

# November 2013 Mineral of the Month

## AUSTINITE

This month our featured mineral is austinite, a rare calcium-zinc arsenate from a classic locality—Mexico’s historic Ojuela Mine, one of the world’s leading sources of fine mineral specimens. Our write-up explains austinite’s mineralogy and recounts the remarkable story of the Ojuela Mine.

### OVERVIEW

**PHYSICAL PROPERTIES:** Chemistry:  $\text{CaZn}(\text{AsO}_4)(\text{OH})$  Basic Calcium Zinc Arsenate (Calcium Zinc Arsenate Hydroxide), often contains varying amounts of copper.

Class: Phosphates, Arsenates, and Vanadates

Group: Adelite

Crystal System: Orthorhombic

Crystal Habits: Usually as minute, elongated, bladed or acicular crystals; also as fibrous crusts and radial nodules.

Color: Usually pale-to-bright green, colorless, or yellowish-white; occasionally white or brown.

Luster: Subadamantine

Transparency: Transparent to translucent

Streak: White to pale green

Refractive Index: 1.763-1.783

Cleavage: Good in one direction

Fracture: Uneven, brittle.

Hardness: 4.0-4.5

Specific Gravity: 4.13

Luminescence: None

Distinctive Features and Tests: Best field marks are green color; minute, bladed or elongated crystals; and occurrence as a secondary mineral in oxidized portions of arsenic-rich zinc deposits. Can be confused with adamite [basic zinc arsenate,  $\text{Zn}_2(\text{AsO}_4)(\text{OH})$ ], which is softer and denser.

Dana Classification Number: 41.5.1.3

**NAME:** Austinite, pronounced AWS-tin-ite, is named in honor of American mineralogist Austin Flint Rogers (1877-1957). A former name is “brickerite.” A copper-rich variety is known as “cuprian austinite.” In European mineralogical literature, austinite appears as *austinit* and *austinita*.

**COMPOSITION:** Austinite’s chemical formula  $\text{CaZn}(\text{AsO}_4)(\text{OH})$  identifies its elemental components as calcium (Ca), zinc (Zn), arsenic (As), oxygen (O), and hydrogen (H). Its molecular weight consists of 15.33 percent calcium, 25.02 percent zinc, 28.66 percent arsenic, 30.60 percent oxygen, and 0.39 percent hydrogen. Austinite, an arsenate mineral, is one of approximately 300 members of the phosphates, arsenates, and vanadates class of minerals that is built, respectively, around the phosphate  $(\text{PO}_4)^{3-}$ , arsenate  $(\text{AsO}_4)^{3-}$ , or vanadate  $(\text{VO}_4)^{3-}$  radicals. All form tetrahedral structures with four oxygen ions surrounding the ion of a metal or semimetal (vanadium is a metal; phosphorus and arsenic are semimetals). Austinite is an allochromatic

# November 2013 Mineral of the Month

mineral. When pure or nearly pure, austinite is colorless or white. But austinite often contains some copper ions which substitute for zinc in the crystal lattice and impart a range of greenish colors. Traces of iron impart yellow and brownish hues. As a secondary mineral, austinite forms in the oxidized zones of zinc- and arsenic-bearing hydrothermal veins and replacement deposits, usually within a host rock of limestone or dolomite.

**COLLECTING LOCALITIES:** Although widely distributed, austinite occurs only in small amounts and rarely in collectible forms. The finest specimens come from Mexico. Other localities are in Chile, Bolivia, Australia, Greece, Namibia, Morocco, Austria, France, China, Germany, Spain, and Zambia. In the United States, austinite is collected in Utah, Nevada, California, New Mexico, and New Jersey.

**HISTORY, LORE & TECHNOLOGICAL USES:** Austinite was unknown until September 1933, when Walter L. Landwehr, a geologist with the American Smelting and Refining Company, collected specimens from a surface outcrop of the Western Utah Copper Company's ore body at Gold Hill in Tooele County, Utah. Landwehr's specimens consisted of well-developed crystals of quartz and adamite, along with minute, colorless crystals that were difficult to identify. Landwehr sent some of the specimens to the mineralogical laboratory of Stanford University in Palo Alto, California, where mineralogist Lloyd W. Staples determined that the tiny, colorless crystals were a new mineral. In 1935, mineralogists recognized this new mineral, which Staples named "austinite" in honor of his department head, the prominent mineralogist Austin Flint Rogers (1877-1957). Because of its rarity and small crystal size, austinite has no use in jewelry. Mineral collectors value austinite for its rarity, unusual chemistry, green color, and interesting associations in composite specimens with other colorful arsenate minerals. Austinite has no technological uses. When present in oxidized base-metal deposits, it has occasionally served as a minor ore of zinc. According to modern metaphysical practitioners, austinite fosters courage, new beginnings and adventures, and protects those who are young, free, and willing to take chances.

**ABOUT OUR SPECIMENS:** Our austinite specimens were collected at the Ojuela Mine at Mapimí in the Mapimí district, Durango, Mexico. The Ojuela Mine is located in north-central Mexico, northwest of the city of Torreón and in the eastern foothills of the Sierra Madre Occidental. This is an arid region of the Chihuahuan Desert where rugged mountain ranges separate broad plains. The elevation of Mapimí and the Ojuela Mine is 6,800 feet. Ojuela is a leading example of the carbonate-replacement deposits that occur in a 900-mile-long belt of folded carbonate rocks known as the Mexican Fold Belt. The Fold Belt sediments, all of marine origin, were laid down between 150 and 65 million years ago and lithified into limestone and dolomite. Between 40 and 25 million years ago, regional volcanism and deep magmatic intrusions forced mineral-laden hydrothermal solutions into the circulation systems within the Fold Belt. Mineralization then occurred by replacement when superheated saline and acidic solutions dissolved sections of the limestone and dolomite. This replacement mineralization formed seven major vertical structures called "chimneys," with associated overlying, horizontal mineralized zones called "*mantos*" (literally "cloaks"). These deposits, rich in silver, lead, and zinc with lesser amounts of gold and copper, were originally emplaced thousands of feet below the surface, then later exposed by surface erosion. Spanish prospectors discovered the Ojuela deposit in 1598. By 1640, Ojuela had become a major source of silver. Over its long life, Ojuela

# November 2013 Mineral of the Month

has produced more than seven million tons of ore that contained on average 15 troy ounces of silver, 15 percent lead, 12 percent zinc, 0.1 troy ounce of gold, and small amounts of copper. Regular ore production ended after World War II. Total production at Ojuela amounts to more than 100 million troy ounces of silver, 700,000 troy ounces of gold, and roughly 200,000 tons of lead and zinc. Although the Ojuela Mine has not produced ore in decades, it is still mined for mineral specimens and may reopen for production mining in the future.

## COMPREHENSIVE WRITE-UP

### COMPOSITION

This is the first time we have featured the rare mineral austinite as our Mineral of the Month. Our austinite specimens are from a classic locality—the Ojuela Mine at Mapimí in Durango Mexico, which many collectors rank as the Western Hemisphere’s greatest source of mineral specimens. Club members may recall that we have previously featured such Ojuela specimens as adamite [basic zinc arsenate,  $\text{Zn}_2(\text{AsO}_4)(\text{OH})$ ] and conichalcite [basic calcium copper arsenate,  $\text{CaCu}(\text{AsO}_4)(\text{OH})$ ]. Austinite, conichalcite, and adamite are all arsenate minerals for which the Ojuela Mine is famed.

Austinite’s chemical formula  $\text{CaZn}(\text{AsO}_4)(\text{OH})$  identifies its elemental components as calcium (Ca), zinc (Zn), arsenic (As), oxygen (O), and hydrogen (H). Its molecular weight consists of 15.33 percent calcium, 25.02 percent zinc, 28.66 percent arsenic, 30.60 percent oxygen, and 0.39 percent hydrogen. As with all molecules, those of austinite consist of positively charged cations and negatively charged anions. The cation or positively charged ion of the austinite molecule consists of one divalent ion of calcium  $\text{Ca}^{2+}$  and one divalent ion of zinc  $\text{Zn}^{2+}$  and has a collective cationic charge of +4. Austinite’s compound anion or negatively charged ion consists of two different radicals (groups of atoms that act as entities in chemical reactions)—the arsenate radical  $(\text{AsO}_4)^{3-}$  and the hydroxyl radical  $(\text{OH})^{1-}$ . In the arsenate radical, arsenic is present in the +5 oxidation state and oxygen in the -2 oxidation state. This produces a collective -3 charge. In the hydroxyl ion, the oxygen ion  $\text{O}^{2-}$  has a -2 charge and the hydrogen ion  $\text{H}^{1+}$  has a +1 charge, which provides a collective -1 charge. The total -4 anionic charge balances the total +4 cationic charge to impart electrical stability to the austinite molecule. In stating austinite’s chemical composition—basic calcium zinc arsenate—the term “basic” refers to the presence of the hydroxyl radical  $(\text{OH})^{1-}$  and notes its alkaline chemical reactivity.

Austinite is one of approximately 300 members of the phosphates, arsenates, and vanadates, a class of minerals that is built respectively around the phosphate  $(\text{PO}_4)^{3-}$ , arsenate  $(\text{AsO}_4)^{3-}$ , or vanadate  $(\text{VO}_4)^{3-}$  radicals. All form tetrahedral structures with four oxygen ions surrounding the ion of a metal or semimetal (vanadium is a metal; phosphorus and arsenic are semimetals). In the arsenate ion, the arsenic ion  $\text{As}^{5+}$  is surrounded by, and bonded covalently to, four oxygen ions ( $4\text{O}^{2-}$ ). Because the four oxygen ions collectively share the resulting -3 charge, the arsenate radical can bond ionically with a number of different metal cations. In austinite, each arsenate ion bonds ionically to one calcium and one zinc ion to form the intermediate, octahedral-shaped, zinc-arsenate radical  $[\text{CaZn}(\text{AsO}_4)]^{1+}$ . This radical, which is unstable because of its +1 charge, covalently bonds into chains of octahedra that establish austinite’s orthorhombic crystal

# November 2013 Mineral of the Month

structure. Spaces between these octahedral chains accommodate hydroxyl ions ( $\text{OH}^{1-}$ ) that bond ionically with alternating calcium and zinc ions to electrically balance the molecule.

Orthorhombic crystals are characterized by three mutually perpendicular axes of different lengths. The most common orthorhombic forms are the pinacoid (characterized by two parallel faces), dipyramid, prism, and dome. Although orthorhombic crystals are often blocky, variations in form are common. When one dimension of the lattice unit cell is noticeably longer than the other two, the crystals are needle-like; when one dimension is notably shorter, the crystals are blocky. Crystal shape is usually determined by the rate of directional growth. Minerals that are chemically complex, or that have complex bonding (austinite has both covalent and ionic bonding), often crystallize in the orthorhombic system. Because of strong covalent bonding along the octahedral chains and weak ionic bonding between the chains, austinite exhibits good cleavage along its ionic-bonding plane.

Austinite's hardness of Mohs 4.0-4.5 is somewhat directional, being greatest along the planes of strong covalent bonding and least along the ionic-bonding plane. The presence of weak ionic bonding accounts for austinite's brittleness. Austinite is unusually dense for a light-colored mineral. The high atomic weights of zinc (65.39) and arsenic (74.92), together with close atomic packing, explain its relatively high specific gravity of 4.13. This specific gravity varies somewhat when copper or other metals substitute for zinc in the austinite lattice. Its substantial density provides austinite with a relatively high index of refraction of 1.763-1.783, roughly equal to that of the sapphire and ruby varieties of corundum [aluminum oxide,  $\text{Al}_2\text{O}_3$ ].

Minerals are generally categorized as idiochromatic or allochromatic. The colors of idiochromatic (self-colored) minerals are caused by essential elements or by the light-absorption properties of the crystal lattice. The colors of allochromatic (other-colored) minerals are due to trace amounts of nonessential elements called chromophores (coloring agents). Austinite is an allochromatic mineral. When pure or nearly pure, austinite is colorless or white. But austinite often contains some divalent copper ions ( $\text{Cu}^{2+}$ ) which substitute for zinc in the crystal lattice to impart a range of greenish colors. Traces of divalent iron (ferrous,  $\text{Fe}^{2+}$ ) impart yellow and brownish hues.

The Dana mineral classification number 41.5.1.3 identifies austinite as an arsenate containing hydroxyl or halogen ions (41). The subclassification (5) defines it by the general formula  $\text{AB}(\text{XO}_4)\text{Z}_q$ , in which "A" may be calcium or lead and "B" may be such divalent metals as zinc, copper, manganese, magnesium, cobalt, nickel, or ferrous iron; " $\text{XO}_4$ " is a phosphate, arsenate, or vanadate radical; "Z" is a hydroxyl or halogen ion; and "q" is a variable quantifier. Austinite is then assigned to the adelite group (1) as the third (3) of 10 members. All adelite-group members are uncommon or rare, crystallize in the orthorhombic system, and share generally similar physical properties. Notice how the following representative members of the adelite group differ only in cationic substitution:

adelite	basic calcium magnesium arsenate	$\text{CaMg}(\text{AsO}_4)(\text{OH})$
conichalcite	basic calcium copper arsenate	$\text{CaCu}(\text{AsO}_4)(\text{OH})$
austinite	basic calcium zinc arsenate	$\text{CaZn}(\text{AsO}_4)(\text{OH})$
cobaltaustinite	basic calcium cobalt arsenate	$\text{CaCo}(\text{AsO}_4)(\text{OH})$

# November 2013 Mineral of the Month

Most adelite-group members participate in mutual, partial solid-solution series. Austinite and conichalcite, however, form a complete solid-solution series with zinc substituting completely for copper and vice versa. Pure austinite is colorless or white, while pure conichalcite is a bright green color. The intermediate phases of the austinite-conichalcite solid-solution series are known as cuprian austinite. Technically, austinite becomes conichalcite when copper replaces 50 percent of the zinc.

As a secondary mineral, austinite forms in the oxidized zones of zinc- and arsenic-rich hydrothermal veins and replacement deposits, usually within limestone or dolomite host rocks. Austinite occurs in close association with such other minerals as smithsonite [zinc carbonate,  $\text{ZnCO}_3$ ], calcite [calcium carbonate,  $\text{CaCO}_3$ ], hemimorphite [basic hydrous zinc silicate,  $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$ ], limonite (an indefinite mixture of hydrous iron oxides), legrandite [basic hydrous zinc arsenate,  $\text{Zn}_2(\text{AsO}_4)(\text{OH}) \cdot \text{H}_2\text{O}$ ], mimetite [lead chloroarsenate,  $\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$ ], and conichalcite.

## ***COLLECTING LOCALITIES***

Although widely distributed in the oxidized portions of base-metal deposits, austinite occurs only in small amounts and rarely in collectible forms. The classic locality for austinite is the Ojuela Mine at Mapimí in the Mapimí District, Durango, Mexico. Another Mexican locality is the Congreso-León Mine at San Pedro Corralitos near Casas Grandes, Chihuahua.

In Chile, austinite is collected at the Veta Negra copper-zinc deposit at Chañarcillo, Copiapó Province, and at the Florida Mine in La Florida district at Diego de Amagro, Chañaral Province, both in Atacama Region. Other localities include the Lili Mine in Laurani District, Aroma Province, La Paz Dept., Bolivia; Puttapa at Leigh Creek, North Flinders Ranges, South Australia, Australia; the Kamareza mine group, Lavrion District, Attiki Prefecture, Greece; the Tsumeb Mine at Tsumeb, Otjikota Region, Namibia; the Bou Azzer, Ambed, and Aït Ahmane mines in the Bou Azzer district, Ouarzazate Province, Souss-Massa-Draâ Region, Morocco; the Kolm-Saigum Mines in the Rauris Valley, Hohe Tauern, Salzburg, Austria; Montferrer in the Pyrénées-Orientales, Languedoc-Roussillon, France; the Laogondou Mine, Ejina County, Alashan Prefecture, Inner Mongolia Autonomous Region, China; the Wolfgang Massen Mine, Schneeberg District, Erzgebirge, Saxony, Germany; the Linda Mariquita Mine at Priat, Terragona, Catalonia, Spain; and the Broken Hill mines in Kabwe District, Central Province, Zambia.

In the United States, austinite is collected at the type locality at the Gold Hill Mine in the Gold Hill district, Tooele County, Utah; the Simon Mine in the Bell district of Mineral County and the San Rafael Mine in the Lodi district of Nye County, both in Nevada; the Mohawk Mine at Pactolus in the Clark Mountain district, San Bernardino County, California; the Buckhorn Mine in the Red Cloud district, Lincoln County, New Mexico; and the Sterling Mine at Sterling Hill in Ogdensburg, Sussex County, New Jersey.

## ***JEWELRY & DECORATIVE USES***

# November 2013 Mineral of the Month

Because of its rarity and small crystal size, austinite has no use in jewelry. Mineral collectors value austinite for its rarity, unusual chemistry, green color, and interesting associations in composite specimens with other colorful arsenate minerals.

## ***HISTORY & LORE***

Austinite was unknown until September 1933, when Walter L. Landwehr, a geologist with the American Smelting and Refining Company, collected specimens from a surface outcrop of the Western Utah Copper Company's ore body at Gold Hill in Tooele County, Utah. Landwehr's specimens consisted of well-developed crystals of quartz and adamite, along with minute, colorless crystals that were difficult to identify. Landwehr sent some of the specimens to the mineralogical laboratory of Stanford University in Palo Alto, California, where mineralogist Lloyd W. Staples determined that the tiny, colorless crystals were a new mineral. Mineralogists approved the new mineral in 1935. A similar mineral that was never properly described had been discovered in Bolivia in 1928 and informally named "brickerite."

At that time of Landwehr's discovery, the prominent mineralogist Austin Flint Rogers (1877-1957) headed Stanford University's mineralogy department. Since Rogers had directed his research, Staples honored his department head, who had already discovered four new minerals himself, by naming the new mineral in his honor. Although it is customary to use an individual's last name in naming new minerals, Rogers already had a mineral named for him (rogersite). So Staples instead used Rogers' first name—Austin—for the new mineral. That turned out well, since "rogersite" would not survive the name and nomenclatural revisions of future decades. The original "rogersite" is now lausenite [hydrous iron sulfate,  $\text{Fe}(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ ]. But the name "austinite" remains as both a valid mineral species and a tribute to one of America's great mineralogists of the early 20<sup>th</sup> century.

According to modern metaphysical practitioners, austinite fosters courage, new beginnings and adventures, and protects those who are young, free, and willing to take chances.

## ***ABOUT THE OJUELA MINE***

In the world of mineral collecting, the Ojuela Mine at Mapimí, Durango, Mexico, is considered hallowed ground, ranking among the world's top-ten specimen-producing localities of all time. Ojuela has yielded 126 individual mineral species, is the type locality for 6 species, and is best known as the source of the finest specimens of such arsenate minerals as austinite and adamite. Its operating history is no less remarkable. Ojuela has produced ore or mineral specimens for 415 consecutive years, a record unmatched by any other mine.

In 1534, Spanish prospectors discovered silver at Taxco in what is now the state of Guerrero, Mexico. This strike initiated a succession of major strikes that extended northward for 500 miles and culminated in the discovery of rich outcrops of chlorargyrite [silver chloride,  $\text{AgCl}$ ] and argentiferous cerussite [silver-bearing lead carbonate,  $\text{PbCO}_3$ ] at Ojuela in 1598. The Spaniards named the mine "*Hojuela*," meaning "leaf-like," and apparently alluding to sheet-like crystals of certain minerals that resembled leaves (*hojas*). The "H" was later dropped and the mine became known worldwide as "Ojuela." Utilizing Native American slave labor, the Spaniards quickly



## November 2013 Mineral of the Month

depleted the surface ores at Ojuela and turned to underground mining. By 1640, Ojuela had become a major source of silver. Using adobe smelting furnaces fired by charcoal, the Spaniards reduced the crushed ores to crude lead-silver alloys, then separated the silver in a simple cupellation process that oxidized the lead, while retaining the molten silver.

Production at Ojuela dropped sharply at the onset of the Mexican war of independence in 1811. Even though the mine and smelter were formally shut down during the revolution, many miners managed to feed their families by continuing to work on their own, smelting the high-grade silver ores in makeshift charcoal furnaces. By the time Mexico gained its independence in 1821, the Ojuela Mine and its crushers and smelters were in ruins. Operations subsequently resumed, but production was limited by outdated mining technology and equipment, lack of roads, trouble with outlaws, and government instability. The mine itself, with dozens of levels and literally hundreds of small shafts and adits, had become a relic representing centuries of poorly planned, piecemeal expansion.

In the late 1870s, after newly elected Mexican president General Porfirio Díaz (1830-1915) eased government restrictions to encourage foreign investment in mining, the United States-based Durango-Mapimí Mining Company purchased the Ojuela Mine and invested \$100,000 to increase silver production. Despite the improvements, daily mine output never exceeded 20 tons of ore and Durango-Mapimí went bankrupt in 1890. Backed by American and European capital, Compañía Minera de Penoles then purchased the mine and hired American mining engineers to completely modernize its operation. Penoles replaced the colonial-aged, adobe furnaces with a modern smelter, built a 15-mile-long railroad to link Mapimí with the Mexican national railroad at Bermejillo, electrified Mapimí and Ojuela, and constructed employee housing. It also hired the firm of American civil engineer and builder of New York's Brooklyn Bridge Washington Augustus Roebling (1837-1926) to construct a narrow, 1,000-foot-long, cable-suspension bridge over a 250-foot-deep arroyo that separated the town from the mine. Most importantly, Penoles increased the depth of the mine from 770 feet to more than 1,800 feet to access large volumes of previously ignored zinc ores.

By 1910, Ojuela had become Mexico's most profitable mine. More than 1,200 miners were turning out 500 tons of high-grade ore per day, from which the smelter recovered one million troy ounces of silver per year, along with huge tonnages of lead and zinc. But Ojuela's prosperity was short-lived. When President Díaz ran for his third term in 1911, national resentment about his involvement with foreign interests exploded into full-scale revolution. The following year, 7,000 rebel troops under revolutionary leader Francisco "Pancho" Villa (1878-1923) mounted bloody attacks on federal strong points at Mapimí and Torreón. Although Mapimí was never attacked again, Ojuela managed only token production until the revolution ended in 1920.

In the early 1920s, core-drill exploration at Ojuela delineated additional ore bodies at depth. Meanwhile, powerful new pumps were dewatering the deeper workings and the combination of high zinc prices and the efficient, new flotation-separation milling process were making the mining of lower-grade ores profitable. Production soared during the late 1920s before profits were again cut short, this time when the Great Depression undermined metal prices. In the early 1930s, when the mine's depth had reached 2,600 feet, additional pumps were installed to remove

## November 2013 Mineral of the Month

6,000 gallons of water per minute from the lower workings. Nevertheless, the lower levels flooded in 1934. Although metal prices rose sharply again during World War II, Ojuela never approached its former production rates. In 1946, Compañía Minera de Penoles relinquished direct operational control and began leasing mine sections to independent cooperatives of miners. Although this lease-mining system yielded only minimal amounts of ore, it survives in today's specimen-mining operations.

Over its long life, Ojuela has produced more than seven million tons of ore which, when compared with modern standards, was phenomenally rich. Economic geologists estimate that an average ton contained 15 troy ounces of silver, 15 percent lead, 12 percent zinc, 0.1 troy ounce of gold, and small amounts of copper. Total production at Ojuela includes more than 100 million troy ounces silver, 700,000 troy ounces of gold, and roughly 200,000 tons of lead and zinc. At today's metal prices, the value of the silver and gold alone would exceed three *billion* dollars.

Ojuela was never recognized for its unusual mineralogy and superb specimens until its was visited in 1927 by Smithsonian Institution geologist William F. Foshag (1894-1956) and Harvard Mineralogical Museum curator Harry Berman (1902-1944). Foshag and Berman amassed a collection of specimens that included several new minerals. As research mineralogists, Foshag and Berman provided the first explanations of why Ojuela was such a prolific source of unusual minerals. The major reason is its extraordinarily large volume of oxidized mineralization. Metal-ore minerals are usually emplaced as deep sulfide deposits that are sometimes later exposed by erosion. As erosion reduces the surface, subterranean water tables are lowered to expose metal-sulfide minerals to free atmospheric oxygen, which initiates a chemical-oxidation process. Oxidation alters sulfides into such secondary, oxygen-bearing minerals as carbonates, oxides, phosphates, and arsenates that often form rare and colorful specimens. While most deposits have shallow water tables not exceeding a few hundred feet in depth, Ojuela's unusual water-table depth of 1,200 feet has enabled huge volumes of overlying sulfide ores to oxidize into secondary minerals.

The second reason that Ojuela is such a prolific source of mineral specimens is its unusual chemistry. Unlike most other deposits, the original sulfides at Ojuela were extremely rich in arsenopyrite [iron arsenic sulfide,  $\text{FeAsS}$ ], which accounted for about 20 percent of the total sulfide weight. Ojuela's primary sulfide-ore minerals are pyrite [iron disulfide,  $\text{FeS}_2$ ], argentiferous galena [silver-bearing lead sulfide,  $\text{PbS}$ ], pyrrhotite [iron sulfide,  $\text{Fe}_{1-x}\text{S}$ ], sphalerite [zinc sulfide,  $\text{ZnS}$ ], and chalcopyrite [copper iron sulfide,  $\text{CuFeS}_2$ ]. These sulfides typically oxidize into goethite [basic iron oxide,  $\text{FeO}(\text{OH})$ ], argentiferous cerussite [silver-bearing lead carbonate,  $\text{PbCO}_3$ ], malachite [basic copper carbonate,  $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$ ], and smithsonite [zinc carbonate,  $\text{ZnCO}_3$ ]. But because arsenic was abundant, these sulfides oxidized instead into an array of secondary lead, zinc, and copper arsenates that are colorful and often rare.

### **TECHNOLOGICAL USES**

Austinite has no technological uses. When present in oxidized, base-metal deposits, it has occasionally served as a minor ore of zinc.



# November 2013 Mineral of the Month

## ABOUT OUR SPECIMENS

Our austinite specimens were collected at the Ojuela (oh-HWAY-la) Mine at Mapimí in the Mapimí (mah-pih-MEE) district, Durango, Mexico. The Ojuela Mine is located in north-central Mexico northwest of the city of Torreón. From Torreón, Ojuela is reached by taking Mexico Route 49 north for 25 miles to Bermejillo, turning west on Mexico Route 30 for 12 miles, then following the signs to the small village of Mapimí four miles to the south. The mine is located in the eastern foothills of the Sierra Madre Occidental. This arid region is typical of the Chihuahuan Desert, where rugged mountain ranges separate broad plains. The plains are 5,000 feet in elevation and sparsely vegetated with cacti, thorny brush, and coarse grass; the adjacent mountains rise to about 10,000 feet and host thin, scrub-oak forests at higher elevations. The elevation of Mapimí and the Ojuela Mine is 6,800 feet.

Ojuela is a leading example of the carbonate-replacement deposits found in a 900-mile-long belt of folded carbonate rocks known as the Mexican Fold Belt. The Fold Belt sediments, all of marine origin, were laid down between 150 and 65 million years ago and later lithified into limestone and dolomite. Limestone is a rock that consists primarily of calcite [calcium carbonate,  $\text{CaCO}_3$ ]. Dolomite, in its petrological context, is a rock consisting mainly of the mineral dolomite [calcium magnesium carbonate,  $\text{CaMg}(\text{CO}_3)_2$ ]. In the early Tertiary Period 60 million to 40 million years ago, stresses generated by colliding tectonic plates deformed these limestone and dolomite formations into the folds and thrusts of today's Fold Belt. Finally, between 40 and 25 million years ago, regional volcanism and deep magmatic intrusions forced mineral-laden hydrothermal solutions into the circulation systems within the Fold Belt.

Mineralization then occurred by replacement when superheated saline and acidic solutions dissolved sections of the limestone and dolomite. This dissolution of carbonate minerals in the limestone-dolomite neutralized the acidic solutions, causing precipitation of sulfide minerals that replaced the carbonates. At Ojuela, this replacement mineralization formed seven major vertical structures called “chimneys,” which fed overlying, horizontal mineralized zones called “*mantos*” (literally “cloaks”). These deposits, rich in silver, lead, and zinc with lesser amounts of gold and copper, were originally emplaced thousands of feet below the surface, then later exposed by surface erosion.

Although the Ojuela deposit has been mined since 1598 (see “About the Ojuela Mine”), specimens did not attract collector attention until 1946, when lease miners working 1,000 feet below the surface encountered large vugs filled with extraordinary adamite crystals. These crystals came to the attention of retired, specimen-savvy Americans living in the region who sent them to dealers in the United States. As these dealers clamored for more specimens, lease miners realized that it was more profitable to sell adamite specimens than it was to mine ore. But when Compañía Minera de Penoles managers learned how many tons of adamite were being sold, they insisted that the miners return ten percent of their proceeds to the company. Few miners complied and instead quietly smuggled adamite specimens out of the mine and sold them to waiting American buyers.

As Ojuela's reputation as a world-class specimen source grew, numerous rock shops stocked with Ojuela specimens began opening in Mapimí, Bermejillo, and Torreón. Throughout the

## November 2013 Mineral of the Month

1950s and 1960s, demand was increased by magazine articles that focused on the specimens' rarity and quality. Serious collectors and leading dealers from the United States began visiting the mine to buy directly from miners or pay the company for permission to collect their own specimens. In its inaugural issue in January 1970, *The Mineralogical Record* reported the 1969 find of two tons of colorless and blue-green adamite crystals. In 1979, miners found vugs lined with spectacular crystals of the rare mineral legrandite [basic hydrous zinc arsenate,  $\text{Zn}_2(\text{AsO}_4)(\text{OH})\cdot\text{H}_2\text{O}$ ]. Miners next recovered fine specimens of purple manganoan adamite, cabinet specimens of which sold for \$10,000 each at the 1982 Tucson (Arizona) Gem & Mineral Show. In 1988, miners recovered turquoise-blue cuprian adamite, and in 1992 golden crystals of ferrous adamite. In 1996, the loose arrangement of specimen collecting and buying at Ojuela ended when Tucson, Arizona-based Top-Gem Minerals contracted with both Compañía Minera de Penoles and the miners' cooperatives, making Top-Gem the sole authorized buyer and wholesale distributor of Ojuela specimens.

Although the Ojuela Mine has not produced ore in decades, it is still mined for mineral specimens. The extent of the underground workings is estimated at more than 250 miles. Although the lower levels are flooded, groups of miners lease upper sections of the mine to recover a variety of specimens, most notably austinite, conichalcite, adamite, and wulfenite [lead molybdate,  $\text{PbMoO}_4$ ].

Ojuela also yields specimens of the rare arsenates paradamite [basic zinc arsenate,  $\text{Zn}_2(\text{AsO}_4)(\text{OH})$ ]; lotharmeyerite [basic hydrous calcium zinc manganese arsenate,  $\text{Ca}(\text{Zn},\text{Mn})_2(\text{AsO}_4)_2(\text{OH},\text{H}_2\text{O})_2$ ]; metaköttigite [basic hydrous zinc iron arsenate,  $(\text{Zn},\text{Fe}^{3+})(\text{Zn},\text{Fe}^{3+}\text{Fe}^{2+})_2(\text{AsO}_4)_2\cdot 8(\text{H}_2\text{O},\text{OH})$ ]; mapimite [basic hydrous zinc iron arsenate,  $\text{Zn}_2\text{Fe}_3(\text{AsO}_4)_3(\text{OH})_4\cdot 10\text{H}_2\text{O}$ ]; ojuelaite [basic hydrous zinc iron arsenate,  $\text{Zn},\text{Fe}_2(\text{AsO}_4)_2(\text{OH})_2\cdot 4\text{H}_2\text{O}$ ]; scorodite [hydrous iron arsenate,  $\text{FeAsO}_4\cdot 2\text{H}_2\text{O}$ ]; carminite [basic lead iron arsenate,  $\text{PbFe}_2(\text{AsO}_4)_2(\text{OH})_2$ ]; villyaellenite [basic hydrous manganese calcium zinc arsenate,  $(\text{Mn},\text{Ca},\text{Zn})_5(\text{AsO}_4)_2(\text{AsO}_3)(\text{OH})_2\cdot 4\text{H}_2\text{O}$ ]; arsenosiderite [hydrous calcium iron oxyarsenate,  $\text{Ca}_2\text{Fe}_3(\text{AsO}_4)_3\text{O}_2\cdot 3\text{H}_2\text{O}$ ]; dussertite [basic hydrous barium iron arsenate,  $\text{BaFe}_3(\text{AsO}_4)_2(\text{OH},\text{H}_2\text{O})_6$ ]; and köttigite [hydrous zinc arsenate,  $\text{Zn}_3(\text{AsO}_4)_2\cdot 8\text{H}_2\text{O}$ ].

Other Ojuela specimens include hemimorphite [basic hydrous zinc silicate,  $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2\cdot \text{H}_2\text{O}$ ]; rosasite [basic copper zinc carbonate,  $(\text{Cu},\text{Zn})_2(\text{CO}_3)(\text{OH})_2$ ]; aurichalcite [basic zinc copper carbonate,  $(\text{Zn},\text{Cu})_5(\text{CO}_3)_2(\text{OH})_6$ ]; calcite [calcium carbonate,  $\text{CaCO}_3$ ]; fluorite [calcium fluoride,  $\text{CaF}_2$ ]; and malachite [basic copper carbonate,  $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$ ].

Limited specimen mining seems likely to continue at Ojuela, at least for the short term. But current high metal prices have encouraged Compañía Minera de Penoles, which still owns the mine, to study the feasibility of resuming full-scale mining of silver-lead and zinc ores.

Study your austinite specimen with an intense light source and a loupe or magnifying glass. Notice that it is a composite of three separate minerals. Austinite is present as drusy coatings of tiny, translucent, green crystals. The green color indicates that your specimen is cuprian austinite, in which copper has replaced some of the zinc and acts as a chromophore to produce the green color. Atop the austinite is a scattering of small, colorless, wedge-shaped calcite crystals that indicate two separate phases of crystallization. In the first phase, hydrothermal

# November 2013 Mineral of the Month

fluids deposited austinite; in the second and final crystallization phase, chemically different fluids precipitated calcite.

The matrix of your specimen consists of orange-brown limonite, which is not a mineral species, but an indeterminate mixture of hydrous iron oxides that forms in oxidation environments. Limonite results from the oxidation of such primary iron-sulfide minerals as pyrite [iron disulfide,  $\text{FeS}_2$ , cubic], marcasite [iron disulfide,  $\text{FeS}_2$ , orthorhombic], and arsenopyrite [iron arsenic sulfide,  $\text{FeAsS}$ ], all of which are abundant at Ojuela. In our specimens, several habits of limonite can be observed, including earthy, massive, and botryoidal. An orange-brown limonite matrix is characteristic of most Ojuela mineral specimens.

Your austinite specimen is a beautiful reminder of the Ojuela Mine which, when it comes to history, ore production, geochemistry and mineralogy, is one of the world's most remarkable mineral deposits.

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Co.; *2008 Fleischer's Glossary of Mineral Species*, Joseph Mandarino and Malcolm Back, The Mineralogical Record Company; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Co.; *Manual of Mineralogy*, Cornelius Hurlbut and Cornelia Klein, Twenty-first Edition, John Wiley & Sons; "Mapimi: Mineral Collectors' Capital of Mexico," P. W. Johnson, *The Mineralogist*, May-June 1962; "High-Temperature, Carbonate-Hosted Lead-Zinc-Silver Massive Sulfide Deposits of Mexico," Peter Megaw and Juan Ruíz, *Economic Geology*, Volume 83, 1988; "Tales from Mexico (Parts I and II)," B. Smith and C. Smith, editors, *Rocks & Minerals*, January-February and March-April 1999; "What's New in Minerals," John S. White, *The Mineralogical Record*, January-February 1970; *Mines and Minerals of Mexico, Volume Two: The Ojuela Mine*, Thomas P. Moore and Peter Megaw, The Mineralogical Record Company, 2003; "Famous Localities: The Ojuela Mine, Mapimí, Durango, Mexico," Thomas P. Moore and Peter Megaw, *The Mineralogical Record*, September-October 2003; "The Crystal Structure of Austinite," L. A. Clark, J. J. Pluth, et al, *Mineralogical Magazine*, Volume 61, 1997; "Chemical and Physical Properties of Austinite in Relation to Conichalcite," Dennis Radcliff and W. Bruce Simmons, *American Mineralogist*, Volume 20, 1971; "Austinite: A New Arsenate Mineral, from Gold Hill, Utah," Lloyd W. Staples, *American Mineralogist*, Volume 20, 1935.

**Mineral of the Month Club & Celestial Earth Minerals**

37-14 61st Street, Woodside, N.Y 11377

Phone # 800-941-5594

[www.celestialearthminerals.com](http://www.celestialearthminerals.com)