September 2013 Mineral of the Month:
Gypsum (variety Selenite; sub variety, Sand Rose)

This month we are featuring the rare sand-rose subvariety of the common mineral gypsum collected from the Sahara Desert in Morocco. Our write-up details the mineralogy and many forms of gypsum, and explains how our specimens were collected at one of the world's most remarkable dune fields.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: Hydrous Calcium Sulfate $CaSO_4 \cdot 2H_20$
Class: Sulfates
Subclass: Hydrous Sulfates
Group: Gypsum
Crystal System: Monoclinic
Crystal Habits: Usually as untwinned prismatic crystals, or bladed, rhombic crystals; occasionally as arrowhead-shaped twins with beveled edges. Thin crystals are slightly flexible; crystals can be warped, bent, or twisted. Inclusions common. Also occurs in granular, fibrous, massive, and earthy forms, and as distinctive, rosette-like, crystal clusters known as "sand roses."
Color: Usually colorless or white, but impurities can create pale shades of gray, yellow, red, and brown. Sand-rose colors are caused by the color of the included sand grains.
Luster: Vitreous to pearly; pearly on cleavage surfaces. Sand roses have a dull luster and coarse surface texture.
Transparency: Usually translucent to transparent; except at thin, crystal edges, sand roses are opaque.
Streak: White
Cleavage: Perfect in one direction, distinct in two others.
Fracture: Conchoidal and splintery; brittle.
Hardness: Mohs 1.5-2.0
Specific Gravity: Usually 2.3-2.4; sand-roses can be as high as 2.5 because of included quartz.
Refractive Index: 1.52-1.53
Luminescence: None
Distinctive Features and Tests: Occurrence in sedimentary and evaporite-type deposits; flexibility in thin crystals; softness; and flat, blade-like crystals.
Dana Classification Number: 29.6.3.1

NAME: The name "gypsum" stems from the Greek *gypsos*, meaning "plaster," a reference to an early use of gypsum. The word "selenite" stems from the Greek *selēnitēs*, literally meaning "stone of the moon" and alluding to the pearly, moon-like luster of its cleavage surfaces. Because of its abundance, worldwide occurrence, varied forms, and many uses, gypsum is known by such other names as "gypsum rock," "gypsite," "alabaster," "satin spar," "lapis

specularis," "oulopholita," "yeso," "gesso," "gypsta," "gypse," "aphroselenon," "acido vitriolo saturata," and "spectacle stone." Rosette-shaped clusters of heavily included selenite crystals are known as "sand roses," "desert roses," "rose rock," "selenite roses," "gypsum roses," and "Sahara roses."

COMPOSITION: Gypsum is a hydrous calcium sulfate that consists of 23.28 percent calcium, 18.62 percent sulfur, 2.34 percent hydrogen, and 55.76 percent oxygen.
It is the most abundant member of the sulfates, a class of nearly 200 minerals in which sulfur and oxygen, as the sulfate radical $(SO_4)^{2-}$, combine with one or more metals. The "$\cdot 2H_2O$" in the chemical formula $CaSO_4 \cdot 2H_2O$ indicates that gypsum is a hydrous (or hydrated) mineral with two molecules of water attached to each parent molecule of calcium sulfate. Selenite, the crystalline form of gypsum, occurs in hydrothermal replacement deposits, volcanic formations, and most commonly in evaporite deposits. Gypsum can occur in evaporite deposits as sand roses that are heavily included, cleavage-separated clusters of blade-shape crystals that resemble the petals of a blooming rose. The sand-rose subvariety consists of gypsum and included grains of quartz sand [silicon dioxide, SiO_2]. In sand roses, the primary mineral by weight and physical characteristics is gypsum, variety selenite, in the form of bladed crystals. The secondary mineral is included quartz in the form of sand particles that impart their color and a rough texture to the selenite crystals.

COLLECTING LOCALITIES: The sand-rose variety of gypsum occurs only in desert regions. Gypsum sand roses are collected in Morocco, Algeria, Tunisia, Namibia, Egypt, Libya, Mali, Chad, and Mauritania. Other sources are in Spain, Argentina, Mexico, Chile, and Australia. In the United States, gypsum sand roses are found in Oklahoma and New Mexico.

HISTORY, LORE & GEMSTONE/TECHNOLOGICAL USES: Gypsum was used in crude plasters in the Middle East as early as 6000 B.C. and later in the construction of Egypt's pyramids as a plaster for interior walls and a binding agent in mortar. The ancient Greeks and Romans used gypsum to make stucco. Gypsum has many important modern uses in ceramic casts, surgical splints, soil conditioners, smelting fluxes, fillers in papers and paints, setting retardants in cement, and drywall. Sand roses have no technological uses, but they have accumulated a rich lore over the centuries. Many cultures thought they were flowers that had turned to stone. Some early Saharan tribes believed that sand roses were a warning to travelers of impending bad fortune; others saw them as a good omen that indicated the nearby presence of water. Native Americans of the Southwest thought that their ancestors had left sand roses as a sign of their earlier presence. After their forced displacement to Oklahoma, the Cherokees believed that sand roses were the tears, turned to stone, of a compassionate god who shared their sorrow. According to modern metaphysical beliefs, sand roses have a gentle energy that increases mental clarity, brings self-awareness and an awareness of the environment, enables one to see inner truths, and provides protection, prosperity, and purification. They are also thought to help recall past lives and see into the future. Gypsum sand roses have no use in jewelry. Collectors value sand roses as display pieces and for their unusual occurrence, rarity, and distinctive, flower-petal shapes.

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ABOUT OUR SPECIMENS: Our specimens of gypsum sand roses were collected in Erg Chebbi ear Erfoud, Errachidia Province, Meknès-Tafilalet Region, Morocco, in northwest Africa. Errachidia Province is bordered on the south by Algeria and the northern edge of the Sahara Desert. The oasis of Erfoud, population 23,000, is the largest town near Erg Chebbi, an 8-mile-wide, 20-mile-long dune field that consists of orange-brown sand dunes as high as 525 feet. Virtually devoid of vegetation, Erg Chebbi perfectly fits the popular image of the Sahara Desert. The sand roses formed in very recent geologic time—perhaps only 10,000 or 20,000 years ago—when groundwater rich in dissolved gypsum permeated the subterranean sand formations. As erosion reduced the surface and the water table dropped, the saturated gypsum solutions precipitated selenite as tiny seed crystals. With further precipitation, clusters of bladed, rhombic crystals developed and grew around the surrounding grains of sand. This included sand distorted the crystal lattices in a manner that caused the planes of perfect cleavage to separate into clusters of flat blades that resembled the petals of blooming roses. Continued surface erosion eventually exposed the sand roses that now lie at or near the surface where they are periodically covered and uncovered by the wind-driven sand. Sand roses from Erg Chebbi are collected in commercial quantities and sold on the international specimen markets.

COMPREHENSIVE WRITE-UP

COMPOSITION

Our Mineral of the Month for September is gypsum [hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$], variety selenite, subvariety sand rose. Sand roses consist of gypsum and included grains of quartz sand [silicon dioxide, SiO_2]. By weight and physical characteristics, the primary mineral is gypsum, which is present as bladed crystals of selenite. The secondary mineral is quartz as sand particles which are included within the selenite crystals. The included quartz sand imparts its color and a rough texture to the selenite crystals.

Gypsum's chemical formula $CaSO_4 \cdot 2H_2O$ shows that it is a hydrous calcium sulfate containing the elements calcium (Ca), sulfur (S), oxygen (O), and hydrogen (H). The molecular weight of gypsum is made up of 23.28 percent calcium, 18.62 percent sulfur, 2.34 percent hydrogen, and 55.76 percent oxygen. Like all molecules, those of gypsum are composed of positively charged cations and negatively charged anions. Gypsum's simple cation is the calcium ion Ca^{2+} with its +2 charge. Its anion is a radical, which is a group of ions of different atoms that behave as entities in chemical reactions. The gypsum anion is the sulfate radical $(SO_4)^{2-}$, in which a single sulfur ion is surrounded by four oxygen ions positioned at the corners of a tetrahedron. In this radical, the sulfur ion S^{6+} has an oxidation state (valence) of +6. The four oxygen ions $4O^{2-}$ each have an oxidation state of -2, thus providing the sulfate radical $(SO_4)^{2-}$ with a -2 charge. This total -2 anionic charge balances the +2 cationic charge to provide the gypsum molecule with electrical stability.

The "$\cdot 2H_2O$" in the chemical formula $CaSO_4 \cdot 2H_2O$ indicates that gypsum is a hydrous (or hydrated) mineral with two molecules of water ($2H_2O$) attached to each parent calcium-sulfate molecule. The chemical formulas of all hydrous minerals end with "$\cdot H_2O$." By convention,

these formulas employ the chemical period (·) to separate the parent mineral from its bonded water. Attached water molecules, known as "water of hydration," consist of electrically neutral water molecules that do not affect the electrical balance of the molecule. In the unusual atomic configuration of water molecules, two hydrogen ions group together on one side of a large oxygen ion. These hydrogen ions retain a small positive charge, while the opposite side of the molecule, dominated by the large oxygen ion, retains a small negative charge. Because of this polarity, water molecules behave as tiny dipole magnets that can attach themselves to other molecules by a weak attraction called "hydrogen bonding." In gypsum, the positive poles of the water molecules are attracted to the slight negative charge of the oxygen ions in the sulfate anion. In the gypsum molecule, water of hydration accounts for 20.93 percent of gypsum's weight.

Gypsum is by far the most abundant of the sulfates, a class of nearly 200 minerals in which sulfur and oxygen, as the sulfate radical $(SO_4)^{2-}$, combine with one or more metals. Because the sulfate radical's two excess negative charges are distributed evenly over its oxygen ions, it can readily accommodate one or more metal cations. Although gypsum is a simple sulfate consisting of a single metal cation and a single sulfate radical, its lattice nevertheless has three different types of atomic bonding. The sulfate radical $(SO_4)^{2-}$ has strong covalent bonds with the four oxygen ions sharing electrons with the single sulfur ion. The negatively charged sulfate radical and the positively charged calcium ion are bonded ionically by the attraction of opposite charges, while the water molecules are attached by very weak hydrogen bonding.

The gypsum crystal lattice consists of repeating, ionically bound calcium and sulfate ions, with each sulfur ion surrounded by its four oxygen ions. Within the lattice, calcium-sulfate molecules form layers which "sandwich" the weakly bound, attached water molecules, an arrangement that accounts for gypsum's perfect, one-directional cleavage. The weak hydrogen bonding and weak ionic bonding explain many of gypsum's physical features, including its softness (Mohs 1.5-2.0), moderate solubility in water, and the flexibility of its thin crystals.

Because hydrogen bonding is strongest at cold temperatures, heat renders gypsum unstable. When gypsum is calcined or heated to sub-fusing temperatures to drive off volatile materials, the hydrogen bonds part to release some of the water of hydration. The result is "calcined gypsum," a hemihydrated powder with the chemical formula $CaSO_4 \cdot ½H_2O$. In calcium sulfate hemihydrate, one water molecule is attached to every two calcium-sulfate molecules. The structure of calcined gypsum is the same as that of natural gypsum, except that half the lattice sites previously occupied by water are vacant. When water contacts calcined gypsum, it immediately reoccupies these vacant sites, establishes hydrogen bonds, and forms a rigid, recrystallized structure like that of natural gypsum. This ability to lose and quickly regain water of hydration gives gypsum many important uses, most notably as a fast-setting plaster.

Although gypsum is found in many different mineralogical environments, it occurs mostly in sedimentary rocks of chemical origin that can form strata more than 30 feet thick. Most gypsum occurs in marine evaporite deposits as stratigraphic beds within alternating layers of shale, sandstone, limestone, or rock salt [halite, NaCl]. Evaporite deposits sometimes create sand-rose forms of gypsum that are heavily included, cleavage-separated clusters of blade-shape crystals

that resemble the petals of blooming roses (see "About Our Specimens"). Sand roses are also formed to a lesser extent by the crystallization of barite [barium sulfate, $BaSO_4$] and celestine [strontium sulfate, $SrSO_4$].

Gypsum occurs in association with dolomite [calcium magnesium carbonate, $CaMg(CO_3)_2$] and barite in hydrothermal replacement deposits, and in volcanic formations by the action of sulfuric acid (H_2SO_4) on calcium-containing minerals. Gypsum is a component of many clays, where it forms when sulfuric acid reacts with limestone, a rock consisting primarily calcium carbonate ($CaCO_3$). Gypsum has a variety of interesting, beautiful, and collectible forms that include selenite, satin spar, and alabaster (see "The Many Faces of Gypsum"). Most gypsum is present as gypsum rock or gypsite, both of which are earthy, massive, impure forms that are the ores of gypsum.

The Dana classification number 29.6.3.1 first identifies gypsum as a hydrated sulfate (29). It is subclassified (6) by the general formula $AXO_4 \cdot nH_2O$, in which "A" is calcium, "X" is carbon, and "n" is a quantifier. Gypsum is then assigned to the gypsum group (3) as the first (1) and only member.

COLLECTING LOCALITIES

Because of gypsum's abundance and worldwide distribution, the collecting localities for such gypsum varieties as selenite, satin spar, and alabaster are numerous. Sand-rose collecting localities are far fewer, however, and are restricted to regions with arid climates and an abundance of quartz sand. Many sand-rose localities are not point-specific, because specimens are collected over broad areas.

Our sand-rose specimens were collected at Erg Chebbi near Erfoud, Errachidia Province, Meknès-Tafilalet Region, Morocco. Other African localities include the Grand Erg Occidental region of Ouargla Province, Algeria; the Grand Erg Oriental region near Douz in southern Tunisia; and the Namibia Desert near Swakopmund, Erongo Region, Namibia. Gypsum sand roses are also found at various, loosely documented localities in Egypt, Libya, Mali, Chad, and Mauritania.

Localities in Spain include Pájara in Las Palmas Province, Canary Islands; La Almarcha, Cuenca, Castile-La Mancha; and Canet de Marat at Maresme near Barcelona, Catalonia. Other sources are Arroyo Saladillo de Garcia in the Bahia Blanca District, Buenos Aires Province, Argentina; and the Samalayuca desert area near Ahumada, Chihuahua, Mexico. Sand roses also occur in parts of the Atacama Desert in northern Chile. The intermittent saline lakes at Bolton, Victoria, Australia, have also yielded sand roses.

In the United States, sand roses are found on the Great Salt Plains near Jet in Alfalfa County, Oklahoma; and near White Sands National Monument at Alamogordo, Otero County, New Mexico.

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JEWELRY AND DECORATIVE USES

Sand roses have no use in jewelry. Collectors value sand-rose specimens for their unusual occurrence, rarity, and distinctive, flower-petal shapes. Because sand roses from different localities vary considerably in color, texture, degree of crystal development, and size, sand-rose collections often consist of specimens representing more than a dozen localities.

HISTORY AND LORE

Gypsum was made into crude plasters in Anatolia (now Turkey) as early as 6000 B.C. By 3700 B.C., it was being used in the construction of Egypt's pyramids as a plaster for interior walls and a binding agent in mortar. The ancient Greeks and Romans used stucco, a fine-grained compound composed of gypsum and marble dust, as plaster and a sculpting and casting material, working it into a variety of ornamental shapes that were polished to a marble-like finish and painted in various colors.

During the Renaissance, gypsum-based plaster served as the substrate of fresco paintings. In churches, white stucco was molded into wall decorations, especially figures of angels, while colored, architectural stucco friezes were popular in plazas, gardens, and pavilions. Stuccowork reached its peak in the 17th and 18th centuries when Baroque and Rococo palaces throughout Europe were decorated with polychrome stucco in elaborately sculpted shapes ranging from humanistic figures to twisted columns and festively adorned altars.

By 1800, "plaster of paris," named after the huge gypsum beds in France's Paris Basin, had become the standard household wall covering throughout Europe, despite the fact that it was very difficult to work with because it set almost instantly. In 1880, additives were discovered that retarded setting time, making plaster of paris ideal for interior finishing, artistic and ornamental applications, and orthopedic casts. In 1888, gypsum found its greatest use ever—as the primary component of drywall for residential and industrial construction (see "Technological Uses").

Sand roses were collected in ancient times and have accumulated considerable lore over the centuries. Some early cultures thought sand roses were flowers that had turned to stone. Early Saharan tribes told many legends about sand roses. Some believed that sand roses were a warning to travelers that bad fortune awaited them and that they would perish and turn to stone. Others saw the sand roses scattered about the desert as good omens that indicated the nearby presence of living flowers in an oasis. Still others believed that sand roses were a reminder of the times when the desert bloomed before their ancestors' sins took away the water. Native Americans of the Southwest thought that their ancestors had left the sand roses as a sign of their earlier presence on Earth. After their forced exodus in the 1830s from the East to the Oklahoma Indian Territory, the Cherokees thought that sand roses were the tears, turned to stone, of a compassionate god who shared their sorrow.

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Gypsum varieties have appeared on the postage stamps of a dozen nations. Sand roses have been featured on Algeria's 70-centime stamp of 1983, Namibia's one-cent stamp of 1991, and Tunisia's 250-millimes stamp of 1997—all nations where sand roses are found.

According to modern metaphysical beliefs, gypsum sand roses have a gentle energy that increases mental clarity, brings self-awareness and an awareness of the environment, allows one to see inner truths, and provides protection, prosperity, and purification. Sand roses are also thought to help to recall past lives and see into the future.

THE MANY FACES OF GYPSUM

Few other minerals have as many diverse habits, forms, and types of occurrence as gypsum. The various forms of gypsum range from unremarkable ores to beautiful sculpting mediums and some of the Earth's most remarkable crystals. Along with sand rose, these include:

Gypsum rock, the primary ore of gypsum, is a loosely consolidated, brownish-gray, sandy marl that consists of about 90 percent hydrous calcium sulfate in the form of selenite grains and particles. It occurs in large, layered, sedimentary deposits that are usually of marine evaporite origin. These shallow deposits are mined by open-pit methods (see "Technological Uses"). Pockets within layers of gypsum rock sometimes contain collectible crystals of selenite.

Gypsite is a low-grade ore that contains only about 50 percent gypsum. It is a loosely consolidated, brownish, sandy or gravelly marl of lacustrine or marine evaporite origin. Like gypsum rock, it occurs in massive, layered deposits that are mined by open-pit methods. Gypsite deposits rarely have selenite specimens. Most of the world's gypsum occurs as either gypsum rock or gypsite.

Selenite, the transparent-to-translucent, crystalline form of gypsum, occurs in a range of pale colors and collectible habits and is found mainly in evaporite deposits and hydrothermal veins, or as geode fillings. Selenite blades, sometimes more than a foot long, are popular items in rock shops. Unusual forms, such as spiraled "ram's horn" crystals and "fishtail" and "swallowtail" twinned crystals, are especially popular among collectors.

The largest and most spectacular mineral crystals in the world, consisting of pure selenite, were discovered in 2000 at Naica, Chihuahua, Mexico, when miners in an underground lead-zinc-silver mine blasted into a natural geodic (geode-like) cave. This horseshoe-shaped cave, now known as *La Cueva de los Cristales Gigantes* (the Cave of the Giant Crystals), is 100 feet long and 35 feet wide. It is filled with transparent-to-translucent selenite crystals, some of which are 36 feet long, 4 feet thick, and weigh an estimated 55 tons. As the largest freestanding crystals ever found, they have received much international publicity and have been the object of intense scientific study. These giant crystals formed when gypsum-rich groundwater filled limestone voids and precipitated gypsum crystals in an environment that provided the space for unrestricted crystal growth. A similar geode in an old lead-zinc-silver mine at Pulpí, Almería, in southern

Spain, had been discovered only a year earlier. This geode, which was 26 feet long, was completely filled with transparent selenite crystals up to five feet in length.

Alabaster, a dense, fine-grained, massive form of nearly pure gypsum, is known as "poor-man's marble." Its colors range from a nearly translucent, snowy white to soft pinks and browns, sometimes in pleasing, mottled patterns. Alabaster is easily carved and makes a superb sculpting medium. Despite its softness, alabaster takes an excellent polish which, with its slight translucency, exhibits a soft glow similar to that of fine marble. Alabaster has been used as a sculpting medium and ornamental stone since ancient times.

Satin spar, the fibrous variety of gypsum, occurs as dense, parallel alignments of fiber-like prisms that interact with light to produce chatoyancy, a silky luster, and even occasional opalescence. Inexpensive specimens of satin spar make eye-catching display pieces. Although soft and somewhat fragile, satin spar is occasionally used in pendants and earrings.

Gypsum sand, which appears as fine, white, sand-like particles, may seem unremarkable. But in huge, surface concentrations, white gypsum sand can be one of the most unusual and beautiful topographical features on Earth. The largest known deposit of gypsum sand is at White Sands National Monument in southern New Mexico, where dunes composed entirely of gypsum sand cover 275 square miles. As the world's largest gypsum dune field, White Sands contains about eight *billion* tons of tiny particles of pure gypsum—enough, were to be mined commercially, to supply all the drywall and plaster manufacturers in the United States for the next 1,000 years. These dunes formed when rain and snowmelt washed gypsum-rich sediments into a closed basin to create a shallow, gypsum-rich lake. Seasonal cycles of filling and evaporating eventually deposited thick layers of selenite. A warming climate then transformed this gypsum-rich lake into a vast salt flat covered with selenite crystals. Cycles of freezing, thawing, wetting, and drying broke these crystals down into fine-grained gypsum sand, which prevailing winds moved to the northeast, depositing it as a formation of glistening, white dunes 10 miles wide and more than 25 miles long. The largest dunes are more 60 feet high. The second largest gypsum dune field, which covers eight square miles, is located in Coahuila, Mexico. A smaller gypsum dune field of four square miles is in the Guadalupe Mountains in western Texas.

TECHNOLOGICAL USES

Because of their rarity, gypsum sand roses have no technological uses. But massive forms of gypsum mined from large evaporite deposits have many important applications. Gypsum-based plaster of paris is used extensively in ceramic and metal molds, and as surgical casts. Granulated natural gypsum is a conditioner for arid, alkaline soils; a bedding material for polishing plate glass; a filler in the manufacture of paints and papers; and a flux for certain reduction-smelting processes. Gypsum, in large quantities, is also the setting retardant for portland cement that enables the cement to be premixed at central plants, then transported elsewhere for use.

Most gypsum is used to manufacture drywall for residential and commercial buildings. In 1888, American entrepreneur and inventor Augustine Sackett (1867-1914) poured a half-inch-thick

layer of plaster of paris onto a cardboard sheet, then covered it with a second sheet. The plaster hardened into inexpensive, rigid panels initially called "plasterboard" or "Sackett board." Cheap, durable, fire-resistant, and a fine thermal insulator, plasterboard was far superior to traditional wooden or lath-and-plaster walls. By the mid-1950s, plasterboard, now known as "wallboard" or "drywall," had revolutionized the construction industry and created a huge demand for gypsum. More than 28 *billion* square feet of drywall products—enough to cover the state of Rhode Island—are now manufactured each year in the United States alone. The wallboard in the average new house now built in the United States contains about seven tons of gypsum.

Gypsum is mined from open pits. Gypsum ore, called "crude gypsum," consists primarily of gypsite or gypsum rock (see "The Many Faces of Gypsum"), along with small amounts of selenite, alabaster, and satin spar. After mining, crude gypsum is coarsely crushed and concentrated. Because gypsum (specific gravity 2.3-2.4) is considerably lighter than such quartz-based gangue materials as common sand (specific gravity 2.65), it is easily concentrated by washing. The concentrate is passed through gas-fired ovens to remove surface moisture and produce an intermediate form of gypsum called "land plaster." This is then ground to a powder and calcined in rotating, gas-fired kilns at temperatures of 250°-300° F. The final product is "stucco," the industrial term for the dry, white, hemihydrate form of calcium sulfate ($CaSO_4 \cdot \frac{1}{2}H_2O$) that is the base material for the manufacture of plaster of paris and wallboard.

Gypsum mining and the manufacturing of gypsum products, mainly drywall, are multi-billion-dollar industries. Worldwide, 150 million metric tons of crude gypsum are mined each year. Most is used in the manufacture of 60 billion square feet (more than 2,000 square miles) of wallboard. China is the leading source of gypsum, accounting for one-third of world mine production. Other important sources are Spain and Thailand. The United States ranks fourth; although it mines 8.5 million metric tons of gypsum annually, it must import an additional 16 million metric tons to meet domestic demand. Crude gypsum now sells for $8 per metric ton, and calcined gypsum for $29 per metric ton. About 12 million metric tons of synthetic gypsum, which is chemically identical to natural gypsum and has the same uses, are produced worldwide each year.

ABOUT OUR SPECIMENS

Our sand-rose specimens were collected in the Erg Chebbi desert near Erfoud, Errachidia Province, Meknès-Tafilalet Region, Morocco. The Kingdom of Morocco is located in northwest Africa directly south of the Strait of Gibraltar. The Atlantic Ocean is to Morocco's northwest, the Mediterranean Sea to the north, Tunisia to the northeast, Algeria to the east and south, and Western Sahara (disputed territory that is administered by Morocco) to the southwest. Covering 172,413 square miles, Morocco, which is somewhat larger than the state of California, is roughly bisected by the southwest-northeast-trending Atlas Mountains. Population, industrial, and agricultural centers are concentrated north and west of the Atlas Mountains along the Mediterranean and Atlantic coasts. The area to the south and east, which includes Errachidia Province, is arid and sparsely populated.

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Errachidia Province is about the size of West Virginia, yet it has only 550,000 residents. It is bordered on the south by Algeria and the Sahara Desert. The oasis town of Erfoud, population 23,000, is the nearest large settlement to Erg Chebbi. The Arabic "*erg*" means "area of windblown dunes." The Erg Chebbi dune field, 30 miles south of Erfoud, is 8 miles wide, 20 miles long, and has four types of dunes. Low, rounded *dome dunes* are the most common and shift with the wind about 50 feet per year. *Barchan dunes*, named from the Arabic word for "rams' horns," are U-shaped crescents with "horns" that point downwind. *Parabolic dunes* form at the edges of dune fields and also have extended "horns," but these point upwind. *Transverse dunes* have gently graded windward slopes, steep downwind slopes, and extend in long, continuous ridges perpendicular to prevailing winds. *Barchan dunes* form in areas of strong winds and are the highest of all dunes. Erg Chebbi dunes are as high as 525 feet and consist of a fine-grained, distinctively colored, orange-brown sand. Essentially devoid of vegetation, Erg Chebbi perfectly fits the popular image of the Sahara Desert. Arab legends say that the Erg Chebbi dunes were made by God to punish local herders who once refused to help weary travelers and to remind them never to refuse aid again.

Several major motion pictures have been filmed at Erg Chebbi, among them *March or Die* (1977), *The Mummy* (1999), *Sahara* (2005), and *Prince of Persia* (2010). Because of its similarity in appearance, topography, and (possibly) certain aspects of geology to some areas of the surface of the planet Mars, European space agencies use the Erg Chebbi region for training and planning exercises in preparation for future manned Martian missions. Because of its proximity to Erg Chebbi and motion-picture and space-agency publicity, Erfoud, a historic settlement on an ancient caravan route to Tombouctou (1,200 miles to the south in Mali), is becoming an adventure-tourism destination. Erfoud now has modern hotels and restaurants, along with guides who offer camelback and hiking trips into Erg Chebbi, as well as collecting trips for Devonian vertebrate fossils and sand roses.

The sand roses of Erg Chebbi formed in very recent geologic time—perhaps only 10,000 or 20,000 years ago—when groundwater rich in dissolved gypsum permeated the subterranean sand formations. As erosion reduced the surface, the water table dropped, causing the saturated, aqueous gypsum solutions to precipitate selenite as tiny seed crystals. With further precipitation, clusters of bladed, rhombic crystals of selenite grew around each "seed" crystal, encapsulating grains of sand as they developed. As the crystals grew into bladed, rhombic shapes, the included sand distorted the crystal lattices to cause the one-directional planes of perfect cleavage to separate and form clusters of flat, bladed crystals that resembled the petals of blooming roses. Continued surface erosion eventually exposed the strata containing these sand roses which are now periodically covered and uncovered by the wind-driven sand.

Gypsum sand roses are popular tourist souvenirs in the Erfoud region. Many Erfoud guides search the edges of the Erg Chebbi dunes to collect sand roses in commercial quantities, selling them either to tourists or to specimen dealers from Mibladen and Midelt, 125 miles to the north. These dealers, who trade primarily in Mibladen vanadinite [lead chlorovanadate, $Pb_5(VO_4)_3Cl$] specimens, then sell the sand roses to international markets. Some sand-rose specimens, especially those sold to Erfoud tourists, are heat-treated to enhance their appearance. Propane-

torch flames are passed over the sand roses to dehydrate the gypsum at the edge of the "petals." This produces bright-white, hemihydrated gypsum that outlines the shape of the "rose." Our sand-rose specimens have not been altered and are completely natural.

As you study your sand-rose specimen, remember that it consists of both the selenite variety of gypsum and quartz sand. The sand is included within the bladed selenite crystals. The orange-brown color of your sand rose is caused entirely by the included sand and is the same distinctive color as the Erg Chebbi dunes. Although your specimen will appear generally opaque, under strong backlighting the thin edges of some of the crystal "petals" will be translucent and nearly colorless. The included sand also imparts a dull luster and coarse texture to the faces of the selenite crystals. Under normal conditions, this selenite would have formed a single crystal or a cluster of a few crystals. But the large quantity of included sand distorted the lattice during its growth to cause separation along the planes of perfect, one-directional cleavage. The positions of the individual bladed crystals or "petals" clearly show how they were "pushed apart" during their development. Your gypsum sand-rose specimen is a beautiful display piece that is a reminder of a most unusual mineral locality—the Erg Chebbi dune field in the Moroccan Sahara Desert.

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