

# February 2014 Mineral of the Month

## ARAGONITE

This month we are featuring specimens of aragonite, a polymorphic form of calcium carbonate, from Morocco. Our write-up explains the origin of their pseudo-hexagonal form and brownish-orange color, and discusses the emergence of Morocco as a source of fine mineral specimens.

### PHYSICAL PROPERTIES

Chemistry: Calcium Carbonate  $\text{CaCO}_3$  Often containing small amounts of strontium, lead, barium, and zinc.

Class: Carbonates

Group: Aragonite

Crystal System: Orthorhombic

Crystal Habits: Usually as short-to-long, prismatic crystals with longitudinal striations and flat terminations; also fibrous, acicular, columnar, and stalactitic; occasionally drusy, compact, granular, and massive, the latter in layered-coralloid (skeletal), pisolitic, oolitic (small, rounded grains), and encrusting forms. Twinning common; untwinned crystals are rare. Twinned crystals form spear, chisel, or pseudo-hexagonal shapes, the latter consisting of three intergrown, individual crystals called “trillings.”

Color: Usually colorless or white, also pale gray, yellow, green, pink, reddish-orange, brownish-orange, purple, and lilac.

Luster: Vitreous to resinous

Transparency: Usually transparent to translucent, sometimes nearly opaque.

Streak: White

Refractive Index: 1.53-1.68

Cleavage: Good in one direction, poor in two others.

Fracture: Subconchoidal, brittle.

Hardness: 3.5-4.0

Specific Gravity: 2.95

Luminescence: Often fluorescent and phosphorescent

Distinctive Features and Tests: Prismatic form, one-directional cleavage, and frequent pseudo-hexagonal shape of twinned crystals. Can be confused with some forms of calcite [calcium carbonate,  $\text{CaCO}_3$ , hexagonal (trigonal)]; both aragonite and calcite effervesce in hydrochloric acid, but aragonite is harder and more dense.

Dana Classification Number: 14.1.3.1

**NAME:** Aragonite, pronounced ah-RAG-uh-nite, is named for its type locality at Molina de Aragón, Guadalajara, Castilla-La Mancha, Spain. Other names for aragonite are “orthorhombic calcite,” “aragon spar,” “chimborazite,” “conchite,” “arragonischer kalkspath,” “iglite,” “igloite,” “oserskite,” and “flos ferri” (flowers of iron), the latter a wormlike intergrowth that resembles branching coral. Variety names based on impurities include strontium-rich “mossottite” or “strontian aragonite,” zinc-rich “nicholsonite,” and lead-rich “tarnowitzite” or “plumbian aragonite.”

**COMPOSITION:** The chemical formula  $\text{CaCO}_3$  shows that aragonite contains the elements calcium, carbon, and oxygen. Its molecular weight is made up of 40.04 percent calcium (Ca), 12.0 percent carbon (C), and 47.96 percent oxygen (O). Aragonite is a member of the carbonates, a class of nearly 100 minerals in which metallic elements combine with the carbonate radical  $(\text{CO}_3)^{2-}$ . Aragonite forms in a number of mineralogical environments in igneous, metamorphic, and sedimentary rocks. It occurs with calcite [calcium carbonate,  $\text{CaCO}_3$ ] and gypsum [hydrous calcium sulfate,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ] in evaporite deposits of chemical-sedimentary rocks; in schists of regional metamorphic rocks; and in massive and disseminated, hydrothermal-replacement deposits. Aragonite is also present in sea-bottom sediments, coral-reef structures, and caves, and it is frequently a replacement mineral in fossils. Aragonite is much less common than calcite, a mineral with which it is polymorphic, meaning that it has an identical chemical composition but a different crystal structure.

**COLLECTING LOCALITIES:** Although uncommon, aragonite is widely distributed and has many collecting localities. Few, however, yield fine specimens. The best aragonite specimens come from Morocco, Spain, and Mexico. Other localities are in Namibia, South Africa, Democratic Republic of Congo, Italy, Austria, the Czech Republic, England, Scotland, Norway, Japan, Russia, Bolivia, Peru, Brazil, Australia, and Canada. In the United States, aragonite is collected in Arizona, California, Colorado, Wyoming, Idaho, Arkansas, Kentucky, Georgia, South Dakota, Louisiana, and Texas.

**HISTORY, LORE & USES:** Scientists recognized aragonite as a mineral species in 1790. The study of aragonite and the aragonite-group minerals played an important role in the 1812 discovery of isomorphism (the similarity of crystalline forms among unlike minerals) and the 1822 discovery of polymorphism (the dissimilarity of crystal forms among chemically identical minerals). The applications of aragonite are similar to those of calcite. It is used to manufacture cement, glass, acid-neutralization and agricultural-liming compounds, calcium-rich fertilizers, animal feeds, and white pigments. Because of its softness, aragonite has only limited use in jewelry and is usually fashioned into beads and irregular chips that are polished, drilled, and strung for wear in pendants and necklaces. Snuffboxes, figurines, and other decorative objects are carved from certain forms of banded aragonite, notably travertine, an aragonite-rich rock that forms in hot-springs environments. Metaphysical practitioners believe that aragonite enhances patience and responsibility, helps prepare for meditation, and reduces stress and anger. Because aragonite is thought to balance emotions and channel energy to constructive ends, it has been a traditional gift to the young.

**ABOUT OUR SPECIMENS:** Our aragonite specimens were collected at the village of Tazouta near the city of Sefrou in Sefrou Province, Féz-Boulemane Region, Morocco. Morocco is located on Africa's northwest shoulder and is south of the Strait of Gibraltar. Tazouta, population 2,000, is 100 miles east of the national capital of Rabat in the northern foothills of the Middle Atlas Mountains. Our specimens occur as clusters of crystals within reddish clay, the latter derived from weathered limestone. The calcium carbonate within the original limestone was deposited as calcite. The chemical action of acidic groundwater later dissolved the calcite within small sections of the limestone to create voids. Calcium-rich and carbonate-rich groundwater then filled these voids and, in conditions of low temperature and low pressure,

precipitated calcium and carbonate ions as aragonite. The limestone voids provided the space necessary for the excellent crystal development seen in our aragonite specimens. Although the aragonite in our specimens exhibits a six-sided shape, it does not crystallize in the hexagonal system. These crystals, which are described as pseudohexagonal, actually consist of three twinned crystals, or “trillings,” each making up one-third or 120° of the 360° crystal. For the past two decades, aragonite specimens from Tazouta have been popular among collectors and have ranked among the world’s best examples of aragonite. The crystals are collected from shallow diggings in outcrops of reddish clay by both commercial miners and individuals who sell them to dealers.

## COMPREHENSIVE WRITE-UP

### COMPOSITION

When we previously featured aragonite as a Mineral of the Month in 2009, our specimens were individual crystals with a delicate purple color from Retamal Ravine near Enguidanos, Cuenca Province, autonomous region of Castilla-La Mancha, Spain. Our current specimens, from Sefrou Province, Féz-Boulemane Region, Morocco, have a very different appearance, occurring as complex clusters of crystals with a brownish-orange color and a bright, vitreous luster. Members who have been with us since 2009 now have the opportunity to compare specimens of the same species from different localities.

The chemical formula  $\text{CaCO}_3$  shows that aragonite contains the elements calcium (Ca), carbon (C), and oxygen (O). Its molecular weight consists of 40.04 percent calcium, 12.0 percent carbon, and 47.96 percent oxygen. Aragonite is a member of the carbonates, a class of nearly 100 minerals in which metallic elements combine with the carbonate radical  $(\text{CO}_3)^{2-}$ . Radicals are groups of different atoms that act as entities in chemical reactions. As the basic structural unit of all carbonates, the carbonate radical consists of a carbon ion ( $\text{C}^{4+}$ ) covalently bound to three equidistant oxygen ions ( $3\text{O}^{2-}$ ). The +4 charge of the carbon ion together with the -6 charge of the three oxygen ions provide the carbonate radical with a collective -2 charge. Carbonate radicals are flat, triangular structures joined by the strong covalent bonds of shared electrons.

All molecules consist of cations (positively charged ions) and anions (negatively charged ions). In simple carbonate minerals such as aragonite, a single metal cation is bound to a single carbonate radical. Aragonite’s cation is the calcium ion  $\text{Ca}^{2+}$  with its +2 charge; its anion is the carbonate radical  $(\text{CO}_3)^{2-}$  with its -2 charge. The balance of the +2 cationic charge and the -2 anionic charge provides the aragonite molecule with electrical stability. As an anhydrous carbonate mineral, aragonite contains neither water molecules ( $\text{H}_2\text{O}$ ) nor hydroxyl ions ( $\text{OH}^-$ ). Of the roughly 70 anhydrous carbonates, only calcite and dolomite [calcium magnesium carbonate,  $\text{CaMg}(\text{CO}_3)_2$ ], are abundant.

Aragonite is a polymorphic form of calcium carbonate. The term “polymorph” refers to a single mineral compound that forms two or more different crystal structures. The word “polymorph” derives from the Greek words *polys* and *morphē*, meaning, respectively, “many” and “form.”

Calcite and aragonite are the most familiar polymorphic minerals. While consist of calcium carbonate and share the chemical formula  $\text{CaCO}_3$ , aragonite crystallizes in the orthorhombic system and calcite in the trigonal subsystem of the hexagonal system. Aragonite and calcite, along with vaterite, are actually trimorphs. Vaterite, a rare, high-temperature mineral with an identical chemistry, crystallizes in the hexagonal system with distinctly different habits of long, thin fibers and small, flat, platy crystals.

Carbonate minerals are the inorganic salts of carbonic acid ( $\text{H}_2\text{CO}_3$ ), a weak acid that consists of hydrogen ions ( $\text{H}^{1+}$ ) and bicarbonate ions ( $\text{HCO}_3$ )<sup>1-</sup>. Carbonic acid forms in shallow conditions when carbon dioxide ( $\text{CO}_2$ ) from the atmosphere or the chemical weathering of carbonate rocks dissolves in water according to the equation  $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$ . Under proper conditions of temperature, pressure, and chemistry, metal ions then bond ionically with the bicarbonate ions to form carbonate minerals and free hydrogen ions. In the case of calcium, this formula is  $\text{Ca}^{2+} + (\text{HCO}_3)^{1-} = \text{CaCO}_3 + \text{H}^{1+}$ .

Among the diagnostic properties of most carbonate minerals is a rapid reaction with acids, notably hydrochloric acid (HCl), to produce a visible effervescence. When contacted by hydrochloric acid, aragonite will effervesce as its carbonate radicals are replaced by the acid's highly reactive chlorine ions  $\text{Cl}^{1-}$ . The chemical equation  $\text{CaCO}_3 + 2\text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$  shows how hydrochloric acid reacts with aragonite to produce calcium chloride, water, and carbon dioxide, the latter a gas that creates the diagnostic bubbles of effervescence.

The aragonite crystal lattice contains alternating rows of calcium and carbonate ions, with nine oxygen ions surrounding each calcium ion. Because of this arrangement, aragonite crystallizes in the orthorhombic system, which has three perpendicular axes of different lengths. Within aragonite's lattice, weak ionic bonding dominates one atomic plane to account for aragonite's single direction of good cleavage. Although aragonite consists of the light elements calcium, carbon, and oxygen, close atomic packing within its lattice imparts a relatively high density (specific gravity 2.95). Close atomic packing also strengthens the atomic bonds to account for aragonite's hardness of 3.5-4.0, which is considerably greater than that of calcite (Mohs 3.0).

Aragonite forms at low temperatures and low pressures in igneous, metamorphic, and sedimentary rocks in several mineralogical environments. It is found with calcite and gypsum [hydrous calcium sulfate,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ] in evaporite deposits of chemical-sedimentary rocks; in schists of regional metamorphic rocks; and in massive and disseminated hydrothermal-replacement deposits. Aragonite also occurs in marine sediments, coral reefs, and caves, and it is a common replacement mineral in fossils. Aragonite is the primary component of such biogenic (produced by living organisms) materials as pearl, mother-of-pearl, coral, the shells of bivalves and univalve mollusks, plankton skeletons, and certain eggshells.

Aragonite commonly occurs as twinned, six-sided prisms. In twinning, minerals develop not as single crystals, but as composites with mathematically and structurally related parts. Twinning occurs during crystal growth when the normal sequence of atomic stacking is disrupted. In aragonite, the disruption of normal crystal growth forms composites with twinning angles of precisely  $120^\circ$ . This produces crystals with three composite twins (or "triplets") that are known as "trillings," each of which occupies one-third or  $120^\circ$  of the  $360^\circ$  crystal. Viewed in cross

section, this structure appears as a more-or-less uniform hexagon. Because aragonite crystallizes in the orthorhombic system and not in the hexagonal system, this six-sided form is properly described as “pseudo-hexagonal.” Twinned aragonite crystals consist of three intergrown, individual crystals with prominent, longitudinal striations.

As an allochromatic (other-colored) mineral, aragonite’s colors are usually created by color-causing, metallic impurities called chromophores. When pure or nearly pure, aragonite is colorless, white, or gray, but traces of impurities create a range of pale colors. Because aragonite forms in the low temperatures and low pressures of shallow environments, it often contains microscopic or small macroscopic inclusions that alter its color and degree of transparency. Inclusions of hematite [iron oxide,  $\text{Fe}_2\text{O}_3$ ] create the reddish color seen in our specimens.

Aragonite’s Dana mineral-classification number 14.1.3.1 identifies it as an anhydrous carbonate (14), meaning a carbonate without hydroxyl ions or attached water molecules. Aragonite is subclassified (1) by the general formula  $\text{ACO}_3$ , in which “A” can be ions of the divalent metals calcium, lead, strontium, barium, magnesium, iron, manganese, or zinc. Aragonite is then assigned to the aragonite group (3) as the first (1) of four members. These members, which all crystallize in the orthorhombic system, include witherite [barium carbonate,  $\text{BaCO}_3$ ], strontianite [strontium carbonate,  $\text{SrCO}_3$ ], and cerussite [lead carbonate,  $\text{PbCO}_3$ ]. Aragonite forms a partial solid-solution series with these minerals through limited cationic substitution, with barium, strontium, and lead ions substituting for calcium ions.

### *COLLECTING LOCALITIES*

Although uncommon, aragonite is widely distributed. Well-developed crystals are rare, however. Our specimens were collected at the village of Tazouta near the city of Sefrou in Sefrou Province, Féz-Boulemane Region, Morocco. Moroccan specimens are also collected at Touissit in Oujda-Angad Province, Oriental Region. Other African localities are the Tsumeb Mine in the Tsumeb district in Otjikoto Region and the Kombat Mine in the Grootfontein district in the Otjozondjupa Region, both in Namibia; the N’Chwaning mines in the Kalahari manganese field in Northern Cape Province, South Africa; and the Shinkolobwe Mine at Kakontwe in the Katanga Copper Crescent, Democratic Republic of Congo.

Spain’s sources include the Río Gallo type locality at Molina de Aragón in Guadalajara Province; and the Retamal and Tornagal ravines and Mingranilla near Enguidanos in Cuenca Province, Castilla-La Mancha. Italian localities include the Santa Barbara and Levane mines at Val d’Arno, Arezzo Province, Tuscany; and the Monte Somma quarries in the Somma-Vesuvius Geological Complex, Naples Province, Campania. Other European sources are the Christandl Quarry at Anger, Styria, Austria; Cicov Hill at Horenice, Ústí Region, Czech Republic; the Eskett Mine at Rowrah, West Cumberland iron field, Cumbria, England; the Brow and Hopeful veins at Leadhills, Strathclyde, Scotland; and the Kongsberg silver mines in Baskerud, Norway.

Other localities are the Matsushiro gypsum mine at Ota, Shimane Prefecture, Honshu Island, Japan; the Dal’negorsk mines, Primorskiy Krai, Far-Eastern Region, Russia; the El Dragón mine at Huanchaca, Quijarro Province, Potosí Department, Bolivia; the Raura district mines in

Catajambo Province, Lima Department, Peru; and the Jacupiranga Mine at Cajati near São Paulo, Southeastern Region, Brazil. Australian localities include the Mt. Isa district at Mt. Isa-Cloncurry, Queensland; the 132 North Mine at Widgiemooltha, Western Australia; and the Burra Burra Mine at Burra, Mt. Lofty Ranges, South Australia. Aragonite also occurs at the Ojuela Mine at Mapimí in Durango and the Santa Rosalía Mine in the Boleó district in Baja California Sur, both in Mexico; and at the Jeffrey Mine at Asbestos, Shipton Township, Richmond County, Québec, Canada.

Localities in the United States include the Mule Mountains at Bisbee in Cochise County and the Hamburg Mine in the Silver district in the Trigo Mountains of La Paz County, both in Arizona; the Jensen Quarry at Jurupa, Riverside County, California; South Table Mountain at Golden, Jefferson County, Colorado; the Leucite Hills in Sweetwater County, Wyoming; the Aragonite Crystal Mine at Clayton, Custer County, Idaho; the Monte Cristo Mine in the Rush Creek district, Marion County, Arkansas; the U.S. Highway 31 road cut at Muldraugh, Hardin County, Kentucky; and the Ladd Lime Quarry at Cartersville, Bartow County, Georgia. Other notable occurrences are South Dakota's Wind Cave National Park, the sulfur domes of Winn and Calcsieu parishes in southwest Louisiana, and the salt domes in Brazoria, Wharton, and Liberty counties in southeastern Texas.

### *JEWELRY AND DECORATIVE USES*

Although aragonite is too soft for use in rings and bracelets, it is fashioned into beads and irregular chips and polished and drilled for wear in pendants and necklaces. Aragonite is often a major component of travertine, a rock formed by the precipitation of calcium carbonate in hot-springs environments. Impurities in the precipitating solutions create banded travertine, which is fashioned into cabochons and such decorative objects as snuffboxes and figurines, and sold as “onyx marble,” “Mexican marble,” “Mexican onyx,” “suisan marble,” and “oriental alabaster.”

Aragonite is also the primary component of coral, pearl, and mother-of-pearl, all biogenic, composite materials consisting of organic and inorganic materials produced through biomineralization processes. Pearl and mother-of-pearl form when the cells of the soft bodies of bivalve and univalve mollusks secrete aragonite and organic materials. As polymer-ceramic composites, pearl and mother-of-pearl have a beautiful luster and unusual mechanical and optical properties. Pearls contain about 90 percent aragonite, 2 percent water, and 8 percent conchiolin, the latter an organic, horn-type substance made of proteins, polysaccharides, and lipids. The conchiolin binds microcrystalline platelets of aragonite together in radially oriented, concentric structures. Both the creamy glow of pearl and the iridescence of mother-of-pearl are caused by aragonite's birefringence, which is the ability to refract light in two slightly different directions.

### *HISTORY & LORE*

Powdered aragonite has served as a bright, white-paint pigment since antiquity. Scientists recognized aragonite as a mineral species in 1790 after studying specimens from the Río Gallo type locality at Molina de Aragón in the former Spanish kingdom of Aragón (now part of

Castilla-La Mancha, Spain). In 1797, German mineralogist Abraham Gottlieb Werner (1747-1817) formally named aragonite after Aragón, a general locality notation that still appears in some modern mineralogical literature. The study of aragonite and the aragonite-group minerals played an important role in the 1812 discovery of isomorphism (the similarity of crystalline forms among unlike minerals) and the 1822 discovery of polymorphism. In 1924, American physicist Lawrence Bragg (1890-1971) defined aragonite's crystal structure using newly developed X-ray diffraction methods.

Aragonite crystals have appeared on Austria's 3.50-shilling stamp of 1984, the five-dollar stamp of the Republic of China (Taiwan) of 1997, Spain's 30-peseta stamp of 1995, and the French Southern and Antarctic Territories' 5.10-franc stamp of 1990. Metaphysical practitioners believe that aragonite enhances patience and responsibility, reduces stress and anger, and helps one to prepare for meditation. Because it is thought to balance emotions and channel energy to constructive ends, aragonite beads and decorative objects are a traditional gift to the young.

### *THE MINES AND MINERALS OF MOROCCO*

In recent decades, Morocco has joined the likes of China, Peru, Madagascar, and Brazil as a major source of fine mineral specimens. Along with aragonite, our Mineral of the Month, Morocco is known for specimens of vanadinite, azurite, anglesite, wulfenite, erythrite, cerussite, and skutterudite. Morocco is also a leading source of fossils, notably those of trilobites and ammonoids.

Morocco's surprising importance as a source of mineral and fossil specimens belies its relatively small geographic size (see "About Our Specimens"). Most of Morocco's mineral and fossil deposits are linked to the nation's dominant topographical feature—the southwest-northeast-trending Atlas Mountains, a 1,500-mile-long mountain system that bisects the country and consists of the High (Haut, Grand) Atlas, Middle (Moyen) Atlas, and Anti Atlas sub-ranges. Most of Morocco's mineralization originated with the two major uplifts of the Atlas Mountains Orogeny. Following the crustal fracturing that accompanied these uplifts, mineral-rich, hydrothermal solutions surged upward into faults to create relatively small, but rich, deposits of silver, lead, zinc, and copper minerals. When ancient, shallow seas covered parts of Morocco, marine sediments created huge formations of phosphate rock.

The Phoenicians were mining silver, lead, copper, and salt in Morocco as early as 1000 B.C. Arabs mined rich outcrops of native silver at Zgrouder in western Morocco around 900 A.D. And by 1400 A.D, the Portuguese were mining silver and lead. Morocco's modern mining era began when France occupied the country in 1912. After Morocco gained its independence in 1956, many colonial-era mines ceased production and were replaced by a smaller number of more efficient, modern operations. Today, Morocco is a significant source of silver, lead, zinc, cobalt, and phosphate rock, with 90 companies mining 20 different mineral resources. Morocco's mining industry employs 40,000 workers and produces 2.7 billion dollars in minerals each year. Despite its small geographic size and an economy that ranks 54<sup>th</sup> in the world, Morocco ranks 2<sup>nd</sup> in production of phosphate rock, 4<sup>th</sup> in barite, 7<sup>th</sup> in silver, 11<sup>th</sup> in lead, and 16<sup>th</sup> in zinc.

Phosphate rock, a sedimentary rock containing microcrystalline apatite-(CaF) [calcium fluorophosphate,  $\text{Ca}_5(\text{PO}_4)_3\text{F}$ ], is Morocco's most valuable mineral resource. During the late Cretaceous and early Tertiary periods, parts of Morocco were submerged beneath shallow, warm seas that teemed with plankton and other tiny invertebrate organisms. Their phosphorus-rich remains mixed with sea-bottom sediments to lithify into massive formations of phosphate rock. Four Moroccan open pits now mine 28 million metric tons of phosphate rock annually, or about one-quarter of the world's production.

An estimated 5,000 Moroccans work in an informal mining sector that collects, processes, and markets specimens of minerals and fossils. Many old, inactive mining districts are now being mined for mineral specimens. Dozens of tour companies escort large numbers of foreign visitors into Morocco's mining districts, where many roads are lined with literally hundreds of makeshift rock shops. Morocco is noted mainly for the following minerals and fossils:

**Vanadinite** [lead chlorovanadinite,  $\text{Pb}_5(\text{VO}_4)_3\text{Cl}$ ] is collected mainly from the areas of Taouz, Mibladen, Oujda, and Touissit. The old mining district of Mibladen is now recognized as a classic locality for vanadinite, yielding specimens with well-developed, bright-red, hexagonal crystals.

**Anglesite** [lead sulfate,  $\text{PbSO}_4$ ] specimens from Touissit are acclaimed as some of the world's finest. Classic Moroccan anglesite specimens have well-developed, sharp-edged, transparent crystals; many are colorless, while others are bright yellow.

**Azurite** [basic copper carbonate,  $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ ] is another collectible mineral from Touissit. Copper-rich seams within lead-zinc mineralization yield crystals up to five inches in length and a half-inch in diameter. In the best specimens, lustrous, sharp-edged, deep-blue azurite crystal clusters are associated with forest-green malachite.

**Wulfenite** [lead molybdate,  $\text{PbMoO}_4$ ] is another well-known Touissit mineral. The best specimens of Moroccan wulfenite have bladed crystals up to one inch in size with bright, rich, orange-yellow and orange-red colors. Many specimens are associated with crystals of white-to-pink barite and colorless cerussite.

**Barite** [barium sulfate,  $\text{BaSO}_4$ ], mainly from the Touissit, Taouz, and Bou Azzer areas, is another popular collectible. Bladed crystals up to one inch in size, often stained a pinkish-red from hematite, occur in tightly packed, undulating clusters in association with wulfenite and cerussite.

**Cerussite** [lead carbonate,  $\text{PbCO}_3$ ] is also found at Touissit. The most desirable specimens are clusters of well-developed, twinned, transparent, colorless or smoky crystals as long as three inches. Many cerussite specimens occur in colorful composites in association with barite and wulfenite.

**Skudderudite** [cobalt arsenide,  $\text{CoAs}_3$ ] and **erythrite** [cobalt arsenate,  $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ ] are collected in the Bou Azzer area near Quarzazate, where cobalt has been mined for decades. The



uncommon mineral skutterudite forms clusters of silver-gray cubes or dodecahedrons with rough, irregular faces. Erythrite, with bright colors ranging from pink, rose, and violet-red to purple, occurs in clusters of bladed crystals up to two inches in size.

**Geodes** are another popular Moroccan collectible, especially those that are filled with agate or lined with colorless or amethystine quartz crystals, most of which are collected from massive basalt formations near Sidi Rahal. Another source of quartz-crystal-lined geodes is the Bou Craa phosphate mine in the Saguia el-Hamra region.

**Ammonoid fossils** are another important export. Morocco supplies large quantities of relieved and polished ammonoid fossils, most of which, along with fossilized dinosaur teeth, trilobites, and crinoids, are recovered near Erfoud, where fossiliferous limestone “plates” up to six feet in size and containing hundreds of individual fossils are mined from open pits.

Many impressive mineral and fossil collections have been assembled solely from Moroccan specimens. And in just the last six years, in further testimony to the quality and quantity of Moroccan minerals specimens, the Mineral of the Month Club has featured hematite from the Ourjane Mine near Alnif, quartz-lined geodes from the Bou Craa phosphate mine in Western Sahara, vanadinite from Mibladen, the sand-rose variety of gypsum from Erg Chebbi, and this month’s featured mineral—aragonite from Tazouta in Sefrou Province.

### *TECHNOLOGICAL USES*

Because aragonite is often one of the minerals (along with calcite) that make up the calcareous content of limestone, it is a commercial source of calcium carbonate. After quarrying, limestone is calcined (roasted) into calcium oxides and oxysilicates that have many uses. Nearly pure aragonite occurs in the Bahamas as thick, sea-bottom layers that are the remains of shells and skeletons of tiny marine organisms. Suction dredges recover large quantities of this sea-bottom aragonite as a raw material to manufacture cement, glass, agricultural acid-neutralization compounds, and calcium-rich fertilizers and animal feeds. Powdered aragonite, or “crystal whiting,” is an unusually brilliant white pigment because its strong birefringence reflects creamy interference colors, while its fluorescence complements the reflection of white light.

Materials scientists have long noted that conch and abalone shells, which consist mostly of aragonite, are substantially harder and tougher than pure crystalline aragonite. This is because the molecular interlayering of aragonite and protein binders imparts a flex to the shell material that resists cracking and abrading. This structural interlayering concept is now used to manufacture load-bearing ceramics for aerospace and computer applications.

### *ABOUT OUR SPECIMENS*

Our aragonite specimens were collected at the village of Tazouta near the city of Sefrou in Sefrou Province, Féz-Boulemane Region, Morocco. The Kingdom of Morocco is located on Africa’s northwest shoulder, directly south of the Strait of Gibraltar. The Atlantic Ocean is to

Morocco's northwest, the Mediterranean Sea to the north, Tunisia to the northeast, Algeria to the east and south, and Western Sahara (a contested territory claimed and administered by Morocco) to the southwest. Covering 172,413 square miles, Morocco is somewhat larger than the American state of California. A former French territory, Morocco gained its independence in 1956. The country is roughly bisected by the southwest-northeast-trending Atlas Mountains (see "The Mines and Minerals of Morocco"), which include the High (Haut, Grand) Atlas, Middle (Moyen) Atlas, and Anti Atlas sub-ranges.

Tazouta, population 2,000, is a village in the northern foothills of the Middle Atlas Mountains about 100 miles east of the national capital of Rabat. At an elevation of 2,800 feet, Tazouta is located just south of the city of Sefrou, population 63,000. An ancient, walled city that dates to 900 A.D., Sefrou is now a regional marketing and commercial center, and is a well-known source of rugs, mutton, and wool.

The regional topography is traced to the two uplifts of the Atlas Mountains Orogeny (see "The Mines and Minerals of Morocco"). The first occurred 300 million years ago when crustal stresses associated with the rifting of the Pangaeian supercontinent uplifted huge blocks of sandstone and iron-rich limestone. Long after erosion had nearly leveled these mountains, the collision of the African and Eurasian plates some 80 million years ago uplifted massive formations of Cretaceous Period limestone, sandstone, and shale.

The calcium carbonate within the original Tazouta limestone was deposited as calcite. Later, the chemical action of acidic groundwater dissolved this calcite, creating voids within the limestone and enriching the groundwater solutions with calcium and carbonate ions. This groundwater eventually refilled the voids where, in conditions of low temperature and low pressure, the calcium and carbonate ions precipitated in the form of aragonite. The voids provided the space necessary for the excellent crystal development of our aragonite specimens.

After pockets of aragonite crystals had formed, the iron-rich limestone weathered into clay with a rich, reddish color caused by particulate hematite [iron oxide,  $\text{Fe}_2\text{O}_3$ ]. This clay, known as *terra rosa*, is common throughout the Mediterranean region where it is used extensively in brick and terra-cotta roof tiles. *Terra rosa* brick and tile products are used so extensively in Marrakech that this trading center in western Morocco is known as the "Red City."

Specimens of well-formed, brownish-orange aragonite crystals from Tazouta reached European markets in the 1960s, but received little attention. Then in the 1980s, after mineral specimens had become big business in Morocco, commercial collectors returned to Tazouta. For the past two decades, Tazouta aragonite specimens have been widely acclaimed among collectors. These crystals are now gathered by commercial specimen miners who sell them to dealers. The crystals are recovered from an open outcrop in a series of shallow diggings and "rat holes." Collecting is usually done in spring, when the runoff of mountain snow provides water to wash the reddish clay from the specimens. The village of Tazouta is often misrepresented in locality notations as the "Middle Atlas Mountains" and the "Tazouta Mine."

As you study your aragonite specimen, notice that the crystal cross sections have the six-sided shape of hexagons. This shape is not indicative of the hexagonal crystal system, however, but

instead results from twinning within the orthorhombic system. Each crystal consists of three composite twins, called “trillings.” Each has a twinning angle of 120° and occupies one-third of the crystal. Because aragonite crystallizes in the orthorhombic system and not the hexagonal system, this six-sided form is known as “pseudo-hexagonal.” Note also the prominent, parallel, longitudinal striations on the prismatic faces and the flat terminations, both of which are diagnostic features of aragonite.

The aragonite crystals have a bright, vitreous luster and range from nearly colorless to a rich brownish-orange. As an allochromatic mineral, pure aragonite is colorless, white, or gray, but traces of impurities, inclusions, coatings, and geophysical radiation can sometimes impart an array of colors. The brownish-orange colors in our specimens are due to microscopic and tiny macroscopic particles of hematite. This hematite, present in the original limestone, was carried in the solutions that precipitated the aragonite and became included within the crystals. Viewed with backlighting, this prominent color zoning is readily apparent. The crystal terminations tend to be very pale or nearly colorless, with the brown-orange color concentrated at the crystal bases. Also, the terminations have the greatest transparency, while the bases are more translucent.

Your specimen has a noticeable “heft” in the hand. Because of its close atomic packing, aragonite is about 10 percent denser than calcite. Therefore, the “heft” of your aragonite specimen is that much greater than the same volume of calcite. Your specimen may also contain small quantities of colorless or white, massive calcite. The rough-textured, brownish-orange material in your specimen is clay that is derived from the weathering of the original limestone. Your specimen is both a fine example of pseudo-hexagonal aragonite and a reminder of the many mineral specimens that are now coming from Morocco.

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