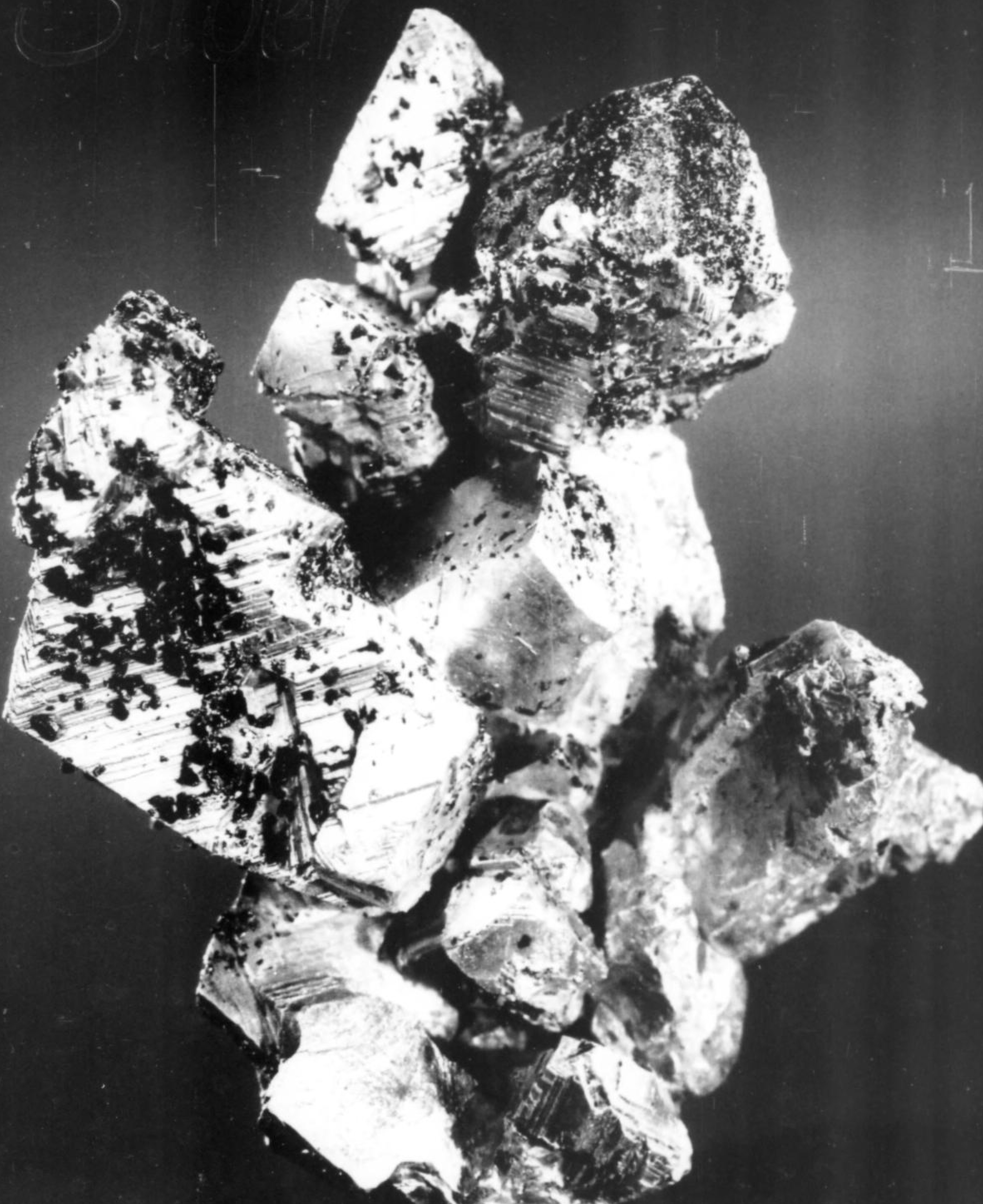
Silver



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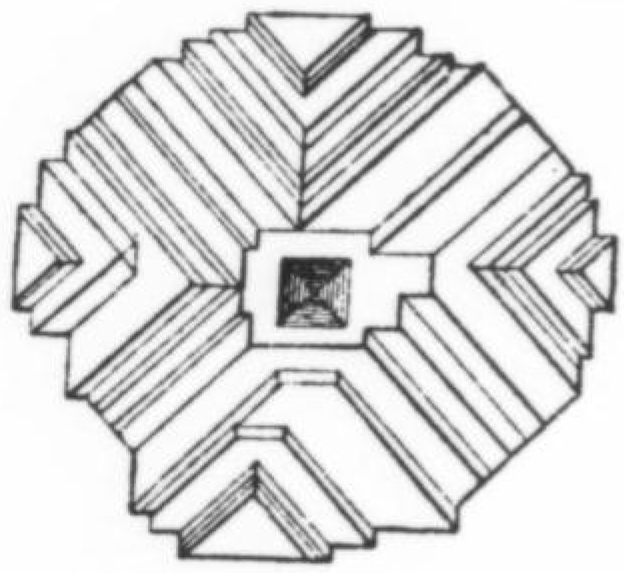
the Mineralogical Record ®

Silver-1

the second special issue in the Precious Metals Series

COVER: SILVER crystals, 3.3 by 4.5 cm, from the Kongens mine, Kongsberg, Norway. (See the article in this issue.) Keith Proctor collection; photo © by Harold and Erica Van Pelt.

notes from the EDITOR



SILVER ISSUE

Among the precious metals, gold has always generated the greatest excitement. Following close behind, however, is silver. Though today only about 2% as valuable by weight, silver was nearly on a par with gold in the ancient world, and still enjoys a high level of popularity. Its appeal is subtle and difficult to define. Certainly there are many other white metals, but the eye discerns a warm richness to silver that all the others lack. Furthermore, silver has been found as superb specimens at many localities throughout the world; mineral collectors have little trouble locating enough specimens on the market to satisfy even the most feverish obsession (providing the budget holds out).

In this issue we take a look at some of the most famous and interesting localities for native silver. Of course there are hundreds, perhaps thousands, of other noteworthy occurrences . . . special issues such as this can never approach completeness. But the localities covered here comprise a good start, and plenty remain for future issues.

Unlike gold, silver forms the basis for an extensive array of additional species (roughly five times as many, in fact), many of which are very attractive and collectible. Whereas we were able to review the gold-containing minerals in the Gold Issue (vol. 13, no. 6), a similar treatment of the silver-containing species currently in preparation promises to take up much of a future special issue all by itself! So, as I said, the current issue is devoted to native silver localities only, and at least two future issues will be devoted to the silver-containing minerals and other important localities not specifically restricted to those famous for native silver.

Readers should find this issue particularly interesting from a cultural standpoint. These are localities rich in mining history and regional flavor; the old drifts and adits are home to countless fascinating stories of hardship and discovery spanning the centuries. The backdrop of silver mineralogy is clearly every bit as colorful as the history of its golden cousin.

EXTRA COPIES of the SILVER ISSUE

People who purchased extra copies of the Gold Issue a few years ago are now happy they did . . . it's selling for $40–50 a copy. We can't guarantee a similar price increase for the Silver Issue but we can tell you this: the press run is identical to that of the Gold Issue. And we are offering our subscribers a discount on extra copies: 30% off the cover price on prepaid orders of five copies or more (40% off if you can give us a resale number). Write to the Circulation Manager now while we still have copies to sell, and build your own little stash of precious silver!

ADVERTISING YOUR MINERALS

Over the years a great many mineral collectors have decided to try their hand at the mineral business. Most of these people know their way around minerals pretty well. One thing they commonly feel insecure about, however, is advertising technique. After ten years of offering advice and listening to feedback from our advertisers (successful and unsuccessful), I've accumulated a fair amount of practical information on what works and what doesn't. This information is now conveniently available in a free 24-page brochure entitled *Advertising Your Minerals.* Topics covered include: "Your Advertising Goal," "Catching the Eye," "Writing Your Text," "Illustrations," "Creative Approaches," "Refreshing Your Ad," and "Evaluating Ad Success." If you've been wanting to advertise but didn't know where to begin, or if you've been advertising in magazines but not getting the response you think you should, you may find this booklet interesting. Write to me for a copy.

GROUP ADS

You've seen them in the *Mineralogical Record*: advertisements for "Arizona Dealers," "Denver Area Dealers," and "California Dealers." Some readers have been wondering how these ads are organized and run, and how a new dealer might sign up to join one.

It began when Betty Roberts (of *Roberts Minerals*) got to talking with some European buyers in California and found out that they had no idea of the existence or location of many California dealers. They would love to make the rounds, they said, but did not know whom to visit. So Betty organized the first cooperative ad for dealers, and signed up a sufficient number of them to warrant buying *two* full-page ads back in 1982. The experiment proved very successful; the advertisers found they were getting good response for *less* than the cost of our smallest ad, a 1-inch box. Furthermore, the "classified" nature of the ads seemed to amplify the effect.

Since then, two more group ads have joined the ranks. "Arizona Dealers" was originally organized by David Shannon, and "Denver Dealers" is run by Jim McGlasson.

These ads are operated under two possible arrangements. If an outside organizer (like Betty, Dave or Jim) wishes to handle it for the group, he or she collects money from each advertiser, by the deadline, and sends me a single check for our standard full-page six-time rate each year. The more advertisers, the less each person pays.

If, on the other hand, the organizer wishes to be relieved of the work, I will handle the ad at a fixed rate per advertiser, regardless of minor fluctuations in the number of dealers signed up. This rate is still less than the 1-inch box cost, but does not decrease as more dealers are added.

At present I am handling the California and Arizona ads. Interested dealers not currently listed may send a check for $210 to cover six issues, and can be added to these listings at any time during the year (not just when the group's six-time contract comes up for renewal). Jim McGlasson still handles the Denver ad, and may be contacted directly through his address listed there.

What about other geographical areas? It has been suggested that a "New England Dealers" ad might be useful, as well as a "Midwest Dealers" ad and an "El Paso Dealers" ad. I'll be happy to handle these if at least ten dealers (for each ad) will send me the required fee. If an insufficient number sign up, the checks will be returned.

· German Silver ·

an historical perspective on silver mining in Germany

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German mines have been yielding up prodigious amounts of silver for at least a thousand years and probably since Roman times. The mines of Freiberg, St. Andreasberg, Schneeberg, Annaberg and Johanngeorgenstadt, among others, have also produced superb mineral specimens which are now in museums and private collections throughout the world.

INTRODUCTION

German native silver in beautiful crystals, filigreed leaves, dendritic masses and curling wires embellishes countless private and public collections the world over. Today the mines of Germany produce hardly any such specimens, but as recently as 25 years ago important finds were still being made in the ancient mines of Saxony. In this article we present an overview of some of the major mining areas and their history, with emphasis on the specimen-producers.

The total world production of silver in 1979 was 11,000 metric tons (about 350 million troy ounces); this is only 7½ times the total gold production, despite the fact that silver is 20 times more common in the earth's crust. Of the silver and gold being mined today, the vast majority is contained in low-grade ore and is not visible to the naked eye.

Germany (East and West) produced about 80 tons of silver in 1979, less than 1% of the world total. Mining in Europe has been going on for many centuries, and most of the important deposits are now exhausted. Early records indicate that in the late 1400s annual production was around 10 tons; in the 1850s production averaged 38 tons, and an even higher output was reached in 1881–1885 when 240 tons per year were extracted. It should be remembered that mining in previous centuries was largely by hand, in highgrade ores, unlike modern mechanized mining which consumes comparatively huge quantities of lowgrade ore.

Native silver is found most commonly in hydrothermal veins and replacements, including many lead-zinc vein deposits having relatively small amounts of primary silver minerals. Secondary enrichment concentrates silver in the upper zones of these deposits, as at Freiberg and Clausthal.

Other vein systems are richer in silver and poorer in lead, as at St. Andreasberg in the Harz Mountains. Related veins carrying cobalt, nickel, bismuth and uranium also can contain remarkable amounts

Figure 1. **Locations of the major silver-producing districts in Germany.**

of silver, as at Schneeberg, Johanngeorgenstadt, Annaberg, Marienberg (all in Saxony) and Wittichen (in the Black Forest).

A third basic type of silver deposit in Germany has a sedimentary origin. Small amounts of metals in marine deposits have been converted to sulfides by bacterial action, creating black schists. Leaves and sheets of native silver are found rarely along fissures. Mansfeld in Thuringia is at the center of this formation, known as the Kupferschiefer ("copper schist"); mining there, as elsewhere, is centuries old.

Although a few new specimens are still collected at various German mines from time to time, they are so rare that the average collector is unlikely ever to see them. For the most part, specimens on the market today were collected long ago, most likely in the 1800s when there was more interest in preserving "natural history" specimens than in previous centuries. The surprising number of such specimens still available as old collections are recirculated attests to the glorious abundance of silver that once poured from portals and shafts across much of Germany.

THE EARLY SPREAD OF SILVER MINING

Silver is surely among the oldest substances known to man. It is renowned for its lustrous whiteness, a feature from which its many names derive. The Latin *argentum* is cognate with the Greek *argyron,* which in turn is derived from *argos* ("shining"). The Hebrew name (*Khesef*) is from a root meaning "pale."

In the ancient world silver was rarer with respect to gold than it is today; Asian precious-metal deposits were richer in gold by far, and in fact Herodotus, the Greek historian (484?–425? B.C.) makes no mention of any silver mines at all in Asia. He does mention a silver mine in Macedonia that used to yield a talent of the metal (27 kg or 875 troy ounces) *per day* to Alexander I.

The richest and most extensive silver mines of antiquity, however, were those of Laurium in Attica, Greece. Xenophon (434?–355? B.C.) describes them as ancient in *his* time, as testified by dumps of waste rock and slag rivalling natural hills in size. The oldest silver coinage in the world was struck from Laurium silver by Phidon of Aegina around 869 B.C., and yet the district did not reach its peak in activity and production until the time of the Peloponnesian War over 400 years later. By the time of Strabo (63? B.C.–21 A.D.) the mines were considered to be completely worked out of highgrade ores.

Diodorus writes that, after the Laurium ores had run out, a fortuitous discovery was made in distant Spain. An intense forest fire on a certain mountainside had smelted surface ores (probably chlorargyrite?) in place, and the molten silver had run down the

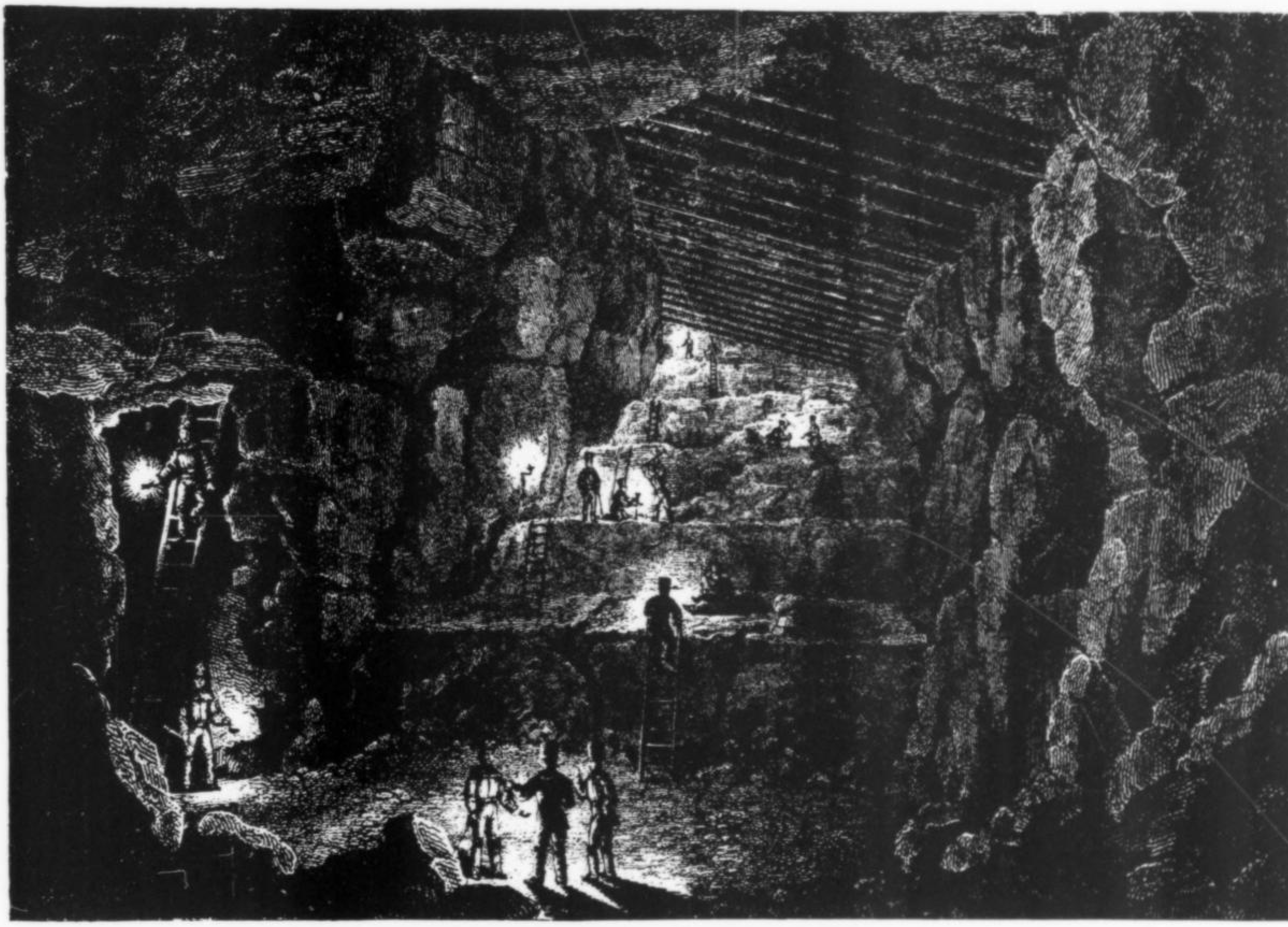


Figure 2. **Interior of a German silver mine, 1830s. Photo Deutsches Museum, München.**

hillside in rivulets before solidifying! Phoenician traders obtained the silver for a trifle from ignorant natives who had no idea what it was; their ships became so overloaded with silver that they used some of it for anchors. Eventually the Phoenicians, via their Western settlement at Carthage, took over mining there (480–206 B.C.), followed by the Romans who operated exclusively with slave labor.

Pliny (62?–113 A.D.) reported that the Romans found some silver in more or less every part of their expanding empire, but the Spanish mines were the richest. Some mines had yielded, for a time, up to 112 kg (3600 troy ounces) daily. The mines are said to have occupied a circle over 60 km in circumference and employed 40,000 miners. Perhaps this richness left the Romans unmotivated to thoroughly prospect and exploit the lands of central Europe, although there is indeed minor evidence of Roman mining in Germany. With the fall of the Roman Empire in 476 A.D., mining in Europe became essentially abandoned for most of the duration of the Dark Ages.

In the eighth century, following the Moorish conquest of Spain, the Saracens reopened many of the old Roman mines on the northern slopes of the Pyrenees and made new discoveries as well, particularly at Zalamea, Constantina and Guadalcanal. Iberian mines once again became the world's chief supplier of silver, but accidental discoveries in and around southern Germany began to reveal additional deposits. The Schemnitz veins were among the first found, perhaps dating back before the Moors. The mines at Kremnitz and Rothausberg were opened in the eighth century, and the famous Rammelsberg deposit was supposedly discovered by a stamping horse (owned by a hunter named Ramm) in the year 968. According to popular tradition, silver was first found in Saxony in the tenth century by men from Halle who noticed silver being turned up by the wheels of their cart.

Despite these comparatively limited discoveries, significant mining on a general scale did not get underway in Germany until around the fourteenth century. Mannix (1913) writes:

> It may be said that mining was practically at a standstill during those dark days of the Middle Ages. Europe was split up into the armed camps of rival feudatories constantly engaged in predatory warfare, during which the stocks of precious metals frequently changed hands. The practical discontinuance of mining was a natural corollary of the social unrest and the general absence of commercial security.

THE BLACK FOREST

Many silver mines were operated in the southern and central Schwarzwald ("Black Forest"), some of them probably known to the early Romans who came through the Rhine Valley nearly 2000 years ago. The deposits consist of hydrothermal veins, generally rather short and narrow.

Wieden

Near the village of Wieden is the old Anton mine, records of which date to 1786 (though mining in the general area began in the

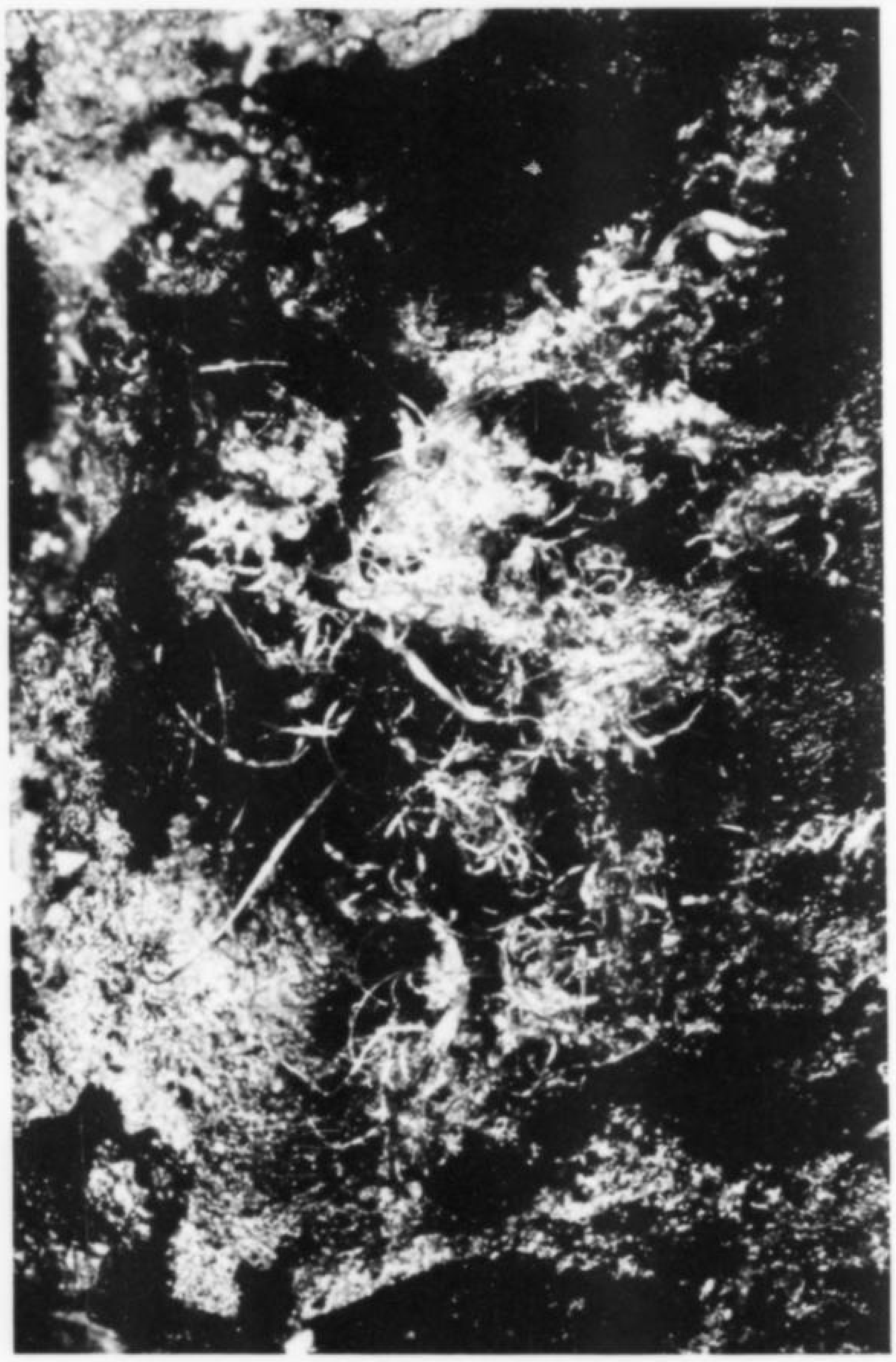


Figure 3. **Fine wire silver on arsenic from the Anton mine, Wieden, in the Black Forest. The view is 1 cm tall. Werner Lieber photo.**

fourteenth century). The deposit consisted mostly of fluorite with small amounts of galena and sphalerite; during the last 50 years, it has been mined for fluorite only. In the 1960s an interesting occurrence was encountered in the deepest workings: a mineralized vein containing native wire silver, proustite, pyrargyrite, stephanite, arsenic and other minerals. The same assemblage was found in the nearby Tannenboden fluorite mine. Both mines have been abandoned for about 15 years.

St. Blasien

Another small mine in the Black Forest is the Gottesehre mine, located near the town of St. Blasien and known since the twelfth century. The deposit is essentially a fluorite-barite vein, but about 20 years ago a single pocket of native silver, argentite and arsenic was found. It proved too small to be of any economic significance, but was quite interesting to mineralogists and collectors. A second small find was made here in 1982.

Wittichen

Considerably more famous are the old mines at Wittichen in the central part of the Black Forest. Wittichen is a pleasant one-hour drive from the town of Offenburg in the Rhine Valley, along the Kinzig River, passing many picturesque villages. The village of Schenkenzell is connected with the old Wittichen monastery by a narrow road. All of the ancient mines are within 2 km of the old church. Mining records indicate dozens of mines in the area, most of them exploiting small veins and stringers 2 or 3 cm in width, but a few on veins up to 50 cm wide. A maximum of about 160 men worked the 20 or so major mines. The oldest workings are the Alt St. Joseph and Gnade Gottes mines, opened in 1517 according to the earliest records on file. These two mines accounted for half the production of the district. Native silver and silver minerals were of first importance, but the Co-Ni-Bi-Ag-U mineralization later was mined for ores to produce the dye cobalt blue ("smalt"), perhaps as early as 1596.

A century later, around 1700, the mines of Wittichen were reactivated, and an extensive system of tunnels and shafts was developed. Mines such as the Adler, Sophia, Neuglück ("new luck") and Simson were opened. The Sophia mine, in 1760, yielded more than 1000 kg of native silver, but such bonanzas were rare. Most of the mines were only modest producers, and all had closed before the end of the 1800s.

Mineral specimens from the Wittichen district are only rarely labeled with a specific mine name; most simply say "Wittichen." Many local collections, public museums and universities as well as private collections across Europe contain Wittichen specimens. Attractively crystallized specimens of native silver are not common; these occurred mostly imbedded in barite and are difficult to expose undamaged. A few enclosed samples show arborescent crystal aggregates, hacky masses and rounded, single crystals of silver up to 2 cm in size. Growths resembling pine trees are among the most aesthetic.

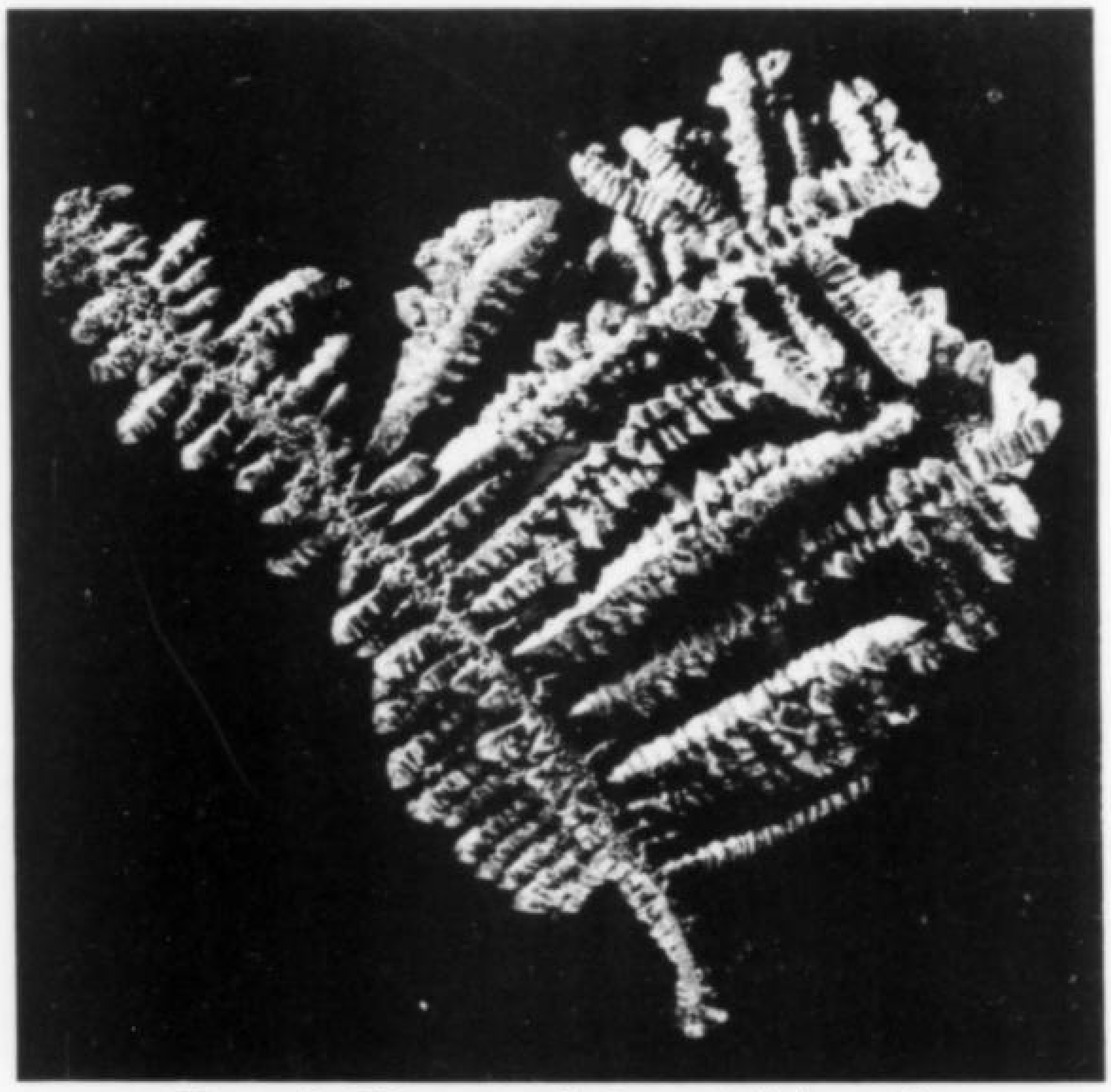


Figure 4. **Silver growth 2 cm tall from the Sophia mine near Wittichen, Black Forest. Werner Lieber photo.**

Sainte Marie-aux-Mines

A brief diversion here is warranted in order to point out the Sainte Marie-aux-Mines area just across the Rhine from the Black Forest, in present-day France. The mineralogy of these old mines, opened in 963 and operated continuously until 1623, is very similar to that of Black Forest mines. Native silver with proustite, pyrargyrite, galena and cobalt-nickel ores were the main products. In 1539 a silver mass weighing 50 kg was removed, and another weighing 250 kg was taken out on 1696. The silver occurred as arborescent aggregates, hairlike masses and wires. Only intermittent, small-scale work has been done here since the seventeenth century, but Sainte Marie-aux-Mines is today the site of a popular annual mineral show.

Figure 5. **Silver crystal group 1 cm tall from the Angelika mine, Nieder-Beerbach, Odenwald Mountains. Werner Lieber photo.**

argyrite, bornite and galena have been found as well. The silver contains up to 10% mercury. A party of three collectors have a claim on the vein now and have christened it the Angelika mine.

SIEGERLAND

The Gonderbach mine is located in eastern Siegerland near the village of Fischelbach about 15 km east of Siegen and 10 km southwest of Laasphe. Mining began in this area at least as early as the fourteenth century, but the 1800s were the most active period. From 1860 to 1890 the hydrothermal galena-sphalerite veins yielded 400 kg of silver and argentite, 2 million kg of galena, 56,000 kg of tetrahedrite (!) and 42,000 kg of pyrargyrite (!). Mining continued intermittently, but the deposits were never particularly rich. The native silver occurred as wires and hairlike masses on galena, sometimes also as sheets and hacky masses to several kg. Only a few collections have Gonderbach specimens.

THE HARZ MOUNTAINS

Few localities worldwide are as famous among collectors and as rich in history as the Harz Mountains. Mining in the Harz region began in the year 968 (or 933 according to some authorities) at Rammelsberg. Around 1004 the mine was abandoned due to plague, but was reopened in 1016. In the 1300s a disastrous cave-in ruined the workings and killed 400 miners; the mine was thereafter abandoned for about 100 years. Mining began at Zellerfeld, Wildemann and Clausthal around the year 1000.

Mineralogically, the most important silver mining area in the Harz is St. Andreasberg, on the southern slope in West Germany.

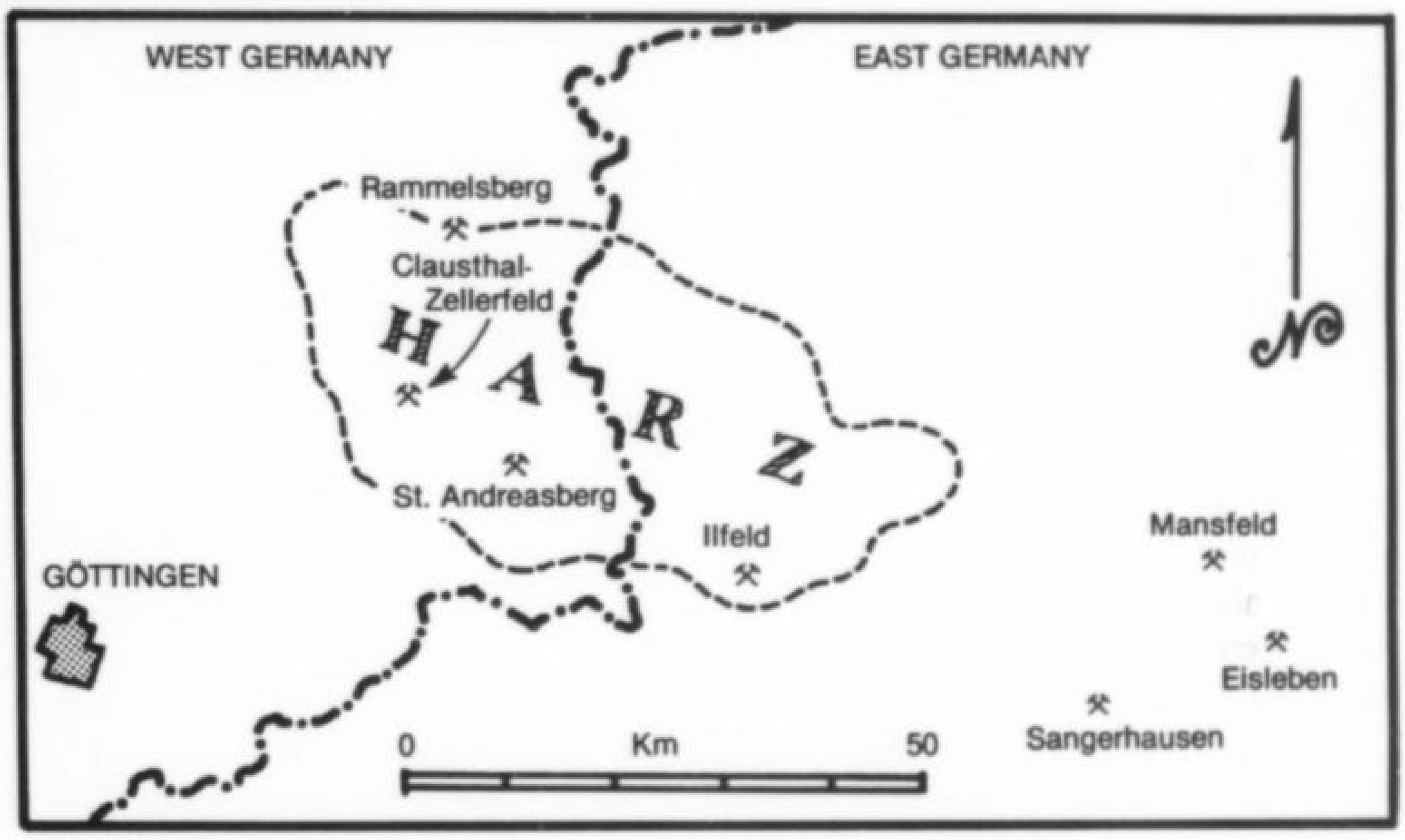


Figure 6. **Mining areas in and around the Harz Mountains.**

ODENWALD MOUNTAINS

Just north of the Black Forest is the Odenwald, between Heidelberg and Darmstadt. These mountains have been deeply eroded, and high-level telethermal deposits (if any) have long since been removed by nature, but a few younger veins do exist. Ancient mining records mention a tenth-century silver mine in the southern part, and in 1581 a "rich silver vein" near Darmstadt was recorded. In this area are two locations known today as Nieder-Ramstadt and Nieder-Beerbach, the latter having yielded some remarkable native silver in the 1970s.

Nieder-Beerbach is a small village about 10 km southeast of Darmstadt. In a nearby gabbro quarry a small calcite-barite-quartz vein is exposed which contains an assemblage of Co-Ni-Bi-Ag-U minerals. The vein is only a few centimeters wide and certainly not economical from a mining standpoint, but a number of fine silver specimens, small crystalline aggregates, dendritic and plumose masses have been found. Argentite, safflorite, skutterudite, chlor-

(The border between East and West Germany bisects the Harz.) A remarkable variety of minerals, over 130 species, are known from the St. Andreasberg mines; the most sought-after are the silver minerals.

The earliest written records at St. Andreasberg date to 1487. Miners named the hill "Andreas Bergk" because the apostle Andrew was considered to be the protector of miners. Despite these early discoveries, the first significantly rich bonanza of silver was not found until 1520, and one of the richest mines, the Samson, was opened in 1521.

The prosperity of St. Andreasberg fluctuated over the centuries. During 1530 to 1580 more than 100 silver mines were opened in rich near-surface ores, using only hammer and chisel. The miners cracked and softened the rock using the "fire setting" technique, burning large quantities of wood at the working faces and virtually denuding the Harz forests in 50 years. Fortunately the use of explosives for mining was introduced in the 1630s, but fire setting

Figure 7. **A view of St. Andreasberg with its mines drawn in 1606 by Zacharias Koch.**

(with wood hauled from ever more distant areas) continued in some mines until as late as 1879. Roughly one cubic meter of wood was needed to produce 1 to 2 tons of ore. From 1560 to 1580 St. Andreasberg yielded more than 1500 kg of silver per year.

St. Andreasberg fell into rapid decline with exhaustion of the richest and most easily mined ores at the end of the 1500s. But a second period of activity began in 1655 and lasted for over 100 years. Depression set in again around 1760, but the area revivied once more in the early 1800s.

Some notable inventions originated in the Harz during the nineteenth century. Steel cable, for example, was first invented in the Clausthal distirct in 1834 and proved greatly superior to rope and steel chains for hoisting. Another unlikely invention, the *Fahrkunst,* was first installed in the Samson mine at St. Andreasberg in 1837. This consisted of two long poles extending down the shaft; as one pole was drawn upward about 3 meters the other was lowered, then their motions were reversed. Miners took hold of handles on one pole and rode it upward 3 meters to the top of its "stride," then transferred to the other pole to be carried up another 3 meters, then back to the first pole, and so on, riding all the way to the surface in half the time it took to climb out by ladder. This saved each miner

Figure 8. **The Andreas taler ("dollar") minted at St. Andreasberg in 1590; 39 mm diameter, 28 grams (0.9 ounce troy). Werner Lieber photo.**

1½ hours (and a great deal of effort) per day. One of the few remaining *Fahrkunst* in the world can be seen today in the Samson mine and it still works perfectly!

In 1890 a body of native silver and dyscrasite (Ag_3Sb) was encountered on the deepest level of the Samson mine and production increased significantly. But shortly thereafter the price of silver went into a decline and by 1910 all of the St. Andreasberg mines had closed, even though the ore veins had not yet been exhausted. Throughout its recorded history from 1521 to 1910 the St. Andreasberg district produced a total of 313 metric tons of silver (10 million

Figure 9. **Miner riding the Fahrkunst in a mine at St. Andreasberg. Each pole has an up and down movement of three meters, in opposing synchronization. The miner steps back and forth between the poles, catching each one at the bottom of its swing, and rides up the shaft.**

troy ounces). The nearby Clausthal district produced 20 times that much silver by processing argentiferous galena . . . economically more rewarding but far less interesting mineralogically.

Native silver was found in all the mines of the St. Andreasberg district, as sheets, wires and small crystals commonly coated by

Figure 10. **Silver with barite on drusy quartz from the recently opened Angelika mine (operated by collectors for specimens) at Nieder-Beerbach, Odenwald Mountains. The silver is 3 cm tall. Photo by Werner Lieber.**

Figure 11. **Silver growth 2.5 cm tall from Reinerzau near Wittichen. This specimen is from a new find made just four years ago in a quarry near a mine that was active from 1727 to 1850. Werner Lieber photo.**

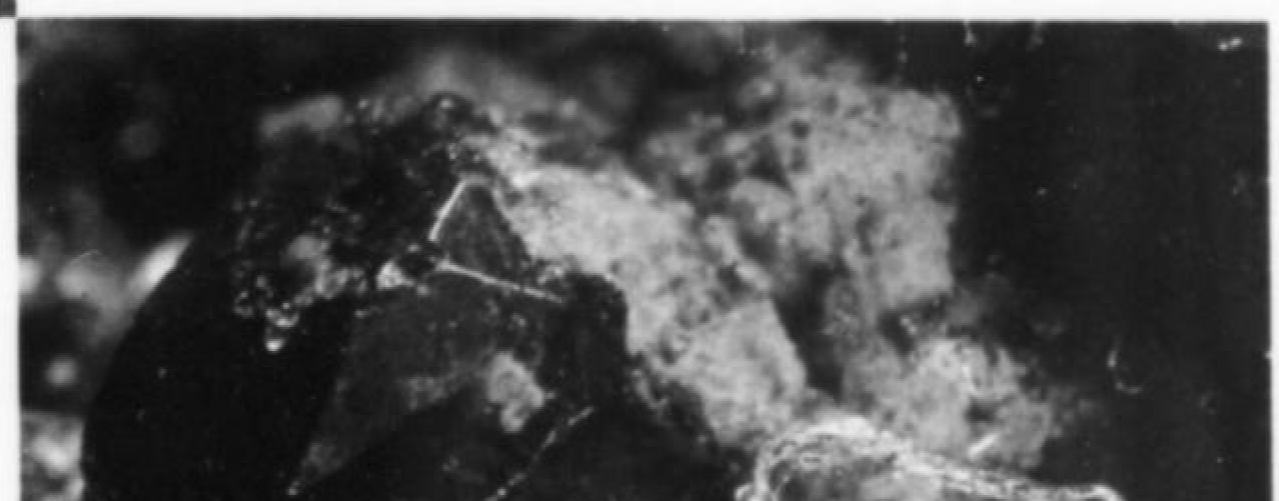


Figure 12. **Wire silver with galena crystals from the Gonderbach mine near Laasphe, Siegerland. The view is 2 cm tall. Werner Lieber photo.**

argentite. Masses of secondary silver up to 40 kg in weight were found. A particularly remarkable occurrence was encountered on the 30-meter level of the Jacobsglück vein: the so-called "silver sand," a mass of small, loose grains to 3 mm composed of octahedral and dodecahedral silver crystals, tiny silver wires, polybasite crystals, chlorargyrite grains, calcite crystals, silver pseudomorphs after pyrargyrite crystals and tiny apophyllite crystals penetrated by silver wires. The "sand" proved to be 75% silver by weight.

St. Andreasberg is better known for rare and beautiful crystallized silver minerals such as dyscrasite, pyrargyrite (in crystals to 10 cm having 45 different crystal forms), proustite, stephanite, miargyrite, polybasite, pyrostilpnite, xanthoconite, sternbergite, argentopyrite, samsonite, native arsenic and native antimony crystals. Beautiful calcite crystals occurred in a wide range of habits, having in total more than 140 different crystal forms found in nearly 400 different combinations!

Most specimens surviving today were collected after 1850, and only in rare cases are the particular veins of origin unknown. The most important veins were the Samson vein (Samson mine, Katharina Neufang mine, Abendröthe mine), the Andreaskreuz vein (Andreaskreuz mine and Drei Ringe mine), the Felicitas vein (Felicitas mine and König Ludwig mine), the Fünf Bücher Mosis vein and mine, the Dorothea and Jacobsglück veins (Dorothea mine, Jacobsglück mine, Claus Friedrich mine, Gottes Segen mine), the Gnade Gottes vein and mine, and the Bergmannstrost vein and mine. The Samson mine has been declared a historic monument, and visitors today can see many interesting relics and remains of early mining.

THE MANSFELD KUPFERSCHIEFER

An ore deposit quite different from others in Germany is the famous *Kupferschiefer* or copper schist of Mansfeld. The town of Mansfeld is located in Thuringia in East Germany, about 65 km

west-northwest of Leipzig. This copper-bearing schist, mined since 1199, is an upper Permian sedimentary unit nearly 30 km in extent. Other mining districts exploiting it include Sangerhausen, Volkstedt and Eisleben.

The metal concentrations in the Kupferschiefer are believed to be the work of sulfide-fixing bacteria acting on trace elements in the water during sedimentary deposition. Hydrothermal solutions invaded the surrounding country rock, generating a wide variety of minerals including silver, niccolite, native bismuth, maucherite, rammelsbergite, safflorite and cobaltite. Open spaces allowed the formation of crystallized and wire silver. Thin fissures and cracks in the Kupferschiefer itself also contain leaves and sheets of silver; specimens of sheet silver on black schist are much sought-after by collectors.

The Kupferschiefer is still an important mining area today, and tremendous quantities of metals have been recovered since the twelfth century. From 1700 to 1950 roughly 8000 metric tons of silver (over 250 million troy ounces) have been produced. This is nearly twice the total output of the Freiberg district in Saxony! Large quantities of rare elements have been produced as well, and Mansfeld was for many years the world's only source of rhenium. Sizeable ore reserves remain, but modern mechanized mining techniques allow few specimens to be saved, and no native silver has been preserved as specimens for at least 20 years.

THE ERZGEBIRGE

The Erzgebirge ("ore mountains") of Saxony and Bohemia is among the most famous mining regions of Europe. This range of mountains, today bisected longitudinally by the East German–Czechoslovakian border, includes such historic districts as Schneeberg, Annaberg, Marienberg, Johanngeorgenstadt and St. Joachimsthal (Jáchymov).

Figure 13. Heavy wire silver coated with argentite, from St. Andreasberg. The specimen is 5 cm tall. Werner Lieber photo.

Figure 14. Important mining districts in the Erzgebirge.

Figure 15. **A view of Schneeberg, Saxony, in 1630.**

Schneeberg

Schneeberg has provided large quantities of valuable mineral specimens including native silver, proustite and erythrite. The earliest written records date back to 1446, and the first major silver discovery was made in 1470 after a period of thorough prospecting and exploration. The following year nearly 3000 kg of silver were produced, and the year after that 6000 kg (190,000 troy ounces). On April 23, 1477, a fabulous discovery was made in the St. Georg mine. The miners had been following a number of different veins, and found that no less than twelve of these veins converged at a single point. At this intersection they encountered a single solid mass of native silver with argentite and stephanite measuring 4 meters long and 1 x 2 meters across! Contemporary reports vary, but suggest the silver in this mass weighed as much as 20 metric tons (640,000 troy ounces). Duke Albrecht of Saxony visited the mine to see this extraordinary sight and, with aristocratic aplomb, had his dinner served using a piece of the enormous block as a table. Two specimens of the "silver table" have managed to survive the five centuries since its discovery, despite a succession of wars, disasters, and the fire-bombing of Dresden in 1945. They are now part of the priceless collection in the Staatliches Museum für Mineralogie und Geologie in Dresden; the curator was kind enough to supply a photo of one of these, the oldest specimens of native silver known.

By 1478 nearly 60 mines had been opened within the town limits of Schneeberg and another 110 just outside. Three years later Schneeberg was declared a "free mining town" by the Duke, and a mint was constructed there in 1500 to coin silver.

Figure 16. **Duke Albrecht of Saxony having his dinner served underground at the St. Georg mine in 1477. For a table he is using part of a 20-ton mass of silver found there, a piece of which still survives (see next figure). Deutsche Fotothek Dresden.**

Figure 17. **A 605-gram chunk from the famous "silver table" found in the St. Georg mine, Schneeberg, in 1477 (see previous figure). Collection of the Staatliches Museum fur Mineralogie und Geologie in Dresden; Barbara Bastian photo, Deutsche Fotothek Dresden.**

In 1520 cobalt blue ("smalt") was invented as a dye, and the Schneeberg mines proved to contain cobalt in abundance. By 1540 smalt was being sold to such distant buyers as Italy and Holland, and had overtaken silver as the most lucrative metal coming from the Schneeberg district.

Additional veins continued to be discovered in the 1500s. One was found by the mint-master of Schneeberg beneath the floor of his own smelter; he named it the "Fruitful Foolishness" mine. Another case involved the discovery of a vein by men digging an outhouse hole for an old woman; it was named "The Poor Widow's Luck" in 1568.

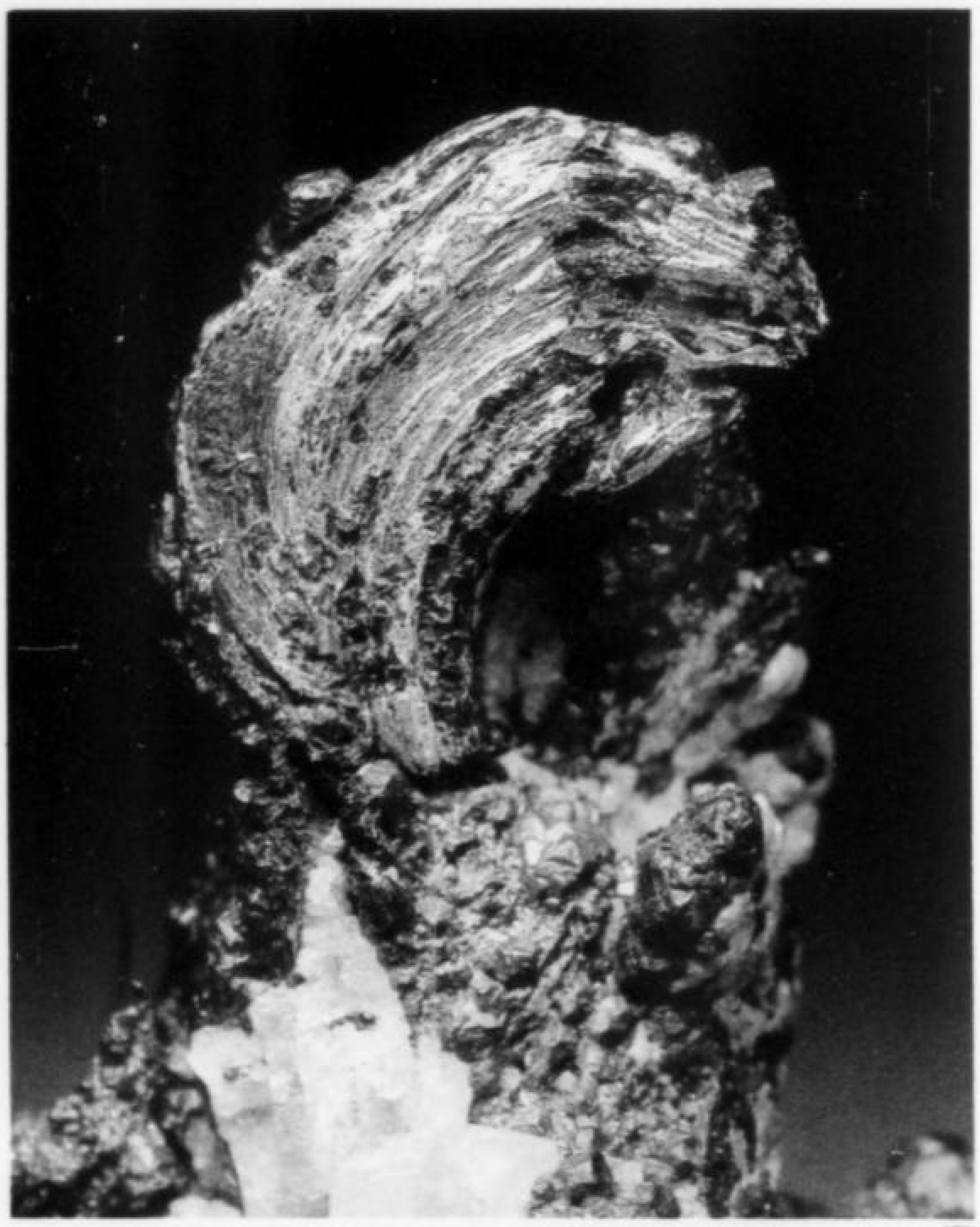


Figure 18. **Silver curl, 1.5 cm, with acanthite from St. Andreasberg. Western Minerals specimen.**

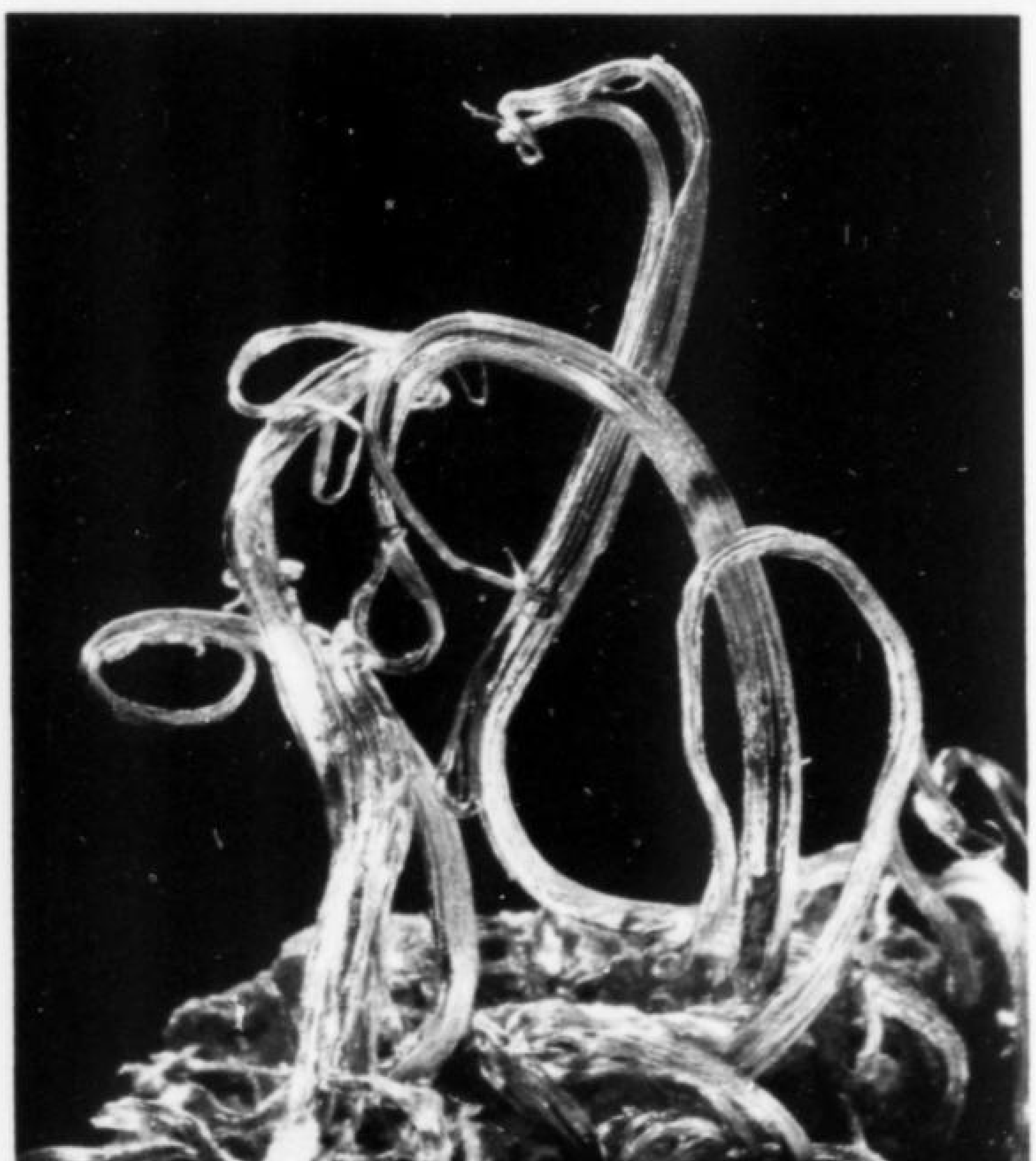


Figure 19. **Wire silver specimen 2 cm tall from Schneeberg-Niederschlema. Werner Lieber photo.**

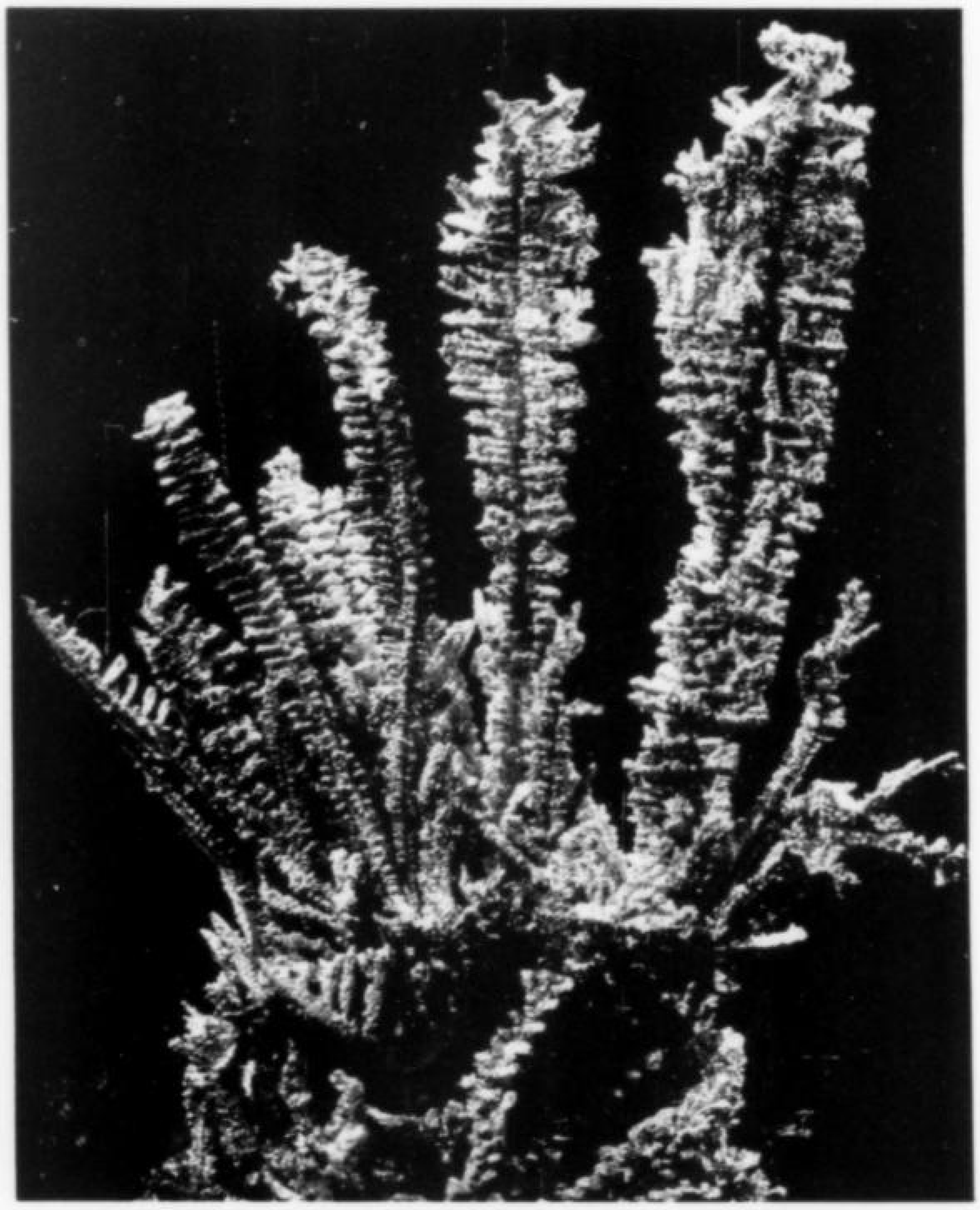


Figure 20. **Silver specimen 2.5 cm tall from Schneeberg-Niederschlema. Werner Lieber photo.**

Silver production gradually diminished as the centuries passed. In 1823 "nickel silver" was invented (an alloy of copper, tin and nickel) and nickel became an important product at Schneeberg. From 1830 onward uranium was mined as a coloring agent for making yellow glass, and quite a large amount was produced before radioactivity became known . . . 86 tons from 1870 to 1906. A spectacular find of secondary uranium minerals, all unkown as species at the time, was made in 1871 at the Weisser Hirsch mine.

Following World War I, Schneeberg went into decline and by 1927 only seven mines were still in operation. But following World War II the search for uranium brought renewed activity to Schneeberg and surrounding areas. Mines at nearby Neustädtel, Niederschlema, Oberschlema, Alberoda and Aue were opened or re-opened including the Weisser Hirsch, Bergkappe, Adam Heber, Priester and Leviten, Gesellschaft, Schindler, St. Daniel, Siebenschleen and Türk mines.

Large outstanding specimens of brilliant red proustite have come from Schneeberg; a suitcase-full of proustite crystals from Schacht 207 was once donated to the Freiberg Mining Academy. Fine specimens of native silver in association with other minerals were

Figure 21. **East German stamps depicting mineral specimens: proustite from the Erzgebirge *(top left)*, silver from Freiberg *(top right)*, proustite from Schneeberg *(bottom left)*, and erythrite from Schneeberg *(bottom right)*.**

Figure 22. **Proustite, 3 cm, from Schneeberg. Werner Lieber photo.**

also found in abundance. Finally, however, in 1957, the last of the mines in the Schneeberg district closed, although there is still a little mining going on in nearby Schlema Valley.

Schneeberg veins, like many others in Germany, contained Co-Ni-Bi-Ag-U minerals. Hundreds of these veins were eventually located, some of them over 2 km long and up to 3 meters wide. Argentite, proustite, pyrargyrite, stephanite, polybasite, native bismuth, skutterudite, safflorite, chloanthite and uranium minerals

Figure 23. Proustite, 3 cm, from Schneeberg. Werner Lieber photo.

Figure 24. **Miners at the Marcus Semmler tunnel, Schneeberg, ca. 1880.**

Figure 25. **A 20-cm wire silver specimen that was collected in the Bergkappe mine, Schneeberg, prior to 1623; it was named the "silver cross." Deutsche Fotothek Dresden.**

were recovered, as well as native silver, particularly in the oxidation zone which extended to a depth of 130–180 meters.

Native silver at Schneeberg occurred as dendritic and arborescent growths, hacky masses, long wires and crystals. Spike-shaped crystals or "teeth" up to 40 cm in length are said to have been removed from the Weisser Hirsch mine, and "several buckets full" of silver wires were taken from the same mine in 1802. Arborescent groups up to 40 cm (15.7 inches) were found in the Priester mine in 1783. Long, spike-shaped crystals were found in the Adam Heber mine as well. A beautiful specimen about 20 cm tall was found in the Bergkappe mine, and was named the "silver cross" (Silbernes Kreuz); it contains a thick silver wire growing from a nest of smaller wires and branching in three directions to form a cross. The Dresden Kunstkammer (art collection) obtained it along with other mineral specimens from the Electoress Sophia in 1623 and it now resides with many fabulous silver specimens in the Museum für Mineralogie and Geologie in Dresden. Silver crystals were also found: cubes up to 1.2 cm at the Sauschwart mine; combinations of cubes, octahedrons and dodecahedrons at St. Daniel's mine; rows of octahedrons on matrix at the Sauschwart and Wolfgang Maassen mines; and pseudomorphs of silver after argentite and proustite at the Sauschwart mine. Many other locations in the neighborhood of Schneeberg have veins of similar composition, varying more or less in the proportion of metals and their minerals.

Johanngeorgenstadt

Johanngeorgenstadt is a famous mining district very near the Czechoslovakian border. The mineralization here is very similar to that at Schneeberg. Important mines include the Gnade Gottes, Neujahrs Maassen, Römischer Adler, Georg Wagsfort, Gottes Segen, Neu Leipziger Glück, and many others. In the years 1802 to 1804 heavy plates of native silver up to 75 cm across and weighing 100 kg were taken from the Neujahrs Maassen mine. Hacky masses, crystals and wires of silver have come from a number of mines in the district, but the most unusual specimens are referred to as "silver agates." These are jasper nodules containing a delicate intergrowth of native silver wires, native bismuth and argentite.

Figure 26. **The last horse-driven hoist near Johanngeorgenstadt. Deutsche Fotothek Dresden.**

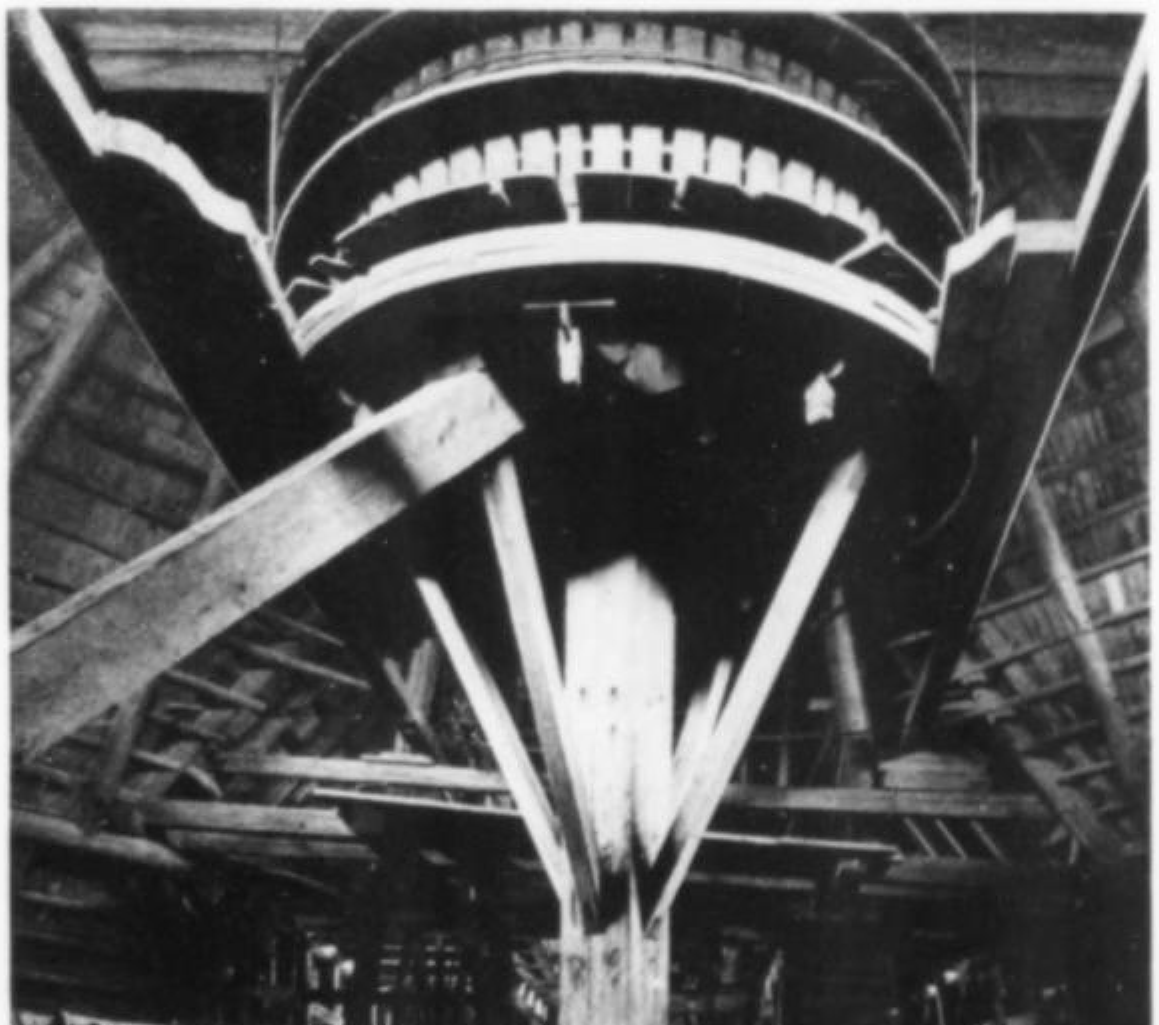


Figure 27. **Inside the horse-driven hoist house near Johanngeorgenstadt, 1935. Deutsche Fotothek Dresden.**

St. Joachimsthal

Across the border into Bohemian Czechoslovakia but still in the Erzgebirge is the district of St. Joachimsthal, renamed Jáchymov in modern times. This famous town is situated 15 km southeast of Johanngeorgenstadt. The ore deposits are similar in mineralogy to those of Schneeberg.

Mining at St. Joachimsthal began in the fifteenth century, and by 1530 over 13,000 miners and mine officers were working in 800 mines in the district. The silver dollar was born here, originally called the Joachimsthaler; over 2 million of them were minted at St. Joachimsthal between 1520 and 1528, containing just under an ounce of silver each. This figure is more impressive when one considers that only 25 Joachimsthalers constituted a satisfactory *annual* wage for a miner in the 1500s.

Some of the St. Joachimsthal mines were fabulously rich, and even in the 1500s several are known to have yielded more than 9 tons (300,000 troy ounces) of silver. Georgius Argicola spent three years there as a medical doctor and gained many insights on mining which were later to appear in his monumental classic *De Re Metallica* (1556).

Interest in uranium grew in the 1800s and a plant for producing yellow uranium dye was built at St. Joachimsthal. Pierre and Marie Curie made their famous discovery of radium using two wagonloads of processing residue from St. Joachimsthal pitchblende as a starting point, and identified emissions they called "radioactivity."

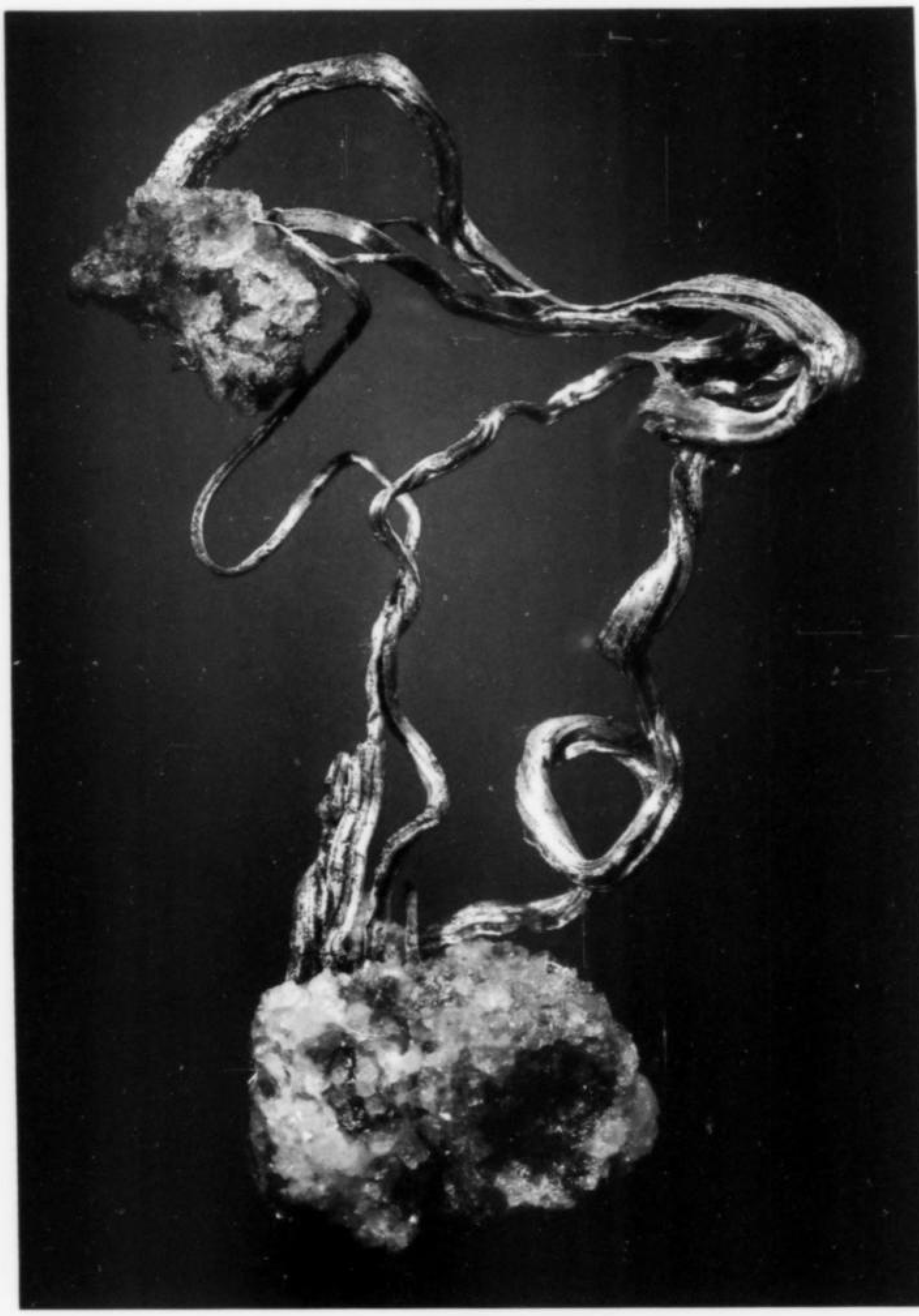
As at Johanngeorgenstadt, fine specimens of proustite, pyrargyrite, stephanite, argentite, native bismuth, bismuthinite, skutterudite and uranium minerals have been recovered at St. Joachimsthal. The silver shows the same habit as at other Erzebirge mines; free-standing spikes, wires and curls have been found in most of the mines in the district, together with calcite, quartz, argentite and proustite.

Annaberg

About 30 km east of Schneeberg is another famous mineral locality: Annaberg, the type locality for annabergite. The first

Figure 28. **Wire silver with argentite, 3.1 cm tall, from Freiberg. Olaf Medenbach photo.**

Figure 29. **Wire silver with quartz, 5.2 cm tall, from Freiberg. Olaf Medenbach photo.**



hydrothermal veins were found here in 1412; eventually more than 300 veins were located, most of them having the typical mineralogy of Schneeberg. These veins were generally about 800 meters long and extend to a depth of 100–400 meters.

In addition to native silver the Annaberg mines have produced dyscrasite, argentite, chlorargyrite, and various minerals containing bismuth, cobalt and nickel. In the deeper levels uranium is found.

Annaberg produced 316 tons of silver from 1496 to 1600, and 7850 tons of silver from 1701–1850. The Marcus Röling was among the most famous mines.

Marienberg

About 17 km northeast of Annaberg is the town of Marienberg, where more than 500 mines on 100 silver veins were once worked. Most of them have the Schneeberg mineralogy. Native silver plates weighing up to 700 grams (1.5 pounds) were found in the Vater Abraham, Alte Drei Brüder, and Junge Drei Brüder mines, and silver wires up to 20 cm in length were found in the Fabian Sebastian mine.

Figure 30. **Wire silver from Annaberg, about 2 cm tall. Werner Lieber photo.**

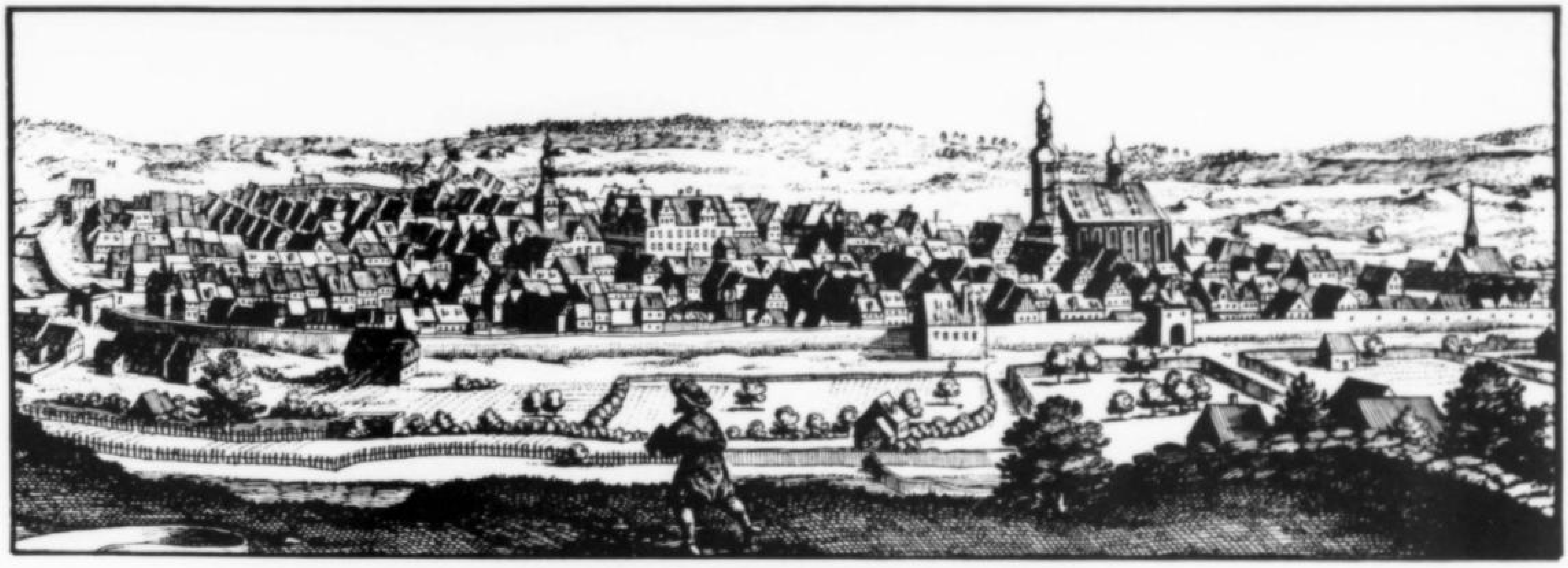


Figure 31. **Marienberg in 1600; engraving by Mathias Merian. Deutsches Fotothek Dresden.**

FREIBERG, SAXONY

Collectors throughout the world are well acquainted with the beautiful silver minerals from Freiberg, Saxony. This famous and richly historic mining district is located just a few kilometers north of the eastern end of the Erzgebirge. Silver was first discovered here in 1163, more than 800 years ago; the workings are among the earliest mining operations in Germany. In 1185 the Margrave Otto der Reiche of Meissen invited miners from the Harz Mountains to settle in the area, and in 1221 it was named Freiberg. During the following decades intensive exploration and mining were carried out and an increasingly large number of silver veins became known. The district grew to 20 km north-south and 10 km east-west, 200 square kilometers virtually covered with mining operations.

The easily accessible ores had been removed by the end of the 1300s, but a second period of prosperity began in the 1500s when tunnels were driven into the mountains to drain the old mines. In total more than 700 mines operated on approximately 1100 different mineralized veins. In 1550 the area was served by no less than 46 silver foundries. Later, yet another period of intensive activity took place, from 1750 through the 1800s.

Abraham Gottlob Werner (1750–1817) here began his research, which was to change the science of mineralogy. It was he who distinguished minerals from the rocks which contain them, and who arranged the minerals into a systematic structure, thereby laying the foundations of modern mineralogy. He taught at the Freiberg Mining Academy (founded in 1765) throughout much of his life.

By the year 1900 only 28 mines in the Freiberg district remained active, employing about 2700 miners. With the coming of World War I mining activity ceased more or less permanently. Two mines were re-opened temporarily in 1937, and a few others after World

Figure 32. **In 1677 the Council of Freiberg presented to the Saxon Elector Johann Georg II a complete miner's parade costume of the most lavish construction. Included was this "frog" lamp, made of gilded silver from St. Daniel's mine at Schneeberg and encrusted with garnets, colorless quartz, opals, amethysts and smoky quartz, all gemstones found in Saxony. It is easily the most extraordinary and valuable miner's lamp in the world today, and currently resides in the famous "Green Vaults" of Dresden. Deutsche Fotothek Dresden.**

War II, but in 1969 the last of these closed down again. From 1163 to 1896 the Freiberg mines yielded a total of about 5250 metric tons of silver (168 million troy ounces).

The hydrothermal veins of the district contain much argentiferous galena. They vary in width up to a meter and extend for several kilometers in length near Bräunsdorf, where native silver, argentite, polybasite, pyrargyrite, stephanite, miargyrite, tetrahedrite, kermesite (!), arsenopyrite, pyrite, quartz and calcite occur; famous mines here are the Neue Hoffnung Gottes and Alte Hoffnung Gottes. Veins 50–150 cm in width and up to 5 km long occur north of Freiberg at Halsbrücke and south at Brand, Erbisdorf and Berthelsdorf, all about 7 km from Freiberg; minerals include arsenopyrite, pyrrhotite, pyrite, chalcopyrite, tetrahedrite, quartz and galena containing up to 0.3% silver. Shorter veins up to a kilometer in length at Brand and Erbisdorf contain native silver, and silver minerals, siderite, rhodochrosite, calcite, tetrahedrite, argentiferous galena, local uranium, and the rare mineral argyrodite (in which Clemens Winkler discovered the new element germanium in 1885). Famous mines include the Beschert Gluck, Himmelfahrt and Himmelsfürst.

The Himmelsfürst mine produced more than 18 tons of silver from 1768 to 1818. In 1857 a specimen of native silver weighing 225 kg was removed. Another beautiful specimen from this mine measures 12 cm in height and consists of long silver wires growing from a matrix of calcite crystals; it was found in 1879 and is today on exhibit in the Freiberg Mining Academy. It was also depicted on an East German postage stamp in 1969 (see Fig. 21).

Other outstanding discoveries in the Freiberg mines include a 15 x 25 x 25 cm, 3.4-kg mass of silver found in the Freiesleben vein of the Himmelsfürst mine at a depth of 606 meters. This specimen is now in the collection of the Staatliches Museum für Mineralogie und Geologie in Dresden. Spike-like crystals of silver 15–30 cm in length were found at the same mine, as well as at the Reicher Bergsegen mine. A pocket in the Mittagssonne mine yielded 10 kg of wire silver in 1819.

Sharp crystals of silver have not been abundant at Freiberg. Cube, octahedron and dodecahedron combinations have come from the Himmelsfürst mine.

A great many more fine specimens from the Freiberg district could be discribed, but the few mentioned here should give a general impression of the mineralization. It is remarkable that so many fine silvers have survived the centuries and may still be seen in collections. A great many historic localities worldwide have not been so fortunate.

CONCLUSION

Despite a thousand years of mining it cannot be said that Germany's numerous deposits of silver are all exhausted. Many were closed because the ore grade was too low, because mining expenses made it uneconomical, or because of wars. In areas so heavily mineralized as to have literally hundreds of productive veins, it seems unlikely that every last one has been discovered. Here and there mineral collectors work low-grade veins and sometimes come up with fine specimens, though only rarely. And a few mines still continue in operation. The boom days, however, are unquestionably gone, and their glory is today represented by thousands of interesting and beautiful mineral specimens in collections everywhere. We can thank the early miners and mine managers for this wealth of historical and mineralogical material which will be available for study and enjoyment for generations to come.

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Kongsberg

Famous mineral localities: the Kongsberg silver mines, Norway

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1350 Copenhagen, Denmark

For over 330 years the silver mines at Kongsberg, Norway, produced the finest known specimens of wire silver, and many of the finest crystalline silvers as well. Museums and private collections throughout the world count Kongsberg silvers among their greatest treasures.

INTRODUCTION

Over the last three and a half centuries the name of Kongsberg has been closely associated with native silver. The town of Kongsberg, founded in 1624 as a result of the silver discovery, is situated on the Laagen River about 80 km west-southwest of Oslo, Norway. In forest-clad hills west of the town, at an elevation of 400–600 meters, are approximately 300 mines which, over the centuries, have produced countless fabulous specimens of silver. In all, more than 1350 metric tons (43 million troy ounces) of silver came from the Kongsberg mines until their closing in 1957.

HISTORY

Though mining in Norway began long before the Kongsberg deposits were discovered, it was rather slow to get started by European standards (see Lieber, previous article). Legends tell of pits near Telemark, Sandsvaer and Eiker where copper, iron, lead and silver ores were found, and an early Latin manuscript on the history of Norway, *Historia Norvegiae* (1170) mentions rich silver deposits in the vicinity of Oslo.

Several of the kings of Denmark-Norway were interested in promoting mining (no doubt to enrich the royal coffers), and they invited miners and mining experts from Germany to help locate and exploit deposits. Generally the properties mined in these early times were quickly abandoned after the easily won surface ores were exhausted.

In 1539 King Christian III proclaimed a mining law protecting the rights of discoverers and encouraging the peasants to explore. But mining remained unpopular because the German hierarchy itself taxed the peasants on everything from housing to transportation of coal and timber the peasants had cut themselves. Discoveries made by local people were therefore kept secret from the German-bred mining managers and the King's own representatives.

When King Christian IV was crowned in 1588 he began an inten-

Figure 1. **Location map.**

sive program to stimulate mining in Norway. He had seen copper, iron and silver mining bring prosperity to Sweden and Germany, and he furthermore had plans to involve himself in the Thirty Years War (1618–1648) and so desired self-sufficiency in these metals. As his predecessors had done, he called in more mining experts, from Freiberg, Saxony, and asked for their assessment of the mining possibilities in Norway. Their opinion, rendered in 1623, held little hope for profitable mining, and the king at first decided to close down the mines owned by the crown. New developments that same year, however, made him change his mind.

One day in early July of 1623, a pair of young shepherds by the name of Jacob Grosvold (13 years old) and Helga Verp were tending their families' herd in the hills near Sandsvaer. The lead bull, so the story goes, whetted his horns against a mountain knoll and scraped off moss to reveal shining silver. The children brought a sample home to their fathers, Christoffer Grosvold and Arne Verp, who immediately recognized the metal. Three days later the children led them to the outcrop and more samples were collected.

At first the discovery was kept secret. But in the fall of that same year Arne Verp was arrested in Skien while trying to sell what the authorities assumed was stolen silver. He was tried in court and had to reveal the truth in order to clear himself of the theft charge. He and Grosvold took the Bailiff to inspect the outcrop, and the Bailiff promptly issued an order that no one, under penalty of death, was to climb the mountain. The news made its way to the king in Copenhagen and, in a proclamation dated December 12, 1623, he threatened severe punishment for all people who had purchased native silver if they did not turn it over to his agents immediately; he also declared all private mining illegal. This contradicted the mining law of 1539, but the king declared that, "through the merciful blessing of almighty God, the silver belongs to the Crown." Having thus declared a gift to himself from God, the king felt obliged to also declare a day of thanksgiving in all churches throughout Norway and Denmark.

As a result of the royal proclamation, a surprising number of peasants in Sandsvaer soon turned themselves in and told of several similar outcrops in the area; so it is quite possible that silver was known at Kongsberg long before 1623.

The shepherd boy, Jacob, as well as his father, eventually worked in the silver mines they helped to discover, and numerous descendants of theirs are to be found in Kongsberg to this day.

In 1624 the king traveled to Norway to inspect the new silver mines. The most important of the four mines then operating was located on the shepherd boy's discovery point and, in honor of the king, was named Kongens Grube (His Majesty's mine). It remained the most prolific mine of the district, eventually reaching a depth of 1076 meters and yielding nearly half of the total district production. The king also chose a site for the new mining town, and it was named Konningsberg in his honor, later shortened to Kongsberg.

The Norwegians themselves had little experience at mining. So the first men to work the Kongsberg mines were Germans transferred in from other Norwegian operations. Additional skilled miners were needed, however, and so another 30 were "imported" from the Harz district in Germany during that first year. By the year 1628, about 150 men, nearly all German, were employed at the mines. German miners continued to immigrate to Kongsberg over the years, commonly receiving top positions; it was not until 1756, after more than 130 years of mining, that a Norwegian was first appointed the chief mining officer.

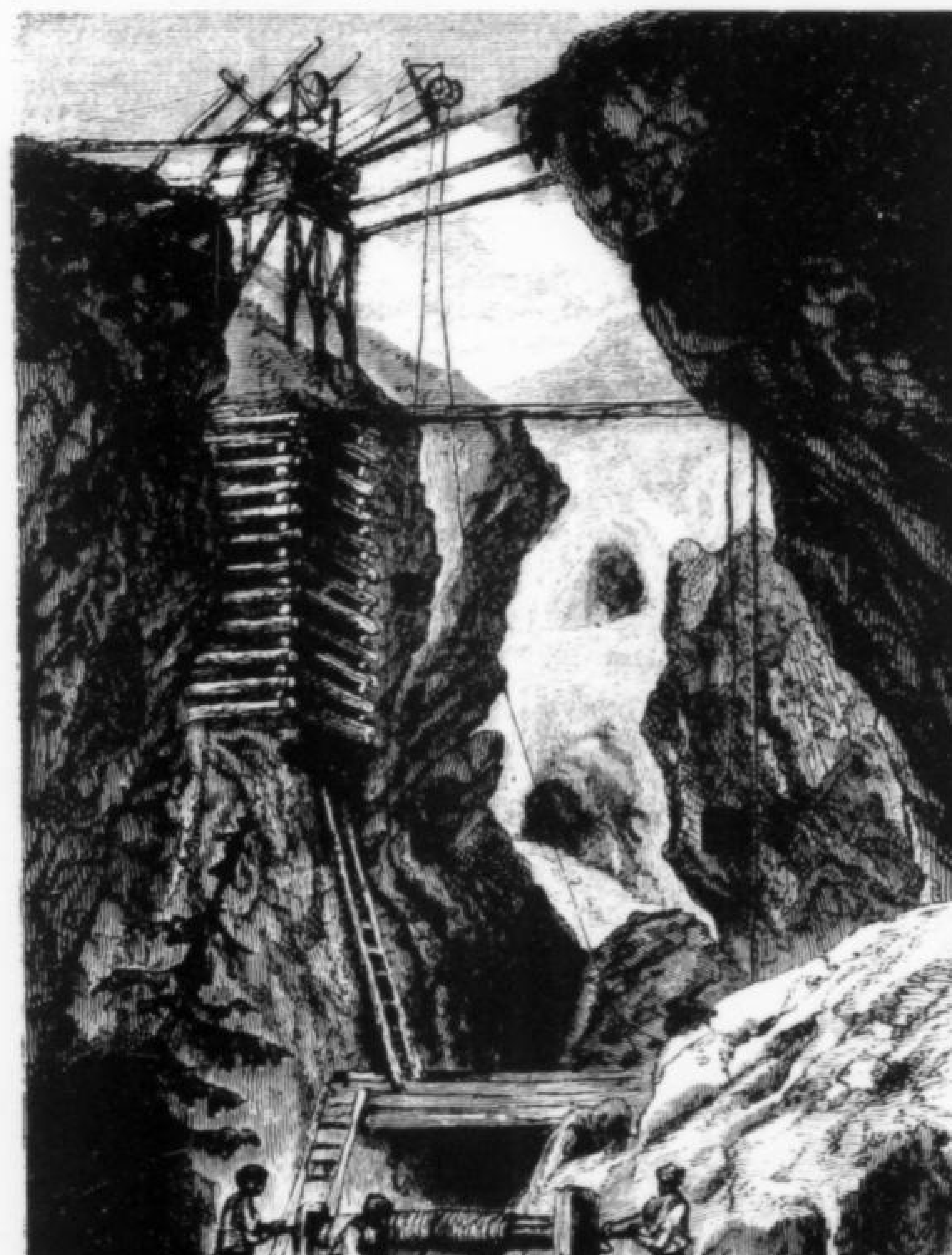

Figure 2. **Kongsberg in the 1600s.**

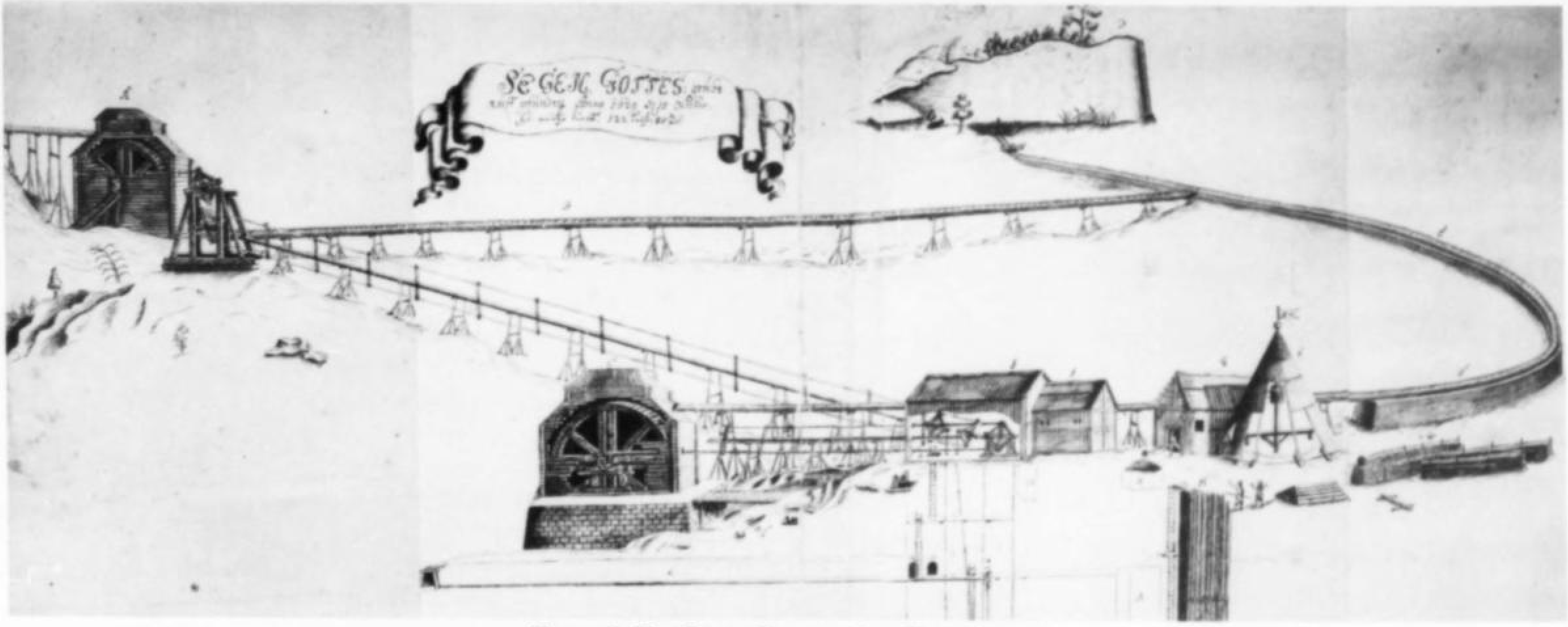

Figure 3. **The Segen Gottes mine, Kongsberg, in 1706 (courtesy Royal Library, Copenhagen). Note reservoir and waterwheels.**

It was not difficult to lure German manpower to Norway. Devastating and seemingly endless wars, high unemployment and miserable conditions were ruining their home country. Over the centuries, these Germans gradually melded into the Norwegian population, but their influence was always strong. The technical language of mining remained German or a slightly Norwegianized variant, and many of the mines received German names, like the Gottes Hülfe in der Noth ("God's help in distress") mine. They introduced social inventions, such as the *Knappschaft* or miner's organization, something previously unknown in Scandinavia. Even today, the German heritage persists in the many German surnames among the Kongsberg population.

In the first years of mining, exploration was directed more or less at random, but soon an understanding of the ore distribution pattern began to emerge. Duval (ca. 1725) summarized this as follows:

> Fahlband and vein form a cross with each other, the fahlband running north-south and the vein east-west. From these two, as man and woman, is the ore conceived as an embryo, and without both of them being present, nothing can develop. Therefore, the old miners named the fahlband the father, the vein the mother, and the silver the son.

Fahlbands are sulfide-rich zones in the country rock, the most important being the Overberget and Underberget fahlbands (discussed further under geology). The discovery of the "fahlband rule" led directly to the discovery of nearly all the well-mineralized areas in 1629–1630.

The tools used in the mines were hammer and chisel, and in the near-surface workings, a procedure known as "fire setting" was used. The idea was to weaken the rock by heating it up with a fire

Figure 4. **Mine train carrying miners out of the Saggrenda portal, 1912 (courtesy Kongsberg Mining Museum).**

Figure 5. **Miners cobbing out native silver in the Samuels mine, ca. 1900 (courtesy Kongsberg mining museum).**

and then cooling it off with cold water. The emerging fractures could then be worked with hammer and chisel. Originally, this method was used only in the upper parts of the mine, but later on – between 1670 and 1870 – it became the principal method used to drive adits. Fire setting was extremely costly in timber and very tiresome, too. The rate of advance was usually only 1 or 2 meters per month. Wood for fire-setting, timbering, smelting and so on was difficult to obtain in the beginning, due to the unwillingness of the peasants.

Though King Christian IV was very enthusiastic about the silver mines, he developed financial problems due to his expensive participation in the Thirty Years War (in which he was defeated). Therefore, in 1628, the Kongberg silver works were handed over to a cooperative society in which the king had a one-eighth share. The crown was ensured an income by a 10% tax and a so-called coin profit, a difference between the bullion value and the face value for minted coins.

The mines functioned under this cooperative society until 1660. In the 1630s the yield was good after a slow start. For instance, in 1637 the production was 1460 kg of silver, which meant a good profit to the holders. Unfortunately, they preferred to remove the profit instead of plowing it back. The principle was to "skim the cream" even if this led to a lowering of the workers' wages or perhaps no wages at all. This created discontent among the miners, but economic planning and consolidation did not have high priority in those days.

The silver mines returned to the crown in 1661, and in the beginning the production of silver was sufficient, approximately 2000 kg, but at the same time, the working expenses increased, so when silver production dropped in the late 1660s the situation became serious. It certainly did no good either that unending friction existed within the administration, a phenomenon that has harmed the silver industry much over the years. The king wanted to be rid of the mines and in the period 1673 to 1683 they were again placed in private hands. This resulted in ten years of ruthless exploitation, leaving the silver mines in a state of chaos. The crown once more resumed control.

The reasons for this crisis were several. The silver ore appeared to be exhausted at depth, a misconception caused by a lack of understanding of the intermittent nature of the vein mineralization. There were also technical reasons. Windlasses had successfully been used for hoisting until a level of 30 m below the shaft collar was reached; horse whims were then used, but the limit of this method (150 meters) was soon reached in several mines. The use of waterpower had been neglected, and so had the construction of haulage adits which would have facilitated transportation and created a potential for using waterpower down in the mines. Finally, bad management compounded these difficulties. A radical modernization of the Kongsberg silver works was absolutely necessary.

In 1685 the king asked Heinrich Schlanbusch from the Harz to investigate the business and to prepare an efficiency study. Later that same year, Schlanbusch was appointed Berghauptmann in Norway. He initiated a comprehensive renovation program including better tools, new machines, reorganization of the staff, reopening of closed mines and better extraction methods in the smelting works. But most important was the beginning of a grand waterpower plant with new reservoirs in the upper hills and aqueducts bringing water to the mine areas, where waterwheels and

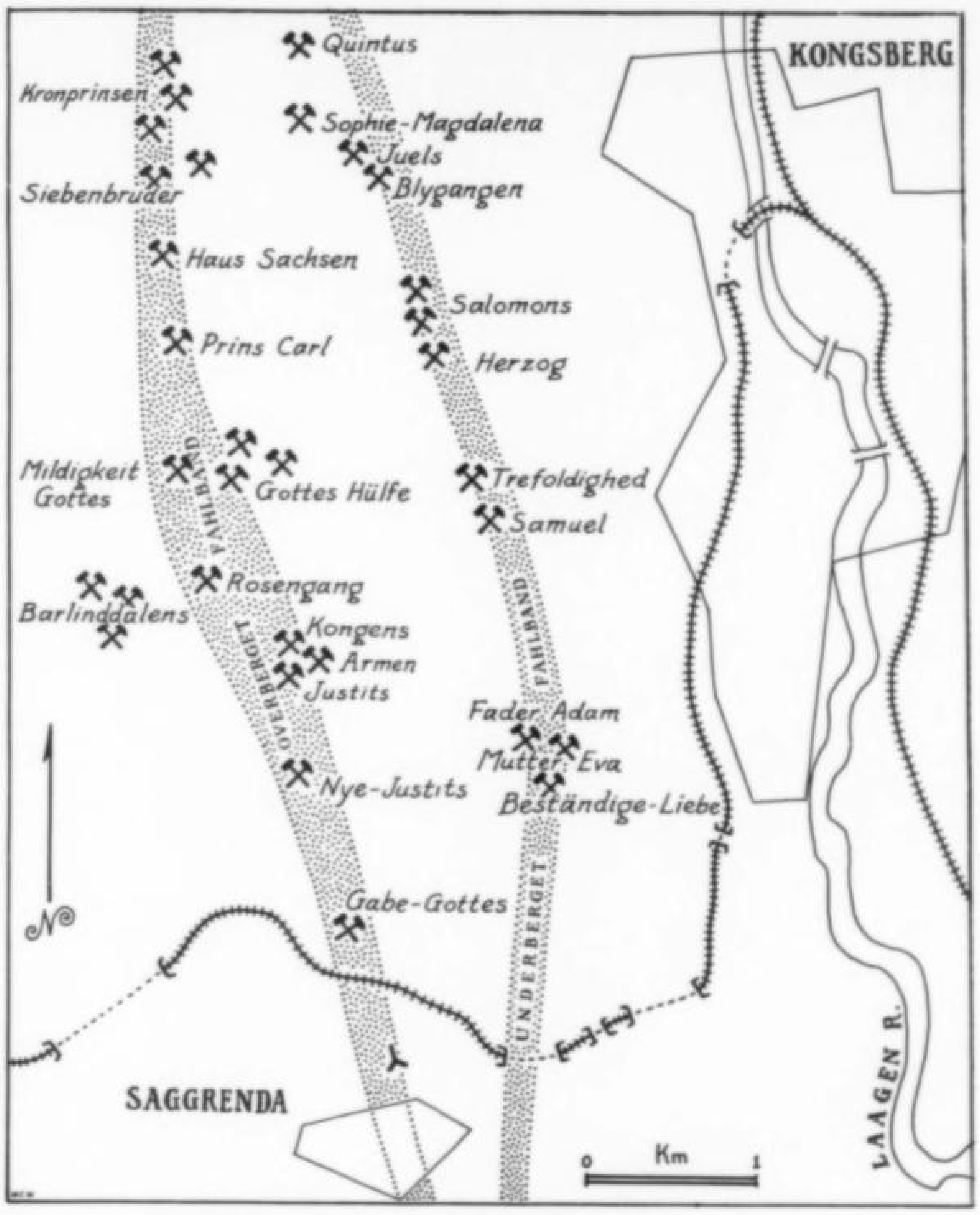

Figure 6. **Map of the Kongsberg district showing major mines (after Wilke, 1976, and Holtedahl, 1960).**

stamp mills were efficiently arranged. The waterwheels were from 5 to 15 meters in diameter and were placed in houses with well-built foundations. There were two kinds of waterwheels: single wheels for pumping from the sump and reversible wheels for hoisting up and down in the shaft to a depth of 300 meters below surface. Below this level, waterwheels were installed underground. Adits were driven from the hillsides to drain the mines and to facilitate the transportation of ore.

The modernization took many years and positive results were not felt immediately. Furthermore, the new measures were incredibly expensive to implement and this fact soon created difficulties for Schlanbusch. He was accused of wasting huge sums on all sorts of "useless things," like a bathing hut for the miners so that they could wash before going home at the end of the week. The criticism he faced at the time hardly seems fair today in view of the overwhelming benefits of his reforms.

Due to the enormous production of silver at Kongsberg, a mint was established there in 1686. The royal mint in Oslo was closed down a few years later, and the Kongsberg mint continued until 1825. The coat of arms of the royal mint includes crossed hammers, a heritage from the bonanza days of Kongsberg.

By the beginning of the eighteenth century, the modernization of the mines had taken hold. New improvements were added, such as Tyrolean drills (1713). As a result, the year 1717 saw a record production of 5100 kg of silver. The good times continued (apart from a short period in the late twenties) until about 1770; the establishment of 78 mines, 24 stamp mills and 2 smelting works in operation produced another new record of 8263 kg of silver in 1768.

The increased production was naturally the by-product of the enormous investment, but it was also the result of a better understanding of the course of the veins. The miners from Freiberg and the Harz were slow to realize exactly how the ore behaved at depth. Gradually, they learned that, in Kongsberg, when a deep vein pinched out, the continuation of the vein system could be found at a deeper level by making crosscuts in the opposite direction of the dip. Usually the individual calcite veins dip 60–80° to the south while the vein system as a whole plunges to the north.

The period 1700–1770 was not only a time of increased silver production, it was also a time of rapidly rising expenses. While the working staff numbered 700 men in 1700, it had grown to 4200 in 1770. The many new installations demanded a large maintenance crew, and the administrative staff had grown beyond reason. These conditions were tolerable for the mines in a period of prosperity, but they were fatal to business when production dropped toward the end of the century. By the year 1800 annual production had fallen below 2340 kg of silver. Meanwhile, the situation in the mines had been deteriorating. Critically important construction of new adits had been neglected, especially on the Overberget fahlband. Exploration was insufficient and, when the silver ore seemed to vanish at depth, the work was spread out to more mines and expenses increased further. Exploitation of the ore was poorly managed and the losses terrible; some 40% of the silver content was lost in stamp mills and smelting works. To reduce expenses, the working staff was cut down and, since maintenance was necessary regardless of production, it was the miners who were laid off. Inefficient bureaucracy was a huge problem in those days; and the operations had suffered a great deal from endless quarrels among the high-ranking personnel, resulting in low morale at all levels and increased thefts of silver. Great efforts were made to repress these

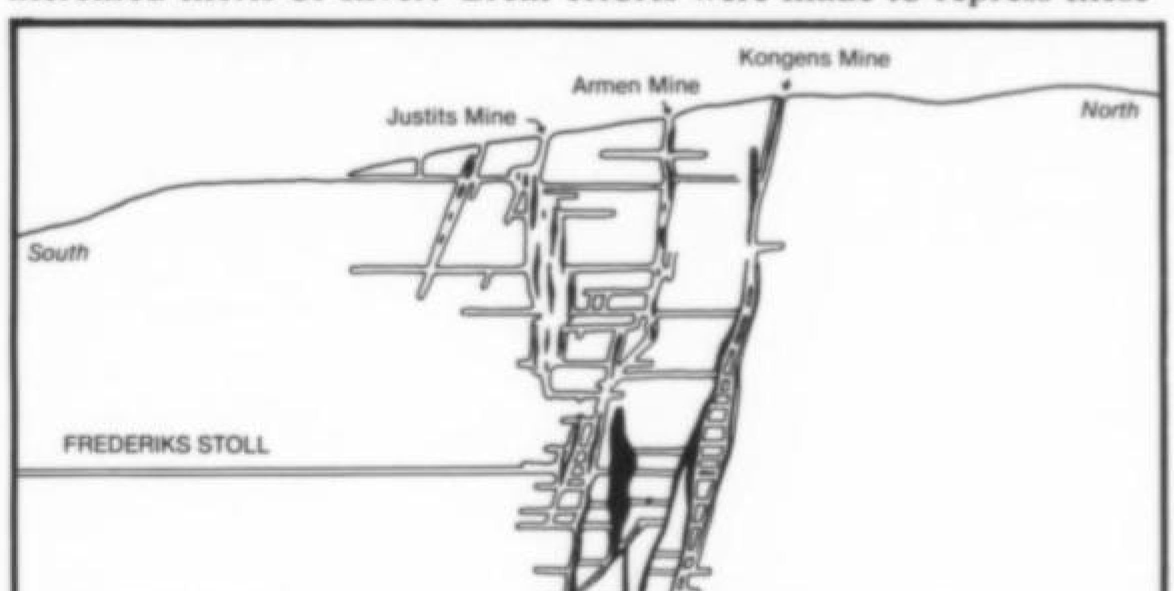

Figure 7. **Vertical section perpendicular to the veins showing silver lodes in the Kongens mine (after Bugge, 1932).**

numerous thefts, but efficient control was difficult and, although strong punishments were introduced – hanging without mercy for the theft of one mark of silver – the losses continued. The temptation was great for a worker, to whom eight marks of silver (2 kg) was more than a year's wages.

At this stage in the crisis, it was realized how important the construction of adits was to the future of the business, and a main adit, the Kristians stoll (*stoll* = adit), was commenced throughout the Overberget fahlband starting in Saggrenda and connecting the important mines Gabe Gottes, Justits, Armen, Kongens, Gottes Hülfe, Prins Carl and Haus Sachsen. Later another adit, the Frederiks stoll, roughly 100 meters above the Kristians stoll, was initiated. The work progressed slowly; 59 years passed before the Gottes Hülfe mine was reached, and the many ventilation shafts proved much more expensive than expected. At the turn of the century, the construction of adits ceased due to a desperate financial situation. The production of silver was now down to the level of 100 years earlier; during the same period the staff had almost trebled and the expenses quintupled.

In 1805 a decision was made to close the Kongsberg mines. It happened quickly and haphazardly, doing great harm to the mining facilities and to the citizens of Kongsberg. A few mines continued on a private basis, but the overall situation was chaotic. The most positive aspect of the period until 1815 was the construction of an iron foundry, from which an arms factory emerged. The arms factory is still in existence.

The participation of the dual kingdom of Denmark-Norway in the Napoleonic Wars was most unsuccessful and in the end, in 1814, Denmark was forced to surrender Norway to Sweden. The union with Sweden lasted until 1905, with Norway enjoying full independence in internal affairs. At that time demands were made to reopen the Kongsberg silver works, and in 1815 the new Norwegian legislature decided to reopen the mines.

The new beginning was cautious and at first only the Justits mine, Armen mine and Kongens mine were made ready, and the Frederiks stoll finished. The working methods were the same as in the old days, but lessons had been learned; the number of employees was limited to 300–400 men. Moreover, greater efficiency in manpower was achieved by building *sakkerhuse,* houses where people who lived far away from the job could stay on working days. After seven years of work, the Frederiks stoll was put through to the Armen and Kongens mines at a depth of 230 meters, but not much silver ore had been found, so in the late twenties, the legislature decided to sell the mines. Before a buyer was found, however, unusually rich ore shoots were discovered in the main vein of the Kongens mine. By the following year (1833), a new record was achieved with a production of 9330 kg of silver; this marked the beginning of a prosperous period which lasted until the end of the nineteenth century.

The strategy during this period of prosperity was to concentrate on the major mines in the Overberget fahlband: the Justits mine, the combined Armen-Kongens mine and later the Gottes Hülfe and Haus Sachsen mines. The Kristians stoll was extended to the Haus Sachsen mine, which meant that all transportation could go to Saggrenda where milling facilities were located. The labor force was kept at 400 men, but, thanks to the Kristians stoll and a series of other improvements, mining productivity increased.

Horse-power railways were introduced in the main adits, the smelting works were made more efficient, and in 1869 the first water column engine was installed in the Gottes Hülfe mine at a level 276 meters below the surface. A reservoir of 7000 cubic meters capacity was built in the mine 112 meters higher and was connected to the engine with pressure pipes. Ore hoisting in the shafts could then reach a speed of nearly 1.5 meters per second. Later, another water column engine was installed in the Kongens mine on the Kristians stoll level to operate the pumps and the *fahrkunst.*

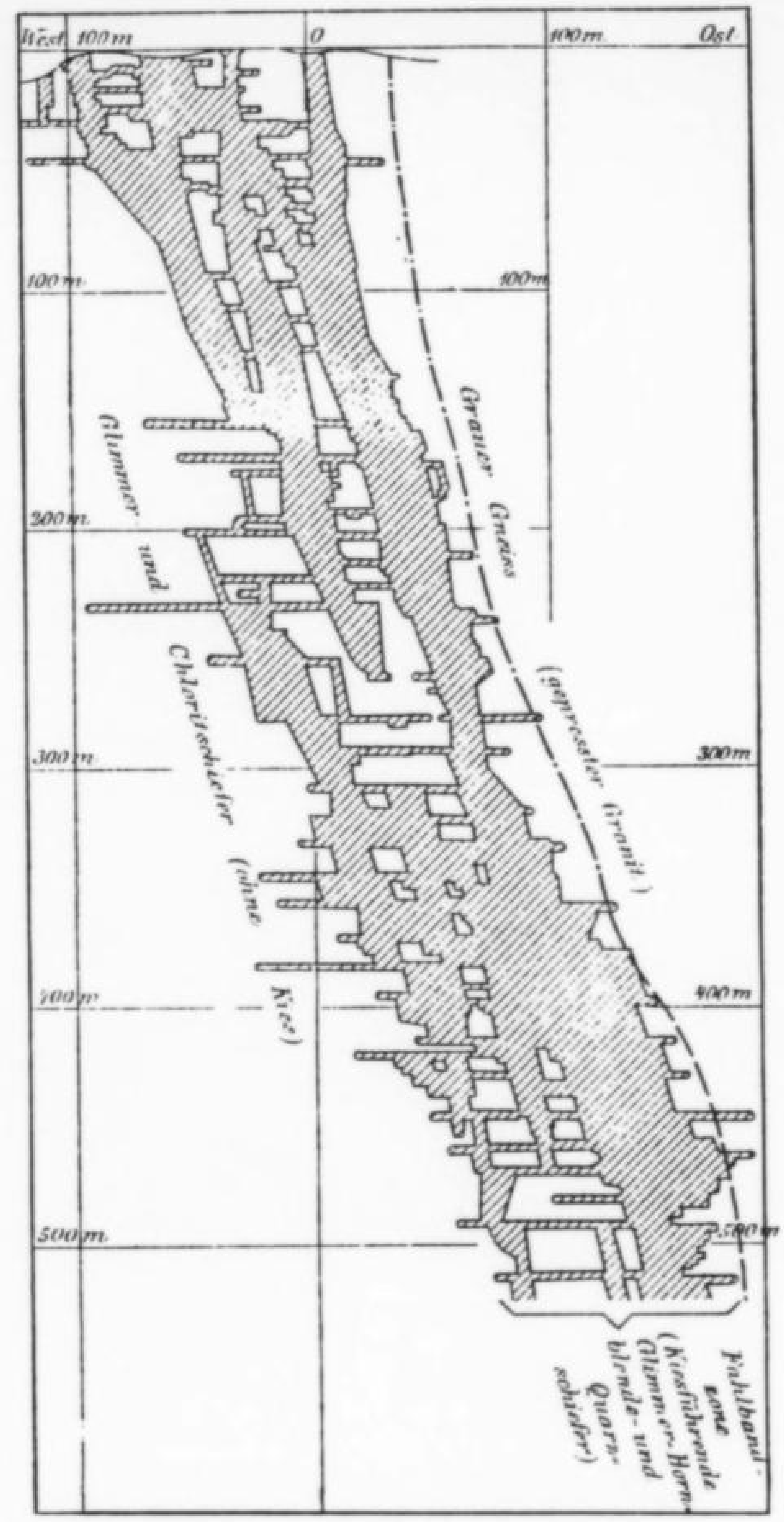

Figure 8. **Vertical section showing workings in the plane of the vein, Kongens mine (Vogt, 1899).**

Steel drills and one-man drilling machines were introduced in 1860 and shortly thereafter dynamite came into use. Fire setting was still in use in some cases but finally, in 1890, when the method was already out of fashion, it was forbidden by law due to health hazards!

The price of silver began to drop in the 1870s, partly because of overproduction worldwide and partly because some countries chose gold as their monetary standard. In order to increase production, some of the mines in the Underberget fahlband (the Samuels, Hellig Trefoldighed and Gabe Gottes mines) were reopened, but the total production declined nevertheless, especially from 1888 on, and from this time on the mines operated at a deficit.

In the beginning of the twentieth century, the silver mines went through a new period of many improvements which resulted in full modernization and efficient operation by the outbreak of the first World War. In 1830 the production averaged 14 kg of silver per man-year; by 1914 it had risen to 40 kg per man-year.

This increase in productivity was due to the introduction of electric power, gasoline locomotives, carbide lamps, exclusive use of the shrinkage stope mining method and new progress in milling methods. A new plant was built in 1911 in Saggrenda, with jaw crushers and cone crushers. The biggest step forward was the in-

Figure 9. **Kongsberg in the 1600s (courtesy Royal Library, Copenhagen).**

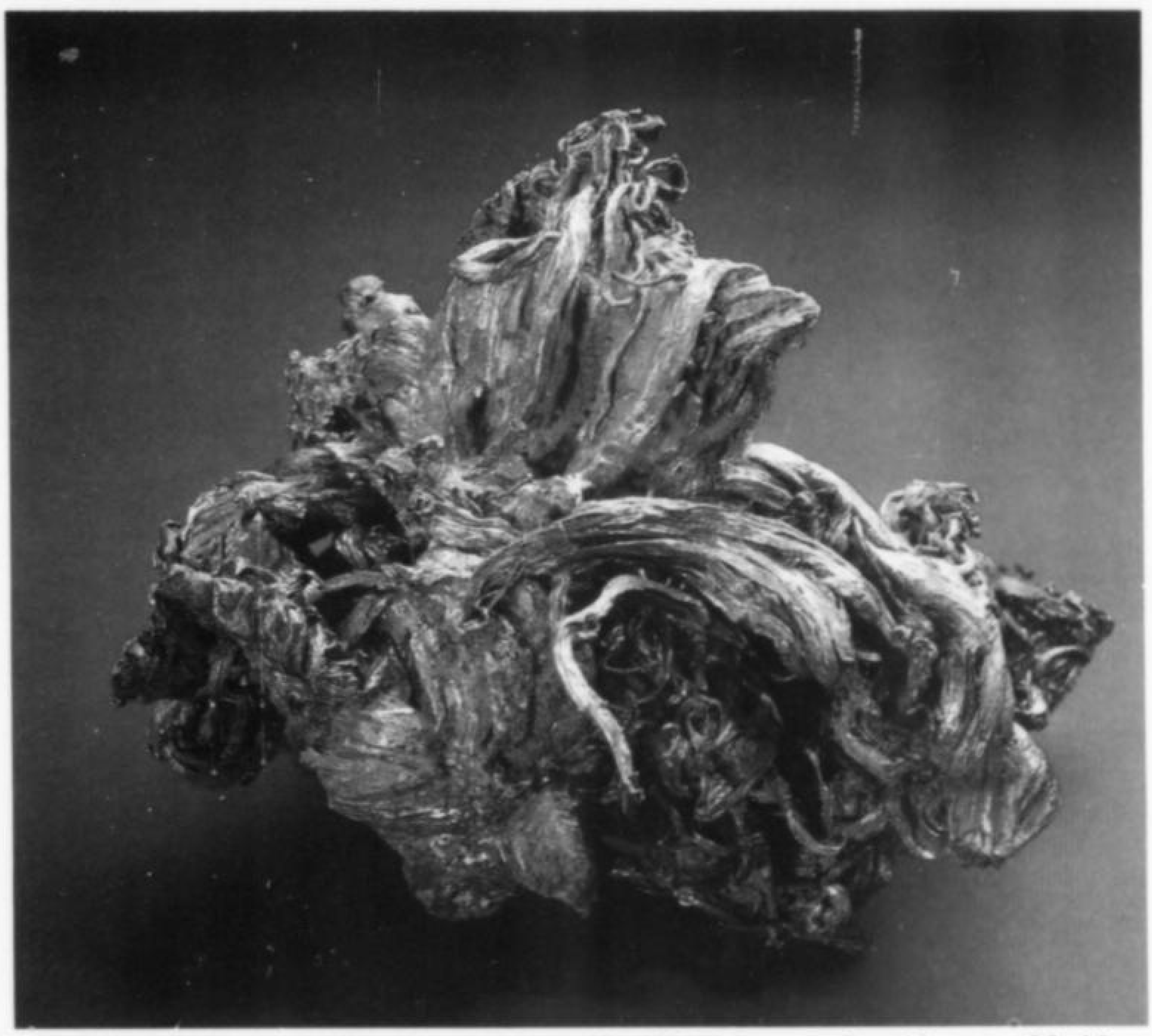

Figure 10. **Large mass of wire silver weighing 12 kg (26 pounds). Kongsberg Mining Museum collection; Tor Ass-Haug photo.**

troduction of the sodium cyanide extraction method for low-grade finely crushed ore.

The annual production of silver peaked in 1915 at more than 15.6 metric tons, of which 5.9 tons came from the Kongens mine and 9.1 tons from the Samuels mine. The latter mine, in the Underberget fahlband, was reopened in 1889; but more than 10 years of fruitless exploration passed before it was discovered that this area had an anomalous ore distribution pattern at depth. Crosscuts to the south revealed rich deposits which, in fact, carried the silver mines through the first decades of this century. Later on, however, the silver thinned out in the Samuels mine as well as in all the others and disappeared approximately at sea level.

By the 1930s one could sense the impending end of silver production. Attempts were made to save the business by producing garnets for abrasives, road material, silver nitrate, etc., but in the long run, it was not possible to fight increasing expenses. The figures were clear: in the 1890s a worker's annual wages were equivalent to the value of 2.5 kg of silver. In 1950 this amount of silver could barely match three weeks' wages. It was therefore not surprising that the legislature in 1955 decided to close down the Kongsberg mines for good. Production finally ceased in 1957.

THE MINING MUSEUM

In 1912 the Kongsberg foundrymaster, C. C. Riiber, and mine director, C. A. Münster, began assembling a collection of Kongsberg mineral specimens, mining tools and items of historical interest. The 100th anniversary of fundamental law was coming in 1914, and the 300-year jubilee of mining at Kongsberg would be celebrated in 1923, so it was determined to begin preparations early for the construction of appropriately impressive displays. The resulting collecting was housed on the first floor of the foundry.

In 1937 the foreman, Bjarne Sanness, first suggested the idea of creating a permanent mining museum at Kongsberg. Additional specimens and archival material were sought and finally, in August of 1945, the museum was officially opened with Sanness as curator. Today one may still visit the old foundry (built in 1844) and see the various exhibits of mining equipment, miniature models of mines and workings, coins and medallions from the Kongsberg mint, and a superb selection of fabulous silver specimens and other minerals from the Kongsberg district.

Adjoining the foundry is an older machine house (still containing a waterwheel) which has been converted into a restaurant. Another house nearby has miniature reconstructions of mining activities as practiced at various times in the past. The old *laborhaus* or miners' quarters, a water-powered crusher, a park area, an open-air stage and a dance floor are all included in the museum grounds.

Following the close of the mines in 1957 the museum took over an area in the neighboring mining town of Saggrenda. These facilities include a workshop, forge, foreman's quarters, and a mine railway which passes through the mountain for 2.3 km, connecting the Kongens mine workings with Saggrenda. These workings are open to tours, and contain an original *fahrkunst,* forges, hauling machines and change room. The Seismological Institute in Bergen maintains a monitoring station there. Up in the mountains the museum has acquired some old mine buildings in the Haus Sachsen area as well.

In 1965 the Kongsberg Silverworks Museum was designated the Norwegian National Museum of Mining and is now known simply as the Bergwerksmuseum. The facilities are open to the public from May 20 to September 1, and are enjoyed by more than 30,000 visitors annually.

The various mining displays are fascinating and well worth the trip, but the collection of silver specimens is a unique experience to behold. The Kongsberg Mining Museum and the Geological Museum in Copenhagen have, together, a majority of the largest and finest surviving Kongsberg silvers, and no mineral collector can have an accurate perspective on silver as a mineral species without seeing these two unsurpassed collections.

GEOLOGY

The Kongsberg district is situated within the Kongsberg-Bamble complex, a part of the Southern Norwegian Precambrian shield. The complex is separated from the Telemark complex to the west by a prominent mylonite zone from Modum in the north to Kristianssand in the south. To the east it borders on Cambrian to Silurian sediments and alkaline rocks belonging to the Permian Oslo Rift. The rift divides the complex into a northern sector (Kongsberg) and a southern sector (Bamble).

Descriptions of the geology of the Kongsberg area have been published by C. Bugge (1917), A. Bugge (1929, 1932), J. A. W. Bugge (1943), Barth (1960), Kayode (1974) and Starmer (1977). Recent age determinations (O'Nions and Heier, 1972; Jacobsen and Heier, 1978) have refined the geochronology of this formation in which at least two periods of metamorphism can be recognized. The oldest part consists of various gneisses, amphibolites, mica schists and quartzites belonging to the so-called Kongsberg period of metamorphism (approximately 1600 million years) (Oftedal, 1981). These rocks, together with younger rocks such as granites, gabbros and diabase dikes, have experienced a later period of metamorphism (approximately 1060 m.y.) in which strong tectonism occurred. The various rocks strike north-south and have a steep dip. Diabase dikes, quartz-breccia veins and silver-bearing calcite veins associated with the Oslo Rift cut the area.

From a mineralogical point of view the most interesting feature of the Precambrian rocks is the formation of fahlbands. According to Gammon (1966) a fahlband is defined as "a concordant layer or lens of sulfidic impregnation in a metamorphic sequence. The sulfides should be in such a quantity that they are too abundant to be classed as accessory minerals, but too sparse to form a massive ore lens. Fahlbands should have a characteristic rusty-brown appearance on weathering." This is an adequate description of the fahlbands in the Kongsberg area where their strike is north-south and conformable with the host rocks. The rusty colored fahlbands vary from 1 to 300 m in width and the strike length can be up to 15 km.

The significance of the fahlbands lies in the fact that silver only occurs where the veins cut the fahlbands (see below). The two most important are the Overberget and the Underberget fahlbands. They include by far the major part of the silver mines, which are thus arranged as pearls on two strings in a north-south direction.

C. Bugge (1917) divided the veins into two generations: the early sulfide-bearing quartz-breccia veins and the later calcite veins with Co-Ni arsenides and native silver.

The quartz-breccia veins are common throughout the area and can be traced eastward into the Oslo region. The dip is very steep and the strike is generally east-northeast, rarely north. The veins are commonly 1 meter in width, but sometimes they expand to more than 10 meters. In Lassedalen, west of Saggrenda, the breccia zone is nearly 80 meters wide. Length along the strike can be more than 6 km.

Breccia is an accurate description of the vein matter considering the high percentage of broken country rock included. The gangue is mainly quartz, but locally calcite or fluorite is abundant. In Lassedalen, for instance, bodies carrying up to 80% fluorite have been mined. The distribution of base metal sulfides is uneven. Some of the richer parts of the veins have been mined in the past. The quartz-breccia veins do not normally carry native silver, but parts of the veins within the fahlbands have been permeated and rejuvenated by the solutions that deposited the silver-bearing calcite veins, and these transformed veins, called "main veins" (C. Bugge, 1917), have often been very rich in silver.

The veins of the second generation are calcite veins with minor amounts of the usual gangue minerals (quartz, fluorite, barite), various sulfides and sometimes native silver and Ni-Co arsenides. In addition, ordinary calcite veins cut the Permian diabase dikes, and it is generally believed that the silver deposit itself is of Permian age and related to events in the Oslo area.

The occurrence of the silver-bearing calcite veins is restricted to the fahlbands and their immediate vicinity. They are very narrow veins from a few millimeters to a maximum of half a meter. The normal width is 5–10 cm. Vugs are common, creating perfect conditions for the growth of beautifully crystallized minerals. The veins are commonly associated with tiny fissures in the surrounding rock and inside the vein itself. The veins are rarely more than 100 meters along the strike and dip. The strike is generally east-west, less frequently north-south. The dips are steep towards the south; in the northern part of the Overberget fahlband they are less steep, roughly 45°. In a few instances, as in the Samuels mine, the vein dips steeply to the north.

The silver-bearing calcite veins often occur in swarms of sheets like venetian blinds, usually with an overall northerly plunge. In some cases, the vein structure is much more complex, and some of the veins do not fit into any system at all.

Some calcite veins have a north-south strike and a dip concordant with the rocks in the fahlbands. The veins are called "strike veins" and they rarely carry silver, but the silver-bearing calcite veins are commonly richer in silver near a strike vein.

"Rotten veins" are mylonitized dislocation fissures with an east-west strike and a 45° to 60° southerly dip. The fissures are filled with a clayey mass of chlorite, muscovite and calcite. They do not carry silver, but their presence also seems to have had an enriching effect on the silver-bearing veins (C. Bugge, 1917). The general trend is for the numbers and the dimensions of the silver-bearing calcite veins to decrease with distance from the rotten veins. C. Bugge (1917) expressed the opinion that the rotten veins represented alteration products of quartz-breccia veins of the first generation.

The mineral association in the silver-bearing veins can be divided into three assemblages: (1) quartz, graphite, fluorite and pyrite; (2) calcite, barite, fluorite, argentite, native silver and Ni-Co arsenides; and (3) calcite and zeolites.

Naturally, most interest has been attached to the question of when and, in particular, where the native silver was deposited. The old fahlband rule from the days shortly after the first find of silver in the 1620s is, correctly phrased, a negative statement: the veins carry no silver away from the fahlbands. In other words, there is no guarantee of finding silver at a cross point, but just a guarantee of finding no silver outside a cross point. It is only natural that this rule has been the subject of much debate in previous years, but most people (especially geologists and miners) are convinced of the validity of the fahlband rule. In addition to the fahlband rule, the following observations on the occurrence of silver have been made: (1) the distribution of native silver is uneven within the veins; (2) the presence of silver in the veins seems to be unrelated to variations in the sulfide content of the fahlbands; (3) the silver content tends to increase in the vicinity of strike veins and rotten veins; and (4) the silver content decreases downwards and seems to cease at a level a few hundred meters below sea level.

Despite centuries of study at Kongsberg, many interesting questions regarding the geology remain unanswered. What was the parent rock which became, through metamorphism, the complex of gneisses and granites in the area? What is the origin of the sulfides in the fahlbands, and why are the sulfides concentrated into bands? When were the sulfides introduced into the fahlbands? Why is there a higher concentration of fahlband sulfides near shear zones? What is the origin of the graphite? Are the diabase dikes in the area related to silver mineralization? Why is the silver content of a calcite vein higher near the relatively barren strike veins? What is the origin of the wire habit for native silver? Did anhedral silver sulfide at Kongsberg precipitate above or below the acanthite-argentite inversion point of 173° C? What is the source of the silver-bearing solutions responsible for Kongsberg's famous silver mineralization? And *why* was silver deposited at vein-fahlband intersections, to a degree apparently unrelated to the sulfide content of the fahlband? This last question is particularly perplexing in view of the fact that sulfides are the principal feature which distinguishes fahlbands from surrounding rocks. Many theories on each of these questions have been proposed, but there is no real consensus. Ridge (1984), who gives an excellent summary of these problems, comments pessimistically:

> The problem as to why the silver (and the other vein minerals) were deposited in the vicinity of the vein-fahlband crossings is not solved, and it is unlikely to be except serendipitously by someone working on another deposit having similar characteristics, if one exists.

MINERALS

Relatively little has been published on the minerals from the Kongsberg silver deposit since the descriptions of Neumann (1944). Naturally, the native silver has attracted much attention, especially in the professional literature; many papers dealing with Kongsberg silver were written in the second half of the nineteenth century (Vogt (1899) and C. A. Münster (1894) to mention two).

Neumann (1944) believes mineralization began at a temperature of 400–500° C with quartz (first), pyrite and calcite. Fluorite and axinite crystallized in that same range, although fluorite formed again later at lower temperatures (200° and 300°). Barite began to form at just under 400°, followed by galena, sphalerite, chalcopyrite, the silver sulfosalts, argentite, marcasite, and then native silver at about 250°. With futher cooling pyrrhotite, nickeline, the diarsenides and, finally, the zeolites formed.

Silver Ag

Native silver was by far the major ore in Kongsberg; the only other argentiferous mineral, argentite, constituted no more than about 5% of the ore.

The occurrence of the silver is usually divided into three types: massive silver, wire silver, and crystal silver. To this should be added silver as coatings found on argentite.

Massive Silver

Massive silver is possibly the most abundant type at Kongsberg. It comprises the interstitially developed silver having an anhedral outer shape determined by the surroundings. Massive silver includes everything from tiny fissure fillings to gigantic lumps. Some of the largest masses recorded had a weight of more than 100 kg; a single one found in 1867 at the Kongens mine was said to weigh close to 500 kg (1100 pounds).

Wire Silver

Wire silver is common at Kongsberg. It occurs as curved bundles of threads often in long, twisted formations and generally striated parallel to the direction of elongation. The width of the thread varies from a fraction of a millimeter to several centimeters and the length can be many centimeters. Often threads are composites consisting of a more or less parallel growth of several "individuals." Many names have been attached to this attractive form of silver: *arborescent silver, tooth silver, ram's horn silver, hair silver, moss silver,* or simply *wire* or *thread silver*; the names are self-explanatory. The tangled masses of fine fibers, called moss silver are rather common. Some moss silver specimens are actually composed of only a very limited number of fibers which seem to be endlessly interwound.

Vogt (1899) pointed out that threads of silver often show crystal faces – sometimes in stepped fashion – and re-entrant angles indicating that the threads actually are long arrays of crystals. Even smooth surfaces of threads and fibers show crystal faces when seen under the microscope. Coarse, unstriated wires bound by obvious crystal faces have been called "baroque silver" (Støren, 1935).

Much fine wire silver may have been formed by dendritic growth. Many specimens give the impression of having been "extruded,"

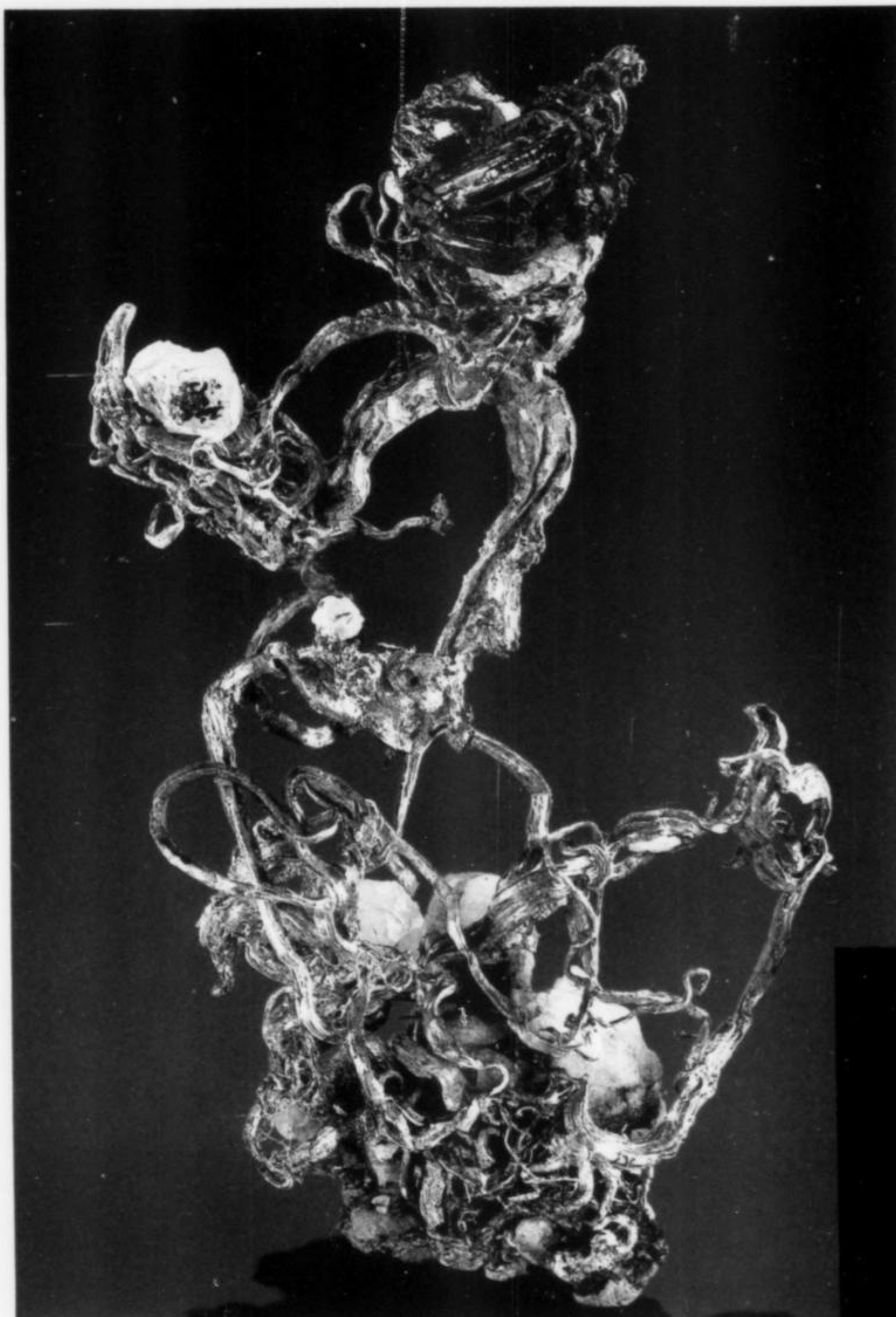

Figure 11. **Wire silver, 9.1 cm tall, with crystals of calcite and black sphalerite. Houston Museum of Natural Science collection; Harold and Erica Van Pelt photo.**

Figure 13. **Coarse wire silver on matrix, 6 cm tall. Eugene Schlepp specimen.**

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Figure 12. **A curl of wire silver 1.5 cm long. Werner Lieber photo.**

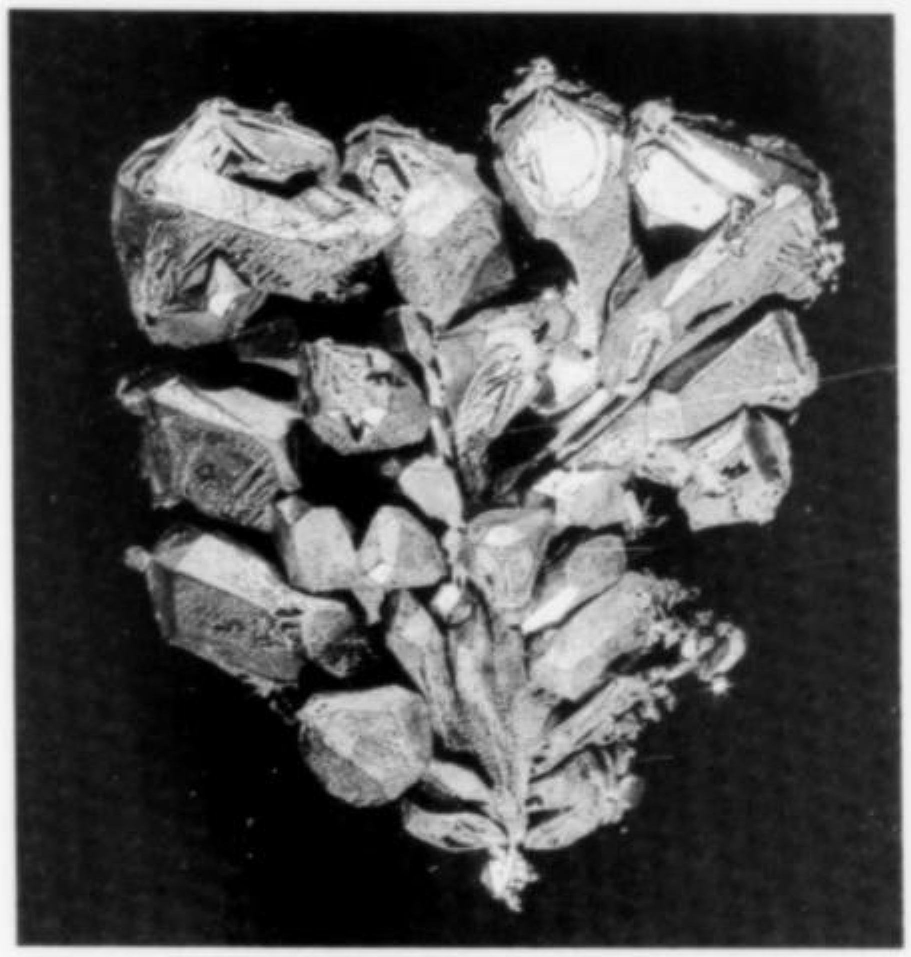

Figure 14. **Crystalline silver group 2.5 cm tall. Photo courtesy of the Geological Museum, Copenhagen.**

Figure 15. **Large cubic crystals of native silver. The twinned crystal in the foreground measures 1 cm. William Larson collection; Harold and Erica Van Pelt photo. Below: diagram of the twin (Goldschmidt).**

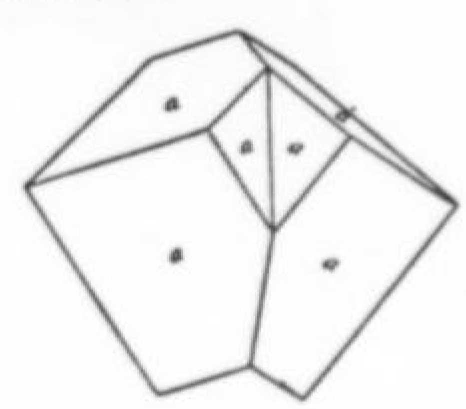

Figure 16. **Very coarse wire silver showing prominent development of crystal faces; 6.1 cm tall. Olaf Medenbach photo.**

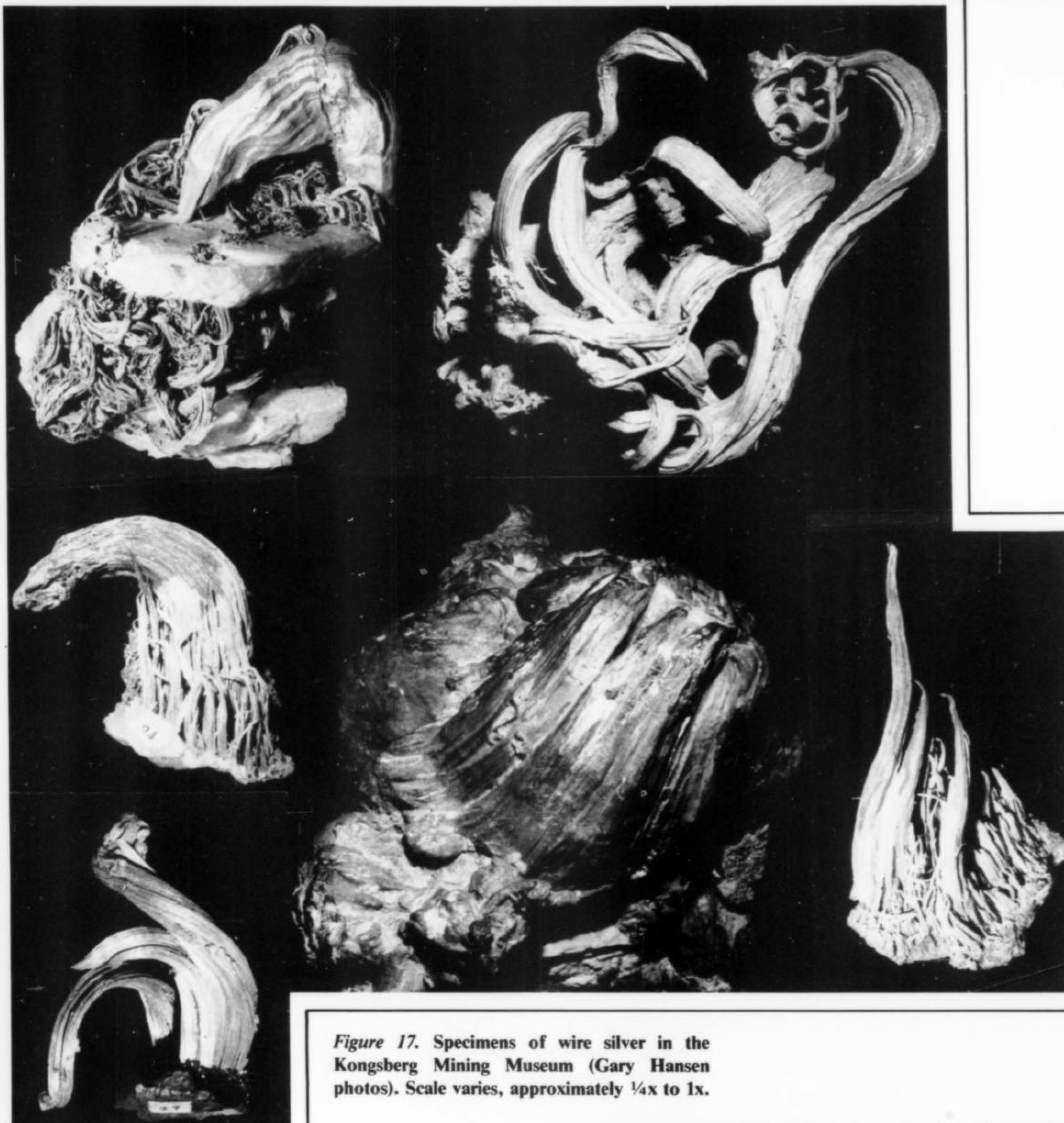

Figure 17. **Specimens of wire silver in the Kongsberg Mining Museum (Gary Hansen photos). Scale varies, approximately ¼x to 1x.**

though this is strictly speaking impossible; growth may have taken place primarily at the interface between silver and rock, forcing up the silver wire with each new layer of growth. Experiments first conducted by Häuy in 1801 have shown that heating argentite will cause threads of silver to grow outward from the argentite surface until the argentite has been consumed. Neumann (1944) suggests that much wire silver at Kongsberg may have been produced in this way. Illustrations of wire silver growing from proustite (Vogt, 1899) suggest proustite as a possible additional source. Various solutions of silver sulfide and sulfate acting on minerals such as cobaltite and argentite have, under experimental conditions, produced growths of wire silver as well (Jensen, 1939). Whether these experiments have any relevance to Kongsberg silver is unknown. Nevertheless, a relationship between silver and argentite does exist; the two minerals are commonly found together, sometimes silver replacing argentite and sometimes the reverse.

Silver has been observed replacing a number of other Kongsberg species including dyscrasite and, surprisingly, quartz.

Crystalline Silver

Crystal habits of silver from Kongsberg have been studied by Rose (1831), Zittel (1860), Sadeback (1878), vom Rath (1869, 1879) and Storen (1935). Well-formed crystals are very rare at Kongsberg, and Münster (1894) commented that "months and years may pass between discoveries of crystals." The following forms have been described: {100}, {111}, {110}, {311}, {210}, {410}, {520} and {721}. The {100} and {111} are the most frequent forms, often in combination and sometimes equally developed (*Mittelkörper* or cuboctahedrons). The size of the crystals can be considerable, more than 3 cm in edge length. Crystals of silver are usually equidimen-

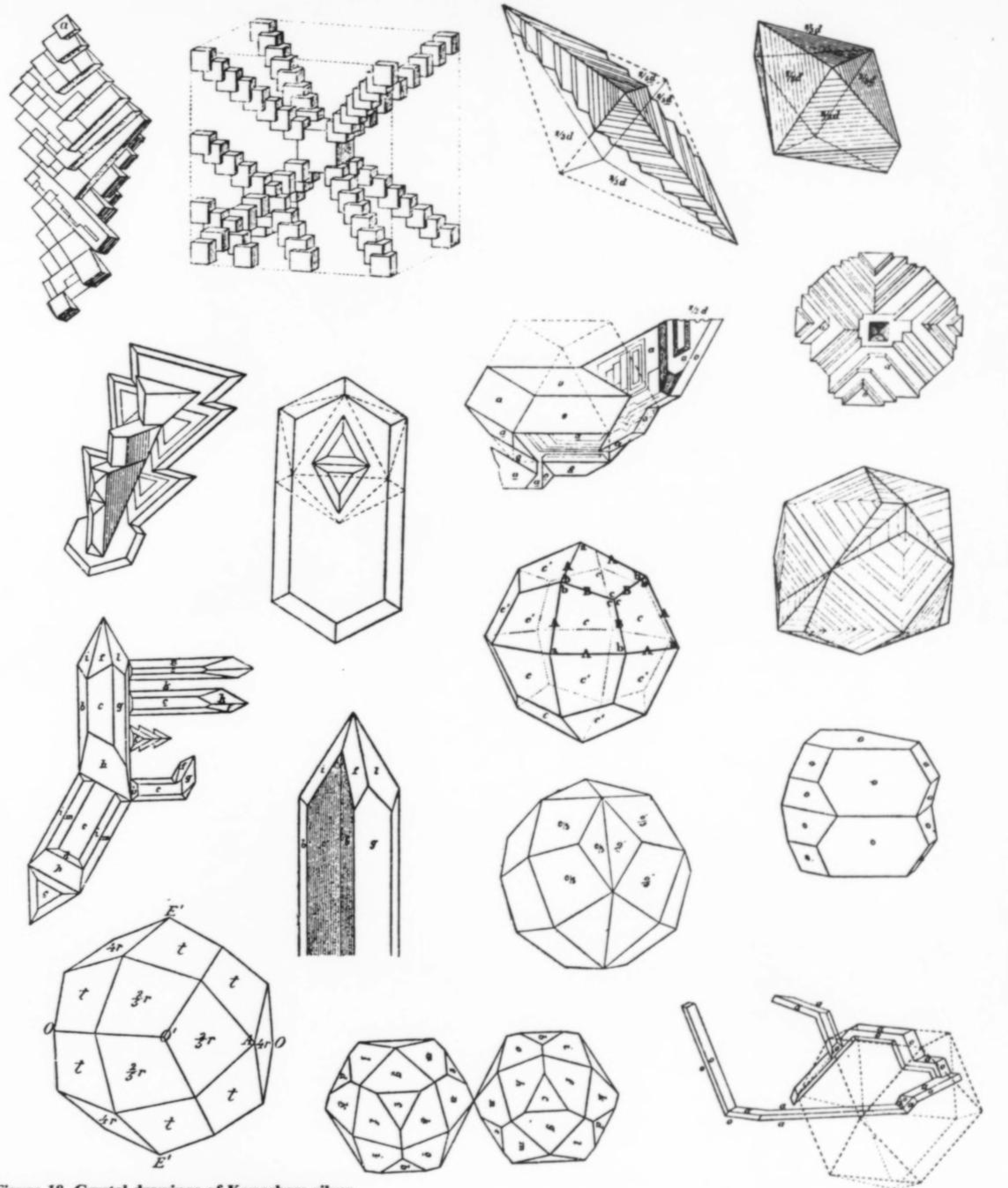

Figure 18. **Crystal drawings of Kongsberg silver (Goldschmidt, 1922).**

sional or platy to laminar. Rarely, a "prismatic" habit has been reported, for instance, a combination of four cube faces and four dodecahedron faces forming a ditetragonal prism (vom Rath, 1869). Platy or laminar crystals are flattened on {111} and show triangular striations due to the oscillatory development of {100} and {111}.

Twins on {111} are common and found mostly as combinations of cube and octahedron. When only cube faces are developed, the twin appears as a pseudotrigonal bipyramid. Other twins dominated by {311} and/or {111} also exhibit pseudotrigonal and pseudohexagonal forms or, if the trapezohedron is other than {311}, a pseudoscalenohedron. Some of these twins are elongated

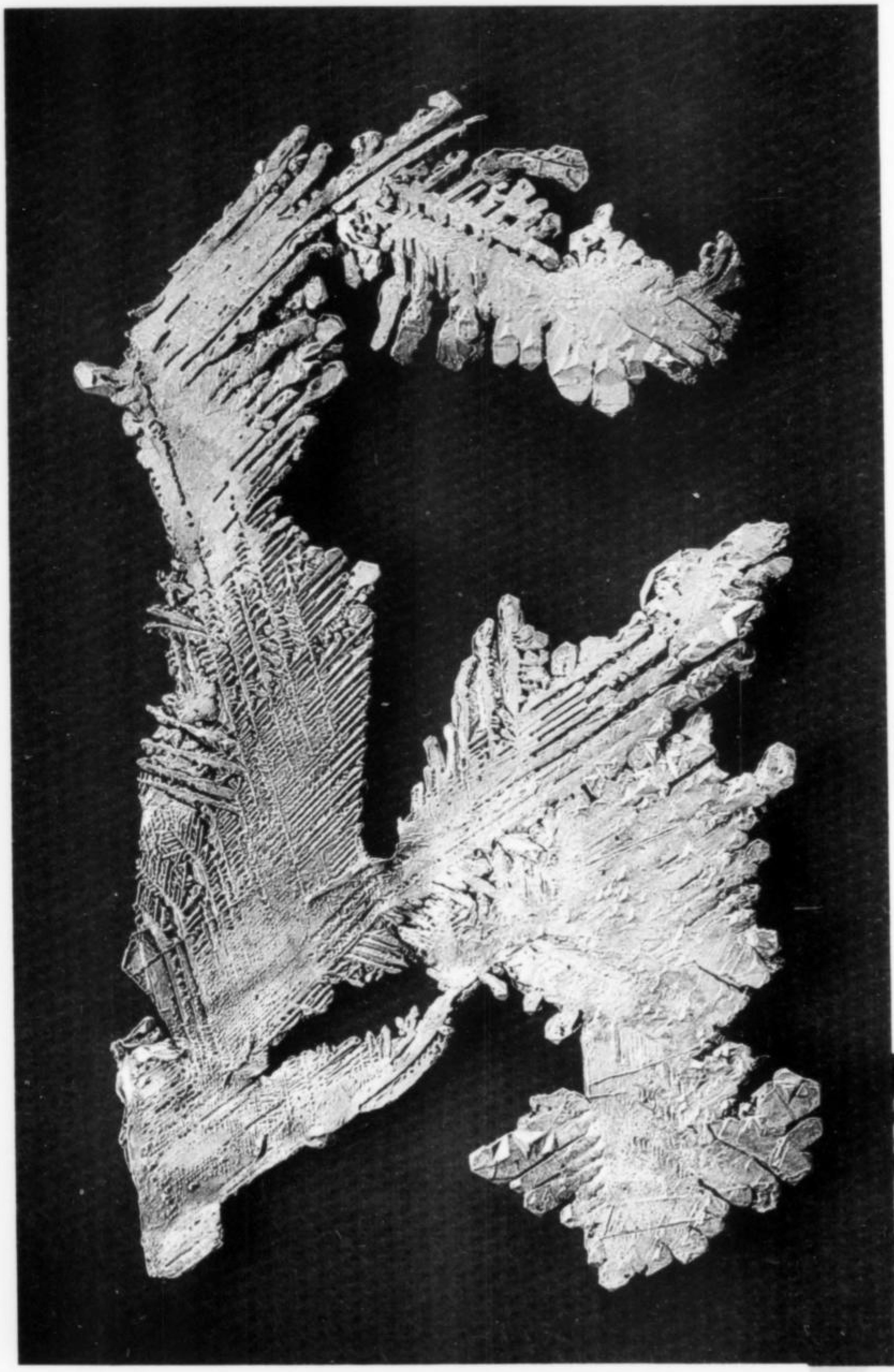

Figure 19. **Flat plate of crystalline silver 6.5 cm across. Photo courtesy of the Geological Museum, Copenhagen.**

Figure 20. **Pyrargyrite crystals to 3 mm on calcite, from Kongsberg. Harvard Mineralogical Museum collection.**

in one direction, and this together with the occasional suppression of individual faces makes it difficult to identify crystal forms. The morphology of the elongated crystals and twins has been studied in detail by Sadebeck (1878).

Composition

Kongsberg silver is usually very poor in gold; the average percentage of gold is less than 0.005%. Locally, especially in some small inferior mines, the gold content is somewhat higher, e.g., 0.35%. Highly auriferous silver has been reported in a few cases where analyses have shown contents between 27 and 53% Au (Neumann, 1944). Hiortdahl (1869) investigated specimens from some of the mines where auriferous silver was found, and he came to the conclusion that (judging from the frequent presence of remnants of

Figure 21. **Arborescent growth of silver culminating in octahedral crystals (Baumhauer, 1889).**

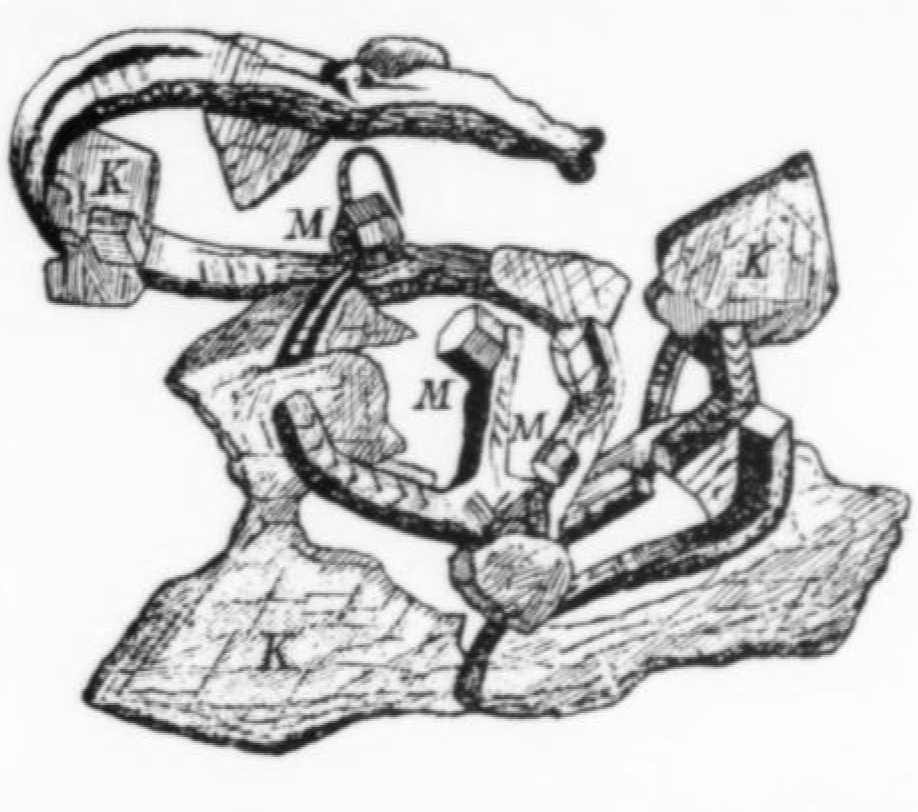

Figure 22. **Coarse wire silver with calcite (K) (Baumhauer, 1889).**

Figure 23. **Cubic crystal group of silver (von Kurr, 1859).**

the quartz-breccia veins) the silver veins have been locally enriched in gold originating from the quartz veins.

Mercury is the minor element most often encountered in native silver from Kongsberg. The average content is 1–2% Hg, but the variation is considerable; up to 23% Hg has been reported (Neumann, 1944). According to Neumann the thready silver is characterized by a distinctly lower content of mercury than other habits.

Traces of other elements, Ni, Co, Cu, Bi, Fe and As, have also been found in Kongsberg silver (Ridge, 1984). But, all things considered, it is amazing how little data has been published in recent years. Much more work, especially microprobe work, remains to be done.

Argentite Ag_2S

Argentite occurs mostly as intersticial masses or as laminae in the veins. Crystals of argentite are rare; when seen they have somewhat corroded surfaces. The crystal forms observed are: {100}, {110}, {211} and {111}.

Two generations of argentite can be distinguished, an early one in association with other sulfides and a later one, very minor, following the precipitation of native silver. The mutual replacement of native silver and argentite has been mentioned above, sometimes resulting in "wire argentite" after wire silver. An apparent cubic penetration twin of argentite is known, but it too may be a replacement of silver.

Calcite $CaCO_3$

Calcite is the main mineral in the silver-bearing veins. It formed almost continuously during the formation of the veins. Sometimes early-formed calcite shows evidence of intervals of resorbtion followed by redeposition, and sometimes calcite has been replaced by native silver which again later has been replaced by calcite (Newmann, 1944).

Calcite at Kongsberg displays quite a variety of crystal forms (Münster, 1883; Morton, 1884; Sansoni, 1890). Based on calcite crystals from the Gottes Hülfe mine, Münster established a morphological age sequence: (1) an early generation of crystals with only $\{10\bar{1}1\}$; (2) crystals with frosty $\{10\bar{1}1\}$ and lustrous {0001}; (3) crystals with $\{21\bar{3}1\}$, $\{21\bar{3}4\}$, $\{8.8.\overline{16}.3\}$ and $\{02\bar{2}1\}$; (4) the latest generation with $\{10\bar{1}0\}$ and $\{01\bar{1}2\}$.

A common occurrence in Kongsberg is the variety *skiferspat* ("slate spar"), calcite with an extreme dominance of {0001}, thus forming thin sheets. The sheets are often oriented in different directions, creating numerous small compartments where small perfect crystals of quartz and pyrite appear. *Skiferspat* calcite is one of the last minerals to have formed.

Graphite C

"Coal blend" (a straightforward translation of the Norwegian *kullblende*) is a name that has always been used for graphite or bitumen at Kongsberg. Chemical analyses show that this graphite consists of 90% to 96% C with minor amounts of O, H, S and N. The physical properties such as hardness and fracture are very much like those of anthracite. Kongsberg graphite has been briefly

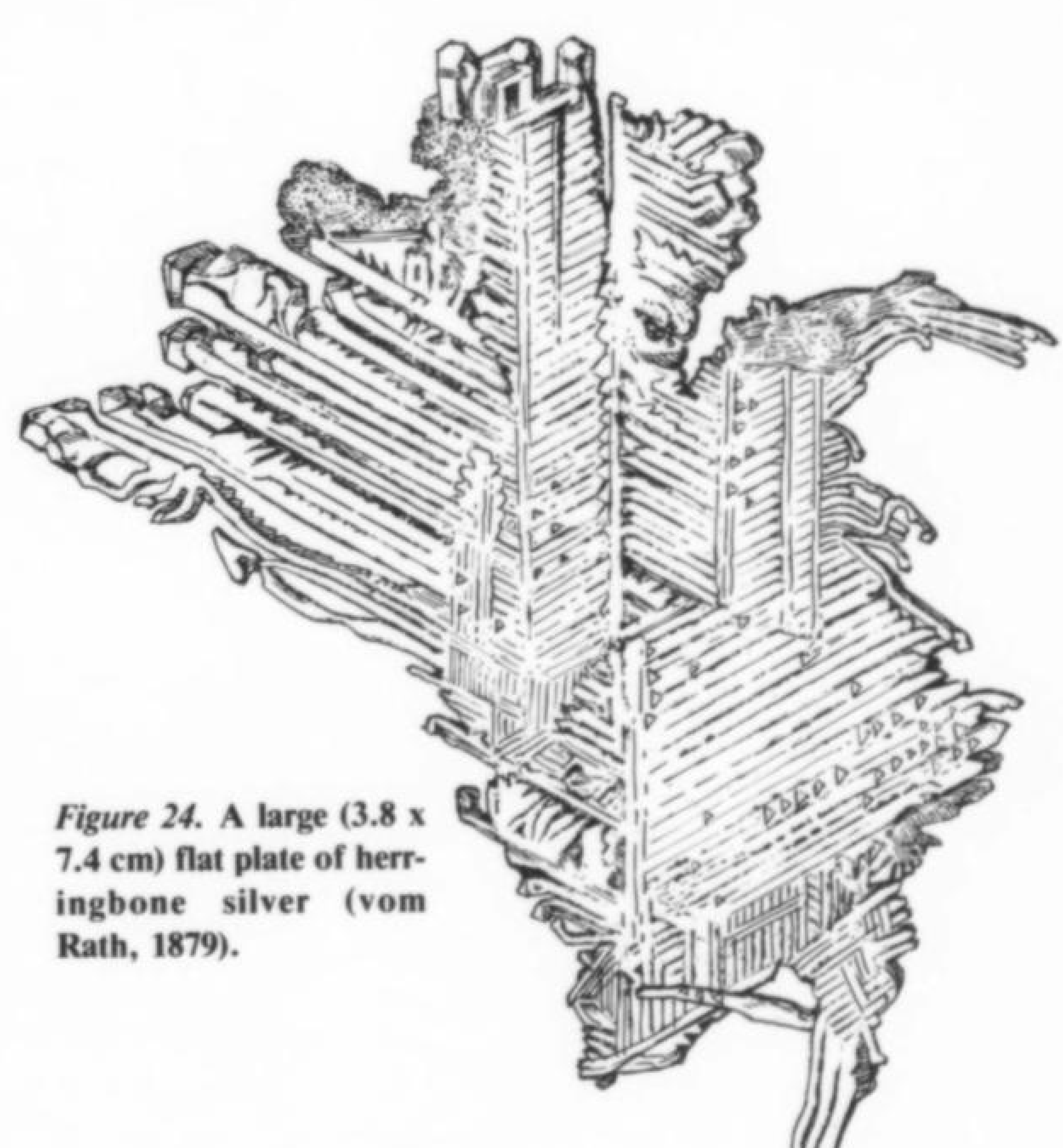

Figure 24. **A large (3.8 x 7.4 cm) flat plate of herringbone silver (vom Rath, 1879).**

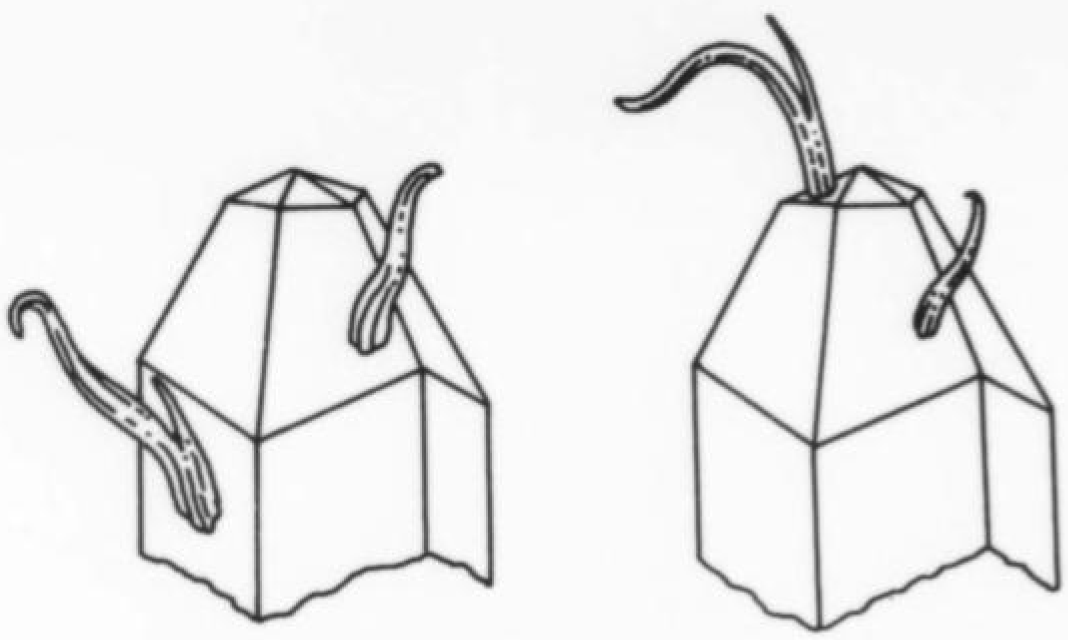

Figure 25. **Sketch showing wire silver growing from the faces of proustite crystals (Vogt, 1899).**

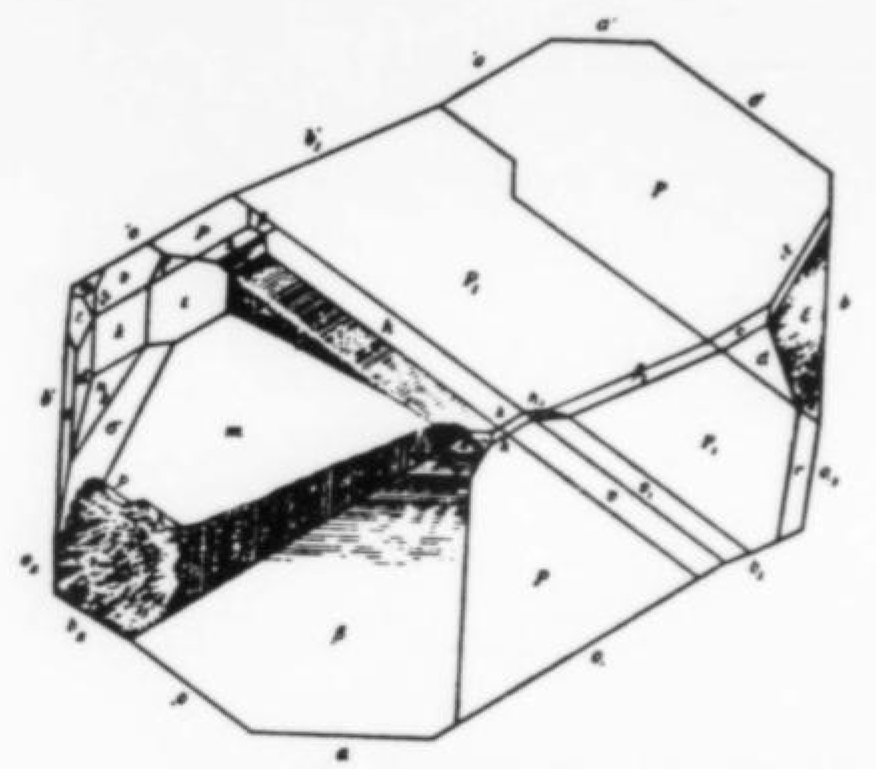

Figure 26. **Drawing of a stephanite crystal from the Gottes Hülfe mine (Neumann, 1944).**

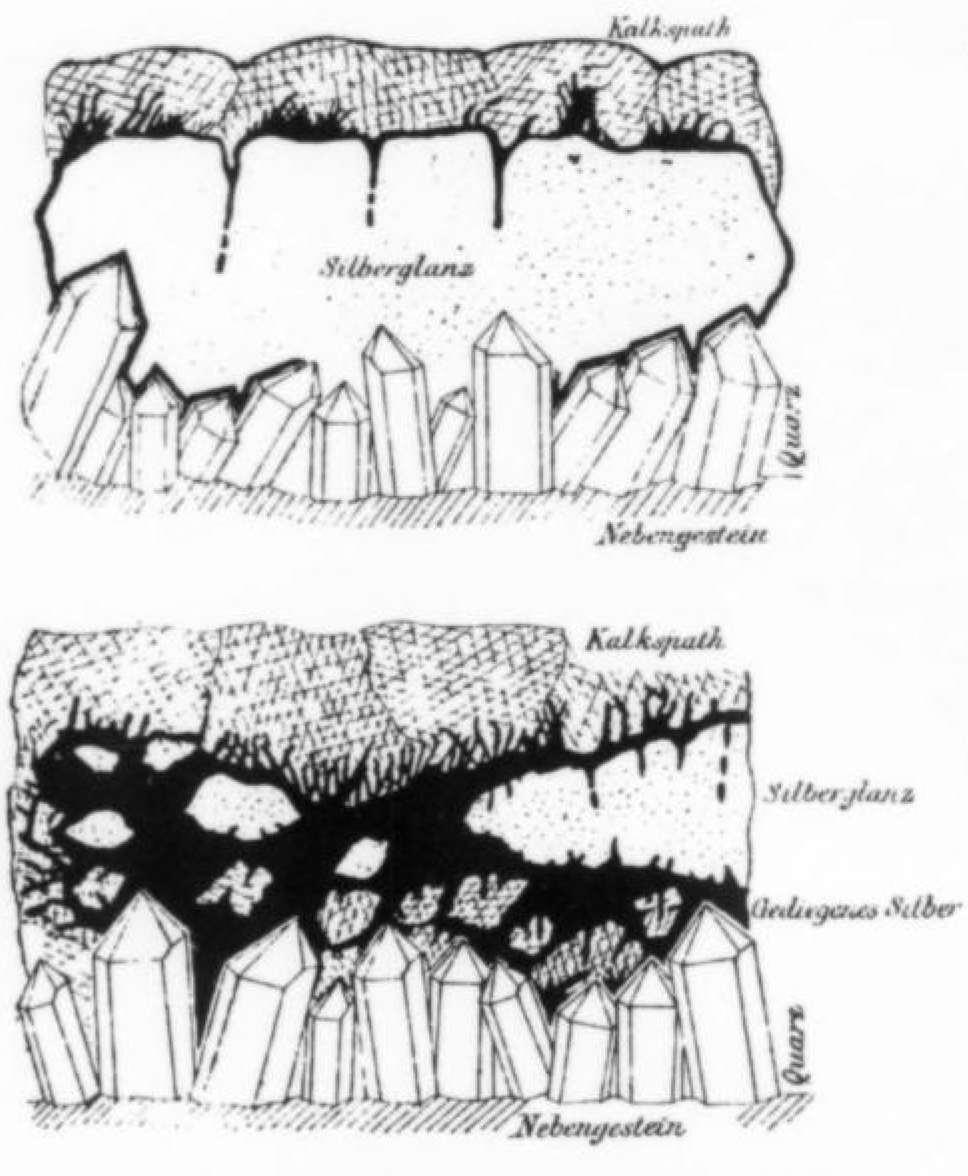

Figure 27. **Diagrammatic sketches showing argentite ("silberglanz"), silver (black), quartz (large crystals) and calcite (cross hatched) as they were found in veins (Vogt, 1899).**

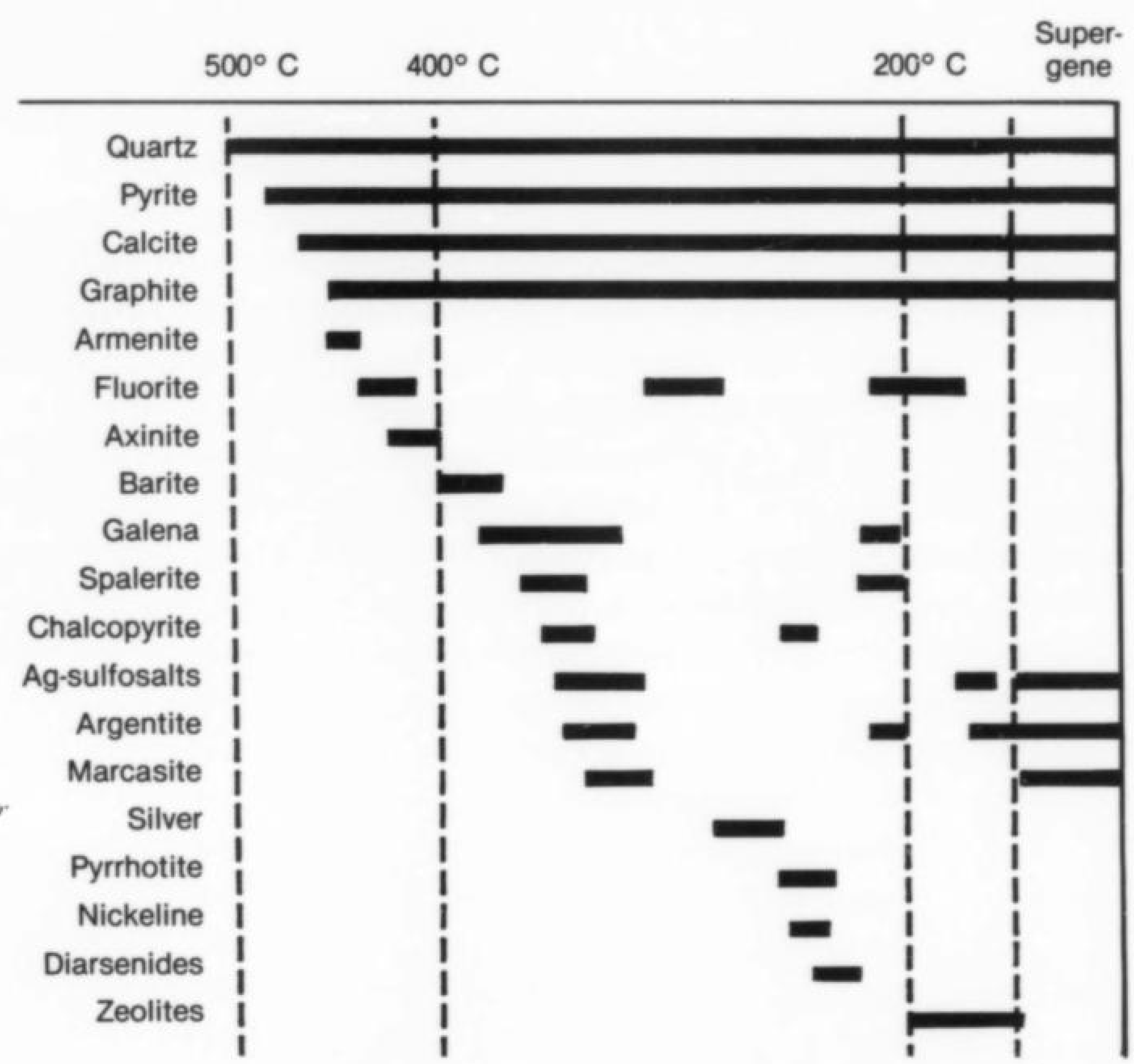

Figure 28. **Paragenetic table for the Kongsberg veins (after Neumann, 1944).**

described by Vogt (1899), Lietz (1939) and Neumann (1944), but no thorough investigation of this material has been published.

The precipitation of graphite was one of the early events in the formation of the silver-bearing veins at Kongsberg. It often occurs in association with native silver and is usually found as oolitic or pisolitic masses. Under magnification the material appears to have been built up from small leaves of graphite, but X-ray analysis (Neumann, 1944) failed to reveal much crystallinity.

Other Minerals

The Kongsberg district is the type locality for two minerals: *anthophyllite* (described by Schumacher in 1801) and *armenite*, $BaCa_2Al_6Si_9O_{30} \cdot 2H_2O$, a mineral of the osumilite group still known as only a few specimens collected in 1877 at the Armen mine (Neumann, 1939). Armenite, which resembles epidote in appearance, was found associated with axinite, pyrrhotite, quartz and calcite.

Purple and green octahedral fluorite is common in the veins, and this distinctive association with fine native silver is occasionally used as a guide in determining Kongsberg as the locality for old specimens lacking labels. Quite a number of crystal forms for Kongsberg fluorite have been described in the early literature.

Interesting crystals of proustite were figured by Vogt (1899) in which wire silver protrudes from the crystals, though surviving specimens are unknown to the author. Neumann (1944) reports "many harmotomes" colored red by proustite-pyrargyrite.

At the Paris Universal Exposition in 1867, the Kongsberg mines were represented by a major display of specimens. Included was a fine hexagonal pyrargyrite crystal measuring 1.9 cm tall by over 1

Table 1. **Minerals from the Kongsberg silver deposit.**

Acanthite	Ag_2S
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Albite	$NaAlSi_3O_8$
Anatase	TiO_2
Anthophyllite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
Apophyllite group	
Argentite	Ag_2S
Armenite	$BaCa_2Al_6Si_9O_{30}\cdot 2H_2O$
Arsenic	As
Arsenopyrite	FeAsS
Axinite group	
Barite	$BaSO_4$
Calcite	$CaCO_3$
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chamosite	$(Fe^{+2},Mg,Fe^{+3})Al(Si_3Al)O_{10}(OH,O)_8$
Chlorargyrite	AgCl
Chlorite group	
Clausthalite	PbSe
Cobaltite	CoAsS
Copper	Cu
Datolite	$CaBSiO_4(OH)$
Dyscrasite	Ag_3Sb
Epidote	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$
Erythrite	$Co_3(AsO_4)_2\cdot 8H_2O$
Fluorite	CaF_2
Galena	PbS
Garnet group	
Gold	(Au,Ag)
Graphite	C
Harmotome	$(Ba,K)_{1\text{-}2}(Si,Al)_8O_{16}\cdot 6H_2O$
Hyalophane	$(K,Ba)Al(Si,Al)_3O_8$
Ilmenite	$FeTiO_3$
Jalpaite	Ag_3CuS_2
Laumontite	$CaAl_2Si_4O_{12}\cdot 4H_2O$
Magnetite	Fe_3O_4
Malachite	$Cu_2(CO_3)(OH)_2$
Marcasite	FeS_2
Montmorillonite	$(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2\cdot nH_2$
Natrolite	$Na_2Al_2Si_3O_{10}\cdot 2H_2O$
Naumannite	Ag_2Se
Nickeline	NiAs
Nickel-skutterudite	$NiAs_{2\text{-}3}$
Orthoclase	$KAlSi_3O_8$
Palygorskite	$(Mg,Al)_2Si_4O_{10}(OH)\cdot 4H_2O$
Pearceite	$Ag_{16}As_2S_{11}$
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$
Prehnite	$Ca_2Al_2Si_3O_{10}(OH)_2$
Proustite	Ag_3SbS_3
Pyrargyrite	Ag_3SbS_3
Pyrite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Quartz	SiO_2
Rammelsbergite	$NiAs_2$
Safflorite	$CoAs_2$
Sepiolite	$Mg_4Si_6O_{15}(OH)_2\cdot 6H_2O$
Silver	Ag
Skutterudite	$CoAs_{2\text{-}3}$
Sphalerite	(Zn,Fe)S
Stellerite	$CaAl_2Si_7O_{18}\cdot 7H_2O$
Stephanite	Ag_5SbS_4
Stilpnomelane	$K(Fe^{+2},Fe^{+3},Al)_{10}Si_{12}O_{30}(OH)_{12}$
Sternbergite	$AgFe_2S_3$
Synchysite	$(Ce,La)Ca(CO_3)_2F$
Tennantite	$(Cu,Fe)_{12}As_4S_{13}$
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
Tremolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

cm across (Blake, 1869).

Pyrite and prehnite have also been found rarely in attractive crystals.

The diarsenides (rammelsbergite, safflorite, skutterudite and nickel-skutterudite) are rare but widely distributed as thin coatings on silver. The sulfosalts such as polybasite, pyrargyrite, proustite and stephanite are extremely rare.

Axinite and barite have also been found in the veins as well-formed crystals.

A fair number of other species, most of them poorly crystallized, have been found in the Kongsberg veins. They are listed along with those mentioned above in Table 1; Neumann (1944) provides a more detailed discussion, particularly regarding polished section studies and the implications for paragenesis.

CONCLUSIONS

The collecting possibilities at Kongsberg today are extremely limited. Upon rare occasion, the dumps will yield small specimens, and collectors have at times made significant discoveries of silver underground, but the majority of the mines are now barred for safety reasons. Nevertheless, more silver probably remains in the old veins and perhaps someday it will become economical once again to reopen them. In the meantime, a huge number of specimens continues to circulate among public and private collections, and the collector today (who can afford it) still has the chance to own specimens from one of the world's most famous silver districts.

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MICHIGAN SILVER

Native silver occurrences in the copper mines of Upper Michigan

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When one thinks of classic crystalline silver, the Keweenaw Peninsula immediately comes to mind. Despite its fame as one of the world's great copper mining districts, the Michigan "Copper Country" has yielded over 16 million troy ounces of silver, including some of the finest crystal specimens known.

INTRODUCTION

The Michigan "Copper Country" is located in Upper Michigan, on the western side of the Keweenaw Peninsula projecting into Lake Superior. Mines were operated on a lode belt 3–6 km in width, extending from the tip of the peninsula near Copper Harbor to the area of the White Pine mine, a distance of some 160 km.

Since the first claims were staked in 1844, these occurrences have generally been considered copper mines, and the silver has been relegated to a peculiar status. Although it was produced in great quantity it was commonly not recorded in company ledgers, and very little was written about it. Miners and mine managers considered it to be their personal property wherever they encountered it. Mine owners of course disagreed, and the dispute was never resolved. In any case, as of 1977 the Michigan copper mines achieved a total *recorded* production of over half a million kilograms (16,469,544 troy ounces) (Leskinen, 1980); the actual total may have been twice that. At the same time, roughly 5 *billion* kilograms (11 billion pounds) of copper were produced (Weege and Pollack, 1971).

Underground workings in the Copper Country are extensive, totalling more than 17,000 km. Deposits are found primarily in Keweenaw and Houghton Counties, but also to a lesser extent in Ontonagon County. At least a small amount of silver has been found in virtually all lodes and fissures mined on the peninsula. But a few of the early mines were so rich in silver that their owners did, in fact, consider them to be silver mines at first; the Isle Royale,* Huron, Portland and the Sheldon, and Columbian mines, to name a few, made most of their early profits in silver. The Lake Superior mine yielded so much silver in the first 10 meters of the shaft that the shareholders were informed it was henceforth to be a silver mine (Murdoch, 1943). Unfortunately, silver was subsequently found to diminish with depth in the mines, and people eventually conceded them to be copper mines after all.

This article will focus on the history and localities of the most important silver-producing mines. *(A major study of the Copper*

* Note: the Isle Royale *mine* is located on the Keeweenaw Peninsula, and not on Isle Royale itself. Early Indian miners worked deposits on the island, but modern commercial mining has been restricted to the peninsula.

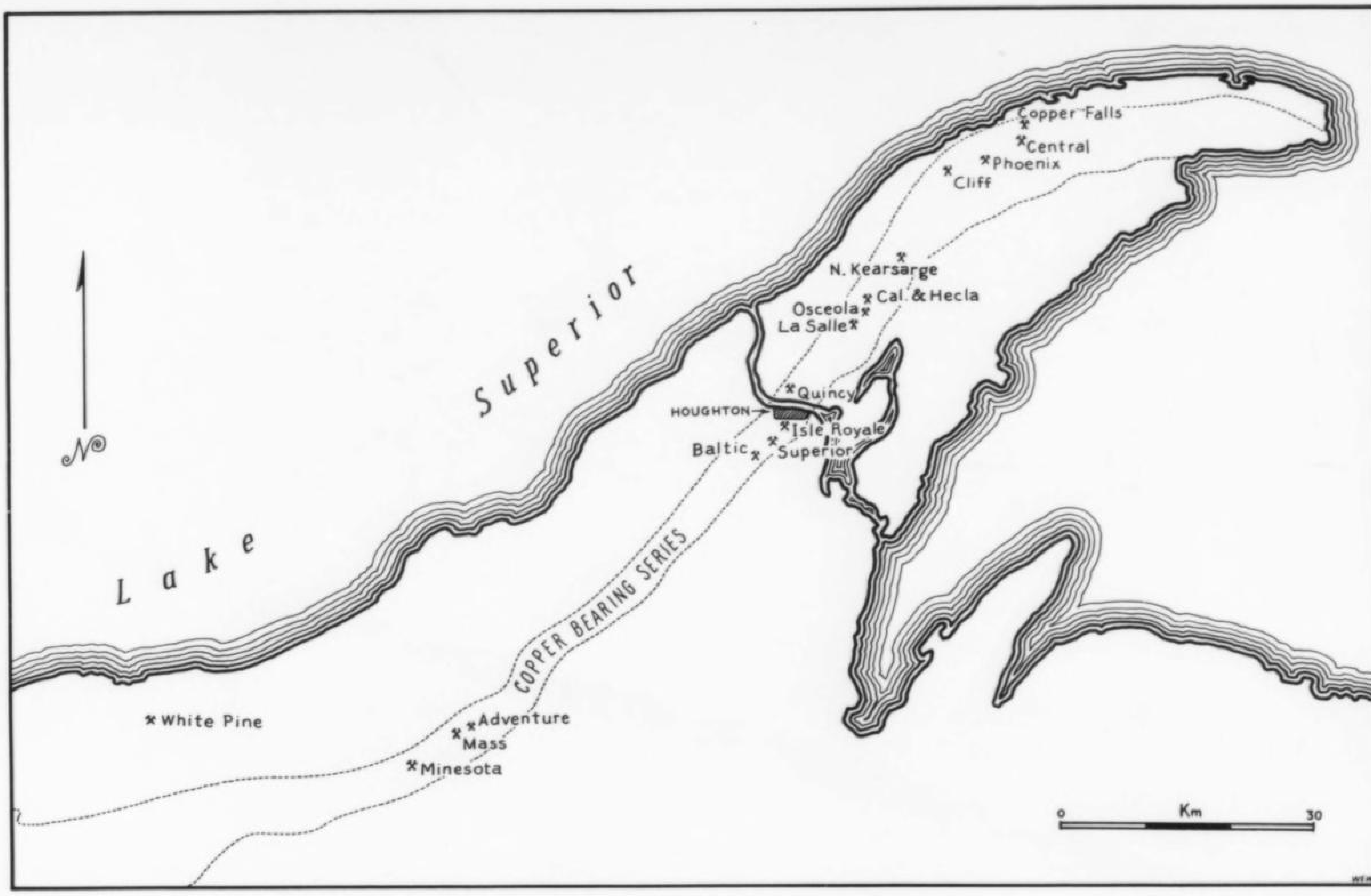


Figure 1. **Location map of important mines along the Michigan copper belt.**

Country in general is in preparation and will include more detail on all of the mines. Ed.) It is important to remember that exploitation proceeded in a complex pattern over the years. Individual mines came under a succession of owners, each of whom may have renamed the mine. Various mines converged underground or were consolidated under a new name, and many individual mines operated extensively in more than one major lode or ore horizon. Some mines operated from a number of different shafts separated by up to 3 or 4 km. Consequently it has proven impossible to obtain full data on all mines and mine names known on the peninsula. Only those which have been reliably substantiated or documented regarding their production of silver specimens and silver ore are discussed here.

HISTORY

Copper (and presumably also silver) were first mined on the Keweenaw Peninsula several thousand years ago by Indians referred to as the Old Copper Culture. They did not live in the area – perhaps the winter climate was too severe – but they made periodic trips there specifically to mine. Carbon dating of mining sites on Isle Royale, and of Indian sites elsewhere containing copper artifacts made from Lake Superior copper, suggests that mining was active roughly from 3800 to 6500 years ago, and most likely continued up to the time of the first French explorers. As many as 10,000 mining pits were dug by the Indians, and the resulting copper spread as trade items from Georgia to Canada.

White men first learned of copper in the Lake Superior area in the early 1600s; Lagarde mentions it in a book published in 1636, and the letters of early Jesuit missionaries make note of copper being used by the Indians. "We have seen it in the hands of the barbarians," wrote Francesco Bressani in 1653 (Thwaites, 1899). Father Jerome Lalemant wrote in 1659 that the coast of Lake Superior is "enriched with copper of such excellence that pieces as large as one's fist are found, already refined." These reports stirred little interest. Had the metal been gold, the story would have been different, but copper was worth too little to be considered anything more than a curiosity in such wild and remote regions.

A century passed and, in 1765, a British trader by the name of Alexander Henry traveled through the Lake Superior region and made note, as others had before him, of "the abundance of virgin copper." A year later he went up the Ontonagon River to see the famous Ontonagan copper boulder mentioned by Father Allouez in 1665. "With an axe I was able to cut off a portion weighing a hundred pounds," he wrote (see Pantell, 1976, for the long story of this famous specimen). Henry subsequently joined forces in 1771 with another Englishman, Alexander Baxter, and for three years they carried out difficult and unsuccessful mining, not for copper but "with a view to the silver" (Henry, published posthumously in 1901). Thus it was that the first "official" mining in the Copper Country was actually for silver.

The dismal failure of Henry's enterprise resulted in further disinterest from everyone. Then in 1830 the area was visited by Douglass Houghton, the mayor of Detroit and a man of some influence. He eventually persuaded the Michigan state legislature to finance a survey of the Upper Peninsula and, since he was so interested in the project, they appointed him State Geologist in 1837 so that he could head up the survey personally. His first report, published in 1841, finally began to stir some interest in the copper-silver deposits, and the government was pressured to get things in order for exploitation. With its usual expedience the Federal

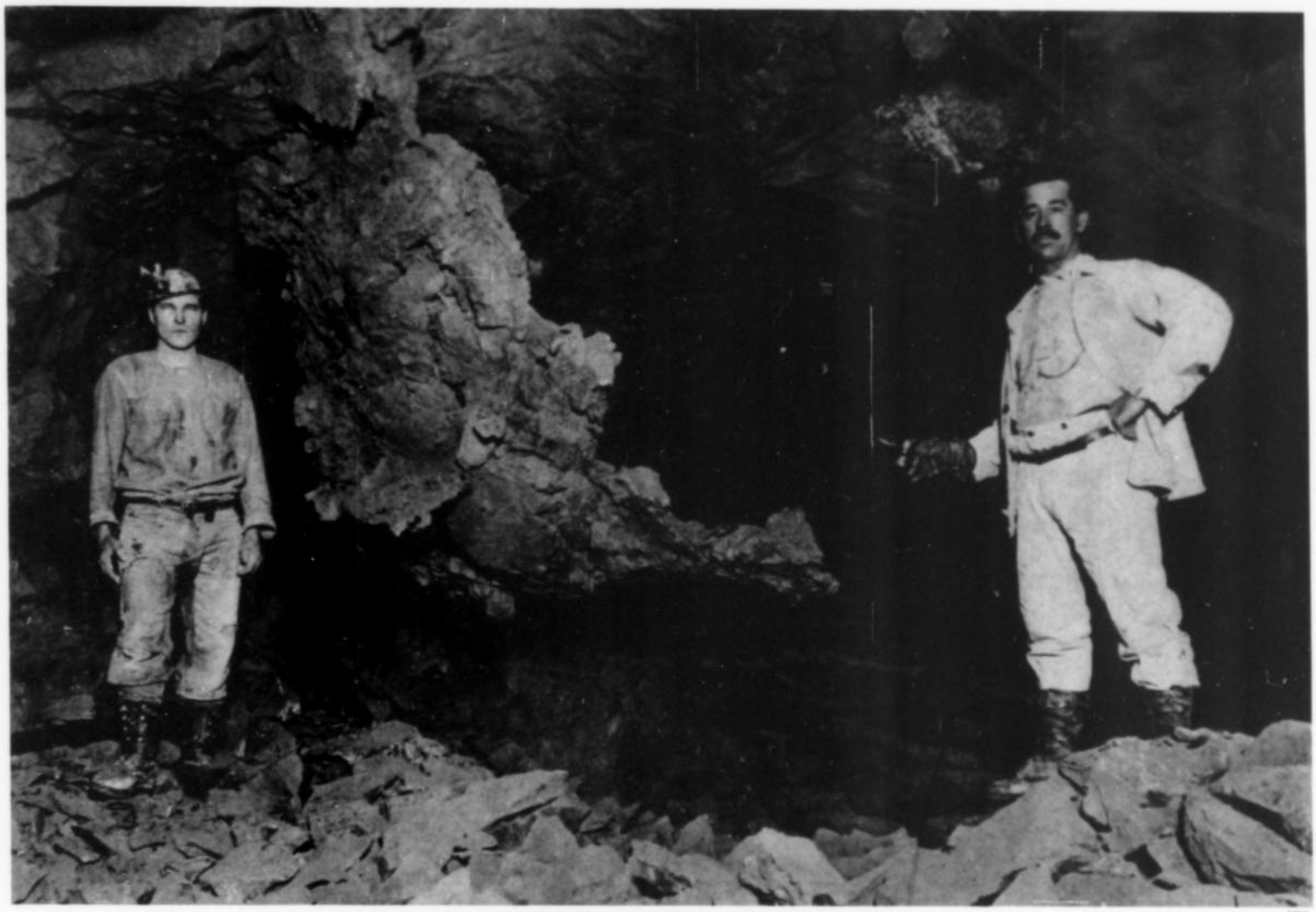


Figure 2. **Mass copper hanging from the back of a stope, ca. 1918. Photo: Mineralogical Record Library.**

Government hoodwinked local Indians out of the required 120,000 square kilometers and moved them elsewhere without ever giving them full payment (Rickard, 1905). In 1844 the first mining permits were issued. Houghton never got to see the great bonanza of silver and copper develop; he drowned when his sailboat capsized in a sudden storm on Lake Superior in 1845.

Boom towns began to spring up all along the peninsula as prospecting and mining got under way. Many deposits were located on the sites of early Indian mining. But the terrain was difficult; one prospector wrote, "Even in the drier seasons you sink to your knees in moss and decayed matter. It's as bad or worse than the Everglades" (Murdoch, 1943).

As mentioned earlier, the highgrading of silver was a universal pastime in the mines. Managers would tell their green recruits to "just set aside the *white copper* for me and I'll pick it up later." But the newcomers soon learned the value of silver and played ingenious games of smuggling against the shift bosses. If caught they simply forfeited the silver to the boss, who pocketed it for himself. This went on throughout the entire history of mining on the peninsula. One retired bar owner I spoke with recalled that miners almost invariably paid for their drinks in raw silver, and people from Chicago passed through periodically to buy it up from the local merchants. A superintendent of the Wolverine mine is reputed to have remarked that all of the automobiles in the town of Gay actually should belong to the mining company because they were purchased with stolen silver (Leskinen, 1980).

Very little mining goes on today in the Copper Country. Most of the famous old mines are shut down and are fast becoming picturesque subjects of industrial archaeology. But the unique flavor of the area remains, and the finest accumulation of Michigan silvers in the world is to be seen at the A. E. Seaman Mineralogical Museum, Michigan Technological University, in Houghton. This remarkably fine collection, with a mineral display area several times the size of the Smithsonian's, is an unequaled treasurehouse of Michigan minerals capable of impressing even the most jaded collector. Nearly all of the specimens pictured here are from the Michigan Tech collection, and these are but a small fraction of what has been preserved there. The museum is open weekdays until 4:30 p.m. except during school holidays, and at other times by appointment with curator Jean Kemp.

GEOLOGY

A vast amount of literature has been published on the Copper Country. The classic paper on the area was written by Butler and Burbank in 1929; Ridge (1972) and White (1968) provide discussions of later studies. The following synopsis is drawn mostly from their work.

Copper and silver, almost entirely in the form of native metals, are contained in rocks of the late Precambrian Keweenawan series. The series consists of silicic and mafic intrusive and extrusive rocks, ash, tuff, shale, sandstone and conglomerate. Most of the rocks in the lower part of the series are flow basalts of the plateau type, in vertical accumulations totaling several kilometers. Intercalated with the basaltic flows are numerous beds of conglomerate in thicknesses from a few centimeters to a meter or more.

Figure 3. **Underground at the Quincy mine, ca. 1890, in the main engine room. Photo: Bentley Historical Library, University of Michigan.**

Metalliferous deposits are of two general types: (1) bedded (lode or tabular) deposits and (2) fissure veins. The bedded deposits include lodes in conglomerate beds and lodes in amygdaloidal basalt flows. The main bedded lodes have been named as follows:

1. Ash Bed amygdaloid *(youngest)*
2. Pewabic amygdaloid
3. Allouez conglomerate
4. Calumet and Hecla conglomerate
5. Osceola amygdaloid
6. Kearsarge amygdaloid
7. Isle Royale amygdaloid
8. Baltic amygdaloid *(oldest)*.

It is interesting to note that over 400 distinct volcanic flows and sedimentary beds have been identified on the peninsula, among which only these 8 have yielded commercial quantities of copper and silver. The Calumet and Hecla conglomerate has been the largest producer, accounting for 45% of total production on the peninsula.

Fissure deposits were formed in the same lower members of the Keweenawan series, although generally in different areas. The fissure deposits taken together have produced only 2% of the district total in metals, less than most of the individual amygdaloids, but a significant proportion of the fine crystallized silver specimens have come from the fissures. Of the 23 fissure deposits that were mined, only seven returned any profits to their investors (Monette, 1978).

Mineralization in the conglomerate beds began with deposition of a reddish alkali feldspar followed by abundant epidote, and a small amount of pumpellyite. After the bulk of the epidote and pumpellyite had formed, native copper began to precipitate along with quartz and calcite and a small amount of chlorite and native silver. The last minerals to form were barite and very small amounts

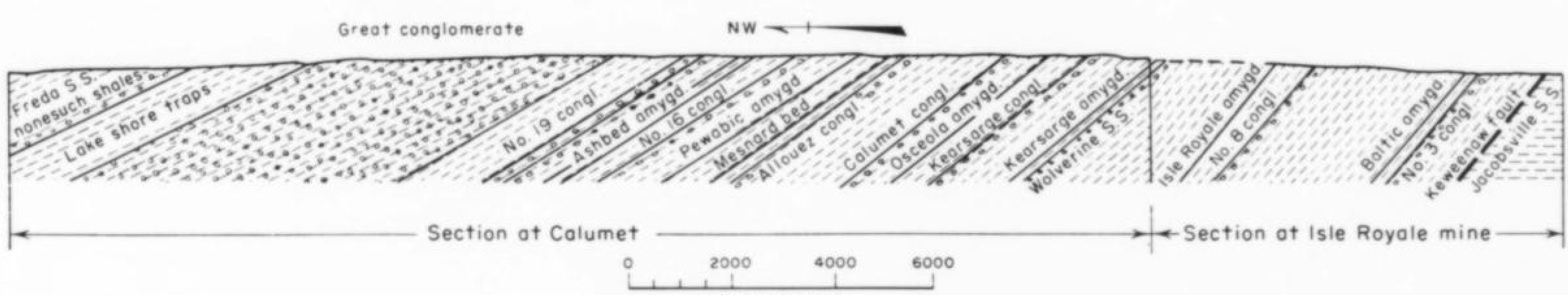


Figure 4. **Cross section through the various conglomerate and amygdaloidal basalt layers (from Broderick, Hohl and Eidemiller, 1946).**

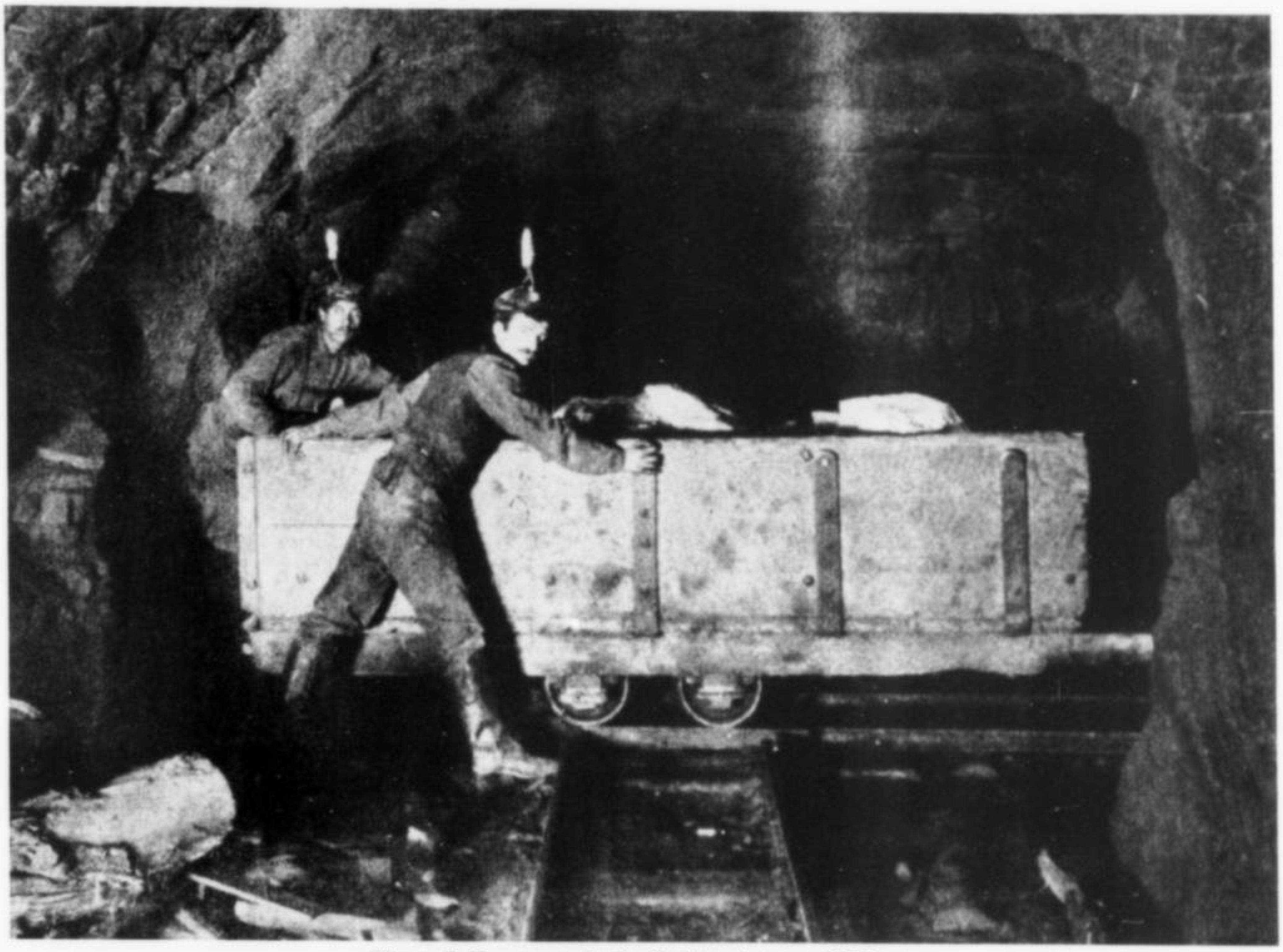


Figure 5. **Trammers in the Baltic mine, ca. 1895.**
Photo: Lee Miller.

of sulfides. Zeolites and related minerals so common in other Copper Country environments are almost entirely absent from the conglomerate beds.

Mineralization in the amygdaloidal basalts was somewhat more complex, beginning with the reddish feldspar and epidote, abundant chlorite and pumpellyite and, toward the end of deposition of these minerals, native copper, quartz and calcite. At the same time datolite, ankerite and sericite developed in locally abundant quantities. Zeolites such as analcime and laumontite formed, along with somewhat more native silver than occurs in the conglomerate beds. Arsenides and sulfides occur in small veins cutting the amygdaloids at various angles.

Fissure veins of three types are known: (1) native copper veins, (2) copper arsenide veins, and (3) copper sulfide veins. All of the deposits having any commercial significance are of the first type. Gangue minerals are the same as in the bedded deposits, mostly feldspar, epidote, chlorite, pumpellyite, quartz and calcite. However, the assemblage of copper and silver species is considerably more varied.

The Michigan copper deposits have been thought by some authors to be of magmatic hydrothermal origin. Wells (1925) proposed that the overwhelming dominance of native copper over sulfides is due to the abundance of Fe^{+3} in the wall rocks, which reacted with hydrothermal copper sulfide. The result, according to this theory, was an exchange of iron for copper in solution, and a precipitation of native copper. The reduction of silver and arsenic in the solutions would have taken place along much the same lines. Iron involved in the exchange would be carried away in solution (pyrite is absent from these deposits).

The extensive magmatic source necessary has remained a problem for theorists. It was assumed to be a large mafic intrusion akin to the Duluth Gabbro Complex or its felsic differentiates, underlying Lake Superior and driving its hydrothermal solutions up-dip through the Keweenawan basalts. Evidence is lacking, however, and current thinking suggests that the copper was leached out of the down-dip, deeply buried basalts themselves. Although the amount of copper mined is enormous and at first seems more than trace constituents could account for, calculations prove otherwise. Roughly 33,000 cubic kilometers of basalt are thought to be involved as a source, and could have yielded 1000 times the total district production of copper (White, 1968). Basalt flows are estimated to extend under Lake Superior to depths as great as 15 km, where temperatures of 300–500° C and pressures of 2.5–4 kilobars prevail. This is certainly adequate to produce lowgrade metamorphism and drive out interstitial water. Low sulfur content would be expected in basalts originally degassed under near-surface conditions; this would later allow the leaching and redeposition of copper and silver instead of sulfides. Paces (1982) demonstrated that mass balance and petrologic mixing calculations require no addition or subtraction of material to account for the bulk chemistry of altered versus unaltered basalts. Scofield (1976) has shown that a copper chlorine complex could have achieved solution concentrations well in excess of 2000 ppm copper derived solely from the basalts themselves, and that this is adequate to explain the Michigan copper deposits.

The result of all this was the deposition of copper and silver on a regional scale, over a vertical range of several kilometers. Silver has been found over much of that range but is far more abundant in the near-surface levels. Radiogenic age dating suggests an age of about 1 billion years for the metamorphism which created these deposits. It is somewhat sobering to think that those lovely, sharp silver crystals in one's showcase are a billion years old.

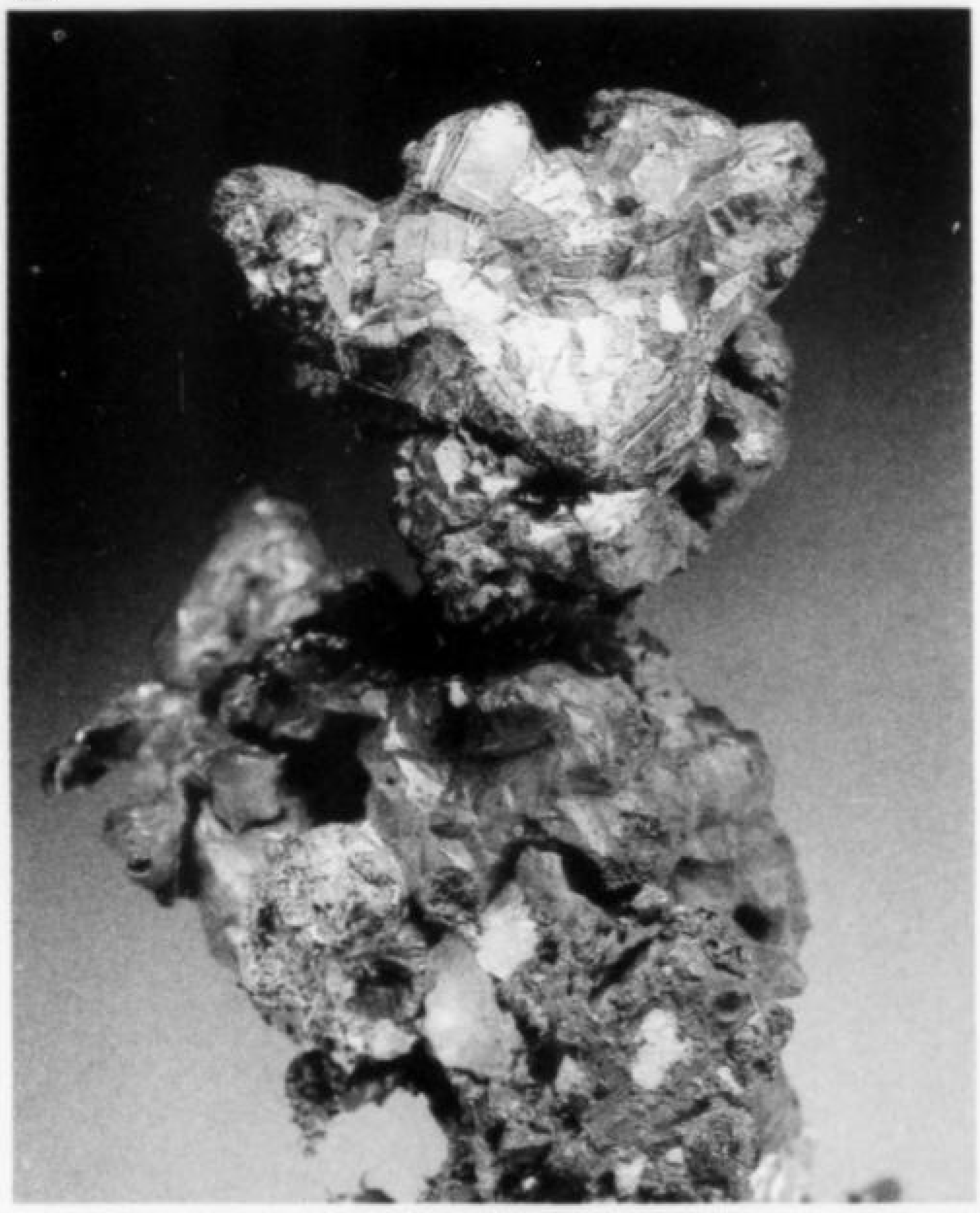
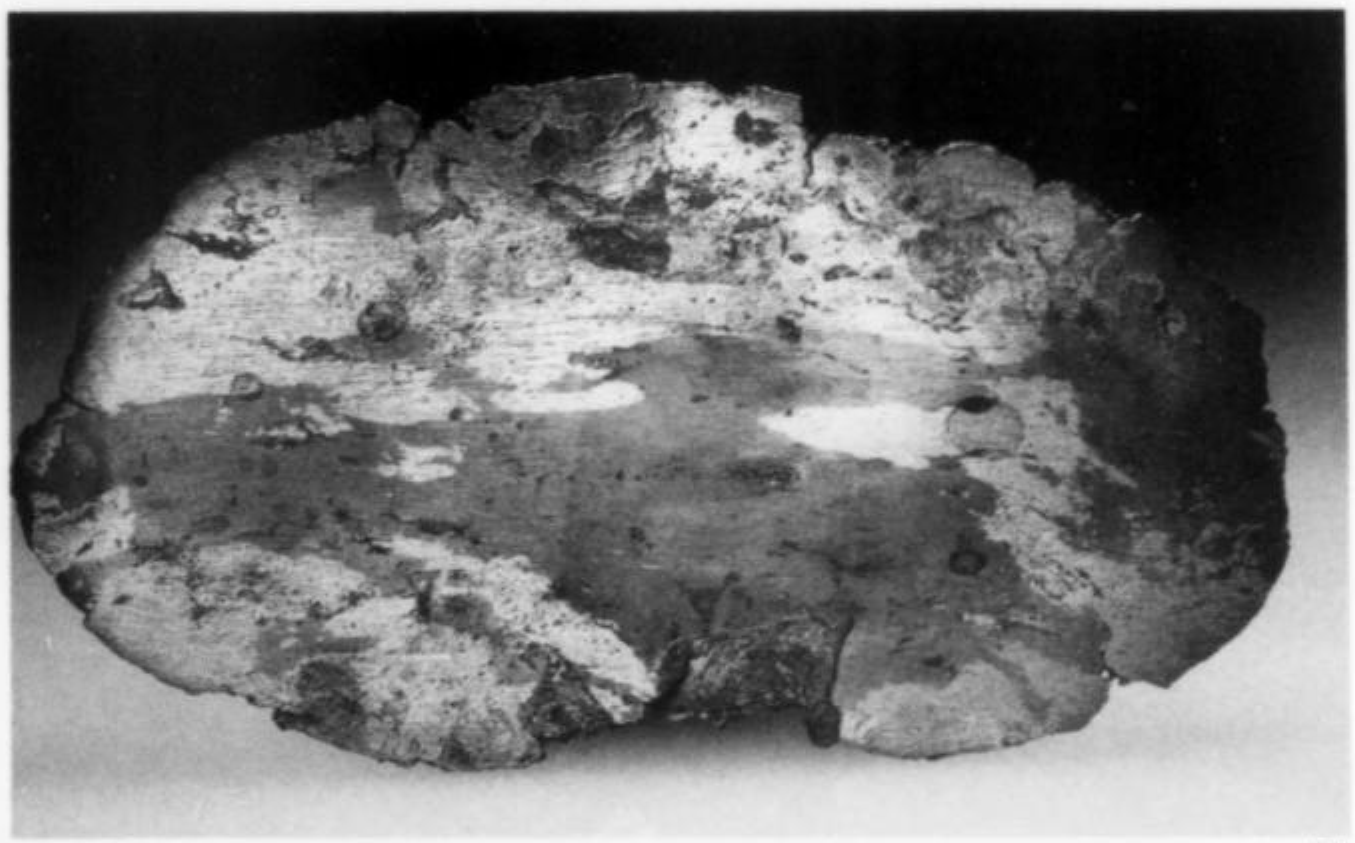


Figure 6. **Silver crystal aggregate 2.9 cm across on copper, from the Baltic mine. A. E. Seaman Mineralogical Museum collection.**

Figure 7. **Large copper-silver "halfbreed" slab 14.8 cm across, from the Calumet and Hecla mine. Harvard Mineralogical Museum collection.**



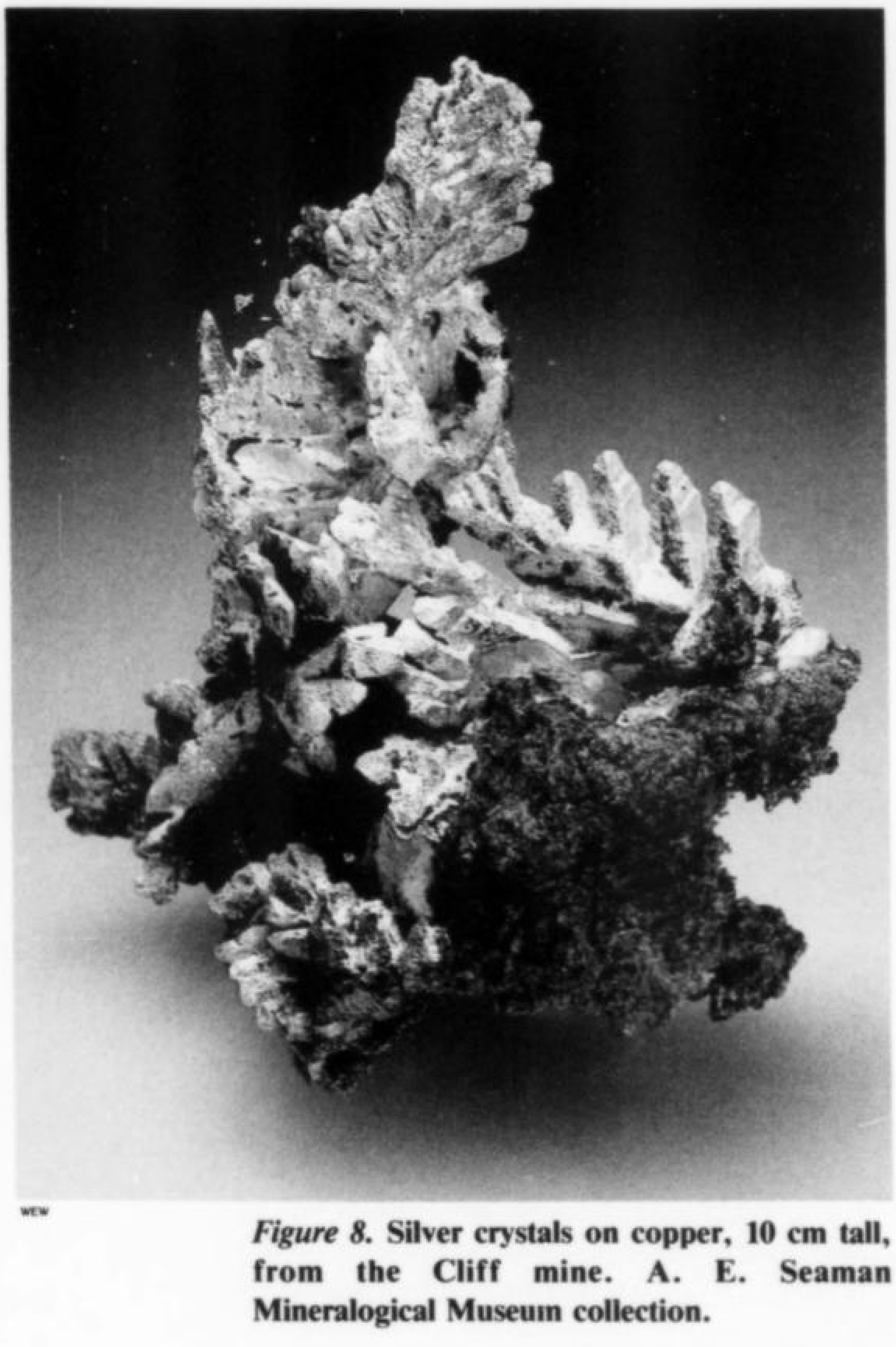


Figure 8. **Silver crystals on copper, 10 cm tall, from the Cliff mine. A. E. Seaman Mineralogical Museum collection.**

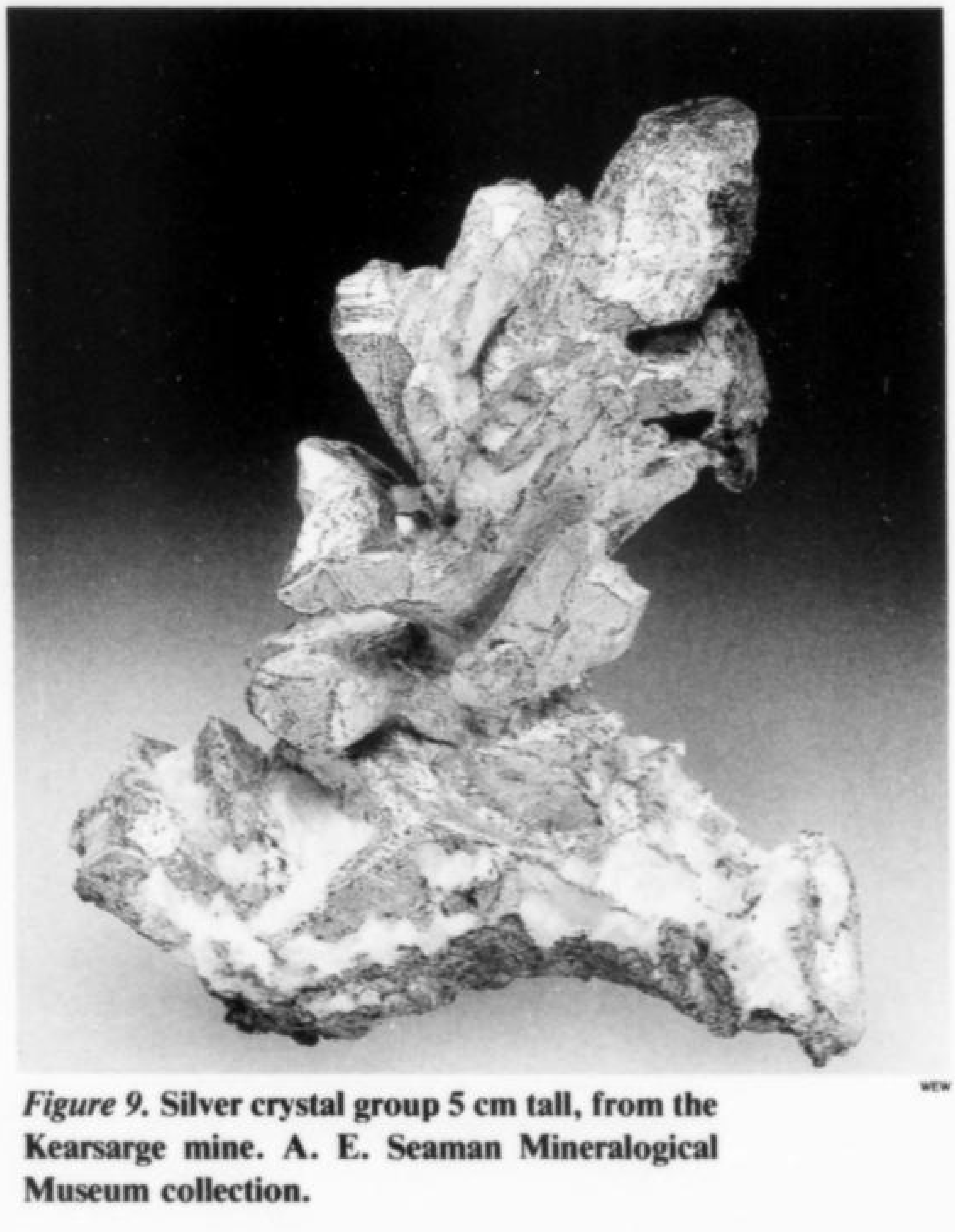


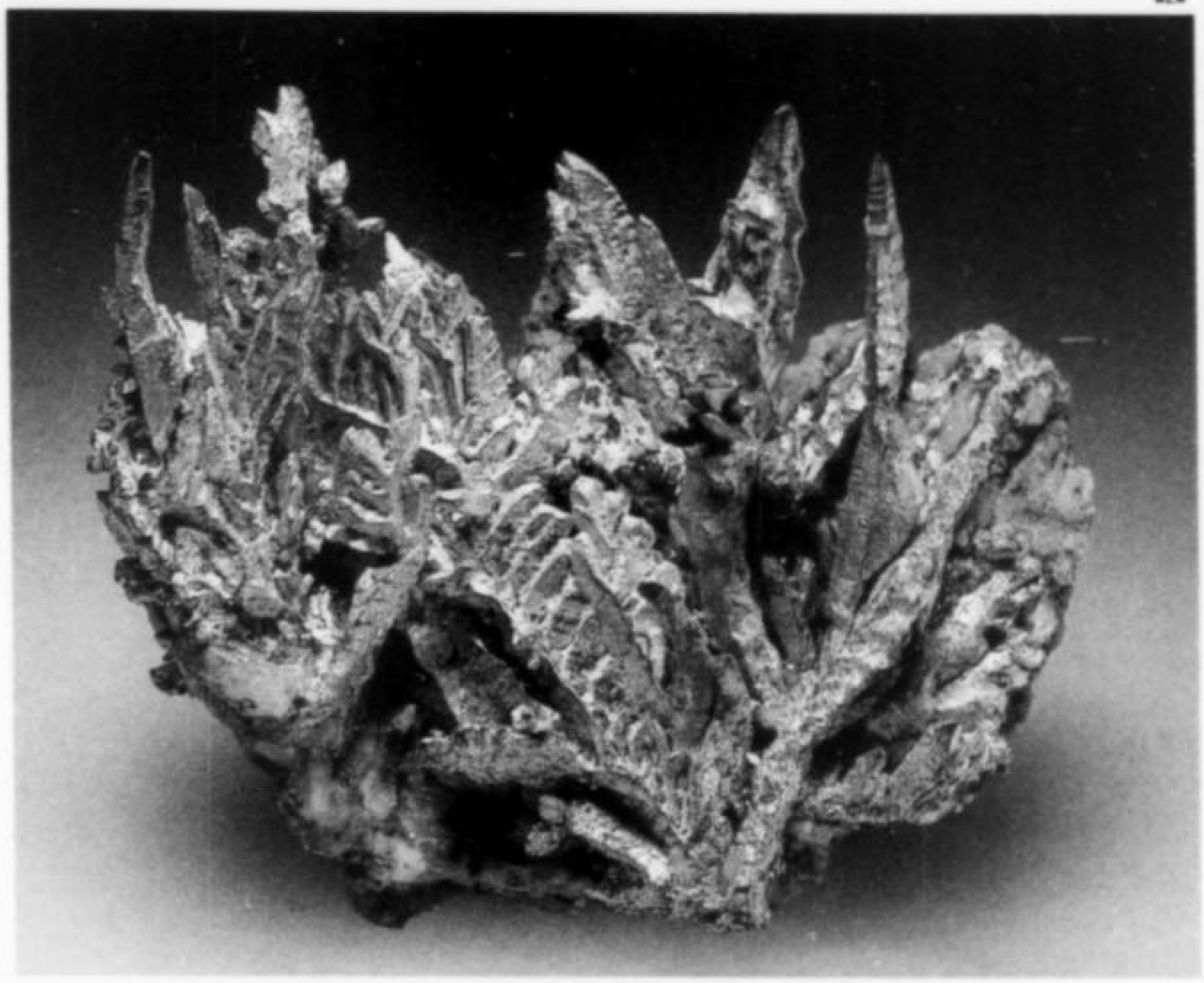
Figure 9. **Silver crystal group 5 cm tall, from the Kearsarge mine. A. E. Seaman Mineralogical Museum collection.**

MINERALOGY

Silver has been found on the Keweenaw Peninsula in a range of crystalline habits, but generally not as wires. It may be that wire silver is generated only by the breakdown of silver sulfides and sulfosalts; since these were not present in the primary ores of the peninsula, wire silver could not form.

The crystalline habits are almost invariably distorted and difficult to orient. Elongation along one axis or another is extremely common, resulting in spikes and very coarse herringbone textures. Rare cubic crystals displaying hopper growth have been found recently near the Copper Falls mine. Octahedron and dodecahedron faces are probably involved in many of the complex intergrowths of

Figure 10. **Silver crystal group 7 cm across from a property of the Michigan Mining Company, most likely the Minesota mine. A. E. Seaman Mineralogical Museum collection.**



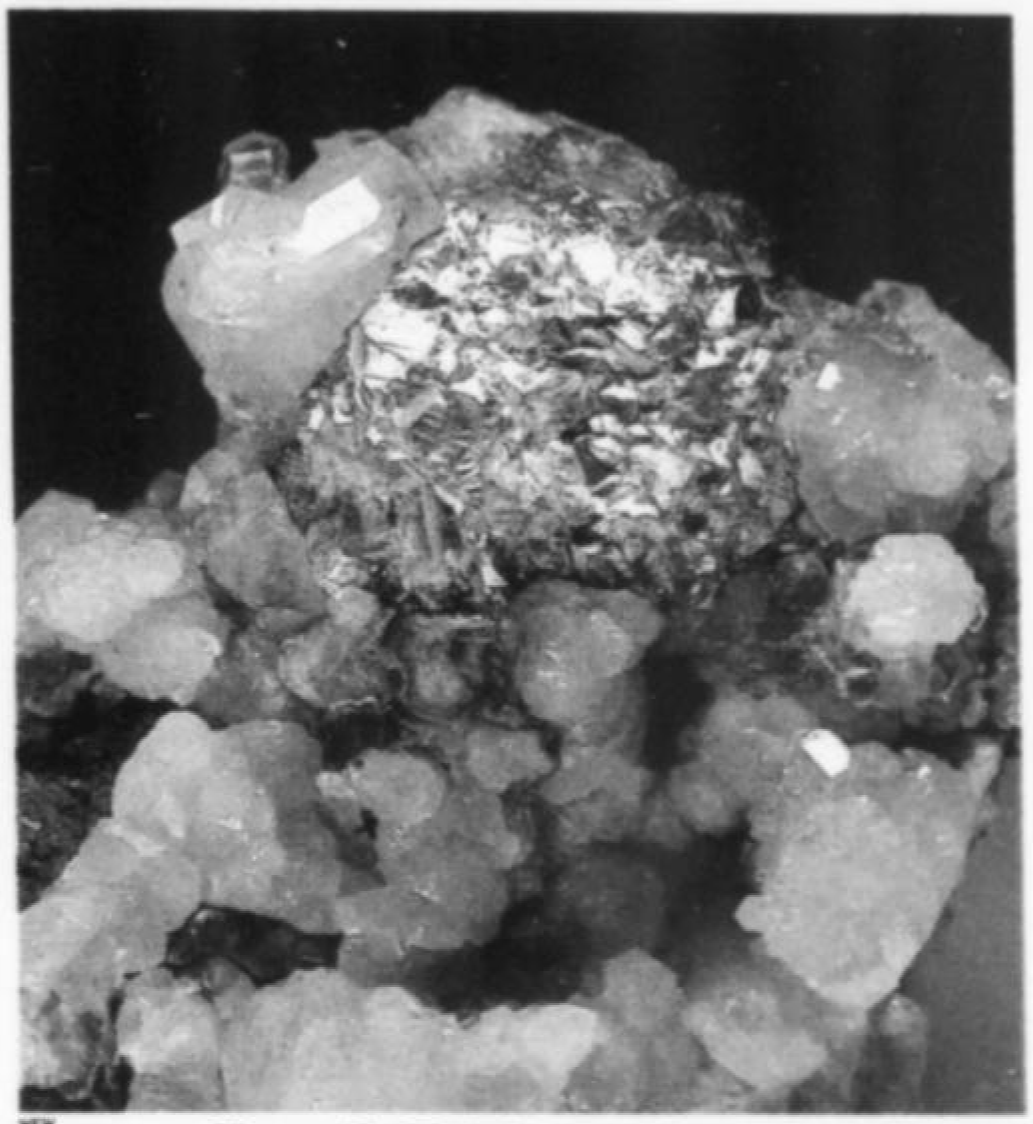
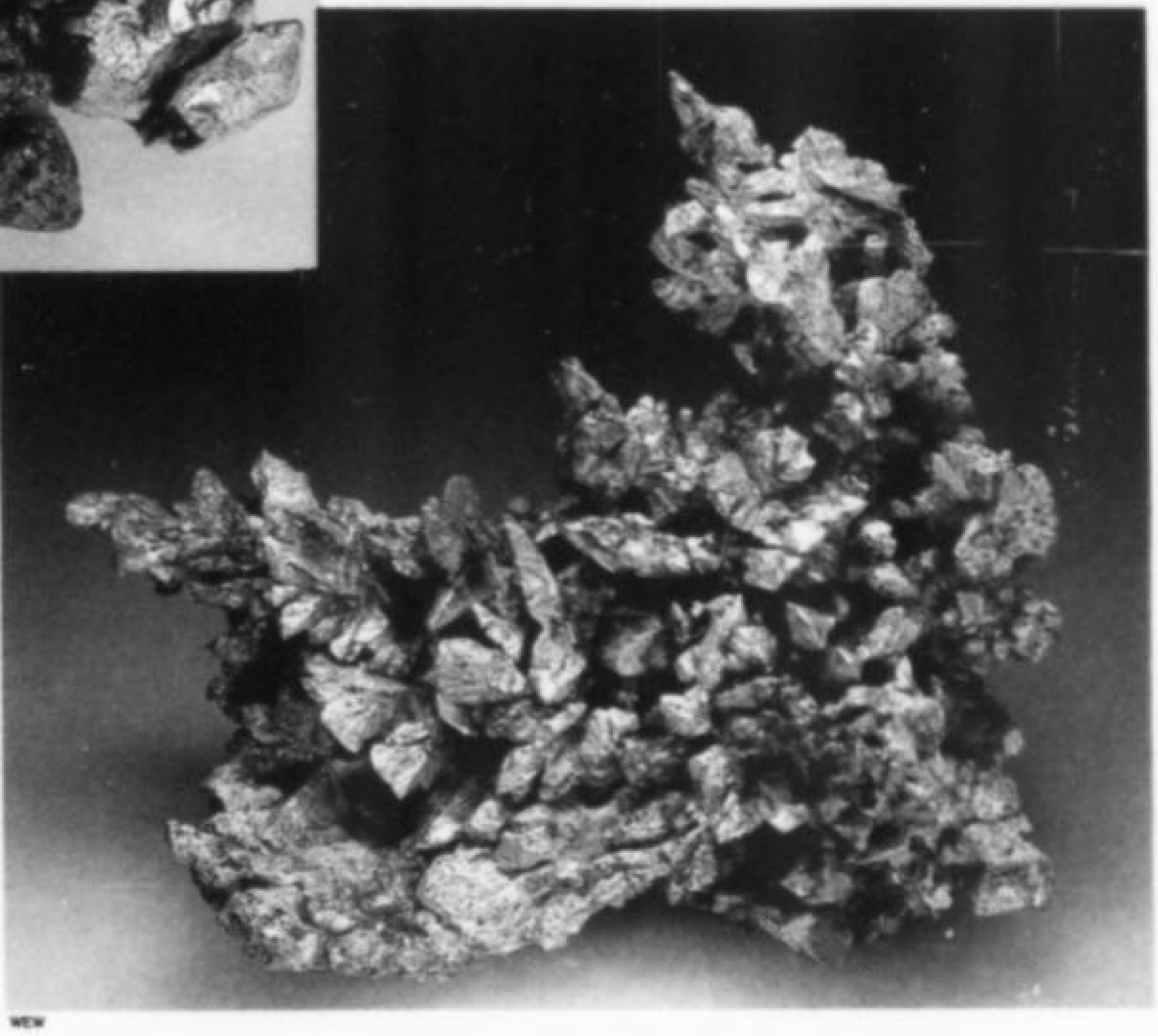


Figure 11. **Globular crystal aggregate of silver, 2.5 cm across, on prehnite from the Pewabic shaft (later the Quincy #6 shaft). A. E. Seaman Mineralogical Museum collection.**

Figure 12. **Silver crystals on copper 6.5 cm across, from the South Kearsarge mine. A. E. Seaman Mineralogical Museum collection.**

Figure 13. **Silver crystals in a possible epitaxial overgrowth on copper crystals, 9 cm across, from the Lake Superior mine in 1910. A. E. Seaman Mineralogical Museum collection.**



crystals, and twinning may also play a part. Unfortunately the morphology and chemical composition of Michigan silver remain relatively unstudied. Not a single crystal drawing or chemical analysis has thus far been located in the literature, though it is difficult to believe that a sufficiently thorough search would not turn something up.

Michigan silver is, of course, most commonly associated with native copper and appears to be later in nearly all cases. A few specimens are known in which copper crystals are perched on silver crystals, but probably 90–99% of existing specimens show silver perched on copper.

A few lumps of copper-silver intergrowths known as "halfbreeds" were found in some of the alluvial gravels but most of the so-called halfbreeds in collections today are actually products of the stamp mill. Mill workers picked the halfbreeds off the conveyor belts as the crushed ore went by. Many such pieces may originally have been fine crystal specimens.

Other associations are essentially the same as for copper. Silver-impregnated calcite crystals are attractive but extremely rare. Silver has been found in the sulfide-arsenide fissures as well, where it occurs with domeykite, algodonite and "whitneyite" (arsenian copper) (Butler and Burbank, 1929). In general, however, silver is increasingly common in the higher levels whereas arsenic increases with depth.

In most cases the habit or appearance of Michigan silver specimens is of little use in determining the exact mine of origin.

THE MINES

As mentioned earlier, probably every mine on the Upper Peninsula has produced a little silver in its time. Some produced much more than others, however, and some have been more fortunate in the number of specimens preserved.

The great majority of existing specimens of Michigan silver appear to have come from the Kearsarge amygdaloid and the mines of the Pewabic amygdaloid, particularly the Kearsarge, Wolverine and Quincy mines. Many other specimens are known from the Copper Falls mine area, the Adventure mine and the Cliff mine, as well as the Calumet and Hecla mines. These are described briefly below. A more complete listing of all mines known with some certainty to have yielded silver specimens is given in Table 1.

The Adventure Mine

The Adventure Mining Company was organized in 1850, and its properties at the extreme southwestern end of the district have remained in operation more or less continuously to the present day. It operated, along with the nearby Mass mine, on the Butler lode, an amygdaloid cut by numerous mineralized fissure veins. Both mines also operated in the Evergreen lode and the Knowlton lode. Early records (Butler and Burbank, 1929) indicate that significant quantities of silver were encountered in both mines. In recent years nice specimens of silver in crude crystals to 2 cm have come from the Adventure mine. The Mass mine is known for its sharp microcrystals of silver.

The Cliff Mine

The Cliff fissure was discovered by James Raymond in 1843, and was one of the first claims filed in the Copper Country. During its productive years, from 1845 to 1883, it yielded over 60,000 ounces of silver, thus earning the distinction of being the most silver-rich fissure in the district. The Cliff mine was the first property on the peninsula to pay dividends to its stockholders, and eventually produced over 17 million kg of copper. Most of this copper was found in the form of enormous masses up to 100 tons, each of which had to be cut apart by hand underground. The fissure cuts the beds at roughly a right angle, dipping steeply to the east (Butler and Burbank, 1929).

Silver crystals perched on copper or prehnite were found in amygdaloidal basalt directly adjacent to the fissure, as well as in the fissure itself. Some silver crystals were found "perched on halfbreed wire, some hanging like bells on copper wires" (Moore and Beger, 1963).

Copper Falls Mine

The Copper Falls Mining Company, one of the earliest in the district, was organized in 1845 and worked five fissure veins and the Ash Bed amygdaloid. The Copper Falls mine was named for a waterfall and stream which even today runs down through the shafts and stopes. Initially, small masses of copper were found in the stream, and these prompted further investigation. Along with a

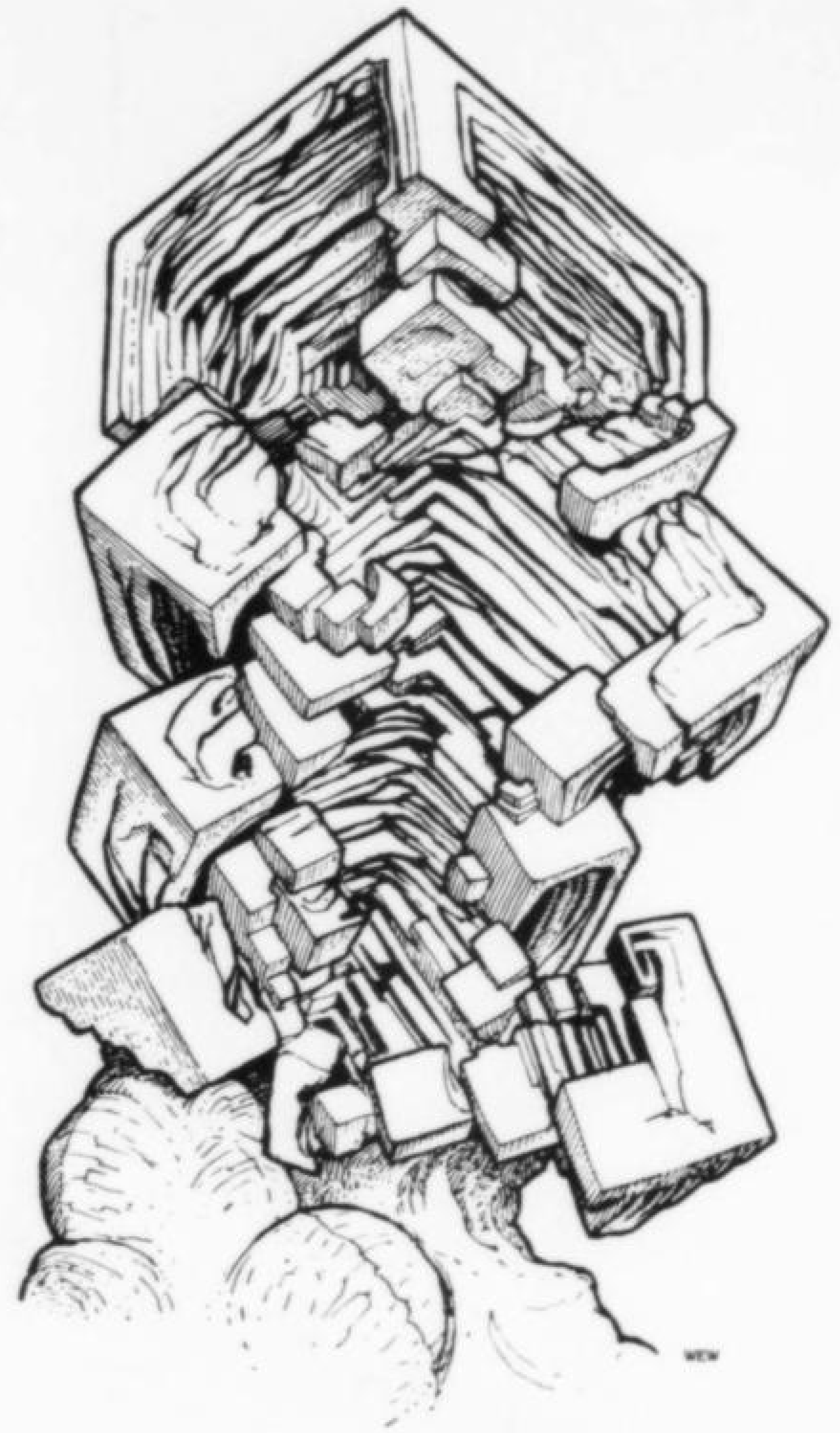


Figure 14. **Skeletal cubic crystal aggregates of silver on prehnite, 1.2 cm tall, from a surface exposure near the Copper Falls mine (collected in 1980). D. Olson specimen.**

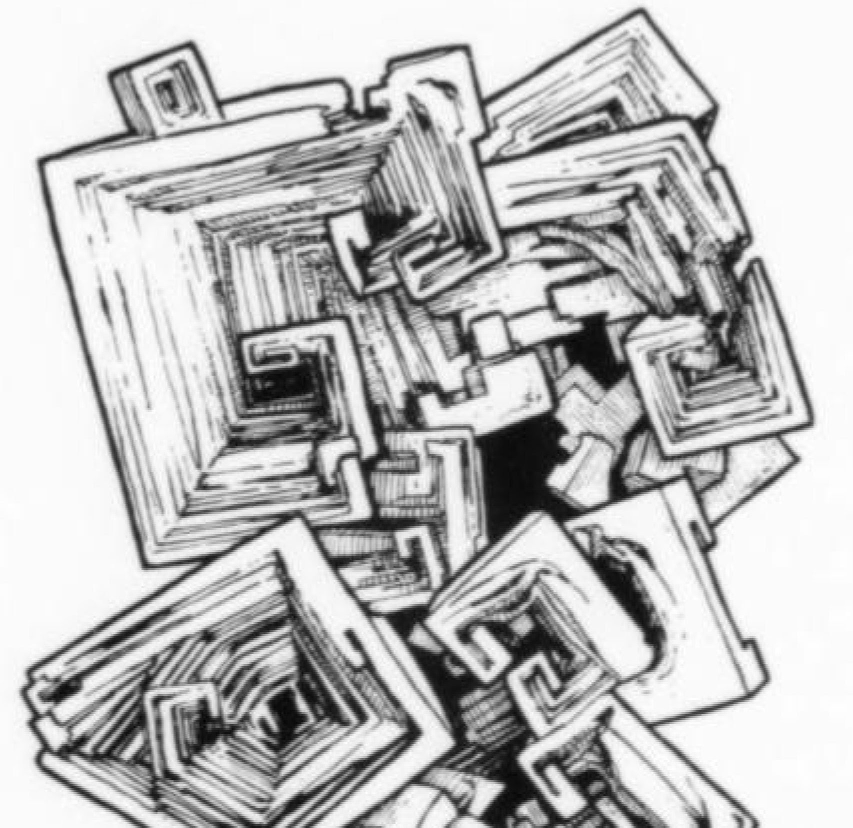


Figure 15. **Large crystal silver group 10 cm tall from the Wolverine mine. A. E. Seaman Mineralogical Museum collection.**

great deal of "mass copper," about 30,000 ounces of silver were recovered and sold in Paris (Monette, 1978). Although it is not recorded where the silver was found, it was most likely taken from one of the fissure veins; the most productive of these by far was the Owl Creek fissure. Around 4 million kg of copper came from the veins and roughly twice that from the amygdaloid bed (Butler and Burbank, 1929). The mine closed in 1893.

In the summer of 1980 a local prospector, using a metal detector, located a small vein on the surface near the Copper Falls mine. It proved to contain vuggy prehnite with superb groups of cubic silver crystals to 5 mm, in specimens up to cabinet size. The pocket appears to be worked out and has been fenced off, but does serve to illustrate that discoveries can still be made.

The Kearsarge Amygdaloid

The Kearsarge amygdaloid probably produced more fine silver specimens than any other lode in Michigan. The most prolific mines (at least the mines most commonly seen on mineral labels in museum collections) are the Kearsarge and the Wolverine, although excellent specimens are known from a number of the others on the lode.

Production from the Kearsarge amygdaloid began at the Kearsarge mine (later called the North Kearsarge) in 1887, followed by the Wolverine in 1895, where the highest grade ore was found. Production ceased in 1967. This rather late and extended activity may account in part for the large number of silvers preserved, since an awareness of specimen values increased in the current century. In all, over a billion kilograms of copper were produced, making it the second largest producer in the district.

Records of silver production are scarce and incomplete, indicating practically nothing for the Kearsarge and Wolverine. A hint may be seen, however, in the more than 1 million ounces recorded for the nearby Calumet and Hecla in 1916–1919. The LaSalle and Osceola mines also had recorded production (Butler and Burbank, 1929).

The Quincy Mine

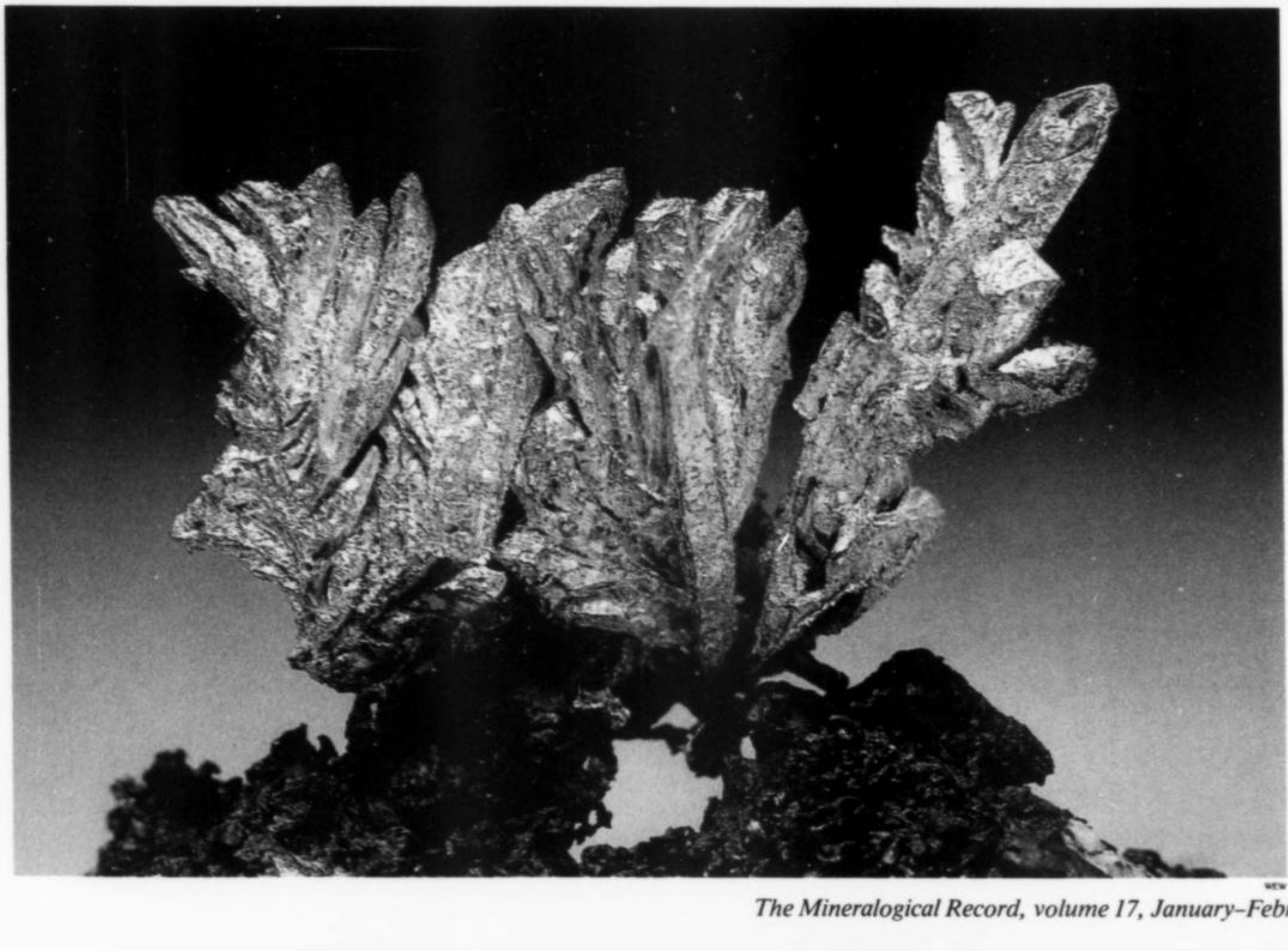
The Quincy mine operated primarily on the Pewabic amygdaloid lode, and is a consolidation of the earlier Old Quincy, Pewabic and Franklin mines, among others. Mining began around 1856, following the discovery of the Pewabic lode by C. C. Douglass at an outcrop worked by ancient Indians. Mines on this lode eventually became the most consistently profitable producers in the district (Lankton and Hyde, 1982), finally closing down in 1967.

Company books record nearly a million dollars in silver removed, probably only a small fraction of the actual total. Perhaps due to the extended life of the mine, a fairly large number of specimens have been preserved.

Figure 16. Complex, globular crystal aggregate of silver, 2.5 cm across, on copper from the Osceola mine. A. E. Seaman Mineralogical Museum collection.

Figure 17. A rare example of copper crystals growing on earlier silver crystals (see also Fig. 16), 6.3 cm as shown, from the Wolverine mine. A. E. Seaman Mineralogical Museum collection.

Figure 18. Silver crystals on copper, 6.3 cm across, probably from the Kearsarge mine. Wayne and Dona Leicht collection.



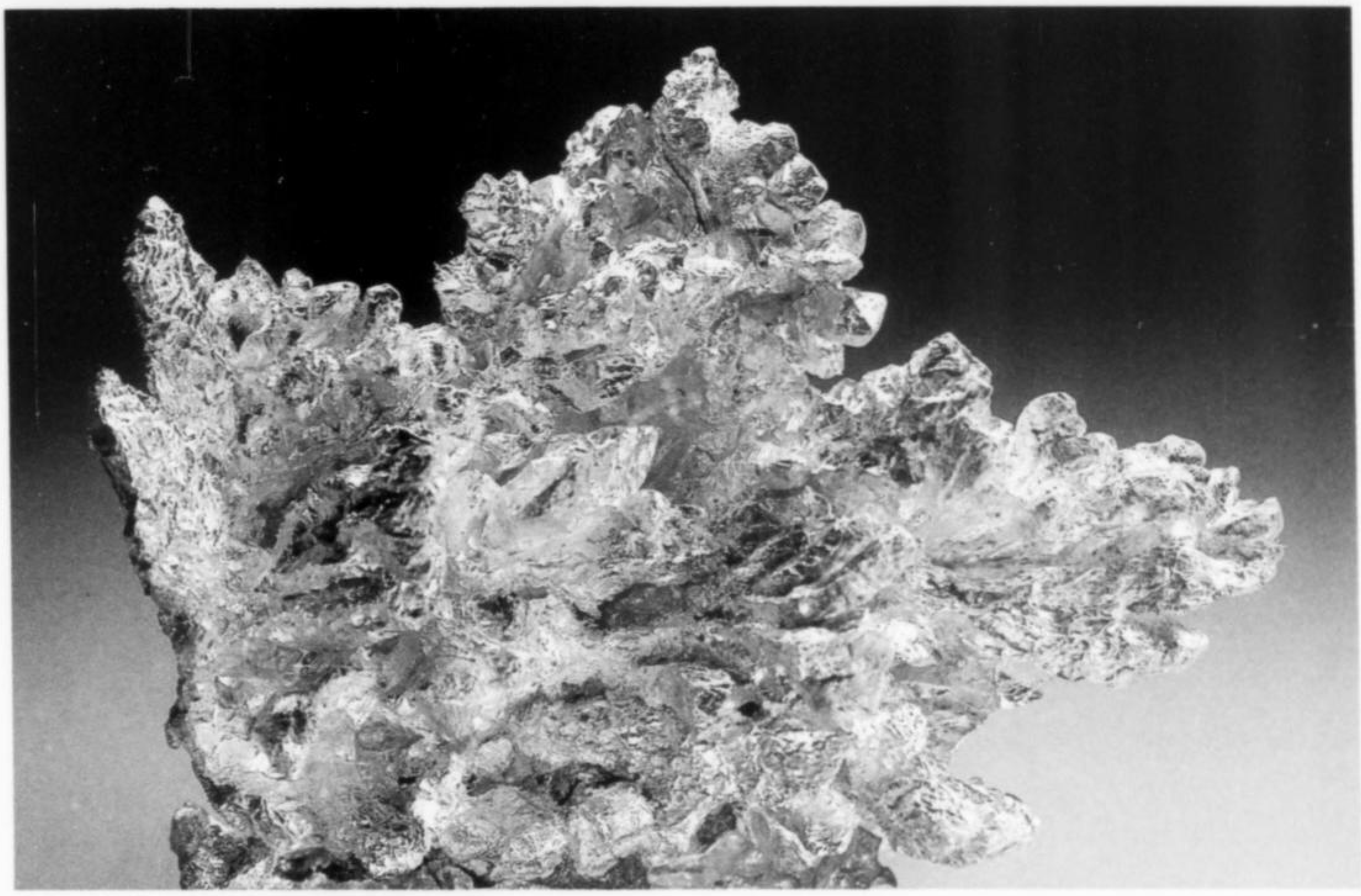


Figure 19. **Large, brilliant crystal fans of silver, 9 cm across, from the Wolverine mine. Don Pearce specimen.**

Figure 20. **Sharp single silver crystals on a copper crystal, 4.5 cm across, from the Wolverine mine. A. E. Seaman Mineralogical Museum collection.**

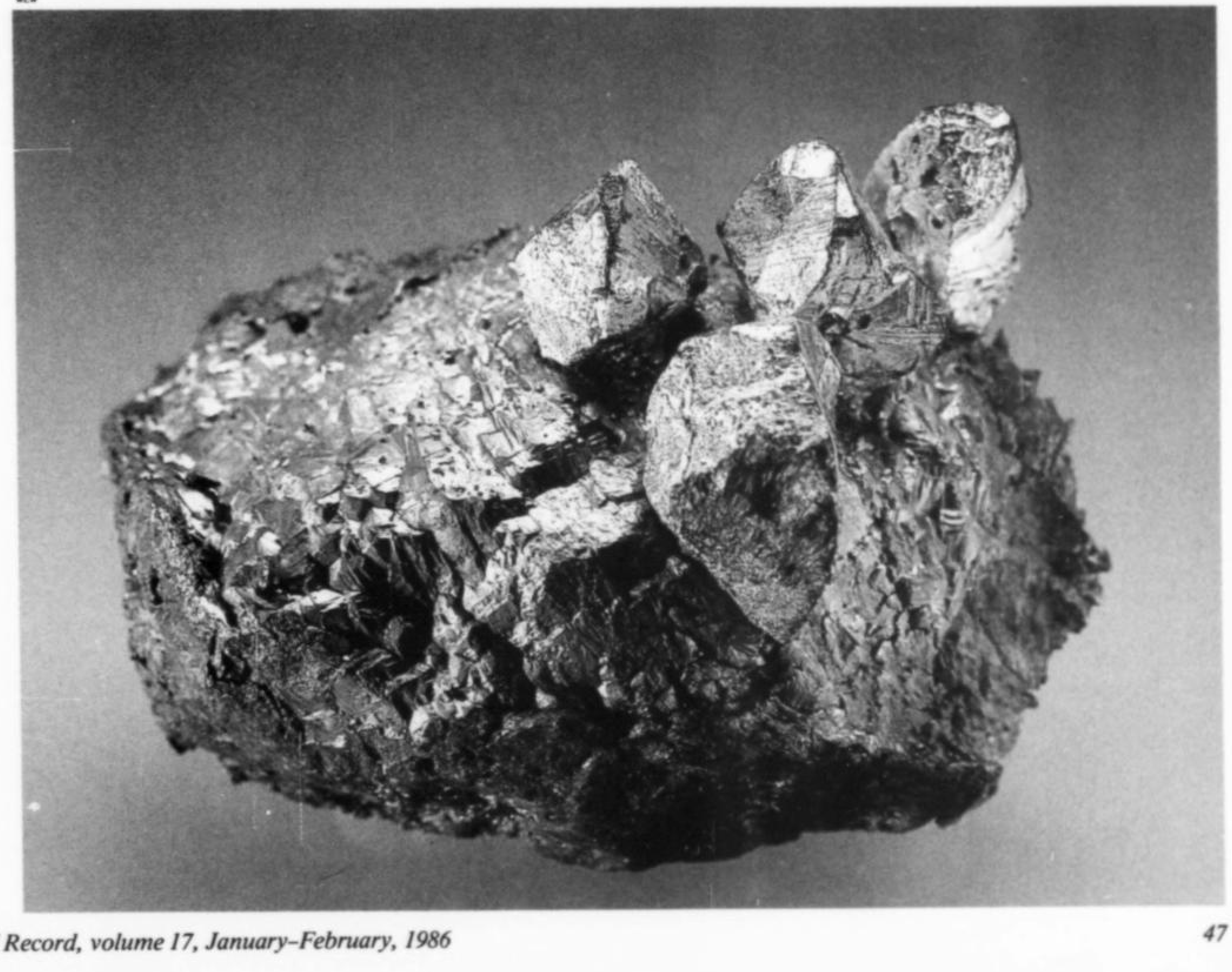


Table 1. **Mines known to have produced crystalline silver specimens.**

Mine Name	*Reference**
Adventure	P
Baltic	P
Calumet-Hecla	P
Central	H, P
Cliff	H, P
Copper Falls	P
Eagle River	H
Franklin	H, P
Isle Royale	H
Kearsarge (North & South)	H, P
(Lake) Superior	H, P
LaSalle	H
Mass	H
Minesota	H, P
National	H
Osceola	H, P
Pewabic	H, P
Phoenix	H
Quincy	H, P
Rockland	H
Seneca	P
White Pine	P
Wolverine	H, P

* H = Heinrich (1976); P = Specimens seen in public and private collections.

The Quincy mine provides an interesting footnote for mining historians: it seems the mine developed a peculiar problem which began around 1906. Major portions of the Pewabic lode had been hollowed out, and these enormous, unsupported stopes began to collapse. Since collapses occurred only in the abandoned workings, no one was hurt, but tremendous volumes of displaced air were forced out into surrounding areas via the many drifts and adits each time a collapse occurred. These were referred to as "air blasts," and the most sudden and forceful ones were known to the miners as "old rousers." Lankton and Hyde (1982) remarked:

> Old rousers of the blood-curdling kind that make your hair stand on end rattled the towns of Houghton and Hancock, as well as the confidence of the underground workers.

Air blasts continued to be an unnerving problem into the 1920s.

CONCLUSIONS

Is there still silver in the ground of the Upper Peninsula? Most certainly there is, as evidenced by the recent discovery near Copper Falls. It is likely that more silver remains underground as well. In fact, there is a legend of sorts among old Michigan miners, which I've heard a number of times over the years. It involves a small room-size pocket lined with native silver crystals that was found in a mine (variously reported as the Phoenix, Eagle River or Cliff mine). After it was broken into, the mine captain had a heavy steel door installed over the entrance to protect it from highgrading. It is said that the door was never again opened, and the silver-lined room is still there, many levels down and underwater.

ACKNOWLEDGMENTS

My thanks to Jean Kemp of the A. E. Seaman Mineralogical Museum for making that fine collection available for study and photography, and to Wendell Wilson for help with the manuscript and photos. Carl Francis of the Harvard Mineralogical Museum and John White of the Smithsonian Institution kindly provided information on specimens in their respective collections. James Paces, Richard Thomssen, Stanley Dyl and Wendell Wilson reviewed the manuscript and provided information for the geology section.

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SILVER ISLET

• famous mineral localities: the Silver Islet mine, Ontario •

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It was just a small knob of rock rising barely a meter or two above the surface of Lake Superior. But in a short span of years Silver Islet yielded important bonanzas of native silver which galvanized the North American mining community. Removing that silver proved to be one of the great engineering challenges of the 19th century.

INTRODUCTION

Silver Islet is located in Lake Superior near the north shore, about 1.5 km off Thunder Cape. The town of Thunder Bay, Ontario, is about 40 km by boat to the northwest, and Isle Royale lies 27 km to the south. The old mining town of Silver Islet is located on the tip of the cape at a minimum distance from the mine. Several old mine buildings and a small museum are maintained there. The mine itself is still under claim, and collecting is not allowed without permission.

The Silver Islet mine is one of Canada's famous localities, but the mineral collector will find Silver Islet silver specimens exceedingly hard to come by. Total production there was relatively small in comparison to the great silver districts of Mexico, Michigan, Europe, Canada and South America. Furthermore, the location was remote from civilization, and the mining of major bonanzas was restricted to the years 1871–1978. Circumstances were therefore not favorable for the preservation of specimens in quantity. Nevertheless, Silver Islet silver can still be acquired on rare occasion and is backed by one of the more interesting and unusual stories in the history of mining in North America.

HISTORY*

Silver was known and mined on the North Shore of Lake Superior for a number of years prior to the discovery of Silver Islet. In 1845 a claim was filed by Joseph Woods on a vein on the mainland; claims in Canada at that time were large (3.2 x 8 km), and "Woods location" included, by accident, Silver Islet.

The following year Woods assigned his claims to the Montreal Mining Company. Unfortunately the terms of the grant reserved all

*Compiled from Macfarlane (1879), Ingall (1889), Blue (1897), and Stickland (1979), among others.

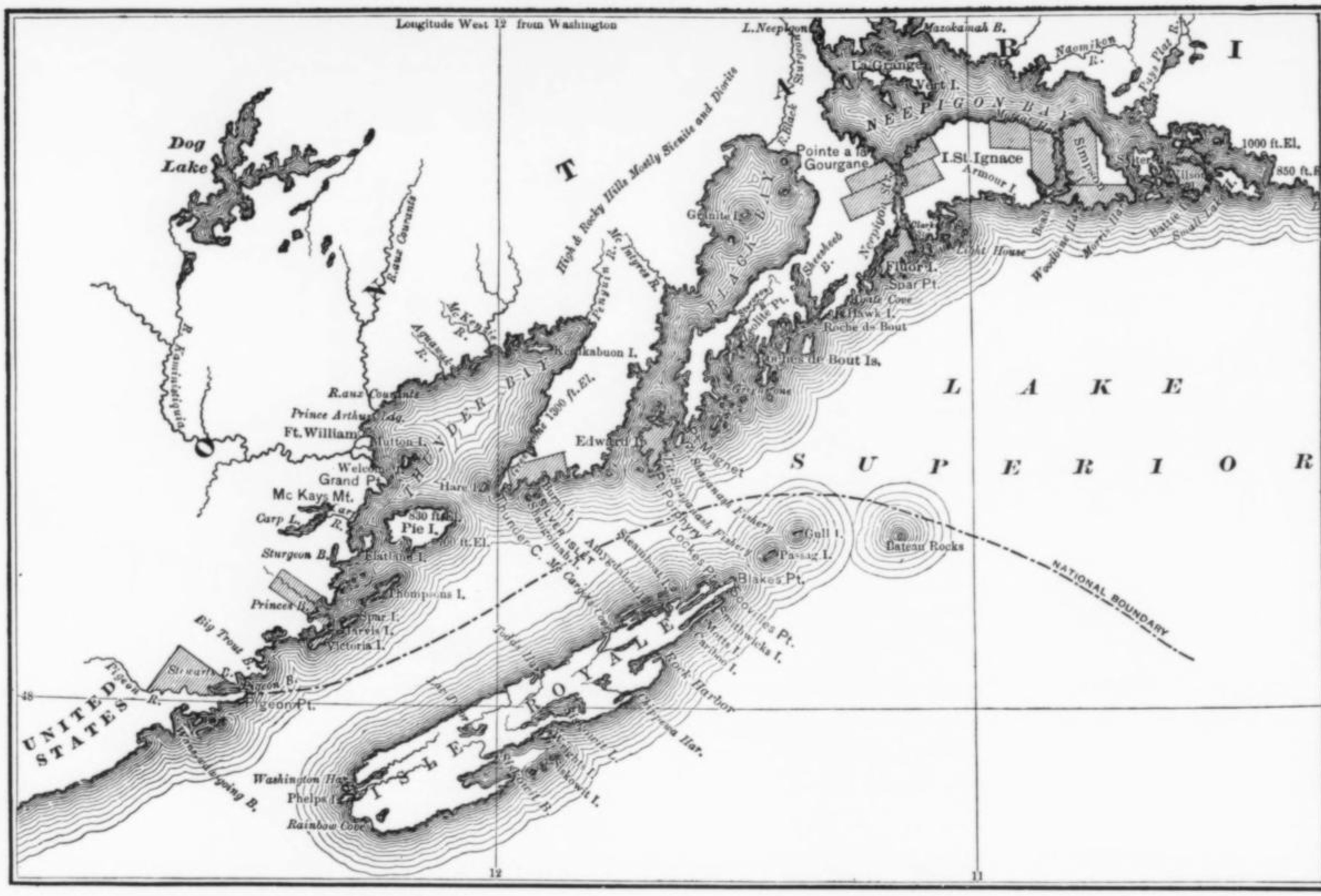

Figure 1. **Map showing part of the North Shore of Lake Superior, and various claims explored by Thomas Macfarlane in 1868. Silver Islet is at center (Macfarlane, 1879).**

gold and silver mining to the British Crown, and so the company did nothing with its Lake Superior silver claims. In the meantime, the British American Mining Company worked a minor silver vein at Prince's location south of Thunder Bay, and the McKellar brothers discovered small silver veins at several points around Thunder Bay. One of these, at Current River, was worked for a while by the Thunder Bay Silver Mining Company in 1868 but the results were not good.

In that same year, 1868, the new legislature of Ontario repealed the regulation withholding silver rights for the Crown, and the Montreal Mining Company decided the time was right to take a closer look at its North Shore holdings.

On the 16th of May, 1868, a party of six men led by Thomas Macfarlane arrived at Thunder Bay aboard the steamer *Algoma.* They had been assigned the task of examining and evaluating the company's several claims. The *Algoma* was heavily loaded with men and mining supplies for the Thunder Bay Company mines, and so Macfarlane and his group paid a visit to those properties first, in order to familiarize themselves with the appearance and manner of emplacement of local ores. Then, in a Mackinaw boat, they traveled down the shore to Jarvis's location and Stewart's location.

Macfarlane decided to prepare a geologic map of Thunder Cape and, as a first step, sent his men to survey the shoreline. This was most easily done from the offshore islands where sightings of the mainland could be taken. Macfarlane (1879) described the resulting discovery:

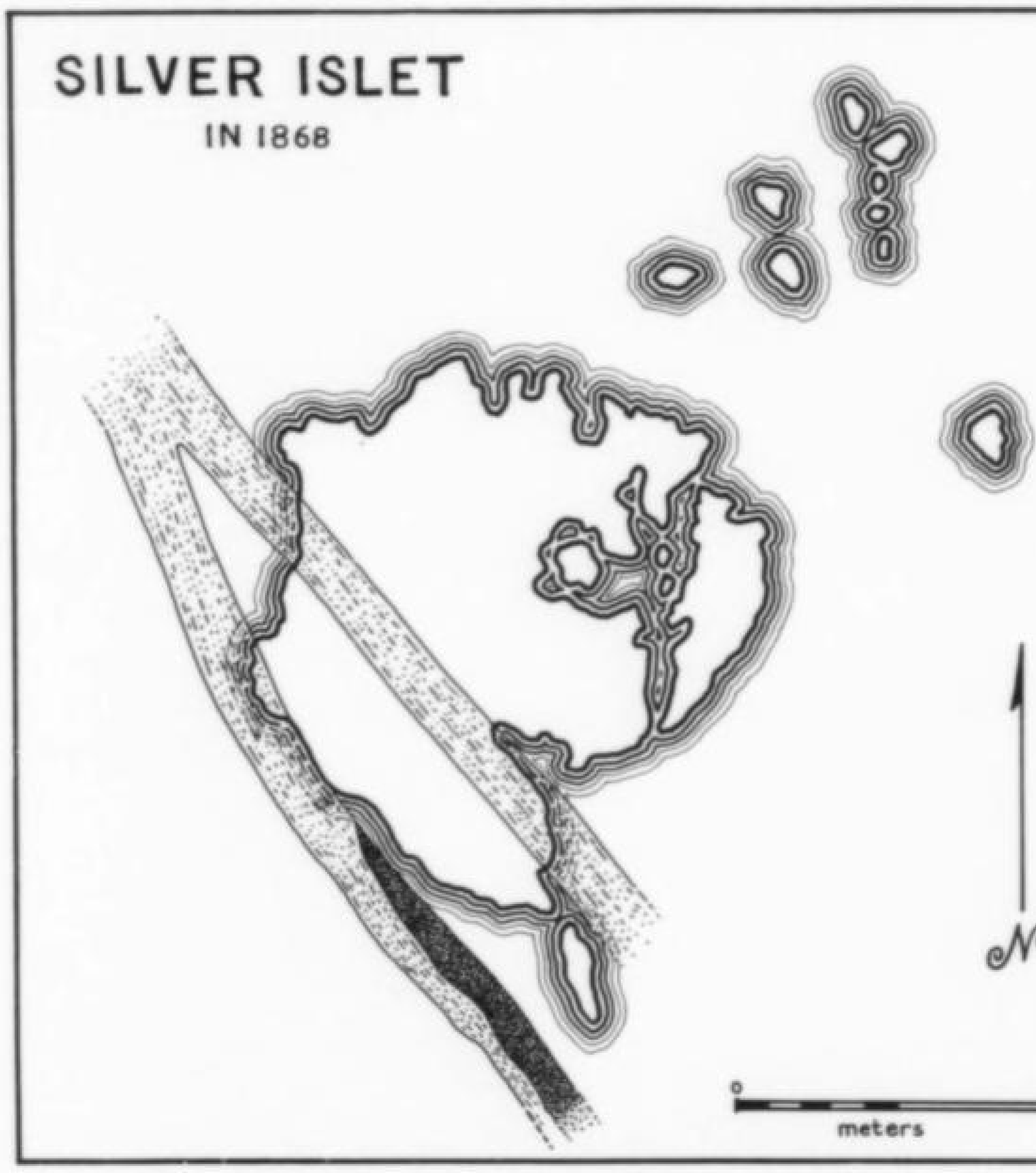

Figure 2. **Silver Islet as it was when first discovered. Note how the vein splits in two, surrounding a "horse" of country rock. The rich part of the outcrop (shown dark) was visible under shallow water (after Macfarlane, 1879).**

Figure 3. **Silver Islet miners ca. 1880 (courtesy Ontario Archives).**

Figure 4. **Silver Islet as seen from nearby Burnt Island (courtesy Ontario Archives).**

I determined to make a complete geologic map of Woods location, and arranged with my assistant, Mr. Gerald C. Brown, to have the shoreline accurately surveyed. It was while engaged planting his pickets on the many islands fronting the location that Mr. Brown first landed on the rock shortly afterwards named by me "Silver Islet," and observed the vein and the galena occurring in it. I then visited the island to obtain specimens, and three men were set to work blasting out some of the galena. One of these men, Mr. John Morgan, found the first nuggets of metallic silver close to the water's edge. A single blast was sufficient to detach all the vein rock carrying ore above the waterline, but farther out large black patches could be observed in the vein under water, some of them with a greenish tinge. On detaching and fishing up pieces of these they were found to consist of galena, with which were intermixed spots of an oxidized black mineral, here and there tinged with green. This black substance I succeeded in reducing on charcoal, before the blowpipe, with a little borax, to metallic silver.

Five days later three packages of vein samples were shipped from Fort Williams to Montreal for analysis; the assay came back at over 2000 ounces per ton, or $1200 for the total sample.

During the summer of 1869 Macfarlane and his men carried on more sampling at Silver Islet. They worked in freezing, waist-deep water, coming out to warm up every 20 or 25 minutes. And their work had to be limited to only the calmest days when the lake was smooth and quiet. Macfarlane had noticed that when the weather was even moderately stormy the little 25-meter islet disappeared completely beneath the waves. Protection from the lake was obviously going to be necessary. Despite these difficulties nearly 5 tons of highgrade ore were recovered and shipped to Montreal for smelting.

A shafthouse was built on the islet and a shaft started, but it was

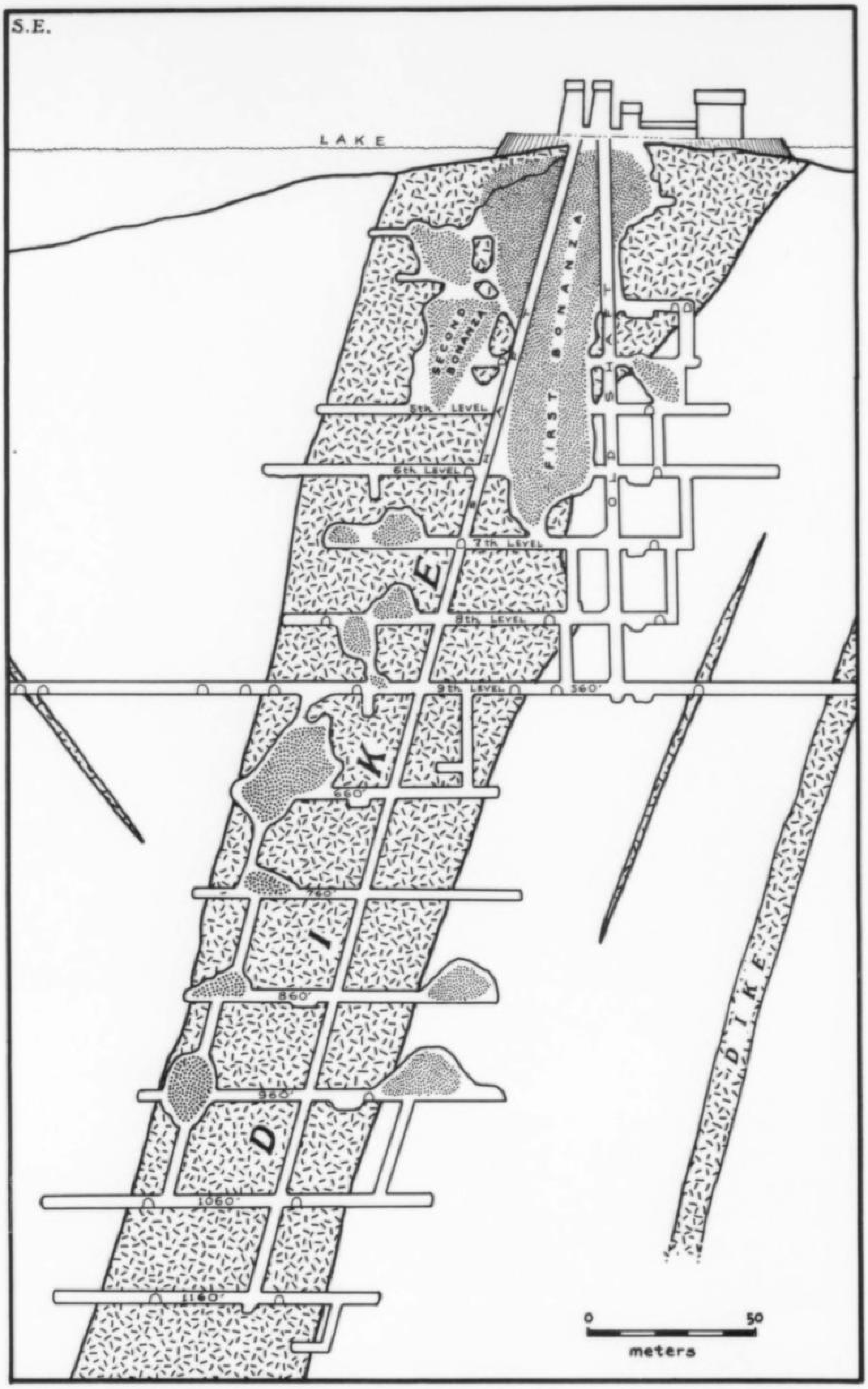

Figure 5. **Underground workings at Silver Islet in 1879 (after Ingall, 1889). Shaded areas are silver ore.**

quickly halted due to an influx of water. The men continued working into the winter, using the lake ice as a platform for underwater blasting on about 10 meters of the vein, then pulling out loose blocks with long-handled tongs and shovels. This resulted in the recovery of nearly 9 more tons of highgrade ore containing nearly 18,000 troy ounces of silver.

Macfarlane was convinced that an investment of $50,000 would be necessary to build appropriate facilities and protect them from the lake. Stockholders in the Montreal Mining Company decided to let someone else take that risk, and sold the property to Major Alexander H. Sibley and a group of investors for $225,000.

Sibley sent engineers to examine the island and make recommendations for the construction of some type of breakwater. One engineer proposed a 10-meter-high stone wall around the island (cost: $2 million). Someone else suggested a smaller wall and a system of pumps (cost: $1 million). Sibley, in desperation, called in another expert, William B. Frue of Houghton, Michigan. Frue spent four days sizing up the island, and was almost killed when a sudden storm trapped him there, but he survived with a new respect for the lake.

People who have not lived and worked on Lake Superior have no real conception of the violence it can rise to during severe storms. It is the largest body of fresh water in the world, 560 km (350 miles) long and nearly 400 meters deep. The extremely long "fetch" (the distance of open water over which waves can generate), combined with powerful storms, results in truly spectacular behavior.

Frue proposed to build a timber breakwater on the southeast side, facing into the storms, and an inner coffer dam as a second line of defense to protect the mouth of the shaft. These temporary constructions could be erected for $50,000 and strengthened as funds from the selling of silver from the mine became available.

The directors of the company jumped at the idea, and Frue

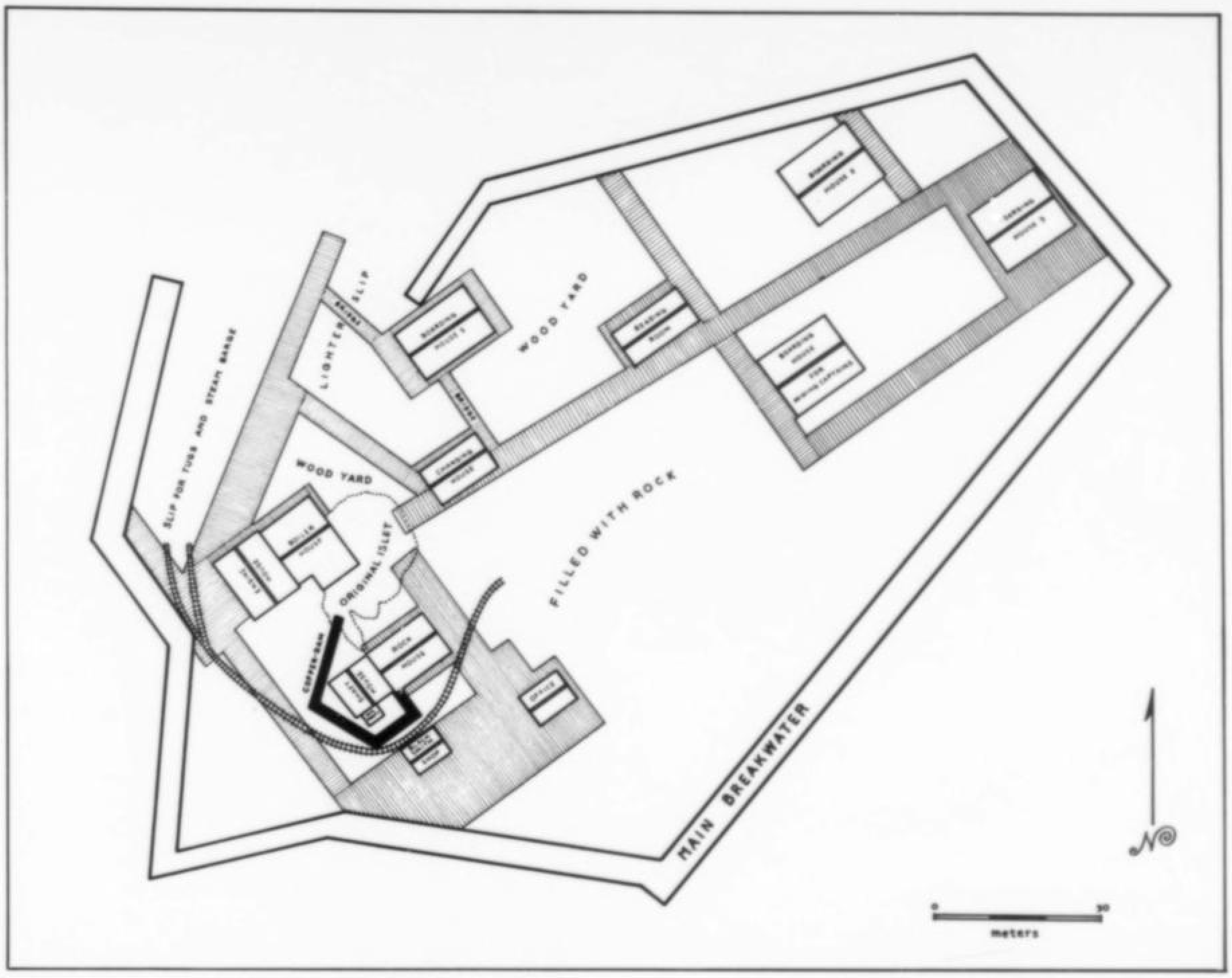

Figure 6. **Plan of Silver Islet in 1879 (after Macfarlane, 1879).**

began preparing for his assault on Lake Superior.

On August 31st, 1870, Frue arrived at Silver Islet on the propeller *City of Detroit* out of Houghton. He brought with him 34 hard, seasoned miners from Michigan's copper country; the party included Cornishmen, Finns, Bulgarians, Italians and Irishmen. Two horses, various pieces of machinery, provisions, mining supplies and over 6000 meters of heavy timbering were unloaded along with the men.

Frue set about constructing a stone and cement coffer dam around the shaft collar, then a rock-filled timber breakwater around the southeast end of the island. Within 30 days, during obligingly calm weather, Frue's men finished the coffer dam and the 140-meter breakwater made of standing cribbing bolted together with steel rods 5 cm in diameter and filled with rock and heavy rubble hauled in from shore. The breakwater stood a proud 4 meters above lake level.

The good weather continued and the men turned quickly to mining. After sinking the shaft for three weeks, they were still in what they considered "low grade" ore . . . only $700 in silver per ton. Then, on the 26th of October, the clouds turned black and a major storm from the southeast headed in. It built steadily and, within three hours, waves were crashing over the main breakwater. Frue evacuated the miners, and everyone sat out the storm on the mainland for a full three days, wondering what would be left of their work on the islet.

When weather finally permitted their return, they saw that little indeed was left. Nearly half the length of the main breakwater had been swept away, its 5-cm steel rods lay twisted and broken. The steam boiler had been toppled (but miraculously not destroyed), the winch was wrecked, and the shaft itself was filled to the brim with rock.

Back to work they went, clearing the shaft and building a bigger, stronger breakwater. A double line of timber cribs 8 meters apart were emplaced and the gap filled with hundreds of tons of rock. A stronger coffer dam around the shaft was built, and mining began again.

The sea remained calm, and suddenly the miners were in bonanza-grade ore. Assays climbed from $4,000 per ton to $11,000, to an astounding $17,257 per ton.* By late September, over $200,000 in silver was stored away in the log shed. Silver Islet stock soared from $100 to over $5,000 per share, and the mining men who had christened the operation "Frue's Folly" were silenced.

Silver Islet was the hottest mining property in the world. Several years were spent mining the great bonanza. Lowe (1882) described this orebody as follows:

> It extended for a (strike) distance of 100 feet on the hanging wall of the main vein, and for nearly a like distance upon the same wall of the east vein. It varied from 6 inches to over 2 feet in width, finally disappearing below the sixth level. The silver did not crop out on the east vein, but was found by crosscutting through the horse of diorite on the 1st level. It extended upward to within 40 feet of the surface. The shape of this bonanza was that of an irregular pear and throughout its extent in both veins it was accompanied by a strong impregnation of graphite which formed the selvage (vein lining) of both veins. The bulk of this bonanza was arborescent silver, more or less mixed with macfarlanite, a rich ore carrying 78% silver.

In the months following this discovery the miners removed as much silver as they could and, before the close of navigation in 1871, packed it aboard a steamer bound for the smelter. Hardly had the steamer left when the temperature fell to − 10° F and the lake began to freeze over. From the southeast came another storm; it hurled tons of ice into the cribbing, tearing it apart with ease. Frue wrote in his report:

> The blacksmith's shop, which stood inside of this breakwater

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* At $1.20 per ounce this would equal 14,381 ounces. There are 29,167 troy ounces in an avordupois ton; therefore, the ore described was apparently 49% native silver by weight.

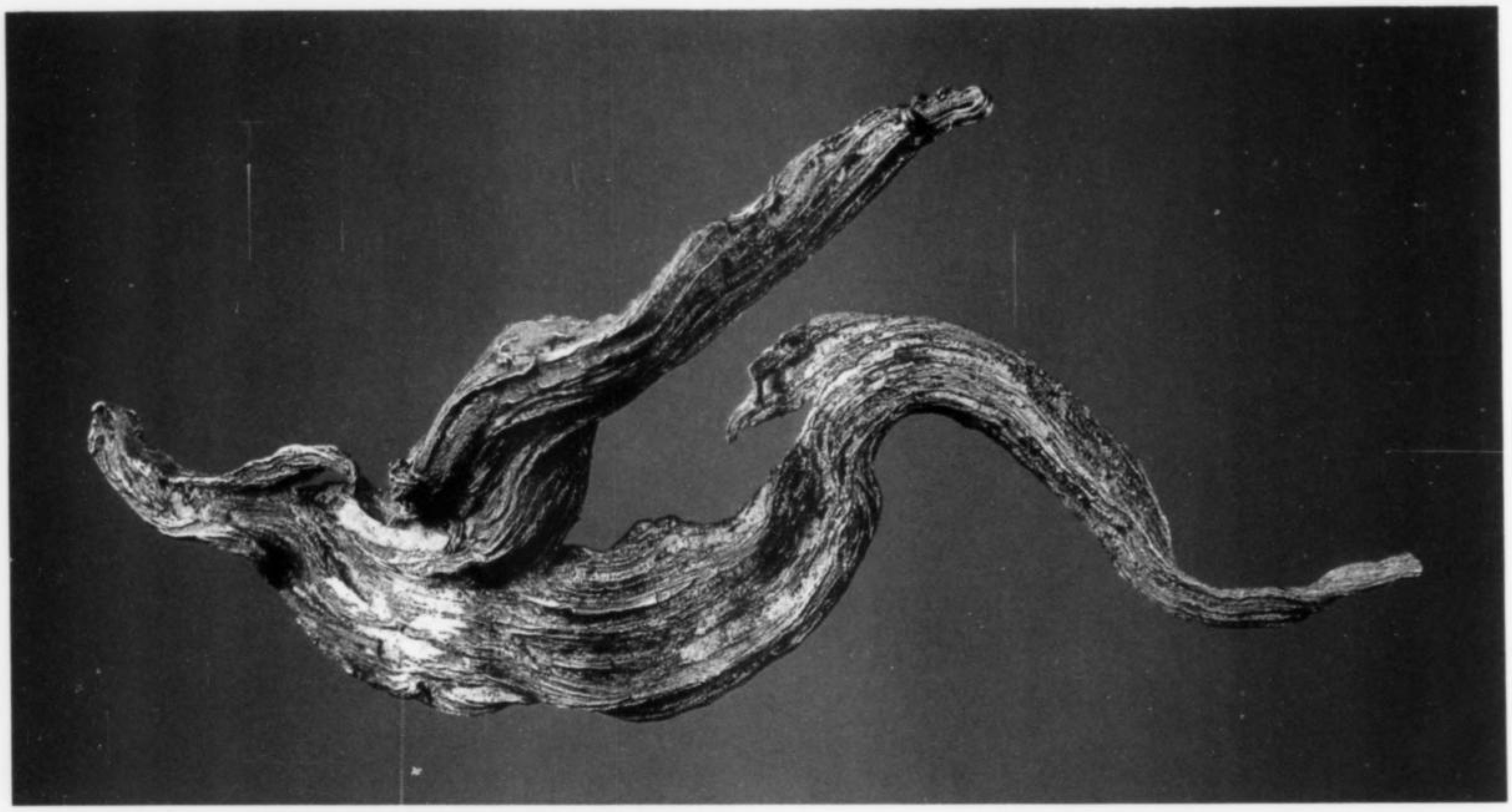


Figure 7. **Heavy wire of silver 8 cm long. Royal Ontario Museum collection; photo by William Robertson.**

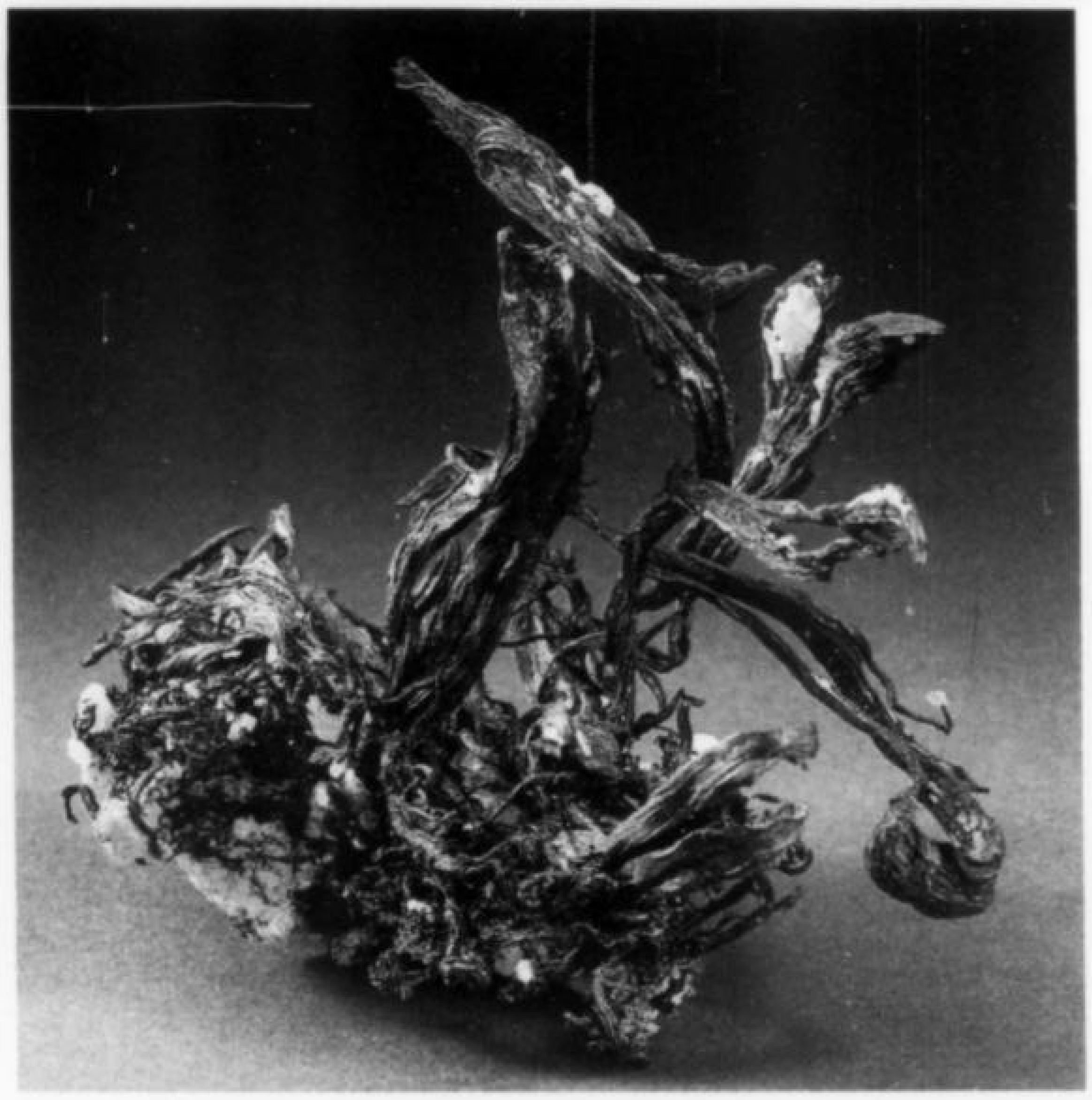


Figure 8. **Wire silver group, 8 x 9 cm. Royal Ontario Museum collection; photo by William Robertson.**

Figure 9. **Wire silver on matrix, 5.5 cm tall. Royal Ontario Museum collection; photo by William Robertson.**

> and about forty feet from its outer face, was completely demolished. In fact, rocks were whirled around the Islet like hailstones, and a number of buildings were damaged to a considerable extent.

Timber and wreckage from Silver Islet were later washed up as far away as Duluth, Minnesota, 320 km distant. Nearly 6,000 meters of timber and 7½ tons of steel bolts were lost. The miners spent days exploring Thunder Cape for stands of pine and cutting them for cabins and yet another breakwater.

The breakwater was rebuilt to a height of 3 meters above the water, and yet a larger space filled with 6,000 tons of rock rubble. Again, it was destroyed, the few remaining heavy timbers battered and chafed so badly they looked like brooms on the end.

The next breakwater was built to a full 23 meters (75 feet) of rock-filled thickness. Frue had to open a stone quarry on the main-

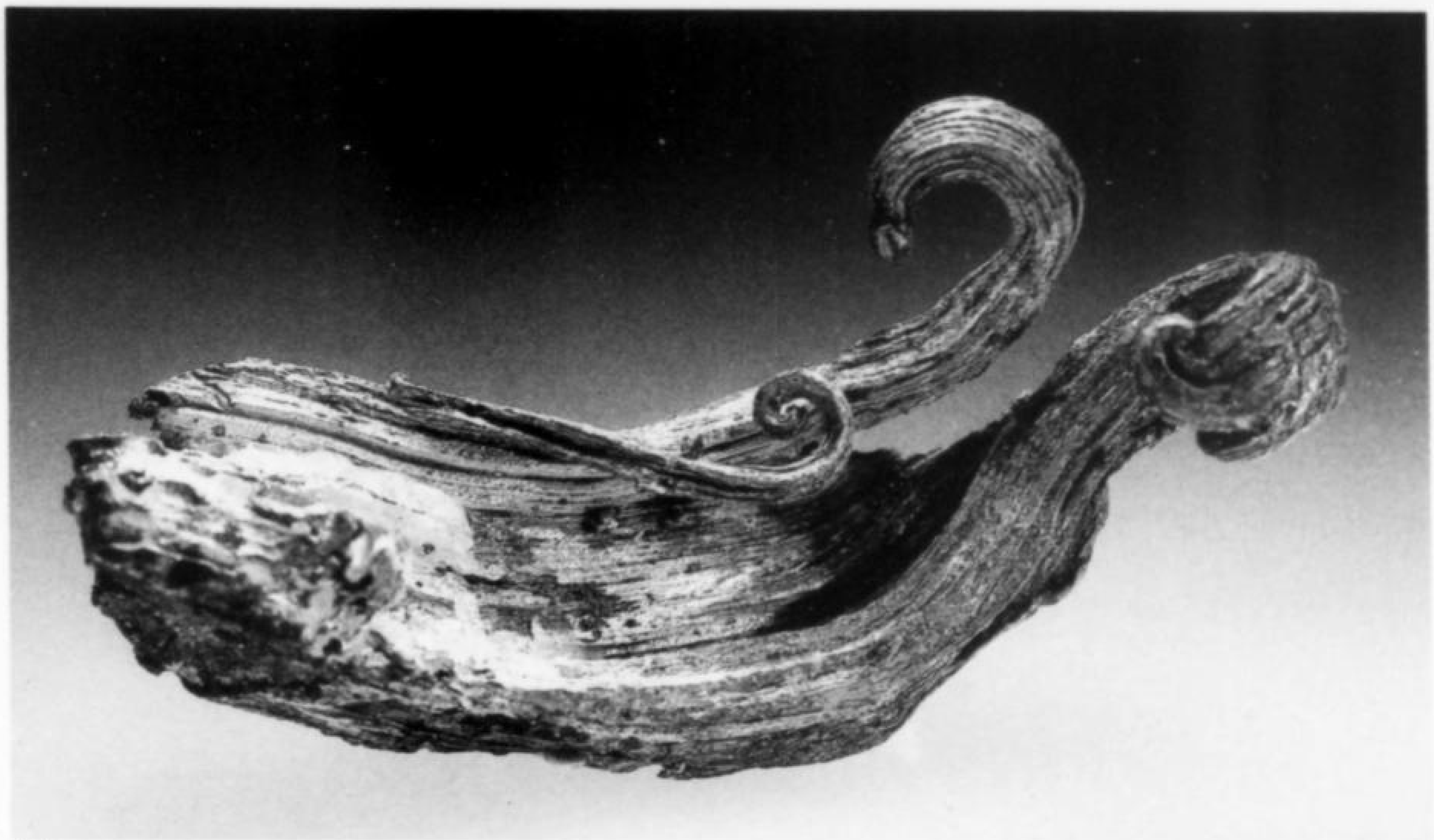
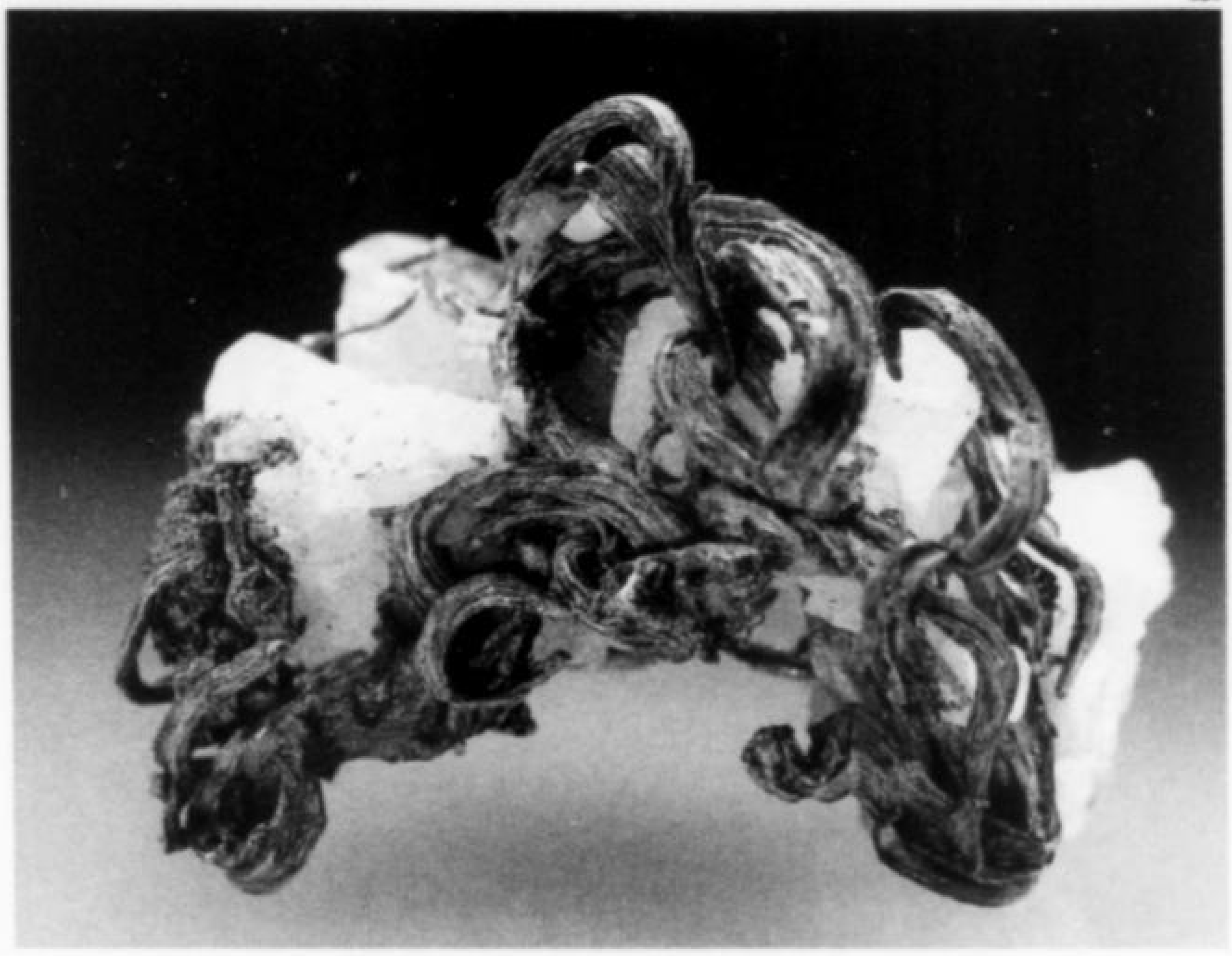


Figure 10. **Wire silver, 3.1 cm long. Wallace Clark collection.**

Figure 11. **Heavy curl of wire silver, 4 cm tall, with tiny argentite crystals to 1 mm in crevices. Milwaukee Museum collection.**

Figure 12. **Wire silver with calcite, 3 cm. Wallace Clark collection.**



land to provide fill for it. It rose 6 meters above the water and, when completed, enclosed an area ten times the size of the original island. The next major storm tore a 30-meter gap in this breakwater too, causing great damage to the machinery, destroying the shaft house and covering the area inside the coffer dam with wreckage. The damage was repaired and mining continued.

With the lumber shortage acute, timbering of the underground workings ceased and pillars of rich native silver ore were left in place for support. Within a few weeks, another $250,000 in silver was removed and shipped. Peaceful weather gave Frue the opportunity to strengthen the timber cribbing of the main breakwater with steel cables, a technique he hoped would add critical flexibility. It seemed he was right when, during subsequent gales, the huge waves rolled over the breakwater but did little damage. Total ore shipped during the summer of 1871 amounted to $1 million in silver.

The Great Lakes were not only a danger to mining but to shipping of the concentrated silver. On October 14, 1871, the steamship

Figure 13. **Inside the breakwater at Silver Islet ca. 1880 (courtesy Ontario Archives).**

Figure 14. **Miners off-duty at Silver Islet ca. 1880 (courtesy Ontario Archives).**

R. G. Coburn took on 30 barrels of Silver Islet silver at Sault Ste. Marie and headed for the smelting facilities at Wyandotte, Michigan. Around 10:00 p.m., the wind quickly rose to gale strength. At 4:00 a.m., the rudder was torn away and the smokestack was blown down, crashing into the cabin. Barrels of silver broke loose and began rolling around the main deck, knocking holes in the bulwarks. Finally, at 7:00 a.m., Captain Demont gave orders to abandon ship, and three lifeboats were successfully launched before the *Coburn* sank. The 30 barrels of silver are still at the bottom of Lake Huron, off Saginaw Bay.

The first bonanza continued with only a moderate decrease in production through 1872, yielding $600,000 in silver. But in early 1873 it began to pinch out. To make matters worse, a heavy flow of water was encountered on a lower level and threatened to flood the mine. Reserve pumps were brought in but proved barely sufficient. Frue sent quickly for a larger pump and it was ready in two weeks but the steamer that was to carry it became frozen in the ice at Houghton harbor. Winter storms descended promptly, the first one driving a tremendous swell before it which surged over the breakwater and hurled a furious flood against the cofferdam, doing $2,000 in damage to the mine buildings.

On the first of December, 1873, however, a storm of rare intensity gathered over Lake Superior. Within minutes after it hit, the entire area within the breakwater was flooded. Twenty meters of the breakwater itself were quickly torn away, followed shortly by the entire remaining structure above the water line. Two men had been left to tend the pumps and keep the steam up, but when cold water crashed into the engine room, the boiler plates buckled and the boiler exploded, killing the men instantly. Frue had also remained on the islet and, for a second time, was nearly killed by a storm.

Figure 15. **Abandoned buildings at Silver Islet, ca. 1886 (courtesy Thunder Bay Historial Museum Society).**

With the mine flooded and its facilities in ruins, the directors called a meeting in New York. Their intent was to close the mine, as their consulting engineers suggested. But Frue attended the meeting as well, and he brought with him a plan for making the island impregnable at last. The directors could not find fault with it, and Frue returned to Silver Islet with a new contract. The *Boston Globe* reported this interesting turn of events as follows:

> The indomitable engineer who has been fighting for some years now to extract the silver from the singular mining property, Silver Islet, in Lake Superior, has decided he is not satisfied with the work of the Creator. He has now undertaken to remake the map. His present endeavor calls for building an entirely new island to his own specifications.

Frue had decided that the islet, as it was, was simply too small to defend so he proposed enlarging it on the lakeward side to 30 times its original area. Ferrying rock out to the island and dumping it was actually a fairly inexpensive procedure, he argued. Furthermore, the enlarged working area would allow the construction of warehouses, storage sheds and bunkhouses for the miners so they could live right on the island.

A huge new quarry was opened on the mainland and a whole flotilla of scows carried rock out to the islet. Some boulders weighed more than 10 tons each. In less than 3 months, the new island had been built, buildings constructed, the mine pumped out by new pumps, and silver found in paying quantities. When the first storm hit, Frue and his 60 men all decided to weather it on the islet; they broke out two barrels of Irish whiskey to help pass the time. Fortunately, their confidence was well-placed; the huge waves lost their destructive power in passing over the great expanse of rock, and Silver Islet was at last secure.

Frue resigned his post at the end of 1875 but, in a letter to Thomas Macfarlane, described a peculiar occurrence which had taken place in the mine just before he left:

> On December 28th, while a party of miners was engaged in drilling a hole in the end of a drift on the eighth level, the drill broke through into a crevice or vug. One of the miners took a candle to look into the drill hole, not being aware that there was a large escape of gas. The gas instantly took fire, sending a flame more than 40 feet out from the working face. The men, of course, threw themselves down on the bottom of the drift and remained there uninjured until the flame subsided, then went scurrying out to the shaft.
>
> After they'd gotten over their fright, they returned to the drift. When within 40 feet of the working face they were horrified when the gas again ignited, filling the level with flame to within three feet of its bottom. The flame extended for a distance of 150 feet towards the shaft. The men again hurriedly threw themselves on the floor.
>
> Some time after this, the men walked into and through the entire length of the drift without any light and inserted a wooden plug into the hole. On the following day no gas was discovered in the drift until a candle was brought close to the plug, when the gas again ignited, giving a jet of flame about 1 foot long which has been burning ever since.

Mining proceeded without interruption through 1876, though silver was sparse. The flow of water underground leveled off at 155 gallons per minute and the new pumps kept it under control. These conditions persisted until the company was heavily in debt and again in danger of closing down. Plans were being made to "rob the pillars" and the roof of the first level where an estimated $350,000 to $500,000 in silver remained, but several small strikes of good ore delayed this plan.

To everyone's relief, a second great bonanza of silver was encountered in 1878, and in one year of furious mining, it yielded over 721,000 troy ounces of silver. Lowe (1882) described the second bonanza as follows:

> In drifting south on the third level, strong impregnations of graphite were found on the hanging wall, which were soon followed to the second bonanza. This deposit of silver was remarkable for its great width, 5 feet solid across the breast, and the occurrence in great quantity of two hitherto unknown compounds of silver, namely, animikite and huntilite. The shape of this bonanza was that of an inverted cone with a base of about 50 feet on the 3rd level with the apex down as far as the fifth level. This deposit was phenomenal in its structure, and a winze in the middle of the deposit to the 4th level, sixty feet, was sunk literally through native silver, the metal standing out boldly from the four walls of the winze. In the breast of the drift it stood out in great arborescent

masses in the shape of hooks and spikes, in gnarled, drawn out and twisted bunches, followed by arborescent silver with intercalated bands of animikite and huntilite. This deposit was struck near the junction of the two veins and the whole extent of the bonanza was strongly saturated with graphite, carrying a selvage of the same on the hanging wall three inches thick. The hanging wall was as smooth and as polished as a mirror. (In some places) the width of the vein was 10 feet . . . arborescent silver was disseminated throughout the whole width of the vein.

The richness of these ores inspired excitement throughout the world. Specimens were exhibited in England, attracting many Cornish miners to Silver Islet. Nevertheless, it was generally difficult to find miners hardy enough to endure the rigors of Silver Islet. Many left after only a single day on the job, complaining of conditions underground. It is perhaps revealing that the mining company had the highly unusual policy of routinely allotting each miner a complimentary double-shot of whiskey before sending him underground every day, and another when he came out.

But life was not altogether bad. Strickland writes:

> On Saturday evening the island became alive with revelry. A brass band was organized and on warm nights the mainlanders would lounge on the docks or on their porches and listen to imperfect renditions of marches and other popular music of the day. They could see the blaze of light from the many lamps in the tavern and some evenings the faint sound of piano and fiddle music echoed across the water, with the steady thumping of the pumps.

The miners were housed in three boarding houses, divided along nationality lines to help minimize brawls: Norwegians in one, Cornishmen in another, and the remaining nationalities in the third. Their wages averaged about $40 a week in 1882.

Upon leaving the mine after each shift, the miners proceeded to the "search house" where they were checked for contraband silver. This did little to prevent highgrading. Most of the miners had previously worked in the copper mines of Upper Michigan, where stealing silver was considered practically a God-given right. They continued this tradition with the usual ingenuity at Silver Islet. In winter they might simply throw chunks of silver out on the lake ice and retrieve them later. In summer they would fasten bags of silver to logs or planks and set them adrift on a calm day, perhaps toward nearby Burnt Island where they could later be found. Having gotten their booty home, they would put the silver in whiskey kegs and bury them in the back yard. At least 17 kegs of smuggled silver are still thought to be buried on the mainland near where the miners' families lived.

When the second big bonanza was struck, Silver Islet stock shot up in price again. But production dwindled rapidly in the following years and, despite exploration down to a depth of 388 meters (1260 feet), no major bonanzas were found at depth. Only one important concentration was found below 110 meters; this was on the 295-meter level and yielded about $30,000 in silver. Plans were again made to install an artificial roof on the first level and remove the rich ore there, a dangerous procedure.

The life-blood of the mine at this time was coal to power the pumps. Without round-the-clock pumping, the mine would quickly fill with water. The worst happened in the fall of 1883. The steamer *John H. Tuttle,* towing barges loaded with Silver Islet's winter supply of coal, became frozen in the channel at Houghton. By March the reserves had run out, the pumps stopped, and the Silver Islet mine became filled with water to the lake level. Directors of the company decided enough was enough and declined to continue work there in the spring. The miners and their families departed, leaving only a single man behind to act as guard and custodian.

For 36 years Silver Islet stood abandoned, but rumors persisted about the extent of silver remaining in the mine. Early in 1920 the firm of Jamison and Peacock of Duluth, Minnesota, took an option on Silver Islet with the intention of exploring for parallel veins. The mine was dewatered down to the fourth level and ore samples taken. Exploratory diamond-drilling penetrated to the east and south, locating a similar vein but with only a low silver content.

In May of 1921, an exploratory drift was started on the fourth level and driven southwesterly along the diabase dike. A narrow vein containing quartz, calcite, galena, sphalerite and a little argentite was encountered but a heavy flow of water forced a shutdown in November.

In 1922 the upper levels were pumped back down to a depth of about 20 meters, and some of the rich ore known to have been left in the roof was carefully removed until the roof had been thinned to about 2 meters in thickness; this yielded over 16,000 ounces of silver, as "animikite" and wire silver.

Periodic re-evaluations of Silver Islet have been made by a number of companies since the 1920s. Divers have brought up numerous samples from the submerged dumps surrounding the islet, particularly in 1960 and again in 1975, and thought was occasionally given to dredging up and reprocessing this material (McDonough, 1976). It was estimated that the dump material contains well over 4 million ounces at about 40–70 ounces to the ton; this seems exceptionally optimistic since it would be nearly twice as much silver as was recovered during the entire history of the mine. Nevertheless, many samples of native silver have been found in the dump material, and it may in fact represent a relatively large reserve of potentially fine native silver specimens held more or less inac-

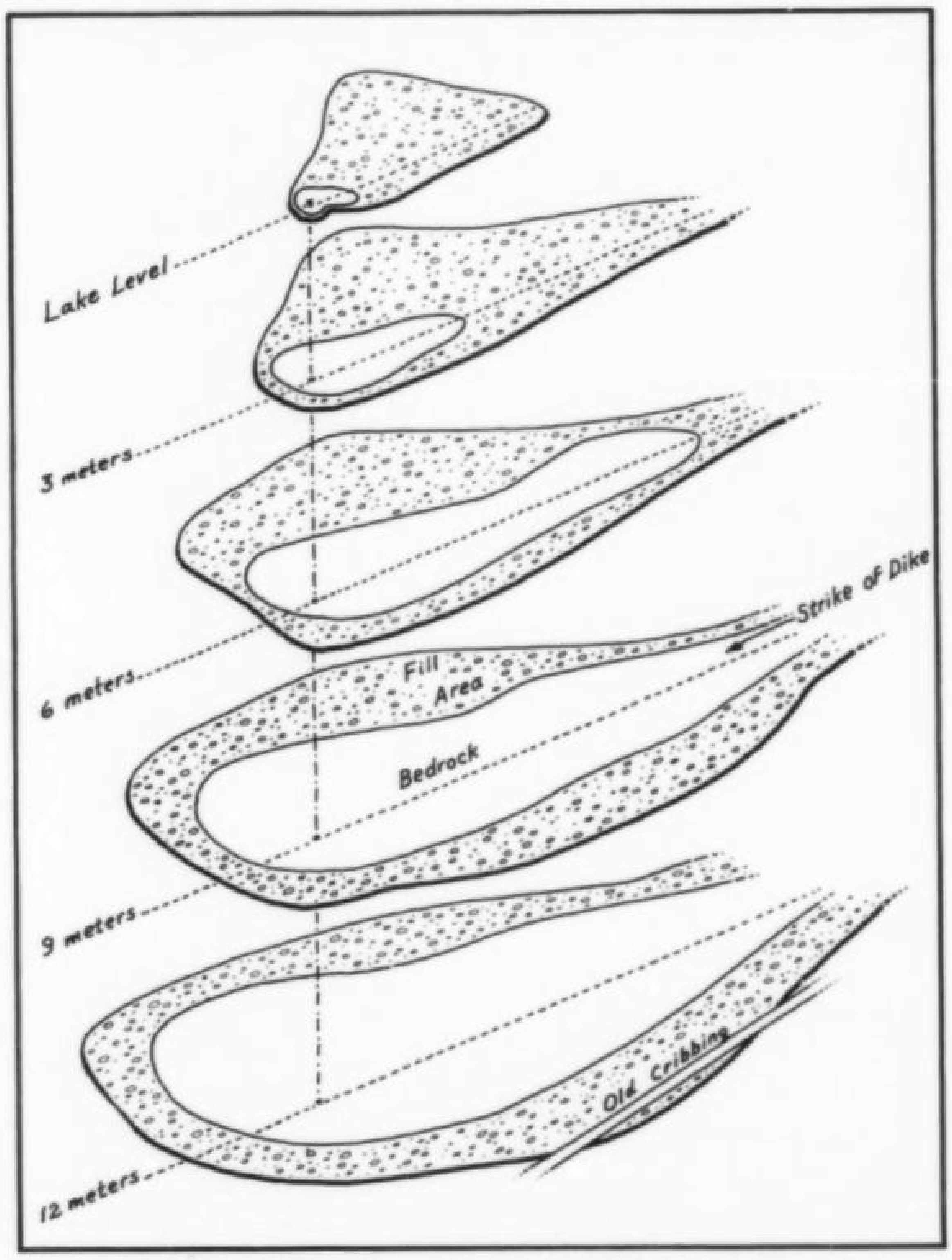


***Figure 16.* Extent of submerged silver-bearing dumps at Silver Islet (after McDonough, 1976).**

Table 1. **Silver production at Silver Islet (compiled from Macfarlane, 1879; Blue, 1897; Ingall, 1887; Sergiades, 1968; Tanton, 1931).**

1868	1,000	troy ounces silver
1869	17,950	
1870	70,887	
1871	520,896	
1872	310,744	
1873	289,764	
1874	250,022	
1875	145,903	
1876	124,981	
1877	23,850	
1878	721,632	
1879	50,000	
1880	36,375	
1881	?	
1882	23,256	
1883	1,874	
1884–1921	nil	
1922	16,652	
1869–1922	2,605,786	ounces (81,118 kg)

cessible for more than a century. The use of modern metal detectors underwater might prove profitable.

The mineral rights to Silver Islet, as of 1979, were held by the three daughters of the late E. J. Cross, who purchased the property in 1935.

GEOLOGY

The general geology at Silver Islet is quite simple. Precambrian Animikie sediments form the country rock of the area. Cutting through these sediments is a large diabase dike of Keweenawan age. Cutting the dike at a right angle is a heavily brecciated fault zone. Vein material cementing the fissures and fault breccia at this crossing contains silver.

The diabase dike strikes N50°E and dips 75° to the southeast. It varies in width from 80 to 110 meters, and has been traced for a distance of nearly a kilometer. Since most of the length of the dike is hidden by the lake, its actual length may be far greater.

The fault zone is accompanied by considerable fracturing and brecciation where it crosses the diabase dike, but relatively little in the surrounding sediments. Hence, vein mineralization found favorable conditions for deposition restricted to the dike and directly adjacent areas. The width of the fault zone within the dike is about 15 meters; it strikes N35°W and dips 70–80° northeast, and has been traced for a length of at least 550 meters. Its supposed continuation on the mainland has been followed for nearly 3 km. Movement along this fault zone, resulting in the development of gouge, slickensides, shear zones and fault breccia, has been estimated as an essentially vertical downthrow of about 100 meters on the east side (Tanton, 1931). A "horse" measuring roughly 74 meters long, 6 meters wide and extending to a depth of 62 meters is suspended in the fault zone, dividing it into two breccia zones each 3 to 5 meters wide. Individual veins comprising the fault zone are typically 2 to 30 cm wide, but masses of vein minerals measuring up to a meter in all directions have been found. Roughly 75% of the volume of the fault zone is vein filling material, including silver.

Vein-forming minerals cement fissures in the fault zone, and occur in irregularly shaped nodules and lenticular masses in fault gouge. Two generations of veining have been identified, referred to by Tanton (1931) as primary and secondary. The primary vein deposits, accounting for 90% or more of total vein volume at Silver Islet, are fine-grained and uniform in texture. The bulk of this vein material consists of a mixture of fine-grained dolomite and quartz in widely variable proportions. The metalliferous minerals (silver, argentite, nickeline, galena, sphalerite, marcasite, cobaltite, skutterudite, domeykite, chalcopyrite, tetrahedrite, breithauptite, millerite and arquerite) occur as microscopically intergrown masses and granular and dendritic clusters varying in compactness. The proportions of constituent minerals vary as well, resulting in what appear to be homogeneous masses. The "minerals" described by early workers as animikite, macfarlanite and huntilite are such mixtures (Parsons, 1921).

Secondary vein deposits consist of discontinuous replacement bodies, veins and vug linings extending at least to a depth of about 200 meters but more prominent closer to the surface. Here a wide range of mineral textures are found, including wires, leaves and nuggets of silver and well-formed crystals of other minerals.

There appears to be some relationship between the deposition of silver and the presence of graphite (McDermott, 1909), an association found at a number of other important silver deposits worldwide.

MINERALS

The mineral of primary interest at Silver Islet is, of course, silver. It was found as masses, sheets, films, ferns, crystals and wire varying in texture from fine moss to coarse, heavy wires. All specimen-grade material came from secondary veins where the silver had been recrystallized from its original fine-grained state, and where it had

Table 2. **Minerals reported from Silver Islet.**

"Animikite"	mixture	2, 4
Annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$	2, 3
Argentite	Ag_2S	1, 2, 3
"Arquerite"	mercurian silver	4
Barite	$BaSO_4$	3
Breithauptite	NiSb	4
Calcite	$CaCO_3$	1, 2, 3
Chalcopyrite	$CuFeS_2$	1, 2, 3
Chlorargyrite	AgCl	1, 2, 3
Chlorite group		6
Cobaltite	CoAsS	3
Dolomite	$CaMg(CO_3)_2$	3
Domeykite	Cu_3As	2, 3
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$	2, 3
Fluorite	CaF_2	6
Galena	PbS	1, 2, 3
Graphite	C	1, 2, 6
Gypsum	$CaSO_4 \cdot 2H_2O$	5
"Huntilite"	mixture	2, 4
"Macfarlanite"	mixture	2, 4
Marcasite	FeS_2	3
Nickeline	NiAs	1, 2, 3
Pyrargyrite	Ag_3SbS_3	1
Pyrite	FeS_2	1, 2
Pyrolusite	MnO_2	3
Quartz	SiO_2	1, 2, 3
Rhodochrosite	$MnCO_3$	1, 3
Silver	Ag	1, 2, 3
Skutterudite	$CoAs_{2-3}$	1, 3
Sphalerite	(Zn,Fe)S	1, 2, 3
Stephanite	Ag_5SbS_4	1
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$	2, 3
Wurtzite	(Zn,Fe)S	7

References: (1) McDermott, 1909; (2) Macfarlane, 1879; (3) Tanton, 1931; (4) Parsons and Thomson, 1921; (5) Satterly, 1977; (6) Ingall, 1889; (7) Lance Hampel, personal communication.

room to grow in open vugs. McDermott (1909) refers to the rare, well-defined crystals but none seem to have survived. Courtis (1887) described an interesting occurrence:

> The breast of the stope showed a coating several inches thick of a spongy silver, in which were imbedded, like plums in a pudding, double-ended quartz crystals. I think a small specimen of this was preserved in the collection at the New York office.

(It is tantalizing to learn that the mining company maintained a collection of some kind, but its eventual disposition is unknown.)

McDermott (1909) mentions plates of silver "to one-fourth inch in thickness and 10 inches square," and silver-impregnated calcite having an opaque yellowish color.

A number of other minerals occurred well-crystallized at Silver Islet. McDermott (1909) mentions well-formed leaves and crystals of argentite, and distinct crystals of rhodochrosite. Ingall (1889) tells of large crystals of galena in vugs, sphalerite crystals, well-formed cubic fluorite crystals (pale green to purple), and well-formed cubic pyrite crystals in vugs. Tanton (1931) observed barite in platy crystalline growths to 2.5 cm, radiating out from centers. Tanton also described a sticky, brownish gray clay he presumed to be saponite, and noted that the early miners used to use this clay to stick their candles to the walls of the workings. (See Table 2 for a complete list of reported species.)

Unfortunately, little else can be said about the mineralogy of Silver Islet. Relatively little work has been done since the mine was in operation, and very few samples are available for study.

CONCLUSIONS

Silver Islet is closed and flooded, a situation which at first appears discouraging. However, numerous opportunities still exist for the recovery of additional specimens. The foremost of these is the remaining roof of the mine, about 2 meters thick of vein material rich in wire silver and the fine-grained silver-cobalt ores. Other locations as yet unmined probably contain silver in the lower workings as well. In addition, there remains the extensive submerged dump surrounding the islet, which appears to contain much silver and yet has lain untouched for over a century. For the treasure hunters, there are 30 barrels of Silver Islet silver still in the wreck of the *Coburn* off Saginaw Bay in Lake Huron, and a possible 17 more barrels buried on the mainland near Silver Islet landing. Metal detectors indeed seem called for.

ACKNOWLEDGMENTS

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Batopilas

famous mineral localities: the Batopilas district, Chihuahua, Mexico

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Since their discovery by the Spanish in 1632, the vein deposits of Batopilas have yielded seven times the total amount of silver produced at Kongsberg, Norway. Most of the silver occurs in native form as wires, crystals and herringbone crystal groups today represented in mineral collections the world over.

INTRODUCTION

The name Batopilas was apparently derived by the early Spaniards from a word in the language of local Tarahumara Indians: *Ba-cho-tigori,* which means "near the river" (Gonzalez-Reyna, 1947). Following usual procedure, the Spanish attached a saint's name to the Indian locality name and christened the site San Pedro de Batopilas.

Vast quantities of silver have been removed from more than 300 mines, claims, veins and workings in the Batopilas district. In recent years, many specimens have come from the New Nevada mine.

The Batopilas mining district is located in extreme southwestern Chihuahua, near the Batopilas River, in a warm, steep valley overlooked by high, picturesque mountains of the western Sierra Madres. Many of the mine entrances are situated on the lower slopes of the surrounding mountains, at an elevation of about 700 to 1200 meters. The mining town of Batopilas, still home to several hundred people, clusters along the river near the southern center of the mineralized area. The area is covered by the Batopilas 1:50,000 quadrangle (G13A41, 1979).

HISTORY

In 1522 Spaniards first discovered silver in Mexico, at Taxco in the state of Guerrero. Within two years, silver was being mined at Pachuca; in 1540 the great deposit at Zacatecas was discovered; and in 1548 the astoundingly rich silver deposits at Guanajuato were found. The King of Spain received regularly his one-fifth share of the silver bullion, as well as impressive natural specimens of native silver. It became clear to the Spanish that Mexico was a treasure-house of silver. In the following decades, Mexico was thoroughly prospected by the Spanish, and modern mining men claim that no important deposits which crop out were missed (Naica is an exception), though some of their discoveries were abandoned as uneconomical to mine at the time.

In 1632 a small band of Spanish *adelantados* or "advance guards" explored the valley of the Batopilas River and found native silver. The discovery point was apparently *in* the river itself, near the bank, where pure, glistening white silver had been stream-polished and kept from tarnishing. They named it the Nevada mine because of this snow-white metal, *nevada* meaning "snowy" or "snow-

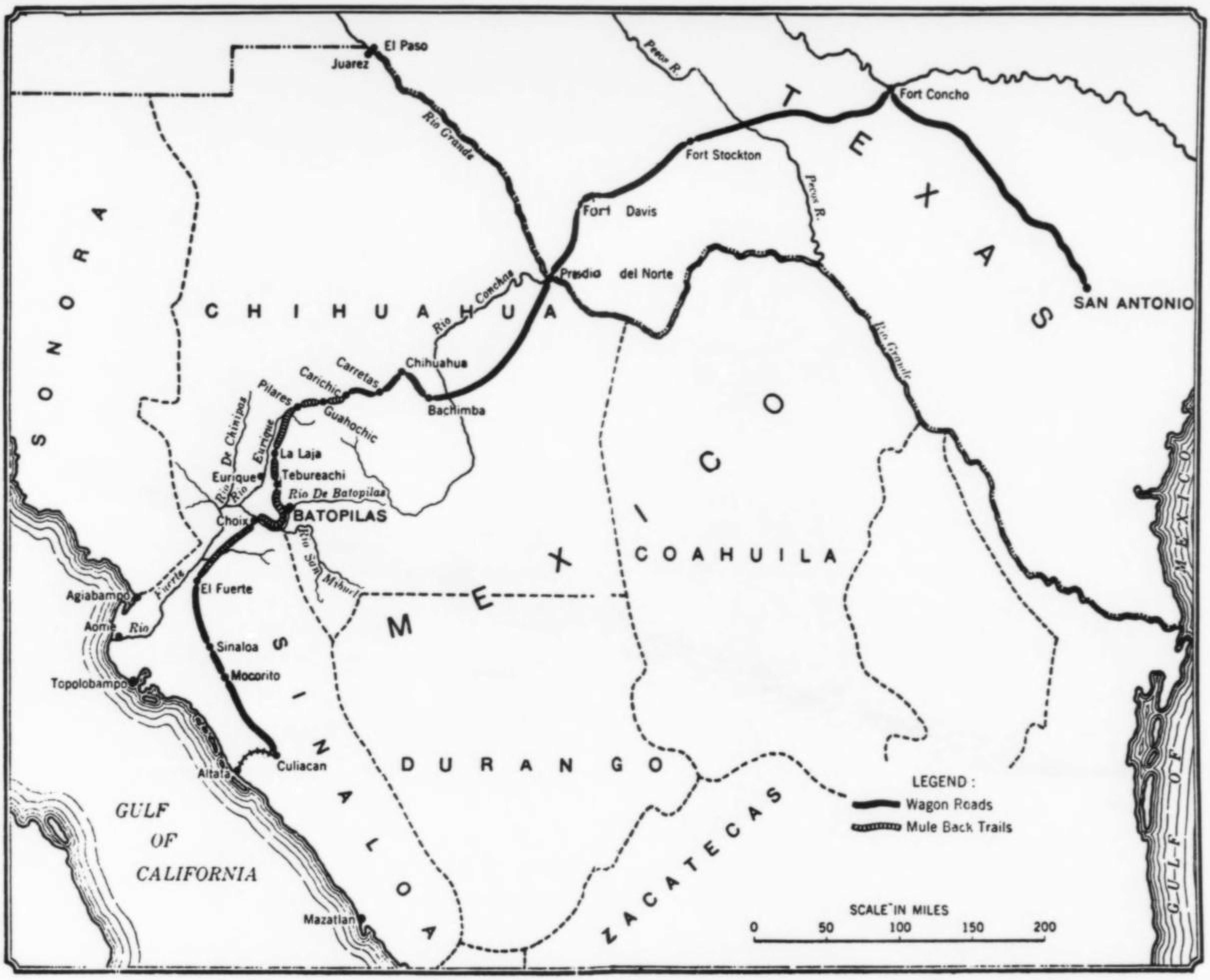


Figure 1. **Location map showing the route taken by Alexander Shepherd and family to Batopilas in 1880 (Shepherd, 1938).**

capped" in Spanish. Specimens from the discovery were packed out and conveyed to the King of Spain in Madrid, who was presumably impressed. Spanish immigration into Mexico increased significantly as a result of the news.

A village developed on the banks of the river, and mining began. Knowledge of those early years is sparse because fires in 1740 and again in 1845 destroyed many records. It is known, however, that one of the Spaniards, Don Rafael Alonzo de Pastrana, encountered a bonanza of silver in his Nuestra Senora del Pilar mine (ca. 1730) which yielded him 40,000 pesos *weekly* for many years. At one time, the weathly Pastrana is said to have invited the Bishop of Durango to visit Batopilas; when the Bishop arrived, he found that Pastrana had laid for him a solid silver sidewalk of ingots leading from the church to the house where the Bishop was to stay. The clergyman, so the story goes, was horrified by this ostentatious display and reproved Pastrana for his vanity (W. D. Pearce *in* Griggs, 1907). Pastrana died in 1760, by which time the main pocket was exhausted and much of the mine had caved in. Even today, however, ancient workings in the Pastrana mine which are still accessible can be seen to have been continuously stoped for over 250 meters (800 feet) in what was rich native silver (Brodie, 1909b).

In 1775 a Mexican miner by the name of Cristobal Perez obtained the rights to work the San Antonio mine. He subsequently struck a bonanza pocket of silver which lasted for 14 years of continuous mining and yielded many millions of dollars. Perez and his son became widely known as two of the most important personages in that part of Mexico, and many stories were told of their wild extravagances. The stories were probably true, because by the time the son died in 1814, the entire fortune had been spent (Brodie, 1910).

In the 1790s another Spaniard, Don Angel Bustamante, came to Batopilas as a merchant and gradually became involved in mining. He tried many times to find a silver pocket and failed. Persevering further, however, he acquired a claim on the Carmen mine and eventually did strike a bonanza which, authorities claim, yielded him a minimum of $14 million. With his wealth he returned to Spain and purchased a Marquisate (becoming the Marquis de Batopilas), though his employees continued to operate his mines for him until 1824 (Tod, 1907; Brodie, 1909).

During the early 1800s, Baron Alexander von Humboldt traveled through Mexico and published numerous reports on the mines. Of Batopilas, he wrote: "Native silver has been found in considerable

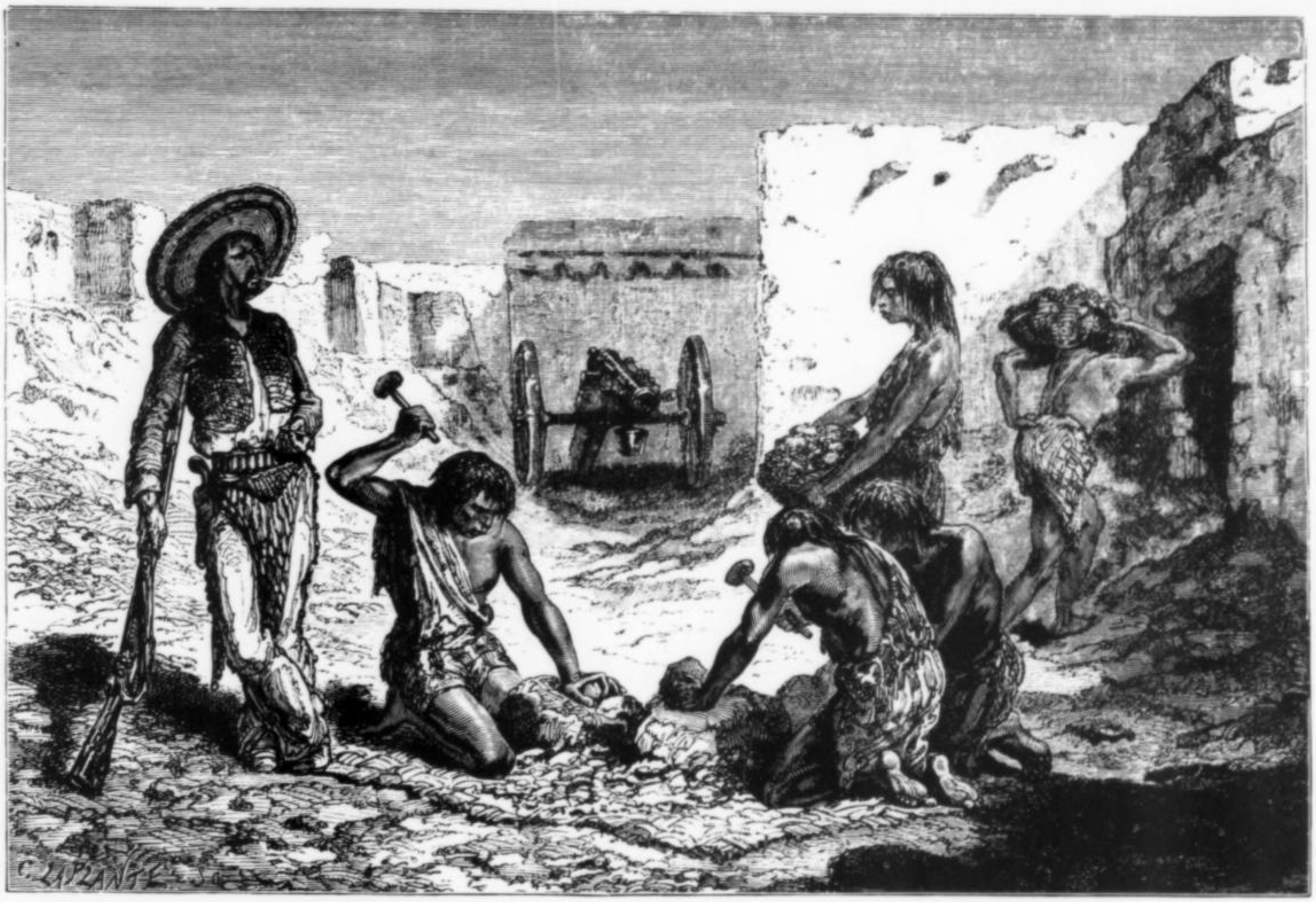


Figure 2. **Indian prisoners employed as forced labor under the Spanish, cobbing out silver ore at a mine in Chihuahua (Simonin, 1869).**

masses sometimes weighing more than 440 pounds in the mines of Batopilas. It is no doubt true that blocks of silver of enormous weight have been extracted" (von Humboldt, 1824).

In the 1820s the Spanish were expelled from Mexico in a bloody war of rebellion, and Batopilas went into recession. The owner of the San Antonio mine, Jose Esparza, officially filed his abandonment of the property in 1820, stating that the town was in a most miserable condition, and that only the Cata mine and the Martinez mine remained active. Little work was accomplished in the district during the first years following the Spanish expulsion (Brodie, 1909).

Then, in 1842, a woman of "strong character" arrived in Batopilas. She was Dona Natividad Ortez and, with the help of her Indian associate, Nepomuceno Avila, she began work at a number of mines. Within a short time, the Santo Domingo, San Nestor and Animas mines had yielded her about $300,000 (Tod, 1907). Under her management, new veins were discovered and mines begun, including the Todos Santos, San Pedro and La Aurora mines. Batopilas was in full swing again.

The San Antonio mine came into the possession of Manuel Mendazona in 1852. He was a merchant from Culiacan who had made some money in the mining districts of Dolores and Guadalupe y Calvo. Among his first projects was a tunnel, called the San Miguel tunnel, which was designed to cut the veins of the Carmen and San Antonio mines near their lowest workings, at a depth of about 150

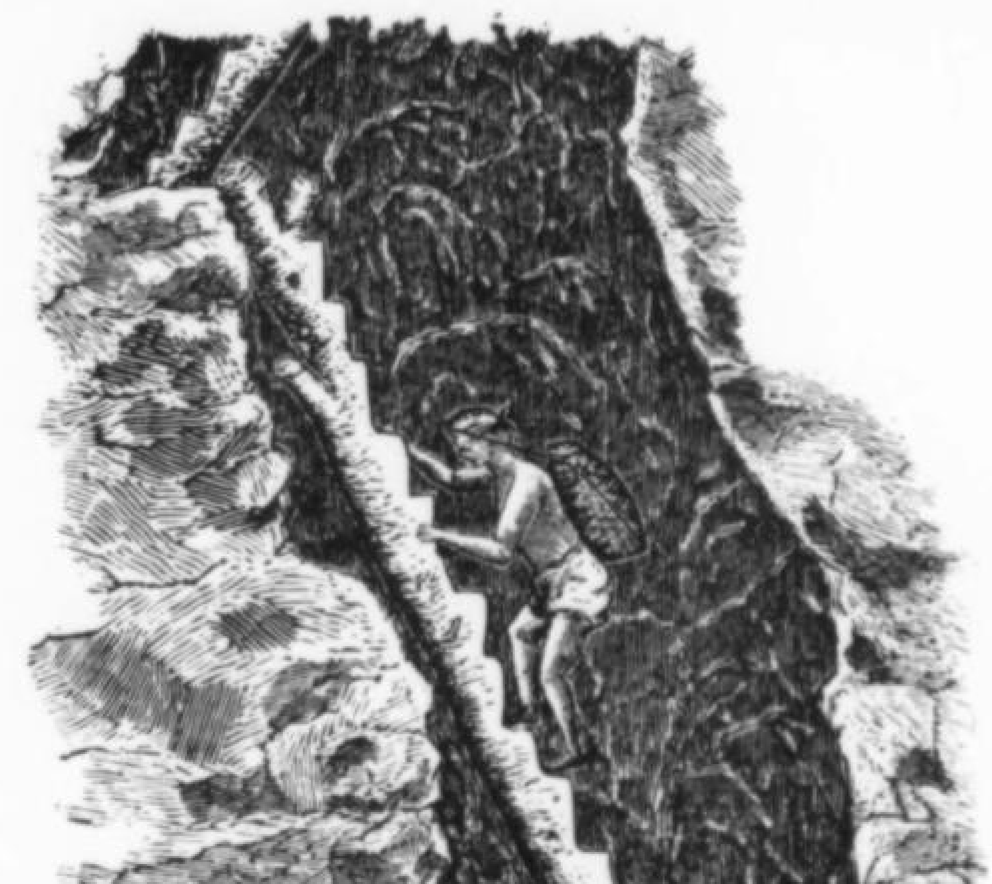


Figure 3. **An early engraving showing native miners; note the notched log known as a *muesca* or "chicken ladder" (Ritch, 1885).**

Figure 4. **Panoramic view of Batopilas, looking west, circa 1900. John Whitmire collection.**

meters below the surface. A tunnel greatly reduced the cost of removing ore from higher workings because hoisting was eliminated. Before the tunnel could be completed, however, Mendazona died in 1856, and in 1861 the property was sold to an American company under the direction of John R. Robinson.

Robinson completed the tunnel to the San Antonio mine, which he had initially intended to work. Along the way, however, the San Miguel tunnel cut a blind vein (one that did not outcrop and had remained unknown up to that point). At first it was not considered important, but it did show some minor indications of silver. Therefore, following completion of the tunnel, Robinson decided to work the new vein for a distance and see what could be found. What he found was a major bonanza of native silver which came to be called the Veta Grande, or "Great Vein." This vein was so rich, and its fame subsequently so widespread, that bandit chiefs arrived periodically to extort tribute; one even seized the mine for two months and, with a crew of 300 men, extracted $100,000 in silver before tiring of the miner's life (Tod, 1907; Brodie, 1909).

Robinson continued to work his holdings in a small way for 19 years. During this time the town slowly grew until, in 1877, it was made the capital of the canton of Andres del Rio (Tod, 1907).

Robinson sold the San Miguel mine in 1880 to another American, Alexander R. Shepherd, the former (and last) Governor of Washington, D.C. Shepherd paid $600,000 for the property and moved to Batopilas with his family to take personal charge of operations. Over 350 other mining claims covering 31 square kilometers (12 square miles) were eventually acquired and consolidated as the Batopilas Mining Company. In 1886 a concession was granted the company by the Mexican government which gave effective control of the entire district. Shepherd ran the operation with the help of his sons, until his death in 1902.

Operations under Shepherd were generally prosperous despite some fluctuations in production and the price of silver. During the first years following 1880, about $1 million were paid in dividends, and the town grew in population from 400 to over 5000 inhabitants. From 1880 to 1906, the production of silver was estimated at 19.5 million ounces (Shepherd, 1935).

Lodes of the rich native silver ore were extremely profitable when found, but very irregular in distribution and difficult to locate. Mining generally followed the veins, which tended to be barren over great lengths between lodes. When heavy silver masses were encountered, usually only a day or two elapsed between blasting of the pocket and casting of the finished silver ingots.

Lamb (1908) mentions an encounter between Alexander Shepherd and a visiting mining engineer who was taking samples from

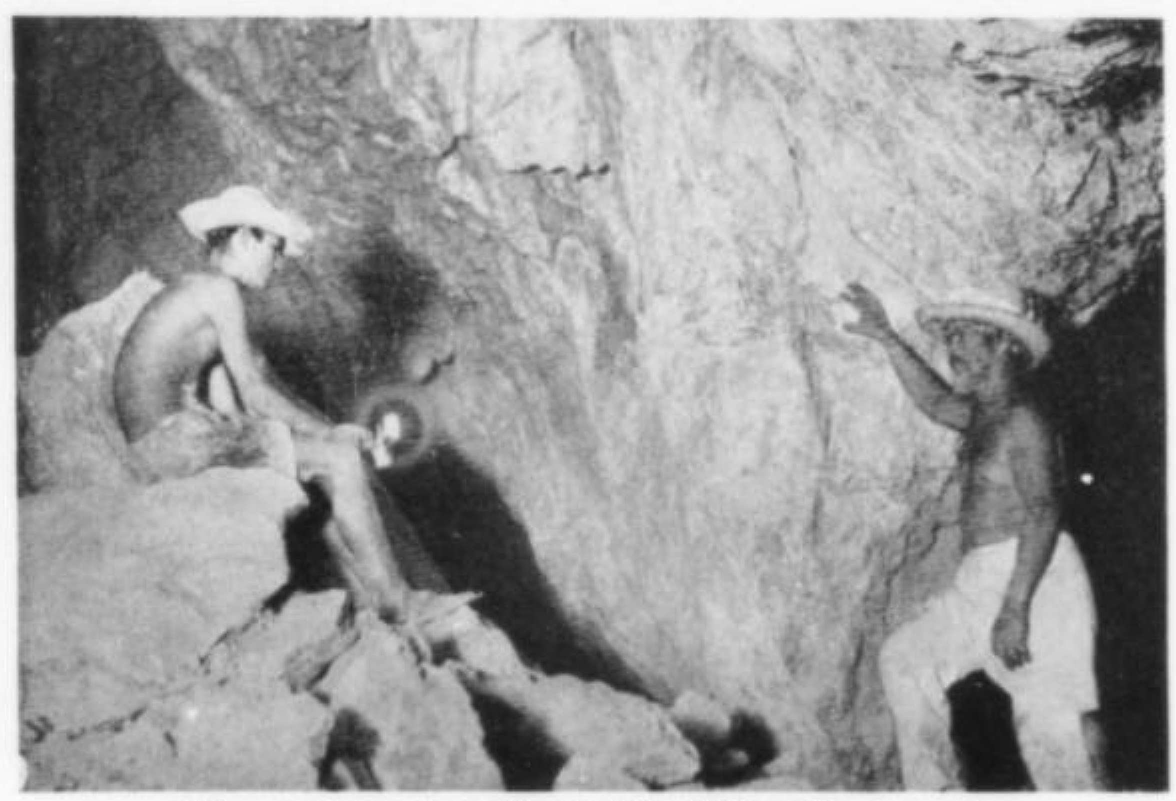


Figure 5. **A stope in the San Miguel mine, ca. 1900 (Shepherd, 1938).**

the various veins in order to determine how much ore was "in sight." Shepherd at length pointed out to the engineer that such a procedure was useless at Batopilas. "We have *no* ore in sight," he said. "Just as soon as it gets in sight, we take it out of sight."

It was the custom for each mine superintendent to telephone headquarters each afternoon and request as many mules be sent up as pocket silver found that day would require for transport. The ore was so unpredictable in its occurrence that sometimes only two mules might be required, and at other times 30 mules might not be enough.

Lamb (1908) relates another story about a time when funds were low, no ore was "in sight," and $90,000 was owed the bank on a

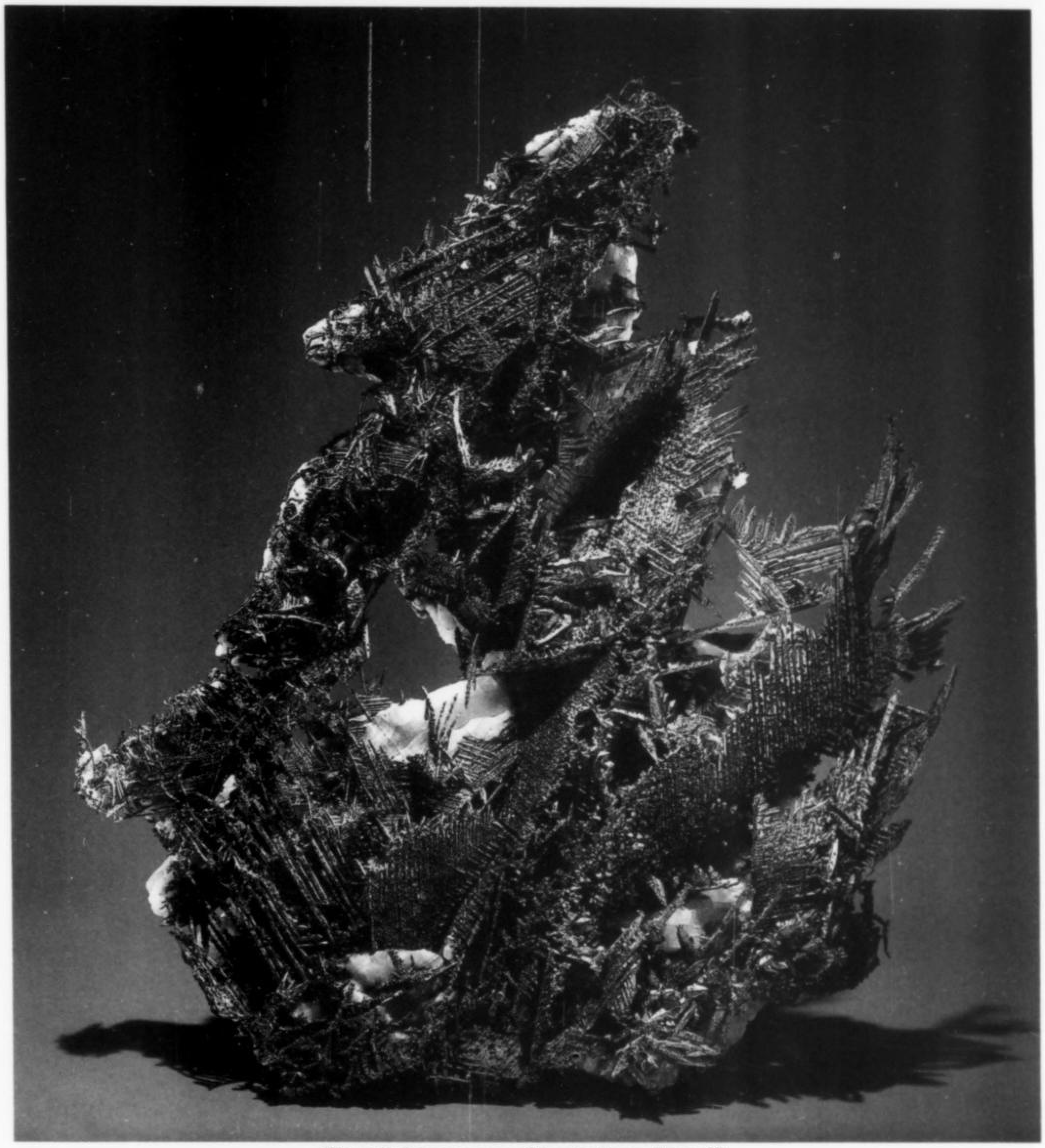


***Figure 6.* Large group of herringbone silver, 18 x 20 cm, from the New Nevada (Nevada Valenciana) mine. Van Scriver Minerals specimen; photo by Harold and Erica Van Pelt.**

draft Shepherd had written recently in New York. The report from the mine at 1 p.m. was gloomy . . . only three mules were required. Just as the staff was becoming seriously worried, another call came in from the mine. The excited superintendent was asking for more mules. "It looks now like about 30 loads, but we're not through it yet. It's going to be hell to get out; it will not shoot; not enough rock mixed in with silver. Send a crew from the shop with cold-cutters!"

During his tenure, Shepherd saw to the construction of numerous buildings and facilities totaling well over $2 million in cost. Stamp mills, Bartlett concentrators, electric generators, air compressors, a small dam for hydroelectric power, a masonry aqueduct 3 km long, amalgamating and retorting facilities, a foundry capable of making castings up to 1100 kg (2500 pounds), an assay office, administrative office, dormitories, a boarding house, a hospital, a bridge over the river and an 800-meter aerial tram were all constructed entirely of materials packed in on mule-back.

The ground held up well, and timbering was hardly ever used except in chutes and other functional constructions.

Shepherd's son, Grant, was five years old when the family moved to Batopilas. Fifty-eight years later, he published his memoirs, entitled *The Silver Magnet; Fifty Years in a Mexican Silver Mine.* His story makes fascinating reading, and gives a rare glimpse into the nature of life and mining at Batopilas. Following are some excerpts from Grant Shepherd's memoirs (1938) of his days at Batopilas, between the years 1880 and 1914.

> When a man in the year 1880 took over a mining business in a locality such as Batopilas, the difficulties were many.

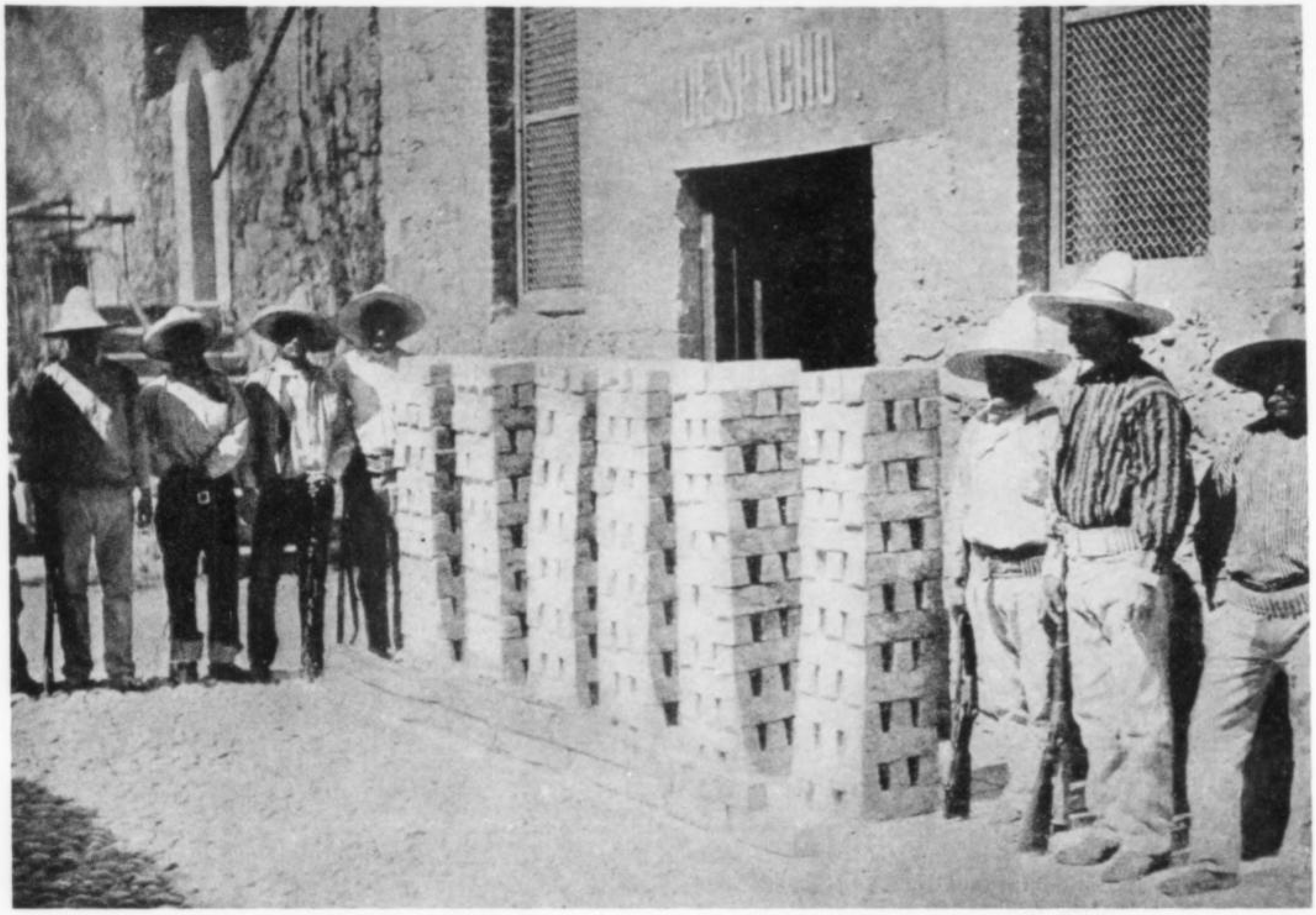


Figure 7. **A particularly large monthly shipment of silver bars ready to leave Batopilas for the Banco Minero in Chihuahua City. Each bar weighs about 30 kg (970 troy ounces; 66 pounds). At today's price of about $6 an ounce this shipment would be worth $1.6 million (Brodie, 1909b).**

There was no rail connection for 600 miles until 1883, when the Mexican Central got as far as El Paso, Texas. Then the distance between the mines and the railroad was reduced to 300 or more miles. But those 300 miles had to be traveled and freight had to be transported across them, for the first 185 miles on the backs of mules, and the last 150 miles on wagons or ox-carts. After a few years' residence in Batopilas, we accepted the unavoidable mountain trip to Chihuahua City as a necessary evil, a part of the essential game of getting the silver bullion from the mines to the market, and, in turn, securing the safe arrival into Batopilas of supplies.

The monthly bullion trains always took not less than 50 bars* of silver bullion worth about $60,000; more often they conveyed 100 bars; on special and unusual occasions they had as many as 200 bars or even more. Since each mule carries only two bars of silver, you will readily understand that these trains were made up of from 30 to 100 or more mules.

As a small boy, I used to come into Chihuahua sitting on the driver's seat of a Concord stagecoach filled with silver bullion, with fourteen mules hitched to it and going at a full gallop. The long whip of the *cochero* would be popping while we swung dizzily round the corners of the narrow streets of the town. We would pull up with a flourish in front of the Banco Minero. The coach I rode was the leading stage, and it was followed by several more, all of them loaded with silver bars.

There were five major mines being worked under my father – the San Miguel, Roncesvalles, Camuchin, Todos Santos and La Descubridora. Ores from each of the mines had to be treated separately and an exact account kept.

Seventy-five to 80% of all silver values contained in Batopilas ore are pure native silver, occurring in irregular masses, plates and crystals imbedded in vein calcite. When the rich pockets or *bonanzas* are encountered there is always a great amount of calcite. The native silver crystals, which have been covered by this crystallization which is quite transparent, are entirely imbedded in it. It is very beautiful.

I worked at various times in each and every mine operated by the company, including the Porfirio Diaz tunnel. It gave me a fine opportunity to study and better understand the vein groups and the variety of ores. Although it may seem strange, in the San Miguel group (the deposits worked through the San Miguel tunnel), the ores of the Veta Grande, Mesquite, Carmen and San Antonio were very dissimilar in appearance. This was because of the divergence of content and crystallization of the various minerals. The ores of the Porfirio Diaz group were also distinctive in appearance; we would pick up a piece of ore and tell from its appearance which vein it came from, and sometimes even which level on a certain vein.

Leather was used in immense amounts, for making *zurrones,* bags for packing of the high-grade ores. Silver sulfide concentrates, after being sewn up tight in canvases, were finally sewn into bags of well-wetted rawhide, which when dry took an ax to open, and in which covering they went all the way to Aurora, Illinois, for smelting.

When my father took over in 1880, the surface outcrops had been worked as deep as possible by primitive methods. On the backs of men, it is possible only to carry ores up lad-

* Each bar weighed 27 to 34 kg (60 to 75 pounds), worth $5200–6500 today, at $6/ounce.

ders for 500 feet more or less. The best peon will carry 100 to 150 pounds in a *zurron* up a distance of 500 to 1000 feet of ladders . . . but he cannot make many such trips a day. Hence the cost becomes prohibitive.

We used horse whims, then steam hoists; afterwards came gasoline hoists, and compressed air drills, and for many years the longest mining tunnel in Mexico, the Porfirio Diaz tunnel. Our total of underground workings was over 75 miles.

The Porfirio Diaz tunnel required several years to drive. It cut all the veins found on the western side of the river. From the portal to the point where it tapped the Roncesvalles vein is 7050 feet. It is continued on this vein and to the Todos Santos vein for 2000 feet more. The old shafts and workings from above are connected with the tunnel; therefore, instead of being compelled to hoist them, the ores roll down to tunnel level, making a much more economical proceeding altogether.

At the World's Fair in Chicago in 1893, our ores from Batopilas took the premium in their class. The biggest piece we exhibited weighed 380 pounds. We had three of our very strongest pack mules bring it out with the regular pack train, and they made the customary 40 miles each day. This was done by changing the load every ten miles, and it was a tremendous nuisance.

The natives thought electric lights to be almost magical when my father first had electricity installed in Batopilas. Never in their lives had they seen or pictured to themselves an electric light. The first night the electric plant was put into commission, one of the men was told to go out and touch a button to light up the place. Instead he got a box of matches and tried to screw off a glass bulb so he could apply a match to the wire!

We had large locomotive headlights placed at strategic points, and a line of electric lights was run into the Porfirio Diaz tunnel. They appeared so beautiful to the natives that many women and children used to come there solely to look into the tunnel to see *las luces tan lindas,* "the so beautiful lights." The throng of admirers grew to be a nuisance, and on a certain evening the superintendent said nothing about explosions when the time came to fire a round of dynamite shots inside the tunnel. When these fulminated with a great detonation in the face of the tunnel, the blast of air out at the entrance was so tremendous that the crowd of Mexican ladies had a bad time of it with their wildly blowing, voluminous skirts. It was thought to be the height of immodesty to show even so much as an ankle (women did not wear bloomers in those days). Therefore, the devastation suffered by their modest sensibilities was sufficient to insure their never returning to the mouth of the tunnel again to see the wonderful electric lights. The superintendent did not fail to receive his share of abuse from these outraged females as they took their departure, sputtering like setting hens.

It was my good fortune once to open up a very ancient mine that lay between two we were working. The company from which we had taken over in 1880 had no record of its existence, nor had we until my brother-in-law came across an ancient map of the San Miguel group in the Department of Mines, Mexico City. He wrote us about this discovery, we investigated, and sure enough after a good deal of digging we found what had once been a tunnel entrance. It was plugged up with heavy stulls of pine whose timbers were over 15 inches in diameter. There were indications that very rich pockets of pretty good size had been taken from these workings, since in places the stopes were of considerable size. We discovered ladders of the old native type, made from a pole 15 or more inches in diameter with notches for steps cut at regular intervals.

Our ores were what is commonly known as high-grade, therefore, much watchfulness had to be exercised to prevent them from being filched. We had a group of trusted employees, native and foreign, who kept themselves on the thinnest edge of readiness to combat the ingenuity of those who hoped to add to their wages by stealing small amounts now and then and carrying them out of the mines on their persons. Some of the methods are worth relating: Say, for instance, you wear your hair quite long, and while you are turning the drill steel and it is cutting through rich silver ore, you must clean your hands of the drill mud. If you wipe your hands on your head, the long hair will get full of mud. When you go home and wash your hair in a basin, you will find you have washed out fine particles of silver . . . after you become expert, as much as a third of an ounce a day. Or suppose you are wearing the native sandal made of heavy sole leather. With patience and skill you can split the sole so as to make a thin pocket into which you can put an ounce of flattened native silver. Another way is to forego your dinner. Take your dinner of hash or beans into the mine in a porridge bowl covered with corn tortillas to prevent spilling. Put the filched silver in the bottom of the bowl, under the beans, and replace the tortillas. Look sick as you reach the mouth of the tunnel to be searched; tell the gatekeeper and searcher that you did not eat your dinner because you had a *dolar muy fuerte* in your stomach. There are other very unique methods. Here is another trick you might attempt, if you can establish a reputation as a *macouchic* smoker. This is a very inferior tobacco. Learning to smoke it is in itself an ordeal that badly shakes the system. Tie up in a bandana a handful of *macouchic* and mix the fine silver in with it before leaving the mine. But our searcher, Don Romulo, is so very expert that he may smile and say, "What heavy tobacco that is! Let me look at it; I am, as you know, an expert on tobaccos." He will do the same thing with your cigars, so do not waste any time hollowing them out and charging them with silver. I have watched Don Romulo search hundreds of men and I honestly believe that he intuitively knew, when they stepped up to be searched, just who did and who did not have contraband silver on him. Many of the miners were superstitious about Don Romulo.

Figure 8. **Miner being searched for contraband silver before leaving the Todos Santos mine, ca. 1900 (Shepherd, 1938).**

It was not all beer and skittles during my thirty-odd years at Batopilas. At times silver went way down in price, we were

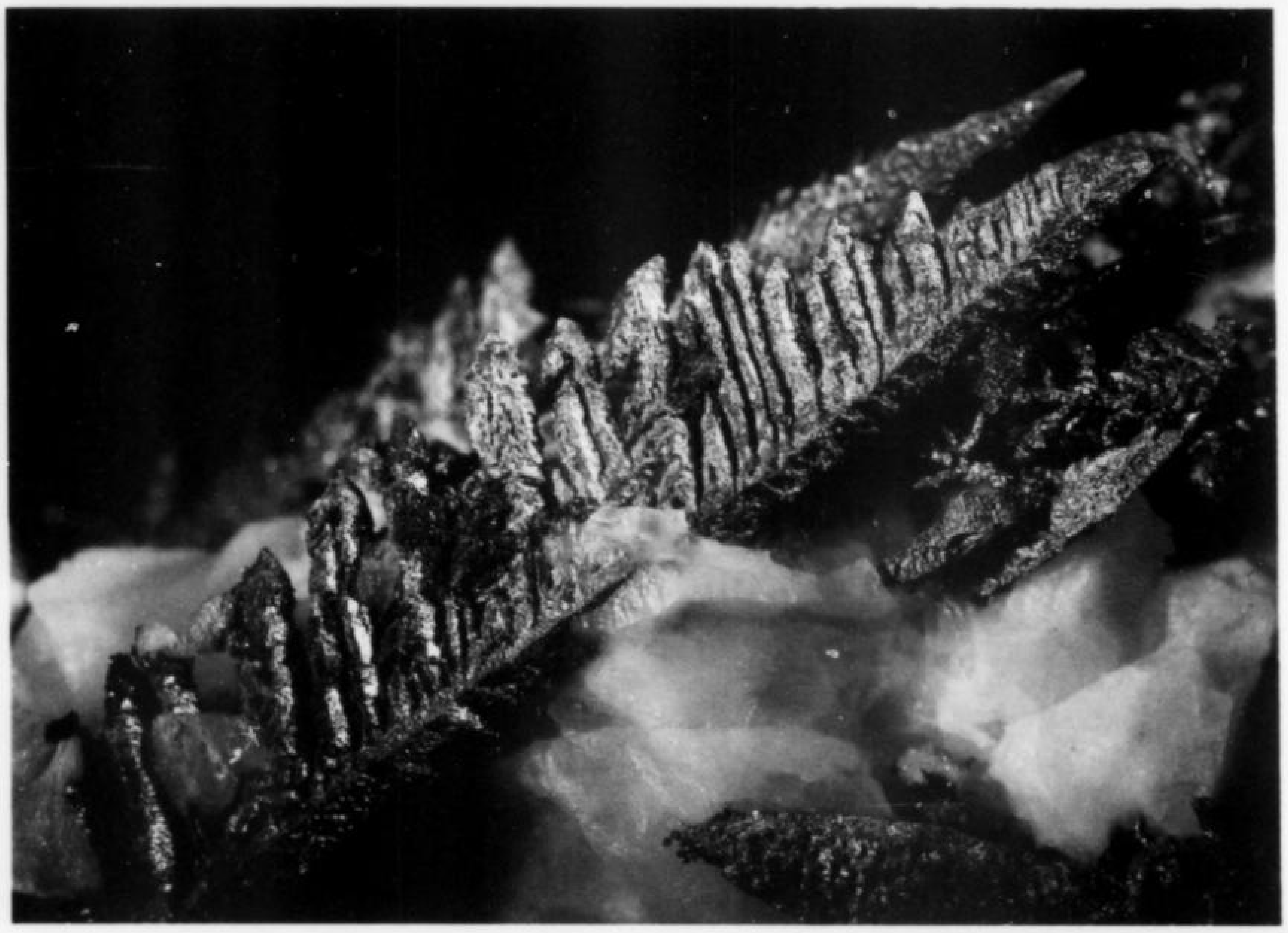


Figure 9. **Silver herringbone crystal with black argentite (acanthite), about 3 cm long. Olaf Medenbach photo.**

Figure 10. **Spiky silver crystals to 2 cm. Olaf Medenbach photo.**

heavily in debt, and we had overreached our overdraft at the Banco Minero in Chihuahua. But before matters hit the absolutely fatal spot at any one time, we would run into a bonanza of greater or lesser extent, and sometimes near the end of the month would knock out anywhere from fifty to a hundred thousand dollars in silver. One month we took out $450,000 in silver, and we had no air drills then. Did we work!

It was not until President Porfirio Diaz was overthrown that our company ever lost a bar of silver or a dollar of payroll money. That great liberator, the oppressed Francisco (Pancho) Villa, stole $38,000 worth of silver bars and buried them in a patio of a house in Chihuahua. He was afraid to convert them into cash, and later when this leader was not so strong in power we recovered the treasure.

After the Mexican Revolution began in 1910, the district went into a more or less permanent decline. The Shepherd sons ceased their operations for good in 1920 after several years of very low production. Intermittent minor production, some by the Santo Domingo Silver Company, took place from 1922 to 1929 and yielded a total of about 800,000 ounces (Gonzalez-Reyna, 1947).

In recent times (1974) a mill was installed at Batopilas by Francisco Lewels and Henry Ehrlinger (*El Paso Times,* 1975), but it was badly designed and could not process typical Batopilas ore. Gabriel Oaxaca and associates attempted a cyanide leaching operation at the Pastrana mine in 1981.

Local residents and occasional small-scale lessees continue to take a modest amount of silver from a few mines and by panning river gravels. As of 1980 only the Nevada Valenciana (New Nevada) and Caballo mines were being worked, but most of the mines in the district remain under claim, and many are reopened and reworked from time to time.

Throughout the history of Batopilas, production has been impressive. Tod (1909) estimates that the Pastrana mine yielded something less than 50 million ounces by itself since its discovery in 1730. LeBrun (*in* Brodie, 1910) estimates that the Carmen and San Antonio mines produced 8 million ounces prior to 1860. Gonzalez-Reyna (1947) gives a figure of 20 million ounces for the Los Tajos mine up to 1820, and another 27 million ounces for the district as a whole under Alexander Shepherd and sons (1880–1920). These few mines alone total up to more than 100 million ounces. Gonzalez-Reyna (1947) suggested an all-time total for the district of about 11 times the Shepherd total, or about 300 million ounces. This seems reasonable considering that no records at all are available for the first century of production, which must have yielded a significant amount.

Three hundred million ounces is a truly staggering amount of silver, equal to nearly 900 cubic meters! That is three times the amount of silver the Bisbee district produced in its lifetime, and *seven times* the total amount of silver mined at Kongsberg, Norway.

GEOLOGY

The epithermal precious-metal province of northwestern Mexico, coinciding more or less with the Mexican volcanic province and the range of mountains known as the Sierra Madre Occidental, is the greatest epithermal silver province in the world.

Wisser (1966) has provided a regional analysis and a comparison

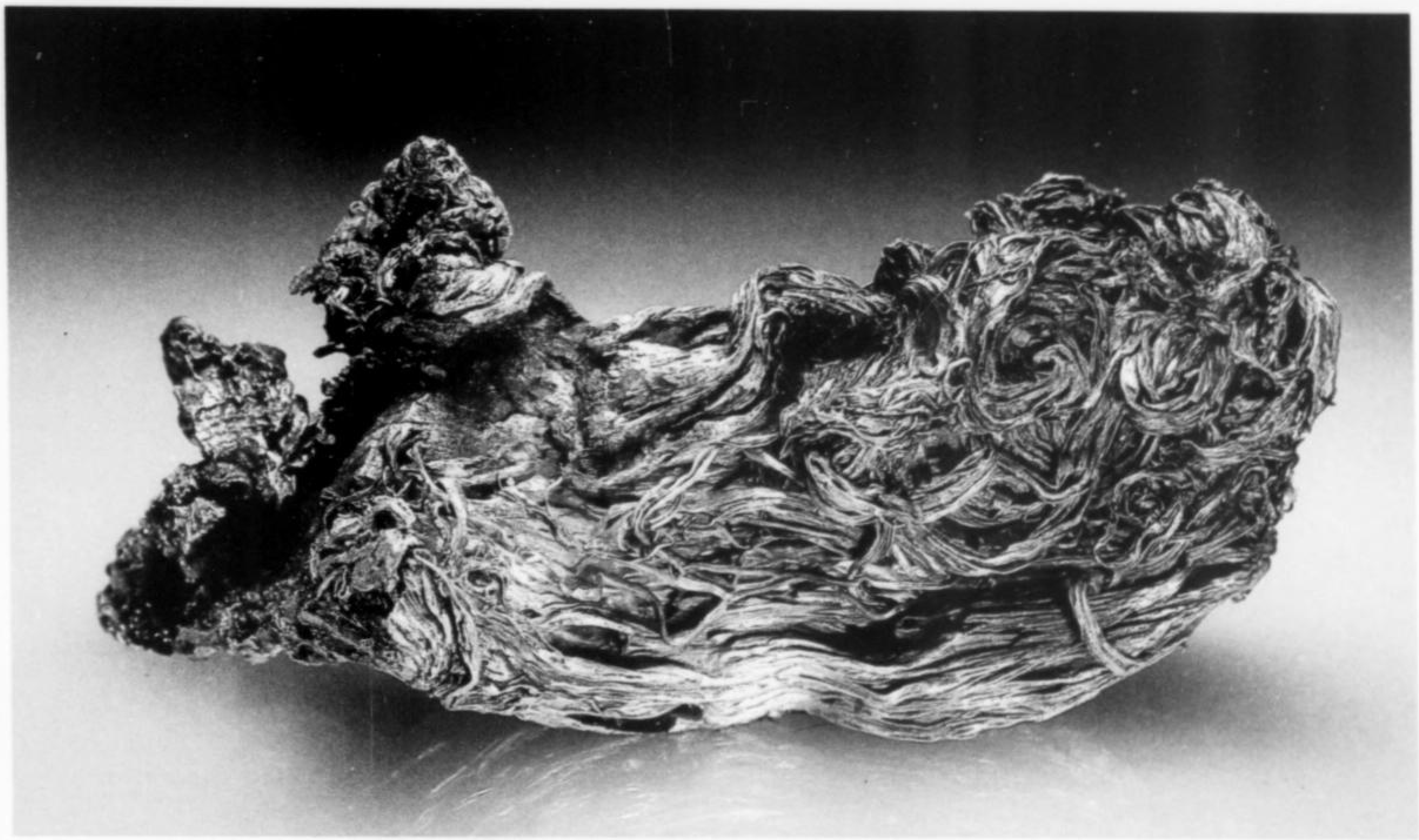


Figure 11. **Large Batopilas wire silver, 10 cm, formerly in the collection of Andrew Carnegie (1835–1919), now in the Miguel Romero collection.**

of the various deposits. He considered the area to be both a structural and a metallogenic unit resembling one extremely large mining district; it extends from near the Arizona border to as far south as Mexico City, nearly 1800 km. Total silver production has never been accurately estimated but is certainly several billion ounces (Pachuca, Guanajuato and Zacatecas alone accounting for nearly three billion ounces). The northwestern portion of the province (Fig. 13) contains over 70 well-documented epithermal districts the total production of which undoubtedly exceeds a billion ounces.

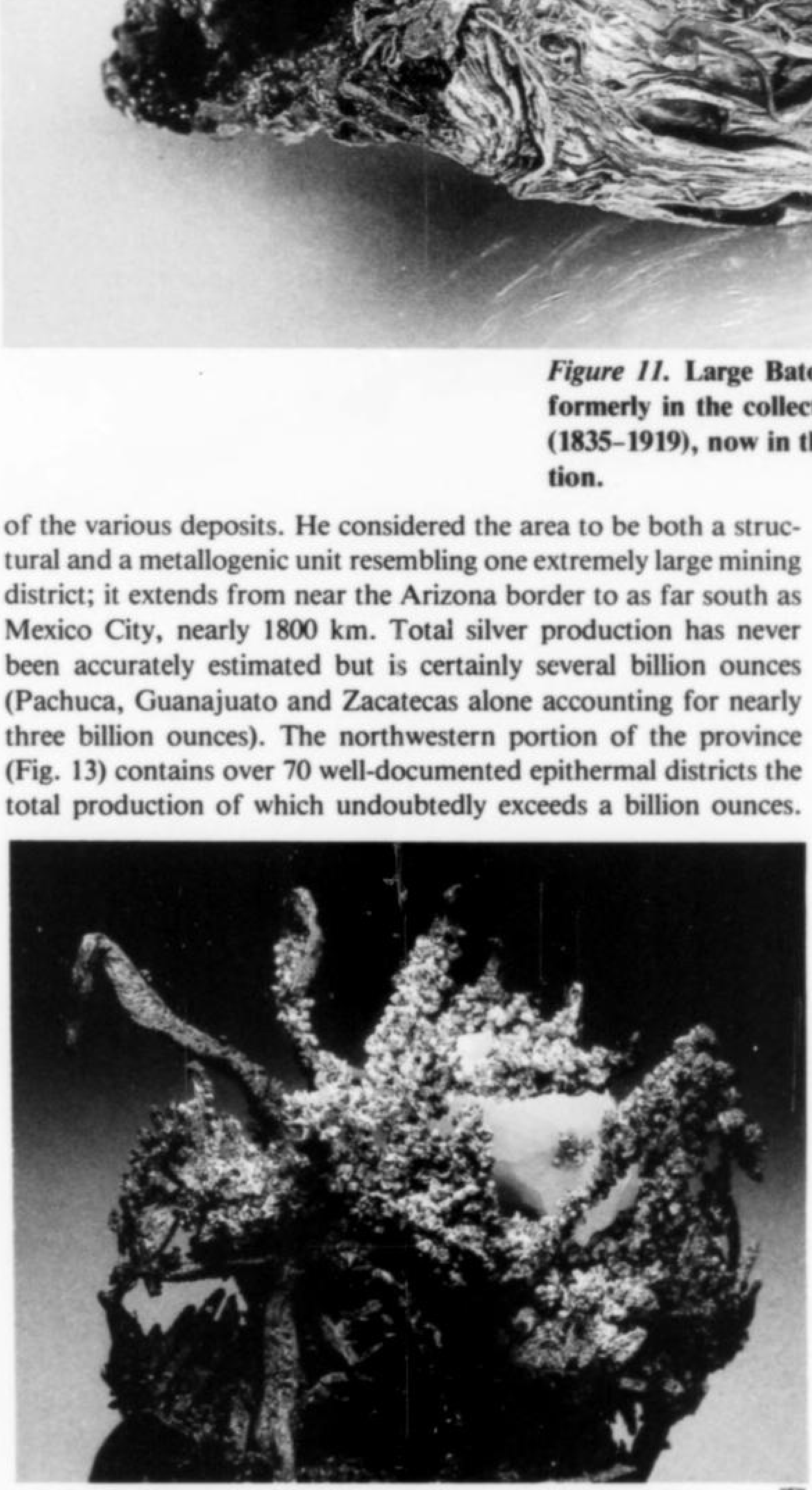


Figure 12. **Primary wire silver coated by black argentite and granular, secondary silver, 3 cm across. E. Schlepp specimen; collected around the turn of the century.**

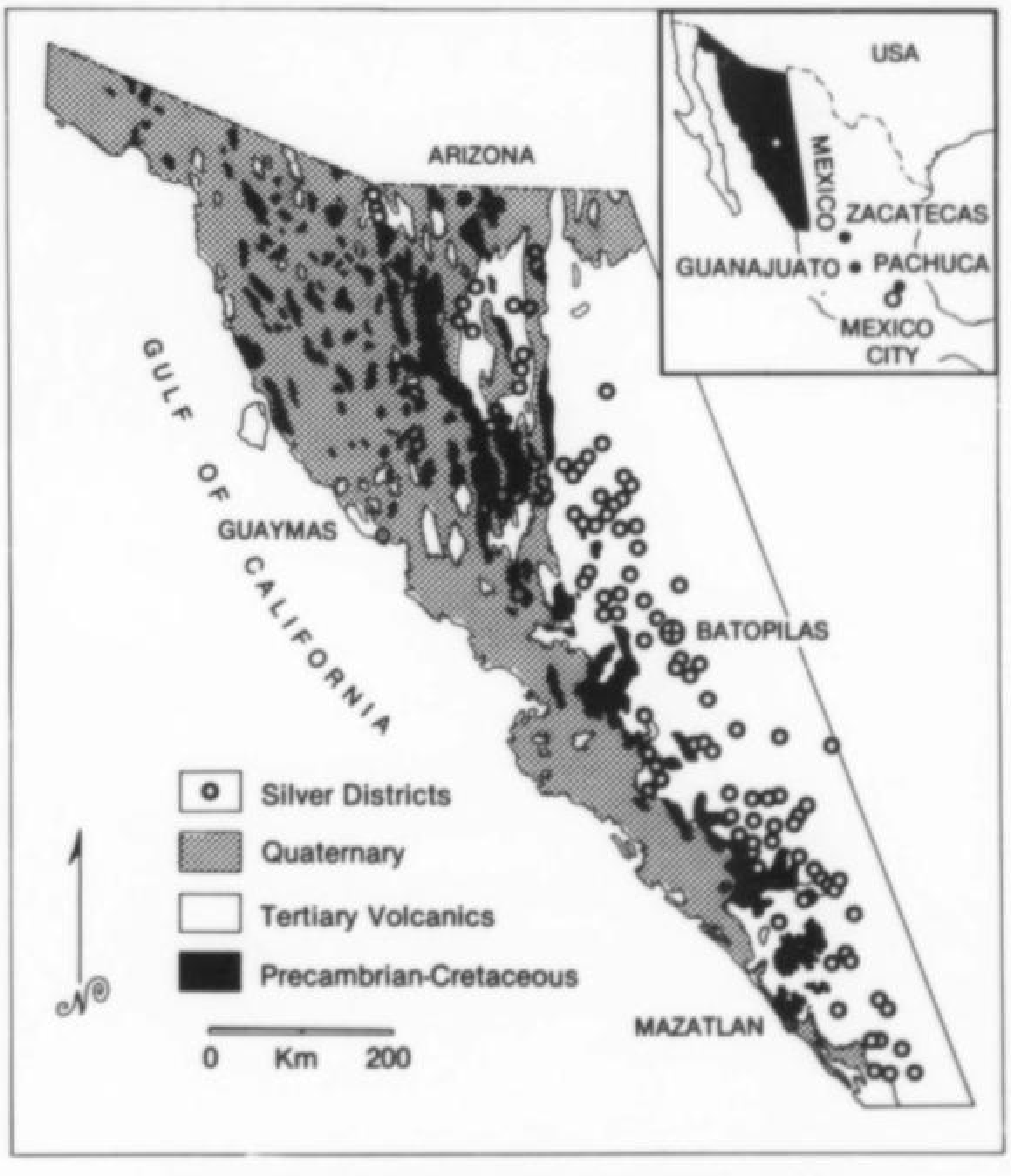


Figure 13. **Northwestern portion of the epithermal precious-metal province of Mexico, showing the locations of over 100 silver and silver-gold mining districts (including Batopilas) relative to the geology of the Sierra Madre Occidental (modified from Wisser, 1966).**

Figure 14. **Ruins of the mine office built by Alexander Shepherd.**

(Batopilas is located approximately in the center of the northwestern portion.) Wisser's theory about the belt is now thought to be an over-simplification, but there is no denying that western Mexico is the world's largest silver anomaly.

The general geology of the province is relatively simple. Basement rocks consisting of limestone, quartzite, sandstone and granitoid masses were repeatedly uplifted along a linear trend known as the Occidental geanticline, the major axis of the Sierra Madre Occidental. A thick sequence of Tertiary volcanic rocks overlies the basement; these consist mainly of intermediate to mafic flows and pyroclastics of andesitic composition. Granitoid or porphyritic stocks invaded the volcanic pile at many places. Epithermal silver mineralization closely following the extensive andesitic volcanism is believed to have taken place during the last (mid-Tertiary) uplift, about 45 million years ago (Bagby, 1979); this mineralization is concentrated along the crest of the geanticline.

Batopilas deposits show some interesting variations or, at least, extremes relative to other districts in the northwest portion of the province. At Batopilas the ore was emplaced in veins relatively low in the volcanic sequence, very near the basement. These veins are, on the average, the narrowest of the 38 major deposits in the province, and yet Batopilas is among the top three producers in the northwest portion of the province (Wisser, 1966). The major ore mineral is native silver whereas in the other districts it is argentite. Calcite is the principal gangue mineral whereas in the other districts it is quartz. The silver/gold ratio at Batopilas is among the highest in the province (about 2200 to 1).

A critical factor controlling the deposition of epithermal silver orebodies is depth below the then-existing surface (Wisser, 1966). These bodies characteristically develop with their upper limits at shallow depths, between 200 and 500 meters. However, close proximity to the basement complex seems to have an effect on the mineralogy, resulting in a higher silver/gold ratio and a lower percentage of gangue in the veins. Proustite and pyrargyrite are somewhat more abundant closer to the basement, and veins tend to be narrower. All of these features are well-represented at Batopilas.

A detailed study of the local geology in the Batopilas area has recently been completed by Wilkerson (1983, unpublished). A summary is given here, supplemented by comments from earlier authors.

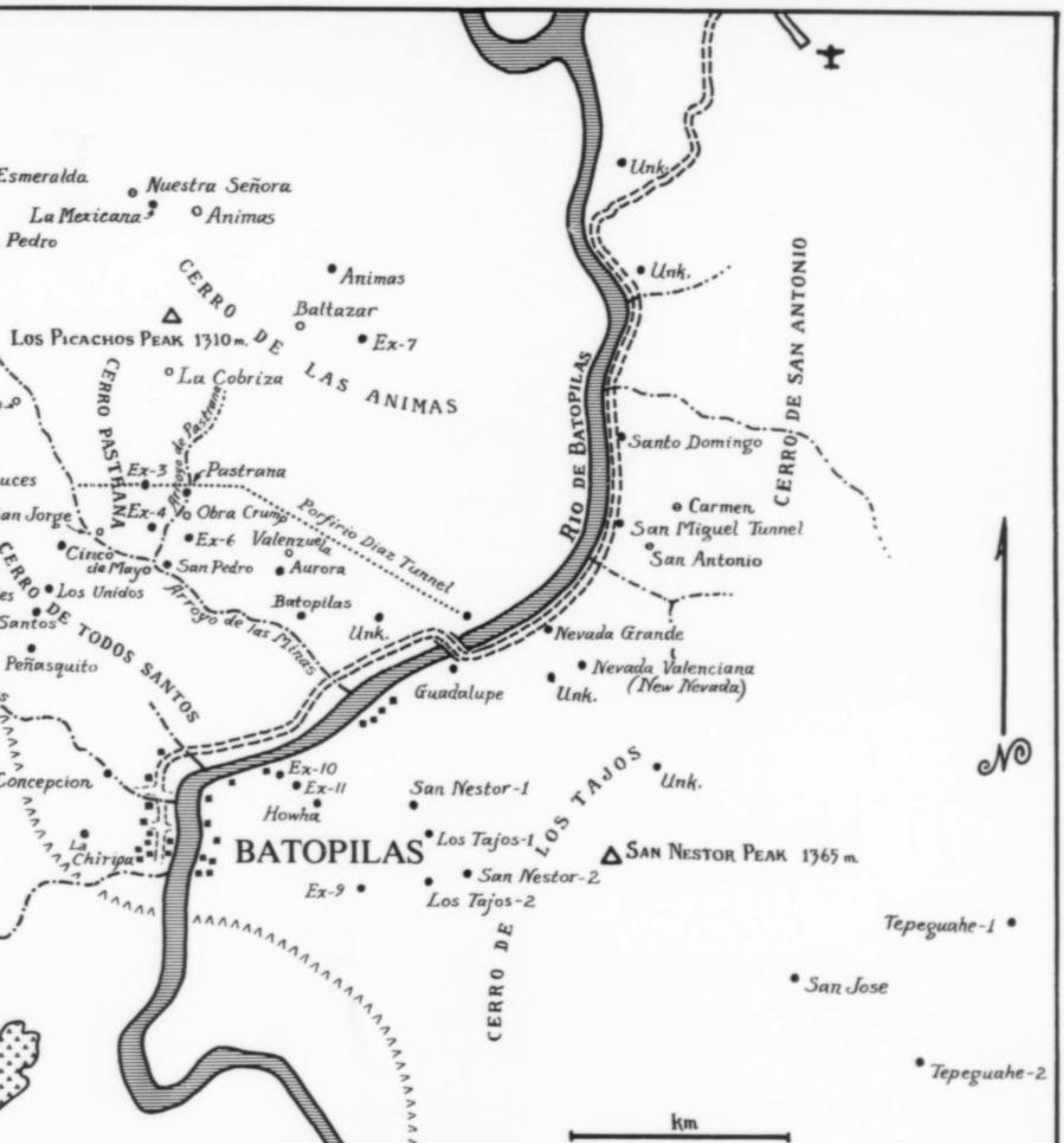
The region surrounding Batopilas consists of an immense series of gorges in a skeletal tableland, ranging in altitude from 500 meters (1600 feet) in the valleys to nearly 2200 meters (7000 feet) on the mesas. At least three distinct dacite flow breccias, all unmineralized, overlie granodiorite, quartz diorite and dacite intrusions. These lower units have been heavily fractured and faulted. Tod (1907) commented that the district is remarkable for its heavily shattered condition and the great number and variety of veins, threads and fracture zones of different ages which intersect in extremely complicated fashion.

Silver mineralization occurs primarily in the Pastrana dacite and dacite porphyry, though a few orebodies have been found in the Tahonas granodiorite and in andesite dikes. The silver forms irregularly shaped, pod-like concentrations in fissure veins connected by stretches of barren vein. Structural controls (flexures, fracture intersections, etc.) are present in some orebodies but apparently absent in others. The most productive veins strike north-south and northeast-southwest (except in the San Miguel mine where a few east-west cross-veins have been worked) and dip from about 65° west to near vertical (Krieger, 1935).

Ore mineralization, as mentioned above, consists primarily of native silver solidly enclosed in calcite and accompanied by lesser amounts of argentite, galena, sphalerite and arsenopyrite, probably deposited at relatively low temperatures (under 250° C). Pyrite is rare or absent.

Three main types of vein were identified by Wilkerson: calcite-silver veins, by far the most important as ore (containing 0–70% galena and sphalerite plus minor argentite and pyrargyrite),

Figure 15. **Map of the Batopilas mining district showing the approximate locations of some of the mines. Solid dots are locations from Wilkerson (1983); open dots are from an unpublished claim map of the Batopilas Mining Company ca. 1912 (courtesy of John Whitmire); bisected dots are from a rough sketch map by Shepherd (1900; first printed in Dahlgren, 1883, 1887). The shaded area at upper left is the uppermost**



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rock unit in the area, the Yerbanis ignimbrite (unmineralized). The shaded area at the bottom is the Las Tahonas copper porphyry, the apparent source of mineralization in the district; the toothed line delimits the barren halo surrounding the intrusion, within which no silver has been found (modified from Wilkerson, 1983).

chlorite-actinolite clay veins (containing 0–50% calcite, galena and sphalerite), and quartz-galena veins (generally free of silver).

The uppermost zones of several veins, especially in the San Miguel group, contain silver halides and secondary silver. Beneath this zone is the heaviest concentration of argentite, proustite and pyrargyrite, accompanied by a little galena and sphalerite (Gonzalez-Reyna, 1947). Wisser (1966) suggests that this is not a secondary enrichment zone but a primary deposition, the mineralogy of which is simply a function of depth below the surface at the time of emplacement. In any case, below this is the zone of native silver, in which the mines of the district operated for the most part. Dahlgren (1883) reported that it was not unusual to find wire silver encrusted with proustite and pyrargyrite at the border between the native silver and the sulfide zones.

A well-developed pattern of mineralogical zoning in the district has been found by Wilkerson to be concentric around the Las Tahonas copper porphyry. A barren halo surrounds the intrusion; around that is the major native silver zone, and near the outer extremities of the silver zone sulfides such as galena and sphalerite are more abundant. Finally, at greatest distance from the intrusion, only galena, sphalerite and quartz are found, without any silver. The overall pattern of mineralized fault-vein orientations is radially concentric (like the spokes of a wheel) around this same intrusion, strongly suggesting a genetic relationship.

Figure 16. **Arborescent argentite (acanthite), mostly showing molds of scalenohedral calcite crystals but in places showing its own morphology. The argentite is on proustite crystals measuring up to 1 cm, some with skeletal terminations indicating partial resorbtion. This specimen was originally almost completely enclosed in calcite; the calcite was removed (with permission) as part of the current study. Height, 10 cm; Smithsonian collection.**

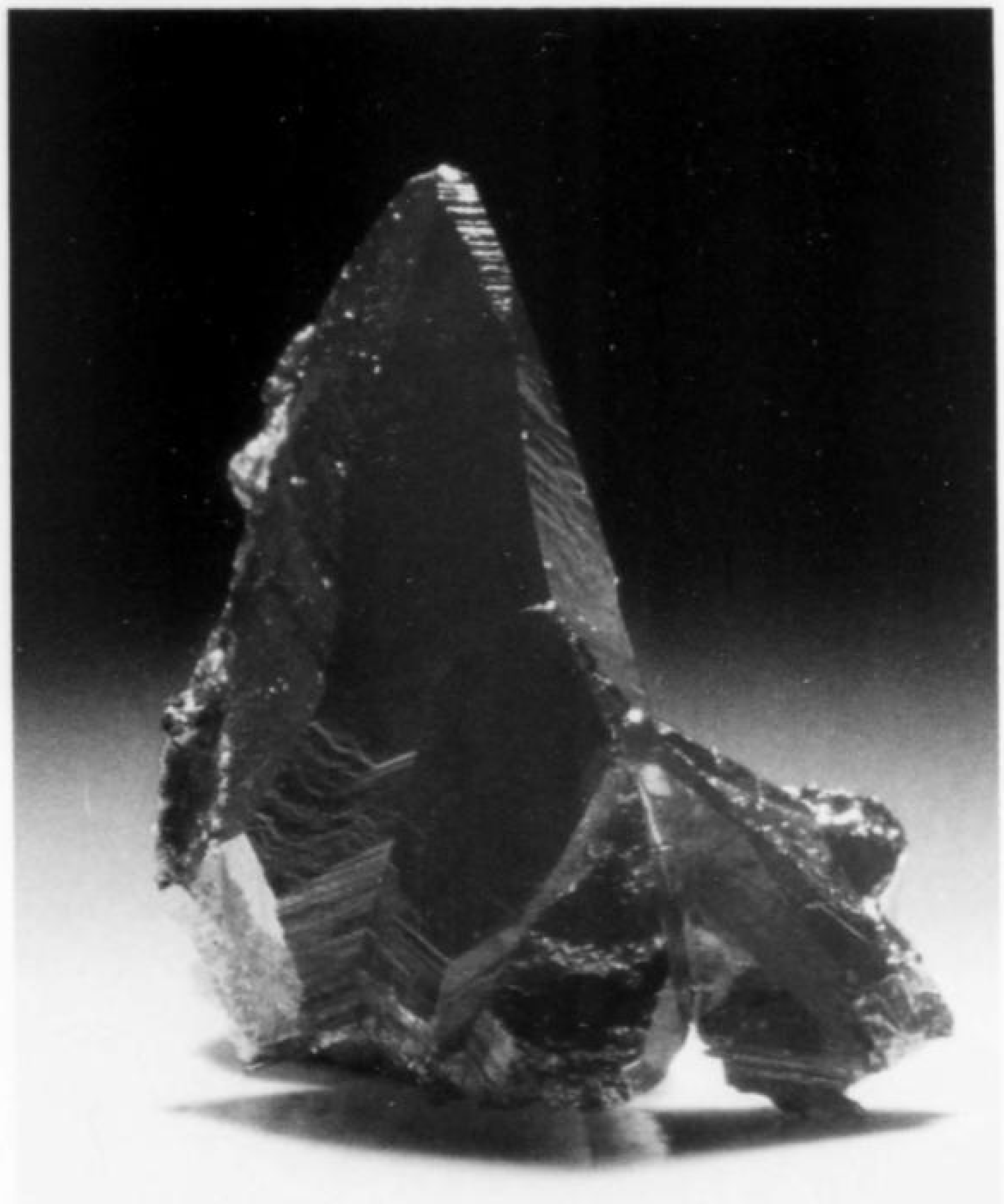


Figure 17. **Superb single crystals of proustite, 3 mm tall. Smithsonian collection.**

THE MINES

Well over 300 mines, claims, veins and workings have been operated in the Batopilas district during the 354 years since silver was first found there. Some of these mines are now lost. Others have changed names or merged with neighboring mines, and some are still intact and distinct. Many have no direct contact with the surface and are reached only through other mines and tunnels.

Mines in the district have been grouped into five categories based largely on location, structure and interconnections: (1) the San Miguel group, (2) the Todos Santos–Roncesvalles group, (3) the Caballo-Camuchin group, (4) the Descubridora–El Triumfo group, and (5) the quartz galena veins (which contain no silver but were mined for flux). The following information on the mines, except as noted, is from Wilkerson's thesis. The intrepid Wilkerson personally mapped over 20 km (12 miles) of abandoned underground workings using a Brunton compass and tape measure. He also managed to salvage rare maps made by the old Batopilas Mining Company. His unpublished set of maps (a few of which are reproduced here) is an invaluable documentation of the patterns of mining and mineralization.

Todos Santos–Roncesvalles group

Most of the mines in this group exploit portions of the Todos Santos calcite-silver vein and the Roncesvalles chlorite-actinolite-

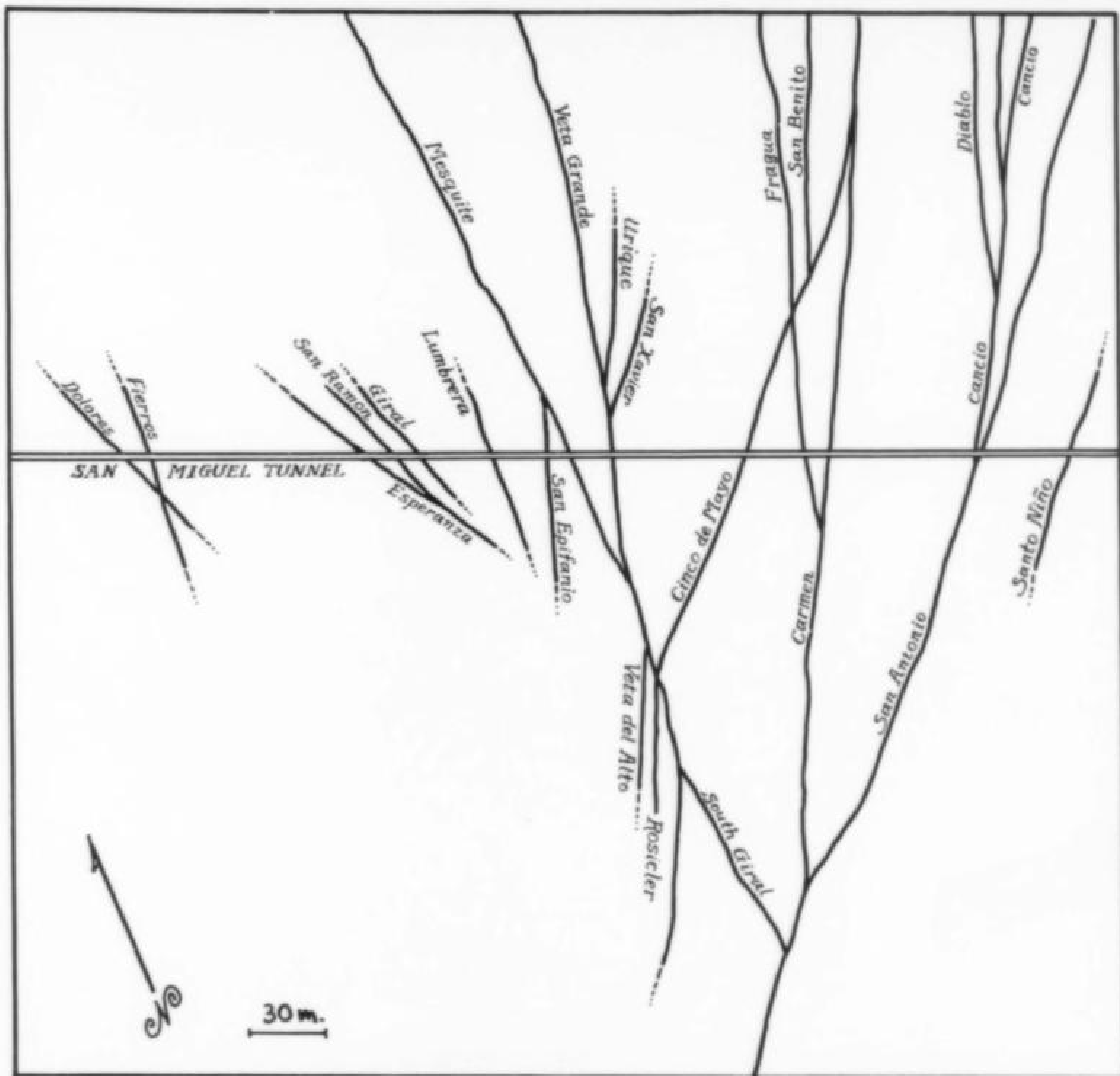
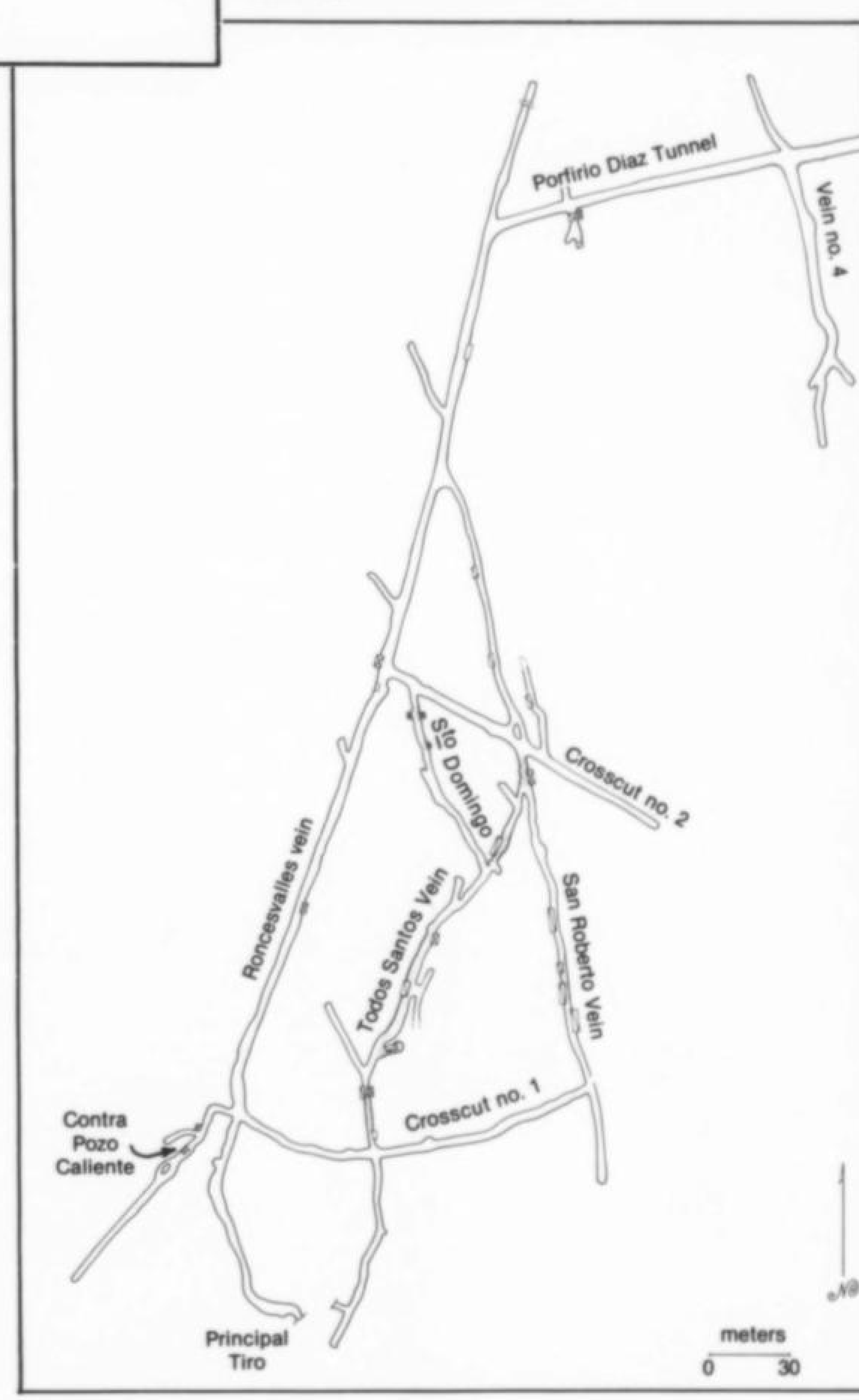


Figure 18. **Horizontal plan showing confluence of the veins in the San Miguel group (Brodie, 1909b).**

Figure 19. **Horizontal plan of the Todos Santos-Roncesvalles group at the level of the Porfirio Diaz tunnel (Wilkerson, 1983). Silver orebodies shaded.**



clay vein. They are located on Cerro Todos Santos, Cerro Pastrana and Cerro de las Animas in the central part of the district (*cerro* = hill). In 1885 the Porfirio Diaz tunnel was driven from near the river level to intersect these veins and facilitate ore haulage. A number of relatively unproductive veins and claims were crossed on the course of the tunnel.

The two major veins have historically been among the most productive in the district, and yet have practically no significant surface expression. All of the Todos Santos vein and some of the Roncesvalles vein are accessible above tunnel level. Many of their complex workings eventually become interconnected because the two veins intersect (the Todos Santos vein probably being a tension gash related to fault movement along the Roncesvalles vein). The old and famous Pastrana mine is among the upper workings.

Orebodies in the Todos Santos vein consist of pod-like masses of native silver encased in calcite up to 3 meters thick and several times that in length. In 1901, for example, such a pocket was encountered at a depth of 550 meters below the surface; it measured 1 x 22 x 46 meters and yielded 2 million ounces of silver (Shepherd, 1935).

The Porfirio Diaz tunnel and most of the Todos Santos workings are controlled today by *Impulsoria de Pequeña Mineria,* headed by Salvador Perea of Chihuahua City.

The Roncesvalles vein is quite different in character, being a breccia vein of the chlorite-actinolite-clay type. It did contain sizeable pods or bonanzas of silver associated with variable amounts of galena, sphalerite, limonite, gypsum and zeolites (including heulandite). The upper levels of the vein were the richest, although bonanza pockets were discovered even in the lowest levels. One particular stope known as Pozo Grande caved in 1970 killing eight men.

A small stoped area just west of the Roncesvalles vein is called the Contra Pozo Caliente ("Hot Raise"); temperatures in that area are uncomfortably hot. In 1975 this stope yielded some large blocks of native silver, contradicting the long-held opinion among miners

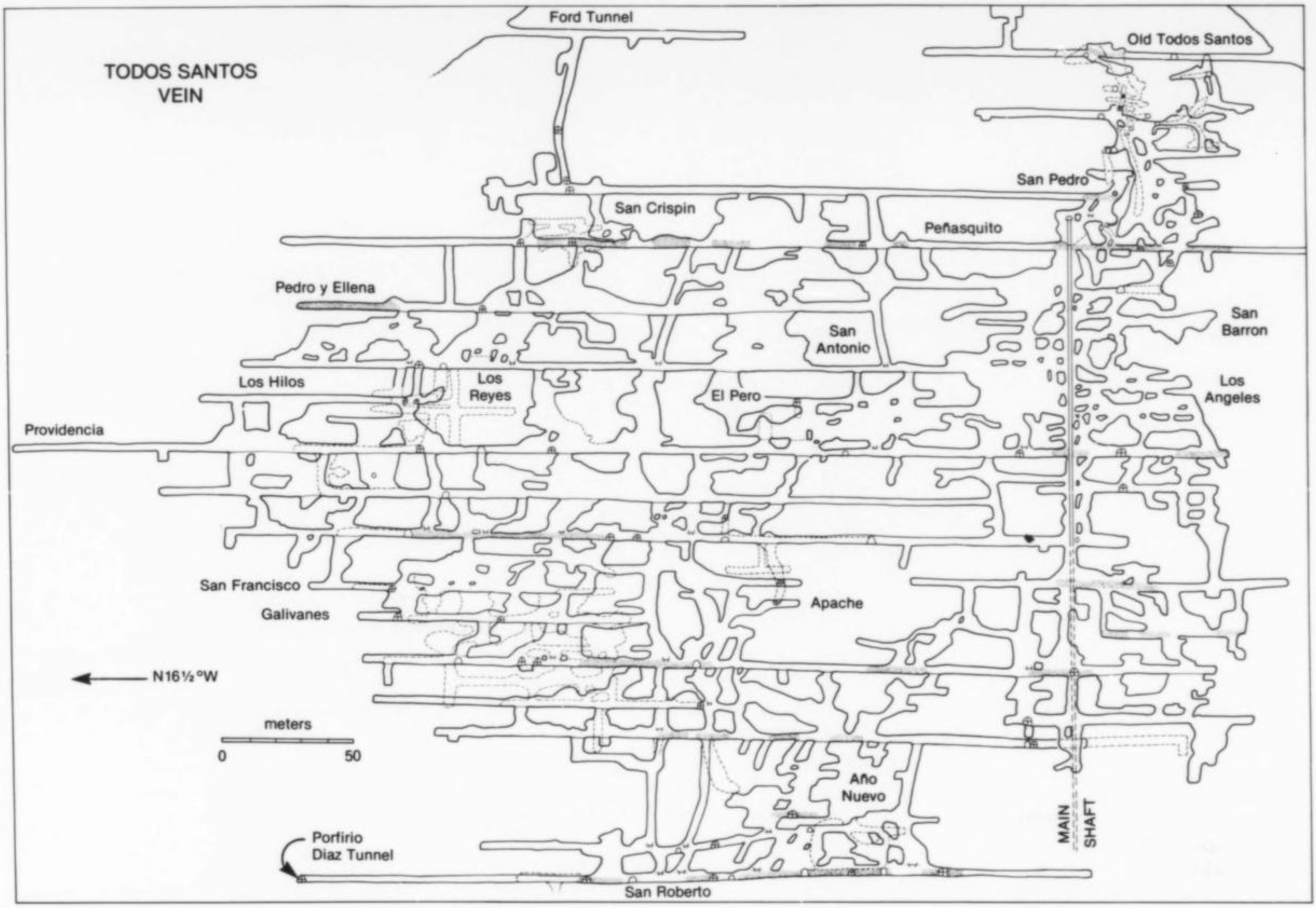


Figure 20. **Vertical projection of workings on the Todos Santos vein (Wilkerson, 1983) after a Batopilas Mining Company map ca. 1906. Native silver pods or bonanzas are shaded, though they are probably larger and more numerous than shown. Workings on other major veins such as the Roncesvalles, Carmen, San Antonio, etc., are equally extensive.**

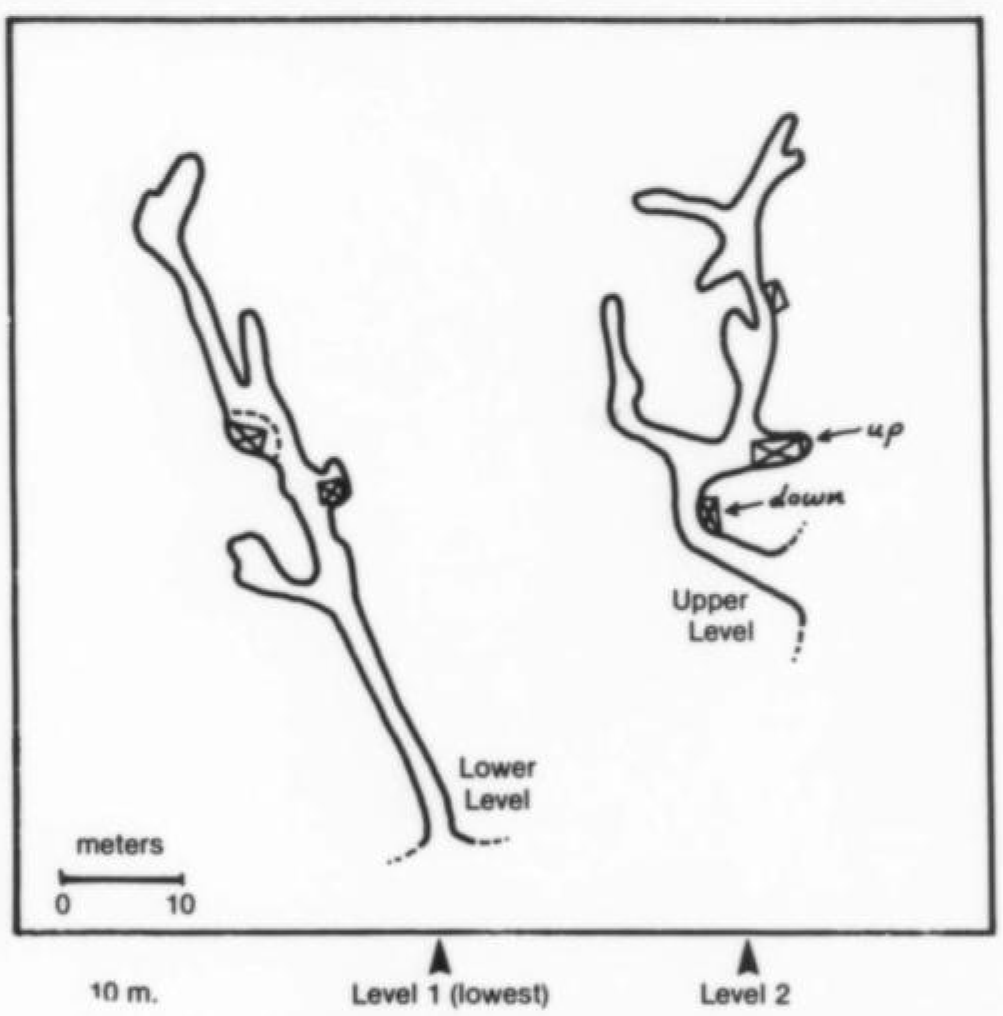


Figure 21. **Workings of the New Nevada or Nevada Valenciana mine from which many specimens have reached the market (Wilkerson, 1983).**

that only barren ground lies west of the Roncesvalles vein (P. Goodell, personal communication).

In Arroyo Dolores, near the town of Batopilas, is the Concepcion mine. These workings were formerly inaccessible but were reopened in 1982 by Manuel Limones for additional exploratory tunneling (results unknown).

The name of the Las Animas mine, among the oldest workings in the district, means "spirits of the dead," a reference to an incident prior to 1740 in which 25 miners died there in a cave-in. The Las Animas mine probably lies on the northeast extension of the Roncesvalles vein, though over 2 km of unexplored and potentially rich ground lie between the Las Animas and Todos Santos–Roncesvalles workings (P. Goodell observation reported by Wilkerson). An unfinished service tunnel aimed at the Las Animas cut a 5-cm pyrite vein, the largest in the district, as well as vugs with scalenohedral calcite crystals.

San Miguel group

The San Miguel group and the Todos Santos–Roncesvalles group are the most important in the district, and are separated by the Batopilas River. The San Miguel group mines and and veins are on the east side, and most of them connect with the San Miguel tunnel. The Veta Grande vein, cut by the tunnel, was worked to a depth of 300 meters below tunnel level in the 1890s (Brodie, 1909b), where good native silver and much arsenopyrite were encountered. The San Antonio and Carmen veins were early producers worked from the surface long before the San Miguel tunnel connected them. In 1905 a lode in the San Antonio vein was removed which measured 1

Figure 22. **A large group of argentite (acanthite) crystals 8 cm long, from the Santo Domingo mine. E. Schlepp specimen.**

x 8 x 12 meters and yielded 2 million ounces of silver; this is more than six times the amount of silver shown in Figure 7 (Shepherd, 1935). The Mesquite vein was reportedly worked to a depth of 460 meters below tunnel level and 400 meters along strike, as well as some significant distance above the tunnel level (Tod, 1907). Workings (currently inaccessible) connect with the Santo Domingo and Nevada Grande mines.

A vein in the Santo Domingo mine appears to have contained the largest single silver pocket in the district, 100 meters long and up to 3 meters wide. Open vugs with scalenohedral calcite crystals are far more common in the San Miguel and Santo Domingo workings than in the Todos Santos–Roncesvalles veins. Sphalerite and galena are also much more common east of the river, and large quantities of arsenopyrite were found in the Nuevo Giral vein.

The original Nevada mine, the discovery point in the district, is apparently buried and cannot be precisely located, but it was probably near the current Nevada Grande mine. Higher up on the hill a short distance is the Nevada Valenciana, formerly known as the New Nevada while specimens were reaching the market (Wilson, 1976, 1981). The Nevada Valenciana is worked for specimens by a consortium of local miners. Each co-owner has a certain day of the week assigned to him. On his work day he directs the excavations, pays the miners, and keeps all of what he discovers . . . there is no split with the other co-owners (Wilkerson, 1983). The mine is small, having been discovered by Manuel Limones in the early 1970s, and has yielded three modest pockets of silver (200 to 450 kg) as well as a large number of small concentrations and silver-bearing vein stringers. Spikey silver crystals and herringbone growths in calcite, some with minor argentite, sphalerite and arsenopyrite, are characteristic of the New Nevada mine (John Whitmire, pers. comm.).

Caballo-Camuchin group

Deposits in the Caballo-Camuchin group, located west of the Todos Santos–Roncesvalles group around Arroyo Caballo and Arroyo Camuchin, are mineralogically and structurally somewhat different. Argillic and chloritic alteration is common around the native silver-calcite pods and limonite is locally abundant.

The Caballo mine was being operated as recently as 1980 by the claimholder, Jose Barfuson. Wilkerson was shown a large specimen of wire silver in calcite (about 50% silver) measuring 30 x 45 x 60 cm (2 feet!); it had been taken from the Caballo mine.

A short distance away at the Marquesa mine is, according to local miners, a large vein of sphalerite.

Descubridora–El Triumfo group

These mines in the westernmost portion of the district have not been extensively developed, although the Descubridora dates back at least to 1814 and was worked by Alexander Shepherd. The remoteness of these deposits from processing facilities in Batopilas has probably hindered their development.

The El Triumfo deposit is unique in the district in that it contains malachite and azurite.

Quartz-galena mines

Five mines scattered about the district contain no silver but do carry significant galena and quartz. These are the Tepeguahe and San Jose mines in the southeast, the La Mexicana mine to the north, the Polvarine mine in the barren area between the Caballo-Camuchin and Todos Santos–Roncesvalles groups, and the San Agustin mine south of the Caballo-Camuchin group. The Tepeguahe mines in particular are said to have yielded prodigious amounts of galena. The general rule at Batopilas seems to be that quartz gangue is associated with high lead and low silver content in veins, whereas calcite gangue shows the opposite relation (Brodie, 1909b).

MINE MAPS AND CATALOG

The mine map shown here is a compilation of information from various sources, primarily Wilkerson (1983) and an unpublished claim map of the Batopilas Mining Company drawn around 1912. Other veins and workings are shown on the Porfirio Diaz tunnel map of Brodie (1909b), the San Miguel group vein map of Brodie (1909b) and various maps of underground workings in Wilkerson (1983).

The catalog of names of mines, veins, claims and workings (Table 1) was compiled from a wider range of sources (see footnote) and with a greater degree of difficulty. Most existing records are incomplete and difficult to interpret. One important source used is Pareja (1883), a privately printed and very rare Mexican publication which includes many claim registrations and abandonment filings from 1738 to 1861. Unfortunately, the study of these is complicated by several factors, including the tendency of claimholders to use the same mine name for different mines. There are, for example, at least four Carmen mines, five Dolores mines, six Guadalupe mines, and no less than seven different San Jose mines. Furthermore, the brief statements regarding location are often cryptic, referring to topographic features not named on any map, and utilizing names for hills and arroyos which have changed several times over the centuries. Another common practice was to say, for example, "near the mine of Don Isidro Mendia" . . . who may have owned many mines, or who perhaps can be found to have owned none! And finally, there appears to be purposeful obfuscation on the part of some claimholders wishing the locations to remain secret, like Juan Francisco Bracamontes who, in 1780, filed a claim and listed the location as "on a reef with sun and air."

Figure 23. **Silver from a pocket in the San Antonio mine, ca. 1909 (Brodie, 1910). No scale is furnished, but the silver sheet at the bottom probably measures 40 to 50 cm (16 to 20 inches).**

Figure 24. **Herringbone silver crystal, 3 cm tall. E. Schlepp specimen.**

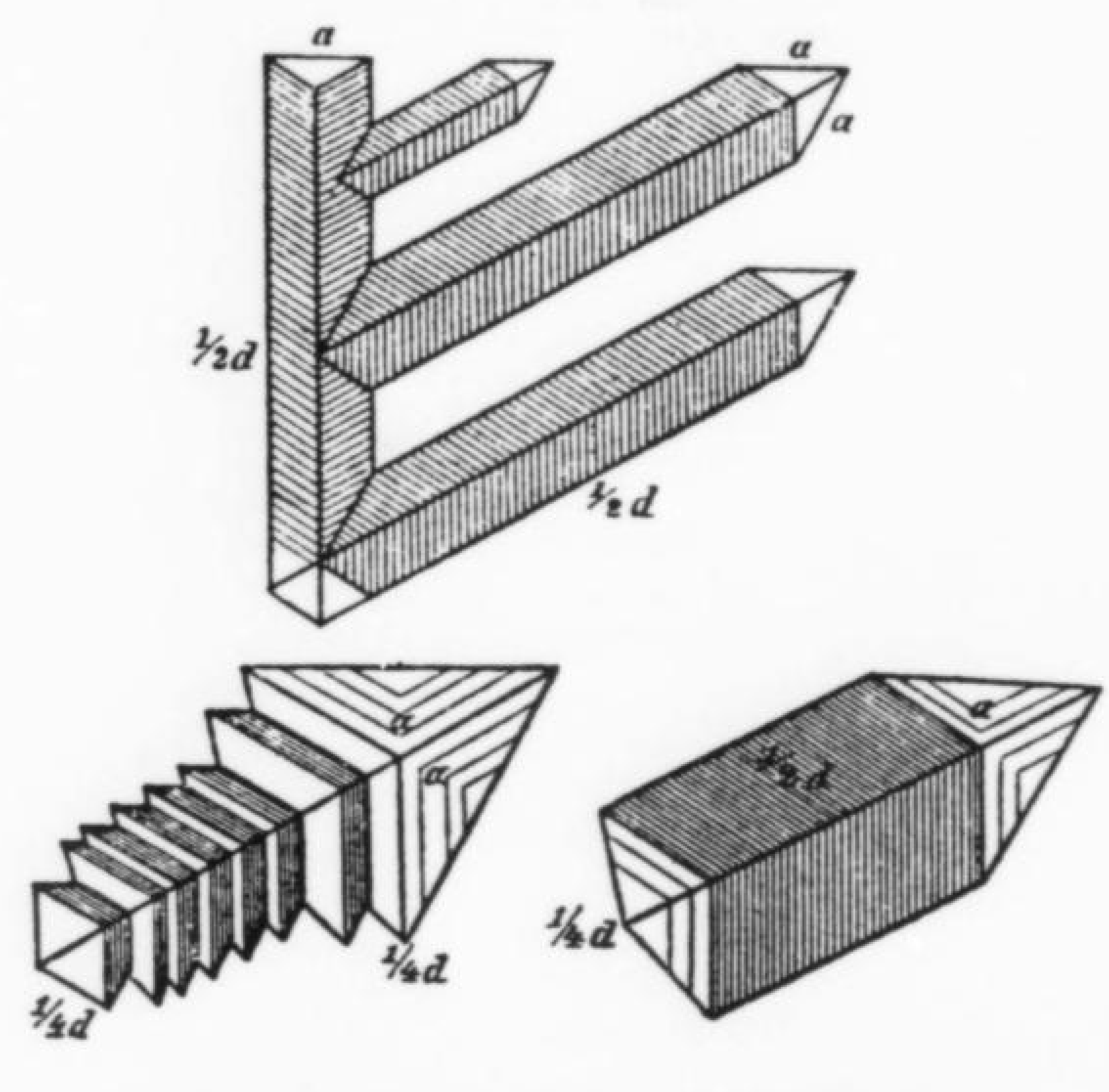


Figure 25. **Crystal drawings of Batopilas silver (Sadebeck, 1876).**

MINERALS

Silver Ag

Approximately 80–90% of the silver produced at Batopilas was mined as native metal, and only 10–20% as sulfides (Shepherd, 1935; Shepherd, 1938). Crystals, wires (some coiled like a watch spring), ferns, plates, balls and masses of great size were encountered. The crystals tend to be elongated spears which, in many cases, occur as herringbone growths. Wire silver in heavy masses was less common, and fine hair-like aggregates were reported often. Large crystalline leaves, plates and masses of irregular shape were also common in the pockets; all habits usually occurred imbedded in milky white to colorless, transparent calcite. Specimens of wire and leaf silver are today very rare.

Although heavy wire silver was found which closely resembles material from Kongsberg, Norway, the most distinctive habit at Batopilas is the herringbone growth of narrow, spike-shaped crystals. This habit is quite rare at Kongsberg; on the other hand, blocky, equant crystals of fair size commonly found at Kongsberg are virtually unknown at Batopilas.

A sizeable quantity of silver specimens reached the market in 1976, and again in 1981 (Wilson, 1976, 1981). These were obtained at the New Nevada (Nevada Valenciana) mine by mineral dealer John Whitmire. The 1976 pocket consisted of about 450 kg (1000 pounds) of silver-impregnated calcite. A third of the pocket had gone to the crusher but Whitmire succeeded in buying the rest from the miners, and he subsequently treated the material with acid to free the silver for specimens. His 1981 lot was at least as large. Other specimen producers include the Santo Domingo, San Miguel, Caballo, San Antonio and La Chiripa mines. The La Chiripa has produced only one pocket, about 80 kg.

Acanthite Ag_2S (pseudomorphous after argentite)

Acanthite (usually referred to as argentite) is relatively common as vein fillings and as cubes, octahedrons and cuboctahedrons typically only a few millimeters in size but rarely reaching 1 cm or more. The argentite was one of the last minerals to form, some-

Table 1. **Catalog of mines, veins, claims and workings in the Batopilas District.**

Name	*Age*[1]	*Location*[2]	*Ref.*[3]
Abundancia	(1907)	?	12
Alarcan (Alicran)	(1883)	TR-can	10,11
Albitria	(1760)	SM-ctj	9
America	(1907)	?	12
America del Sur	(1907)	?	12
Los Angeles	(1743)	TR-can	9,12,14
Animas (San Antonito	(1742)	TR-can	1,2,4,8,9,10,14
Animas Chica	(1852)	TR-can	12
Animas Tunnel	(1883)	TR-can	10,14
Ano Nuevo	(1906)	TR-cts	14
Apache	(1906)	TR-cts	14
Arbitrios	(1883)	TR-cpa	1,2,4,9,10
La Aurora	(1840s)	TR-can	1,2,4,7,10
Aurora Tunnel	(1885)	TR-can	14
Balbanera	(1770)	TR-can	9
Ballinas (Viejo)	(1912)	TR-can	7,8
Ballinas Sur	(1912)	TR-cts	7,8
Baltazar	(1912)	TR-can	7,8
La Barcha	(1743)	?	9
Batopilas Tunnel	(1883)	TR-can	10
Buena Esperanza	(1909)	TR-cts	7,14
Buenavista	(?)	TR-can	11
Buenos Aires	(1909)	TR-cts	7,14
Burma	(1909)	CC-cpu	7,14
El Caballo	(1742)	CC-cpu	7,8,11,14
El Camuchin	(1816)	CC-cpu	1,2,3,4,7,8,9,14
Camuchin del Sur	(1912)	CC-ctc	8
Cancio	(1909)	SM-csa	7
Candelaria	(1741)	TR-can	9
Carbonera	(1883)	TR-can	10
Carmen	(1744)	SM-csa	1,2,4,9,14
Carmen (II)	(1778)	TR-cpa	9
Carmen (III)	(1816)	CC-ctc	9
Carmen (IV)	(1846)	TR-cts	9
Carmen Chiquito	(1883)	SM-csa	7,10
Carolina	(1883)	TR-can	10,11
Cata	(1815)	TR-cpa	5,9,10
Charles Hector	(1968)	TR-cpa	14
La Chiripa	(1970s)	TR-near Batopilas	15
Cinco de Mayo (Estrella)	(1912)	TR-cpa	7,8,14
Cinco de Mayo (II)	(1883)	SM-csa	7,10
Cinco Senores	(1745)	?	9
La Cobriza	(1912)	TR-can	7,8
La Concepcion	(1740)	SM-csa	9
La Concepcion (II)	(1744)	TR-can	9
Consolacion	(1742)	SM-csa	8,9
Consolacion (II)	(1912)	TR-cts	7,8
Contra Obra	(1906)	TR-cts	14
Contra Pozo Caliente	(1909)	TR-cts	14
Coria	(1742)	TR-can (?)	9
Corpus Cristi	(1742)	?	9
Cortes	(1883)	TR-cts	10
La Cosinera	(1763)	SM-csa	8,9
Crucero (10 de Enero)	(?)	TR-cts	14
Las Cruces	(1912)	TR-cts	8
Las Cruzades	(1907)	?	12
Cuatro de Julio	(1907)	?	1,2,4
La Cuchilla	(1923)	?	3
Demacias	(1907)	?	12
Demacias Nopal	(1907)	?	12
Descubridora	(1814)	DT	1,2,3,4,8,9,10,14
Diablo	(1909)	SM-csa	7,14
Dios te Guie	(1883)	TR-cts	10
La Divina Pastora	(1781)	TR-can	9
Dolores	(1883)	TR-cts	7,8,9,14
Dolores (II)	(1741)	SM-csa	7,9,14
Dolores (III)	(1742)	TR-can	9
Dolores (IV)	(1744)	TR-cpa	9
Dolores (V)	(1814)	CC-cpu	9
La Dura	(1909)	TR-can	7
Echevarria	(1814)	?	9
Entre Puntas	(1809)	TR-cts	7,14
Escondida	(?)	DT	14
El Escritorio	(1770)	TR-cts	8,9
La Esmeralda	(1912)	TR-can	8
Esperanza	(1889)	DT	14
Espiritu Santo (II)	(1763)	SM-csa	9
Estaca de Judio	(1907)	?	12
Excavation no. 2	(?)	TR-cts	14
Excavation no. 3	(?)	TR-cpa	14
Excavation no. 4	(?)	TR-cpa	14
Excavation no. 5	(?)	TR-cpa	14
Excavation no. 7	(?)	TR-cpa	14
Excavation no. 9	(?)	SM-ctj	14
Excavation no. 10	(?)	SM-ctj	14
Excavation no. 11	(?)	SM-ctj	14
Fenix	(1907)	?	12
Los Fierros	(1796)	SM-csa	7,9,10,14
Ford Tunnel	(1906)	TR-cts	14
Fragua	(1883)	SM-csa	7,10,14
Galeana	(1907)	?	12
Gamuchino	(?)	?	1
Garfield	(1909)	TR-cpa	7
Gavilanes	(1906)	TR-cts	7,14
General Tunnel	(1883)	SM-csa	10
George Washington Tunnel	(1909)	CC-?	7
Giral	(1907)	SM-csa	1,2,3,4,7,14
Golodrinas	(1906)	TR-cts	14
Gortari	(1741)	?	9
Guadalupe	(1740)	TR-cts	9
Guadalupe (II)	(1740)	TR-cts	9
Guadalupe (III)	(1743)	SM-csa	9
Guadalupe (IV)	(1770)	TR-can	9
Guadalupe (V)	(1801)	SM-ctj	9
Guadalupe (VI)	(1817)	DT	9
Guamuchle	(1909)	TR-can	7
Guatimoc	(1909)	TR-cts	7
Hermosa	(1883)	TR-can	10,11
Hidalgo	(1912)	CC-cpu	8
Los Hilos	(1906)	TR-cts	14
Howha	(?)	SM-ctj	14
Humberto I	(1907)	?	12
Independencia	(1883)	SM-csa	10
Jesus Maria	(1776)	SM-ctj	9
Jesus Maria (II)	(1782)	TR-cpa	9
Juana de Areo	(?)	?	13
Juan Aguirre	(1909)	TR-can	7
Juarez	(1909)	TR-cpa	7
La Junta	(1906)	TR-cts	14
La Ladrillera	(?)	CC-cpu	14
Loreto	(1742)	TR-can	9
Loreto (II)	(1779)	CC-cpu	9
Lumbrera	(1883)	SM-csa	7,10
La Luz	(1755)	TR-can	9
La Luz (II)	(1759)	TR-cts	9
La Luz (II)	(1767)	SM-csa	9
Mala-noche	(?)	TR-can	11
La Marqueza	(?)	CC-cpu	14
Martinez	(1830)	TR-can	5,7,9,10,11
Mendocena	(1907)	SM-csa	12
Mesquite	(1883)	SM-csa	1,2,4,7,10,14
Mesquite	(?)	DT	14
La Mexicana	(1909)	TR-cts	7,14
Miramonte	(1907)	?	12
Moctezuma (San Ygnacio)	(1883)	TR-cts	10
La Moghomera	(1912)	CC-cpu	8
Monserrate	(1814)	SM-ctj	9
Moreno	(1909)	?	7
Nevada	(1632)	SM-csa	2,8
Nevada Grande Tunnel	(1907)	SM-csa	12,14
Nevada Valenciana (New Nevada)	(1970s)	SM-csa	6,14
Nuestra Senora	(1742)	TR-can	10
Nuestra Senora de las Angustias	(1814)	TR-can	9
Nuestra Senora de la Barcha	(1742)	CC-cpu	9
Nuestra Senora de la Estrella	(1767)	TR-can	9
Nuestra Senora de la Guia	(1814)	TR-cts	9
Nuestra Senora del Pilar	(1740s)	?	1,2
Nuestra Senora de Regla	(1754)	TR-cpa	9
Nuestra Senora del Rayo	(1776)	SM-csa	9
Nuestra Senora de la Salud	(1741)	SM-csa	9
Nueva Pertenencia	(1883)	CC-cpu	10
Nuevo Giral	(1909)	SM-csa	2,7
Nuevo Mundo	(1906)	TR-cts	8
Nunez	(1742)	SM-csa	9
Obra Crump	(1912)	TR-cpa	8
Orichic	(1907)	?	12
Pacheco	(1909)	TR-cpa	7
Palestina	(1909)	TR-can	7
Palo Blanco	(1907)	TR-can	7,12
Panadero	(1739)	TR-can	9
La Parrena	(1741)	TR-can	9
Pastrana	(1730)	TR-cpa	3,11,14
La Paz	(1763)	?	9
Pedmesa	(1907)	?	12
Pedro Y Ellena	(?)	TR-cts	14
Penasquito	(1830s)	TR-cts	2,7,10,14
El Penasco	(1741)	TR-cts	8
Penasco Grande	(1883)	TR-cts	10
Pineda	(1883)	TR-cpa	10,11
Piramide	(1907)	?	12
Pitaya	(?)	TR-can	11
Plaza Gallos	(1909)	SM-csa	7,14
Polvarine	(?)	TR-cts	14
Poniente	(1771)	SM-csa	9
Porfirio Diaz Tunnel	(1885)	TR-can	8,14
Portal	(?)	TR-can	11
Porvenir	(1907)	?	12
Potosi	(1909)	TR-can	7
Pozo Grande	(1909)	TR-cts	14
Primavera	(1907)	?	3,12
Providencia	(1906)	TR-cts	7,14
La Purisima	(1807)	CC-ctc	9
Quien Sabe	(1883)	SM-csa	7,10,11
Rata	(1883)	SM-csa	10
Recompensa	(1907)	?	12
El Refugio	(1808)	TR-can	9
El Refugio (II)	(1814)	SM-ctj (?)	9
Los Remedios	(1912)	CC-cpu	8
Los Reyes	(1745)	TR-can	9
Roncesvalles	(1759)	TR-cts	2,3,4,7,8,9,10,14
Rosa Linda	(?)	CC-ctc	14
El Rosario	(1912)	DT	8
El Rosario (II)	(1743)	TR-cpa	9
El Rosario (III)	(1782)	TR-cts	9
El Rosario (IV)	(1743)	TR-can	9
Rosicler	(1909)	SM-csa	7
El Sacramento	(1740)	SM-csa	1,2,9
El Sacramento (II)	(1912)	CC-cpu	8
Salamanquesa	(1909)	TR-can	7
San Agustin (Palo Verde)	(1815)	CC-ctc	3,8,14
San Alejandro	(1743)	SM-csa	9
San Andres	(1760)	?	9
San Angel	(1912)	CC-cpu	8
San Antonio	(1740)	TR-can	9
San Antonio (II)	(1742)	TR-cts	9
San Antonio (III)	(1743)	SM-csa	7,9,14
San Antonio (IV)	(1809)	CC-ctc	7,9,14
San Antonio Chiquito	(1883)	TR-can	10
San Barron	(1906)	TR-cts	14
San Benito	(1909)	SM-csa	7
San Carlos	(1909)	TR-cpa	7
Sanchez	(1883)	TR-cts	10,11
San Crispin	(1906)	TR-cts	14
San Cristobal	(1767)	TR-cpa (?)	9
San Epifanio	(1907)	SM-csa	7,12
San Estevan	(1746)	SM-csa	9
San Federico	(1909)	TR-cts	7
San Felipe	(?)	?	12
San Felix	(?)	?	2
San Francisco	(1740)	SM-csa	9
San Francisco (II)	(1906)	TR-cts	14
San Gabriel	(1907)	?	12
San Gonzalo	(?)	TR-can	11
Sangre de Cristo	(1856)	TR-can	9
San Guillermo	(1883)	TR-cts	10
San Ignacio	(1909)	TR-cts	7
San Ignacio Chiquito	(1909)	TR-cts	7
San Jorge	(1883)	TR-cts	8,10
San Jose	(1738)	TR-can	7,9

Name	*Age*[1]	*Location*[2]	*Ref.*[3]
San Jose (II)	(1741)	TR-cts	9
San Jose (III)	(1742)	SM-csa	9
San Jose (IV)	(1775)	SM-ctj	9
San Jose (V)	(1784)	CC-cpu	9
San Jose (VI)	(1809)	TR-cts	9
San Jose (VII)	(1810)	CC-ctc	9
San Juan Bautista	(1817)	DT	9
San Juana de Arco	(1907)	?	12
San Juan Nepomucena	(1775)	CC-cpu	8,9
San Juan Nepomuceno (II)	(1809)	SM-csa	9
San Luis	(1817)	TR-cpa	7,9
San Martin	(1883)	TR-can	7,8,10
San Miguel	(1746)	SM-csa	1,2,3,4,8,9,14
San Miguel (II)	(1756)	TR-cpa	7,9
San Miguel (III)	(1814)	CC-cpu	9
San Miguelito	(1907)	TR-can	7,10
San Miguel Tunnel	(1852)	SM-csa	1,2,3,4,8,9,10,14
San Nestor	(1842)	SM-ctj	2,3,9,14
San Nestor (II)	(1883)	TR-can	10
San Nicolas	(1749k)	SM-csa	9
San Pedro	(1742)	SM-csa	9
San Pedro (II)	(1793)	TR-can	9
San Pedro (III)	(1883)	TR-can	8,9
San Pedro (IV)	(1809)	CC-cpu	9
San Rafael	(1746)	SM-csa	9
San Ramon	(1906)	TR-cts	14
San Ramon (II)	(1909)	SM-csa	7
San Ricarrdo	(1909)	SM-csa	7
San Roberto	(?)	TR-cts	7,14
San Rombre	(1909)	SM-csa	14
Santa Aurelia	(1923)	?	3
Santa Barbara	(1741)	SM-csa	9
Santa Barbara (II)	(1743)	TR-cpa	9
Santa Cecilia	(?)	TR-can	11,12
Santa Eduwigis	(1814)	TR-can	7,9
Santa Gertrudis	(1743)	TR-can	9
Santa Isabel	(1744)	SM-ctj (?)	9
Santa Juliana	(1816)	TR-cpa	7,9
Santa Lucina	(1907)	?	12
Santa Maria	(1883)	TR-can	3,7,8,10
Santa Maria de Gracia	(1742)	SM-csa	9
Santa Martina	(1883)	TR-can	3,9
Santa Nina	(1883)	SM-csa	10,14
Santa Rita	(1762)	TR-can	9
Santa Rosa	(1923)	?	3
Santa Teresa	(1769)	TR-can	7,9,10
Santiago	(1801)	CC-cpu (?)	9
El Santo Apostal	(1784)	TR-cpa	9
Santo Domingo	(1742)	SM-csa	1,8,9
Santo Domingo (II)	(1883)	TR-cpa	7,10
Santo Exehomo	(1745)	SM-csa	9
Santo Nino	(1743)	TR-can	3,9
Santo Nino (II)	(1861)	SM-csa	3,7,9
Santo Tomas	(1741)	TR-can	7,9
Santo Tomas (II)	(1883)	TR-cpa	7,10
San Vincente	(1764)	SM-csa	7,9
San Xavier	(1909)	SM-csa	7
Satevo	(1765)	?	9
Serastegui	(1743)	TR-cpa	9
Sesmas	(1909)	CC-cpu (?)	7
Sin Nombre (no name)	(1764)	?	9
Sin Nombre (no name)	(1808)	TR-can	9
Sin Nombre (no name)	(1800)	CC-ctc	9
Smoke	(?)	SM-csa	14
El Socorro	(1764)	TR-cpa	9
El Socorro (II)	(1809)	TR-can	9
La Soledad	(1739)	TR-can	9
La Soledad (II)	(1742)	SM-csa	9
La Soledad (III)	(1742)	TR-cts	9
Los Tajos	(1824)	SM-ctj	1,3,10,14
Tepeguahe	(?)	SM-ctj	14
La Tescalama	(1883)	CC-cpu	8,10,14
Three Holy Kings	(1910)	?	5
Tierra Blanca	(?)	?	1
Tiro Porfirio Diaz	(1910)	TR-cts	14
Tiro Principal	(?)	TR-cts	14
Todos Santos	(1840s)	TR-cts	1,2,3,4,7,8,10,14
El Toro	(1910)	TR-cts	14
Tres Hermanos	(1907)	?	12
La Trinidad	(1759)	TR-can	9
La Trinidad (II)	(1759)	SM-csa	9
El Triumfo	(?)	DT	14
La Union (Unidos?)	(1845?)	TR-cts	3,14
Urique	(1909)	SM-csa	7
Vaca (Vallines)	(1883)	TR-can	7,10,11
Vaca Chiquita	(?)	TR-can	11
Vaca Grande	(?)	TR-can	11
Valenzuela	(1883)	TR-can	2,8,10
Valenciana	(1907)	TR-cts	7,12
La Vereda Tunnel	(1907)	?	12
Vertical	(1909)	CC-cpu	7,14
Veta del Agua	(1883)	TR-can	10,11
Veta del Alto	(1909)	SM-csa	7
Veta del Bajo	(?)	?	7
Veta de la Entrada	(1909)	TR-cts	14
Veta Grande	(1860s)	SM-csa	1,2,4,7,10,14
Veta Negra	(1909)	TR-cts	7,14
Veta Nueva	(1909)	CC-cpu	7
La Victoria	(?)	DT	14
La Vivaca	(1907)	?	1,2,4

[1] Claims filed on these dates may not be the first for the mine but are the earliest known. Many claims were filed between 1740 and 1745; a large proportion of these are probably re-registrations of earlier claims following destruction of all mining records in the fire of 1740. The original claims on many of these probably date back to the 1600s.

[2] Wilkerson (1983) divides the mines into four groups based on geography and structure: the *Todos Santos–Roncesvalles group (TR),* which covers three hills or ridges, Cerro Todos Santos (cts), Cerro de Pastrana (cpa) and Cerro de las Animas (can); the *San Miguel group (SM),* which covers Cerro San Antonio (csa) and Cerro de los Tajos (ctj); the *Caballo-Camuchin group (CC),* occupying Cerro los Tachos (ctc) and Cerro de Pulpito (cpu); and the *Descubridora–El Triumfo group (DT)* located on Cerro Tahonitas.

[3] Compiled from: **1**. Johnson (1965); **2**. Gonzalez-Reyna (1947); **3**. Salinas (1923); **4**. Tod (1907); **5**. Brodie (1910); **6**. Wilson (1976, 1981); **7**. Brodie (1909a, b); **8**. Batopilas Mining Company claim map (ca. 1912), unpublished; **9**. Pareja (1883); **10**. Dahlgren (1883, 1887); **11**. Gonzalez-Reyna (1956); **12**. Griggs (1907); **13**. W. D. Panczner file data; **14**. Wilkerson (1983); **15**. John Whitmire, personal communication.

times preceding and sometimes following calcite.

A fine specimen of crystalline leaf silver in the Harvard collection (freed from enclosing calcite during the course of this study) shows triangular octahedral faces across the leaves, and epitaxially oriented acanthite pseudomorphs here and there. The acanthite crystals have triangular bases paralleling the silver faces, and come to a point, as if the corner of a cube were penetrating the sheet of silver.

Crystals of acanthite perched on herringbone silver are rather common from the New Nevada mine (Wilson, 1976). A group of large, distorted cubes, some up to 1.6 cm on edge, is labeled as having come from the Santo Domingo mine (Eugene Schlepp specimen).

Proustite Ag_3AsS_3

Proustite and pyrargyrite (Ag_3SbS_3) were encountered in the higher levels of some mines, especially east of the river, but none in recent times (i.e., at the New Nevada mine). Very few specimens were saved, most of them as gifts to museums by the mining company. Several proustite specimens labeled Batopilas are in the Smithsonian collection. One (#C-791) is a section of vein material about 8 cm thick; it consists of white calcite breccia fragments enclosing arborescent silver and cemented by black acanthite. An open fissure face on one side of the specimen is covered by transparent calcite crystals to 9 mm which are partially overlain by a druse of small (to 2 mm) proustite crystals and a small patch of xanthoconite crystals (X-ray identification by P. J. Dunn). The sequence of crystallization represented by this specimen is: silver, calcite-I, brecciation, argentite-I, fracturing, calcite-II, proustite and xanthoconite.

Another Smithsonian specimen examined (#C-5948) is a section of calcite-filled vein showing some broken surfaces of proustite and acanthite. After removal of the enclosing calcite a remarkable specimen emerged (Fig. 16). Proustite crystals to more than 1 cm are capped by growths of acanthite to several centimeteers. The proustite crystals show resorption and fracturing, although the smaller crystals are in better condition, particularly one superb 3-mm microcrystal (Fig. 17). The sequence appears to be: fracturing, argentite-I (massive, dull, poorly crystalline), proustite, partial resorption and fracturing of proustite, calcite-II (no enclosed silver; partially enclosed proustite), and argentite-II, followed upon cooling by inversion of the argentite to acanthite.

It is a great tragedy that so few proustite specimens from Batopilas have survived. The mineral was not at all rare in some mines, and the miners even had a name for proustite as ore: *cardenillas.* A vein in the San Miguel group (of which no descriptions have survived) was suggestively named the Rosicler* vein. Old mining men in Mexico remember seeing crystals of proustite to 2 cm. W. D. Pearce (*in* Griggs, 1907) wrote:

> A feature of the mines at Batopilas is the magnificent specimens of native and ruby silver produced . . . the specimens of ruby silver are among the finest found in any country.

Most crystals of proustite were probably covered by vein calcite which no one in those days would have bothered to remove. The specimens which were saved for a time on the desk or mantle or window sill of a mining engineer's office were, no doubt, the rare examples having unenclosed crystals. There is little question that uncounted thousands of superb museum-quality proustites went to the crusher or were saved for a time and discarded. Very close to nothing remains today as evidence of one of the world's greatest proustite occurrences.

Other Species

A Canfield specimen in the Smithsonian collection (#C-3417) still carries an old label glued to the back which reads "Wire Silver, Batopilas, Mexico." The unusual thing about this old piece is that the silver wires are imbedded in and protruding from well-formed, colorless, transparent to translucent crystals of harmotome and heulandite measuring up to 1 cm.

Small crystals of arsenopyrite to about 1 mm (X-ray identified, Pete J. Dunn, pers. comm.) occur on New Nevada mine silver specimens as groups and sprays.

Other species previously reported from Batopilas but not seen during the present study are listed on Table 2.

Table 2. **Minerals reported from the Batopilas district.**

Species	*Composition*	*Ref.**
Acanthite	Ag_2S	1,3,7,8
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	7
Arsenic	As	1,2,4
Arsenopyrite	$FeAsS$	1,2,3,8
Azurite	$Cu_3(CO_3)_2(OH)_2$	7
Barite	$BaSO_4$	3
Bromargyrite	$AgBr$	2
Calcite	$CaCO_3$	1,2,4,7
Chalcanthite	$CuSO_4\cdot 5H_2O$	4
Chlorargyrite	$AgCl$	3
Chlorite group		7
Clays, unidentified		7
Dolomite	$CaMg(CO_3)_2$	4
Dufrenoysite	$Pb_2As_2S_5$	5
Freieslebenite	$AgPbSbS_3$	5
Galena	PbS	1,2,3,4,7
Gypsum	$CaSO_4\cdot 2H_2O$	7
Harmotome	$(Ba,K)_{1-2}(Si,Al)_8O_{16}\cdot 6H_2O$	6
Heulandite	$(Na,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$	6
Iodargyrite	AgI	5
Litharge	PbO	4
Malachite	$Cu_2(CO_3)(OH)_2$	7
Massicot	PbO	4
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	1,3
Proustite	Ag_3AsS_3	1,2,3,4,6
Pyrargyrite	Ag_3SbS_3	1,2,3,4
Pyrite	FeS_2	1,2,3,4,7
Quartz	SiO_2	1,2,3,7
Rammelsbergite	$NiAs_2$	1,3
Safflorite	$CoAs_2$	1,3
Silver	Ag	1,2,3,5,6,7
Sphalerite	$(Zn,Fe)S$	1,2,3,4,7
Stephanite	Ag_5SbS_4	5
Xanthoconite	Ag_3AsS_3	8

*Compiled from: **1**. Johnson (1965); **2**. Gonzalez-Reyna (1947); **3**. Krieger (1935); **4**. Salinas (1923); **5**. Dahlgren (1883, 1887); **6**. Smithsonian specimen; **7**. Wilkerson (1983); **8**. X-ray identification by P. J. Dunn, pers. comm. (1985).

FUTURE POTENTIAL

There is no doubt that major pockets of silver remain to be found in the Batopilas area. Alexander Shepherd, Jr. (1935) writes in an unpublished report that over 100 veins and stringers were cut in the course of the Porfirio Diaz tunnel, but that these had never been explored because all manpower was directed to veins previously under exploitation. Approximately 20 major veins and stringers were worked from 1880 to 1910, and during that time more new veins were encountered than had been known at the start. Shepherd (1935) felt that more promising ground remained to be worked when operations ceased in 1910, than was known when his father's operation began in 1880; at least 40 major unworked veins remain. In addition, there was no discernible decrease in silver content with depth – major bonanzas were found even on the lowest levels – therefore, the lower limit of mineralization still remains to be discovered.

It must be remembered that at Batopilas veins are largely barren except where the major pockets occur, and the only way to find these is to mine along the veins. One apparently unpromising vein cut by the San Miguel tunnel was followed to the Veta Grande bonanza.

This sporadic and thus far unpredictable placement of ore has made it necessary to mine along nearly every vein in the district to assure that nothing is missed. To ameliorate cash-flow problems, it was necessary to operate several mines simultaneously through a fairly large and well-equipped mining company. In recent decades no large company has been willing to undertake the risk of setting up a major operation where *no* ore is actually in sight. Small hit-and-miss operators have instead been pecking away at Batopilas, and even under such limited attack important pockets have been encountered.

Therefore, it is likely that tons of beautiful native silver remain in the ground at Batopilas, and will probably stay hidden unless stumbled upon by small operators, or unless a major advance in instrumental exploration techniques is devised.

* *Rosicler* is an old Spanish mining term for the "ruby silvers." *Rosicler claro* is proustite; *rosicler oscuro* is pyrargyrite (Halse, 1926).

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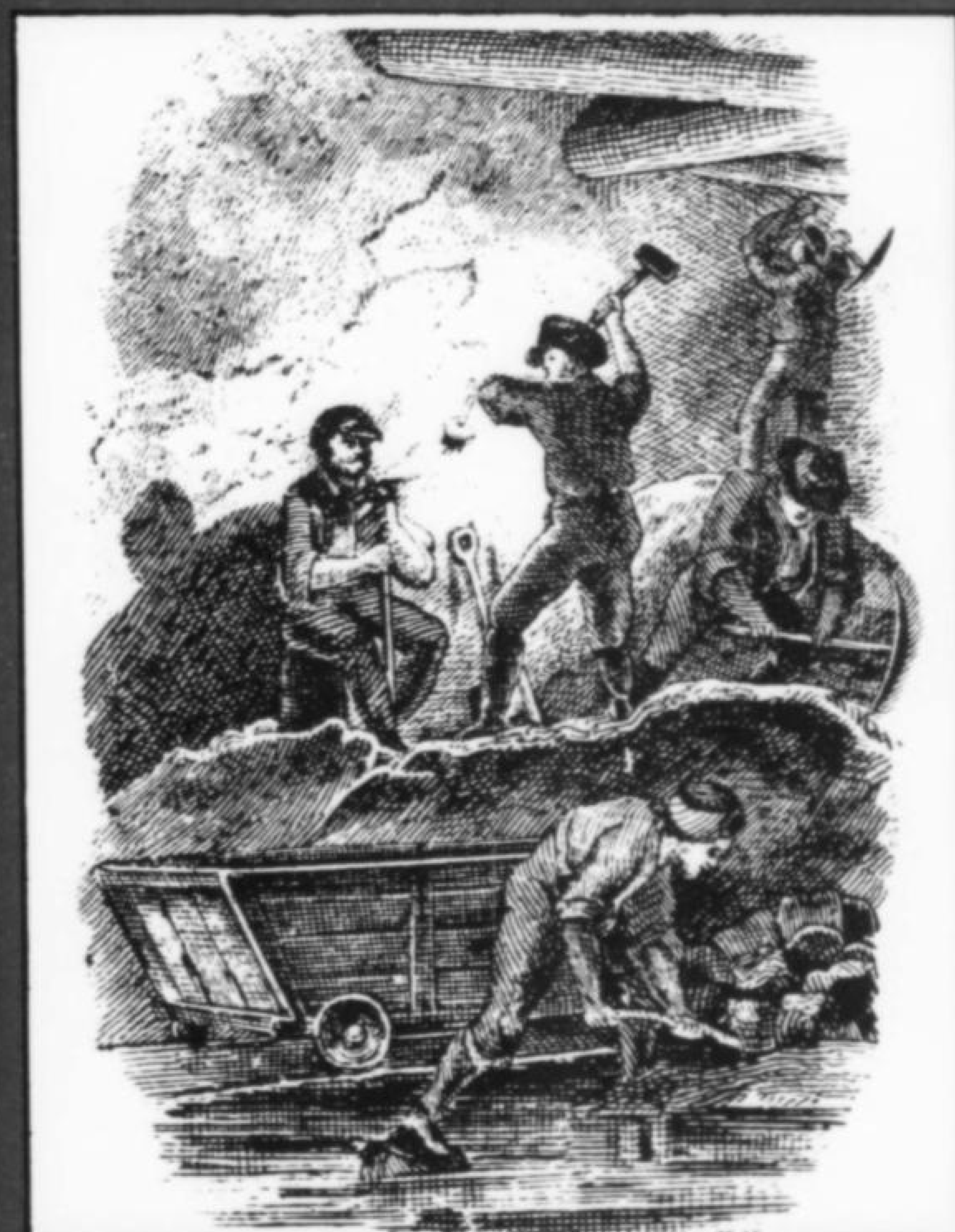

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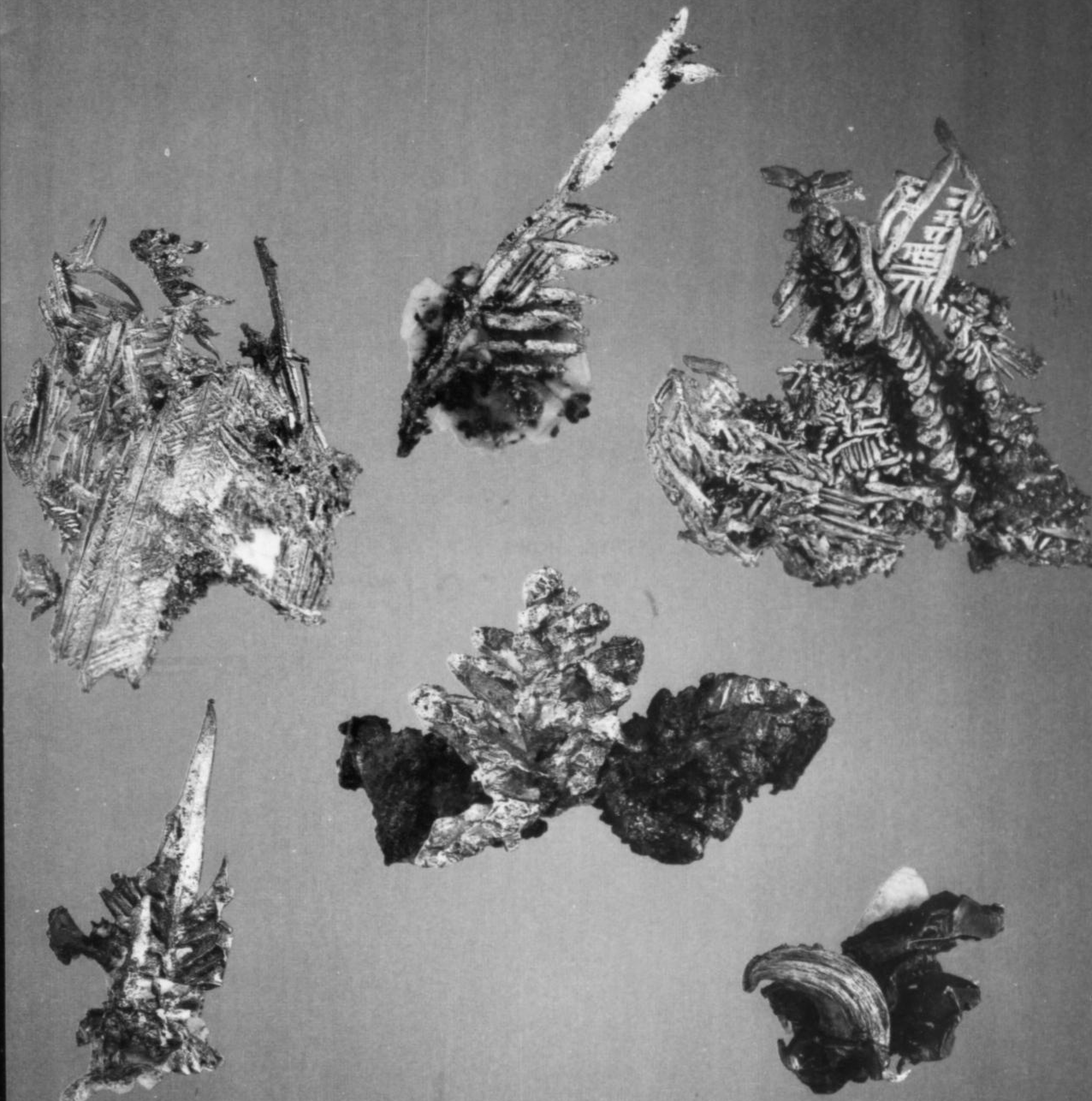

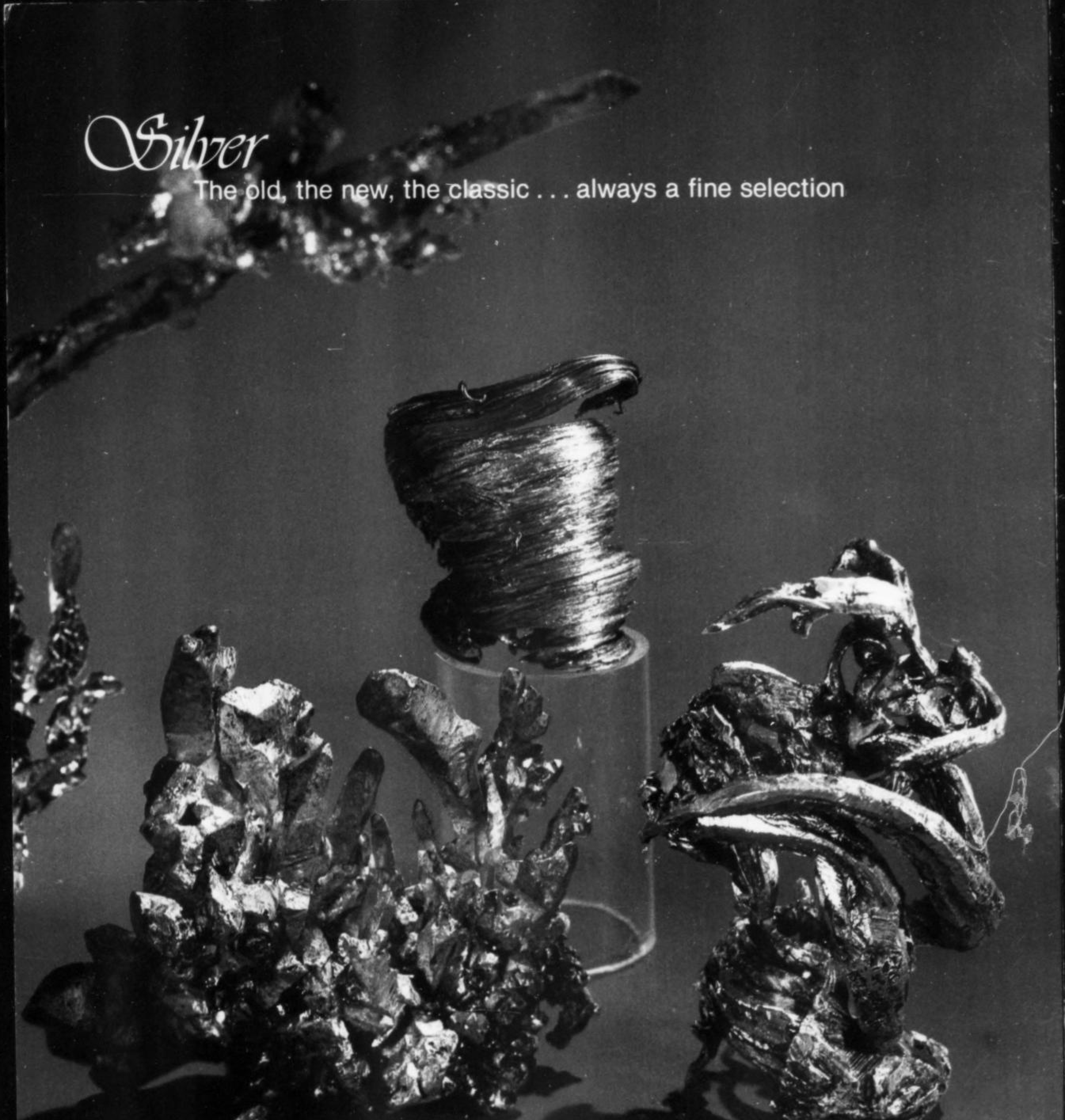
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