October 2003 Mineral of the Month: Pyrite

> *"The Huanzala mine in Huanuco Department is famous for producing the best pyrite specimens in the world."* – Mineralogical Record, May-June 2003

PHYSICAL PROPERTIES

Chemistry: FeS_2 Iron Disulfide. May contain nickel, cobalt, silver, and gold.
Class: Sulfides Group: Pyrite
Crystal System: Isometric
Crystal Habits: Cubes and pyritohedra (pentagondodecahedra, or dodecahedra with pentagonal faces), less commonly as octahedra, or combinations thereof, in both individual crystals and crystal clusters; often twinned and striated; also as granular, globular, radiating, drusy, fibrous, mammillary, and stalactitic masses, and as nodules and aggregations.
Color: Pale brass-yellow, yellowish-gray to gray; may tarnish (oxidize) to yellow-brown; sometimes iridescent.
Luster: Metallic
Transparency: Opaque
Streak: Greenish-black
Cleavage: None
Fracture: Conchoidal; brittle
Hardness: 6.0-6.5
Specific Gravity: 4.9-5.2
Luminescence: None
Distinctive Features and Tests: Pale brass-yellow color, hardness, striated crystal faces, ability to spark on sharp mechanical impact and to become weakly magnetic after heating. Pyrite has been confused with chalcopyrite and other metal sulfides and with native gold.
Dana Classification Number: 2.12.1.1

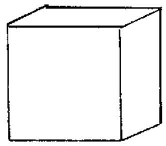

Figure 1 Pyrite cube

NAME

The name "pyrite" (pronounced PIE-rite) freely translates to "fire mineral" and derives from the Greek *pyr*, or "fire," an allusion to the mineral's ability to spark when struck with metal. "Pyrites" (note plural usage) refers generally to all similar-appearing metal sulfides.

Because of its great abundance and varied forms, pyrite has many secondary names. The most familiar is "fool's gold," a reference to pyrite's similarity in color to that of native gold. Pyrite is also known as "iron pyrite," and its cobalt- and nickel-rich varieties are respectively known as "cobaltian pyrite" and "nickelian pyrite" or "bravoite." Flat, disc-like, radiating forms of pyrite found in certain coal shales are called "pyrite dollars" or "pyrite suns." "Iron crosses" and "iron-cross twins" refer to penetration twins of pyritohedra with shapes reminiscent of Maltese crosses. In the jewelry trade, pyrite is often called marcasite, which is correctly the name for a polymorph of pyrite. Other names for pyrite, all of which date to the 19th century, are "schwefelkies," "kaltschedan," "leber pyrites," "lebereisener," "leberschlag," "vitriolkies," "marchasita," and "sideropyrite."

COMPOSITION

Its chemical formula, FeS_2, indicates that pyrite contains the elements iron (Fe) and sulfur (S). In atomic weight, pyrite consists of 46.55 percent iron and 53.45 percent sulfur. Within the pyrite molecule, the +2 charge of the single ferrous ion (Fe^{+2}) balances the -2 charge of the two covalently bonded sulfur ions. Normally, a single sulfur ion has an ionic charge of -2, +4, or +6. But in the case of pyrite, the two sulfur ions act as a polyatomic ion, in which a single atomic charge is determined by the nature of covalent electron sharing. In pyrite, the polyatomic grouping of two sulfur ions produces a single -2 charge which balances the +2 charge of the ferrous iron in the pyrite molecule. Because cationic substitution is common, pyrite may contain varying but significant amounts of silver, gold, and especially nickel and cobalt, all of which cause variations in hardness, density, and color.

Within the sulfide class of minerals, the pyrite group includes those with an isometric crystal structure and a related chemistry. The general formula for the pyrite group is AXY or AX_2, in which the "A" cation can be iron, gold, cobalt, copper, manganese, nickel, platinum, palladium, ruthenium, or osmium, and the "X" and "Y" anion can be sulfur, arsenic, antimony, bismuth, selenium, or tellurium. Although the pyrite group is quite large, only pyrite itself is an abundant or familiar mineral. Pyrite forms a solid-solution series with cattierite, or cobalt disulfide (CoS_2), and intermediate grades are generally referred to as cobaltian pyrite.

As the most widespread and abundant of all sulfides, pyrite occurs in association with hundreds of minerals and in all mineralogical environments from pegmatites and hydrothermal vein deposits to carbonatites, regional metamorphic rocks and skarns, and sedimentary formations. Pyrite's most notable environments are hydrothermal vein and replacement deposits in which many well-developed crystals often occur with quartz and other sulfides such as chalcopyrite (copper iron sulfide, $CuFeS_2$), galena (lead sulfide, PbS), and sphalerite (zinc sulfide, ZnS). Under certain conditions, pyrite will replace the organic matter in fossils in a process called pyritization.

Pyrite superficially resembles a variety of other minerals. Bits of massive pyrite, aptly called "fool's gold," are generally similar in color to native gold. However, gold is much softer (Mohs 2.5-3.0) and produces a golden-yellow streak, unlike pyrite's greenish-black streak. Pyrite's metallic luster and brassy color are similar to those of other sulfide minerals including chalcopyrite, bravoite (iron nickel sulfide, $[(Ni, Fe)S_2]$); cobaltite (cobalt sulfarsenide, [(Co,Fe)AsS]); and cattierite (cobalt disulfide $[CoS_2]$).

Pyrite is most often confused with chalcopyrite, which will be our featured mineral in November. As we will see, chalcopyrite has a more golden-yellow color than pyrite and is considerably softer (Mohs 3.5-4.0). Although these two minerals share a generally similar chemistry, the presence of copper in chalcopyrite creates a different type of atomic bonding, causing it to crystallize in the tetragonal system rather than the isometric system. The many interesting comparisons that exist between pyrite and chalcopyrite will be explained in detail next month.

Pyrite is also similar in appearance to marcasite, an iron disulfide (FeS_2) that is a pyrite polymorph, that is, a mineral with an identical chemistry but with a different crystal structure. Marcasite's density, hardness, and metallic luster are similar to that of pyrite, but it has a lighter color and crystallizes in the orthorhombic system as tabular or prismatic crystals. Pyrite forms in all mineralogical environments, but marcasite forms only in near-surface, low-temperature, high-acid environments.

Because the pyrite lattice is bound primarily by covalent sulfur-sulfur bonds, it has an inherent chemical instability and oxidizes readily in the presence of water and free oxygen to form free iron ions and sulfuric acid. In nature, pyrite oxidation occurs slowly at a rate linked to that of surface erosion and the movement of subterranean water tables. An excellent example of pyrite oxidation is **gossan**, a deposit of limonite (a mixture of iron oxides and hydroxides) that directly overlie lower veins of unoxidized pyrite. In highly mineralized areas where surface erosion has rapidly exposed pyrite, the oxidation products are readily apparent. Sulfuric acid acidifies nearby surface water flows which subsequently carry much dissolved iron.

PYRITE CRYSTALLOGRAPHY

Pyrite crystallizes in the isometric system, one of seven crystal-structure systems that are defined by three or four axes of equal or unequal length intersecting at the crystal center. In the isometric system, three equal axes are perpendicular to the three pairs of opposing faces on the basic six-sided cube, as seen in Figure 2. Variations of this cubic shape are the 4-faced tetrahedron, the 8-faced octahedron, the 12-faced dodecahedron, and the 24-faced cubic trapezohedron, as seen in Figures 3-6. Pyrite crystals are especially interesting, as they can assume any of these forms or any combination thereof.

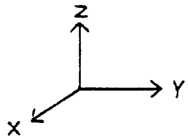

Figure 2 Isometric system axes

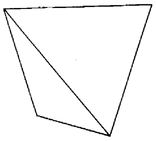

Figure 3
Tetrahedron

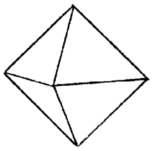

Figure 4
Octahedron

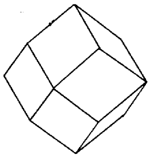

Figure 5
Dodecahedron

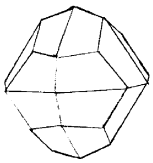

Figure 6
Trapezohedron

Dodecahedrons have four basic forms categorized by face shape: symmetrical and asymmetrical pentagonal faces (five-sided polygons), delta-shaped faces (four-sided polygons), and rhombic faces (four-sided diamond-shaped polygons). The pentagonal dodecahedrons are termed pyritohedrons because they are most commonly found on pyrite.

In pyrite's cubic crystal lattice, iron atoms occupy each corner and the middle of each face with a pair of sulfur atoms midway along each edge. Bonding occurs primarily between the sulfur atoms. Because sulfur's strong affinity for electrons does not permit ionic bonding, these sulfur-sulfur bonds are covalent with shared electrons. But because the iron atoms are not well-shielded from each other, some degree of metallic bonding also exists within the pyrite lattice. The predominant covalent bonding accounts for pyrite's brittleness, while a lesser degree of direct metallic bonding explains its metallic luster. The rigid cubic shape of the lattice accounts for pyrite's considerable hardness.

With its many crystal habits, pyrite obviously lacks the near-perfect crystalline symmetry of such other cubic minerals as galena (lead sulfide, PbS), which adhere rigidly to a simple cubic habit. In the galena lattice, lead atoms alternate with a single sulfur atom. But in pyrite, the iron ions alternate with pairs of sulfur atoms that are always staggered in alternate directions, thus disrupting the simple cubic symmetry. The critical points in recognizing pyrite crystal habits (or those of many other isometric minerals) are the angles between the individual faces, which always remain constant. Because isometric minerals usually favor certain habits over others, habit is a key to identification.

Pyrite crystals often exhibit diagnostic striations which enhance their complexity and overall attractiveness. Pyrite striations are formed by the twinning of cubic and pyritohedral crystals and the subsequent convergence or juxtaposition of two or more faces. During the growth process, one of these faces becomes truncated or "overgrown" by the other, yet nevertheless leaves its mark as visible edges, or stria. These edges, which are usually formed by repetitively juxtaposing internal pyritohedron edges on cube faces, often cover entire faces. Pyrite striations, which are always perpendicular to those on adjacent faces, are usually parallel, but sometimes triangular or crossed. In "cathedral pyrite," striation cross-patterns are reminiscent of the roof angles in Gothic cathedrals, hence the name.

When dilution eventually decreases the acidity, the iron precipitates out of solution as "yellow boy," a bright-yellow iron hydroxide which stains creek banks and beds a characteristic, bright yellow-orange color. Prospectors have long considered “yellow boy” an indication of mineralized areas upstream.

Pyrite’s chemical instability should be considered when storing specimens, especially in warm, humid climates which accelerate oxidation. Large pyrite crystals are the most stable. Because very fine-grained pyrite has a greatly expanded surface area, it is most prone to oxidation and can develop a white or gray efflorescent (flower-like) coating of iron sulfates and sulfuric acid that can damage labels and boxes.

COLLECTING LOCALITIES

Because of its abundance and occurrence in many mineralogical environments, pyrite collecting localities are found worldwide. In Europe, large, well-developed cubes are found at near Logroño, Soria, and La Rioja in northeastern Spain, and in the so-called “pyrite belt” of metal-sulfide deposits west of Seville in southwestern Spain. Near-perfect cubic pyrite also occurs at Rio Marina, Elba, Italy. Asian, African, and Australian mines have yielded many fine pyrite specimens, but the best may come from South America, where Bolivia and Peru are currently the world’s premier pyrite sources. Mines at Oruro and Colavi, Bolivia, yield excellent specimens. In Peru’s Huanuco state, the Huanzalá Mine, is known for its fine clusters of octahedral crystals.

In the United States, many multi-metal sulfide mines have produced fine pyrite specimens. Especially notable are the cubes and pyritohedrons from the American Mine in Bingham Canyon, Utah, and from several mines at Park City, Utah. Superb Colorado specimens have come from the Leadville district and the nearby Climax molybdenum mine, the Gilman district, and the Rico and Telluride districts. Tri-State zinc-lead mining district of southwestern Missouri and adjacent Kansas and Oklahoma has yielded many large, well-developed cubes. Bright “pyrite suns” are found in coal shales at Sparta, Illinois. Fine cubes and dodecahedra have been collected at the Huff Quarry at Huntsville, Ohio, and unusual, distorted octahedra from Pennsylvania’s French Creek Mine.

JEWELRY & DECORATIVE USES

Pyrite crystals have served as gemstones and for decorative use since antiquity. Glittering bits of pyrite also enhance the value and attractiveness of lapis lazuli, or lazurite (sodium calcium aluminum silicate with sulfur, $(Na,Ca)_{7-8}(Al,Si)_{12}(O,S)_{24}[(SO_4),Cl_2,(OH)_2]$). Archaeologists have recovered pyrite crystals in jewelry and decorative objects from Egyptian tombs.

Pyrite, marketed as “marcasite,” was popular in the Victorian era of the late 1800s, when faceted, polished, reflective pyrite was set in pendants, brooches, necklaces, and bracelets. Typical Victorian styles used hundreds of tiny, glittering, faceted pyrite stones mounted on sterling silver. This style regained popularity during the Art Deco jewelry period of the 1920s and 1930s, and is quite popular today.

Pyrite continues to fill a niche in the jewelry market as polished beads in sizes ranging from 6mm to 12mm, which are strung for use in necklaces, bracelets, and dangling earrings. Also popular is drusy “rainbow” pyrite– natural coatings of tiny, iridescent pyrite crystals on base rock-fashioned into cabochons for mounting in pendants, brooches, and earrings. In addition, pyrite is cut into small “roses” for use as edging stones.

Because of its highly reflective crystal faces, availability, affordability, wide range of interesting crystal habits, and visual appeal, pyrite has always been enormously popular among mineral collectors and is perhaps the most widely collected of all minerals. Pyrite may have fired the interest of more beginning collectors than has any other mineral. With a price range to suit everyone, small specimens of beautiful pyrite crystals can be purchased for only a few dollars, while rare or unusually fine cabinet specimens can cost thousands of dollars.

HISTORY & LORE

Pyrite has been known since antiquity. In the earliest written reference, Greek philosopher and naturalist Theophrastus (372?-287 B.C.), in his treatise *On Stones*, described grains of pyrite embedded in lapis lazuli. By medieval times, metalworkers were manufacturing sulfuric acid from pyrite, while healers used pyrite to treat disorders of the throat and the circulatory system. In western South America, the Incas and other cultures used the smooth faces of large pyrite cubes as mirrors and believed that the reflected images provided a way to look into one's soul.

Pyrite's ability to spark when struck with iron or another hard mineral has long made it a valued "fire-starter." In the late 1400s, pyrite was the preferred sparking material in European wheel-lock firearms. Sparking occurs when a sharp impact produces extreme heat and pressure within a miniscule area of the pyrite surface, thus breaking molecular bonds to cause instant oxidation and the release of additional heat in the form of a spark. Pyrite was later replaced in sparking devices by flint and iron (or steel), in which the hard flint (microcrystalline quartz) shaved off tiny slivers of iron, generating sufficient heat to ignite the bits of iron as a spark.

In the early 1700s, pyrite was one of the first minerals to be scientifically identified by its elemental components, iron and sulfur. After later researchers in the 1800s had determined the chemical identities of similar metal sulfides, true pyrite became known as "iron pyrite," and chalcopyrite as "copper pyrite," differentiating terms which still have limited usage today. Pyrite has been featured on the postage stamps of Armenia, Cyprus, Ecuador, New Zealand, and Spain.

Modern metaphysicists believe that pyrite (and its polymorph marcasite) supplements one's physical energy with the energy of the sun, increases stamina, stimulates the intellect, and helps to transform thought into intelligent action. Pyrite is also thought of as a shield stone that protects its wearer from both negativity and physical risk.

TECHNOLOGICAL USES

Pyrite has occasionally served as an ore of iron, but only during regions and in periods when more massive deposits of primary iron ores such as magnetite (ferrous and ferric iron oxide, $FeFe_2O_4$) and hematite (ferric oxide, Fe_2O_3) were not available. Pyrite has been more valuable as an ore of sulfur, an element used to manufacture sulfuric acid (H_2SO_4), an important feedstock in chemical manufacturing. Today, pyrite is no longer an important ore of sulfur, due to the huge amounts of sulfur recovered from the emissions produced by burning coal, smelting sulfide ores, and "cracking" natural gas and crude petroleum. The very limited amount of pyrite still recovered, mostly from metal-mine wastes and mill tailings, serves as a coloring agent in the manufacture of amber-colored glass bottles.

Knowledge of pyrite oxidation chemistry has proven extremely valuable. Structural, or building, stone such as granite and marble is carefully analyzed before quarrying to assure that it free of pyrite which might oxidize over time, thus compromising the structural integrity of the stone or staining its finish.

Equally important is understanding the role of pyrite oxidation in mine-drainage pollution. Although pyrite oxidation is a natural phenomenon, the mining of coal and metal-sulfide ores exposes huge quantities of pyrite to rapid oxidation. The large quantities of sulfuric acid produced by the oxidation of pyrite-rich mine waste and mill tailings dissolve many heavy metals which, in sufficient concentration, are toxic to aquatic life. The associated precipitation of iron hydroxide also degrades stream habitat. Understanding the chemical oxidation of pyrite is therefore essential to eliminating potential mine-drainage pollution problems and to remediating old pollution problems.

ABOUT OUR SPECIMENS

Although mineral deposits are Peru's primary natural resource, (it has large deposits of silver, iron ore, gold, lead, zinc, and petroleum,) it is only within the last thirty years that more than a handful of fine mineral specimens have been made available to dealers and collectors. Prior to this, although some wonderful specimens did find their way into collections and museums worldwide, most were (read on only if you dare) destroyed.

Our wonderful specimens come from the Huanzalá Mine, about 250 km north of Lima, the capital of Peru. Mining operations here date back to 1721, but modern-day, large-scale mining dates back to just 1964. By 1981, the Huanzalá mine was producing 900 metric tons of lead/zinc ore per day. (Actually, the Huanzalá mine is composite of several mines and associated operations.) Mineral specimens began arriving on the market in the 1980's, and by the end of the decade Huanzalá was famous among collectors for producing some of the world's finest pink fluorite and for huge pyrite specimens, the latter being gobbled up by interior decorators for use in homes and offices. Some of these weighed upwards of 200 lbs.!

In addition to the world's best pyrite specimens, Huanzalá also produces other sulfides, such as chalcopyrite [$CuFeS_2$], enargite [$CuAsS_4$], galena [PbS], sphalerite [(Zn,Fe)S], and tennantite [$(Cu,Ag,Fe,Zn)_{12}As_4S_{13}$], as well as calcite [$CaCO_3$], dolomite [$CaMg(CO_3)_2$] and quartz [$SiO_2$]. Rare minerals found here in excellent specimens include the sulfides arsenopyrite [FeAsS], pyrrhotite [$Fe_{1-x}S$], and wurtzite [(Zn,Fe)S], as well as apatite, barite [$BaSO_4$], hübnerite [$Mg^{2+}WO_4$], and scheelite [$CaWO_4$], among many others. As the Mineralogical Record puts it: “Huanzala undoubtably will be known in the future as one of the world's greatest mineral localities.” Already, museums around the world have been stocking up on fine Huanzalá and other Peruvian specimens.

It has been a delight to have the opportunity to examine so many specimens from the marvelous locality. We have been able to observe the many crystal forms described in the write-up, a real challenge, as most crystals are combinations of these forms. It is remarkable how, even in the simplest crystal class, so many unique and complex faces can be produced! We have also come to appreciate the high luster of these specimens, as well as the pronounced striations on many of the crystals. It is easy to see why these are called the world's best pyrite specimens!

References: *Manual of Mineralogy*, Klein and Hurlbut, John Wiley & Sons; *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *1999 Glossary of Mineralogical Species*, J. A. Mandarino; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Rocks and Minerals,* Joel Arem, Geoscience Press; *Gemstone and Mineral Data Book*, John Sinkankas, Geoscience Press; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; “Peruvian Minerals: an Update,” Jaroslav Hyrsl and Zolina Rosales, *The Mineralogical Record*, May-June 2003; “Mines and Minerals of Peru: Raura-Huanzala Group,” Jack A. Crowley, Rock H. Currier, and Terry Szenics, *The Mineralogical Record*, July-August 1997; “Pyrite,” Bob Jones, *Rock & Gem*, October 1994; “Pretty, Problematic Pyrite,” Steve Voynick, *Rock & Gem*, May 1998; “Connoisseurs' Choice: Pyrite, Park City, Utah,” Robert Cook, *Rocks & Minerals*, November-December 1993; “Colorado Pyrite,” Barbara Muntyan, *Rocks & Minerals*, July-August 1994; “Leadville,” J. M. and G. C. Shannon, and “Rico,” R. Barnes, *The Mineralogical Record*, May-June 1985; “Pyrite Crystals from the Duff Quarry,” R. P. Richards and S. C Chamberlain, *The Mineralogical Record*, November-December 1987; “Pyrite Crystals from Soria and La Rioja Provinces, Spain,” M. Calvo and E. Sevillano, *The Mineralogical Record*, November-December 1989; “The Crystal Forms of Pyrite,” R. I. Gait, *The Mineralogical Record*, July-August 1978.