

July 2013 Mineral of the Month: Celestine

Celestine, our Mineral of the Month for July, is a strontium sulfate from a classic locality in Madagascar. Our write-up explains the origin of its delightful blue color and provides an overview of the element strontium.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: SrSO_4 Strontium Sulfate, often containing varying amounts of barium and lead.

Class: Sulfates

Subclass: Anhydrous Sulfates

Group: Barite

Crystal System: Orthorhombic

Crystal Habits: Usually thin-to-thick, tabular or elongate crystals with three-dimensional cleavage; also nodular and fine-grained massive or as fibrous veinlets and radiating aggregates; occasionally granular and lamellar.

Color: Usually pale blue with pronounced color zoning in which the blue color is apparent only in parts of the white or colorless crystals; also colorless and white; occasionally pale shades of red, orange, brown, or green. Crystals may appear colorless in transmitted light.

Luster: Vitreous, pearly on cleavage planes.

Transparency: Transparent to translucent

Streak: White

Cleavage: Perfect in one direction, good in a second, and distinct in a third.

Fracture: Uneven, brittle.

Hardness: 3.0-3.5

Specific Gravity: 3.9-4.0

Luminescence: Usually fluoresces yellow or blue in ultraviolet light.

Refractive Index: 1.625-1.639

Distinctive Features and Tests: Association with halite [sodium chloride, NaCl], strontianite [strontium carbonate, SrCO_3], calcite [calcium carbonate, CaCO_3], and gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$] in sedimentary, evaporite deposits. Can be confused with pale-blue barite [barium sulfate, BaSO_4], which is considerably more dense, but rarely color-zoned. When dropped into a flame, tiny particles of celestine burn with distinctive, diagnostic, bright-red flashes.

Dana Classification Number: 28.3.1.2

NAME: The name “celestine,” pronounced SELL-ess-teen or sell-ESS-teen, is derived from the Latin *caelestis*, meaning “of the sky” or “celestial,” and alluding to its pale-blue, sky-like color. Until the mid-1980s, celestine was formally known as “celestite,” a name that still appears in mineralogical references. Other names for celestine are “coelestin,” “celestina,” “celestite,” and “schätzit.” Barium-rich varieties are known as “barian celestine” or “barytocelestine.” In European mineralogical literature, celestine appears as *celestina* and *celestin*.

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COMPOSITION: Celestine, or strontium sulfate, is one of nearly 200 members of the sulfate mineral class. Celestine consists of 47.70 percent strontium, 34.84 percent oxygen, and 17.46 percent sulfur. Although widely distributed in the Earth's crust, individual celestine occurrences are rarely large in size. Because of its moderate solubility in water, celestine occurs primarily as an evaporite mineral. Limestone is also a common mineralogical environment for celestine. Smaller amounts of celestine are found in granite pegmatites, hydrothermal vents in association with calcite and quartz, and in sedimentary deposits as geodes, nodules, and concretions. The origin of color in celestine has been long debated. The current theory focuses on "color centers." Color centers are imperfections in the crystal lattice that are often caused by natural geophysical radiation, the energy of which boosts electrons from their normal positions. When these energized electrons lose their energy, they accumulate in vacant lattice sites called "traps." Trapped electrons absorb only certain wavelengths of light, thus altering the absorption-reflection characteristics of the crystal. In celestine, trapped electrons absorb only the red wavelengths of the visible spectrum, while reflecting the blue wavelengths.

COLLECTING LOCALITIES: The finest celestine specimens come from Sakoany in the Boeny Region of Madagascar. Celestine is also collected in Germany, England, Scotland, Spain, Turkmenistan, Canada, Mexico, Argentina, and Greenland. In the United States, celestine occurs in Ohio, Virginia, New York, Michigan, Pennsylvania, Texas, New Mexico, Arizona, and California.

HISTORY, LORE, & USES: Celestine was recognized as a distinct mineral species shortly after the element strontium was discovered in 1790. It was first named "coelestin," then quickly renamed "celestine." In the early 1900s, celestine was renamed again, this time as "celestite." Finally, in the 1980s, the name "celestine" was restored. Celestine has a spectacular occurrence at Crystal Cave at Put-in-Bay on South Bass Island, Ottawa County, Ohio, where the walls of a limestone cave are covered with large, well-developed celestine crystals, some as long as three feet and weighing 300 pounds. Crystal Cave is open to visitors today. Because of its softness (Mohs 3.0-3.5), celestine has no use in jewelry, although it is occasionally faceted into collectors' gems. Celestine is the primary ore of strontium. Finely ground celestine serves as a filler in certain white paints, putties, plasters, and caulking agents. Most celestine is chemically converted to strontium carbonate, the basic feedstock for industrial use or conversion to other strontium compounds. With its soft, blue color and distinctive crystal structure, celestine makes fine display pieces as both singular and composite specimens. Modern metaphysical practitioners believe that celestine enhances creative expression, reduces stress, provides peace of mind, aids in recalling dreams and communicating with spiritual realms, and helps in adjusting to higher states of awareness.

ABOUT OUR SPECIMENS: Our celestine specimens were collected near the village of Sakoany, Mitsinjo District, Boeny Region, on the northwestern coast of Madagascar. The Republic of Madagascar occupies an island in the Indian Ocean 400 miles off Africa's east coast. It is the world's largest island nation and fourth largest island. Celestine crystals were discovered in surface gravels in the 1960s a short distance west and northwest of the village of Sakoany and not far from the coastal city of Mahajanga. The source was found to be celestine geodes in the sandy soil. Local diggers began collecting the geodes in 1967. These geodes are

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sedimentary in origin and occur in layers of sandy marls that were deposited during the Lower Paleocene Epoch and are about 55 million years old. The celestine geodes formed when low-temperature, strontium-rich, circulating groundwater contacted sulfur-rich organic remains. This organic material caused the strontium to precipitate as strontium sulfate in the form of celestine geodes, nodules, and concretions. The Sakoany mining area covers three square miles and is marked by hundreds of pits and waste piles. Miners manually sink 30-to-45-foot-deep, rectangular shafts through the loosely consolidated sediments. When they reach the geode-rich layers, they dig lateral drifts in the hope of encountering the geodes. As many as 70 or 80 miners are at work at any one time during the dry season when flooding is not a problem. Sakoany has been the world's leading source of fine celestine specimens since mining began there in 1967. The estimated reserves of geodes indicate that Sakoany will remain the leading source of celestine specimens for many years to come.

COMPREHENSIVE WRITE-UP

COMPOSITION

The chemical formula SrSO_4 identifies celestine as strontium sulfate, a mineral containing the elements strontium (Sr), sulfur (S), and oxygen (O). Celestine's molecular weight is made up of 47.70 percent strontium, 34.84 percent oxygen, and 17.46 percent sulfur. Like all molecules, those of celestine consist of positively charged cations and negatively charged anions. Celestine's simple cation is the strontium ion Sr^{2+} with its +2 charge. Its anion is the sulfate ion $(\text{SO}_4)^{2-}$. This compound anion, also called a "radical," is composed of a group of atoms of different elements that are bound together and act as a chemical entity. In the sulfate radical, a single sulfur atom is surrounded by four oxygen atoms that are positioned at the corners of a tetrahedron. The sulfur ion S^{6+} has a +6 charge and the four oxygen ions 4O^{2-} have a collective -8 charge, thus providing the sulfate radical with a collective -2 charge. The +2 cationic charge balances the -2 anionic charge to provide the celestine molecule with electrical stability. Celestine is a member of the sulfates, a class of minerals in which oxygen and sulfur combine with one or more metals. Because the sulfate radical's two excess negative charges are distributed evenly over its four oxygen ions, it can bond to a wide variety of metal cations and hydroxyl ions, and can readily attach water molecules as water of hydration. Accordingly, the sulfate mineral class is large and complex, with nearly 200 members.

Although celestine is a simple sulfate with a single metal cation, its molecule and lattice are bound together by two types of atomic bonding. The sulfate radical $(\text{SO}_4)^{2-}$, is held together by strong, internal covalent bonds in which the four oxygen atoms and the single sulfur atom share electrons. But the sulfate radicals and strontium cations are bound ionically by the attractive force between opposite charges. In celestine, the positively charged strontium ion is attracted to the negative charge of the oxygen ions within the sulfate radical.

The weak ionic bonding between the strontium cation and the sulfate anion is the dominant lattice bonding that explains many of celestine's physical properties. In ionic bonding, the attractive forces are exerted more or less equally in all directions so that every anion is completely surrounded by cations and vice versa. This creates a three-dimensional, repeating

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arrangement within the crystal lattice. Celestine's relatively weak ionic bonding throughout the lattice explains its softness of Mohs 3.0-3.5. Close atomic packing within the lattice and the substantial atomic weight of strontium (87.62) account for celestine's relatively high specific gravity of 3.9-4.0. Celestine crystallizes in the orthorhombic system, which is characterized by three mutually perpendicular axes of different lengths. Orthorhombic crystals are usually blocky in appearance, but if one axial direction is noticeably shorter than the other two, the crystals may be tabular, as is often the case with celestine. Celestine's three cleavage directions of perfect, good, and distinct are explained by the unequal axial lengths of its orthorhombic crystal.

Because ionic bonds are vulnerable to the dipolar action of water, celestine is moderately water-soluble, which is why it occurs primarily as an evaporite mineral. Evaporites form in enclosed basins from the evaporation of saline lake water or seawater that is rich in dissolved mineral salts, most often sulfates, chlorides, and carbonates of sodium, potassium, and calcium. Because strontium is considerably less abundant than any of these elements, celestine is a less common mineral than such evaporites as gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$] and calcite [calcium carbonate, CaCO_3]. In sedimentary evaporite deposits, celestine is often associated with gypsum, calcite, halite [sodium chloride, NaCl], and strontianite [strontium carbonate, SrCO_3]. Limestone is also a common mineralogical environment for celestine. Celestine also occurs in smaller quantities in granite pegmatites, in hydrothermal vents in association with calcite and quartz, and in sedimentary deposits in the form of geodes, nodules, and concretions. Although celestine is widely distributed in the Earth's crust, large occurrences are rare.

The origin of color in celestine has long been debated. The occasional non-blue colors have been attributed to trace amounts of such chromophores (coloring agents) as copper and sulfur. Most perplexing has been the cause of celestine's characteristic pale-blue color, which has been attributed to traces of iron, barium, lead, or potassium that substitute for strontium. The current theory focuses on "color centers," which are imperfections in the crystal lattice that are often caused by natural geophysical radiation, the energy that boosts electrons from their normal positions. When these energized electrons lose their energy, they accumulate in vacant lattice sites called "traps." Trapped electrons absorb only certain wavelengths of light, thus altering the absorption-reflection characteristics of the crystal. In celestine, trapped electrons absorb only the red wavelengths of the visible spectrum, while reflecting the blue wavelengths. This theory of radiation-induced color centers is supported by the fact that strontium has a high chemical affinity for the rare, radioactive element radium, even the tiniest traces of which can disrupt the normal celestine lattice. Research also indicates that traces of potassium within the celestine lattice, while not directly causing the "celestine-blue" color, stabilize the color centers to make the color more permanent.

The Dana mineral classification number 28.3.1.2 first identifies celestine as an anhydrous sulfate (28), or a sulfate without attached water molecules (water of hydration). Celestine is then subclassified (3) by the general formula A^{2+}SO_4 , in which "A" can be a divalent ion of barium, strontium, or lead. Celestine is then assigned to the barite group (1) as the second (2) of three members. The three barite-group members are:

28.3.1.1	barite	barium sulfate	BaSO_4
28.3.1.2	celestine	strontium sulfate	SrSO_4

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28.3.1.3 anglesite lead sulfate PbSO_4

All three barite-group members crystallize in the orthorhombic system and differ only in their cations. Barium, strontium, and lead ions all have +2 charges and generally similar ionic radii that facilitate cationic substitution. Celestine therefore often contains varying amounts of lead and barium. The ions of barium and strontium are so similar that celestine and barite form a continuous, solid-solution series. Intermediate phases of this barite-celestine solid-solution series are known as barian celestine or barytocelestine.

COLLECTING LOCALITIES

As a widely distributed mineral, celestine has numerous collecting localities. The finest specimens are found at Sakoany, Mitsinjo District, Boeny Region, Madagascar. German specimens come from the celestine quarries at Hamm and Münster in Nordrhein-Westfalen; and the Woeltjebuche celestine deposit at Springe and the Konrad Mine at Salzgitter, both in Niedersachsen. English specimens are from the Yate quarries at Yate in South Gloucestershire and Peak Hill near Sidmouth in Devon. Celestine also occurs at Strontian, Argyllshire, Scotland. Spanish specimens come from Puente Tablas at Jaén in Andalusia, and El Esbornacs at Lleida in Catalonia. Sources in Turkmenistan include Lebap Welayaty in Beinev-Kyr, the Kap-Kutan cave systems in the South Tien-Shan Mountains, and the Gaurdak Mine at Chardzhov. Canadian sources include Cheverie, Hants County, Nova Scotia; the Amherstberg Quarry at Amherstberg, Ontario; and the Big Fish River area in Yukon Territory. Mexican specimens are found at the Rancho de Mojina Mine at Ahumada, Chihuahua; the Ojuelo, Padre, and Vergel mines at Mapimí, Durango; and the Melchor Múzquiz fluorite deposit in Coahuila. Celestine stalactites occur at Cerro Mallín Quemado in Neuquén, Argentina. The largest known celestine occurrence is the Karstryggen sedimentary deposit in Tunu, Greenland.

An especially notable celestine occurrence in the United States is Crystal Cave at Put-in-Bay on Lake Erie's South Bass Island in Ottawa County, Ohio (see "History & Lore"). Other sources are the limestone quarries at East Stone Gap in Wise County, Virginia; the Erie Canal cuts and the Pekin Quarry at Lockport, Niagara County, New York; the Scofield, Borin Brothers, and Woolmith quarries at Maybee in Monroe County, Michigan; and the Susquehanna Quarry at East Salem in Juniata County and the celestine type locality at Bell's Mills near Bellwood, Blair County, both in Pennsylvania. In Texas, celestine occurs at Bull Creek in Austin in Travis County and at Adamsville in Lampasas County; in New Mexico, at Carlsbad Caverns and adjacent Lechuguilla Cave in Eddy County; in Arizona, at the Clip and Blaine mines in the Trigo Mountains district in La Paz County; and in California at the Billie Mine in Death Valley in Inyo County and at numerous mines in the Calico-Daggett borate-mining district in San Bernadino County.

JEWELRY & DECORATIVE USES

Although celestine's relatively high refractive index (1.625-1.639) is similar to that of topaz [aluminum fluorosilicate, $\text{AlSiO}_4(\text{F},\text{OH})_2$], its softness of Mohs 3.0-3.5 precludes its use as a

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gemstone. Also, its pale-blue color lacks the distinctiveness and visual appeal necessary for a colored gemstone. Celestine is occasionally faceted into collectors' gems. With its soft, blue color and distinctive crystal structure, celestine makes fine display pieces as both singular and composite specimens. Composite specimens of pale-blue celestine on bright-yellow crystals of elemental sulfur are a classic mineral collectible.

HISTORY & LORE

Although known since antiquity, celestine was confused with other evaporite minerals until the late 18th century. Celestine was recognized as a distinct mineral species only after the element strontium had been discovered in 1790 (see "About Strontium"). In 1791, a German traveler collected thin crystals of a pale-blue mineral from Bell's Mills, near Bellwood in Blair County, south-central Pennsylvania. He took them back to Germany and brought them to the attention of German chemist Martin Heinrich Klaproth (1743-1807), who identified them as a new mineral, but one of uncertain composition. In 1798, Klaproth demonstrated that the Pennsylvania specimens were strontium sulfate. German geologist and mineralogist Abraham Gottlob Werner (1750-1817) then named the new mineral "coelestin," from the Latin *caelestis*, meaning "of the sky" or "celestial," and alluding to its sky-like, pale-blue color. That name, however, was soon changed to "celestine."

In the early 1900s, the name "celestine" was formally changed to "celestite" to be more in keeping with many other mineral names that ended in "-ite." When the International Mineralogical Association was established in 1958, its Committee on New Minerals and New Mineral Names became the global authority on mineral names. In the 1980s, this committee reevaluated many "grandfathered" mineral names and, to honor tradition, restored the name "celestine." This has since caused some confusion, because all mineralogical and mining texts, mineral field-collecting guides, and glossaries published before the mid-1980s, many of which are still in use, employ the term "celestite."

In 2002, a group of fifth-grade students in Pennsylvania, after learning that Bell's Mills near Bellwood in Blair County, Pennsylvania, was the type locality for celestine, petitioned the Pennsylvania House of Representatives to declare celestine the official state mineral. Their proposal was introduced as a bill and sailed through the State House by a vote of 295-1. But upon reaching the Pennsylvania State Senate, the bill died in committee, leaving the state without an official mineral.

Celestine has a spectacular occurrence at Crystal Cave at Put-in-Bay on South Bass Island, Ottawa County, Ohio. While digging a well in 1897, a German immigrant winemaker discovered a limestone cave with its walls covered by large, well-developed celestine crystals, some three feet in length and weighing 300 pounds. For several years, the crystals were mined as a source of strontium for use in fireworks manufacturing. But when Prohibition was enacted, the winemaker discontinued mining and converted the cave into a tourist attraction, surviving Prohibition on his tourism earnings, while other local wineries went bankrupt. Crystal Cave remains open to visitors today.

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Celestine has been featured on the 150-franc postage stamp of Mali in 1998. Modern metaphysical practitioners believe that celestine enhances personal creative expression, reduces stress, provides peace of mind, aids in recalling dreams and communicating with spiritual realms, and helps in adjusting to higher states of awareness.

TECHNOLOGICAL USES

Celestine is the primary ore of strontium. Strontianite [strontium carbonate, SrCO_3], a much less common mineral, is a minor ore that accounts for only a small fraction of strontium production. To warrant mining, celestine deposits must grade at least 50 percent in purity and be relatively free of calcium and barium, which are costly to separate. With the exception of one strontianite mine in China, all 25 strontium mines now operating worldwide exploit celestine from surface or near-surface sedimentary deposits. The mined ore is crushed, washed, and gravitationally concentrated. About 400,000 metric tons of celestine are mined worldwide each year. China is the leading source and accounts for half the world's production. Spain is the second largest source with 36 percent of the world's celestine output. The United States, the leading consumer of celestine and strontium compounds, imports 100 percent of its requirements. One metric ton of concentrated celestine ore grading 90 percent strontium sulfate now sells for about \$60. Finely ground celestine serves as a filler in certain white paints, putties, plasters, and caulking agents. Most celestine, however, is chemically converted to strontium carbonate, the basic feedstock for industrial use or conversion to other strontium compounds.

ABOUT STRONTIUM

Our Mineral of the Month, celestine, is by far the most abundant strontium-containing mineral. Although strontium, pronounced STRON-tee-um, is not a well-known element, its compounds have many important uses in science and industry.

As one of the alkaline-earth metals, strontium is closely related to calcium and barium. It is a soft, ductile, malleable metal with a very high level of chemical activity. To prevent rapid atmospheric oxidation, elemental strontium must be kept under a liquid hydrocarbon such as mineral oil or kerosene. Freshly cut, elemental strontium has a soft, silvery-white color, but oxidizes rapidly in atmospheric oxygen to a dull yellow. When finely powdered, strontium is pyrophoric and will ignite spontaneously when exposed to air at room temperature. Strontium has an atomic number of 38, an atomic weight of 87.62, a very low Mohs hardness of 1.5, and a melting temperatures of 1431° F. (777° C.). Strontium's specific gravity of 2.54 makes it a bit less dense than aluminum.

As the 15th most abundant element in the Earth's crust, strontium is about as common as sulfur. Because of its high level of chemical reactivity, it does not occur free in nature. Although widely distributed, large concentrations of strontium-bearing minerals are uncommon. Of the approximately 160 strontium-bearing minerals, only two—celestine and strontianite [strontium carbonate, SrCO_3][—]are relatively common. All other strontium-bearing minerals are uncommon or rare.

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In 1790, Scottish chemist Adair Crawford (1748-1795) studied specimens of an unfamiliar mineral collected near the village of Strontian in Argyllshire, Scotland. Crawford and his colleague, Scottish military surgeon and chemist William Cruickshank (ca. 1755-ca. 1811) concluded that these specimens were chemically different from such other “heavy spars” as barite [barium sulfate, BaSO_4] and witherite [barium carbonate, BaCO_3] and represented a new mineral. Crawford and Cruickshank also concluded that this new mineral, which they named “strontianite” after its place of discovery, also contained a previously unidentified element that appeared chemically similar to barium. In 1793, Thomas Charles Hope (1766-1844), professor of chemistry at the University of Glasgow, and German mineralogist Martin Heinrich Klaproth (1743-1817) proposed naming the new element “strontites” after the village of Strontian. In 1808, English chemist Sir Humphry Davy (1778-1829) isolated the new element and renamed it “strontium” in keeping with the names of the other alkaline-earth elements.

The German sugar-beet industry began using strontium compounds in the mid-1800s. German sugar refiners converted celestine, obtained from nearby quarries at Hamm and Münster in Nordrhein-Westfalen, to strontium hydroxide (hydrated strontium), which they used to clarify crude sugar solutions and raise pH levels to facilitate the precipitation of sugar crystals. These German quarries supplied most of the world’s celestine until a larger deposit was opened at South Gloucestershire, England, in the 1880s. The English quarries supplied the German demand for celestine until 1910, when sugar-beet refiners replaced celestine with hydrated lime [$\text{Ca}(\text{OH})_2$]. The English quarries remained the world’s largest source of celestine (and thus of strontium) until the 1950s.

Strontium’s other important early use was in creating red colors in pyrotechnics. When strontium salts burn, they undergo a rapid reduction-oxidation reaction in which the salt is reduced to elemental strontium which immediately burns, or oxidizes, emitting an intense light at a highly visible, red wavelength. By the mid-1880s, strontium nitrate was the standard, red coloring agent in both fireworks and in safety, signal, and railroad flares. Celestine mining boomed during World War I, when large quantities of strontium were needed for military tracer ammunition. When the United States War Production Board declared strontium a strategic material during World War II, celestine mining boomed again, this time in California and Texas. Domestic celestine mining ended in 1959.

During the 1960s, technology revolutionized strontium’s uses. The mass production of cathode-ray-tube, color-television sets necessitated the development of a glass that could block potentially hazardous X-ray emissions. Strontium oxide (along with barium oxide) was added to all television faceplate glass, not only to block radiation but also to transmit a more brilliant image. In 1970, federal law required that strontium-bearing and barium-bearing glass be used in the faceplates of all televisions sold in the United States. The current, rapid decline in the manufacture of cathode-ray tubes, which are being replaced by other display devices, has caused a significant decline in celestine demand and mining.

Another major use of strontium is in ferrite-ceramic magnets, which are manufactured by heating together particles of iron oxide and strontium carbonate to form strontium hexaferrite. Although strontium hexaferrite has a lower magnetic-energy level than other permanent-magnet materials,

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it resists both demagnetization and corrosion and is very inexpensive to fabricate into complex shapes. Today, most magnets manufactured worldwide consist of strontium hexaferrite and are used in everything from motors for automotive windshield wipers and power-windows to medical magnetic-resonance imaging (MRI) equipment, audio-system speakers, and “refrigerator-door” decorative magnets. Today, 85 percent of all strontium compounds are used to manufacture special glasses and strontium hexaferrite magnets. Elemental strontium, however, has few applications. It is most commonly used as a minor alloying additive in aluminum to improve its casting qualities for the manufacture of automotive wheels and engine blocks.

Strontium has four, naturally occurring isotopes that are used in forensic archaeological investigations. Because the proportion of strontium isotopes present in human bones varies regionally, researchers use strontium-isotope measurements to trace ancient migration patterns and to separate commingled human remains. Strontium isotopes are also used in medicine to treat bone cancer and osteoporosis.

ABOUT OUR SPECIMENS

Our celestine specimens were collected near the village of Sakoany, Mitsinjo District, Boeny Region, on the northwestern coast of the Republic of Madagascar. On older maps, this area appears as part of Mahajanga Province. In 2009, national redistricting replaced Madagascar’s original six provinces with 22 newly designated regions.

The Republic of Madagascar, which occupies an island in the Indian Ocean 400 miles off Africa’s east coast, is 800 miles long in a north-south direction and roughly 250 miles wide. Covering 226,656 square miles, Madagascar is nearly the size of the state of Texas. It is the world’s largest island nation and fourth largest island. With a tropical climate tempered by the Indian Ocean and high inland elevations, Madagascar’s ecological zones include grasslands, semiarid deserts, tropical rain forests, and savannah woodlands.

African and Arab ethnic groups comprise most of Madagascar’s population of 20 million. Madagascar’s colonial era began in the mid-1800s when British and French colonists arrived to establish coffee and vanilla plantations. France made Madagascar a protectorate in 1885 and a colony in 1896. Madagascar received its independence in 1960. Since then, the island nation has unfortunately been plagued by corruption and ethnic conflicts and its governments have endured several rebellions. Madagascar is one of the world’s poorest nations, with 80 percent of the national workforce employed in agriculture. Although the island is rich in minerals, mining is limited to ilmenite [iron titanium oxide, FeTiO_3], rutile [titanium oxide, TiO_2], chromite [iron chromium oxide, FeCr_2O_4], and a variety of decorative stones and gemstones, including celestine.

Mahajanga (“Majunga” in the French spelling), a major port city with a population of 140,000, is about 250 air miles north-northwest of the national capital of Antananarivo. It is a tourist center known for its beaches and pleasantly warm climate. The regional economy is based largely upon shrimping and the agricultural production of coffee, sugar, and coconuts. The small village of

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Sakoany, population 150, is 12 miles southwest of Mahajanga across Bombetoka Bay on the west bank of the mouth of the Betsiboka River. The 360-mile-long Betsiboka River has suffered severe environmental degradation. Uncontrolled erosion resulting from rampant deforestation to clear upstream lands for farms and pastures causes the orange-colored Betsiboka River to deposit huge volumes of sediments into Bombetoka Bay. The residents of Sakoany support themselves by raising zebu cattle, fishing, growing rice, and mining celestine specimens.

In the 1960s, cattle herders discovered scattered celestine crystals in surface gravels a short distance west and northwest of Sakoany. The source was soon found to be celestine geodes in the sandy soil. Local diggers began mining the geodes in 1967. These celestine geodes were well-received at international gem-and-mineral shows and quickly gained great popularity among collectors for their exquisite blue color and exceptional crystal development. The geodes are sedimentary in origin and occur in layers of sandy marls that were deposited during the Lower Paleocene Epoch and are about 55 million years old. Celestine formed when low-temperature, circulating groundwater contacted sulfur-rich, organic remains. This groundwater was probably seawater that contained fairly high levels of strontium. The sulfur-rich, organic remains caused the strontium to precipitate as strontium sulfate in the form of celestine geodes, nodules, and concretions.

The mining area covers three square miles and is marked by hundreds of pits and waste piles. Mining celestine nodules is done entirely by manual methods. Miners sink 30-to-45-foot-deep, narrow, rectangular shafts through the loosely consolidated sediments. Once at the geode layers, they dig lateral drifts in the hope of encountering geodes. Digging stops only when the concentration of geodes diminishes or the oxygen level in the unventilated workings can no longer sustain physical activity. As many as 70 or 80 miners are working at any one time during the dry season when flooding is not a problem. The sediments, although only loosely consolidated, are reasonably stable and do not require timbering or other forms of ground support. The workings do not extend below the water table, where the ground would likely become unstable and flooding would occur. Sakoany miners recover between 10 and 50 tons of geodes each year.

The geodes consist of essentially pure celestine. Within the geodes, the celestine crystals are well-formed with sharp edges and a bright, vitreous luster. Individual crystals have been found as large five inches, although most are much smaller. The color ranges from pale-to-medium blue. Some crystals are translucent, but most are transparent and many are of gem quality. Most geodes range in size from a few inches to about one foot in diameter; the largest are about three feet in diameter. Dealers visit Sakoany to buy the celestine geodes as soon as they are mined. Since the geode deposits were discovered, Sakoany has been the world's leading source of fine celestine specimens. Substantial estimated reserves of geodes indicate that Sakoany will remain the leading source of celestine specimens for many years to come.

As you examine your specimen, note first its pale-blue color. This color, which is characteristic of most celestine specimens, is caused by color centers (see "Composition") and is apparent only in reflected light. When viewed with transmitted light (backlighting), the crystals appear almost colorless, which is a diagnostic feature of celestine. When viewed from a distance, the celestine crystals appear to be more-or-less uniformly colored. But on close inspection, the prominent

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color zoning of celestine becomes apparent. The crystals have a bright, vitreous luster; a few may be translucent, but most are transparent and even gemmy. The crystals are orthorhombic in form with a blocky, tabular habit, sharp edges, and pointed or wedge-shaped terminations.

Your specimen is a portion of a spherical geode, which is a hollow nodule lined with crystals. The curvature of the specimen's exterior reflects its geodic origin. The grayish-white, exterior coating consists of sandy sediments that are cemented together with massive celestine. Note also that your specimen has an unusual "heft" in the hand. This is due to the relatively high density of celestine (specific gravity 3.9-4.0), which is 25 percent greater than that of quartz.

Your celestine specimen is a souvenir of Madagascar and a reminder of the local economic importance of collecting mineral specimens in many nations of the Third-World.

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