May 2012 Mineral of the Month: Azurite

This month we are featuring “suns” and nodules of bright-blue azurite on white kaolin clay. Our write-up explains their unusual origin in the remote Australian outback and discusses some of the other interesting members of the carbonate-mineral group.

OVERVIEW

PHYSICAL PROPERTIES

Figure 1. Azurite "sun" on white kaolin clay.

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, 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: Best field indicators are azure-blue color, light-blue streak, effervescence in hydrochloric acid, and association with malachite. Azurite is softer than the blue minerals lazulite and lazurite. Can be confused with bright-blue linarite, but linarite does not effervesce in hydrochloric acid.
Dana Classification Number: 16a.2.1.1

NAME The word **“**azurite” stems from the Persian *lāzhuward*, meaning “heaven” or “blue,” alluding to the mineral’s blue color. Azurite has also been known as “azure copper ore,” “blue copper ore,” “blue copper,” “blue malachite,” “caeruleum,” “bergblau,” “kupfer lazure,” and “chessylite.” Powdered azurite pigment is called “copper blue,” “mountain blue,” “blue bice,” and “blue verditer.” In European mineralogical literature, azurite appears as *azurit* and *azurita*.

COMPOSITION: Azurite is one of 192 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 the presence of copper and to a lesser extent by the nature of its crystal structure. Copper, the essential metal in azurite, is a powerful pigmenting agent for the colors blue and green. Azurite crystallizes in the monoclinic system, which has three axes of unequal length, two of which are mutually perpendicular. As a secondary mineral, azurite occurs in the shallow, oxidized portions of copper deposits from the reaction of carbonic acid with copper-

sulfide minerals or the reaction of copper-bearing solutions on calcite. Azurite is associated with malachite, cuprite, chalcopyrite, calcite, chalcocite, chrysocolla, and linarite.

COLLECTING LOCALITIES: Azurite is collected in Australia, China, Russia, Namibia, Morocco, Democratic Republic of Congo, Zambia, South Africa, France, Germany, Mexico, Chile, Argentina, and Bolivia. In the United States, azurite is found in Arizona, Colorado, California, Montana, Nevada, New Mexico, Utah, Idaho, Oklahoma, Michigan, Arkansas, Pennsylvania, and New Jersey.

HISTORY, LORE, & GEMSTONE/TECHNOLOGICAL USES: Azurite has been known since antiquity. Powdered azurite has served as a blue paint pigment and green ceramic glaze since about 3500 B.C. Azurite was a primary ore of copper during the early Bronze Age. Medieval physicians prescribed powdered azurite to alleviate ailments of the throat, spleen, and spine, and believed that azurite necklaces could ease pulmonary and bronchial congestion. Some of the Native American cultures of the southwestern United States considered azurite to be a sacred stone that connected its wearers with spirit guides. During the Middle Ages and the Renaissance, powdered azurite was the primary blue pigment used by European artists. Azurite was chemically differentiated from malachite and recognized as a new mineral species in 1824. Modern metaphysical practitioners believe that azurite helps to identify and dispense with unwanted past beliefs and open the mind to higher levels of intellectual receptivity. Although azurite is relatively soft and brittle, its deep, azure-blue color makes it a popular gemstone, mainly as beads and cabochons in bracelets, necklaces, and pendants. Azurite crystals are sometimes faceted into collectors' gems. In massive and banded forms, azurite is an ornamental stone that is fashioned into trinket boxes, ashtrays, figurines, paperweights, and inlay pieces. Until the early 1900s, azurite from shallow, oxidized deposits was a primary ore of copper.

ABOUT OUR SPECIMENS: Our azurite specimens were collected at the Malbunka Copper Mine near Areyonga, MacDonnellshire, Northern Territory, Australia. The Malbunka Copper Mine, located near the geographic center of Australia, is about 90 miles west of Alice Springs, a city of 26,000 that is central Australia's economic, cultural, and transportation hub. The mine, which has never produced copper ore and is mined only for mineral specimens, exploits exposed strata of the heavily weathered, 600-million-year-old Namatjira Formation, a mixed sedimentary formation of sandstone, siltstone, mudstone, shale, and clay. Our azurite specimens formed within layers of kaolin clay, consisting mainly of the mineral kaolinite. Within these clay layers, copper-rich groundwater flowed through horizontal seams, precipitating azurite as crystal clusters in the shape of disk-like "suns" and semi-spherical nodules. Our specimens were collected by an Australian specimen miner who leases the site from the Aboriginal Malbunka Clan and operates it during the cool months of the Australian summer. Our composite specimens consist of azurite suns or nodules on a matrix of near-white kaolin clay. After mining, each specimen is subjected to a carefully controlled water spray that wears away the soft clay to expose the azurite suns and nodules.

10 YEARS AGO IN OUR CLUB: Actinolite, Wrightwood, San Bernardino County, California. This was a good month--Gold-level specimens consisted of lots and lots of long thin actinolite needles with some associated matrix, and were on the larger size of what we typically send. Of course, there was no Platinum-level then, as that idea did not take shape until the end of 2004, when we started getting a few larger pieces each month and offering them to a handful of Club members. The May 2002 newsletter says "when we began in 1996, our goal was to have 400 members. We now have about 260 members, so we are now more than two thirds of the way toward that goal. Thank you! And a special thank you to those of you who quickly renew your membership, making it a lot easier on us." Due to the great interest aroused by the article about us in the December 2012 issue of *Rock & Gem* magazine, we are now close to 600 members, with over 160 Platinum-level members! We are so thankful to each one of our dear members, who each contribute to making our Club a success, and hope you will be with us for many years to come!

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COMPREHENSIVE WRITE-UP

COMPOSITION

This is our 195th month of operation, and marks the fifth time we have sent Club members beautiful pieces of amazing azurite! The intensity of the azure-blue color can have an emotional effect on mineral lovers, which is why we are happy to revisit this marvelous mineral! We first featured azurite in September 1996, sending choice specimens from a then-recent find at the Daye Copper Mine, Hubei Province, China, to the smattering of members we had at that time. We don't see this azurite available at shows now!

Next time we featured azurite was more than eight years later, in December 2004, when we sent pieces from a new find at the Blue Jay Mine, Lemhi County, Idaho. These were a lighter shade of blue than the Chinese pieces we had sent eight years earlier, and we wanted to feature this American locality from the "Gem State." Four years later, we came across another lot of intensely gorgeous Chinese azurite, this time from the Liufengshan Mine, Anqing-Guichi mining district, Chizhou Prefecture, Anhui Province, China, and knew members would love them like we did, so we sent them in December 2008.

Then when choice pieces of drusy azurite on large matrix from the famous Morenci Mine in Arizona became available to us in 2010, we knew we had to feature it again, which we did in February 2011. Every piece we picked out in Gold-level size is gone, and we are working hard to find more! And when these amazing azurite suns and nodules came to our attention, even though we had just featured azurite the year before, we had to do it--they are just too amazing to pass up! And of course you had the opportunity to pass on this azurite, as you do every month on every mineral, and still receive and read this write-up on the unique way these specimens formed. Will we feature azurite again in the near future? We have no plans to do so, but if another amazing lot became available, we would certainly consider it!

As indicated by its chemical formula $Cu_3(CO_3)_2(OH)_2$, azurite is a basic copper carbonate (or copper carbonate hydroxide) containing the elements copper (Cu), carbon (C), oxygen (O), and hydrogen (H). Its molecular weight is made up 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 pairs of different radicals (groups of atoms of different elements that act as entities in chemical reactions). These include 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 one of 192 members of the carbonate class of minerals, in which metallic elements combine with the carbonate radical $(CO_3)^{2-}$. The carbonate radical is the fundamental structural unit of all carbonates. It has a flat, triangular shape in which a central carbon ion (C^{4+}) is covalently bound by shared electrons to three equidistant oxygen ions ($3O^{2-}$). Within this radical, the +4 charge of the carbon ion C^{4+} and the collective -6 charge of the three oxygen ions $3O^{2-}$ provide the carbonate radical with a total -2 charge. Carbonate minerals form when these negatively charged carbonate radicals bond ionically to positively charged metal ions.

Azurite's 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 squares. These units link together in three-dimensional structures through covalent bonding between the oxygen ions of adjacent carbonate radicals. Azurite crystallizes in the monoclinic

system, which has three axes of unequal length, two of which are mutually perpendicular. Because bonding strength varies considerably along its three lattice planes, azurite's cleavage is perfect to good in one direction, good in a second, and fair in a third. Weak ionic bonding between the copper, carbonate, and hydroxyl radicals explains azurite's brittleness and relatively low hardness of 3.5-4.0. Azurite's high density (specific gravity 3.7-3.8) is due to the essential, relatively heavy metal copper (atomic weight 58.93), which accounts for more than half of its molecular weight.

Most carbonates are colorless, white, or only lightly colored, but azurite is an obvious exception. As an idiochromatic (self-colored) mineral, azurite's characteristic azure-blue color is caused by the essential element copper and to a lesser extent by the nature of its crystal lattice. Copper is a powerful chromophoric (color-causing) agent for the colors blue and green. Divalent copper ions (cupric, Cu^{2+}) cause the azurite crystal lattice to absorb all white-light wavelengths except those of blue, which are reflected as azurite's diagnostic azure-blue color.

A diagnostic feature of azurite (and most carbonates) is the effervescence—a bubbling effect due to the release of gases—that occurs in contact with hydrochloric acid (HCl). This effervescence is produced when the acid's highly reactive chlorine ions (Cl^{1-}) replace the carbonate radicals in carbonate minerals. With azurite, this reaction proceeds according to the formula $Cu_3(CO_3)_2(OH)_2 + 6HCl = 3CuCl_2 + 4H_2O + 2CO_2\uparrow$ 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 diagnostic bubbles of effervescence are caused by the rapid release of carbon-dioxide gas.

Azurite and malachite are both basic copper carbonates, crystallize in the monoclinic system, occur in the same mineralogical environments, and have similar chemical and physical properties. Azurite specimens often contain some malachite, and vice versa. But azurite and malachite also have important differences. As the less oxidized mineral, azurite occupies an earlier stage in the oxidation process. Both minerals crystallize directly from aqueous solutions, but because azurite requires less oxidation energy to form from aqueous solutions, it usually precipitates before malachite. But when higher levels of oxidation energy are available, malachite will crystallize before azurite. Because azurite is less oxidized than malachite, it is less chemically stable. When exposed to water, azurite slowly oxidizes 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 react to yield three molecules of malachite and one molecule of carbon dioxide. The oxidation of azurite into malachite is a very slow process that often produces color gradations between blue and green. Because azurite is unstable and oxidizes into malachite, the latter is the more abundant of the two minerals.

Azurite is a secondary mineral that occurs in shallow, oxidized portions of copper deposits and forms either from the reaction of carbonic acid (H_2CO_3) with copper-sulfide minerals or the reaction of copper-bearing solutions with calcite [calcium carbonate, $CaCO_3$]. Azurite is frequently associated with malachite, 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 $(Cu,Al)_2H_2Si_2O_5(OH)_4nH_2O$], and linarite [basic lead copper sulfate, $PbCu(SO_4)(OH)_2$]. Azurite also forms as pseudomorphs after malachite, as atmospheric conditions cause the alteration of malachite to azurite–and sometimes back to malachite!

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.

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COLLECTING LOCALITIES

Our azurite specimens were collected at the Malbunka Copper Mine near Areyonga, MacDonnellshire, Northern Territory, Australia. Other Australian azurite localities are the Aerial and Silent Sisters mines at Wyloo Homestead, Western Australia; the Burra Burra Mine at Burra in the Mt. Lofty Ranges, South Australia; the Broken Hill district at Broken Hill, New South Wales; and the Great Australia Mine in the Cloncurry district, Mount Isa-Cloncurry region, Queensland.

Chinese specimens come from the Liufengshan copper mine in the Anqing-Guichi mining district near Guichi, 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 mine in Lanping County, Nujiang Autonomous Prefecture, Yunnan Province. Russian specimens are found at the Dalnegorsk Mine at Primorskiy Kray, Magadianskaya Oblast', Far-Eastern Region. Among Africa's azurite localities are 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, Central Province, Zambia; and the Wessels Mine at Hotazel in the Kalahari Manganese Fields, North Cape Province, South Africa.

In Europe, azurite occurs at Chessy-les-Mines at Chessy, Rhône, Rhône-Alpes, France, and the Bad Lauterberg mines in the Harz Mountains of Lower Saxony, Germany. Mexican sources include the Ojuela Mine at Mapimí, Durango; the San Cristóbal Mine at La Huacana, Michoacán; the San Carlos Mine at Mazapíl, Zacatecas; and the Chantuplán mines near Taxco, Guerrero. Other localities are in Bolivia at the Veta Verde and María Elena mines near Coracora in Pacajes Province, La Paz Department, and the Llallagua Mine near Llallagua in Bustillos Province, Potosí Department; in Chile at the Manto Cuba Mine at Inca de Oro, Atacama Region; and in Argentina at the Caplitas mines at Andagala, Catamarca.

Azurite localities in the United States include the Warren district near Bisbee in Cochise County; the Bluebird Mine at Globe in Gila County; the Verde district mines at Jerome in Yavapai County; and the Morenci Mine at Morenci in Greenlee County, all in Arizona. Among Colorado's localities are the Sherman and Adelaide mines in the Leadville district in Lake County, and the Bandera Mountain mines at Silverton in San Juan County. California's localities include 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 Bernadino County. Other sources are the Continental Pit at Butte, Silver Bow County, Montana; the Bullfrog Mine at Beatty, Nye County, Nevada; the Kelly and Graphic mines at Magdalena, Socorro County, New Mexico; the Bingham Canyon Mine in the Oquirrh Mountains in Salt Lake County, and the Hidden Treasure Mine in the Ophir district of Tooele County, both in Utah; the Blue Jay mine in Lemhi County, and the Hub and Paymaster mines in the Lava Creek district, Butte County, all in Idaho; the Eagle-Picher Mine at Cheta, 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, Sevier County, Arkansas; and the French Creek mines at St. Peters, Chester County, Pennsylvania.

JEWELRY & DECORATIVE USES

Despite its brittleness and relative softness (Mohs 3.5-4.0), azurite's deep-blue color makes it a prized gemstone for use as beads and cabochons in necklaces, bracelets, and pendants. Although azurite takes an excellent polish, it dulls quickly with scratching. Crystals are sometimes faceted into collectors' gems, but because large azurite crystals are rare and can appear black and opaque, collectors' gems are rarely

more than two carats in weight. In massive and banded forms, azurite is a popular ornamental stone that is fashioned into trinket boxes, ashtrays, figurines, paperweights, and inlay pieces. Given their vivid, azure-blue color, unusual crystal habits, and affordability, azurite specimens are widely collected. Specimens can range from a few dollars for small specimens from prolific sources to many thousands of dollars for choice specimens from famous localities such as Tsumeb, Namibia, and Bisbee, Arizona.

HISTORY & LORE

Because of its unusual, bright-blue color and occurrence in shallow, accessible copper deposits, azurite has attracted attention since antiquity. By 3500 B.C., powdered azurite was already widely used as a blue pigment for paints and as a green glaze for ceramics. Azurite and malachite were the first ores of copper during the early Bronze Age, and anthropologists believe that the association of native copper and bright-blue azurite helped early metalworkers understand the relationship between metals and metal ores. During medieval times, physicians prescribed the ingestion of powdered azurite to treat throat, spleen, and spine ailments, and believed that azurite necklaces eased pulmonary and bronchial congestion. Some Native American cultures of the American Southwest considered azurite a sacred stone that connected its wearers with spirit guides. During the Middle Ages and later Renaissance, powdered azurite was the primary blue pigment used by European artists. Fine azurite particles produced a light-blue color, while coarser particles created darker blues. Italian Renaissance artists referred to azurite pigment as *azurro della magna*, literally “great blue.” By the mid-1600s, artists noticed that the blue paints in older works were slowly turning green. Centuries later, scientists determined that this discoloration was caused by the slow oxidation of blue azurite into green malachite.

Although scientists realized that azurite was a carbonate mineral in the early 1800s, they were unable to chemically distinguish it from malachite. Because smelting azurite and malachite yielded almost the same amount of metallic copper, they assumed azurite to be a color variety of malachite. French mineralogist and geologist François Sulpice Beudant (1787-1850) chemically differentiated these two minerals in 1824. Working with specimens collected from the oxidized-copper deposit at Chessy-les-Mines at Chessy, Rhône, France, Beudant demonstrated the compositional differences 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 azurite and malachite.

As an indicator mineral, azurite has long helped prospectors to identify valuable deposits of copper, lead, zinc, gold, and silver. In the late 1800s, prospectors discovered the great copper deposits of the western U.S. by investigating the blue stains of azurite (and the green of malachite) in outcrops. Until miners turned their attention to deep copper-sulfide ores in the early 1900s, azurite was a primary ore 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 intellectual receptivity. Wearing azurite is thought to ease rheumatic pain and discomfort, a benefit that some practitioners attribute to the mineral’s copper content.

TECHNOLOGICAL USES

Until the early 1900s, azurite was a major ore of copper; it still occasionally serves as a minor ore. Special paints still employ powdered azurite as a traditional blue pigment. Such pigments are used today to honor human traditions not just in oil painting, but in dyeing various kinds of clothing.

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THE CARBONATE MINERALS

Azurite is a member of a relatively small, but interesting class of minerals—the carbonates. Most of the 192 carbonate minerals are uncommon or rare. Two, however, are abundant and of great industrial importance, while several others are former ores of copper. A number of carbonates are gemstones and/or popular collectible minerals. Many exhibit a distinctive, rhombohedral crystal habit and all have unusual methods of formation.

As explained in "Composition," the fundamental structural unit of carbonate minerals is the carbonate radical $(CO_3)^{2-}$, a flat, triangular structure consisting of a central carbon ion (C^{4+}) covalently bound to three equidistant oxygen ions ($3O^{2-}$). The three-fold symmetry of this triangle is reflected in the three-fold symmetry of many carbonate minerals. Most simple carbonates (those having a single cation and anion) such as calcite crystallize in the hexagonal system, the external shape of which is a multiple of three-fold symmetry. Simple carbonates usually crystallize in the trigonal (or rhombohedral) subsystem, which has three axes of equal length with angles between them of other than 90 degrees. The basic form of this subsystem is the rhombohedron, a six-sided polygon with parallelogram sides. In chemically complex carbonate minerals or in simple carbonates that have metal cations with unusually large radii, the basic trigonal lattice structure becomes distorted, which explains why complex carbonates and those with cations with large radii crystallize in the orthorhombic or monocline systems.

Carbonate minerals form in several ways, most commonly in shallow environments where carbonic acid (H_2CO_3) reacts with various metal salts. 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. An example is the reaction of carbonic acid with periclase [magnesium oxide, MgO] to form water, carbon dioxide, and magnesite [magnesium carbonate, $MgCO_3$] according to the formula $2H_2CO_3 + MgO = 2H_2O + CO_2 + MgCO_3$.

Carbonates also occur in metamorphic rocks, chemical-sedimentary environments, hydrothermal veins, and carbonatites. The formation of carbonatites—igneous rocks in which calcite and dolomite [calcium magnesium carbonate, $CaMgCO_3$] are essential minerals—is the least understood. Most geologists believe that carbonatites have a deep-seated magmatic origin, but they remain uncertain about the source of the carbonates. The prevailing theory is that carbon and carbonate minerals were subducted from the Earth's surface along the edges of colliding tectonic plates and drawn deep into the mantle to be melted into magma. Hundreds of millions of years later, igneous intrusions brought the magma with its content of previously subducted carbon and carbonate minerals back to the surface as essential constituents of carbonatite deposits.

The Dana mineral-classification system divides the 192 carbonate minerals into five sub-classes, as described here:

***Acid carbonates** have at least one "free" hydrogen ion that is not part of a radical or an attached water molecule. The 14 members acid of the carbonates are represented by nahcolite or soda ash [hydrous sodium acid carbonate, $Na_3H(CO_3)\cdot 2H_2O$].*

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Anhydrous carbonates *contain no attached water molecules; among the 49 members are such familiar minerals as calcite, rhodochrosite [manganese carbonate, $MnCO_3$], and siderite [iron (ferrous) carbonate, $FeCO_3$].*

Hydrated carbonates *contain attached molecules of water. Among the 39 members are such minerals as ikaite [hydrated calcium carbonate, $CaCO_3 \cdot 6H_2O$].*

Carbonates with hydroxyl or halogen ions *include 71 members and are represented by azurite.*

Compound carbonates *have compound anions that contain carbonate radicals as well as borate $(BO_3)^{2-}$ or sulfate $(SO_4)^{2-}$ radicals. The 19 members include such minerals as leadhillite [basic lead sulfate carbonate, $Pb_4(SO_4)(CO_3)_2(OH)_2$].*

Calcite is the most abundant carbonate mineral. In the form of limestone, calcite is of great industrial importance. Limestone, a sedimentary rock consisting of at least 50 percent calcite, is quarried worldwide by the millions of tons as dimension stone for building purposes and as a source of calcium for conversion to calcium silicates for the manufacture of cement. The second most abundant carbonate mineral is dolomite [calcium magnesium carbonate, $CaMgCO_3$]. Dolomite rock, which consists of at least 50 percent dolomite, has uses similar to those of limestone. Marble, a sculpting medium and dimension stone, is metamorphosed or recrystallized limestone that contains as much as 90 percent calcite. Another valuable carbonate mineral is nahcolite or soda ash [hydrous sodium acid carbonate, $Na_3H(CO_3) \cdot 2H_2O$], large quantities of which are used in the manufacture of window glass, glass bottles, toothpaste, processed foods, laundry detergents, and baking soda. Magnesite [magnesium carbonate, $MgCO_3$] is mined as a source of both magnesia [synthetic magnesium oxide, MgO] and magnesium metal.

Along with oxides, phosphates, and sulfates, carbonates occur in the shallow, oxidized zones of metal deposits, which made the readily accessible to miners. Azurite and malachite were formerly important ores of copper. Smithsonite [zinc carbonate, $ZnCO_3$] and cerussite [lead carbonate, $PbCO_3$] were also formerly important ores, respectively, of zinc and lead.

Some carbonate minerals are very popular among mineral collectors. Calcite often forms large, eye-catching crystals in a variety of habits. Blue azurite, green malachite, and smithsonite in several lovely shades are also widely collected as specimens. The most valuable of the collectible carbonate minerals is rhodochrosite [manganese carbonate, $MnCO_3$], which occurs as transparent, blood-red, rhombohedral crystals and also in a pink, banded, massive form. The most familiar carbonate-mineral gemstones are azurite, malachite, and rhodochrosite. The most unusual carbonate-mineral gemstone is aragonite [calcium carbonate, $CaCO_3$], the orthorhombic polymorph of calcite. Aragonite is the main mineral in nacre or "mother-of-pearl," the beautiful, multicolored, iridescent coating on the inside of certain mollusk shells that is widely used in jewelry.

ABOUT OUR SPECIMENS

Our azurite specimens were collected at the Malbunka Copper Mine near Areyonga, MacDonnellshire, Northern Territory, Australia. The Northern Territory covers 520,902 square miles in north-central Australia. Nearly the size of the state of Alaska, the Northern Territory has only 230,000 residents and is one of the least populated non-polar regions in the world. The Malbunka Copper Mine, which is near the

geographic center of the Australian continent, is 90 miles west of Alice Springs, an isolated city of 26,000 that is the economic, cultural, and transportation hub of central Australia. The regional elevation is about 1,700 feet; the climate is arid, with less than 11 inches of annual precipitation. In January (the Australian summer), the average high temperature is nearly 100˚ F. But the average July high temperature of 68˚ F. makes Alice Springs a popular winter-vacation area and the jumping-off point for treks into the vast outback.

From Alice Springs, the Malbunka Copper Mine is reached by a 60-mile-long, sealed (paved), one-lane road that leads west to the town of Hermansburg, population 460. An unpaved track then continues west for another 30 miles to the mine site, which is 12 miles east of Areyonga, a bush settlement with 150 residents, most of whom are Aboriginals. Areyonga, formerly Utju, appears on some maps as “Areyonga School” and “Areyonga Mission.” The map coordinates of the Malbunka Copper Mine are 132˚ 25’ 12” west longitude and 24˚ 07’ 32” south latitude. The mine is hidden in the low, rugged hills of the Gardiner Range, a geological remnant of a once-higher mountain system that was uplifted more than a billion years ago. The Gardiner Range is covered only by sparse desert vegetation.

The Malbunka Copper Mine is a minor deposit that is formally classified as a “non-economic copper occurrence” that is mined only for mineral specimens. Aboriginal prospector Albert Namatjira discovered the deposit in the late 1940s, when he investigated the green-blue surface staining of oxidized copper minerals. Originally known as “Namatjira’s Copper Prospect” and the “Areyonga Copper Deposit,” this deposit was first described in Australian geological reports in 1953. But its remoteness and small size, together with low grades and the erratic nature of its copper mineralization, precluded its development as a commercial copper mine.

The Malbunka copper deposit is part of the Namatjira Formation, a mixed sedimentary formation that was laid down some 600 million years ago during the Cambrian Period of the late Precambrian Era. This weathered, stratigraphically complex formation consists of mixed layers of brown sandstone; gray oolitic siltstone; buff-to-cream-colored, carbonate-rich mudstone and shale; and white kaolin clay consisting mainly of the mineral kaolinite [basic aluminum silicate, $Al_2Si_2O_5(OH)_4$]. Although the Namatjira Formation has never been closely studied, geologists believe that copper was emplaced at depth as sulfide minerals. As erosion reduced the surface, these copper sulfides eventually became exposed to the oxidizing effects of atmospheric oxygen and acidic groundwater. Groundwater eventually dissolved these copper sulfides, transporting and redepositing the copper in the form of the colorful, oxidized copper minerals azurite, malachite, atacamite [basic copper chloride, $Cu_2Cl(OH)_3$], chrysocolla [hydrous basic copper aluminum silicate $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_20$], and cuprite [cuprous oxide, Cu_2O].

The only remaining copper-sulfide mineral in the Namatjira Formation is chalcocite [copper sulfide, Cu_2S]. Most of the oxidized copper minerals are present in disseminated particles. The azurite, however, formed in a stratigraphically controlled deposition sequence within layers of kaolin clay. Kaolin clay consists mainly of kaolinite, a two-layer phyllosilicate formed by the weathering of feldspar minerals that usually occurs as a light-colored clay that is a valuable raw material for the manufacture of china and firebrick. Kaolin clay is largely impervious to water. Because water is unable to penetrate these clay layers, it flows horizontally atop or beneath the layers or through horizontal seams within the layers. These impermeable kaolin-clay layers are the key to understanding how our specimens of azurite formed as disk-like suns and semi-spherical nodules. When acidic, copper-rich groundwater circulated through the Namatjira Formation, it was unable to move vertically through the clay layers, and instead migrated horizontally through seams within the layers where conditions of temperature and chemistry precipitated the copper as azurite. But because space within the clay seams was limited, the azurite crystals developed in the shape of flat, disk-like suns or semi-spherical nodules.

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Figure 2. Traditional mine owners with collector Dehne McLaughlin.

When these azurite suns and nodules were first collected in 1982, they attracted considerable attention on international specimen markets and were snapped up by collectors. In 2005, Australian miner and mineral dealer Dehne McLaughlin decided to reopen the site. But before he could obtain the necessary lease for specimen mining, a problem with the site's name had to be resolved. Under Australian Aboriginal law, sites within an Aboriginal clan's "country" can only be named for members of that particular clan. But the copper site, which was on the traditional land of Malbunka Clan, had been named for prospector Albert Namatjira, who was not a clan member. Attorneys for the Malbunka Clan petitioned the government of the Northern Territory to change the name before the site could be leased again. In late 2005, the government, concluding that the original names "Namatjira's Copper Prospect" and "Areyonga Copper Deposit" were indeed illegal, formally renamed the site "Malbunka Copper Mine."

The Malbunka Copper Mine is now leased and operated by Dehne McLaughlin under the terms of the Northern Territory Aboriginal Land Rights Act of 1976. He pays annual rental and royalty fees to the Malbunka Clan and an annual administration fee to the Northern Territory Central Land Council. With wife Maureen, he operates the mine during the cool months of the Australian summer. At this underground operation, a shallow decline leads to short horizontal drifts along the kaolin-clay layer. The soft clay is removed manually to prevent damage to the azurite suns and nodules, which are removed intact with their clay matrix to maximize visual appeal and value. When recovered, the azurite suns and nodules are partially covered by the clay. Each specimen is then exposed to a carefully controlled water spray that wears away the soft clay to expose the suns and nodules. This is performed as quickly as possible, because prolonged contact with water will soften the clay and threaten the integrity of the specimens.

As you examine your specimen, note first the diagnostic, deep-blue color and bladed or tabular shape of the azurite crystals within the sun or nodule. The shape of the sun or nodule (disk-like or semi-spherical) indicates the shape of the original void within the clay-layer seams in which the azurite crystallized. The light-colored, fine-grained matrix is high-quality kaolin clay consisting of about 90 percent kaolinite and serves as a wonderful background. Even when dry, kaolin clay is soft and is easily indented with a fingernail. We hope you enjoy the fifth installment of this gorgeous mineral–will we feature it again?

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