

November 2005 Mineral of the Month: Celestine

We are delighted to be featuring celestine, one of the world's most beautiful minerals and mineral names. Call it celestite or celestine, it is an important ore of strontium, but is even more treasured for its exceptional crystal forms and colors. And we never thought we would have an opportunity to obtain celestine from this rare and remote location in Turkmenistan!

PHYSICAL PROPERTIES

Chemistry: SrSO_4 Strontium Sulfate, often containing some barium
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; rarely granular and lamellar.
Color: Usually pale blue with pronounced color zoning in which the blue color tints only parts of white or colorless crystals; also colorless and white; less commonly pale shades of red, orange, brown, or green.
Luster: Vitreous, pearly on cleavage planes
Transparency: Transparent to subtranslucent
Streak: White
Cleavage: Perfect in one direction, good in a second, and distinct in a third
Fracture: Uneven, brittle; fractures into tiny conchoidal fragments
Hardness: 3.0-3.5
Specific Gravity: 3.9-4.0
Luminescence: Sometimes fluorescent
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. Sometimes confused with pale-blue barite (barium sulfate, BaSO_4), which has considerably greater density. Unlike barite, celestine often exhibits color zoning. When scraped into a flame, tiny particles of celestine burn with distinctive and characteristic bright-red flashes.
Dana Classification Number: 28.3.1.2

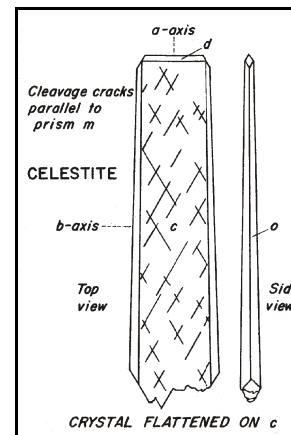


Figure 1. Flattened celestine crystal, from *Mineralogy* by John Sinkankas, used by permission.

NAME

Correctly pronounced “SELL-ess-teen,” this month’s mineral takes its name from the Latin *caelestis*, meaning “of the sky” or “celestial,” a reference to its pale-blue color. Until the mid-1980s, celestine was formally known as “celestite” (see *History & Lore*). Other names for celestine include “celestina,” “celestite,” and “schätzit.” Barium-rich varieties are known as “barian celestine” or “barytocelestine.”

COMPOSITION

The chemical formula SrSO_4 identifies celestine as strontium sulfate, a mineral containing the elements strontium (Sr), sulfur (S), and oxygen (O). The molecular weight of celestine is made up of 47.70 percent strontium, 34.84 percent oxygen, and 17.46 percent sulfur. Within the celestine molecule, the +2 charge of the strontium cation balances the -2 charge of the single sulfate anion.

Sulfates are compounds of oxygen and sulfur with one or more metals. Oxygen and sulfur form the sulfate ion, or radical $[(\text{SO}_4)_2^-]$. The term “radical” refers to a group of atoms of different elements that are bound

November 2005 Mineral of the Month: Celestine

together and act as a chemical entity. In the sulfate radical, a single sulfur atom is surrounded by four oxygen atoms positioned at the corners of a tetrahedron. The radical's two excess negative charges are distributed evenly over the oxygen atoms. Due to the many ways that sulfate anions can accommodate one or more metal cations, the sulfate mineral group is large and complex, with nearly 200 members.

Although celestine is a simple sulfate with a single metal cation, its molecule and lattice are held together by two different 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 anion and the strontium cation are bound ionically, that is, by the force that holds together a distinctly metallic ion with a distinctly nonmetallic and oppositely charged ion or radical. In celestine, the strontium ion with its positive divalent charge is attracted to the negative divalent charge of the sulfate radical.

Despite the presence of intermolecular covalent bonds, the celestine lattice is held together primarily by weaker ionic bonds that impart 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 arrangement within the crystal lattice. This three-dimensionality is reflected in celestine's three cleavage directions that are perfect, good, and distinct. Unlike many ionically bound minerals that crystallize in the cubic system (such as halite) with perfect cleavage in three directions, celestine's cleavage, while three-dimensional, varies in directional strength because of the unequal axial lengths of its orthorhombic crystal. Celestine's relatively weak ionic lattice bonding also accounts for its softness of Mohs 3.0-3.5. And because ionic bonds are vulnerable to the dipolar action of water, celestine is moderately soluble in water.

Celestine's solubility explains its occurrence primarily as an evaporite mineral. Evaporites form in enclosed basins from evaporation of saline lake water or seawater that is rich in dissolved mineral salts, notably those of the sulfates, chlorides, and carbonates of sodium, potassium, and calcium. Because strontium is considerably less abundant than these elements, celestine is a much less common mineral than such evaporites as gypsum (hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or calcite (calcium carbonate, CaCO_3). In sedimentary evaporite deposits, celestine is often associated with gypsum, calcite, halite, and strontianite (strontium carbonate, SrCO_3). Limestone, a sedimentary rock consisting chiefly of the mineral calcite, is among the most common mineralogical environments for celestine. Although celestine is widely distributed in the Earth's crust, individual occurrences are rarely large. Celestine also occurs in smaller quantities in granite pegmatites and in hydrothermal vents in association with calcite and quartz.

Along with barite (barium sulfate, BaSO_4) and anglesite (lead sulfate, PbSO_4), celestine is a member of the barite group. Barium, strontium, and lead have similar ionic radii and combine with the sulfate radical to form minerals that crystallize in the orthorhombic system. Similarity of ionic size also enables barium and lead to substitute for strontium within the celestine crystal lattice to form three solid-solution series, the most common of which is the barite-celestine series. Intermediate phases of the barite-celestine solid-solution series are known as barian celestine or barytocelestine.

Mineralogists have long debated the origin of color in celestine and have, at various times, attributed its occasional pale orange and green colors to trace amounts of such chromophores (coloring agents) as copper, sulfur, and even colloidal gold. Most perplexing has been the cause of celestine's characteristic pale-blue color, which has been attributed to everything from traces of iron phosphate to the substitution of barium and lead for strontium. But during the 1960s, when analysis of blue celestine specimens sometimes revealed high levels of chemical purity that discredited the chromophore theory, attention shifted to traces of potassium, an element with a chemical affinity for strontium. More recent studies indicate that celestine's blue color is caused by "color centers." Color centers are imperfections in the crystal lattice often due to natural geophysical radiation, the energy of which removes electrons from their

November 2005 Mineral of the Month: Celestine

normal positions. When these energized electrons lose their energy, they come to rest 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 end of the visible spectrum, while reflecting the blue end. This theory of radiation-induced color centers is supported by the fact that strontium has a very high chemical affinity for the rare, radioactive element radium, even the most minute traces of which could disrupt the normal celestine lattice. Research also indicates that traces of potassium within the celestine lattice, while not causing the “celestine-blue” color, stabilizes the color centers to make the color more or less permanent.

Strontium, the metal cation in the celestine molecule, is one of the alkaline earth metals. It is a soft, ductile, malleable metal with a very high level of chemical activity. Strontium is bright, silvery-white when freshly cut, but oxidizes rapidly in the atmosphere to a dull yellow. Finely powdered, elemental strontium will ignite spontaneously in air. Strontium ranks 15th among the elements in crustal abundance. Because of its chemical activity, strontium never occurs as a native metal. Of the 160 minerals that contain strontium, by far the most abundant are celestine and strontianite (strontium carbonate, SrCO₃).

COLLECTING LOCALITIES

Celestine is widely distributed and has numerous collecting localities. Fine specimens occur at Sakoany, Vallée de la Sofia, Mahajanga Province, Madagascar. In Spain, pale-blue crystals to four inches in length are collected at Puente Tablas at Jaén in Andalusia, and at El Esbornacs at Lleida in Catalonia. In the British Isles, celestine occurs at Peak Hill, Sidmouth, Devon, England, and at Strontian, Argyllshire, Scotland (the type locality for strontianite). Fine specimens also come from three localities in the former Soviet Republic of Turkmenistan, as detailed under *About Our Specimens*.

In Mexico, fine specimens are found at the Rancho de Mojina Mine at Ahumada, Chihuahua, and the Ojuela, Padre, and Vergel mines at Mapimí, Durango. Canadian celestine occurrences include those at Cheverie, Hants County, Nova Scotia; the Amherstburg Quarry at Amherstburg, Ontario; and the Big Fish River area in the northern Yukon Territory.

The United States also has many celestine localities. These include Crystal Cave at Put-in-Bay on Lake Erie's South Bass Island in Ottawa County, Ohio; the limestone quarries at East Stone Gap in Wise County, Virginia; earth cuts along the Erie Canal and the Pekin Quarry at Lockport in 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 in Blair County, Pennsylvania. In Texas, celestine sites include Bull Creek within the Austin city limits in Travis County and Adamsville in Lampasas County; in New Mexico, at Carlsbad Caverns and adjacent Lechuguilla Cave in Eddy County; in Arizona, at the Clip, Blaine, and other nearby mines in the Trigo Mountains district in La Paz County; and in California at the Billie Mine, Death Valley, Inyo County and at numerous old celestine mines in the Calico-Daggett borate-mining district, San Bernadino County.

JEWELRY & DECORATIVE USES

Although celestine has a relatively high refractive index (1.625-1.639) similar to that of topaz [aluminum fluorosilicate, AlSiO₄(F,OH)₂], its great softness of Mohs 3.0-3.5 precludes its use as a gemstone. Also, its pale-blue color lacks the intensity necessary for visual appeal as a colored gemstone. Celestine is faceted only occasionally 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 considered a classic mineral collectible.

November 2005 Mineral of the Month: Celestine

HISTORY & LORE

Although celestine has been known since antiquity, it remained confused with other evaporite minerals until the late 18th century. Recognition of celestine as a distinct mineral came only after the discovery of strontium itself. In 1790, Scottish chemist Adair Crawford (1748-1795) studied a strange mineral obtained from Strontian, Argyllshire, Scotland. After concluding that it probably contained a new element, he named the mineral strontianite. Three years later, studies by Scottish chemist Thomas Charles Hope (1766-1844) and German mineralogist Martin Heinrich Klaproth (1743-1817) supported Crawford's idea that strontianite contained a previously unidentified element. Finally, in 1798, Hope proved the existence of a new element in strontianite which he named strontium, after the village of Strontian, the type locality for strontianite.

Meanwhile, in 1791, a German traveler collected specimens of a thin, fibrous, pale-blue mineral from Bell's Mills, near Bellwood in Blair County in south-central Pennsylvania. He later brought them to Germany and to the attention of Martin Heinrich Klaproth who identified them as a new mineral. Then, in 1798, immediately following Hope's discovery of strontium, Klaproth realized that the Pennsylvania mineral was a sulfate of strontium. German geologist and mineralogist Abraham Gottlob Werner (1750-1817) then named the new mineral celestine after its heaven-like color.

The name "celestine" served until the early 1900s, when it was formally changed to "celestite" to be more in keeping with most other mineral names that ended in "-ite." When the International Mineralogical Association was established in 1958, its Commission on New Minerals and New Mineral Names became the global authority on mineral names. In the 1980s, this commission reevaluated some grandfathered mineral names and formally restored the name "celestine." This has since led to some confusion, since all mineralogical texts, field guides, and glossaries published prior to the mid-1980s, many of which are still used today, employ the term "celestite."

In 2002, a group of fifth-grade students 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 State Senate, the bill died in committee, and Pennsylvania is still without an official state mineral. Celestine has been featured on the 150 Communauté Financière Africaine franc stamp of Mali in 1998.

According to modern metaphysical belief, celestine enhances personal creative expression, reduces stress, provides peace of mind, helps adjust to higher states of awareness, and aids in recalling dreams and communicating with spiritual realms.

TECHNOLOGICAL USES

Celestine is the primary ore of strontium. With the exception of one strontianite mine in China, all 30 strontium mines now operating worldwide exploit celestine ores. Most celestine ore is obtained by open-pit mining of surface or near-surface celestine deposits. After mining, the ore is crushed, washed, and gravitationally concentrated. The celestine is then chemically converted to strontium carbonate, the basic feedstock for industrial use or conversion to other strontium compounds.

Prior to the 1960s, strontium was used only to create red colors in pyrotechnics. When strontium salts burn, they undergo a rapid reduction-oxidation reaction in which the salt is first reduced to elemental strontium which immediately burns, or oxidizes, emitting an intense light at a unique and highly visible red wavelength. By the mid-1800s, strontium salts, most often strontium nitrate, were being used to manufacture fireworks and safety, signal, and railroad flares. Celestine mining boomed during World War

November 2005 Mineral of the Month: Celestine

It was when strontium was needed for military tracer ammunition. When the War Production Board declared strontium a strategic material during World War II, celestine mining boomed again. In the United States, California and Texas were the leading celestine producers. 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 development of a glass that could block potentially hazardous x-radiation. Strontium carbonate proved the perfect additive to television faceplate glass, not only blocking radiation but transmitting a more brilliant image. In 1970, federal law required that the faceplates of all televisions sold in the United States be made of strontium glass. Meanwhile, researchers also developed ferrite-ceramic magnets by heating together iron oxide and strontium carbonate to form strontium hexaferrite. Although strontium hexaferrite has a lower energy level than other permanent-magnet materials, it resists demagnetization and corrosion and is very inexpensive to fabricate into specific shapes. Today, three quarters of all magnets manufactured worldwide consist of strontium hexaferrite. They 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" magnets.

Today, 85 percent of all strontium is used to manufacture television- and computer-faceplate glass and ferrite magnets. Elemental strontium has few uses--its most important use is as a minor alloying additive in aluminum to improve its casting qualities in the manufacture of automotive engine blocks and wheels.

Some 400,000 metric tons of celestine are currently mined worldwide each year. The leading producers are Mexico and Spain, which together account for 75 percent of world production. They are followed by China and Turkey. Since the United States has no active celestine mines, it is the leading importer of celestine ore and strontium compounds. One metric ton of celestine ore concentrated to 90 percent strontium sulfate sells for about \$53.

ABOUT OUR SPECIMENS

This is now the second time we have featured this marvelous mineral, the first time being December 2000, when we sent Club members beautiful blue crystals from the aforementioned Madagascar locality. There is little doubt that this is the only mineral we are likely to feature from Turkmenistan, and finding information on the celestine localities has been quite a challenge. We have featured minerals from surrounding areas--diopside from Kazakhstan to the north in September 2001, and orpiment from the Caucasus on the other side of the Caspian Sea in May 2005.

The Republic of Turkmenistan, has a population of nearly six million, and a land boundary of 188,455 square miles. Desert and semiarid terrain cover 80% of the country, including the Karakum or Garagum, one of the world's largest sand deserts, which covers most of the interior. The official language is Turkmen, and the three largest Turkmen tribes are the Tekke in the center, the Ersary on the eastern Afghanistan border, and the Yomud in the west. Sunni Muslims account for about 85% of the population.

Turkmenistan has substantial reserves of oil and natural gas in the Caspian Sea area and in the Karakum desert, and other natural resources include deposits of coal, sulfur, magnesium, and salt. Just five Turkmenistan localities have produced mineral specimens of note, with celestine found at three. The first is Mine No. 3 of the Guardak deposit, near Charjew, in eastern Turkmenistan, as seen on the map in Figure 2. Celestine, calcite, gypsum, and halloysite are found here, and this mine is the type locality, along with a Russian occurrence, for para-alumohydrocalcite, a mineral we will never feature. Celestine also occurs at the Kap-Kutan Cave System, in the Kugitangtou Ridge, southeastern Turkmenistan, as seen on the map. The Kap-Kutan, or Cupp Coutunn Karst Cave System (all of these Turkmenistan localities have

November 2005 Mineral of the Month: Celestine

multiple spellings), is, like the Cave of Swords at Naica, Chihuahua, Mexico mentioned in last month's write-up, one of the world's greatest wonders—a cave system containing breathtaking, awe-inspiring crystalline formations of gypsum, aragonite, celestine, epsomite, and other minerals in forms resembling draperies, trees, snowflakes, ice beds, desert shrubs, needles, and many more. Absolutely awesome!

Our specimens come from Mount Beineu-Kyr (or Beinev-Kyr) in northwestern Turkmenistan, as seen on the map. They were collected in the 1940's by the two Russian geologists who had discovered the deposit, removing some 3000 pounds

worth! The celestine lot then came under control of the Soviet mineral and fossil exportation department, called something along the lines of "Exportsovatzvety." When the Soviet government was breaking up and the departments were becoming privatized in the 1990's, these same geologists were offered the remaining mineral stock, more than 80 tons worth! Unfortunately, they died within six months of one another, leaving the huge inventory for their families to disperse. An American gem dealer traveling through Russia in 1994 was offered the lot, made the purchase, and soon had 160,000 pounds of Russian minerals sitting in his warehouse! Imagine trying to sort, separate, and identify such a lot while running a gem business! He did at times sell small portions, and we actually bought a few pieces from this lot at high prices several years ago from a Canadian dealer. Realizing he would never find the time to sort everything, he recently sold the remaining 150,000 pounds of minerals to a group of investors/mineral collectors in southern California, who got in touch with us. We were stunned to see so much of this amazing celestine, and immediately made arrangements to feature it, and hopefully, several other Russian minerals in the near future.



Figure 2. Turkmenistan celestine localities

If you take a close look at the crystals on your piece, you will notice how they resemble the flattened crystal drawing in Figure 1, and may even note some of the cleavage cracks depicted there. The clear crystals sit atop a layer of reddish-brown celestine, a previous growth, probably colored by hematite inclusions. The matrix consists of sedimentary clay and limestone. Yes, this month's mineral has much to recommend it: the most common strontium mineral, excellent crystals, and a heavenly name and color!

References: *Dana's New Mineralogy*, Eighth Edition; 2004 *Fleischer's Glossary of Mineral Species*, J. A. Mandarino and M. E. Back, The Mineralogical Record, Inc.; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *Manual of Mineralogy*, 21st Edition, Cornelius Klein and Cornelius S. Hurlburt, Jr., John Wiley & Sons; "What's New in Minerals: Costa Mesa Show 2003," Tom Moore, *The Mineralogical Record*, March-April 2004; "Coloring Mechanisms in Celestite," Lawrence Bernstein, *American Mineralogist*, Vol. 64, 1979; "Celestine from East Salem, Pennsylvania," Jeri Lee Jones, *Rocks & Minerals*, March-April 1983; "Strontium," Joyce Oates, 2004 *Minerals Yearbook*, United States Geological Survey; "Connoisseur's Choice: Celestine from the Maybee Quarry, Monroe County, Michigan," Robert B. Cook, *Rocks & Minerals*, March-April 1992; "Pennsylvania Geology," Pennsylvania Bureau of Topographic and Geologic Survey, Fall 2003; "Rediscovery of Lampasas Celestine," Joe Lobell, *Rocks & Minerals*, March-April 1992; "The Nomenclature Debacle," John S. White, *Rocks & Minerals*, May-June 2004; "Celestine, Strontianite . . . Strontium," Steve Voynick, *Rock & Gem*, October 2003; *The Economics of Strontium*, Roskill Information Services, Ltd., 1992; "Kazakhstan and Middle Asia—A Brief Mineralogical Guide," Alexander A. Evseev, *World of Stones* No. 8, 1995; Minerals of the Cupp Coutann Karst Cave System, Southeast Turkmenistan," Vladimir A. Maltsev, *World of Stones* No. 2, 1993.