January 2009 Mineral of the Month: Quartz Geode

This month's mineral is the rock-crystal variety of quartz in one of its most fascinating and beautiful forms: geodes from the Bou Craa phosphate mine in the Western Sahara desert of Africa. The write-up explains in a special section how geodes are formed, and examines the history of the huge Bou Craa deposit and its effect on the peoples of the Western Sahara. We hope you will also enjoy a special section on misleading and incorrect locality names. This is the first write-up with our new feature of a two-page overview of the mineral and its properties in brief, followed by our usual in-depth article.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: SiO_2 Silicon Dioxide
Class: Silicates
Subclass: Tectosilicates
Group: Quartz
Crystal System: Hexagonal
Crystal Habits: Usually long, prismatic crystals striated crosswise and frequently terminated by double rhombohedrons shaped like hexagonal pyramids; less frequently short prisms to nearly bipyramidal; sometimes distorted, skeletal, and drusy; also granular, disseminated, and massive (microcrystalline). Twinning common.
Color: Colorless, white, pink, rose-red, yellow, pale orange, lilac, purple, pale-brown, brown, near-black
Luster: Waxy and vitreous to dull
Transparency: Translucent to opaque
Streak: White
Refractive Index: 1.55
Cleavage: None
Fracture: Conchoidal to subconchoidal and irregular; brittle to tough.
Hardness: Mohs 7.0
Specific Gravity: 2.65
Luminescence: Impurities sometimes produce a weak green-to-white fluorescence
Distinctive Features and Tests: Best field marks are vitreous to greasy luster, crosswise-striated hexagonal crystals, and hardness
Dana Classification Number: 75.1.3.1

NAME The name "quartz," pronounced kwarts, is derived from the German *Quarz*, which is thought to have originated from the Slavic word *kwardy*, meaning "hard." The term "geode," pronounced JEE-ode and referring to a hollow rock structure lined with crystals, comes from the Greek *geodes*, meaning "earthlike," a reference to its generally spherical shape. Folk names for geodes include "eagle stone," "aetites," "echites," "aquileus," and "thunder eggs."

COMPOSITION Quartz, chemical formula SiO_2, consists of the semimetal silicon (Si) and oxygen (O) and contains 46.74 percent silicon and 53.26 percent oxygen. Quartz is a member of the silicates, a group in which silicon and oxygen combine with one or more metals or semimetals. The basic building block of silicate minerals is the silica tetrahedron $(SiO_4)^{4-}$, in which a silicon ion is surrounded by four equally spaced oxygen ions positioned at the corners of a tetrahedron (a four-faced polyhedron). Quartz, which is found in various quantities in virtually all igneous, metamorphic, and sedimentary rocks, forms in three ways: as a component of crystallizing magma in intrusive and extrusive formations; by the crystallization of silica-rich, hydrothermal fluids; and by the downward percolation of silica-rich groundwater. Quartz-filled geodes form when silica-rich groundwater fills voids and precipitates silica as quartz crystals.

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Because of omnidirectional covalent bonding, quartz crystals have neither cleavage planes nor a center of symmetry. Quartz also has a substantial hardness of Mohs 7.0 due to close atomic packing which strengthens the bonding within the lattice. The light atomic weights of silicon (28.09) and oxygen (16.00) account for quartz's relatively low specific gravity of 2.65. Rock crystal is colorless or "water clear," but trace impurities in quartz can create a wide range of colors in the other quartz varieties.

Geodes are generally defined as rock cavities with interiors that are lined with crystals or other mineral matter. They are typically oblate spheroids that range from a fraction of an inch to "walk-in" sizes and can be hollow, partially hollow, or completely filled with crystalline material. Geodes occur within volcanic and sedimentary formations. In volcanic formations, geodes originate as gas bubbles (vesicles) in lava that later fill with silica-rich groundwater that precipitates mineral crystals, usually of quartz or the zeolite minerals, on the vesicle walls. Sedimentary geodes form when calcite concretions dissolve to create a void, which is later filled with mineral-rich groundwater that precipitates crystals.

COLLECTING LOCALITIES Quartz geodes are collected in Western Sahara, Africa; in Brazil in the Soledade region of Rio Grande do Sul state; in Mexico at the Mesteno Ranch near Las Choyas, Chihuahua; in Australia at Agate Creek in Queensland; and in Germany at the Juchem Quarry at Niederwörrensbach near Idar-Oberstein in Rheinland-Phalz, Germany. In the United States, the most prolific sources of quartz-filled-geodes are the Dugway geode field in Tooele County, Utah; the Madras thunder-egg beds in Jefferson County, Oregon; and the Keokuk geode field in southeastern Iowa and adjacent areas of Missouri and Illinois.

HISTORY, LORE, & USES Rock crystal and rock-crystal-filled geodes have been collected since antiquity for their beauty and alleged mystical qualities. In medieval times, rock-crystal-filled geodes were associated with fertility and childbirth and physicians prescribed powdered rock crystal to relieve general pain and to treat renal and intestinal ailments. Rock-crystal-filled geodes were also used in the manner of crystal balls to diagnose disease and predict the future. Today, quartz geodes, in sizes ranging from a few inches to several feet and costing anywhere from a few dollars to thousands of dollars each, make eye-catching display pieces, especially the large, amethyst-lined geodes from southern Brazil.

ABOUT OUR SPECIMENS Our quartz-filled geodes come from the Bou Craa phosphate mine in Western Sahara, a politically disputed region in northwest Africa that is now occupied by Morocco. Western Sahara, which is the size of the state of Colorado, is sparsely populated and has a hot, desert climate. The Bou Craa phosphate deposit was formed between 75 million and 50 million years ago when the region was covered by a shallow, warm sea that teemed with plankton and other tiny invertebrate organisms. The phosphorus-rich remains of these organisms mixed with sea bottom sediments and eventually lithified into deposits of phosphate-rich rock. The Bou Craa mine is one of the world's largest sources of phosphate, which is used in agricultural fertilizers and chemical manufacturing. Our quartz-filled geodes, which are separated by hand from the phosphate ore, have four parts: an exterior coating; a layer of massive quartz; coarse, drusy quartz crystals; and a hollow center. Use a small, bright light source to reveal the intricacy and beauty of your quartz-filled geode—and to see why geodes are called "miniature crystal caves."

10 YEARS AGO IN OUR CLUB We featured olivenite [$Cu^{2+}_2(AsO_4)(OH)$], a rare arsenate mineral that forms a series with adamite, from the Majuba Hill mine, Antelope District, Pershing County, Nevada. Specimens consisted of very small, acicular, green to black olivenite crystals on matrix. We also offered Club members a selection of other rare minerals from this prolific mine on our Offer sheet.

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COMPREHENSIVE WRITE-UP

COMPOSITION

Having featured two varieties of microcrystalline quartz in 2008 (jasper in August and agate in September), we're happy to complete the triumvirate by shining the spotlight on these beautiful quartz-lined geodes. You should be an expert on quartz, its modes of formation, and many varieties by now!

Quartz, chemical formula SiO_2, consists of the semimetal silicon (Si) and oxygen (O). Its molecular weight is made up of 46.74 percent silicon and 53.26 percent oxygen. The cation or positively charged ion in the quartz molecule is the silicon ion (Si^{4+}) with a +4 charge. The anion or negatively charged ion consists of two oxygen ions ($2O^{2-}$) with a collective -4 charge. The quartz molecule derives its electrical stability from the balance of its +4 cationic and -4 anionic charges.

Chemically, quartz is a member of the oxides, minerals in which metals or semimetals are combined with oxygen. Structurally, however, quartz is a member of the silicates, a group in which silicon and oxygen combine with one or more metals or semimetals. Because modern mineral-classification systems prioritize structure above chemical composition, quartz is classified as a silicate. The silicates are the largest and most abundant of all mineral classes. Silicon and oxygen are also the most abundant elements in the Earth's crust, together comprising 75 percent of its total weight.

The basic building block of quartz and all silicate minerals is the silica tetrahedron $(SiO_4)^{4-}$, in which a silicon ion is surrounded by four equally spaced oxygen ions positioned at the corners of a tetrahedron (a four-faced polyhedron). In the silicates, silica anions join together with metallic or semimetallic cations in repeating chains to form seven types of structures: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); sheet silicates (phyllosilicates); and framework silicates (tectosilicates). Quartz is a framework silicate or tectosilicate, a large subclass that includes the abundant feldspar group of complex aluminum silicates containing potassium, calcium, and/or sodium minerals.

Quartz in various quantities is a constituent of virtually all igneous, metamorphic, and sedimentary rocks. Quartz is also the most thoroughly studied mineral, and knowledge of its structure is a prerequisite to understanding the structures of other silicate minerals. In the quartz crystal lattice, each silica tetrahedron shares all four of its oxygen ions, which bond covalently to the silicon ions of adjacent tetrahedra. In this arrangement, each silicon ion is surrounded by four oxygen ions, and each oxygen ion by two silicon ions. This satisfies the -4 charge of each individual tetrahedron, so that no other ions are necessary for electrical stability. The result is the infinite, three-dimensional structure of quartz in which each balanced molecular unit is described by the formula SiO_2. The bonding within the quartz lattice is exclusively covalent. Because covalent bonding exerts omnidirectional strength, quartz crystals have neither cleavage planes nor a center of symmetry. Quartz's substantial hardness of Mohs 7.0 is due to its absence of cleavage and to the high bonding strength derived from close atomic packing. Yet despite its close atomic packing, the light atomic weights of silicon (28.09) and oxygen (16.00) give quartz a relatively low specific gravity of 2.65.

Quartz forms in three basic ways: as a component of crystallizing magma in both intrusive and extrusive formations; by the crystallization of silica-rich, hydrothermal fluids; and by the downward percolation of silica-rich groundwater. Quartz-filled geodes form in the cooler temperatures and reduced pressures of near-surface rock when silica-rich groundwater fills voids and precipitates silica as quartz crystals (see "About Geodes").

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As an allochromatic mineral, the color of quartz is determined not by essential elemental components or the nature of its crystal structure, but by traces of nonessential, color-producing elements called chromophores that create a wide range of hues. Pure quartz, or rock crystal, is colorless or "water clear." Many hues have varietal names: rose quartz is pink to rose-red; amethyst is lilac to purple; milky quartz is white; smoky quartz is pale-brown to near-black; and citrine is yellow to golden.

The Dana mineral classification number 75.1.3.1 first identifies quartz as a tectosilicate or framework silicate (75). The subclassification (1) next defines it by the chemical formula SiO_2 and a four-oxygen coordination in which the silicon cations are bound to four oxygen ions. Quartz is then assigned to the quartz group (3) as the first (1) and only member. The subclassification (SiO_2 with four-oxygen coordination) includes several other minerals that are polymorphs of quartz. These minerals, which have identical chemistries but different crystal structures, are cristobalite (tetragonal), tridymite (triclinic), coesite (monoclinic), and stishovite (tetragonal).

ABOUT GEODES

Geodes are typically oblate spheroids that range in diameter from a fraction of an inch to "walk-in" sizes. Geodes are generally defined as rock cavities with interiors that are lined with crystals or other mineral matter. Geodes have discrete, outer mineral layers of sufficient hardness and durability to maintain their generally spherical structure as entities after they weather free from their host rock. Geodes can be hollow, partially hollow, or completely filled with crystalline material.

Geodes form within two different mineralogical environments: extrusive magmatic (volcanic) formations and active (subject to groundwater circulation) sedimentary environments. In volcanic formations, geodes originate as gas bubbles (vesicles) in lava that later fill with circulating groundwater rich in silica or other elements. As temperatures and pressures decrease, the dissolved mineral components precipitate out of solution to form crystals on the vesicle walls. Volcanic geodes are generally spherical, reflecting their origin as gas bubbles within the solidifying magma. The interior of volcanic geodes is usually filled with crystals of quartz or the zeolite-group minerals.

Sedimentary geodes, which include our specimens, are more complex and diverse in origin, shape, and mineral content. Sedimentary geodes most often occur in formations of calcareous marine sediments such as limestone and dolomite rock. Limestone contains at least 50 percent calcite [calcium carbonate, $CaCO_3$]; dolomite rock contains at least 50 percent dolomite [calcium magnesium carbonate, $CaMg(CO_3)_2$]. Most sedimentary geodes originate as calcite concretions—small zones within the sediments that are heavily cemented by calcite. These concretions often form where organic remains of plants and animals have decomposed to create an anaerobic (oxygen-poor), alkaline environment that encourages calcite to precipitate from circulating, calcium-rich, acidic groundwater. Later, if the groundwater chemistry changes and becomes acidic, it dissolves the calcite to leave a void. Mineral-rich groundwater can then refill the void and, under the right conditions, precipitate minerals as crystals that fill or partially fill the void. Sedimentary geodes most often contain quartz, but can also contain such minerals *as calcite, barite [$BaSO_4$], gypsum [selenite, $CaSO_4 \cdot 2H_2O$], pyrite [FeS_2], and strontianite [$SrCO_3$]. Unlike the generally spherical shape of volcanic geodes, the shape of sedimentary geodes is often elongated or irregular.*

In quartz-filled geodes, the crystallization process begins when a minute crystal, called a seed crystal, forms from a silica solution. This crystal grows as the silica-rich fluids cool, depositing new silica tetrahedra on the crystal lattice. Given slow cooling, sufficient space for unrestricted growth, and a supply of silica-rich fluids, the growing quartz crystals assume a basic hexagonal form and partially fill the void, as is seen in our specimens. Because of the myriad different factors that affect their formation, no two geodes are ever identical.

COLLECTING LOCALITIES

Quartz, mainly as crystals, crystal clusters, and grains, is abundant and found throughout the world. However, quartz-filled geodes are relatively rare and have few collecting localities. Our quartz geodes were collected at the Bou Craa phosphate mine in the Laâyoune-Boujdour-Sakia el-Hamra region of Western Sahara, Africa. Other notable African sources of quartz geodes are the quarries at Ait Ourir in Marrakech Prefecture in the Marrakech-Tensift-El Haoux Region of Morocco, and the Brandberg and Goboboseb mountains near Uis in the Erongo Region of Namibia.

Quartz in its wonderful variety of purple amethyst geodes are collected in large quantities in South America, notably in Brazil in the Soledade region of Rio Grande do Sul state and in the adjoining areas of Uruguay and Argentina. Quartz geodes are commercially collected in Mexico at the Mesteno Ranch near Las Choyas, Chihuahua. In Australia, rock-crystal-filled geodes occur at Agate Creek near Georgetown in northern Queensland. The best-known European source of quartz geodes is the historic Juchem Quarry at Niederwörrensbach near Idar-Oberstein in Rheinland-Phalz, Germany.

In the United States, quartz geodes are collected in Colorado at the Twin Mountains geode field at Del Norte in Rio Grande County and near Wolf Creek Pass in Mineral County; in Oregon at the Madras thunder-egg beds in Jefferson County; in Utah at the Dugway geode field 40 miles south of Tooele in Tooele County; in Texas in the southern Quitman Mountains in Hudspeth County; and in California at the Hauser geode beds at Wiley Well near Blythe in Riverside County. The nation's largest and most prolific geode area is the greater Keokuk geode field that lies within a 35-mile radius of Keokuk, Iowa, and covers parts of extreme southeastern Iowa and adjacent areas of Missouri and Illinois. Quartz geodes also occur at Harrodsburg in Monroe County, Indiana; along the Green River near McKinney in Lincoln County, Kentucky; and at Loretto in Lawrence County, Tennessee.

JEWELRY AND DECORATIVE USES

Quartz geodes, in sizes from a few inches to six feet and costing anywhere from a few dollars to thousands of dollars each, make eye-catching display pieces. Large amethyst-lined geodes from southern Brazil are sometimes called "amethyst cathedrals" and are among the most sought-after of all natural treasures. "Cathedrals" of especially large size or with intensely violet crystals or other fascinating features sell for many thousands of dollars. One of the joys of attending as many shows as we do is the opportunity to see large amethyst geodes and experience the breathtaking beauty and unimaginable and unusual shapes and forms they take, not to mention the crystals of calcite, selenite, hematite, and other minerals they sometimes contain. These possess an attraction that never fades.

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At large gem and mineral shows such as in Tucson or Denver, there is usually one dealer breaking open geodes on the spot, using a pipe cutter and chain, allowing buyers to be the first to view the hidden treasure inside the geode. The geode splitting usually attracts a lot of attention, a lot of oohing and aahing, and few buyers go away unhappy,

Small quartz-lined geodes from Brazil are often cut into two and sold as “Agate Pots,” or cut in half and sold in pairs as “Mini Cocos,” while other geodes are cut into thin slices for use in jewelry making.

HISTORY AND LORE

Rock crystal and rock-crystal-filled geodes have been collected since antiquity for both their beauty and alleged mystical qualities. Many ancient cultures considered rock crystal to be water from the heavens that the gods had frozen into eternal ice. Our modern word “crystal” stems from the Greek *krystallos*, meaning “ice” or “crust.” Rock crystal was a sacred object in many ancient temples, including those of the Mayas and Aztecs.

In medieval times, rock-crystal-filled geodes were associated with fertility and childbirth. The German philosopher, theologian, and naturalist Albertus Magnus (Albert Count von Bollstädt, Albert the Great, ca. 1200-1280) suggested that women wear geodes to attract love and avoid miscarriages. Medieval physicians prescribed powdered rock crystal to relieve general pain and to alleviate the symptoms of renal and intestinal ailments. Medieval Europeans believed that eagles placed geodes in their nests to impart strength and vitality to their young. Rock-crystal-filled geodes, used in the manner of crystal balls, were thought to be able to diagnose disease and foretell the future.

According to modern metaphysical practitioners, rock crystal is the “universal crystal” because of its many properties that include the ability to hone insight, enhance spiritual development, improve concentration, refine focus, and energize the mind. The shapes of geodes are thought to concentrate the powers of their interior crystals and to serve as contemplative objects to facilitate meditation and looking beyond the surface of situations. In the workplace, geodes are believed to increase one’s productivity.

Quartz geodes have appeared on the 25-franc postage stamp of The French Territory of the Afars & Issas in 1971, the 1-lev stamp of Bulgaria in 1995, the 70-pfennig stamp of the German Democratic Republic (East Germany) in 1974, and the 1.50-shilling stamp of Kenya in 1977. Rock crystal has been featured on the 400-sucre stamp of Ecuador in 1997, the 1-franc stamp of The French Southern and Antarctic Territories in 1998, and the 50-centimes stamp of Switzerland in 1958.

In 1965, the Oregon state legislature designated the thunder-egg geode as its official state rock. The Iowa state legislature decreed the Keokuk geode to be its official state rock in 1967. Geode State Park, named for the regional Keokuk geodes, is located at Lowell, Iowa.

TECHNOLOGICAL USES

Quartz-filled geodes have no direct technological applications, but their study has contributed to the overall knowledge of quartz formation and to the laboratory synthesis of quartz. Thin wafer sections of quartz crystals are used in electronic filters, frequency controls, and timers for communications equipment, watches, computers, and televisions. Natural rock crystal was formerly used for these applications, but was replaced by synthetic quartz in 1950. Today, more than 1,000 tons of synthetic quartz are used each year in electronic and optical applications. In quartz synthesis, natural rock crystal is ground to a powder, then dissolved in molten hydroxides in high-temperature, high-pressure autoclaves. The actual crystallization of synthetic quartz is similar to that of natural hydrothermal quartz. In the synthesis process, thin wafers cut from natural rock crystal serve as seed crystals to initiate crystallization of structurally perfect, synthetic quartz crystals.

LOCALITY NAMES . . . AND GAMES

In our write-ups, we try to provide as much detailed information as possible about the source of each month's mineral, including exact geographic location, local color, history, geology, and how the specimens were collected. We put much time and effort into documenting the sources of our specimens and are usually successful in providing detailed, accurate locality information, often because we obtain the specimens directly from the miners or collectors. But the stated localities of minerals in many specimen markets are not always accurate. There are two general reasons for this. First, specimens often pass through the hands of many miners, collectors, and dealers en route to their final market. Along the way, poor record-keeping and confusion over actual source names can lead to overly generalized or inadvertently misstated localities. Second, because commercial mineral collecting is a very competitive business, localities are at times considered proprietary information and are purposely misrepresented or not reported at all. A closer look at these reasons provides an interesting, behind-the-scenes look into the sometimes secretive and mysterious world of commercial mineral collecting.

***Poor Documentation**: Mineral locality names are sometimes erroneous or generalized because of poor documentation, usually on the part of the miners and collectors who gathered the specimens. An example is this month's mineral. Although we have documented the precise source of our quartz-filled geodes as the Bou Craa phosphate mine in the Saguia el-Hamra region of Western Sahara, these same specimens are appearing with their origin attributed variously to "Western Sahara"; "Smara," an oasis town northeast of Bou Craa through which the specimens may have passed; "Spanish Sahara," the outdated, pre-1976 name for Western Sahara; "El Aaiún," the capital city of Western Morocco through which the specimens actually did pass; and "Morocco," the nation that currently occupies Western Sahara. The first time we saw these geodes for sale the locality was listed simply as "Western Sahara"!*

***Increase Specimen Value**: Localities are sometimes misrepresented in order to increase specimen value. Specimens from classic localities, that is, sources known for specimens of superior quality, size, color, crystal form, and overall aesthetic appeal, command higher prices then do those from lesser localities. Also, specimens from mines with long and colorful histories tend to have higher values than do those from anonymous sites. An example of an often-misrepresented locality is the Ojuela Mine at Mapimi, Durango, Mexico. Ojuela, a 400-year-old former silver mine is the classic locality for adamite [$Zn_2(AsO_4)(OH)$], our Mineral of the Month for May 2008. Our adamite is positively documented as originating at Ojuela, but that is not always true with all "Ojuela" specimens. Some specimens, notably those of adamite, azurite [$Cu_3(CO_3)_2(OH)_2$], malachite [$Cu_2(CO_3)(OH)_2$], and aurichalcite [$(Zn,Cu)_5CO_3(OH)_2$] are actually collected at other Mexican mines, but are misrepresented as Ojuela material by miners in hopes of obtaining higher prices from buyers.*

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***Deter Theft or Competition**: Specimen localities are sometimes only generally described or are misrepresented entirely in order to deter theft or competition. Reports of new specimen recoveries always attract competing buyers, miners, and commercial collectors to the locality. At remote sites that cannot be watched continuously, theft of specimens by competing miners or unauthorized visitors is always a possibility. To prevent such problems, miners and buyers sometimes do not disclose the locality, or they misrepresent it in a manner that does not attract unwanted visitors.*

***Locality is in a Restricted Area**: Mineral specimens are sometimes collected in restricted areas. An example is our Mineral of the Month for May 2007—brookite [titanium dioxide, TiO_2]. The only locality information we could provide was the Khârân District in the Balochistan Province of Pakistan. Khârân is a remote, undeveloped, sparsely populated expanse of mountains and desert about the size of Vermont and New Hampshire combined. It is a frontier district on the Iranian border in which ethnic-separatist groups and tribal chieftains foment violence, while smugglers, refugees, and armed paramilitary groups roam freely. Large sections of Khârân are set aside as secret nuclear-testing and rocket-launching sites and are closed to unauthorized visitors. Our brookite specimens may have been collected in a restricted area by adventurous individuals who were not authorized to be there.*

***Political Problems**: Mineral localities are sometimes misrepresented because of political problems, especially in areas like the border of Afghanistan and northern Pakistan, one of the world's richest mineral-specimen and gemstone areas. Because of military activities and political tensions, this border is technically closed and cross-border trade is banned. But indigenous miners from both nations frequently smuggle gemstones and specimens across the border to seek the best prices for their material. Miners stating the true sources of their often-smuggled specimens could run into serious problems with military authorities, a concern more important to them than is providing accurate locality information.*

Some mineral localities are not disclosed or are misrepresented for a combination of these reasons. Because intrigues and risks are sometimes part of the game of commercial mineral collecting, remember that there can be much more to mineral specimens, especially those from foreign localities, than meets the eye. And be ready to update your locality information on your labels as the need arises!

ABOUT OUR SPECIMENS

Our quartz-filled geodes come from the Bou Craa phosphate mine in the Laâyoune-Boujdour-Sakia el-Hamra region of Western Sahara, a politically disputed region that the Kingdom of Morocco claims as its Laâyoune Province. Western Sahara is located on the northwest shoulder of Africa and is bordered by Morocco to the north, Algeria to the east, Mauritania to the southeast and south, and the Atlantic Ocean to the west. Western Sahara has a population of 300,000, and its area of 102,000 square miles makes it equal in size to the state of Colorado, with a hot, arid climate. It consists mostly of trackless desert with only a few scattered oasis settlements and coastal towns. Its economy is based almost entirely on phosphate mining at Bou Craa and on fishing and phosphate-processing at the capital city of El-Aaiún).

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Since 1400 A.D., the area that is now Western Sahara has been occupied or claimed at various times by Spain, France, Portugal, Morocco, Algeria, and Mauritania. In 1904, Spain occupied the area and established the protectorate of Spanish Sahara. The Spanish presence was limited to a few coastal towns, while Sahrawi nomads, the native ethic group, controlled the interior. In 1942, geologists discovered a phosphate deposit near the remote oasis town of Bou Craa 60 miles southeast of El Aaiún. After core drilling revealed the exceptional size and grade of this deposit in 1962, the Spanish developed a large open-pit mine that began production in 1972. To transport the phosphate rock from the mine to the processing facilities at El Aaiún, engineers constructed a 60-mile-long, automated conveyor belt, the longest such system in the world.

In 1975, Spain's hold on Spanish Sahara weakened when Morocco exerted historic claims to the region, while Algeria, Mauritania, and the Sahrawis exerted similar claims. Burdened by a faltering economy and the political chaos that followed the death of its longtime dictator Francisco Franco (1892-1975), Spain realized that the loss of its protectorate was inevitable, yet desperately wished to retain part of its interest in the rich Bou Craa phosphate mine. In 1976, Spain pulled out of Spanish Sahara and transferred sovereignty (illegally, according to United Nations protocol) of the northern two-thirds of Spanish Sahara, now called Western Sahara, to Morocco. Spain also illegally ceded the southern one-third of Western Sahara to Mauritania. These territorial cessions infuriated the Sahrawis and the Algerians.

Morocco immediately took over the Bou Craa mine. In return for the controversial Spanish territorial cession, Morocco allowed Spain to retain a 35-percent interest in the mine. Meanwhile, Sahrawi nationalists formed the Popular Front for the Liberation of Sakia el Hamra and Rio del Oro (the Polisario Front). Supported by Algeria, Polisario launched guerilla raids to disrupt operations at the Bou Craa mine, and even mounted attacks into both Morocco and Mauritania. Mauritania relinquished its claims and made peace with Polisario in 1979, leaving Morocco, which now occupied all of Western Sahara, to continue fighting Polisario alone. By that time, many Sahrawis had sought exile at refugee camps in nearby Tindouf, Algeria, from which Polisario continued its regular raids into Western Sahara.

To protect the Bou Craa mine, the Moroccan government took a drastic step to keep the Polisario guerillas out. In 1981, it began construction of a 2,000-mile-long, nine-foot-high, sand-and-rock berm. Called the "Moroccan Wall" or simply "The Berm," this fortification is backed up by airfields, military patrols, electronic surveillance and radar installations, and artillery emplacements. The wall was completed in 1987 and continues to prevent the Polisario guerillas from freely entering most of Western Sahara and interfering with the operation of the Bou Craa phosphate mine.

The phosphate deposits at Bou Craa consist of sediments laid down during the late Cretaceous Period and the Paleocene and Eocene epochs of the early Tertiary Period between 75 million and 50 million years ago. This region was then submerged beneath a shallow, warm sea that teemed with plankton and other tiny invertebrate organisms. The phosphorus-rich remains of these organisms mixed with sea bottom sediments and eventually lithified into massive formations of phosphate rock, a variable mixture of microcrystalline fluorapatite [calcium fluorophosphate, $Ca_5(PO_4)_3F$] and lesser amounts of carbonate-fluorapatite [basic calcium phosphate carbonate fluoride, $Ca_5(PO_4,CO_3)_3(F,OH)$], chlorapatite [calcium chlorophosphate, $Ca_5(PO_4)_3Cl$], and hydroxylapatite [basic calcium phosphate, $Ca_5(PO_4)_3OH$].

The Bou Craa phosphate deposit, one of the world's richest, consists of two phosphate-bearing layers, each 200 feet thick, ten miles long, and grading 80 percent contained phosphorus pentoxide (P_2O_5). It is mined by two enormous, track-mounted, "walking" draglines of the type used in the big open-pit coal mines of the western United States. The Bou Craa mine produces some three million metric tons of phosphate rock each year. After mining, this rock is crushed and placed on the 60-mile-long conveyor belt for transport to El Aaiún Plage, a processing facility near El Aaiún. There, it is washed with seawater and gravitationally concentrated, then washed again with freshwater obtained from a desalinization plant. Finally, it is conveyed eight miles to a deepwater wharf on the Atlantic Ocean and loaded onto ships for distribution to world markets. Refined phosphate rock is used to manufacture agricultural fertilizers and phosphoric acid, the latter an important feedstock in chemical manufacturing. The ore reserves of the Bou Craa mine, an estimated 132 million metric tons, are sufficient for more than 40 years of operation at the current rate of production.

Our quartz-filled geodes are a by-product of phosphate mining at Bou Craa. Within this deposit, the geodes occur in the upper phosphate layer and in the overburden material directly atop this layer. These geodes originated as calcite-rich nodules (see “About Geodes”) within the original marine sediments. Circulating acidic groundwater dissolved away the calcite to create hollow voids that were later refilled when silica-rich solutions precipitated quartz crystals to form the geodes.

These geodes present two problems in phosphate mining. First, because of their hardness (quartz: Mohs 7.0), the geodes quickly abrade the cones and jaws of the steel crushers. Second, crushed quartz is difficult to separate from the phosphate during secondary processing phases. Mined ore is conveyed to a first-stage coarse crusher, then to a secondary fine crusher. Along the way, it is visually screened by workers who pick the distinctively shaped geodes from the ore-filled conveyor belts. Quantities of these geodes have found their way to mineral-specimen markets in Morocco only during the past year.

Our quartz-filled geodes have four basic parts: an exterior coating; a layer of massive quartz; coarse, drusy quartz crystals; and a hollow center. The exterior coating consists of the yellowish, host phosphate or limestone rock. Beneath the exterior coating, a thin layer of massive or microcrystalline white quartz provides the “shell” that strengthens the geodes sufficiently for them to survive the mining process. Next are clusters of coarse, drusy quartz crystals. These quartz crystals, which number in the thousands, are water-clear, flawless, gem-quality rock crystal. With a loupe or magnifying glass, notice the extraordinary development of these short, hexagonal, perfectly terminated quartz crystals. Use a variety of light sources, including small penlights, to reveal the intricacy and beauty of these superbly developed crystals—and to see why quartz-filled geodes are called “miniature crystal caves.”

We were pleased to observe that our geodes react to both short and longwave ultraviolet light, giving off a nice yellow color in both. The yellow color comes from the layer of massive white quartz that encases the inside of the geodes rather than from the drusy quartz. Perhaps a small amount of another element was trapped in the massive quartz as it crystallized, and its presence accounts for the fluorescence. Obviously, the water-clear drusy quartz crystals do not contain such impurities, or they would not be so clear.

We hope we have given you lots to think about and appreciate as you examine your “miniature crystal cave.” Too bad we can’t shrink ourselves and examine our quartz-lined geodes from the inside!

References: *Dana’s New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *2004 Glossary of Mineralogical Species*, J. A. Mandarino and Malcolm E. Back; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Gems and Jewelry*, Joel Arem, Geoscience Press; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; *Complete Guide to Rocks & Minerals*, John Farndon, Heritage House, 2007; “The Right to Self-Determination and Natural Resources: The Case of Western Sahara,” Hans Morton Haugen, *Law, Environmental and Development Journal*, University of London, March 2007; “Mineral Industries of Morocco and Western Sahara,” Harold R. Newman, *2006 Minerals Yearbook*, United States Geological Survey; “Phosphate Rock,” Stephen M. Jasinski, *2007 Minerals Yearbook*, United States Geological Survey.