

July 2009 Mineral of the Month: Aragonite

This month's mineral, aragonite, was collected from exposures of a Triassic-age sedimentary formation in Spain. Our unusual specimens are twinned crystals that exhibit both pseudomorphic and polymorphic forms. Read on to learn about the cause of their rare purple color, the interesting polymorphic relationship between aragonite and the familiar mineral calcite, and to become an expert on "trillings."

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: Calcium Carbonate CaCO_3 Often containing small amounts of strontium, lead, barium, and zinc

Class: Carbonates

Group: Aragonite

Crystal System: Orthorhombic

Crystal Habits: Usually short-to-long prismatic with longitudinal striations, also fibrous, acicular, columnar, and as stalactitic aggregates; sometimes drusy, compact, granular, and massive, the latter in layered coralloid (skeletal), pisolitic, oolitic (small, rounded grains), and encrusting forms; untwinned crystals rare; twinned crystals form spear, chisel or pseudo-hexagonal-prismatic shapes; twins commonly consist of three intergrown, individual crystals called "trillings."

Color: White, colorless, pale hues of gray, yellow, green, pink, purple, and lilac

Luster: Vitreous to resinous

Transparency: Transparent to translucent

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: Fluorescent and phosphorescent

Distinctive Features and Tests: Prismatic, one-directional cleavage and pseudo-hexagonal shape of twinned crystals. Can be confused with certain forms of calcite [calcium carbonate, CaCO_3]; both aragonite and calcite effervesce in hydrochloric acid, but aragonite is harder and more dense.

Dana Classification Number: 14.1.3.1

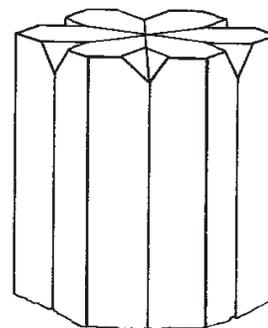


Figure 1. Aragonite crystal. Drawings courtesy of *Mineralogy* by John Sinkankas, used by permission.

NAME Aragonite, pronounced ah-RAG-uh-nite, is named for its type locality at Molina de Aragón, Guadalajara, Castilla-La Mancha, Spain. We wonder why, since Aragón is pronounced ah-rah-GAWN, with the accent on the last syllable, this month's mineral is not pronounced ah-rah-GAWN-ite? Oh well. Other names for aragonite include "aragon spar," "chimborazite," "conchite," "arragonischer kalkspath," "iglite," "igloite," "oserskite," and "flos ferri" ("flowers of iron"), the latter a wormlike intergrowth resembling branching coral. Informal variety names based on contained impurities include strontium-rich "mossottite" or "strontian aragonite," lead-rich "tarnowitzite" or "plumbian aragonite," and zinc-rich "nicholsonite."

COMPOSITION: Aragonite, chemical formula CaCO_3 , contains the elements calcium (Ca), carbon (C), and oxygen (O). Its molecular weight is made up of 40.04 percent calcium, 12.0 percent carbon, and 47.96 percent oxygen. Aragonite forms in a wide variety of mineralogical environments in igneous, metamorphic, and sedimentary rocks. It occurs with calcite [calcium carbonate, 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

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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 is frequently a replacement mineral in fossils. Aragonite is much less common than calcite, a mineral with which it is polymorphic, meaning that it shares the identical chemical composition of calcium carbonate but crystallizes in a different structure.

COLLECTING LOCALITIES: Aragonite is collected in Spain near Enguidanos and Mingranilla in Cuenca Province; and at the type locality at the Río Gallo at Molina de Aragón in adjacent Guadalajara Province, both in the autonomous region of Castilla-La Mancha. Aragonite is found in Italy at the Santa Barbara and Levane mines at Val d'Arno, Tuscany; in Austria at the Christandl Quarry in Styria; in the Czech Republic at Cicov Hill in the Ústi Region; and in England at the Eskett Mine at Rowrah in Cumbria. Fine specimens come from the Matsushiro gypsum mine at Ota, Japan, and from the Tazouta Mine in Sefrou Province, Morocco. This latter locality furnished the specimens we sent to Club members when we first featured aragonite in June 2000.

Sources in the United States include the Aragonite Crystal Mine at Clayton, Idaho, and the Monte Cristo Mine in Marion County, Arkansas. At South Dakota's Wind Cave National Park, drusy aragonite makes up the glittering, white "frost" that covers the walls of underground "rooms."

HISTORY, LORE, & USES: Scientists recognized aragonite as a distinct mineral species in 1790. The study of aragonite played an important role in the 1822 discovery of polymorphism (the dissimilarity of crystal forms among chemically identical minerals). Aragonite 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. Snuff boxes, figurines, and other decorative objects are carved from certain forms of banded aragonite. According to metaphysical practitioners, 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 has been a traditional gift for the young.

ABOUT OUR SPECIMENS: Most of our specimens were collected at Retamal Ravine near the village of Enguidanos in Cuenca Province in the autonomous region of Castilla-La Mancha, Spain. Their source is the Keuper sedimentary formation of Triassic age, which consists of intermixed layers of sandstone, limestone, shale, gypsum, clay, and marl. They were recovered by commercial mineral collectors from outcrops of soft marl, a mixture of calcareous silt and clay, by digging, washing, and screening the sediments. Our aragonite crystals formed in relatively recent geologic time when calcite dissolved and recrystallized in the form of aragonite. Although our specimens exhibit a six-sided shape, they do not crystallize in the hexagonal system. They are actually pseudohexagonal, twinned crystals or "trillings" composed of three composite parts, each of which make up one-third or 120° of the 360° crystal.

10 YEARS AGO IN OUR CLUB: Tetrahedrite from Casalpaca District, Peru. This is the only mineral from the sulfosalts class that we have obtained in sufficient quantity so as to feature it in our Club! Sulfosalts are complex sulfide minerals with the general formula AB_2S_3 , where A represents a metal such as copper, lead, or silver; B represents a semi-metal such as arsenic, antimony or bismuth; and S is sulfur or rarely selenium. The write-up highlighted the difficulty of purchasing minerals in Peru, saying in part: "Those who venture to the mines to purchase specimens are advised to bring four wheel drive vehicles, along with their own food and drinking water, and some good all-around antibiotics and painkillers. Why? Because most mining takes place at altitudes over 12,000 feet, where altitude sickness is common, and where water cannot be boiled at high enough temperature to kill all the bacteria in it." Such knowledge makes us appreciate the efforts and sacrifices involved in procuring the minerals we enjoy—don't take it for granted!

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COMPREHENSIVE WRITE-UP

COMPOSITION

This is now the third time we have featured aragonite. In June 2000, we sent Club members specimens similar in form to this month's aragonite, but with a root beer brown color, from the Tazouta Mine at Sefrou in Sefrou Province in the Fés-Boulemane Region, Morocco. In January 2004, we sent matrix specimens containing sharp yellow aragonite prisms, from the Northern Lights Mine, Warsuk range, Mineral County, Nevada. We're excited to have procured these unusual lilac to purple pieces this month!

With a chemical formula of CaCO_3 , 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 $(\text{CO}_3)^{2-}$. The carbonate radical, the fundamental structural unit of all carbonates, consists of a central carbon ion (C^{4+}) covalently bound to three equidistant oxygen ions (3O^{2-}). The +4 charge of the carbon ion together with the -6 charge of the three oxygen ions provide the carbonate ion with a collective -2 charge. Carbonate anions are flat, triangular structures held together by the strong bonds of covalently shared electrons.

In simple carbonate minerals such as aragonite, a single metal cation is bound to a single carbonate radical. The aragonite cation is the calcium ion Ca^{2+} with its +2 charge; the anion is the carbonate radical $(\text{CO}_3)^{2-}$ with its -2 charge. The balance of cationic and anionic charges provides the aragonite molecule with electrical stability. As an anhydrous carbonate mineral, aragonite contains no water molecules (H_2O) or hydroxyl ions $(\text{OH})^{1-}$. Of the roughly 70 anhydrous carbonates, only calcite and dolomite [calcium magnesium carbonate, $\text{CaMg}(\text{CO}_3)_2$], are abundant. Aragonite is much less common than calcite, a mineral with which it is polymorphic, meaning that it has an identical chemistry, but a different structure (see "The Phenomenon of Mineral Polymorphism").

Carbonate minerals are the inorganic salts of carbonic acid (H_2CO_3), which consist of hydrogen ions (H^{1+}) and bicarbonate ions $(\text{HCO}_3)^{1-}$. Carbonic acid forms in near-surface conditions when carbon dioxide (CO_2) from the atmosphere or the chemical weathering of carbonate rocks dissolves in water according to the formula $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$. Under proper conditions of temperature, pressure, and chemistry, metal ions then bond ionically with the resulting bicarbonate ions to form carbonate minerals and free hydrogen ions. In the case of calcium, this formula is $\text{Ca}^{2+} + (\text{HCO}_3)^{1-} = \text{CaCO}_3 + \text{H}^{1+}$.

Aragonite, calcite, and most other carbonate minerals react readily with acids, notably hydrochloric acid (HCl). In contact with hydrochloric acid, aragonite will effervesce as the acid's extremely reactive chlorine ions (Cl^{1-}) quickly replace the carbonate radicals in the aragonite. The chemical formula $\text{CaCO}_3 + 2\text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$ shows how hydrochloric acid reacts with aragonite to produce calcium chloride, water, and carbon dioxide, the latter a gas that forms diagnostic bubbles of effervescence.

The aragonite crystal lattice is built upon alternating rows of calcium and carbonate ions, with each calcium ion surrounded by nine oxygen ions. This arrangement causes aragonite to crystallize in the orthorhombic system, which is characterized by three perpendicular axes of different lengths. Within this lattice, weak ionic bonding dominates one atomic plane to account for aragonite's single direction of good cleavage. Although aragonite consists of light elemental components, it has a relatively high density (specific gravity 2.95) because of close atomic packing within its lattice. Close atomic packing also shortens the distance between ions within the lattice, thus strengthening the atomic bonds to account for aragonite's moderate hardness of 3.5-4.0.

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Aragonite forms in conditions of low temperature and low pressure in igneous, metamorphic, and sedimentary rocks in a variety of 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 sea sediments, coral-reef structures, and caves, and is a common replacement mineral in fossils. Because of its affinity for magnesium and sulfate ions, aragonite frequently precipitates with gypsum and brucite [magnesium hydroxide, $\text{Mg}(\text{OH})_2$]. 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.

The Dana mineral-classification number 14.1.3.1 identifies aragonite as an anhydrous carbonate (14) without hydroxyl ions or attached molecules of water. Aragonite is subclassified (1) by the general formula ACO_3 , in which "A" can be ions of such divalent metals as calcium, lead, strontium, barium, magnesium, iron, manganese, and zinc. Aragonite is then assigned to the aragonite group (3) as the first (1) of four members. These members, all crystallizing in the orthorhombic system and sharing similar, but not identical chemistries, include witherite [barium carbonate, BaCO_3], strontianite [strontium carbonate, SrCO_3], and cerussite [lead carbonate, PbCO_3]. Aragonite forms partial solid-solution series with these minerals through limited cationic substitution in which barium, strontium, and lead ions substitute for calcium ions.

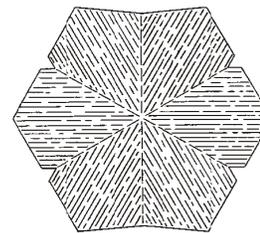


Figure 2. Top view of pseudo-hexagonal aragonite crystal.

Aragonite commonly occurs as twinned, six-sided prisms, the form seen in our specimens. In twinning, minerals develop not as single crystals, but as composite crystals with their parts mathematically and structurally related. 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° , resulting in crystals with three composite twins (or in this case, "triplets") known as "trillings." Each of the three parts of a trilling occupies one-third or 120° of the 360° crystal, as seen in the drawing in Figure 2. When viewed in cross section, this structure appears as a uniform hexagon. Because aragonite crystallizes in the orthorhombic system and not the hexagonal system, this six-sided form is called "pseudo-hexagonal." Most 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 wide range of pale colors. In aragonite, pink is caused by cobalt, purple and lilac by manganese, yellow by cadmium and iron, and green or green-blue by copper. Two other factors can also contribute to aragonite's color. Aragonite that forms in the low temperatures and low pressures of shallow sediments often contains microscopic or small macroscopic inclusions that can alter both color and degree of translucency. The ionizing effects of natural geophysical radiation can also disrupt aragonite's normal lattice structure to create purple colors (see "About Our Specimens").

With its many mineralogical associations, color variations, and crystal habits, some of which are similar to those of calcite, aragonite can be difficult to identify and is often confused with calcite. Because of their identical chemistries, aragonite and calcite both effervesce in hydrochloric acid. When prepared in thin section and viewed through a polarizing microscope, aragonite can sometimes be distinguished from calcite on the basis of cleavage and twinning. However, X-ray diffraction is often required to positively differentiate these two species.

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THE PHENOMENON OF MINERAL POLYMORPHISM

In its mineralogical context, the term “polymorph” refers to a single mineral compound that exists in two or more different crystal structures. The word “polymorph” derives from the Greek words polys and morph, meaning, respectively, “many” and “form.” Calcite and aragonite are among the most familiar of the polymorphic minerals. Both consist of calcium carbonate and share the chemical formula CaCO_3 , but aragonite crystallizes in the orthorhombic system and calcite in the rhombohedral system. Along with vaterite [calcium carbonate, CaCO_3], aragonite and calcite are actually trimorphs. Vaterite, which has an identical chemistry, is a high-temperature mineral that crystallizes in the hexagonal system as long, thin fibers and small, flat, platy crystals.

The German chemist and mineralogist Eilhardt Mitscherlich (1794-1863) discovered the phenomenon of mineral polymorphism in 1822. Mitscherlich developed an intense interest in mineralogy while studying medicine and chemistry. In 1818, he began studying the angles and forms of mineral crystals, focusing on the work of British chemist William Wollaston (1766-1828), who in 1812 had discovered isomorphism (the similarity of crystalline forms between unlike minerals). Working with calcite crystals, Mitscherlich noted that the crystal-face angles of calcite varied with heating—the first evidence of the phenomenon of polymorphism. Mitscherlich’s discovery helped to overturn the prevailing but erroneous view of French crystallographer René-Just Haüy (1743-1822) that crystals consisted of “integral molecules,” essentially microcrystals of the same shape that could not be further subdivided. But based on his understanding of polymorphism, Mitscherlich instead proposed that crystals consisted of tiny units. Although aligned in a fixed structure, these units sometimes thermally expanded or contracted to alter that structure—an important concept that would contribute to the evolution of atomic theory a century later.

Today, mineralogists explain polymorphism as a structural alteration caused by changes in the sizes of atoms when subjected to different conditions of temperature and pressure, and to the resultant effects on atomic bonding arrangements. As pressure increases, the volume of a crystal will decrease to a point where it can sometimes achieve stability in a different structure. Similarly, a rise in temperature increases the vibration of atoms and expands the orbits of their electrons, thus increasing their effective sizes, which can also alter the atomic-bonding arrangements within the crystal structure. Polymorphic minerals do not necessarily have to crystallize in different crystal systems; they need only to differ in their atomic-bonding arrangements, atomic structures, and physical properties.

Aragonite and calcite are textbook examples of polymorphs because of their significant physical and structural differences. In calcite, the carbonate ions are aligned in the same direction and lie within a single plane. But in aragonite, they lie in two planes that are aligned in opposite directions, thus disrupting the rhombohedral symmetry of calcite. The aragonite group further differs in structure from the calcite group in that its metal cations are shielded by nine rather than six oxygen ions. With its orthorhombic structure, aragonite has a single plane of good cleavage, while calcite, with its rhombohedral structure, has perfect rhombohedral cleavage in three directions. In the aragonite structure, atomic packing is much closer than in the calcite structure. This makes aragonite (specific gravity 2.95) significantly denser than calcite (specific gravity 2.7). Because closer atomic packing shortens the length of atomic bonds to increase bonding strength, aragonite (Mohs 3.5-4.0) is considerably harder than calcite (Mohs 3.0).

The combination of temperature, pressure, and chemistry at the time of crystallization determines whether calcium carbonate will crystallize in the orthorhombic system as aragonite, in the rhombohedral system as calcite or, albeit rarely, in the hexagonal system as vaterite. The presence of barium, strontium, lead,

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magnesium, and sulfate ions in mineral fluids favors the formation of aragonite, while high concentrations of calcium ions favor the formation of calcite. But as the calcium-ion concentration of the crystallizing fluids gradually deplete, calcium carbonate may complete its crystallization as aragonite, which explains why some calcite-crystal terminations (the final part of crystal growth) consist of aragonite.

Polymorphic minerals have different structural stabilities at different conditions of temperature and pressure. At the ambient temperature and pressure of the Earth's surface, calcite is stable and will retain its rhombohedral structure indefinitely. Aragonite, however, is metastable, meaning its stability is limited, and structural transformation is therefore possible or even probable. Over very long periods of time, aragonite will transform to calcite, often forming calcite-after-aragonite pseudomorphs. When heated to 400 ° F. with no increase in pressure, aragonite will spontaneously transform to calcite.

Interestingly, aragonite is the polymorphic member of the aragonite-group minerals. Aragonite-group minerals have large metal cations that achieve stability in an orthorhombic structure. Calcite-group minerals, which have smaller metal cations, are stable in the rhombohedral structure. Calcium ions, however, have a "borderline" radius that enables calcium carbonate to crystallize as calcite under most conditions, but as aragonite under conditions of low temperature and pressure. Because the radius of the calcium ion is right at the dividing point in stability, calcium ions are stable in the calcite structure, but unstable in the aragonite structure.

Thanks to advanced analytical methods and greater understanding of crystallography, many new minerals now being recognized by mineralogists are rare polymorphs of previously recognized species.

Among the many familiar polymorphic minerals are:

- 1. Carbon (C): diamond (cubic), graphite (hexagonal), lonsdaleite (hexagonal), and chaoite (hexagonal).*
- 2. Iron disulfide (FeS₂): pyrite (cubic), marcasite (orthorhombic).*
- 3. Silicon dioxide (SiO₂): quartz (hexagonal), cristobalite (tetragonal), tridymite (triclinic), coesite (monoclinic), and stishovite (tetragonal). The latter four are metastable at ambient temperature and pressure and eventually transform to quartz.*
- 4. Titanium dioxide (TiO₂): brookite (orthorhombic), anatase (tetragonal), and rutile (tetragonal).*
- 5. Aluminum silicate (Al₂SiO₅): kyanite (triclinic), andalusite (orthorhombic), sillimanite (orthorhombic).*
- 6. Potassium aluminum silicate (KAlSi₃O₈): orthoclase (monoclinic) and microcline (triclinic).*
- 7. Manganese dioxide (MnO₂): pyrolusite (tetragonal), ramsdellite (orthorhombic), and akhtenskite (hexagonal).*

The phenomenon of isomorphism is an interesting counterpart to polymorphism. The word isomorphism derives from the Greek words isos and morph, respectively meaning "equal" and "form" or "same form."

Isomorphous minerals have differing chemistries, but identical or nearly identical crystal structures. Examples are the aragonite-group members witherite [barium carbonate, BaCO₃], strontianite [strontium carbonate, SrCO₃], and cerussite [lead carbonate, PbCO₃]. Despite their different chemistries, the similar atomic radii of barium, strontium, and lead enable all to crystallize in the orthorhombic system with identical atomic-bonding arrangements and atomic structures.

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COLLECTING LOCALITIES

Although uncommon, aragonite is widely distributed in a wide range of mineralogical environments. However, relatively few collecting sites yield truly fine crystals. Our Platinum-level and Gold-level specimens were collected at what is now recognized as a classic locality for aragonite—Retamal Ravine near the village of Enguidanos in Cuenca Province in the autonomous region of Castilla-La Mancha, Spain. Among other nearby sources in Cuenca Province are Tornagal Ravine and the village of Mingranilla, which is where our Silver-level aragonites were collected. We almost always send all Club members specimens from the same locality, but sometimes it is not possible, and this is one of those months—not enough small aragonites are found at Retamal Ravine, not nearly what we need for our Silver-level members. Happily, good quality specimens with the same crystal form but a different color are collected at this nearby locality. Specimens are also collected at the aragonite type locality along the Río Gallo at Molina de Aragón in neighboring Guadalajara Province.

Aragonite specimens are collected in Italy at the Santa Barbara and Levane mines at Val d'Arno, Arezzo Province, Tuscany, and the numerous quarries at Monte Somma in the Somma-Vesuvius Geological Complex, Naples Province, Campania; in Austria at the Christandl Quarry at Anger, Styria; in the Czech Republic at Cicov Hill at Horenic in the Ústi Region; in England at the Eskett Mine at Rowrah in the West Cumberland iron field in Cumbria; in Scotland at the Brow and Hopeful veins at Leadhills, Strathclyde; and in Norway at the Kongsberg silver mines in Kongsberg, Baskerud.

Morocco provides fine aragonite specimens, notably from the Tazouta Mine at Sefrou in Sefrou Province in the Fés-Boulemane Region, and the Toussit district mines at Toussit in Oujda-Angad Province in the Oriental Region. In Namibia, specimens come from the Tsumeb Mine in the Tsumeb district in the Otjikoto Region, and the Kombat Mine in the Grootfontein district in the Otjozondjupa Region. South African specimens are collected at the N'Chwaning mines in the Kalahari manganese field in Northern Cape Province. Another notable African source is the Shinkolobwe Mine at Kakontwe in the Katanga Copper Crescent of the Democratic Republic of Congo.

Australian sources include the Mt. Isa district in the Mt. Isa-Cloncurry area of Queensland, the 132 North Mine at Widgiemooltha in Western Australia, and the Burra Burra Mine at Burra in the Mt. Lofty Ranges in South Australia. In Japan, specimens are collected at the Matsushiro gypsum mine at Ota in Shimane Prefecture on Honshu Island; in Russia at the Dal'negorsk mines in Primorskiy Krai in the Far-Eastern Region; in Bolivia at the El Dragón mine at Huanchaca in Quijarro Province in Potosí Department; in Peru at the Raura district mines in Catajumbo Province in Lima Department; and in Brazil at the Jacupiranga Mine at Cajati near São Paulo in the Southeastern Region.

In North America, aragonite specimens are collected in Mexico at the Ojuela Mine at Mapimí in Durango and the Santa Rosalía Mine in the Boleó district in Baja California Sur; and in Canada at the Jeffrey Mine at Asbestos in Shipton Township, Richmond County, Québec. Localities in the United States include the Mule Mountains caves near 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 in Riverside County, California; South Table Mountain near Golden in Jefferson County, Colorado; the Leucite Hills in Sweetwater County, Wyoming; the Aragonite Crystal Mine at Clayton in Custer County, Idaho; the Monte Cristo Mine in the Rush Creek district of Marion County, Arkansas; the U.S. Highway 31 road cut at Muldraugh in Hardin County, Kentucky; and the Ladd Lime Quarry at Cartersville in Bartow County, Georgia. Aragonite is common in the sulfur domes of Winn and Calcsieu parishes in southwest Louisiana, and in the salt domes in Brazoria, Wharton, and Liberty counties in southeastern Texas. Drusy, white aragonite makes up the glittering “frost” that covers the walls of several underground chambers at South Dakota's Wind Cave National Park.

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JEWELRY & DECORATIVE USES

Although too soft for use in rings and bracelets, aragonite is fashioned into beads, scarabs, and polished chips that are drilled and strung for wear in pendants, necklaces, and earrings. Golden aragonite is especially popular in wire-wrap, silver-pendant settings. Aragonite is often the primary component of travertine, a rock formed when calcium carbonate precipitates in hot-springs environments. Impurities in the precipitating solutions sometimes create attractive color banding. Banded travertine is cut into cabochons and decorative objects such as snuffboxes and figurines and marketed as “onyx marble,” “Mexican marble,” “Mexican onyx,” “suisan marble,” and “oriental alabaster.” A tremendous amount of this material, mined in Pakistan, is fashioned into plates, cup, vases, bookends, spheres, and eggs and sold at shows as “onyx.” This is confusing to new and casual collectors, who may assume the material to be the onyx variety of quartz—we wish they would just call it “travertine,” or at least “travertine onyx,” to avoid confusion. Now we’re starting to see similar large objects made of lovely Chinese marble but called jasper! Why can’t we just call things by their correct name?

Aragonite is the primary component of coral, pearl, and mother-of-pearl, all composite, biogenic materials consisting of organic and inorganic materials that form through the process of biomineralization. Pearls and mother-of-pearl form from aragonite and lesser amounts of organic materials secreted by the cells of the soft bodies of bivalve and univalve mollusks. Pearl and mother-of-pearl are well-structured, polymer-ceramic composites with unusual mechanical and optical properties and a beautiful luster. 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 a radially oriented, concentric structure. Both the creamy glow of pearls and the iridescence of mother-of-pearl are caused by aragonite refracting light in two slightly different directions, an optical phenomenon known as birefringence.

HISTORY & LORE

Finely ground aragonite has served as a bright, white paint pigment since antiquity. Scientists first recognized aragonite as a distinct mineral species in 1790 after studying specimens collected at the type locality at the Río Gallo at Molina de Aragón in what was then the autonomous Spanish kingdom of Aragón (now part of Castilla-La Mancha, Spain). In 1897, aragonite was formally named after Aragón by German mineralogist Abraham Gottlieb Werner (1747-1817). This “Aragón” locality notation still survives 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 between unlike minerals) and the 1822 discovery of polymorphism, as explained in the special section on “The Phenomenon of Mineral Polymorphism”. American physicist Lawrence Bragg (1890-1971) defined aragonite’s crystal structure using X-ray diffraction in 1924.

Aragonite has been featured on Austria’s 3.50-shilling stamp of 1984, the Republic of China’s (Taiwan) five-dollar stamp of 1997, and the French Southern and Antarctic Territories’ 5.10-franc stamp of 1990. An aragonite trilling very similar to our specimens was featured on Spain’s 30-peseta stamp of 1995. Aragonite in the form of pearls has appeared on the 15-pyas stamp of Myanmar in 1968 and the 1.50-shilling stamp of Tanzania in 1986. French Polynesia, a leading source of natural pearls, has featured pearls on its 10-franc stamp of 1982 and its 66-franc and 84-franc stamps of 1995.

Metaphysical practitioners believe that aragonite enhances patience and responsibility, reduces stress and anger, and helps one to prepare for meditation. Because it is believed to balance emotions and channel energy to constructive ends, aragonite has been a traditional gift for the young.

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TECHNOLOGICAL USES

Because aragonite is often part of the calcareous content of limestone (along with calcite), it is an industrial source of calcium carbonate. After quarrying, limestone is calcined (roasted) into calcium oxides and oxysilicates that have many industrial uses. Nearly pure aragonite is found in the Bahamas where it occurs in massive sea-bottom layers that are the remains of shells and skeletal parts of tiny marine organisms. In mass-mining operations, suction dredges pump aragonite granules to the surface as a water slurry. The aragonite is then used to manufacture cement, glass, acid-neutralization and agricultural liming compounds, and calcium-rich fertilizers and animal feeds. Powdered aragonite, or “crystal whiting,” is an excellent white pigment because its strong birefringence reflects creamy interference colors, while its fluorescence complements the reflection of white light to impart brilliance.

Materials scientists have studied conch and abalone shells, which consist of 99 percent aragonite, to determine why they are substantially harder and tougher than pure crystalline aragonite. They concluded that molecular interlayering of aragonite and protein binders provides a slight flex to the shell material that resists cracking and abrading, a concept now applied to the manufacture of special load-bearing ceramics for aerospace and computer applications. Petrologists (scientists who study rocks) research the structural stability of aragonite because the eventual transformation of aragonite to calcite has a pronounced effect on the character of certain calcareous sedimentary rocks.

ABOUT OUR SPECIMENS

Our Platinum- and Gold-level aragonite specimens were collected at Retamal Ravine near the village of Enguidanos, Cuenca Province, in the autonomous state of Castilla-La Mancha, Spain. This area is 60 air miles west of the Mediterranean coast and port city of Valencia. Enguidanos, population 500, is a small village at an elevation of 2,200 feet in the foothills of the Serrania de Cuenca range just north of the Contreras Reservoir. The hills are covered by thin pine forests and the rugged topography is marked by steep ravines. Enguidanos was first settled by Greek traders about 300 B.C. Its name stems from a Greek word meaning “place of abundant waters,” a reference to the many nearby hillside springs. About 200 A.D., Romans occupied the area and erected a small stone fortress, the ruins of which are visible today. Moorish domination began about 900 A.D. During the “Christian” reconquest in the late 1400s, Enguidanos was the site of one of the battles that evicted the Moors from Spain. Today, Enguidanos is a picturesque mountain village with steep streets, sidewalks with wooden handrails, and interesting old architecture. Residents mainly raise sheep and goats and make pottery.

Retamal Ravine, several miles south of Enguidanos, is one of many local, steep ravines eroded by seasonal runoff. These ravines expose the Keuper Formation, a stratigraphically complex formation of marine and continental sediments laid down in Triassic time some 220 million years ago. The Keuper Formation consists of intermixed layers of sandstone, limestone, shale, gypsum, clay, and marl, the latter a crumbly earth made up mainly of sand, clay, and considerable amounts of calcium carbonate. Over much of east-central Spain, the marl strata of the Keuper Formation contain aragonite crystals. Most crystals are small and poorly developed, but at Retamal Ravine and several other nearby sites, the crystals are large and well-developed.

Geologists believe that the calcium carbonate within the Keuper Formation marl was originally deposited as calcite. The marl strata also hosted nodules of gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$]. Erosion later exposed the calcareous marl layers to the chemical action of acidic groundwater, which dissolved the small gypsum nodules to leave voids. The acidic groundwater then dissolved some existing

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calcite to form solutions rich in calcium and carbonate ions. This calcium-rich groundwater eventually filled the voids left by the gypsum nodules and, in conditions of low temperature and low pressure, precipitated in the form of aragonite. The voids provided the space necessary for the excellent crystal development seen in our aragonite specimens. These crystals are gathered periodically by commercial collectors who wait for seasonal runoff water to expose new marl strata in the ravine walls. They then excavate these soft marl strata, screening and washing the sediments in water to recover the aragonite crystals.

In examining your specimen, first study the crystal form, the cross section of which exhibits the six-sided shape of a hexagon. This shape is not indicative of the hexagonal crystal system, but reflects twinning within the orthorhombic system. The crystal consists of three composite twins (or in this case, “triplets”) known as “trillings,” each with a twinning angle of precisely 120°. Each of the three trillings occupies one-third or 120° of the 360° crystal. Because aragonite crystallizes in the orthorhombic system and not in the hexagonal system, this six-sided form is correctly called “pseudo-hexagonal.” If your specimen has smaller secondary crystals on the main crystal, these will also have a pseudo-hexagonal shape. Note the prominent parallel striations on the long crystal faces. These straight, longitudinal, hairline grooves are actually crystal-face edges produced by the repeated displacement of internal glide planes within the developing, twinned crystal lattice.

The color of Platinum- and Gold level aragonites specimens ranges from purple to lilac. As an allochromatic mineral, aragonite is colorless or white when pure, but can exhibit a range of colors because of other factors. First, the translucency to near-opacity of your specimen is due to inclusions of silt and mineral particulate matter that were part of the sedimentary environment in which the crystal grew. The delicate purple color is caused either by traces of a chromophore or the effects of radiation, or both. In aragonite, traces of manganese impart purple-to-lilac colors. It is also possible that the color in your specimen is at least partly caused by natural geophysical radiation from uranium- and thorium-bearing minerals. Radiation can distort the crystal lattice in a manner that causes it to reflect the blue-violet portion of the visible spectrum. The color of our specimens is likely due to a combination of inclusions, a manganese chromophore, and the effects of geophysical radiation. Collectors of rare gemstones would like to obtain faceted stones cut from this purple aragonite, but the crystals are too heavily included to be facet worthy. This lends credence to the theory that the purple color is caused by inclusions. Whatever is causing the unusual color is also blocking the fluorescence and phosphorescence often encountered in aragonite, as our specimens are generally inert under both short- and long-wave ultraviolet light.

Your specimen has a noticeable “heft” in the hand. Because of its close atomic packing, aragonite has 10 percent greater density than calcite. Therefore, the weight or “heft” of your aragonite specimen will be that much greater than an equal volume of calcite. Your specimen may also exhibit small quantities of calcite, which appears as a bright, white mineral. This calcite may have been deposited after the aragonite crystal formed in conditions that became favorable for calcite precipitation, or it may be calcite that has replaced metastable aragonite. But don’t worry—since further aragonite-to-calcite alteration will require thousands and perhaps millions of years, you’ll have lots of time to enjoy your aragonite specimen.

References: *Dana’s New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *1999 Glossary of Mineralogical Species*, J. A. Mandarino; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *An Introduction to Crystal Chemistry*, R. C. Evans, Cambridge University Press, 1966; *The Complete Guide to Rocks & Minerals*, John Farndon, Hermes Houses, 2007; “Scientists Mimic Structure of Seashells To Make Coatings,” Sandia National Laboratories press release, July 20, 1998; “Aragonite,” Bob Jones, *Rock & Gem*, October 1981; “Aragonite,” Frederick Pough, *Lapidary Journal*, June 1985; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company, 1977; *Fossils: An Introduction to Prehistoric Life*, William Matthews III, Barnes & Noble Books, 1962; “Aragonite from Cicov Hill in the Czech Republic,” Michal Filippi and Taroslav Hyrs, *The Mineralogical Record*, March-April 2004; “Refinement of the Crystal Structure of Aragonite,” N. L. Dal and L. Ungaretti, *American Mineralogist*, Volume 56, 1971