

## ***July 2011 Mineral of the Month: Aquamarine***

This month's mineral is aquamarine, a gem variety of beryl from a recently recognized, classic locality in Namibia. Our write-up explains the mineralogy and rich lore of aquamarine, as well as the history and remarkable properties of the metal beryllium.

### **OVERVIEW**

### **PHYSICAL PROPERTIES**

Chemistry:  $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$  Beryllium Aluminum Silicate, often containing sodium, lithium, and cesium.

Class: Silicates

Subclass: Cyclosilicates (Ring Silicates)

Group: Beryl

Crystal System: Hexagonal

Crystal Habits: Usually as hexagonal (six-sided) prisms with flat terminations and prominent, lengthwise striations; also massive, compact, and columnar.

Color: Beryl ranges from colorless and white to blue, bluish-green, green, yellow, golden-yellow, pink, and red. The aquamarine variety of beryl is blue to greenish-blue and occasionally grayish-blue.

Luster: Vitreous

Transparency: Transparent to translucent

Streak: Colorless to white

Cleavage: Poor in one direction

Fracture: Uneven to conchoidal; brittle.

Hardness: 7.5-8.0

Specific Gravity: 2.66-2.92

Refractive Index: 1.577-1.583

Distinctive Features and Tests: Best field marks are hardness, six-sided prisms with flat terminations, transparency, blue to greenish-blue color, and occurrence in granite pegmatites.

Dana Classification Number: 61.1.1.1

**NAME** The name aquamarine, pronounced ahh-kwa-mah-REEN, stems from the Latin *aqua marina*, literally meaning "sea water" in allusion to its blue and greenish-blue colors. Aquamarine is also known as "blue beryl" and "aqua." In European mineralogical literature, aquamarine appears as *Aquamarin*, *aquamarina*, and *akvamarin*.

**COMPOSITION:** Beryl, which consists of 5.03 percent beryllium, 10.04 percent aluminum, 31.35 percent silicon, and 53.58 percent oxygen, is a cyclosilicate, the most structurally interesting and complex of all silicate subclasses. As is typical of cyclosilicates, beryl is hard and durable and usually forms elongated crystals with longitudinal striations. Beryl crystallizes in the hexagonal system, which is characterized by four axes, three of which are of equal length and lie in a common plane with angles of precisely  $120^\circ$  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. As an allochromatic or "other-colored" mineral, beryl's color is determined by the trace presence of accessory elements. In aquamarine, traces of iron ions that replace those of beryllium distort the beryl lattice in a manner that causes it absorb all red, yellow, violet, and most green wavelengths of white light, and to reflect only blue with hints of green. Beryl occurs primarily in granite pegmatites and to a lesser extent in the schists of regional metamorphic rocks.

**COLLECTING LOCALITIES:** The world's leading aquamarine localities include Erongo Mountain in Namibia; Flanarantsoa Province, Madagascar; the Southern Region of Malawi; Zambezia Province,

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Mozambique; the pegmatites of Brazil's Minas Gerais state; and Pakistan's Northern Areas. Other localities are in Zambia, Zimbabwe, Nigeria, Tanzania, Afghanistan, China, India, Mexico, Norway, Russia, Sri Lanka, and Northern Ireland. In the United States, aquamarine is found in California, Colorado, Connecticut, Maine, and Idaho.

**HISTORY, LORE, & GEMSTONE/TECHNOLOGICAL USES:** Mineralogists determined the chemical composition of beryl in 1797 and soon learned that aquamarine was a color variety of that mineral. Beryl's crystal structure was defined by X-ray diffraction methods in 1922. Thanks to its substantial hardness, excellent transparency, distinctive blue color, relatively high refractive index, abundance, and occurrence in gem-quality crystals of unusual size, aquamarine has been a popular gemstone since medieval times. The value of aquamarine gems is based not on size, but on moderately intense blue color, degree of transparency, and freedom from most inclusions. Aquamarine gems are available in the classic oval, round, rectangular, octagonal, and square cuts, as well as complex trillion, pear, and heart-shaped styles. Aquamarine is worn in brooches, necklaces, earrings, and bracelets, but is most familiar as a ring stone. Fine gems of three or more carats now sell for about \$500 per carat. The prices of smaller aquamarine gems, which have relatively pale colors and thus limited popularity, are considerably lower. Although gem-quality aquamarine has been synthesized in laboratories, it is not cost-effective in comparison with natural aquamarine. Until the 1960s, all non-gem forms of beryl, including aquamarine, were the primary ores of beryllium, a metal with many uses in science and industry. According to modern metaphysical practitioners, aquamarine provides foresight and courage, enhances happiness, intelligence, and youthful qualities, and alleviates anxiety-related stress.

**ABOUT OUR SPECIMENS:** Our aquamarine 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 about 125 miles northwest of the national capital of Windhoek. The local climate is warm and semiarid, with only eight inches of rain annually that supports a sparse, brushy, "thornveld"-type of vegetation. The origin of our specimens goes back 135 million years ago to the late Jurassic Period when a volcanic system subsided and collapsed to form a caldera. This fractured caldera was then intruded by magma that emplaced the alkaline (silica-poor) Erongo granite formation. This intrusion solidified very slowly, leaving pockets of residual magma that were enriched with such unusual elements as tin, tungsten, boron, fluorine, and beryllium. In areas where gases created cavities, final solidification of the residual magma took place on a mineral-by-mineral basis with the growth of large, well-developed crystals. These crystal-filled pegmatite pockets, now exposed by erosion, are the source of our specimens. Erongo Mountain first attracted attention as specimen locality in early 1999, when native diggers uncovered small pegmatite pockets containing aquamarine crystals that quickly found their way to international markets. Diggers made a major discovery on Easter Sunday in 2000, opening a large pegmatite pocket filled with spectacular aquamarine crystals with an unusually intense, clean blue color. Erongo Mountain has since been recognized as a classic locality for aquamarine. The aquamarine-containing pegmatite pockets, or "nests," as the local diggers call them, are exposed on the nearly sheer sides of granite cliffs. The most easily accessible pockets have now been depleted of crystals. Because the remaining pockets are very difficult to reach and to work, aquamarine production from Erongo Mountain has declined steadily in recent years.

**10 YEARS AGO IN OUR CLUB:** Astrophyllite, Mount Eveslogchorr, Khibiny Massif, Kola Peninsula, Murmanskaja Oblast', Russia. Pronounced a-STROF-a-lite, the name comes from the Greek words for "star," "leaf," and "rock." At this now-classic site, the astrophyllite crystalizes as bunches of golden to reddish-brown strawlike crystals, frozen in matrix. We were really excited about these attractive specimens, which were just reaching the market—so excited that we hope to feature astrophyllite again in the coming months! If it works out, you can look forward to a uniquely beautiful piece coming to you!

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## **COMPREHENSIVE WRITE-UP**

### *COMPOSITION*

Aquamarine is not a distinct mineral species, but a color variety of the mineral beryl. Other color varieties of beryl include, of course, the valuable gemstone Emerald; Morganite, which is pink, rose or peach colored; Heliodor, which has pale yellow to rich golden color; Goshenite, which is colorless; and Bixbite, also known as red beryl or "red emerald." ("Red Emerald"—talk about a contradiction in terms!) We featured red beryl, believe it or not, in March 1999, sending crystals from the Violet Mine, Wah Wah Mountains, Beaver County, Utah. This was prior to the mine's closing, and of course we have far fewer members in 1999. A collector who has supplied numerous specimens to us over the years made a couple of fruitful collecting trips to the mine and provided us with enough pieces to satisfy our needs. If you were in the Club then, imagine how much your specimen might be worth now that the mine has been closed for many years! The specimen we kept for our collection was remarkable in that, while examining it, the matrix broke open to reveal an even better crystal hidden inside! Not that we recommend that you break your piece apart, if you were fortunate to get one from us then . . .

So now more than twelve years later, we are delighted to be able to spotlight another of beryl's color varieties! First we'll start with the basics about the mineral beryl. Beryl's chemical formula  $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$  shows that it contains 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  $3\text{Be}^{2+}$  with a collective +6 charge, and two aluminum ions  $2\text{Al}^{3+}$ , also with a collective +6 charge. This provides a total +12 cationic charge. Beryl's compound anion is a radical, 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  $6\text{Si}^{4+}$  and 18 oxygen ions  $18\text{O}^{2-}$  provide a total -12 anionic charge. This total -12 charge of the  $(\text{Si}_6\text{O}_{18})^{12-}$  anion balances the +12 charge of the compound cation  $(\text{Be}_3\text{Al}_2)^{12+}$  to provide the beryl molecule with electrical stability.

Beryl is a member of the silicates, the largest and most abundant class of minerals, in which silicon and oxygen are combined 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 surround a silicon ion and are positioned at the four corners of a tetrahedron. The oxygen ions are bound to the silicon ion by strong covalent bonding. In silicate minerals, silica anions and metal cations are bound 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).

As a cyclosilicate, beryl is a member of the most structurally interesting and complex of all silicate subclasses. Remember that the silicate structural unit is the silica tetrahedron  $(\text{SiO}_4)^{4-}$ . Cyclosilicates form when these 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. Instead of forming chain-type structures, these short, linked silica units come together in a ring structure. In beryl, each ring consists of six  $(\text{SiO}_3)^{2-}$  units, the six-sided geometry of which is apparent in the external, hexagonal shape of beryl crystals. Beryl's six-sided rings are arranged in flat sheets. Beryllium and aluminum ions bond ionically between the sheets, holding the sheets together 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—the reason why beryl has only poor cleavage in one direction. The rings within adjacent, superposed sheets are aligned in a manner that creates channels

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to accommodate traces of a number of accessory metal ions, some of which impart distinctive colors to beryl's gemstone varieties. Like most cyclosilicates, beryl is quite hard and durable and usually forms elongated, longitudinally striated crystals. Because unusually strong ionic bonding complements its strong, covalent oxygen-oxygen bonding, beryl has a Mohs hardness of 7.5-8.0, much greater than that of quartz [SiO<sub>2</sub>]. Despite relatively close atomic packing, beryl has a low specific gravity of 2.66-2.92, making it only slightly denser than quartz. This is explained by the relative lightness of all of beryl's essential elements: beryllium, atomic weight only 9.01; aluminum, 26.98; silicon, 21.09; and oxygen, 16.00.

Beryl crystallizes in the hexagonal system, which has four axes, three of which are of equal length and lie in a common plane separated by angles of precisely 120°. 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, in which six faces are arranged parallel to the hexagonal axis. Beryl crystals have an unusually broad range of sizes, from only fractions of an inch to 12 or more feet in length, the latter weighing several tons each.

As an allochromatic or "other-colored" mineral, beryl's color is determined by the trace presence of accessory elements, rather than by its essential elements or the nature of its crystal lattice. Pure beryl is colorless, but its lattice is particularly susceptible to trace-element distortion. Red beryl is produced by traces of trivalent manganese Mn<sup>3+</sup>, pink morganite by divalent manganese Mn<sup>2+</sup>, golden-yellow heliodor by trivalent iron (ferric) Fe<sup>3+</sup>, and emerald by trivalent chromium Cr<sup>3+</sup>. In aquamarine, traces of divalent iron (ferrous, Fe<sup>2+</sup>) replace beryllium (Be<sup>2+</sup>) to distort the beryl lattice, causing it to absorb all red, yellow, violet, and most green wavelengths of white light, and to reflect only blue with occasional hints of green.

The Dana mineral-classification number 61.1.1.1 first identifies beryl as a cyclosilicate with six-membered rings (61). It next defines beryl by an (Si<sub>6</sub>O<sub>18</sub>)<sup>12-</sup> ring structure and the presence of either hydroxyl or aluminum ions (1). Beryl is then assigned to the beryl group (1) as the first (1) of four members, the other three of which are chemically complex and rare.

Beryl occurs primarily in granite pegmatites in association with quartz [silicon dioxide, SiO<sub>2</sub>], microcline and orthoclase [both potash feldspar group, potassium aluminum silicate, KAlSi<sub>3</sub>O<sub>8</sub>], and muscovite [mica group, basic potassium aluminum silicate, KAl<sub>3</sub>Si<sub>3</sub>O<sub>10</sub>(OH)<sub>2</sub>]. Beryl also occurs to a lesser extent in the schists of regional metamorphic rocks in association with quartz, microcline, orthoclase, muscovite, and almandine [garnet group, iron aluminum silicate, Fe<sub>3</sub>Al<sub>2</sub>(SiO<sub>4</sub>)<sub>3</sub>].

### ***COLLECTING LOCALITIES***

Our aquamarine specimens were collected at Erongo Mountain in the Usakos and Omaruru districts, Erongo Region, Namibia. Another Namibian source is the Tsaobismund pegmatite in the nearby Karibib District. Other African localities include the Sakavalana Mine at Ambatovita, Ambatofinadrahana District, Amoron'i Mani Region, Flanarantsoa Province, Madagascar; the Mangochi District in the Southern Region of Malawi; the Muiâne pegmatite, Alto Ligonha District, Zambezia Province, Mozambique; the Kaplinkese Mine, Lukusuzi National Park, Eastern Province, Zambia; St. Anne's Mine at Mwami, Karoi District, Mashanoland West, Zimbabwe; the Gwantu pegmatites in Kaduna State, Nigeria; and the Uluguru Mountains in the Dar es Salaam Region, Tanzania.

In Brazil's Minas Gerais state, large quantities of aquamarine are found at the Batatal and Papamel mines at Marambaia in the Jequitinhonha Valley; the Ipé Mine at Governador Valadares in the Doce Valley; the Miguri Mine at Teófilo Otoni in the Mucuri Valley; and the Santa Maria de Itabira and Ponte da Raiz mines at Santa Maria de Itabira. Brazilian aquamarine is also recovered from the Ursina, Mimoso do Sul, and Concordia mines at Mimoso do Sul in Espírito Santo. Several important aquamarine sources are located

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in Pakistan's Northern Areas, notably at Skardu and the Shigar, Braidu, and Basha valleys in the Skardu District; and in the Haramosh Mountains and Hunza Valley in the Gilgit District.

Other localities are the Nilaw-Kolum pegmatite field, Du Ab District, Nuristan Province, Afghanistan; the Karur District pegmatites in Tamil Nadu, India; the Delicias Mine, El Rodeo, Baja California Norte, Mexico; the Elgkauåsen Tunnel at Røyken, Buskerud, Norway; the Nerchinsk gem mines at Nerchinsk, Chitinskaya Oblast', Transbaikalia, Eastern-Siberian Region, Russia; the Ratnapura gem gravels in the Ratnapura District, Sabaragamuwa Province, Sri Lanka; and Mourne Mountain in County Down, Northern Ireland, United Kingdom. Chinese localities include the Chengjawan pegmatite, Anyuan District, Pingxiang Prefecture, Jiangji Province; and the Huya tungsten-tin-beryllium deposit at Mt. Xuebaoding, Mianyang Prefecture, Sichuan Province.

In the United States, aquamarine occurs 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 Inyo beryl claims on Haystack Mountain near Lone Pine, Inyo County. Other localities are the summit areas of Mt. Antero and Mt. White in Chaffee County, Colorado; the Hewitt Gem Quarry at Haddam and the Strickland pegmatite at Portland, both in Middlesex County, Connecticut; the Bumpus Quarry and adjacent pegmatite quarries near Albany, Oxford County, Maine; and the Upper Cramer Lake pegmatites in the Sawtooth Batholith, Custer County, Idaho.

### ***JEWELRY & DECORATIVE USES***

With its substantial hardness, excellent transparency, distinctive blue color, relatively high refractive index, abundance, and occurrence in large, gem-quality crystals, aquamarine has been a popular gemstone since medieval times. Aquamarine's value is based upon moderately intense blue color, high degree of transparency, and minimal inclusions. Unlike blue sapphire [corundum, aluminum oxide,  $\text{Al}_2\text{O}_3$ ], aquamarine's blue color is never intense and is, in fact, sometimes too pale for gem use. Moderately-to-slightly-intense, clean, blue colors with little or no significant green or gray components are most desirable and valuable. While most gem-quality aquamarine has a water-like transparency, it is rarely free of inclusions. Inclusions in aquamarine tend to concentrate near the base of the prism, which can appear translucent or even semi-opaque. The terminal end, from which aquamarine gems are usually cut, has the fewest inclusions and greatest transparency. This reflects the fact that many crystals tend to form more rapidly at first, allowing more inclusions and imperfections to occur, and then more slowly toward the termination, which can often be clear and free from inclusions.

With a Mohs hardness of 7.5-8.0 (much greater than that of quartz and nearly equal to that of topaz), aquamarine can endure everyday wear in jewelry. Aquamarine gems are available in the classic oval, round, rectangular, octagonal, and square cuts, as well as more complex trillion, pear, and heart-shaped styles. Aquamarine is worn in brooches, necklaces, earrings, and bracelets, but is most familiar as a ring stone. Because aquamarine gems usually exceed 3 carats and are often 10 or 20 carats in weight, they are ideal for "cocktail"-style rings. Aquamarine is traditionally mounted in white metal, usually white gold, but also in silver and occasionally in platinum.

Because it can be cut into large gems, aquamarine has an unusual price structure. The per-carat price of most gems, including diamond [C], emerald, topaz [ $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$ ], and ruby and sapphire [corundum,  $\text{Al}_2\text{O}_3$ ], varies greatly with individual gem size. Although a one-carat diamond or ruby gem may be valued at \$1,000, the per-carat value of a three-carat stone of the same grade is many times higher. But the per-carat value of aquamarine, whether in a 5-carat gem or a 20-carat gem is basically the same. Thus, aquamarine's per-carat value depends not upon the size of the gem, but on color, cut, transparency, and only minimal amounts of visible inclusions. And large aquamarine gemstones can be affordable!

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The largest-known, gem-quality aquamarine crystal, mined in 1910 in Minas Gerais, Brazil, measured 19 inches in length and 17 inches in diameter, and weighed 70 pounds. A 13-pound, rough piece of the greenish-blue outer portion of this crystal is exhibited at the American Museum of Natural History in New York City. The British Museum of Natural History in London displays a flawless, 879.5-carat, step-cut, blue-green aquamarine gem from this same crystal. The largest single aquamarine crystal ever to be cut completely into gems was mined in 1992, also in Brazil. Known as the Dom Pedro Aquamarine, it weighed 16 pounds and was transparent throughout. The Dom Pedro Aquamarine was cut in Idar-Oberstein, Germany, by the noted German gemstone designer and master cutter Bernd Munsteiner (1943 -).

Many aquamarine gems are heat-treated at temperatures of 600° F. (312° C.) to 1200° F. (648° C.) to remove any greenish hues and to slightly intensify their blue color. This treatment is permanent in normal jewelry use (it can be reversed by irradiation) and is standard in the jewelry industry. In recent decades, the aquamarine market has been somewhat erratic. During the 1960s and 1970s, Brazilian aquamarine dominated the market and wealthy Brazilians often acquired quantities of fine aquamarine, both as investments and to keep prices high. Aquamarine prices reached record levels of \$500 per carat in 1980, but soon plummeted as inexpensive, irradiated blue topaz (also from Brazil) flooded the market. Another factor in the price drop was the increased availability of natural aquamarine from newly discovered sources in eastern Africa. Aquamarine prices have since stabilized and recovered. Fine gems of three or more carats now again sell for about \$500 per carat. Smaller aquamarine gems, which have paler colors and thus limited popularity, can be purchased for considerably less. Although gem-quality aquamarine has been synthesized in laboratories, is not cost-effective in comparison with natural aquamarine.

### ***HISTORY & LORE***

The oldest known aquamarine artifacts are amulets recovered from Greek tombs dating to 480 B.C. According to Roman scholar Pliny the Elder (Gaius Plinius Secundus, A.D 23-79), the Emperor Nero (Nero Claudius Caesar Drusus Germanicus, A.D. 37-68) sometimes wore eyeglasses made of “emerald.” Modern scholars believe that Nero’s eyeglasses were actually fashioned from aquamarine, a crystal with much greater size and transparency than emerald. Because aquamarine’s color so closely resembles the blue waters of the Mediterranean, the stone acquired superstitious lore connected to the sea. Romans believed that aquamarine was sacred to their false god Neptune. Mariners sometimes wore aquamarine talismans engraved with the likeness of Neptune to protect them on voyages. A common medieval belief was that aquamarine possessed its greatest powers when immersed in water. Physicians of the era placed aquamarine in water, which they then used as a tonic to treat ailments of the heart, liver, stomach, mouth, and throat, and to alleviate the effects of poisons. Aquamarine was also used to represent eyes in ornate statues, in hopes that it would give their owners the ability to see into the future! These statues were sometimes placed to overlook the sea in the hope that their aquamarine “eyes” would calm storms and assure the safe return of ships.

In the mid-1600s, a large supply of high-quality aquamarine began to reach Europe from the Portuguese colony of Brazil. As prices became more affordable, the popularity of aquamarine gems soared. Not coincidentally, the word “aquamarine,” from the Latin *aqua marina*, appeared in the English language about 1670. In the early 1800s, not long after the element beryllium had been discovered (see “Beryllium”), mineralogists learned that blue aquamarine, pink morganite, green emerald, colorless goshenite, and golden-yellow heliodor were all color varieties of beryl. Aquamarine gems again came into favor in the mid-1800s, when German immigrants in Brazil began systematically mining large quantities of gem-quality rough, which they shipped to Idar-Oberstein, Germany. During this time, Brazilian aquamarine fueled much of Idar-Oberstein’s growth as an internationally known stonecutting center. The crystal structure of beryl was defined by X-ray diffraction methods in 1922.

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In 1912, the United States' National Association of Jewelers formally adopted aquamarine as the birthstone for the month of March, and aquamarine later became the suggested gift gem for 18<sup>th</sup> wedding anniversaries. On April 30, 1971, the Colorado Legislature designated aquamarine as the official state gemstone in recognition of the fine aquamarine crystals recovered from the summit areas of Mt. Antero and Mt. White in Chaffee County. Aquamarine was featured on the 15-pfennig stamp of the German Democratic Republic (East Germany) in 1974, the 1.30-real stamp of Brazil in 1977, the 3-schilling stamp of Kenya in 1977, the 15-cent stamp of South West Africa in 1979, and the 200-riel stamp of Cambodia in 1998. According to modern metaphysical practitioners, aquamarine provides foresight and courage, enhances happiness, intelligence, and youthful qualities, and alleviates the effects of anxiety-related stress.

### **TECHNOLOGICAL USES**

Until the 1960s, non-gem varieties of beryl served as the primary ore of beryllium, a metal with many uses in science and industry (see "Beryllium").

### **BERYLLIUM**

*Beryl's two essential cationic components are the familiar metal aluminum and the decidedly unfamiliar metal beryllium. Beryllium is a gray, brittle, alkaline-earth metal with a high melting point of 1287° C. (2349° F.). It ranks 51<sup>st</sup> in crustal abundance, about the same as tin, uranium, and arsenic. It does not occur free in nature, but is found in about 100 minerals, only two which have been of economic importance. With an atomic weight of only 9.01, beryllium is the second lightest metal; only lithium, atomic weight 6.94, is lighter. Although just one-third the weight of aluminum, beryllium's stiffness is greater than that of carbon steel. Beryllium's primary use is in exotic alloys, but its X-ray transparency and neutron-absorbing properties give it many other high-tech applications in science and industry.*

*Until 1797, mineralogists believed that beryl consisted only of aluminum silicate. But that year, French chemist Louis-Nicholas Vauquelin (1763-1829) analyzed several gemstone varieties of beryl and found that each specimen yielded aluminum oxide (elemental aluminum had not yet been isolated), from which he separated the oxide of a previously unknown element. He named this new element "glucinium" after the sugar glucose, a reference to the sweet taste of its salts. Working independently in 1828, the German chemist Friedrich Wöhler (1800-1882) and his French counterpart Antoine Alexandre Brutus Bussy (1794-1882) isolated "glucinium" in an impure metallic form. In 1847, "glucinium" was renamed "beryllium," after the only mineral then known to contain it—beryl. Chemists finally succeeded in isolating pure beryllium by electrolysis in 1898.*

*Beryllium remained a laboratory curiosity until the 1930s, when it was used as an alloying agent to harden copper and as a component of the phosphor coatings of newly developed fluorescent light tubes. Another important use was as an X-ray "window" to protect delicate X-ray tubes while absorbing little if any of the X-ray energy. Demand for beryllium increased rapidly during and after World War II, creating a shortage of the metal. Beryl was then the only known ore of beryllium. As prices soared, the mining of beryllium-rich, granite pegmatites became quite profitable. Miners occasionally struck it rich when they encountered huge crystals of opaque, common beryl. Containing as much as five percent beryllium by weight, these massive crystals, sometimes 12 feet long and weighing four tons each, were true bonanzas. Through the 1950s, numerous small pegmatite mines, mostly in Maine, South Dakota, and New Mexico, yielded an ample supply of beryllium.*

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*But by 1960, the beryllium-rich pegmatites in the United States were nearly depleted and could no longer satisfy the booming demand for the metal for use in new, lightweight, aerospace alloys. As the nation began importing beryl from the Brazilian pegmatite fields, prospectors searched for new domestic beryl deposits, focusing their efforts on west-central Utah's Topaz-Spor Mountain region. By chance, a geologist analyzed samples of the local tuff, an earthy volcanic rock, and was surprised to detect beryllium. Analysis revealed that the beryllium-rich mineral within the tuff wasn't beryl at all, but bertrandite [basic beryllium silicate,  $\text{Be}_4\text{Si}_2\text{O}_7(\text{OH})_2$ ]. Geologists then learned that groundwater had leached beryllium from formations of volcanic rhyolite, then redeposited it as tiny, disseminated bertrandite crystals within the porous tuff. Although the beryllium-rich tuff graded only 0.5 percent bertrandite, it occurred in large, shallow deposits suitable for inexpensive, open-pit mining. The start of mining at Spor Mountain in 1969 immediately made the United States self-sufficient in beryllium. Still the world's largest known beryllium deposit, Spor Mountain now provides most of the 150 tons of elemental beryllium produced worldwide each year.*

*Today, beryllium is used mainly as an alloying agent to increase the hardness, melting points, corrosion resistance, insulating and casting properties, stiffness, and dimensional stability of many metals. Lightweight beryllium alloys are used extensively in supersonic aircraft and spacecraft. Metallic beryllium is the "window" material in virtually all medical, industrial and scientific X-ray devices. The metal is also important in nuclear industries. When bombarded by alpha radiation, beryllium emits a limited and easily controllable stream of neutrons. And because it absorbs and deflects neutrons, beryllium is used to clad nuclear fuel rods and the fissile material in nuclear weapons. Other uses include wire alloys for multiplexing systems that simultaneously carry hundreds of electronic signals through single wires, and as structural supports and dopants for semiconductors. Although beryllium products (and beryllium-bearing mineral specimens) are completely safe to use and handle, the dust released when beryllium is fabricated is highly toxic. Prolonged exposure causes a debilitating lung condition known as berylliosis and certain forms of cancer. With record demand for beryllium, a single pound of the refined metal now costs \$400.*

### **ABOUT OUR SPECIMENS**

Our aquamarine specimens were collected at Erongo Mountain in the Usakos and Omaruru districts, Erongo Region, Namibia. This is the second time we have featured a mineral from this productive locality, the first being tourmaline in August 2003. At that time, we could not be certain if the specimens we sent were of the more common schorl [ $\text{Na}(\text{Fe}^{2+})_3\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ ] or of a rarer member of the tourmaline group, foitite [ $\text{Fe}^{2+}_2(\text{Al},\text{Fe}^{3+})\text{Al}_6\text{Si}_6\text{O}_{18}(\text{BO}_3)_3(\text{OH})_4$ ], so we just labeled them as black tourmaline. However, the question was clarified somewhat in a special issue of the *Mineralogical Record* in September-October 2006 devoted entirely to Erongo minerals, which stated that "detailed analyses of Erongo tourmalines in the Harvard collection have shown that most are schorl and only a few are foitite," though testing was still underway at that time. This special issue may be available as a back issue at the Minrec.org web site if anyone wants to delve more deeply into this amazing locality, and marvel at the dozens of exceptional specimens lovingly photographed for the article.

Located in southern Africa, Namibia is bounded by the Atlantic Ocean to the west, Angola to the north, Botswana to the east, and South Africa to the south. Covering 318,259 square miles, Namibia's area roughly equals that of the combined states of Texas and Oklahoma. Because much of Namibia is arid desert, its population is only 2.2 million, making it the second least-densely populated sovereign nation in the world behind Mongolia. Dutch and British traders first penetrated the region in the 1700s. In 1884, Britain annexed certain coastal areas to its Cape Colony (now South Africa), while Germany claimed adjacent coastal sections and parts of the interior as its Südwestafrika (South-West Africa) colony. During World War I, British troops from South Africa occupied South-West Africa. South Africa assumed regional



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administration in 1920, then annexed South-West Africa in 1946. In the 1960s, South-West Africa People's Organization (SWAPO) guerrilla forces began operating against South African troops. In 1968, the United Nations renamed the region Namibia and appointed an international council to supervise its affairs and plan for its independence. Fighting between South African troops and SWAPO rebels continued through the 1980s. In 1992, Namibia adopted a SWAPO-controlled, Western-style, constitutional government and received its full independence. Today, Namibia's economy relies on farming, ranching, and mining, the latter for diamonds, gold, copper, and uranium.

Erongo Mountain, a prominent, semicircular mountain about 18 miles in diameter, is located in central Namibia, 100 miles northeast of the coastal city of Swakopmund, 125 miles northwest of the national capital of Windhoek, and 10 miles north of the towns of Usakos and Karibib on the Windhoek-Swakopmund highway. The local climate is semiarid and warm, with only eight inches of rain annually that supports a sparse, brushy, "thornveld"-type of vegetation. Erongo Mountain is geologically complex, with both extrusive (volcanic) rocks and granitic plutonic rocks. About 135 million years ago during the late Jurassic Period, a volcanic system collapsed to form a caldera. The thoroughly fractured caldera was then intruded by magma that replaced the Erongo Granite, a formation of alkaline (silica-poor) granite. The Erongo granite formation intruded into weakened zones around the circular edge of the caldera to form a ring-shaped system of dikes.

This intrusion solidified very slowly, leaving pockets of residual magma that were enriched with such unusual elements as tin, tungsten, boron, fluorine, and beryllium. This residual magma finally solidified into zones that contained economic concentrations of tin and tungsten, as well as small pegmatites of extremely coarse-grained granite. The final solidification of the pegmatites took place literally on a mineral-by-mineral basis, with large, well-developed crystals growing wherever gases had created cavities.

The first geological and mineralogical studies of Erongo Mountain were conducted in the early 1900s, when the region was under German control. In the 1920s, prospectors discovered rich outcrops of ferberite [iron tungstate,  $\text{FeWO}_4$ ] and cassiterite [tin oxide,  $\text{SnO}_2$ ]. Several tin-tungsten mines began operation there in the 1930s, the largest of which was the Krantzberg Mine with ores that graded nearly 60 percent tungsten. During the 1950s alone, the Krantzberg Mine produced more than 1,000 tons of tungsten concentrate. The mine finally closed in 1979.

Prior to the late 1990s, Erongo Mountain provided few notable mineral specimens. Native diggers sometimes recovered and sold specimens of schorl [tourmaline group, basic sodium iron aluminum borosilicate,  $\text{NaFe}_3\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ ] and quartz. Then in early 1999, these diggers unexpectedly broke into several small pegmatite pockets containing fine aquamarine crystals that found their way to international markets where they were snapped up by collectors. This find was reported that same year in the "What's New in Minerals" column in the prestigious *Mineralogical Record*.

As demand for Erongo Mountain aquamarine soared, increasing numbers of diggers arrived to search for pegmatites. Along with more aquamarine, they also found fine specimens of jet-black schorl and complexly twinned orthoclase [potash feldspar group, potassium aluminum silicate,  $\text{KAlSi}_3\text{O}_8$ ] crystals. On Easter Sunday, 2000, the diggers opened a major pegmatite pocket of spectacular aquamarine crystals with unusually intense, clean, blue colors. These "Easter Pocket" aquamarines were widely acclaimed in



Figure 1. Road map showing the Usakos and Omaruru Districts in Namibia, courtesy of Bruce Cairncross.

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Europe and in the United States and again received mention in *The Mineralogical Record*. Later that same year, diggers recovered other collectible mineral specimens, including yellow beryl (heliodor), gemmy monazite-Ce [cerium lanthanum neodymium phosphate, (Ce,La,Nd)PO<sub>4</sub>], Japan-law twinned quartz, emerald-green fluorite [calcium fluoride, CaF<sub>2</sub>], and the finest crystals of jeremejevitte [aluminum fluoroborate, Al<sub>6</sub>(BO<sub>3</sub>)<sub>5</sub>F<sub>3</sub>] ever seen. In 2006, *The Mineralogical Record* presented a feature article on Erongo Mountain minerals by Bruce Cairncross, South Africa's preeminent mineralogist. The cover featured an extraordinary, unusually deep-blue, seven-inch aquamarine specimen that confirmed Erongo Mountain's status as a classic locality for aquamarine.

For the second month in a row, we are featuring specimens collected from sheer cliffs in southern Africa! Like collecting aegirine on Mount Malosa, Malawi, collecting aquamarine, tourmaline, and other mineral specimens at Erongo Mountain is a dangerous undertaking. Although the mountain's perimeter is accessed by a dirt road, the rugged interior is reached only by foot trails. The aquamarine-containing pegmatite pockets, or "nests," as the local diggers call them, are exposed on the nearly sheer sides of granite cliffs. Although most cliffs are less than 200 feet high, they are nevertheless dangerous and have claimed several lives, most recently that of a digger who fell to his death in February 2011. The most easily accessible pegmatite nests have been depleted of crystals. Because the remaining nests are difficult to reach and work, aquamarine production from Erongo Mountain has declined in recent years.

When examining your specimen, first note the distinctive, hexagonal cross section of the prism (this may be modified in some specimens), the longitudinal striations, and the flat terminations, all of which are diagnostic properties of beryl. As is typical in beryl, the inclusions within the crystal are concentrated near the base of the prism; the termination end consists of gem- or near-gem-quality aquamarine with relatively few inclusions and a high degree of transparency. A few specimens may show fragments of secondary minerals that are abundant in the Erongo Mountain pegmatites. Most common are jet-black, coarsely striated crystals of schorl and short, blocky, cream-colored crystals of microcline and orthoclase [both potassium aluminum silicate, KAlSi<sub>3</sub>O<sub>8</sub>].

Along with their aquamarine crystal, we sent Gold-level members this month one of our AS100 acrylic squares and a small amount of our MT1 Mineral Tack in case they would like to mount their crystal to better display it. We have these supplies, as well as plastic "Perky Boxes" in a variety of sizes, that can be used to protect and display your minerals. We have a list of "Mineral Stands and Supplies" we would be happy to send to you if you request it. Your specimen is a fine example of the aquamarine variety of beryl and a souvenir of the world's most recently discovered source of fine aquamarine—Namibia's Erongo Mountain. May it find a worthy place in your collection!

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold; *2008 Fleischer's Glossary of Mineral Species*, Joseph Mandarino and Malcolm Back; *The Curious Lore of Precious Stones*, George Frederick Kunz, 1913, Dover Books reprint; *Simon & Schuster's Guide to Gems and Precious Stones*, Cipiani, Borrelli, Lyman, 1999, Simon & Schuster Fireside Books; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold; *Gemstones of North America*, John Sinkankas, Geoscience Press; *Emerald and Other Beryls*, John Sinkankas, Geoscience Press; *Color Encyclopedia of Gemstones*, Joel E. Arem, Van Nostrand Reinhold; *Gem & Crystal Treasures*, Peter Bancroft, Western Enterprises, 1984; *Field Guide to the Rocks and Minerals of Southern Africa*, Bruce Cairncross, Random House Stiuk, 2005; *Beryl and its Color Varieties: Aquamarine, Heliodor, Morganite, Goshenite, Emerald, and Red Beryl*, Dmitriy Belakovskiy, John Bradshaw, Bruce Cairncross, et al, Lithographie LLC, 2005; "Beryllium: From Beryl to Bertrandite," Steve Voynick, *Rock & Gem*, August 2010; "What's New in Minerals: The Fifteenth Annual Rochester Academy of Science Mineralogical Symposium," George W. Robinson and Vandall T. King, *The Mineralogical Record*, September-October 1989; "What's New in Minerals: Munich Show 1999," Jeffrey A. Scovil, *The Mineralogical Record*, July-August 2000; "Aquamarine from the Erongo Mountains, Namibia," Bruce Cairncross, *The Mineralogical Record*, January-February 2002; "What's New in Minerals: Denver Show 2001," Thomas P. Moore, *The Mineralogical Record*, January-February 2001; "Famous Mineral Localities: The Erongo Mountains, Namibia," Bruce Cairncross and Uli Bahmann, *The Mineralogical Record*, September-October 2006.