

November 2003 Mineral of the Month: Chalcopyrite

Last month's mineral, pyrite, is made up of the elements iron and sulfur. This month's mineral, chalcopyrite, which for ages was assumed to be pyrite, consists of the same two elements with the addition of a third, copper. Does that addition really make a significant difference? We invite you to read on and decide for yourself!

PHYSICAL PROPERTIES

Chemistry: CuFeS_2 Copper Iron Sulfide Often contains silver, gold, and nickel.
Class: Sulfides Group: Chalcopyrite
Crystal System: Tetragonal
Crystal Habits: Pseudo-tetrahedral, sharp and distinct when small, but becoming curved, striated and otherwise irregular with increasing size; as equant, wedge-shaped, often twinned, or resembling distorted tetrahedra; usually striated in different directions; also massive, compact, granular, botryoidal, and disseminated.
Color: Brass-yellow, golden-yellow; tarnish often iridescent in variable golds, greens, yellows, or reds, less often in blues, purples, or black.
Luster: Metallic
Transparency: Opaque
Streak: Greenish-black
Cleavage: Poor in one direction
Fracture: Uneven, brittle
Hardness: 3.5-4.0
Specific Gravity: 4.1-4.3
Luminescence: None
Distinctive Features and Tests: Hardness, color, tarnish, and brittleness.
Chalcopyrite is often confused with pyrite, but it is much softer and has a more golden color, and with native gold, but it is quite brittle, whereas gold is malleable and has a more buttery-yellow color.
Dana Classification Number: 2.9.1.1

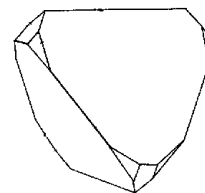


Figure 1 Disphenoid chalcopyrite crystal form, closely resembling a tetrahedron. From Mineralogy by John Sinkankas, used by permission.

NAME

The name "chalcopyrite" derives from the Greek *chalko*, or "copper," and *pyrite*, from the Greek *pyr*, loosely meaning "fire mineral." It is correctly pronounced kal-koe-PYE-rite: evidently, most mineral names that begin with "ch" are pronounced like "k," for example, chalcanthite (KAL-kan-thite) and chalcedony (kal-SED-oh-nee.) Chalcopyrite is also known as "copper pyrite," "cupropyrte," "yellow copper," "yellow copper ore," "peacock ore," and "peacock copper ore." Other names are "kupferkies" and "kupferisinerz."

COMPOSITION

This month's mineral is the seventh we have featured from the sulfides class of minerals, after realgar [AsS] in August 1996, marcasite [FeS_2] in February 1997, orpiment [As_2S_3] in November 1997, stibnite [Sb_2S_3] in February 1998, sphalerite [$[(\text{Zn},\text{Fe})\text{S}]$] in December 1998, and pyrite [FeS_2] in March 1996 and October 2003. As you can see from the chemical formulas, members of the sulfides class all have sulfur as the anion, with various metals and semi-metals as the cations.

Because of having similar properties, the rarer selenides, tellurides, arsenides, and antimonides are usually grouped with the sulfides, with the elements selenium, tellurium, arsenic, and antimony,

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respectively, occupying the place of sulfur in the crystal structure. Minerals of the sulfides class, of which there are more than 350 including most metal-ore minerals, tend to be very dark in color or metallic in luster, heavy, weak and brittle. Minerals of this class are often found in the kind of well-formed, showy specimens we all love!

Among the sulfides, chalcopyrite is the name of both a mineral group and a mineral in the group. The group is made up of four minerals that crystallize in the tetragonal system and has the general formula CuBX_2 , in which "B" can be iron, gallium (Ga), or indium (In), and the "X" anion can be sulfur or selenium (Se). The chalcopyrite group includes eskebornite, copper iron selenide $[\text{CuFeSe}_2]$, which forms a series with chalcopyrite; gallite, copper gallium sulfide $[\text{CuGaS}_2]$; and roquestite, copper indium sulfide $[\text{CuInS}_2]$. Chalcopyrite itself is by far the most abundant and familiar member of its namesake group. The mineral lenaite, silver iron sulfide $[\text{AgFeS}_2]$, is related to chalcopyrite, and some authorities include in the chalcopyrite group.

As is evident by its chemical formula, CuFeS_2 , chalcopyrite contains the elements copper (Cu), iron (Fe), and sulfur (S). In atomic weight, chalcopyrite consists of 34.63 percent copper, 30.43 percent iron, and 34.94 percent sulfur. Within the chalcopyrite molecule, the combined +4 charge of the copper (Cu^{+2}) and iron (Fe^{+2}) cations balances the combined -4 charge of the sulfur (S^{2-}) anion.

Chalcopyrite's chemistry, metallic luster and brassy color are similar to that of pyrite (iron disulfide, FeS_2), last month's featured mineral. As we explained in that write-up, pyrite crystallizes in the isometric system, usually as cubes, dodecahedra, or octahedra. But chalcopyrite, because of the copper within its crystal lattice, crystallizes in the tetragonal system. Chalcopyrite's relatively simple crystal lattice is closely related to that of sphalerite (zinc sulfide, ZnS) and even to that of diamond (C). To visualize the chalcopyrite crystal lattice, first consider the simple diamond lattice in which carbon atoms are tetrahedrally linked by covalent bonds—each carbon atom is linked to three others in the four corners of a tetrahedron, as depicted in Figure 2. Alternately replacing all the carbon atoms with those of zinc and sulfur produces the zinc sulfide structure, in which each zinc atom is surrounded by four sulfur atoms, and each sulfur atom by four zinc atoms (Figure 3.). (Chalcopyrite's structure is so closely related to that of sphalerite that the two minerals often form intergrowths. Furthermore, when free-growing chalcopyrite crystals develop on sphalerite crystals, the faces of both species always exhibit a clear parallel arrangement.)

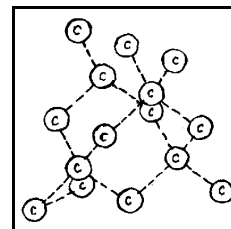


Figure 2

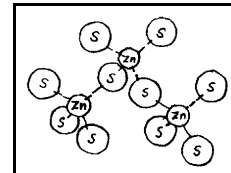


Figure 3

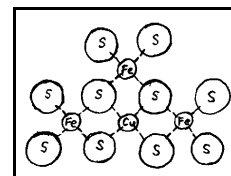


Figure 4

To create the chalcopyrite lattice, simply replace the zinc atoms with alternate copper and iron atoms (Figure 4.) Diamond, sphalerite, and pyrite, of course, crystallize in the isometric system, forming cubes, octahedrons, dodecahedrons, and variations of the three, including the tetrahedron. The addition of the element copper to the chalcopyrite crystal structure modifies it so much that it is classified in the tetragonal system. A common tetragonal form for chalcopyrite is the disphenoid, as seen in Figure 1 on page 1, defined as a closed form consisting of two upper faces that alternate with two lower faces, offset by 90° . The disphenoid closely resembles a tetrahedron, a form made up of four triangular surfaces, like a pyramid, a common form found in minerals of the isometric system, like pyrite. The disphenoid looks so much like the tetrahedron that some call it a pseudo-tetrahedron.

Unlike the sulfur-sulfur bonds that dominate in the pyrite lattice, chalcopyrite's lattice is based primarily on metal-sulfur bonds which have a covalent, or electron-sharing, character. In this arrangement, the copper

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and iron atoms can form only a limited number of bonds in four tetrahedral or six octahedral directions. Expressed differently, the copper and iron atoms occupy alternate tetrahedral or octahedral “holes” within a surrounding sulfur framework. In each chalcopyrite lattice unit, copper and iron atoms always occupy exterior positions. Because sulfur atoms do not shield these exterior copper and iron atoms, chalcopyrite has a characteristic metallic luster and softness. Because of cationic substitution, chalcopyrite can contain varying amounts of other metals such as silver, gold, nickel, indium, tellurium, thallium, selenium, or platinum. Substitution of these elements for copper or iron causes significant variations in chalcopyrite’s physical properties of hardness, specific gravity, and color.

Oxidation produces chalcopyrite’s characteristic tarnish and iridescence. The tarnish is a microscopically thin, oxidation surface film consisting of various copper oxides and hydroxides. The phenomenon of iridescence occurs when the thickness of the tarnish layer, which amounts to only a few atoms, approximates that of the wavelength of light. When light strikes this thin tarnish film, it reflects from both the upper air-tarnish surface and the lower chalcopyrite-tarnish surface. Because air and the tarnish film have different indices of refraction, they reflect different wavelengths of light. When these two reflections join together, some wavelengths are destroyed by interference, while others are reinforced to produce vivid iridescent colors. The names “peacock ore” and “peacock copper ore” refer to the colorful iridescence of chalcopyrite, as well as to that of bornite, a copper iron sulfide with the chemical formula Cu_5FeS_4 .

COLLECTING LOCALITIES

Like pyrite, chalcopyrite is abundant and occurs in many mineral environments. As the most abundant copper mineral, chalcopyrite is found in carbonatites, regional metamorphic rocks and skarn, and most notably in hydrothermal veins in association with pyrite, chalcocite, and gold. Also like pyrite, chalcopyrite is present in most sulfide deposits and is closely associated with other sulfides and copper minerals, along with quartz, fluorite, barite, dolomite, and calcite. Chalcopyrite is also hydrothermally emplaced as disseminated bits in porphyry rock to form major deposits of low-grade copper ore.

Chalcopyrite is the mineral that begins a sequence of copper deposition and redeposition. Most copper is initially emplaced hydrothermally in the form of chalcopyrite. But chalcopyrite oxidizes readily at or near the surface when exposed to free oxygen and water, altering into secondary copper oxides and carbonates. Because of the increased solubility of these secondary minerals, the copper is often transported in aqueous solutions and redeposited at depth in zones of secondary enrichment to form valuable ore bodies.

As an abundant mineral occurring in a variety of mineralogical environments, chalcopyrite has many collecting sites worldwide. Localities in Cornwall, England, have yielded large, well-formed chalcopyrite crystals, as have sites in Japan’s prefectures of Akita, Ugo, and Tochigi. Rio Tinto, Spain; Cavnic, Herja, and Baia Sprie, Romania; and Chenzu, Hunan Province, China, have all produced good specimens. Mexican copper and silver mining areas at La Bufa, Chihuahua; Charcas, San Luis Potosí; and Mazapil, Zacatecas, have provided large chalcopyrite disphenoid crystals that look like tetrahedra. Fine Australian crystals have come from Tumby Bay and the Moonta Mines in South Australia, while superb botryoidal specimens are found at Tasmania’s Mt. Magnet Mine. Excellent specimens are also collected in Bolivia and Peru, most notably from the historic mining areas of Peru’s Cerro de Pasco Province, as we will discuss.

In the United States, nice chalcopyrite specimens have come from the underground and open pit copper mines of southern Arizona and Butte, Montana; the multi-metal mines of Colorado; Pennsylvania’s French

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Creek Mine; and the Tri-State zinc-lead mining district of Missouri, Oklahoma, and Kansas. In Canada, the Noranda Mine in Quebec's Rouyn district has provided fine specimens of iridescent chalcopyrite on quartz.

JEWELRY & DECORATIVE USES

Chalcopyrite has only occasionally been faceted into small reflective stones and cut *en cabochon* for jewelry use, or made into carvings, eggs, and spheres. The manufacturers of such objects no doubt are hoping the chalcopyrite will tarnish and give off the wonderful iridescent quality that would make such pieces much more desirable. Pyrite, marketed in jewelry under the name "marcasite," has the same general appearance as polished chalcopyrite, and is much more widely used because of its brighter and lighter color and greater hardness.

Chalcopyrite, with its gleaming metallic luster, varied crystal habits, and ready availability, has long been popular among collectors both as individual and composite specimens. Like pyrite, chalcopyrite specimens have a wide price range. While excellent representative specimens are inexpensive, one-of-a-kind cabinet-sized specimens can cost thousands of dollars.

Many rock and souvenir shops offer inexpensive, iridescent-blue specimens of "peacock copper ore" or "peacock ore" that are usually labeled as "bornite." In most cases, these specimens are actually chalcopyrite that has been treated with acid to enhance its iridescence.

HISTORY & LORE

Chalcopyrite has been known since antiquity and has variously served as ores of iron, copper, and sulfur. Until the early 1800s when chemists were able to positively establish the composition of many sulfide minerals, chalcopyrite was often generally classified as "pyrite." To differentiate it from pyrite, chalcopyrite was given the name "copper pyrite," which is still used occasionally today.

Chalcopyrite has been featured on a Portuguese 6.5-escudo stamp in 1971, and on Ecuador's 60-centavo stamp of 1960 and its 600-sucre stamp of 1977.

Medieval physicians believed that chalcopyrite treated disorders of the pulmonary system and alleviated fevers, inflammations, and infections. Modern metaphysicists believe that chalcopyrite enhances perception, acts as a connective force in interaction with other cultures, and helps remove energy blockages that interfere with meditation.

TECHNOLOGICAL USES

As the primary ore of copper, chalcopyrite accounts for nearly 95 percent of all the copper mined in the world today. Before the early 1900s, however, chalcopyrite had little value as a copper ore. At that time, the primary copper ores were near-surface deposits of copper oxides and carbonates such as azurite and malachite, both basic copper carbonates with the respective chemical formulas $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ and $\text{Cu}_2\text{CO}_3(\text{OH})_2$, and cuprite, or cuprous oxide (Cu_2O). These shallow carbonate and oxide ores often contained more than 50 percent copper by weight and could be smelted directly without prior concentration.

By 1900, as the need for copper for electrification and industrial uses skyrocketed, these shallow, rich, oxidized copper ores had been mined out. Prospectors and miners had already found enormous, deeper

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deposits of unaltered, chalcopyrite-based ores which, although low in grade, contained huge amounts of copper. But the development of both mechanized, mass-mining methods and efficient ore-concentration processes were needed before these deposits could be mined economically.

In the early 1900s, metallurgical engineer Daniel Jackling (1869-1956), working at Bingham Canyon, Utah, first employed large steam shovels and ore-haulage trains in open-pit mining and successfully applied the new flotation-separation process on a large scale. Flotation separation utilizes the tendency of oil-covered mineral particles, including chalcopyrite and other sulfides, to adhere to air bubbles. In flotation separation, finely ground ore slurries are mixed with an oily reagent, then vigorously aerated in tanks. Mineral particles adhere to the rising bubbles and float off as an oily froth, while the particles of non-mineralized rock, called gangue (pronounced "gang"), fall to the bottom. The flotation concentrate is then smelted to recover the metal.

Modern flotation separation is a precise science. Most copper mills use a mix consisting of ground limestone and water to provide a basic pH, along with pine oil to make bubbles, an alcohol to strengthen the bubbles, and a "collector" chemical called potassium amyl xanthate. The potassium amyl xanthate molecule is a five-carbon chain, one end of which is polar and sticks to sulfide minerals. The other end is nonpolar, repels water, and attracts the molecules of pine-oil bubbles. This binds the chalcopyrite particles to the rising pine-oil bubbles and floats them off. By carefully adjusting the pH, mill workers can cleanly separate the waste pyrite from the valuable copper-bearing chalcopyrite.

Some of the world's greatest mines exploit chalcopyrite deposits. Today, the site where Daniel Jackling pioneered the flotation-separation process is Kennecott Utah Copper's Bingham Canyon Mine. The Bingham Canyon open pit, now in its second century of copper production, is the largest man-made excavation on Earth, measuring 2.5 miles across and 0.5 miles deep. Bingham Canyon has yielded a phenomenal 15 million tons of copper metal, more than any other single mine in history, along with significant amounts of gold, silver, molybdenum, and platinum, all recovered from the flotation separation and smelting of chalcopyrite.

Today, nearly one billion tons of low-grade chalcopyrite ore is mined around the world to produce nine million tons of copper per year. The world's largest underground mine is Chile's El Teniente Mine, where the ore consists of disseminated chalcopyrite that grades just 1.1 percent copper. Copper's most important uses are in the manufacture of electrical wire and cable and as the primary alloying agent in the production of brass and bronze.

ABOUT OUR SPECIMENS

When the Tucson Gem & Mineral Show chose "Minerals of the Andes" as its show theme for 2002, it focused the attention of collectors to the mineral treasures found in Columbia, Peru, Bolivia, Chile, and Argentina. Among the best-loved sites in these countries are two in Peru, the Huanzalá mine, where last month's pyrite came from, and the Huaron mines, where this month's specimens were dug. This latter locality is sometimes referred to as the Huaron district or the San Jose de Huayllay district.

This district is a relatively small mining complex, about 3 km by 4 km in size, near the city of Huayllay, located about 100 miles northeast of Lima, the capital of Peru. Here the mines have been operating since 1914, and produce mainly lead and zinc ore, with smaller amounts of copper and minor amounts of silver. About twenty mines are active in the district, all basically just different means to reach the same ore bodies, and most specimens are simply labeled as coming from "Huaron." However, since 1985, the Animón Mine has been producing the majority of the mineral specimens from the complex. In its issue

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dedicated to Mines and Minerals of Peru, *the Mineralogical Record* calls this the Alimon mine, evidently a misprint. It is from the Animón mine that our specimens come, and that issue of the *Record* states that Animón “became a major supplier in about 1985 of “textbook-perfect” chalcopyrite, sphalerite, pyrite, and other attractive minerals,” including dolomite, galena, quartz, and rhodochrosite. Other minerals coming from the district include ankerite, barite, calcite, enargite, polybasite, and tetrahedrite.

Geologists believe that the minerals of the district were deposited during three major periods, in fracture zones of sedimentary rock that had previously been intruded by quartz monzonites and quartz monzonite dikes, which caused the fracturing. (Monzonite is a group of igneous rocks formed at great depth, containing alkali feldspar and plagioclase, little or no quartz, and commonly augite.) In the first period, milky quartz, pyrite, enargite, and tetrahedrite were formed, then later broken apart when the fractures were reopened, and finally cemented together by the minerals formed during the second major period, namely, milky quartz, brown sphalerite, and galena, along with botryoidal siderite, dolomite, and rhodochrosite. The third period again involved fracturing, then the depositing of new minerals by means of hydrothermal action, including the carbonate minerals siderite, dolomite, rhodochrosite, and calcite. The MR states: “As a final pulse during this late-stage deposition, barite, pale to reddish amber-colored sphalerite, galena, tetrahedrite, polybasite and chalcopyrite were deposited.”

All this geologic activity left a cornucopia of shapes, forms, and colors for mineral collectors to enjoy. A close examination of your specimen might reveal some of these outstanding features: exceptional quartz crystals, “porcupine-like aggregates of long, thin, tapered crystals projecting out from the matrix, frequently with a divergent habit,” as the MR article calls them, sometimes with small, dark, blood-red inclusions of hematite; sphalerite as tetrahedral, octahedral, and tristetrahedral crystals of blackish-brown color, often as the matrix of the specimen; and lustrous dark-grey crystals of galena and very bright cubes of pyrite, with occasional minor dolomite and calcite. The chalcopyrite is particularly fascinating, mainly forming as the disphenoids mentioned earlier, often twinned, often coated by microscopic crystals of chalcopyrite, sphalerite, and other sulfides. Some crystals are tarnished, and the MR says that pyrite crystals are sometimes “embedded in the chalcopyrite like raisins in a cookie.” Sounds yummy!

Have you enjoyed these two sulfides these past two months? So alike, so different, so fascinating!

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