

September 2011 Mineral of the Month: Anhydrite

This month's mineral is from the famed Naica Mine, a classic locality in Mexico which produces the world's finest anhydrite specimens. After explaining anhydrite's mineralogy and close relationship with gypsum, our write-up describes Naica's "Cave of the Giant Crystals"—a geode-like cave filled with the world's largest, most spectacular freestanding crystals!

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: CaSO_4 Calcium Sulfate

Class: Sulfates

Subclass: Anhydrous Sulfates

Group: Anhydrite

Crystal System: Orthorhombic

Crystal Habits: Usually massive, granular, or compact; also fibrous in parallel, radiated, or plumose (mica-like) aggregates; occasionally nodular. Crystals, which are rare, have tabular or prismatic habits.

Color: Usually colorless or white; also gray, bluish, reddish, and pale lavender.

Luster: Vitreous on crystal faces; pearly on cleavage surfaces.

Transparency: Usually translucent; rarely transparent.

Streak: White

Refractive Index: 1.569-1.618

Cleavage: Perfect in one direction, good in two others, at 90 degrees

Fracture: Subconchoidal to uneven, brittle

Hardness: 3.0-3.5

Specific Gravity: 2.97

Luminescence: Occasionally fluorescent

Distinctive Features and Tests: Rectangular cleavage fragments; vitreous luster on crystal faces, pearly luster on cleavage surfaces; frequent occurrence in evaporite beds; and association with gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$].

Dana Classification Number: 28.3.2.1

NAME The name "anhydrite," pronounced ann-HIGH-drite, stems from the Greek *anhydros*, meaning "without water" and alluding to its anhydrous state as opposed to the hydrous state of the chemically similar mineral gypsum. Anhydrite has been known as "anhydrous sulfate of lime," "anhydrous gypsum," "dry gypsum," "cube spar," "karstenite," and "muriacite." "Vulpinite," a scaly, massive variety, is sometimes cut and polished as an ornamental stone; "Angelite" is a deep-blue variety. In European literature, anhydrite appears as *anhidrita*, *anhidrit*, and *Anhydrit*.

COMPOSITION: Anhydrite, chemical formula CaSO_4 , consists of 29.44 percent calcium (Ca), 23.55 percent sulfur (S), and 47.01 percent oxygen (O). Anhydrite is a member of the sulfates, a class of nearly 200 minerals in which sulfur and oxygen, combined as the sulfate radical $(\text{SO}_4)^{2-}$, bond with one or more metals. Anhydrite crystallizes in the orthorhombic system with three mutually perpendicular axes of different lengths. Weak ionic bonding explains anhydrite's relative softness of Mohs 3.0-3.5 and its moderate solubility in water. Because of its solubility, anhydrite forms mainly as an evaporite mineral and is a major rock-forming mineral in many chemical sedimentary rocks. Anhydrite also occurs to a lesser extent in carbonatites, zeolite pockets within basalt formations, hydrothermal veins, and volcanic fumarole deposits. Anhydrite is chemically similar to gypsum. Both are calcium sulfates, but gypsum contains water of hydration and anhydrite does not. As an allochromatic or "other-colored" mineral, anhydrite's color is determined by traces of accessory elements, rather than by its essential elements or the nature of its

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crystal lattice. Pure anhydrite is colorless or white, but traces of such nonessential elements as iron and manganese produce a range of pale colors.

COLLECTING LOCALITIES: The finest anhydrite specimens come from the Naica Mine at Naica in Chihuahua, Mexico. Specimens are also collected in Cuba, Canada, Austria, Germany, Switzerland, Poland, Ukraine, Italy, Bolivia, Peru, Chile, Democratic Republic of Congo, Japan, Namibia, and South Africa. In the United States, anhydrite occurs in Texas, Louisiana, Alabama, Arizona, California, Colorado, Michigan, Missouri, New Jersey, New Mexico, New York, Oklahoma, and Virginia.

HISTORY, LORE, & GEMSTONE/TECHNOLOGICAL USES: German mineralogist Abraham Gottlieb Werner (1747-1817) described anhydrite as a new mineral species in 1794 after studying specimens from the Hall salt mine near Innsbruck, Styria, Austria. Mineralogists determined the atomic structure of anhydrite in 1922 using X-ray diffraction methods. Anhydrite has no technological uses. According to modern metaphysical practitioners, blue varieties of anhydrite remove emotional blocks, especially those regarding resentment.

ABOUT OUR SPECIMENS: Our specimens are from the Naica Mine at Naica, Municipio de Saucillo, Chihuahua, Mexico, an area that is 230 miles south of El Paso, Texas. Spanish prospectors discovered the Naica multi-metal deposit in 1794 and mined it for silver. The Naica Mine has operated more-or-less steadily for more than 200 years and produces lead, zinc, and smaller amounts of silver, copper, and gold. Its historic production exceeds 40 million tons of ore. Naica is Mexico's oldest producing mine, its leading source of lead, and southern Chihuahua's biggest private employer. Its mineralization was emplaced between 40 and 25 million years ago, when mineral-rich, hydrothermal fluids intruded formations of Cretaceous limestone to deposit sulfide minerals and dissolve parts of the limestone to create voids for the growth of well-developed crystals. Naica first became recognized in the 1970s as a source of mineral specimens, initially for crystals of fluorite and pyrite. In 1981, miners blasted into a fault that was lined with thousands of flat, square-terminated, pale, blue-gray anhydrite crystals that established Naica as a classic locality for anhydrite. Previously, anhydrite neither had a classic locality nor was considered an especially collectible mineral. In 2000, Naica miners discovered a natural geodic (geode-like) cave now known as *La Cueva de los Cristales Gigantes* (the Cave of the Giant Crystals). This horseshoe-shaped cave is 100 feet long, 35 feet wide, and is filled with crystals of the gypsum (var. selenite), some of which are 36 feet long, 4 feet thick, weigh an estimated 55 tons, and are the largest freestanding crystals ever found. Naica's crystal cave continues to receive international publicity and scientific study.

10 YEARS AGO IN OUR CLUB: Dioptase, Altyn-Tyube, Karagandy Province, Kazakhstan. "One of the most beautiful of all minerals, its rich emerald-green color lighting up any collection," wrote George Letchford English in his 1934 book *Getting Acquainted with Minerals*. We agree! Our specimens were from the prolific type locality, small intensely green crystals on an earthy brown matrix. We'll have to look for more in Denver this year! The excitement created by the beauty of our featured mineral in September 2001 was overshadowed by the shock and sadness over the destruction of 9/11. When the first news reports started coming in, Richard was with our then 17-year-old son Keenan at a hotel in Utah en route from the Gem & Jewelry show in San Mateo (San Francisco area) to Denver for the show, while Cheryl was at home, preparing to fly to Denver to meet up with her family. (Her flight was subsequently canceled.) In Denver, most vendors seemed to be going through the motions in the wake of the magnitude of the tragedy. We remember writing in our newsletter at the time that in the mineral world, collectors and dealers from all around the earth, including many from the Arab lands, seem to be able to unite in a common love for minerals. Yet the world is so divided by religious fanaticism, prejudice, intolerance, and hatred, that we wonder who really has the ability to unite people and bring peace to the earth? Certainly millennia of human history have proven that humans cannot achieve this desirable goal!

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COMPREHENSIVE WRITE-UP

COMPOSITION

We first sent lovely specimens of sky-blue anhydrite from this same locality of Naica, Mexico, to about 180 Club members in June 1998. This was before the amazing discovery of the Cave of the Giant Crystals, as described further in this write-up. Amazingly, these new specimens were found along the same fault and were created by the same forces as the ones we sent last century, as we will see.

Anhydrite, chemical formula CaSO_4 , contains the elements calcium (Ca), sulfur (S), and oxygen (O). Anhydrite's molecular weight is made up of 29.44 percent calcium, 47.01 percent oxygen, and 23.55 percent sulfur. Like all molecules, that of anhydrite is composed of positively charged cations and negatively charged anions. Anhydrite's simple cation is the calcium ion Ca^{2+} with its +2 charge. Its anion is a radical, a group of ions of different atoms that behaves as an entity in chemical reactions. The anhydrite anion is the sulfate radical $(\text{SO}_4)^{2-}$, in which a single sulfur atom is surrounded by four oxygen atoms positioned at the corners of a tetrahedron. The sulfur ion S^{6+} has an oxidation state of +6. The four oxygen ions 4O^{2-} each have an oxidation state of -2, and a collective charge of -8. This provides a total anionic charge of -2 to balance the cationic charge of +2 and impart electrical stability to the anhydrite molecule.

Anhydrite is a member of the sulfates, a class of nearly 200 minerals in which sulfur and oxygen, as the sulfate radical $(\text{SO}_4)^{2-}$, combine with one or more metals. Because its two excess negative charges are distributed evenly over the oxygen atoms, the sulfate radical can easily accommodate one or more metal cations. Although anhydrite is a simple sulfate with a single metal cation, its lattice exhibits two different types of atomic bonding. The sulfate radical $(\text{SO}_4)^{2-}$ is held together by strong covalent bonds with the four oxygen atoms sharing electrons with the single sulfur atom. The negatively charged sulfate radical and the positively charged calcium ion are bonded ionically by the attraction of opposite charges.

Weaker ionic bonding dominates within the crystal lattice and accounts for anhydrite's relative softness of Mohs 3.0-3.5 and its moderate solubility in water. In ionic bonding, the attractive forces are exerted more-or-less equally in all directions so that cations surround every anion and vice versa. This creates a three-dimensional, repeating arrangement within the lattice that is reflected in anhydrite's three cleavage planes that are perfect in one direction along the plane of predominant ionic bonding, and good in two other directions. Anhydrite crystallizes in the orthorhombic system, with three mutually perpendicular axes of different lengths. Its varying directional cleavage strength is due to the unequal axial lengths of the orthorhombic crystal. Orthorhombic crystals are usually blocky in appearance, but growth conditions or chemistry can elongate one axis, as is seen in anhydrite and certain other minerals.

Because of its solubility, anhydrite forms primarily as an evaporite mineral. It is a major rock-forming mineral in evaporite deposits of chemical sedimentary rocks, where it is associated with halite [sodium chloride, NaCl], calcite [calcium carbonate, CaCO_3], and gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$]. Anhydrite makes up about three percent of the various salts in most salt domes and occurs nearly pure in massive formations in the upper caprock zones of salt domes after groundwater has leached away the halite. Nodular forms occur when anhydrite replaces gypsum in sedimentary deposits in dehydrating environments. Anhydrite also occurs to a lesser extent in carbonatites (carbonate-rich igneous rocks) with gypsum and barite [barium sulfate, BaSO_4]; in zeolite pockets within basalt formations with calcite and zeolite minerals (a group of hydrated, complex aluminum silicates); in hydrothermal veins with calcite and quartz [silicon dioxide, SiO_2]; and in volcanic fumarole deposits.

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As an allochromatic or “other-colored” mineral, anhydrite’s color is determined by traces of accessory elements, and not by its essential elements or the nature of its crystal lattice. Pure anhydrite is colorless or white, but traces of the nonessential elements iron and manganese create a range of pale colors. Reddish colors are caused by the divalent manganese ion Mn^{2+} substituting for calcium in the lattice; blue and lavender hues are due to ions of divalent iron (ferrous) Fe^{2+} .

The Dana mineral-classification number 28.3.2.1 first identifies anhydrite as an anhydrous acid sulfate or normal sulfate (28). Acid sulfates contain hydrogen ions; anhydrite, with no hydrogen ions, is a normal sulfate. Anhydrite is then subclassified by the chemical formula $A^{2+}XO_4$, in which “A” can be divalent ions of calcium, barium, strontium, or lead, and “X” is the sulfur ion S^{6+} . Anhydrite is then assigned to the anhydrite group (2) as the first and only member (1). The perceived color of transparent or translucent anhydrite is a function of reflected light only. When a specimen is backlit and viewed with transmitted light, it appears nearly colorless. This is because the wavelengths of white light are selectively absorbed only through reflection; transmitted white light passes through the crystal lattice with virtually no wavelength absorption.

Our featured mineral is closely related to gypsum. How? Both anhydrite [calcium sulfate, $CaSO_4$] and gypsum [hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$] are calcium sulfates. But gypsum is a hydrous mineral that contains two attached molecules of water. In the water molecule, a large oxygen atom is covalently bonded to two small hydrogen atoms that group together on one side of the oxygen atom. These two hydrogen atoms retain a weak positive charge, while the opposite side of the molecule, dominated by the large oxygen atom, retains a weak negative charge. Water molecules thus behave as tiny dipole magnets. Hydrogen bonding, also called polar bonding, forms when the faintly positive poles of water molecules attract the electrons of other atoms. In gypsum, the positive poles of water molecules are attracted to the slight negative charge of the oxygen atoms in the sulfate radical. Because hydrogen bonding is strongest at cold temperatures, gypsum becomes unstable when heat parts its weak hydrogen bonds to drive off its water of hydration. Whether calcium ions and sulfate ions will crystallize from aqueous solutions as anhydrite or gypsum therefore depends upon temperature (and to a lesser extent, pressure and chemistry). With available water and low temperatures, anhydrite can hydrate and transform to gypsum. Conversely, in the absence of water and with high temperatures, gypsum can dehydrate into anhydrite. Gypsum is stable below 136° F. (57.7° C.); anhydrite is stable above this temperature. This gypsum-anhydrite temperature-stability boundary (which varies somewhat with chemistry and pressure) is important in understanding the origin of the Naica Mine’s huge gypsum crystals (see “Naica’s Cave of the Giant Crystals”).

It is interesting to compare the physical properties of anhydrite and gypsum. At Mohs 3.0-3.5, anhydrite is considerably harder than gypsum (Mohs 2.0) because gypsum’s water molecules separate calcium ions and sulfate ions, thus weakening its ionic bonding. Because this same increase in inter-ionic distance also decreases density, gypsum’s specific gravity is only 2.32. The specific gravity of anhydrite, with its much closer atomic packing, is a substantially higher 2.97. Water of hydration also affects crystallization. While anhydrite crystallizes in the orthorhombic system, gypsum crystallizes in the monoclinic system because water of hydration alters its crystal lattice. And because anhydrite can hydrate into gypsum, and gypsum can dehydrate into anhydrite, these two minerals often form mutual pseudomorphs, with gypsum assuming the orthorhombic external shapes of anhydrite, and anhydrite assuming the monoclinic external shapes of gypsum.

COLLECTING LOCALITIES

Although anhydrite is abundant and widely distributed, it rarely occurs as well-developed crystals and therefore has relatively few collecting localities. Our specimens are from the Naica Mine at Naica,

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Municipio de Saucillo, Chihuahua, Mexico. Another Mexican source is the El Boleo Mine in the Boleo district near Mulegé in Baja California Sur. Cuban specimens come from the El Cobre Mine in the Sierra Maestra Mountains near Santiago de Cuba, Oriente Province. Canadian specimens are collected at the Faraday Mine in Faraday Township, Hastings County, Ontario.

In Europe, Austrian specimens come from the anhydrite type locality at the Hall salt mine near Innsbruck and from the nearby Altaussee salt mine at Bad Aussee, both in Styria; and from the Dürrenburg salt deposit near Hallein, Salzburg. Other European localities are the Hänigsen and Wathlingen potash works in Lower Saxony and the Gröna Mine in the Stassfurt potash deposit near Egain in Saxony-Anhalt, both in Germany; the Simplon Tunnel at Simplon Pass near Brig, Valais, Switzerland; the Wieliczka Salt Mine at Wieliczka, Malopolskii, Poland; and the Volodarsk-Volynsii salt deposit in Zhytomyr Oblast', Ukraine. Italian specimens come from the Somma-Vesuvius Geological Complex, Naples Province, Campania; the Campiano Mine at Montieri, Grosseto Province, Tuscany; and Volpino and Averara in the Brambara Valley, Bergamo Province, Lombardy.

Other localities include the Pulacayo Mine at Huanchaca, Antonio Quijarro Province, Potosí Department, Bolivia; the Casapalca Mine at Casapalca, Huarochiri Province, Lima Department, and the Morococha district mines in Yauli Province, Junin Department, both in Peru; the San Francisco Mine at Caracoles, Antofagasta Province, Antofagasta Region, Chile; the Shinkolobwe Mine in Katanga's Copper Crescent, Democratic Republic of Congo; the Yonaibata and Kono mines at Yama-gun, Fukushima Prefecture, Tohoku Region, Honshu Island, Japan; the Kombat Mine at Kombat, Grootfontein District, Otjozondjupa Region, Namibia; and the Nababeep tungsten mines in the Okiep Copper District, Namaqualand, Northern Cape Province, South Africa. Over the years, we have seen a couple of very pretty anhydrite specimens of a light purple color from a couple of these localities.

In the United States, anhydrite is abundant in the Louisiana and Texas salt domes, especially those of the Louisiana parishes of Ascension, Calcasieu, Iberia, Iberville, Lafourche, Plaquemines, St. Mary, Terrebonne, and Winn; and the Texas counties of Brazoria, Brewster, Chambers, Culberson, Duval, Fort Bend, Galveston, Hardin, Harris, Jefferson, Liberty, Matagorda, Pecos, Presidio, Travis, Van Zandt, and Wharton. Other localities are the Union Salt Well in Clarke County, Alabama; the Ajo copper mine at Ajo, Pima County, Arizona; the Furnace Creek borate district in Inyo County, Bristol Dry Lake in San Bernadino County, and Mono Lake in Mono County, all in California; the Camp Bird Mine at Ouray in Ouray County and the Howardsville mines in the Silverton district in San Juan County, both in Colorado; the Champion Iron Mine at Champion in the Marquette Iron Range, Marquette County, Michigan; the limestone quarries of Washington and St. Louis counties, Missouri; the Haledon traprock quarries of Passaic County, New Jersey; the Carlsbad potash district in Eddy and Lea counties, New Mexico; the Lockport and Niagara Falls dolomite quarries in Niagara County, New York; the Southard gypsum quarries in Blaine County, Oklahoma; and the Stodler and Rosenberger quarries in Fairfax County, Virginia.

JEWELRY & DECORATIVE USES

Anhydrite has only limited use in jewelry. Crystals of an unusual, deep-blue variety known as "Angelite" are sometimes wrapped in silver wire for wear as pendants. The Angelite variety comes mainly from Peru, where it is fashioned into cabochons, massage points, discs, spheres, eggs, and other forms, and is quite popular among the metaphysical crowd. A scaly, massive variety called "Vulpinite" is collected at Volpino in Bergamo Province, Lombardy, Italy, and cut and polished as an ornamental stone that is similar in appearance to the alabaster variety of gypsum. Collectors value specimens of anhydrite crystals for their rarity, unusual habits, and mineralogical associations. Anhydrite from the Naica Mine in Mexico is the most beautiful and striking yet found, and the finest specimens are eagerly sought by sophisticated collectors around the world. We have one piece that may end up on display in a museum in the future!

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HISTORY & LORE

German mineralogist Abraham Gottlieb Werner (1747-1817) described anhydrite as a new mineral species in 1794 after studying specimens from the Hall salt mine near Innsbruck, Styria, Austria. Werner determined that the mineral's chemical composition did not include water, but was otherwise identical to that of gypsum. In 1804, he named the new mineral "anhydrite" to reflect its anhydrous state and to differentiate it from the hydrous mineral gypsum. Mineralogists determined the atomic structure of anhydrite in 1922 using newly developed X-ray diffraction methods. Modern metaphysical practitioners believe that blue varieties of anhydrite remove emotional blocks, especially those regarding resentment.

TECHNOLOGICAL USES

Anhydrite has no technological uses.

NAICA'S CAVE OF THE GIANT CRYSTALS

The Naica Mine has always been well-known within Mexico as that nation's oldest operating mine, its largest producer of lead, and the biggest private employer in southern Chihuahua. But apart from mining professionals and mineral collectors, Naica had little international name recognition until the year 2000, when miners discovered a cave filled with the largest and most spectacular freestanding mineral crystals ever found. Since then, descriptions and photographs of these 36-foot-long, beautifully developed, transparent prisms of selenite (the crystalline variety of gypsum) have appeared in publications ranging from Time and Newsweek to National Geographic Magazine and in virtually every geological and mineralogical journal in the world.

This major discovery was preceded by a smaller find in December 1999, when two Naica miners, brothers Eloy and Javier Delgado, were driving a ventilation tunnel 900 feet underground. After blasting the tunnel face, Eloy Delgado noticed a small opening in the rock and crawled through to find a geodic-type cave about 25 feet in diameter. Inside, the beam from his cap lamp reflected off a bright, eye-like object, which turned out to be the reflective face of a four-foot-long, transparent selenite crystal, hundreds of which protruded from the walls and floor of the small cave. Because of this eye-like reflection, Delgado named his discovery the Cueva del Ojo de la Reina—the "Queen's-Eye Cave."

Caves filled with selenite crystals had been found in the Naica Mine since the 1800s. In 1910, miners working 370 feet underground discovered a narrow cave 280 feet long with its walls covered with thin, four-foot-long selenite crystals. Because of these sword-like crystals, it became known as Cueva de las Espadas—"Cave of Swords." At the time, these were the largest selenite crystals ever found. The mine owners sealed off the Cave of Swords with wooden doors to preserve it for the enjoyment of visiting dignitaries. Many of the world's major museums eventually acquired specimens from the Cave of Swords. Some of these crystals are exhibited today in the Janet Annenberg Hooker Hall of Geology, Gems, and Minerals at the National Museum of Natural History (Smithsonian Institution) in Washington, D.C.

Both the Cave of Swords and the Queen's-Eye Cave, however, pale before the remarkable discovery made at Naica in April 2000. This time, Eloy Delgado and another miner, José Alvédez Lofra, were driving an exploration tunnel 930 feet underground. Engineers had only recently increased the rate of pumping to lower the water table sufficiently to enable miners to penetrate the Naica Fault without risking potentially disastrous flooding of the mine's lower levels. Before going off shift, the two miners blasted the tunnel

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face. Returning the next morning, Delgado saw a small opening and squeezed in to investigate. He later recalled his heart beating so rapidly that he nearly fainted from excitement when he saw a fantastic jumble of enormous selenite crystals.

Delgado reported his discovery to supervisors who immediately suspended work in the exploration tunnel. The jumble of huge crystals made venturing into the new cave difficult, while the cave's environment made it extremely dangerous. The air temperature within the cave was nearly 150 °F. (about 65 °C.) and the humidity was 100 percent—conditions that could be fatal within 15 minutes without special breathing systems and thermal-protection equipment. Shortly after this discovery, a lone miner did nevertheless enter the cave to collect crystals. Sadly, he was found dead the following day, his body in a condition that witnesses described as “baked.” Supervisors then ordered the installation of a steel door for safety purposes and to protect the cave for scientific study by maintaining its natural temperature and humidity as closely as possible.

The horseshoe-shaped cave, now known as Cueva de los Cristales Gigantes (Cave of the Giant Crystals), is 100 feet long, 35 feet wide, and 20 feet high. Its largest crystals are 36 feet long, 4 feet thick, and weigh an estimated 55 tons—the largest freestanding crystals ever found. One of the first journalists to see the cave reported: “Most of the crystals are water clear, very sharp and firmly anchored. They show the classic monoclinic form of single crystals. In the open area of the cavern, away from the walls and jutting from the floor at various angles, are huge shafts of selenites up to four feet thick. They extend from floor to ceiling, crossing and crisscrossing at odd angles, sometimes growing into each other, sometimes growing free until they attach to the ceiling.”

Naica's Cave of the Giant Crystals has attracted dozens of geologists, mineralogists, and speleologists from around the world who have pieced together the cave's origin. They concluded that the same hydrothermal fluids that created the Naica ore deposit between 40 and 25 million years ago also created the caves. These caves were later enlarged by water rich in sulfuric acid produced by the oxidation of pyrite and other sulfide minerals. Fluids associated with later nearby volcanic action then dissolved large quantities of anhydrite from lower formations of Cretaceous limestone before circulating through the upper mineralized zones. The temperatures of these fluids, which were rich in calcium and sulfate ions, was about 170 °F. (76.6 °C.). In “Composition,” we explained that anhydrite is stable above 136 °F. (57.7 °C.), while gypsum is stable below this temperature. After filling the limestone voids, these solutions cooled to below the gypsum-anhydrite stability level, causing the calcium ions and sulfate ions to crystallize from solution in the form of gypsum. The huge size and exceptional development of these crystals indicate that cooling took place slowly over a very long period of time.

In 2006, an international group of earth scientists organized the Naica Project, an effort to study and promote awareness of Naica's Cave of the Giant Crystals. Funded by a consortium of universities, companies (including Industrias Peñoles, the owner of the Naica Mine), and government and private organizations, the Naica Project has since explored, mapped, and photographed the caves; studied the mineralogy of the selenite crystals and the geology of the caves; developed special breathing systems and thermal-protection equipment for use in the cave's hostile environment; and produced collections of images and audiovisual documentaries that have been distributed worldwide. Because Naica is a working mine and the cave environment is dangerous, the Cave of the Giant Crystals is not open to the general public. However, a quick internet search will lead to reports, photos and videos of these phenomenal crystals and the scientific study related to them.

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Only continuous pumping, which consumes large amounts of costly electricity, keeps the cave and the lower mine workings from flooding. How long pumping will continue depends upon the time required to mine Naica's remaining ore reserves. Naica currently has sufficient reserves for about 10 years of mining, an estimate that could be extended if new ore is discovered. This has posed a dilemma for scientists. "Should we continue to pump water to keep the caves available for future generations? Or do we stop pumping and return the scenario to its natural origin, allowing the crystals to continue growing?" asks Juan Manuel García-Ruíz, a geological researcher from Spain's University of Granada, who calls the Cave of the Giant Crystals the "Sistine Chapel of Crystals." Industrias Peñoles and Naica Project scientists have recently provided the answer. When production at Naica ends, the Cave of the Giant Crystals will be sealed with concrete, the pumps turned off, and the mine allowed to flood. The cave will then return to its natural environment—and may never be seen again by human eyes.

ABOUT OUR SPECIMENS

Our specimens were collected at the Naica Mine at Naica, Municipio de Saucillo, Chihuahua, Mexico. Naica is 230 miles south of El Paso, Texas, 80 miles south of the state-capital city of Chihuahua, and 20 miles west of the small city of Saucillo on Mexico Route 45. Naica, current population 4,000, was founded in 1827 as a community to support the Naica Mine. It is located in a semi-desert environment at an elevation of 3,360 feet on the northern side of the Sierra de Naica, a minor mountain range covered by sparse, brushy vegetation. The name "Naica," pronounced NYE-ka, is a Spanish derivation of a Tarahumara Indian word for "a shady place."

Spanish prospectors discovered oxidized silver mineralization here in 1794, when Mexico was still part of New Spain, the northernmost viceroyalty in Spain's colonial empire. This was the last major mineral discovery in Mexico during the 300-year-long colonial period. Spanish miners employed surface and shallow underground methods to mine the deposit for silver and small amounts of gold. The Mexican war of independence that began in 1811 curtailed production at Naica. Mining resumed a decade later when Mexico won its independence, but production was plagued by the mines remote location, poor roads, outdated mining technology, raids by outlaws and Apaches, and government instability. In the late 1870s, after Mexican president General Porfirio Díaz (1830-1915) reduced government restrictions to encourage foreign investment in mining, capital from the United States began to trickle into Naica. Deeper shafts revealed mineralization that was much more varied and extensive than originally thought. After the Naica Mining Company modernized its operations in 1900, Naica became a major source of lead and zinc, along with smaller amounts of silver, gold, and copper. But its prosperity was cut short by the onset of the Mexican Revolution in 1911. When the Naica Mining Company refused to financially support the revolution, troops murdered two of the mine's managers and forced the mine to shut down from 1912 to 1922.

Naica is one of the northernmost carbonate-replacement deposits within the Mexican Fold Belt, a 900-mile-long trend of folded carbonate rocks. The marine sediments in the Mexican Fold Belt were laid down between 150 and 65 million years ago and lithified into calcareous limestone and dolomite rock. In early Tertiary time 60 to 40 million years ago, tectonic stresses deformed these limestone and dolomite formations into the folds and thrusts of today's Mexican Fold Belt. Finally, between 40 and 25 million years ago, regional volcanism and magmatic intrusions forced mineral-laden, hydrothermal solutions upward into the fault-circulation systems. Mineralization occurred by replacement when superheated, acidic solutions dissolved sections of the limestone and dolomite formations. The dissolving carbonate minerals neutralized the acidic solutions, precipitating sulfide minerals that "replaced" the carbonates. At Naica, these replacements formed vertically oriented, mineralized zones called "chimneys" and horizontal oriented, mineralized zones known as "mantos" (literally "blankets"). Rich in metals, these deposits

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originally formed far below the surface, then were exposed by surface erosion millions of years later. The Naica geology is unusually complex because it also exhibits skarn characteristics created when the original magmatic intrusions metamorphosed parts of the existing limestone.

In 1952, when cumulative ore production had surpassed 21 million tons, Compañía Minera de Peñoles (now Industrias Peñoles) consolidated the Naica district, including the Ramon Corona, Maravilla, Lepanto, and Gibraltar mines, into a single operation called the Naica Mine. Previously, the Naica district had mined only oxidized ores no deeper than 350 feet, the original level of the water table. Now Peñoles sealed off 22 miles of oxidation-zone workings and began dewatering the mine to access the deep sulfide ores. Core-drill exploration revealed that the deposit included 90 vertical ore chimneys, 12 of which are considered major, along with 14 large, horizontal *manto* ore zones, some of which are 2,000 feet long, 250 feet wide, and 30 feet thick. The main ore minerals are pyrite [iron disulfide, FeS₂], argentiferous (silver-bearing) galena [lead sulfide, PbS], sphalerite [zinc sulfide, ZnS], and chalcopyrite [copper iron sulfide, CuFeS₂].

The Naica Mine is accessed by several external shafts and winzes (internal shafts) and a declined tunnel. Water and heat are major operational problems. Continuous pumping is necessary to both access the deep sulfide ores and prevent the lower mine workings from flooding. An underground system of large, electrically powered pumps operates around the clock to remove 24,000 gallons of water *per minute*. The mine is also exceedingly hot. Despite a powerful, new ventilation system, the air temperature in the lower production workings is 95 degrees F. (35° C.) with 95 percent humidity.

Naica's many interesting gangue minerals include andradite [garnet group, calcium iron silicate, Ca₃Fe₂(SiO₄)₃]; calcite [calcium carbonate, CaCO₃]; celestine [strontium sulfate, SrSO₄]; conichalcite [basic calcium copper arsenate, CaCu(AsO₄)(OH)]; copper [Cu]; covellite [copper sulfide, CuS]; cuprite [copper oxide, Cu₂O]; fluorite [calcium fluoride, CaF₂]; linarite [basic lead copper sulfate, PbCu(SO₄)(OH)₂]; malachite [basic copper carbonate, Cu₂(CO₃)(OH)₂]; molybdenite [molybdenum disulfide, MoS₂]; quartz [SiO₂]; arsenopyrite [iron arsenic sulfide, FeAsS]; gypsum; and anhydrite. Naica first attracted the interest of mineral collectors in the 1970s when mineral dealers from the U.S. visited regularly to buy specimens from miners eager to supplement their incomes. Among the first extraordinary Naica specimens to reach the international markets in 1976 were superbly developed, clear-to-green, one-inch fluorite cubes on matrices of modified, cubic galena crystals and near-black sphalerite crystals. Other specimens included unusually well-developed crystals of andradite, pyrite, and arsenopyrite.

Two Naica minerals of special interest are gypsum and anhydrite. The Naica Mine has the largest crystals of gypsum (var. selenite) ever found (see "Naica's Cave of the Giant Crystals"). Interest in anhydrite as a collectible mineral also originated at Naica. Prior to 1981, anhydrite had neither a classic locality nor much demand as a collectible mineral. But that year Naica miners blasted into a fault that was lined with thousands of flat, square-terminated, pale, gray-blue anhydrite crystals. When these crystals reached specimen markets, Naica immediately became the classic locality for anhydrite.

Our specimens were collected since 2007, after miners again blasted through the same fault where the first anhydrite crystals were collected in 1981. The tolerance of mineral collecting at the Naica Mine is a matter of some disagreement. According to some sources, the Naica Mine has an unusual mineral-collecting arrangement. Unlike many mines, Naica management has never objected to miners collecting and selling specimens for personal gain, provided, of course, that collecting does not interfere with production. Naica's shops, restaurants, bars, and hotels offer literally thousands of mineral specimens for sale, all brought from the underground by Naica's miners. Management sometimes even acts as an agent to sell specimens to foreign dealers, using the proceeds to help fund such events as dinners, dances, and picnics for the miners and their families.

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Another source with insight on the mine's workings states just the opposite, reporting that the mining company is locked in an ongoing battle with the miner over unauthorized collecting. The mining company is paying for ore production, and production suffers when miners are collecting minerals for themselves rather than giving attention to their duties. In addition, collecting in unapproved areas is dangerous, as the miners are working hurriedly for fear of detection, and sometimes are injured or even killed while doing so. Finally, the mining company feels that the miners are actually stealing company property. To solve these problems, the mining company feels justified in dynamiting crystal-lined pockets—no crystals means no collecting means no problems! And this is evidently what was done to this marvelous anhydrite-producing pocket where our specimens were collected, making us wonder when or if another exceptional pocket will be found, and if its crystalline contents will reach the surface even if one is discovered.

We hope that the first view of the mining company's practices is more accurate—how enlightened it would be for them to show support for their workers and regard for the amazing crystals formed millions of years ago, and allow the miners to benefit from their preservation! Mining is tremendously expensive, and the mining company needs to make a profit, but these other considerations deserve a place in their thinking, too. The emphasis on the “bottom-line” profit so prevalent today needs to be rethought, not just for the sake of all the mineral specimens that have been destroyed by mining companies, but much more importantly for the benefit of all mankind.

After more than two centuries of mining more than 40 million tons of ore, the Naica mine may be nearing the end of its operating life. Production levels are already more than 1,000 feet deep and dewatering expenses are mounting. Nevertheless, core-drilling exploration recently discovered a new, deep *manto* deposit containing about two million tons of relatively high-grade ore. Further discoveries would, of course, extend the mine's operating life, which is now estimated at 10 years.

As you examine your specimen, note first its pale, gray-blue color that is caused by traces of divalent iron. This color is most apparent when viewed in reflected light; when viewed with transmitted light (backlit), the specimen will appear nearly colorless. Your specimen consists of groups of elongated crystals in parallel or near-parallel alignment and having distinctive, flat terminations, a habit unique to Naica that cannot be confused with the habits of anhydrite specimens from other localities. Notice that the squared termination faces have a vitreous luster, while the smooth, slightly rounded cleavage surfaces at the base of the specimen have a softer, pearly luster. This difference in luster between crystal faces and cleavage surfaces is a diagnostic feature of anhydrite. Your specimen is more than a fine example of anhydrite from a classic locality—it is a memento of Mexico's famed Naica Mine, the home of the world's largest freestanding crystals!

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