

Mineral of the Month Club May 2017

BERYL var. GOSHENITE

This month's featured mineral is goshenite, the colorless variety of beryl, or beryllium aluminum silicate, from the pegmatites of Namibia. Our write-up explains the mineralogy, history, and lore of goshenite, and discusses the many colored-gem varieties of beryl.

OVERVIEW

PHYSICAL PROPERTIES:

Chemistry: $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ Beryllium Aluminum Silicate

Class: Silicates

Subclass: Cyclosilicates (Ring Silicates)

Group: Beryl

Crystal System: Hexagonal

Crystal Habits: Usually as hexagonal (six-sided) prisms, often with flat or modified-flat terminations; also massive and compact.

Color: Beryl can be colorless or white to blue, green, yellow, pink, and red; goshenite crystals are colorless; massive forms are white.

Luster: Vitreous

Transparency: Goshenite crystals are usually transparent to translucent; massive forms are translucent to opaque.

Streak: Colorless to white

Cleavage: Poor in one direction

Fracture and Tenacity: Uneven to conchoidal; brittle.

Hardness: 7.5-8.0

Specific Gravity: 2.66-2.92

Luminescence: None

Refractive Index: 1.577-1.583

Distinctive Features and Tests: Best field marks for goshenite are hardness; six-sided prisms with flat or modified-flat terminations; lack of color; and occurrence primarily in granite pegmatites.

Dana Classification Number: 61.1.1.1

NAME: The word "goshenite," pronounced GAH-shun-ite, is derived from the town of Goshen, Massachusetts, where this mineral variety was first named. Goshenite is also known as "clear beryl," "white beryl," and "white aquamarine." In European mineralogical literature, goshenite appears as *goshenit* and *goshenita*. The word "beryl" stems from *bēryllion*, the Indo-Aryan word for the mineral. Beryl appears in European mineralogical literature as *berilo*, *berylita*, and *Berylit*.

COMPOSITION & STRUCTURE: Beryl is a member of the silicates, the largest class of minerals, in which silicon and oxygen combine with one or more metals. Beryl, a cyclosilicate

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and the most structurally complex of all silicate subclasses, consists of 5.03 percent beryllium, 10.04 percent aluminum, 31.35 percent silicon, and 53.58 percent oxygen. Hard and durable, it forms short-to-elongated crystals, usually with distinctive, flat terminations. Beryl crystallizes in the hexagonal system, which is characterized by four axes, three of equal length and lying in a common plane with angles of 120° between them. The fourth, or hexagonal, axis is perpendicular to the plane of the other three and may be of any length. Beryl's most common habit is the hexagonal prism, in which six faces are parallel to the hexagonal axis. Because of close atomic packing, beryl's atomic bonding is unusually strong and explains its substantial Mohs hardness of 7.5-8.0. Despite its close atomic packing, the low atomic weights of its essential elements give beryl a low specific gravity of 2.66-2.92. When pure or nearly pure, beryl is colorless (goshenite.) But beryl is an allochromatic or "other-colored" mineral, in which traces of accessory elements create a wide range of colors. Beryl occurs primarily in granite pegmatites and to a lesser extent in the schist and marble of regional metamorphic rocks. The red variety of beryl is only found in vugs of rhyolitic rock.

COLLECTING LOCALITIES: The goshenite variety of beryl is collected in Namibia, Zambia, Zimbabwe, Russia, Sri Lanka, Myanmar, China, Afghanistan, Pakistan, Portugal, Italy, the Czech Republic, Brazil, Argentina, Canada, and the United States (California, Colorado, Virginia, North Carolina, New Hampshire, Maine, and Connecticut.)

HISTORY, LORE & GEMSTONE/TECHNOLOGICAL USES: Because of its substantial hardness, transparency, relatively high refractive index, abundance, and occurrence in large, gemmy crystals, goshenite has served as a gemstone since Roman times, when it was also cut into eyeglass lenses. In 15th-century Europe, metaphysical practitioners used large, transparent goshenite crystals as "crystal balls" for divining the future. Following the discovery of the element beryllium in the early 1800s, mineralogists learned that colorless goshenite, blue aquamarine, pink morganite, green emerald, green beryl, and golden-yellow heliodor were all color varieties of beryl. Beryl's crystal structure was defined by X-ray diffraction methods in 1922. Although goshenite many excellent gemological attributes include hardness and a relatively high refractive index, it is colorless and lacks a distinct, visual identity. Nevertheless, goshenite gems are attractive and valued primarily by degree of transparency, freedom from flaws, and quality of cutting. Large gem sizes up to 20 carats are common, and most faceted goshenite today is acquired by gem collectors. Goshenite gems, backed with silver or colored foil, were often used in the past to simulate other, more valuable colored gems. Colorless beryl was not given a variety name until the early 1900s, when a farmer near Goshen in north-central Massachusetts began collecting beryl crystals from granite pegmatites and selling them commercially. He referred to his colorless beryl specimens as "goshenite," after the name of the nearby town. The name stuck and became the variety name that is used for colorless beryl today. Goshenite, a former ore of beryllium, has no current technological uses. Modern metaphysical practitioners believe that goshenite improves the ability to learn and think analytically, facilitates creativity, and clarifies inner visions during meditation. Goshenite is also thought to promote sharp eyesight.

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ABOUT OUR SPECIMENS: Our goshenite specimens were collected at Erongo Mountain in the Usakos and Omaruru districts, Erongo Region, Namibia. Erongo Mountain, a prominent, semicircular mountain 18 miles in diameter, is located in west-central Namibia 125 miles northwest of Windhoek, the national capital. The regional climate is warm and semiarid, with only eight inches of annual rainfall to support a sparse, brushy, “thornveld”-type vegetation. Our specimens formed some 136 million years ago during the late Jurassic Period when a volcanic system collapsed to create a fractured caldera that was intruded by granitic magma. As the magma solidified, it left behind pockets of residual magma enriched with such unusual elements as tin, tungsten, boron, fluorine, and beryllium. This residual magma solidified very slowly on a mineral-by-mineral basis to form pegmatites, in which mariolitic (gas-formed) cavities provided space for the growth of large, well-developed crystals. These pegmatites, later exposed by erosion, are the source of our specimens. Erongo Mountain first attracted attention as a source of mineral and gemstone specimens in early 1999 and is now recognized as a classic locality for the goshenite and aquamarine varieties of beryl. These pegmatite pockets or “nests,” as the native diggers call them, are exposed on the sides of sheer granite cliffs. The most accessible pockets are now depleted of crystals. Crystal recoveries at Erongo Mountain have declined in recent years because the remaining pockets are difficult to reach and dangerous to work.

COMPREHENSIVE WRITE-UP

COMPOSITION & STRUCTURE

Goshenite is the colorless variety of beryl [beryllium aluminum silicate, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$], which contains the elements beryllium (Be), aluminum (Al), silicon (Si), and oxygen (O) in the proportions of 5.03 percent beryllium, 10.04 percent aluminum, 31.35 percent silicon, and 53.58 percent oxygen. Like all molecules, those of beryl consist of a cation (positively charged ion) and an anion (negatively charged ion). Beryl's compound cation consists of three beryllium ions 3Be^{2+} and two aluminum ions 2Al^{3+} , both with collective +6 charges that create a total +12 cationic charge. Beryl's compound anion is a radical, which is a group of atoms that acts as an entity in chemical reactions. The beryl anion is the silica radical $(\text{Si}_6\text{O}_{18})^{12-}$, in which 6 silicon ions 6Si^{4+} and 18 oxygen ions 18O^{2-} provide a total -12 anionic charge to balance the total +12 cationic charge and provide the beryl molecule with electrical stability.

Beryl is a member of the silicates, the largest class of minerals, in which silicon and oxygen combine with one or more metals. The basic silicate structural unit is the silica tetrahedron $(\text{SiO}_4)^{4-}$, in which four equally spaced oxygen ions positioned at the four corners of a tetrahedron around a silicon ion. These oxygen ions are bound to the silicon ion by strong covalent bonding. In silicate minerals, silica anions and metal cations bond together like polymers (repeating chains) to form seven types of structures: double tetrahedral silicates (sorosilicates); framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); sheet silicates (phyllosilicates); independent tetrahedral silicates (nesosilicates); and ring silicates (cyclosilicates).

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Beryl is a cyclosilicate, the most structurally complex of all silicate subclasses. In cyclosilicates, silica tetrahedra share two of their oxygen ions with adjacent tetrahedra. Because each tetrahedra effectively loses one of its oxygen ions, this arrangement creates groups of linked $(\text{SiO}_3)^{2-}$ units. Rather than forming chain-type structures, these stubby, linked silica units combine into ring structures. In beryl, each ring consists of six $(\text{SiO}_3)^{2-}$ units, creating a six-fold geometry that is apparent in the external, hexagonal shape of its crystals. Within the crystal lattice, beryl's six-sided rings are arranged in flat sheets. Beryllium and aluminum ions bond ionically between these sheets, joining the sheets and balancing the negatively charged oxygen ions within the ring tetrahedra. Because intra-sheet distances are very small, the ionic bonding between the sheets is unusually strong. This strong ionic bonding is the reason that beryl has only poor, one-directional cleavage and a very substantial hardness of Mohs 7.5-8.0, much greater than that of quartz [silicon dioxide, SiO_2] at Mohs 7.0. Despite its close atomic packing, beryl has a relatively low specific gravity of 2.66-2.92 (only slightly greater than that of quartz) because of the low atomic weights of its essential elements: beryllium, 9.01; aluminum, 26.98; silicon, 28.09; and oxygen, 16.00.

Beryl crystallizes in the hexagonal system, which has four axes, three of equal length and lying in a common plane and separated by angles of precisely 120 degrees. The fourth axis, called the unique or hexagonal axis, is perpendicular to the plane of the other three and may be of any length. Beryl's most common habit is the hexagonal prism with six faces that are arranged parallel to the hexagonal axis. Beryl crystals range in length from a fraction of an inch to many feet. Like most cyclosilicates, beryl usually crystallizes as short-to-elongated prisms with distinctive, flat or modified-flat terminations.

As an allochromatic or "other-colored" mineral, beryl's color is caused by traces of accessory elements that distort its crystal lattice, and not by its essential elements or the inherent nature of its lattice. The colorless variety (goshenite) is pure or nearly pure beryl. However, the ring structures within the adjacent, superposed sheets of beryl's crystal lattice are aligned in a manner that creates channels that readily accommodate traces of accessory metal ions called "chromophores" (color-causing agents), which can impart distinctive colors. Red beryl is produced by traces of trivalent manganese ions Mn^{3+} , pink morganite by divalent manganese ions Mn^{2+} , golden-yellow heliodor by trivalent iron (ferric) ions Fe^{3+} , emerald by trivalent chromium ions Cr^{3+} , green beryl by a mix of divalent iron (ferrous) ions Fe^{2+} and trivalent iron ions, and aquamarine by divalent iron ions (see "The Gem Varieties of Beryl").

The Dana mineral-classification number 61.1.1.1 first identifies beryl as a cyclosilicate with six-membered rings (61). It is then defined by its $(\text{Si}_6\text{O}_{18})^{12-}$ ring structure and the presence of either hydroxyl or aluminum ions (1). Beryl is assigned to the beryl group (1) as the first (1) of five members.

Beryl occurs primarily in granite pegmatites in association with quartz, schorl [tourmaline group, basic sodium iron aluminum borosilicate, $\text{NaFe}_3\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3$], microcline and orthoclase [potash-feldspar group, potassium aluminum silicate, KAlSi_3O_8], and muscovite [mica group, basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$]. Beryl also occurs to a lesser extent in

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the schist of regional metamorphic rocks with quartz, microcline, orthoclase, muscovite, and almandine [garnet group, iron aluminum silicate, $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$]. Red beryl occurs only in vugs of rhyolite.

COLLECTING LOCALITIES

Our goshinite specimens were collected at Erongo Mountain in the Usakos District, Erongo Region, Namibia. Namibian goshenite is also found at Omaruru in the Omaruru District and at the Tubissis pegmatite in the adjacent Karibib District. In Zimbabwe, goshenite is found at the St. Anne's Mine at Mwami in Karoi District, Mashanoland West; and in various mines of the Muturo District in Mashanoland East. Goshenite is also collected at the Kaplinkese Mine in Lukusuzi National Park, Eastern Province, Zambia.

Other sources include the Nerchinsk gem mines at Nerchinsk, Chitinskaya Oblast', Menza District, Transbaikalia, Eastern-Siberian Region, Russia; the Ratnapura gem gravels, Ratnapura District, Sabaragamuwa Province, Sri Lanka; and the Ghaung-gyi, Kin, Kyuak-Phat-That, Mogok Valley, and Mogok Township mines in Pyin-Oo-Lwin District, Myanmar. China's goshenite sources are the Huya tungsten-tin-beryllium deposit at Mt. Xuebaoding, Mianyang Prefecture, Sichuan Province; and the Altlay Mine in the Kokotay pegmatite field, Fuyun County, Aletai Prefecture, and the Jing'erquan pegmatite field in Hami County, Hami Prefecture, both in Xinjiang Province. In Afghanistan, goshenite is collected in the Nilaw-Kolum pegmatite field in the Du Ab District in Nuristan Province, and at Dara-i-Pech in the Chapa Dara District of Konar Province. Localities in Pakistan's Northern Areas include Skardu and the Shigar, Braidu, and Basha valleys in the Skardu District, and the Haramosh Mountains and Hunza Valley in the Gilgit District.

European localities include Chãs da Tavares, Manquaide, Viseu District, Portugal; the Groggo d'Oggi Quarry at Campo dell'Elba, Elba island, Livorno Province, Tuscany, Italy; and the U obrazku Quarry, Pisek, South Bohemia Region, Bohemia, Czech Republic. Among Brazil's goshenite sources are the Alto da Onça pegmatite at Picuí in the Borborema Mineral Province, Paraíba; and the Macaco Mine at Conselheiro Pena, Araçuaí, Minas Gerais. Goshenite is also collected at the SD-2 pegmatite in Tanti, Punilla Department, Córdoba, Argentina. Canadian sources include the Little Nahanni River at Tungsten, Northwest Territories; and the Tanco Mine at Bernic Lake, Lac-du-Bonnet area, Manitoba.

In the United States, goshenite is found in California at the Pala Chief and Elizabeth R. mines in the Pala district and at the Little Three and Hercules mines in the Ramona district, all in San Diego County; and at the Audrey Lynn Mine at Cahuilla, Cahuilla District, Riverside County. Other localities are Mt. Antero and Mt. White in Chaffee County, Colorado; the Morefield Pegmatite at Wingerham, Amelia County, Virginia; and the Rist and American Gems mines at Hiddenite, Alexander County, North Carolina. New Hampshire's sources include the Beryl Mountain Quarry at Acworth and the Franklin Playter Quarry at Springfield in Sullivan County; and the Island Mine at Alstead in Cheshire County. In Maine, goshenite is found at the

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Littlefield and Pulsifer quarries in Auburn, Androscoggin County; and at numerous quarries at Stoneham, Paris, Newry, Norway, Hebron, Greenwood, and Buckfield in Oxford County. Connecticut's sources include the Hewitt Gem Quarry at Haddam and the Strickland pegmatite at Portland, both in Middlesex County; and the Brack gem prospect at Glastonburg in Fairfield County.

JEWELRY & DECORATIVE USES

Goshenite's many fine gemological qualities include a substantial hardness (Mohs 7.5-8.0), excellent transparency, and absence of flaws. It also occurs in large, gem quality crystals, cuts easily into any gem shape, and takes a fine polish. But as a colorless stone without a distinct visual identity, it is the least valuable of the beryl gemstones that include green emerald, blue aquamarine, pink morganite, golden-yellow heliodor, and red beryl (see "The Gem Varieties of Beryl").

Despite its lack of color, large amounts of goshenite were once faceted into gems for jewelry use, but not sold as goshenite. Many goshenite gems were backed with silver or colored foil and mounted in expensive gold or silver settings. Before the availability of such modern diamond simulants as cubic zirconia (CZ), silver-foil-backed goshenite gems, with their artificially created fire and brilliance, were a popular diamond look-alike. Red-foil-backed goshenite resembled ruby; blue-foil-backed goshenite, depending upon color intensity of the foil, resembled aquamarine or blue sapphire; and green-foil-backed goshenite resembled emerald. Many foil-backed goshenite gems were misrepresented as the more valuable ruby, sapphire, and emerald gems. Foil-backed goshenite is rarely seen in today's jewelry markets because of the abundance of high-quality, colored-gem simulants. Artificially irradiated goshenite exhibits very bright and unusual colors; because these colors not permanent, irradiated goshenite has very limited use in jewelry.

Although it lacks a distinctive color, faceted goshenite is nevertheless a very attractive gem that shares the same refractive index as emerald, aquamarine and other colored varieties of beryl. Goshenite gems are usually mounted in silver settings as rings, pendants, earrings, and brooches. Their value is determined by degree of transparency, freedom from flaws, and quality of cutting. Faceted goshenite gems of 2 to 4 carats cost about \$100; gems of 5-10 carats about \$200; and gems of 10-20 carats about \$500. Translucent, white, massive goshenite is sometimes cut and polished into cabochons with an attractive "milky-opal" appearance. Most faceted goshenite is acquired by gem collectors, who value it for its excellent transparency and freedom from flaws. Goshenite collectors' gems range in size from 20 to 40 carats.

Goshenite crystals, as both individual crystals and composite specimens, are collected for their well-defined hexagonal structure. In composite specimens, goshenite is associated with such other pegmatite minerals as albite [sodium aluminum silicate, $\text{NaAlSi}_3\text{O}_8(\text{OH})_2$], muscovite [mica group, basic potassium aluminum silicate, $\text{KAl}_2\text{Si}_3\text{O}_{10}$], schorl [tourmaline group, basic sodium aluminum iron borosilicate, $\text{NaFe}_3\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_4$], elbaite [tourmaline group,

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basic sodium aluminum lithium borosilicate, $\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5})\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_4$, quartz [silicon dioxide, SiO_2], and fluorapatite [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$].

HISTORY & LORE

Goshenite has been known at least since the 1st century A.D., when Romans used it as a diamond simulant, despite its lesser brilliance and fire. According to Roman scholar Pliny the Elder (Gaius Plinius Secundus, A.D. 23-79), the Roman Emperor Nero (Nero Claudius Caesar Drusus Germanicus, A.D. 37-68) sometimes wore eyeglasses made of “emerald.” Modern scholars believe that these eyeglass lenses were actually fashioned not from emerald, but from goshenite or pale aquamarine, which are abundant and available in large, transparent crystals. Medieval metaphysical practitioners used large, transparent goshenite crystals as “crystal balls” for divining the future.

Early scientists assumed that green emerald, blue aquamarine, pink morganite, colorless goshenite, green beryl, and golden-yellow heliodor were all different mineral species. But after the element beryllium was discovered in the early 1800s, mineralogists realized that these were actually all color varieties of the mineral beryl. Colorless beryl, however, was not given a variety name until the early 1900s, when Alvan G. Barrus of Goshen in north-central Massachusetts began collecting crystals from nearby granite pegmatites. Barrus ran classified ads for mineral specimens in the 1920s and 1930s. In 1934, he published a *Rocks & Minerals* article titled “The Famous Old Locality at Goshen,” in which he referred to colorless beryl as “goshenite,” after the name of the nearby town. The name stuck and goshenite is the variety name of colorless beryl today.

Mineralogists used newly developed X-ray diffraction methods to define the crystal structure of the beryl color varieties in 1922.

TECHNOLOGICAL USES

Until the 1960s, non-gem-quality beryl was the only ore of beryllium, a gray, brittle, alkaline-earth metal with a high melting point of 2349° F. (1287 ° C.). Beryllium ranks 51st in crustal abundance, about the same as tin and uranium. Beryllium is found in approximately 100 minerals, but does not occur free in nature. With a low atomic weight of 9.01, beryllium is the second lightest metal; only lithium (atomic weight 6.94) is lighter. Although just one-third as dense as aluminum, beryllium has much greater stiffness and structural strength. Beryllium’s primary use is in exotic alloys; its X-ray transparency and neutron-absorbing properties also give it many other applications in science and industry. Today, beryllium is obtained by mining volcanic tuffs rich in bertrandite [basic beryllium silicate, $\text{Be}_4\text{Si}_2\text{O}_7(\text{OH})_2$].

THE GEM VARIETIES OF BERYL

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Beryl has seven different varieties. Along with colorless goshenite, our Mineral of the Month, these include green emerald, green beryl, blue aquamarine, pink morganite, golden-yellow heliodor, and red beryl. As noted in “Composition & Structure,” pure or nearly pure beryl is colorless. But certain chromophoric trace elements create a wide range of colors and color intensities. As a cyclosilicate, beryl has a ring-type, sheet structure that is aligned in a manner that creates channels to accommodate these chromophores. The primary chromophores in beryl are divalent and trivalent ions of iron, trivalent ions of chromium, trivalent ions of vanadium, and divalent and trivalent ions of manganese, all of which replace some divalent beryllium ions and trivalent aluminum ions in the beryl-crystal lattice. This replacement alters the light-reflecting properties of the lattice to create a range of attractive colors. Four beryl color varieties form primarily in granite pegmatites; one forms in metamorphosed limestone and shale; and one forms as a condensate in rhyolitic vugs. Having discussed colorless goshenite in our write-up, let’s now consider beryl’s other six color varieties.

EMERALD: Along with the corundum [aluminum oxide, Al_2O_3] gemstones sapphire and ruby, emerald, the green color variety of beryl, is one of the classic, precious colored gemstones. Emerald’s green color is caused primarily by trivalent chromium ions Cr^{3+} that replace some trivalent aluminum ions Al^{3+} in the beryl-crystal lattice. In some emeralds, the green color is caused by trivalent vanadium ions V^{3+} partially replacing trivalent aluminum ions. Emerald is usually heavily flawed with cracks and inclusions that compromise both its transparency and structural integrity. It is so sensitive to pressure and shock that the popular “emerald cut,” a step-cut rectangle with truncated corners, was developed specifically for this gem to reduce the pressure incurred during cutting. Flawless emeralds are rare; “clean” stones with a deep, green color and minimal flawing are extremely valuable and can cost as much as \$250,000 per carat. In dollar value, emeralds are the leading colored gem imported into the United States. Emeralds most often occur in metamorphosed strata of limestone and shale, and to a lesser extent in granite pegmatites. The best emeralds come from Colombia, followed by Brazil, Zambia, and Zimbabwe. Emeralds are also mined in Nigeria, Afghanistan, Pakistan, and Russia. In the United States, limited numbers of gem-quality emeralds are found in North Carolina. Emerald is the birthstone for the month of May and the suggested gift for the 20th and 35th wedding anniversaries.

GREEN BERYL: Green beryl is a pale-green variety of beryl that gemologists do not consider as emerald. Unlike emerald, in which chromium ions create the deep-green color, green beryl’s pale-green color is due to divalent iron (ferrous) ions Fe^{2+} and trivalent iron (ferric) ions Fe^{3+} that replace both divalent beryllium Be^{2+} ions and trivalent aluminum ions Al^{3+} in the beryl crystal lattice. Because of its very pale and sometimes muddied color, green beryl has little use as a gemstone.

AQUAMARINE: Blue to blue-green aquamarine is the most popular of the beryl gemstones. The word “aquamarine” stems from the Latin *aqua marina*, literally meaning “seawater” and alluding to the variety’s blue color, which is created when divalent iron (ferrous) Fe^{2+} ions replacing divalent beryllium ions Be^{2+} in the beryl-crystal lattice. This partial replacement

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causes beryl to reflect only blue and blue-green colors. Because of its substantial hardness, excellent transparency, distinctive color, abundance, and occurrence in large, gemmy crystals, aquamarine is a popular gemstone. Aquamarine's gem value is based not on size, but upon color intensity, degree of transparency, and the absence of inclusions. Available in a wide variety of cuts and styles, aquamarine gems are worn in rings, brooches, necklaces, earrings, and bracelets. Because aquamarine gems usually exceed 3 carats and can approach 20 carats in size, they are ideal for "cocktail"-style rings. Aquamarine is traditionally mounted in white gold, silver, or platinum. Fine gems of three to five carats sell for about \$500 per carat. Smaller gems, which exhibit less color intensity, are much more affordable. Aquamarine is the birthstone for the month of March and the suggested gift for the 18th wedding anniversary. Most aquamarine comes from Namibia, Brazil, Pakistan, and Afghanistan. In the United States, aquamarine is found in Colorado, California, and Maine.

MORGANITE: The color of morganite, the pink variety of beryl, is caused by divalent manganese ions Mn^{2+} replacing divalent beryllium ions Be^{2+} within the beryl-crystal lattice. Morganite colors are soft and range from purplish-pink to pink and orange-pink. Morganite was named for American financier and noted gem collector J. Pierpont Morgan (1837-1913) at the suggestion of George Frederick Kunz (1856-1932), America's first gemologist. Morganite gems, which have excellent transparency and few inclusions, are mounted in silver settings and worn in rings, necklaces, and pendants. Because large, gemmy crystals are common, faceted morganite gems usually weigh at least three carats. Flawless morganite gems with good color in the three-to-five-carat range cost about \$800. Morganite collectors' gems often exceed 20 carats in weight, with museum specimens exceeding 100 carats. Most morganite comes from Brazil; other sources include Mozambique, Namibia, Afghanistan, Russia, and Zimbabwe. In the United States, morganite crystals are found in California and Maine.

HELIODOR (GOLDEN BERYL): Heliodor, the yellow variety of beryl, ranges in color from brownish-yellow and greenish-yellow to lemon-yellow and golden-yellow. The word "heliodor" stems from the Greek word *helios*, meaning "sun," and *dōron*, or "gift," and literally means "gift of the sun," alluding to its sun-like color. Heliodor colors are created when trivalent iron (ferric) ions Fe^{3+} replace trivalent aluminum ions Al^{3+} in the crystal lattice. Heliodor has excellent transparency; its most desirable color is a clean lemon-yellow. Most heliodor comes from Brazil; other sources are Madagascar, Namibia, and the Ukraine. Large, gemmy crystals of heliodor are common and faceted collectors' gems often exceed 100 carats in size. The largest-known heliodor gem is a 2,054-carat stone that is displayed at the Hall of Gems in the National Museum of Natural History (Smithsonian Institution) in Washington, D.C.

RED BERYL: Red Beryl, the rarest of all beryl color varieties and one of the rarest of all gemstones, has a saturated red color that ranges from orange-red to purplish-red, with cranberry-red being the most desirable. The red coloration is caused by trivalent manganese ions Mn^{3+} that partially replace the trivalent aluminum ions Al^{3+} in the crystal lattice. Red beryl is the only beryl variety that does not occur in granite pegmatites. It forms only in rhyolitic vugs as a condensate of beryllium-rich and manganese-rich gases. Like emerald, red beryl is very heavily included, usually sub-transparent, and occurs only in small crystals. Because of its rarity and the

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high price of specimens, it is rarely faceted. The few gems that are faceted are usually less than 0.15 carats in size. The largest known red beryl gem weighs eight carats. The finest red beryl gems can cost \$10,000 per carat. Limited commercial quantities of red beryl come only from Utah.

ABOUT OUR SPECIMENS

Our specimens of the goshenite variety of beryl were collected at Erongo Mountain in the Usakos and Omaruru districts, Erongo Region, Namibia. Located in southern Africa, Namibia adjoins the Atlantic Ocean on the west, Angola on the north, Botswana on the east, and South Africa on the south. Covering 318,259 square miles, Namibia's area roughly equals that of the combined American states of Texas and Oklahoma. Because much of Namibia is arid, inhospitable desert, its population is only 2.2 million, making it the world's second least-densely populated nation after Mongolia. In 1884, Great Britain annexed part of the region to its Cape Colony (now South Africa), while Germany claimed adjacent sections as its Südwestafrika (South-West Africa) colony. During World War I, South Africa occupied South-West Africa, then assumed regional administration in 1920 before finally annexing South-West Africa in 1946. In 1968, the United Nations renamed the region "Namibia" and appointed an international council to supervise its affairs prior to independence. Fighting between South African troops and the South-West Africa People's Organization (SWAPO) rebels continued through the 1980s. In 1992, Namibia adopted a SWAPO-controlled, constitutional, Western-style government and received its independence. Today, Namibia's economy relies on farming and ranching, along with diamond, gold, copper, and uranium mining.

Erongo Mountain, a prominent, semicircular mountain 18 miles in diameter, is located in central Namibia, 125 miles northwest of the national capital of Windhoek, and 10 miles north of the towns of Usakos and Karibib. The local climate is warm and arid; an annual rainfall of just eight inches supports the brushy, "thornveld" vegetation. Erongo Mountain is geologically complex, with both extrusive (volcanic) rocks and granitic (plutonic) rocks. About 136 million years ago in the late Jurassic Period, a volcanic system collapsed to form a caldera. Magma then intruded this fractured caldera to emplace the alkaline (silica-poor) Erongo Granite as a ring-shaped system of dikes that contained numerous pegmatites. German geologists conducted the first mineralogical studies of Erongo Mountain in the early 1900s. In the 1920s, prospectors discovered pegmatite outcrops rich in ferberite [iron tungstate, FeWO_4] and cassiterite [tin oxide, SnO_2]. Several tin-tungsten mines opened in the 1930s, the largest being the Krantzberg Mine where ores graded as high as 60 percent tungsten.

Prior to the late 1990s, Erongo Mountain provided only specimens of schorl and quartz. Then in 1999, local specimen "diggers" discovered small pegmatite pockets filled with fine crystals of goshenite and aquamarine, with colors grading between the two varieties. These caught the interest of collectors in Europe and the United States, driving demand and prices for Erongo Mountain specimens upward and attracting many native diggers. Along with goshenite and aquamarine, the diggers also recovered jet-black schorl and twinned crystals of orthoclase

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[potash-feldspar group, potassium aluminum silicate, KAlSi_3O_8]. Other valuable specimens included the heliodor variety of beryl; gemmy monazite-Ce [cerium lanthanum neodymium phosphate, $(\text{Ce}, \text{La}, \text{Nd})\text{PO}_4$]; Japan-law twinned quartz; emerald-green fluorite [calcium fluoride, CaF_2]; and exceptional crystals of jeremejevite [aluminum fluoroborate, $\text{Al}_6(\text{BO}_3)_5\text{F}_3$]. In 2006, *The Mineralogical Record* printed a feature article on Erongo Mountain minerals by Bruce Cairncross, South Africa's preeminent mineralogist.

Collecting conditions at the Erongo Mountain pegmatites are difficult. Dirt roads follow the mountain's perimeter, but only foot trails access the rugged interior. The crystal-containing pegmatite pockets or "nests," as the local diggers call them, are exposed on the sides of sheer, 200-foot-high granite cliffs. Unstable and dangerous, these cliffs have claimed the lives of several diggers.

Because the most accessible pegmatite nests have been cleaned out and the remaining nests are difficult to reach, fewer numbers of Erongo Mountain specimens are reaching the international specimen markets.

When studying your goshenite specimen, note first the nearly perfect, hexagonal cross sections of the prisms and their flat terminations, which is the primary crystal habit of all beryl varieties. The goshenite crystals are colorless and are heavily included, with the greatest degree of transparency at the termination end. The prism surfaces are partially covered with a secondary growth of small, shiny, flat crystals of muscovite [mica group, basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$] and are stained orange-brown with hematite [iron oxide, Fe_2O_3].

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