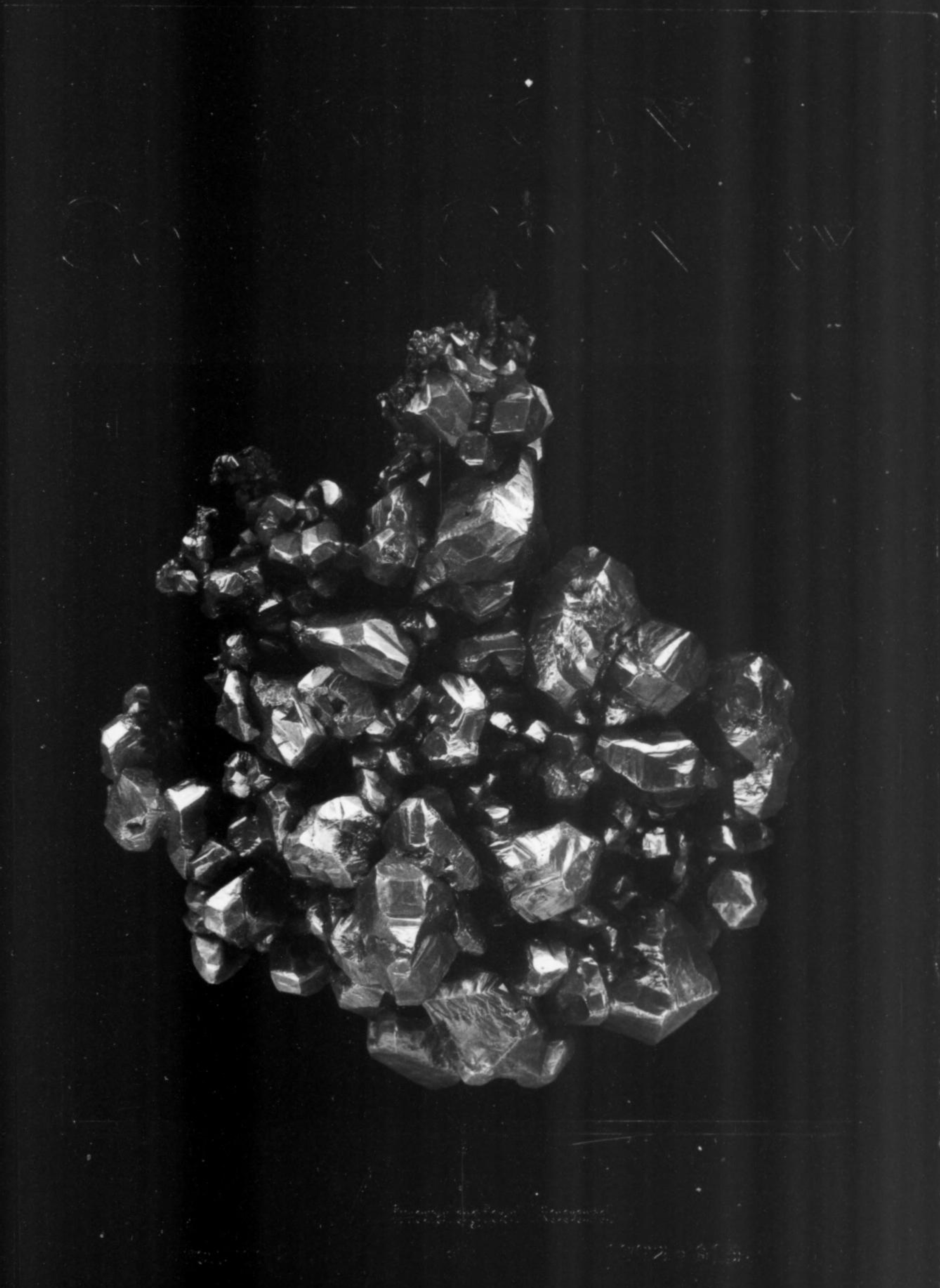

Miners with a large mass of native copper in the Quincy mine ca. 1918.
(Michigan Technological University Archives, Houghton)

Dedicated to the Memory of
Donald Pearce
(1941–1989)
The "Copper King"

The

# MICHIGAN COPPER COUNTRY

by Marc L. Wilson
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and Stanley J. Dyl II
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**FRONT COVER:**
Native copper crystal group, 13.6 cm, from an unknown mine in the Michigan Copper Country. Richard A. Kosnar collection; formerly in the collection of B. S. Butler who (with W. S. Burbank) wrote the classic work on the copper deposits of Michigan in 1929. Photo by Wendell E. Wilson.

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# PREFACE

Over the past 150 years, many investigators have published the results of their studies on the unique copper and silver mineralization of the Keweenaw Peninsula, Michigan's "Copper Country." Among these, *U.S.G.S. Professional Paper* 144 by Butler and Burbank (1929) is considered to be the classic for the district. Many of these works are currently out of print or are obscure and difficult to locate. While this issue cannot take the place of previous works, the authors hope that information compiled and presented here with the results of our own observations and research will serve as an overview of the district and as a framework from which interested persons may launch their own investigations.

Throughout the text, detailed or unique information is cited as to source while generalized information is not. Information on the geology and origin of the copper deposits was compiled from Jackson (1850), Pumpelly (1871), Lane *et al.* (1891), Hubbard (1898), Grout (1910), Van Hise and Leith (1911), Butler and Burbank (1929), Broderick (1929, 1931, 1935, 1952), Broderick *et al.* (1946), Cornwall (1951a, 1951b), Stoiber and Davidson (1959), Ensign *et al.* (1968), White (1968), Jolly and Smith (1972), Babcock (1974, 1975, 1976), Robertson (1975), Scofield (1976), Wold and Hinze (1982), Kelly *et al.* (1986), Bornhorst *et al.* (1988) and Hinze *et al.* (1990).

The geologic maps of Butler and Burbank (1929), Cornwall (1954a, 1954b, 1954c, 1955), White *et al.* (1953), Cornwall and Wright (1954, 1955, 1956a, 1956b), Wright and Cornwall (1954), Davidson *et al.* (1955) and White and Wright (1956) provided information on the location and associated geology of the mines in the district.

Historical and production information is summarized from Dablon (1669–70), Foster and Whitney (1850), Stevens (1900–1911), Rickard (1905), Van Hise and Leith (1911), Hore (1912–1915), Weed (1914–1920, 1922, 1925), Hopper (1916–1918), Barrett (1920–1925), Kellogg (1925), Pardee (1928), Fisher (1929), Broderick (1931), Murdoch (1943), Chase (1945), Gates (1951), Benedict (1952), Jamison (undated), Jamison (1963, 1969), White (1968), Chaput (1971), Lankton and Hyde (1982), Halsey (1983), Kemp (1985), and Olson (1986).

The mineralogy information presented in the text represents the results of the authors' observations and research unless otherwise cited. Particularly important references are Heinrich (1976) and works on microminerals of Moore and Beger (1963) and Behnke (1983, 1986). Observations on the crystallography of copper were built upon the works of von Jeremejew (1877), vom Rath (1878), Fletcher (1880) and, especially, Dana (1886). Identification of crystal forms for this study was accomplished using contact goniometric techniques.

M.L.W.
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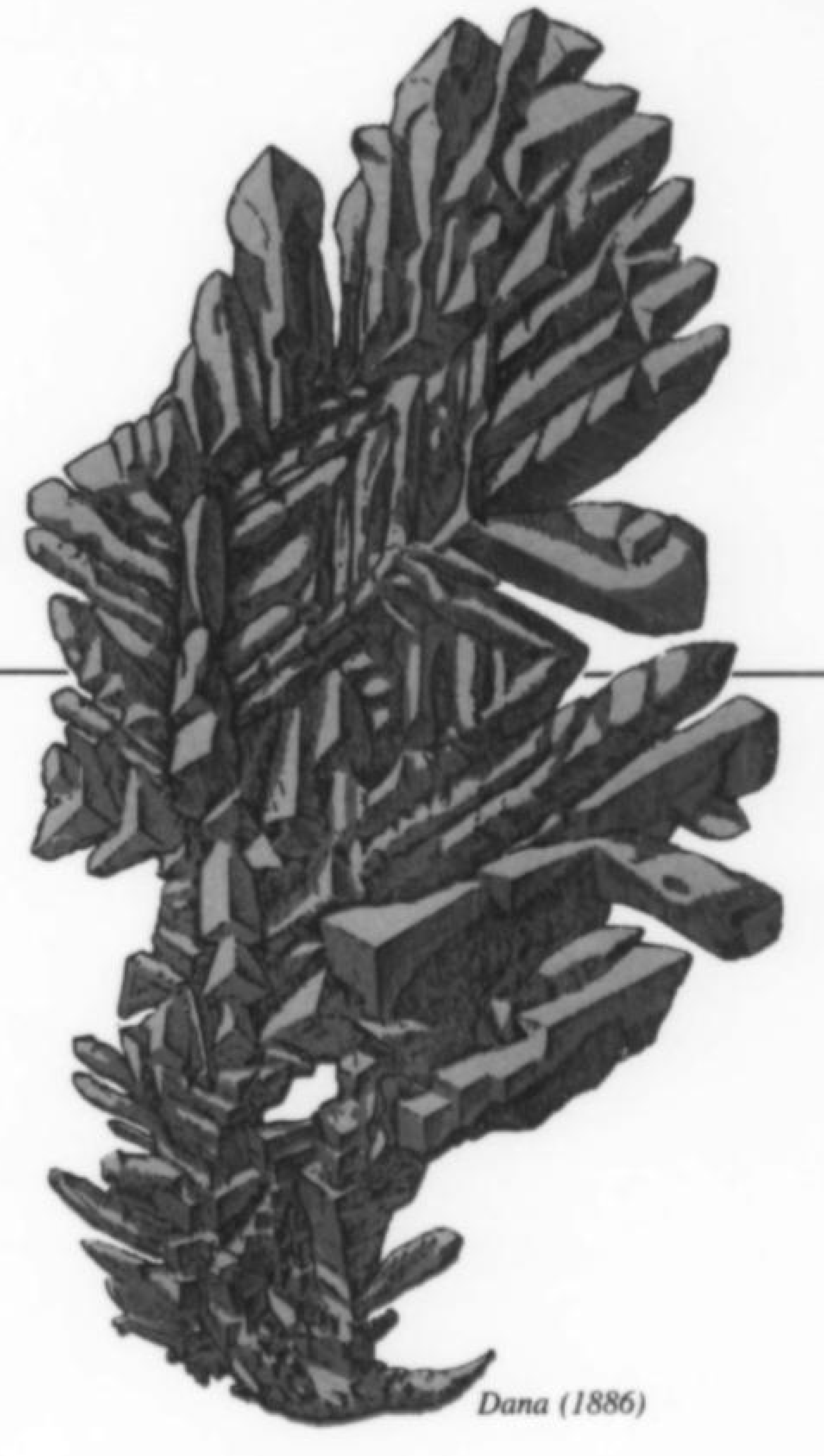
# INTRODUCTION


Dana (1886)

The first European to own a specimen of Keweenaw copper was probably Samuel de Champlain (1567–1635), French explorer and founder of the city of Quebec (1608). He had made friends with the local Algonquin Indians, and was presented with a specimen of solid copper which he described as being "a foot long, very handsome and quite pure." It had come, said the Indians, from "the bank of a great river flowing into a great lake," surely the place where the Ontonagon River empties into Lake Superior. Thus the history of collecting Keweenaw minerals is very nearly as old as the history of mineral collecting itself (which began in Germany around 1530). It continues with unabated enthusiasm today, among professionals and amateurs worldwide.

Michigan's famous "Copper Country," the Keweenaw Peninsula, has a long and complex history of mining, a fascinatingly unique geological context, and a tradition among miners of mineral collecting and specimen preservation which goes back more than a hundred years. Michigan copper and silver specimens have been sought and admired by nearly every mineral collector and museum curator since well before the turn of the century. Happily, this long-standing hunger for specimens has been consistently met by the steady production of countless thousands of fine examples, not only of copper and silver but also of a wide range of other species, many of them still collectible as attractive microcrystals on the dumps.

The abundance of specimens is a fortunate circumstance made possible by the vuggy nature of the fissure veins, the immense size of the deposits, the extensive mining undertaken largely by hand techniques, and the local tradition of respect for the preservation of specimens. The basic statistics are impressive: over 13 billion pounds of copper and 16 million ounces of silver produced since 1845, extracted through 11,000 miles of underground tunnels and workings!

The published literature on the Copper Country could fill a small library all by itself; hefty tomes have been devoted solely to bibliographies on this rich mining district. For an entertaining review of the area's long and colorful history, *Boom Copper* by Angus Murdoch is highly recommended. First published in 1943, it has been reprinted regularly ever since then. Even better is Larry Lankton's *Cradle to Grave; Life, Work and Death at the Lake Superior Copper Mines* (1991), published by Oxford University Press. Lankton is a faculty member at Michigan Technological University, and is perhaps the leading authority on the history of Copper Country mining. Individual mines have been described in popular works such as Lankton and Hyde's *Old Reliable; an Illustrated History of the Quincy Mining Company* (1982), and Donald Chaput's *The Cliff; America's First Great Copper Mine* (1971). For an earlier treatment, readers may enjoy the book by T. A. Rickard, *The Copper Mines of Lake Superior* (1905). Foster and Whitney's *Report on the Geology and Topography of a Portion of the Lake Superior Land District in the State of Michigan, part 1, Copper Lands,* was published in 1850 by the 31st Congress and is today considered a collector's item by Copper Country afficionados. But the classic work in the professional literature is Butler and Burbank's *The Copper Deposits of Michigan,* published in 1929 as U.S. Geological Survey Professional Paper 144.

It seems like an almost impossible task simply to read everything about the Keweenaw. But the farther one gets into the literature, the more tantalizing it becomes, and the more appreciation one feels as a collector for Copper Country minerals, books and collectible mining artifacts. The Copper Country indeed has a culture all its own, which is as deep and as old as the magnificent, cold blue lake that surrounds it.

**Wendell E. Wilson**

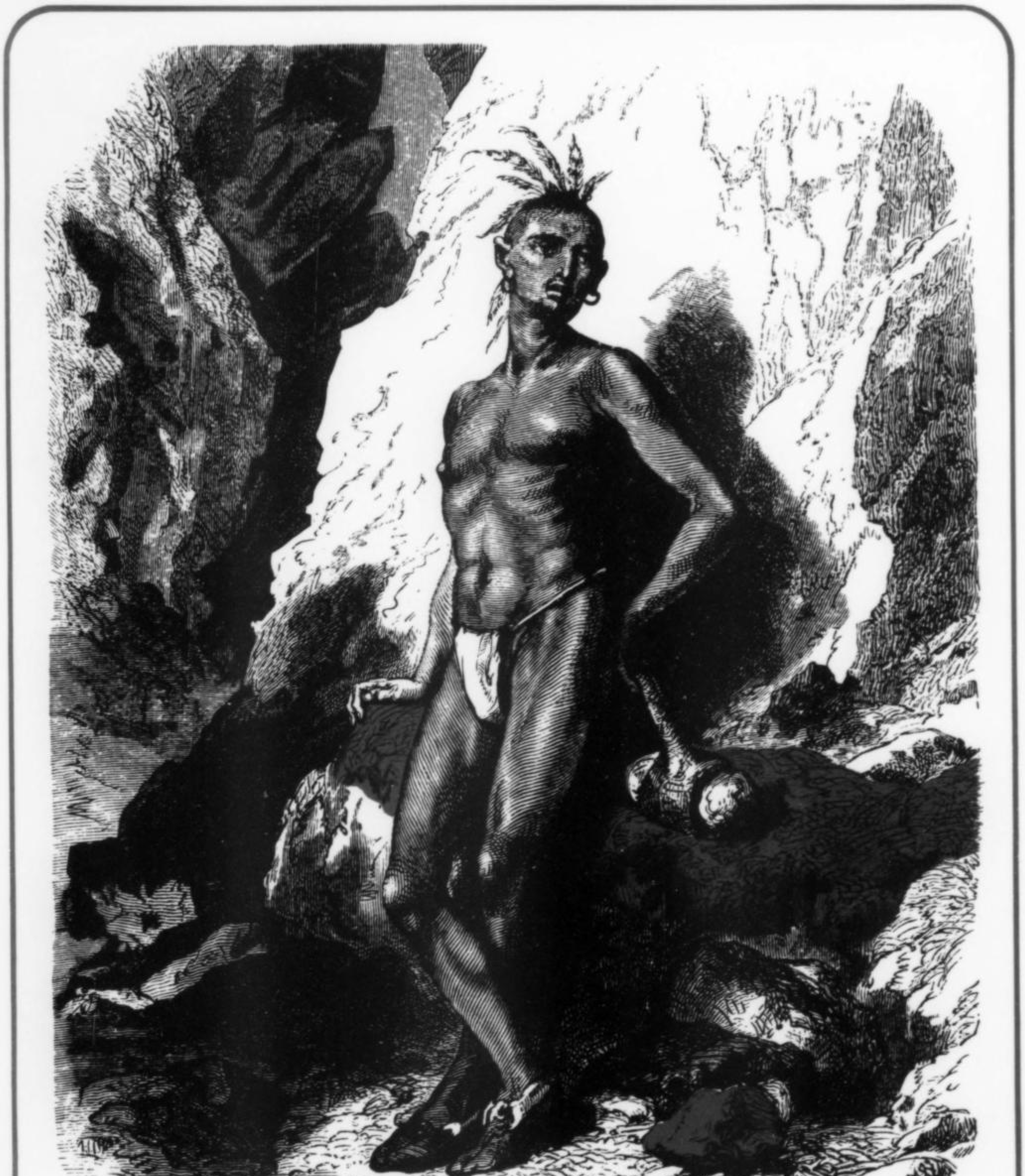


*Figure 1.* **An early Indian copper miner of the Lake Superior area, with his stone hammer, as depicted by Louis Simonin (1869) in *Mines and Miners*.**

# HISTORY

The vast reserves of "red metal" in Michigan's Keweenaw Peninsula were first tapped by prehistoric Indians some 5000 years ago (Halsey, 1983). Excavation pits, littered with ancient stone hammers or "mauls" or, more rarely, cold-worked copper tools, weapons and ornaments, have been found throughout the entire length of the peninsula, and on Isle Royale. Serious inspection of these primitive mining sites in historic times led to the discovery of copper-rich orebodies like the Calumet and Hecla Conglomerate (Benedict, 1952).

Later Indian tribes were also cognizant of the copper wealth of the Keweenaw, and initially worked many sites. However, several hundred years before the arrival of European explorers, the native miners inexplicably abandoned their efforts. The Indians were reluctant to reveal copper sites to newcomers, and the copper deposits became enveloped in a shroud of superstition.

Local legend told of a supernatural event that occurred on Michipicoten Island in eastern Lake Superior. Four natives, after gathering some copper-bearing rocks nearby, in order to heat the stones to boil water and make a meal, were confronted by a "loud, angry voice," accusing them of "robbing the cradles and playthings of my children." The Indians left immediately—so terrified that three died before they reached land. The one remaining "robber" survived just long enough

***Figure 2*. The Ontonagon copper boulder (size greatly exaggerated); engraving in Rickard (1905) made from a drawing done in 1819.**

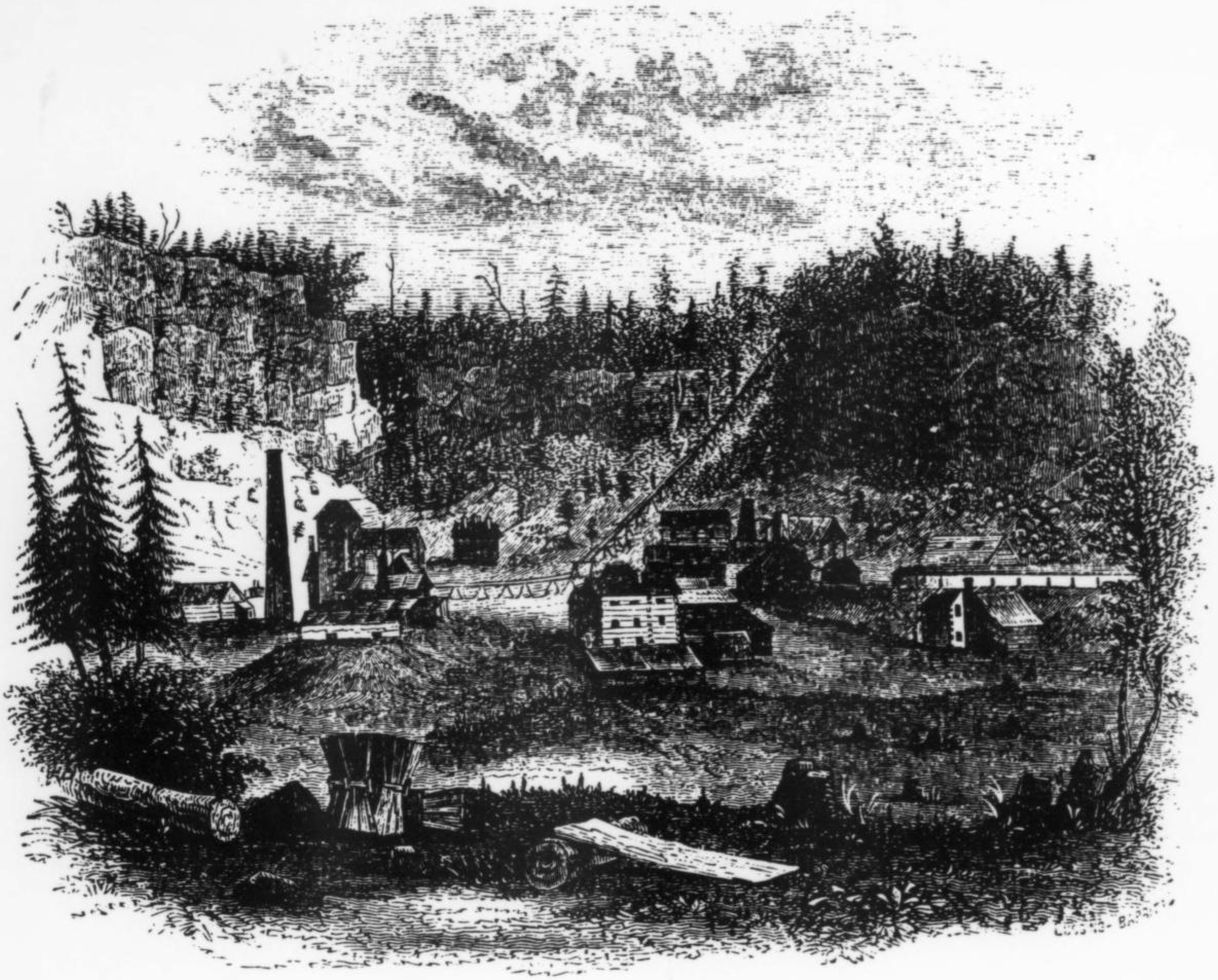


*Figure 3*. **The Cliff mine in the 1850's.**

to tell his macabre tale at home, and expired shortly thereafter (Dablon, 1669–1670).

Ghost stories did not deter enterprising French fur traders and adventurers, however. Pioneer explorer Pierre Esprit Radisson knew of the copper, as did trader Pierre Le Sueur who actually formed a "mining" company in 1690. However, this venture was later discovered to be a "front" for illegal beaver trapping (Chaput, 1971).

A genuine attempt was made by Louis Denis, Sieur de la Ronde, commandant of a French outpost near modern Ashland, Wisconsin. He searched the south shore of Lake Superior for copper, sent samples to Paris for analysis, and in 1734 began work on deposits along the Ontonagon River. Smelting and shipping were even contemplated, until an age-old conflict between Sioux and Chippewa tribes reignited, interrupting further development (Kellogg, 1925).

The French lost their North American empire to Great Britain in 1763, and interest in the mineral potential of the Lake Superior region stirred once more. Englishman Alexander Henry had seen copper on the Ontonagon River as early as 1765, while fur-trading. Henry outfitted an expedition in 1771, at a British settlement near present-day Sault St. Marie. He built a 40-ton sloop and sailed a crew of miners to a site on the Ontonagon River, near modern Victoria, Michigan. Having established a winter base of operations, he returned to the "Soo," only to have his crew follow him home the following June of 1772. Mining had indeed progressed in his absence—the miners "had penetrated forty feet into the hill; but on arrival of the thaw, the clay on which, on account of its stiffness, they had relied and neglected to secure it by supporters, had fallen in" (Ruppe, 1883). This misfortune signaled the collapse of the entire venture, and successful copper mining had to wait almost three-quarters of a century.

The Treaty of Paris, in 1783, recognized the legitimacy of a new country—the United States of America. The Lake Superior region was fortunately included within the territorial jurisdiction of the infant nation, and government officials were not unaware of its mineral potential. As early as 1800, Congress authorized President Jefferson to investigate the copper resources, as well as Indian titles to the land, with a view to their acquisition (Chase, 1945). Nothing, however, came of the matter, until interest flared up again some 20 years later.

Under the authority of the Secretary of War, General Lewis Cass, Territorial Governor of Michigan, conducted an expedition that traversed Lake Superior's southern shore. One of his principle objectives was examination of the area's old mining sites. Henry R. Schoolcraft, the party's geologist and mineralogist, mentioned seeing the deposits and, in particular, "a boulder of pure copper" imbedded in rock on the Ontonagon River. The "Ontonagon Boulder" soon became widely known, and was later removed with great difficulty by a Detroit entrepreneur named Julius Eldred—only to be confiscated by the U.S.

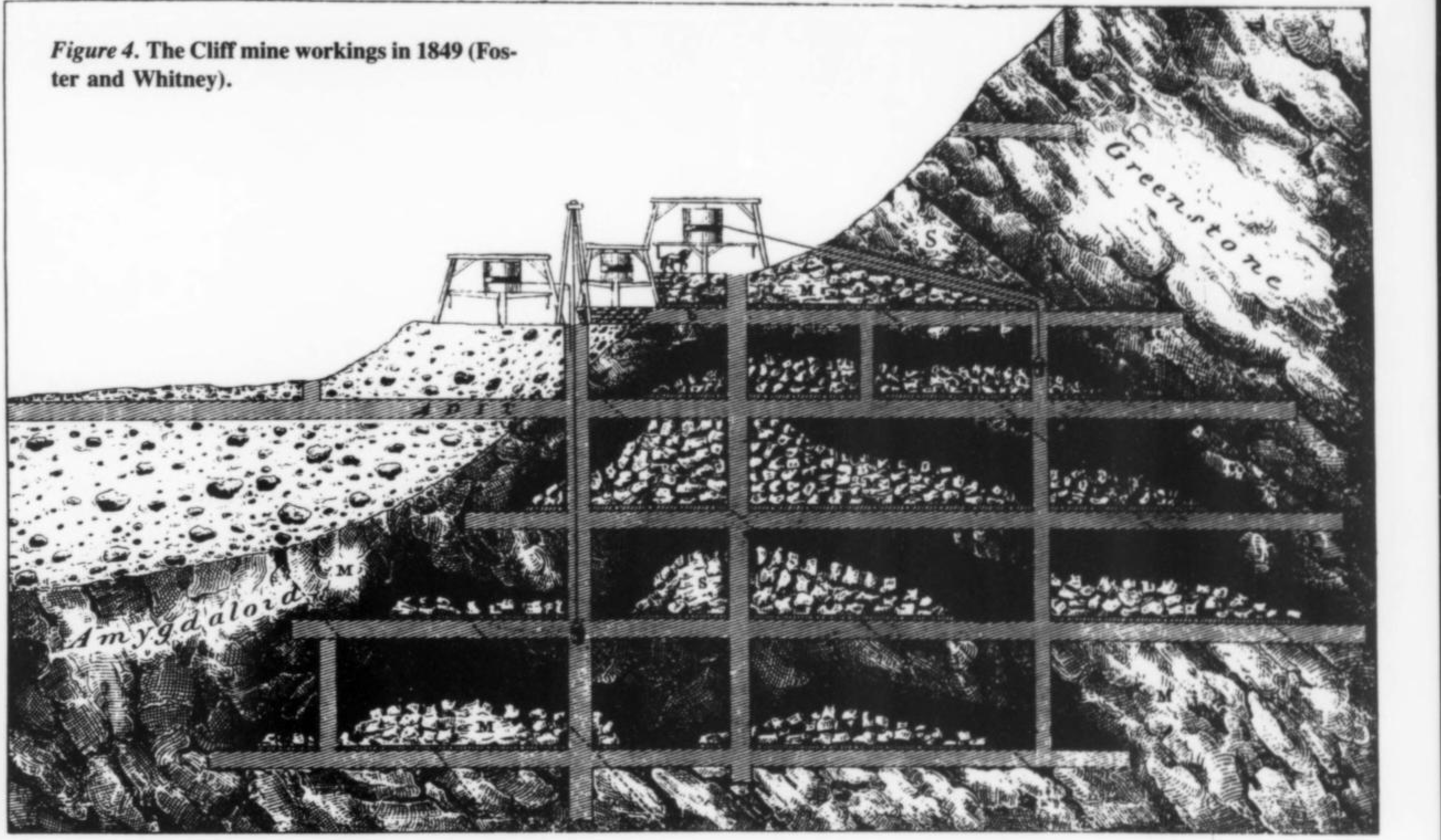



*Figure 4*. **The Cliff mine workings in 1849 (Foster and Whitney).**

government for exhibition in the nation's capital. It can still be seen there today at the Smithsonian Institution.

Schoolcraft became a frequent visitor to the northern wilderness, and, on trips in 1831 and 1832, brought along a brilliant scientist and physician named Douglass Houghton. Houghton, a transplanted New Yorker living in Detroit, was something of a 19th century "wunderkind." He studied medicine at the age of 16 and at the age of 20 graduated from Renssalaer Scientific School with a Bachelor of Arts degree; he stayed on as assistant professor of chemistry and natural history, and was licensed as a physician following his graduation. Houghton served as surgeon and botanist for the Schoolcraft expeditions, saw the copper deposits for himself and even sampled the famous "Boulder." His initial contact with the Lake Superior wilderness sparked a "love affair" with Michigan's Upper Peninsula that continued to the end of his short life.

Before his tragic death in 1845, in a boating accident on Lake Superior near Eagle River, Michigan, Houghton served as state geologist. His appointment in 1837 was one of the new state's first legislative acts. The indefatigable Houghton made numerous surveys of the Upper Peninsula between 1840 and 1845, and in 1841 he published a cautiously optimistic geologic report that encouraged careful development of the copper resources. Caution notwithstanding, Houghton's appraisals unintentionally sparked the first mining boom in U.S. history.

Interest in the mineral potential of Michigan's northern wilderness had been permanently awakened. The Federal government took steps to "extinguish Indian titles" and officially secure Keweenaw land for serious development. So it was that, in 1842, the Treaty of La Pointe was concluded, whereby the Chippewa Indians ceded all the territory west of the Chocolay River (west of Marquette) to as far west as Minnesota's St. Louis River, and south to the boundary of previously acquired lands. The region was now open to settlement under the land laws of the U.S.

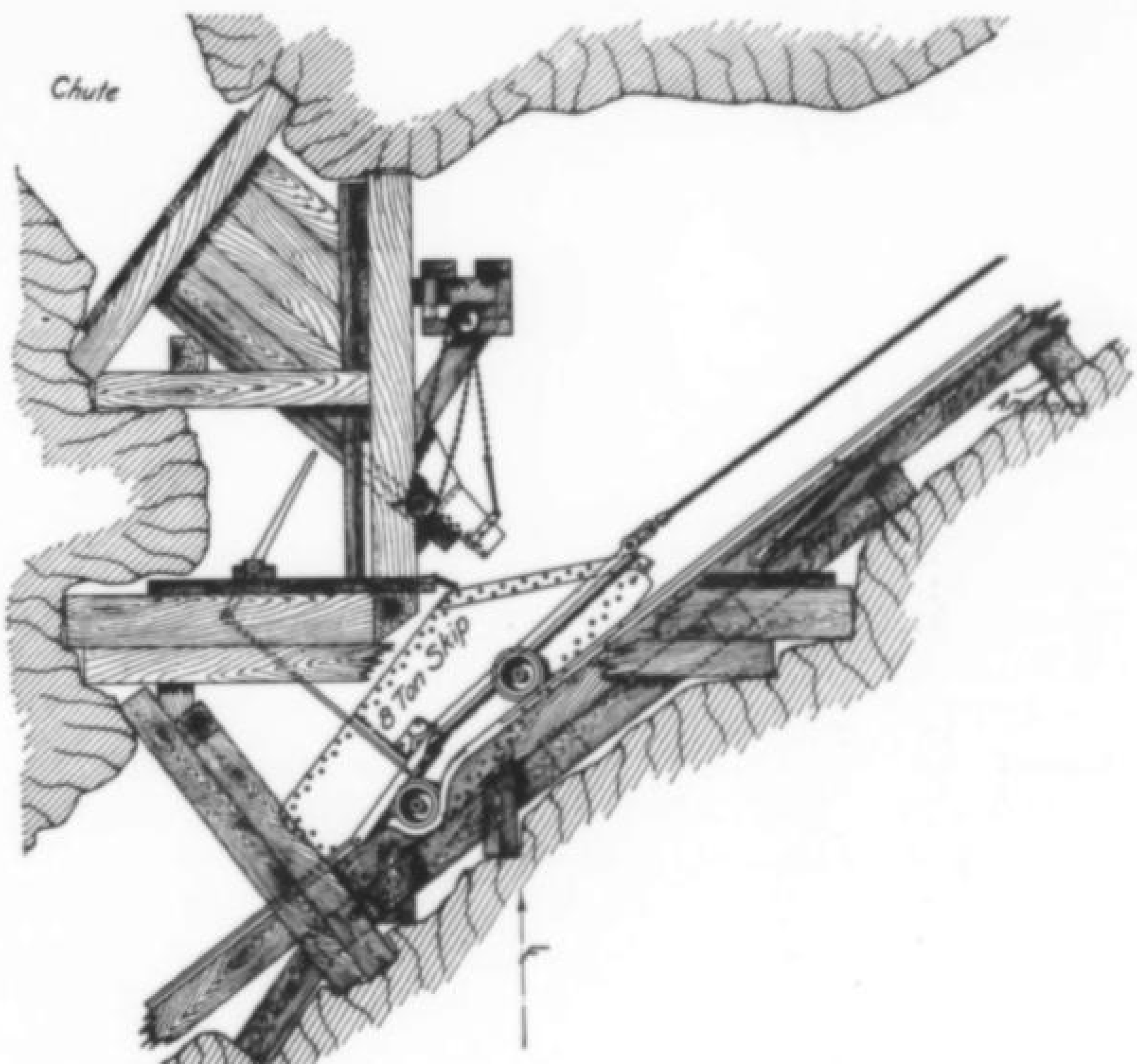



*Figure 5*. **Arrangement for loading a skip (Rickard, 1905).**

The question that now plagued government officials was how to distribute the rights to mine copper. It was eventually decided to grant leases under provision of a Congressional Act of 1807, that governed lead mining already in progress in Wisconsin. The War Department was placed in charge of supervising the leasing process in the summer

***Figure 6.*** **Large timber supports in the Tamarack mine, near the #5 shaft. (MTU Archives)**

of 1843, and a Mineral Agency was established on Porter's Island at Copper Harbor. A few prospectors were already arriving, and by the end of the year nearly 100 exploration permits had been issued—the "boom" was on.

At first, permits bestowed the right to explore 9 square miles of territory; this was decreased to one square mile in 1845. After a permit holder had located copper, he could apply for a lease, by producing $20,000 in security bonds. The lessee was then allowed to explore for one year and mine for three years, with two additional extensions of three years each. The government, in turn, expected a royalty of 6% of the profit for the first three years of mining, and 10% thereafter.

Translating a dream into reality was not easy, and in the first two years of the "boom" there was little real mining. The Keweenaw Peninsula, at the time, was a genuine wilderness—heavily wooded with numerous swamps—and the winter weather was severe. Hundreds of men, poorly equipped for the most part, tramped through virgin forest, blasting every promising outcrop but finding nothing most of the time. The majority of the fortune-seekers turned to the less arduous but more profitable activity of speculation—that is, buying and selling "promising" claims.

Boom soon went to bust when the War Department ceased issuing permits in 1846. It was alleged that the Mineral Agency had illegally issued mining permits. Skullduggery aside, instances of conflicting claim boundaries were numerous, and since the security bond requirement of $20,000 was not inconsiderable, it was alleged that politics had some role in changing many permits to leases. Custody of Michigan mineral lands was shifted to the Department of the Treasury, with the stipulation that tracts be sold at no less than $5.00 an acre—a price that fell to $1.50 in 1850.

Some individuals, however, were serious about making a profit from actual mining, and formed companies right from the start. Most were organized as corporations under Michigan state laws, with the maximum corporate charter term set at 30 years. Capital investment was capped at $500,000, divided into 20,000 $25 shares of stock. Shares issued were not fully paid in, but were assessable to the full face value. Company directors, numbering three to nine (at least one had to be a Michigan resident) could levy assessments as required, and could put a negligent stockholder's shares up for sale if he failed to meet a properly advertised deadline within 60 days. Thus, the typical method of opening a mine was to keep the initial assessments as low as possible, and rely on mining enough copper during the first two years to pay for development (Gates, 1951).

Boston capitalists soon became the principle investors in Michigan copper mining. New England financiers had already underwritten copper mines in Nova Scotia. The original permit holders of the district's earliest venture, the Lake Superior Mining Company, sought monetary support from wealthy Bostonians. By the 1850's a copper mining section was in full swing on the Boston Stock Exchange.

Corporate administration of mining activity was conducted through a company-appointed official known as an "agent." As the company's on-site representative, he was responsible directly to the Board of Directors only, and wielded great supervisory authority. Immediately subordinate were at least two superintendents—one to oversee surface operations and the other supervising work underground. The latter

***Figure 7.* Miners ready to descend into the Quincy mine, ca. 1900. (MTU Archives)**

official usually possessed the title of "head mining captain," and guided a hierarchy of captains and sub-captains, who in turn directed the mine crews. Mine captains were usually promoted from the ranks of miners who showed above-average skill, resourcefulness, and administrative potential. In situations where the agent knew little about mining, the head captain would have independent status with responsibility only to the Board. Large-scale operations like the Cliff might have a major supervisor for individual departments, but this was the exception. In general, managerial simplicity was the rule, and one that made for flexible control (Gates, 1951).

Mine operators looked to Cornwall, England, for experienced miners and mine supervisors. This trend was early established, and continued well into the 20th century. Cornishmen had already been exploiting tin and copper deposits at home for over a century, and upon employment in the Michigan copper fields, many rose to positions of considerable responsibility as mine captains and superintendents. Eng-

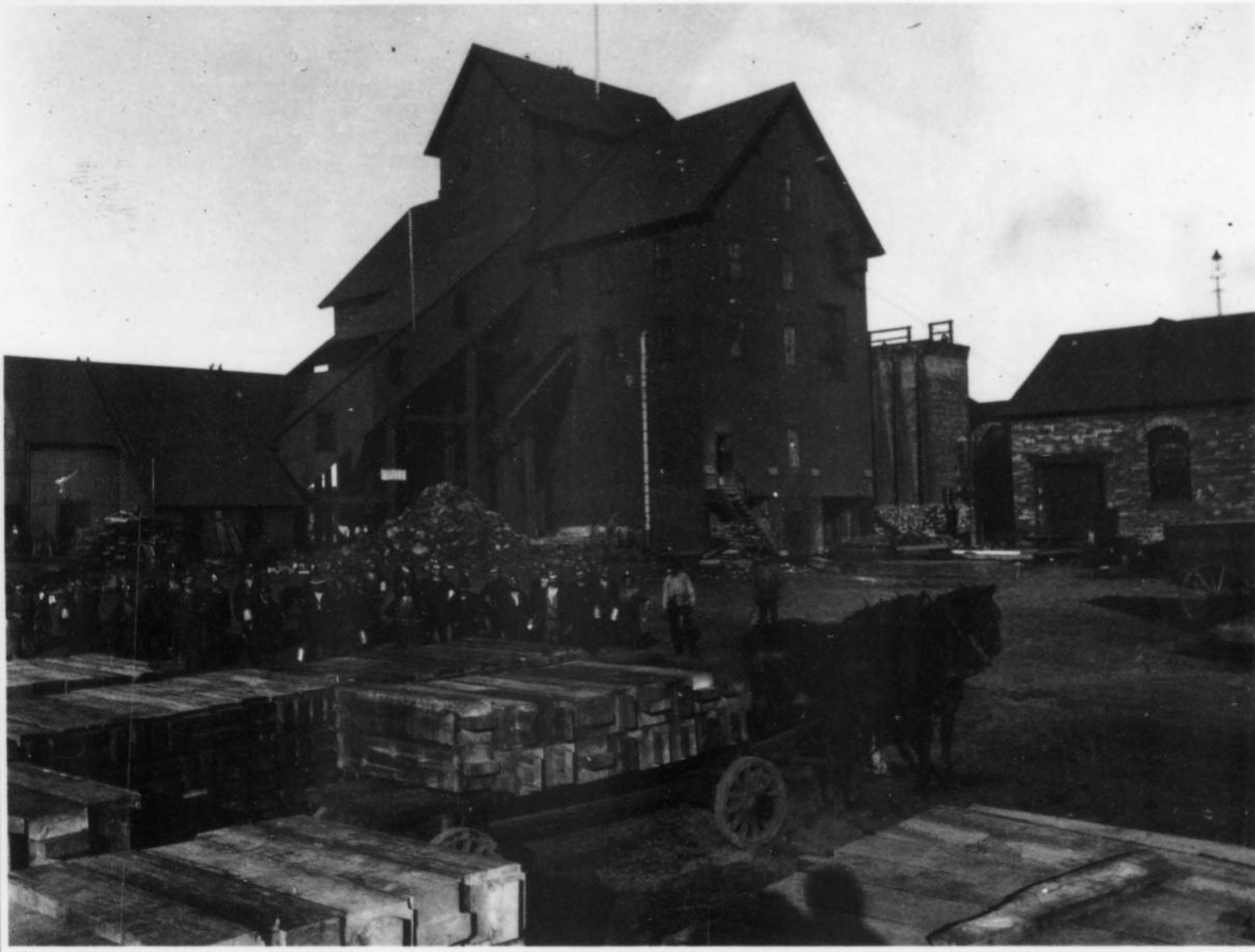


***Figure 8*. The Calumet & Hecla shaft #5.**
**(MTU Archives)**

lish, German and Irish miners were also numerous, and ethnic rivalry—especially between Cornish and Irish crews—became legendary. Later, in the 1870's and 80's, other groups became important to the settlement of the region. These included French-Canadians, Italians, Norwegians, Swedes and Finns in significant numbers, as well as Croatians, Slovenians and Poles. French-Canadian and Finnish workers generally preferred surface duty, although many of the latter were also excellent miners. The backbreaking job of pushing ore cars—called "tramming"—fell mostly to those of Slavic, Finnish or Italian descent. The debilitating nature of this work in particular, and the fact that trammers were often among the lowest paid employees, was one of many factors that figured in the district's labor problems.

Most of these early mining efforts centered around exploiting "fissure deposits" in Keweenaw or Ontonagon County. Prime targets were large veins of solid copper occurring transverse to the strike of ore-bearing lava flows. The Lake Superior (later reorganized as the Phoenix mine), the Copper Falls, the Cliff and the Central mines were the four largest operations in Keweenaw County; also important were the Minesota [sic] and National mines in Ontonagon County.

The Cliff mine has the distinction of being the first truly profitable venture in the district. The Pittsburgh and Boston Mining Company that managed the Cliff, had already been mining tenorite—black copper oxide—at Copper Harbor. One of the Harbor sites was located on the outskirts of a military outpost, Fort Wilkins, that had been established to oversee an orderly settlement of the area, and expedite the departure of the Indians. Although there is still some speculation about the details, credit for discovery of the Cliff fissure is generally given to company agent John Hays. Hays' "claim" turned out to be a genuine bonanza, eventually paying $2,327,000 in dividends on an investment of $110,000—a return of 2000%! (Gates, 1951).

Ontonagon County's Minesota mine (the second "n" having been lost to a clerical error in the company's articles of corporation) has the distinction of being the richest Michigan copper mine, in terms of the amount of copper per volume of rock. The largest single copper mass ever found was discovered on March 7, 1857, below adit level and west of No. 5 shaft. It measured 3.8 x 5.7 x 14 meters, weighed 527 tons, and required successive black powder charges—some 25 and 30 kegs strong—to dislodge (Stevens, 1902). Twenty-one persistent miners spent 15 months reducing the behemoth to manageable proportions, and generated 27 tons of copper "chisel chips" in the process.

The technology used at mines like the Cliff and the Minesota was primitive even by the standards of the day. Mining was done by hand, in shifts composed of three-man teams. One crewman held a steel drill against the target rock face, while his two partners alternately hammered away, thus boring a hole for a black powder charge. When the hole was deep enough, the drillman signaled that it was time to stop by placing his thumb over the drill head. Rock surrounding the copper was blasted out, and liberated masses were dissected using hammers and chisels. hand-cut copper "fans" were commonly made upon a bosses' request for "V.I.P.'s." Horse-driven rope-wound spools known as "whims" raised or lowered suspended iron buckets called "kibbles" that were used to remove ore, and often miners as well.

Native silver, occurring with the copper, proved to be an unexpected bonus, and contributed to the excitement that characterized the district's early days. Indeed, a small percentage of the white metal was naturally present; this produced a premium combination of high conductivity and workability, and made "lake copper" the standard against which all other copper was compared. Silver specimens brought up in miner's lunch buckets found their way into many fine local mineral collections, and often helped support a worker's family. Unfortunately,

Lake Superior copper. The mining companies retained ownership of the product until delivered to the proper port facility, where it was shipped to the various foreign and domestic customers. During the 1840's and 50's, consumption of copper increased markedly because of its use in sheathing wooden naval vessels, brass manufacture, and military and artistic products. A wider use of iron, however, in the decades that immediately followed, contributed to a generally declining market. Eventually, copper rebounded near the turn of the century, as the new, expanding electrical and communications industries increased consumer demand.

More advanced mining and milling techniques awaited the development of the second major type of copper deposit—the amygdaloid lodes. Here, native copper had filled almond-shaped gas cavities or

***Figure 9.*** **Mine Captains at the South Hecla mine in 1908. (MTU Archives)**

hopes for a silver mine were not to be realized. Though sometimes locally abundant near the surface, silver was never plentiful enough to warrant large-scale development.

Most of the native copper taken from fissure mines could be sent directly to the smelter. The small amounts of leaner ore that required processing were brought to stamp mills, where batteries of Cornish gravity stamps—iron-shod wooden pestles—hammered away at the ore, while streams of water carried away fine material down troughs and over jigging screens, all designed to aid in concentrating the dense, but fine copper particles. The lighter waste-rock refuse known as tailings were removed to a pre-determined disposal site. The resulting copper-rich concentrate, called "mineral," was shipped to the smelter where, with the larger mass fragments, it was melted down and cast into various shapes, including ingots, for distribution and sale.

New York and Boston were the primary markets for smelter-refined

vesicles located at the top (and to a more limited extent at the bottom) of individual basaltic lava flows; the filled vesicles are then called "amygdules." These orebodies came into prominence in the 1850's, at a time when the fissure deposits were reaching (and in some cases passing) their peak. Though not as rich, they were much greater in extent, and far more valuable as long-term, lower-grade reserves. Attention would soon be focused on mining in Houghton County, at the expense of the pioneer operations in Keweenaw and Ontonagon Counties.

By the 1860's, managers of both fissure and amygdaloid mines had to deal with the logistics of employing workers and hauling ore out of mines of increasing depth. At the end of a tiring shift, the available means of ascent for exhausted miners was a long "refreshing" climb up a ladder (some were nearly a thousand feet long) to the surface.

J. W. V. Rawlings, engineer at the Cliff mine implemented a solution that worked for a while, and was adopted by fissure and early amyg-

***Figure 10*. Quincy mine, the #2 shaft-rockhouse ca. 1895. (MTU Archives)**

daloid mines alike: the "man engine." These devices were first used in the Samson mine in the Harz Mountains, Saxony, in 1837, and by the early 1840's were in use in Cornwall, England. The invention (called a *Fahrkunst* in German) consisted of a series of 21-inch platforms fastened to a spruce connecting rod. These rods were fastened to steam-driven, wood-frame bobs that moved in alternating sequence: one descended while the other ascended. An ascending miner would step on a platform and rise up until the next higher one on the neighboring rod had descended to the low point in its cycle. He would then jump onto that one just as it began rising, and so on, until he reached the mouth of the mine shaft. While still a dangerous proposition (miners occasionally missed a step . . .), it was a vast improvement (Chaput, 1971).

Within a few years mine depths exceeded the practical limit of the man engine, and steam-driven "hoists"—engines operating huge cable-wrapped drums—were installed throughout the district to raise and lower men, ore, supplies and equipment. Lengths of cable could be added as needed, to keep pace with underground development. Mines soon became laced with miles of track, as wheeled ore cars called "skips" replaced the kibble. Man cars, in turn, replaced man engines, offering the convenience of seating. Hand-drilling did not change with the advent of the amygdaloid mines. Black powder, however, soon gave way to stick charges containing 50% nitroglycerin.

Low-grade amygdaloid ore could not be sent directly to the smelter; "mineral dressing" (ore processing) was a must. Stamp mills became larger and more numerous, and the system for extracting the copper more complex. Gravity stamps were used initially with some success, but they eventually gave way to a more powerful and efficient crusher, the steam stamp. A bewildering array of concentrating apparatus: Evans buddles, Collom jigs, Wilfley tables, and others, found their way into the mill. These devices were worked into increasingly sophisticated separation schemes designed to efficiently increase the amount of copper extracted per ton of rock, and minimize the loss of fine metal particles.

The great Quincy, Pewabic and Franklin mines were early amygdaloid mines. All three mined the Pewabic lode at a profit, with the Quincy taking the lead. The latter, the most conservatively managed company in the district, made dividend payments consistently over a 60-year period and was known as "Old Reliable." Other amygdaloid producers include the Osceola mine on the Osceola lode; the Ahmeek, Mohawk, Wolverine and North and South Kearsarge mines on the Kearsarge lode; the Isle Royale on the Isle Royale lode, and the Atlantic mine, which profitably worked the very low grade Ashbed Amygdaloid. The last "big" amygdaloid deposit discovered was the Baltic lode, mined by Copper Range Company's Champion, Baltic and Trimountain mines.

The discovery of the Calumet and Hecla Conglomerate in the 1860's saw the opening of the third type of "Lake" copper deposit, the conglomerate lode. This unbelievably rich orebody was first located by surveyor E. J. Hulbert, who was also an experienced mine promoter. Hulbert purchased the land with the backing of Boston capitalist Quincy Adams Shaw. He quickly realized the potential of the copper-rich, felsite-pebble "puddingstone," and hastily developed the site. His haphazard handling of the operation, compounded by shaky financial manipulations, soon prompted Shaw to request Hulbert's resignation and replace him with a more level-headed manager, his brother-in law Alexander Agassiz.

Although Agassiz's experience with mining was rather limited, he was honest, persevering and knew how to pick and use experts. Within a remarkably short time (though not without considerable difficulty) Agassiz had the Calumet and the Hecla mines running smoothly. By the end of 1869 the Hecla paid its first dividend of $100,000, with the Calumet following suit eight months later. On March 24, 1871, the two companies were consolidated as the Calumet & Hecla Mining Company (colloquially known as "C&H")—and a mining legend was born.

With the rise of the C&H, Michigan dominated the American copper market from the late 1860's to the mid-1880's. Lankton (1991) writes:

> Sited atop the Calumet conglomerate lode—the Keweenaw's richest copper deposit by far—C&H alone accounted for 43% of all Lake copper produced through 1925, and for half of all dividends. Take away its highly profitable performance, and the district only broke even. Calumet & Hecla made the district a clear winner and a producer of wealth . . . [dominating] the Lake Superior copper industry. Until the rise of Copper Range Consolidated in the early twentieth century, C&H had no legitimate rivals. It set standards for wages, for company paternalism and for technologies. Because Boston investors had launched C&H, [many] New England fortunes were made [in the Copper Country].

The only Michigan mine to even come close was the Tamarack mine, the fifth largest U.S. producer in 1892. The Tamarack also mined the Calumet and Hecla Conglomerate, the lower portions of which were located by Cornish mining captain John Daniell in a spectacular feat of engineering. Daniell proposed to intersect the conglomerate over 300 meters below the surface by sinking a vertical shaft. Tamarack crews reached the orebody just 5 meters short of Captain Daniell's predicted depth.

By this time, the Rand air drill had replaced the time-honored hand drill, increasing C&H's production 20% by 1882, with a corresponding 20% reduction in total work force. Milling methods were refined as more powerful versions of the steam stamps were introduced, as well as ball mills for regrinding tailings. The real breakthrough in recovering finely divided copper came in 1912, when C&H metallurgist

***Figure 11*. Timber supports in the Baltic mine, ca. 1918. (MTU Archives)**

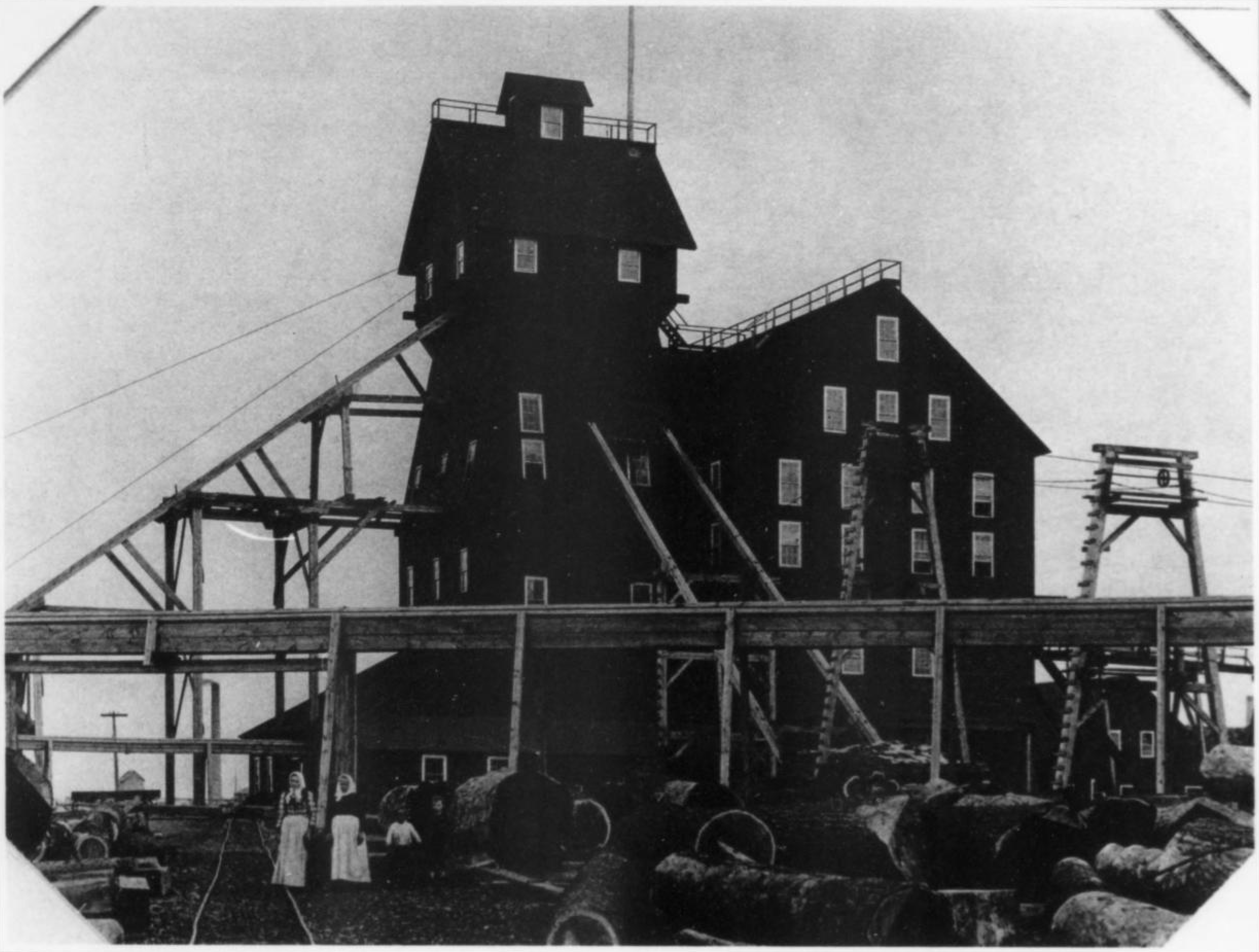


*Figure 12.* **The Tamarack mine. (MTU Archives)**

C. H. Benedict developed an ammonia leaching process that made secondary recovery a multimillion-dollar adjunct to normal copper production.

By the end of the First World War, it was apparent that the Michigan copper district had reached its maximum level of maturity, and was gradually slipping into decline. C&H General Manager James McNaughton recognized the signs as early as 1901, and took steps to tighten up his operation. But consolidation, retrenchment and sophisticated reclamation programs could not completely compensate for declining copper values. The district's mines were old and largely past their prime. A serious labor strike in 1913 received nationwide press coverage and left bitter scars on management and labor, scars not entirely healed even today, and motivated many experienced workers to seek employment in the Arizona and Montana copper fields. These mines had begun to overtake C&H in copper production as early as the mid 1880's. Anaconda, Kennecott and Phelps-Dodge became the new "copper kings."

The Great Depression dealt Michigan's copper industry a blow from which it never fully recovered. As mine after mine closed, long-time residents gradually began migrating to larger population centers like Detroit and Chicago, where there was at least the hope of employment. Between 1910 and 1940, the Michigan "Copper Country" lost 40,000 residents, nearly 20,000 of whom left between 1920 and 1930. The three remaining copper companies: C&H, Copper Range and Quincy, attempted to forestall the inevitable by diversifying their capital into perhaps more promising ventures. Nevertheless, Calumet and Hecla finally closed in 1968, and the Quincy Mining Company ceased to exist in 1986. Only the Copper Range Mining Company survives from the "golden age," operating the White Pine mine for copper sulfides. And the Caledonia mine is also still active, being mined for specimens by Red Metal Minerals.

Prospects for renewed mining still persist as exploration for sulfide ore continues in northern Houghton and Keweenaw Counties. Meanwhile, legislators in Washington are debating the creation of a Keweenaw National Historic Park to preserve some of the area's famous mining sites at Calumet and Quincy. And so, in spite of depressions, disputes and declines, hope for a bright future is still very much alive in Michigan's Copper Country.

# MASS COPPER

by T. A. Rickard
from *The Copper Mines of Lake Superior* (1905)

*The following turn-of-the-century report, reprinted here in full, gives some further background on the large masses of copper found in the early days of mining.*

It is believed by many people usually well informed, that in the mines of the Lake Superior region there are bodies of metallic copper so large that it has been found impracticable to extract them. I remember being told seriously seven years ago that in the Michipicoten district, on the north shore, there were rich copper lodes that were not profitable because the metal occurred in masses so huge that they could not be mined successfully. Similar statements appear frequently in popular accounts of the copper country. But recent investigation of this interesting matter enables me now to dissipate a fallacy which has retained a curiously sustained vitality since the days of Alexander Henry and Douglass Houghton.

The white men who first crossed the lake and penetrated the forests of the peninsula, found evidence of earlier attempts to extract the copper. We know that the Indians worked the metal that outcropped massively at many localities; and there are those who maintain that this was also done by an earlier race of higher capacities long since vanished. Testimony to their effort is shown by the battered fragments of copper dug out of old abandoned workings. Such is the one illustrated on the preceding page; this weighed three tons, and was taken from a pit 16.5 ft. deep at McCargo Cove, on Isle Royale; it exhibits the marks of stone hammers or hatchets. There is good reason to suppose that the Indians built fires around the masses of copper which were too large to be removed; and that after removing the adhering rock, loosened through the effect of the heat, they separated portions

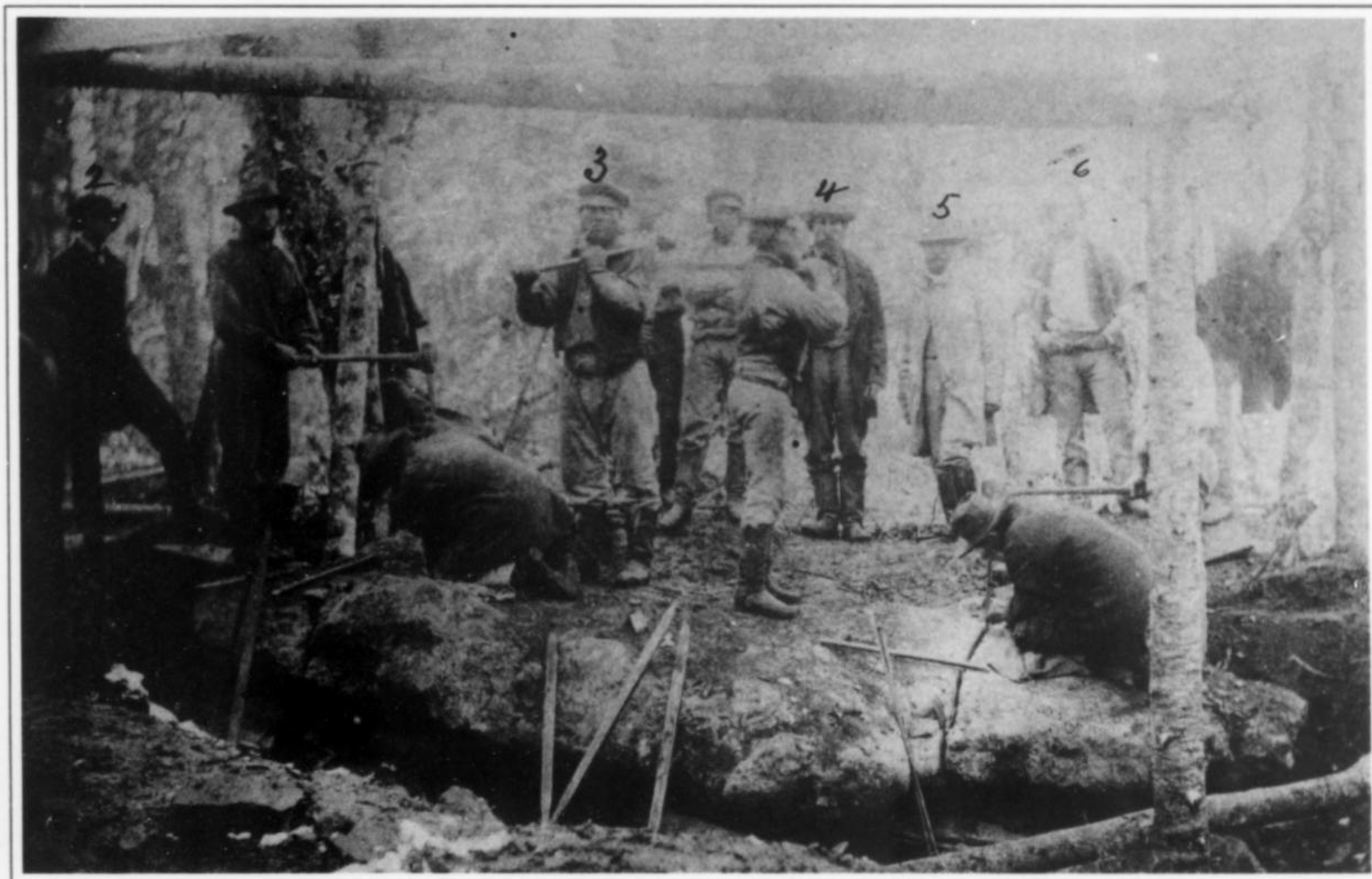



***Figure 13*. The "Mesnard mass" of float copper, 18 tons in weight, as it was being cut up by hand chisels in 1862.**

*Figure 14.* **A 6000-pound mass of copper found in ancient Indian workings, in a pit 16.5 feet deep at McCargo Cove on Isle Royale. The marks of crude stone hammers cover its surface. (MTU Archives)**

with their hatchets by pounding the copper into waves, as shown in the illustration, until it was finally forced apart in small fragments. Furthermore, the reports of the early *voyageurs* made mention of the celebrated 'copper rock,' an immense boulder of metal found on the right bank of the Ontonagon river; it was visited by the first explorers and travelers, who testified that there was nothing like it anywhere in the world. This mass weighed about four tons; it appeared to be out of place, and may have been moved, by the Indians, thus far from the outcrop of the Minesota lode, a distance of two miles only. It was floated down the river on a raft by Julius Eldred in 1843 to the village of Ontonagon, to be seized subsequently by the United States Government and shipped to Washington, where it can now be seen at the Smithsonian Institution. On inquiry at the Smithsonian Institution, I was informed that this Ontonagon boulder, as it now stands in the National Museum, weighs 6,500 pounds. From a pamphlet by Mr. Charles Moore, entitled 'The Ontonagon Copper Bowlder in the U.S. National Museum,' and issued by the Government printing office at Washington in 1897, I extracted the following data. According to Henry R. Schoolcraft, a member of the expedition that endeavored to bring it away, the greatest length of the mass was 3 feet 8 inches, and its greatest width 3 feet 4 inches. He gave a sketch of the locality, which is given in the frontispiece. The final effort to remove this unwieldy lump of metal is described thus: "It took a week for the party of 21 persons to get the rock up the 50-foot hill near the river; then they cut timbers and made a stout wooden railway track, placed the rock on the car, and moved it with capstan and chains as houses are moved. For four miles and a half, over hills 600 ft. high, through valleys and deep ravines; through thick forests where the path had to be cut; through tangled underbrush, the home of pestiferous mosquitoes, this railway was laid and the copper boulder was transported; and when at last the rock was lowered to the main stream, nature smiled on the labors of the workmen by sending a freshet to carry their heavily-laden boat over the lower rapids and down to the lake."

The Government paid $5,664.98 to Julius Eldred and sons for their time and expenses in purchasing and removing the boulder. In regard to the agency which moved it from its place in a neighboring lode to the banks of the Ontonagon river, the balance of evidence ascribes it to the Indians; though it is possible that unknown early white adventurers did the work. In referring to this question, Mr. Moore gives the following interesting information:

"During the winter of 1847–48, Mr. Samuel O. Knapp, the agent of the Minesota mine, observed on the present location of that mine a curious depression in the soil, caused, as he conjectured, by the disintegration of a vein. Following up these indications, he came upon a cavern, the home of several porcupines. On clearing out the rubbish, he found many stone hammers; and, at a depth of 18 ft., he came upon a mass of native copper 10 ft. long, 3 ft. wide, and nearly 2 ft. thick. Its weight was more than 6 tons. This mass was found resting upon billets of oak supported by sleepers of the same wood; there were three courses of billets and two courses of sleepers. The wood had lost all its consistency, so that a knife-blade penetrated it as easily as if it had been peat; but the earth packed about the copper gave that a firm support. By means of the cobwork the miners had raised the mass about five feet, or something less than one-quarter of the way to the mouth of the pit. The marks of fire used to detach the copper from the rock, showed that the early miners were acquainted with a process used with effect by their successors. This fragment had been pounded until every projection was broken off, and then had been left, when and for what reason is still unknown. From similar pits on the same location came ten carloads of ancient hammers, one of which weighed 39½ pounds and was fitted with two grooves for a double handle. There were also found a copper gad, a copper chisel with a socket in which were the remains of a copper handle, and fragments of wooden bailing bowls. At the Mesnard mine, in 1862, was found an 18-ton boulder that the 'ancient miners' had moved 48 ft. from its original bed."

The large bodies of metallic copper found in the lodes of Lake Superior are known as 'mass.' The mines which first established the

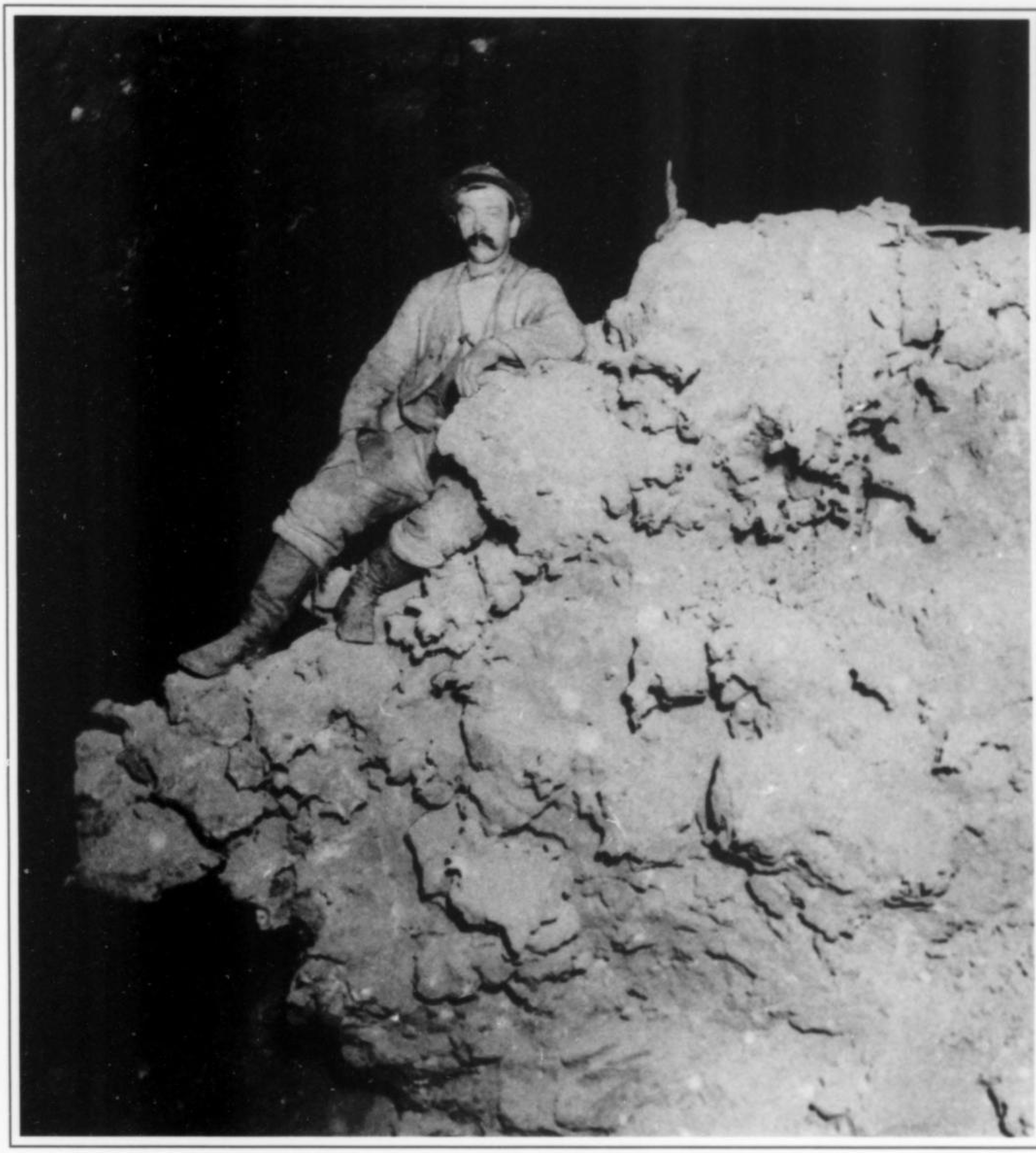


***Figure 15.* Miner sitting on a large mass of copper in the Quincy mine, ca. 1890. (MTU Archives)**

fame of this region, such as the Cliff, Phoenix, Central, Minesota, and National, were all characterized by the occurrence of 'mass.' These chunks of copper were found near the surface, and for years they continued to be encountered underground in great quantity. Such mines required but little capital; they needed chiefly the labor of cutting the metal and of hoisting it to daylight. 'Mass mining,' therefore, characterized the early days. Had the Calumet & Hecla, which has always yielded a strictly stamp-mill product, been discovered in the first decade of development, it probably would have been a failure. The discovery of the Calumet conglomerate came when the rudiments of mining had been learned and when the 'mass' mines were approaching exhaustion.

Two-thirds of the output of the Cliff mine was in the form of masses; some of them yielded from 100 to 150 tons, and as late as 1875 one of 40 tons was taken out. These irregular bodies of metal require special mining methods, for it is impossible to drill into them or to use picks in the ordinary way. Professor Blake has described the usual practice in words that I cannot improve: "The miner picks out or excavates a passage or chamber upon one side of the mass, laying it bare as far as possible over its whole surface. It is usually firmly held by its close union with the veinstuff, or by its irregular projections above, below and at the end. If it cannot be dislodged by levers, the excavation of a chamber is commenced behind the mass, and this excavation is made large enough to receive from 5 to 20 or more kegs of powder. Bags of sand are used for tamping, and the drift is closed up by a barricade of refuse and loose dirt." Reference is made to this

***Figure 16.* A huge mass of copper hanging from the back of a stope in the Ahmeek mine, ca. 1919.**

method in the description of the effort which was made to extricate the great mass found in the old Minesota mine.

The Minesota mine, in the Ontonagon district, was celebrated for large masses. The largest was found in 1857; its greatest length was 46 ft., its greatest breadth 18.5 ft., and its greatest thickness 8.5 ft. The mean width was 12.5 ft., and the mean thickness 4 ft. Twenty men labored 15 months to remove it from the rock; some of the cuts had a face of 16 sq. ft., and the cutting-up yielded 27 tons of copper chips. The weight was estimated at 500 tons, but I shall have more to say about this directly.

The circumstances of this work are told graphically by Geo. D. Emerson, whose statement is quoted in 'The Mineral Statistics of Michigan' for the year 1880. "They uncovered a series of masses with an eastward inclination for the length of 70 to 80 ft., and going out of sight both above and below. It was at once apparent that they had something very valuable, but they had no conception of the immense thing which a few days' work disclosed. At one convenient point they broke away behind the copper so as to get in a sand blast

*Figure 17.* **A large mass of copper hanging from the ceiling of a stope in the Baltic mine, ca. 1918. (MTU Archives)**

of five or six kegs of powder. They stripped the mass further, and again fired without result. Again they fired nine kegs of powder, and the mass remained unmoved. Breaking the rock around for a considerable distance, 18 kegs of powder were shot off without effect, and again 22 kegs, and the copper entirely undisturbed at any point After further clearing, 25 kegs were shot off under the copper, and it was thought with some effect. But a final blast of 30 kegs, or 750 lb., was securely tamped beneath the mass and fired. As soon as the smoke cleared away a mass of copper 45 ft. long and 3 to 5 ft. in thickness, apparently very pure, and which will probably weigh 300 tons, had been shot out and was ready for cutting up. The blast had torn the immense body from its bed without exhibiting a sign of breaking or bending in any place, so great was its thickness and strength. It was torn off from other masses, which still remain in the solid rock."

They had exploded 110 kegs, or 2,750 lb. of powder! One might remark that, had the copper proved less resisting to the violent efforts of these miners, it would not have possessed the value in art and industry which we accord to it. The tenacity of the metal, as recognized by these workers underground, may have hindered its easy partition, but it certainly is one of the qualities for which it commands a price when it reaches the surface. However, the mass, whose removal is told so well in the above quotation, was undoubtedly the largest single body of metallic copper ever mined. Its weight has been variously stated in many reports as having been 500, 530, or 585 tons. Quite recently, however, certain papers covering the business of the Minesota mine were found by Mr. Samuel Brady, the manager of the Michigan mine, which is the successor of the old Minesota, and the data therein contained prove that the celebrated mass weighed 420 tons. These bodies of copper are extremely irregular in thickness; they are ragged in form and straggle through the lode until they nearly connect with other monstrous nuggets. Such was the character of the series of masses encountered in the Bay State mine, now the Phoenix, forty years ago. These aggregated some 600 tons; but they were bodies, none of which singly exceeded 200 tons, connected by strings of metal. Therefore,

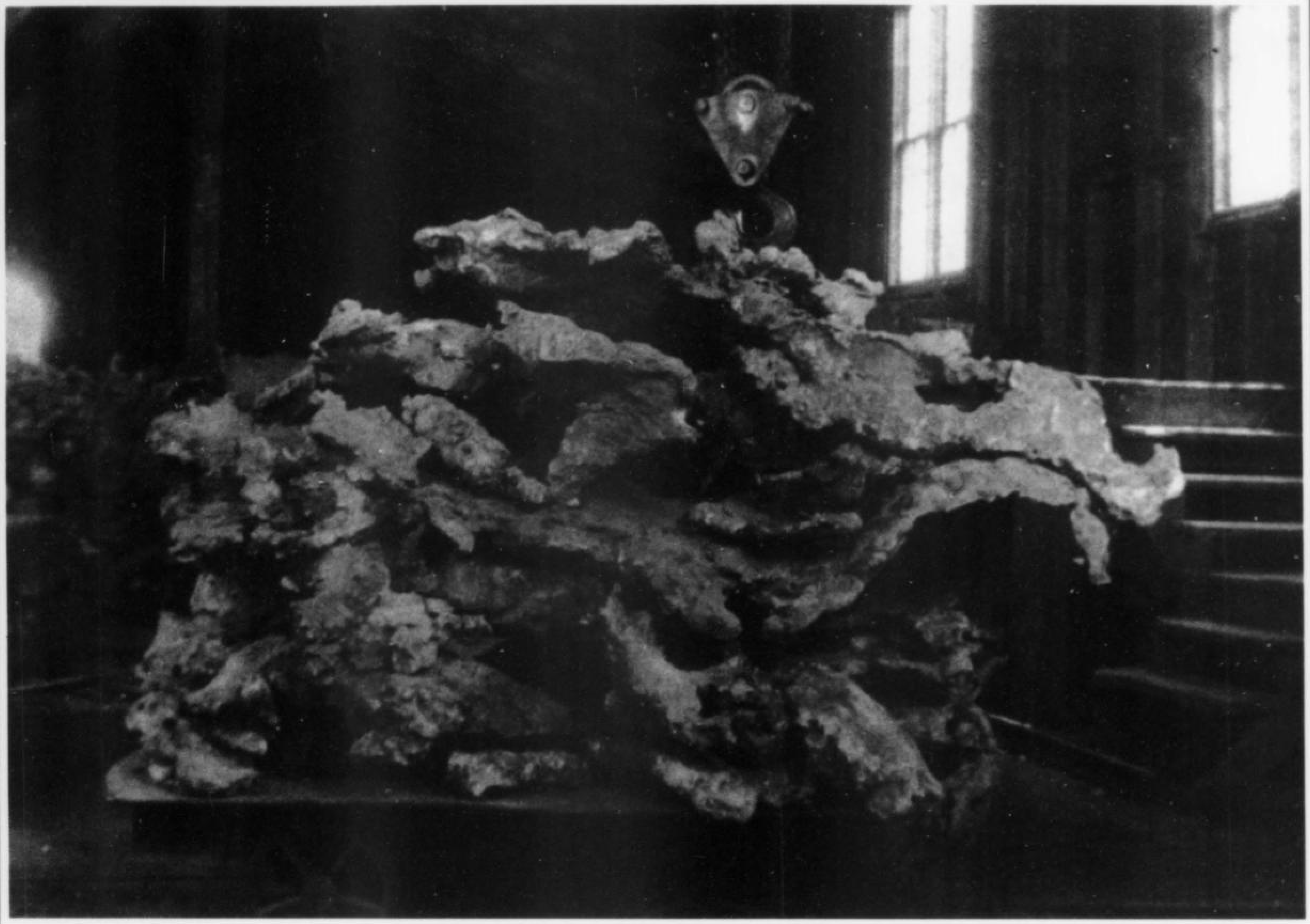


***Figure 18.* Mass copper on a flatbed ore car at the Calumet & Hecla mine, ca. 1895. (Arizona Historical Society)**

the fact remains that 420 tons is the largest single mass of native copper recorded in the history of mining.

The practice then was, and still is, to cut the mass with cape chisels having a 3/4-in. bit, the successive chips being about 1/8 in. thick. The narrow strips obtained from this operation, when made by skillful operators, and in the absence of any flaw or included rock along the course of the chisel, are taken in one cut through the entire 'mass.' The earlier method was to carry the chip about 1/8 in. thick, as stated, and of equal thickness on both sides; but later this was changed to a more rapid way, the chips thinning to an edge and alternating, as is usual with a cutting made by a chisel of this kind, the process being similar to the driving of a key-way. The narrow strips obtained from this operation are only about half the length of the groove which yielded them, because the metal becomes pressed together and thickened by the blows of the cutters. Certain men made a specialty of this work and became expert, so as to cut a square foot of surface per shift; this meant that one man held the chisel and guided it along the line of cut, while two others struck the chisel alternately with sledgehammers. The cost averaged $12 to $14 per sq. ft. Nowadays, when the cutters are not often needed and special skill is not available, the cost (when done by hand) is greater. At the Michigan mine the pneumatic hammer has been used recently for cutting mass, and with success. Mr. Brady informs me that the actual cost of cutting two masses in this mine, during the current year, was $3.15 per sq. ft., exclusive of power. The cost of cutting the 420-ton mass, previously described, appears, according to a letter of Capt. William Harris, bearing date of October 3, 1865, to have been $12 per square foot.

At the Quincy some masses have been found in recent years, but no big ones. Five or six tons is the limit for convenient handling, but, of course, this will depend largely upon the shape of the mass. Larger bodies are cut so as to yield pieces suitable for tramming and hoisting. The time taken in the cutting depends upon the shape; sometimes a narrow neck connects two outlying portions, in which case the division is facilitated. The photograph on the opposite page illustrates the cutting of a mass weighing six tons.

It will be obvious that masses of portable size are less expensive to extract than the very big ones; or, to put it in another way, six lumps of 5 tons each and needing no cutting, will yield more profit than one of 30 tons, which may require to be cut into five or six portions. It is said that the great mass of the Minesota mine did not leave much of a margin for profit, for this reason; and it is obvious, from the description already given, that a good deal of vain effort was expended in extricating that elephantine chunk; but the wages of even the 20 men mentioned, who worked 15 months to remove it, would aggregate only $18,000 at the most, and against this there would be the 420 tons of copper; this would yield about 79 per cent refined copper, or 324.17 tons, which, at $400 per ton, net cash on delivery, after deducting cost of transport, conversion and sale, would

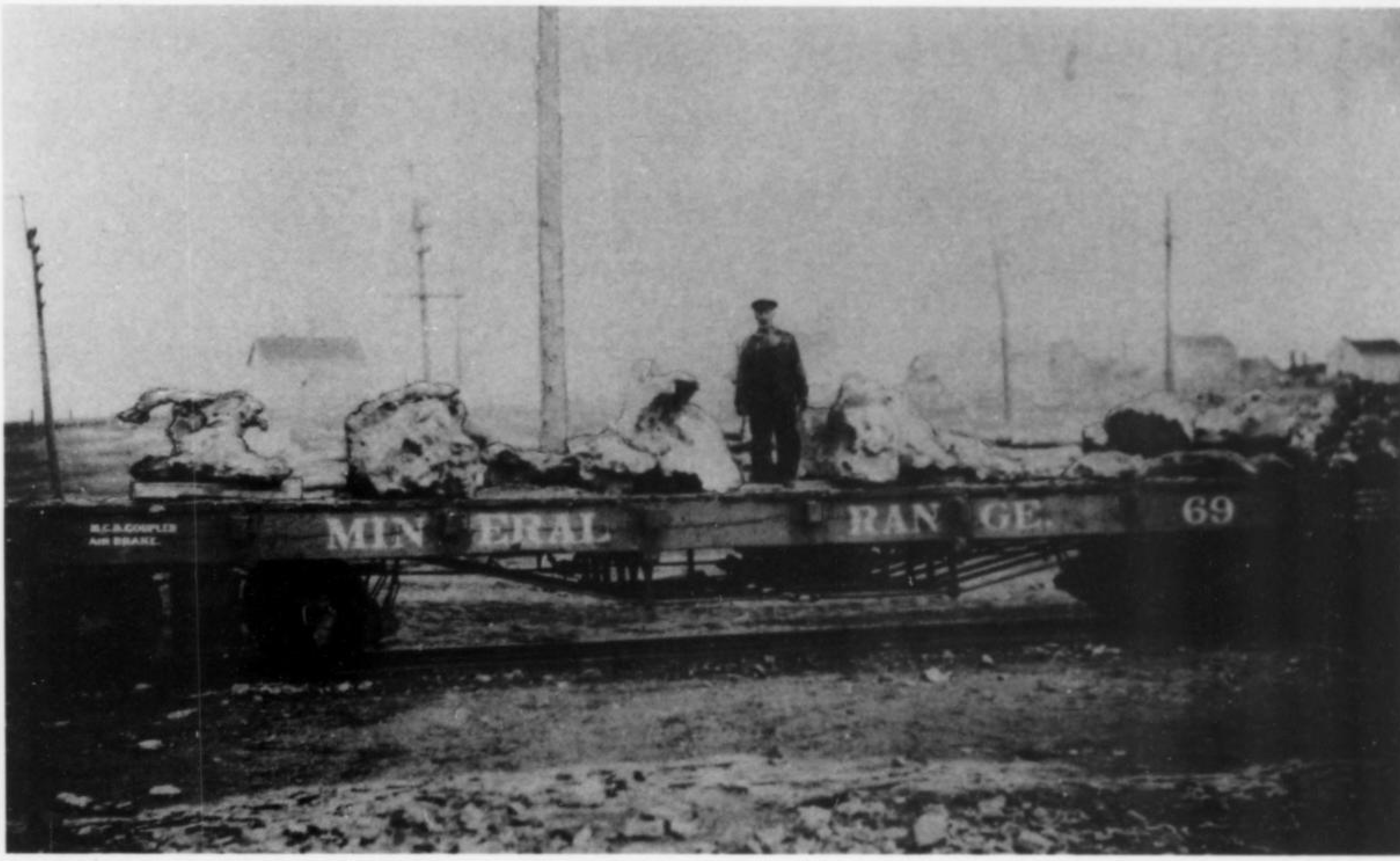


*Figure 19.* **Flat-bed railroad car taking mass copper to the smelter. (MTU Archives)**

yield a total of $129,668, so that the mining cost represents only 14 per cent of the value realized. As a matter of fact, the chips obtained in cutting are usually enough to pay for the cost of the operation. The 27 tons of chips taken from the Minesota mass were worth, under the conditions and prices of 1857, not less than $8,500; and it is certain that the cost of extracting this particular mass was extraordinary, on account of its size and the difficulty of getting it out of the lode. It can be asserted confidently that no one in the Lake Superior country is afraid to encounter mass copper for fear it should prove unprofitable!

Incidentally, it will be interesting to refer to the occurrence of native silver. The largest piece of pure silver found within the last few years was in the Mass mine, and it weighed 12 lb. This piece formed part of the Michigan mineral exhibit at St. Louis. In 1873 a small boy, while 'cobbing' or selecting bits of copper rock in the dump of the National mine, at Rockland, broke, from a piece of conglomerate, a lump weighing 16 lb. Capt. J. C. Thomas, now at the Michigan mine, and formerly at the Cliff, states that he has seen pieces of practically pure metal weighing from 25 to 30 lb. taken from the Cliff mine, as much as $500 worth being extracted in a single night by the men, who presumably did not report the fact to the office. Many thousands dollars have been taken from the mines of Lake Superior in the form of silver secreted by workmen, not to mention the specimens which now enrich museums all over the world.

# GEOLOGY

## Background

The native copper deposits of the Keweenaw Peninsula have intrigued investigators for over 150 years. When the first serious attempts to study the district were undertaken following Douglass Houghton's 1841 report, native copper was still considered very rare and economic concentrations of the native metal were unprecedented. Early investigators were perplexed by the deposits and assumed the copper to have been emplaced in a molten state, accompanying or sometime following the extrusion of the host basalt. It was not until the theories of plate tectonics and continental drift became widely accepted that a viable explanation for the lithologies and structures of the district became available. Even then the mineralizing solutions were believed to have had a magmatic origin. Recent studies by Scofield (1976) and others have indicated that the mineralizing solutions consisted of formational brines which were heated by burial and migrated up porous zones in the tilted and faulted host rocks, leaching elements from the rocks in passing and depositing them nearer the surface. The extent to which magmatic solutions may have interacted with these formational brines is still unknown.

Excellent detailed accounts of the geology and mineralogy of these deposits can be found in Butler and Burbank's *U.S.G.S. Professional Paper* 144 (1929), in the works of Stoiber and Davidson (1959), White (1968), Jolly and Smith (1972), Heinrich (1976), Scofield (1976), and in GSA Memoir 156 edited by Wold and Hinze (1982), among others. A number of additional works for the interested reader are listed in the bibliography.

## Geologic History

Approximately 1.2 billion years ago the mid-continent region of present North America was ripped apart by an incipient rift system which extruded vast quantities of flood basalts from fissures and volcanoes. The rift failed after 100 to 200 million years of intermittent volcanism, leaving a sinuous scar of mafic extrusive and intrusive rocks stretching across the central part of the continent. Geophysical surveys have traced this feature from eastern Kansas northward into western Lake Superior. From there it curves southward through eastern Lake Superior and into the lower peninsula of Michigan. This ancient rift system is presently exposed only in the western portion of the Lake Superior district. Volcanism in this area peaked about 1.1 billion years ago with the extrusion of over 7,400 meters of basalt and andesite flows (the Portage Lake Volcanics) in a slowly subsiding structural basin. Clastic sedimentation followed, and continental glaciation blanketed the region with up to 175 meters of till and outwash.

## Rock Types

### *Extrusive Rocks*

The first extrusive rocks to issue from the fissure system were the two flows of the South Range Volcanics or Powder Mill Group. The earlier of the two, the Siemens Creek Formation, consists of a basalt flow with pillow structures at its base and some quartzite inclusions from the underlying basement of older metasediments. This indicates extrusion into a shallow basin with some water and reworked or unconsolidated sediments present. The Kallander Creek Formation followed with flows of intermediate composition. The South Range Volcanics are poorly exposed but are believed to exceed 6,000 meters in thickness. Core samples examined show some similarities to the mineralogy and alteration observed in the overlying Portage Lake Volcanics.

The Portage Lake Volcanics consist of several hundred separate flows with thicknesses ranging from less than 1 meter to more than 500 meters. Textures (pipe amygdules) and mineralogy of the bases of these flows indicate they were extruded under subaerial conditions onto fairly wet surfaces. These surfaces were probably composed of moist sediments or the weathered tops of previous flows. The flows were extruded from several sources along the fissure system and often vary laterally in thickness with respect to each other.

A total of 22 interflow conglomerates are included within the Portage Lake Volcanics. These predominately felsic sedimentary beds include both conglomerates and sandstones derived from the older metasediments and volcanic highlands exposed around the basin margin, with only minor contributions from the younger basaltic flows. The conglomerate beds may reach thicknesses of 120 meters but pinch and swell laterally and often pinch out entirely, leaving the boundaries between flows marked by thin layers of weathered basalt. The conglomerate units were deposited by fluvial systems and as alluvium or piedmont fans, possibly under arid to semi-arid conditions.

### *Clastic Rocks*

The Portage Lake Volcanics are overlain by a group of sedimentary rocks of Precambrian age known as the Oronto Group, which consists of the Copper Harbor Conglomerate, the Nonesuch Formation and the Freda Sandstone.

The Copper Harbor Conglomerate is composed of the Great Conglomerate, the Lake Share Traps and the Outer Conglomerate in ascending order. The Great Conglomerate is very similar to the interflow conglomerates of the Portage Lake Volcanics and is up to 710 meters thick. The Lake Shore Traps, which represent the last gasp of Keweenawan extrusive volcanism, are a series of flows interlayered with the conglomerates, and are similar to the basalts of the Portage Lake Volcanics. They reach a total thickness of up to 600 meters in the northern portion of the district and thin towards the south, reaching a thickness of 300 meters near Calumet. The flows pinch out completely near Houghton and reappear further south in the district. The Outer Conglomerate is the uppermost unit of the Copper Harbor Conglomerate and may reach thicknesses of 800 meters or more. The Copper Harbor Conglomerate represents an alluvial-fan clastic wedge with minor extrusives; it reaches thicknesses of up to 2,100 meters. Stromatolites within the Outer Conglomerate indicate deposition in shallow ephemeral lakes under arid to semi-arid conditions.

The Nonesuch Formation consists of 75 to 215 meters of dark gray, unmetamorphosed, argillaceous siltstone with subordinate sandstone and shale units of Precambrian age. It is conformable and often gradational with the Copper Harbor Conglomerate, and may be traced northward from Wisconsin to near Calumet, where it dips beneath Lake Superior. The Nonesuch Formation is locally hydrocarbon-rich and was deposited under reducing lacustrine and deltaic conditions.

The Freda Sandstone conformably overlies the Nonesuch Formation and is gradational with it. It is a red-brown sandstone with subordinate siltstone which reaches thicknesses in excess of 1,500 meters in Michigan and may exceed 4,000 meters in other portions of the district. The sands were probably deposited as fluvial and floodplain deposits under more oxidizing conditions than the Nonesuch Formation.

It is generally accepted that the Oronto Group is overlain, probably conformably, by a series of red sandstones, conglomerates, siltstones and shales known as the Jacobsville Formation in Michigan and the Bayfield Formation in Wisconsin. An alternative theory holds that the Jacobsville is time-equivalent to the Portage Lake Volcanics (Babcock, 1974, 1975 and 1976). These sandstones represent fluvial deposition under mostly oxidizing conditions and reach thicknesses of 900 to 3,000 meters.

### *Intrusive Rocks*

Intrusive rocks are not common within the copper district. They consist of mafic dikes, which appear to be related to the onset of volcanic activity, and younger, more acidic intrusions. A number of rhyolite and related intrusions are scattered throughout the district; in the Porcupine Mountains of Ontonagon County, a few rhyolite flows occur within the uppermost Portage Lake Volcanics. A few of these bodies are mineralized but only the felsites of the Indiana mine and the syenodiorite and granophyre of the Mt. Bohemia intrusion have shown economic potential. The structural relationship between these intrusions and the country rocks, particularly a small rhyolite plug northeast of Houghton which intrudes the Freda Sandstone, indicates a relatively young age for this acidic volcanism.

## Structural History

The structural history of the Michigan copper district started with the incipient continental rifting mentioned previously. This initially took the form of a gently subsiding basin which may have been fault-bounded, as is typical of current rift-valley grabens. Continued subsidence throughout the deposition of the volcanic and clastic sequences resulted in a progressive steepening of the dips of earlier flows and a thickening of individual flows basinward (Butler and Burbank, 1929). An angular divergence of up to 15 degrees thus exists between the dips of the uppermost units of the Portage Lake Volcanics and the more steeply dipping basal units. This angular divergence increases to approximately 20 degrees when measured from the top of the younger Copper Harbor Conglomerate.

The rift system began to fail and volcanism became less intense at about the time of deposition of the Copper Harbor Conglomerate. The deposition of the Lake Shore Traps and the later acidic extrusive and intrusive rocks marked the effective end of volcanism in the district. Subsidence of the Lake Superior Basin continued throughout the deposition of the Nonesuch Formation, Freda Sandstone and the Jacobsville Sandstone. This was followed by a period of compressive tectonic activity which resulted in numerous folds and faults, especially along the edges of the Lake Superior Syncline.

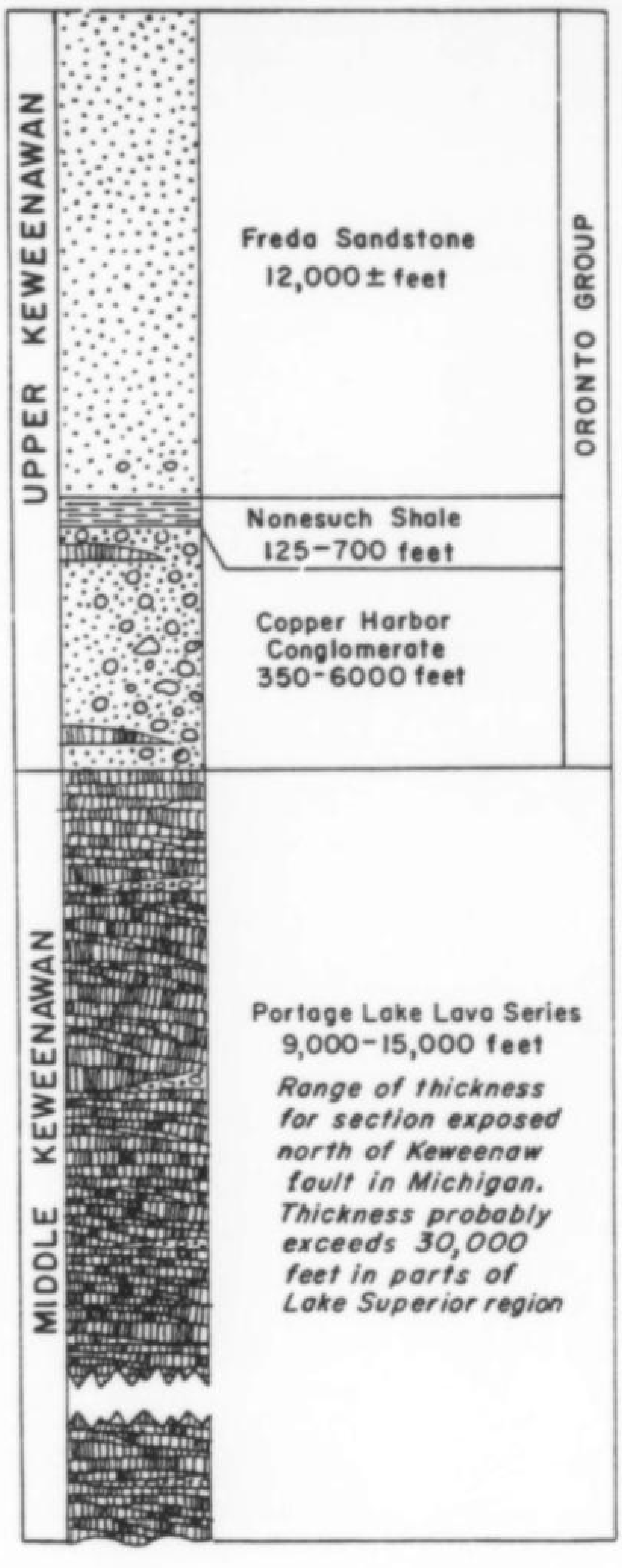



*Figure 20.* **Geologic column of the Portage Lake volcanics and overlying sedimentary rocks of the Keweenaw Peninsula (White, 1968).**

The most important fault in the district is the Keweenaw Fault; this structure defines the eastern boundary of the copper district for a distance of between 160 and 250 kilometers. The Keweenaw Fault is a high-angle to low-angle reverse fault which has thrust the basalts of the Portage Lake Volcanics into contact with the younger Jacobsville Sandstone to the east. The fault strikes approximately parallel to the strike of the basalt flows and is displaced intermittently along its length by other cross-cutting faults. Drag along the Keweenaw Fault has resulted in tilting of the Jacobsville Sandstone to vertical in at least one area, and has been reported to have overturned beds of the volcanic sequence in one mine (Butler and Burbank, 1929).

Numerous other faults occur in the district, including bedding plane faults and steeper faults, both normal and reverse, which cut the volcanic sequence at angles ranging from nearly parallel to nearly perpendicular to the strike. These faults range from minor fractures and joints with little or no apparent displacement to major faults with displacements of dozens of meters.

A major change in strike in the Portage Lake Volcanics occurs northeast of Calumet. Folding and faulting at this flexure effectively twisted the volcanic sequence, resulting in a steepening of the dips of the formations by 20 to 30 degrees, measured from north to south. Steepening of the dips continues south of Portage Lake, reaching nearly vertical at the Baltic and Champion mines.

## Mineralization

Mineralizing solutions are believed to have consisted of saline, slightly alkaline fluids at temperatures of between 180° and 300° C (Scofield, 1976). The solutions percolated upward following porous fault and fracture zones, amygdaloidal flow tops (and bottoms) and interflow conglomerate units. Timing of the mineralization was probably concurrent with the final compressional tectonic activity and subsequent relaxation. This is evident from abundant mineralized faults and fractures, reactivation of mineralized faults resulting in "slickened sides," mineralized bodies abruptly truncated by faults, and other geologic criteria (Butler and Burbank, 1929). Bornhorst *et al*. (1988) have dated the mineralizing event at approximately 1,050 million years.

Deposition of ore and gangue minerals occurred in the same porous areas which served earlier as channelways for the solutions and resulted in three major deposit types: fissure deposits, amygdaloid deposits and conglomerate deposits. The ore mineralogy of each is roughly similar, consisting of native copper and native silver as the primary ore minerals with copper sulfides and arsenides as isolated but sometimes important secondary ore minerals. Gangue consists of calcite, quartz, epidote, pumpellyite, prehnite and various zeolites and related minerals.

Sulfide mineralization is sparse in the district and has been of economic importance only locally.

### *Fissure Deposits*

The earliest and the most spectacular deposits mined in the district have been the fissure deposits. The Copper Country boasted fissure deposits ranging from small fractures filled with calcite, laumontite and other gangue minerals, up to large fault zones which contained masses of native copper weighing several hundred tons. Native silver was a very important by-product from these mines, often providing as much revenue as the copper itself. The fissures were found in every size and orientation, and are widely distributed throughout the district. Although the earliest mined and most famous fissures are located in the extreme northern and southern portions of the district, other fissures contributed significantly to production at both amygdaloid and conglomerate mines where they were encountered.

### *Amygdaloid Deposits*

Mineralization in the amygdaloidal basalt flows of the Portage Lake Volcanics was confined largely to the vesicular and fragmental portions in the upper and lower extremes of the flows. The massive interiors of the flows were not mineralized, nor were they usually altered to any great extent. Native copper filled vesicles, fractures and other voids in the brecciated flow tops, creating large low-grade deposits which are roughly stratiform in nature. Local pockets of high-grade ore in the form of masses of native copper were found where fault zones or unusually large voids were encountered in the basalts. As in the fissure deposits, native silver was an important by-product in the upper portions of the amygdaloid mines.

Alteration associated with the mineralization consisted of pervasive albitization and pumpellyitization of the basaltic groundmass with widespread deposition of epidote, pumpellyite and prehnite in vesicles and fractures.

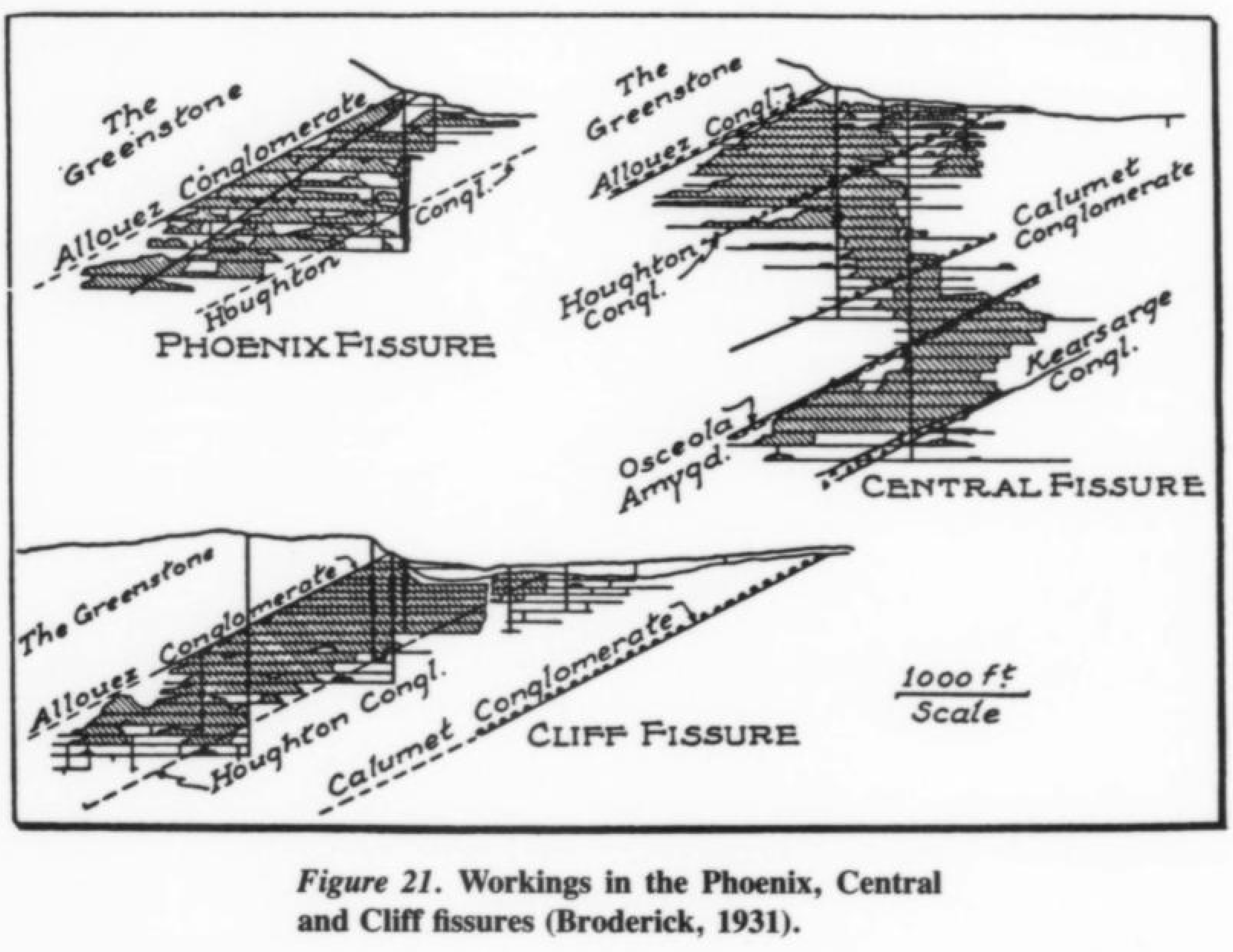



***Figure 21*. Workings in the Phoenix, Central and Cliff fissures (Broderick, 1931).**

### *Conglomerate Deposits*

Ore mineralization in the conglomerate deposits consists of native copper and lesser amounts of silver which fill interstitial voids around clasts in the conglomerates and associated sandstones. The copper often replaces the fine-grained matrix of the conglomerates, resulting in pebble-size to cobble-size clasts surrounded by native copper and silver. Native copper also replaced cobble-size to boulder-size clasts,

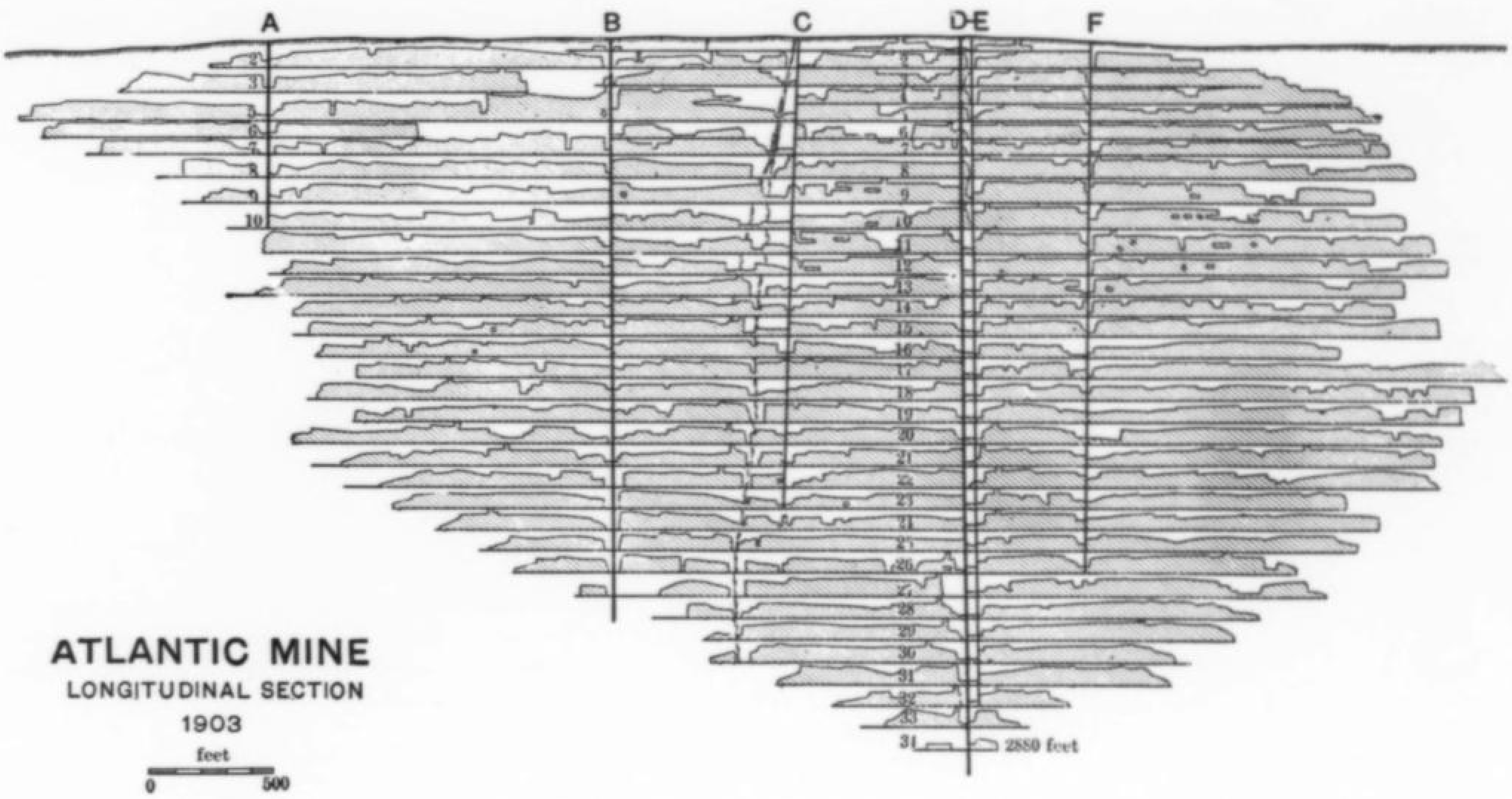



***Figure 22*. Workings in the Atlantic mine in 1905 (Rickard).**

resulting in copper pseudomorphs of the boulders or hollow casts of the boulders where replacement was incomplete. These casts, locally termed "skulls," frequently contained chlorite interiors with quartz and feldspar relicts of the original material. Copper pseudomorphs of laumontite, feldspars and other minerals were often found within the skulls and in rare cases their interiors are lined with copper crystals. Late-stage minerals such as barite have also been found within the chlorite-filled interiors of the skulls.

Alteration within the conglomerate deposits was very similar to that of the amygdaloid deposits. In addition to the chlorite alteration of clasts mentioned above, deposition of epidote and pumpellyite was common, although on a vastly lesser scale than that observed in the amygdaloids.

### *Nonesuch Shale Deposits*

The Nonesuch Shale hosts copper mineralization of economic significance in Ontonagon County near White Pine, Michigan. At the site of the White Pine mine, the formation is approximately 200 meters thick and overlies about 115 meters of the Copper Harbor Conglomerate. Mineralizing fluids are believed to have traveled laterally through the conglomerate and percolated upward to react with the pyritiferous siltstones, shale and sandstones above. Mineralization is largely confined to the lower 20 meters of the Nonesuch Shale and the uppermost portions of the underlying Copper Harbor Conglomerate. The ore consists of native copper and silver in the lowermost portion of the mineralized body and grades upward into a large, disseminated sulfide (predominantly chalcocite) body which hosts the majority of the ore mined. Native silver is a common by-product in the lower portions of the orebody and in fracture fillings.

### *Other Sulfide and Arsenide Deposits*

Although various sulfides have been reported from throughout the district, significant concentrations other than the Nonesuch Shale deposit mentioned above are rare. The Baltic Amygdaloid in Houghton County hosted large amounts of chalcocite with some other sulfides and arsenides, and the Baltic and Champion mines exploited these minerals along with the usual native copper.

Other areas of significant sulfide mineralization have been reported to be associated with the acidic intrusives at Mt. Bohemia and elsewhere in Keweenaw County.

Copper arsenides and arsenical copper were common in several portions of the district, and arsenide veins were mined as ore at the Mohawk mine in Keweenaw County. Arsenides of nickel and cobalt were sometimes associated with those of copper.

### *"Oxide Zone" Mineralization*

There is no evidence of widespread supergene enrichment in the deposits of the Copper Country. However, isolated localities exist which host minerals associated with the oxidized zones of supergene deposits in other mineral districts. These minerals probably occur as a result of deep weathering of the deposits. The most important of these deposits is the Allouez mine in Keweenaw County. Cuprite crystals in excess of 7 mm have been found associated with massive cuprite, chrysocolla and native copper in the Allouez Conglomerate at this site. The abundance and size of the cuprite crystals and the quantity and distribution of other oxide-zone minerals present at this locality indicate a pre-mining origin for these minerals.

A similar deposit of chrysocolla and associated minerals, including a host of microminerals which are unusual for the district, occurs in the amygdaloid at the Algomah mine in Ontonagon County. The major ore minerals at this small mine site were apparently chrysocolla and a black copper oxide identified as paramelaconite.

A third anomalous deposit in the district is associated with the intrusions at Mt. Bohemia and the Mendota mine in Keweenaw County. Mineralization consisting of native copper, chalcocite and other sulfides is present within the intrusive bodies, in the adjacent amygdaloidal flow tops and in associated fissures (Robertson, 1975). Of most interest to the collector is the calcite gangue of the Lac La Belle and Mendota fissures which hosts a variety of minerals including outstanding malachite crystals. The malachite occurs as balls of radiating acicular crystals which may exceed 1 cm in diameter and as blocky crystals 5 mm or more in length. The crystals occur singly and as rosettes on calcite crystals which are often coated with chrysocolla and manganese oxide dendrites. Small amounts of chalcocite

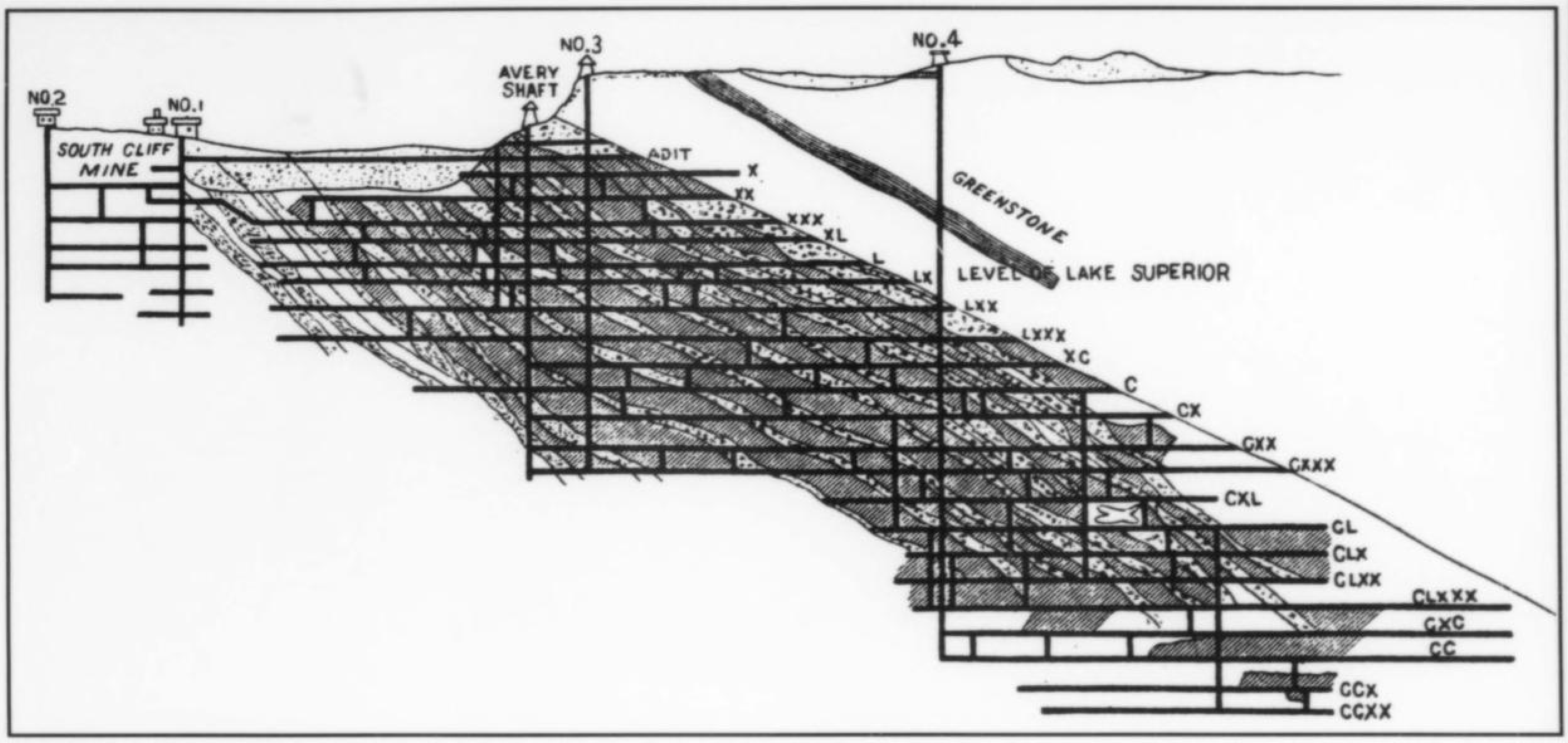



*Figure 23.* **The Cliff mine workings in 1881.**

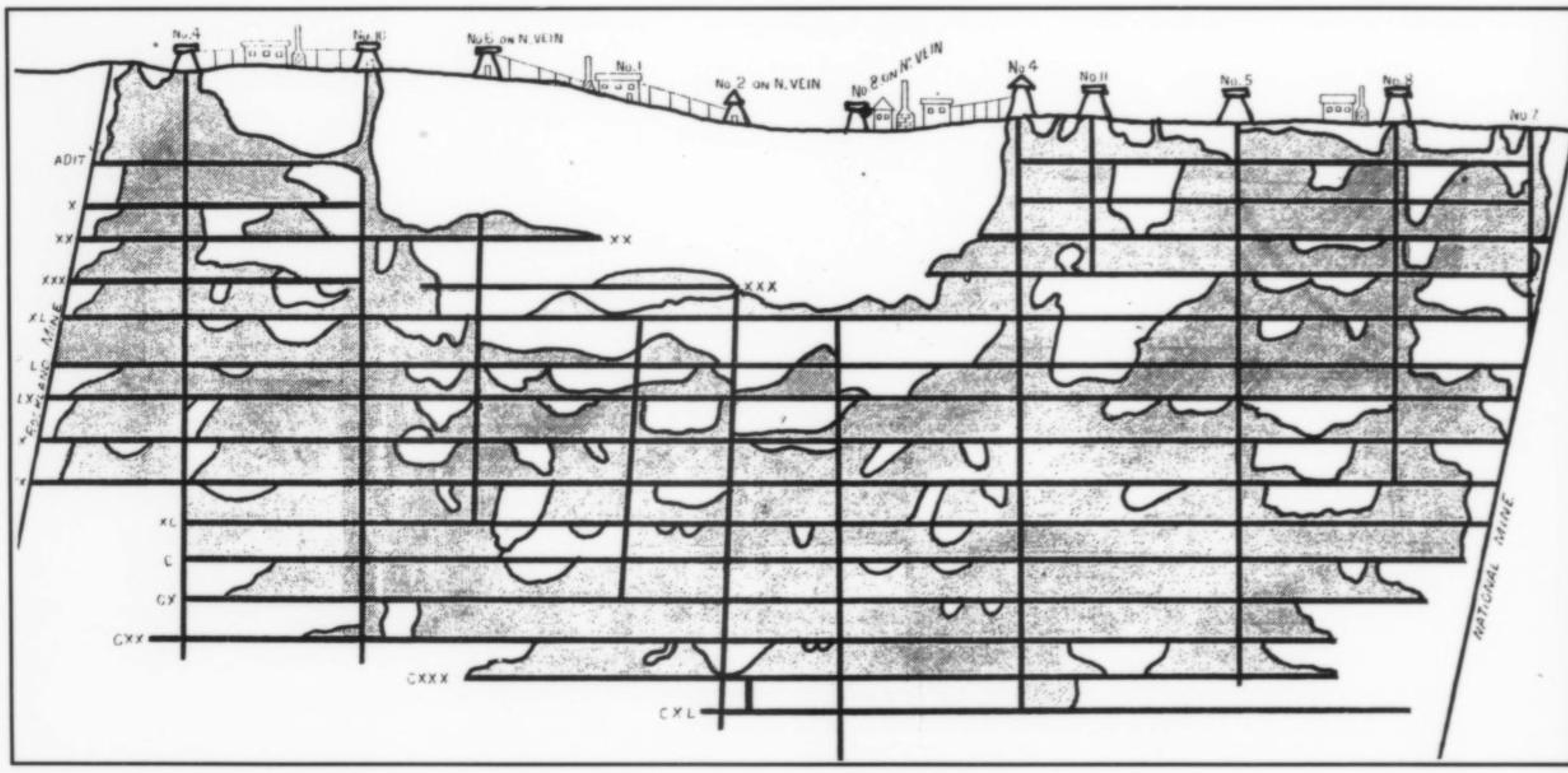



*Figure 24.* **The Minesota mine workings in 1881.**

and adularia found in the calcite gangue are believed to be relicts of a calcite-chalcocite-adularia vein system (K. Schafer, personal communication). It is believed that this mineral assemblage was acted upon by meteoric waters resulting in the deposition of a secondary suite of oxide-zone minerals. Whether this represents a true supergene process or merely deep weathering of the chalcocite-rich veins is not known.

Other occurrences of oxide-zone minerals which have an unquestioned pre-mining origin are rare but can be found in isolated instances in the district, as crystals that are typically of very small size. Where present, such crystals are usually protected as inclusions within gangue minerals associated with the primary mineralizing event. Some examples include malachite inclusions in prehnite from the Centennial #1 and #2 mines, kinoite inclusions in quartz and calcite from the Laurium and La Salle mines, and an almost ubiquitous cryptocrystalline coating of cuprite and/or tenorite on uncleaned copper crystals. This coating of copper oxides is prevalent on copper crystals throughout the district, often including those encased in calcite. This indicates that oxidizing conditions existed at least locally during the final stages of mineralization, possibly resulting from ore solutions mixing with meteoric waters.

# OCCURRENCES

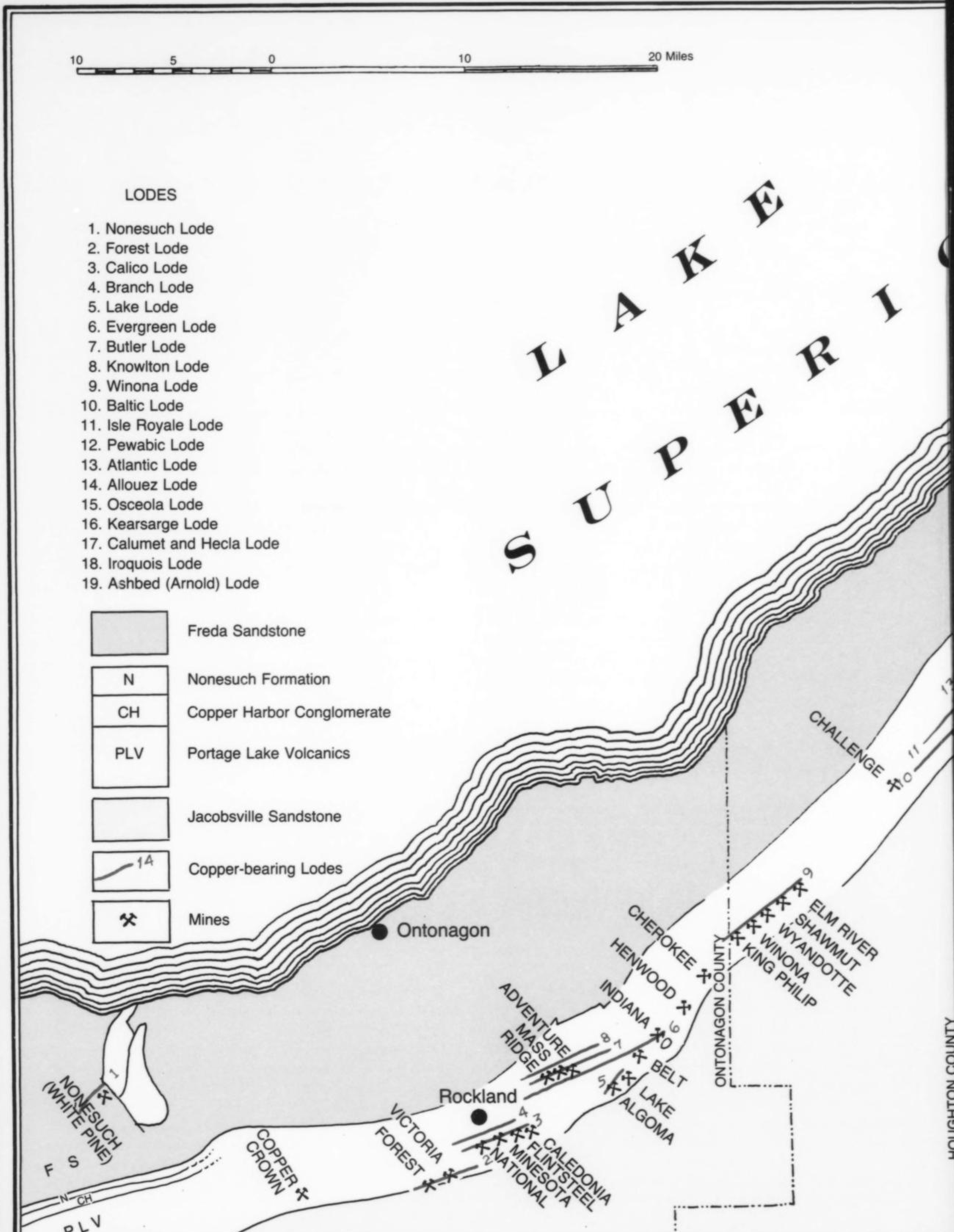
Although excellent crystallized copper and silver specimens have been produced from most of the major mines, some mines have been credited with more specimens than others. This may have resulted from an unusually large number of specimens produced from a specific locality, the relative ease of removing specimens from a particular site, old collections preserved in museums reflecting the original collectors' association with or preference for specimens from certain mines, or the notoriety of a mine caused by historical events or special treatment given to it by a popular author. All too frequently this last presents a complicating factor in that specimens whose exact locality of origin are unknown may be erroneously attributed to a locality which is currently well-known, either through ignorance of other localities or in the hope of increasing its value to collectors particularly interested in that locality. However, well-crystallized specimens of copper and/or silver were common wherever large voids were encountered in the heavily mineralized portions of the district. This is particularly true of the fissure and amygdaloid mines where large voids are fairly common, but less true in the conglomerate mines where large voids are usually confined to fault zones. The interstitial spaces of the conglomerate matrix are generally too small to allow the development of large, well-formed crystals.


Because many mines in the district worked more than one lode while in other cases several mines worked the same lode, and because the character of each lode was relatively constant throughout its mineralizated extent, it is more appropriate to discuss occurrences in each fissure and lode deposit rather than the individual mines. In the following discussion, much of the lithologic and historic information has been compiled from Butler and Burbank (1929), various issues of the *Copper Handbook* (1900–1914) and the *Mines Handbook* (1916–1931), other works cited in the bibliography, and the author's own observations. Production figures are largely from White (1968).

**The Phoenix Fissure**

In 1844, the Lake Superior Copper Company became the first organized company to explore and acquire land in the district. Several veins in Keweenaw County were discovered and the ground looked good, but the work proved fruitless, and in 1849 the Lake Superior Copper Company sold its holdings to the Phoenix Copper Company. This included the future site of the famous, but ill-fated, Phoenix mine which produced over 17 million pounds of copper, over 25,000 ounces of silver and many of the finest copper specimens in existence, but no profit.

The Phoenix Copper Company worked the fissure from 1850 to 1853. From 1855 to 1917 the company worked intermittently on the nearby Ashbed amygdaloid of the Phoenix and Garden City (later Caton Mining) properties, and work was not recommenced on the Phoenix and adjacent Robbins (West Vein) fissures until 1863. The Phoenix Copper Company purchased the Bay State Mining Company in 1868, became the Phoenix Consolidated Copper Company in 1899, and later acquired the St. Clair shaft on the nearby St. Clair fissure. The Phoenix Consolidated Copper Company was sold to the Keweenaw Copper Company in 1923 and was later acquired by the Calumet & Hecla Consolidated Copper Company. In all, the Phoenix fissure was opened by three shafts, the Robbins (West Vein) fissure by three



10
5
0
10
20 Miles
LODES
1. Nonesuch Lode
2. Forest Lode
3. Calico Lode
4. Branch Lode
5. Lake Lode
6. Evergreen Lode
7. Butler Lode
8. Knowlton Lode
9. Winona Lode
10. Baltic Lode
11. Isle Royale Lode
12. Pewabic Lode
13. Atlantic Lode
14. Allouez Lode
15. Osceola Lode
16. Kearsarge Lode
17. Calumet and Hecla Lode
18. Iroquois Lode
19. Ashbed (Arnold) Lode
Freda Sandstone
N
Nonesuch Formation
CH
Copper Harbor Conglomerate
PLV
Portage Lake Volcanics
Jacobsville Sandstone
14
Copper-bearing Lodes
Mines
LAKE
SUPERI
Ontonagon
Rockland
CHALLENGE
CHEROKEE
HENWOOD
INDIANA
ADVENTURE
MASS
RIDGE
BELT
LAKE
ALGOMA
ELM RIVER
SHAWMUT
WYANDOTTE
WINONA
KING PHILIP
ONTONAGON COUNTY
HOUGHTON COUNTY
NONESUCH
(WHITE PINE)
VICTORIA
FOREST
COPPER
CROWN
CALEDONIA
FLINTSTEEL
MINESOTA
NATIONAL
F S
N
CH
PLV

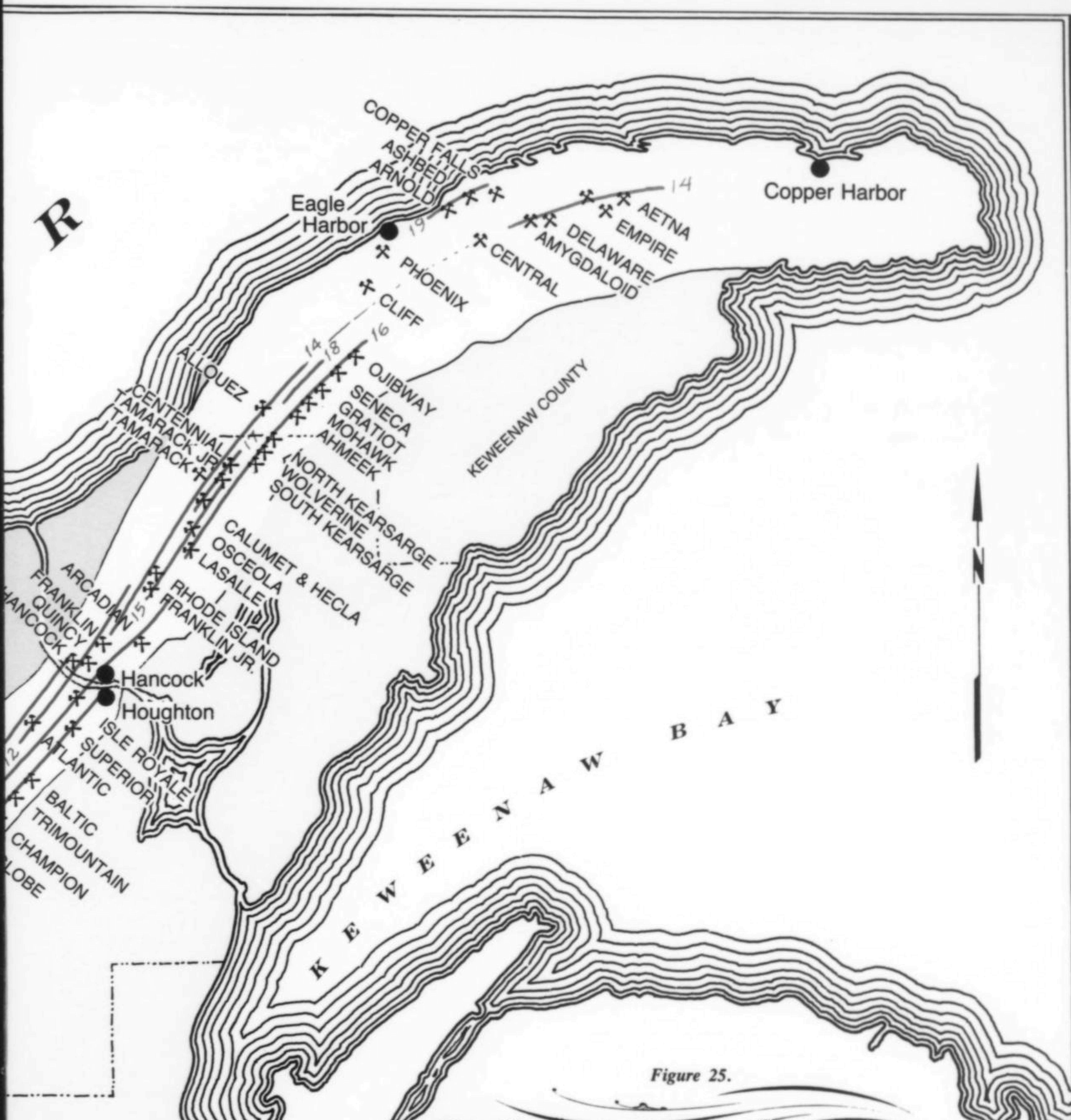

R
COPPER FALLS
ASHBED
ARNOLD
Eagle Harbor
Copper Harbor
AETNA
EMPIRE
DELAWARE
AMYGDALOID
CENTRAL
PHOENIX
CLIFF
ALLOUEZ
CENTENNIAL
TAMARACK JR.
TAMARACK
OJIBWAY
SENECA
GRATIOT
MOHAWK
AHMEEK
NORTH KEARSARGE
WOLVERINE
SOUTH KEARSARGE
KEWEENAW COUNTY
CALUMET & HECLA
OSCEOLA
LASALLE
RHODE ISLAND
FRANKLIN JR.
ARCADIAN
FRANKLIN
QUINCY
HANCOCK
Hancock
Houghton
ISLE ROYALE
SUPERIOR
ATLANTIC
BALTIC
TRIMOUNTAIN
CHAMPION
LOBE
K E W E E N A W   B A Y
N
Keweenaw
MINES & LODES
WEW

*Figure 25.*

shafts, the St. Clair and Babbitt fissures by one shaft each, the Phoenix Ashbed workings by six shafts and the Garden City Ashbed workings by four shafts.

The Phoenix mine has produced many outstanding mineral specimens but there is little hope of determining in which of the many workings most specimens originated. Phoenix copper crystals exhibit a variety of tetrahexahedral forms as well as euhedral dodecahedrons, octahedrons and cubes, myriad combinations resulting in more complex crystal habits. A mottled black-and-red tarnish is typical of many Phoenix mine copper specimens, but such tenorite and cuprite coatings were common from all fissure deposits and many amygdaloid lodes. The feature is unfortunately not diagnostic of any one mine.

Few silver crystals were available for study from this locality and those were distorted tetrahexahedrons *h*. Copper and silver crystals are usually associated with one or more additional species including calcite, quartz, analcime, apophyllite, barite, prehnite and epidote.


Many of these contain copper inclusions, and calcite crystals occasionally enclose copper phantoms. Analcime crystals, to 1 cm or more in diameter, may exhibit complex groupings such as those described by Penfield in 1885. These sometimes coat calcite or copper crystals, themselves being partially covered by small (1 mm or less), stubby, milky quartz crystals.

**The Cliff Fissure**

The Cliff fissure, in Keweenaw County, was first opened by the Cliff mine (Pittsburgh and Boston Company) in 1845. The Cliff mine was the first mine in the district to produce copper by systematic mining techniques, and became the first to show a profit when $60,000 was paid in dividends in 1849. A total of $2,518,620 was paid out in dividends from 1849 to 1883, making the Cliff one of only 3 fissure mines to show an overall profit.

After the original discovery at the Greenstone amygdaloid bluff, the fissure was traced to the northwest and southeast a total of almost 2 miles, and in 1853 and 1859 the South Cliff and North Cliff mines were reorganized from the original Pittsburgh and Boston holdings. The Cliff property was sold to the Cliff Copper Company in 1871, and the mine remained open until 1887. The property was later purchased and explored by the Calumet & Hecla Consolidated Copper Company. The fissure was opened by a total of five shafts at the South Cliff and four shafts and an adit at the North Cliff mines. Total production from the Cliff fissure exceeded 38 million pounds of copper (Butler and Burbank, 1929) and 60,000 ounces of silver (Olson, 1986).

Many fantastic cabinet-size specimens of crystallized copper and silver have been produced from the Cliff fissure. These are commonly associated with calcite, quartz, analcime, apophyllite, prehnite, epidote or pumpellyite. Microcrystals of these still abound on the waste rock piles of the Cliff workings. Fine specimens of arborescent copper crystal clusters to small cabinet size exhibiting cube, octahedron and tetrahexahedron *h* faces have been (recently?) collected from the North Cliff area. Silver crystals from the Cliff fissure exhibit the cube modified by tetrahexahedron *h* in smaller crystals, and also the branching clusters of elongated, twinned tetrahexahedrons that are so typical of the district, in larger crystals.

**The Copper Falls Fissures**

The Copper Falls Company began work in 1845 on the Old Copper Falls fissure in Keweenaw County which was exposed in the falls of Owl Creek (Butler and Burbank, 1929). The Pethrick Mining Company was set off from the original property in 1861 to mine the nearby Pethrick fissure (later known as the Copper Falls fissure) and reorganized into the Ashbed Mining Company in 1880. These companies mined six fissures and the adjacent Ashbed Amygdaloid lode. The Old Copper Falls fissure hosted two shafts, the Copper Falls (Pethrick) fissure carried nine shafts, the Owl Creek fissure had five shafts, the Child and Bigelow fissures each had one shaft, and the Hill fissure hosted no less than nine shafts. In addition, two shafts were opened for the Ashbed workings. The Arnold Mining Company, formed in 1863 to mine the Ashbed Amygdaloid and an associated fissure from two shafts along Jacobs Creek to the west, acquired the property of the Copper Falls Mining Company in 1898.

Mineralization of the Ashbed Amygdaloid is apparently similar to that of the adjacent fissures, and there is no readily discernible difference in specimens from the fissures and amygdaloid. Copper and silver crystal specimens are generally less common from this area than from other prominent fissure deposits. An outstanding exception consists of a number of fine, small (1 to 5 mm), hoppered, cubic silver crystals associated with corroded copper, slightly weathered prehnite, and barite from a small occurrence near the Copper Falls fissure. This is a surface exposure, now worked out, reportedly discovered by a local prospector using a metal detector in 1980 (Olson, 1986).

Fine datolite crystals up to 5 mm in diameter, usually containing copper flecks as inclusions which result in a pinkish cast, brick-red analcime and natrolite, and calcite have also been produced from the area.

**The Minnesota Fissure**

The Minnesota fissure in Ontonagon County was discovered in the bottom of a prehistoric mine pit in 1847 (1848?) and the Minesota

[sic] mine was opened in 1848. This was followed quickly by the National mine later in 1848 and the Rockland mine which was set off from the Minesota property in 1853. The Minesota and Rockland mines were later bought by the Michigan Copper Mining Company which in turn merged with the Mohawk Mining Company in 1923. Ore was mined from the Minnesota fissure, which occurred in and followed the strike of the Minnesota Conglomerate, the related Branch fissure and the adjacent Minnesota Conglomerate and Calico Amygdaloid. The tremendously rich Minnesota (and Branch) fissure, in addition to being the top producing fissure in the district (over 61 million pounds of copper and 21,000 ounces of silver), also has the distinction of having produced, as mentioned earlier, the largest single mass of copper discovered in the Copper Country—approximately 527 tons [or 420 tons; see p. 22]. The Minnesota fissure was opened by a total of 30 shafts, including nine of the Minesota mine, eleven of the Rockland mine, eight of the National mine, and two others to the southwest. Unfortunately, few specimens from these mines have survived.


## The Central Fissure

The Central fissure in Keweenaw County, located in 1854, was first opened by the Central mine in 1855 and produced until 1898. The Central Mining Company operated five shafts along the mile-long fissure. Total production exceeded 51 million pounds of copper and 14,000 ounces of silver, and dividends of $2,518,620 were paid out to investors, making the Central, along with the Cliff and Minesota, one of the three profitable fissure mines in the district.

The copper crystals of the Central mine are predominantly tetrahexahedrons, sometimes modified by the cube or dodecahedron, and commonly form in arborescent clusters. Associated minerals include silver, calcite, quartz, adularia, prehnite, pumpellyite, datolite and, rarely, microscopic crystals of actinolite, hematite and chalcocite. Some of the best copper specimens produced from the district originated from the Central fissure although they are usually indistinguishable from those of the Phoenix and Cliff. A major difference appears to be a general lack of apophyllite and the presence of adularia and datolite at the Central mine.

## The Pewabic Amygdaloid Lode

In 1848 the Quincy Mining Company was formed to explore the region around Portage Lake for fissure deposits. This was followed by the formation of the Pewabic Mining Company in 1853, which began exploration for fissure deposits in the same area of Houghton County. When the Pewabic Mining Company discovered the Pewabic Amygdaloid lode in 1856, both companies ceased operations on fissures and started mining the rich amygdaloidal basalts. These became the first companies to successfully mine the amygdaloid lodes in the Copper Country.


The Concord Mining Company, formed in 1864 to mine the Arcadian amygdaloid, was consolidated with the Pewabic Mining Company in 1868, separated from it in 1879, and was bought by the Arcadian Copper Company in 1898. The Franklin Mining Company (later known as the Franklin Company) began mining the Pewabic Amygdaloid in 1857. The Albany & Boston Mining Company was formed in 1860, expanded mining operations to include the Albany & Boston (Allouez) Conglomerate in 1864, became the Peninsula Copper Mining Company in 1882, and was finally sold to the Franklin


Company in 1894 and renamed the Franklin Jr. property. The Franklin Jr. property hosted four shafts which worked the Pewabic Amygdaloid, two shafts which worked the Allouez Conglomerate, and an exploration shaft on the Kearsarge Amygdaloid. The Rhode Island Mining Company was formed in 1860, although work on the first shaft was not begun until 1898. Like the Albany & Boston Mining Company, the Rhode Island Mining Company mined both the Pewabic Amygdaloid and the Allouez Conglomerate, and was eventually absorbed by the Franklin Company. The Rhode Island property hosted three shafts.

The Quincy Mining Company became the dominant company mining the Pewabic Amygdaloid, absorbing the Pewabic Mining Company in 1891, the Mesnard and Pontiac properties in 1897, and the old Franklin mine from the Franklin Company in 1908. Other properties were purchased from the St. Mary's Mineral Land Company in 1901, the Arcadian Copper Company in 1906, and the Hancock Consolidated Mining Company in 1915 and 1919. The Quincy Mining Company had 9 shafts on the Pewabic Amygdaloid, with another 3 exploration shafts on the St. Mary's property.

Other companies which mined or explored the Pewabic Amygdaloid include the Hancock Mining Company (later the Sumner Mining Company in 1873, the Hancock Copper Mining Company in 1879 or 1880, and the Hancock Consolidated Mining Company in 1906), which mined the Pewabic Amygdaloid and the "Hancock lodes" with four shafts. The Hancock lodes consisted of the Quincy, West, Hancock (Sumner) and other amygdaloids. The Naumkeg Copper Company which explored the Pewabic Amygdaloid, the Ashbed/Atlantic Amygdaloid and the "Hancock lodes" with one (?) shaft and four adits.

The Pewabic Amygdaloid actually consists of at least six separate, relatively thin amygdaloidal flows. These flows are typically brown or greenish brown in color with the flow tops oxidized to a distinctive red color. The Pewabic Amygdaloid eventually produced over 1 *billion* pounds of copper, an uncertain amount of silver, and many superb crystallized copper and silver specimens.

The Pewabic Amygdaloid is probably best known for the calcite crystals it has produced. These include water-clear individual crystals to 15 cm or more, fantastically complex twinned crystals and large, perfect scalenohedral crystals enclosing copper phantoms. The copper crystals are usually complex, twinned and distorted, exhibiting tetrahexahedral forms as well as the cube and dodecahedron. Silver crystals typically form arborescent masses of elongated twinned tetrahexahedrons. Other associated species include quartz, calcite, pumpellyite, epidote, prehnite, microcline, adularia, analcime, porcelaneous datolite, laumontite and hematite.

**The Isle Royale Amygdaloid Lode**

The Ohio and Isle Royale Mining Company, originally formed in 1845 to mine copper on the island of Isle Royale, transferred its operations to the Keweenaw Peninsula south of Portage Lake in 1852 and discovered the Isle Royale Amygdaloid (also known as the Grand Portage Amygdaloid) in Houghton County. Although this discovery predated the discovery of the Pewabic Amygdaloid, development was slow and dividends were not paid until after the company was reorganized as the Isle Royale Copper Company, Inc., in 1899.

The Portage Mining Company was formed in 1852 to mine the Grand Portage Amygdaloid, was reorganized as the Grand Portage Mining Company in 1869, and suspended operations in 1884. The Huron Mining Company was organized to mine the Isle Royale Amygdaloid in 1853, opened the Huron mine in 1855, was renamed the Agawam mine in 1868, was again renamed Houghton mine in 1871, and was reorganized as the Huron Copper Mining Company in 1880.

Following years of sporadic activity, the Ohio and Isle Royale Mining Company acquired the Huron Copper Mining Company and the Grand Portage Mining Company, becoming the Isle Royale Consolidated Mining Company in 1897. In 1899 it acquired the property of the Miners' Copper Company, formed in 1898 from the Frue and Dodge prospects, and became the Isle Royale Copper Company, Inc. The Isle Royale Copper Company had a total of seven main shafts and at least seven older, or subsidiary, shafts on the Isle Royale Amygdaloid, plus at least one shaft on the nearby Baltic Amygdaloid.

The Shelden Mining Company was formed to mine the Grand Portage Amygdaloid to the north of the Ohio and Isle Royale Mining Company property in 1853. In 1860 the property was sold and the Columbian Mining Company was organized. This company was re-

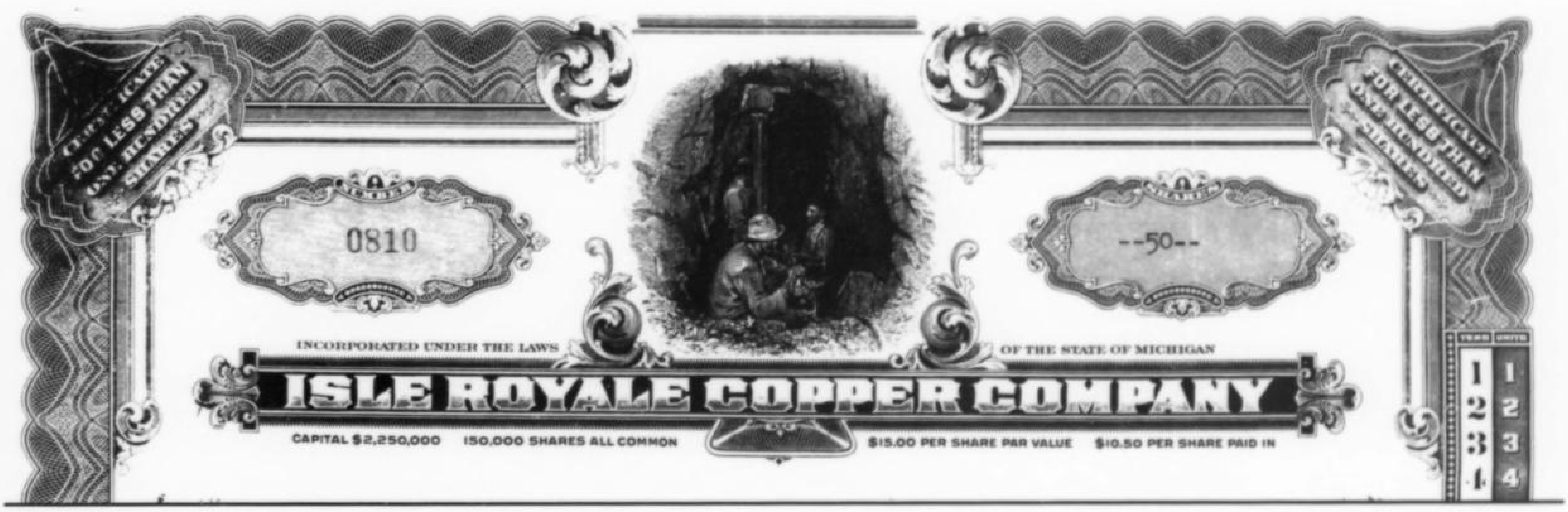

named the Shelden & Columbian Copper Company in 1864, and became idle in 1870. One shaft was operated by the Shelden & Columbian Copper Company.

The Isle Royale Amygdaloid is a coarsely fractured amygdaloidal basalt flow with a thick flow-top breccia. The flow tops are heavily oxidized and range in color from various shades of gray to brick red. Rocks in the mineralized zones are altered to a green to greenish gray color, or are bleached brown or gray with an appearance of having been burned. Approximately 341 million pounds of copper have been produced from the Isle Royale Amygdaloid.

Large copper and silver crystals from the Isle Royale Amygdaloid are rare. Usually, copper crystals occur as small (1 mm or less) individuals on prehnite, and are associated with silver, epidote, pumpellyite, quartz and calcite. Copper crystals are usually tetrahexahedrons, sometimes modified by the dodecahedron or, rarely, the octahedron. Euhedral dodecahedrons also occur. Wire copper crystals, composed of tetrahexahedrons, dodecahedrons, or combinations of the two, are common locally and may have silver crystals suspended from them. Silver crystals are also usually small and associated with copper and prehnite. Silver in this association crystallizes as the cube modified by the tetrahexahedron *h*.

Other minerals include analcime, porcelaneous datolite, laumontite, hematite, barite and saponite (as pseudomorphs after clinochlore). Calcite which crystallized late in the mineralizing sequence rarely forms as bright orange rhombohedral crystals associated with white calcite, prehnite or analcime.

Many of these minerals, usually as microcrystals, may still be collected on the old mine dumps of the Isle Royale and other mines.




**The Atlantic (Ashbed) Amygdaloid Lode**

The amygdaloidal basalt lode known as the Atlantic in the southern portion of the district and as the Ashbed in the north, was discovered in 1864 and was mined until 1906 when the Atlantic mine was destroyed by air-blasts created by massive caving of the older workings. In the north, the lode was first opened by the old fissure mines discussed previously. Companies which mined the Ashbed Amygdaloid include the Phoenix Copper Company, the Copper Falls Mining Company, the Garden City Mining Company, the Pethrick Mining Company, the Humboldt Copper Company, the Ashbed Mining Company and the Arnold Mining Company.

The Atlantic Amygdaloid was first mined south of Portage Lake by the South Pewabic Mining Company in 1865. In 1872 the Atlantic Mining Company was formed by the consolidation of the South Pewabic Mining Company and the Adams Mining Company. The Atlantic Mining Company successfully mined the lode from six shafts until 1906 when the mine was destroyed by cave-ins and air-blasts. One shaft was then opened to the southeast to explore the Baltic Amygdaloid but little ore was found. Exploration continued until 1911 when the properties of the Atlantic Mining Company were taken over by the Copper Range Consolidated Company. The Atlantic Amygdaloid was also mined by the Hancock mine on the north shore of Portage Lake.

The Atlantic, or Ashbed, Amygdaloid is a scoriaceous basalt (almost a sandy conglomerate composed of basalt fragments). Highly oxidized and largely fragmental, it is commonly chocolate-brown to red in color and soft compared to other basaltic lodes in the district. The Atlantic and other mines which worked the lode produced almost 143 million pounds of copper.

The mineralogy of the Ashbed workings are detailed under the various fissure deposits and little can be added from the Atlantic workings except for rare cryptocrystalline azurite coating small pieces of gangue material.

the north of the various Osceola Amygdaloid workings.

The Osceola Amygdaloid is largely a fragmental lode with some non-brecciated cellular amygdaloidal zones below an extensive brecciated flow top. The thickness of the lode varies considerably and abruptly along its strike. The Osceola Amygdaloid is generally highly


**The Osceola Amygdaloid Lode**

The Osceola Mining Company, formed in 1873 to mine the Calumet and Hecla Conglomerate, discovered the Osceola lode in 1877. Production began in 1879 and the Osceola Mining Company became the Osceola Consolidated Mining Company in 1879 with the acquisition of the Opechee property. In 1897 the Tamarack Junior Mining Company and Kearsarge Mining Company were acquired. With the acquisition of the Kearsarge property, renamed the North Kearsarge mine, the Osceola Consolidated Mining Company expanded its operations to include production from the Kearsarge Amygdaloid lode. This was followed by the opening of the South Kearsarge mine in 1899.

The Osceola Consolidated Mining Company worked the Osceola lode from six shafts until 1920 when production was halted. The company was taken over by the Calumet & Hecla Consolidated Copper Company in 1923, and the property has been the focus of intermittent interest since that time. In addition to its workings on the Osceola Amygdaloid, the Osceola Consolidated Mining Company holdings included three shafts on the Calumet and Hecla Conglomerate, the Tamarack Junior mine with two shafts on the Calumet and Hecla Conglomerate, and the North Kearsarge mine with four shafts and the South Kearsarge mine with two shafts on the Kearsarge Amygdaloid.

Other companies to mine the Osceola Amygdaloid lode include the Tecumseh Copper Company in 1880 with two shafts, the Centennial Mining Company in 1891 from two shafts, the Calumet & Hecla Mining Company in 1904 with six shafts, and the Allouez Mining Company with two shafts. The very similar Iroquois Amygdaloid lode was opened by the Iroquois mine with production from two shafts to

oxidized to a light or medium gray color and often has a bleached or burned appearance, especially in sandy or scoriaceous areas which resemble the Ashbed Amygdaloid. The Osceola Amygdaloid was the fourth most productive amygdaloidal lode in the district with over 560 million pounds of copper produced. Many superb specimens of copper, silver, datolite and other species have been preserved from the Osceola Amygdaloid.

Copper crystals range from clusters of large, distorted tetrahexahedrons, some modified by trapezohedrons, to small tetrahexahedral or dodecahedral crystals on prehnite. These last are commonly associated with small silver crystals and may occur as wires exhibiting tetrahexahedral development. Silver crystals to 1 cm occur as cubes modified by the tetrahexahedron *h* and as larger crystals in branching aggregates of elongated, twinned tetrahexahedrons.

Perhaps the most significant specimens to be produced from the Osceola Amygdaloid are datolite crystals, with a slight greenish cast, to 8 cm or more on a matrix of prehnite. These lustrous, euhedral crystals are the best datolite crystals from the district and compare favorably with any other datolite occurrences in the world. Other minerals produced from the lode include calcite, quartz, epidote, pumpellyite, microcline and adularia.

**The Kearsarge Amygdaloid Lode**

The most productive amygdaloid lode in the Copper Country, the Kearsarge, was discovered in 1874 and first opened by the Wolverine mine in 1882. The Wolverine Mining Company became the Wolverine Copper Mining Company in 1890 and was absorbed by the Mohawk Mining Company in 1923. The Wolverine Copper Mining Company operated four shafts on the Kearsarge lode and an exploratory shaft on the Osceola lode to the west. The Mohawk Mining Company was formed in 1898 to mine copper arsenide fissures and the Kearsarge lode from lands of the old Fulton Mining Company (formed in 1853 to mine the Fulton fissure from four shafts). The Mohawk Mining Company acquired the Wolverine Copper Mining Company and the Michigan Copper Mining Company (consisting of the old Minesota, Rockland and Superior mines) in 1923 and closed the Wolverine mine in 1925 pending further exploratory work. In all, the Mohawk Mining Company operated six shafts on the Kearsarge lode in addition to those of the Wolverine mine.

The Kearsarge Mining Company was formed in 1887 to mine the Kearsarge lode north of the Wolverine property and south of the future site of the Mohawk mine. In 1897 the Osceola Consolidated Mining Company absorbed the Kearsarge Mining Company, renamed its four shafts the North Kearsarge shafts, and, in 1899, opened the South Kearsarge mine with two shafts located to the south of the Wolverine property.

solidated Mining Company, the Centennial Copper Mining Company, the Ahmeek Mining Company, and the Allouez Mining Company in 1923 to form the Calumet & Hecla Consolidated Copper Company.

South of the Calumet & Hecla property, the Kearsarge Amygdaloid was mined by the Laurium Mining Company in 1910 (?) with one shaft, and the La Salle Copper Company in 1906 with four (or five?) shafts, and investigated by many others. North of the Mohawk property, the lode was mined by the Gratiot Mining Company beginning in 1910. The property of the Gratiot Mining Company was acquired by the Seneca Copper Corporation in 1920 which became the Seneca Copper Mining Company in 1925. In all, the Seneca mine operated four shafts, two of which were shafts of the old Gratiot mine.

Further north, the Kearsarge Amygdaloid lode was worked by the Ojibway Mining Company with two shafts, and investigated by the Kearsarge shaft of the Cliff mine and two (three?) shafts of the Miskwabik exploration, among others.

The Kearsarge Amygdaloid has been traced for over 35 miles along the Keweenaw Peninsula. Although in places it is actually two or


Between the North Kearsarge and Mohawk properties lies the Ahmeek mine. Originally formed in 1880, the Ahmeek Mining Company started its first shafts on the Kearsarge lode in 1903. Ore from the Kearsarge Amygdaloid and the Mass fissure was mined from four shafts of the Ahmeek mine, which later became the Ahmeek Branch of the Calumet & Hecla Consolidated Copper Company upon consolidation with that company in 1923. The Allouez Mining Company, originally formed in 1859 to mine the Allouez Conglomerate, also mined the Kearsarge Amygdaloid in this area starting about 1905. Like the Ahmeek Mining Company, the Allouez Mining Company was absorbed by the Calumet & Hecla Consolidated Copper Company in 1923.

South of the South Kearsarge mine, the Kearsarge lode was mined from two shafts of the Centennial Copper Mining Company. Formed as the Schoolcraft Mining Company to mine the Calumet and Hecla Conglomerate in 1863, the company became the Centennial Mining Company in 1878, expanded to include production from the Osceola Amygdaloid in 1891 and became the Centennial Copper Mining Company in 1896. In 1898 the company suspended operations on the Calumet and Hecla Conglomerate lode, and in 1900 suspended operations on the Osceola Amygdaloid lode and began production from the Kearsarge Amygdaloid lode. The company continued production from the Kearsarge lode until 1923 when it was absorbed by the Calumet & Hecla Consolidated Copper Company.

The Calumet & Hecla Mining Company began production from both the Osceola and Kearsarge amygdaloid lodes from two shafts each in 1904. This company was consolidated with the Osceola Con-

more thin basalt flows, the Kearsarge Amygdaloid generally consists of a highly oxidized flow-top breccia underlain by well-developed banded amygdule zones and massive basalt. The color ranges from a strong brick-red in the oxidized portions of the flow to a purple-gray in the less oxidized basalt. Epidote is very common in the Kearsarge Amygdaloid and often gives mineralized areas a pronounced greenish cast. The Kearsarge lode produced over 2 billion pounds of copper and many of the finest crystallized copper specimens now in existence.

A large number of very fine crystallized silver specimens has also been preserved from the mines on this lode. Although this may represent a greater than average amount of "high-grading" by miners (who considered silver encountered during mining operations as their property and a fringe benefit of the job), it may also indicate that an unusually large number of silver specimens were available from the deposit. Recent examinations of mine sites throughout the district conducted over the period of years by the author indicate that silver is apparently more common in the waste rock piles of mines on the Kearsarge Amygdaloid than those of mines on other lodes. Moreover, the silver from the Kearsarge is more likely to form as concentrated masses exhibiting well-crystallized forms rather than as many smaller specks. Whether this actually indicates a higher than average silver crystal content for Kearsarge ores, as opposed to unrepresentative sampling, or whether it is a function of the sheer volume of Kearsarge material available for study is still unknown.

As in most other deposits of the district, the most common forms for copper crystals in the Kearsarge lode are the various tetrahexahedrons, usually in twinned and distorted masses. Other forms observed include the dodecahedron, cube, octahedron and a host of combinations such as the cube modified by octahedron, and dodecahedron modified by tetrahexahedron and trapezohedron. Silver crystals also follow the norm for the district, with larger crystals forming branching aggregates of elongated, twinned tetrahexahedrons and smaller crystals forming cubes, the tetrahexahedron *h* or combinations of the two.

Virtually every common mineral from the district may be found from one mine or another along the Kearsarge lode. By far the most common, and perhaps diagnostic of specimens from the Kearsarge Amygdaloid, are euhedral epidote crystals occurring as individual crystals or druzy crusts with small quartz crystals in most open spaces within the lode. Both epidote and the associated quartz are generally 3 mm or less in size, although epidote crystals reaching sizes of up to 5 mm have been observed.

Quartz crystals, in addition to the small crystals discussed above, are euhedral, clear to milky individuals or clusters of crystals up to several centimeters in length. Quartz from the Kearsarge lode often encloses other minerals as anhedral to euhedral inclusions. These include copper from the Centennial #1 and #2 mines and the Laurium mine; kinoite, which forms faint blue phantoms in the quartz, from the Laurium and La Salle mines; and a member of the chlorite group or, rarely, hematite, which forms phantoms within the quartz and also coats crystals from the Ojibway mine. Quartz crystals are often partially or completely coated by saponite, earthy hematite, epidote, chlorite or copper and commonly are encased in calcite.

Other minerals observed include calcite, prehnite, pumpellyite, various copper arsenides from the Mohawk area, microcline, adularia, datolite crystals with copper inclusions, white porcelaneous datolite nodules, analcime, rare barite crystals from the Centennial mines and microcrystals of chalcocite, calumetite from the Centennial mines, and at least two unidentified species.

controlled by the Copper Range Company and the St. Mary's Mineral Land Company.

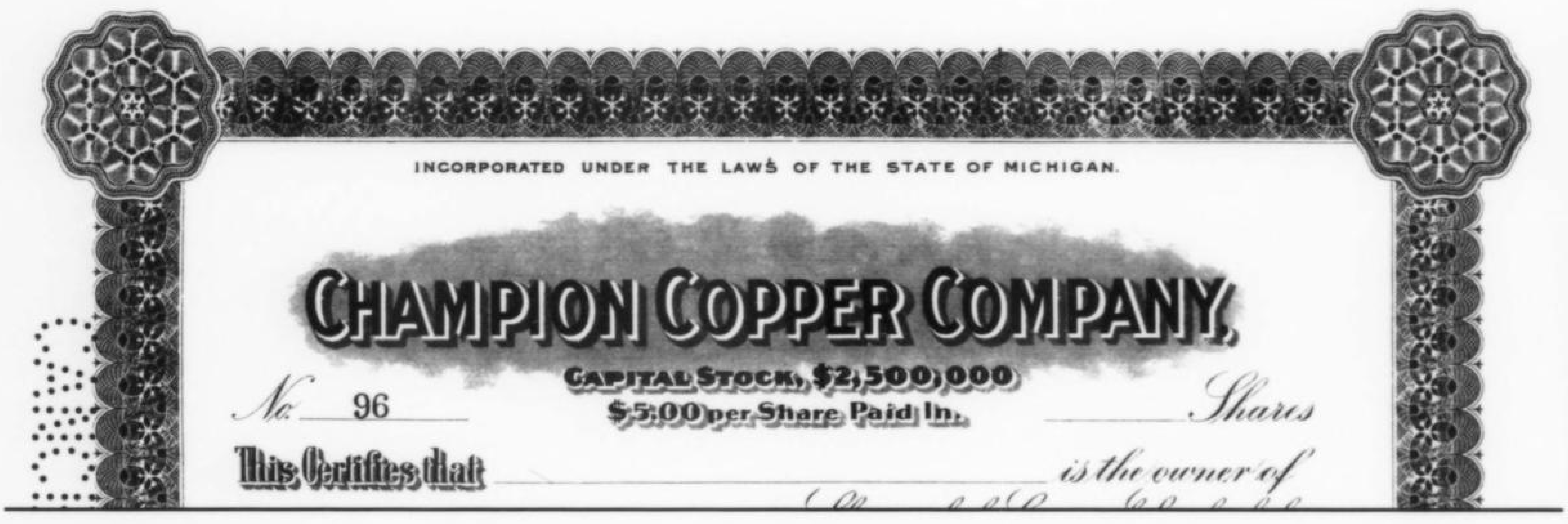
The Baltic lode was investigated further to the south by the Globe Mining Company and the Challenge Mining Company, each with one shaft, and the Contact Copper Company and Wyandot Copper Company as part of larger exploration programs. To the north of the Baltic Mining Company property, the Section 16 shaft of the Atlantic Mining Company investigated the Baltic lode from 1901 to 1911. In 1911 the Copper Range Company purchased the Atlantic Mining Company and, in 1925, dissolved it and absorbed its assets.

North of the Atlantic mine Section 16 shaft, the Superior and West amygdaloid lodes are believed to be northern extensions of the Baltic and West Baltic lodes, respectively. The Superior Copper Company was formed to mine the Superior lode in 1904 with first production in 1908. The mine produced from two shafts until 1920 and was purchased by the Calumet & Hecla Consolidated Copper Company in 1925. North of the Superior Copper Company, the Houghton Copper Company (1910) mined the Superior lode from one shaft from 1915 to 1917.

The Baltic horizon was traced further north by two shafts of the Isle Royale Copper Company and by explorations of the Arcadian Consolidated Copper Company to the north of Portage Lake.

The Baltic Amygdaloid is a relatively thick, dense, dark basalt with a well-developed flow-top breccia. Although well oxidized, the lode is not as thoroughly oxidized as the Kearsarge or some of the other amygdaloid lodes, and is usually a dark gray or reddish gray color. An abundance of iron-rich carbonates in the mineralized portions of the lode gives the more highly oxidized rocks of the Baltic Amygdaloid a rich brownish cast.

Stratigraphically above the Baltic Amygdaloid is a very similar but thinner basalt flow known as the West Baltic Amygdaloid. Mineralization in this lode is apparently identical with that of the Baltic lode




**The Baltic Amygdaloid Lode**

The Baltic Amygdaloid lode in Houghton County was first discovered by test pits in 1882 on land owned by the St. Mary's Canal Mineral Land Company. The Baltic Mining Company was organized in 1897, purchased the mine site, and began production in the following year. Production was stopped in 1916, and in 1917 the company was absorbed by the Copper Range Company. In all, the Baltic Mining Company sank six shafts on the property.

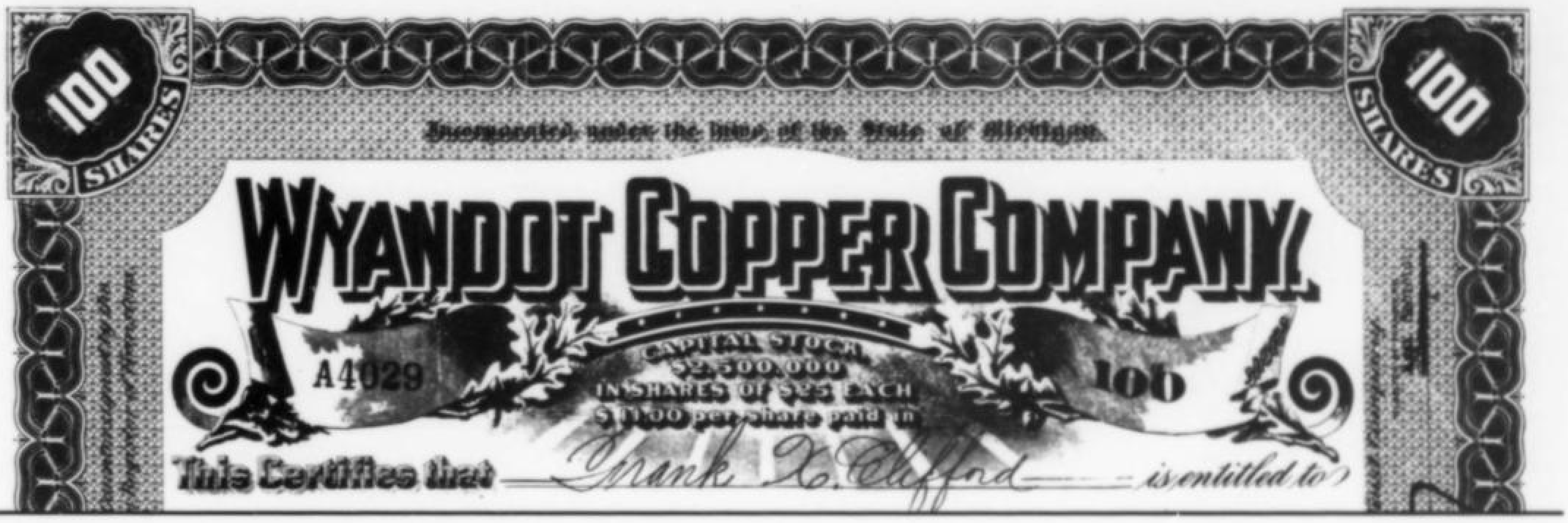
South of the Baltic Mining Company property, the Trimountain Mining Company with four shafts and the Champion Copper Company (1899) with five shafts began production from the Baltic lode in 1902. The Trimountain Mining Company was absorbed by the Copper Range Company in 1923, and the Champion Copper Company was jointly

and the two are usually grouped together under the same name.

The Baltic Amygdaloid was the second most productive amygdaloid lode in the district, producing, along with the closely related Superior Amygdaloid, over 1.8 billion pounds of copper.

Few copper and silver crystal specimens have survived to the present time. Most of those studied are from the Champion mine and consist of arborescent groups of small crystals exhibiting tetrahexahedral, dodecahedral or cubic forms. Some cubic copper crystals were observed to be modified by the tetrahexahedron *h*. No silver crystal specimens were available for study.

Quartz, calcite and various copper sulfides and arsenides are also common from the Baltic amygdaloid, but rarely as high-quality crystal specimens.




## The Evergreen Lodes

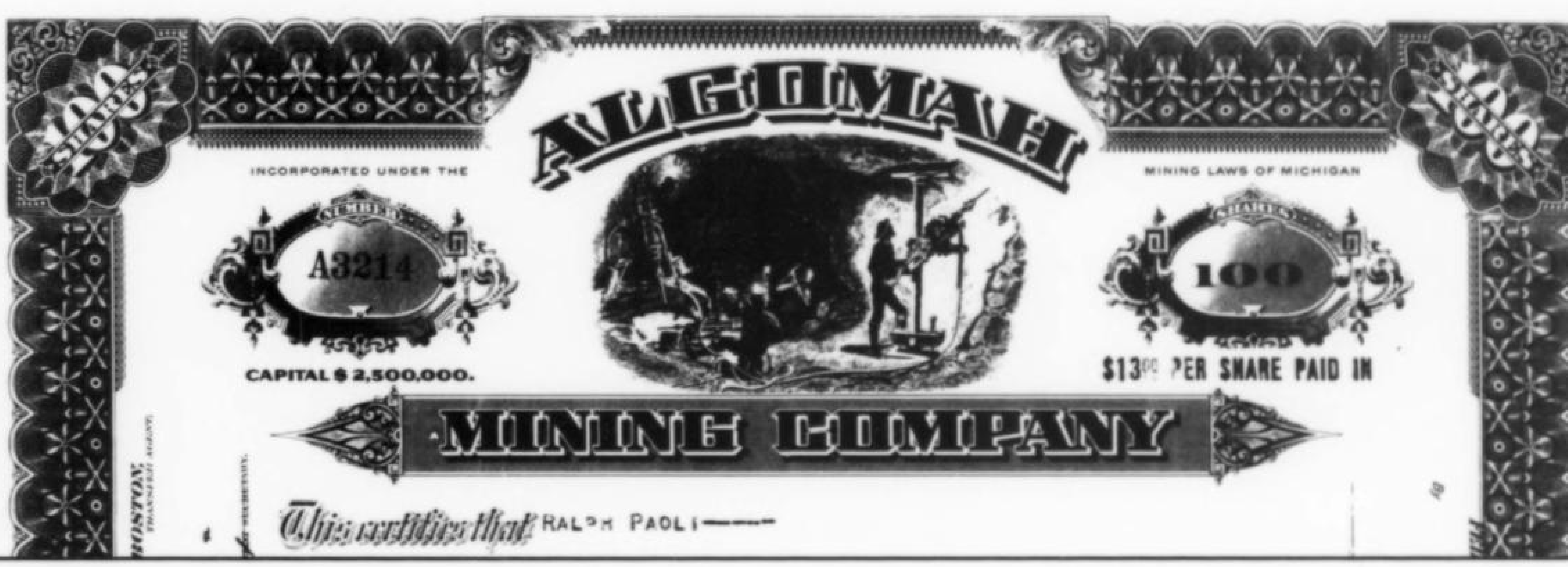
The Evergreen Series in Ontonagon County, comprised of the Knowlton, Merchant, Mass, North Butler, Butler, South Butler, Ogima, Evergreen, and other amygdaloid lodes, was first investigated in 1848 by the Piscatauqua mine.

The Piscatauqua mine was sold to the Bohemian Mining Company in 1853, which was sold, in turn, along with the Great Western and Algonquin (later known as the Penn) properties to the Belt Mining Company in 1882. No serious attempt to mine these properties was undertaken until they were consolidated, along with the Chippewa property, by the Lake Copper Company in 1905. This company, and later the closely associated North Lake Mining Company (1908) and the South Lake Mining Company (1909, formerly the Aztec Mining Company of 1863) began production from the Evergreen Series and the related Lake lode in 1909.

Other companies to mine the Evergreen Series and related amygdaloids include the Adventure Consolidated Copper Company (1898) consisting of the Adventure (1850), Hilton (formerly Ohio, 1850), Merchants (1853), and Knowlton (1853) properties; the Toltec Consolidated Mining Company (1855) composed of the Toltec and Farm (1851) properties; the Mass Consolidated Mining Company (1899) consisting of the Ridge (1850), Mass (1855), Ogima (1857), Merrimac (1863), Hazard (?), and, later, the Evergreen Bluff (1853) properties; the Caledonia Mining Company (1863, formerly the Nebraska Mining Company of 1853) which was bought by the Flint Steel Copper Company (1871, formerly the Flint Steel River Mining Company of 1850) in 1871; and many others including the Norwich (1855), the Firesteel (1852), the Algomah (1852) which worked the Algomah Amygdaloid, the Victoria (1899, formerly the Cushin of 1849) which worked the Forest Amygdaloid, and the Indiana (1862) which originally started operations in a red felsic intrusive body.

The Evergreen Series is currently being worked for specimens by Richard Whiteman of Red Metal Minerals. Superb specimens in every size range have been produced and many of the specimens used in this study were supplied from the Caledonia and other properties of this (and the Adventure mine of a previous) mining venture.

The amygdaloids of the Evergreen Series are generally massive basalts with fewer amygdules than the flows to the north. Mineralization is usually confined to well-developed flow-top breccias or fissures of all sizes which are very common in the area. The bright red and green color of the mineralized portions of these lodes, caused by an abundance of red feldspar and green epidote and pumpellyite in the altered rock, makes them distinct from the mineralized lodes to the north. Records are incomplete but the Evergreen Series and related amygdaloids apparently produced over 85 million pounds of copper (White, 1968).




Copper crystals of the Evergreen series generally follow the district norm in crystal habits. The tetrahexahedrons *e* and *h* are most common and are commonly twinned and distorted, with the dodecahedron, usually modified by the trapezohedron *n*, the cube, usually modified by the tetrahexahedron *h* or the octahedron and various complex combinations of the common forms. An exceptional specimen, collected from the waste rock piles of the South Lake mine in 1973, contains a perfectly formed 3-mm twinned tetrahexahedron *e* modified by the docdecahedron.

Silver crystals also follow the district norm, with smaller crystals occurring as cubes, the tetrahexahedron *h* or combinations of the two, and larger crystals as elongated, twinned tetrahexahedrons.

Epidote from the Evergreen Series is usually less vitreous and more poorly crystallized than that of the northern deposits and is commonly a lighter shade of green. This, combined with the close association with red microcline, is sometimes diagnostic of specimens from this portion of the district. Microcline adularia, commonly containing copper inclusions, can also be diagnostic of specimens from the Evergreen Series due to its bright orange color and more widespread occurrence compared with specimens from the north.

Quartz is also a common accessory mineral. Quartz crystals from the Evergreen Series average 2 to 5 mm but may reach lengths of several centimeters or more. Quartz from these deposits commonly contains inclusions of copper as small anhedral blebs and euhedral crystals. Calcite, rarely containing tenorite or chalcocite as inclusions, is common as complex scalenohedrons which often exhibit "girdle twinning."

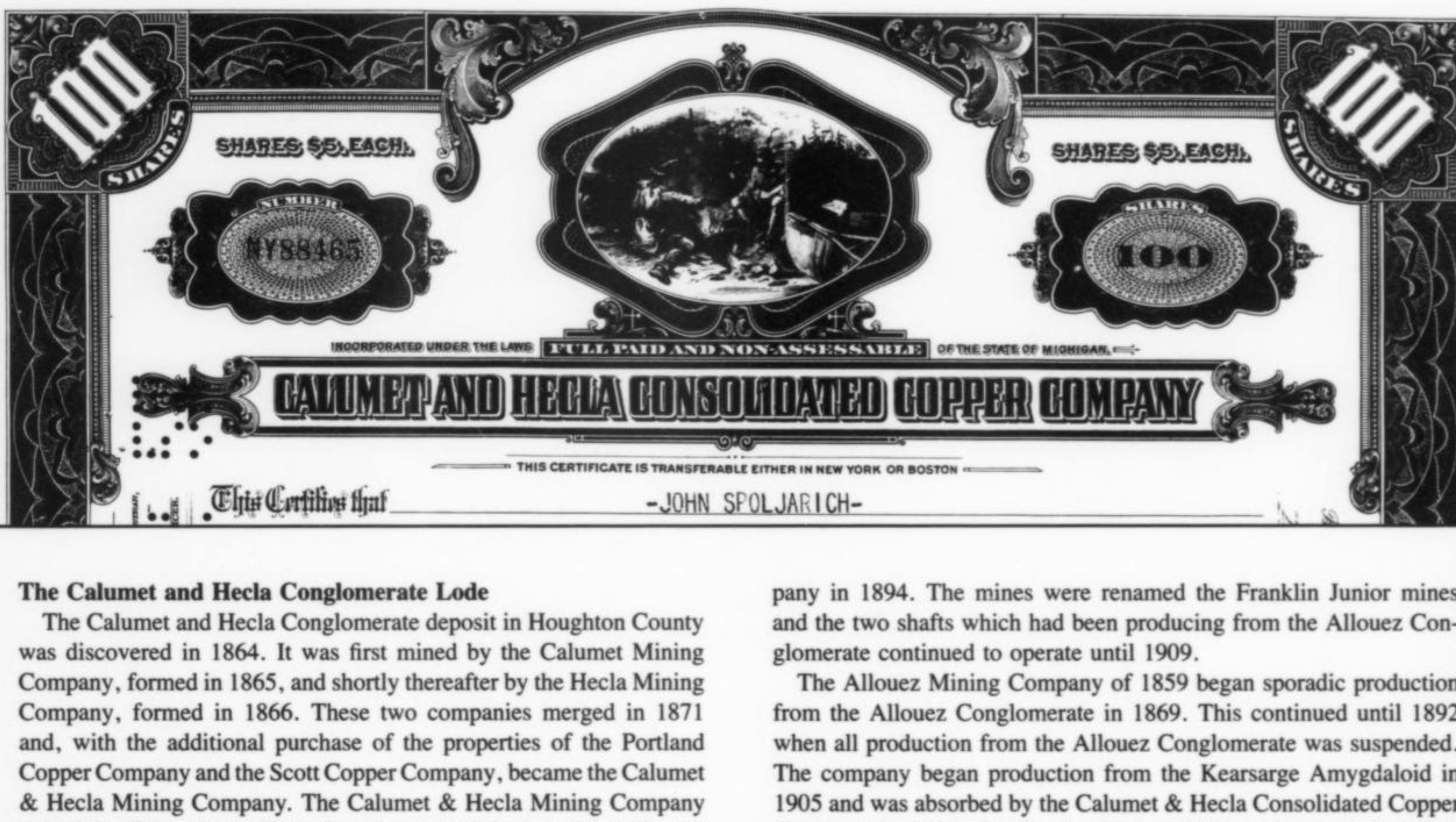
Other minerals include prehnite, porcelaneous datolite, hematite and analcime. Microcrystals of chalcocite have been observed on copper from the Adventure mine and earthy tenorite commonly coats copper vugs in the Mass mine. Particularly stunning are bright, untarnished, 1-mm cubic silver crystals, sometimes modified by the tetrahexahedron *h,* in vugs of jet-black tenorite-coated copper from the Mass mine.

Hecla Mining Company in 1917, and the other companies with production from the Calumet and Hecla conglomerate were merged with the Calumet & Hecla Mining Company in 1923 to form the Calumet & Hecla Consolidated Copper Company. This, along with the sinking of the Red Jacket shaft, brought a total of 34 shafts on the Calumet and Hecla Conglomerate under the control of the Calumet & Hecla Consolidated Copper Company. The Calumet and Hecla Conglomerate was the most productive lode in the district with total production exceeding 4.2 billion pounds of copper.

Copper crystals from the Calumet and Hecla Conglomerate are usually of the tetrahexahedral form. Silver crystallized as cubes modified by the tetrahexahedron *h* in small crystals and as elongated, twinned, tetrahexahedrons in larger crystals. Associated minerals include calcite, quartz, epidote, pumpellyite, members of the chlorite group and, rarely, powellite and barite.

**The Allouez Conglomerate**

The Allouez Conglomerate lode in Houghton and Keweenaw Counties (originally named the Albany and Boston Conglomerate) was discovered by the Albany & Boston Mining Company in 1860 with first production in 1864. The company was renamed the Peninsula Copper Mining Company in 1882, and was sold to the Franklin Company in 1894. The mines were renamed the Franklin Junior mines and the two shafts which had been producing from the Allouez Conglomerate continued to operate until 1909.




**The Calumet and Hecla Conglomerate Lode**

The Calumet and Hecla Conglomerate deposit in Houghton County was discovered in 1864. It was first mined by the Calumet Mining Company, formed in 1865, and shortly thereafter by the Hecla Mining Company, formed in 1866. These two companies merged in 1871 and, with the additional purchase of the properties of the Portland Copper Company and the Scott Copper Company, became the Calumet & Hecla Mining Company. The Calumet & Hecla Mining Company mined the Calumet and Hecla Conglomerate lode from 16 shafts and in 1904 began production from the Kearsarge and Osceola amygdaloid lodes with two shafts on each.

Other companies to open mines on the Calumet and Hecla Conglomerate include the Osceola Mining Company (later the Osceola Consolidated Mining Company) in 1873 with three shafts, the Centennial Mining Company (later the Centennial Copper Mining Company) in 1878 with seven shafts, the Tamarack Mining Company in 1882 with five shafts, and the Tamarack Junior Mining Company, set off from the Tamarack Mining Company in 1888 and absorbed by the Osceola Consolidated Mining Company in 1897, with two shafts.

The Tamarack Mining Company was absorbed by the Calumet &

The Allouez Mining Company of 1859 began sporadic production from the Allouez Conglomerate in 1869. This continued until 1892 when all production from the Allouez Conglomerate was suspended. The company began production from the Kearsarge Amygdaloid in 1905 and was absorbed by the Calumet & Hecla Consolidated Copper Company in 1923. In all, the Allouez Mining Company had four shafts on the Allouez Conglomerate lode. Total production was somewhat in excess of 72.5 million pounds of copper.

Far to the north, the Conglomerate Mining Company mined the Allouez Conglomerate and various fissures from the Delaware mine in 1882. The Delaware mine hosted 5 shafts on the Allouez Conglomerate.

Other mining companies, including the Rhode Island Mining Company (later the Rhode Island Copper Company), explored the Allouez Conglomerate, but little production followed.

Mineral species occurring in the Allouez Conglomerate include copper, silver, calcite, quartz, epidote, chrysocolla, and cuprite. One


specimen of copper crystals found on the waste rock piles of the Allouez mine in 1973 exhibited twinned and distorted tetrahexahedral development.

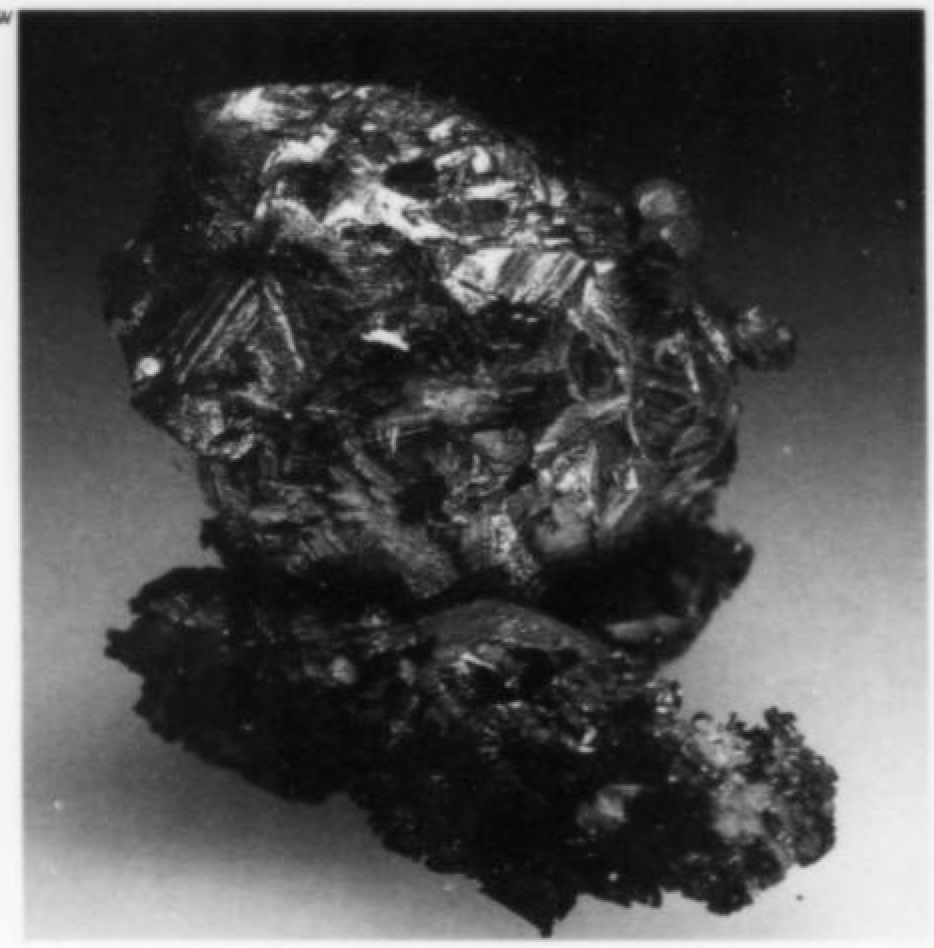
**The Nonesuch Shale**

The Nonesuch Shale deposit in Ontonagon County is of such unique character that it is usually considered separately from other deposits in the Copper Country. Although mining ventures had been undertaken in the area since 1845, it was not until 1867 that the Nonesuch Mining Company first attempted to mine the disseminated copper deposits of the Nonesuch Shale. The Nonesuch Mining Company concentrated its efforts on obtaining the native copper found in the lowermost and faulted portions of the unit, and ignored the much more prevalent sulfides which occurred just above the native copper zone. Some copper and silver were produced, but most of the copper was too finely divided to be recovered with existing technology, and the mine never showed a profit.

The Calumet & Hecla Mining Company took an interest in the Nonesuch Shale in 1909, and in 1912 opened the Number 1 shaft of the White Pine mine on the site of an older shaft started in 1881. Three more shafts followed and in 1915 the White Pine Copper Company began production as a subsidiary of the Calumet & Hecla Mining Company. The White Pine Copper Company was sold to the Copper Range Company in 1937 and new technologies for mining and milling the finely-disseminated ore were developed. These techniques proved successful, and in 1955 the White Pine Copper Company resumed production with an output of over 62 million pounds of copper—more than three times the total previous production of the entire Nonesuch Shale deposit. By 1965, over 1 billion pounds of copper had been produced and production continues to the present day.

All specimens studied from the Nonesuch Shale deposit originated from the White Pine mine. In addition to crystals of copper and silver, crystals of calcite, chalcocite, marcasite, chalcopyrite, galena and superb crystals of barite have been found, mostly in calcite veins filling fractures. Kerogen and lighter hydrocarbons occur in sufficient quantities to sometimes prove a nuisance to miners and are commonly present on crystal specimens. Copper crystals are usually tetrahexahedrons and silver crystals usually form as small cubes which may be modified by the tetrahexahedrons *h* and *e*. Larger silver crystals, while rare, were observed to exhibit the tetrahexahedral forms *e* and *h* with the octahedron, cube and dodecahedron as minor modifiers. Recently, spectacular specimens of elongated, wire-like, cubic copper crystals were produced, some with a thin coating of silver on the copper.

# COPPER & SILVER



Copper and silver are closely related in the Copper Country and similarities in occurrence, associated minerals and crystal habit are extensive. Both minerals have been observed from virtually all major deposits in the district, and museum-quality specimens have been preserved from most. Native copper was the primary ore mineral in the Copper Country and its widespread occurrence there is unique among mining districts. Native silver, in lesser amounts, is equally widespread but is generally confined in occurrence to the upper portions of the deposits.

Copper and silver often occur together in what have come to be known as "half-breeds." Half-breeds frequently consist of rounded nuggets of intermixed copper and silver up to many centimeters in diameter. These nuggets are not actually mineral specimens in the strict sense because most are a product of the district's stamp and ball mills. The copper and silver, although naturally occurring, have been mashed together by the pounding of the mills and their original forms thus altered to their present nugget-like shape. Such specimens exhibit a rounded, pounded appearance and, when cut, often display a distorted or smeared crystal form.

Legitimate nuggets of copper and silver do occur in the glacial till of the district. These nuggets, sometimes weighing tons, are known as "float copper" because they "floated" in the ice of glaciers after being ripped from the bedrock by the glacial erosion process. Such specimens were deposited with the glacial gravels ("float") as the ice melted away and can still be found in glacial deposits throughout the district and beyond.

Of far more value to collectors are half-breed specimens consisting of intermixed copper and silver crystals. The deposition of silver generally postdated that of copper but many specimens exist which clearly show copper deposition during and after silver crystallization. Usually, copper crystals on silver represent a second or third generation of copper mineralization; the silver is often perched upon earlier copper crystals. Rarely, such late-stage copper encases euhedral crystals of minerals normally associated with the final stages of mineralization in the district. An example is a perfectly formed barite crystal partially encased by euhedral copper crystals from the Humboldt mine in Keweenaw County. Paragenetic studies by the authors indicate that up to three generations of copper and two generations of silver miner-

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***Figure 26. (above)* Silver crystal aggregate, 2.5 cm, on copper, from the Osceola mine. Seaman Museum collection.**

***Figure 27. (left)* Copper-silver "half-breed" slab, 14.8 cm, from the Calumet & Hecla mine. Harvard collection.**

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alization may exist in some portions of the district.

In some cases silver coats copper crystals as an epitaxial overgrowth. Such coatings have been observed on specimens from the White Pine and Caledonia mines in Ontonagon County, the Isle Royale and Laurium mines in Houghton County, and the Cliff and other mines in Keweenaw County. Superb specimens of cubic silver microcrystals in an epitaxial relationship to larger copper crystals of cubic, octahedral and tetrahexahedral habit have been noted from the Ojibway mine in Keweenaw County.

**Figure 28.** ***(right)*** **Type 1 branching growth in Michigan copper (Dana, 1886).**

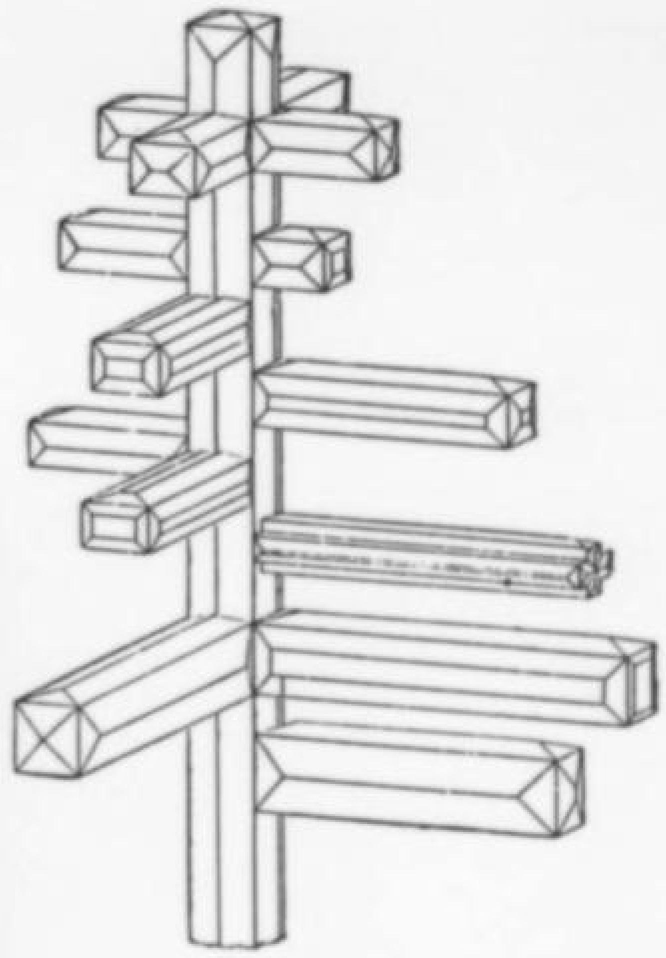


**Figure 29. Branching copper crystals (Type 1), 7 cm, from the Champion mine. Seaman Museum collection.**

Copper commonly forms pseudomorphs of other minerals from the district. Excellent specimens of copper replacing microcline, laumontite, and porcelaneous datolite have been found; and copper coatings on quartz, calcite, adularia, epidote and prehnite are common. Copper is also present as inclusions in quartz, calcite, prehnite, adularia, barite, datolite, analcime, apophyllite, laumontite and natrolite.

## CRYSTALLOGRAPHY

Copper and silver crystals of the Copper Country exhibit a wide variety of habits ranging from unmodified versions of simple forms to complicated crystals exhibiting a combination of forms. Both copper and silver crystallize in the isometric (cubic) crystal system. The most common forms are the cube *a*{001}, dodecahedron *d*{011}, octahedron *o*{111} and various forms of tetrahexahedrons (especially *h*{014}, *e*{012}, and *l*{035}). Numerous other forms occur as modifiers of these basic forms, but do not occur as unmodified forms themselves. Combinations of these forms result in complex copper crystals of wide variety. An excellent detailed study of copper crystallography was published by Dana (1886).

Copper and silver twin according to the spinel law on the (111) or octahedral plane. Twins are usually of the simple contact variety although they may be distorted by elongation, and interpenetration twins have been reported (Dana, 1886). Twinned crystals of both copper and silver are common in the Copper Country.

Two basic types of simple parallel grouping of copper crystals have been described by Dana (1886). In the first (Type 1), crystals are elongated along one or more of the cubic axes with repeated growth along their lengths. This results in a 3-dimensional arborescent form with "branches" at right angles to the "stem." This type is most frequently observed with crystals exhibiting the form of the cube or tetrahexahedron, particularly *h*.


**Figure 30. Type 1 branching copper crystals, 7.6 cm, Keweenaw Peninsula. Seaman Museum, ex George B. Robbe collection.**

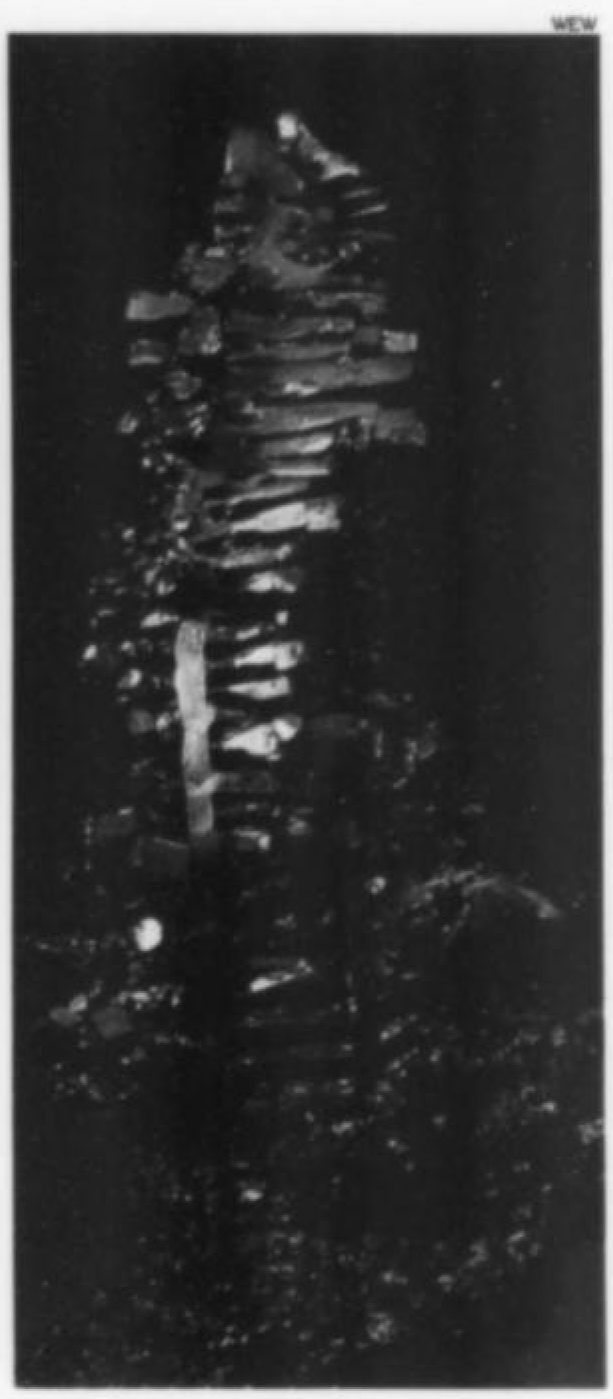


**Figure 31. Copper from the Champion mine, 9.5 cm, showing Type 1 branching pattern. Louis Lafayette collection; photo by Debra Wilson.**

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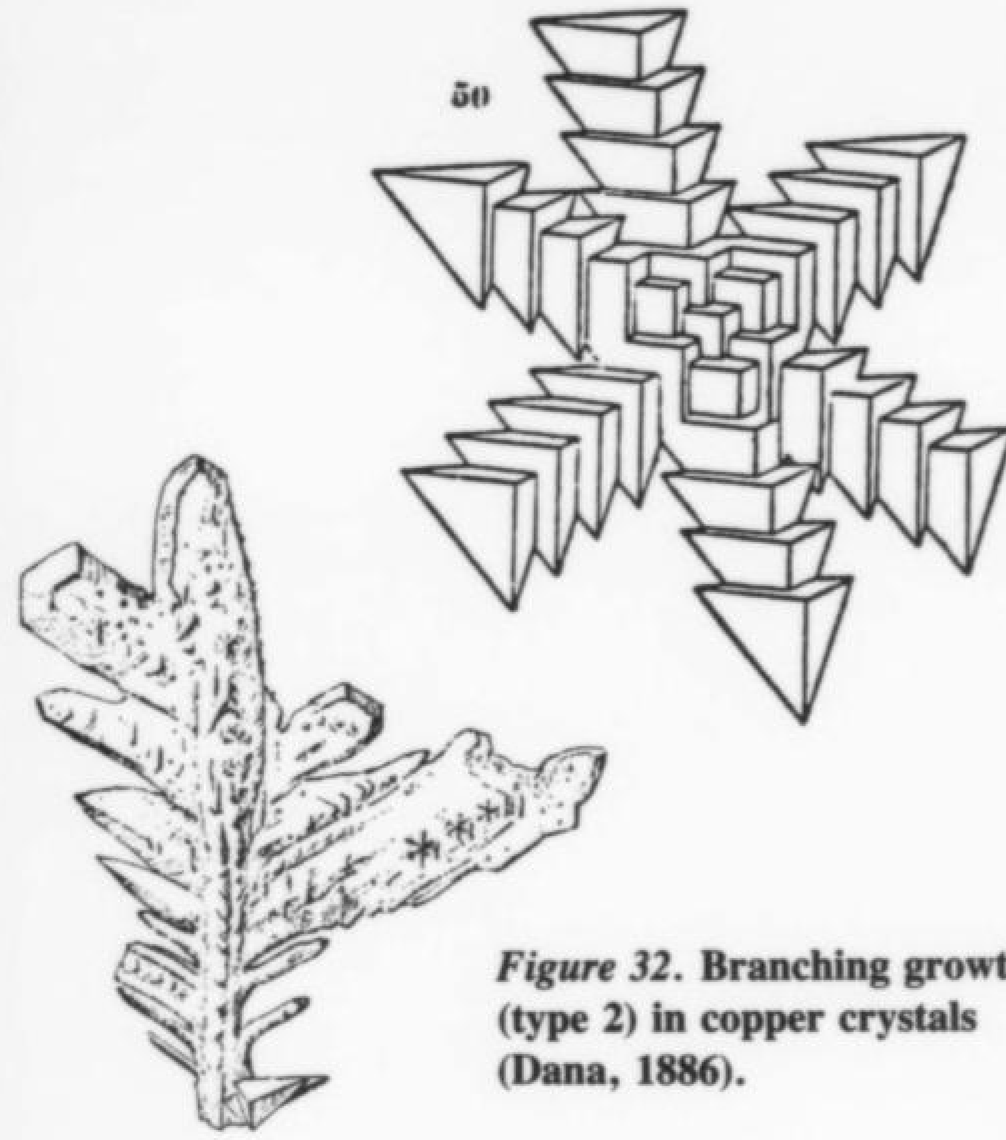


*Figure 32*. **Branching growth (type 2) in copper crystals (Dana, 1886).**

*Figure 33. (left)* **Copper crystal group, 12 cm wide, showing twinned plates of Type 2 growth. Michigan; Wayne State University collection.**

In the second type (Type 2), crystals are twinned and elongated in the plane of the octahedron (111) with elongation along one of the diagonals of the octahedron within the twinning plane. Repeated growth of crystals elongated along the two remaining diagonals of the octahedron yield a two-dimensional arborescent form with branches at a 60° angle to the stem. This type is most frequently observed with crystals exhibiting the form of the tetrahexahedrons or cube with the

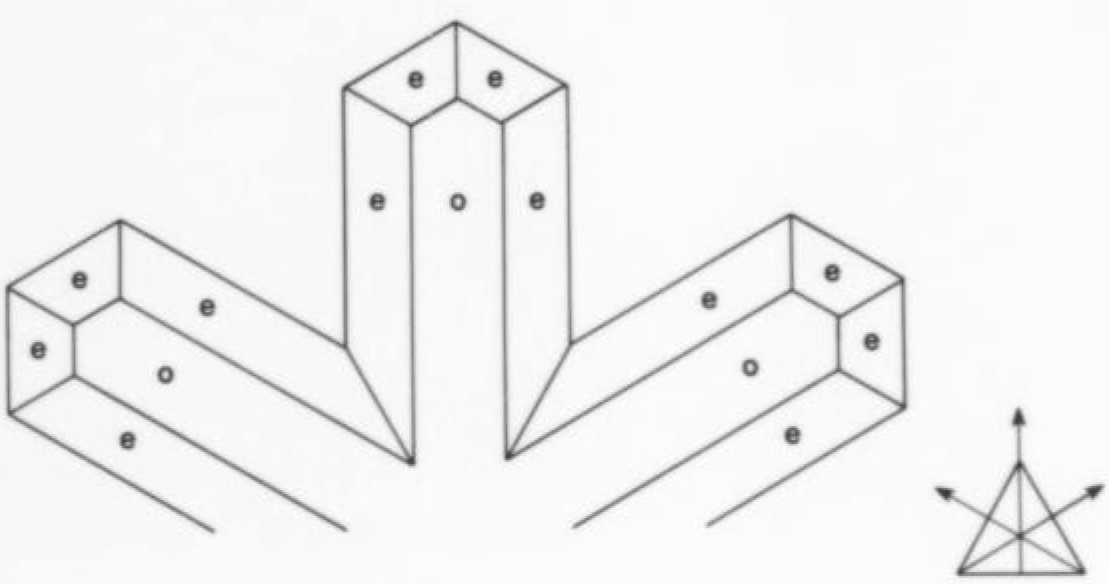


*Figure 34*. **Branching growth (Type 2) in silver and copper crystals.**

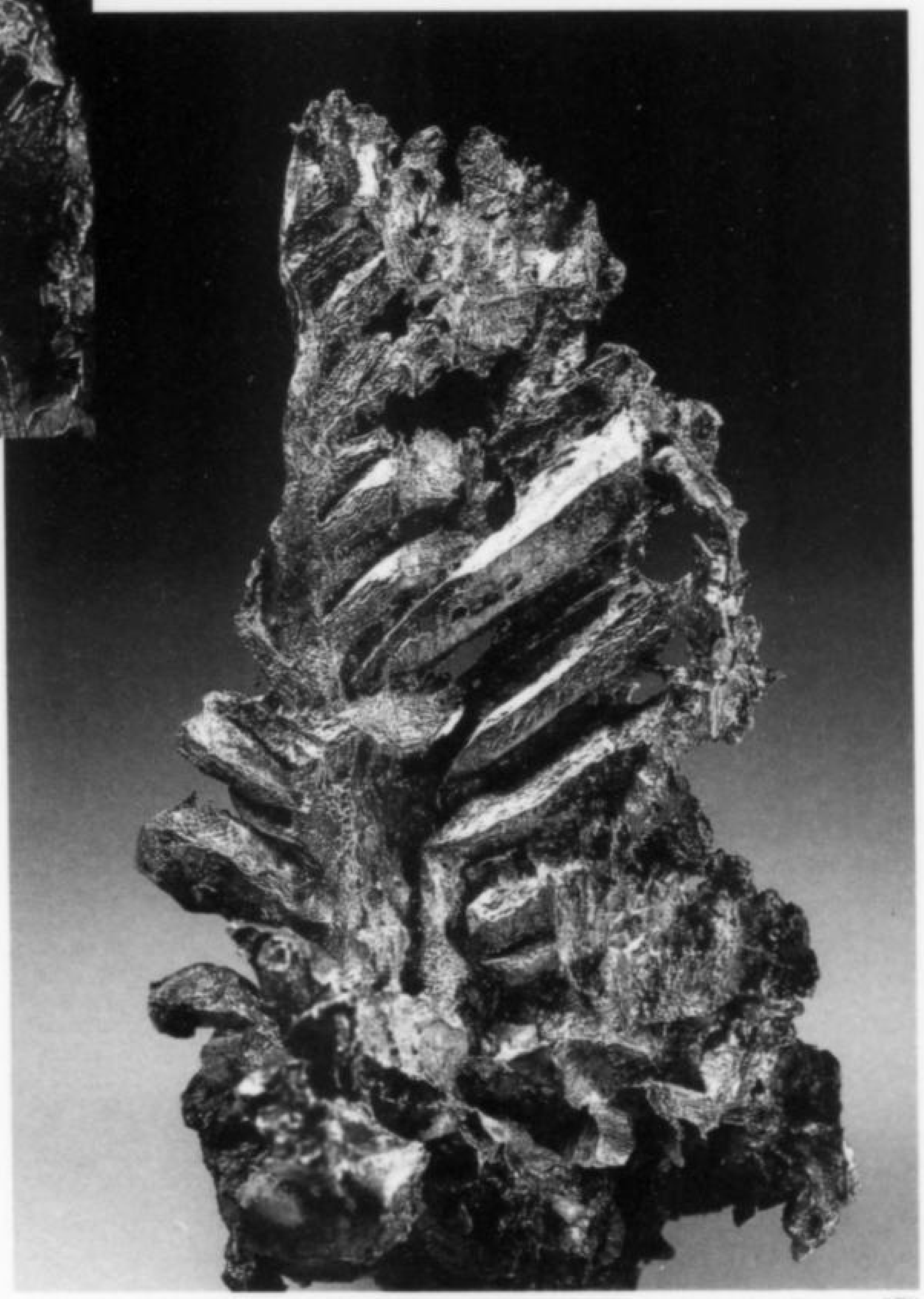

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*Figure 35*. **Silver crystal group, 6.1 cm, showing Type 2 branching from the Seneca mine. Terry Wallace collection.**

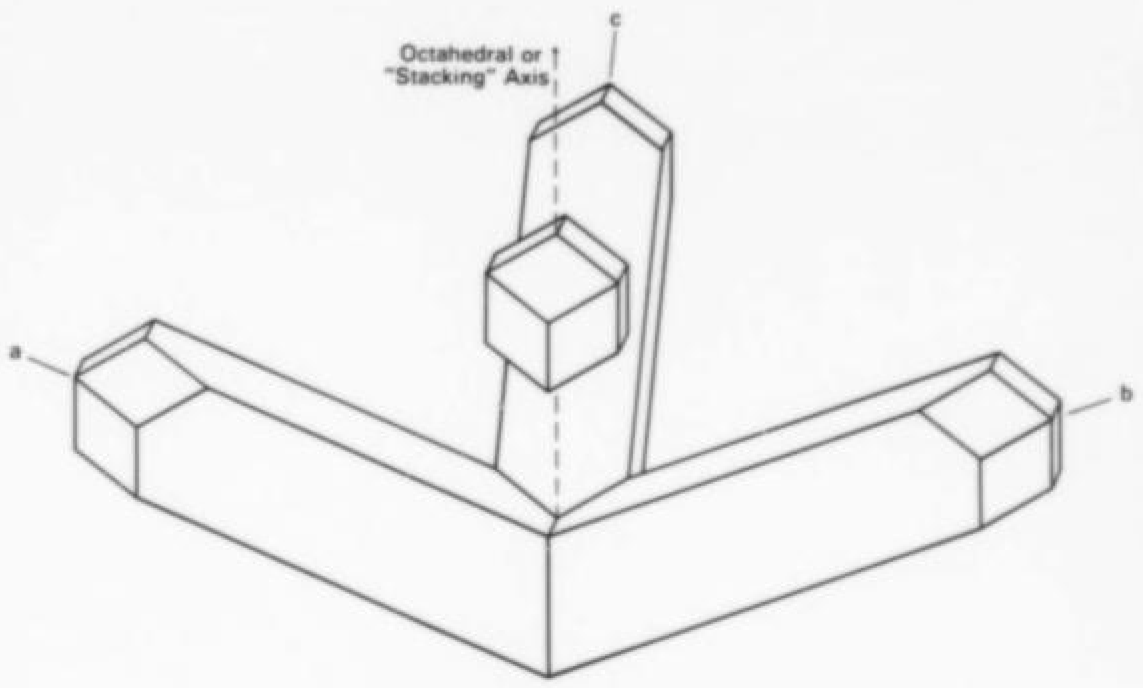



*Figure 36*. **Branching growth (Type 3) in copper crystals.**

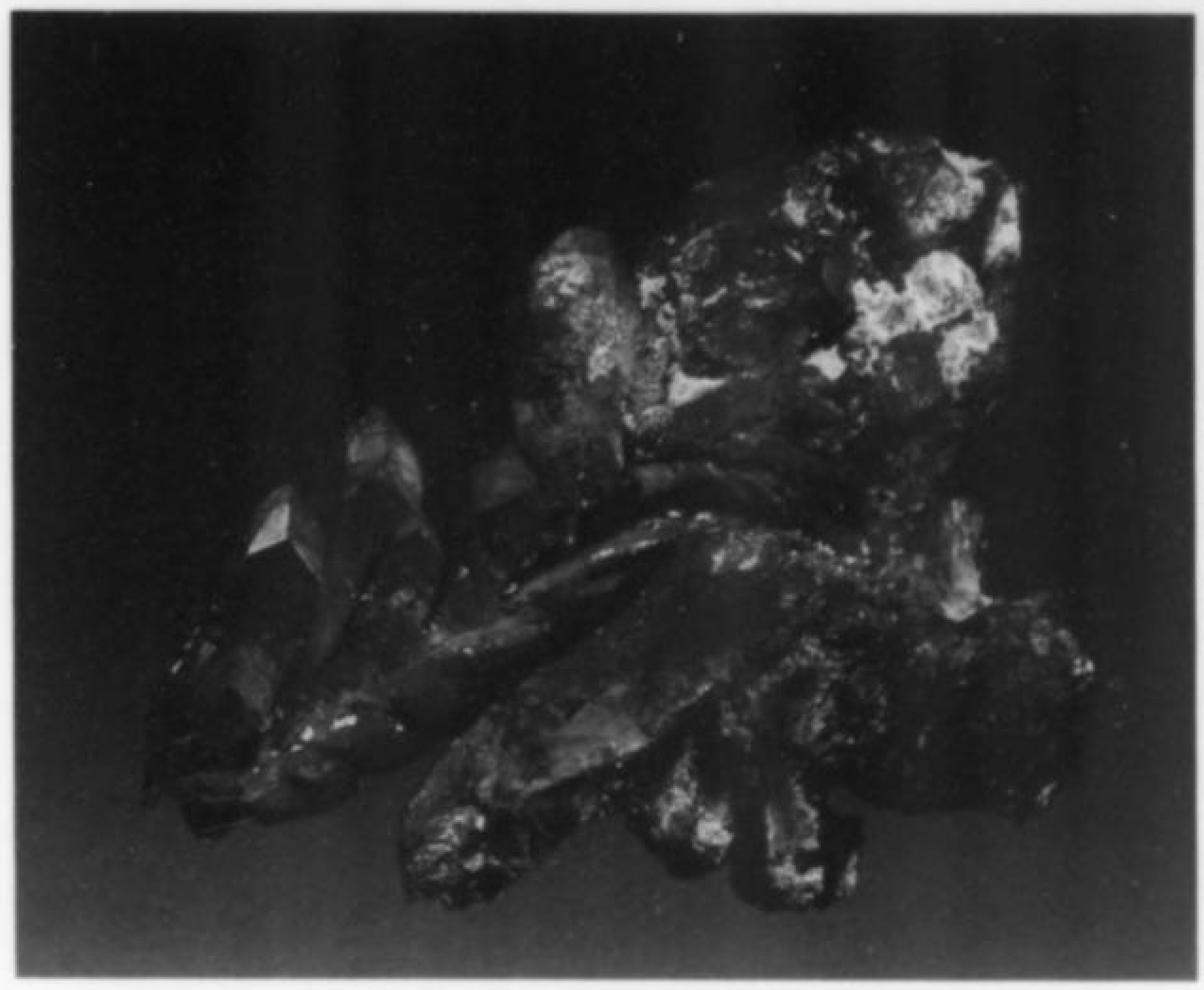


*Figure 37*. **Copper crystals, 5 cm, showing reddish cuprite patina and Type 3 arborescent growth, from the Phoenix mine. The green material is a mixture of microcrystaline adularia and atacamite. Marc and Debra Wilson collection; photo by Debra Wilson.**

octahedron, dodecahedron and other forms as frequent modifiers. This type of grouping is common for copper and represents the most common form for larger silver specimens from the Copper Country.

A third type of grouping (Type 3), has been observed in this study in copper specimens from the Phoenix mine in Keweenaw County. As in Type 1, the crystals are elongated along the cube axes. This grouping is repeated along an octahedral axis resulting in a three-dimensional arborescent form with branches joining at an angle of 60° to the octahedral axis and at 120° to each other when viewed down that axis. This form was observed in several specimens consisting of dodecahedral crystals modified by the trapezohedron *n*, and a hexoctahedron (*y* (18,10,5)?) among others.

A systematic examination of copper specimens from throughout the district (for this study) has shown that most reported crystal habits may be found at most localities if enough specimens are studied. Thus, there does not appear to be any relationship between the crystal habit of copper or silver and the locality or lode of origin within the district. Rather, the crystal habit of both copper and silver appear to be related to the sizes of the individual crystals. This is graphically illustrated by specimens of copper crystals, 4 mm or less in diameter, in close association with prehnite and commonly also with quartz and calcite. Such specimens are common from most amygdaloid lodes throughout the district. Of thousands of specimens examined in this study, nearly 70% of the copper crystals with identifiable forms proved to be the tetrahexahedron {057}, and half the remainder are this form modified to some extent by the dodecahedron. (The identification of the form {057}, not previously reported from the district, was determined by contact goniometric techniques and should be considered preliminary until confirmed by reflection goniometric techniques.) The remainder are comprised of dodecahedrons, with the cube and octahedron as rare minor modifying forms. Larger copper crystals display a much higher proportion of other tetrahexahedral forms as well as the dodecahedron, cube and octahedron. Similarly, silver crystals of less than 1 mm diameter are usually simple cubes, the tetrahexahedron *h* or a combination of the two. Larger silver crystals almost invariably form branching aggregates of elongated, twinned tetrahexahedrons of the forms *e* or *h* such as those discussed above.

Tetrahexahedrons are the most common forms for copper crystals from the Copper Country. Dana (1886) identified seven tetrahexahedral forms for copper. The three forms *h*{014}, *e*{012} and *l*{035} appear to be the most common in Michigan, with the form {057} as an important possible fourth. These rarely occur as unmodified crystals; they are commonly associated with the cube, octahedron, dodecahedron and each other as well as less common forms.

Tetrahexahedral copper crystals are often twinned on the (111) plane and are commonly elongated. This is particularly true of the form *e*,

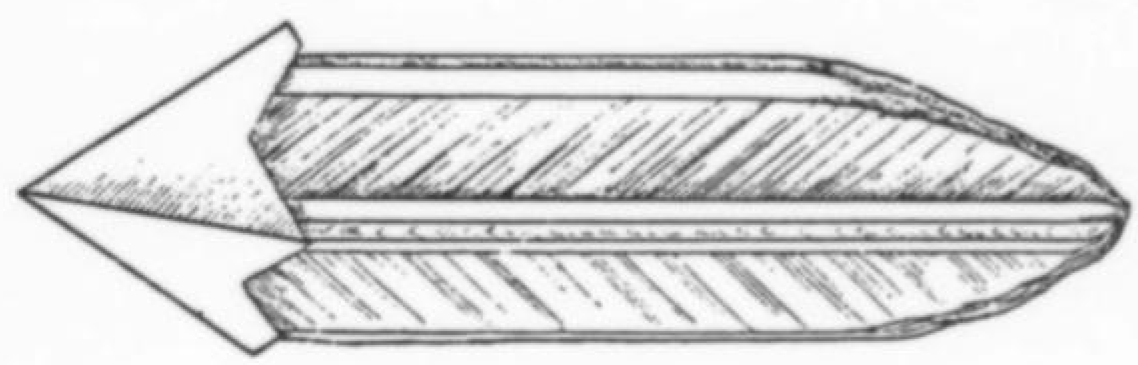


*Figure 38*. **Elongated copper crystal showing striations (Dana, 1886).**

which is sometimes modified by the octahedron, the dodecahedron, and the tetrahexahedral form *h*. Very beautiful specimens of copper result when these elongated twins form complex branching aggregates of parallel-growth crystals. Hoppered tetrahexahedrons, although rare, do occur.

Wire copper crystals of the tetrahexahedral form {057} are commonly associated with prehnite. These crystals are single tetrahexahedrons which have grown hundreds of times further in one crystallographic direction than in the others. Wire crystals are usually curved due to imperfections in the crystal lattice and may branch and terminate in euhedral crystals.

The dodecahedron most commonly occurs as crystals 2 mm or less in diameter associated with prehnite. Careful study under high magnification is often required to distinguish these from the very similar tetrahexahedrons {057} and *l*. Dodecahedral copper crystals associated with prehnite can form wires similar to the tetrahexahedron {057}. The unmodified dodecahedral form is less common in larger copper crystals although dodecahedral crystals 9 cm and more in diameter have been observed. Dodecahedral copper crystals are commonly

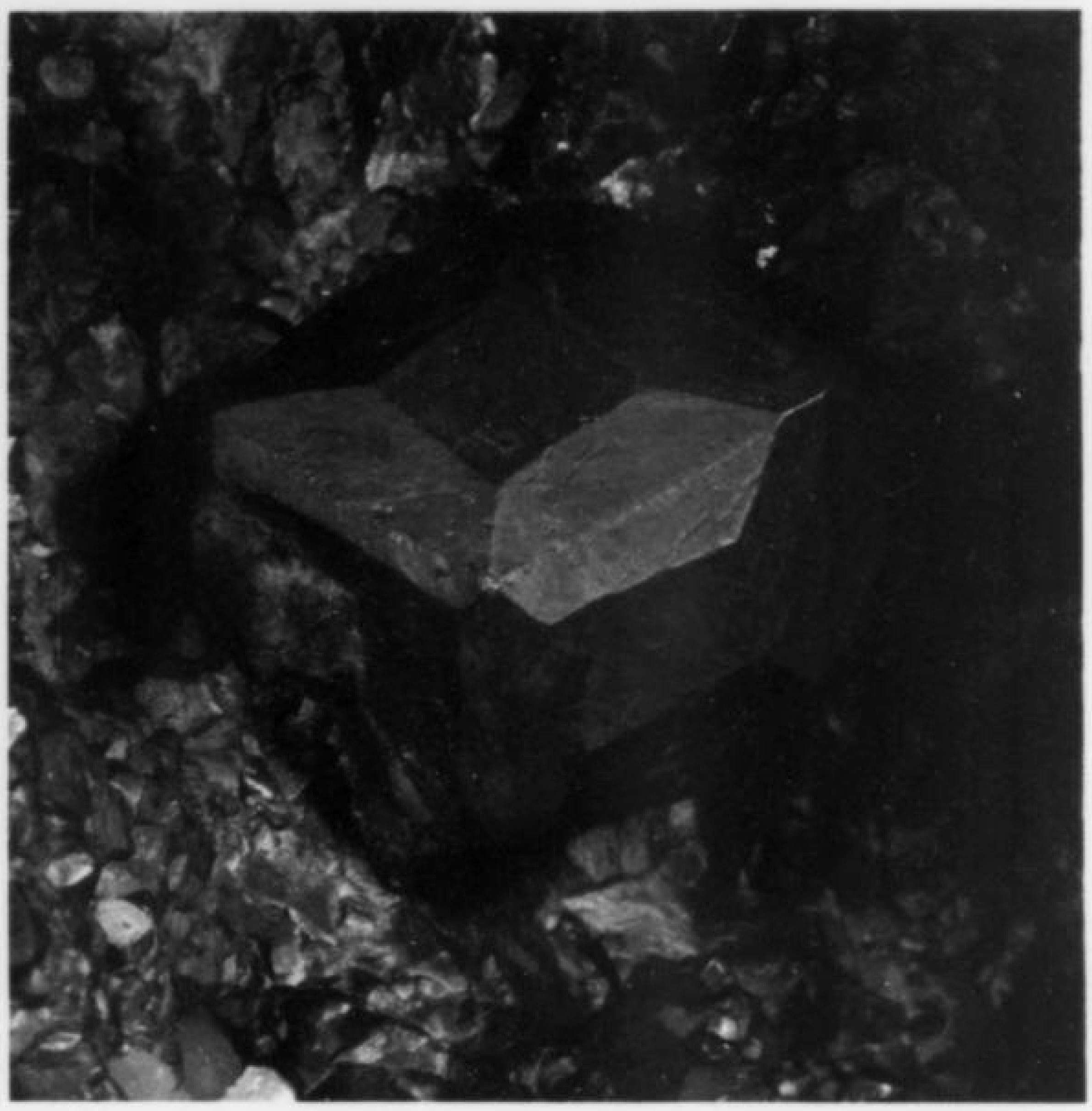
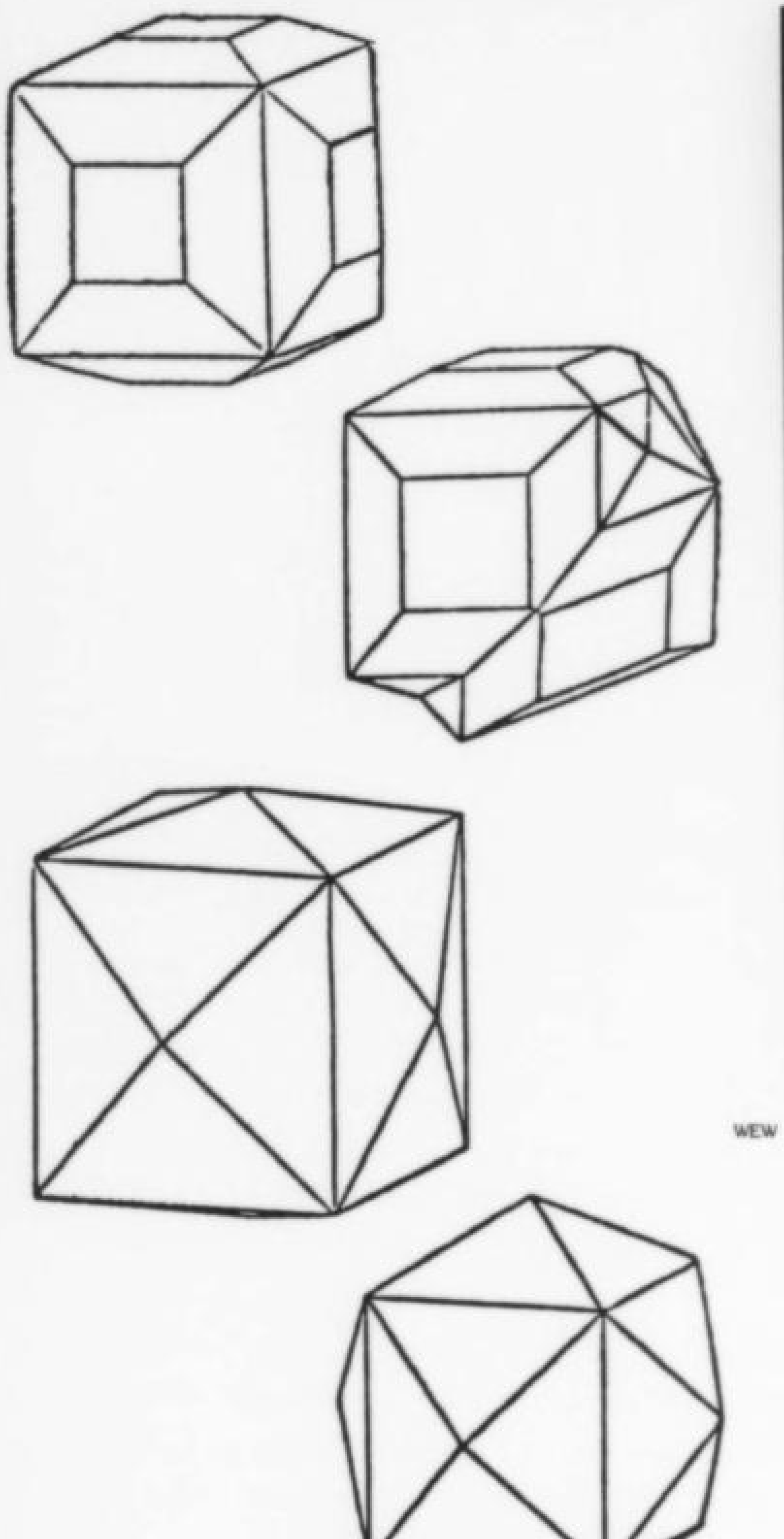


**_Figure 39_. Spiral wire copper, 9 mm, probably resulting from a screw dislocation; from the Osceola mine. Marc and Debra Wilson collection; photo by Debra Wilson.**

**_Figure 40_. Well-developed copper crystal showing cube and tetrahexahedron faces, 1.5 cm, from the Keweenaw Peninsula. Gilbert Gauthier collection; photo by Nelly Bariand.**



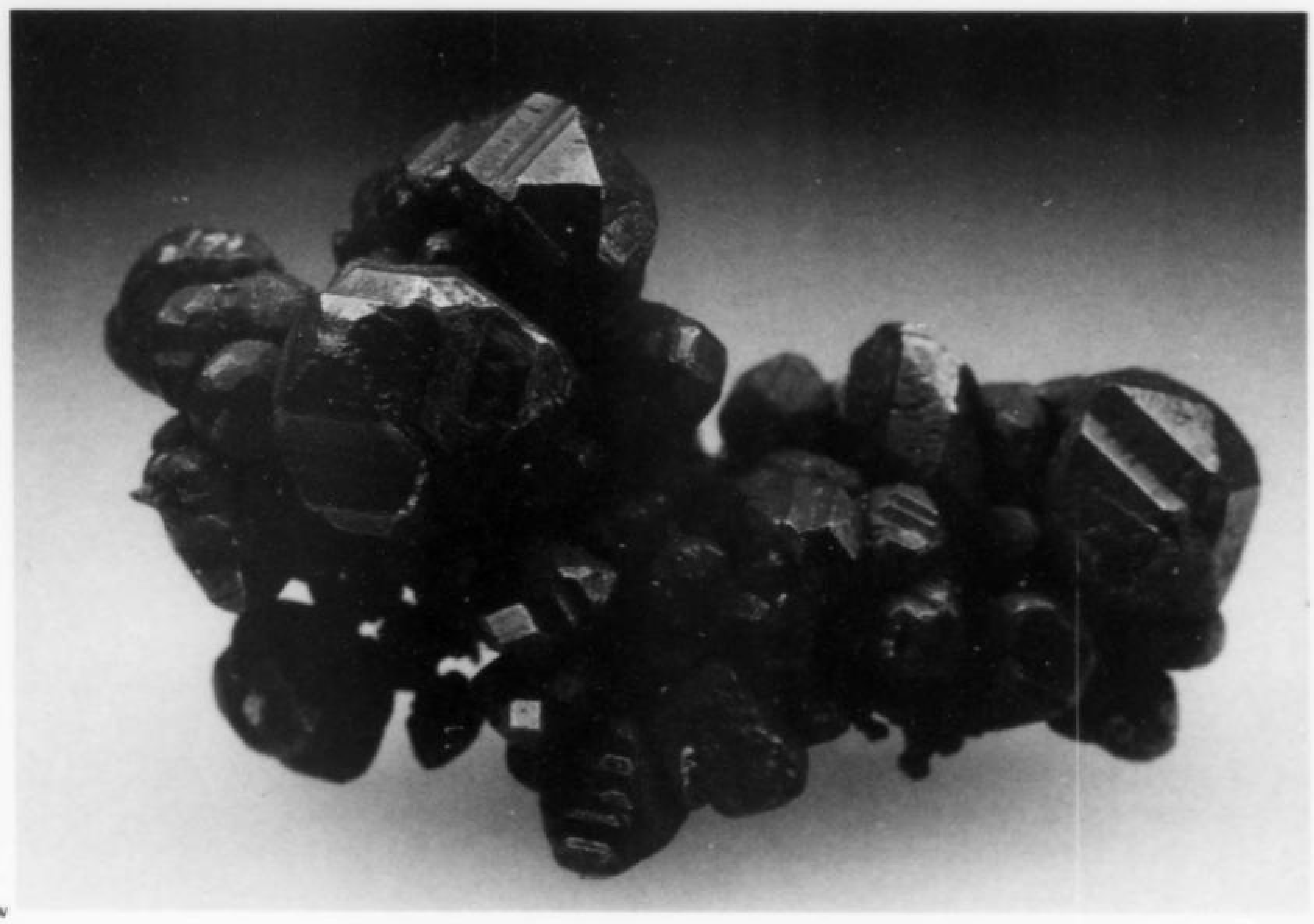



**_Figure 41_. Unusual copper crystal group, 4.6 cm, showing tetrahexahedral faces in oscillatory growth, from the Keweenaw Peninsula. Seaman Museum collection.**

**_Figure 42_. Simple tetrahexahedrons (bottom), and modified by the cube (top); copper from Michigan. The upper right drawing shows the common contact twinning on (111) (Dana, 1886).**

modified by the trapezohedron *n*(112), which bevels the edge of the dodecahedron.

The cube is an unusual habit for copper crystals in the Copper Country. This form rarely occurs unmodified; it is usually associated with the tetrahexahedron *h* and less commonly with other tetrahexahedrons or the octahedron. Hoppered cubes of copper have been produced from several localities, and branching aggregates of twinned parallel-growth crystals also occur, although more rarely than the

*Figure 43*. Copper crystal showing tetrahexahedral habit, 5.7 cm, from the Keweenaw Peninsula, Michigan. Wayne State University collection.

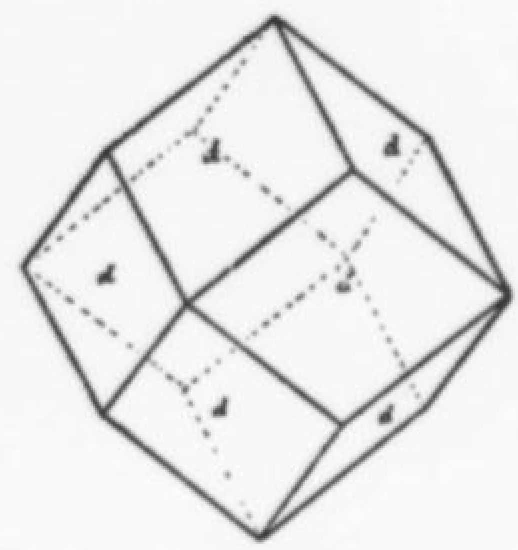


*Figure 44*. Simple dodecahedron.

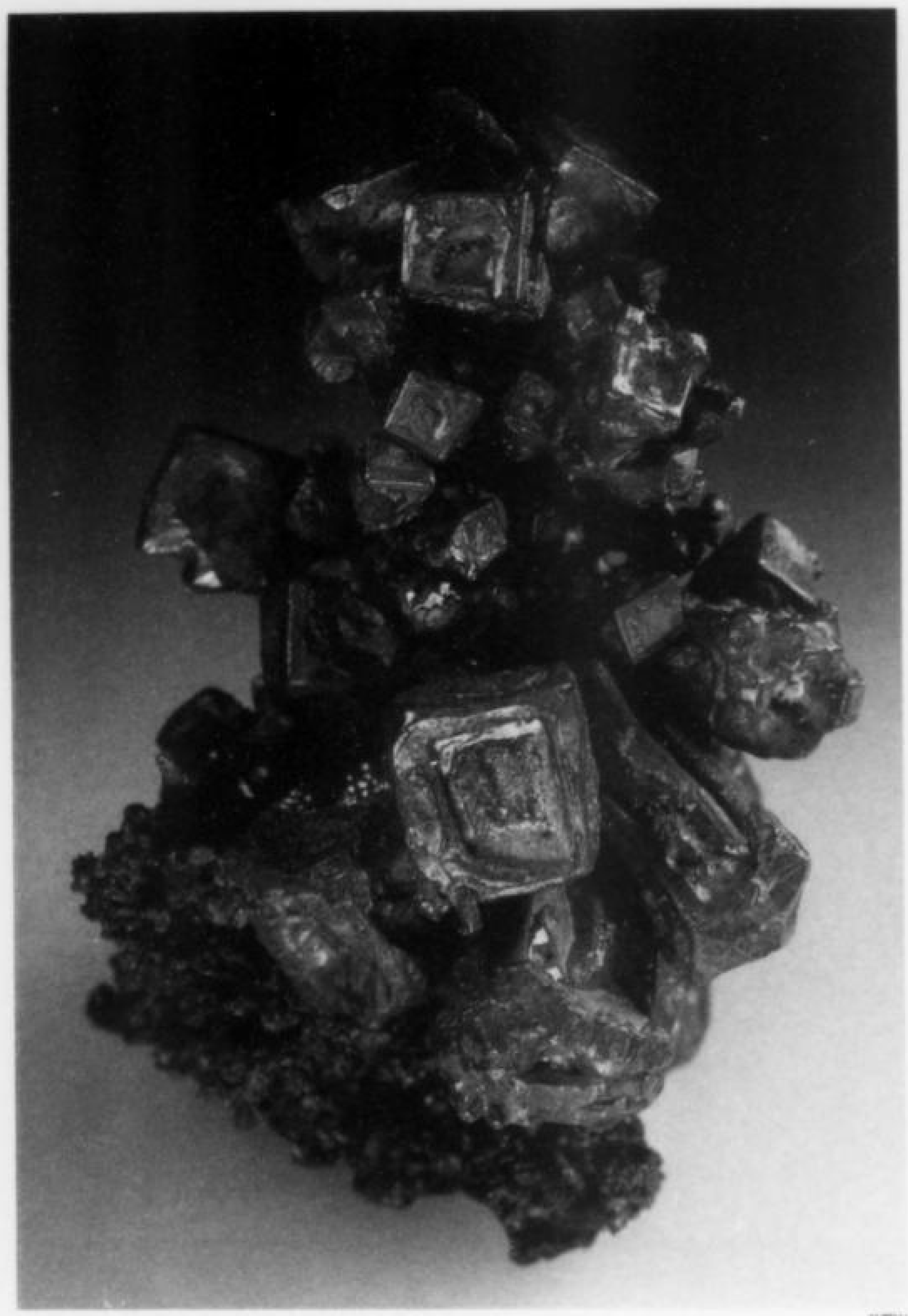
*Figure 45*. Large dodecahedral crystals of copper: *(left)* 3.3 cm, modified by narrow trapezohedron faces, from the Calumet & Hecla mine. Seaman Museum collection, ex Donald C. Gabriel collection. *(right)* 3.2 cm, on matrix, from the Osceola mine. Seaman Museum collection, ex John T. Reeder collection.

*Figure 46*. Tetrahexahedral copper crystal on matrix, 5.8 cm, probably from Houghton County. Richard Kosnar collection.

similar tetrahexahedral groupings. The cube is a common modifier of other forms observed in the district.

The octahedron is the rarest of the simple forms of copper crystals in Michigan. It is extremely rare as an unmodified form and is almost exclusively observed as a modifier of other crystal forms. Octahedral copper crystals are usually modified by the dodecahedron which bevels the edges or by the cube which truncates the corners.

Like copper, silver crystallizes in the isometric crystal system in the same four basic crystal forms. The abundance of these forms differs between copper and silver however.



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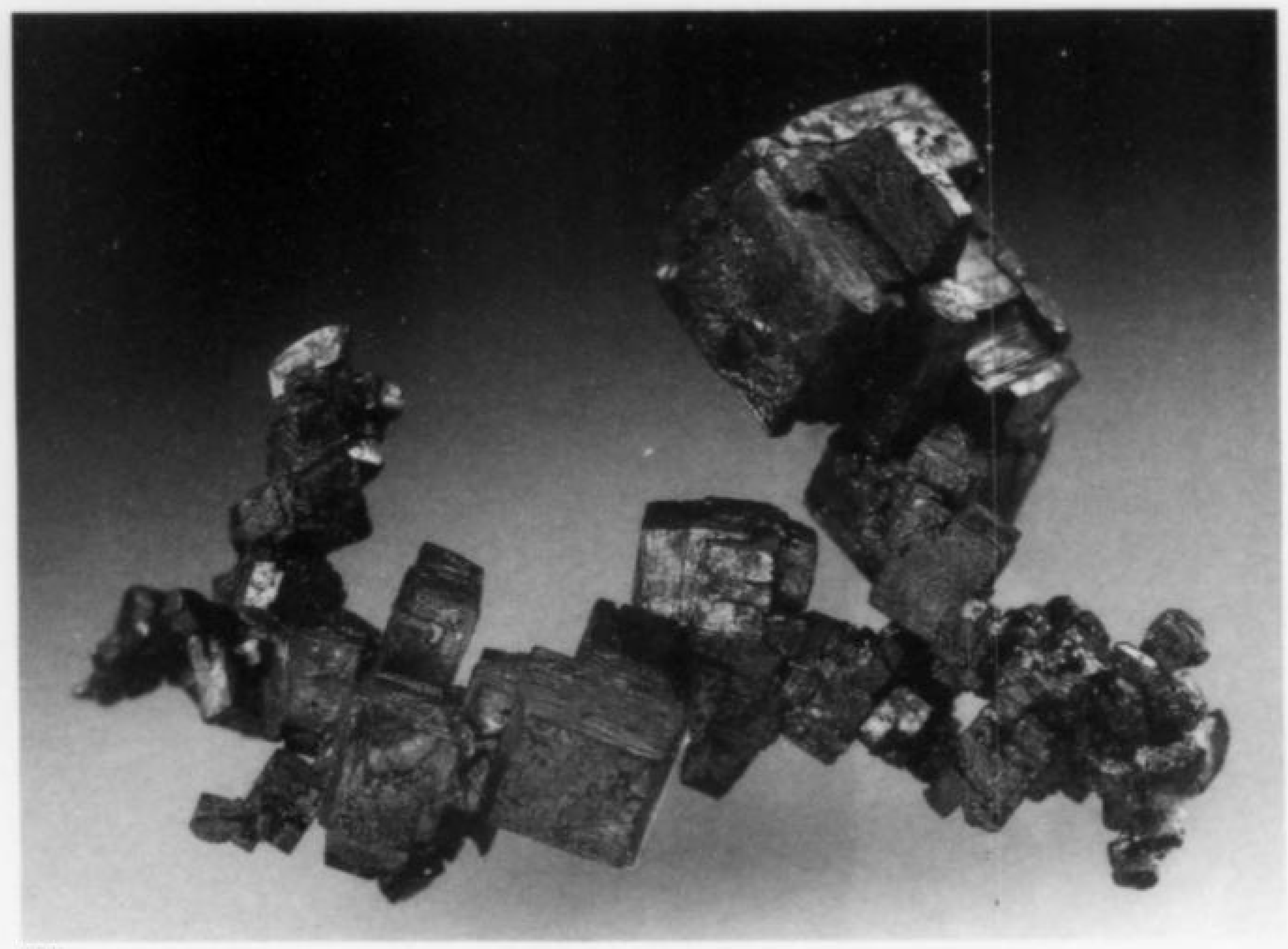

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*Figure 47*. **Cubic copper crystal group, 3.6 cm, from the White Pine mine. Seaman Museum collection.**

*Figure 48*. **Hoppered cubic copper crystal group, 5.8 cm, from the Ahmeek mine. Seaman Museum collection, ex Donald C. Gabriel collection.**

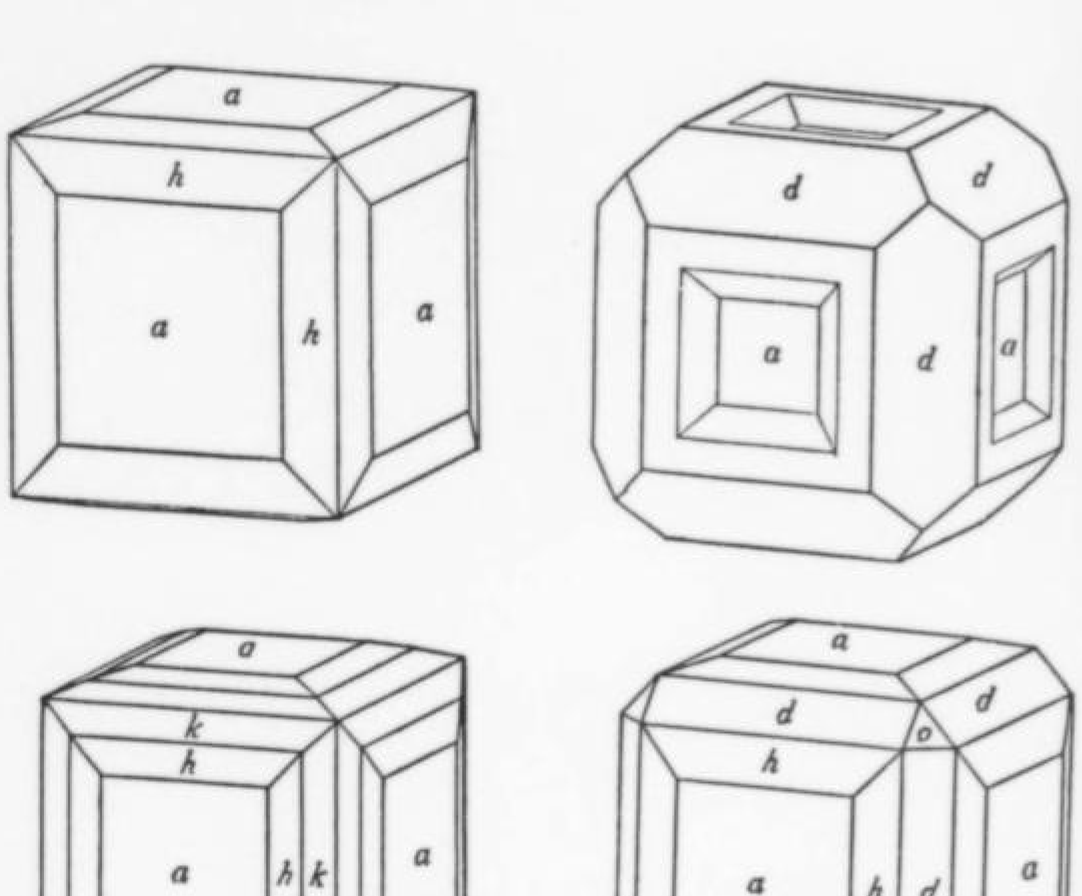

*Figure 49*. **Cube habits showing various modifications, from Michigan (Dana, 1886; vom Rath, 1878).**

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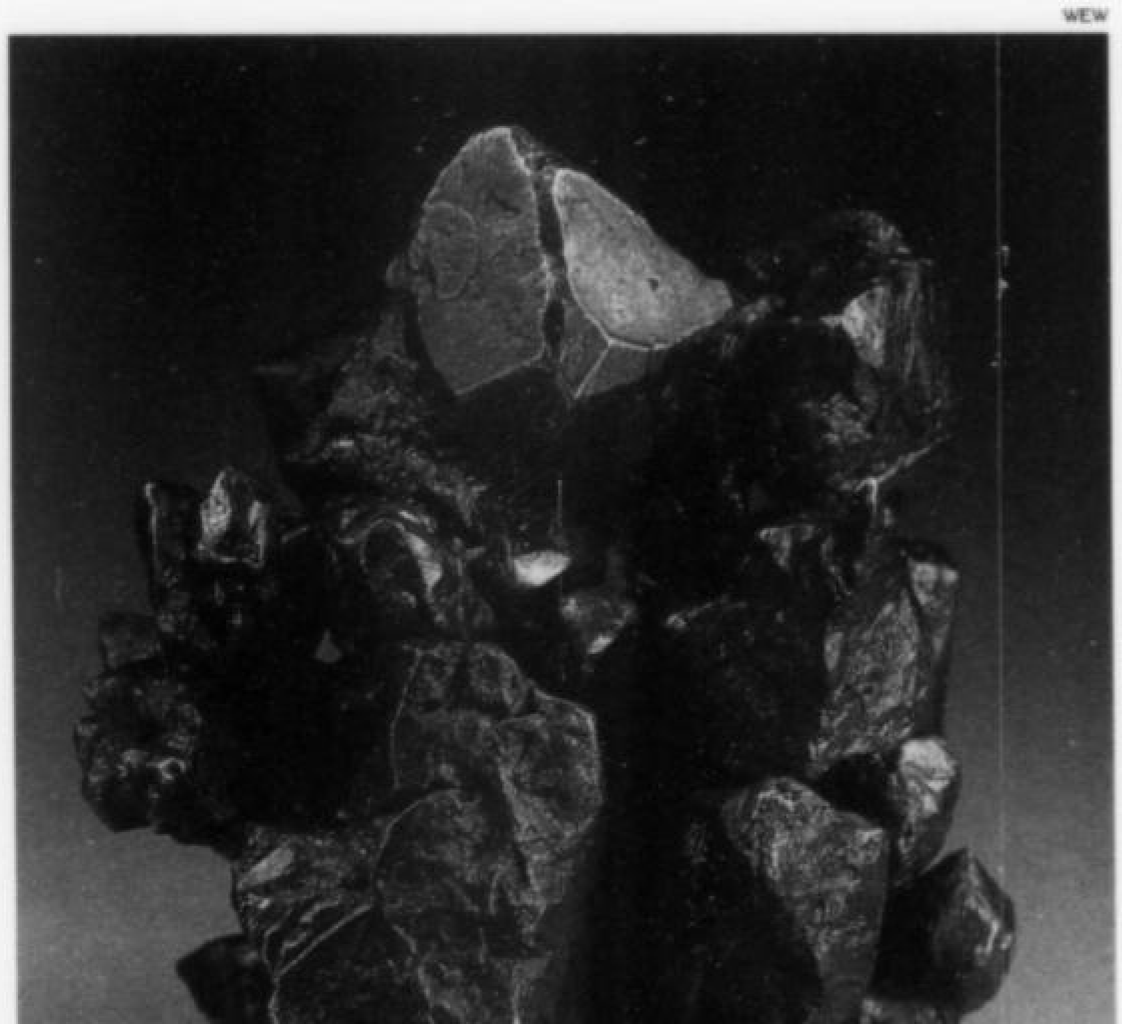


*Figure 50*. **Copper crystal group, 5.4 cm tall, showing rare octahedron modified by hexoctahedron, from Houghton County. Richard Kosnar collection, ex B. S. Butler collection.**

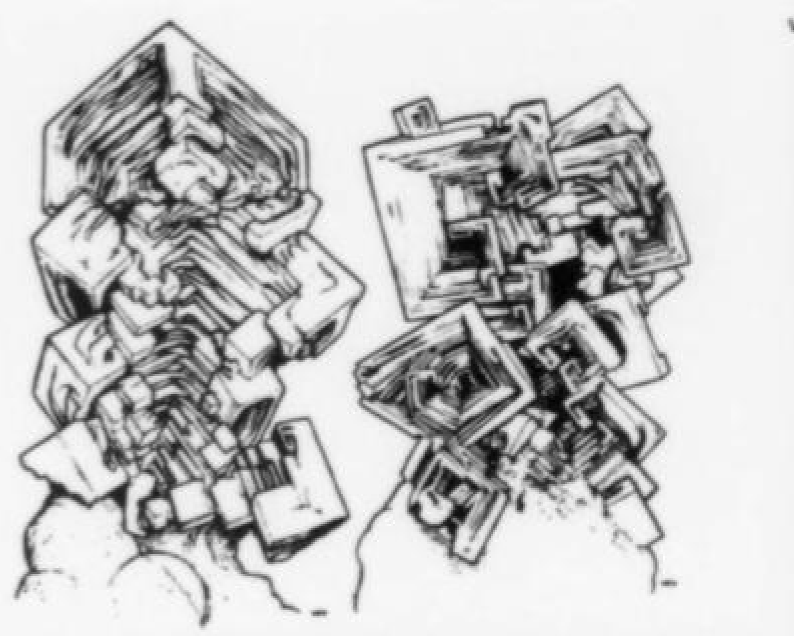


*Figure 51. (above)* **Skeletal cubic crystal aggregates of silver on prehnite, 1.2 cm tall, from a surface exposure near the Copper Falls mine (collected in 1980). D. Olson specimen.**

*Figure 52. (right)* **Silver, in hoppered cubic crystals, 3.8 cm across, from the same outcrop near the Copper Falls mine. Don Olson collection.**

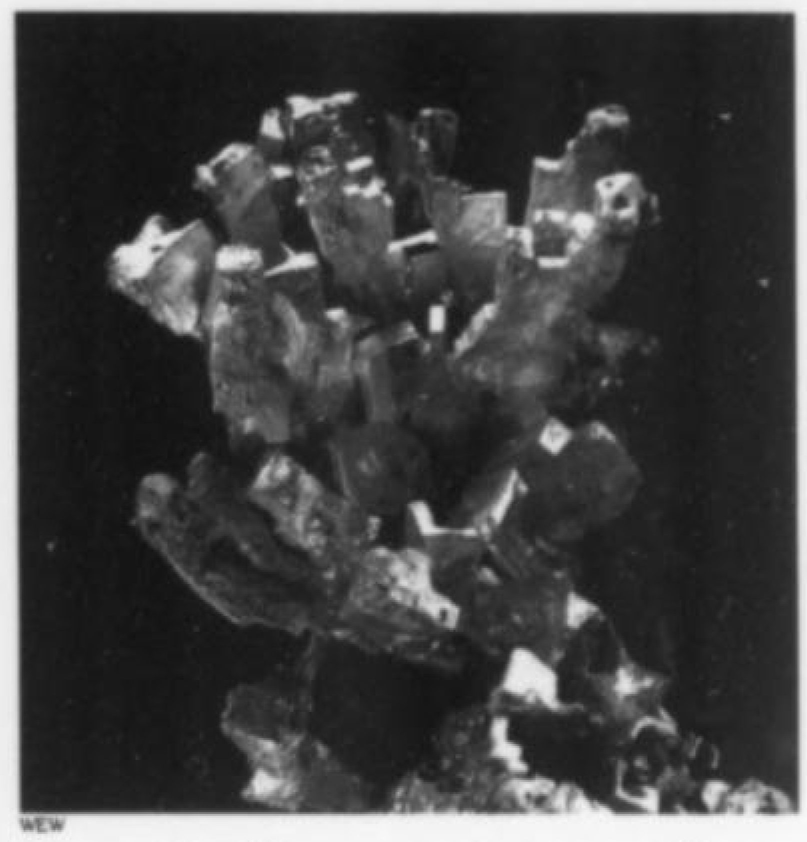


*Figure 53.* **Silver crystal group, 3.0 cm, showing cubic habit, from near the Copper Falls mine. Don Olson collection.**

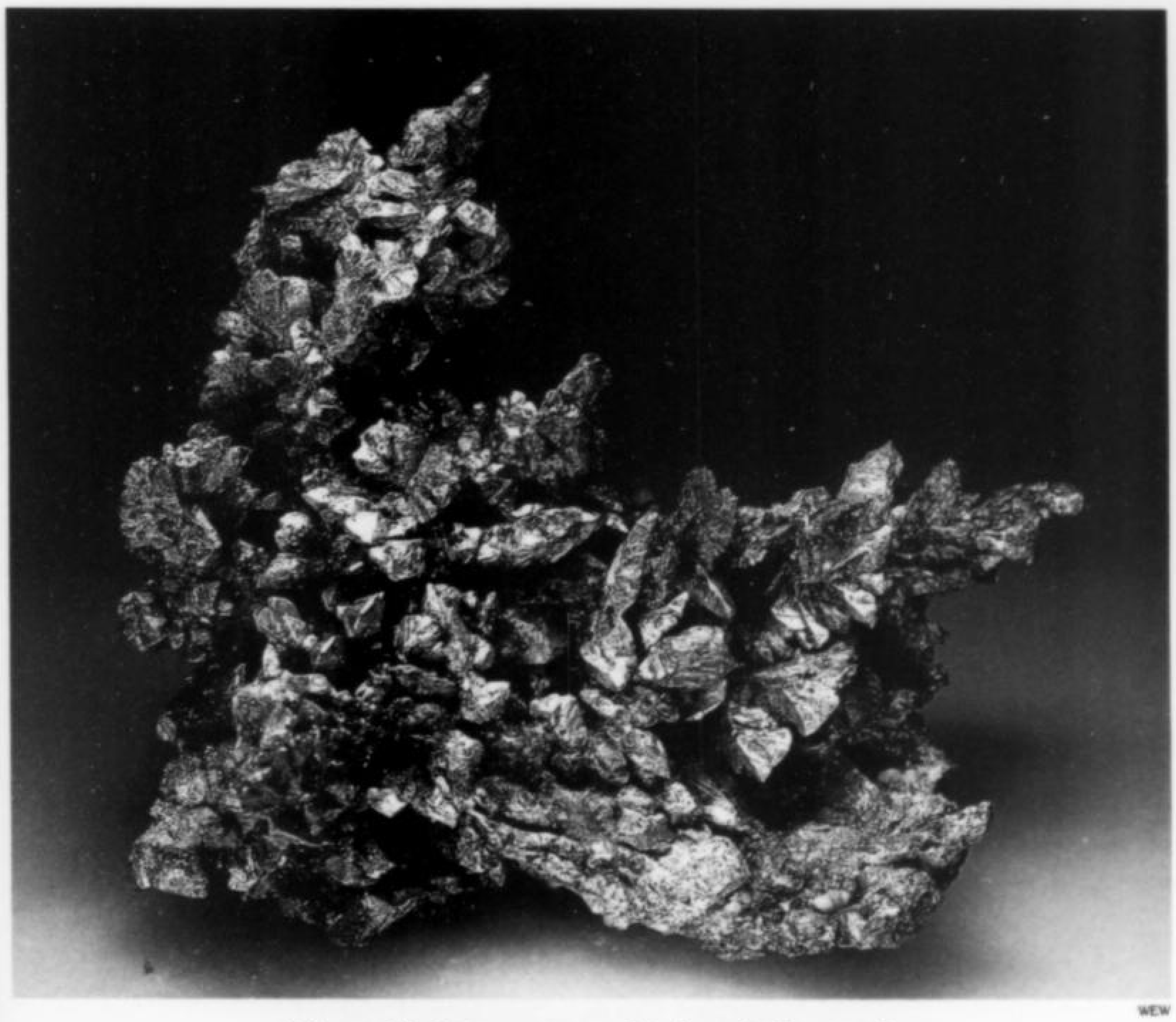


*Figure 54.* **Intergrown and twinned silver and copper crystal group, 9 cm, from the Lake Superior mine. Seaman Museum collection.**

The most common form for silver crystals in the Copper Country is the elongated twinned tetrahexahedron discussed above. Silver in this form generally occurs in complex branching aggregates of parallel-growth crystals. Untwinned tetrahexahedral crystals of silver have been observed but are rare. The cube and octahedron are common modifiers of silver tetrahexahedrons, both twinned and untwinned.

The cube is also a common form for silver in Michigan and occurs as twinned aggregates similar to those of the tetrahexahedrons mentioned above. Unmodified cubes are unusual and are most often observed in crystals 1 mm or less in size. Larger cubes are commonly modified by tetrahexahedrons but may occur as superb hoppered individuals and clusters at some localities.

The dodecahedron is very rare as a form for silver crystals in the Copper Country, but spectacular specimens have been observed. The octahedron is encountered only as a modifying form among silver crystals from the Copper Country. However, as with copper, twinned cubes and tetrahexahedrons which could be mistaken for octahedrons are common.

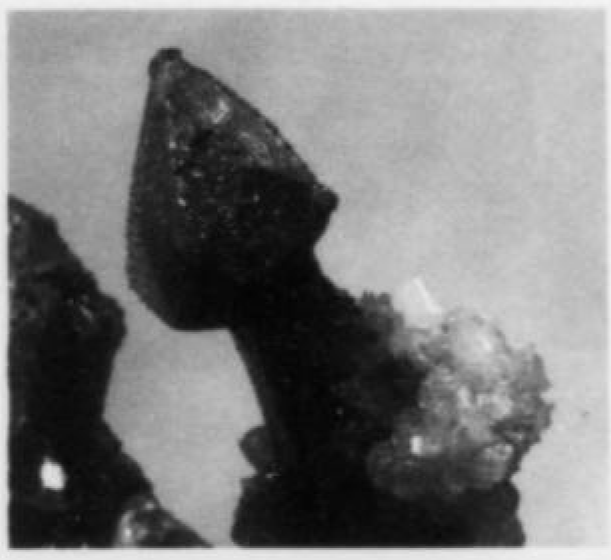


***Figure 55. (left)*** **Sceptered, twinned tetrahedral copper crystal, 1.8 cm, from the Caledonia mine; with tenorite coating and pink adularia. Marc and Debra Wilson collection; photo by Debra Wilson.**

***Figure 56. (below)*** **Copper crystal group, 8.7 cm, with prehnite, from the Phoenix mine. Seaman Museum collection, ex Joseph Rawlings collection (chief engineer at the Cliff mine, ex John T. Reeder collection.**

***Figure 57.*** **Copper crystal group *(above)*, from "Lake Superior," 3.7 cm tall. Harvard collection.**

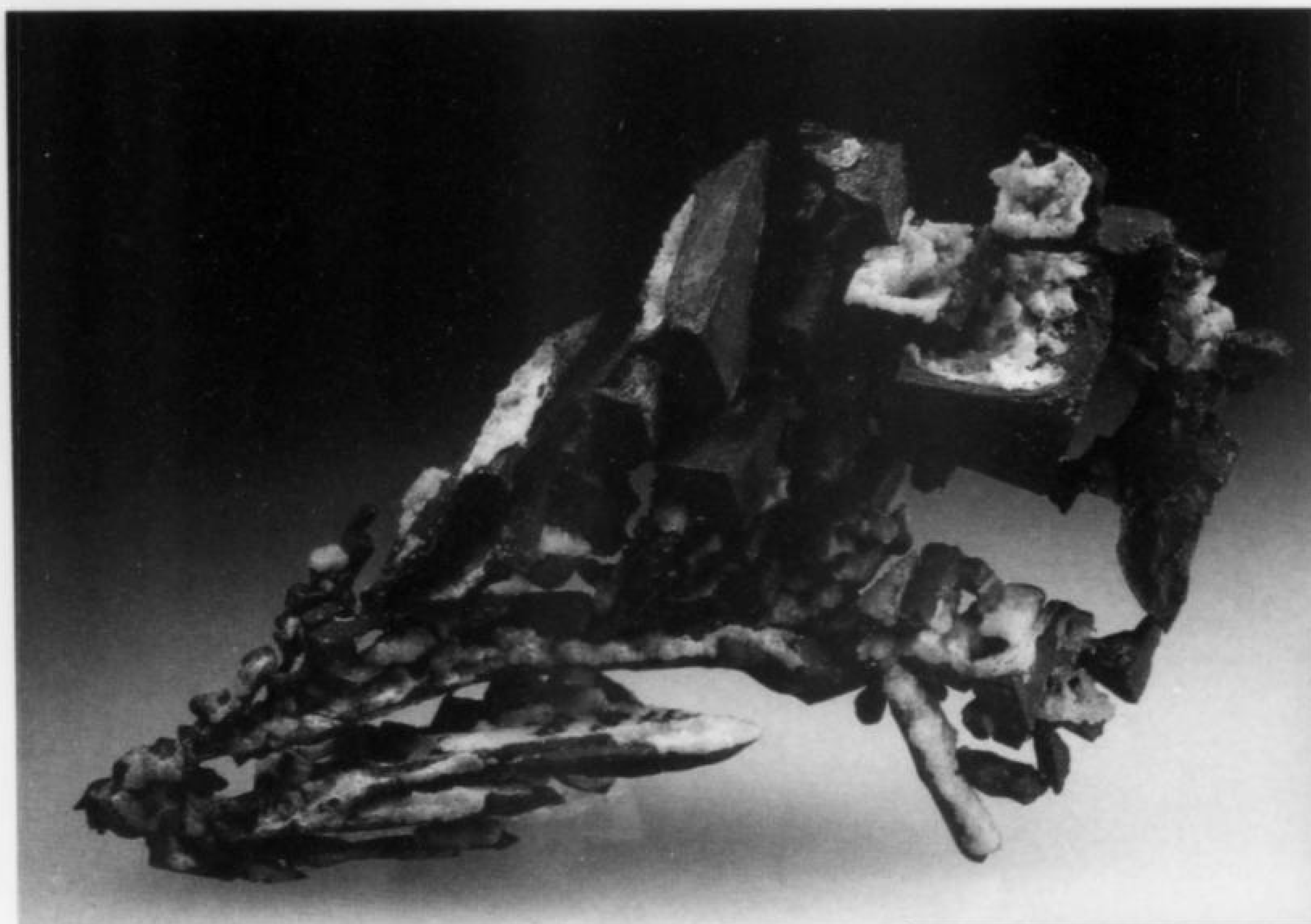


***Figure 58. (right)*** **Copper crystal group, 6.3 cm, with reddish cuprite oxidation coating, from the Kearsarge lode. Seaman Museum collection, ex William Weir collection (Captain at Calumet & Hecla's South Hecla branch).**

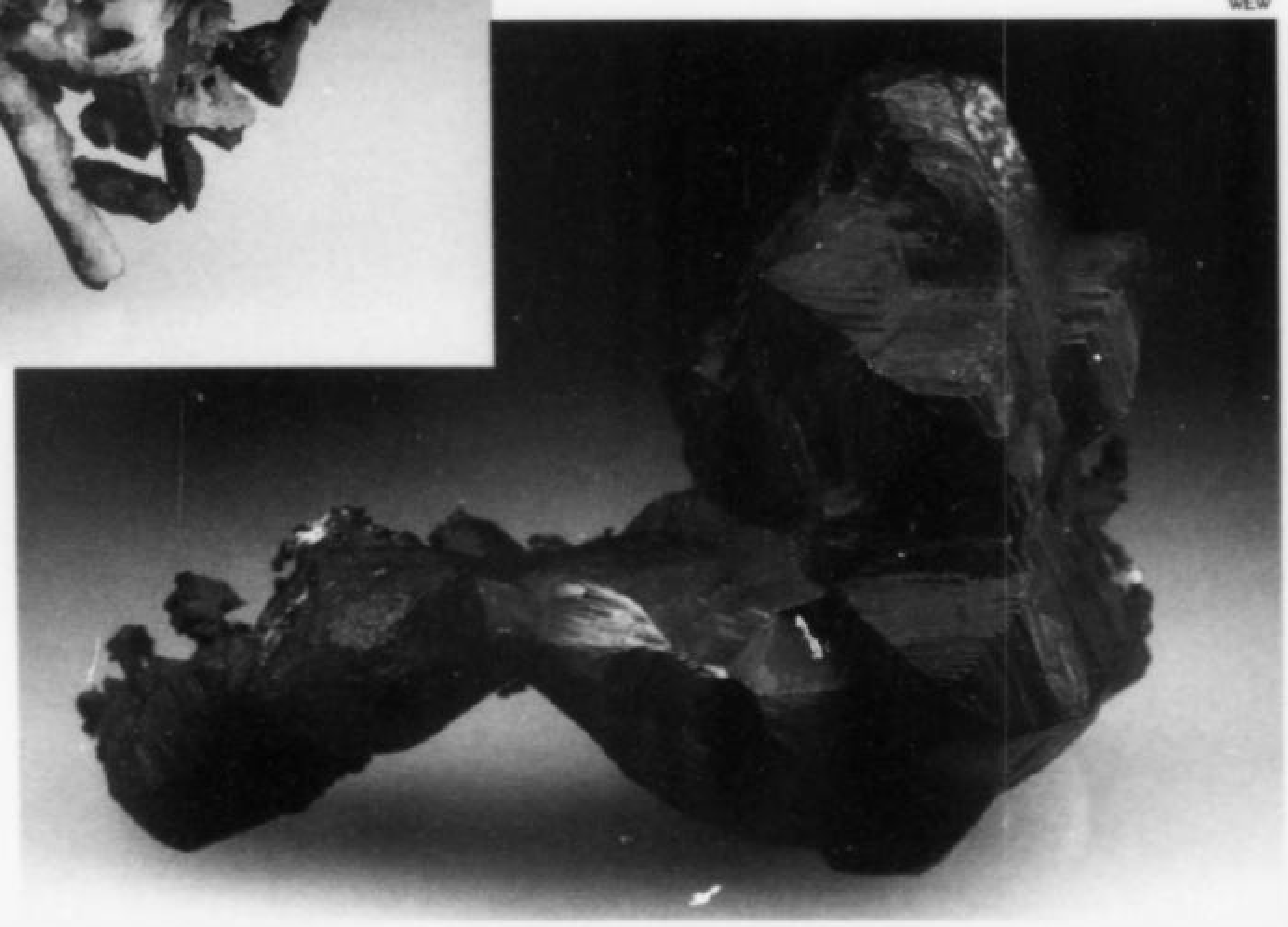
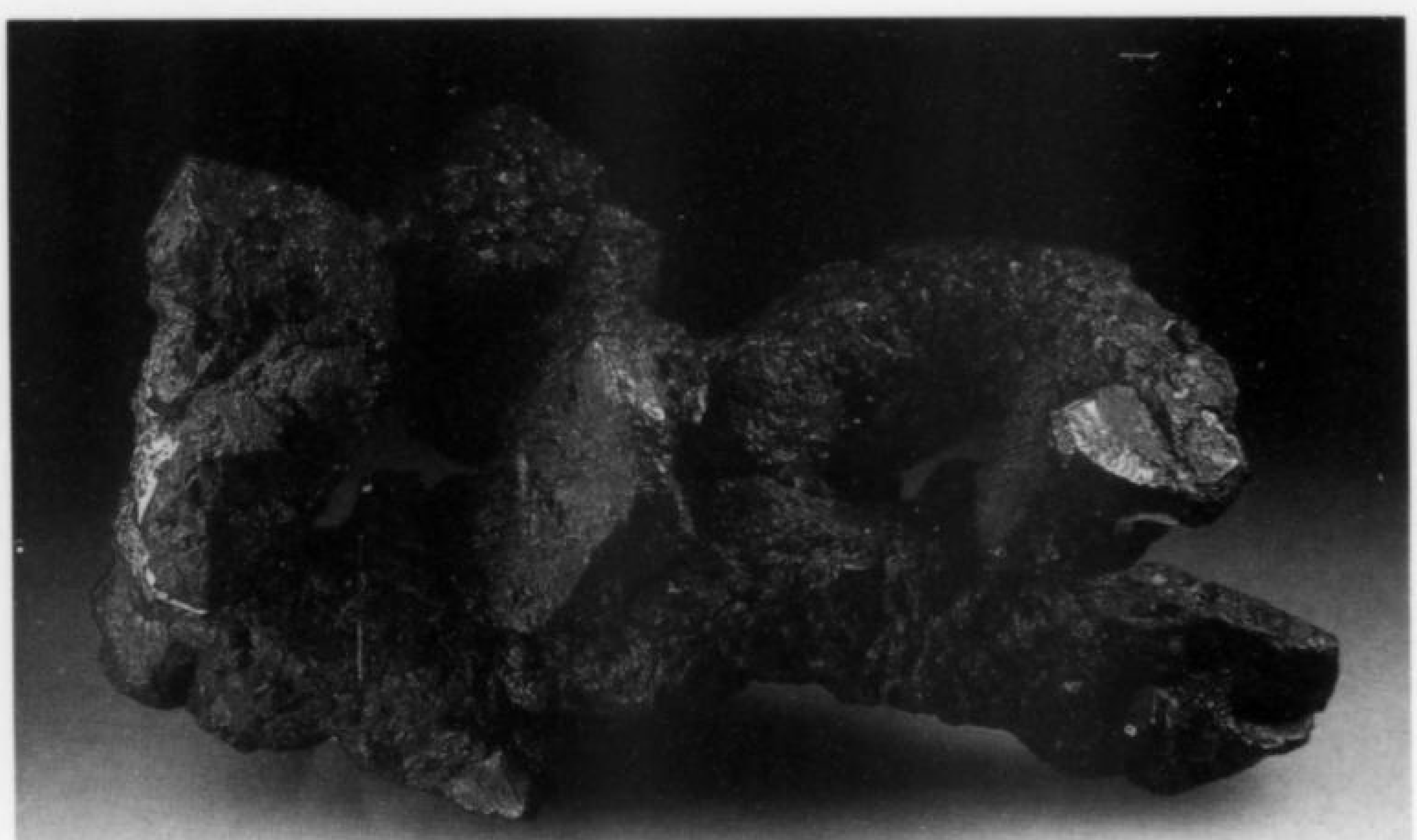


***Figure 59. (below)*** **Copper, in eurved, irregular, vermiform crystals, 10.8 cm, from the Quincy mine. Gene Schlepp collection.**



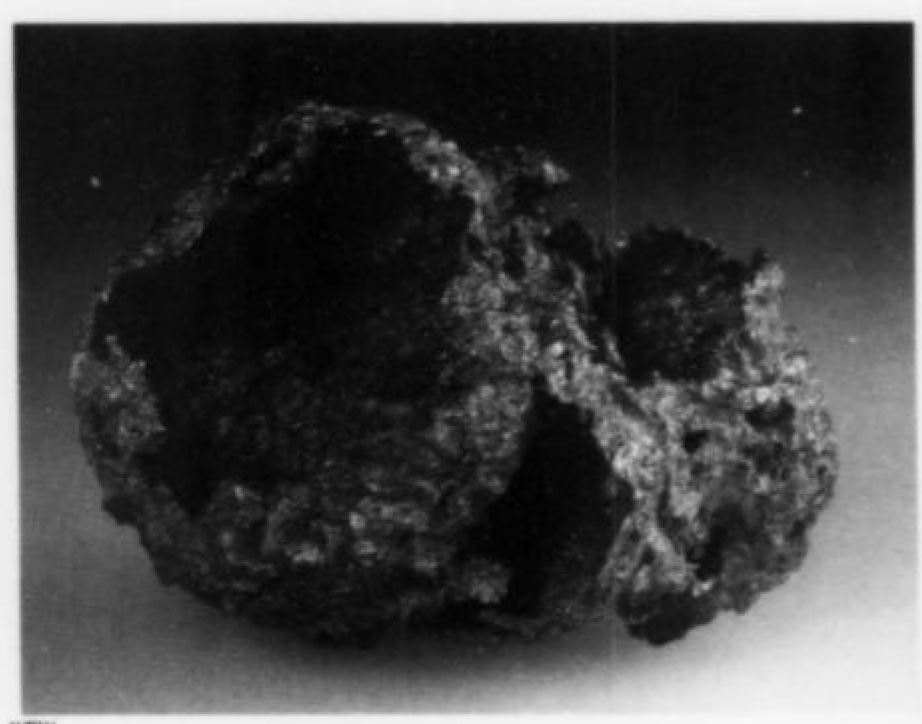
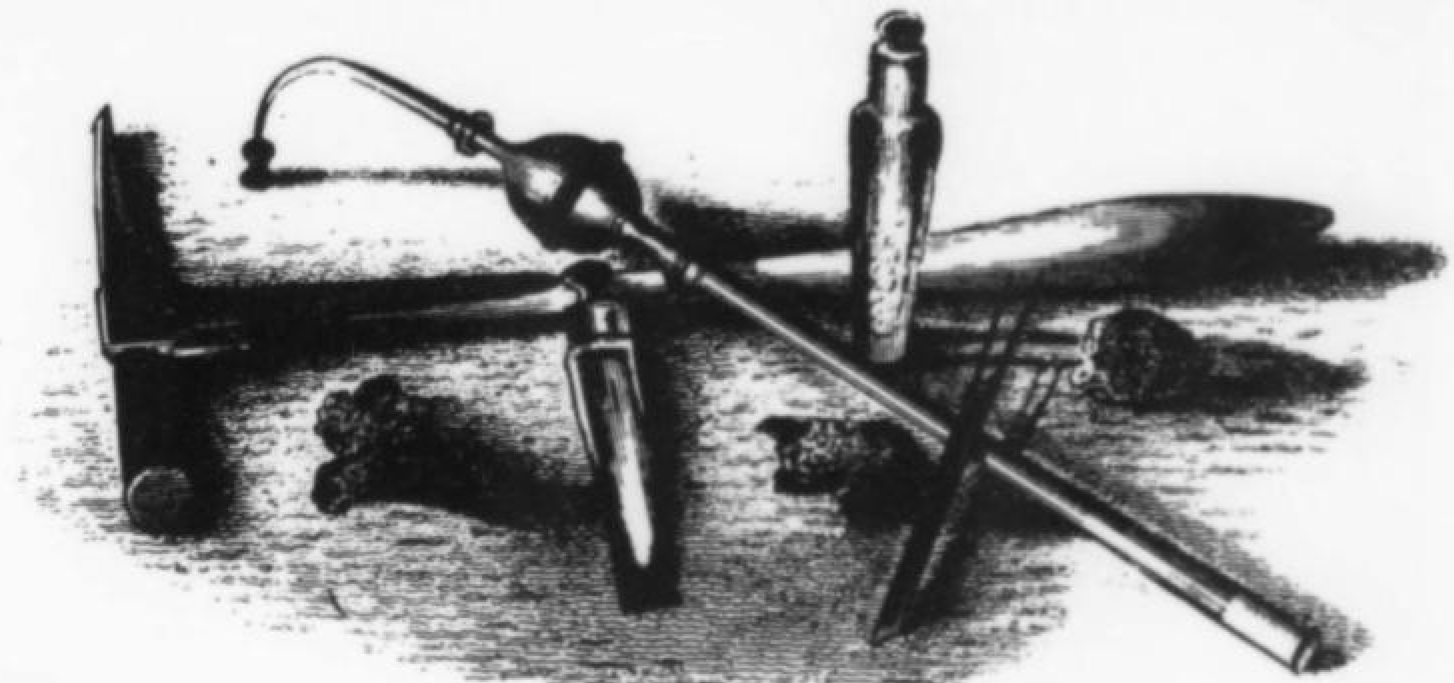


***Figure 60.*** **Copper "skull," 5.8 cm, from the Centennial no. 3 mine. Don Olson collection.**



# MINERALOGY

The great anomaly of Michigan's Copper Country is the fact that the overwhelming majority of the ore mined has consisted of native copper—a mineral which is relatively rare in most other commercial copper deposits. The outstanding groups of crystalline copper and the superb, large, euhedral, single copper crystals from this district are unmatched for crystal perfection, size and quality in comparison with any other district in the world. In contrast, the more common oxides, sulfides and other copper minerals that are so prevalent in other famous mineral localities are unusual, and good-quality crystal specimens of these species are almost completely lacking in the Michigan copper district.

This being the case, micromineral collectors avidly seek out such rarities as chalcocite, malachite, azurite, cuprite, kinoite and numerous more esoteric copper minerals which may be found in small amounts on waste rock piles scattered throughout the district. Many of the sites where these specimens have been collected in the past have been exposed to weathering for long periods of time, over 100 years in some cases. Therefore, there is some question as to whether these minerals, typically associated with the oxidized zones of other mineral districts, are part of the true mineralizing sequence in the Copper Country, or have resulted from post-mining weathering. Although micromineral specimens of these species can be found in representative samples from throughout the district, larger crystals which are identifiable without magnification and are of unquestioned pre-mining origin are far more rare.

Another item which should be noted is that some mineral species may have come about as a result of mining activities. This is particularly true of the chlorides (which may have resulted from the interaction of saline mine waters with the freshly exposed ores) and the nitrates (which were not noted by the miners in the mines until after the relatively recent introduction of Ammonium Nitrate-Fuel Oil blasting compounds to the district; Louis Lafayette, personal communication). The fact that some of these species are water soluble and occur in fairly wet environments supports a theory of post-mining or syn-mining origin for these minerals. Similar arguments have been advanced for some occurrences of halite, gypsum and other evaporite minerals.

Because of the vast number of mine sites in the district and the fact that microcrystals of almost any mineral common to the district may be found with diligence at most sites, it is beyond the scope of this work to attempt to catalog all mineral occurrences in the district. The following catalog of minerals will therefore concentrate on mineral species and will identify only those localities which are of particular interest due to rarity of occurrence or the exceptional quality of specimens produced.

**Acanthite** $Ag_2S$

Acanthite has been found at the White Pine mine in Ontonagon County, in association with silver and erythrite.

**Actinolite** $Ca_2(Mg,Fe^{+3})_5Si_7O_{22}(OH)_2$

In 1989 microscopic acicular actinolite crystals were discovered associated with prehnite, datolite, copper and hematite at the Central mine in Keweenaw County. Identification was based on optical properties and electron microprobe analysis.

***"Adularia"*** (see microcline)

**Albite** $NaAlSi_3O_8$

Albite occurs as microcrystals lining vesicles and fractures in the Osceola and Kearsarge lodes. It is associated with microcline adularia and other species, and is a widespread alteration product of the basalts of the volcanic sequence (Heinrich, 1976).

**Algodonite** $Cu_6As$

Algodonite occurs as sharp microcrystals and massive material at the Champion mine on the Baltic lode and the Mohawk mine on the Kearsarge lode. It is associated with arsenian copper and copper arsenide minerals (Heinrich, 1976).

**Analcime** $NaAlSi_2O_6 \cdot H_2O$

Analcime occurs as euhedral crystals from less that 1 mm to over 6 cm in diameter at numerous localities throughout the district. Colors range from water-clear and colorless to snow-white, orange and brick-red, commonly with copper inclusions. It is associated with calcite, quartz, copper, natrolite, fluorapophyllite, and other minerals of the district. Complex crystal composites which form around a single crystal nucleus, described as re-entrant twins by Penfield in 1885, are common in some localities, particularly in the fissure deposits of Keweenaw County.

**Anhydrite** $CaSO_4$

Pale lavender microcrystals of anhydrite occur in the Isle Royale

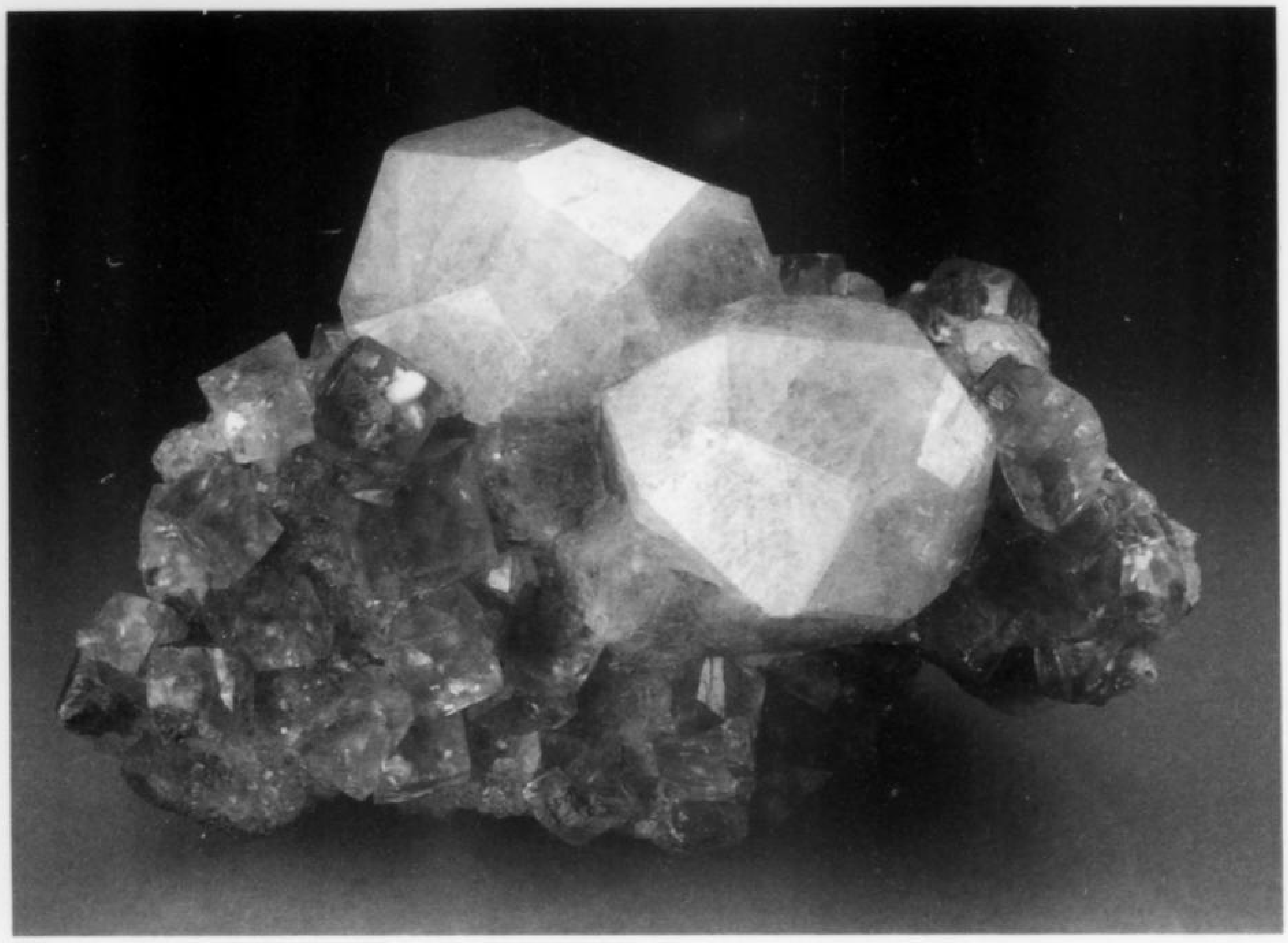


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*Figure 63*. **Analcime crystals with golden pseudocubic calcite, 5.5 cm, characteristic of the Phoenix mine. Seaman Museum collection, ex D. C. Gabriel collection.**

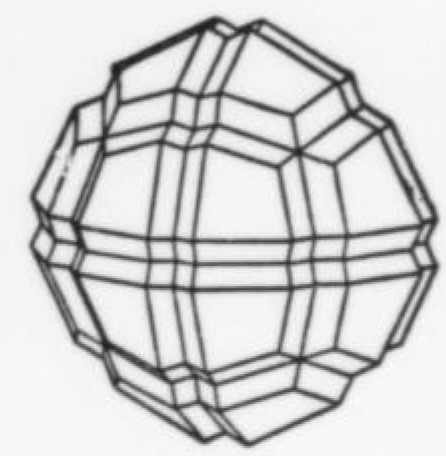

*Figure 61*. **Analcime from the Keweenaw Peninsula (Penfield, 1895).**

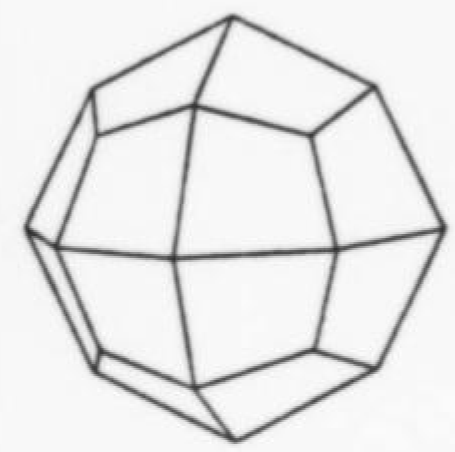

*Figure 62*. **Simple trapezohedron habit typical of Michigan analcime.**

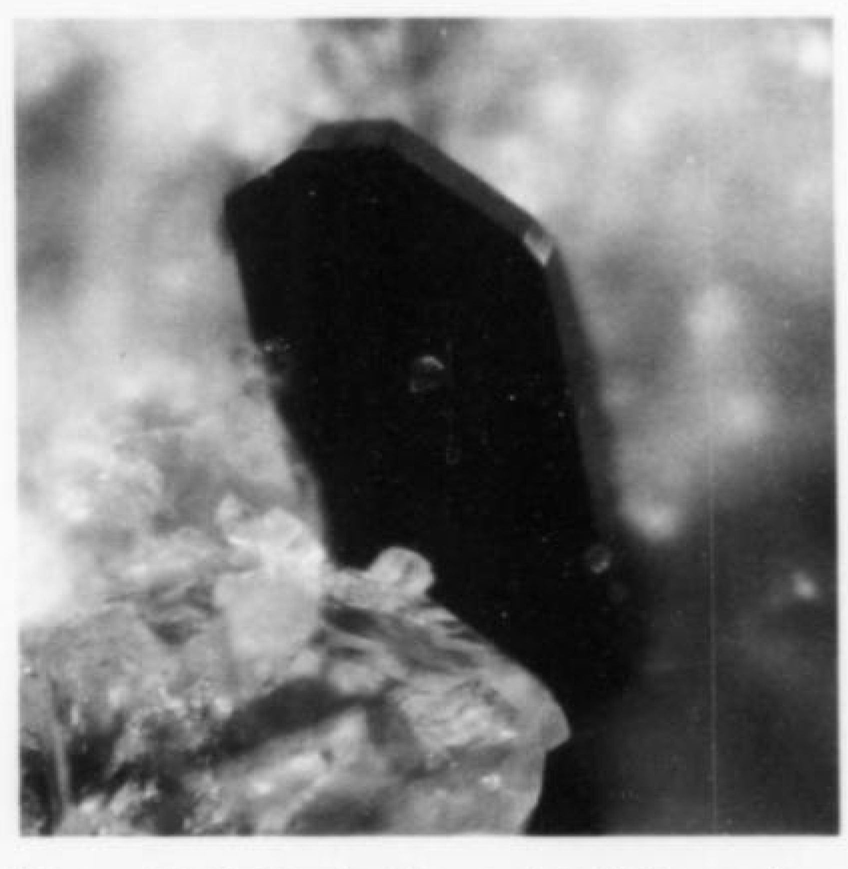

*Figure 64*. **Babingtonite crystal, 0.8 mm, from the Cliff mine. Dan Behnke collection and photo.**

lode in Houghton County. They are associated with siderite, gypsum and dolomite (Heinrich, 1976).

**Ankerite** $Ca(Fe^{+2},Mg,Mn)(CO_3)_2$

Ankerite occurs as massive material in the Baltic and Isle Royale lodes in Houghton County (Heinrich, 1976). Although recognizable crystals have not been reported, microcrystals may well exist.

**Annabergite** $Ni_3(AsO_4)_2 \cdot 8H_2O$

Annabergite occurs with other massive arsenates and arsenides in the Mohawk mine on the Kearsarge lode in Keweenaw County (Heinrich, 1976).

**Anthonyite** $Cu(OH,Cl)_2 \cdot 3H_2O$

Anthonyite occurs as lavender microcrystals in the Centennial #1 and #2 mines in Houghton County. It is associated with other halides and copper minerals (Heinrich, 1976).

**Atacamite** $Cu_2Cl(OH)_3$

Microcrystals of atacamite have been found at the Algomah mine in Ontonagon County, the Centennial #1 and #2 mines in Houghton County and the Allouez mine in Keweenaw County. It is associated with other halides, chrysocolla and other copper minerals (Heinrich, 1976). It has also been discovered as a secondary stain on copper and microcline adularia from the Phoenix mine in Keweenaw County.

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

Azurite is extremely rare in the Copper Country. It usually consists of very fine crystals or cryptocrystalline stains on well-oxidized rocks such as those from the Atlantic mine in Houghton County.

**Babingtonite** $Ca_2(Fe^{+2},Mn)Fe^{+3}Si_5O_{14}(OH)$

Babingtonite was found at the Cliff mine in 1972, as lustrous black microcrystals to 2 mm (Dan Behnke, personal communication).

**Barite** $BaSO_4$

Barite occurs in small amounts throughout the district. Fine crystals, although rare, have been produced from the Phoenix mine, Humboldt mine, Copper Falls mine and other localities in Keweenaw County, the Centennial #1 and #2 mines, mines on the Isle Royale lode and elsewhere in Houghton County, and in several localities in Ontonagon County. The habit is platy, and the color is gray, greenish gray and creamy white to colorless. Associated minerals include calcite, quartz, hematite, prehnite and copper. In the White Pine mine in Ontonagon County, barite crystals occur in sizes from microscopic to in excess

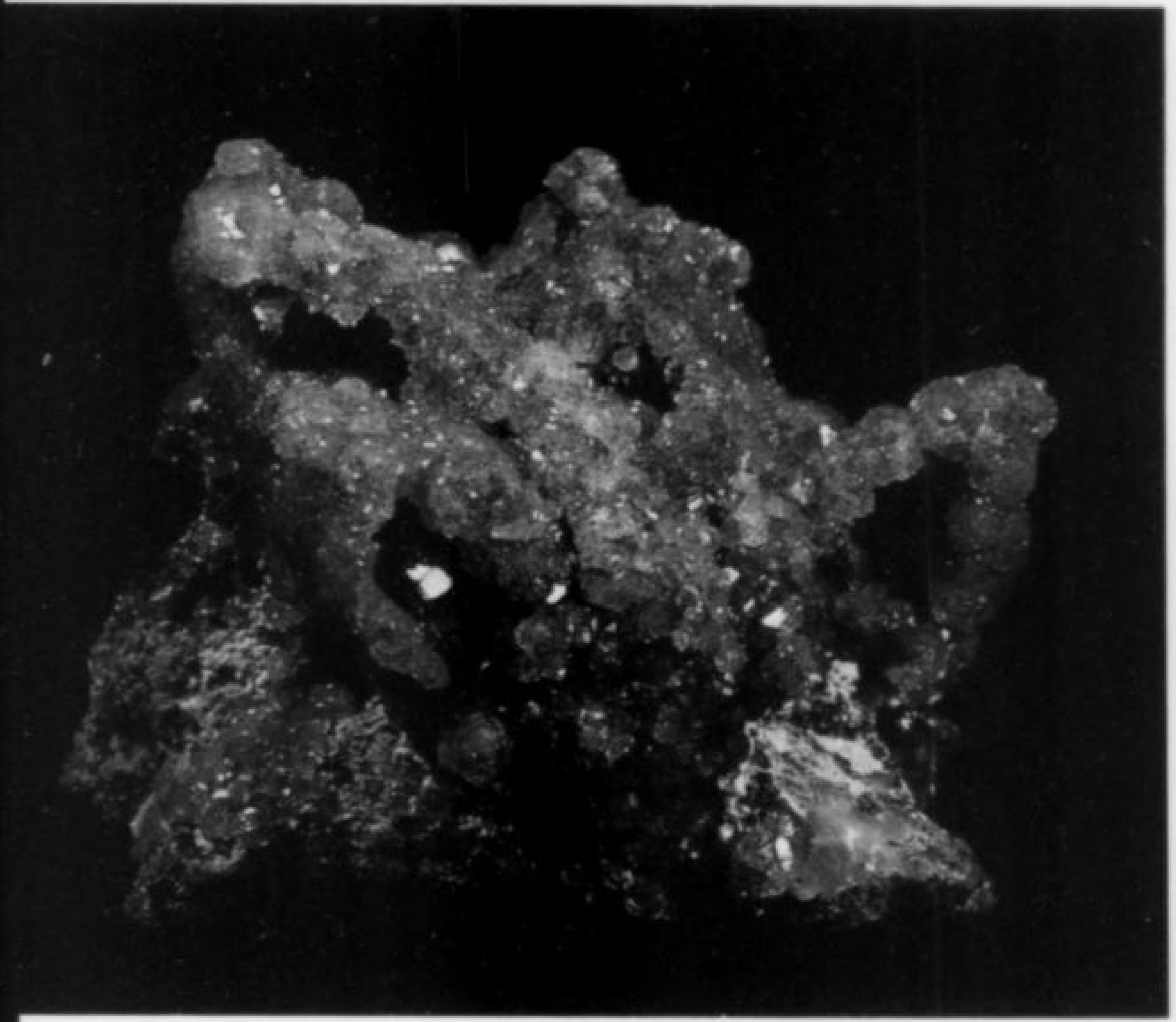

Figure 65. (left) Analcime with copper inclusions, forming molds after calcite crystals; a later generation of calcite crystals encloses copper within the molds. The specimen, 5.8 cm tall, is from the Phoenix mine. Marc and Debra Wilson collection; photo by Debra Wilson.

of 7 cm. Barite roses have been found with fluorite in calcite veins cutting the Copper Harbor Conglomerate in Keweenaw County.

**Bastnaesite-(Ce)** $(Ce,La)(CO_3)F$

Bastnaesite-(Ce) is an unusual rare-earth mineral found in microscopic amounts in the Nonesuch Formation (Heinrich, 1976).

**Bornite** $Cu_5FeS_4$

Bornite occurs in small amounts at various localities throughout the district. Occurrences include the White Pine mine in Ontonagon County, the Baltic, Isle Royale and Kearsarge lodes in Houghton County and the Mendota mine in Keweenaw County. It is associated with various other sulfides and gangue minerals (Heinrich, 1976).

**Braunite** $Mn^{+2}Mn_6^{+3}SiO_{12}$

Braunite has been found as blebs and crystals at the Manganese mine in Keweenaw County (Behnke, 1986). It is associated with pyrolusite, orientite, manganite and barite (Heinrich, 1976).

**Brochantite** $Cu_4(SO_4)(OH)_6$

Brochantite was reported by Bee and Dagenhart in 1985 from the Clark mine in Keweenaw County (Behnke, 1986).

**Brucite** $Mg(OH)_2$

Brucite has been found in the Isle Royale and Kearsarge lodes as massive material and as an alteration product of laumontite (Heinrich, 1976).

**Buttgenbachite** $Cu_{19}Cl_4(NO_3)_2(OH)_{32}\cdot 2H_2O$

This mineral has been found in the Centennial #1 and #2 mines in Houghton County. It is associated with cuprite and malachite and is post-mining in origin (Heinrich, 1976).

**Calcite** $CaCO_3$

The Copper Country has long been famous for the spectacular calcite crystals produced from various mines throughout the district. The crystals occur in every size from microscopic to larger than 18 cm in length. Twins are common, as are numerous complex forms composed of myriads of unusual crystal faces. Colors range from water-clear and colorless to pale yellow, gray, brown, orange, black, and red to pure white. Inclusions within calcite crystals are very common, especially chalcocite and/or tenorite in the mines in the southern portions

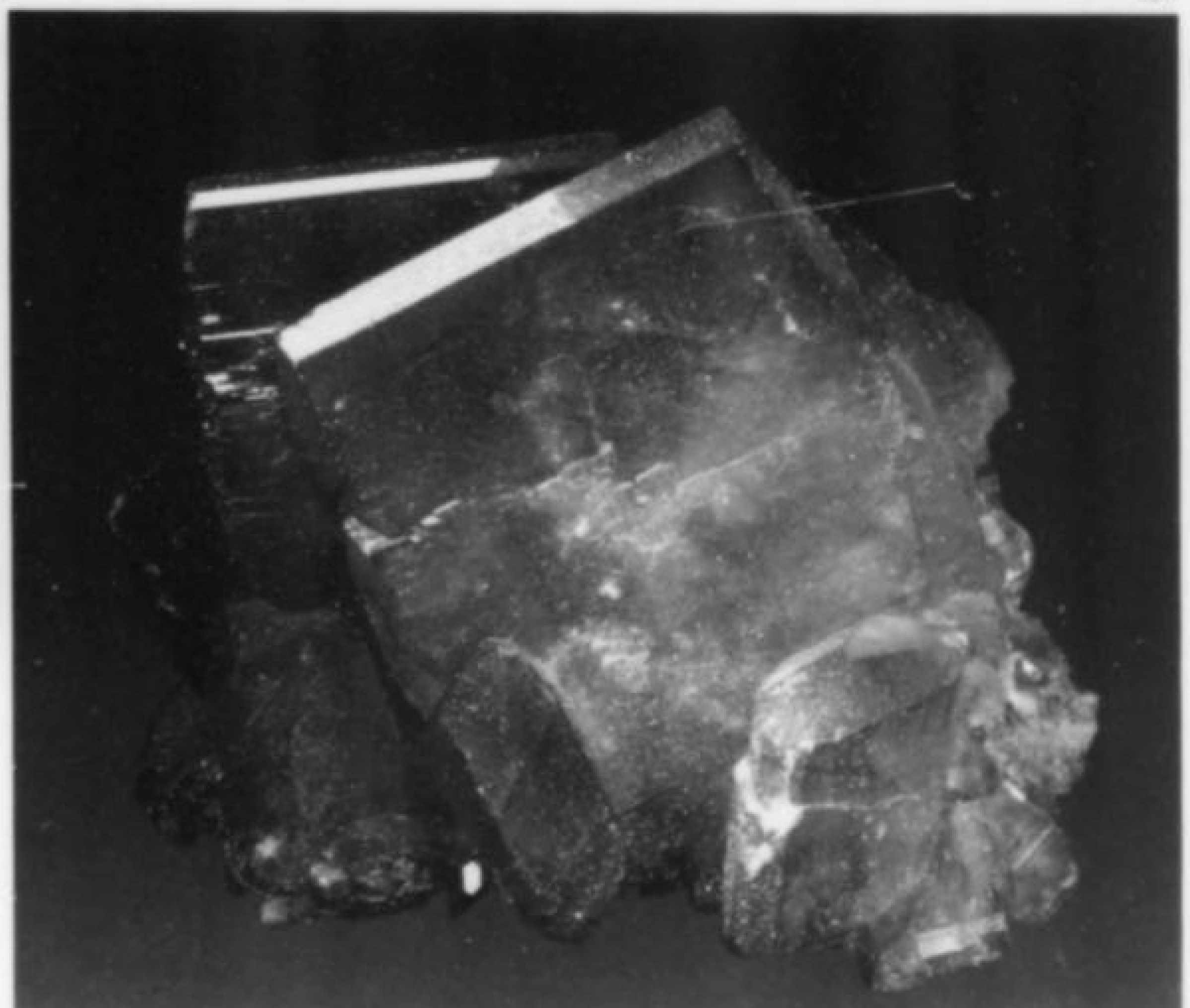

Figure 66. Barite crystals to 6.4 cm, from the White Pine mine. Marc and Debra Wilson collection; photo by Debra Wilson.

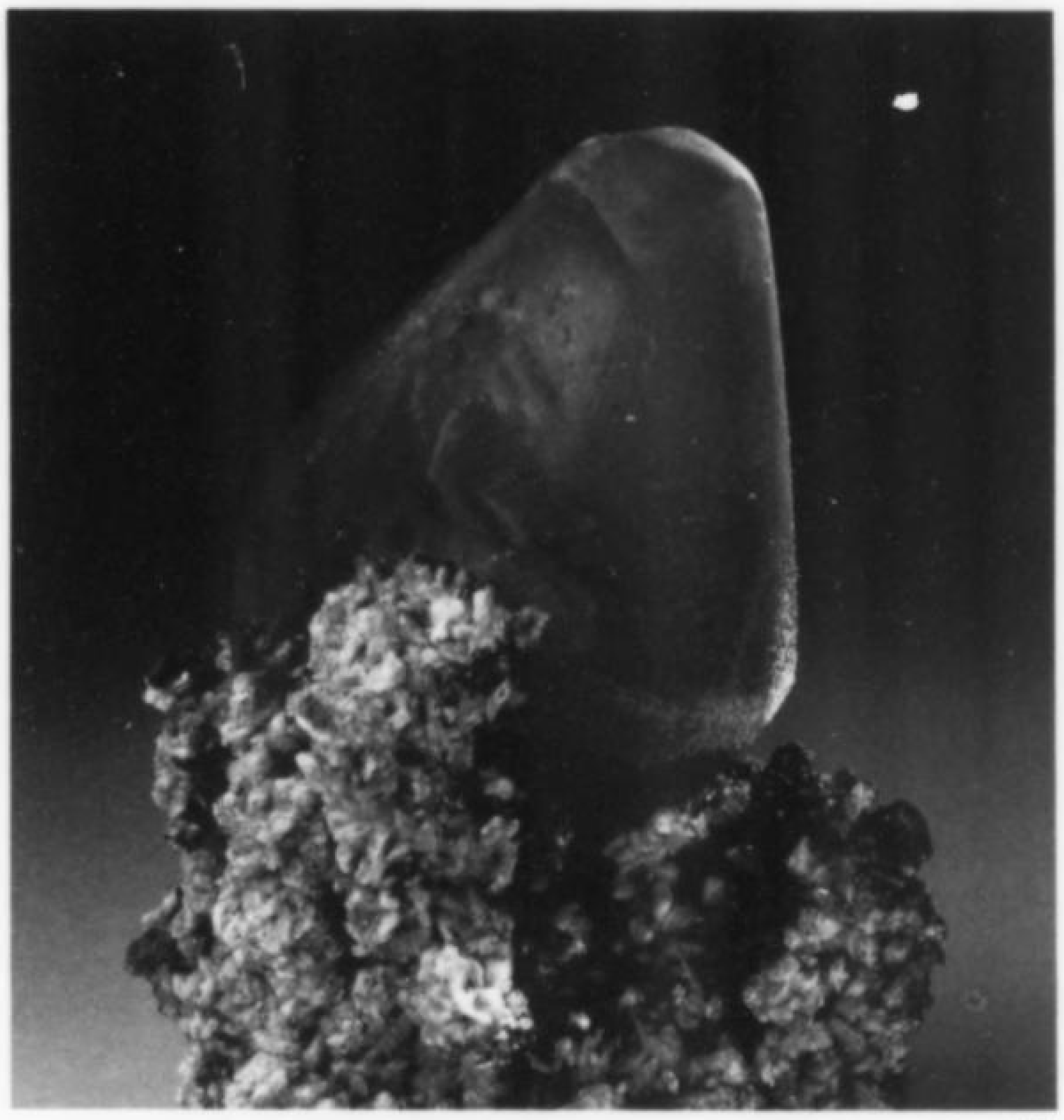

Figure 67. Orange calcite crystal, 3.6 cm, from the Adventure mine. Seaman Museum collection, ex Dr. and Mrs. Paul Trudgen collection.

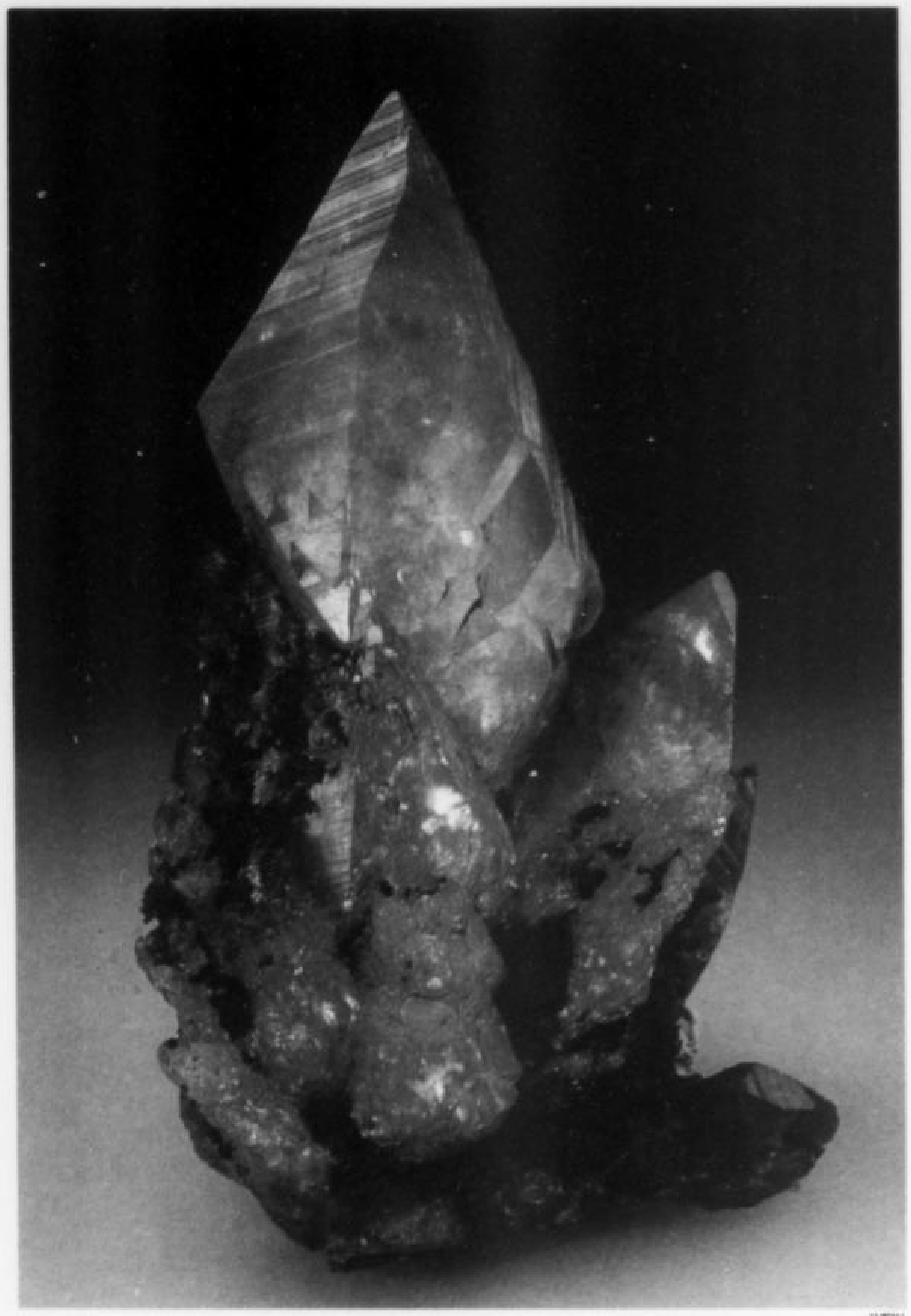

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*Figure 69*. Copper in calcite crystal group, 8.5 cm, from the Franklin mine. Seaman Museum collection, ex John T. Reeder collection.

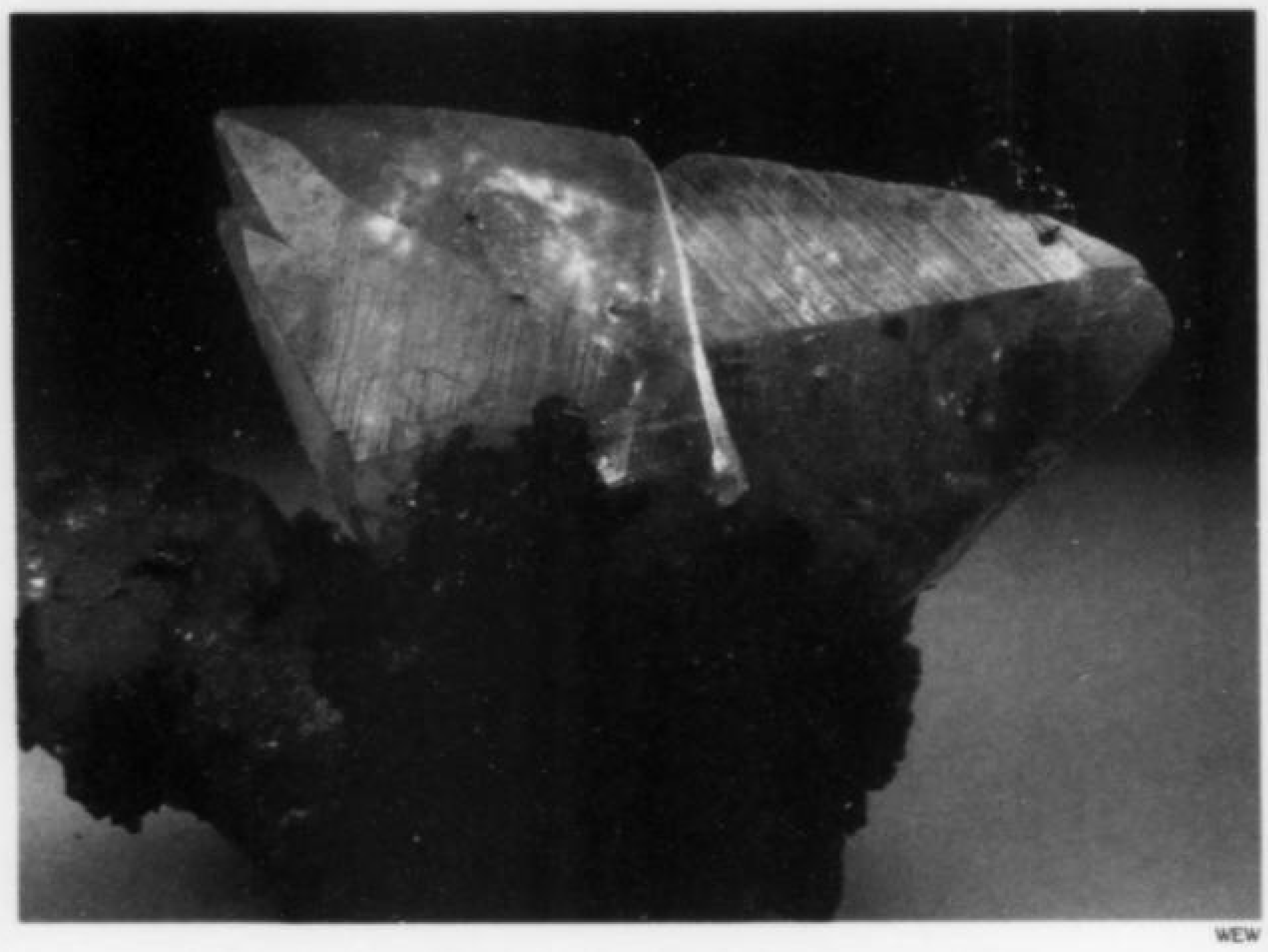

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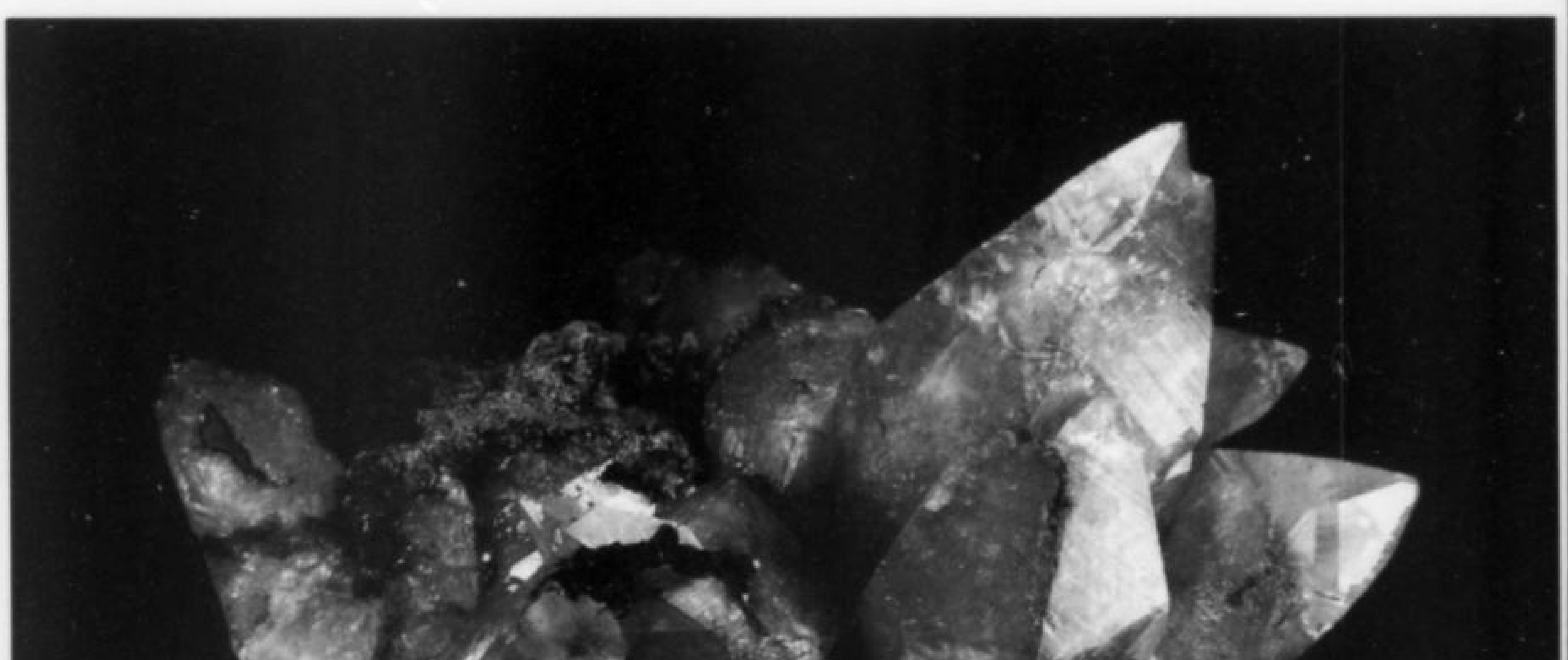
*Figure 68*. Copper in butterfly-twin calcite crystal, 4.5 cm, from the Quincy mine. Seaman Museum collection, ex John T. Reeder collection, ex Thomas Whittle collection (Quincy Mine Captain, 1889–1912).

of the district, cuprite (variety *chalcotrichite*) in the Allouez mine in Keweenaw County, native copper throughout the district, and numerous other species. By far the most impressive and most sought after by collectors are transparent scalenohedral crystals with bright copper phantoms inside. Beautiful specimens of calcite with copper phantoms have been found in numerous mines throughout the district.

Some of the more famous localities for fine calcite specimens include the Adventure, Mass, Caledonia and other mines in Ontonagon County; numerous mines on the Isle Royale, Pewabic, Osceola and Kearsarge lodes in Houghton County; and the Kearsarge and Ashbed lodes and fissure mines in Keweenaw County. Many excellent works have been completed on the calcite crystals of the Copper Country

*Figure 70*. Copper in calcite crystal group, 22 cm tall, from the Quincy mine. Seaman Museum collection, ex Thomas Whittle collection (Quincy Mine Captain, 1889–1912). Photo by Ron Bentley.



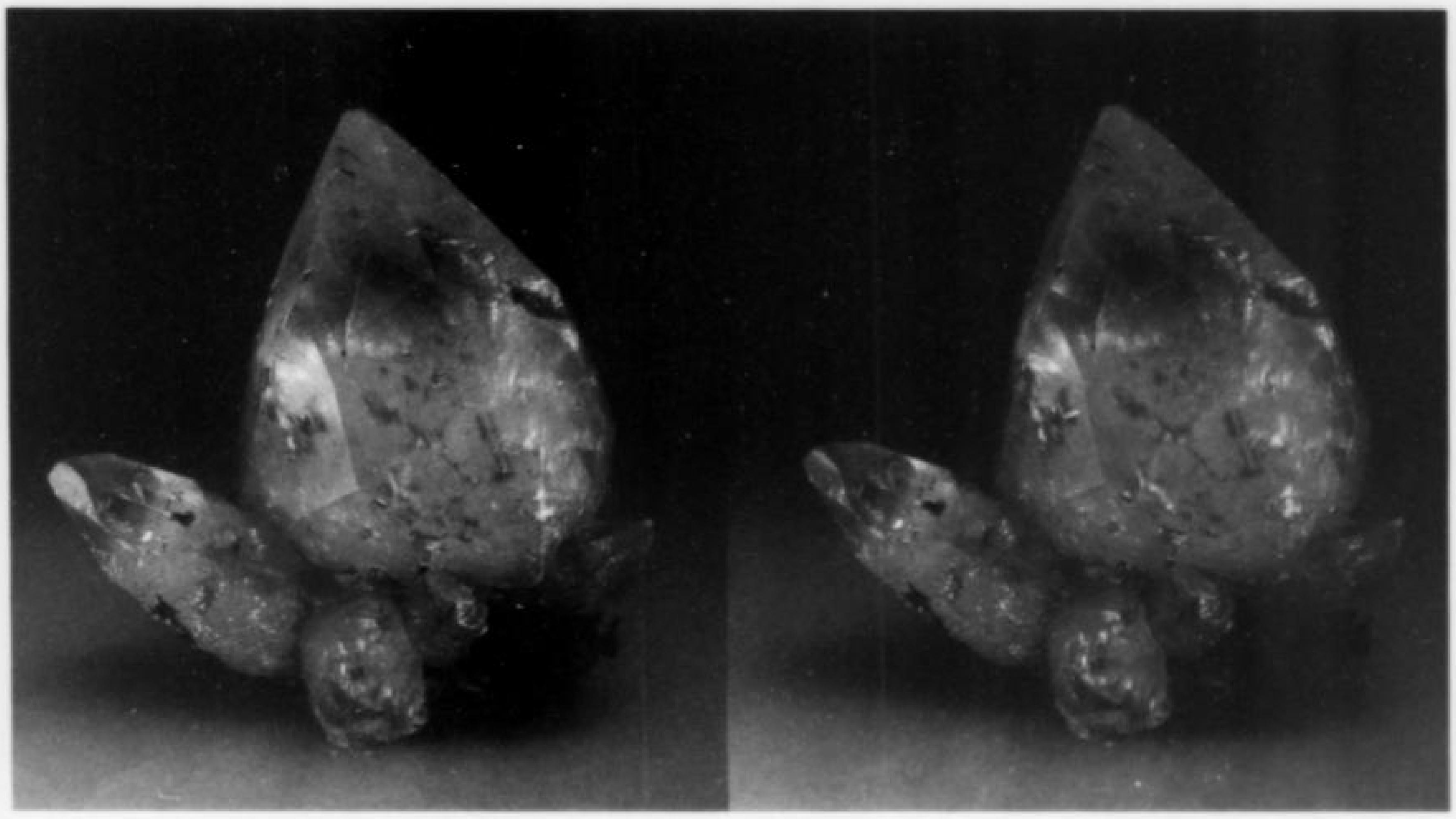


*Figure 71*. **Copper in calcite crystals, 3.8 cm, from the Quincy mine. Seaman Museum collection, ex Lucius L. Hubbard collection. (Stereopair)**

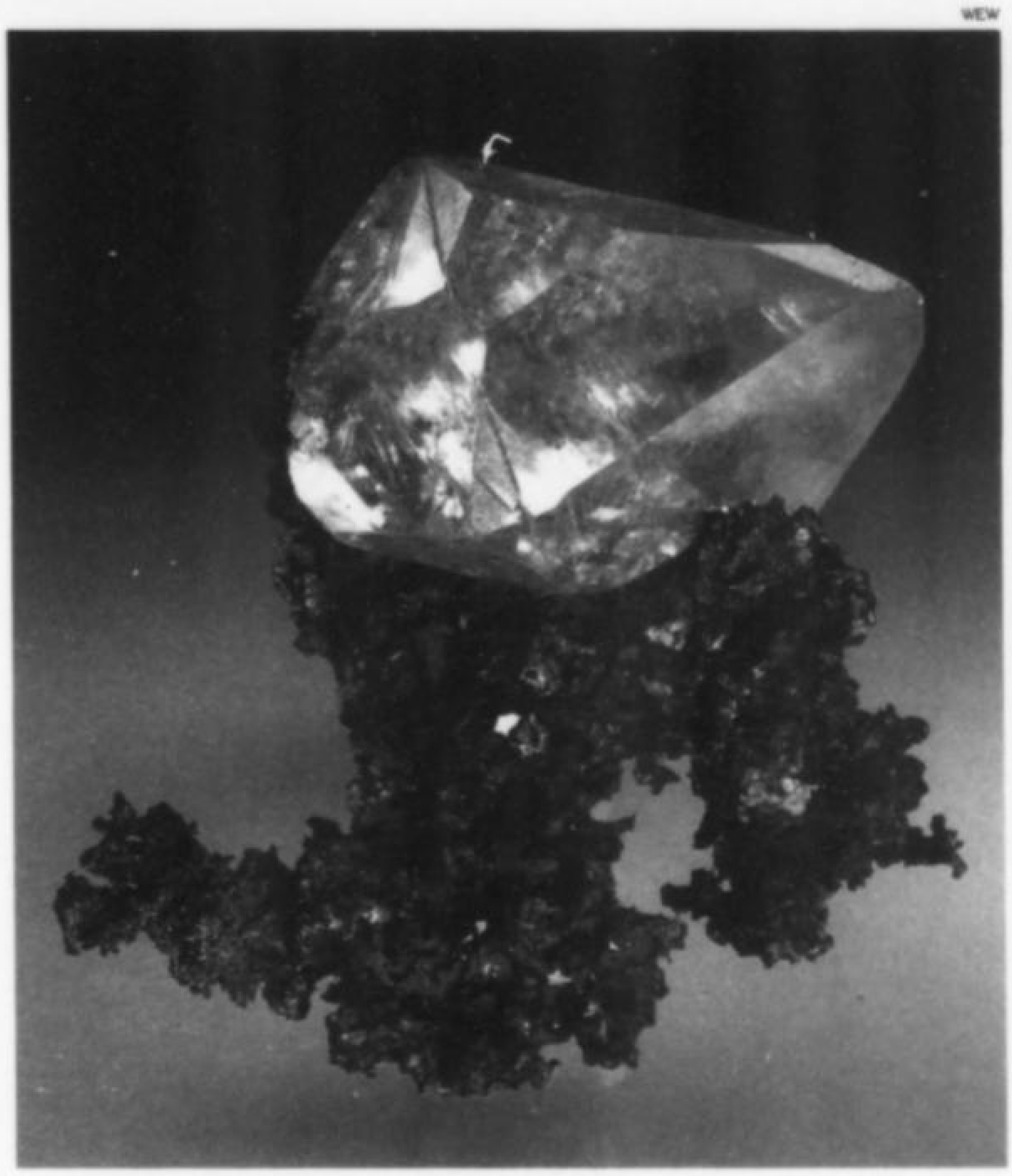


*Figure 72*. **Calcite crystal, 3 cm, partially enclosing copper, from the Quincy mine. Seaman Museum collection, ex John T. Reeder collection.**

and more information may be obtained from Palache (1898), Palache (1944), and numerous others.

**Calumetite** $Cu(Cl,OH)_2 \cdot 2H_2O$

Calumetite occurs in the Centennial #1 and #2 mines in Houghton County. It is believed to have been formed by acidic mine waters interacting with ore minerals (Heinrich, 1976).

**Chabazite** $CaAl_2Si_4O_{12} \cdot 6H_2O$

Chabazite has been reported from the northeastern tip of the Keweenaw Peninsula and elsewhere in Keweenaw County. It is reportedly associated with other zeolites (Heinrich, 1976).

**Chalcocite** $Cu_2S$

Chalcocite occurs in minor quantities throughout the district. Microcrystals have been found at many mine sites on the Kearsarge lode in Houghton and Keweenaw counties, in the fissure deposits of Keweenaw County, and in the Adventure mine in Ontonagon County. Exceptionally fine microcrystals have been found at the Seneca #2 mine in Keweenaw County where they occur with analcime, calcite and possibly apophyllite (K. Schafer, personal communication). Larger crystals have been produced from the White Pine mine in Ontonagon County. Associated minerals often include copper, prehnite, calcite, analcime, malachite and other copper minerals. Chalcocite also occurs as microscopic inclusions in calcite crystals from the Quincy mine in Houghton County; the Kingston, Central and Mendota mines in Keweenaw County; and the South Lake, Adventure, and Mass mines in Ontonagon County, among others.

**Chalcopyrite** $CuFeS_2$

Chalcopyrite has been found as microcrystals at the White Pine mine in Ontonagon County and as anhedral masses and vein fillings elsewhere in the district. An exceptional specimen with rounded crystals in excess of 2 mm in size reportedly came from the Baltic mine on the Baltic lode in Houghton County. Chalcopyrite is associated with other sulfide minerals, calcite, quartz and other species common to the district.

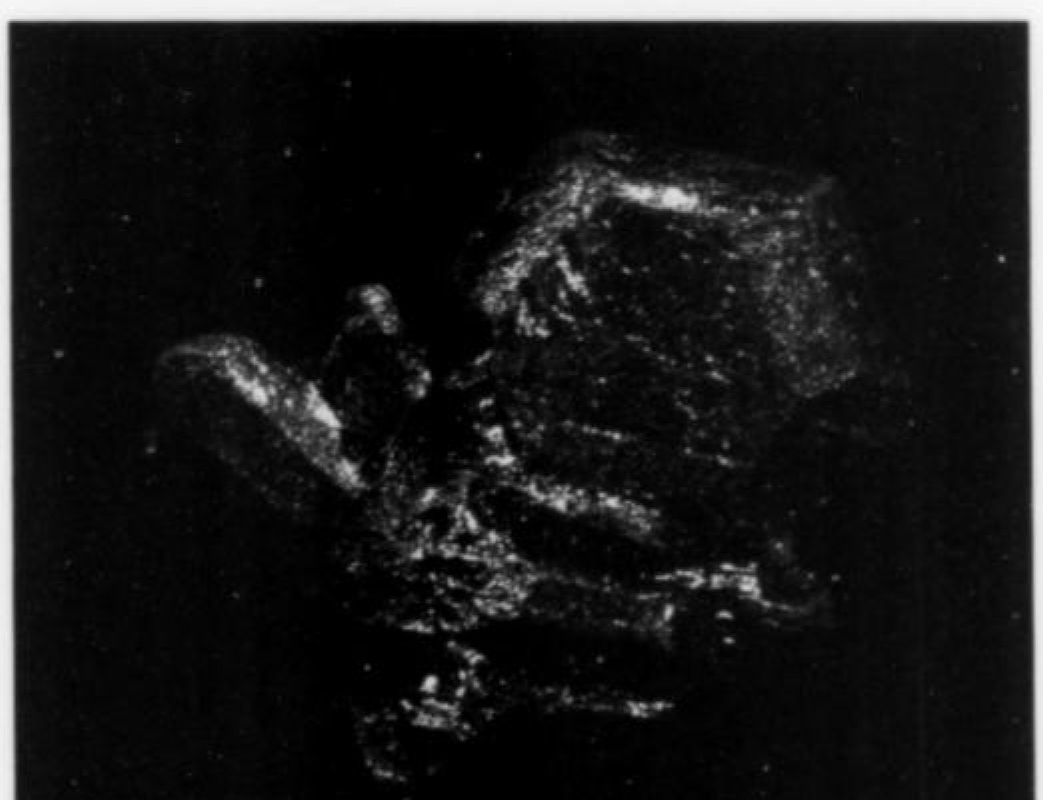


*Figure 73*. **Chalcocite crystal group, 6.3 mm, from the White Pine mine. Dan Behnke collection and photo.**

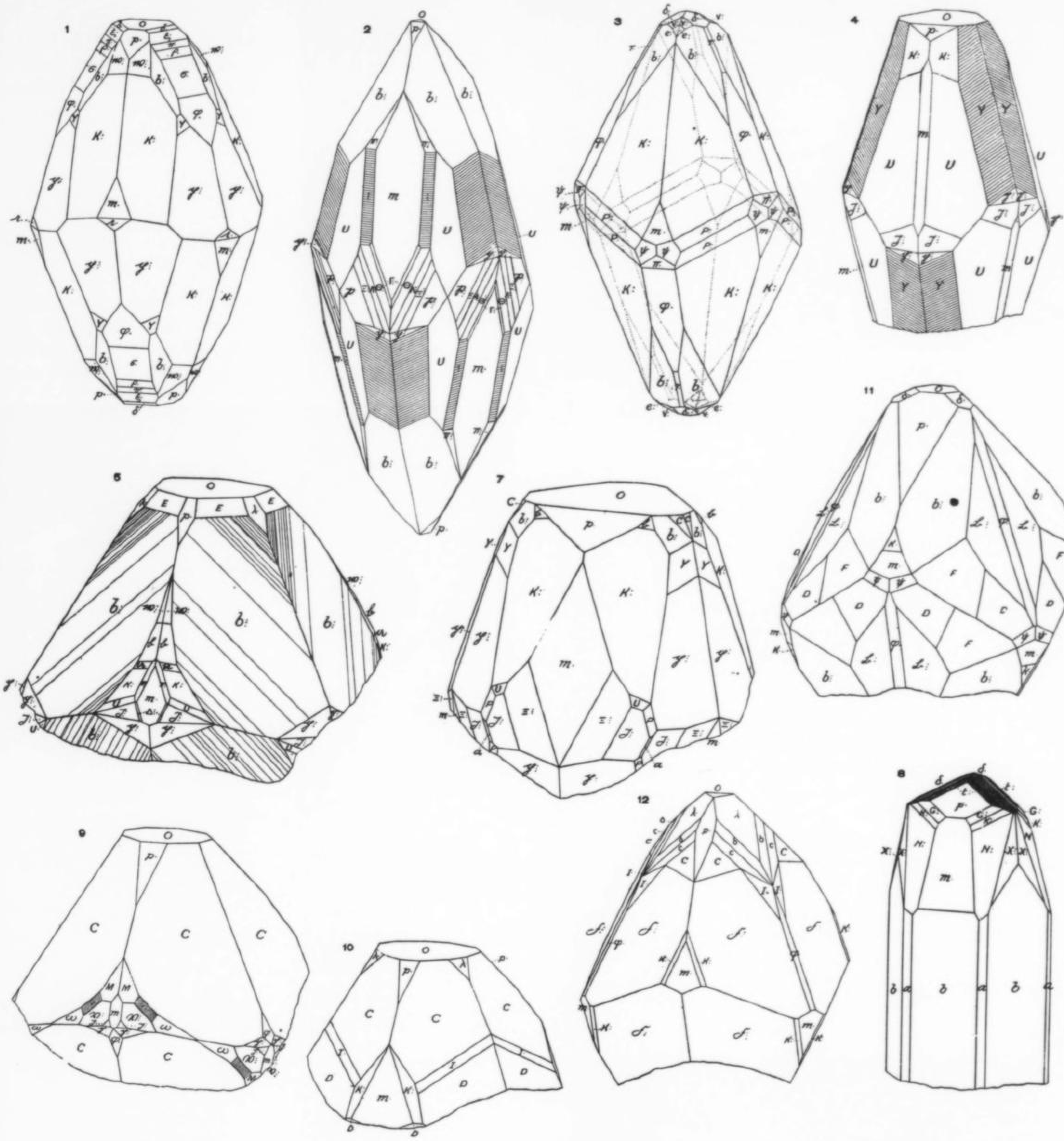
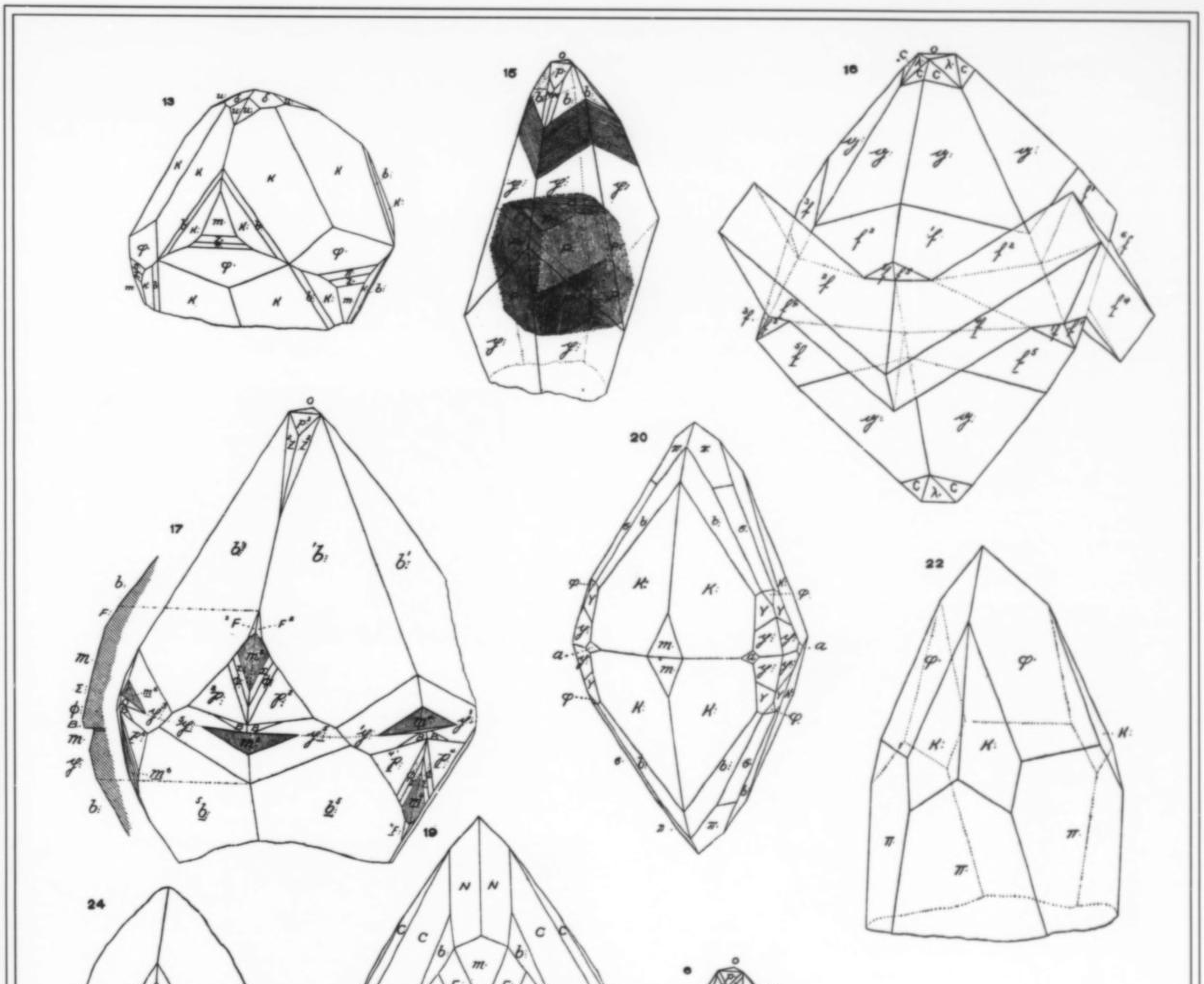


***Figure 74.*** **Calcite crystals from the Keweenaw Peninsula (Palache, 1898). (1) Copper Falls mine, (2) Central mine, 1.3 cm, (3) Minesota mine, 2.5 cm, (4) 6 mm, (5) minute crystal, (6) 7.6 cm, (7) 2.5 cm, (8) size and locality not given, (9) 3.8 cm, (10) Phoenix mine, small, (11) about 1 cm, with copper inclusions, (12) minute crystal, (13) Ridge mine, Ontonagon County, 2.5 cm, (14) 5 cm, water-clear, (15) Central mine, 2.5 cm, with copper inclusions, (16) 6.3 cm, (17) 6.3 cm, (18) Quincy mine, 5 cm, (19) 2.5 cm, (20) Copper Falls mine, 5 cm, (21) minute crystal, (22) Ridge mine, 2.5 cm, (23) 6 mm, and (24) 5 cm. Palache borrowed these specimens for study from the Bement, Hubbard, Harvard, Whiting, Munich, Brush, Pumpelly, Chynoweth, Vaux, Smyth and Schoonmaker collections.**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**Chamosite** $(Fe^{+2},Mg,Fe^{+3})_5Al(Si_3Al)O_{10}(OH,O)_8$

Chamosite is a chlorite-group mineral frequently found as an alteration product of basalt. "Thuringite," a ferrian variety, is common throughout the district (Heinrich, 1976).

**Chlorargyrite** AgCl

Chlorargyrite was reported from the district near the turn of the century (Van Hise and Leith, 1911). No specimens were available for authentication by this study.

**Chlorite Group** $(Mg,Al,Fe^{+2})_6(Si,Al)_4O_{10}(OH)_8$

Chlorite-group minerals are common wherever altered basalts exist in the Copper Country. They often line vesicles and fractures and are frequently found as an alteration product of fault gouge material, in some cases showing slickensides. Chlorite-group minerals identified in the district include: clinochlore (variety "pennine" or "penninite"), ferroan clinochlore ("ripidolite" or "prochlorite"), chamosite and ferroan chamosite ("thuringite"). Chamosite has been reported in the past as "delessite," and "melanolite" and "diabantite," all now considered obsolete terms (Heinrich, 1976; Fleischer and Mandarino, 1991).

**Chloritoid** $(Fe^{+2},Mg,Mn)_2Al_4Si_2O_{10}(OH)_4$

Chloritoid is similar to the minerals of the chlorite group and is found associated with them (Heinrich, 1976).

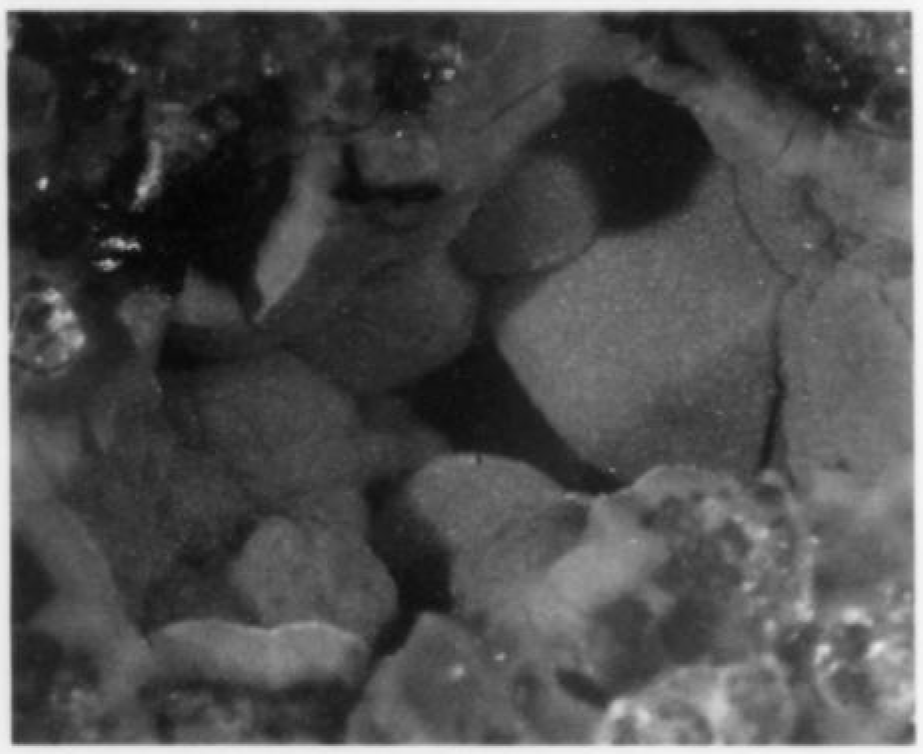

***Figure 76.*** **Chrysocolla-lined vug, 5.1 mm, from the Mendota mine. Dan Behnke collection and photo.**

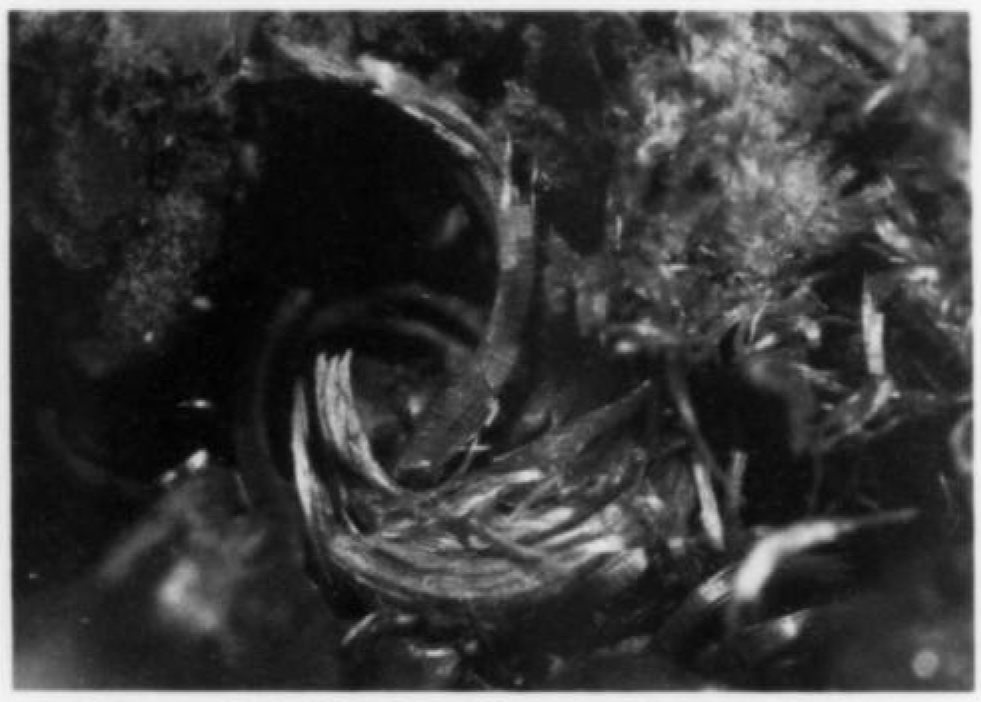

***Figure 77.*** **Chrysocolla pseudomorph after malachite ribbons to 1.8 mm, from the Boston Road prospect, Houghton County. Dan Behnke collection and photo.**

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

Chrysocolla occurs at several locations in the Copper Country. It is abundant at the Algomah mine in Ontonagon County where it constituted one of the major ore minerals along with tenorite and paramelaconite; and in the Allouez Conglomerate, especially at the Allouez mine, in Keweenaw County. Chrysocolla also occurs in a massive vein in Copper Harbor and in small concentrations at various other localities throughout the district. One exceptional locality is the Mendota mine in Keweenaw County where it is found as a coating on calcite crystals associated with malachite crystals and balls, and cuprite.

**Clinochlore** $(Mg,Fe^{+2})_5Al(Si_3Al)O_{10}(OH)_8$

Clinochlore is a chlorite-group mineral common throughout the district.

**Copper** Cu

Copper occurs as euhedral to subhedral crystals, anhedral masses, vein fillings (sheet copper), vesicle fillings (shot copper) and as pseudomorphs after calcite, laumontite, microcline, adularia and porce-

***Figure 75.*** **Tenorite-coated copper crystal from the Phoenix mine, showing the development of tetrahexahedron growth ridges on an octahedron face as described by Dana (1886). Collection of Marc and Debra Wilson; photo by Debra Wilson.**

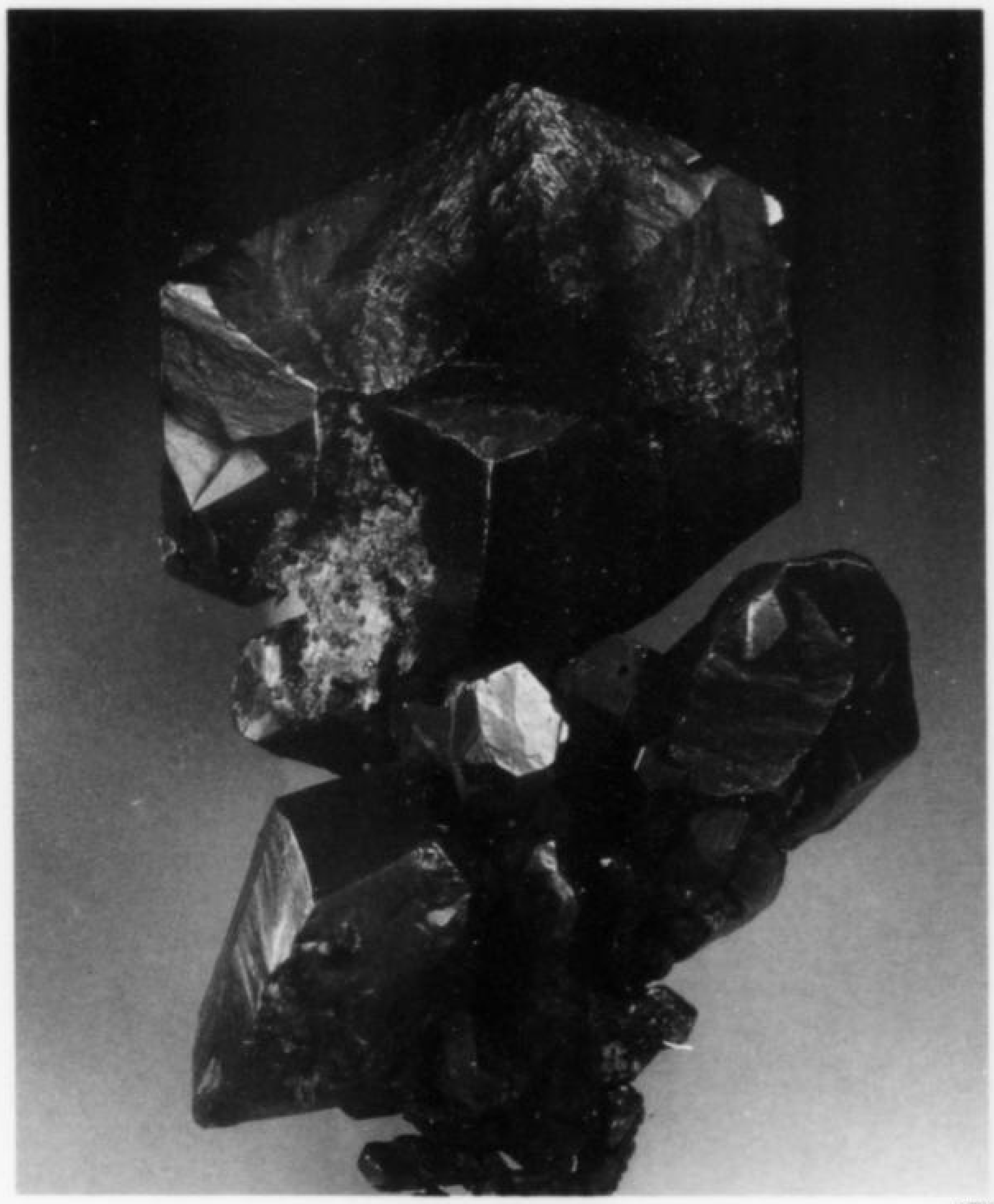

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***Figure 78.*** **Copper crystal group, 5.6 cm, from the Centennial mine. Seaman Museum collection, ex John T. Reeder collection.**

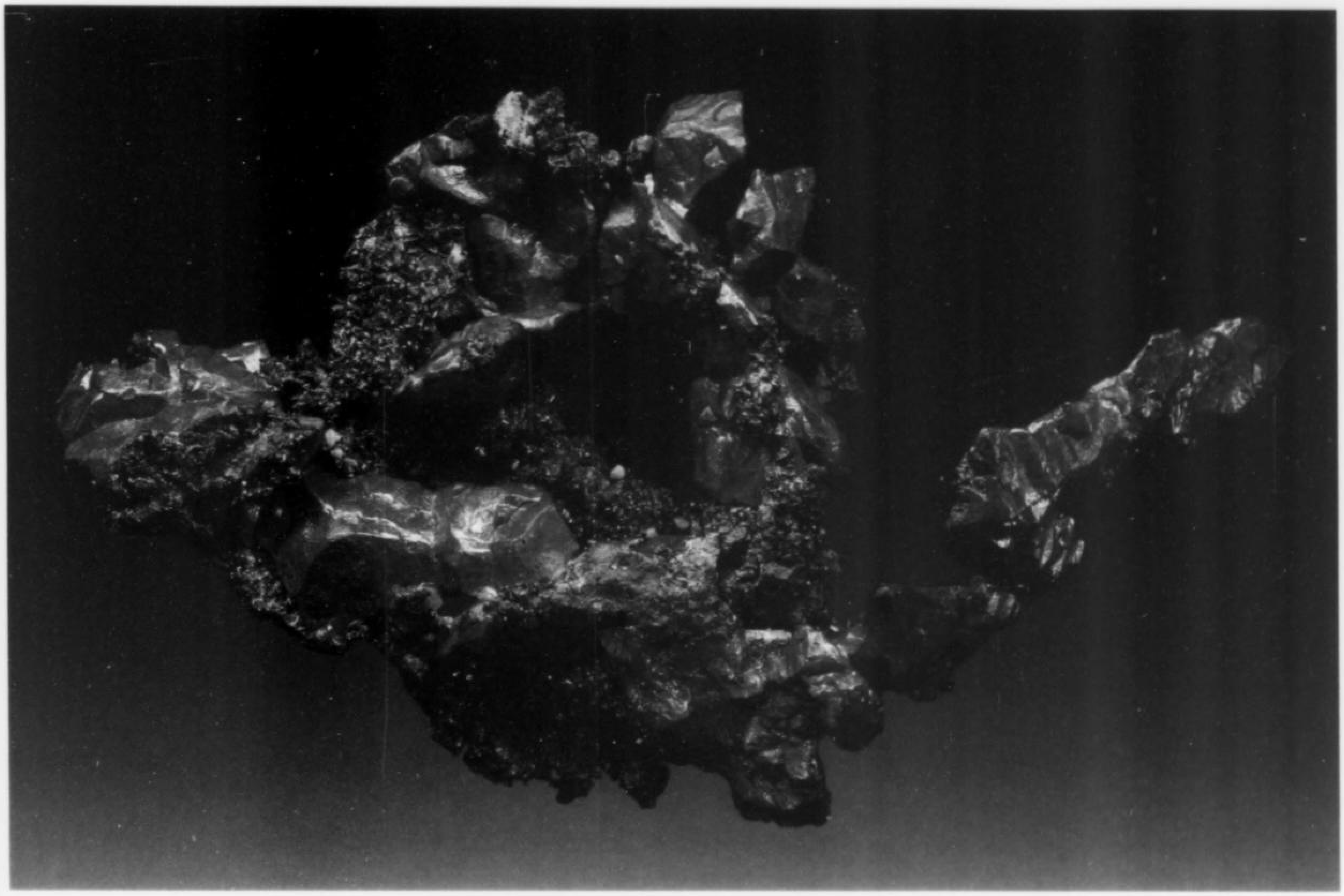

***Figure 79*. Large native copper specimen, 29.5 cm, from the Franklin mine. Seaman Museum; collected by Charles Kendall.**

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***Figure 80*. Single crystal of copper, 3.4 cm tall, from the Phoenix mine. Don Olson collection.**

***Figure 81*. Copper crystal group, 8.3 cm, from the Central mine. Seaman Museum collection, ex Donald C. Gabriel collection.**

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*Figure 82*. **Copper crystal group, 13.3 cm, from the Phoenix mine. Seaman Museum collection.**

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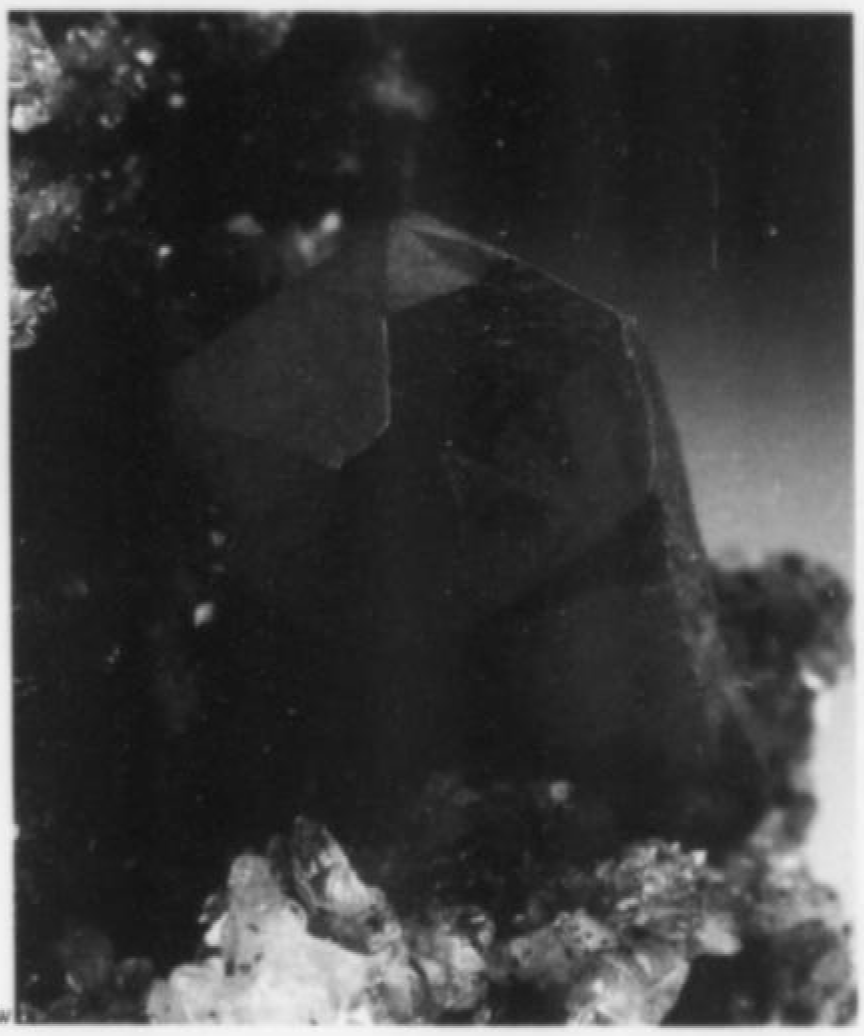
*Figure 83*. **Copper crystal group, 15.9 cm, showing red and black (cuprite and tenorite) patina, from the Phoenix mine. Seaman Museum collection.**

*Figure 84.* **Copper crystal, 4.8 cm, on matrix from the Calumet mine (?), Houghton County. Richard Kosnar collection.**

*Figure 85.* **Reddish (cuprite patina) copper crystal, 2.2 cm, on quartz matrix with pumpellyite, from the Quincy mine. Seaman Museum collection, ex John T. Reeder collection.**



laneous datolite. It also occurs commonly as inclusions in, coatings on and casts after most major minerals in the district, including calcite, quartz, prehnite, microcline, analcime, laumontite and datolite. In addition to the above, it is associated with silver, epidote, pumpellyite, natrolite, barite and many other species. Copper is nearly ubiquitous within the district, excellent crystal specimens having been produced from nearly every mine at one time or another. Many superb microcrystals and, occasionally, larger crystals may still be found on waste rock piles throughout the district.

**Covellite** CuS

Covellite is a rare species in the Copper Country, occurring as an alteration product of chalcocite. It has been noted in the White Pine mine in Ontonagon County and the Cliff and Mendota mines in Keweenaw County (Heinrich, 1976). It is associated with chalcocite, digenite, chalcopyrite, bornite, pyrite, hematite and greenockite. Minute crystals of covellite and chalcocite occur as inclusions in calcite crystals from the Kingston mine in Keweenaw County.

**Cuprite** $Cu_2O$

Cuprite is widespread in the district although well-formed crystals are not common. Superb octahedral cuprite crystals in excess of 7 mm have been found at the Allouez mine in Keweenaw County. They occur in the interstices of the Allouez Conglomerate and are associated with chrysocolla, native copper and malachite. The acicular variety has also been noted at the Allouez mine, where it forms inclusions in calcite, coloring it a bright red. Microcrystals have been found at the Algomah mine in Ontonagon County and the Mendota mine in Keweenaw County. Numerous other localities host microcrystals but most are believed to be a result of post-mining weathering of other copper minerals.

Cuprite also occurs as a cryptocrystalline coating with tenorite on copper crystals. The coating is most commonly found on crystals from northern Houghton and Keweenaw counties but has been noted in numerous other localities throughout the district. Some copper specimens show discrete microscopic crystals of cuprite on their surfaces but these are usually of a post-mining origin.

**Datolite** $CaBSiO_4(OH)$

Datolite is a common mineral throughout the district. It occurs in two distinct forms: as discrete, vitreous crystals and as porcelaneous nodules within the altered basalt flow tops. The porcelaneous variety, which is unique to the Copper Country, has a cauliflower-like surface and ranges in color from white to gray, brown, red, orange, yellow and various pastel shades including green. It commonly contains copper inclusions and is valued by local collectors for its beauty as a lapidary material.

Attractive crystal specimens have been produced from the Osceola and other mines on the Osceola lode, the Laurium and other mines on the Kearsarge lode, various mines on the Ashbed lode and some

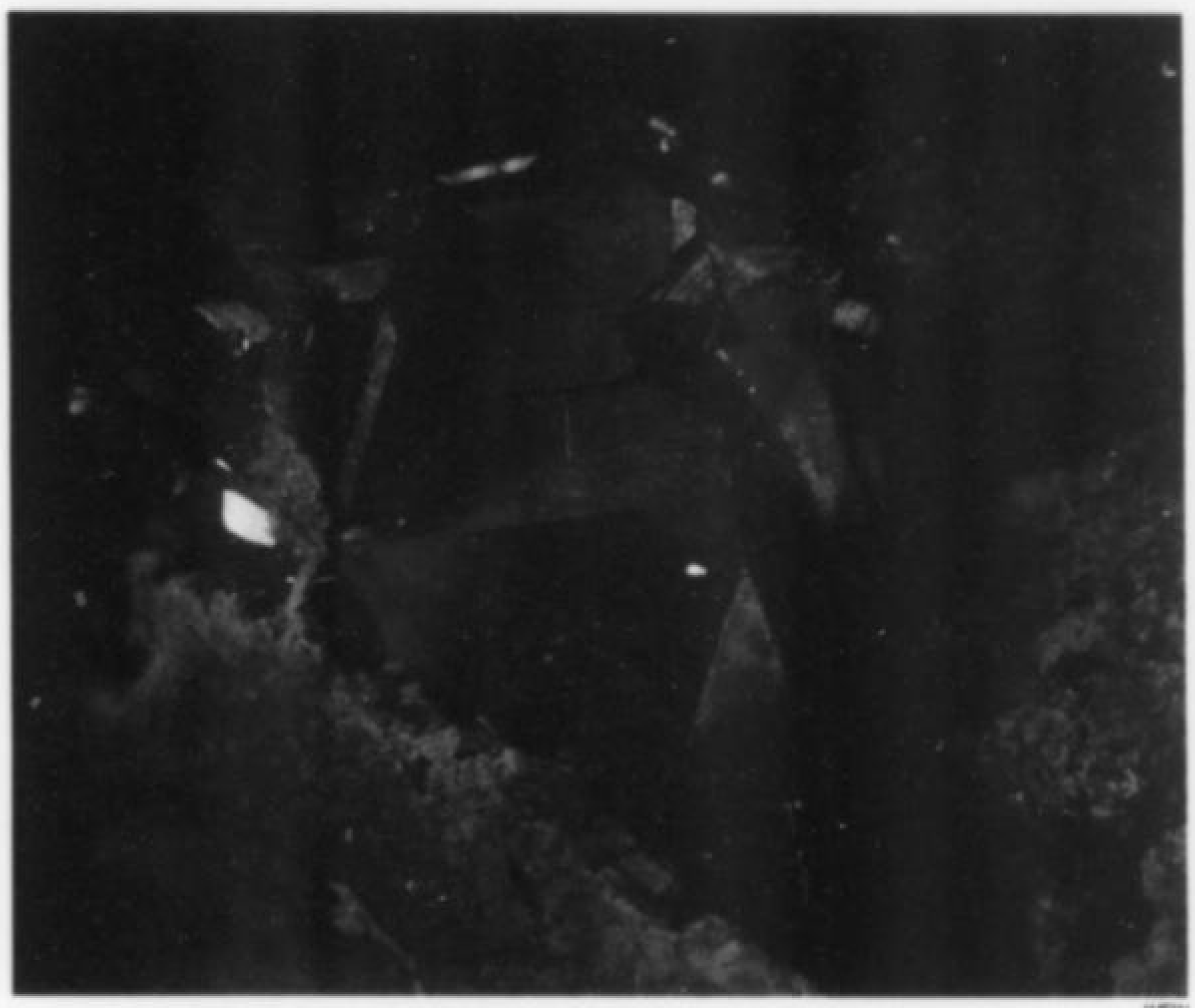
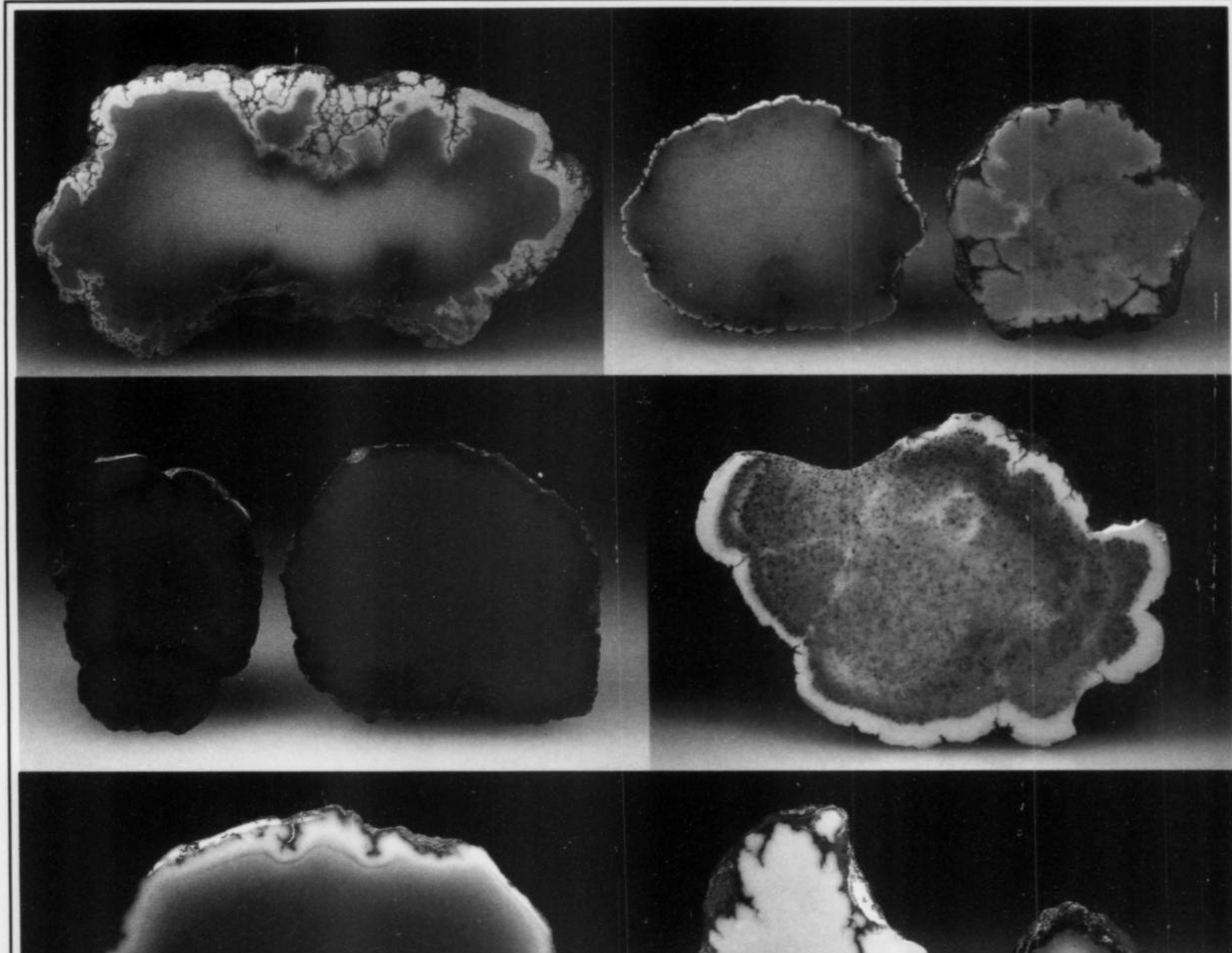


*Figure 86.* **Cuprite crystals to 1.4 cm, from the Allouez mine. Seaman Museum collection, ex John T. Reeder collection.**



WEW Collection of Wayne Sukow

*Figure 87*. **Datolite nodules. Clockwise from top-left: Clark mine (8.4 cm); Delaware mine (4.5 cm, 3.8 cm); Centennial mine (10.6 cm); Lake Superior, off Manitou Island (left, 4.6 cm) and off High Rock Point (right, 3.3 cm); with copper, from the Amygdaloid mine (3.3 cm); Calumet & Hecla mine (3.6 cm); Lake Superior, off Isle Royale (left, 5.7 cm) and off High Rock Point (right, 5.9 cm); Mass mine (7.1 cm); Caledonia mine (5.0 cm, 5.7 cm).**

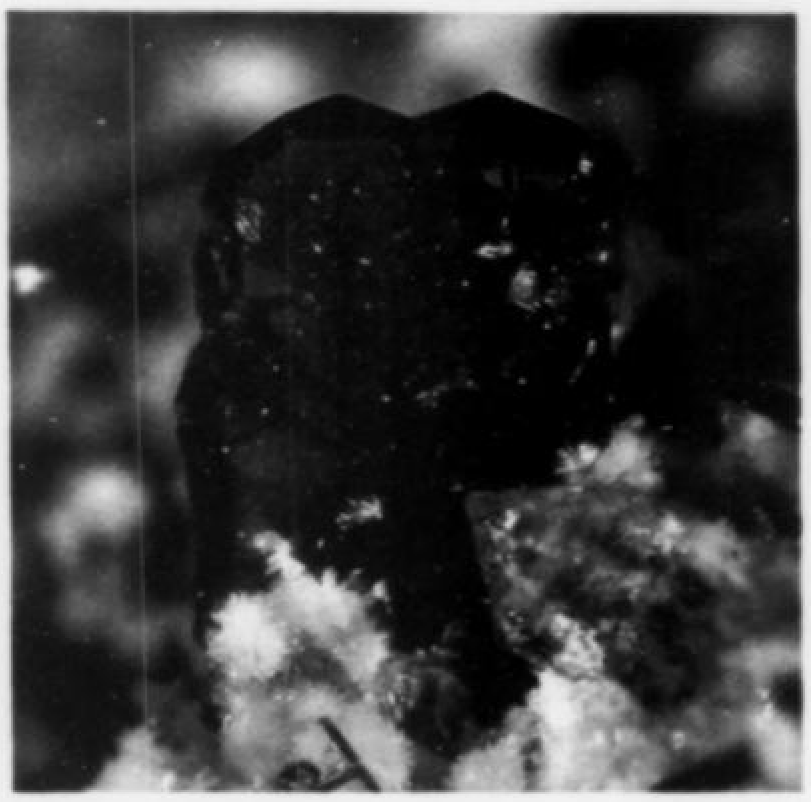


*Figure 88*. Epidote crystal, 1 mm, from the Laurium mine, Houghton County. Dan Behnke collection and photo.

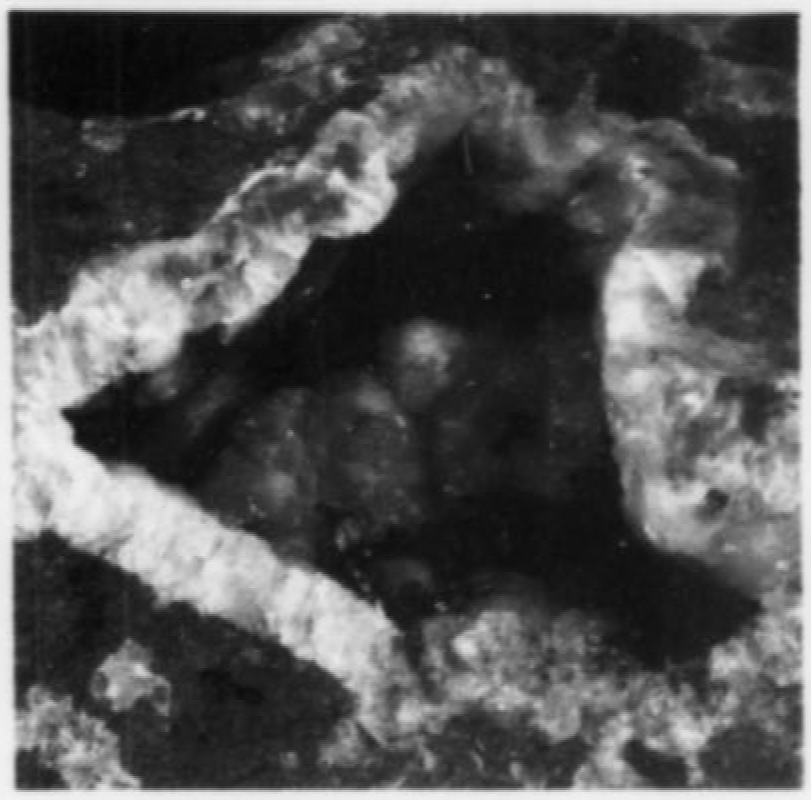


*Figure 89*. Prehnite-lined pocked in basalt, 3.8 cm, with copper crystals; from the Isle Royale mine. Debra Wilson photo.

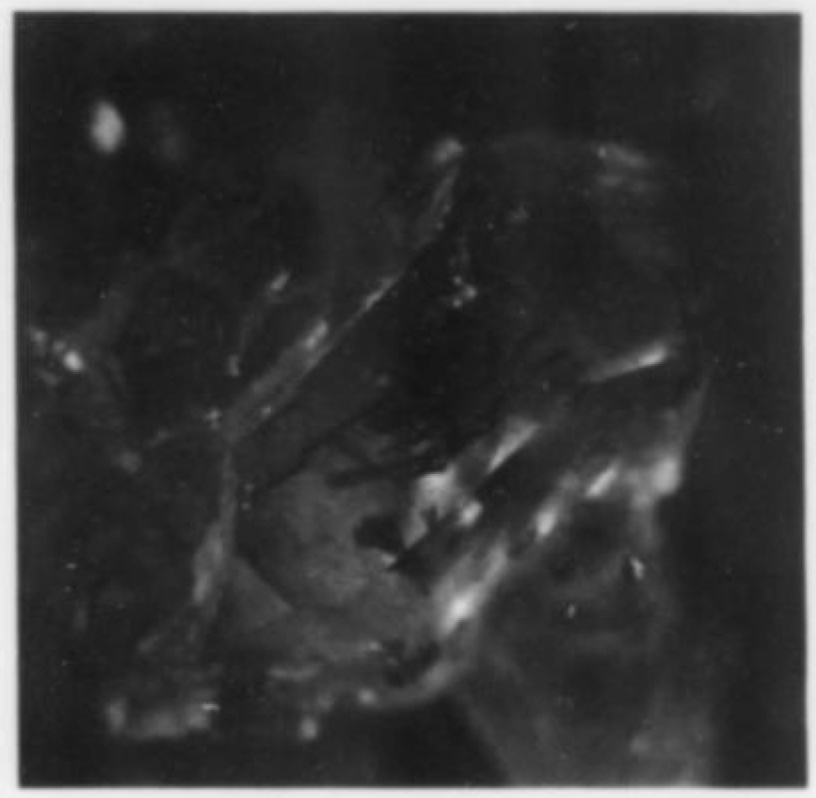


*Figure 90*. Kinoite in a 1.7-mm quartz crystal, from the Laurium mine. Dan Behnke collection and photo.

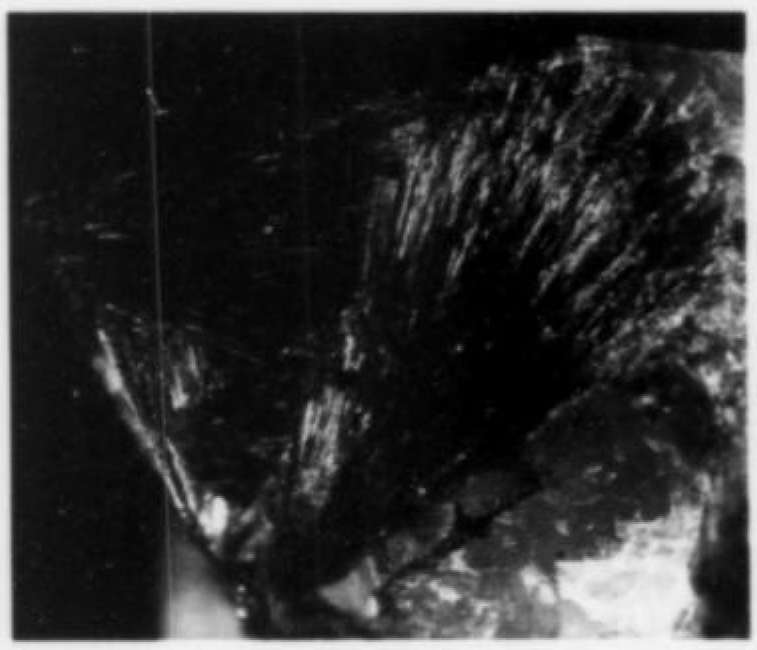


*Figure 91*. Macfallite from the Manganese mine, Copper Harbor. Dan Behnke collection and photo.

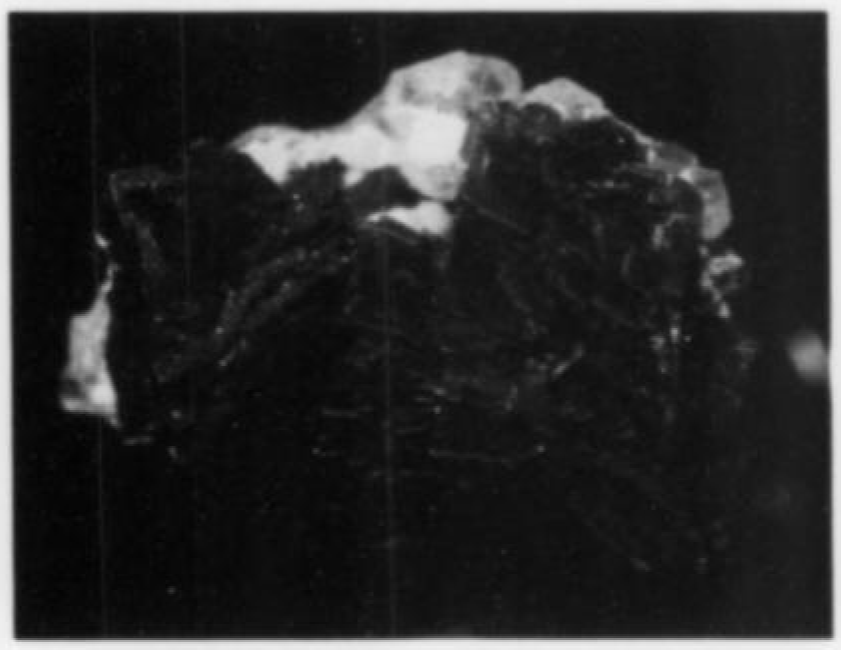


*Figure 92*. Malachite crystal group, 8.3 mm across, from the Mendota mine. Dan Behnke collection and photo.

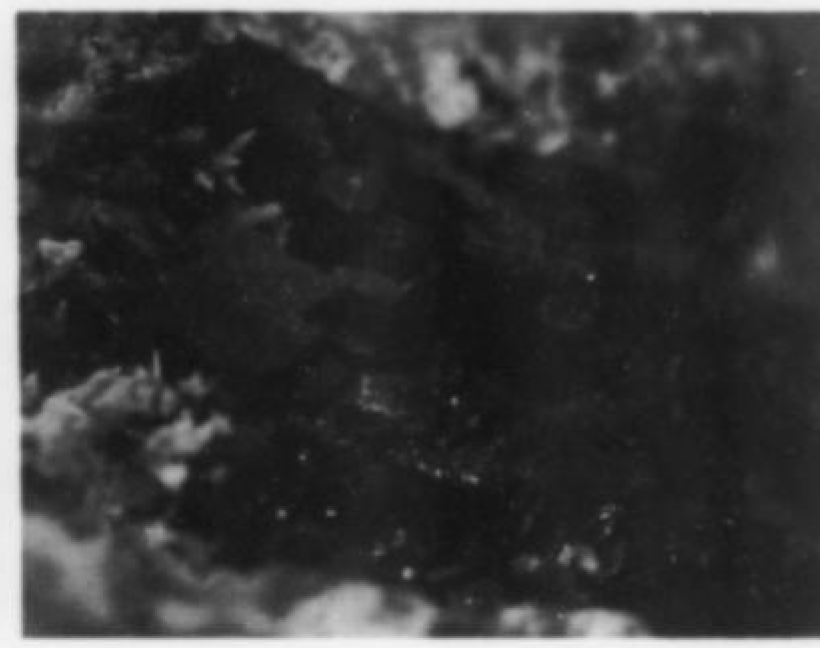


*Figure 93*. Paramelaconite crystal group, 0.7 mm; Algomah mine, Ontonagon County. Dan Behnke collection and photo.

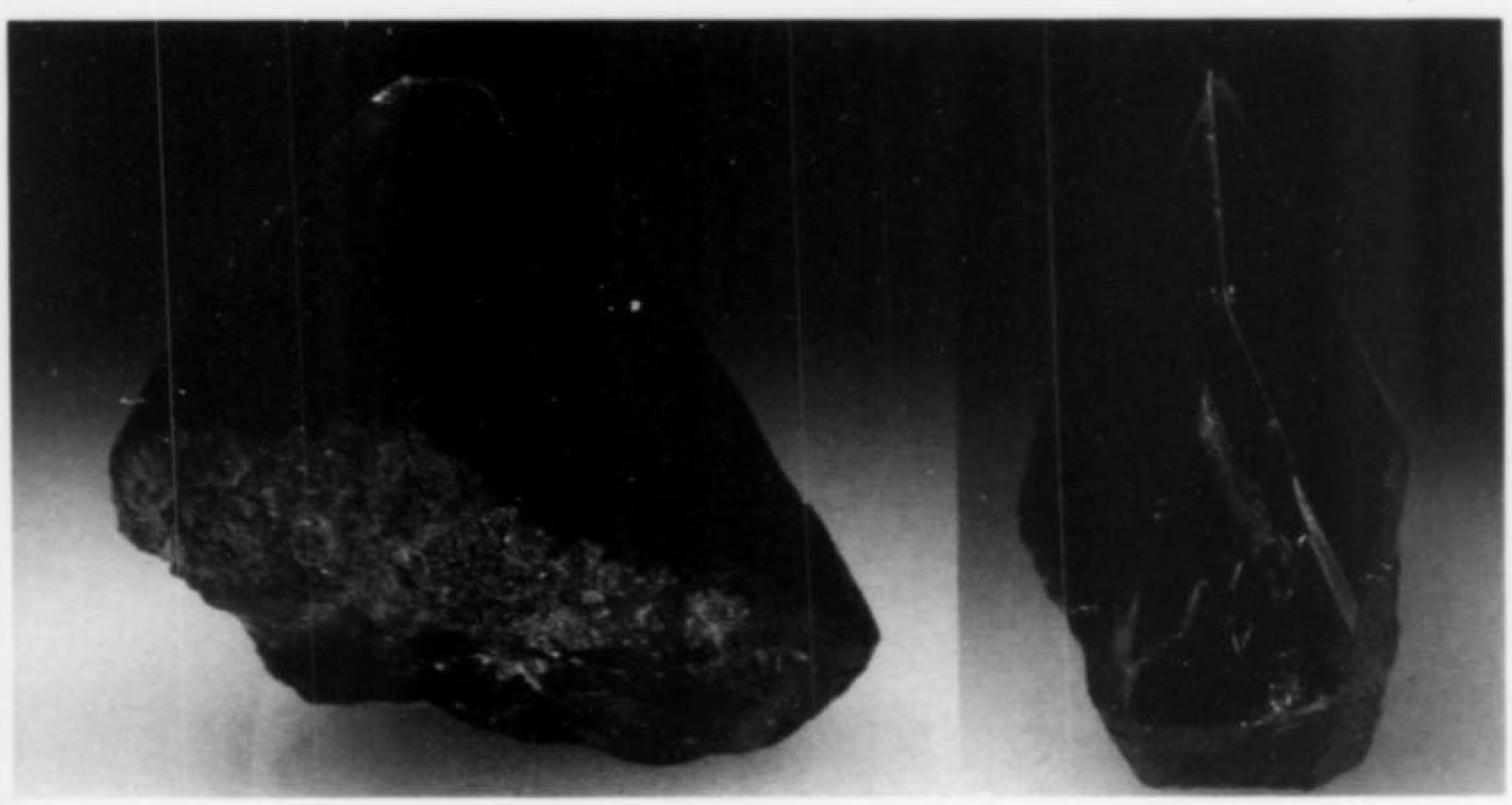


*Figure 94*. Giant, black powellite crystal, 4.5 cm, from the Tamarack mine, #3 shaft. Seaman Museum collection, ex John T. Reeder collection.

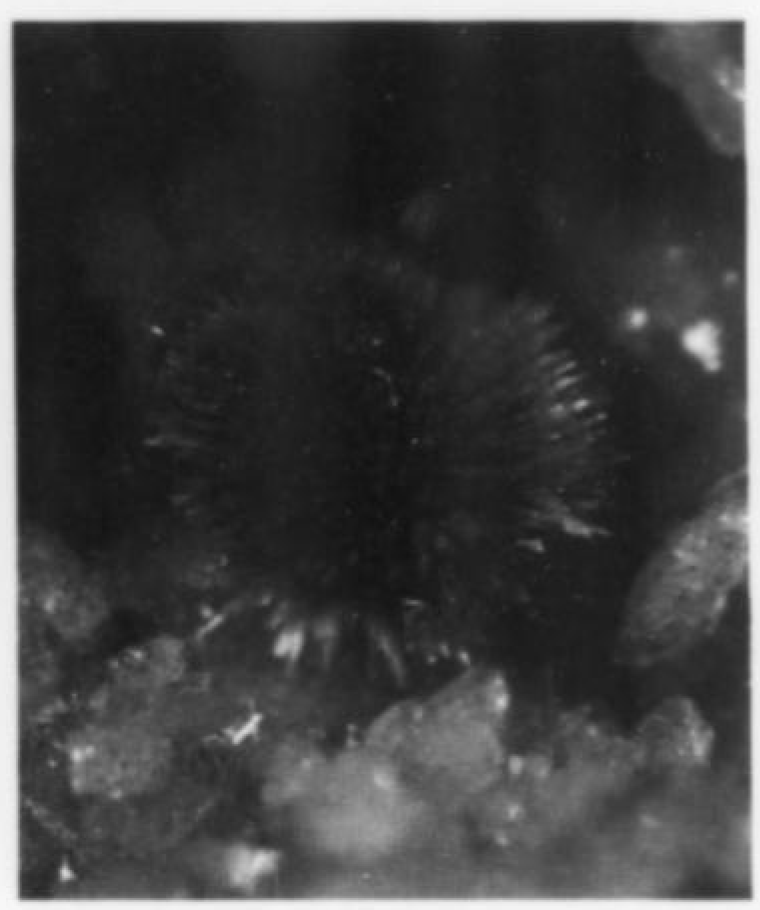


*Figure 95*. Pumpellyite-Mg tuft, 0.8 mm, from the Cliff mine. Dan Behnke collection and photo.

of the fissure mines in Keweenaw County. The largest crystals originate from the Osceola mine. Datolite crystals from this locality are transparent to translucent, often with a slight greenish cast, and may exceed 8 cm in length. Native copper is common as inclusions which impart a reddish hue to the crystals in some localities, especially those from the Copper Falls and Laurium mines. Associated minerals include prehnite, copper, calcite, quartz, analcime, natrolite and microcline.

**Digenite** $Cu_9S_5$

Digenite occurs mixed with chalcocite and other sulfides and oxides in the White Pine mine in Ontonagon County and the Cliff and Mendota mines in Keweenaw County (Heinrich, 1976).

**Dioptase** $CuSiO_2(OH)_2$

Microcrystals of dioptase have been reported from the Algomah

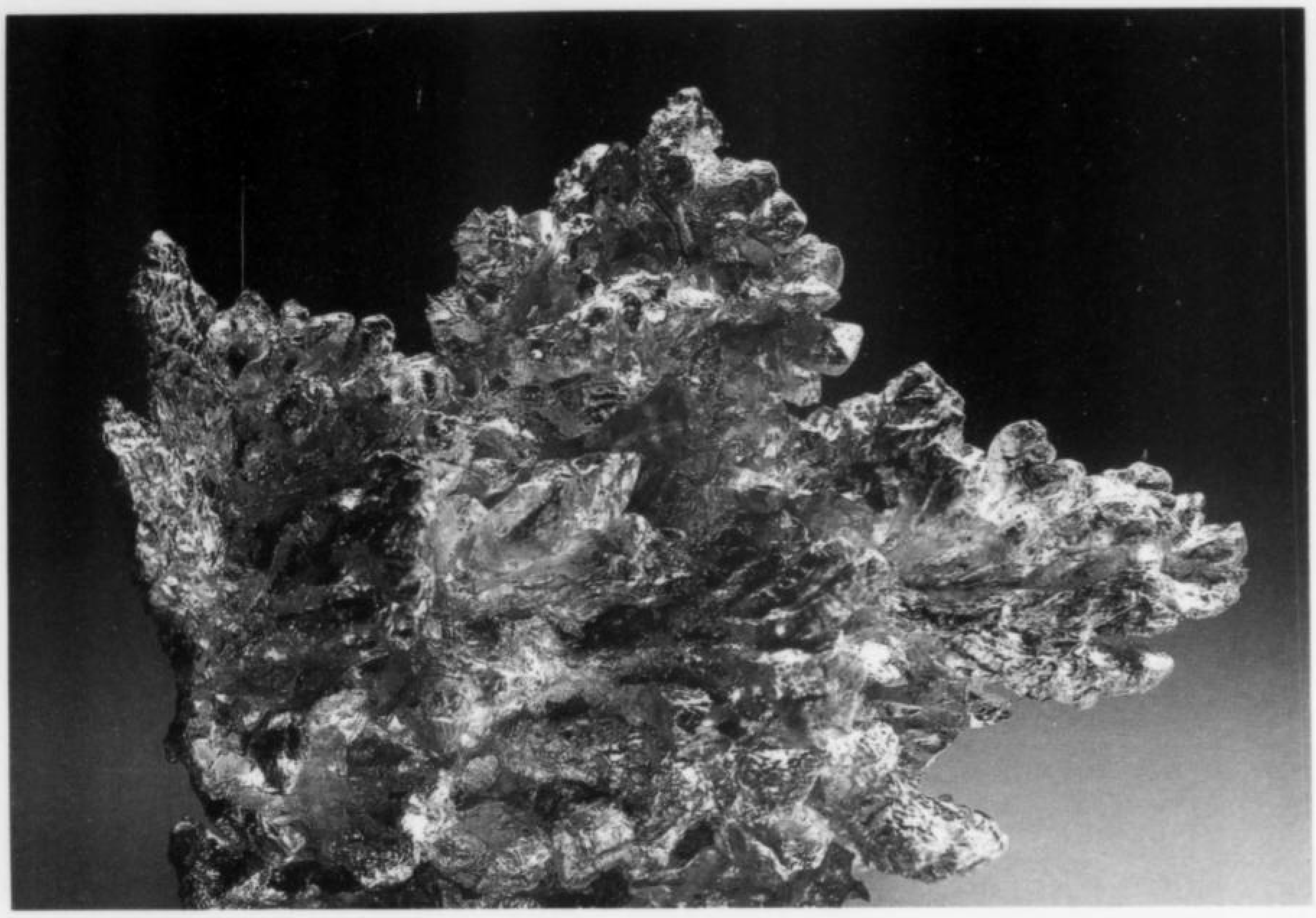


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***Figure 96*. Silver crystal group, 9 cm across, from the Wolverine mine. Collection of the late Don Pearce.**

***Figure 97*. Silver crystal group, 6.8 cm, on calcite and basalt from the Kearsarge mine. Richard A. Kosnar collection.**

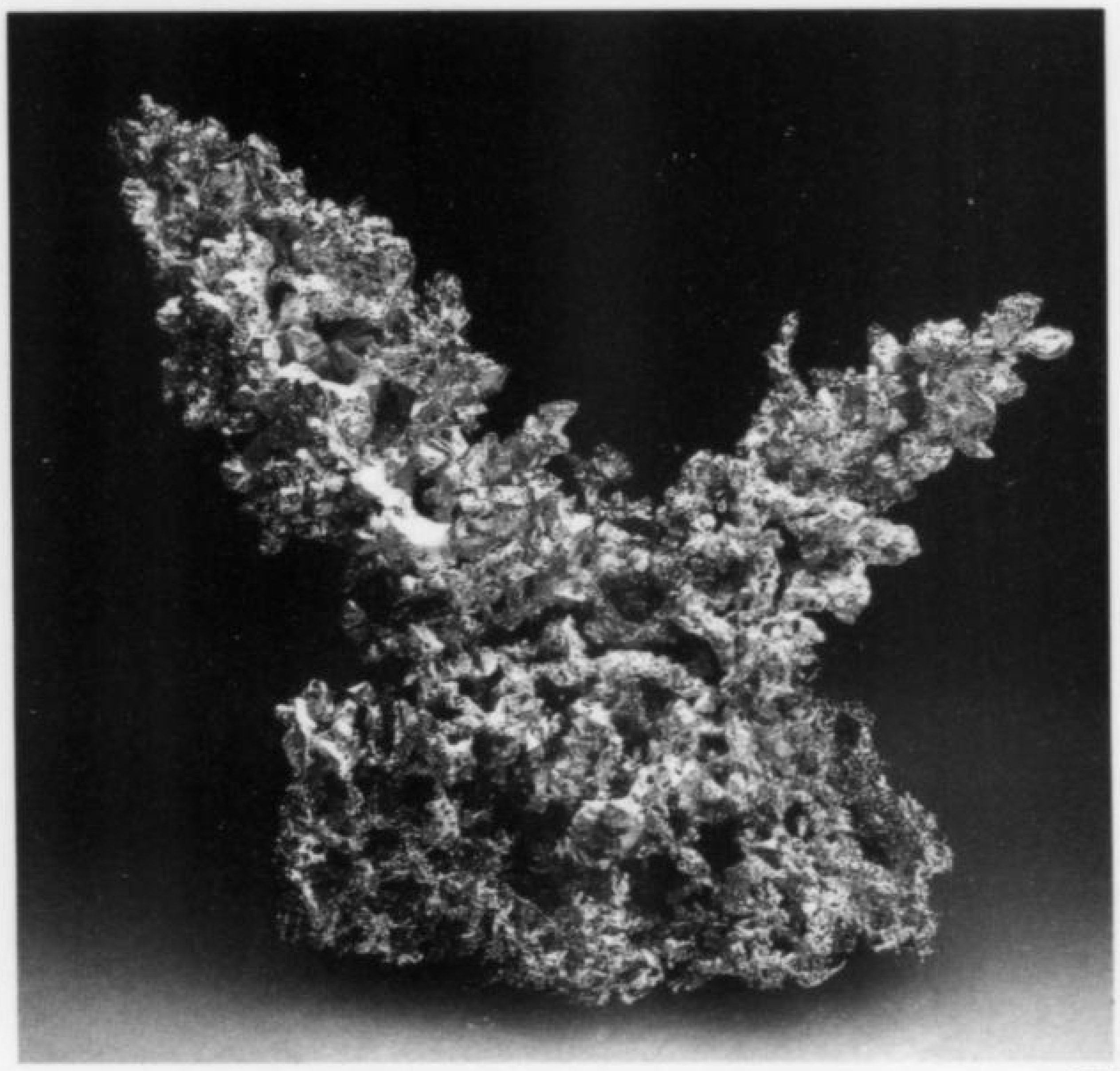

***Figure 98*. Silver crystal group, 9.5 cm, from near Copper Falls. Don Olson collection.**

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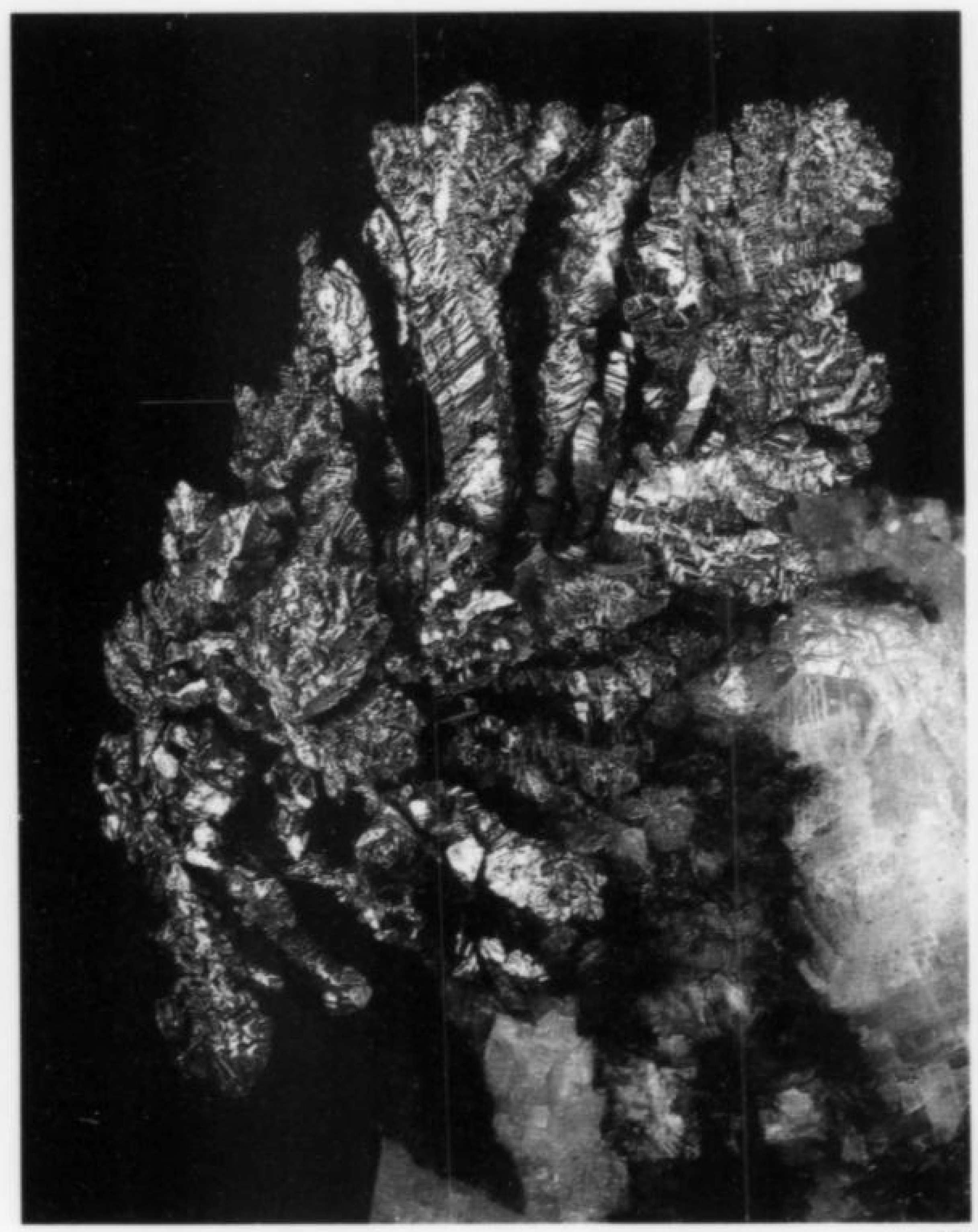

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mine in Ontonagon County and elsewhere in the district (Heinrich, 1976).

**Djurleite** $Cu_{31}S_{16}$

Djurleite has been found as microscopic grains associated with chalcocite and other sulfides at the White Pine mine in Ontonagon County (Heinrich, 1976).

**Dolomite** $CaMg(CO_3)_2$

Dolomite has been reported from the district but no specimens were available for authentication by this study.

**Domeykite** $Cu_3As$

Massive domeykite has been produced from the Mohawk mine and other mines on the Kearsarge lode in Keweenaw County. Much material sold as "mohawkite" for lapidary purposes is in reality domeykite.

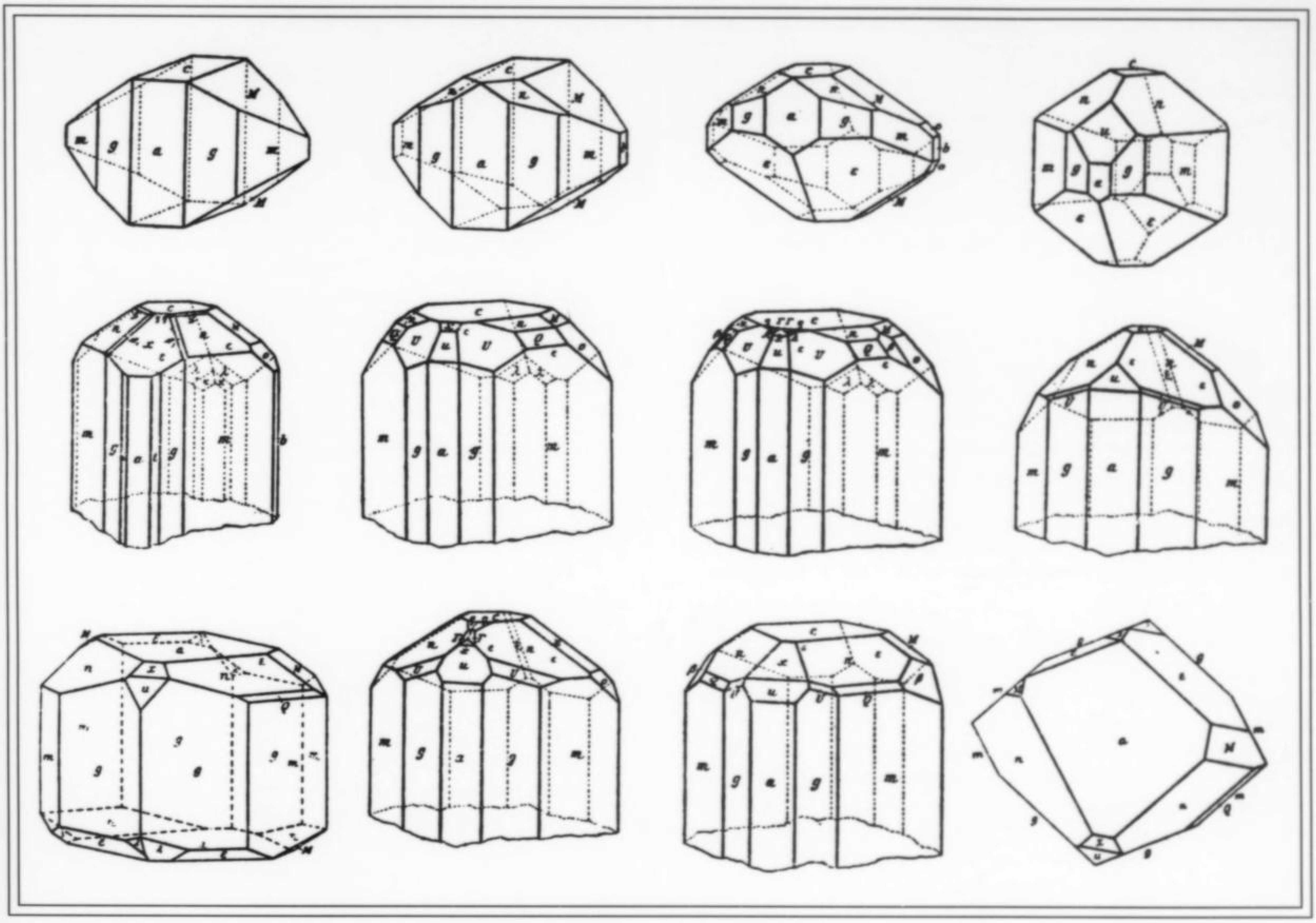

***Figure 99*. Datolite crystals from the Clark, Copper Falls, North Cliff and Tamarack mines (see Goldschmidt, 1918).**

**Epidote** $Ca_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$

Epidote is present throughout the district lining vesicles and fractures in altered basalt flow tops and, less commonly, in the interstices of conglomerates. The color ranges from lime-green to green-black depending on the iron content. Crystals are tabular in habit, usually with curved faces, and range in size from microscopic to 5 mm or more. Epidote is a major gangue mineral associated with the main copper mineralization and is associated with most other minerals in the district. The most common associated minerals include copper, pumpellyite, prehnite, calcite and quartz.

**Erythrite** $Co_3(AsO_4)_2 \cdot 8H_2O$

Erythrite has been reported from the Mohawk mine in Keweenaw County where it forms a coating on copper arsenides (Heinrich, 1976). A second locality for erythrite was recently discovered in the White Pine mine in Ontonagon County, where it is intimately associated with silver and acanthite.

**Faujasite** $(Na_2,Ca)Al_2Si_4O_{12} \cdot 8H_2O$

One specimen of this zeolite was reportedly found at the Copper Falls mine in Keweenaw County (Butler and Burbank, 1929).

**Fluorapophyllite** $KCa_4Si_8O_{20}(F,OH) \cdot 8H_2O$

Fluorapophyllite is a relatively uncommon species for the Copper Country. It has been reported from the Isle Royale mine in Houghton County and various mines, predominantly in fissure deposits, in Keweenaw County. Exceptionally beautiful crystals over 1 cm in length have come from the Phoenix mine, and other equally fine specimens have originated at the Cliff mine. The fluorapophyllite occurs in two distinct habits. Aggregates of slender plates associated with copper are the more common, whereas blocky crystals with pyramidal terminations, often associated with analcime, occur more rarely. Commonly associated minerals include calcite (often enclosing copper phantoms), analcime, barite, copper and silver.

**Fluorite** $CaF_2$

Fluorite is rare in the Copper Country. It occurs in only limited amounts at a few locations, mostly in calcite veins in Keweenaw County. Colors include purple, white and green. It is associated with calcite and barite. Few distinct crystals have been found.

**Galena** PbS

Galena has been reported as occurring in small amounts at the South Cliff mine in Keweenaw County (Butler and Burbank, 1929) and in the White Pine mine in Ontonagon County, where it is associated with other sulfide minerals (Heinrich, 1976). Microcrystals have been reported from the White Pine mine and elsewhere (Behnke, 1983).

**Goethite** FeO(OH)

Microcrystals of goethite have been reported from the Caledonia mine in Ontonagon County (Richard Whiteman, personal communication) and in amygdules of the Lake Shore Traps in Keweenaw

County, where they are associated with hematite and other species (James K. Uhelski, personal communication).

**Greenockite** CdS
Greenockite occurs in microscopic amounts with other sulfides in the White Pine mine in Ontonagon County (Heinrich, 1976).

**Guerinite** $Ca_5H_2(AsO_4)_4 \cdot 9H_2O$
Guerinite is a rare secondary arsenate associated with other arsenates coating copper arsenides from the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Gypsum** $CaSO_4 \cdot 2H_2O$
Gypsum has been found in small amounts at many localities throughout the district. It is usually associated with saline mine waters and it is possible that many of the reported occurrences are a result of mining activity. Reported localities include various mines on the Evergreen Series, Baltic lode, Isle Royale lode, Pewabic lode, Osceola lode and the Kearsarge lode, among others.

**Halite** NaCl
Like gypsum, halite has been found associated with saline mine waters. Its occurrence probably results from mining activities.

**Hematite** $Fe_2O_3$
Hematite has been found in minor amounts in many localities throughout the district. Crystals are typically platy; sizes range from microscopic to more than 3 mm. Hematite has been reported from several sources in Ontonagon County and the Isle Royale and Kearsarge lodes in Houghton and Keweenaw counties. It occurs as microscopic platy crystals associated with prehnite at the Cliff mine and has recently been discovered with prehnite, datolite and actinolite at the Central mine in Keweenaw County. It has also been identified in amygdules in the Lake Shore Traps of Keweenaw County (James K. Uhelski, personal communication). Hematite crystals are associated with calcite, quartz, prehnite and goethite among others. Earthy hematite forms stains, druses and balls on quartz and calcite crystals from both the Isle Royale and Kearsarge lodes in Houghton County.

**Heulandite** $(Na,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36} \cdot 12H_2O$
Heulandite is extremely rare in the Copper Country. It has been reported from the northeastern tip of the Keweenaw Peninsula and in amygdules from the Lake Shore traps near Agate Harbor in Keweenaw County. Only two well-formed crystals, 3 to 4 mm in length and orange-white in color, were found at the Agate Harbor locality.

**Julgoldite-($Fe^{+2}$)** $(Ca_2F^{+2}(Fe^{+3},Al)_2(SiO_4)Si_2O_7)(OH)_2 \cdot H_2O$
Julgoldite-($Fe^{+2}$) has been reported as microcrystals associated with prehnite from the Clark mine in Keweenaw County (Behnke, 1983).

**Kaolinite** $Al_2Si_2O_5(OH)_4$
Kaolinite is a clay mineral which occurs as a weathering product of various minerals in the district, especially feldspars.

***"Keweenawite"***
"Keweenawite" is a discredited species, now considered to be a mixture of algodonite, domeykite and arsenian copper (Heinrich, 1976).

**Kinoite** $Ca_2Cu_2Si_3O_8(OH)_4$
Kinoite is a very rare mineral which forms as microscopic inclusions in quartz and calcite at the Laurium and La Salle mines in Houghton County (Ruotsala and Wilson, 1977; Wilson, 1977). Kinoite has also been reported as inclusions in calcite from the Northwestern mine in Keweenaw County (Thomas Morris Jr., personal communication). It is azure-blue in color and typically forms partial phantoms within quartz crystals. Copper, silver, epidote, quartz, calcite and saponite are common associated minerals.

**Langite** $Cu_4(SO_4)(OH)_6 \cdot 2H_2O$
Langite has been reported by Bee and Dagenhart in 1985 from the Clark mine in Keweenaw County (Behnke, 1986).

***"Ledouxite"***
"Ledouxite" is a discredited species now considered to be a mixture of algodonite, domeykite and arsenian copper (Heinrich, 1976).

**Laumontite** $CaAl_2Si_4O_{12} \cdot 4H_2O$
Laumontite is perhaps the most common zeolite in the Copper Country. It occurs as pearly white and pink vein and vesicle fillings in most portions of the district, and as crystals in various localities. Laumontite readily dehydrates to leonhardite and commonly completely decrepitates. Because of this, crystals rarely last long after collection. Laumontite is frequently associated with and may be pseudomorphically replaced by copper.

**Lavendulan** $NaCaCu_5^{+2}(AsO_4)_4Cl \cdot 5H_2O$
This is a rare secondary mineral reportedly associated with other arsenates coating copper arsenides in the Mohawk mine in Keweenaw County; Heinrich (1976) reported it as "freirinite," a discredited species now considered to equal lavendulan.

**Macfallite** $Ca_2(Mn,Al)_3(SiO_4)(Si_2O_7)(OH)_3$
Macfallite has been reported as microcrystals in radiating clusters associated with calcite, orientite and braunite at the Manganese mine in Keweenaw County (Behnke, 1983).

**Malachite** $Cu_2(CO_3)(OH)_2$
Malachite is relatively common in the district as acicular crystals of 1 mm or less in length, and as a cryptocrystalline oxidation product on weathered copper and copper-bearing rocks. Malachite occurs at the Algomah mine in Ontonagon County; the Champion, Atlantic, Isle Royale and Centennial mines in Houghton County; the Allouez, Cliff and Mendota mines in Keweenaw County; and many other localities throughout the district. Much of the malachite in the Copper Country is the result of post-mining weathering of material in mines and on waste rock piles. Some exceptions include the Centennial #1 and #2 mines, where malachite occurs as inclusions in prehnite, and the Mendota mine where crystals in excess of 5 mm have been collected. Commonly associated minerals include calcite, copper, chalcocite, cuprite, chrysocolla and prehnite.

**Manganite** MnO(OH)
Manganite is a rare species in the Copper Country. It has been found as microcrystals in the Calumet & Hecla Conglomerate and at the Manganese mine in Keweenaw County where it is associated with other oxide minerals (Heinrich, 1976).

**Marcasite** $FeS_2$
Marcasite has been found as microcrystals in the White Pine mine in Ontonagon County, associated with other sulfide minerals and calcite. The crystals frequently form inclusions in calcite crystals at this locality.

**Maucherite** $Ni_{11}As_8$
Maucherite occurs as a rare species associated with other arsenides in the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Microcline** $KAlSi_3O_8$
Microcline is common throughout the district as red crystals lining vesicles and fractures in altered basalt flow tops and as massive fracture and amygdaloid fillings (Klein, 1939). Microcline crystallized early in the mineralizing sequence and is often covered by later mineral species. At the Kingston mine in Keweenaw County, secondary intermediate microcline forms a coating on calcite crystals on a matrix of corroded intermediate microcline in the Kingston Conglomerate.

Dana (1898) and Fleischer and Mandarino (1991) state that adularia is a variety of orthoclase. However, Heinrich (1976) states that what has been called "adularia" from Michigan's Copper Country is actually a variety of microcline. In general practice, the varietal term "adularia" is applied to all polymorphs of relatively pure, low-temperature K-feldspar regardless of structural state. The "adularia" of the Copper Country crystallized late in the mineralizing sequence and is found throughout the district. It is characterized by crystals up to 7 mm in length which range in color from white through flesh-pink to light orange. The crystals are commonly twinned and are associated with copper, silver, calcite, quartz, epidote and other species. Adularia from the South Lake and other mines in Ontonagon County sometimes exhibits inclusions of minute copper flecks which form phantoms within the crystals.

**Mirabilite** $Na_2SO_4 \cdot 10H_2O$

Mirabilite has been reported as a post-mining efflorescence on rocks of the Isle Royale mine in Houghton County (Heinrich, 1976).

***"Mohawkite"***

"Mohawkite" is a discredited species now considered to be a mixture of algodonite, domeykite and arsenian copper (Heinrich, 1976). The term "mohawkite" is today commonly used for any and all massive copper arsenides sold for lapidary purposes.

**Molybdenite** $MoS_2$

Molybdenite has been reported in microscopic amounts from the White Pine mine in Ontonagon County (Heinrich, 1976).

**Monazite-(Ce)** (Ce,La,Nd,Th)$PO_4$

Monazite-(Ce) has been reported from the Centennial mine in Houghton County where it is associated with anthonyite (Heinrich, 1976).

**Muscovite** $KAl_2(Al,Si_3)O_{10}(OH,F)_2$

Muscovite, in the form of sericite, is found in amygdules and breccias associated with calcite, particularly at the Isle Royale mine in Houghton County (Heinrich, 1976).

**Nantokite** CuCl

Nantokite has been reported from the Algomah mine in Ontonagon County where it is associated with other oxide-zone minerals (Heinrich, 1976).

**Natrolite** $Na_2Al_2Si_3O_{10} \cdot 2H_2O$

Natrolite occurs in the Copper Country as elongated prismatic crystals typically 2 mm or less in thickness and up to several cm in length. The mineral is usually white or colorless although it occurs as brick-red crystals at the Copper Falls mine in Keweenaw County. Other localities include the Saint Clair mine and various mines on the Ashbed and Kearsarge lodes. Exceptional crystals have been produced from the Seneca #2 mine in Keweenaw County. Associated minerals include calcite, analcime, datolite, copper, prehnite and laumontite. The closely related zeolites scolecite ($CaAl_2Si_3O_{10} \cdot 3H_2O$) and mesolite ($Na_2Ca_2(Al_6Si_9)O_{30} \cdot 8H_2O$) may also occur in the district, considering that they are easily confused with natrolite. Mesolite has been reported by Heinrich (1976) from Isle Royale as reddish brown tufts in basalt vesicles.

**Nickeline** NiAs

Nickeline has been reported as occurring with copper arsenides in the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Nickel-Skutterudite** (Ni,Co)$As_3$

Chloanthite, an arsenic-deficient variety of nickel-skutterudite, occurs with other arsenides in fissures cutting the Kearsarge lode in Keweenaw County, particularly in the Mohawk mine (Heinrich, 1976).

**Orientite** $Ca_2Mn_3Si_3O_{10}(OH)_4$

Orientite occurs as radiating clusters of microcrystals and as vein fillings with calcite at the Manganese mine in Keweenaw County (Heinrich, 1976).

**Paramelaconite** $Cu_2^{+1}Cu_2^{+2}O_3$

Paramelaconite occurs as massive material associated with chrysocolla and as crystals up to 8 mm in length at the Algomah mine in Ontonagon County. Some pseudomorphs of paramelaconite after quartz have been noted from this locality. Associated minerals include chrysocolla, tenorite, malachite, dioptase and other species. It has also been reported from the Mass mine in Ontonagon County (Heinrich, 1976).

**Pararammelsbergite** $NiAs_2$

Pararammelsbergite occurs with other arsenides in veins at the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Paratacamite** $Cu_2(OH)_3Cl$

Paratacamite occurs with other oxide-zone minerals at the Algomah mine in Ontonagon County (Heinrich, 1976).

**Pharmacolite** $CaHAsO_4 \cdot 2H_2O$

Pharmacolite is a weathering product found on the surfaces of arsenides at the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Picropharmacolite** $H_2Ca_4Mg(AsO_4)_4 \cdot 11H_2O$

Like pharmacolite, this is a weathering product found on the surfaces of arsenides at the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Plancheite** $Cu_8Si_8O_{22}(OH)_4 \cdot H_2O$

Plancheite occurs as dark blue fibers and vein fillings associated with paramelaconite at the Algomah and Mass mines in Ontonagon County. It also reportedly forms pseudomorphs after dioptase at the Algomah mine (Heinrich, 1976).

**Posnjakite** $Cu_4(SO_4)(OH)_6 \cdot H_2O$

Posnjakite has been reported by Bee and Dagenhart in 1985 from the Clark mine in Keweenaw County (Behnke, 1986).

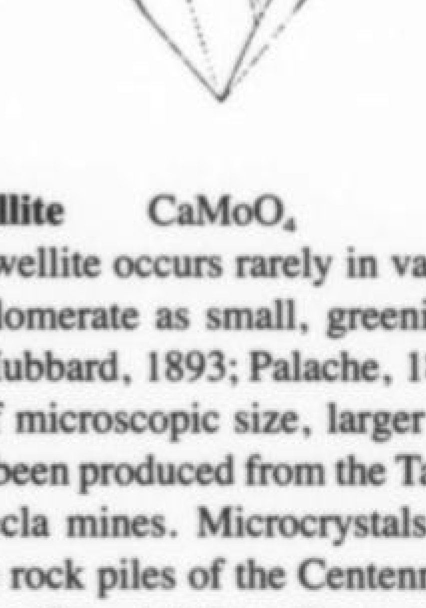

***Figure 100*. Powellite from the Keweenaw Peninsula (Palache, 1899).**

**Powellite** $CaMoO_4$

Powellite occurs rarely in various mines on the Calumet and Hecla Conglomerate as small, greenish black crystals and masses (Koenig and Hubbard, 1893; Palache, 1899). Although the majority of crystals are of microscopic size, larger crystals, some up to 10 cm in length, have been produced from the Tamarack, Red Jacket and other Calumet & Hecla mines. Microcrystals of powellite have been found on the waste rock piles of the Centennial #3 mine using an ultraviolet light. Outstanding, bright yellow, euhedral powellite crystals to nearly 3 mm have been found on the waste rock piles of the Minesota mine in Ontonagon County, where they are associated with calcite, quartz and copper. Analyses of powellite from this locality show it to be pure, without detectable tungsten.

**Prehnite** $Ca_2Al_2Si_3O_{10}(OH)_2$

Prehnite has been found as spherules, botryoidal masses and discrete crystals throughout the district. Individual crystals are platy in habit and seldom exceed 2 mm in size. Colors range from pale whitish green to dark green and almost black, with apple-green being the most common. Associated minerals include copper, silver, epidote, pumpellyite, datolite, analcime, calcite and quartz. Although prehnite is common district-wide, with notable specimens produced from the fissure mines of Keweenaw County, most specimens observed in the present study originated from the Isle Royale, Osceola and Iriquois lodes in Houghton and Keweenaw counties.

**Pumpellyite-(Fe⁺²)** $Ca_2Fe^{+2}Al_2(SiO_4)(Si_2O_7)(OH)_2 \cdot H_2O$

Pumpellyite-($Fe^{+2}$) has been reported as minute scales lining cavities in prehnite from the Clark mine in Keweenaw County (Behnke, 1986).

**Pumpellyite-(Mg)** $Ca_2MgAl_2(SiO_4)(Si_2O_7)(OH)_2 \cdot H_2O$

Pumpellyite-(Mg) occurs throughout the district, lining vesicles and fractures in altered basalt flow tops and, more rarely, the interstices in conglomerates (Palache and Vassar, 1925). The color ranges from olive-green to dark green. Crystals are acicular in habit and range in size from microscopic to several millimeters. Pumpellyite is a major gangue mineral in the district and is commonly associated with copper, epidote, prehnite, calcite and quartz. The gem variety "chlorastrolite," commonly known as "greenstone," occurs as amygdule fillings and is the state gem of Michigan (Williams, 1957).

**Pyrite** $FeS_2$

Pyrite is very rare in the Copper Country except in the White Pine mine where it occurs in large quantities as microscopic grains associated with other sulfide minerals.

**Pyrolusite** $MnO_2$

Pyrolusite occurs as blebs and microcrystals associated with other oxide minerals at the Manganese mine (Behnke, 1986). It has also been reported as being associated with copper minerals at the Clark mine in Keweenaw County (Heinrich, 1976).

**Quartz** $SiO_2$

Quartz is one of the most common gangue minerals in every portion of the district. Crystals range in size from microscopic to many centimeters in length. They are water-clear and colorless to milky white. Quartz crystals commonly contain inclusions of copper flakes, blebs and crystals, pumpellyite, chlorite and, less commonly, silver, kinoite and hematite. The most common associated minerals include copper, silver, prehnite, epidote, pumpellyite and microcline although many other species may be closely associated. Although large cabinet-size specimens are unusual, superb crystals have been produced from the Red Jacket shaft on the Calumet and Hecla Conglomerate in Houghton County, various mines on the Isle Royale, Pewabic, Osceola and Kearsarge lodes in Hougton and Keweenaw counties and many mines in Ontonagon County. Agate is a variety of quartz that is common as vesicle fillings in basalts in many portions of the district and is prized as a lapidary material. Rare amethystine quartz has been found in Keweenaw County.

**Rammelsbergite** $NiAs_2$

Microcrystals of rammelsbergite occur with other arsenides and arsenates from the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Rauenthalite** $Ca_3(AsO_4)_2 \cdot 10H_2O$

Rauenthalite has been reported as being associated with other arsenates and arsenides from the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Saponite** $(Ca,Na)_{0.33}(Mg,Fe^{+2})_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$

Saponite is an expandable-lattice smectite-group clay mineral common as an alteration product and as vesicle and fracture fillings throughout the district. Saponite pseudomorphs after clinochlore have been found associated with analcime and calcite in mines on the Isle Royale lode and associated with epidote and quartz at the Laurium mine on the Kearsarge lode. Spiky acicular saponite crystals (composition confirmed by microprobe analysis) from the Laurium mine have been shown by X-ray diffraction techniques to have crystallized in their expanded state (A. P. Ruotsala, personal communication). Such crystals are extremely rare outside of the Copper Country, and this represents a significant occurrence. The crystals are waxy gray or buff in appearance and are associated with quartz, calcite, epidote, earthy hematite balls, copper and kinoite.

**Silver** Ag

Native silver occurs as euhedral to subhedral crystals, anhedral masses and as vein and vesicle fillings in most of the major mines in the Copper Country. Silver is commonly associated with epidote and the best silver crystals usually occur in areas of heavy epidotization of the hosting rock. Other commonly associated minerals include copper, calcite, quartz, microcline, prehnite, analcime and fluorapophyllite. Silver forms very thin coatings on copper crystals and sheets but this usually tarnishes (oxidizes) completely in a matter of months once exposed to the atmosphere, and is entirely removed upon subsequent cleaning of the specimen. Superb crystals of native silver have been produced throughout the district (Olson, 1986). Some of the more prolific localities have been the mines on the Isle Royale, Pewabic, Osceola and Kearsarge lodes in Houghton and Keweenaw counties, the fissure mines of Keweenaw County and numerous mines on the Evergreen Series in Ontonagon County.

**Skutterudite** $CoAs_{2-3}$

Smaltite, an arsenic-deficient variety of skutterudite, is associated with other arsenides at the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Sphalerite** ZnS

Sphalerite has been reported in microscopic amounts from the White Pine mine in Ontonagon County and elsewhere in the district where it is associated with other sulfide minerals (Heinrich, 1976).

**Stilbite** $NaCa_2Al_5Si_{13}O_{36} \cdot 14H_2O$

Stilbite has long been reported as a rare zeolite from various localities throughout the district. Its true extent is difficult to determine as many "stilbite" specimens observed are in reality microcline adularia. Some stilbite specimens from the Central mine and other localities in Keweenaw County consist of red-orange crystals up to several millimeters in length which form coatings on a matrix of basalt.

**Synchisite-(Ce)** $Ca(Ce,La)(CO_3)_2F$

Synchisite-(Ce) is a rare mineral reported in minute quantities with calcite at the White Pine mine in Ontonagon County (Heinrich, 1976).

**Tenorite** CuO

Tenorite has been found in many localities throughout the district. It was mined as ore at Copper Harbor in Keweenaw County and at the Algomah mine in Ontonagon County, but is rarely found in quantity elsewhere. Tenorite has been reported from the Allouez and other mines in Keweenaw County and the Mass, Adventure and other mines

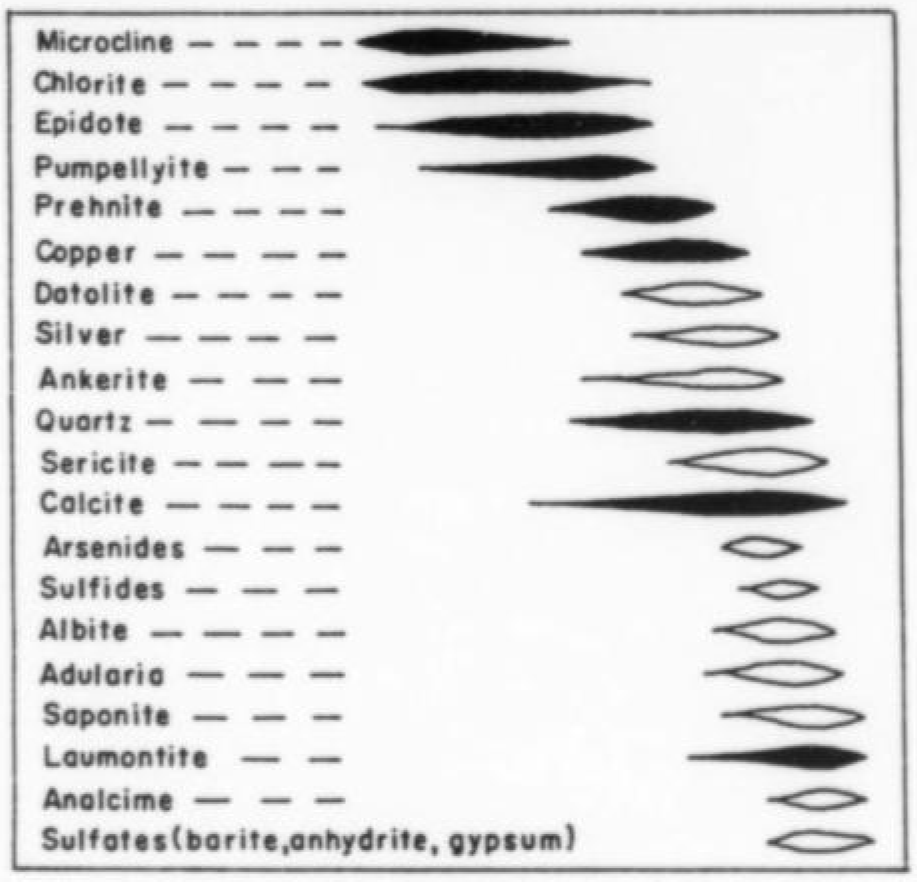


***Figure 101.*** **Generalized paragenesis of secondary minerals in the Copper Country (White, 1968). Dark indicates relative abundance; white indicates relative scarcity of the species.**

on the Evergreen Series in Ontonagon County. It also forms as a cryptocrystalline coating with cuprite on copper crystals throughout the district.

**Thomsonite** $NaCa_2Al_5Si_5O_{20}\cdot 6H_2O$

Thomsonite occurs as radiating crystal aggregates filling vesicles and veins in basalt in many portions of the district. It is white, pink and green in color and is commonly found as beach pebbles suitable for lapidary purposes, along with agates and prehnite, on the shores of Lake Superior in Houghton and Keweenaw counties.

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

Tremolite (variety byssolite) has been reported from the Centennial mine in Houghton County (Heinrich, 1976).

**Tyrolite** $Cu_5Ca(AsO_4)_2(CO_3)(OH)_4\cdot 6H_2O$

Tyrolite is a very rare mineral, associated with arsenides at the Mohawk mine in Keweenaw County (Heinrich, 1976).

**Vladimirite** $Ca_5H_2(AsO_4)_4\cdot 5H_2O$

Vladimirite is a very rare mineral associated with arsenides at the Mohawk mine in Keweenaw County (Heinrich, 1976).

***"Whitneyite"***

"Whitneyite" is a discredited species now considered to be a mixture of algodonite and arsenian copper (Heinrich, 1976).

**Xonotlite** $Ca_6Si_6O_{17}(OH)_2$

Xonotlite is a rare mineral reported from Isle Royale. It occurs as radiating, pale pink fibers commonly mistaken for wollastonite in the past (Heinrich, 1976).

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Many persons have shared their time, expertise and collections during the course of this study and the authors wish to thank them for their valuable contributions. Dan Behnke and Karl Schafer provided much information on micromineral occurrences in the district. Paul F. Hlava of Sandia National Laboratories provided microprobe analyses, and Chris McKee of the New Mexico Bureau of Mines and Mineral Resources conducted X-ray studies of many specimens. Some of the crystal drawings were constructed using the SHAPE program on computer facilities graciously made available by the New Mexico Bureau of Mines and Mineral Resources.

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# THE SEAMAN MINERAL MUSEUM

## MICHIGAN TECHNOLOGICAL UNIVERSITY, HOUGHTON

by **Wendell E. Wilson**
and **Stanley J. Dyl II**

### INTRODUCTION

Because of the abundance, appeal and wide distribution of Copper Country minerals, an experienced collector today is liable to have seen hundreds of specimens, even though he may never have set a Vibram-soled foot in the Keweenaw. He may be confident that, having seen so many specimens *ex situ,* he therefore knows Copper Country minerals rather well. But he would be quite wrong. No one who has yet to visit the Seaman Mineral Museum in Houghton can possibly "know" Michigan copper and silver. It is an essential pilgrimage for every collector, curator, mineralogist and mineral dealer to make if they wish to be truly knowledgeable on the subject. Having seen it, one's personal standard for what constitutes an "extraordinary" Michigan specimen will forever be raised.

Like many of the great European collections, the Seaman Mineral Museum (Kemp, 1985) originated as an adjunct to a mining school in a rich and extensive ore field. The Michigan Mining School was established by an act of the State Legislature in 1885, and held its first classes in the Houghton Firehall in 1886. Two years later it moved into a fine new sandstone building with a copper-roofed tower and a "museum and lecture room" for the mineralogical laboratory and the already fast-growing collection of minerals.

### A. E. SEAMAN

Arthur Edmund Seaman (1853–1937) was born near Grand Rapids, Michigan, and came to the Upper Peninsula to work as a timberman. He developed a knowledge of rocks and minerals on his own, and was hired by the Michigan Geological Survey in 1885. When the Survey and the Mining School were separated in 1892, Seaman went with the school. There he served as a teaching assistant until 1893, then as an instructor, finally earning his B.S. degree there in 1895 on the basis of his part-time studies.

By 1897, when the name of the school was changed to the Michigan College of Mines, Seaman was already a full professor and was named head of the Department of Geology and Mineralogy. In the succeeding years, Seaman worked enthusiastically to build the college's mineral collection (and also to build his own private collection, which he later donated to the college). Thanks to his influence, the collection acquired a vast number of donations, especially from alumni, and was always held in high regard by the College administration. He was given the titles of Professor Emeritus and curator of the museum when he retired from active teaching in 1928. The mineral *seamanite* $[Mn_3^{+2}(PO_4)B(OH)_6]$, from Iron County, Michigan, was named for him in 1930; and the museum itself was renamed in Seaman's honor in 1932, five years before his death.

### HISTORY OF THE COLLECTION

The mineral collection numbered roughly 7,000 specimens by 1888. During the following two years, in a stunning leap, no less than *20,000* mineral specimens were added to the collection, bringing the total to 27,000. Of these, 10,000 specimens were considered to be in the "lecture collection" (good, illustrative or attractive examples not to be used in destructive analysis), and 17,000 comprised the "practice collection" for student use. An 1896 inventory listed the value of the exhibited portion of the collection as $500 . . . not extravagant, but certainly a serviceable nucleus on which to build.

Over the years, many alumni and local residents donated collections to the museum, but many specimens were purchased as well. Seaman assessed all students $1 per course for the purchase of new specimens, and arranged for administration approval of much additional funding for the same purpose. During 1894, for example, specimens were purchased from George L. English (New York), Henry A. Ward (Rochester), Edwin F. Howell (Washington, DC), Dr. Adam August Krantz (Bonn) and Dr. Albert E. Foote (Philadelphia), all prominent mineral dealers of the day. A large French-made exhibit case filled with fine minerals was purchased from A. E. Foote at the Paris Exposition in 1900, and for many years thereafter was preserved as the "Paris Collection." By 1900–1901 the "Exhibition Collection" numbered 1,000 mineral specimens.

In 1902 the collection was formally identified as the Geological-Mineralogical Museum, and was installed on the third floor of the Science Hall (later known as Hubbell Hall). In 1907 the state legislature voted to provide a new fireproof building for the library, the administrative offices, and "the geological and mineralogical museum." This was a very wise and intelligent appropriation, considering how many important collections in other cities were destroyed by fire in the first decades of the twentieth century. A museum inventory the following year placed the value of the minerals at $6,700. The museum specimens were moved to the new brick building (known as Administration Hall) in 1908, where they occupied the entire second floor. Kemp (1985) wrote:

> The collection in the new administration building was held in great esteem for its comprehensive and well-arranged sequences

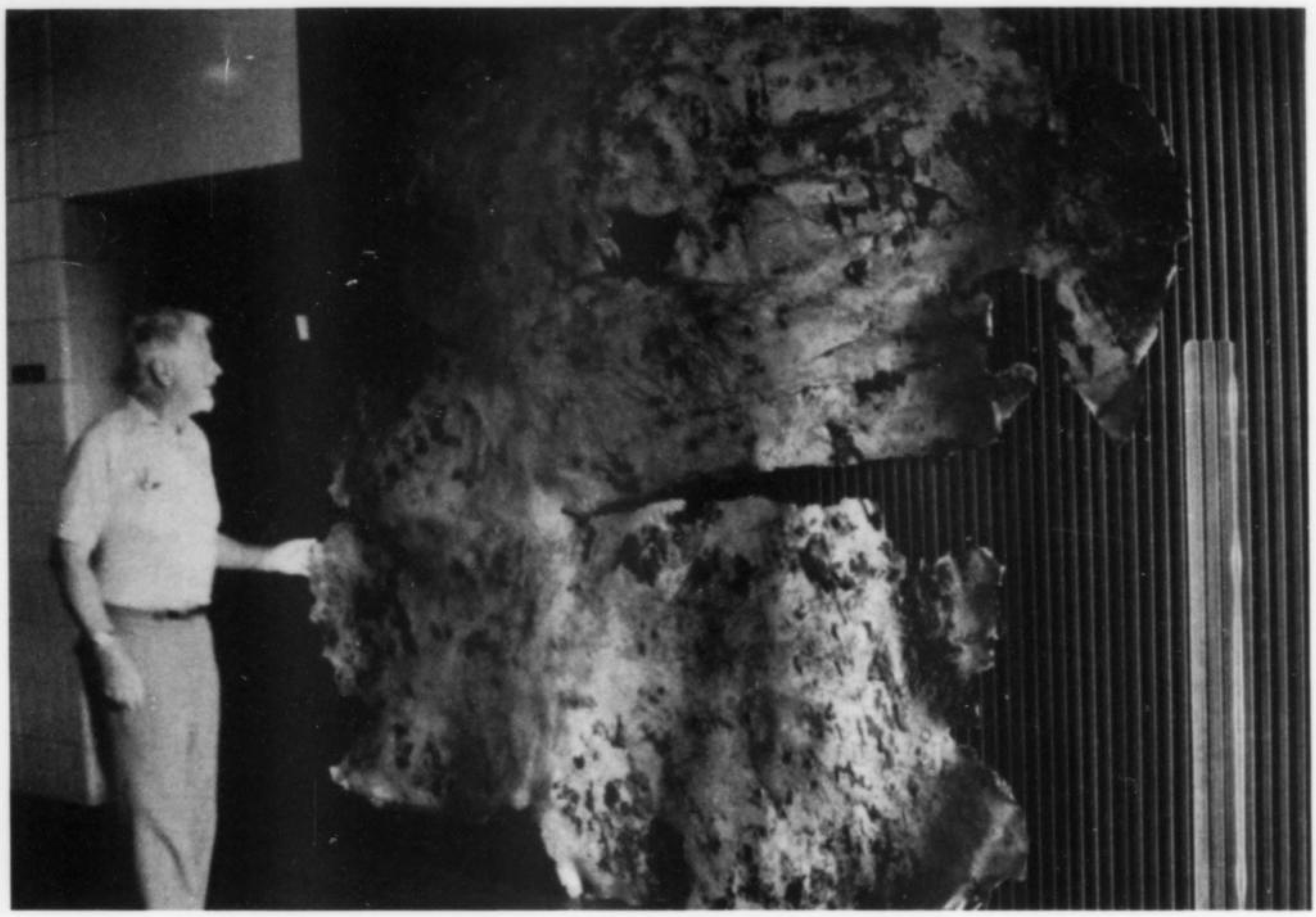

***Figure 102*. Copper sheet, about 140 kg, from the White Pine mine. Standing by the specimen is Bill Wyllys Seaman, grandson of A. E. Seaman.**

of minerals. The minerals were displayed according to Dana. Specimens of each species were further arranged in order for the U.S. localities, beginning with the Upper Peninsula, then other North American countries, and, finally, European and remaining countries of the world. There were classifications according to crystallography, physical properties, and crystal oddities. Sequences of rock specimens completed the educational collections.

In 1931 a new engineering building (Hotchkiss Hall) was constructed, and the mineral museum was moved to new quarters on the top (fourth) floor, directly above the Geology and Mineralogy Department. The floor was reinforced especially to withstand the weight of the specimens. By this time the Dana collection alone occupied over 100 cases, and there was also a vast rock collection, extensive exhibits of Copper Country and Iron Country minerals, and a collection of ores. In the middle of it all stood the "Paris Collection," still in its original display cabinet. Many private collections acquired over the years were kept individually intact (a rarity . . . most museums distribute acquired collections into their "general collection" and in later decades have often found it difficult or impossible to identify which specimens came from which collection). These were arranged around the perimeter of the room. On the north wall hung a large, full-length portrait of Douglass Houghton.

Following Seaman's death in 1937, Kiril Spiroff was promoted to the position of curator (he had been assistant curator since 1935). Due largely to his friendly and knowledgeable influence, many donations from private individuals and mining companies continued to pour in. Spiroff resigned his curatorship in 1942 to take a position as supervisor of the Isle Royale mine. From 1943 to 1948 Professor Wyllys Seaman (son of A. E. Seaman and a 1907 graduate of the school) served as curator.

Although the Geology Department moved into a new building in 1957, the museum stayed where it was. Spiroff had returned to the college, and had served informally as curator for a number of years. In 1964 the curatorial position was officially restored and Professor Spiroff was appointed; he held the position until 1975, having retired from teaching in 1971. He was awarded an honorary PhD in 1970. Jean Petermann Kemp took over the position for the next 11 years; and upon her retirement in 1986, Stanley J. Dyl II was appointed curator. He still serves in that position today.

Hotchkiss Hall was scheduled for demolition, and the museum was officially closed in October of 1973. Jean Kemp, Pat Peterson, Karl Schafer and Marc Wilson (then a student), along with a host of other volunteers, spent nine weeks packing the mineral collection into 3,500 boxes for temporary storage in the basement of the library.

Ground was broken for a new building in 1974, and the facility was ready for occupancy in June of 1976. A small specimen of native copper was imbedded in the cornerstone. By 1978 all but a few cases had been installed and, during that summer, over 3,000 visitors toured the exhibits. The collection remains there today, occupying the entire fifth floor of what is known as the Electrical Energy Resources Center, on the campus of Michigan Technological University. The carpeted galleries contain roughly 20,000 specimens on exhibit (over *eight times* the number on public display at the Smithsonian Institution).

## COLLECTIONS ACQUIRED

The Seaman Museum owes much of its current prominence to the donation and purchase of dozens of fine collections. Alumni of the school have been particularly generous, and many other local residents have seen fit over the years to present their personal cabinets of minerals to the museum. Many of these early collections have been preserved largely intact, especially those rich in Copper Country minerals. It is interesting to note, however, that the largest and most important collections have, for the most part, been donated by non-alumni, such as D. C. Gabriel, E. Wm. Heinrich, L. L. Hubbard, G. A. Koenig and J. T. Reeder. Following is a roughly chronological listing of the more important collections and donations acquired since the founding of the museum.

EMERSON, LUTHER G. (died 1898) consulting civil and mining engineer for the Allouez, Copper Falls, Franklin, Huron, Pewabic, Phoenix and Franklin mines. In 1883, Emerson was considered "beyond question the most experienced man in his profession within the region." His collection of 550 mineral specimens was the first private collection donated to the school. Parts were shown in the Michigan exhibit at the 1893 Columbian Exposition.

KOENIG, GEORG AUGUSTUS (Dr.) (1844–1913), educated at Harvard, Berlin and Freiberg, Professor of Chemistry and head of the department at the College from 1892 to 1913. He taught at the University of Pennsylvania before coming to Michigan and was a colleague of Frederick Genth. Michigan Mining School President M. E. Wadsworth called Koenig "the best and most noted mineral chemist in the U.S." The famous German crystallographer Paul Groth actually made a trip to Houghton to examine Koenig's laboratory-grown domeykite crystals. He described at least 13 new mineral species, of which two: bementite and paramelaconite, are still valid. The museum has co-types of both species; his bementite label reads: "from C. S. Bement, 1887."

FITCH, RICHARD SMITHSON (dates unknown), alumnus and student of A. E. Seaman who collected extensively in Colorado and the Tri-State Lead Belt, and donated many specimens. His small but fine collection contains outstanding examples of Colorado vivianite, Missouri calcite and galena, and a superb Mexican hemimorphite.

GERRY, JOHN (dates unknown), mine captain born in England, worked in the Michigan iron mines in Marquette County. His collection contains excellent examples of Lake Superior hematite and goethite.

BROWN, ELBRIDGE GERRY (born 1840), supply clerk for the Calumet and Hecla mine. His small but fine collection consists of Copper Country specimens augmented by fine minerals from other turn-of-the-century localities.

PARKER, W. H. (dates unknown), Salt Lake City, Utah, mineral dealer. Sold the cream of his collection—400 choice cabinet pieces—to the museum for $750 in 1920. He appraised the suite at twice the value. Although later distributed throughout the Dana-classified collection, these specimens are still discernible by their "Parker number." The museum still has Parker's catalog and the original correspondence between Parker and A. E. Seaman describing the transaction. Sometime earlier, the museum purchased from Parker an exceptional, comprehensive suite of rare copper and associated minerals from Utah's Tintic district.

RAWLINGS, JOSEPH W. V. (born 1826), from Cornwall, England; worked as an engineer for the Cliff, Minesota and other early Cooper Country mines. While serving as chief engineer at the Cliff, he built the first Cornish-style man engine in North America. His collection includes fine Copper Country material, as well as good North American and European specimens.

LAWBAUGH, ALBERT ISAAC (1844–1923), physician for the Phoenix and Osceola mines, and later head of the Tamarack mine hospital. He performed the first successful appendectomy using anesthesia in the Copper Country. His collection, containing exceptional Copper Country specimens, was given to the museum, along with its fine, curved-glass china cabinet.

SMITH, FREDERICK (1835–1929). Born in Germany, he served as agent for the Allouez and later for the Mohawk and Wolverine mines. His large collection of fine Copper Country minerals is still housed in its original custom-built birds-eye-maple cabinet. Included is a Durham fluorite acquired from Lazard Cahn. Some specimens shown in the 1893 Columbian Exposition are still in the cabinet.

METTE, HERBERT B. (1896–1976), alumnus. His Copper Country collection is also housed in its original antique china cabinet. It contains some fine copper-in-calcites from the Quincy mine.

KELLY, WILLIAM (dates unknown), General manager of Penn Iron Mines, and Michigan College of Mines Board of Control member. He donated a superb, diverse suite of calcite specimens from the Vulcan mine in Dickinson County, Michigan, one of the mines he administered.

LAMEY, CARL ARTHUR (1892–1985), alumnus and son-in-law of A. E. Seaman; Professor Emeritus of Geology at Ohio State University. He donated a comprehensive suite of geodes from Bloomington, Indiana.

HUBBARD, LUCIUS LEE (Dr.) (1849–1933), educated at Harvard, Bonn and Heidelberg, he joined the staff of the Michigan Geological Survey and the Michigan Mining School in 1890. In 1893 he left to become State Geologist, a post he held until 1899, when he resigned to head geological exploration for the then-new Copper Range Company, managed by William A. Paine (Paine-Webber). He discovered the southern extension of the Baltic lode, the last big native copper deposit found in the district, which became the Champion mine. Hubbard later became the Champion's general manager. He served as a member of Michigan Tech's Board of Control, and as regent of the University of Michigan from 1910 to 1933. His immense personal collection consisted of high-quality specimens from the Copper Country and Europe. A suite of Hubbard's calcite crystals was described and drawn by famous Harvard crystallographer Charles Palache in his classic 1898 paper on Lake Superior calcites.

REEDER, JOHN THORLEY (1857–1937), clerk and purchasing agent for the Osceola and Tamarack mines. He acquired many fine Copper Country specimens directly from miners and retired pioneer mine captains and officers. He augmented his unparalleled local suites with superb North American and foreign specimens. An early color photographer, he valued aesthetic specimens, as well as unique ones. Included among the latter are arguably the world's largest powellite crystals from the Calumet and Hecla mine and the Tamarack mine. Acknowledged in its day as one of the district's finest, the collection was stored in a windowless brick addition connected to this dining room by a bank vault door. It was acquired by the museum shortly following his death. Reeder's collection is to the Seaman Museum what Bement's is to the American Museum, and Roebling's to the Smithsonian. Museum staff and serious Michigan collectors still evaluate Copper Country specimens against this standard, and evaluate whether or not a specimen is "Reeder quality."

SEAMAN, ARTHUR EDMUND (1853–1937), established and first curated the museum. Also served as Professor of geology and mineralogy and geology department head. His extensive personal mineral collection, including samples of the rare mineral seamanite, was donated to the museum upon his death.

DENGLER, THEODORE (1871–1940), alumnus and successor to Fred Smith as agent of the Mohawk and Wolverine mines. He donated a suite of massive copper specimens—including halfbreeds—from these mines. One crystallized copper from the Mohawk mine measures 46 x 61 cm and has flattened, twinned crystals up to 7.6 cm.

BAXTER, CHARLES HOMER (1889–1944), alumnus and head of the Michigan College of Mines civil and mining engineering departments. His small but fine collection includes a unique iridescent chalcopyrite from the Loretto mine, Dickinson County, Michigan, and rare yellow barite crystals from the Lucy mine, Marquette County, Michigan.

AYRES, VINCENT L. (Dr.) (1908–1947), Michigan Tech crystallography and petrology instructor. He built a comprehensive study collection of rough and cut gem minerals which was purchased from his widow in 1948.

WHITTLE, THOMAS B. (1845–1912), Quincy mining captain from 1889 to 1912. His collection—also housed in its original antique china cabinet—contained some of the finest copper-in-calcite specimens ever recovered. It was turned over to the museum by his widow in 1949.

DENNING, REYNOLDS MCCONNELL (1916–1967), alumnus and mineralogist known for his research into the directional hardness in diamond. He taught at Michigan Tech and later at the University of Michigan. During World War II he worked at the Siglo Viente mine in Llallagua, Bolivia, and donated a comprehensive collection of Bolivian minerals to the Museum around 1952. His widow, Helen Green Denning, established a memorial fund in 1980 for purchasing additional specimens for the Denning Collection.

COLLINS, EDWIN JAMES (1875–1956), alumnus, vice president of the Calumet and Arizona Mining Company and member of Michigan College of Mines Board of Control. His collection includes a fine copper-stained calcite from the Bisbee District and a large, showy hematite-stained quartz group from the Chandler mine, Tower, Minnesota.

WILLS, CHARLES V. (1874–1964). He was born in Ishpeming, Michigan, and raised in Calumet, Michigan. He became an electrical engineer of the Calumet and Arizona mine, and later for Phelps Dodge. While working in Arizona, he made frequent collecting trips to the Copper Country via the Tri-State Lead Belt and the Illinois Fluorspar district. His fragile but valuable collection of midwest and southwest minerals—including some choice wulfenites—was acquired by the museum upon his death.

ROBBE, GEORGE B. (1884–1963), an alumnus (1913) who worked at the Quincy mine after graduation and then moved to Utah. While working for the Utah Copper Company at Bingham Canyon in the 1920's, he pioneered in chemical extraction techniques for copper ore beneficiation. He and his wife (died 1981) acquired a wealth of beautiful crystal and lapidary specimens which she donated to the museum following his death. The collection required twelve days for packing by two people. A stunning suite of polished variscite nodule slabs from Grantsville and Lucin, Utah, is included.

CHAPOTON, RICHARD T. (1950–1972), alumnus. His collection was acquired after his untimely death while still a student, and includes some fine duplicates from the Cranbrook Institute of Science collection. A large segment formed the beginning of the museum's micromount collection.

TURNER, SCOTT (Dr.) (1880–1972), alumnus. Director of the Bureau of Mines during the Hoover administration. The museum received his comprehensive, world-wide collection of ore minerals after his death.

SEAMAN, WYLLYS ARTHUR (1886–1972), son of A. E. Seaman, an alumnus of the school (M.S. 1907) and curator of the museum from 1943 to 1948. He was a meticulous field collector, who left to the museum 3,400 superbly documented geological and mineralogical specimens from the Lake Superior Basin.

DRIER, ROY W. (Dr.) (died 1974), Professor of Metallurgy at Michigan Technological University. He studied the origin of silver-copper intergrowths and arsenic zonation in native copper. He was also an acknowledged local authority on the prehistoric copper culture in the Keweenaw. His collection included thousands of pounds of copper specimens, domeykite, a few fine "half-breeds," some out-of-state minerals, mauls and other artifacts from prehistoric mining. It was donated to the museum by his brother, Charles, following his death.

PINGER, ALLEN W. (died 1975), geologist for the New Jersey Zinc Company. His extensive reference collection consisted of minerals from Franklin, New Jersey, including many fine fluorescent specimens.

BABCOCK, LARRY LLOYD (Dr.) (born 1940), alumnus and mineralogist. He studied the unique and complex manganese mineral paragenesis at the Champion iron mine, Marquette County, and donated valuable reference suites from this locality, from the Copper Country and from South Dakota pegmatites.

HENDERSON, FRANK W. (Dr.) (living), optometrist in Houghton, Michigan. His collection, donated in 1978, includes a significant number of attractive display specimens.

BURCHENAL, JOYCE (died 1981), alumnus who purchased many fine display specimens for the museum, and donated specimens from her own collection, including datolite, Lake Superior agate and a unique gold on crystallized copper from Chile.

HEINRICH, E. WILLIAM (Dr.) (1918–1991), Emeritus Professor of Mineralogy and Emeritus Curator of the Mineralogical Collections of the University of Michigan. Editor of the *American Mineralogist* (1971–76), *Geochemical News* and *Geokhimya* (in translation, 1957–1961). With a major focus on petrology, paragenetic mineralogy, geochemistry and economic mineralogy, his world-wide fieldwork covered a broad range of mineral deposits—especially micas and radioactive raw materials. He was one of the world's leading authorities on carbonatites and pegmatites. His 15,000-specimen collection, acquired by the museum over a nine-year period, is rich in paragenetic suites from key world-wide carbonatite and pegmatite localities.

MARTALOCK, DEAN L. (died 1988), dermatologist from Lacrosse, Wisconsin. He left a large species collection as a testamentary bequest, which increased the museum's species total from 997 to 2362!

GABRIEL, DONALD C. (living), retired Ford Motor Company executive of Detroit. He donated his 3500-specimen collection in 1987 which, together with the Heinrich collection, constitutes the most important collection acquisition since the Reeder collection. Included are strong suites of Copper Country; Clay Center, Ohio; Mexican; Canadian; American and foreign specimens. Many of the latter were purchased in the 1940's from Dr. Otto Runge, a famous Delaware collector and senior dye-stuffs chemist for DuPont. Included in the Runge purchase was a small but extremely fine crystallized gold suite that originally comprised half of Pohndorf's (the well-known Denver mineral dealer) personal gold collection.

## CONCLUSION

Despite its unique treasures, the Seaman Museum itself is not well known among mineral collectors. It seems to be common knowledge that to fully appreciate Cornish minerals, for example, one must visit the British Museum, and that in order to "know" Kongsberg silver there is no substitute for a visit to the Kongsberg Mining Museum. But the Seaman Museum? Most collectors, even in the American Midwest, respond with a blank stare and wonder to themselves why anyone would take the trouble to go all the way up *there*. Admittedly, Houghton seems remote . . . it is not on the way to anywhere. "Beyond the most distant wilderness and remote as the moon," is how Patrick Henry described it to the U.S. Congress in 1843. And the winter weather on the peninsula is formidable (nearly 400 inches of snow fell in 1978!), but the area is a paradise for cross-country skiers and snowmobilers. In the summertime a trip through Upper Michigan can be a delightful, scenic experience and an interesting vacation by any standards. The peninsula is less than a day's drive from Chicago, Milwaukee or Minneapolis and only 11 hours from Detroit. The mineral collector should be aware that a world-class museum collection awaits him there, and that a visit will be rewarding.

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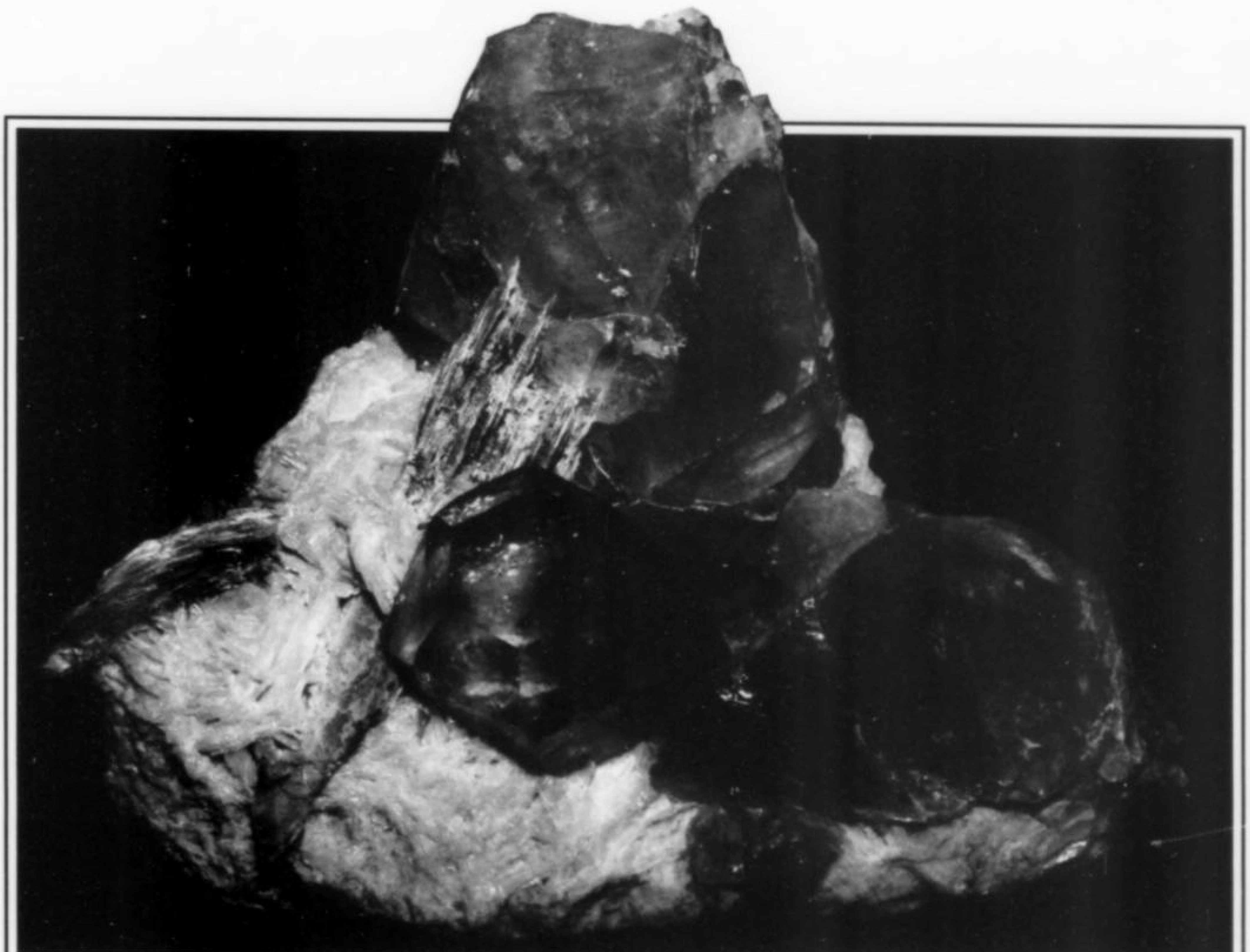


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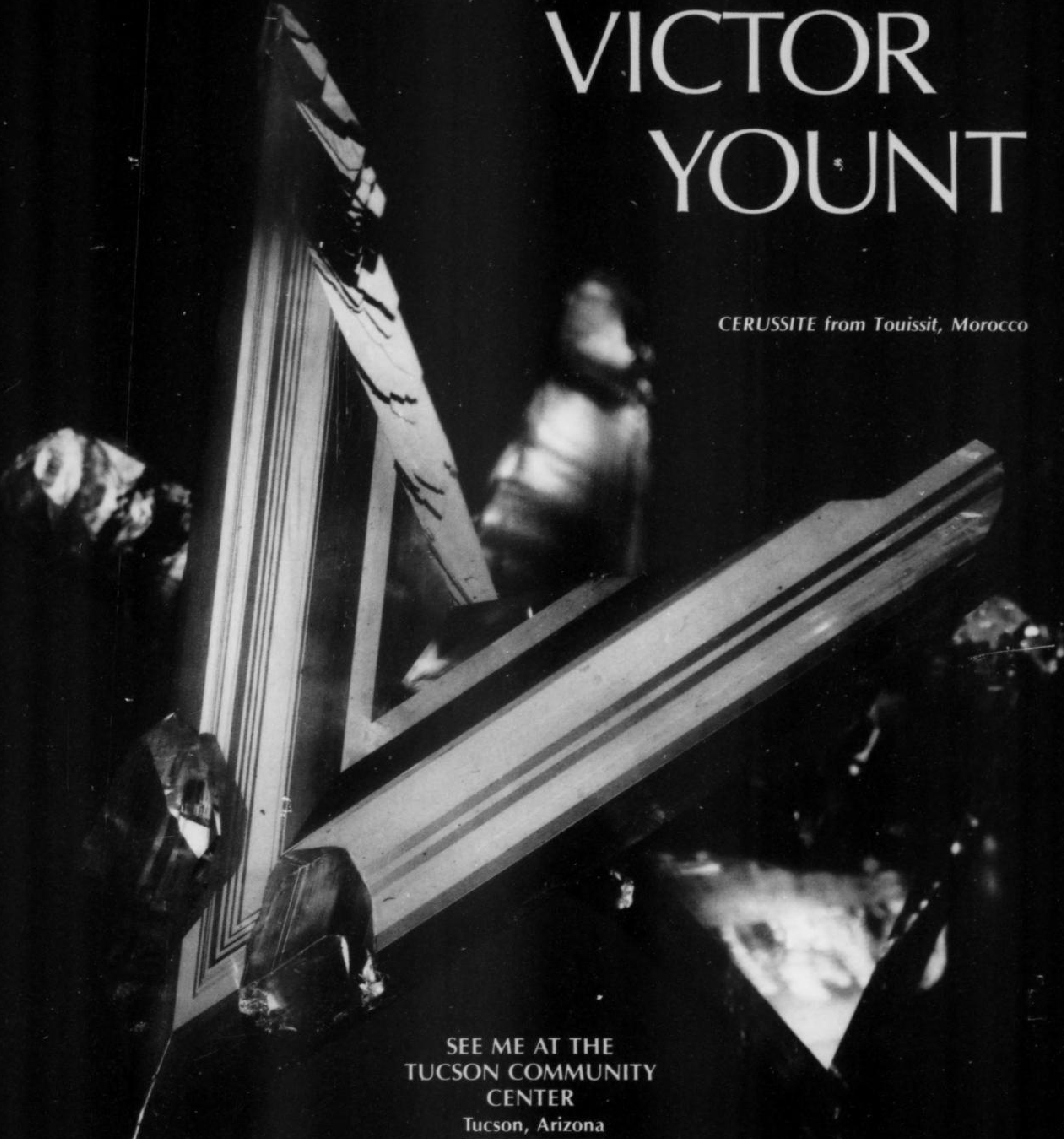

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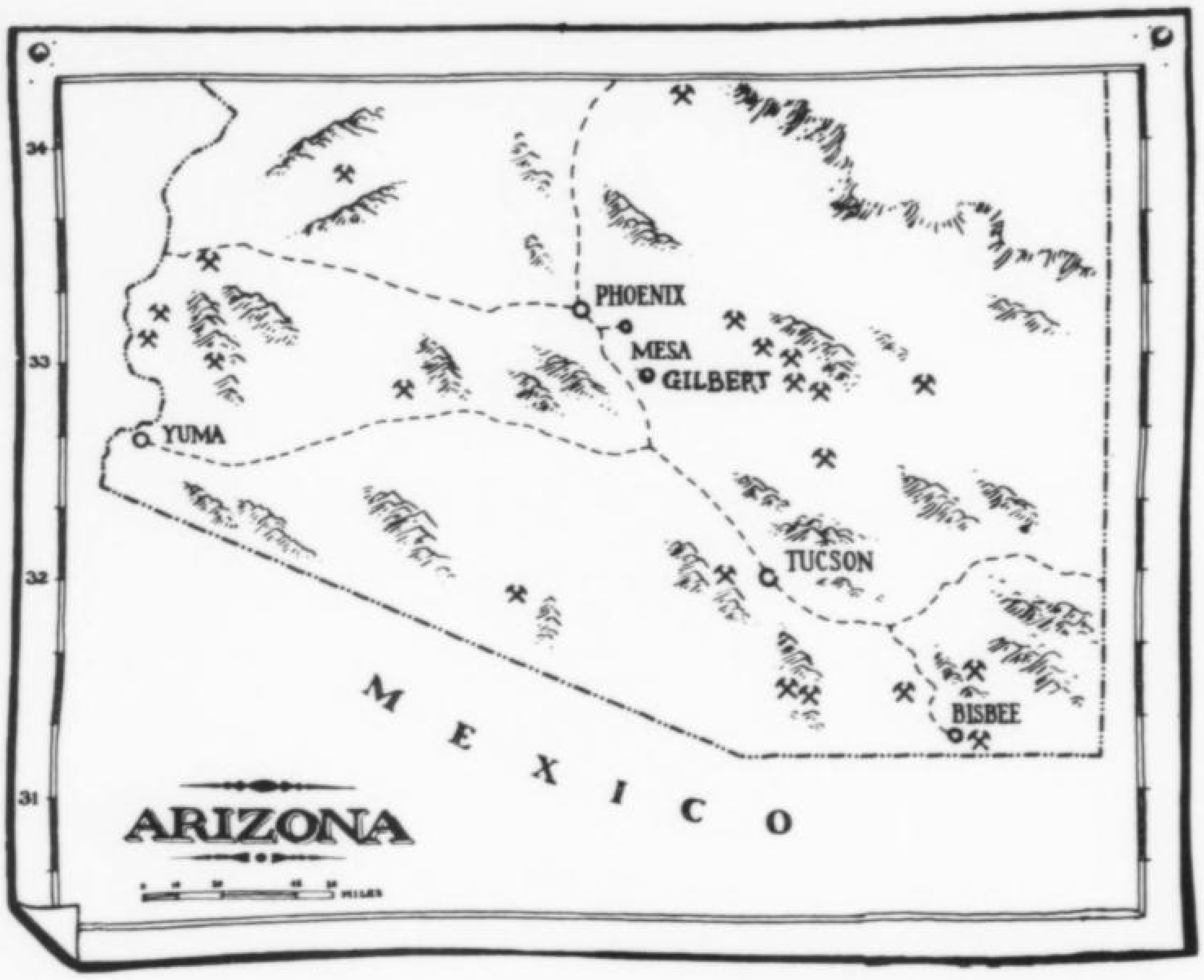


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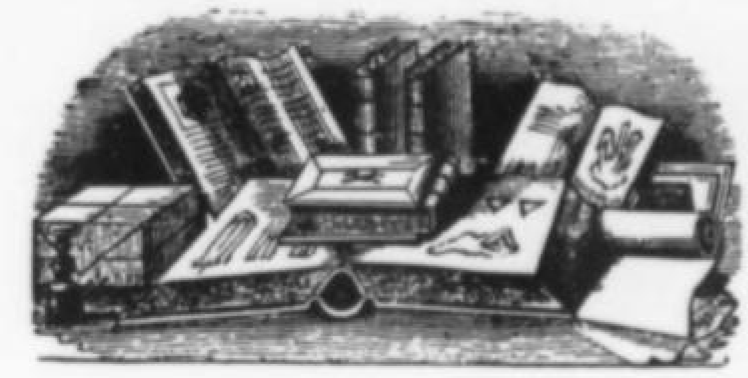

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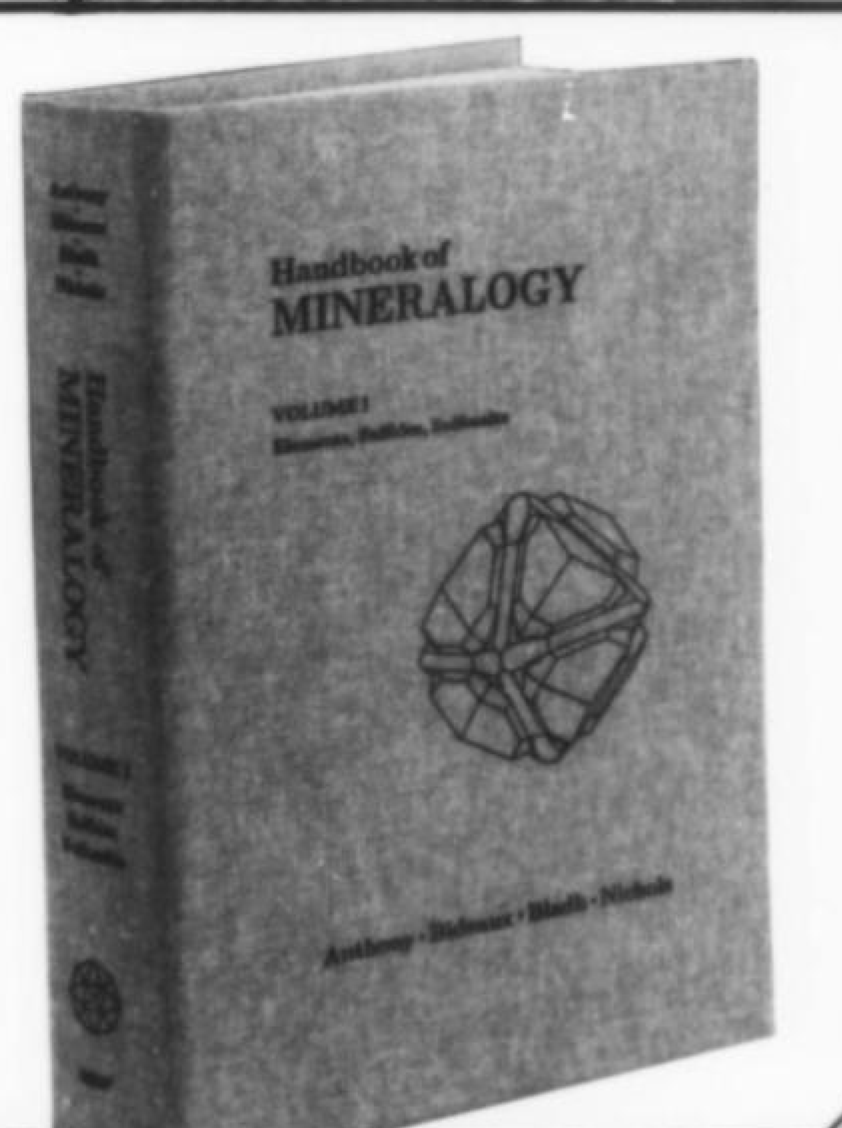


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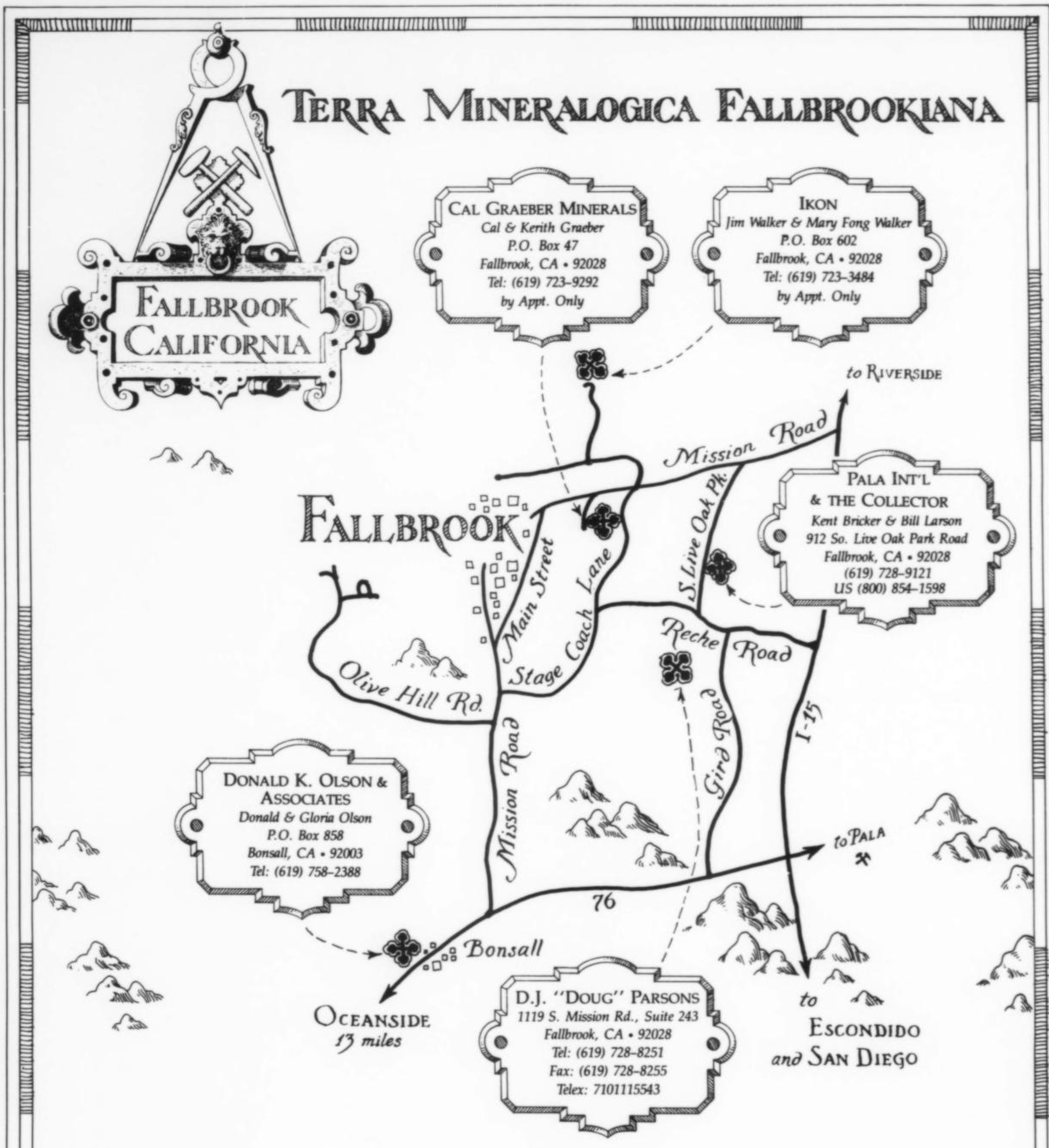

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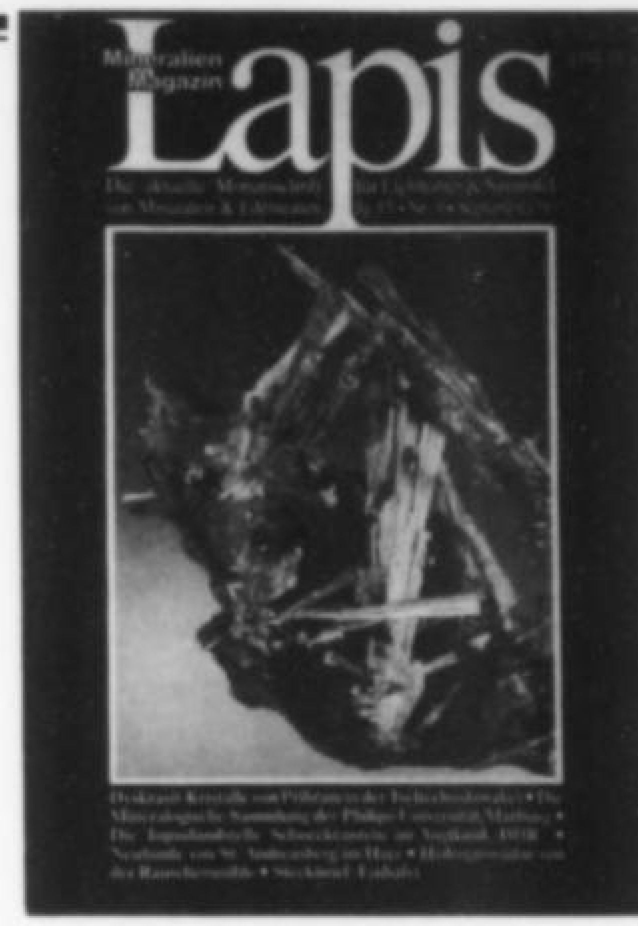
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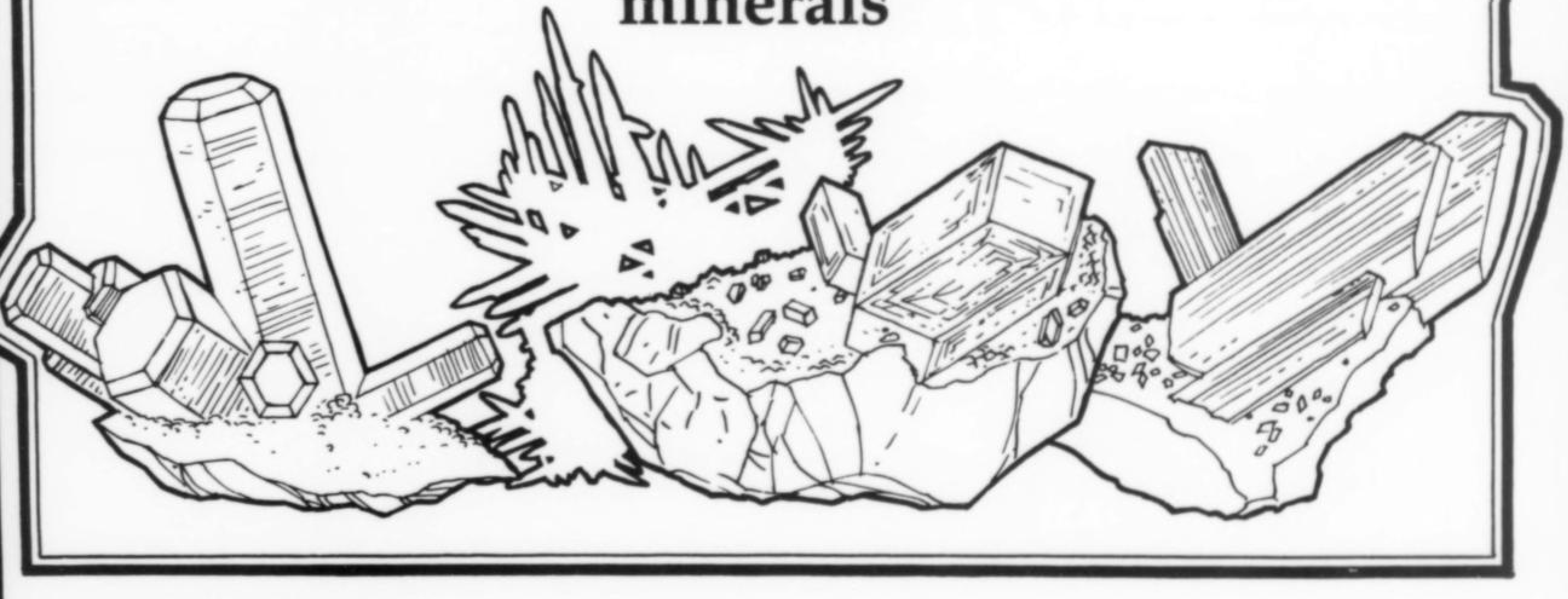

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"Man engine" in the Quincy mine, ca. 1895.
(MTU Archives)