February 2011 Mineral of the Month: Azurite

Can any other mineral match the breathtaking beauty of intensely blue azurite? This month we focus on this colorful, hydrous copper carbonate from Arizona's famed Morenci Mine. Our write-up explains azurite's mineralogy, its use as both an ornamental stone and as an early ore of copper, and the history and technological development of one of the world's greatest copper mines.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $Cu_3(CO_3)_2(OH)_2$ Basic Copper Carbonate (Copper Carbonate Hydroxide)
Class: Carbonates
Subclass: Carbonates with hydroxyl or halogen anions
Group: Azurite
Crystal System: Monoclinic
Crystal Habits: Usually as prismatic crystals in tabular or bladed habits, often thin in one direction; crystal faces sometimes faintly wavy or striated; also occurs in earthy, massive, stalactitic and stalagmitic, radiating, fibrous, crusty, and botryoidal forms.
Color: Azure blue; also light blue to dark blue.
Luster: Vitreous, brilliant
Transparency: Transparent and translucent to opaque
Streak: Light blue
Cleavage: Perfect-to-good in one direction, good in a second, fair in a third.
Fracture: Conchoidal; brittle
Hardness: Mohs 3.5-4.0
Specific Gravity: 3.7-3.8
Luminescence: None
Refractive Index: 1.730-1.838
Distinctive Features and Tests: Azure-blue color, light-blue streak, and close association with malachite [basic copper carbonate, $Cu_2(CO_3)(OH)_2$]. Azurite is softer than such blue minerals as lazulite [basic magnesium aluminum phosphate, $MgAl_2(PO_4)_2(OH)_2$] and lazurite [basic sodium calcium aluminum oxychlorosulfosilicate, $(Na,Ca)_8Si_6Al_6O_{24}[(SO_4),S,Cl,(OH)]_2$]. Can be confused with bright-blue linarite [basic lead copper sulfate, $PbCu(SO_4)(OH)_2$], but azurite effervesces in dilute hydrochloric acid, while linarite does not.
Dana Classification Number: 16a.2.1.1

NAME Azurite, pronounced "AZH-ur-ite," is named for its azure color. The word "azure" is rooted in the Persian *lâzhuward*, meaning "heaven" or "blue." Alternative names for azurite include "azure copper ore," "blue copper ore," "blue copper," "blue malachite," "caeruleum," "bergblau," "kupfer lazure," and "chessylite." Blue pigments made from azurite are known as "mountain blue," "blue bice," and "blue verditer." Italian artists referred to azurite pigment as "*azurro della magna,*" literally, "great blue." In European mineralogical literature, azurite appears as *azurit* and *azurita*.

COMPOSITION: Azurite is one of the nearly 100 members of the carbonate class of minerals. The chemical formula $Cu_3(CO_3)_2(OH)_2$ identifies azurite as a basic copper carbonate (or copper carbonate hydroxide) containing the elements copper (Cu), carbon (C), oxygen (O), and hydrogen (H). Azurite's molecular weight consists of 55.31 percent copper, 37.14 percent oxygen, 6.97 percent carbon, and 0.58 percent hydrogen. As an idiochromatic (self-colored) mineral, azurite's azure-blue color is caused by its crystal structure and essential chemical composition, rather than by accessory chromophores (coloring agents). Copper, the essential metal in azurite, is a powerful pigmenting agent for the colors blue and

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green. Azurite crystallizes in the monoclinic system, which is defined by three axes of unequal length, two of which are perpendicular to each other. As a secondary mineral, azurite is found in the shallow, oxidized portions of copper deposits and forms either from the reaction of carbonic acid with copper-sulfide minerals or from the reaction of copper-bearing solutions with calcite. Azurite is often associated with malachite, cuprite, chalcopyrite, calcite, chalcocite, chrysocolla, and linarite.

COLLECTING LOCALITIES: Notable azurite sources in the United States include are found in Greenlee, Cochise, Gila, and Yavapai counties in Arizona. Azurite is also collected in Colorado, California, Montana, Nevada, New Mexico, Utah, Idaho, Oklahoma, Michigan, Arkansas, Pennsylvania, New Jersey, and Maryland. Other localities are in China, Russia, Namibia, Morocco, Democratic Republic of Congo, Zambia, South Africa, France, Germany, Australia, Mexico, Chile, and Bolivia.

HISTORY, LORE, & GEMSTONE/TECHNOLOGICAL USES: Since about 3500 B.C., powdered azurite has served as a blue pigment and a green glaze for pottery. Along with malachite, azurite was one of the first ores of copper in the early Bronze Age. Medieval physicians prescribed powdered azurite to alleviate ailments of the throat, spleen, and spine, and suggested wearing azurite necklaces to ease pulmonary and bronchial congestion. To certain southwestern Native American cultures, azurite was a sacred stone that connected its wearers with spirit guides. During the Middle Ages and the later Renaissance, powdered azurite was the primary blue pigment used by European artists. According to modern metaphysical practitioners, azurite helps to identify, and dispense with, unwanted past beliefs, thus enabling the mind to achieve higher levels of consciousness and intellectual receptivity. Because of its relative softness and brittleness, azurite's use in jewelry is limited to beads and cabochons for wear in necklaces and pendants. Crystals are sometimes faceted into collectors' gems. Massive and banded azurite is a popular ornamental stone that is fashioned into trinket boxes, ashtrays, figurines, paperweights, and inlay pieces. Until the early 1900s, azurite mined from shallow, oxidized deposits was one of the primary ores of copper.

ABOUT OUR SPECIMENS: Our azurite specimens were collected at the Morenci Mine at Morenci in the Shannon Mountains, Greenlee County, in southeastern Arizona. The Morenci Mine, just north of Morenci, consists of five open pits, three of which are currently being mined. The mine property, owned by Freeport-McMoRan Copper & Gold, Inc., covers 6,000 acres (about 9.4 square miles). Morenci is North America's biggest copper mine and one of the world's largest. During its 139-year history, Morenci has produced an estimated 40 *million* tons of copper. Morenci exploits a copper-porphyry deposit, which is a large, deep, copper-enriched, porphyry intrusion underlying the remnants of shallow deposits of high-grade, oxidized copper minerals. Our specimens were recovered by commercial collectors in 2008 from a remnant of a shallow, oxidized deposit. This remnant deposit was exposed when a section of the west rim of the main pit had been blasted to accommodate a new ore-haulage road. Today, Morenci mines 63,000 tons of ore per day to recover about 400,000 tons of copper each year, along with 500 tons of molybdenum and small amounts of gold and silver. Ore reserves are pegged at 2.2 billion tons grading 0.5 percent copper, enough for 20 more years of mining.
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10 YEARS AGO IN OUR CLUB: Uvarovite, Sarany, Permskaya Oblast', Middle Urals, Ural Region, Russia, the emerald-colored green garnet named in honor of Russian statesman and mineral collector Count Sergei Semeonovich Uvarov (1786-1855). As we wrote then: "This month's mineral is beautiful in (at least) two ways: As an array of brightly colored, emerald-green crystals on a gray matrix, twinkling like stars in the nighttime sky; and, if viewed up close with a magnifying lens, as near-perfect though very small crystals! As you look at your piece in the light, remember that each sparkle you see is caused by the light being reflected off a tiny crystal face!" Fine specimens continue to grace the specimen market today and are usually available. We have some, let us know if you're interested in obtaining a specimen.

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COMPREHENSIVE WRITE-UP

COMPOSITION

For the fourth time now in fifteen years, we are featuring amazing azurite. First time was in September 1996, our seventh month in operation, when we had only a couple of dozen members, to whom we sent outstanding specimens from the Daye Copper Mine (Fengjiashan Mine), Edong Mining District, Daye County, Huangshi Prefecture, Hubei Province, China. We always want to have an exceptional mineral to feature in December, so we featured azurite for the second time in December 2004, sending eager Club members choice pieces of drusy azurite on matrix from the Blue Jay Mine, Leadore District, Lemhi County, Idaho, our first and only featured mineral from the "Gem State." Circumstances provided another opportunity to feature outstanding Chinese azurite, so in December 2008 we sent pieces collected at the Liufengshan copper mine in the Anqing-Guichi mining district near Guichi in Chizhou Prefecture, Anhui Province, China. Though it has been only two years, how could we turn down an opportunity to obtain intensely colored pieces from this historic mine? The best part of it is being able to learn more about the importance of Arizona's Morenci Mine.

The chemical formula $Cu_3(CO_3)_2(OH)_2$ indicates that azurite is a basic copper carbonate (or copper carbonate hydroxide) containing the elements copper (Cu), carbon (C), oxygen (O), and hydrogen (H). Azurite's molecular weight consists of 55.31 percent copper, 37.14 percent oxygen, 6.97 percent carbon, and 0.58 percent hydrogen. Like all molecules, those of azurite consist of positively charged ions called cations and negatively charged ions called anions. Azurite's simple cation consists of three copper (cupric) ions $3Cu^{2+}$ with a collective +6 charge. Its compound anion contains two radicals (groups of atoms of different elements that act as entities in chemical reactions), two carbonate radicals $2(CO_3)^{2-}$ and two hydroxyl radicals $2(OH)^{1-}$. The collective -4 charge of the two carbonate radicals and the collective -2 charge of the two hydroxyl radicals provide a total -6 anionic charge to balance the +6 cationic charge and provide the azurite molecule with electrical stability.

Azurite is a member of the carbonates, a class of nearly 100 minerals in which metallic elements are combined with the carbonate radical $(CO_3)^{2-}$. This carbonate radical, the fundamental structural unit of all carbonates, is a flat, triangular structure consisting of a central carbon ion (C^{4+}) covalently bound by shared electrons to three equidistant oxygen ions ($3O^{2-}$). The +4 charge of the carbon ion and the -6 charge of the three oxygen ions provide the carbonate radical with a collective -2 charge. Carbonate minerals are formed when these negatively charged, triangular carbonate radicals bond ionically to positively charged metal ions.

Carbonate minerals are the salts of carbonic acid (H_2CO_3). Carbonic acid, which consists of hydrogen ions (H^{1+}) and bicarbonate ions [$(HCO_3)^{1-}$], forms in near-surface conditions when atmospheric carbon dioxide (CO_2) or carbonate ions $(CO_3)^{2-}$ from carbonate rocks dissolve in water according to the formula $H_2O + CO_2 = H_2CO_3$. Under proper conditions of temperature, pressure, and chemistry, free metal ions can then bond ionically with bicarbonate ions to form carbonate minerals. Azurite and most other carbonates effervesce in contact with hydrochloric acid (HCl). Effervescence occurs because the acid's reactive chlorine ions (Cl^{1-}) replace the carbonate radicals in carbonate minerals. In azurite, this effervescence reaction is written as $Cu_3(CO_3)_2(OH)_2 + 6HCl = 3CuCl_2 + 4H_2O + 2CO_2\uparrow$? and shows quantitatively how azurite and hydrochloric acid react to form copper chloride ($CuCl_2$), water (H_2O), and gaseous carbon dioxide (CO_2), the latter producing the diagnostic bubbles of effervescence.

The azurite crystal lattice consists of repeating square units composed of two oxygen ions (from the carbonate radicals) and two hydroxyl radicals that are bound ionically to each copper ion and positioned at the sides of the square. These units are linked together in three-dimensional structures by covalent bonding between the oxygen ions of adjacent carbonate radicals. Azurite crystallizes in the monoclinic system, which is defined by three axes of unequal length, two of which are perpendicular to each other. Because bonding strength varies along the three lattice planes, azurite's cleavage is perfect-to-good in one direction, good in a second, and fair in a third. Azurite's brittleness and relatively low hardness of 3.5-4.0 are due to the weak ionic bonding between the copper, carbonate, and hydroxyl radicals.

Although most carbonates are colorless, white, or only lightly colored, azurite is an exception. As an idiochromatic (self-colored) mineral, azurite's characteristic, azure-blue color is caused by the nature of its crystal structure and essential chemical composition, rather than by accessory chromophores (coloring agents). Copper, the essential metal in azurite, is a powerful pigmenting agent for the colors blue and green. Copper ions cause the azurite crystal lattice to absorb all the white-light wavelengths except those within a narrow band of pure blue, which it reflects as a diagnostic azure-blue color.

As a secondary mineral, azurite occurs in the shallow, oxidized portions of copper deposits and forms either from the reaction of carbonic acid with copper-sulfide minerals or from the reaction of copper-bearing solutions with calcite [calcium carbonate, $CaCO_3$]. Azurite is usually associated with malachite [basic copper carbonate, $Cu_2(CO_3)(OH)_2$], cuprite [cuprous oxide, Cu_2O], chalcopyrite [copper iron sulfide, $CuFeS_2$], calcite [calcium carbonate, $CaCO_3$], chalcocite [copper sulfide, Cu_2S], native copper [Cu], chrysocolla [hydrous basic copper aluminum silicate $(Cu,Al)_2H_2Si_2O_5(OH)_4nH_20$], and linarite [basic lead copper sulfate, $PbCu(SO_4)(OH)_2$].

The Dana mineral-classification number 16a.2.1.1 first identifies azurite as a carbonate with hydroxyl or halogen anions (16a). The subclassification (2) defines it by the general formula $(AB)_3(XO_3)_2Z_q$, in which "A" or "B" are divalent metal ions such as copper (Cu^{2+}), "X" is a tetravalent non-metal such as carbon (C^{4+}), "Z" is a hydroxyl or halogen ion, and "q" is a variable quantity. Azurite is then assigned to the azurite group (1) as the first (1) and only member.

Azurite and malachite are both basic copper carbonates that crystallize in the monoclinic system, occur in the same mineralogical environments, and share many chemical and physical properties. Specimens of azurite often contain some malachite, and vice versa. Yet despite their similarities, azurite and malachite also have important differences. As the less oxidized mineral, azurite occupies an earlier stage in the oxidation process than does malachite. Both azurite and malachite crystallize directly from aqueous solutions. Because azurite requires less oxidation energy to form in an aqueous mineralogical environment, it usually precipitates out of solution before malachite. However, when greater amounts of oxidation energy are available, malachite can crystallize before azurite. Because azurite is less oxidized than malachite, it also has less chemical stability. When exposed to water (H_2O), azurite will slowly oxidize into malachite according the formula $2[Cu_3(CO_3)_2(OH)_2] + H_2O \rightarrow$? $3[Cu_2(CO_3)(OH)_2] + CO_2$. In this reaction, two molecules of azurite and one molecule of water combine to yield three molecules of malachite and one molecule of carbon dioxide. The oxidation of azurite into malachite is a very slow, gradual process that is often reflected in color gradations between blue and green. Azurite's chemical instability and tendency to eventually oxidize into malachite explain why malachite is more abundant.

COLLECTING LOCALITIES

Azurite occurs in all oxidized copper deposits. In Arizona, azurite is collected at the Morenci Mine at Morenci in Greenlee County (source of our specimens), the Warren district mines at Bisbee in Cochise County, the Bluebird Mine at Globe in Gila County, and the Verde district mines at Jerome in Yavapai County. Azurite is found in Colorado at the Sherman and Adelaide mines in the Leadville district in Lake County, and the Bandera Mountain mines at Silverton in San Juan County; in California at the Empress and Cerro Gordo mines in the Darwin district in the Argus Range of Inyo County, and the Mohawk Mine in the Clark Mountains of San Bernardino County; in Montana at the Continental Pit at Butte in Silver Bow County; and in Nevada at the Bullfrog Mine at Beatty in Nye County. Other sources are the Kelly and Graphic mines at Magdalena in Socorro County, New Mexico; the Bingham Canyon Mine in the Oquirrh Mountains of Salt Lake County, and the Hidden Treasure Mine in the Ophir district of Tooele County, both in Utah; the Hub and Paymaster mines in the Lava Creek district of Butte County, Idaho; the Eagle-Picher Mine at Cheta in Jackson County, Oklahoma; the Champion Mine at Painesdale, Houghton County, and the Algoman mines at Mass City, Ontonagon County, both in Michigan; the Bellah and Steward mines at Gillham in Sevier County, Arkansas; the French Creek mines at St. Peters in Chester County, Pennsylvania; the Schuyler Mine at North Arlington, Bergen County, New Jersey; and the Hunting Hill, Rockville, and Bardon quarries at Rockville in Montgomery County, Maryland.

Chinese specimens come from the Liu Feng Shan (Liufengshan) copper mine in the Anqing-Guichi mining district near Guichi in Chizhou Prefecture, Anhui Province; the Shilu Mine in Yangchun County, Yangjiang Prefecture, Guangdong Province; the Chengmenshan copper-molybdenum-gold deposit at Jiurui, Jiurui Prefecture, Jiangxi Province; and the Jinman copper mines in Lanping County, Nujiang Autonomous Prefecture, Yunnan Province. Russian specimens are found at the Dalnegorsk Mine at Primorskiy Kray, Magadianskaya Oblast', Far-Eastern Region. African azurite localities include the Tsumeb Mine at Tsumeb, Otjikoto Region, and the Kombat Mine at Kombat, Grootfontein District, Otjozondjupa Region, both in Namibia; the Toussit mines at Toussit in Oujda-Angad Province in Morocco's Oriental Region; the Shangulowé Mine at Kambove, Katanga Province, Democratic Republic of Congo; the Kabwe (Broken Hill) Mine at Kabwe in Zambia's Central Province; and the Wessels Mine at Hotazel in the Kalahari Manganese Fields, North Cape Province, South Africa.

Europe's localities include Chessy-les-Mines at Chessy, Rhône, Rhône-Alpes, France, and the Bad Lauterberg mines in the Harz Mountains of Lower Saxony, Germany. Australian azurite comes from the Aerial and Silent Sisters mines at Wyloo Homestead in Western Australia; the Burra Burra Mine at Burra in the Mt. Lofty Ranges, South Australia; the Broken Hill district at Broken Hill in New South Wales; and the Great Australia Mine in the Cloncurry district of the Mount Isa-Cloncurry region of Queensland. Mexican sources include the Ojuela Mine at Mapimí in Durango; the San Cristóbal and China mines at La Huacana in Michoacán; the San Carlos Mine at Mazapíl in Zacatecas; and the Chantuplán mines near Taxco in Guerrero. Specimens are also collected in Bolivia at the Veta Verde and María Elena mines at Coracora in Pacajes Province, La Paz Department, and at the Llallagua Mine at Llallagua in Bustillos Province in Potosí Department; in Chile at the Manto Cuba Mine at Inca de Oro in Chañaral Province in the Atacama Region; and in Argentina at the Caplitas mines at Andagala in Catamarca.

JEWELRY & DECORATIVE USES

Because of its relative softness (Mohs 3.5-4.0) and brittleness, azurite's use in jewelry is restricted to beads and cabochons for wear as necklaces and pendants. Although azurite takes a high polish, it dulls quickly due to scratching. Crystals are sometimes faceted into collectors' gems, but because large azurite crystals tend to appear black, azurite collector gems are rarely larger than one carat. In its massive and banded forms, azurite is a popular ornamental stone that is fashioned into trinket boxes, ashtrays, figurines, paperweights, and inlay pieces.

With its vivid, azure-blue color, unusual crystal habits, and affordability, azurite is one of the most widely collected minerals. Being found in large quantities in many worldwide localities translates to affordable prices for most azurite, with many opportunities for self-collecting as well! The finest azurite specimens, from well-known or closed localities such as Tsumeb or Bisbee, or with large or unusual crystals, or in combination with malachite or other minerals, can cost thousands of dollars or more.

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HISTORY & LORE

Powdered azurite has served as a blue pigment since at least 3500 B.C. Ancient cultures also used powdered azurite as a green glaze for pottery. Along with malachite, azurite was one of the first ores of copper in the early Bronze Age, and anthropologists believe that the association of native copper and azurite helped early metalworkers to understand the relationship between native metals and metal ores. Medieval physicians prescribed powdered azurite to treat throat, spleen, and spine ailments, and suggested wearing azurite necklaces to ease pulmonary and bronchial congestion. To certain southwestern Native American cultures, azurite was a sacred stone that connected its wearers with spirit guides. During the Middle Ages and the later Renaissance, powdered azurite was the primary blue pigment used by European artists. Finely ground azurite provided a lighter blue color, while coarser azurite particles produced more intense blues. Italian artists referred to azurite pigment as *azurro della magna*, literally meaning "great blue." Azurite-based paints were used in many classic works of art until the mid-1600s, when artists realized that the blue colors of older works were slowly turning green. Centuries later, scientists learned that this discoloration was actually caused by the slow oxidation of azurite into malachite (see "Composition").

By 1800, scientists knew that azurite was a carbonate mineral, although they were unable to chemically distinguish it from malachite. Because smelting azurite and malachite yielded almost the same amount of metallic copper, azurite was initially thought to be a color phase of malachite. The two minerals were chemically differentiated in 1824 by the French mineralogist and geologist François Sulpice Beudant (1787-1850). Working with specimens collected from the oxidized-copper deposit at Chessy-les-Mines at Chessy, Rhône, Rhône-Alpes, France, Beudant demonstrated the compositional difference between the two basic copper carbonates and assigned the name "azurite" to the blue mineral. In 1928, researchers used X-ray diffraction techniques to reveal the subtle differences in the monoclinic structures of each mineral.

Prospectors have long used azurite as an indicator mineral to help locate valuable deposits of copper, lead, zinc, gold, and silver. In the late 1800s, prospectors discovered the great copper deposits of the western United States by investigating the blue stains of azurite—and the green of malachite—in outcrops (see "The Morenci Mine"). Until the early 1900s, azurite was one of the primary ores of copper.

Azurite has appeared on Zimbabwe's 77-cent stamp of 1993, Kazakhstan's 20-tenge stamp of 1997, Switzerland's 30-centime stamp of 1960, Namibia's 10-cent stamp of 1991, Chile's 150-peso stamp of 1996, and the United States' 29-cent stamp of 1992. Modern metaphysical practitioners believe that azurite helps to identify, and dispense with, unwanted past beliefs, thus enabling the mind to achieve higher levels of consciousness and intellectual receptivity. When worn on the body, azurite is thought to ease rheumatic pain and discomfort, a benefit that some traditional medical practitioners attribute to the mineral's copper content.

TECHNOLOGICAL USES

Until 1910, azurite was a major ore of copper; it still occasionally serves as a minor ore. Azurite is also used as a blue pigment in special paints. Coarsely ground azurite retains its characteristic intense blue color, while finely ground azurite produces a lighter shade of blue, similar to the diagnostic color of its streak. When mixed with oil for use in paint, azurite turns slightly green, and when mixed with egg yolk, it becomes green gray. When heated gently, azurite produces a deep blue pigment used in Japanese painting techniques. (If heated too much, it becomes black.) Azurite was the most important blue pigment in European painting throughout the middle ages and the Renaissance, and is still in use today.

THE MORENCI MINE

The Morenci Mine, the source of our azurite specimens, is a legend in American mining. As a source of exceptional specimens of azurite and other minerals, Morenci rightly takes its place among the localities producing "American Mineral Treasures," as highlighted at the 2008 Tucson Gem & Mineral Show and in the accompanying book of the sane name that chronicles America's greatest mineral localities.

Located in southeast Arizona (see "About Our Specimens"), Morenci is now recognized as North America's largest copper mine. During its 139-year history, Morenci has produced an estimated 40 *million* tons of copper--an almost inconceivable number! Morenci's operational history and technological advancement are representative of Arizona's entire copper-mining industry.

As early as 1000 A.D., Native Americans were mining turquoise from blue-green outcrops at what is now Morenci. These same copper-rich outcrops were later known to Spanish explorers in the 1700s, Mexican prospectors in the 1830s, and U.S. Army patrols in the 1850s. But Apache raids and the area's remoteness prevented mining until 1870, when prospectors staked copper claims and found financial backers to establish two copper companies that began mining in 1872. The shallow, oxidized ores consisting of chrysocolla, azurite, and malachite graded nearly 50 percent copper and were some of the richest copper ores ever mined in the world. Although supplies had to be hauled in by mule-drawn wagons, sometimes over hundreds of miles, and Apache raiders routinely disrupted production, mining was still profitable because the extraordinarily rich ores could be directly smelted in simple, charcoal-fired furnaces. During the first ten years of mining from shallow underground workings, ore grades averaged more than 20 percent copper, meaning that every ton of ore contained 400 pounds of metallic copper. Due to the inefficiency of early smelting, however, only about 350 pounds of copper were actually recovered from every ton of ore.

In 1881, the Longfellow Mine, the district's largest, took on a partner—the Phelps Dodge Company, a prosperous, New York-based metal-trading company. After the railroad arrived in 1882 and Phelps Dodge capital had funded expansion, the Longfellow Mine began producing 7,000 tons of copper per year. In 1897, Phelps Dodge renamed the Longfellow property "Morenci" after a Michigan town, and increased annual production to 20,000 tons of copper. By then, the high-grade, oxidized surface ores were nearly mined out. Miners next drove deeper underground workings to exploit the remaining oxidized ores and began mining the sulfides of the porphyry ore body, both of which graded about four percent copper. By 1913, two new mills were employing the newly developed flotation-separation process to concentrate ores prior to smelting, helping to boost annual production to 70,000 tons of copper. By World War I, Morenci had turned exclusively to the deep sulfide ores.

By 1920, Morenci had produced more than one million tons of copper. But now the best sulfide ores that graded about two percent copper were rapidly being depleted. Core-drilling had revealed enormous remaining tonnages of sulfide ores, but these graded only about one percent copper—too "lean" to be mined profitably by costly underground methods. When copper prices plummeted during the Great Depression, Phelps Dodge suspended mining operations and began developing a huge open pit by removing 200 feet of overburden. Production resumed in 1942, just in time to help meet the emergency demand for copper during World War II. Through the 1950s, 1960s, and 1970s, Morenci expanded into a system of five adjacent open pits supported by two new flotation-separation mills and two smelters that produced 400,000 tons of copper per year, along with smaller quantities of by-product gold, silver and molybdenum. Morenci was the site of the "1983 Arizona Copper Strike"—the longest labor strike in

Arizona history. Despite repeated instances of sabotage and violence, Phelps Dodge managed to keep the mine operating with permanent replacement labor. The strike ended with the decertification of several local unions in 1986, a labor defeat that continues to impact national labor-management relations today.

In the mid-1980s, the average ore grade at Morenci declined to only 0.6 percent copper, while mining, milling, and smelting costs continued to increase. Morenci then pioneered the large-scale, hydrometallurgical extraction of copper from low-grade sulfide ores by introducing the SX-EW (solvent extraction-electrowinning) process. In SX-EW, open-pit ore is finely crushed, placed in dumps, and treated with acid to leach out the copper. The copper-bearing, acidic solutions are then captured and treated with organic solutions that extract the copper through an ion-exchange process. Finally, a reverse ion-exchange process recovers the copper from the organic solution. This final, copper-rich, concentrated solution is passed through electrolysis vats where metallic copper is recovered as anodes ready for shipment to refineries. Because it eliminates the need for both costly flotation-separation concentration and smelting, the inexpensive SX-EW process enables lower-grade sulfide ores to be profitably mined. In 2007, Morenci introduced a concentrated-leaching method using medium-temperature and medium-pressure autoclaves to rapidly leach crushed ore. Copper anodes are then produced by direct electrolysis, eliminating the ion-exchange steps of the SX-EW process.

Also in 2007, Freeport-McMoRan Copper & Gold, Inc., a major international producer of copper and gold, acquired the Phelps Dodge Company and the Morenci Mine. Today, Morenci mines 63,000 tons of ore per day and uses both the SX-EW and concentrated-leaching processes to recover about 400,000 tons of copper each year, along with 500 tons of molybdenum and small amounts of gold and silver. The remaining ore body is 4,200 feet long, 2,600 feet wide and 800 feet deep. Reserves are pegged at 2.2 billion tons of ore grading 0.5 percent copper, enough for 20 more years of mining. The main open pit is now 6,620 feet (1.25 miles) long and 3,800 feet wide.

Morenci Mine tours are available. We found a brochure online at http://www.visitgrahamcounty.com/freeportminebrochure/ with information on the tours, and hope to visit Morenci after the Tucson Gem & Mineral show in the near future! Some years ago, we drove down and spent the night at an historic hotel in Bisbee. While there, we toured the mine, looked at some Bisbee turquoise, browsed the unique stores in town, absorbing the historical significance of this amazing mine!

ABOUT OUR SPECIMENS

As noted, our azurite specimens were collected at the Morenci Mine at Morenci in the Shannon Mountains, Greenlee County, Arizona. Morenci is the largest copper mine in North America and one of the largest in the world. The town of Morenci, population 1,800, is located in southeastern Arizona, 110 air miles northeast of Tucson and 18 air miles west of the New Mexico state line. The only nearby towns are Clifton and Plantsite, populations 2,200 and 600 respectively, both a few miles to the south. At an elevation of 4,747 feet, Morenci lies in a broad ecological transition zone that separates the lower deserts from the higher pine forests. The terrain consists of low, rolling hills covered by creosote bush and mesquite, with thin growths of scrub oak and conifers appearing at the higher elevations. The economies of Morenci, Clifton, and Plantsite are dependent, directly or indirectly, upon operations at the Morenci Mine. Located just north of Morenci, the Morenci Mine consists of five open pits, three of which are currently being mined. The mine property, which covers 6,000 acres (about 9.4 square miles), and the company town of Morenci are both owned by Freeport-McMoRan Copper & Gold, Inc. (See "The Morenci Mine" for historical details.)

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The Morenci Mine exploits a massive copper-porphyry deposit. In its geological context, the term "porphyry" refers to igneous rock containing conspicuous crystals (phenocrysts) in a finer-grained groundmass. In its mining context, "copper-porphyry" refers to porphyry-type rock that has been secondarily enriched by copper mineralization. Copper-porphyry deposits are concentrated in southeastern Arizona and adjacent areas of New Mexico and Mexico. These "two-phase" deposits consist of an original, upper oxidized deposit, remnants of which may still exist, and a lower, much larger, enriched porphyry deposit of copper-sulfide minerals. The formation of copper-porphyry deposits began when magma intruded existing country rock. In the Southwest, numerous intrusions were emplaced between 150 million and 50 million years ago. During or shortly after emplacement, copper-rich, hydrothermal solutions circulated upward through the fractured country rock around the periphery of the intrusions. Above these intrusions, in conditions of decreased pressure and temperature, these solutions precipitated copper-sulfide minerals. After erosion eventually exposed this mineralization, reaction with atmospheric oxygen and acidic groundwater (see "Composition") oxidized these sulfides into rich deposits of chrysocolla [hydrous basic copper aluminum silicate, $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$], azurite, and malachite. Over millions of years, groundwater dissolved much of the copper in both the sulfide and oxidized deposits, then percolated downward into the underlying porphyritic intrusions where the copper precipitated out of solution as disseminated copper-sulfide minerals, mainly chalcopyrite [copper iron sulfide, $CuFeS_2$] and chalcocite [copper sulfide, Cu_2S]. Geologists refer to this type of secondary mineralization as "supergene enrichment" (literally "post-formation mineralization") and to the mineralized porphyry rock as a "copper-porphyry" deposit.

In general configuration, Arizona-type copper-porphyry deposits have a deep, massive, copper-enriched, porphyry intrusion underlying the remnants of shallow deposits of high-grade, oxidized copper minerals. The sulfide ores, consisting of disseminated chalcopyrite and chalcocite, offer few specimen-collecting opportunities. Most collectible mineral specimens are found in the upper oxidized zones and include azurite, malachite, chrysocolla, turquoise [hydrous basic copper aluminum phosphate, $CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$], pyrite [iron disulfide, FeS_2], quartz [silicon dioxide, SiO_2], brochantite [basic copper sulfate, $Cu_4(SO_4)(OH)_6$], wulfenite [lead molybdate, $PbMoO_4$], native copper (Cu), and andradite [garnet group, calcium iron silicate, $Ca_3Fe_2(SiO_4)_3$].

Morenci is a classic locality for turquoise and copper-mineral specimens. Anthropologists believe that Native Americans mined the original, shallow, oxidized copper outcrops for turquoise as early as 1000 A.D. Morenci turquoise, which ranges in color from light azure to electric blue, is distinctive for its unusual pyrite matrix that polishes to a bright, silver-like color. Morenci turquoise was widely traded during prehistoric times. Using chemical "fingerprinting" techniques, mineralogists have identified Morenci turquoise at cultural sites as distant as present-day Mexico City. During the 1880s, Morenci miners collected turquoise in quantity, selling to traders as a source of secondary income. As turquoise jewelry gained great popularity in the United States and Europe in the 1890s, Morenci turquoise was recognized as some of the finest in the Southwest. The shallow, oxidized ore at Morenci also yielded superb specimens of azurite and malachite. By 1900, most leading American museums, including the National Museum of Natural History (Smithsonian), New York City's American Museum of Natural History, and Chicago's Field Museum were displaying spectacular specimens of crystalline azurite and botryoidal malachite from the Morenci Mine.

The quantity of turquoise and azurite and malachite specimens from Morenci declined sharply after 1900, when miners began turning their attention to the deep, sulfide ores. But during the 1960s and early 1970s, when rapid expansion of the open pits regularly exposed remnants of the upper oxidized ore bodies, the recovery of turquoise and azurite and malachite specimens reached its peak in both quantity and quality. When mineral collectors, including both employees and non-employees, began to interfere with mining operations, the Morenci Mine instituted a new policy regarding the collection of mineral specimens. Both

Morenci employees and private collectors were henceforth prohibited from collecting specimens anywhere on the company property. Permission to collect specimens that had been exposed by mining operations was granted only to experienced commercial collectors who had obtained company leases for specific sections of the mine. Many of Morenci's specimen-collection policies have since been adopted by other Arizona copper mines. Our specimens were recovered by commercial collectors in 2008 after the main pit's west rim had been widened by blasting to accommodate a new ore-haulage road. These blasting operations exposed remnants of the original oxidized copper deposit that contained our azurite specimens.

As you examine your specimen, first note the granitic matrix rock to which the azurite crystals are attached. This rock consists primarily of quartz and orthoclase [potassium aluminum silicate, $KAlSi_3O_8$], a potash feldspar. Although the rock has undergone extensive weathering and alteration, areas of gray, translucent quartz can be seen on many specimens. The lighter-colored, opaque areas adjacent to the quartz are orthoclase, which has been partially altered to a hard clay. The yellow and brown staining is hematite [iron oxide, Fe_2O_3]. The azurite consists of coatings of small, thin, bladed, azure-blue crystals atop the matrix rock that formed when carbonic acid in groundwater oxidized copper-sulfide minerals. Study the azurite crystals closely with an intense light source and a magnifying glass or loupe. Many individual, bladed azurite crystals are "stacked" in parallel arrangements. Under magnification, certain crystal faces will appear faintly wavy and exhibit parallel striations, characteristics that are common in azurite. Your Morenci azurite specimen represents one of the important, early ores of copper and is a souvenir of North America's largest, oldest, continuously operated copper mine.

As we approach the fifteenth anniversary of our Mineral of the Month Club next month, we cannot help but reflect back on some of the amazing minerals we have featured over the years. Azurite figures prominently in these recollections, and joins fluorite and pyrite as the only minerals we have featured four times (not including different varieties of quartz.) Amazingly, another outstanding find of azurite has been made recently at a copper mine in Australia, in the unusual form of flattened, radiating discs, and who knows--it may be possible to obtain enough of these wonderful pieces and feature azurite a fifth time!

But of course more important than the minerals we have examined are the amazing Club members we have come to know over the years! Some of you have been with us for ten years or more, and we cannot express in words how appreciative we are! California members we may see fairly regularly at shows, while many others we have gotten to know only by the sound of their voice over the telephone, or the expressions they use in their Emails. Some longtime Club members have passed away during the years, and we have felt as if we lost a friend. Others have married, started school, finished school, and accomplished other milestones. So may we close with a huge "THANK YOU!" to all of you for supporting us in our passion, not only for beautiful and exciting minerals, but for studying them as well!

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