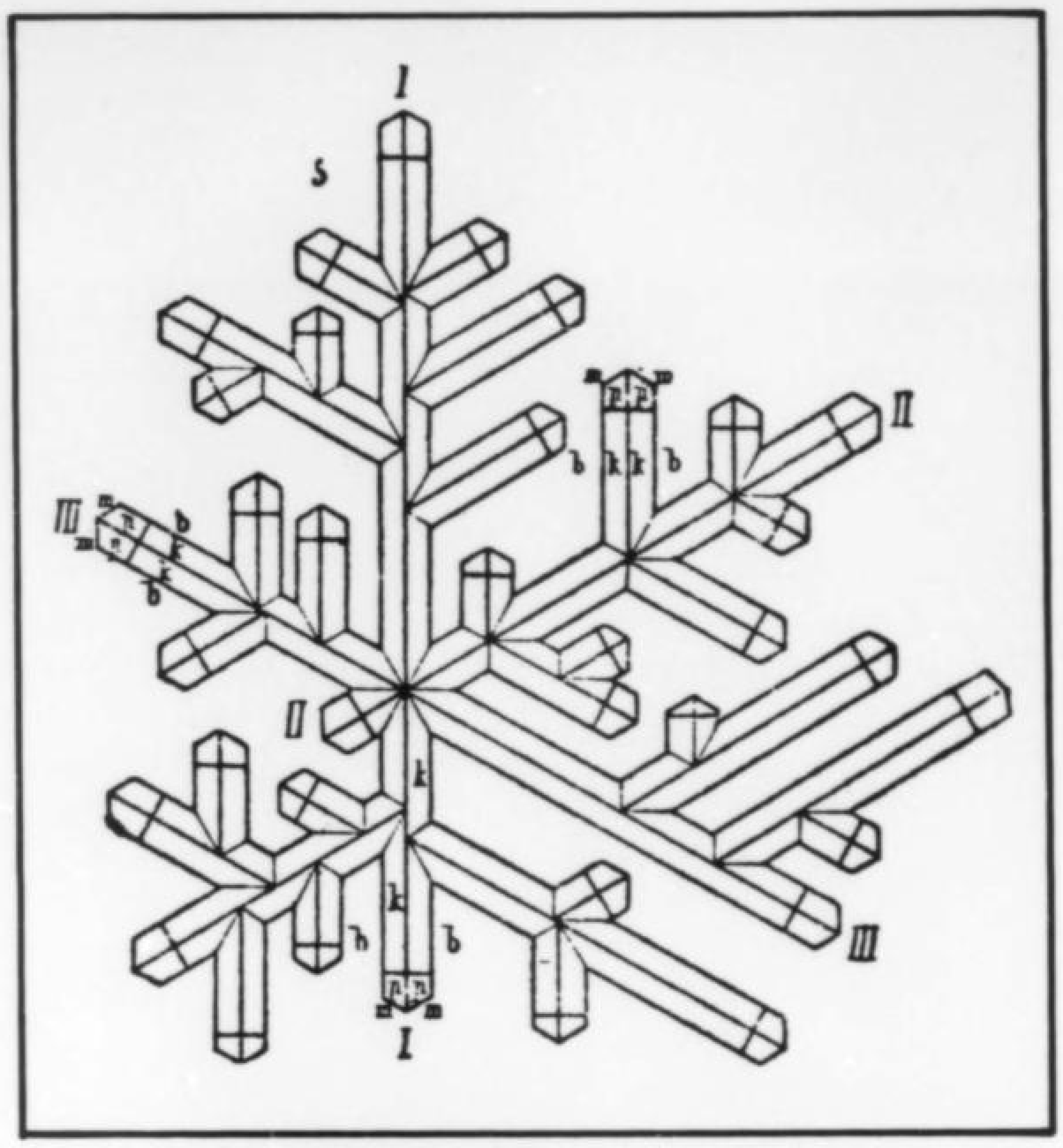


Figure 18. **Reticulated cerussite, Friedrichssegen mine (Goldschmidt, 1913).**

Bromargyrite Ag(Br,Cl)

Bromargyrite has not been noted from other German localities but, in the future, through intensive study by collectors, it probably will be.

Bromargyrite is found on the dumps as yellow to yellow-green wax-like crusts. Crystal surfaces cannot be identified. The soft and malleable nature of the mineral easily distinguishes it from iodargyrite (good cleavability). Bromargyrite is commonly accompanied by native silver.

Cerussite $PbCO_3$

Cerussite from the Ems district enjoyed considerable popularity among collectors particularly in earlier years before the arrival of cerussite from Tsumeb, Namibia. Finds from Friedrichssegen were spectacular.

Seligmann (1876) worked on cerussite extensively, mainly studying the crystallography. He actually considered cerussite to be more important than pyromorphite. The best cerussite was found at the time of the big resurgence in mining around 1870. Seligmann (1876) describes "completely transparent crystals up to 6 centimeters in size with beautifully lustrous faces, and larger ones robbed of their gloss by ocherous limonite." Furthermore, he reports "beautiful samples, sometimes weighing many pounds."

In the Friedrichssegen mine cerussite was formed by the effect of carbon dioxide-containing water on the lead-containing veins.

Cerussite as *weissbleierz* ("white-lead-ore") was so thick in places that it was mined as ore. Faces on crystals in the lower levels were highly glossy, while crystals in the upper levels often were dulled by limonite and appeared disintegrated.

Cerussite from the Friedrichssegen mine has a tabular habit and is predominantly twinned. Contact and penetration twins as well as triplets forming large crystals by further intergrowth have been observed.

The pseudomorphism involving cerussite should also be pointed out. While Bluhme (1867) speaks of pseudomorphs of barite after cerussite, Seligmann (1877) doubts this observations and presumes Bluhme's sample to be a pseudomorph of anglesite after cerussite;

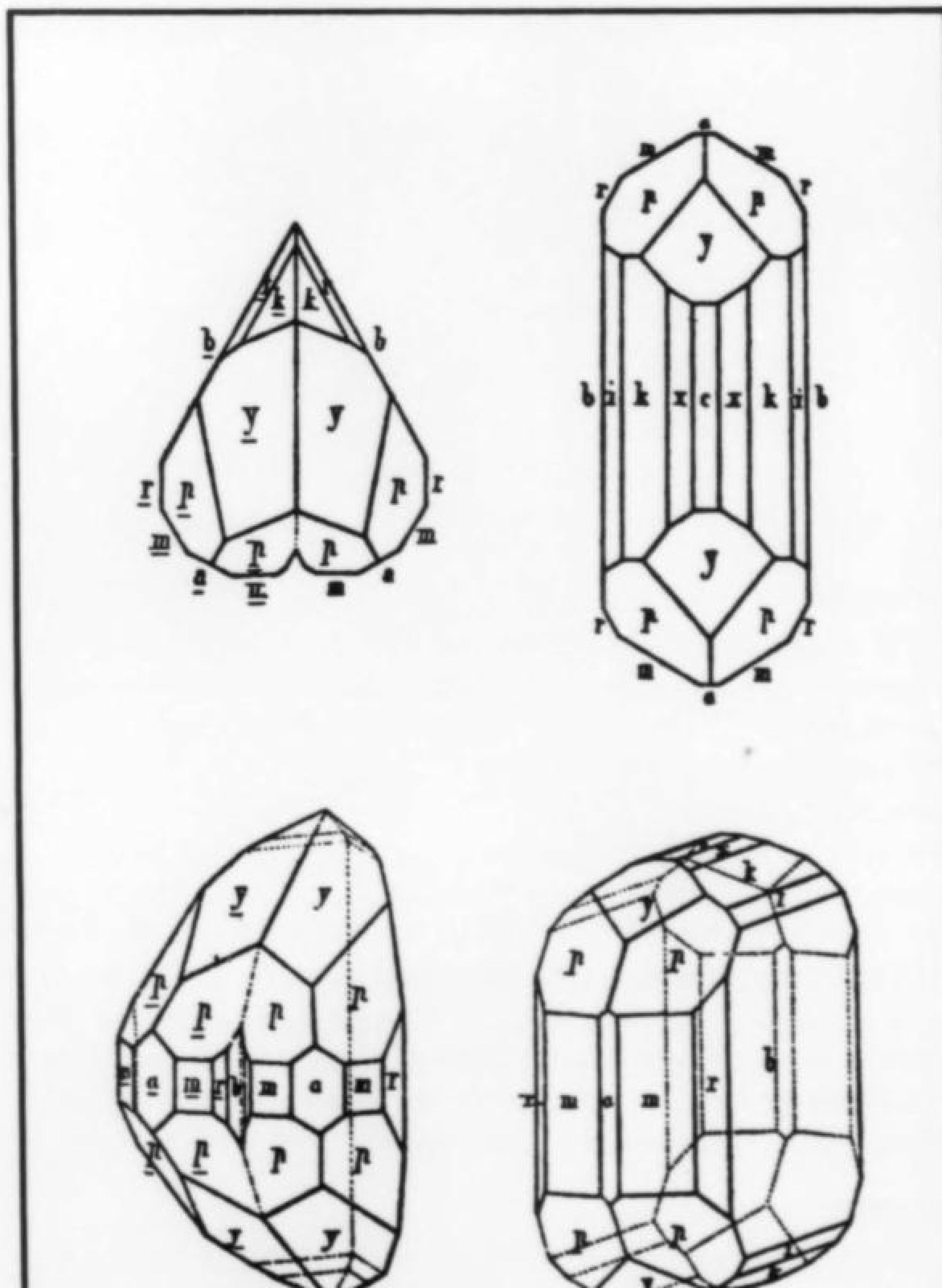


Figure 19. **Cerussite crystals, Friedrichssegen mine (Goldschmidt, 1913).**

this was because he himself had found some samples, but none leading to barite. He further mentions pseudomorphs of pyromorphite after cerussite.

The *Schwarzbleierz* ("black-lead-ore") variety also occurs at Bad Ems. This is cerussite impregnated by very small particles of black galena.

Cerussite occurring together with malachite and azurite (as described by Seligmann, 1877) has appeared repeatedly in the last few years.

Finally it should be noted that many cerussite specimens, especially those without matrix, look very much like specimens from Tsumeb.

Chalcopyrite $CuFeS_2$

While Seligmann (1876) described crystallized chalcopyrite from the Friedrichssegen mine as a rarity, it occurred frequently in the other mines. Very often it was accompanied by galena, but could also be found associated with quartz crystals. Display-quality specimens from these locations are not known.

Figure 20. **Copper crystal group 3 cm tall from the Bergmannstrost mine. Fricke collection; photo by R. Bode.**

Copper Cu

Known among collectors for its native copper is the Bergmannstrost mine. From here come copper aggregates in the form of arborescent intergrowths having a characteristic green oxide layer; many of these have been offered for sale recently at mineral shows.

This habit of copper is actually a recent crystallization formed when copper in solution in the mine water precipitates along rails laid for the ore cars.

Seligmann (1876) described the paragenesis of copper formed by the reduction of cuprite. Copper can be found in a variety of different habits; in addition to arborescent, moss-like aggregates, growths showing distinct crystals up to 5 mm exist.

Occasionally copper crystals sitting on cerussite have been found. Such crystals are not very distinctly formed. Additionally, massive copper was found in the veins in the form of thin scales and thicker plates.

Interesting also are crystals consisting of native copper on the outside, but carrying cuprite as the nucleus.

Seligmann (1876) describes finds made around 1875 on the fifth level consisting of "sponge-like masses" of native copper and apparently occurring in larger amounts. A distinguishing feature of the copper from the Bergmannstrost mine is the coarse, breccia-like quartz on which the copper rests.

Of lesser importance are the occurrences in the other mines, crystals up to 1 cm in size. Also worth noting is the galena referred to as *Bleischweiß*, a laminated and deformed variety known especially from the Mercur and Rosenberg mines.

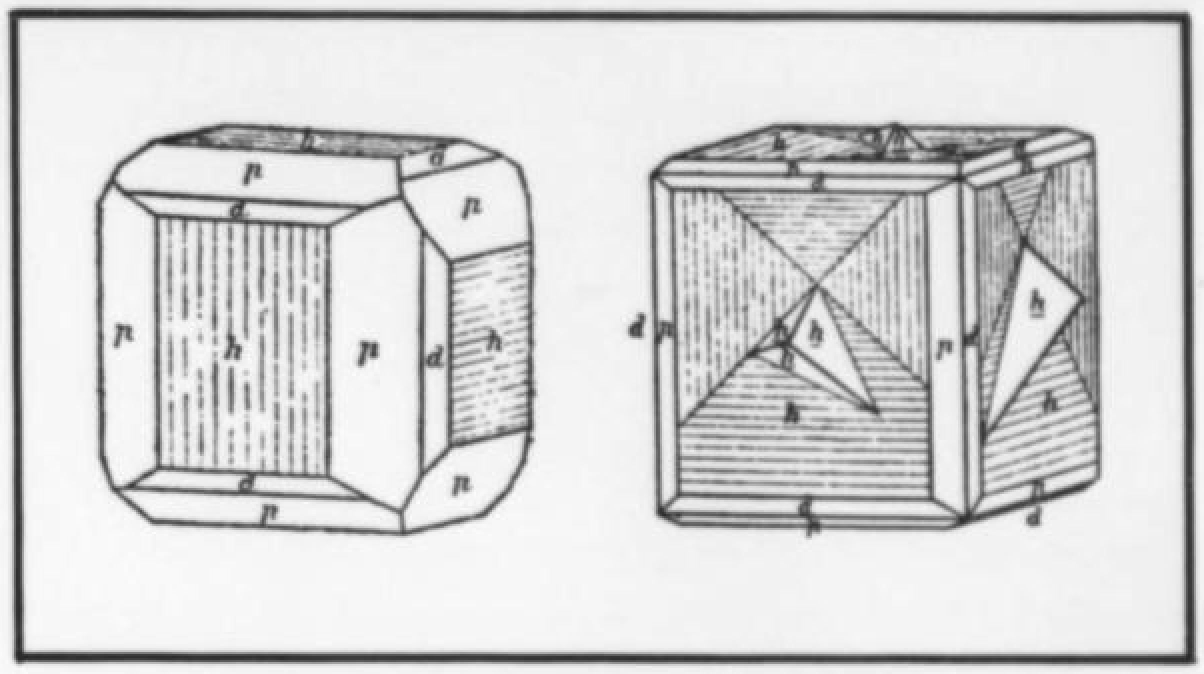


Figure 22. **Gersdorffite crystals, Friedrichssegen mine (Goldschmidt, 1918).**

Gersdorffite NiAsS

This nickel sulfide is among the rarities of the Ems district. While it can still be found today in very small amounts on the dumps, historical finds at the Friedrichssegen mine produced striated cubes to 3 mm in size, as well as massive material. Its occurrence in the Pfingstwiese mine is limited to interspersed particles in quartz, sometimes as distinct crystals.

An occurrence in the Fahnenberg vein has also been reported, where gersorffite mineralization in the form of a pocket 28 meters in length and 19 meters in height was found. The vein carried calcite as the matrix (Krümmer, 1912).

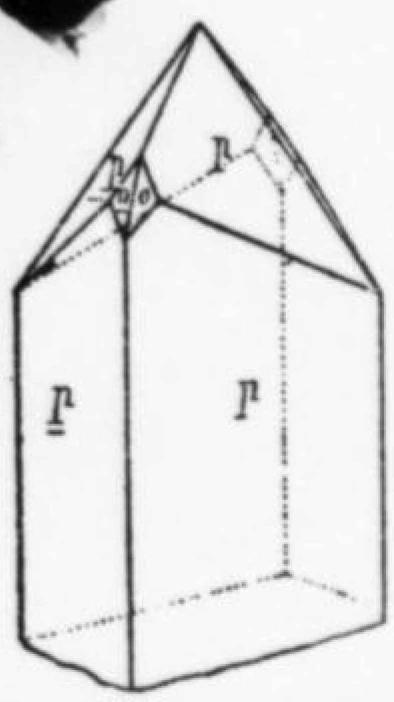


Figure 21. **Copper crystal, Friedrichssegen mine (Goldschmidt, 1918).**

Hinsdalite $(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$

Hinsdalite occurs in very small, colorless, rhombohedral crystals together with pyromorphite, linarite and kaolinite.

Hopeite $Zn_3(PO_4)_2 \cdot 4H_2O$

Hopeite in tabular, colorless crystals occurs partially intergrown as rosette-shaped aggregates.

Moschellandsbergite Ag_2Hg_3

This rare silver amalgam was found many years ago in the Friedrichssegen mine, fourth level. It occurred in quartz nests in the form of twisted, moss-like branching platelets and aggregates of dark gray color, sometimes embedded in cerussite crystals to several centimeters in size. The outside of the aggregates is covered with a

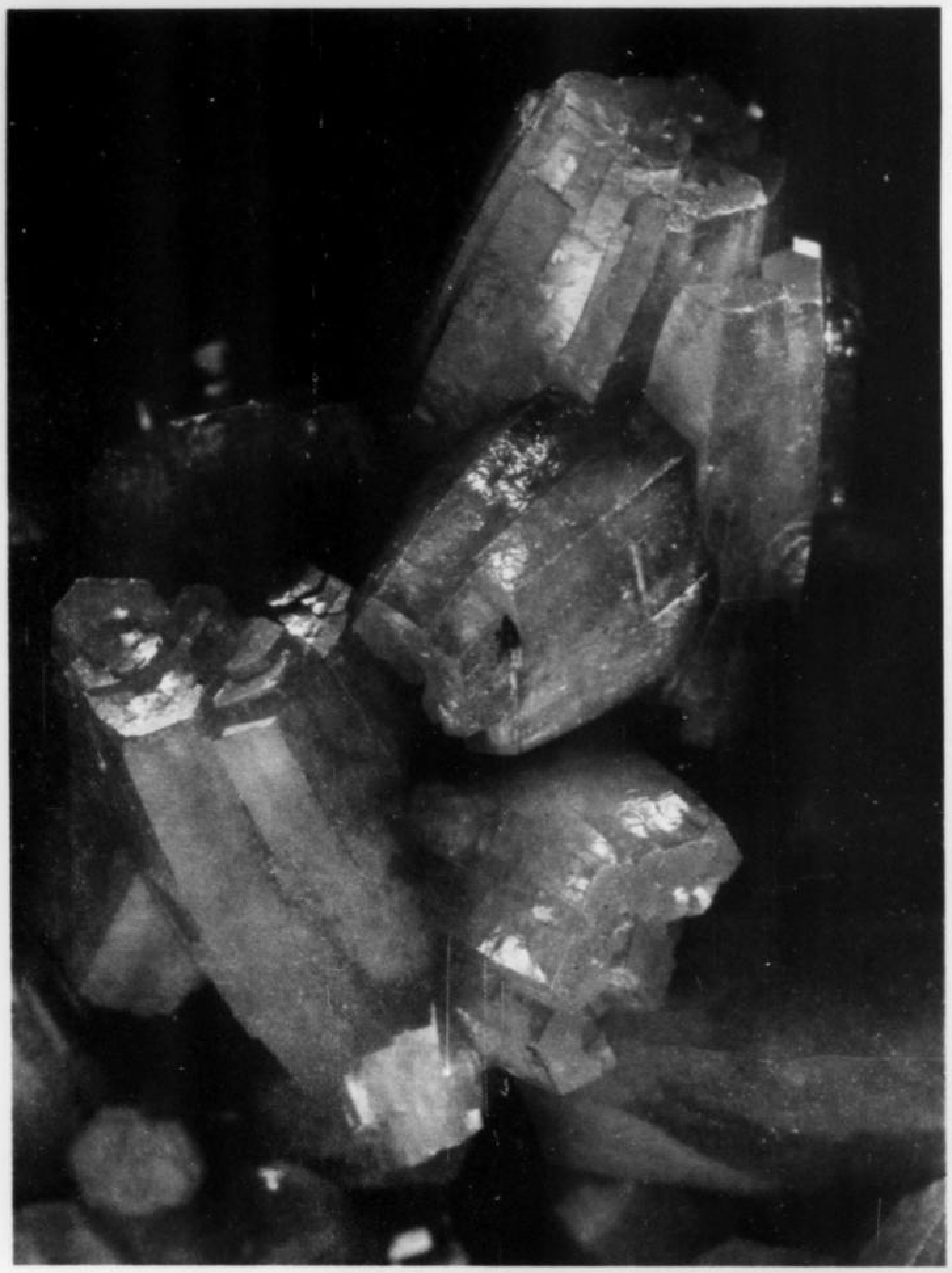


Figure 23. **Pyromorphite crystals to 1.5 cm from the Friedrichssegen mine. Photo by Werner Lieber.**

Figure 24. **Multiply-terminated pyromorphite crystal 1 cm tall, Friedrichssegen mine. S. Müller collection; photo by R. Bode.**

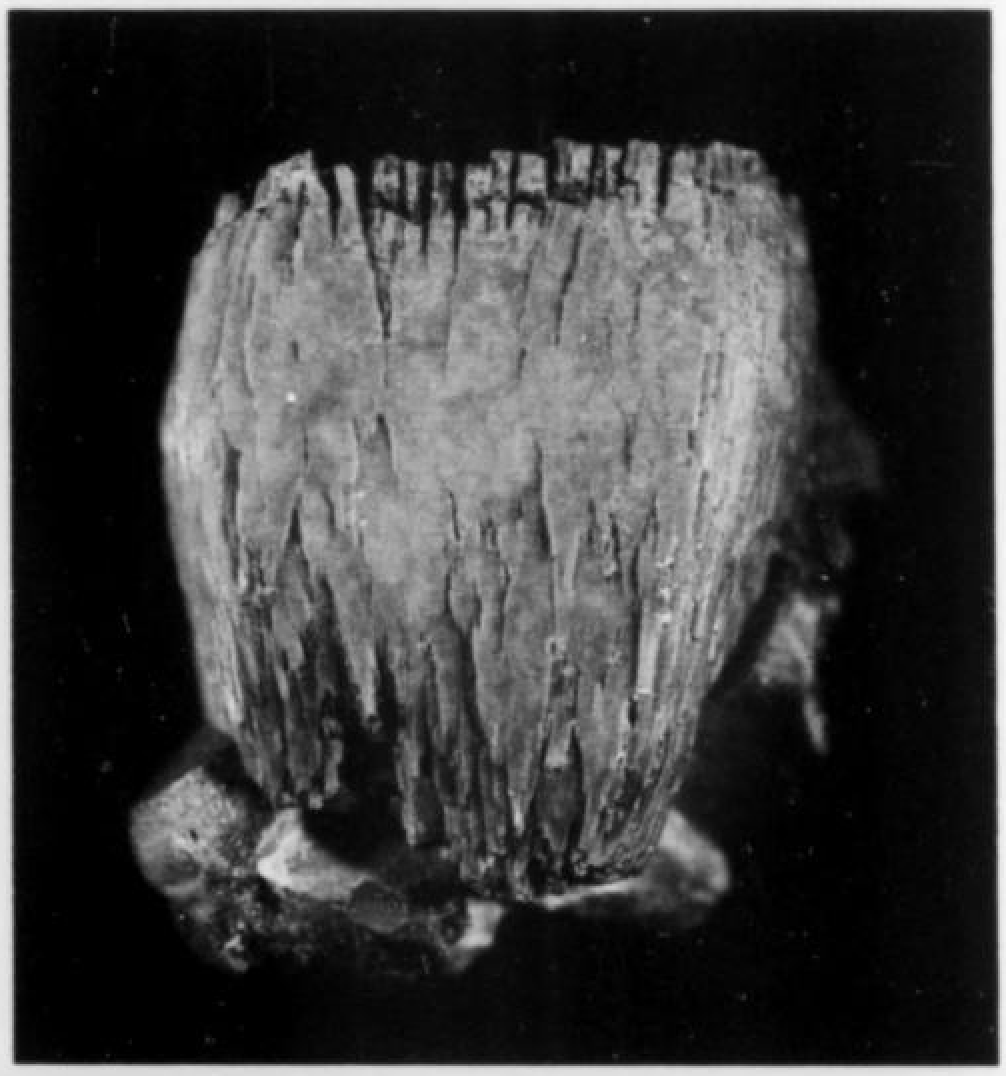


Figure 25. **Color-zone pyromorphite crystals to 1 cm, Rosenberg mine. Photo by Werner Lieber.**

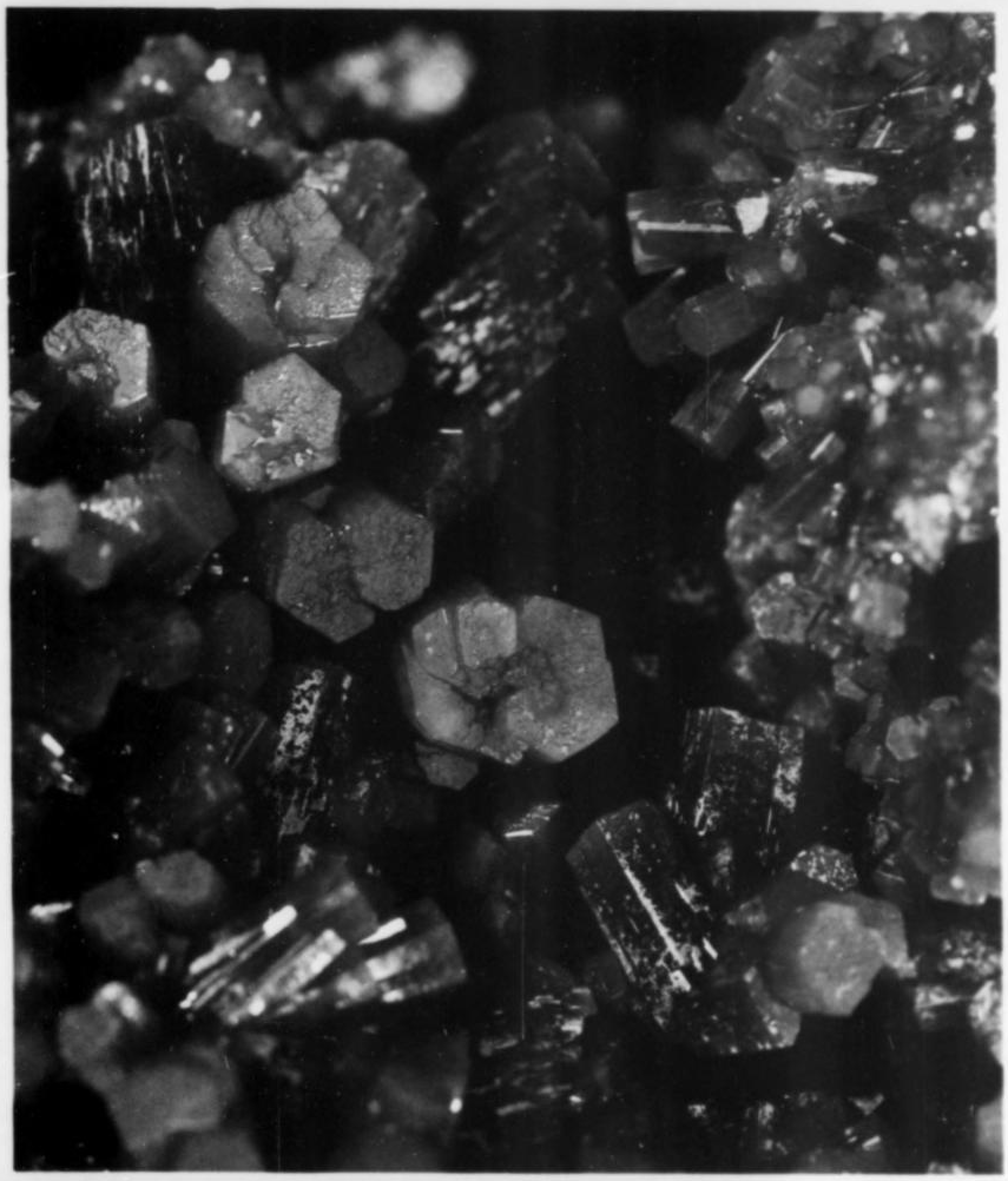
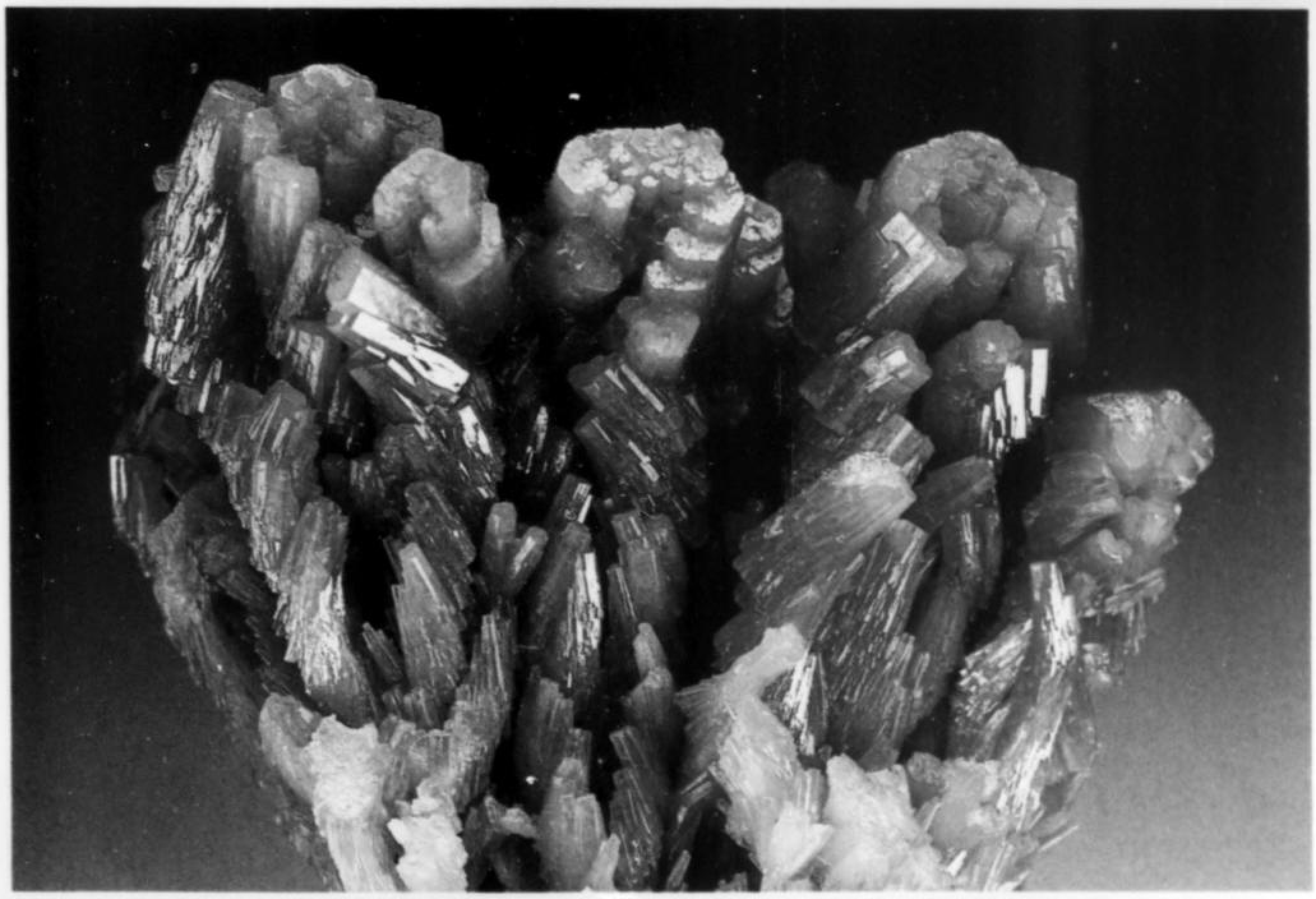


Figure 26. **Brownish red pyromorphite crystals to 2 cm, Ems district (probably Friedrichssegen mine). Sorbonne collection; photo by Nelly Bariand.**

Figure 27. **Pale brown pyromorphite crystal group 5.8 cm across, probably from the Rosenberg mine. Wayne and Dona Leicht collection; photo by Wendell Wilson.**



thin copper-colored layer; the inside, though, has a silvery white, shiny, metallic appearance.

The occurrence of native gold on the dump of the Friedrichssegen mine was first mentioned by Bode (1979) as recognizable only under the microscope. More of the same material was later recovered. Horst Knop, a collector from Koblenz, was able to study some of these samples under the electron microprobe at the University of Gent, Belgium. His study was limited to testing for the existence of various elements. Surprisingly, in all three samples which appeared visually to contain gold, no gold could be found. The samples actually proved to contain a combination of silver and mercury, and thus are probably related to moschellandsbergite. Therefore, the occurrence of native gold at the Friedrichssegen mine is questionable.

Namuwite $(Zn,Cu)_4(SO_4)(OH)_6 \cdot 4H_2O$

Namuwite was first described in 1981 by Bevins *et al.* It was discovered in an old collection sample from the National Museum of Wales, found in the Aberllyn mine near Gwynned in North Wales.

The find on the dump of the Friedrichssegen mine is the first occurrence of namuwite in Germany. Here, namuwite occurs in very small, tabular, pale green crystals of hexagonal form. It is commonly associated with serpierite.

Plumbogummite $PbAl_3(PO_4)_2(OH)_5 \cdot H_2O$

Plumbogummite is supposed to bear a resemblance to pyromorphite, but is covered with "warts," according to Sandberger (1884). It occurred in "light brown, faintly translucent crusts, with countless crystals shimmering in the sunlight," says Sandberger.

Pyrite and Marcasite FeS_2

Though very common as massive material, pyrite and marcasite occur only rarely as good crystals in the Ems district. Mahr (1912) described pyrite crystals not exceeding 2 mm, with marcasite often in association. He also described radiating sheaves of pyrite associated with quartz from the Friedrichssegen mine.

Pyromorphite $Pb_5(PO_4)_3Cl$

In 1979, on the occasion of the mineral show in Bad Ems, the first issue of *Emser Heft* appeared. Pyromorphite from Bad Ems had been one of the German minerals most in demand for a long time. And yet it could not be bought or traded for. No pyromorphite from Ems was on the market.

Certainly, this situation has changed today. It can be said without doubt that no other mineral has seen such a renaissance as the *Emser Tönnchen* ("Ems barrels"). Five years ago it was virtually impossible to obtain green pyromorphite from Ems, but today it is much easier (but not inexpensive, to be sure) to acquire. Praise is due to the dealers who, with perseverence, were able to locate Ems pyromorphite specimens and thus were able to supply the collector. Many specimens were at first repatriated to Germany from the U.S., where Friedrichssegen pyromorphite was temporarily undervalued. Yet today the situation is again reversed and higher prices are paid in the U.S. than in Europe.

No other locality in Germany has yielded pyromorphite in such large crystals and such a variety of colors, ranging from water-clear and colorless to yellow, green, brown and almost black. Whereas in the Friedrichssegen mine mainly the brown types were found, and the smaller, green crystals appeared only rarely, the opposite was true in the northern mines.

Of all the mines in the Ems district, Friedrichssegen is the best known. The most spectacular find on record came from here in 1867; a huge pocket was opened up on the third level. Seligmann (1867) reported that:

> It was 10 meters long, approximately, had the same height, and a width of 2 meters. Its surfaces were covered with brown pyromorphite to a thickness of a third of a meter and showed a dense grouping of many crystals. Beautiful deposits, some of them weighing more than a hundredweight, are still contained in Friedrichssegen and bear witness to the magnificence of this find. Large amounts of these have come into circulation through the Krantz'sche Mineraliencomptoir. Obviously, the pocket must be viewed as a cavity which developed by surface waters dissolving the matter originally deposited, probably siderite, remnants of which can still be found. Later the brown pyromorphite created peculiarly shaped stalactites. These are hollow tubes of rough pyromorphite, covered all around with crystals of the same material, hanging from the ceiling and falling off after the waters filling the pocket had drained.

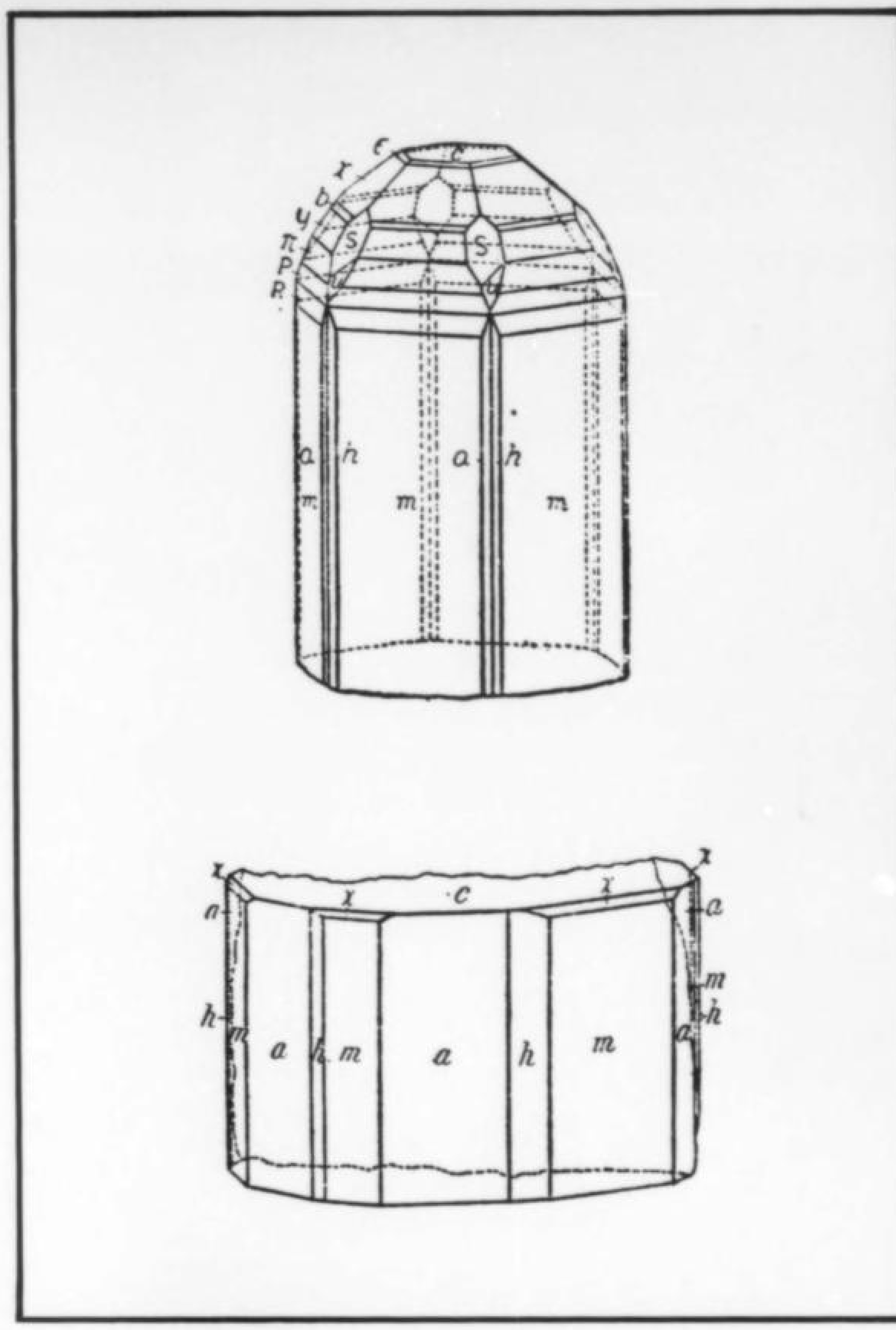


Figure 28. **Pyromorphite crystals, Friedrichssegen mine (Goldschmidt, 1922).**

Dark-brown crystals showing a white zonal structure near the terminations are typical of the Friedrichssegen mine. The green *Tönnchen* ("barrels") from the Bergmannstrost mine, also showing light caps (zonal structure) on the terminations, must be considered a rarity. The best green crystals, much in demand, come mainly from the neighboring Pfingstwiese, Mercur and Rosenberg mines. Whereas barrel-shaped crystals with smooth surfaces came from Pfingstwiese and Mercur mines, the Rosenberg mine produced acicular, parallel intergrowths. Cauliflower-shaped crystals, formed in the cavities of the disintegrated quartz, are also found at Rosenberg. Specimens of this habit are relatively common in collections.

Only rarely is pyromorphite found in association with other minerals. The matrix consists mainly of disintegrated limonite or

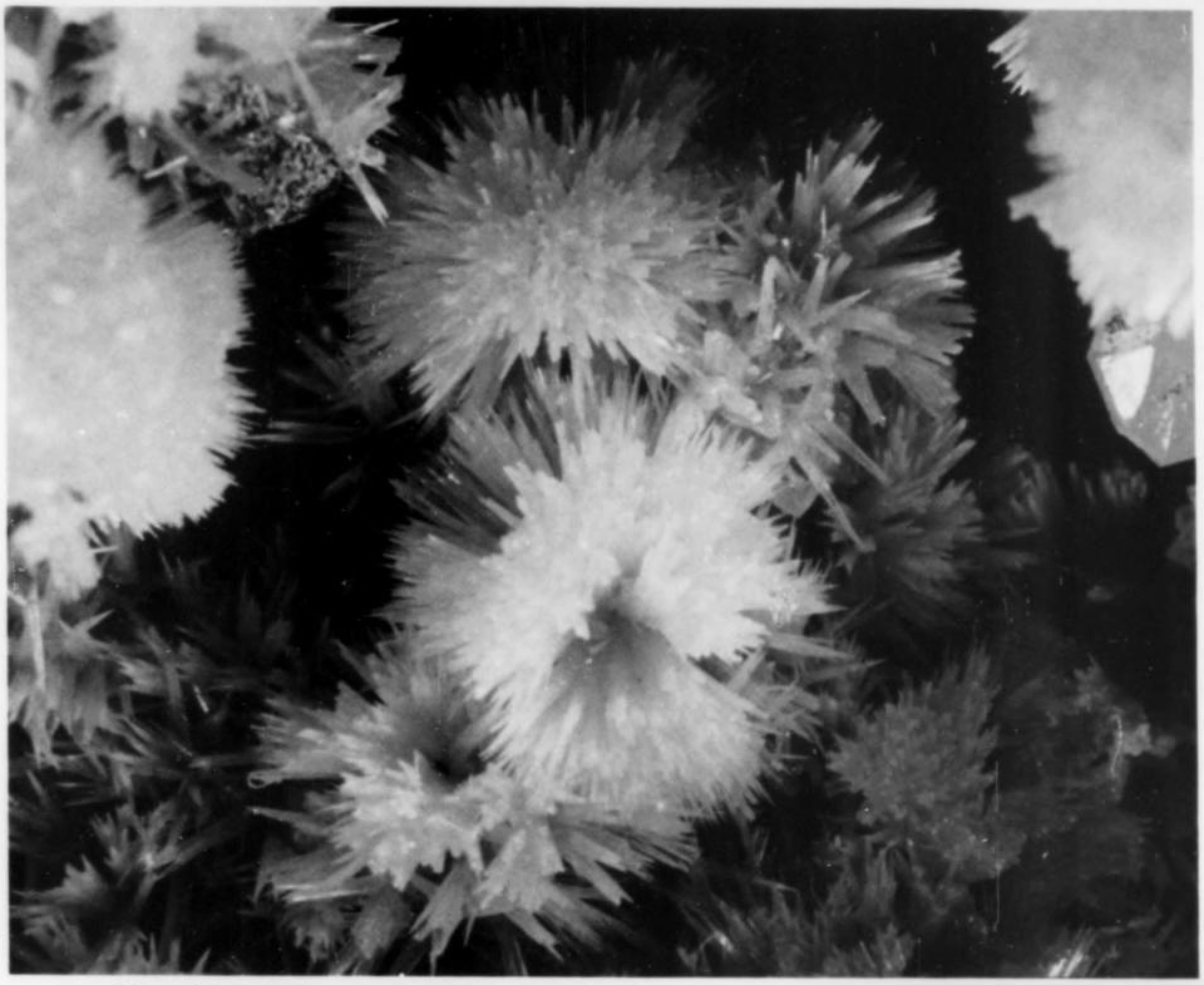


Figure 29. **Acicular pyromorphite crystals to 5 mm, Königstiel tunnel, Rosenberg mine. Estrov collection; photo by R. Bode.**

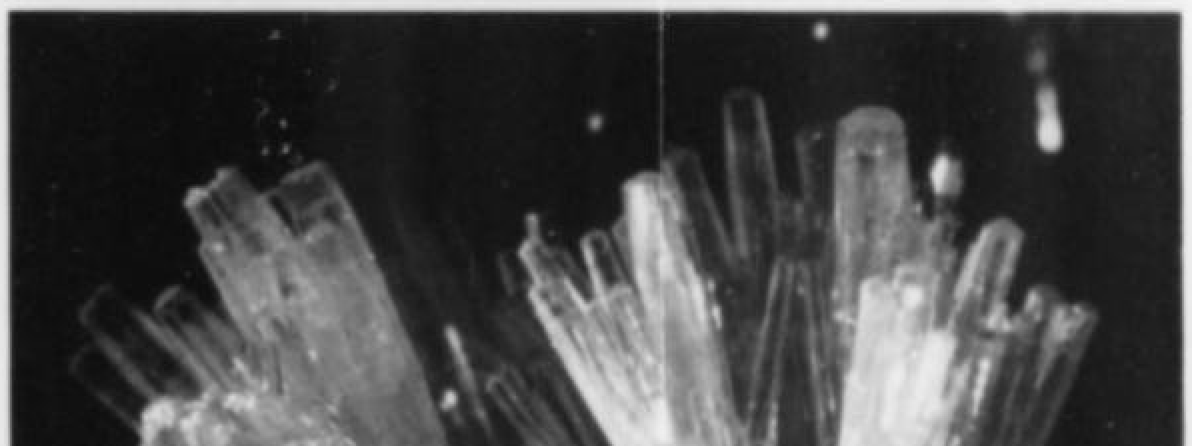


Figure 30. **Colorless, transparent pyromorphite crystals to 1.5 cm, Rosenberg mine. The crystals fluoresce under longwave ultraviolet light. Photo by Werner Lieber.**

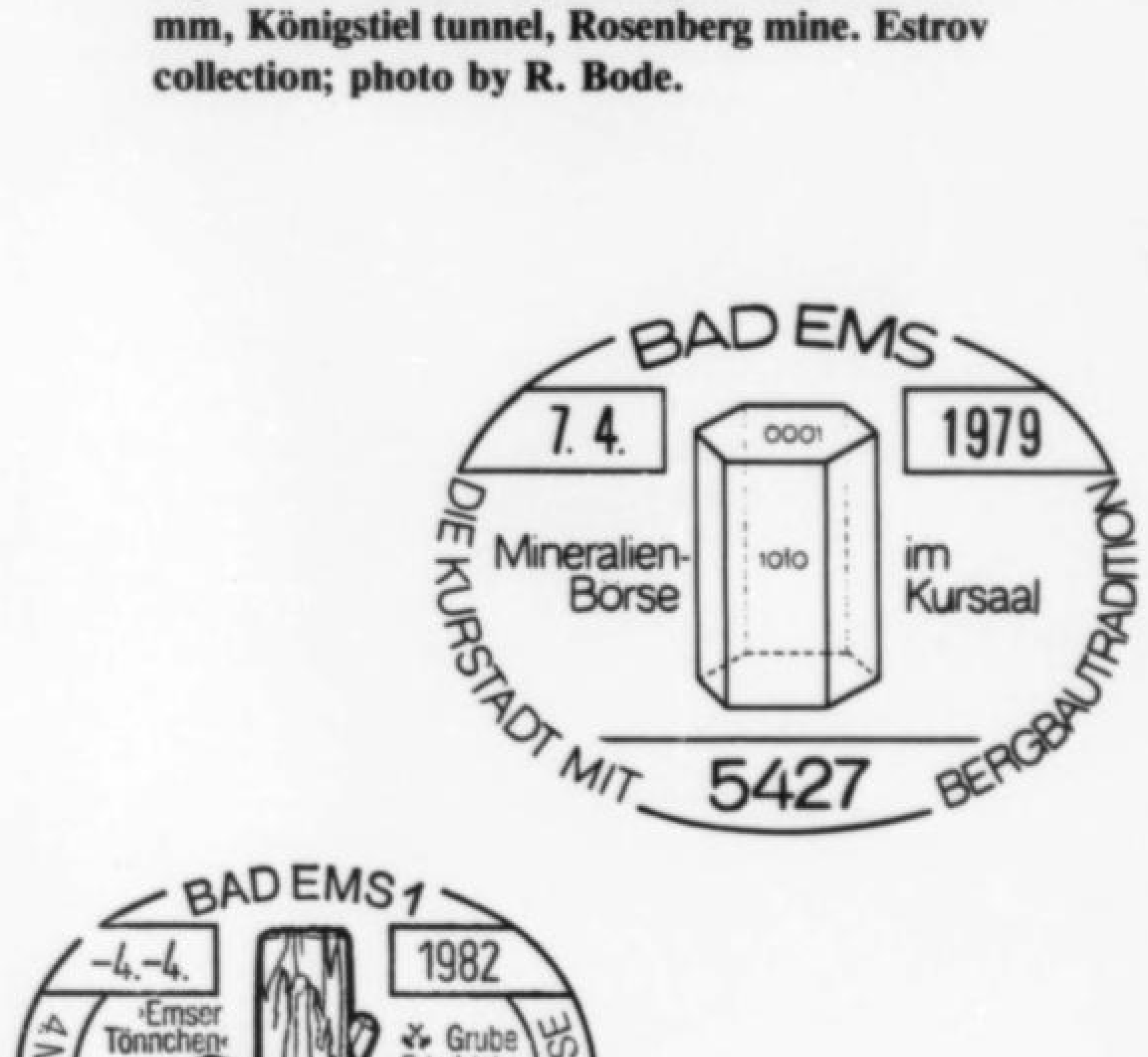
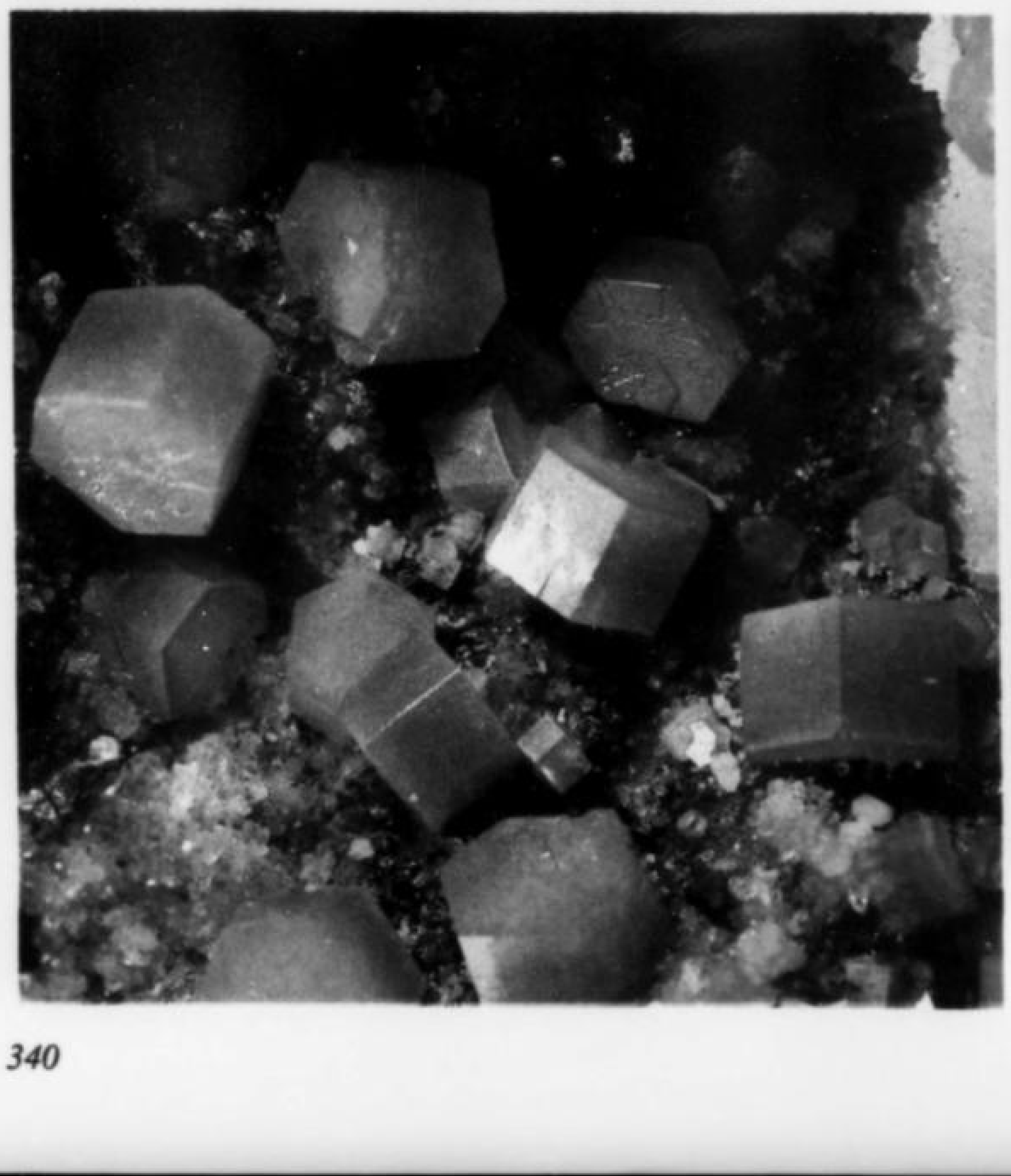


Figure 31. **Postmarks prepared especially for the mineral show in Bad Ems in 1979, 1982 and 1983.**

Figure 32. Brown pyromorphite crystals to 1.5 cm, Friedrichssegen mine. Olaf Medenbach collection and photo.

Figure 33. Pale colored pyromorphite crystals to 3 mm from the Rosenberg mine. G. Schweisfurth collection; photo by R. Bode.



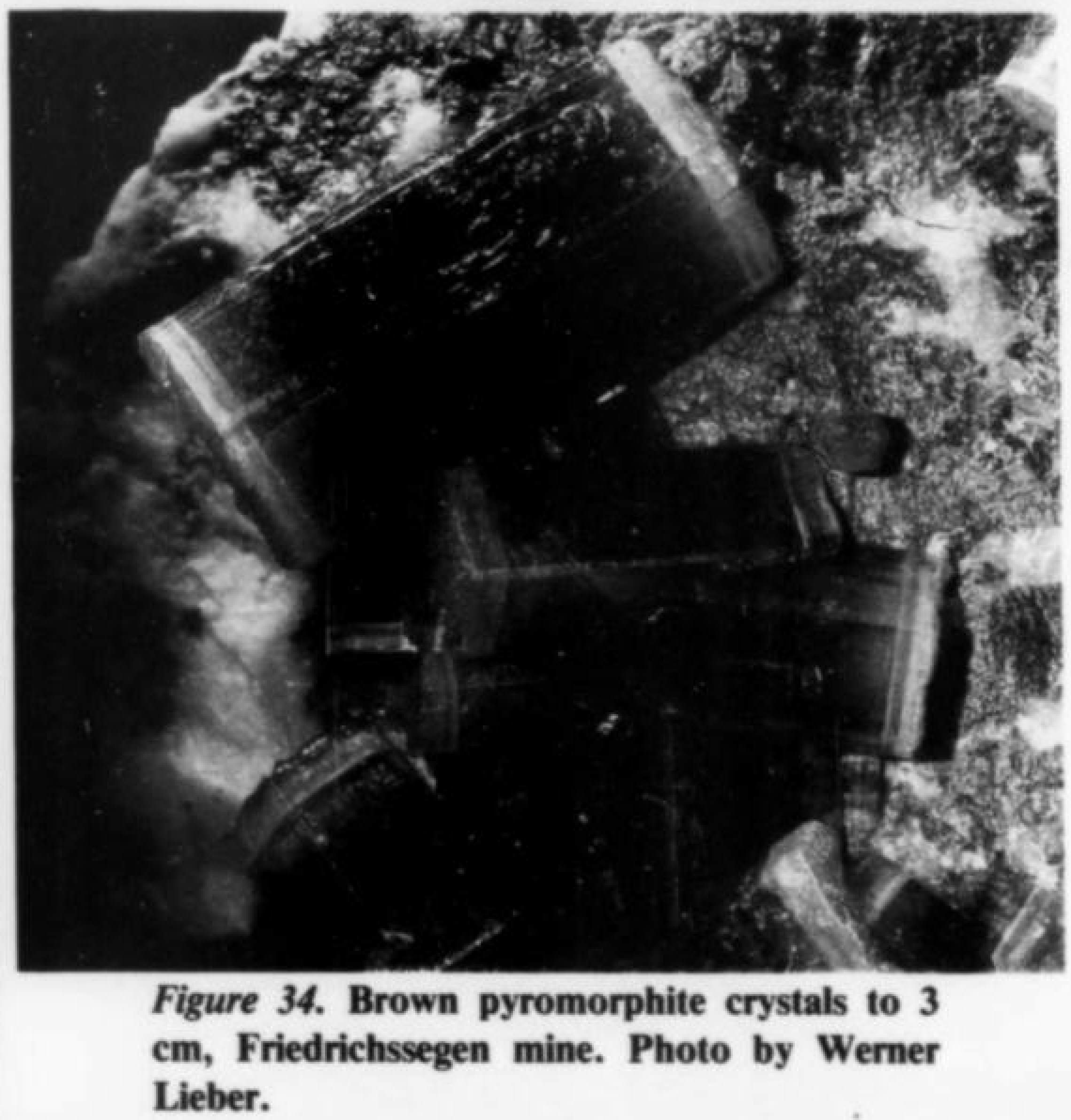


Figure 34. Brown pyromorphite crystals to 3 cm, Friedrichssegen mine. Photo by Werner Lieber.

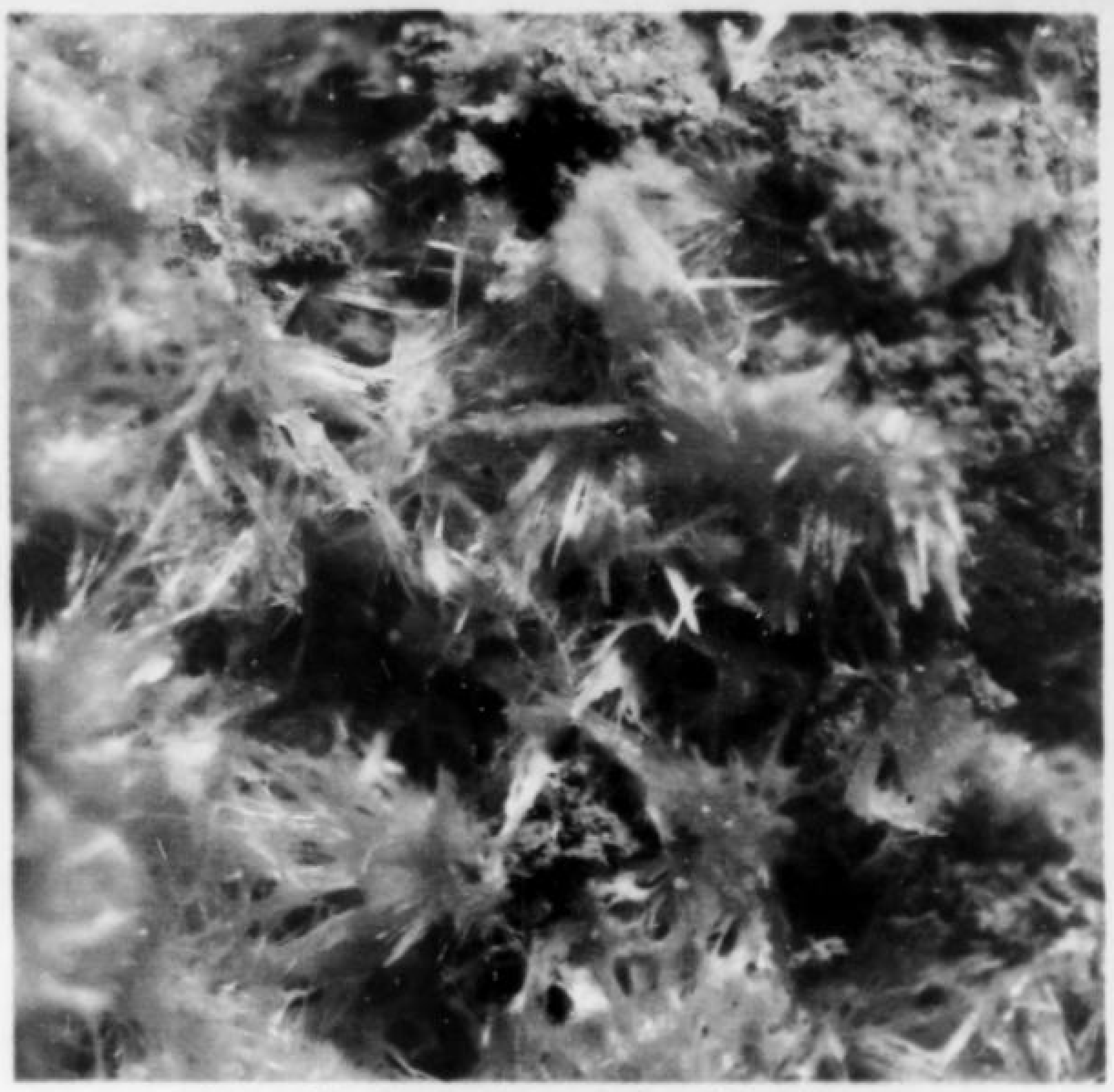


Figure 35. **Serpierite crystals, Friedrichssegen mine dump. The view is 3 mm across. Ternes collection; photo by R. Bode.**

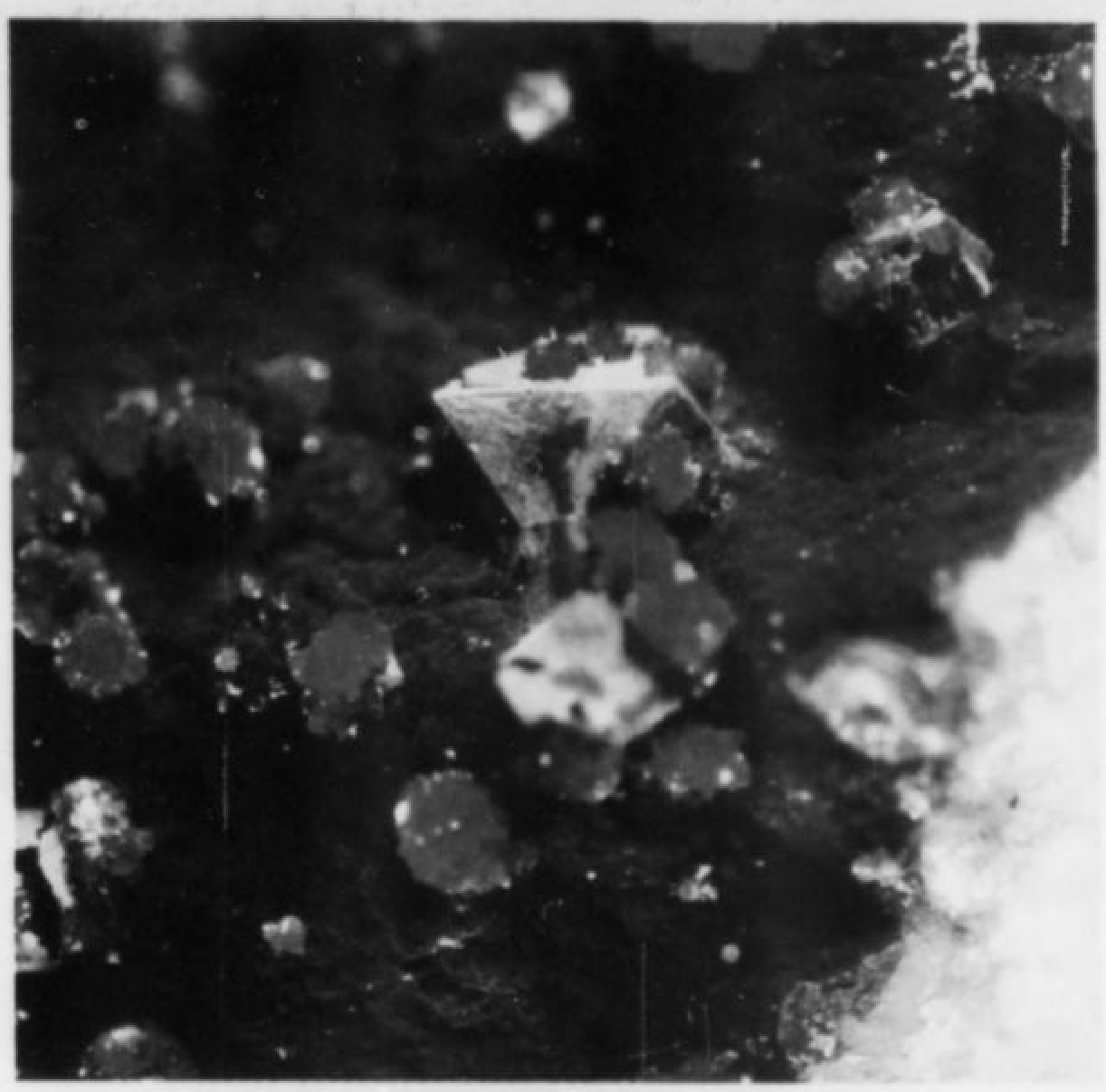


Figure 36. **Brilliant green tufts of brochantite less than 1 mm in size, with altered cuprite octahedrons, from the dump of the Friedrichssegen mine. Ternes collection; photo by R. Bode.**

Figure 37. **Twinned sphalerite crystal 8 mm across, Rosenberg mine. R. Bode collection and photo.**

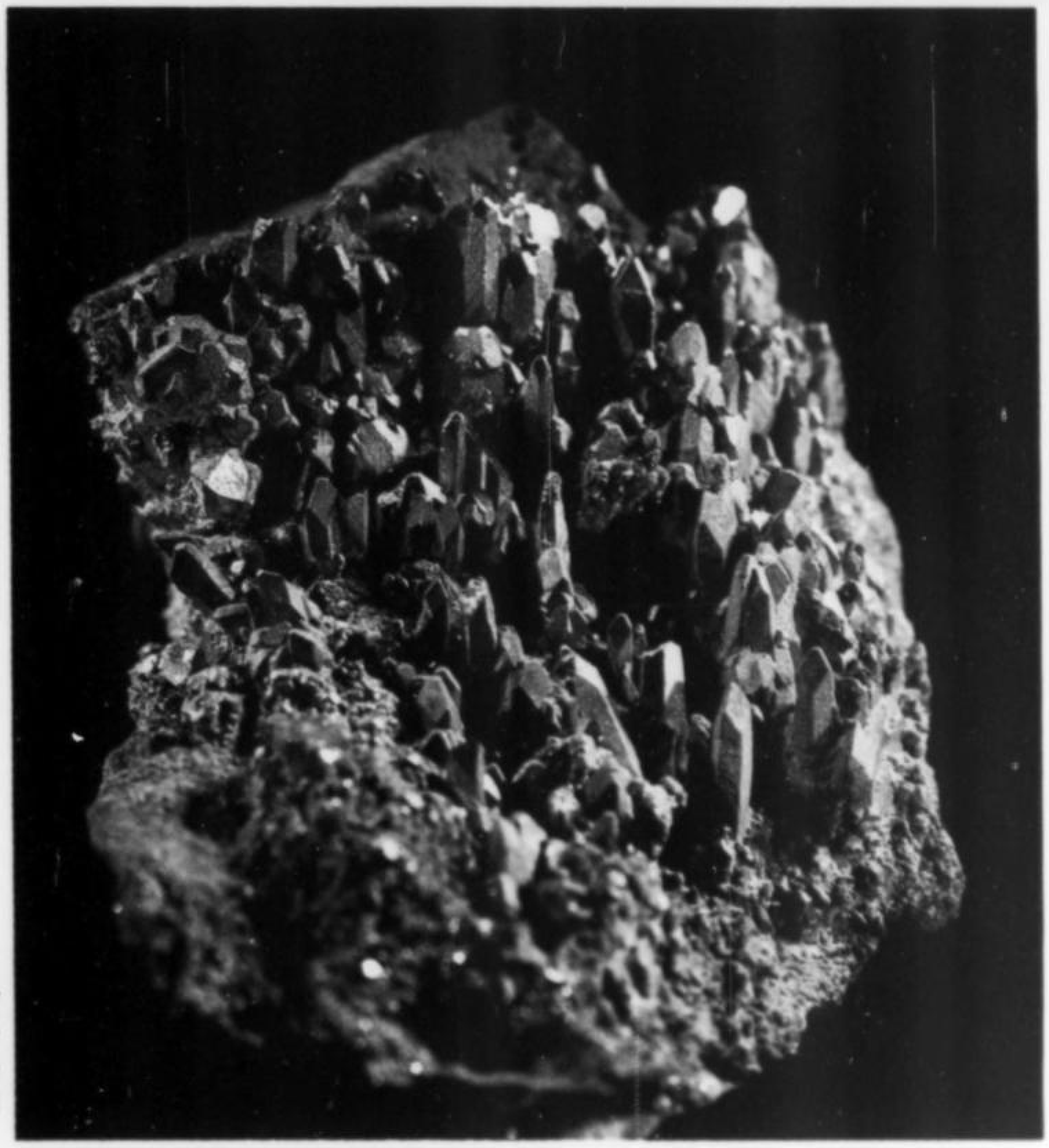


Figure 38. **Galena pseudomorphs after scalenohedral calcite crystals, with sphalerite and chalcopyrite, Friedrichssegen mine. The specimen is 5 x 6 cm. R. Bode collection and photo.**

quartz, rarely massive galena. At the Rosenberg mine pyromorphite bundles growing on small quartz crystals have been found. In some cases cerussite forms the matrix for pyromorphite crystals.

Today pyromorphite specimens can still be found on the dump of the Friedrichssegen mine. The quality cannot be compared to that of historical finds, of course.

Schulenbergite $(Cu,Zn)_7(SO_4,CO_3)_2(OH)_{10}\cdot 3H_2O$

The dump of the Friedrichssegen mine is the sixth location in Germany for schulenbergite. This mineral, described for the first

Table 1. **Minerals of the Ems district.**

Species	Habit or reference	Location
ELEMENTS		
Copper	Arborescent, to 15 cm; rarely crystals to 5 mm, typically covered with green alteration layer	Friedrichssegen, Bergmannstrost
Silver	Small mossy and arborescent aggregates, rare	Friedrichssegen (also dump)
Moschellandsbergite	Dark-gray, mossy and rope-like aggregates, inside pure white	Friedrichssegen (also dump)
Sulfur*	Small, dirty-light-yellow, multi-faced crystals, rounded edges; in cavities in galena	dump
SULFIDES		
Chalcocite	"Large amounts" (Krümmer, 1912)	Friedrichssegen
Argentite	Lead-gray to silver-gray, covering on cerussite	Friedrichssegen
Sphalerite	Light yellow, ruby-red, almost black; crystals to 1 cm, associated with galena	in all veins
Chalcopyrite	Rarely crystallized	in all veins
Tetrahedrite-Tennantite	(Krümmer, 1912)	Friedrichssegen
Galena	Crystals to 4 cm; dull as well as highly lustrous surfaces; associated with sphalerite, quartz	in all veins
Cinnabar	Red, powdery sprinklings; in small druses	dump
Millerite	(Anonymous, 1893)	Friedrichssegen
Linnaeite	(Anonymous, 1893)	Friedrichssegen
Covellite	(Krümmer, 1912)	Friedrichssegen
Pyrite	Crystals rare, to 2 mm	Friedrichssegen
Gersdorffite	Rarely cubic crystals to 3 mm; commonly massive	Friedrichssegen Mercur
Marcasite	Similar to pyrite	
Bournonite	(Anonymous, 1893)	Friedrichssegen
HALIDES		
Bromargyrite	Wax-like crusts, yellow to yellow-green, soft	dump
OXIDES		
Cuprite	Octahedrons to 3 mm; similar to native copper; massive on dumps	Friedrichssegen (also dump)
Tenorite	Black, powdery sprinklings	dump
Hematite	(Krümmer, 1912)	upper zone in Friedrichssegen
Quartz	Short-columned crystals, 2 cm maximum, water-clear, milky	in all veins
Pyrolusite Manganite Lepidocrocite Goethite Psilomelane	According to Krümmer (1912) in the upper oxidation zone	Friedrichssegen
Coronadite*	Acicular black crystals in limonite	dump
Limonite	Loose, earthy masses	Friedrichssegen
Gibbsite*	White to pale green masses	dump
CARBONATES		
Calcite	Rare crystals	
Siderite	(Krümmer, 1912)	
Dolomite	(Krümmer, 1912)	
Ankerite	(Krümmer, 1912)	
Cerussite	Very good, many-faced, tabular crystals to 6 cm	Friedrichssegen (also dump)
Azurite	Small crystals associated with malachite and cerussite	Friedrichssegen, Rosenberg
Malachite	Like azurite	
Dundasite*	Millimeter-sized, white radiating needles associated with cerussite	dump
SULFATES		
Anglesite	(Bluhme, 1867)	Mercur
Brochantite*	Emerald-green, millimeter-size crystals	dump
Linarite	Blue, very small crystals	dump
Hinsdalite*	Millimeter-sized, colorless, rhombohedral crystals associated with pyromorphite	dump
Morenosite	Thin crusts on gersdorffite	Mercur, dump
Gypsum	Colorless needles	dump
Langite		dump
Posnjakite		dump
Devilline*	Green to blue-green tabular crystals; also thin, radiating needles	dump
Serpierite	Long, tabular; blue; also radiating, matted aggregates	dump
Schulenbergite	Tabular, thin, often rosette-shaped crystals; pale blue-green	dump
Namuwite	Small, tabular crystals; pale green	dump
PHOSPHATES, ARSENATES		
Plumbogummite	Light brown, translucent crusts	Friedrichssegen
Pyromorphite	Barrel-shaped; fine needles; single crystals to 3 cm; colorless, brown, green	all mines
Hopeite*	Colorless, thin, tabular crystals; also rosettes	dump
SILICATES		
Hemimorphite	Grape-shaped aggregates (Krümmer, 1912)	Friedrichssegen
Kaolinite	Fine-grained masses, colorless to light blue; soft	dump

*First description for the locality.

time when it was found on the dump of the Glücksrad mine, Oberschulenberg Harz, in 1982, occurs in small, tabular, often rosette-shaped, pale green-blue crystals. Sometimes hexagonal forms can be found.

Serpierite $Ca(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$

Serpierite is found as long, tabular blue crystals. Sometimes the needle-like crystals are matted into radiating aggregates. Serpierite is more common than devilline.

Silver Ag

Native silver from the Ems district is one of the great rarities. It occurred very rarely and in very small amounts. Similar to the copper finds is a sample from the Friedrichssegen mine in which native silver, sitting on cerussite, is formed as mossy to arborescent aggregates. On limonite a second habit can be found: small, thin platelets showing a pseudo-hexagonal habit (Seligmann, 1876). In one instance Seligmann also observed native silver accompanied by pyromorphite. Lately some fortunate discoveries of native silver in the form of wire-like rolls were made on the Friedrichssegen dump.

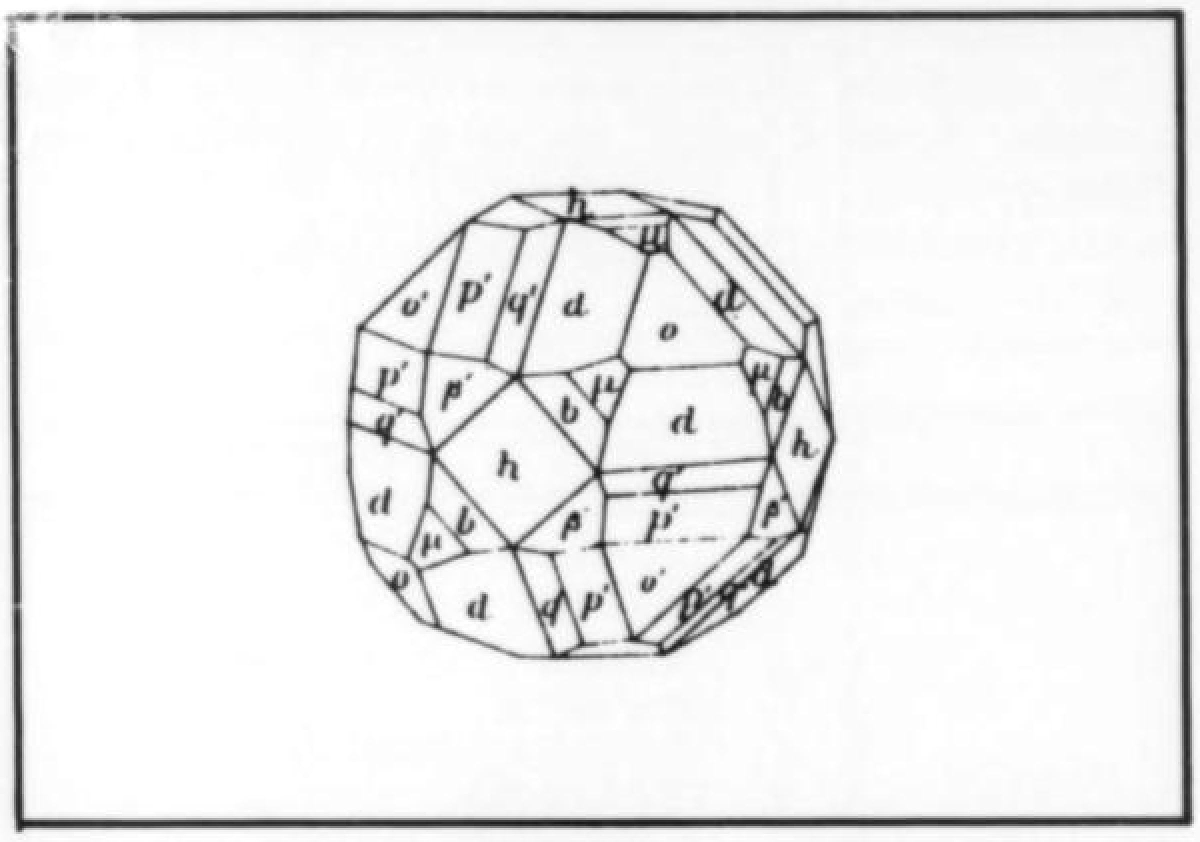


Figure 39. **Sphalerite crystal, Friedrichssegen mine (Sadebeck, 1876).**

Sphalerite (Zn,Fe)S

Occurrences of sphalerite at Bad Ems were minor. Specimens in collections today show sphalerite almost always accompanied by galena. These pieces came mainly from the Mercur and Bergmannstrost mines. In the past, dark-brown, almost black crystals high in iron were found at the Friedrichssegen mine. In the Neuhoffnung mine crystals of pale yellow, ruby-red, and almost black color have been found. The red crystals from "Oberlahnstein" described by Hintze (1912) probably came from the Friedrichssegen mine.

Sulfur S

Sulfur is described here for the first time from the Ems district. Discoveries of sulfur have been made within the last few years in the dumps of the Friedrichssegen mine. Sulfur is found in cavities in galena in the form of pale yellow, many-faced crystals with mostly rounded edges.

ACKNOWLEDGMENTS

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Figure 40. **Design for a Bad Ems commemorative medal.**

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Vanadinite

from touissit, morocco, and comments on Endlichite

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INTRODUCTION

The superb groups of very large crystals of "pyromorphite" which began to appear around 1979 from the Touissit mine, near Oujda, Morocco, are in fact vanadinite. Crystals on these specimens are characterized by their remarkable size (commonly 2 to 3 cm in length), and beauty. Their cream to almost silvery beige surface color, near adamantine luster, and striking zoning set these specimens apart from all others. When samples from this discovery showed up on mineral dealers' shelves, they were labeled either "pyromorphite" or "*endlichite,*" but no analyses were ever offered to support either name. Microprobe analyses for this study have shown that the crystals are unquestionably vanadinite, with only a few percent of As_2O_5.

THE LOCALITY

The mine of record for the Smithsonian's two specimens (NMNH numbers 149530 and 161181) is the Touissit mine, which is only one in a cluster of some eight mines scattered over about 18 km and known as the Touissit–Bou Beker mining district. The specimens are believed to have come from Puit XI ("shaft 11"). The district is located in eastern Morocco, 40 km south of Oujda. The locality is described as a strata-bound lead deposit of late Tertiary age (Rajlich, 1983). All of the mines in the district are being worked in the same limestone unit, a part of which continues into Algeria.

Minerals reported from the district (Rajlich, 1983; Barthoux, 1922) include galena, sphalerite, chalcopyrite, bornite, pyrite, marcasite, cerussite, smithsonite, azurite, anglesite, wulfenite, hydrozincite, vanadinite, pyromorphite, dolomite, calcite, aragonite and greenockite. Additionally the author has identified mottramite, malachite, barite and covellite, all alleged to have been found in the Touissit mine.

The mine has already become justifiably famous for at least three minerals produced in recent years. Large and sharp V-shaped cerussite twins rival the best ever found at any locality. The extraordinary azurite crystal groups are equal to the best from Tsumeb (Wilson, 1980; Sullivan, 1980). Finally, the anglesite specimens from this mine are undeniably the best there are from any locality. They are found in very large bladed crystals which, at times, are an electric sulfur yellow in color. The color is so beautiful and the quality of the crystals so exceptional that some superb faceted gems have been cut from this material. Unfortunately, those who are selling these specimens at or near the mine discovered that dipping them in bleach would alter the surface color to a very attractive reddish orange. In the bleach-dip process, lead from anglesite is ap-

Figure 1. **Road sign near Touissit, Morocco.**

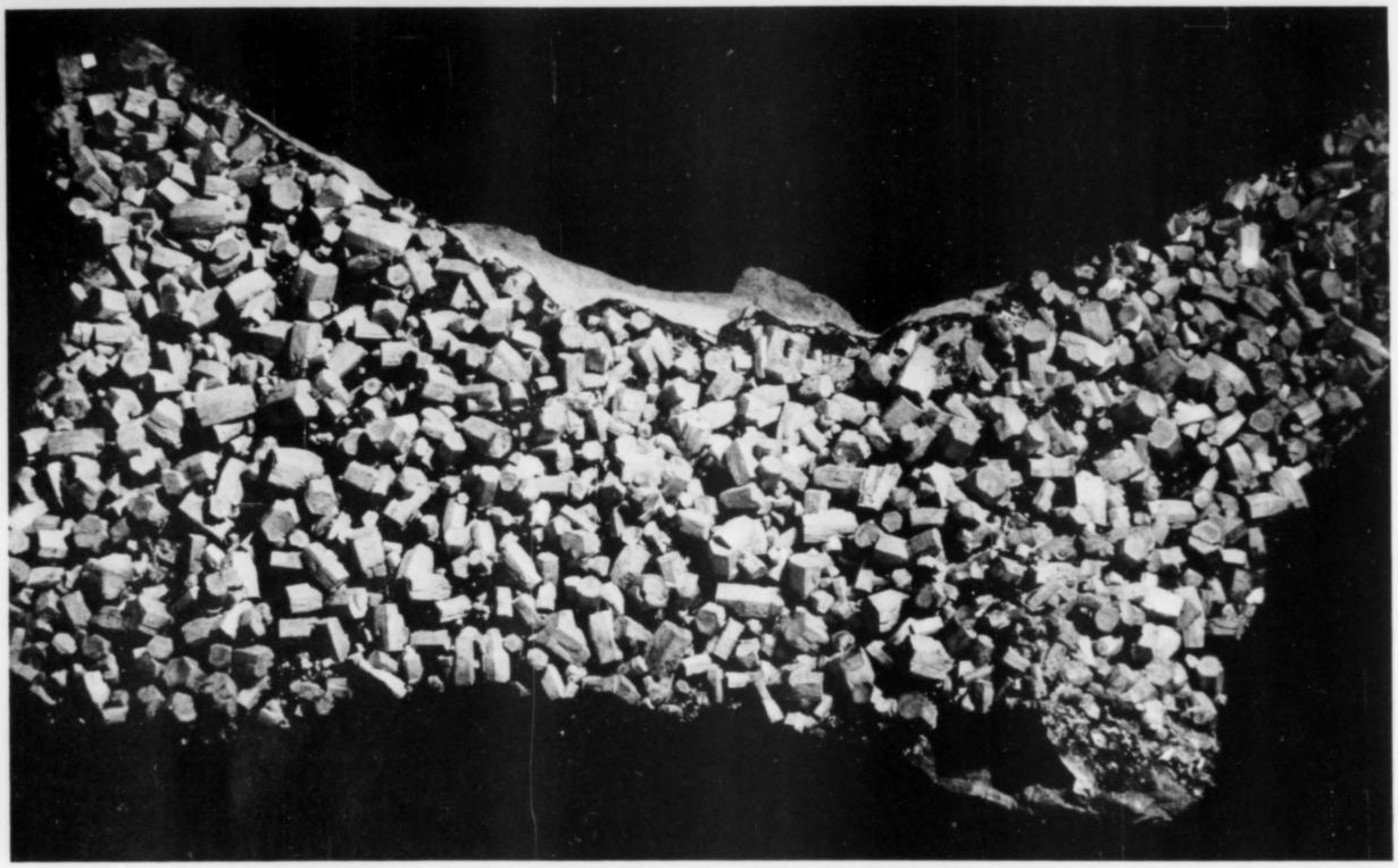

Figure 2. **Cream-colored vanadinite specimen 57 cm long (22.4 inches), from Touissit, Morocco. USNM specimen number 161181; photo by Dane Penland.**

parently converted to one of the lead oxides: litharge, massicot, or minium. The reaction produces a very thin film of intense red-orange color over the entire surface of the treated crystals (see Yount, 1984, and Weise, 1984).

VANADINITE

Crystals of vanadinite from the Touissit mine are rounded and moderately barrel-shaped, typical of many minerals in the apatite group. The only forms observed are the prism and pinacoid, and the length of the crystals is nearly always double the width. Specimens from this occurrence tend to be large. The overall size of the specimen shown in Figure 1 is 4 x 31 x 57 cm, a huge bowtie-shaped plate. Three distinct zones are readily discernible on the vanadinite crystals. The outermost (*c*) is a thin zone, about 1 mm, that is creamy white to almost silvery grey to tan in color and more opaque than the interior zones. It can be broken off cleanly from the underlying zone. The two interior zones (core is *a*, middle *b*) are of approximately equal thickness, they are essentially the same color, and they are considerably more translucent than the surface zone. The color varies from pale caramel-brown to pale olive-green. It is possible, on some of the crystals at least, to also break these two portions apart cleanly. Thus it appears that during the growth of the crystals there were two major disruptions causing physical discontinuities—discontinuities which do not delineate distinct compositional changes. In addition to the three zones between which physical separations occur, there are numerous other zones throughout the crystals where colors alternate sharply from light to dark shades. The smaller specimen (NMNH #149530) has very light tan caps of less than 1 mm in thickness which also can be cleanly separated from the crystals.

In many major mineral collections there are specimens that greatly resemble these new vanadinites, and these have always been properly identified as vanadinite. Vanadinite from this occurrence, given as Gebel Mahser by Barthoux (1922) has been analyzed (Criddle and Symes, 1977) and found to contain about 1% each of As_2O_5 and P_2O_5; this is nearly pure vanadinite and substantially less arsenic-containing than the new specimens from the Touissit mine (Table 1).

The locality of Barthoux (1922), given as Gebel Mahser, is believed by the writer to be in the vicinity of the present-day Touissit mine; Barthoux mentions visiting a galena mine which had been opened in the calcareous dolomites of Gebel Mahser, 25 km south of Oudja. The description of the vanadinite seen by Barthoux and the appearance of specimens from that locality that are in the National Museum of Natural History's mineral collection indicate that they most likely came from the same mine, and they are remarkably similar to the newer specimens from Touissit. Great confusion reigns, unfortunately, over the spelling of the old mine name which is named for a mountain (Gebel = mountain). Barthoux (1922) used Gebel Mahser, Palache *et al.* (1951) used Djebel Mahseur under vanadinite but Jebel Mahser under wulfenite, and the following variety of spellings was observed on specimen labels in the National Collections:

Djebel Masheur
Djebel Mashser
Djebel Masher
Jebel Mahsseur
Djbel Mahsen

The problem is, of course, that these are all phonetic translitera-

Figure 3. **Detail of the specimen in Figure 2. Photo by Dane Penland.**

tions from Moroccan and there is probably no one form that is necessarily more correct than another. The writer's inclination is to favor the usage of Barthoux (Gebel Mahser).

The only associated mineral observed on the new specimens is mottramite. The large Smithsonian specimen (#161181), which is in the form of a flat slab, is covered by a druse of sharp, dark olive-green mottramite crystals upon which the vanadinite was precipitated. The mottramite crystals are in the form of simple dipyramids. Most of the exposed mottramite has a thin black crust over it which also gives a mottramite X-ray pattern. The surface of the mottramite crystals is not black where they had been covered by later precipitated vanadinite, which means that the black crust is post-vanadinite.

Both of the minerals were X-rayed, but as the patterns for vanadinite and mottramite are not definitive, they were also analyzed with the electron microprobe. The former is overwhelmingly vanadinite, containing only about 2.5 to 3% As_2O_5. Both the *a* and *b* zones were analyzed, and the inner or core *a* zone revealed slightly higher levels of arsenic than were found in the *b* zone. Table 1 shows the analyses of zones *a* and *b*, compared with the ideal composition of vanadinite.

Table 2 shows the analysis of mottramite from the Touissit mine, in which the ratio of copper to zinc is 7:3. It is compared with the ideal composition of a hypothetical compound exactly in the middle of the descloizite-mottramite solid-solution series, a series in which any ratio of copper to zinc appears to be possible. If one cared to be more precise, this mineral might be termed a zincian mottramite.

THE STATUS OF ENDLICHITE

Many of the collectors and mineral dealers who have been handling the new specimens of vanadinite from Morocco, and also much of the reddish pyromorphite found in recent years at the Bunker Hill mine, Idaho, have succumbed to the urge to call it *endlichite. Endlichite* is one of a large number of varietal names serving no useful purpose, names that should be relegated to the status of obsolete.

Table 1. **Chemical analyses of vanadinite from the Touissit mine.**

	$Pb_5(VO_4)_3Cl$ Ideal	Touissit mine* zone (a)		Touissit mine* zone (b)	
PbO	78.80	79.78		79.88	
ZnO	–	1.11		1.16	
CuO	–	0.73		0.75	
NiO	–	0.51		0.49	
FeO	–	0.23		0.23	
V_2O_5	19.26	15.20	19.45	16.24	19.46
As_2O_5	–	3.13		2.49	
P_2O_5	–	1.12		0.78	
Cl	2.50	2.8		2.9	
	100.56	104.61		104.92	
O = Cl	0.56				
	100.00				

*NMNH #161181

Table 2. **Chemical analysis of mottramite from the Touissit mine.**

	$(Cu,Zn)Pb(VO_4)(OH)$ Ideal (Cu:Zn = 1:1)	Touissit mine* (Cu:Zn = 7:3)
PbO	55.30	55.49
CuO	9.86	13.46
ZnO	10.08	5.96
V_2O_5	22.53	21.64
As_2O_5	–	0.72
P_2O_5	–	0.96
H_2O	2.23	n.d.
	100.00	98.23

*NMNH #161181

The name was introduced by Genth and vom Rath (1885) for white to yellowish white or straw-yellow vanadinite-mimetite from the Lake Valley mines, Sierra County, New Mexico. Genth and vom Rath reported that several samples were analyzed and the ratio of As_2O_5 to V_2O_5 in all of them was about 1:1. Clearly they did not believe that the approximation of a 1:1 ratio was fortuitous, because they wrote, "the mineral (endlichite) is a combination of one molecule of mimetite with one molecule of vanadinite = $Pb_5Cl(AsO_4)_3$ + $Pb_5Cl(VO_4)_3$." Their interpretation was a perfectly reasonable one in view of the limited number of analyses available to them, each having been done on a different sample and each of a different color and habit.

Later analyses of samples of vanadinite and mimetite from other localities (tabulated in Palache *et al.*, 1951) indicated that there may be complete substitution in this series. Subsequent studies by Cockbain (1968) suggest that the series isn't quite complete, that there is a discontinuity in the range of $A{:}X$ ratios between 2.50 and 2.60, where A is lead and X may be either V or As in the general formula $A_5(XO_4)_3Cl$ for the vanadinite-mimetite series.

Genth and vom Rath's suggestion of 1:1 ordering of vanadium and arsenic can be discredited on structural grounds alone. The hexagonal structure has only one equipoint for tetrahedrally coordinated ions, therefore no ordering is possible and all V:As ratios are solely a function of the relative solution activities of the ions at the time of crystallization. A ratio of 1:1 can certainly occur by accident, but the distribution of V and As among the tetrahedral sites will be random, and the ratio will have no particular significance.

One of the unfortunate things about an indefinite term such as *endlichite* – at least it is popularly considered indefinite – is that it is easily misused. There is a tendency to refer to any vanadinite with arsenic in it (and some pyromorphites as well) as *endlichite,* regardless of the amount. This is done in spite of it being apparent that Genth and vom Rath intended the name to apply to crystals midway in the vanadinite-mimetite series, having equal amounts of vanadium and arsenic.

This author advocates abandonment of the unnecessary term *endlichite.* Vanadinite with arsenic in its composition is properly described as arsenian vanadinite. Mimetite with vanadium is vanadian mimetite.

ACKNOWLEDGMENTS

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Hawleyite and Phosphate Minerals

from bethel church, indiana, including a second occurrence for ferrostrunzite

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INTRODUCTION

Ferrostrunzite, the iron analog of strunzite, was first described by Peacor *et al.* (1983) from sedimentary rocks at Mullica Hill, New Jersey, a phosphate locality discussed by Henderson (1980). They speculated that, although ferrostrunzite is rare at the New Jersey location, it may be common in other places where alleged strunzite occurs in "the absence of manganese-bearing phosphates." We have found ferrostrunzite to be abundant in the weathered black shale at a location in Indiana. In keeping with the prediction of Peacor *et al.* (1983), ferrostrunzite occurs in a host rock that is markedly deficient in manganese, containing less than 200 parts per million (ppm) Mn, versus a crustal average of 950 ppm for this element. The low manganese content for the host rock is particularly striking in view of the high abundances of other heavy metals such as vanadium, molybdenum and zinc in the Excello shale and other shales of its type (Vine and Tourtelot, 1970; Coveney and Martin, 1983).

In addition to ferrostrunzite, several other iron phosphate minerals are present in the shale; for example, leucophosphite, aluminian strengite, phosphosiderite and vivianite (Table 1). All of the phosphate minerals except phosphosiderite and strengite are present as well-formed microcrystals. Most of these are sufficiently abundant to be of interest to collectors and, with the possible exception of vivianite, none have previously been reported from Indiana. In addition to the phosphate minerals, we report here one of the few occurrences of hawleyite at a U.S. locality.*

LOCATION and HISTORY

The Bethel Church fossil dig and phosphate locality lies about 600 meters southeast of the Bethel Church in the Patoka State Fish and Wildlife Area, Pike County, Indiana, within the northwest quarter of Section 3, T3S, R7W, located on the Augusta 7½-minute U.S. Geological Survey quadrangle (Fig. 1). The site consists of a 20- by 40-meter fossil fish dig opened in 1981 in the highwall of an abandoned coal strip mine (Fig. 2). The highwall, dating from the early 1960s, exposes the Excello shale containing both fish fossils (mainly sharks) and phosphate minerals. The shale exposure extends at least 100 m east and west of the fish dig, and other exposures exist in the area, but these have not yet been examined for secondary phosphate minerals. Persons interested in access to the site should contact the Manager, Patoka State Fish and Wildlife Area, Winslow, Indiana.

The secondary phosphate minerals were discovered in July 1983 while several of the authors were sampling for geochemical studies at the Bethel Church Excello shale exposure being worked by Dr. Rainer Zangerl for fish fossils.

* Hawleyite has been reported by Pemberton (1983) from the Crestmore quarry, Riverside County, California. Richard C. Erd (personal communication) has identified it from Mono County, California, and a 1981 list of specimens for sale from Mineralogical Research Company lists hawleyite from Hanover, New Mexico.

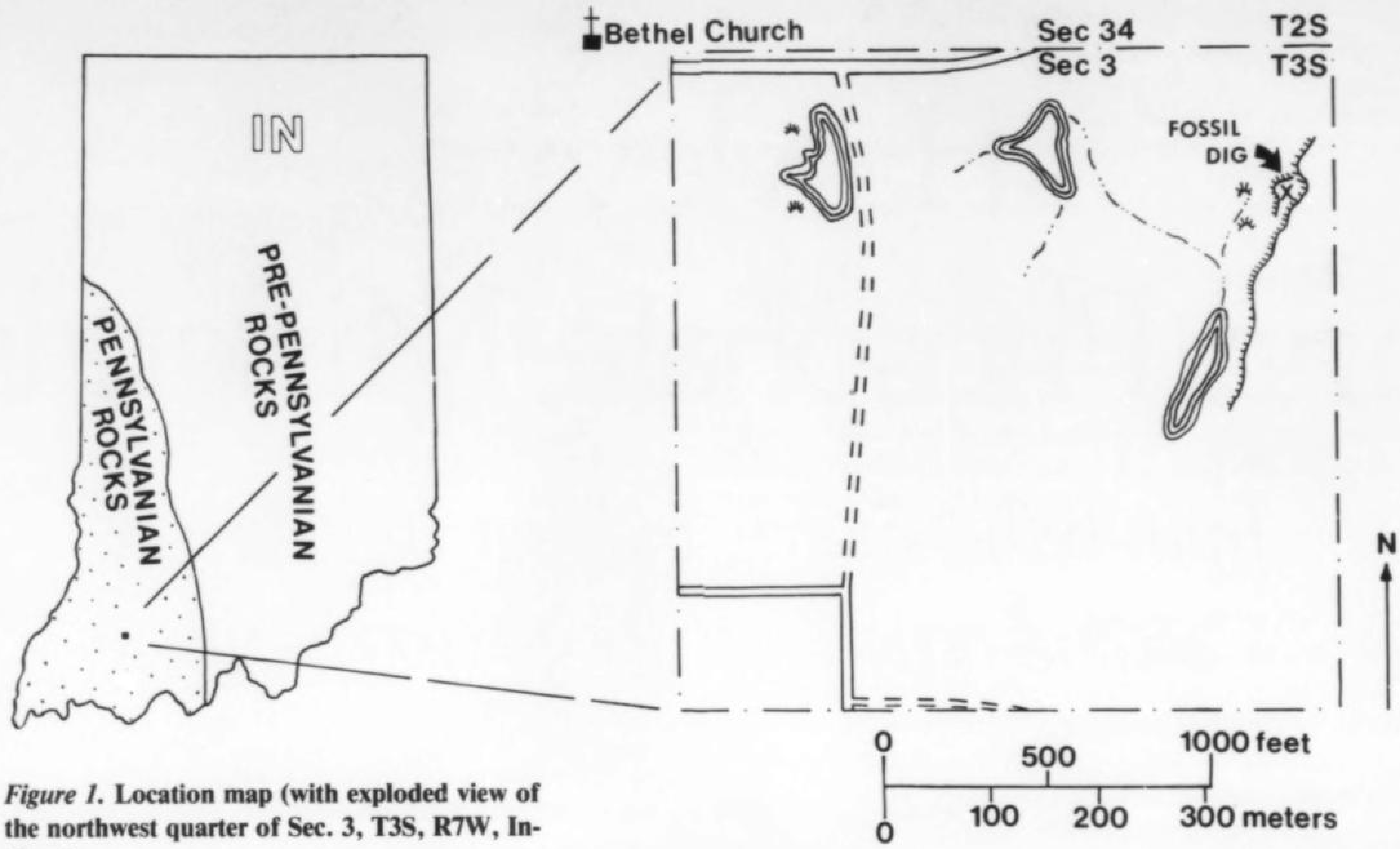

Figure 1. **Location map (with exploded view of the northwest quarter of Sec. 3, T3S, R7W, Indiana).**

GEOLOGY

Named for a town in northeastern Missouri, the Excello shale member of the Petersburg formation (Shaver *et al.,* 1970) is a black shale which crops out over a wide area extending from Indiana to Oklahoma. The Excello is typical of the black shales that occur over coals in Middle Pennsylvanian-age cyclothems, along the eastern edge of the Illinois Basin. Salient characteristics include thinness (less than 1 m), large heavy-metal tenors, and high organic matter content (20–50%). Locally, there are concentrations of fish fossils (especially shark remains) and phosphatic nodules, many of which may have originally been coprolites or gastric residue pellets derived from sharks (Zangerl and Richardson, 1963).

Like the Mecca quarry shale of Zangerl and Richardson (1963), the Excello shale and about 25 other similar Mid-continent Pennsylvanian-age shales characteristically contain various heavy metals. Whole-rock analyses indicate values ranging from hundreds to thousands of parts per million of vanadium, chromium, nickel, zinc, selenium, molybdenum, cadmium, and uranium (Coveney and Martin, 1983). Such metal values are ubiquitous over tens of thousands of square kilometers of outcrop and subsurface occurrences of the shales.

It is generally believed that metalliferous black shales were deposited in shallow Pennsylvanian seas beneath stagnant, oxygen-deficient bottom waters. The heavy metals may have been deposited at the time of sedimentation or possibly were added subsequently by mineralizing solutions. Such relations are currently under investigation by the authors, among others. The interested reader is referred to Coveney and Martin (1983) for more details on possible origins and for a more complete list of references on this aspect.

Pennsylvanian shales of the Midwest are commonly enriched in phosphate. For example, P_2O_5 contents of 1–3% are typical for the Pennsylvanian-age Hushpuckney shale of Kansas City. The Pennsylvanian shales of the eastern edge of the Illinois Basin, such as the Excello shale of Bethel Church, and the Mecca Quarry shale of Indiana, normally contain lesser quantities of phosphorus, however. Ordinarily, the Indiana shales carry less than 1% P_2O_5, but sporadic concentrations exceeding 5% phosphate are found, mostly as nodules. Such is the case for Bethel Church where clusters of phosphate nodules and their secondary products are concentrated at the east end of the shale exposure.

The Excello contains 6.5–10.5% iron. This is higher than most black shales which average about 2% Fe (Vine and Tourtelot, 1970). The Excello contains only minor amounts of manganese. Grades of manganese for Pennsylvanian-age black shales typically fall in the range of only 50–200 ppm on a whole rock basis, well below the crustal average of 950 ppm for this element. As manganese is an essential element for the formation of strunzite, it is not surprising that ferrostrunzite, instead, occurs in the Excello shale.

MINERALS

The following descriptions cover only those minerals which are likely to be of interest to mineral collectors. (Other phosphate minerals, for example Al-free strengite and fluorapatite, occur only as microscopic grains.) All minerals have been identified from X-ray powder diffraction photographs (114.6-mm Debye-Scherrer camera, Ni-filtered, CuKα radiation), supplemented by electron microprobe analysis and other techniques where appropriate. All specimens described are housed in the Museum of Geosciences, University of Missouri – Kansas City (UMKC). Excepting hawleyite (CdS), all minerals described are iron phosphates, most of which have not previously been described as occurring in Indiana. However, many of the phosphates have previously been reported from weathering profiles and sedimentary settings. For example, leucophosphite, first described as forming from the action of bird guano on serpentinite in Australia, has been found as colorful crystals in metalliferous shale from Nevada (Zientek *et al.,* 1979). Nevertheless, crystalline examples of the minerals reported here are most typically collected from pegmatite occurrences, rather than from sedimentary host rocks. Just as in pegmatite occurrences, the Indiana phosphates originated through alteration of primary phosphate material, probably as a result of natural weathering processes. However, because the phosphate locality is in the headwall of a long-abandoned strip mine, it is possible that some of the minerals were formed subsequent to excavation.

Figure 2. Bethel Church phosphate location. (Rainer Zangerl pointing out Excello shale outcrop to authors Allen and Blankenship.)

Figure 3. Dark green beraunite crust surrounding a white ball of phosphosiderite and overgrown partly with orange ferrostrunzite (lower right). From the crust of the diadochite nodule. The phosphosiderite ball is about 0.5 mm in diameter. UMKC specimen.

Figure 4. Beraunite needles with crust of diadochite nodule. (SEM photo; width of view is 300 μm.)

Beraunite $Fe^{+2}Fe_5^{+3}(PO_4)_4(OH)_5 \cdot 4H_2O$

Beraunite occurs as clusters of 2–3 mm long capillary hairs, on the rim of the one diadochite nodule found loose on the mine dump (Fig. 3). In some cases the beraunite needles are arranged in sprays resembling corn rows (Fig. 4).

Diadochite $Fe_2^{+3}(PO_4)(SO_4)(OH) \cdot 5H_2O$

Diadochite occurs as (~ 100 μm) microcrystals and seems to be quite rare, as it was found on the waste dump as only a single nodule measuring approximately 6 cm across (Fig. 5). Despite its

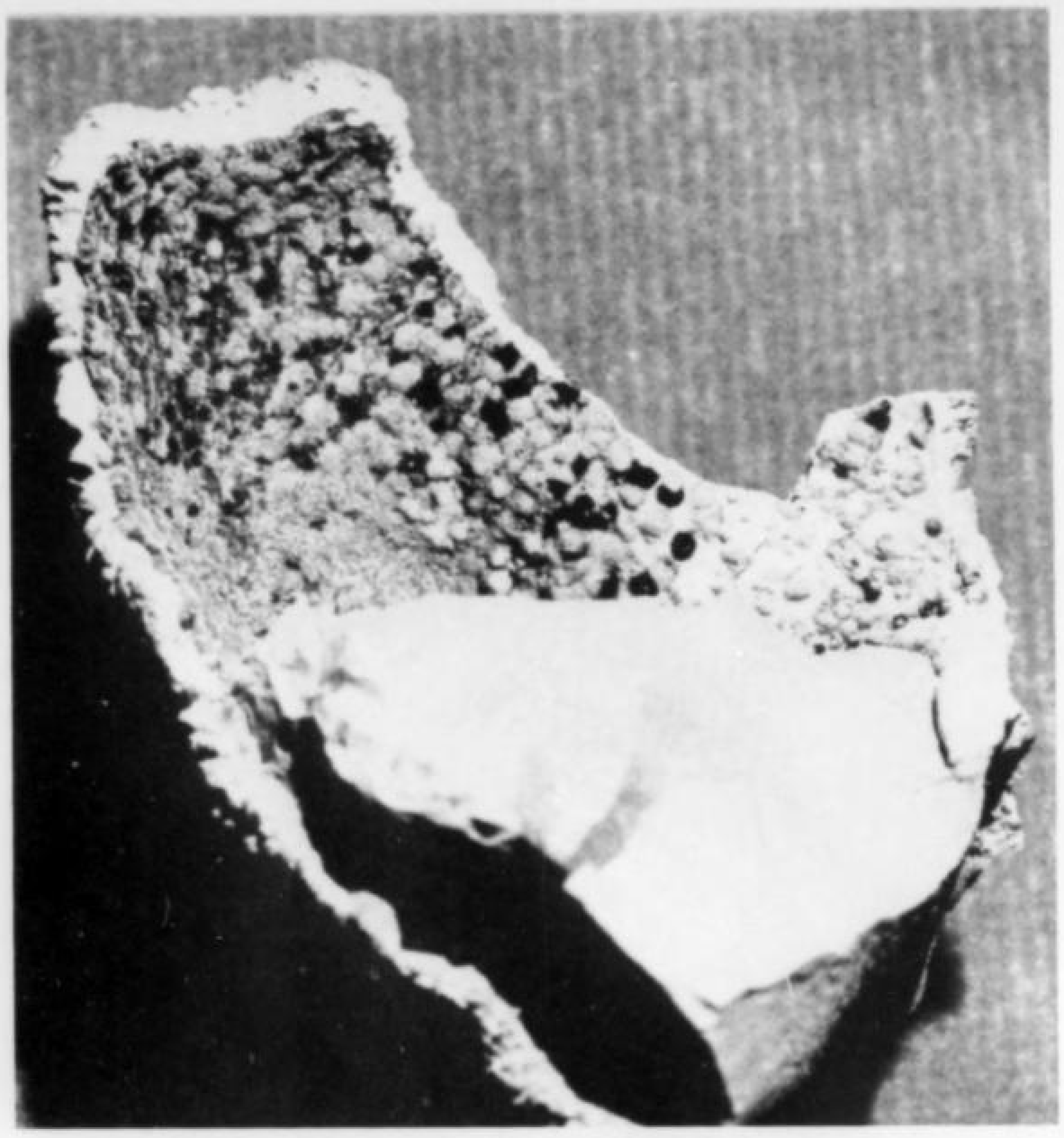

Figure 5. **Fragment of 6-cm diadochite nodule, Bethel Church phosphate location, Museum of Geosciences, University of Missouri – Kansas City (UMKC) specimen. Dark balls of leucophosphite are approximately 1 mm in diameter. Angular chunk to upper right consists of diadochite. White rind is phosphosiderite. Light gray balls and crust are ferrostrunzite. Darker gray crust is beraunite. Photo by Jon Dunn.**

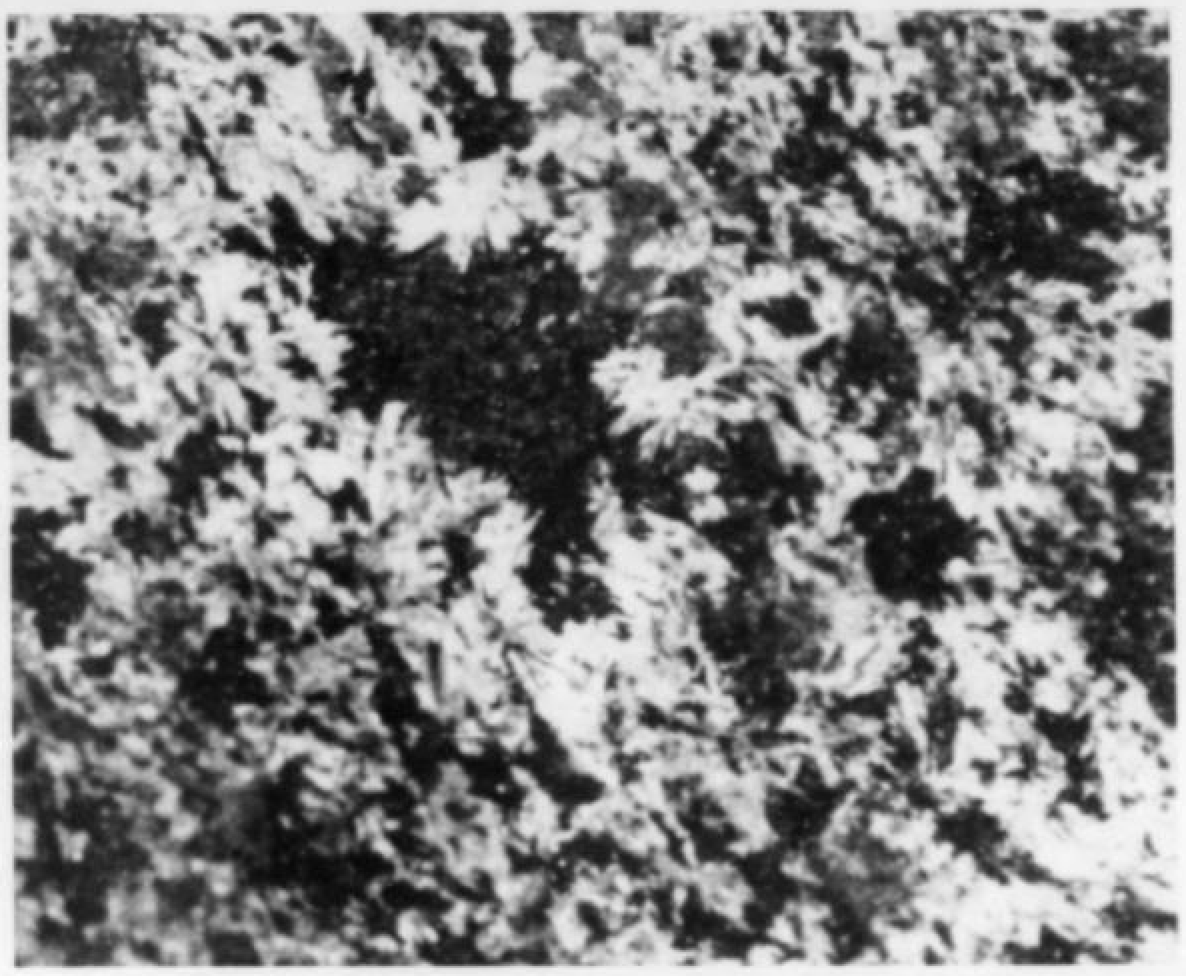

Figure 6. **Tufts of ferrostrunzite crystals to 0.4 mm on shale bedding plane. UMKC specimen. Photo by Jon Dunn.**

Figure 7. **Ferrostrunzite with aluminian strengite on shale. (SEM photo; width of view is 46 μm.)**

Figure 8. **Ferrostrunzite needles on leucophosphite crystals from crust of diadochite nodule. (SEM photo; width of view is 110 μm.)**

rarity, the diadochite is of special interest because it is coated by a thin (~ 3 mm) rind containing some of the finest specimens of ferrostrunzite and leucophosphite and because it contains the only beraunite and phosphosiderite found at the locality.

Ferrostrunzite $Fe^{+2}Fe_2^{+3}(PO_4)_2(OH)_2 \cdot 6H_2O$

Ferrostrunzite occurs principally as tufts of colorless to straw-yellow, radiating, capillary crystals lying along bedding planes and, to a lesser extent, along joints in the shale (Fig. 6). In this occurrence it is commonly associated with euhedral vivianite crystals or aluminian strengite (Fig. 7) or with both minerals. Characteristically, the individual ferrostrunzite crysals in the shale are about 50–200 μm in length and about 5–10 μm thick. The mineral is sufficiently abundant in this occurrence that we found about 100 specimens in two hours of collecting.

Excellent examples of ferrostrunzite also occur in the single diadochite nodule, in which the mineral forms well-developed capillary fibers (Fig. 8) ranging in color from the typical straw-yellow of strunzite-group species to white, bright orange or brown. In some cases, the ferrostrunzite needles show evidence of corrosion on their tips (Fig. 9).

A cell refinement based on monochromatized CuKα X-ray diffractometry of Indiana ferrostrunzite yields the following parameters: a = 10.173(5)Å; b = 9.783(5)Å; c = 7.395(11)Å; α = 88°44′; β = 97°36′; γ = 117°36′; V = 645.9(9)Å^3.

Ferrostrunzite has an ideal formula of $Fe(Fe)_2(PO_4)_2(OH)_2 \cdot 6H_2O$. The chemical formula for Indiana ferrostrunzite is close to $Fe_{.95}Fe_{1.9}Mn_{.005}(PO_4)_2(OH)_2 \cdot 6H_2O$. For our specimens, we have determined the combined water and hydroxyl content to be approximately 27.5% (by measurements of the weight losses accompanying incremental heating of two samples over the range 50–200° C). This value is within 1% of the water and hydroxyl content predicted from the ideal formula for ferrostrunzite (28.4%). The remaining constituents (43.17% combined FeO and Fe_2O_3, 29.91%

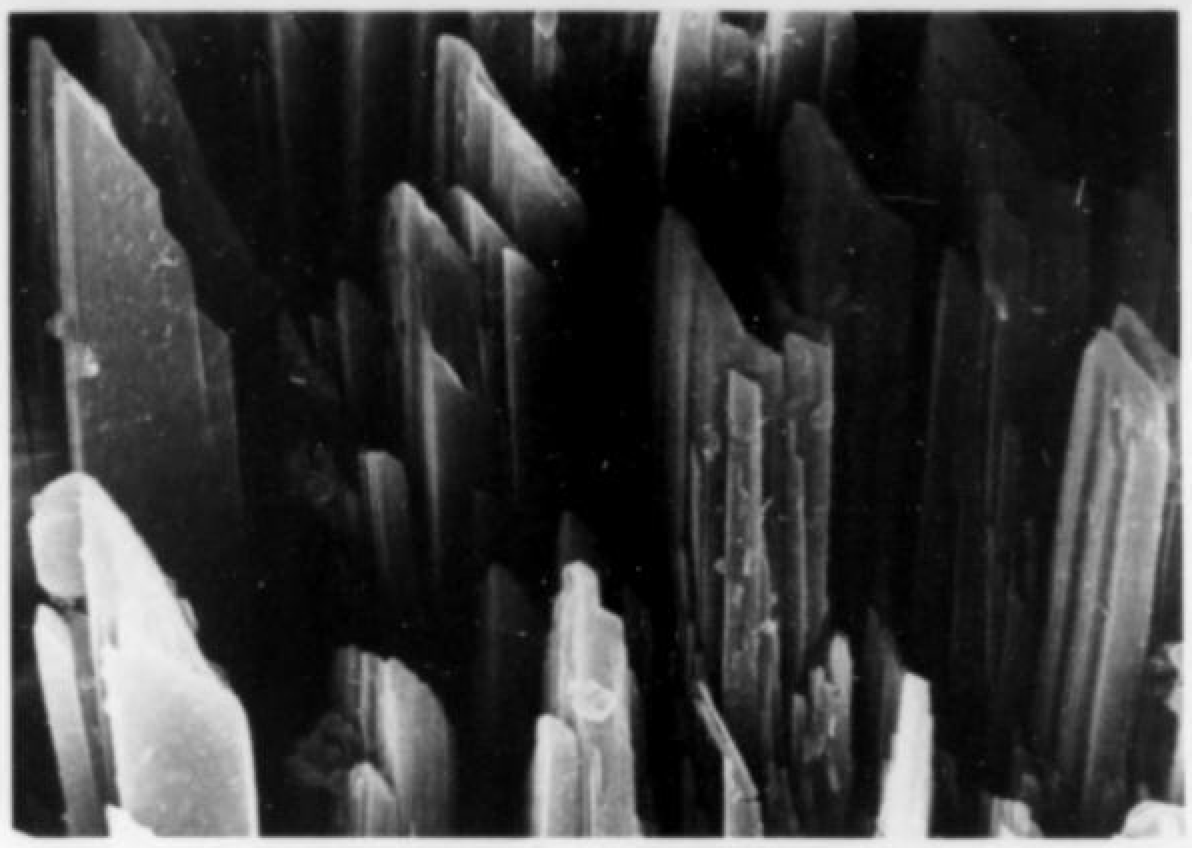

Figure 9. **Corroded ferrostrunzite crystals from crust of diadochite nodule. (SEM photo; width of view is 36 μm.)**

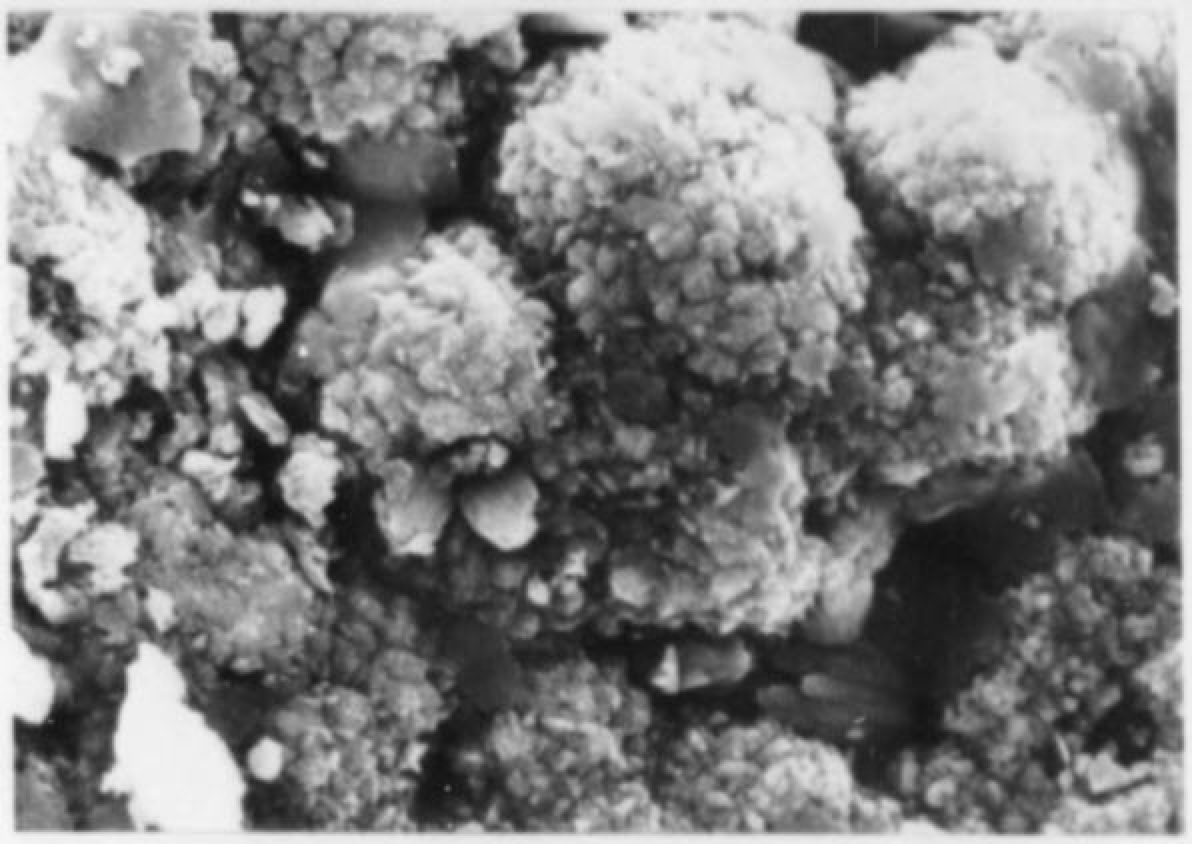

Figure 10. **Hawleyite clumps. (SEM photo; width of view is 26 μm.)**

P_2O_5, and 0.06% MnO) were determined by electron microprobe analysis with almandine, Ba-chlorapatite, and rhodochrosite as standards for Fe, P, and Mn (operating voltage of 15 KV; a sample current of 15 nanoamperes, measured on brass). The ratio of Fe^{+3} to Fe^{+2} is assumed to be 2:1 in accordance with the ideal formula.

Debye-Scherrer X-ray powder patterns for Indiana ferrostrunzite compare well with that of the New Jersey ferrostrunzite (Peacor *et al.*, 1983). It should be noted, though, that several lines appearing in diffractometer tracings of the Indiana ferrostrunzite were not reported for the New Jersey material, e.g., 8.62Å (25), 8.46Å (15), and 3.20Å (30). (All of these extra lines, however, can be indexed with the calculated powder pattern generated from our cell-refinement data.) It also should be mentioned that the pattern for Indiana ferrostrunzite radically differs from that of the strunzite-like mineral reported from Belgium by Van Tassel (1966). Of more serious concern, however, is the fact that the powder patterns for Indiana ferrostrunzite match as well with Frondel's (1957) Hagendorf strunzite pattern as it does for the New Jersey pattern. We have resolved this ambiguity by electron microprobe analysis and X-ray fluorescence analysis for iron and manganese. The results, indicating a preponderance of iron, clearly point to ferrostrunzite as the identity of the Indiana mineral. Generalizing from our experience, we can only conclude that a chemical test to supplement X-ray data would ordinarily be necessary to distinguish between strunzite and ferrostrunzite.

Hawleyite CdS

Hawleyite, the isometric dimorph of greenockite, which was first described from an occurrence in the Yukon, is found along joints and in association with fossil plant remains within the Excello shale at Bethel Church. A bright orange to yellow pulverulent material, it provides a striking contrast to the jet black shale in which it occurs. A particularly fine example consists of yellow-orange hawleyite splotches on the surface of a flattened plant stem measuring 20 cm by 1.5 meters. The hawleyite from this occurrence consists of rounded, irregular clumps of anhedral crystals (Fig. 10). Some hawleyite is associated with white barite (Fig. 11) and traces of sphalerite. Although hawleyite is present in comparatively unweathered shale, it too may be a product of the early stages of weathering.

At the original occurrence, Traill and Boyle (1955) found hawleyite forming as a result of the action of acid ground waters on primary sulfide minerals. These workers suggested that, "Much material previously identified as greenockite by casual hand specimen examination may prove to be hawleyite when identified by X-ray diffraction." Subsequently Jedwab and Van Tassel (1978) found that many samples from Belgium, labeled as greenockite, are actually hawleyite. Hence hawleyite may be far more widespread than generally supposed. Probably this situation would be altered if more U.S. samples of CdS were investigated by X-ray techniques. However, there is a possibility that hawleyite *is* comparatively rare in the United States. This is because the most important domestic ores containing Zn and the allied element, Cd, are hosted by carbonate rocks that would tend to neutralize the acid solutions needed to form hawleyite.

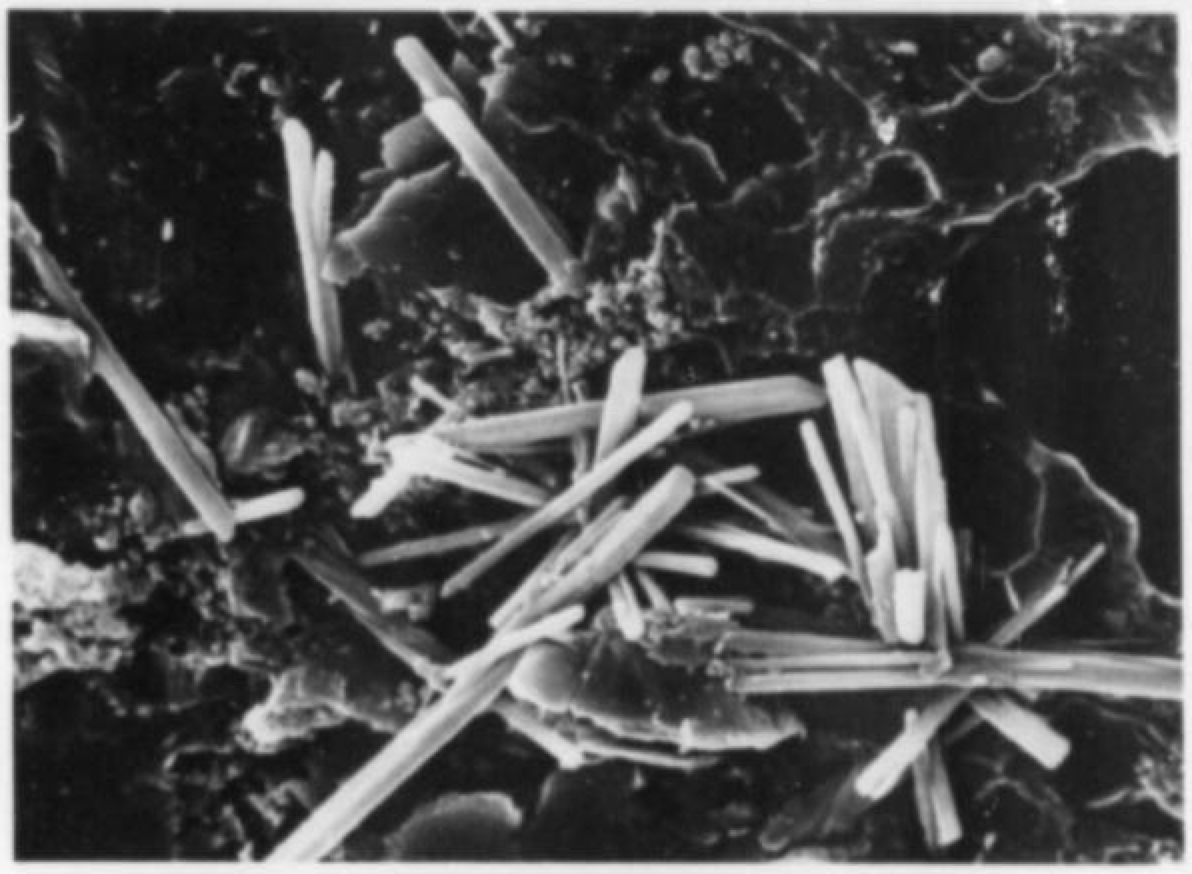

Figure 11. **Barite crystals with hawleyite clumps on coaly plant fragment from Excello shale. (SEM photo; width of view is 31 μm.)**

Leucophosphite $KFe_2^{+3}(PO_4)_2(OH)_2 \cdot 2H_2O$

Leucophosphite occurs chiefly as very lustrous, greenish brown, equidimensional crystals in thin veinlets cross-cutting fluorapatite nodules in the black shale. The finest examples at the Bethel Church dig, however, occur in the crust of the diadochite nodule which contains tiny balls consisting of adamantine, nearly opaque, green-brown, wedge-shaped crystals (Fig. 12). In some cases, leucophosphite balls occur embedded in diadochite (Fig. 13).

Phosphosiderite $Fe^{+3}PO_4 \cdot 2H_2O$

Phosphosiderite (metastrengite), probably the least interesting (to collectors) of the secondary phosphate minerals from Bethel Church, occurs mainly as white chalky material (Fig. 5) in the crust

Figure 12. **Leucophosphite ball from diadochite nodule. (SEM photo; width of view is 1100 μm.)**

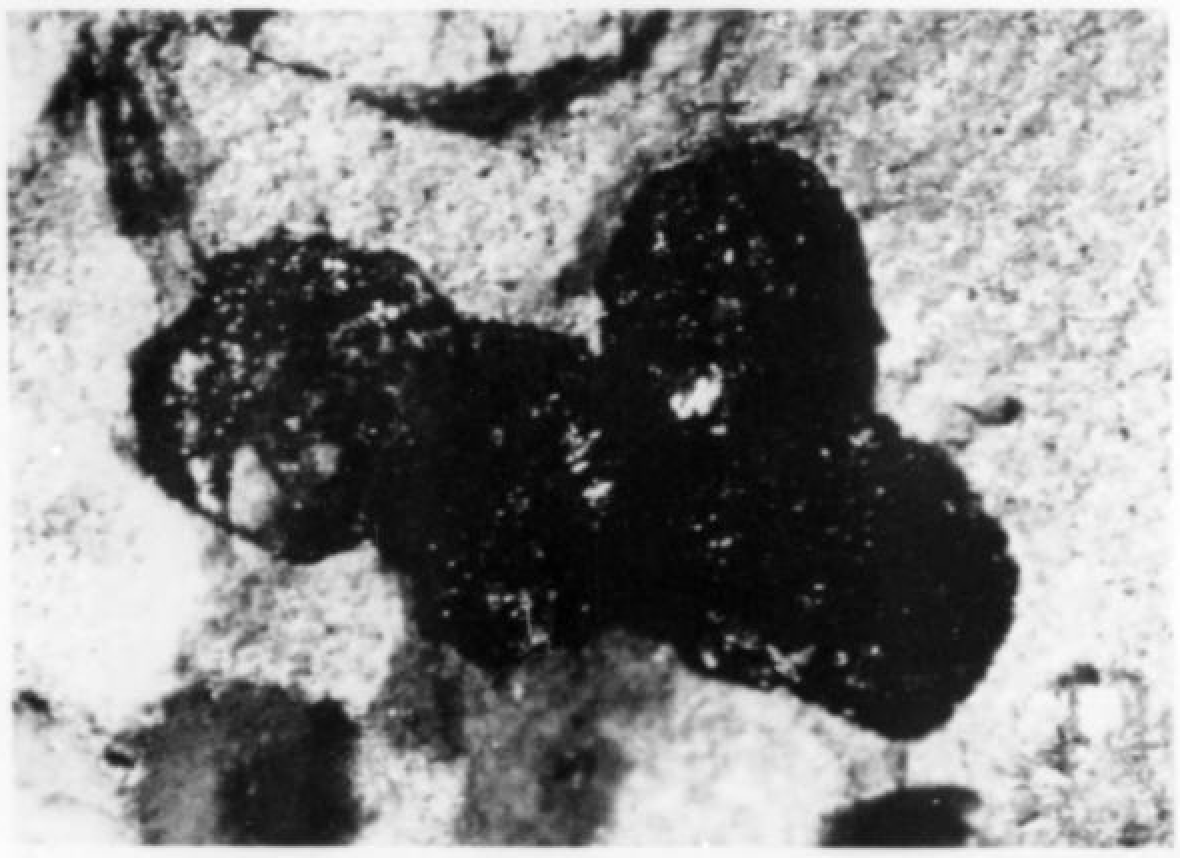

Figure 13. **Leucophosphite balls (0.5 mm) embedded in diadochite. White ball in cavity is phosphosiderite; the adjacent light gray ball, composed of radiating crystals, is ferrostrunzite. UMKC specimen. Photo by Jon Dunn.**

of the diadochite nodule. In some cases it occurs as 0.5–1 mm white balls embedded in diadochite (Fig. 13) or surrounded by crusts of other iron phosphates (Fig. 3).

Strengite (aluminian) $(Fe^{+3},Al)PO_4 \cdot 2H_2O$

Aluminian strengite (*barrandite*) occurs as microscopic, light gray, 20–50 μm ellipsoids on the bedding planes of the shale and associated with ferrostrunzite. Scanning electron microscopy reveals that the microscopic clusters of strengite consist of rows of radiating crystals (Fig. 7).

Vivianite $Fe_3^{+2}(PO_4)_2 \cdot 8H_2O$

It was the flashy, bright, 1–2 mm crystals of vivianite occurring on black shale that first drew our attention to the phosphate minerals of Bethel Church. This mineral is the most common of the secondary phosphates at the locality. The mineral occurs as stubby prisms, as radiating aggregates, and, to a lesser extent, as blue powdery material. Most of Bethel Church vivianite crystals are clearly secondary, occurring chiefly as fresh prisms and rosettes (Fig. 14) scattered along the surfaces of open joints and dilated bedding planes. Some of the powdery material and a few crystals of vivianite occur in cavities within phosphate nodules and may be diagenetic in origin, similar to the vivianite at the Mullica Hill, New Jersey, occurrence described by Henderson (1980). Although the Indiana vivianite scarcely rivals the spectacular material from Virginia, there are some good microspecimens present and attractive, small cabinet-sized examples can be found.

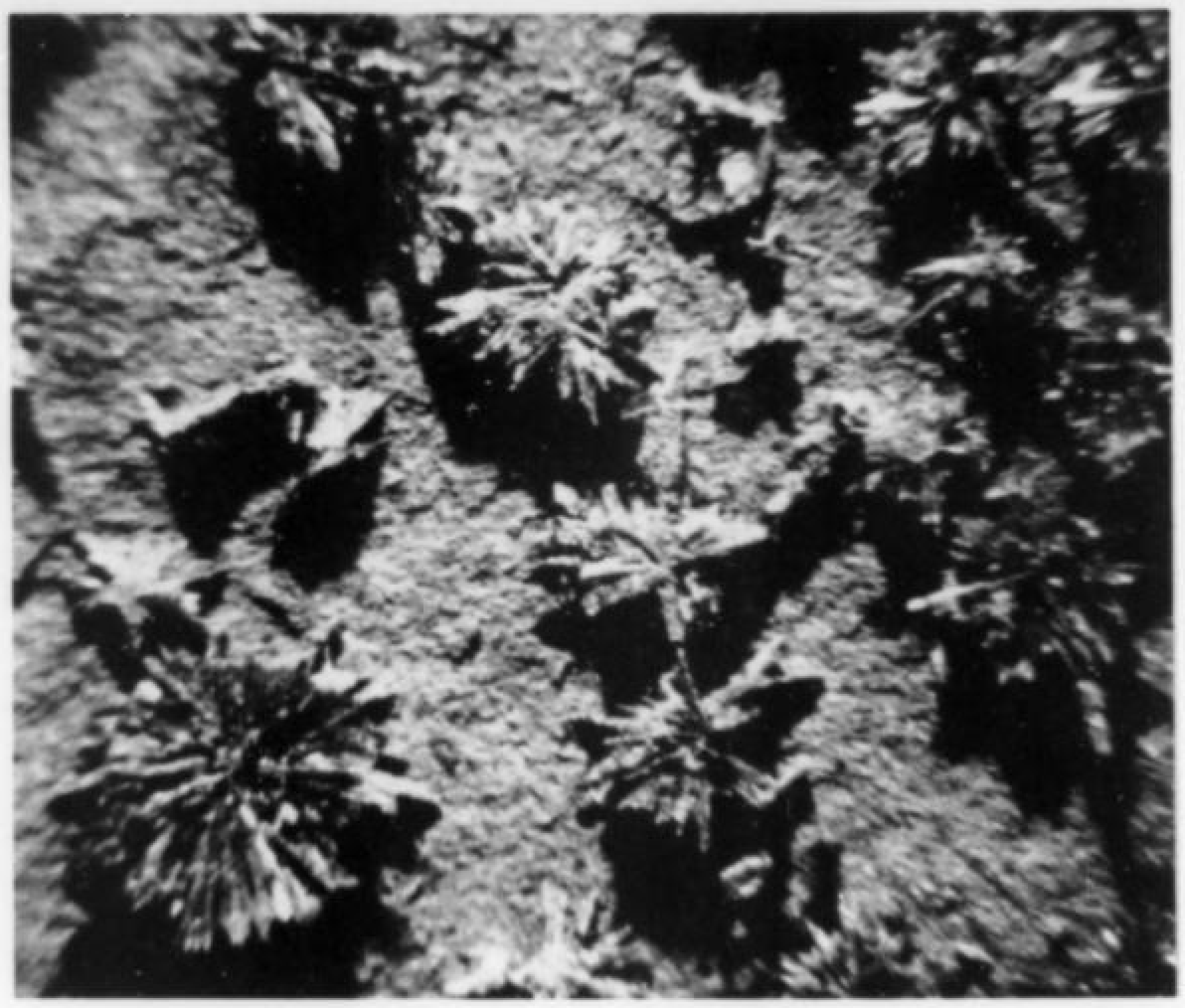

Figure 14. **Vivianite rosettes to 5 mm on shale bedding plane. UMKC specimen.**

DISCUSSION

The secondary iron phosphates in the shale at the Bethel Church locality were formed by the action of meteoric waters. Most likely the weathering processes involved acid waters that leached iron, aluminum and, to a lesser extent, potassium from the shale matrix to react, in turn, with fluorapatite nodules or dissolved phosphate, thus forming the principal secondary phosphate minerals (vivianite, ferrostrunzite, aluminian strengite, and leucophosphite). Clearly the abundances of fluorapatite nodules and iron in the shales are critical factors for the formation of the minerals found. No less critical to the occurrence is the paucity of manganese which explains the overwhelming predominance of iron phosphates and the absence of any secondary manganese minerals such as strunzite.

The origin of the peculiar nodule containing diadochite and several other crystalline phosphate minerals is unclear owing to the small quantity of sample material and because the one nodule found occurred loose in the mine dump. It is possible, however, that this nodule formed as a pyrite or marcasite concretion which reacted with dissolved phosphate during weathering to precipitate ferroan sulfate-phosphate. The crust, surrounding the diadochite and containing ferrostrunzite, beraunite, phosphosiderite and leucophosphite, may have formed at a later stage or as a result of a diffusion gradient that resulted in a dominance of phosphate ions along the exterior margin of the nodule, during the initial weathering.

Iron phosphate minerals are abundant in the Excello shale at Bethel Church. We find it curious that no secondary phosphates containing the other heavy metals known to occur in the shales have been found at the Bethel Church location. For example, one might expect to find hopeite ($Zn_3(PO_4)_2 \cdot 4H_2O$) or other zinc phosphate mineral species. Possibly the absence of such minerals is related to a relative immobility of heavy metals other than iron in the weathering zone of such locations.

Table 1. **Phosphate minerals occurring at the Bethel Church location, Pike County, Indiana.**

Name	*Chemical Formula*	*Occurrence*
Beraunite	$Fe^{+2}Fe_5^{+3}(PO_4)_4(OH)_5 \cdot 4H_2O$	In crust on diadochite nodule
Diadochite	$Fe_2^{+3}(PO_4)(SO_4)(OH) \cdot 5H_2O$	As loose 6-cm diameter nodule found on mine dump
Ferro-strunzite	$Fe^{+2}Fe_2^{+3}(PO_4)_2(OH)_2 \cdot 6H_2O$	As radiating fibers on bedding planes, fluorapatite nodules and joints in black shale and in crust of diadochite nodule
Fluor-apatite	$Ca_5(PO_4)_3F$	As micro-crystalline nodules and in fossil fish fragments in black shale
Leuco-phosphite	$KFe_2^{+3}(OH)(PO_4)_2 \cdot 2H_2O$	In fluorapatite nodules and in crust on diadochite nodule
Phospho-siderite	$Fe^{+3}PO_4 \cdot 2H_2O$	As white crust on diadochite nodule
Strengite (aluminian)	$(Fe^{+3},Al)PO_4 \cdot 2H_2O$	With ferrostrunzite on bedding planes in black shale
Vivianite	$Fe_3^{+2}(PO_4)_2 \cdot 8H_2O$	Along bedding planes, joints and in fluorapatite nodules in black shale

Questions remain about just how widespread the secondary phosphate mineralization is. It could be merely local. It is worth noting, however, that the discovery of the unusual phosphate minerals of the Bethel Church location was largely an accidental by-product of geochemical and paleontologic studies of the shales. Prospects seem favorable for locating other, and possibly better, phosphate mineral collecting localities in southern Indiana. Moreover, it is conceivable that more prolific locations exist elsewhere in the outcrop belt of the Midcontinent Pennsylvanian-age black shales that occur in a region extending from Pennsylvania to Kansas and from Iowa to southern Missouri and Oklahoma. Although these occurrences exist outside the normal haunts of mineral collectors, it is possible that other ferrostrunzite locations are waiting to be found in the Midcontinent by the patient collector.

SUMMARY

The Bethel Church phosphate locality contains ferrostrunzite, vivianite, aluminian strengite and leucophosphite in abundance and lesser amounts of beraunite, diadochite and phosphosiderite. This is the second occurrence yet described for ferrostrunzite and the first Indiana occurrence for most of the other iron phosphate minerals. All of these minerals occur as secondary species in moderately to heavily weathered black shale beds in the Excello member of the (Middle Pennsylvanian) Petersburg formation. Also present is hawleyite, very few occurrences of which are known in the U.S. The extent of the occurrence is uncertain. It may be confined to the 300-m outcrop containing the Bethel Church fossil fish dig. However, numerous unexamined outcrops of Excello shale and similar Pennsylvanian black shales occur elsewhere within the same abandoned mine and in the surrounding region and may well contain similar phosphate minerals.

ACKNOWLEDGMENTS

We are particularly grateful to Rainer Zangerl for leading us to the Bethel Church fossil dig which he has conducted for the past two years in cooperation with the land owner, Interstate Commercial Corporation, the State of Indiana Department of Natural Resources, and in particular, John Wade, manager of the Patoka Fish and Wildlife area. Dr. Zangerl's enthusiastic encouragement of our studies, only marginally related to his principal interest in paleoichthyology, and both his and Mrs. Zangerl's hospitality in the field are sincerely appreciated. We thank Donald R. Peacor for helpful correspondence regarding ferrostrunzite and also for introducing Coveney and Simmons to secondary phosphate minerals during the late 1960s when they were in Ann Arbor. The manuscript was typed by Deb Fitzwater of the Department of Geosciences, UMKC. Jon Dunn of UMKC Audiovisual assisted with photography. David Wayne assisted with electron probe analyses and Woody Dahl provided SEM photography. This work is a consequence of on-going research into the mineralogy and geochemistry of Pennsylvanian-age black shales supported by the National Science Foundation (Grant EAR-82 18742 to Coveney).

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Fluorapatite

from the king lithia mine, custer county, south dakota

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INTRODUCTION

The pegmatites of South Dakota's Black Hills are known for their outstanding assemblages of rare and well-crystallized phosphate minerals. Included among these are fluorapatite crystals of various habits ranging in color from white to green, blue, lavender and amethystine purple. Recently, a large pocket zone of unusual, gemmy, indigo-blue fluorapatite crystals with white stripes perpendicular to the *c* axes was uncovered at the King Lithia mine near Keystone, Custer County. Considering that the locality has previously produced blue and white zoned fluorapatite only as microcrystals (W. L. Roberts, personal communication), the recently found crystals up to 1.3 cm in size are quite remarkable.

LOCATION

Keystone is located approximately 29 km (18 miles) southwest of Rapid City, South Dakota, very close to the Mt. Rushmore National Memorial (Fig. 1). Fine apatite crystals in a variety of colors and habits have been found in many pegmatites throughout the surrounding area. Some of the more famous apatite producers include the White Cap mine, the Peerless mine, the Dan Patch mine and the Hugo mine which, in 1948, produced fluorapatite from a single crystal weighing approximately 2,000 pounds (Roberts and Rapp, 1965).

The pegmatites are Precambrian in age and occur as discordant plugs and dikes and concordant sheets intruding generally fine grained quartz-mica schists of varying composition. Examples of concentrically zoned, layered and unzoned pegmatites are found in relatively close proximity within the district (Landes, 1928).

Mining in the Keystone district has been active since the late 1800s with production including gold, feldspars, lithium minerals, beryl, muscovite, cassiterite and columbite-tantalite. Individual mines consist of one or more pegmatitic bodies commonly ranging in size from a few meters to a few hundred meters in dimension.

The specimens used in this study originate from a small pegmatite approximately 3.2 km (2 miles) southeast of Keystone (Fig. 1). Some confusion exists as to the proper name for this locality; the King lode, King Lode mine, King Lithia prospect and King Lithia mine seem to be among the most preferred. Most local collectors refer to this pegmatite as the King Lithia mine.

OCCURRENCE

The fluorapatite crystals described here were found in a vuggy pocket zone approximately 3.7 meters long by 60 cm in height and width. Individual vugs were lined with iron-stained albite crystals up to 1.3 cm, and quartz crystals, some of which were sceptered, up to 6 mm. Larger quartz and albite crystals (usually badly etched) up to several centimeters in diameter partially filled many of the vugs, leaving little or no room for well-formed crystals of fluorapatite to develop. Other minerals associated with the fluorapatite crystals include columbite-tantalite crystals and limonite pseudomorphs after siderite.

MORPHOLOGY AND COLOR ZONING

The zoning is apparently the result of three separate generations of growth. The first generation consists of a translucent, colorless, tabular crystal with prominent basal pinacoid and pyramidal terminations and small prism faces. The second generation is a thin, nearly opaque white coating on first generation crystals. Gemmy indigo-blue fluorapatite formed the third generation which covers the pyramid and pinacoid faces of second generation crystals. Growth of third generation fluorapatite began along the edge formed by the intersection of the pyramid (*x*) and prism (*m*) faces of each crystal. This formed a raised blue rim which extended parallel to the *c* axis in a hopper growth and then grew inward to eventually fill in the hopper. In intermediate versions, this resulted in a blue crystal with white-bottomed cavernous terminations and a white equatorial stripe. As third generation growth continued, the cavernous termination closed, resulting in a tabular blue fluorapatite crystal with a white equatorial stripe. The final stage of development was observed in only a few specimens as elongate pris-

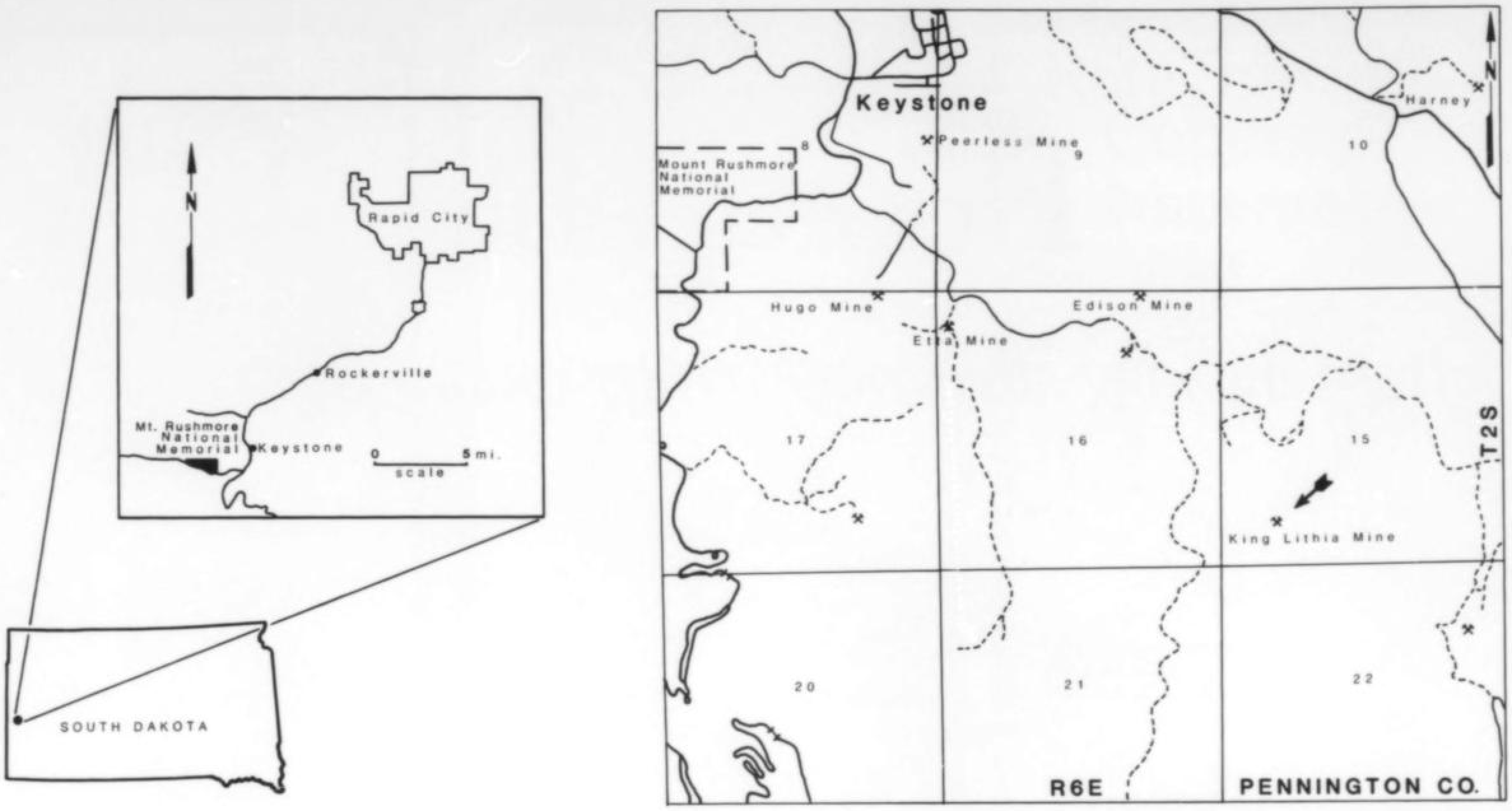

Figure 1. **Maps showing Keystone, South Dakota, and vicinity.**

matic crystals with white equatorial stripes. These stages of crystallization are represented by the crystal drawings shown in Figures 2 through 6, which were computer-generated using the SHAPE program (Dowty, 1981).

Since the blue third-generation fluorapatite grew as an extension in the *c* direction of second generation crystals, it can be seen that the diameter of the final crystal was not altered by third generation growth.

In addition to well-formed single crystals, aggregate crystals composed of dozens of individuals stacked together in hexagonal arrays were found. These are usually composed of elongated third-generation crystals stacked parallel to the *c* axis, although aggregates of first- and second-generation crystals were also found. Another habit commonly found was radiating rosettes up to 1.3 cm in diameter. Second and, less commonly, first-generation individuals form these rosettes.

Several other colors and habits of fluorapatite were encountered within a meter or two of the major pocket zone. These included lustrous white cockscombs; clear, tabular, sea-green individuals; and tabular to prismatic, lavender to amethystine purple clusters and singles. Of most interest are the complex forms of the deep purple crystals which exhibit some unusual faces and uncommon proportions. These purple crystals were commonly associated with the second-generation rosettes mentioned above. Several distinct color zonations were observed in single, elongated, prismatic, purple crystals. Milky centers in some of these specimens are identical to the tabular, white, second-generation crystals observed in the indigo-blue specimens. Unlike the blue crystals, however, the purple fluorapatite completely surrounds the white center.

CHEMISTRY

Fluorapatite crystals were analyzed by electron microprobe analysis using an MAC 400 electron microprobe coupled with a KEVEX 5100 energy dispersive spectrometer system. Probe spot size was approximately 5 μm in diameter, and traverses across a number of zoned apatite crystals were made in 0.1 to 0.5 mm intervals. Replicate analyses on Smithsonian apatite standard 10421 indicated a precision of about $\pm$ 1% of the reported value for CaO and P_2O_5 and approximately $\pm$10% for MnO, Cl and SiO_2. Accuracy is similar for all elements.

Average chemical analyses are reported in Table 1. P_2O_5, CaO and SiO_2 for zoned apatites vary only within the limits of determined precision and are therefore considered to be invariant. Variations in MnO and Cl, however, show a strong relationship to zonation. Blue zones contain high concentrations of MnO, up to 2 weight %, and only trace amounts of Cl. White zones contain relatively high concentrations of Cl, up to 1.5 weight %, and moderate amounts of MnO. (The translucent, milky color of this zone is produced by abundant micro-inclusions.) Colorless, transparent cores contain only trace amounts of Cl and variable but low amounts of MnO compared to other zones. Chemical zonation within apatite crystals indicates a temporal variation in the chemistry of the fluid from which the crystals grew. MnO content in the fluid gradually increased throughout the period of crystal growth. The intermediate white zone documents an abrupt increase followed by an equally abrupt decrease in Cl content, accompanied by a short period of rapid grain growth.

Purple crystals show similar amounts of CaO and SiO_2 compared to zoned crystals, however P_2O_5 is distinctly higher (Table 1). These purple crystals are homogeneous throughout and contain abundant MnO. Cl, however, was not detected in even trace amounts in any of the purple grains analyzed.

POCKET ZONATION

Crystals representing every stage of development described were encountered in the pocket zone. First-generation crystals were common in the peripheral zones of the mineralized area. Second-generation crystals, typically occurring as aggregate roses, were found in the inner portions of the pocket zone. In the central vugs of the pocket zone, all three generations were represented as single crystals having three color zones.

A cross-section of the pocket zone mirrors the growth history of

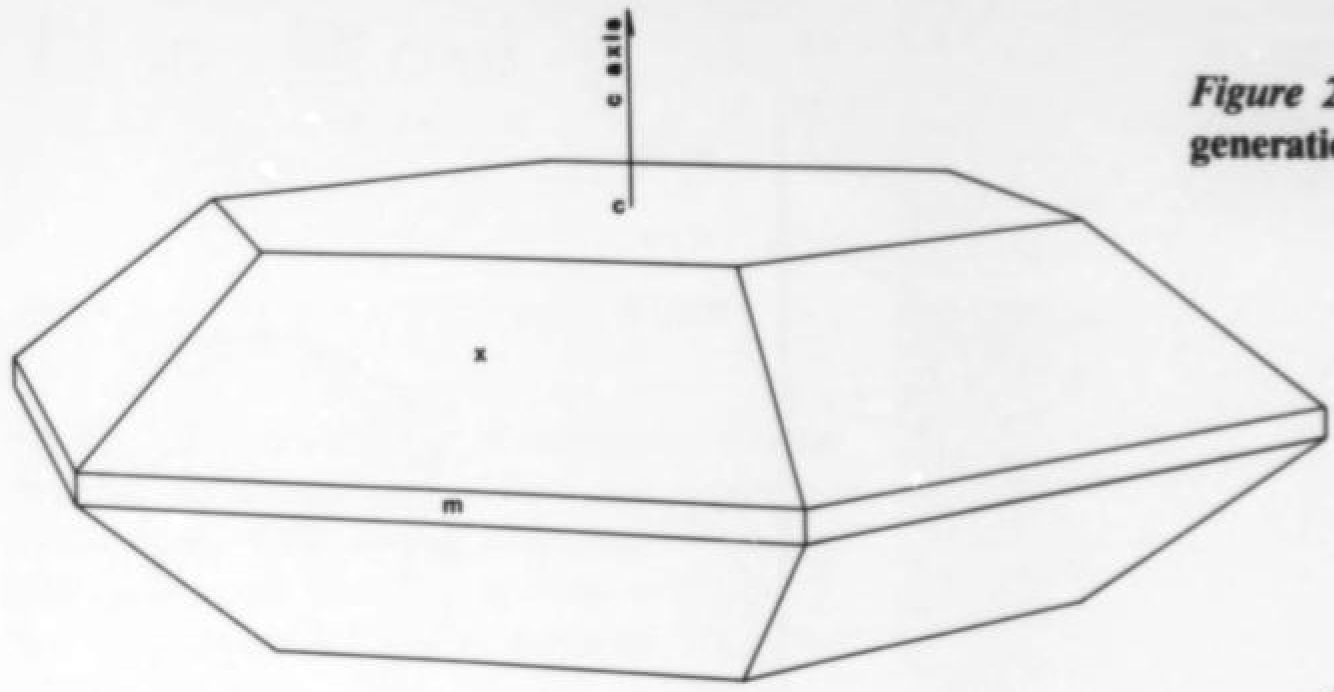

Figure 2. **Tabular, translucent, colorless first-generation fluorapatite crystal.**

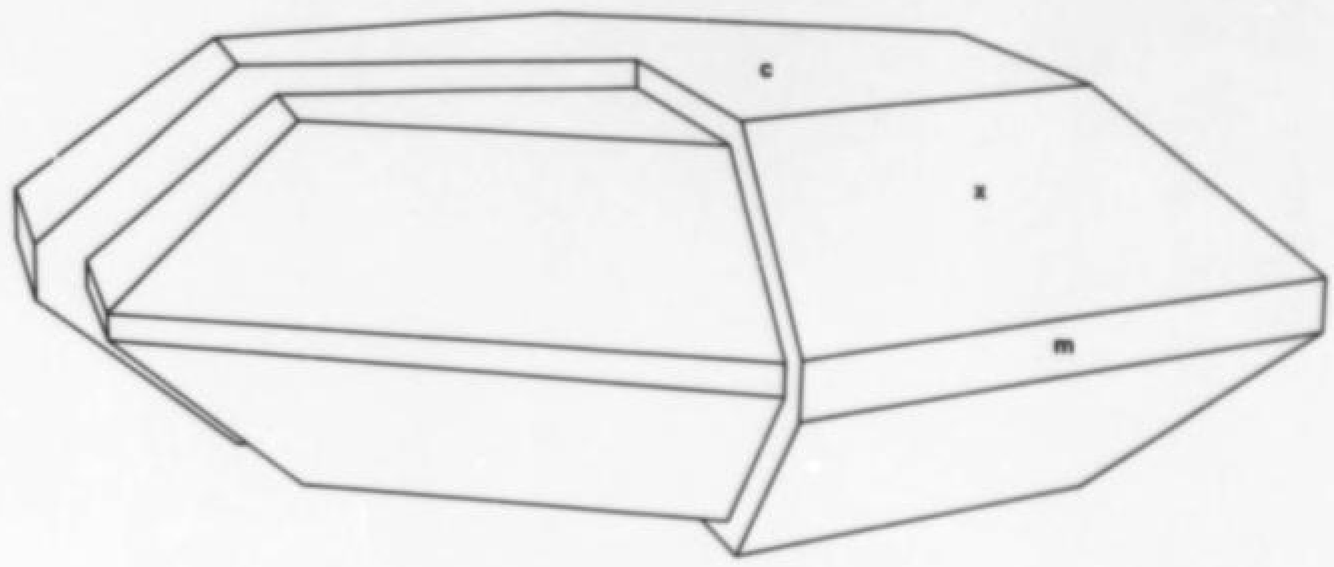

Figure 3. **Partial cutaway view of opaque, white, second-generation crystal enclosing first-generation growth.**

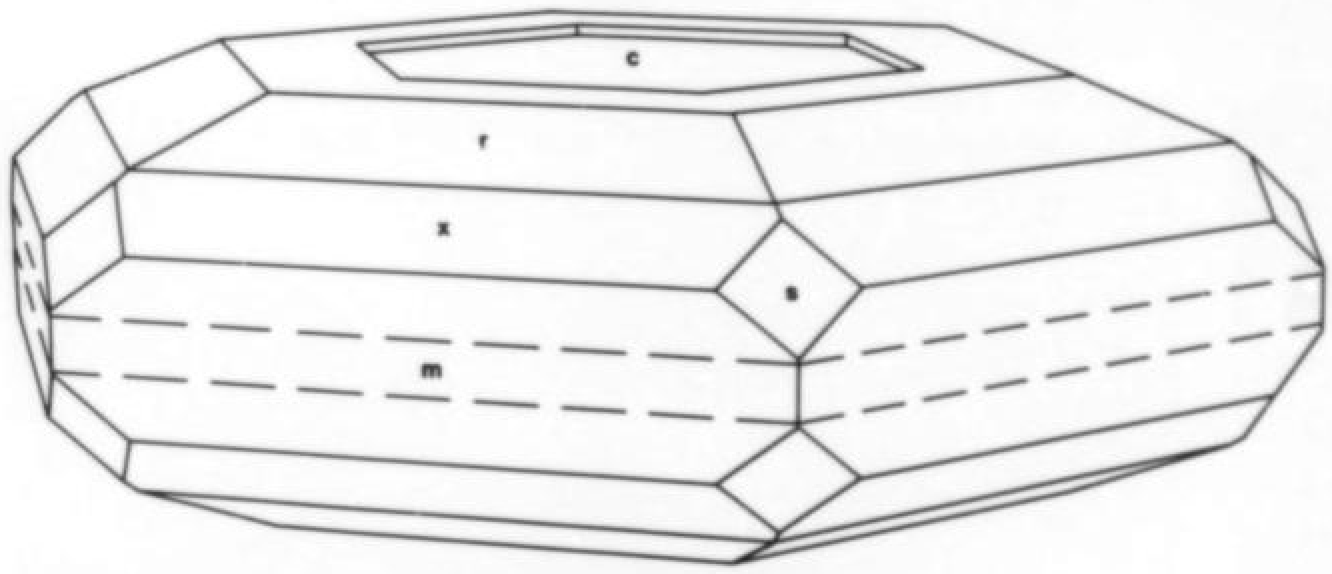

Figure 4. **Indigo-blue third-generation crystal at intermediate stage of growth. Note that the base of the cavernous termination is formed by the *c* face of the enclosed second generation. The white stripe in *m* faces caused by exposure of second-generation growth is shown bordered by dashed lines.**

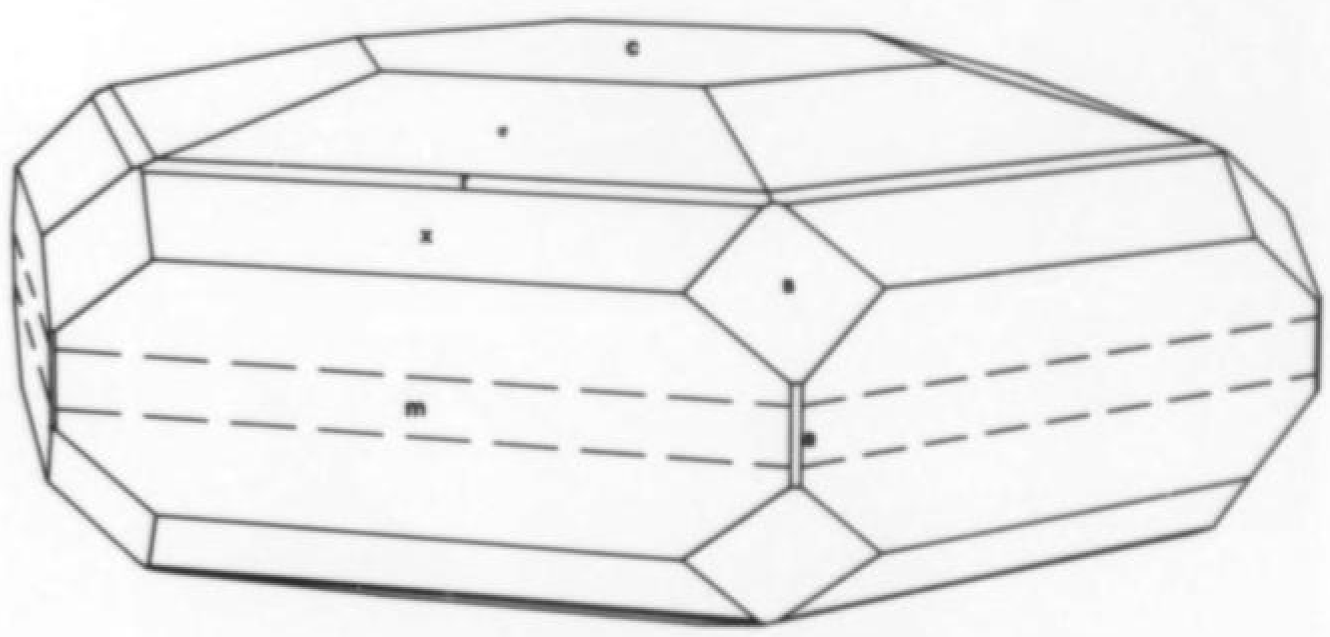

Figure 5. **Indigo-blue third-generation crystal at advanced stage of growth. The white stripe in *m* faces caused by exposure of second-generation growth is shown bordered by dashed lines.**

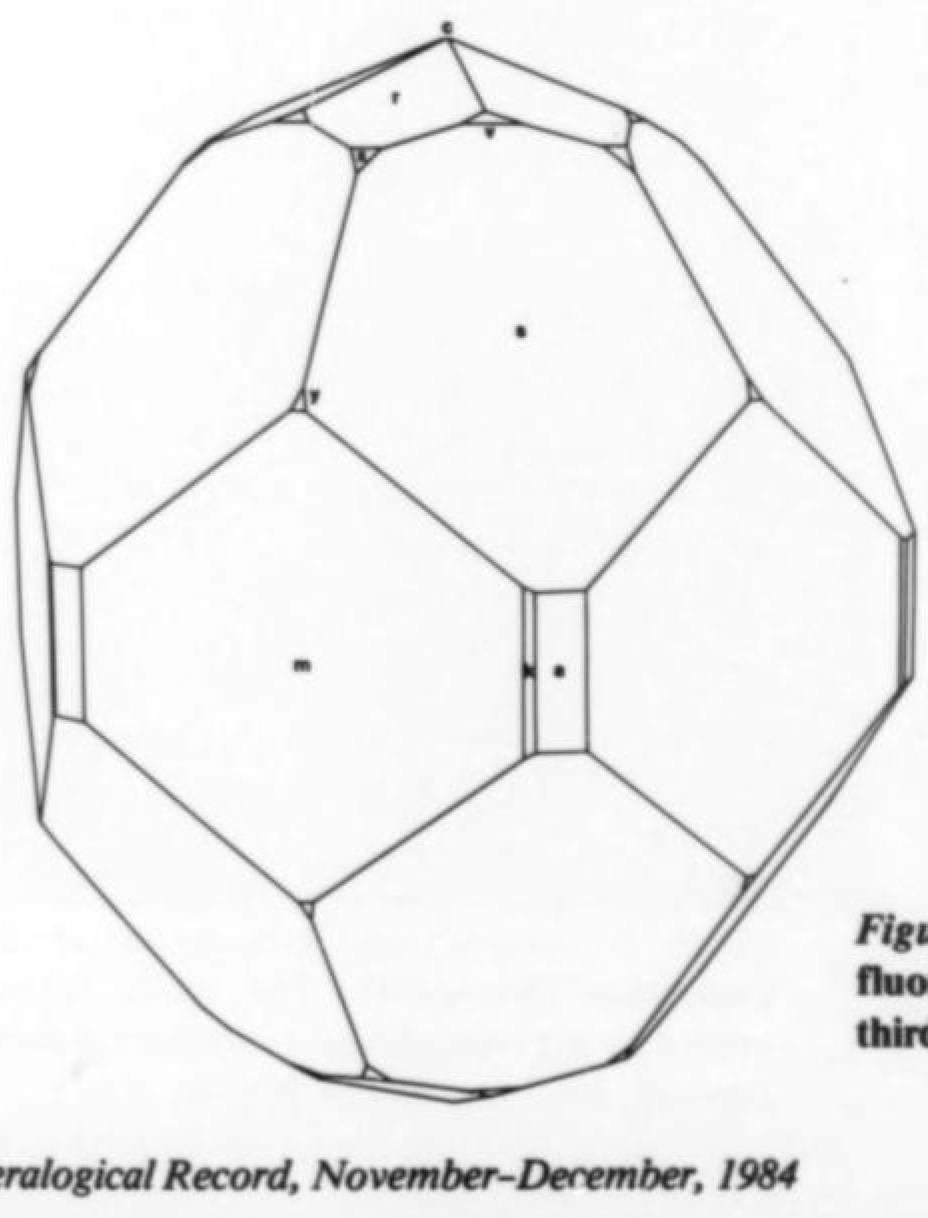

Figure 6. **Complex amethystine purple fluorapatite crystal. This appears to represent a third or fourth generation of growth.**

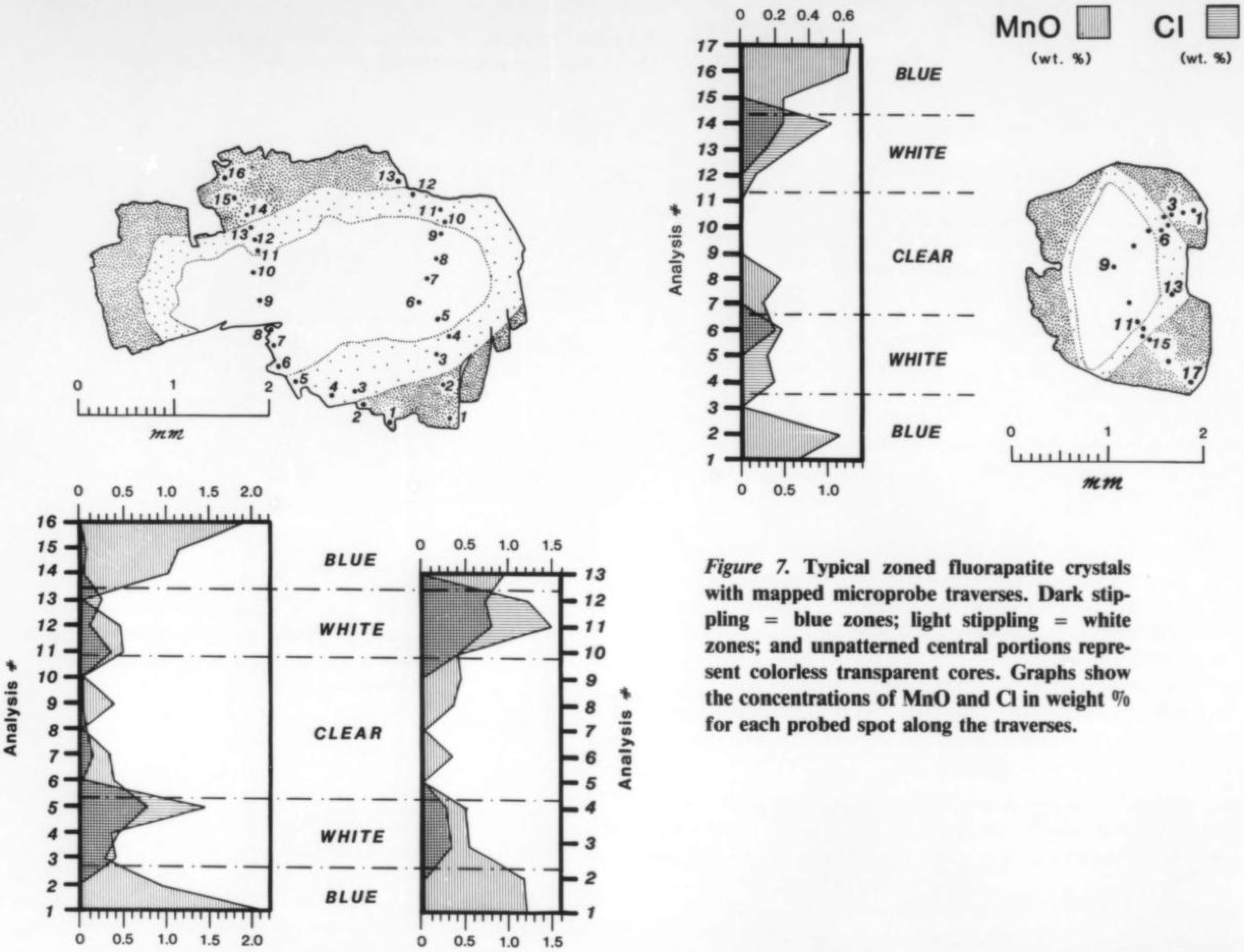

Figure 7. **Typical zoned fluorapatite crystals with mapped microprobe traverses. Dark stippling = blue zones; light stippling = white zones; and unpatterned central portions represent colorless transparent cores. Graphs show the concentrations of MnO and Cl in weight % for each probed spot along the traverses.**

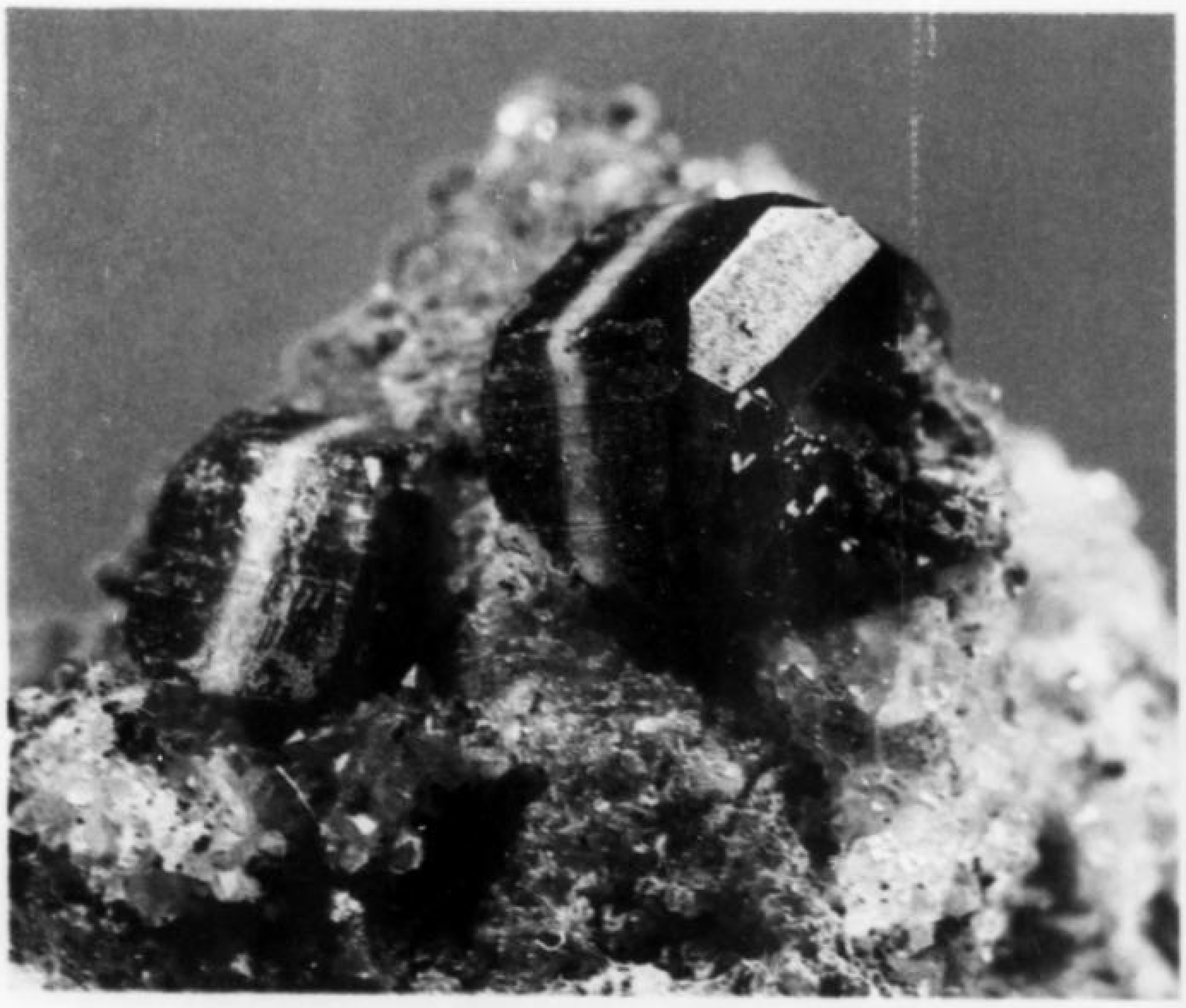

Figure 8. **Indigo-blue third-generation fluorapatite crystals with cavernous terminations. White stripes are caused by partially enclosed second-generation growth. The large crystal is 3 mm long. Photo by Debra Wilson.**

Figure 9. **Complex aggregate crystal of third-generation fluorapatite. The milky center is caused by enclosed second-generation growth; 6 mm tall. Photo by Debra Wilson.**

Figure 10. **Indigo-blue fluorapatite crystal showing white stripe and white-based cavernous termination. This crystal is intermediate-stage third-generation and corresponds to Figure 3. The large crystal is 6 mm in diameter. Photo by Debra Wilson.**

Figure 11. **Single sheaf-like aggregate crystal of advanced-stage third-generation fluorapatite. Note that the *m* face of the second generation growth forms a broad white stripe while the pyramidal termination is visible through the transparent indigo-blue third-generation growth. The crystal is 6 mm long. Photo by Debra Wilson.**

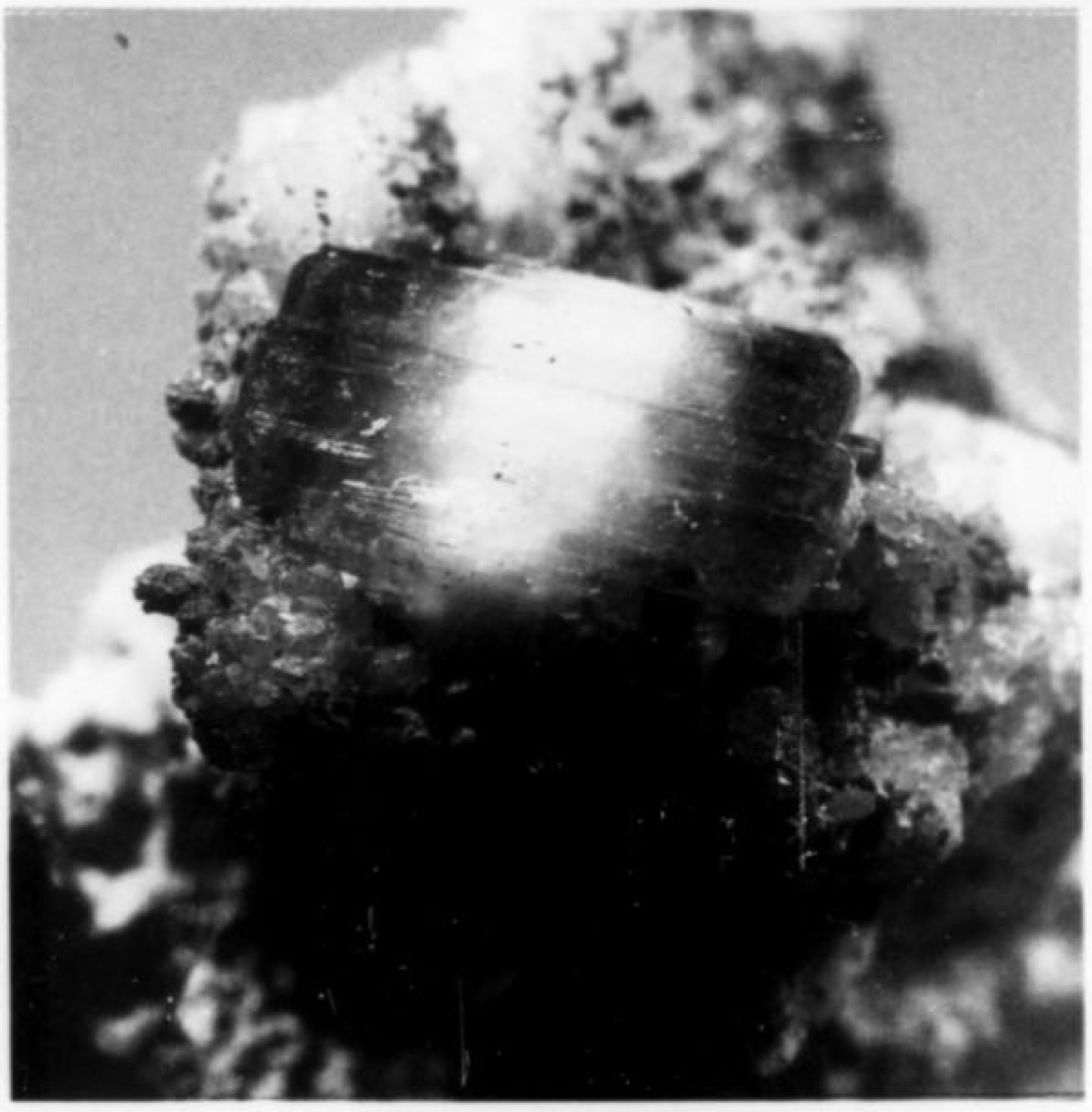

Figure 12. **Indigo-blue third-generation fluorapatite crystals with white stripes caused by partially enclosed second-generation growth. The large crystal is 3 mm thick. Photo by Debra Wilson.**

Table 1. **Microprobe analyses of King Lithia mine fluorapatite.**

	Blue (N[1] = 18)		Zoned Apatite White (N = 26)		Clear (N = 18)		Purple (N = 14)	
	X[3]	S[4]	X	S	X	S	X	S
[2] SiO_2	0.26	0.025	0.27	0.023	0.30	0.024	0.25	0.022
P_2O	41.56	1.12	41.39	0.90	41.72	0.90	42.90	0.53
CaO	53.91	0.39	54.28	0.55	53.94	0.55	54.18	0.48
MnO	1.21	0.44	0.40	0.29	0.21	0.29	1.15	0.27
Cl	0.01	0.02	0.43	0.39	0.01	0.39	0	0
Total	96.95		96.77		96.18		98.48	
OH, F[5]	3.05		3.23		3.81		1.52	

[1] N = Number of individual analyses.
[2] The small but consistent amount of Si found is assumed to substitute for P in tetrahedral sites.
[3] X = Mean oxide value in weight %.
[4] S = Standard deviation in weight %.
[5] OH and F calculated by difference.

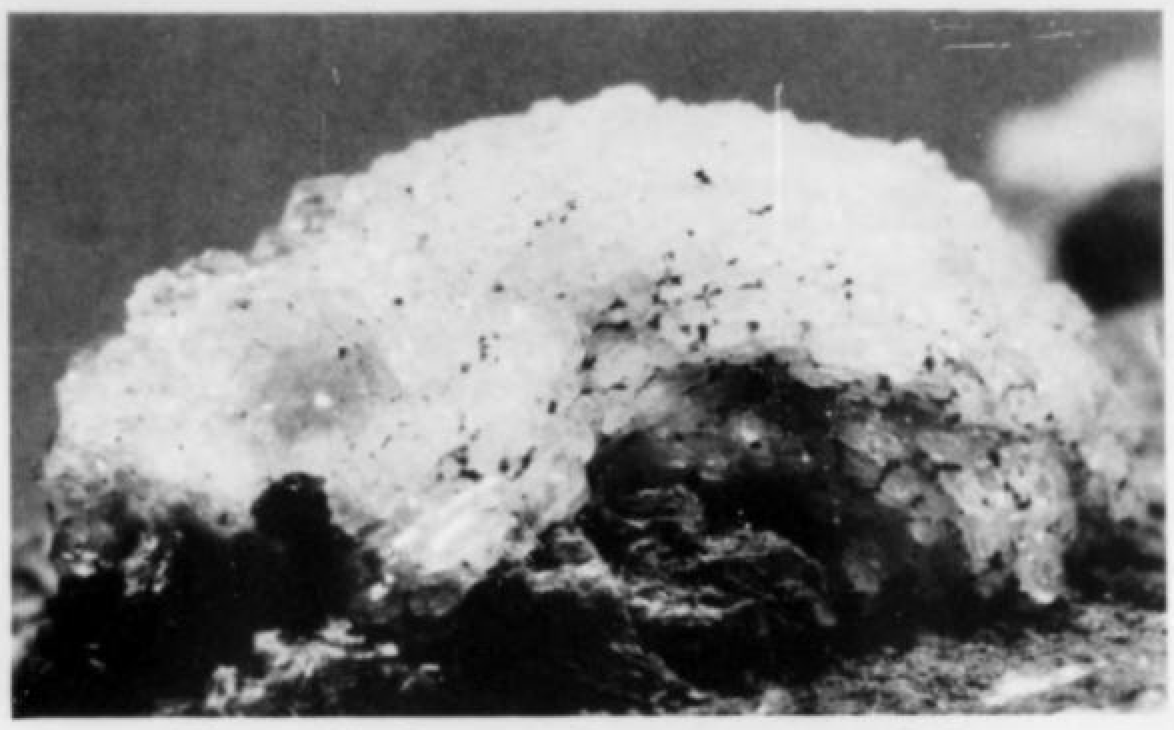

Figure 13. **Rosette of transparent, colorless fluorapatite crystals. Individual crystals average 1.5 mm. Photo by K. E. Schafer.**

Figure 15. **Complex amethystine purple fluorapatite crystals displaying an uncommon combination of unusual faces and proportions. A line drawing of this crystal is shown in Figure 6. The large crystal is 6 mm long. Photo by K. E. Schafer.**

a single complete crystal. Mineralization in the fringe of the pocket zone was arrested at an early stage of apatite formation, while crystals in the center of the pocket area grew to completion. This suggests that when prospecting for apatite crystals in this type of pegmatitic setting, occurrences of early stage poorly formed crystals should be noted. While not usually of specimen grade themselves, they may represent the edge of a mineralized pocket containing more attractive and exotic specimens a few meters away.

ACKNOWLEDGMENTS

The authors wish to thank Eric Dowty for the use of his computer program "SHAPE" and GeoSpectra Corporation for the use of its computer facilities. Special appreciation is expressed to Willard L. Roberts whose highly contagious energy and enthusiasm inspired this study. Debra Wilson and K. E. Schafer provided the specimen photography.

Figure 14. **White second-generation fluorapatite crystal with blue third-generation growth fringing the edges formed by the intersection of *x* and *m* faces. The crystal is 3 mm across. Photo by K. E. Schafer.**

Figure 16. **Fluorapatite rosette composed of milky white second-generation crystals; 1 cm in diameter. Photo by K. E. Schafer.**

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Notes from Italy

by **Gianni Porcellini**

Southwestern Sardinia

I'm pleased to say that, judging from the response, my first column on Italian minerals (January-February 1984) appears to have proven interesting for many readers. Consequently I'm back, this time to say something about the minerals of Sardinia.

Sardinia is a large island, almost exactly the size of New Hampshire, located in the middle of the western Mediterranean. Like the slightly larger island of Sicily, it is Italian soil, though separated from the mainland by nearly 200 km. The Sardinian coastline and clear blue waters are among the most beautiful in the Mediterranean. And Sardinia's people have an interesting history, as one might guess from the many ancient *nuraghi* or conical dolmens scattered about the isle. Much of Sardinian history centers on the hundreds of mineral deposits worked during the last 3000 years, primarily veins containing lead, zinc, barite, fluorite, copper, silver and molybdenum. Many of these workings are concentrated in the southern end of the island, but all are currently inactive and abandoned due to the depressed Italian mining industry.

It is still possible to obtain good mineral specimens in Sardinia by visiting some of the old miners still living in the area. These gentlemen are poor but friendly and generous. High prices are rarely asked, and in fact they sometimes insist on presenting you with a specimen as a gift rather than letting you pay for it.

For this installment I will deal only with the southwestern corner, a region known as Iglesiente. (Next time I'll cover the northern side, which is very rich in volcanic minerals.) Among the small mining towns one can visit are Iglesias, Montevecchio, Gonnesa, Guspini, Arbus, Fluminimaggiore, Nebida, Masua, Bindua, Dumusnovas and Carbonia. It is also worthwhile to visit some of the thousands of mine dumps in the area, where interesting microminerals can be collected. The most famous are the Monteponi, Montevecchio, Malfidano, Ingortosu, Gennamari, Arenas, Tiny, Sa Duchessa, Santa Lucia, San Giovanni, Punta Sa Torre, Seddas Moddizis, Monte Acqua, Is Murvonis, Barega, Villamassargia, Masua, Nebida, Su Corovau and Baraxiutta mines, among others.

In past years I have sometimes vacationed on Sardinia, most recently in 1982. Springtime and autumn are the best seasons in which to visit; summers tend to be very hot and dry.

Among the first specimens I was offered in Sardinia were some long prismatic to acicular pyrite crystals from the Monteponi mine near Iglesias. The pyrite lay on a matrix of pinkish dolomite crystals about 4 cm square, priced at nine or ten dollars each. One specimen, about 10 cm across, was priced at $20, whereas thumbnails ran two or three dollars . . . certainly reasonable. This pyrite looks very much like millerite, and the miners sell it as millerite, but it's definitely very nice pyrite.

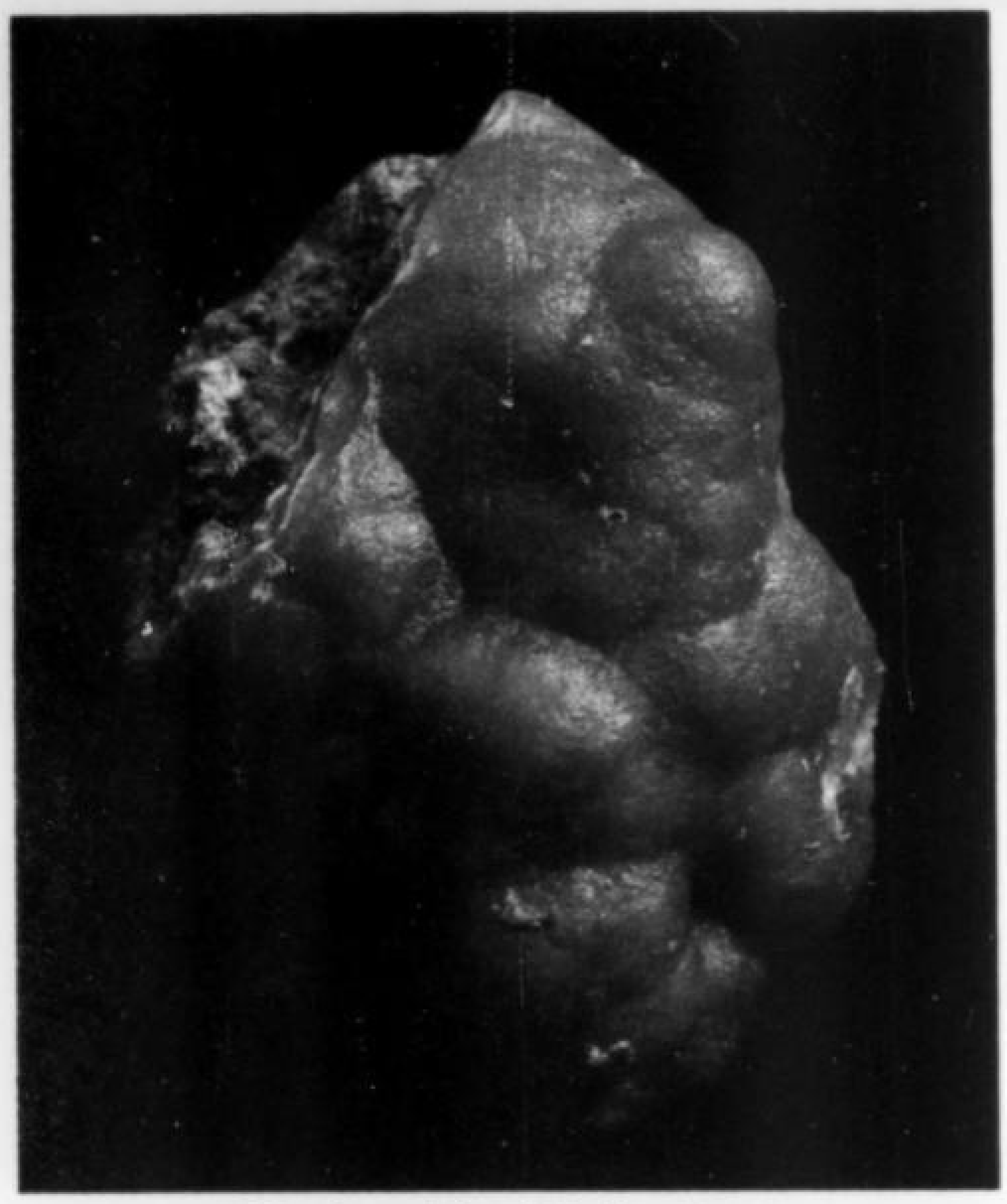
From the same locality come excellent specimens of bright, lustrous, cubic and cuboctahedral galena to about 1 cm on an edge. The crystals occur on a matrix of white dolomite crystals. A 5 x 8-cm specimen having many crystals was priced at $18, and a smaller one about 3 x 4 was six dollars.

Monteponi is famous for large, lustrous, colorless anglesite crystals in vugs in galena. A specimen having one 1-cm crystal on a 4 x 5-cm matrix was offered for $17; thumbnails and micros go for two or three dollars. Anglesite is becoming harder to obtain, though, and will probably cost more in the future.

The famous green anglesites from the Montevecchio district are now almost impossible to find. Recently I saw a few micro and thumbnail specimens, the crystals up to perhaps 5 mm, offered at the spring Bologna show for $50 to $60.

And what can I say about Sardinia's most famous specimens: phosgenite crystals? I almost haven't the heart to quote you prices for these extremely rare beauties. At the house of one miner I saw two specimens, and was given to believe that he loved these crystals more than his own wife. Before he would discuss a price, he went on at some length about how the lower levels of the Monteponi mine are flooded with seawater and permanently closed, etc., etc. Slowly he enunciated that the price might be around $600 . . . or more.

On the following day I visited some miners near the town of Domusnovas. Very fine, cubic crystals of purple fluorite 1 cm on an edge were available, some with small, elegant tufts of colorless



Hemimorphite, Iglesias; 5 cm.

hemimorphite. The prices were very reasonable; a 10-cm specimen (4 inches) cost about eight dollars, and nice miniatures could be had for a mere two dollars. Miniatures of pale yellow hemimorphite crystals on white hemimorphite crystals were four to five dollars. Another miner had some splendid cerussite specimens, among the nicest micro cerussite to be found in Europe. Milky white crystals to 5 mm, having a variety of forms and habits, are perched on dark brown limonite. The beauty of these specimens is that the cerussite crystals have formed as isolated individuals scattered across the matrix, making for good thumbnails and especially micromounts, and priced at only three or four dollars each. According to the miner, the cerussite was collected at the old Su Corovau mine near Domusnovas.

Some days later I visited the old Sa Duchessa mine where I found some microcrystals of connellite (a first for this mine), blue botryoidal smithsonite, tabular to bipyramidal crystals of yellow wulfenite, nice reticulated cerussite, malachite tufts, cyanotrichite, greenish brown garnets, chrysocolla and brochantite on the dump (written up in more detail in the Jan.-Mar. 1984 issue of *Rivista Mineralogica Italiana*).

On a particularly hot day I decided it might be nice to visit the beach at Buggeru, not far from Fluminimaggiore, for a swim. Late in the afternoon I picked over the nearby dumps of the Santa Lucia fluorite mine. Fluorite is common there in crystals to about 1 cm, as is attractive, tabular to prismatic, colorless barite. A few rare crystals of fluorite were found having a cube-octahedron-dodecahedron combination. Fluorite can be found here in a wide variety of colors: white, yellow, pale blue, purple, pale green, and also red to brown from limonite inclusions. Other minerals from the dumps include colorless, platy hemimorphite on fluorite and quartz, and "nail-head" calcite crystals to 2.5 cm.

The Barega mine, not far from Iglesias, is famous for large, yellow barite crystals. Smaller barite crystals have been found in many outcrops on a small hill near Villamassargia. While near Iglesias I had time to visit another small mine: the Seddas Moddizis mine. Getting there was difficult because the mine has been closed for many years and the old mine road required some hard work with a shovel before it was passable. Only a few small dumps are worth searching, but they did yield some good microminerals. Most common is red sphalerite on dolomite; more rare is pale brown cerussite. Complex crystals of galena, some cuboctahedral and some rather tabular in habit, could be found, and quartz was common. Rare groups of hemimorphite on dolomite turned up, as well as some extremely rare tufts of dundasite.

Dundasite also occurs at another mine in the area: the Punta Sa Torre mine near Gonnesa. White tufts and balls of dundasite are found on cerussite crystals, in some cases associated with dark, acicular plattnerite and pale green pyromorphite. Unfortunately the matrix is rather friable.

Some readers wrote to me asking about Italian dealers in cabinet-size specimens. There are few dealers in large specimens in Italy, although people like Gian Carlo Fioravanti (19/20 via Pie di Marmo, Rome) and Alfredo Ferri (C.so Vercelli, 7, 20144 Milan) come to mind. Of course many private collectors sell specimens, but they prefer to do so in their own homes and are not accustomed to mail order. On the other hand, I can provide plenty of recommendations regarding thumbnail and micromount dealers; just write to me if interested.

Until next time, I send you friendly greetings from Old Europe!

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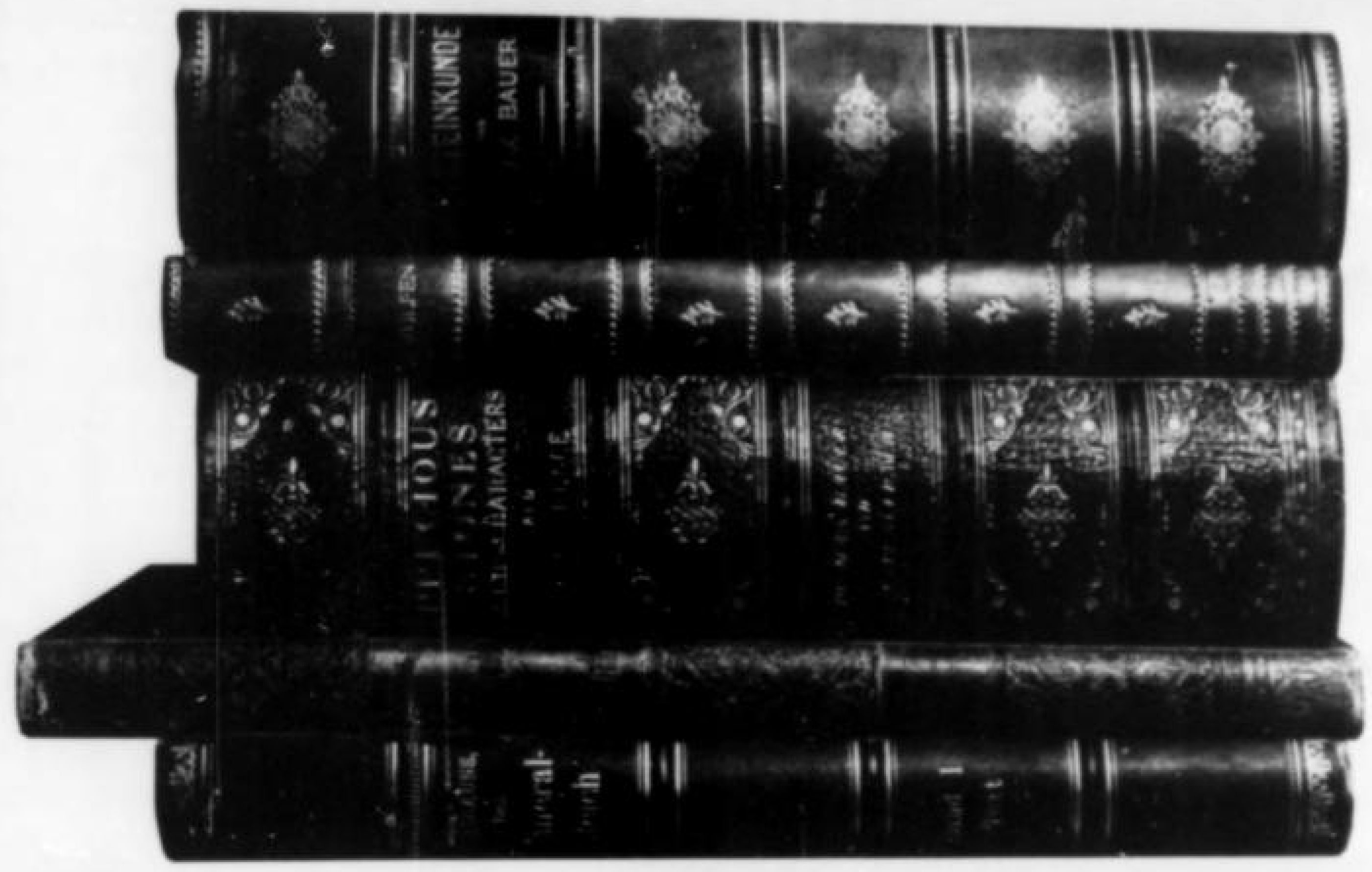
47047 Rimini, Italy



Book Reviews

Gem & Crystal Treasures by Peter Bancroft. Published jointly (1984) by Western Enterprises and Mineralogical Record Inc., hardcover, 488 pages, 320 color photographs, 667 black and white photos. Available from Mineralogical Record Book Dept., P.O. Box 1656 Carson City, Nevada 89702, $60 plus $4 postage. Signed and numbered leather edition (quantity limited), $225 plus $5 postage.

Gem & Crystal Treasures by Peter Bancroft is the kind of book one sees in a bookshop, takes in hand, riffles through some pages, and decides immediately that it is worth taking home. It's not even necessary to be particularly interested in gem and mineral crystals, or to know the author, to arrive at this happy conclusion. The sad fact is, there are so few "fun" books in mineralogy (unlike the abundant supply for most other hobbies) that the mineral collector hardly knows how to react to one when it appears. This is a "fun" book. It is full of legend, lore, speculation, personal experience and collecting expertise.

The organization of the book is almost encyclopedic. One hundred localities, all producers of specimens of particular interest to collectors, are treated. One might ask, "Why not 200?" or "Why not 87?" or some other number. Obviously, 100 is a nice number so why not stop there! There is a rough order of treatment of the 100, starting with 24 United States occurrences, 10 Brazilian occurrences clustered about midway, and Eastern European and Russian localities bringing up the rear. The prologue, consisting of a testimonial to the prospector, plus addenda consisting of a map marking the location of all 100 occurrences, an important list of suggested collateral readings and a detailed index round out the contents.

The arrangement of the material might be expected to cause problems of "dead spots" in the distribution of photographs with which the book is well peppered. Obviously, care has been taken to see that this doesn't happen. The book remains attractive throughout, although the impact does weaken somewhat toward the end (reader exhaustion?).

Admittedly, there are questions of selection which will vex some collectors. For example, why were Paterson, New Jersey, and Westfield, Massachusetts, and Haddam Neck, Connecticut, and French Creek, Pennsylvania, left out? Why were one quarter of the United States occurrences chosen in California and three of those from San Diego County? One can only answer that it is the author's prerogative to make his own choices, and this is as it should be.

The general treatment of each occurrence does vary somewhat in quality, quantity and style. And it is difficult in some cases to distinguish between local storytelling lore and the actual events – fact from legend – since much of the content is based on hearsay rather than recorded fact or personal experience. As is always the case in compendia of this sort, some confusion inevitably arises from the liberal use of earlier publications. But professional mineralogists will find little to quibble about since what mineralogy is included is substantially correct. In his preface the author stipulates that technical data would be kept in low profile. All of these objections are of little consequence if one keeps in mind that the book was never intended to be all-inclusive but is nevertheless the best accumulation of legend, lore and fact about mineral specimen sources ever published and is also an interesting sharing of one man's personal interaction with this accumulation.

The photographs – and there are many of them – capture, carry and hold the reader's interest. I count 985 excluding the beautifully illustrated end-papers. They run the full gamut from the sublime to the ridiculous. My own photographic tastes don't run to prospectors half eaten by coyotes, the hanging of George Butts or the mummified miners' daughters from Guanajuato. And yet, I was delighted to see famous author Dr. Frederick Pough scrabbling in the dirt, noted collector James Minette bottoms up in a borax sump, photographer Erica Van Pelt overwhelmed by a monstrous mineral specimen, and editor Anne Voileau of *Monde et Mineraux* fraternizing with the natives of Mibladen, Morocco. Such treasured snapshots are now saved for posterity. It is amazing how most of the assembled photographs are new to mineral hobbyists and have not become hackneyed and shopworn by frequent earlier use in other publications.

The crowning glory of the book, however, is the remarkable suite of color photographs of mineral specimens. In recent years, most serious collectors have been delighted to see such fine photographs appearing with increasing frequency. Lee Boltin started the trend with his earlier work in *The Mineral Kingdom* and *The Gem Kingdom*. Now the Van Pelts have established themselves as top masters of the art and technique. Although the quality of the Van Pelt photographs in this book sags a trifle here and there, a number of their works are absolute masterpieces which will stand as mineral "Rembrandts" for all time. As a start, I would like to see the following elected to the mineral and gem specimen photographic hall of fame: tourmaline carving on page 14, the azurite-malachite on page 75, benitoite on page 92, neptunite on page 97, rhodochrosite on page 182, tourmaline on page 191, indicolite on page 208, tourmaline on page 228, rhodochrosite on page 334, sulfur on page 352, pyromorphite on page 365, silver on page 407. These alone seem to me to justify the price of the book. At the same time it is exciting to see equally fine work by other photographers as with the zincite photograph on page 21 and stibnite on page 256 by Dane Penland of the Smithsonian, the tourmaline on page 107, the aquamarine on page 233 and the crocoite on page 253 by Earl Lewis, the softly done rose quartz on page 223 by Karl Hartmann, turquoise on page 288 by S. Rebsamen, sulfur on page 353 by Henry Janson, to say nothing of the best stephanite photograph in existence on page 413 by Frantisek Tvrz. Some of the specimen ownership data given in the photo captions is apparently outdated, but this is the result of a decision made early on to credit the person who was the owner at the time the photograph was made (he being the one who risked all that handling of the specimen and in many cases arranged and paid for the photograph); a number of the pictured specimens have by now moved on to other collections, particularly the Perkins Sams collection.

Making too much of small quibbles regarding *Gem & Crystal Treasures* would be a great mistake. Rather, all of us will want to own a copy. Most of us will ultimately feel we owe Dr. Bancroft, and those he graciously acknowledges, a vote of thanks for some highly enjoyable mineralogical reading and a valuable addition to our mineralogical libraries.

Paul E. Desautels

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***Grundwissen in Geologie* (1984) by Martin Stirrup and Hans Heierli. Published in German by Ott Verlag Thun. Originally published in English (1980) under the title *Geology, the Science of the Earth,* by Cambridge University Press, Cambridge, England. Hardcover, 276 pages, DM 49.00 (overseas postage not included). Distributed by Franckh Kosmos Verlagsgruppe, Postfach 640, D-7000, Stuttgart 1, West Germany.**

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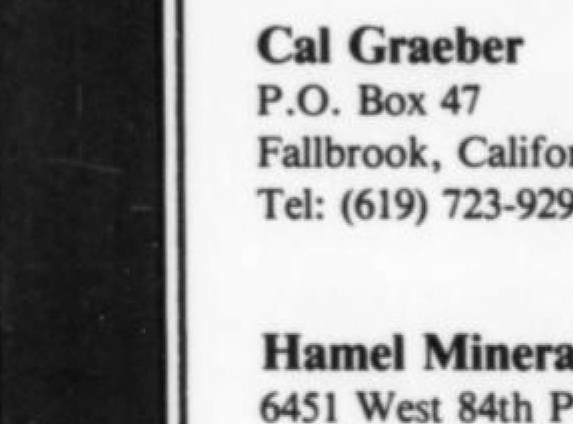

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