September 2009 Mineral of the Month: Copper

We are pleased to feature one of the most collectible of all minerals—native copper from an historic, underground mine in Upper Michigan's classic Keweenaw locality. Our write-up explains the complex geological origin and many forms of native copper, along with Keweenaw's remarkable mining history.

OVERVIEW

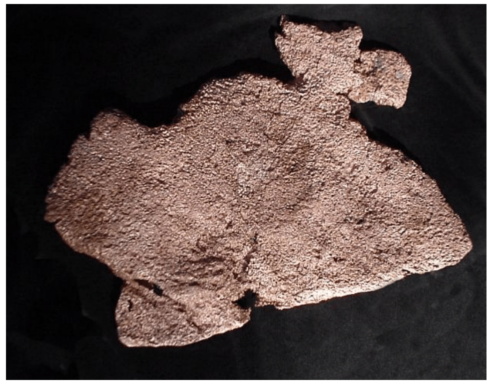

Figure 1. Copper mass.

PHYSICAL PROPERTIES

Chemistry: Cu Copper, usually containing small amounts of silver, iron, lead, bismuth, arsenic, and antimony.
Class: Native Metals
Group: Gold
Crystal System: Isometric (Cubic)
Crystal Habits: Usually dodecahedral, rarely cubic or octahedral; crystals are always crudely developed and often flattened, elongated, or otherwise distorted; also as masses, scales, plates, lumps, dendrites, wires, and branching aggregates.
Color: Copper-red to pinkish-red on clean surfaces; tarnish green to greenish black.
Luster: Metallic; shiny on fresh surfaces.
Transparency: Opaque
Streak: Copper-red to pink
Refractive Index: None (opaque)
Cleavage: None
Fracture: Hackly, malleable
Hardness: 2.5-3.0
Specific Gravity: 8.9
Luminescence: None
Distinctive Features and Tests: Best field marks are color, surfaces, malleability, and green-to-greenish-black tarnish. Copper cannot be confused with any other mineral.
Dana Classification Number: 1.1.1.3.1

NAME The word copper, pronounced KAH-per, comes from the Late Latin word *cuprum*, which stems from the Latin *Cyprium*, literally "metal of Cyprus" or "Cyprian metal," a reference to an early copper source on the Mediterranean island of Cyprus. In European mineralogical literature, copper appears as *Kupfer* (German), *cobre* (Spanish), and *rame* (Italian).

COMPOSITION: Copper is a reddish metal with a bright, metallic luster. At Mohs 2.5-3.0, copper is slightly harder than gold and silver. In crustal abundance, copper ranks 25th among the elements and is more abundant than silver (66th), but less common than iron (4th). Copper's specific gravity of 8.9 makes it slightly more dense than iron (s.g. 7.9) and less dense than silver (s.g. 10.5). Copper has a relatively low melting point of 1965˚ F. (1085˚ C.) and is nearly as malleable and ductile as silver. Native copper never occurs pure, but always contains small, varying quantities of arsenic, antimony, bismuth, iron, lead, or silver. Native copper is deposited in fractures and fissures of basaltic rocks by copper-rich groundwater solutions and is frequently associated with calcite, cuprite, and zeolite minerals. Small amounts of native copper also occur in disseminated, hydrothermal replacement deposits.

Copper crystallizes in the isometric (cubic) system in a close-packed structure. Within the copper lattice, copper atoms occupy each corner of a cube and the center of each of the cube's six faces. In this

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configuration, each atom is surrounded by 12 identical atoms. This close-packed cubic structure explains copper's relatively high density (specific gravity 8.9).

COLLECTING LOCALITIES: The Keweenaw district in northwestern Upper Michigan is a classic locality that yields the world's most numerous, largest, and best-developed copper specimens. The Keweenaw district covers parts of Keweenaw, Houghton, and Ontonagon counties. Notable mine sources include the Caledonia, Algomah, Belt, Superior, Minesota [sic], Michigan, and Cherokee mines in Ontonagon County; the Baltic, Calumet, Centennial, Franklin, Quincy, Isles Royal, Arcadian, and La Salle Mines in Houghton County; and the Ahmeek, Copper Falls, Star, Clark, Delaware, Mohawk, Iroquois, and Seneca mines in Keweenaw County. Other localities in the United States are the Chino Mine in the Santa Rita district of Grant County, New Mexico; and the Ajo Mine at Ajo in Pima County, Arizona. Native copper also occurs in Utah and Montana. Foreign specimens come from Chile, Peru, Bolivia, Cyprus, China, and the Democratic Republic of Congo.

HISTORY, LORE, & USES: Native copper was the first utilitarian metal ever used. As early as the earliest recorded history, bits of native copper were being hammered into simple tools and implements. From the so-called Copper and Bronze ages to the present, copper has been vital to every level of our technological advancement. Native copper was the primary ore of copper for thousands of years, but is now only a minor ore of the metal. Copper, the world's third most widely used metal after iron and aluminum, is employed mainly to manufacture electrical and electronic equipment, alloys, and coinage. Copper is an essential nutrient for all higher forms of plant and animal life, and medical researchers believe that copper and certain copper compounds reduce inflammation and boost the immune system. The wearing of copper bracelets is a popular folk remedy to alleviate joint pain and swelling due to arthritis and rheumatism. According to modern metaphysical practitioners, copper heals the mind and body, projects the energy of mineral crystals, and assists in communicating.

ABOUT OUR SPECIMENS: Our native copper specimens were collected at the Caledonia Mine near Mass City, Ontonagon County, in Upper Michigan's Keweenaw district. The 70-mile-long, 15-mile-wide Keweenaw Peninsula, which extends northeastward into Lake Superior, is known as Michigan's "Copper Country." These deposits formed when copper-rich, hydrothermal solutions circulated through basalt formations where an iron-rich, sulfur-deficient environment caused the copper to precipitate as native metal. Native Americans at Keweenaw collected copper from the surface and shallow pits as early as 2000 B.C. and worked it into simple implements and ornaments. Commercial mining at Keweenaw began in 1844 and lasted for 152 years. The Caledonia Mine began production in 1863 and is now operated by commercial collectors to obtain native-copper specimens. Current owner Richard Whiteman of Red Metal Minerals acquired the Caledonia's mineral rights in 1985 and reopened the 2,000-foot-long tunnel specifically to mine native-copper specimens. Red Metal Minerals has since collected thousands of pieces of native copper, the largest weighing 1.5 tons, and is now the district's largest supplier of specimens which include both native copper and rare, "half-breed" pieces consisting of native copper and native silver.

10 YEARS AGO IN OUR CLUB: Atacamite [$Cu^{2+}_2Cl(OH)_3$], La Farola Mine, Cerro Pintado, Copiapó Province, Chile. Our specimens consisted of slender prismatic crystals of bright green color on matrix. Pronounced at-a-CAM-ite, the name comes from the Atacama (at-a-CAM-a) Desert, Chile, where it was initially discovered about 1801 A.D. The Atacama Desert is the most arid region of the world, covering about 140,000 quare miles of northern Chile. In the days of writing with quill and ink, before blotting paper was widely used, a fine powdered sand called "writing sand" was used to speed drying of the ink. The finest "writing sand" came from Chile, and consisted of ground atacamite. Quality specimens of atacamite still come from Chile, and if we see enough at one time, we would love to feature it again!

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COMPREHENSIVE WRITE-UP

COMPOSITION

The term "native copper" refers to copper that occurs in an elemental or metallic form. Native elements are rare among minerals. Of the approximately 4,400 recognized mineral species, only 21 metals, semimetals, and nonmetals occur in significant quantities in native form. Of the 46 metals, only 13 with low levels of chemical reactivity exist in native form. Among these are gold (Au), silver (Ag), copper (Cu), tantalum (Ta), lead (Pb), mercury (Hg), iron (Fe), and the platinum-group metals platinum (Pt), palladium (P), osmium (Os), rhodium (Rh), ruthenium (Ru), and iridium (Ir). In the past, we have featured native sulfur (S, August 1997, May 2004), gold (December 1999), copper, diamond (C, March 2003), and silver (April 2009) in our Mineral of the Month. We first featured copper in September 1998, sending specimens from the Caledonia Mine, same as this month.

Copper is a reddish metal with a bright, metallic luster. At Mohs 2.5-3.0, copper is slightly harder than gold and silver. In crustal abundance, copper ranks 25th among the elements and is considerably more abundant than silver (66th), but much less common than iron (4th). With a specific gravity of 8.9, copper is more dense than iron (s.g. 7.9), but less dense than silver (s.g. 10.5). Copper has a relatively low melting point of 1965˚ F. (1085˚ C.) and a malleability (ability to be shaped) and ductility (ability to be drawn into wire) approaching that of silver. Native copper never occurs pure, but always contains some arsenic, antimony, bismuth, lead, iron, or silver. Copper, gold and silver are all closely related and fall into column IB of the periodic table of elements. Of these metals, copper is the most reactive and gold the least—the reason why most gold in existence occurs in native form, while native copper is rare.

A freshly exposed or cleaned native copper surface has a diagnostic copper-red color. Because of copper's reactivity, this surface quickly develops a green-to-black tarnish that is produced when the metal reacts with atmospheric oxygen, sulfurous gases, and carbonic acid. Oxidation from atmospheric oxygen produces a dark film of cuprite [copper oxide, Cu_2O], while reaction with hydrogen sulfide creates a dark film of chalcocite [copper sulfide, Cu_2S]. Carbonic acid produced from the reaction of atmospheric carbon dioxide and water creates a coating of green malachite [basic copper carbonate, $Cu_2(CO_3)(OH)_2$]. The greenish-black surface coloration that occurs on all specimens of weathered native copper is usually a combination of these oxidation products.

As one of the 27 transition metals, copper has valance electrons in its two outermost atomic orbitals and exhibits properties that are midway between the most and least electropositive elements. Copper has an atomic number of 29 and its atomic nucleus consists of 29 protons and 35 neutrons. This nucleus is surrounded by 29 electrons (which electrically balance the protons) that are positioned in four orbitals or shells. The first or inner shell has 2 electrons, the second shell has 8, the third 18, and fourth or outer shell only 1. The manner in which energy interacts with this single outer electron gives copper very high electrical conductivity (second only to that of silver) and high thermal conductivity. With oxidation states of 0, +1 and +2, copper can give up its single outer electron in its +1 oxidation state (cuprous), give up an additional electron from its third shell in its +2 oxidation state (cupric), or retain all its electrons in its 0 oxidation state. The chemically stable 0 oxidation state enables copper to exist as a native metal.

Copper crystallizes in the isometric (cubic) system in a close-packed structure. Within the copper lattice, copper atoms occupy each corner of a cube and the center of each of the cube's six faces. In this configuration, each atom is surrounded by 12 identical atoms. This close-packed cubic structure explains copper's relatively high density (specific gravity 8.9). When copper atoms are brought together in close packing, their single outer electrons move freely throughout the lattice. The copper lattice is held together entirely by metallic bonding, which is based on the attraction of moving, free electrons and their collective attraction to the positively charged nuclei. When shearing forces are applied to copper, metallic bonding enables lattice sections to slip along their atomic planes to deform rather than fracture, thus explaining copper's great malleability and ductility. Slippage of atomic planes under mechanical stress accounts for copper's softness of 2.5-3.0.

Because copper has a great affinity for the common element sulfur, most of the copper in existence occurs as sulfide minerals, such as chalcocite [Cu_2S], covellite [Cu_2S], bornite [Cu_5FeS_4], and chalcopyrite [$CuFeS_2$]. Native copper forms only in sulfur-deficient mineralogical environments, as fracture and fissure fillings in basaltic volcanic rocks, deposited when circulating, copper-bearing groundwater solutions react with iron in the basalt. Because of iron's higher chemical reactivity, it displaces the copper in solution causing it to precipitate in elemental form. Native copper in basaltic environments is often associated with calcite [$CaCO_3$], cuprite [Cu_2O], and the zeolite group of hydrated aluminosilicates. Smaller amounts of copper also occur in disseminated hydrothermal replacement deposits.

The Dana mineral classification number 1.1.1.3 first identifies copper as a native element (1). The subclassification (1) then defines it as a metal other than those of the platinum group. Copper is next assigned to the gold group (1) as the third (3) of five members, the other members being gold (1), silver (2), lead (4), and aluminum (5). Some mineralogists do not include lead and aluminum with the gold group. While these two metals also crystallize in the cubic system, they do not share the chemical properties of gold, silver, and copper.

COLLECTING LOCALITIES

Our native copper specimens were collected at the Caledonia Mine in the Keweenaw district near Mass City in Ontonagon County in Upper Michigan. The Keweenaw district, which covers parts of Keweenaw, Houghton, and Ontonagon counties, provides the world's most numerous, largest, and best-developed copper specimens. Other collecting localities in Ontonagon County include the Algomah, Belt, and Superior mines at Mass City, the Minesota [sic] and Michigan mines at Rockland, and the Cherokee Mine at Winona. Native copper is also collected in Houghton County at the Baltic Mine at Baltic, the Calumet Mine at Calumet, the Centennial Mine at Centennial, the Franklin Mine at Franklin, the Quincy Mine at Hancock, the Isles Royal mines at Hancock, the Arcadian Mine at Ripley, and the La Salle Mine at Osceola. Keweenaw County sources include the Ahmeek mine at Ahmeek, the Northwestern mines at Central, the Copper Falls and Star mines at Copper Falls, the Clark Mine at Copper Harbor, the Delaware Mine at Delaware, and the Mohawk, Iroquois, and Seneca mines at Mohawk. Most of these localities can be found on the map in Figure 2.

Among other U.S. localities are the Wood Copper Mine in Cleburne County, Alabama; the Copper Lume Mine at North Mountain in Montgomery County, Arkansas; the Bleeding Hill, Copper Mountain, and Hinch mines in Crawford County, and the Copper Hollow Mine at Stanton in Franklin County, both in Missouri; the Bristol Mine at Bristol in Hartford County, Connecticut; the California Mine in the Rico district, Dolores County, Colorado; the Lodi No. 4 and Murdok mines in the Last Chance district, Plumas County, California; the Gold Hill Mine at Gold Hill in Tooele County, Utah; the Chino Mine (Santa Rita Pit) in the Santa Rita district of Grant County, New Mexico; the Empire-Nevada open-pit copper mine at Yerington in Lyon County, Nevada; and mines at East Ridge and Butte in the Butte district, Silver Bow County, Montana. Arizona sources include the Ajo Mine at Ajo in Pima County; the Ray Mine and Pearl Handle Pit at Ray in the Mineral Creek district of Pinal County, where our April 1999 chrysocolla specimens were found; and in Cochise County at the Hilltop, Gray, and Blacksmith mines in the California district of the Chiricahua Mountains, and the Republic, Mammoth, and Copper Chief mines in the Cochise district.

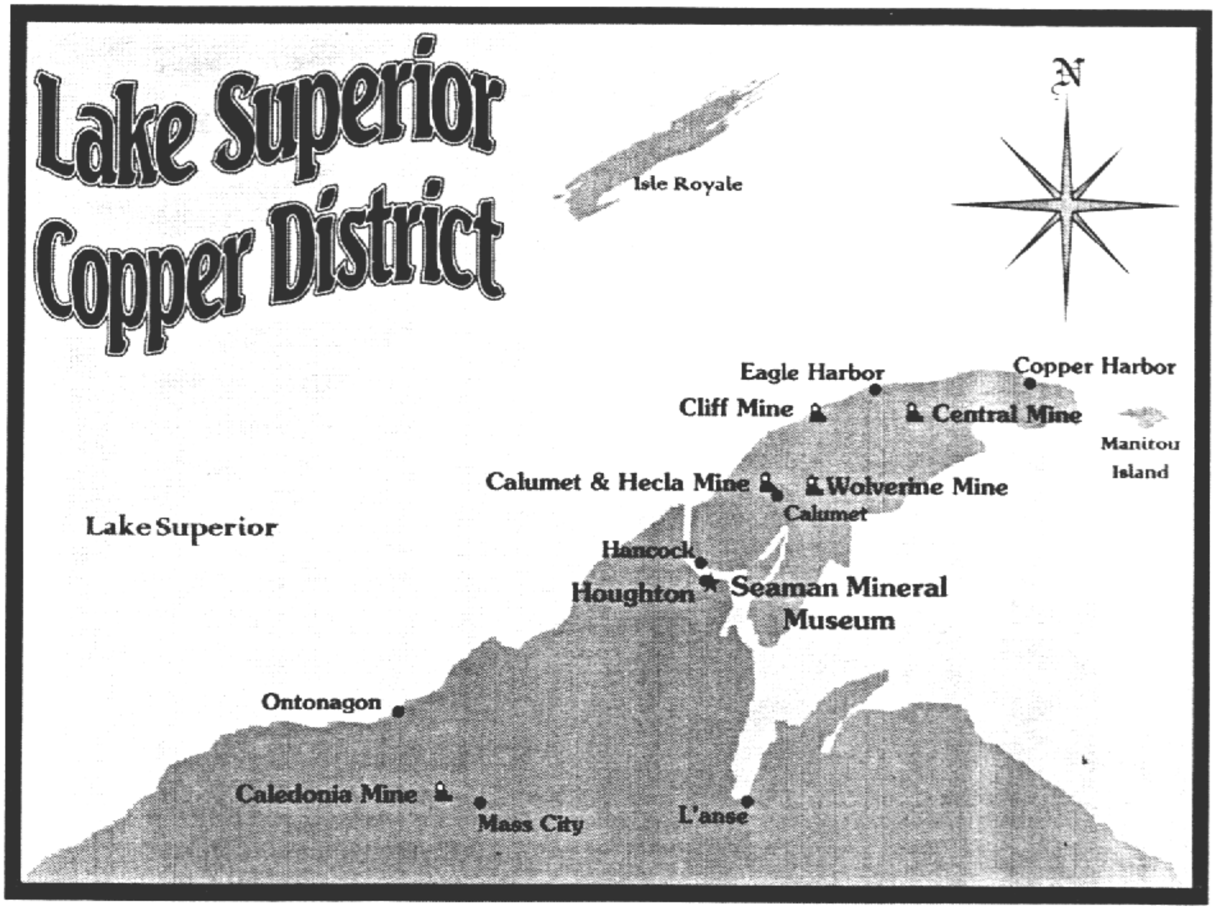

Figure 2. Copper mines of Ontonagon County, Michigan. Map courtesy of A.E. Seaman Mineral Museum.

Among the notable foreign native-copper sources are the Milpillas Mine near Cananea, Sonora, Mexico; the War Eagle Mine in the Whitehorse Copper Belt near Whitehorse, Yukon, Canada; the Cerro Blanco mines in Capiapó Province in the Atacama Region of Chile; the El Cobre Mine at Santiago in Oriente Province, Cuba; the Siglo Veinte and Llallagua mines at Llallagua in Bustillo Province, Potosí Department, Bolivia; and the Casapalco Mine at Casapalco in Huarochiri Province, Lima Department, Peru. European specimens are collected in Italy at the Calamita Mine at Capoliveri on Elba Island in Livorno Province, Tuscany; on the island of Cyprus (Republic of Cyprus) at the Skouiriotissa Mine in the Nicosia District; in Norway at the Kongsberg silver mines at Kongsberg, Baskerud; in Sweden at the Jakobsberg and Kittel mines at Nordmark in Värmland; and in England at the Relistian Mine in Cornwall's Sterth-Gwinthian district.

In Africa, native copper occurs in the Democratic Republic of Congo at the Shinkolobwe Mine in the Katanga Copper Crescent in Katanga (Shaba); in Namibia at the Kombat Mine at Kombat in the Grootfontein district, Otjozondjupa Region; and in Zambia at the Kabwe Mine at Kabwe in the Central Province. Other sources are the Shiromaru Mine at Okutama in the Kanto Region of Honshu Island, Japan; the Itauz Mine at Dzehezkazgan in Zhezqazghan Oblysy, Kazakhstan; and the Great Australia Mine in the Cloncurry-Mt. Isa district in Queensland, Australia. Among Chinese sources are the Chengmenshan copper-molybdenum-gold deposit in the Jiiurui district in Jiujiang County, Jiujiang

Prefecture, Jiangxi Province, and the Tongnuijing copper-molybdenum-gold deposit in the Yushan ore field at Huanining in Anging Prefecture, Anhui Province.

JEWELRY & DECORATIVE USES

With its rich, reddish luster and ability to take a bright polish, copper has been a popular jewelry metal since antiquity. Today, polished copper is used mainly in bracelets, brooches, and earrings. Some wire artists use copper wire when wrapping gemstones. Bright pieces of acid-cleaned, rough native copper are mounted as pendants. Polished copper is widely used in such decorative objects as embossed plaques and wall hangings, vases, trays, and "display" kitchenware.

Fine pieces of native copper, among the most eye-catching and sought-after of all mineral specimens, are found in virtually all notable mineral collections. Museums around the world display native-copper specimens, most of which have been collected from Upper Michigan's Keweenaw district. The most famous native-copper specimen, the 1.5-ton "Ontonagon boulder" (see "The Saga of Keweenaw Copper"), is displayed in the Smithsonian Institution in Washington, D.C.

HISTORY & LORE

Copper's impact on world history and technological development cannot be overstated. Archaeologists are uncertain whether gold or copper was the first metal ever used, but native copper, was the first *utilitarian* metal. Since the dawn of recorded history, the earliest metalworkers were hammering bits of native copper into simple tools and implements. The "Copper Age," the period when a particular culture's tools and weapons were made primarily of copper, occurred at different times in different regions. Early in history, certain Asian cultures were melting native copper in drafted charcoal furnaces and making simple castings. Archaeologists believe that these early metalworkers also attempted to melt certain minerals, such as malachite, that were often associated with native copper. This led to the awareness that malachite contained copper in a nonmetallic form, and thus to the development of smelting techniques to extract metals from metal-bearing mineral compounds.

Native copper remained the primary source of copper for millennia. The "Bronze Age" came about when early metalworkers mixed native copper with tin to make bronze, an alloy with greater hardness and durability than copper and one that could be fabricated into more useful utensils, tools, and weapons. By 1500 B.C., the Mediterranean island of Cyprus was producing most of the world's copper. Knowledge gained though the mining and working of native copper was later applied to iron. But even during the height of the subsequent "Iron Age," copper remained indispensable. Despite iron's great hardness and durability, it corroded much faster than copper, especially in saltwater environments. In the 1700s, brass, a copper-zinc alloy, came into common use. Native copper remained the primary ore of copper until 1900, when advanced mining, milling, and smelting technologies made possible the large-scale use of abundant sulfide copper ores.

The Bible, at Genesis 4:22, calls Tubal-cain, a pre-deluge descendant of Cain, the "forger of every sort of tool of copper and iron." About 1000 B.C., Israelites under King Solomon's rule mined copper south of the Dead Sea for use in making pots, basins, pans, shovels, and forks, along with doors, gates, pillars, and musical instruments, some destined for use at the great temple to Jehovah in Jerusalem.

Copper also has a long medicinal history. The Smith Papyrus, an Egyptian medical text that dates to 2200 B.C., cites the effectiveness of pulverized copper in sterilizing wounds and treating drinking water. The Eber Papyrus of 1550 B.C. prescribed copper to treat headaches, burns, and itching. Greek and Roman physicians used the metal and its compounds to treat an even wider variety of ailments. The Greek physician Hippocrates (ca 460 - ca 377 B.C.), known as the father of medicine, treated ulcers and infections with copper, while Roman scholar Pliny the Elder (Gaius Plinius Secundus, 23-79 A.D) used the metal to treat intestinal worms, mouth sores, and ear infections.

Copper is an essential nutrient for all higher forms of plant and animal life. Most medical researchers now recognize the anti-inflammatory properties of copper and its benefits to the immune system. The beneficial effects of moderate consumption of red wine are attributed partially to high levels of copper in the skin of red-wine grapes. Since the 1960s, many sufferers of arthritis and rheumatism have worn copper bracelets to alleviate joint pain and swelling.

Modern metaphysical practitioners believe that copper's high electrical and thermal conductivity make it effective in healing the mind and body, projecting the energy of mineral crystals, assisting in communicating, and increasing self-esteem. Specimens of native copper were first featured on the six-makuta postage stamp of the Democratic Republic of Congo of 1969. Since then, native copper has appeared on the 42-cent stamp of Canada and the 29-cent stamp of the United States, both in 1992.

THE SAGA OF KEWEENAW COPPER

As early as 2000 B.C., Middle Archaic Native American cultures in the Keweenaw (pronounced KEY-weh-naw) region collected float copper—native copper lying on the surface—to fashion into simple jewelry and such utilitarian objects as knives, scrapers, fishhooks, chisels, awls, and axes. Between 2000 B.C. and 1500 B.C, the trade in Keweenaw copper was impacting nearly half of North America. During this time, the "Old Copper Culture," a group of Late Archaic tribes in the Keweenaw region, collected large quantities of native copper from the surface or mined it from excavations as deep as 30 feet. Using cold-hammering and annealing techniques, these Native American metalworkers created edged tools and weapons along with beads, bracelets, and headbands. Although little else is known about the Old Copper Culture, it did trade copper extensively. While most of this copper was used within 300 miles of its source, some was much more widely distributed. Keweenaw copper, identifiable because of its unique metallurgical composition, has been found in cultural sites across much of Canada and as distant as Georgia and Mexico. After the mysterious demise of the Old Copper Culture, descendant tribes continued to utilize Keweenaw native copper, but on a lesser scale.

French explorers arriving in Keweenaw in the early 1600s noticed that the indigenous Chippewas utilized copper utensils and ornaments. French missionary Claude Allouez (1622-1687) provided the first documentation of Keweenaw native copper in 1667, noting that the Chippewas would not disclose the sources of the metal. That same year, French missionary Claude-Jean Dablon (1618-1697) reported a 1.5-ton mass of copper, considered sacred by the Chippewas, along the Ontonagon River. The first French attempts to mine Keweenaw copper in 1743 failed because of conflict with the Chippewas. After the British seized control of the region from the French, fur trader Alexander Henry (1739-1824) reported a profusion of float copper at Keweenaw. In 1772, Alexander and his men drove a 40-foot-long tunnel into a hillside of frozen clay. But because clay was not the host rock for the copper float, as Henry had assumed, the project failed.

The 1783 Treaty of Paris turned the Keweenaw region over to the newly established United States. In 1828, Michigan territorial governor Lewis Cass (1782-1866), assisted by geologist Henry R. Schoolcraft (1793-1864), explored Keweenaw. In 1831, Schoolcraft returned with a young scientist named Douglass

Houghton (1810-1845). Impressed with the quantity of the native-copper float, Houghton collected many samples for assay, including one from the same 1.5-ton copper boulder that Frenchman Claude-Jean Dablon had seen 164 years earlier. When Michigan became a state in 1837, Houghton became its first state geologist. One of his initial projects was to resurvey the Keweenaw region and publish a detailed report of the native-copper deposits in 1841.

Detroit businessman Julius Eldred (1788-1851) was particularly intrigued with Houghton's description of the already-legendary, 1.5-ton mass of native copper. Eldred sailed to Keweenaw, inspected the so-called "Ontonagon boulder" and bought it from Okondoken, the Chippewa chief, for $105. In 1843, Eldred moved the celebrated boulder to Detroit and displayed it for a per-person price of 25 cents. Citing a violation of federal mineral rights, the War Department seized the boulder, though it paid Eldred $5,600 for his expense in moving it. Finally in 1860, the War Department donated the Ontonagon boulder to the Smithsonian Institution in Washington D.C., where it is displayed today.

Houghton's widely-read report coupled with excitement over the Ontonagon boulder triggered America's first great mineral rush. Thousands of prospectors, adventurers, and speculators descended upon the Keweenaw district, a narrow, 75-mile-long belt trending northeast-southwest from the tip of the Keweenaw Peninsula through present-day Keweenaw, Houghton, and Ontonagon counties. The richest concentrations of native copper occurred in a 2.5-mile-wide, 25-mile-long strip of land in Keweenaw and Houghton counties. The first underground mines, the Phoenix, Cliff, Central, and Minesota [sic] mines began production on fissure veins in 1844. Although, mining was still primitive and relied on hammers, hand steels, and black powder, the profits were huge because the 99-percent-pure native copper required no smelting before use. These early mines produced coarse "barrel copper," which was mined from fissure veins in basalt, then crushed, separated manually, and packed in barrels for shipment. Smaller bits of copper were separated gravitationally from the crushed basalt on mechanical shaker tables. Fissure-vein mining was risky, because the underground drifts sometimes missed the rich copper veins. Nevertheless, Keweenaw miners found hundreds of copper masses weighing more than a ton each. The Cliff Mine produced an 81-ton, 50-foot-long copper mass. The largest copper mass ever found, from the Minesota Mine, measured 46x18x9 feet and weighed 527 tons. Miners worked for a year to chisel the huge mass into pieces small enough to fit up the mine's narrow shaft.

Before the 1840s, there was little interest in mineral collecting in the United States. But at Keweenaw, both mine owners and miners built spectacular collections of native copper, native silver, and calcite for their own pleasure and to sell to outside collectors and museums. Many of the greatest early-American mineral collections were built around specimens of Keweenaw native copper.

Keweenaw miners soon turned from fissure veins to the stratiform copper deposits that were hosted in layers of conglomerate rock. Although considerably lower in grade, they were far greater in size and could be mass-mined from large underground stopes. The Quincy Mine was the first to successfully mine conglomerate deposits in 1856. The richest conglomerate mine was the Calumet, which the Calumet & Hecla Mining Company opened in 1865.

By providing a large, domestic supply of copper at a time of critical need, the Keweenaw mines contributed enormously to the economic growth and industrial development of the United States during the second half of the 19th century. The manufacture of batteries, generators, telegraph wires, telephones, and electric lighting all depended upon Keweenaw copper. Also, the underground expertise that emerged from the Keweenaw mining experience would later prove invaluable in developing the metal deposits found in *the western United States. From 1845 until 1900 when mining began in the West's large copper-sulfide deposits, Keweenaw was the nation's top copper-producing district, accounting for 90 percent of national production.*

After 1900, most Keweenaw copper companies were consolidated under the control of the Calumet & Hecla Mining Company and the Copper Range Company. Keweenaw copper production peaked in 1916 at 266 million pounds (133,000 thousand tons). By the 1950s, only a handful of mines were still producing, most of them only chemically leaching copper from old stamp-mill sands. The last great Keweenaw mine was the White Pine. In 1955, the Copper Range Company expanded this small mine into a major producer. Most White Pine ore was not native copper, but chalcocite [copper sulfide, Cu_2S]. When the White Pine finally shut down in 1996, it had produced 1.8 million tons of copper.

The linear extent of the Keweenaw underground workings is estimated at 10,000 miles and total copper production at 15.5 billion pounds, or 7.75 million tons, three-quarters of which was mined as native copper. Miners also recovered 16 million troy ounces (roughly 460 tons) of by-product silver. Although the district still has large deposits of native copper at depth, the district is no longer able to compete economically with the inexpensive copper produced by mass open-pit mining low-grade sulfide ores in the western states and foreign nations.

With its mines closed, the Keweenaw economy is now based on logging and tourism. To help preserve the rich Keweenaw mining heritage, the National Park Service established the Keweenaw National Historical Park in 1992. This two-unit historical park includes two of the district's largest mines—the Quincy and the Calumet. Other Keweenaw mining-related attractions include a half-dozen historical museums and several underground mine tours. Houghton also is the home of Michigan Technological University and its A. E. Seaman Mineral Museum. The Seaman Museum displays 5,500 mineral specimens, including the world's finest collection of Keweenaw native copper.

TECHNOLOGICAL USES

Native copper, once the primary ore of copper; is now a very minor ore of the metal. Of the 10 million metric tons now mined each year, only an insignificant amount comes from native copper. Copper, the world's third most widely used metal after iron and aluminum, has a myriad of uses based on its high electrical and thermal conductivity, malleability, resistance to corrosion, and alloying capabilities. Today, most copper is used for electrical wire and cable, switches, contacts, power-generation equipment, motor brushes and armatures, and electronic devices. Another major use is to manufacture brass (copper-zinc), bronze (copper-tin), sterling (silver-copper), and exotic alloys with aluminum, beryllium, titanium, and other metals. Copper has long served as a coinage metal and is present in virtually all modern coins except those made of gold or platinum.

Coincidentally, we gave the history of the Nickel coin last month, and this month we have information on the Penny. At shows, when highlighting copper specimens, we ask visitors which U.S. coins are currently made of copper. Few know the correct answer: all coins except pennies! The Lincoln Memorial cent was the last copper penny minted, in 1982; its composition was 95% copper, with 4% tin for greater hardness. Since then, pennies are made of zinc with a pure copper plating. During the late 1970's, the U.S. Treasury announced that it cost almost a penny to make a penny, and the change to zinc saved $40 million per year. The British halfpenny, introduced in 1280 by King Edward I and originally made of silver, was removed from circulation for the same reason in 1984. In the United States, all silver was eliminated from the dime and quarter in 1965; in 1970, silver was removed from the half-dollar and dollar, except for special collector coins. The end of the penny in the U.S. may be in sight, as about six billion of them disappear each year; one Florida recycling plant says it finds 100,000 pennies each week in the garbage!

ABOUT OUR SPECIMENS

Our native-copper specimens are from the Caledonia Mine near Mass City, Ontonagon County, in Upper Michigan's Keweenaw district, most of which is located on the 70-mile-long, 15-mile-wide Keweenaw Peninsula that extends northeastward into Lake Superior. The greater Keweenaw mining district, known as Michigan's "Copper Country," covers parts of Keweenaw, Houghton, and Ontonagon counties. This region of low, pine-forested hills is bordered on the north by Lake Superior and on the west and south by Wisconsin. The largest town in the district is Houghton, population 8,000.

The Keweenaw district is home to the largest known concentration of native-copper deposits and the only district in the world where native copper occurs in sufficient quantity to constitute a primary ore of the metal. The complex origin of these deposits can be traced to their location on the southern limit of North America's Mid-Continent Rift System, a crustal deformity that stretches from Kansas northeast to Lake Superior, then southeast to Lake Erie. This rift system formed about 1.1 billion years ago when a rising mantle plume of magma uplifted the entire region, doming the crust and causing it to pull apart to form a sunken rift. The mantle plume eventually erupted over several million years, flooding the surface with basaltic magmas. At Keweenaw, these eruptions formed more than 200 individual lava flows that geologists collectively call the Portage Lake Volcanics Complex. The largest single flow covers 2,000 square miles and contains 360 cubic miles of basaltic lava. Between eruptions, each flow became weathered and accumulated layers of sediments before being covered by subsequent eruptions. These trapped sediments eventually lithified into layers of conglomerate rock alternating with layers of basalt.

The original basalt contained large amounts of iron, small amounts of copper, and traces of silver. It was also deficient in sulfur because of extensive degassing (emitting of sulfurous gases) during eruption and solidification. Some one billion years ago, burial metamorphism of the lower basalt strata generated hydrothermal fluids that dissolved and concentrated much copper and silver. As these solutions circulated through the iron-rich basalt, they encountered decreasing temperatures and pressures. The iron, which is more chemically reactive than copper and silver, displaced the copper and silver from solution. Because of the sulfur deficiency, most of the copper precipitated as native metal that is quite pure and metallurgically distinctive, containing only one-half percent silver and minor amounts of arsenic. This native copper was emplaced in fissure veins and stratiform or conglomerate deposits. The fissure veins are sometimes massive and run nearly perpendicular to the lava bedding. Stratiform deposits consist of particles, nodules, and smaller masses of copper disseminated throughout conglomerate rock. Many of these deposits were exposed about 12,000 years ago when Pleistocene glaciers sculpted the current Keweenaw topography. Glacial scouring left large quantities of native copper, from tiny nodules to huge masses and all covered with a greenish oxidation patina, scattered about the surface.

The Caledonia Mine, the source of our specimens, opened in 1863 with two 200-foot-deep shafts and a 300-foot long tunnel. The mine soon expanded with four additional tunnels accessing a mineralized "cross-vein" where the Knowlton, South Knowlton, Mass, and Butler conglomerate lodes intersected to form a large ore deposit grading 1.25 percent copper. The Caledonia had produced 900,000 pounds (450 tons) of copper by the time a fire destroyed the mill in 1870. The mine reopened in 1873 and by 1881 had produced another 330,000 pounds (165 tons) of copper, including one mass weighing 40 tons. The mine was then inactive until 1937, when the Calumet & Hecla Company drove a new, 2,000-foot-long adit and conducted a diamond-core-drilling exploration program. But production was minimal until 1950, when core drilling discovered a high-grade lode. During the next eight years, the mine yielded five million pounds (2,500 tons) of copper. In 1971, the Copper Range Company and the United States Bureau of Mines evaluated the mine's potential for in-situ leaching, but dropped the plan over fears of potential groundwater pollution.

Red Metal Minerals acquired the Caledonia's mineral rights in 1985 and reopened the 2,000-foot-long tunnel specifically to mine native-copper specimens. Red Metal Minerals has since collected thousands of pieces of native copper, the largest weighing 1.5 tons, and is now the district's largest supplier of specimens which include both native copper and rare, "half-breed" pieces consisting of native copper and native silver. The Caledonia also yields specimens of "dogtooth" crystals of white calcite [calcium carbonate, $CaCO_3$], crystals of green epidote [basic calcium aluminum iron silicate, $Ca_2Al_2(Fe,Al)Si_3O_{12}(OH)$], moonstone adularia [orthoclase, potassium aluminum silicate, $KAlSi_3O_8$], and datolite [basic calcium borosilicate, $CaBSiO_4(OH)$]. Datolite occurs as porcelaneous, white nodules within basalt gas cavities. Inclusions of tiny, native-copper crystals diffused throughout the datolite create a distinctive, rich, orange-red color. Datolite nodules are cut into thin, translucent slabs to display their beautiful colors and copper inclusions.

Our native-copper specimens are generally massive, but many exhibit scales, plates, lumps, dendrites, wires, and crudely developed crystals. When mined, these specimens were covered with a green-black oxidation coating of copper carbonates and oxides and some residual pieces of conglomerate host rock. They have been cleaned with oxalic acid to display the color, texture, and form of the native copper. The reddish color of native copper is distinctive and cannot be confused with that of any other native metal. The small green areas in the specimens are copper carbonate. Some specimens also show dull, gray-green pieces of the host conglomerate rock. What interesting features do you note in your specimen?

Some of our specimens will exhibit crudely crystallized copper forms. Copper crystallizes in the isometric or cubic system, but rarely forms cubic or octahedral crystals. Most copper crystals occur as crudely developed, 12-sided dodecahedrons that are usually distorted or elongated. These can appear singularly or in clusters, with each crystal about one-eighth inch or less in size. The rough, irregular surface of your specimen will have small areas that are almost mirror-like in their smoothness. These can be individual faces of dodecahedral crystallized copper. Because of extreme distortion, often only one smooth face will be apparent. Other distorted crystals can be recognized by their generally round, dodecahedral shape. The edges of some specimens also exhibit dendritic, wire, and scale shapes.

Necessary both to human life and the progress of civilization, copper is truly an essential element. And when found in an uncombined state, it is wonderful to examine and display!

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September 2009 Mineral of the Month: Copper

COPPER-SILVER "HALF-BREEDS"

Of the roughly five million tons of native copper that have been collected and mined in the Keweenaw region of Upper Michigan, the rarest and most valuable forms are "half-breed" specimens—pieces of native copper intergrown with native silver. Miners adopted the name "half-breed" for these specimens shortly after the Keweenaw underground mines opened in the 1840s. The origin of the name is the derogatory term then commonly used for the offspring of mixed Native American and Caucasian parentage. Since their discovery in the Keweenaw mines in the 1840s, copper-silver half-breeds have been in great demand by mineral collectors and museums.

The presence of native silver at Keweenaw did create certain operational problems. In the 1840s, a pound of copper was worth 20 cents, while a single troy ounce of silver was worth one dollar. Miners, well aware that the value of a single troy ounce of native silver nearly equaled their entire wage for a grueling, 12-hour underground shift, "high-graded" all the native silver possible for their personal use, selling it either as melted-down bullion or as specimens to collectors for premium prices. When mine owners, who considered high-grading as nothing more then theft, demanded the practice be halted, miners retorted that they were paid only to mine copper and not silver. Many of the great Keweenaw half-breed specimens seen in museums and prestigious collections today were "saved" from the crushers by mines who hid them in their lunch buckets and secreted them out of the mines.

Copper-silver half-breeds form through a complex interaction of temperature, pressure, and chemistry. Keweenaw native copper contains about 0.5 percent silver, meaning that the hydrothermal solutions that emplaced it contained a similar ratio of copper and silver ions. During the emplacement process when iron in the basalt host rock displaced the copper and silver ions from solution, they usually precipitated together as an intimate mixture of copper and silver. Occasionally, however, the delicate mechanism of temperature, pressure, and chemistry was upset in a manner that caused only copper to precipitate, thus leaving a solution abnormally rich in silver ions. Eventually, if this silver-rich solution was not replenished by renewed hydrothermal circulation, changes in temperature and pressure sometimes caused the silver ions to precipitate atop the native copper as nearly pure native silver. Usually, the silver has precipitated onto the copper; in rare instances, the copper has precipitated onto the silver. Precipitation often occurs in epitaxy, that is, with the crystal habit of the precipitating metal mimicking the crystal habit of the substrate metal. Most specimens are comprised almost entirely of copper, with a small but distinct group of silver perched on the copper!

Copper-silver half-breed specimens are almost unknown outside the Keweenaw district, and even there they are quite rare. Most specimens are no more than an inch or two in size. There are exceptions, however. The largest known copper-silver half-breed specimen weighs 1,091 pounds and is displayed at the Lizzadro Museum of Lapidary Arts in Elmhurst, Illinois, which we visited some years ago. (We inadvertently drove thorugh a red light trying to find the museum in Elmhurst–fortunately for us, the local policeman who pulled us over took note of our enthusiasm for visiting the museum and let us off.) Half-breed specimens occur in only a few Keweenaw mines, notably the Calumet, Kearsarge, and Hancock mines in Houghton County; the Caledonia, Mass, Michigan, Red Jacket, and White Pine mines in Ontonagon County; and the Cliff and Silver Cliff mines in Keweenaw County. The only active source of copper-silver half-breeds is the Caledonia Mine near Mass City in Ontonagon County—the source of our specimens. We have several dozen of these unique specimens available, from about $15 and $20 to $100 and up according to size and quantity, so please call or Email us for information if you are interested in obtaining one of these rarities for your collection.