

Mineral of the Month Club July 2017

CHRYSOCOLLA

This month we are featuring chrysocolla, an oxidized, blue-green copper mineral from Chile. Our write-up explains chrysocolla's mineralogy and gemology, and discusses the mining history and minerals of Chile.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $(\text{Cu,Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$ Basic Hydrous Copper Aluminum Acid Silicate (actual composition varies)

Class: Silicates

Subclass: Phyllosilicates

Group: Chrysocolla

Crystal System: Orthorhombic

Crystal Habits: Often botryoidal; also occurs in drusy, massive, stalactitic, stalagmitic, crusty, and earthy forms. Crystals, which are rare, are acicular or fibrous.

Chrysocolla usually occurs as microcrystalline or amorphous masses.

Color: Blue, greenish-blue, bluish-green, and green; impurities occasionally create bluish-black and brownish colors.

Luster: Vitreous to greasy, waxy, earthy, and dull.

Transparency: Translucent to opaque

Streak: White to pale shades of blue and green

Cleavage: None

Fracture: Uneven to subconchoidal; brittle.

Hardness: 2.5-3.5

Specific Gravity: 1.9-2.4

Luminescence: None

Refractive Index: 1.575-1.636

Distinctive Features and Tests: Best field-identification marks are blue, greenish-blue, bluish-green, and green colors; lack of well-developed crystals; low density; softness; and occurrence in oxidized, copper-rich environments in association with other blue-green, oxidized copper minerals. Can be confused with turquoise [basic hydrous copper aluminum phosphate, $\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$] and bluish-green smithsonite [zinc carbonate, ZnCO_3].

Dana Classification Number: 74.3.2.1

NAME: The name "chrysocolla," pronounced kriss-uh-KOLL-uh, stems from the Greek words *chrysos*, meaning "gold," and *kolla*, or "glue," alluding to a similar material used in ancient Greece as a gold-soldering flux. Chrysocolla has also been known as "chrysocollite,"

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“chrysocole,” “chalstaktite,” “cornuite,” “demidovite,” “dillenbergite,” “liparite,” “copper pitchblende,” “somervillite,” and “lianca.” “Aluminian chrysocolla” is an aluminum-rich variety, “cyanochalcite” is a copper-rich variety, and “aluminian-ferrian chrysocolla” is rich in iron and aluminum. “Gem silica,” a valuable gemstone, is a silicified form of chrysocolla. “Eilat stone,” or “King Solomon’s stone,” an intergrowth of chrysocolla, turquoise, azurite, and malachite, is found only in Israel. In European literature, chrysocolla appears as *chrysocolle*, *chrysocola*, and *Chrysokoll*.

COMPOSITION & STRUCTURE: The molecular weight of chrysocolla with the ideal chemical formula $(\text{Cu,Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$ is made up of 33.86 percent copper, 2.05 percent aluminum, 1.93 percent hydrogen, 17.10 percent silicon, and 45.06 percent oxygen. The composition of individual specimens varies considerably. Chrysocolla is a member of the silicates, a large group of minerals in which one or more metals or semimetals combine with silicon and oxygen. Despite its poorly defined crystal structure, chrysocolla is subclassified as a sheet silicate or phyllosilicate. As a secondary copper mineral, chrysocolla forms in the oxidized or altered portions of copper-rich deposits, usually in alkaline chemical environments and in association with azurite [basic copper carbonate, $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$]; malachite [basic copper carbonate, $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$]; cuprite [copper oxide, Cu_2O]; limonite (a variable mixture of iron oxides and hydroxides); and quartz [silicon dioxide, SiO_2]. Chrysocolla usually forms crusts, drusy coatings, and fracture fillings, and also occurs as pseudomorphs. Chrysocolla is an idiochromatic or “self-colored” mineral in which colors are caused by essential elements and/or the light-absorption properties of the crystal lattice. Chrysocolla’s diagnostic blue, greenish-blue, bluish-green, and green colors are due to the essential element copper, a powerful chromophore (color-causing agent) for the colors blue and green. Although chrysocolla is believed to crystallize in the orthorhombic system, which is characterized by three mutually perpendicular axes of different lengths, mineralogists question its validity as a mineral species because of its variable chemical composition and poorly defined crystal structure. In a 2005 chemical and structural study of chrysocolla, researchers concluded that it is not compositionally homogenous, but actually consists of several oxidized copper minerals, primarily spertiniite [copper hydroxide, $\text{Cu}(\text{OH})_2$] and other related species that are intergrown with microcrystalline quartz and various amorphous-silica materials.

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

HISTORY, USES & LORE: Although used since antiquity as a soldering flux and minor gemstone, chrysocolla has long been confused with azurite, malachite, turquoise and other oxidized copper minerals. It was recognized as a distinct mineral species in 1808. Pure chrysocolla is a soft, fragile material with a bright, intense, sky-blue color that only rarely occurs in thicknesses sufficient for gemstone use. Most chrysocolla used in jewelry consists of

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chalcedony (microcrystalline quartz) or opal that is heavily included with microscopic particles of chrysocolla. Known as “gem silica,” this material has a bright, blue-green color and hardness sufficient to take a fine polish and withstand use in jewelry. Nicely colored, gem-quality, rough chrysocolla can cost as much as \$100 per ounce. Various forms of chrysocolla are widely misrepresented as turquoise. Also, gray or white chalcedony is often dyed blue and sold as gem silica. Because it has been confused with other similarly colored, oxidized copper minerals, chrysocolla has no lore or ancient medicinal uses. Modern metaphysical practitioners believe that chrysocolla is a stone of communication, calmness, and peace that aids in verbal and telepathic expression, facilitates the emergence of truth and wisdom, discharges negative energies, and enhances feminine energies.

ABOUT OUR SPECIMENS: Our specimens of chrysocolla were collected in the Inca de Oro district near Inca de Oro, Chañaral Province, Atacama Region, Chile. The Atacama Region, one of Chile’s 15 administrative units that are comparable to American states, occupies the southern part of the Atacama Desert, the world’s driest non-polar desert. The capital of Atacama, Copiapó, has 200,000 residents and is a regional trading center and a hub of mining activity. Inca de Oro is located 50 miles north of Copiapó at an elevation of 4,800 feet. Inca de Oro, population 1,000, is an isolated town on the floor of the Llano de Varas, a barren, arid valley floor that receives less than one inch of rainfall per year and is nearly devoid of vegetation. The mineralization of the Atacama region is linked to the Andean Orogeny (mountain-building episode) that created the Andes Mountains some 60 million years ago. Associated mineral-rich, hydrothermal solutions surged through fractured dioritic and granitic rock to precipitate various metallic minerals in erratic vein systems. In the Atacama Region, fractures were filled primarily with chalcopyrite [copper iron sulfide, CuFeS_2], bornite [copper iron sulfide, Cu_5FeS_4], and chalcocite [copper sulfide, Cu_2S], along with significant amounts of gold [element, Au] and molybdenite [molybdenum disulfide, MoS_2]. Erosion subsequently reduced the surface to expose the upper sections of these vein systems, enabling atmospheric oxygen and groundwater to alter the sulfides into such oxidized copper minerals as chrysocolla, cuprite, azurite, and malachite.

COMPREHENSIVE WRITE-UP

COMPOSITION & STRUCTURE

The International Mineralogical Association, the global association of mineralogists that approves the naming and nomenclature of minerals, continues to recognize chrysocolla as a mineral largely because of historical tradition. But because of chrysocolla’s poorly defined crystal structure and variable chemical composition, some mineralogists now suggest that it should correctly be reclassified as a mineraloid (a mineral-like material that does not meet the full qualifications of a mineral); others consider it to be a mixture of several mineral species. In this write-up, we consider chrysocolla a valid species, use its ideal chemical formula, and describe its currently accepted orthorhombic crystal structure.

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Chrysocolla's ideal chemical formula $(\text{Cu,Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$ shows that it consists of the elements copper (Cu), aluminum (Al), hydrogen (H), silicon (Si), and oxygen (O). This ideal formula represents a hypothetical chemical model; the actual chemical composition of chrysocolla varies widely. Using the ideal formula, chrysocolla's molecular weight is made up of 33.86 percent copper, 2.05 percent aluminum, 1.93 percent hydrogen, 17.10 percent silicon, and 45.06 percent oxygen.

Like all molecules, those of chrysocolla are made up of an electrically balanced mix of positively charged cations and negatively charged anions. Both cations and anions can be radicals, which are groups of different ions that behave as entities in chemical reactions. The compound cation in the chrysocolla molecule consists of two copper-aluminum radicals $2(\text{Cu,Al})^{2+}$ with a collective +4 charge. In this radical, the comma indicates proportionally variable amounts of copper and aluminum. The chrysocolla cation also contains two hydrogen ions 2H^{1+} with a combined +2 charge. Thus, the total cationic charge is +6. Chrysocolla's anion consists of the silica radical $(\text{Si}_2\text{O}_5)^{2-}$ and four hydroxyl ions $4(\text{OH})^{1-}$, which have a combined -6 charge. The +6 cationic charge balances the -6 anionic charge to provide the chrysocolla molecule with electrical stability.

The " $\cdot n\text{H}_2\text{O}$ " in chrysocolla's chemical formula indicates that it is a hydrous (or hydrated) mineral with a variable number of water molecules (H_2O), called "water of hydration," attached to each parent molecule. The "n" denotes a variable number of attached water molecules which are electrically neutral and do not affect the electrical balance of the parent molecule. Water molecules are configured with two hydrogen ions 2H^{1+} grouped closely together on one side of a large oxygen ion O^{2-} . These grouped hydrogen ions retain a small positive charge, while the opposite side of the molecule, dominated by the large oxygen ion, retains a small negative charge. Because of this polarity, water molecules behave as tiny dipole magnets that can attach themselves to other molecules by a weak attraction called "hydrogen bonding."

Chrysocolla's chemical formula is sometimes stated as $(\text{Cu}_{2-x},\text{Al}_x)\text{H}_{2-x}\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$, in which "x" denotes cationic and anionic variables. In this formula, the relative proportions of copper and aluminum vary so significantly that aluminum may not even be present. The resulting shift in the electrical charge in the copper-aluminum radical $(\text{Cu}_{2-x},\text{Al}_x)^{2+}$ is balanced by a quantitative change in the hydrogen ions $(\text{H}_{2-x})^{2+}$. These isolated or "free" hydrogen ions are indicated by the term "acid" in chrysocolla's chemical name—basic hydrous copper aluminum acid silicate.

Chrysocolla is a member of the silicates, a large group of minerals in which one or more metals or semimetals combine with silicon and oxygen. The basic silicate structural unit is the silica tetrahedron $(\text{SiO}_4)^{4-}$, which is a silicon ion surrounded by four equally spaced oxygen ions positioned at the four corners of a tetrahedron (a four-faced polyhedron). In the silicates, silica anions and metal or semimetal cations join together in repeating chains to form seven types of structures: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates

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(sorosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); framework silicates (tectosilicates); and sheet silicates (phyllosilicates).

Despite uncertainties about its structure, chrysocolla is currently classified as a sheet silicate or phyllosilicate, the latter word derived from the Greek word *phyllon*, or “leaf.” In most sheet silicates, each silica tetrahedron shares three oxygen ions with adjacent tetrahedra to create thin, sheet-type structures that extend indefinitely in two directions. These sheets consist of a checkerboard-like arrangement of alternating “strips” of three tetrahedra, each linked together at their corners. In chrysocolla, the tetrahedra within these flat sheets form four-member and/or eight-member rings. This arrangement leaves one remaining, negatively charged oxygen ion at each tetrahedral apex that attracts water molecules. Drawn by their dipolar, positive charge, these water molecules fill the spaces between the apices of the silica tetrahedra to partially satisfy the remaining tetrahedral negative charge. The water molecules are attached only by very weak hydrogen bonds that exist between the faintly positive poles of the water molecules and the negative charge of each tetrahedral apex. Stacks of these hydrated silica sheets are then bound together by layers of positive metal ions which satisfy their remaining negative charge.

Phyllosilicates are subclassified structurally into two-layer or three-layer groups. Chrysocolla exhibits a poorly developed, three-layer or “2:1” structure, with tetrahedral and octahedral layers of metal and hydrogen ions bonded ionically between two hydrated silica sheets. The middle layer consists of copper, aluminum, and hydrogen ions “sandwiched” between two tetrahedral silica layers. Within each of these three-layer sheets, a combination of ionic and strong covalent bonding creates cohesive sheet units. But the ionic attraction *between* the three-layer groups is weak. This explains chrysocolla’s low Mohs hardness of 2.5-3.5, which is much softer than other silicate minerals. Even though chrysocolla consists of about one-third copper, loose atomic packing results in a very low specific gravity of 1.9-2.4. Chrysocolla is currently thought to crystallize in the orthorhombic system, which is characterized by three mutually perpendicular axes of different lengths. Minerals that are chemically complex, or that have complex bonding (chrysocolla has both covalent and ionic bonding), often crystallize in the orthorhombic system. Chrysocolla’s poorly developed crystal structure accounts for its lack of cleavage and the fact that it rarely forms visible macrocrystals, which are believed to occur only in acicular or fibrous habits.

The Dana classification number 74.3.2.1 identifies chrysocolla as a phyllosilicate with modulated layers (74). It is subclassified as a phyllosilicate with joined strips in its layered structure (3). Chrysocolla is then assigned to the chrysocolla group (2) as the first (1) and only member.

As an idiochromatic or “self-colored” mineral, chrysocolla’s diagnostic blue, greenish-blue, bluish-green, and green colors are caused by the essential element copper, a powerful chromophore (color-causing agent) for the colors blue and green. Because of its variable composition, chrysocolla colors range considerably in hue and intensity. Clean, blue colors indicate a high copper content and few impurities. Paler blues and a shift toward green indicate a higher aluminum content and the presence of impurities.

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As a secondary copper mineral, chrysocolla forms in the oxidized or altered portions of copper-rich deposits, usually in alkaline chemical environments. It is associated with azurite [basic copper carbonate, $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$]; malachite [basic copper carbonate, $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$]; cuprite [copper oxide, Cu_2O]; limonite (a variable mixture of iron oxides and hydroxides); and quartz [silicon dioxide, SiO_2]. Chrysocolla forms crusts, drusy coatings, and vein and fissure fillings, and also occurs as pseudomorphs that replace other secondary minerals.

COLLECTING LOCALITIES

Our chrysocolla specimens are from the Inca de Oro district near Inca de Oro in Chañaral Province, Atacama Region, Chile. Other South American localities are the Veta Verde and María Elena mines near Coracora in Pacajes Province in La Paz Department, and the Llallagua Mine near Llallagua in Rafael Bustillos Province in Potosí Department, both in Bolivia; and the Caplitas mines at Andagala, Catamarca, Argentina. Peruvian sources include the Acarí copper mine in Caraveli Province in Arequipa Department, the Lily Mine at Pisco Umay in Ica Department, and the mines in Cañete Province in Lima Department. Among Mexico's sources are the Ojuela Mine at Mapimí, Durango; the San Cristóbal Mine at La Huacana, Michoacán; the San Carlos Mine at Mazapil, Zacatecas; and the Chantuplán mines near Taxco, Guerrero. In Canada, chrysocolla is collected at the Gaspé copper mine at Murdochville, Gaspésie-Îles-de-la-Madeleine, Québec.

In Europe, chrysocolla occurs at Chessy-les-Mines at Chessy, Rhône, Rhône-Alpes, France; and the Bad Lauterberg mines in the Harz Mountains of Lower Saxony, Germany. Chinese specimens come from the Liu Feng Shan 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, Magadanskaya Oblast', Far-Eastern Region. Africa's 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 in Oujda-Angad Province in Morocco's Oriental Region; the Shinkolobwe Mine at Kambove in the Katanga Copper Crescent, Katanga Province, Democratic Republic of the 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. The "Eilat stone" variety of chrysocolla occurs only at the King Solomon Mine in the Timna Valley near Eilat, HaDarom District, Israel. Australian localities include the Aerial and Silent Sisters mines at Wyloo Homestead and Ashburton Downs Station at Ashburton Downs in 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; the Great Australia Mine in the Cloncurry district, Mount Isa-Cloncurry region, Queensland; and the Wombat Hole Prospect at Benambra, Victoria.

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Chrysocolla 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. Colorado's sources include 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, chrysocolla occurs 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 Bernadino County. Other sources in the United States 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 Hub and Paymaster mines in the Lava Creek district, Butte County, Idaho; 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; the French Creek mines at St. Peters, Chester County, Pennsylvania; and the Schuyler Mine at North Arlington, Bergen County, New Jersey.

JEWELRY & DECORATIVE USES

Although pure chrysocolla has a bright, intense, sky-blue color, it is soft and fragile, and rarely occurs in thicknesses sufficient for gemstone use. Its softness (Mohs 2.5-3.5) makes it difficult to polish and limits its use in jewelry. Most chrysocolla used as a gemstone actually consists of microscopic particles of chrysocolla included within chalcedony [microcrystalline quartz, silicon dioxide, SiO_2] or opal [hydrous silicon dioxide, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$]. Silicification intensifies chrysocolla's color and greatly increases its hardness to create the gemstone known as "gem silica." Gem silica may be uniformly colored or varicolored; its bright-blue colors compare with those of top-quality turquoise. Varicolored chrysocolla, which is usually intergrown with azurite, malachite, and other oxidized copper minerals, exhibits mixed blue and green colors. Nicely colored, gem-silica rough in pieces large enough to be cut into gems costs as much as \$100 per ounce. Top-quality chrysocolla cabochons ready for jewelry cost about \$2 per carat, or roughly \$280 per ounce. Chrysocolla gems are classic examples of the saying "caveat emptor" (let the buyer beware). Various forms of chrysocolla are frequently mislabeled as turquoise, while gray chalcedony is often dyed blue to simulate gem silica.

"Eilat stone," also known as "King Solomon's stone," is the national stone of Israel. An intergrowth of chrysocolla, turquoise, azurite, and malachite, it is found only at the King Solomon Mine in the Timna Valley near Eilat, Israel's southernmost city, a source that is now closed. But because it was a popular souvenir from Israel for decades, imported imitations from copper mines in Africa and Arizona are often misrepresented as "Eilat stone" and sold to tourists.

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Collectors value chrysocolla for its bright colors and association with other colorful, oxidized copper minerals.

HISTORY & LORE

The ancient Greek philosopher and naturalist Theophrastus (ca 372-ca 287 B.C.) first used the name “chrysocolla” in 315 B.C. The word combines the Greek *chrysos*, meaning “gold,” and *kolla*, or “glue,” and alludes to a chrysocolla-like material used as a gold-soldering flux. Although it has served as a minor gemstone for several millennia, chrysocolla has long been confused with azurite, malachite, turquoise, and other oxidized copper minerals. French mineralogist and geologist André-Jean François Marie Brochant de Villiers (1772-1840) recognized chrysocolla as a mineral species in 1808 and revived its ancient Greek name. Brochant de Villiers helped pioneer the investigative work that differentiated the oxidized copper minerals.

Chrysocolla has appeared on the 100,000-zaire postage stamp of Zaire (now the Democratic Republic of the Congo) in 1996; the 1,350-Congolese franc stamp of the Democratic Republic of the Congo in 2011; and Indonesia’s 700-rupiah stamp of 1997. Because of its confusion with other similarly colored, oxidized copper minerals, chrysocolla has no specific lore or traditional medicinal uses. Modern metaphysical practitioners believe that chrysocolla is a stone of communication and calmness that aids in verbal and telepathic expression, facilitates the emergence of truth and wisdom, discharges negative energies, and enhances feminine energies.

Because of chrysocolla’s variable chemical composition and poorly developed crystal structure, mineralogists are currently debating its status as an accepted mineral species. In 2005, a joint French-American research team used infrared spectroscopy, scanning X-ray transmission microscopy, and X-ray diffraction methods to determine that chrysocolla is not a compositionally homogenous mineral as previously assumed. Instead, it apparently consists of several oxidized copper minerals, primarily spertiniite [copper hydroxide, $\text{Cu}(\text{OH})_2$] and similar species that are intergrown with chalcedony and opal [hydrous silicon dioxide, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$]. This study also noted that the assumed orthorhombic structure of chrysocolla may actually be based on spertiniite’s orthorhombic structure, rather than on any definable structure of chrysocolla itself. Accordingly, the study concluded that chrysocolla’s recognition as a unique mineral species should be reconsidered. To date, the International Mineralogical Association, the organization of mineralogists that is responsible for recognizing and naming mineral species, has not acted on this proposal to discredit chrysocolla as a mineral species.

THE MINES AND MINERALS OF CHILE

Many minerals collectors know that Chile is one of the Western Hemisphere’s leading sources of mineral specimens, most of which are obtained as by-products of a booming mining industry that

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leads the world in the production of copper and lithium, ranks third in molybdenum, and is also a significant source of gold and silver.

Chile's mining legacy goes back to pre-Columbian times when indigenous cultures began mining rich outcrops of gold and copper. Much later, the Incas moved south from what is now Peru into northern Chile to mine placer deposits of gold. Following the Incan conquest in the early 16th century A.D., the Spanish arrived to mine copper and gold. Although production records are incomplete, historians believe that during the 18th century the Spanish in northern Chile mined 32,000 troy ounces of gold, 160,000 troy ounces of silver, and 80,000 tons of copper, shipping it via the Straits of Magellan to Buenos Aires, Argentina, and then to Spain.

After Chile gained its independence in 1818, Chilean prospectors discovered rich silver deposits near Copiapó, which became a trading center for the many regional silver, copper, and gold mines. During the 1870s, as plummeting silver and copper prices created a severe economic depression in Chile, nitrate mining emerged as a major industry. The Atacama Desert of northern Chile and adjacent areas of Peru and Bolivia held large deposits of both guano and saltpeter (sodium nitrate, NaNO_3), both rich sources of nitrogen for the manufacture of explosives and fertilizers. A territorial dispute over access to the nitrate deposits erupted into the War of the Pacific (the "Saltpeter War") that raged from 1879 to 1883, with Chile fighting both Peru and Bolivia. The war was fought at sea, in the Atacama Desert, and in the Bolivian highlands. Chile eventually won territorial concessions from both Peru and Bolivia that played a major role in the future mining of nitrate and copper.

By 1900, Chile, with some 100 small "nitrate towns" scattered across the Atacama Desert and along its northern coast, was supplying most of the world's nitrates. When the development of nitrate-synthesis processes in the early 1920s ruined the market for natural nitrates, Chile redirected its interest back to its vast, undeveloped copper resources. By the 1950s, Chile had three of the world's largest open-pit copper mines: Chuquibambilla, El Teniente, and El Salvador, each with its own company town, concentrator, and smelter. In the 1990s, Japanese, American, and Australian interests funded a major expansion and modernization of Chile's copper-mining industry.

Today, Chile's mining industry has 75,000 workers; the value of its annual mine production, mostly from copper, tops \$30 billion. With 25 major copper mines turning out 5.7 million tons of copper each year, Chile leads the world in copper production accounting for one-third of global output. The nation also recovers 30,000 tons of molybdenum, 1.6 million troy ounces of gold, and 5 million troy ounces of silver per year as byproducts of copper mining. In addition, as the leading producer of lithium, the key component of lithium batteries, Chile recovers 60,000 tons of lithium compounds per year from evaporation ponds and brine wells in the Atacama Desert.

With its abundance of copper mineralization and an arid climate that creates deep oxidized zones, Chile is a major source of colorful, copper-mineral specimens. Many of these specimens are

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collected at the Chuquicamata Mine, the world's largest open pit. Chuquicamata is the type locality for 19 copper-mineral species, many of which are rare and not found elsewhere. Along with such familiar copper minerals as chrysocolla, native copper, azurite, malachite, brochantite, and cuprite, Chile is also a source of such unusual species as salesite [basic copper iodate, $\text{Cu}(\text{IO}_3)(\text{OH})$]; kröhnkite [hydrous sodium copper sulfate, $\text{Na}_2\text{Cu}(\text{SO}_4)_2 \cdot 2\text{H}_2\text{O}$]; antlerite [basic copper sulfate, $\text{Cu}_3(\text{SO}_4)(\text{OH})_4$]; ammineite [ammonium copper chloride, $\text{CuCl}_2 \cdot 2\text{NH}_3$]; atacamite [basic copper chloride, $\text{Cu}_2\text{Cl}(\text{OH})_3$]; and bonatite [basic copper sulfate, $\text{CuSO}_4 \cdot 3\text{H}_2\text{O}$].

TECHNOLOGICAL USES

Chrysocolla has no current technological uses; in the past, it has occasionally served as minor ore of copper and as a soldering flux.

ABOUT OUR SPECIMENS

Our specimens of chrysocolla are from the Inca de Oro district near Inca de Oro, Chañaral Province, Atacama Region, Chile. Located in southwestern South America, Chile is bordered on the north by Peru, on the east by Bolivia and Argentina, and on the west by the Pacific Ocean. With 292,259 square miles, Chile is slightly larger than the American state of Texas and has a population of 17 million. The Atacama Region, one of Chile's 15 administrative units (comparable to American states), occupies the southern part of the Atacama Desert, the world's driest, nonpolar desert. The Atacama Region is the size of American state of South Carolina, but has only 300,000 residents. Atacama's capital, Copiapó, was founded in the early 1700s. With a current population of 200,000, Copiapó is the regional trading center for a vast area. Inca de Oro, elevation 4,800 feet, is 50 miles north of Copiapó. With a population of 1,000, Inca de Oro is an isolated town on the floor of the Llano de Varas, a barren, arid valley that receives less than one inch of rainfall per year and is nearly devoid of vegetation.

The mineralization of the Atacama region is linked to the Andean Orogeny (mountain-building episode) that created the Andes Mountains some 60 million years ago. This uplifting of dioritic and granitic basement rock was accompanied by volcanic activity that emplaced such volcanic rocks as andesite and dacite. Associated mineral-rich, hydrothermal solutions surged through the fractured dioritic and granitic rock to precipitate metallic minerals in numerous, erratic veins. These minerals consisted mainly of chalcopyrite [copper iron sulfide, CuFeS_2], bornite [copper iron sulfide, Cu_5FeS_4], and chalcocite [copper sulfide, Cu_2S], along with significant amounts of gold [element, Au] and molybdenite [molybdenum disulfide, MoS_2]. Erosion subsequently reduced the surface to expose the upper parts of these vein systems, enabling atmospheric oxygen and groundwater to alter the sulfides into chrysocolla, cuprite, azurite, malachite, and other oxidized copper minerals.

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Inca de Oro is located in a geological zone characterized by massive copper-porphyry deposits. The term “porphyry” refers to igneous rock containing conspicuous crystals (phenocrysts) in a fine-grained groundmass. In its mining context, “copper-porphyry” refers to porphyry-type rock that has been secondarily enriched by copper mineralization. Copper-porphyry deposits formed after magma intruded country rock and copper-rich, hydrothermal solutions circulated upward through fractures around the periphery of the intrusions and precipitated copper-sulfide minerals. After erosion eventually exposed this mineralization, contact with atmospheric oxygen and acidic groundwater oxidized the sulfide minerals. Over millions of years, groundwater dissolved the copper mineralization, then percolated downward into the underlying porphyritic rock where the copper precipitated out of solution in the form of disseminated copper-sulfide minerals, mainly chalcopyrite and chalcocite. Geologists refer to this type of secondary mineralization as “supergene enrichment” (literally “post-formation mineralization”) and to the bodies of mineralized porphyry rock as “copper-porphyry” deposits.

The sprawling Inca de Oro mining district has dozens of small gold and copper mines, including both underground operations and open pits. Many of these small mines will be consolidated into the planned Inca de Oro Mine, a major open-pit operation that will exploit a copper-porphyry deposit containing 260 million tons of ore grading 0.4 percent copper per ton, 0.13 grams of gold per ton, and 1.62 grams of silver per ton. Over its projected ten-year life, annual production will amount to 50,000 tons of copper, 40,000 troy ounces of gold, and 480,000 troy ounces of silver. The deposit, in which an overlying, oxidized layer caps deeper sulfide ores, contains 54 mineral species and is the type locality for szenicsite [basic copper molybdate, $\text{Cu}_3(\text{MoO}_4)(\text{OH})_4$]. This deposit has yielded mineral specimens since it was first explored in the 1990s.

As you examine your specimen, note that the bright-blue chrysocolla occurs as a drusy coating on a vug wall. The chrysocolla is covered with a delicate, secondary drusy coating of transparent, colorless, terminated crystals of macrocrystalline quartz. When examined with a loupe under an intense light source, the quartz appears as a lustrous, colorless coating of tiny, terminated crystals. The matrix of your specimen is partially altered granite with visible phenocrysts of quartz, feldspar minerals, and muscovite [basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$]. This altered granite has been mineralized by copper-bearing solutions which have deposited small sections of other blue-green, oxidized copper minerals along with brownish-orange cuprite [copper oxide, Cu_2O]. Your chrysocolla specimen is a souvenir of northern Chile and the world's greatest copper-mining region.

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