December 2003 Mineral of the Month: Forsterite, variety Peridot

"*By the dawning of ancient Egypt, swarthy sailors had landed on a tiny island in the Red Sea. Treeless and scorched by a brutal sun, the bleak land offered no food or water– but glittering olive-green crystals lay scattered about on the ground.*" – Peter Bancroft, Gem & Crystal Treasures

PHYSICAL PROPERTIES

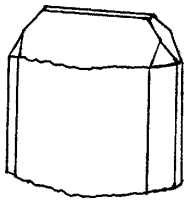

Figure 1 Typical forsterite crystal found at Zirbirget Island

Chemistry: $MgSiO_4$ Magnesium Iron Silicate
Class: Silicates
Subclass: Nesosilicates (independent tetrahedral silicates)
Group: Olivine
Crystal System: Orthorhombic
Crystal Habits: Commonly as compact or granular masses, loose or embedded grains, volcanic (basaltic) nodules, grains in alluvial gravels, and as granular xenoliths (prominent fragments of rocks or minerals included in other rocks) in magnesium-rich volcanic rock. Crystals are rare, usually as flattened tabular and box-shaped crystals, striated vertically.
Color: Olive green and lime green to yellow-green, yellow-brown, brown
Luster: Vitreous
Transparency: Transparent to translucent
Streak: Colorless
Refractive Index: 1.65-1.69 (increases with iron content)
Cleavage: Indistinct in two directions at right angles
Fracture: Conchoidal
Hardness: 6.5-7.0 (increases with magnesium content)
Specific Gravity: 3.2-3.4 (increases with iron content)
Luminescence: None
Distinctive Features and Tests: Best field indicators are green-yellow color, hardness, and association with such mafic rocks as basalt, peridotite, and gabbro.
Dana Classification Number: 51.3.1.2

NAME

The English word "peridot" stems from the French *péridot*, which in turn may derive from the Arabic *faradat*, or "gemstone." Frequently mispronounced, peridot's correct pronunciation in PAIR-ee-doe. The parent group for peridot and for the forsterite-fayalite series is olivine, pronounced OLL-uh-veen, which stems from the Greek *olivin*, or "olive," a reference to the group's predominant olive-green colors. Forsterite is named for the German naturalist Johann R. Forster (1729-1798) and is correctly pronounced FOR-stir-ite. Fayalite is named for the Azores island of Faial where it was first described and is pronounced FAY-a-lite.

For many centuries, peridot was confused with, and referred to, as both "emerald" and "topaz." Other names for peridot include "chrysolite," "evening emerald," "boltonite," "white olivine," "precious olivine," and "Hawaiian tears." The meteoritic form of gemmy olivine is known as "olivinoid" and "pallasite."

COMPOSITION

We thought we should title this write-up to reflect the currently approved way of designating our specimens, as "peridot" is of course an accepted gem name but not an accepted mineral name. When

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crystals of the olivine group minerals forsterite and fayalite are fashioned for use in decoration, then the name peridot is completely correct, while purists in the mineral world want to call the crystals by their officially accepted mineral designations. You may also hear these crystals referred to simply as olivine, however, the term "olivine" refers not to a separate mineral species, but to a mineral group and a mineral series. The olivine group consists of four minerals, orthorhombic silicates of the general formula $A^{2+}{}_2SiO_4$, where A^{2+} = Fe, Mg, Mn, Ni. Group minerals include fayalite [$Fe^{2+}{}_2SiO_4$], forsterite [Mg_2SiO_4], liebenbergite [$(Ni,Mg)_2SiO_4$], and tephroite [$Mn^{2+}{}_2SiO_4$]. Olivine is also used to refer to a graded, solid-solution series between the end-members forsterite and fayalite. The olivine series involves cationic, solid-solution substitution of magnesium and iron with no effect on the basic crystal structure.

Ideally, forsterite is pure magnesium silicate and fayalite is pure iron silicate. However, these pure forms are not believed to occur in nature. But for the sake of discussion, pure forsterite would contain the elements magnesium, silicon, and oxygen. In the ideal forsterite molecule, the combined +4 charge of the magnesium cation balances the combined -4 charge of the silicate anion [$(SiO_4)^{-4}$], which derives from the +4 charge of the silicon ion (Si^{-4}) and the collective -8 charge of four oxygen (O^{-2}) ions. In atomic weight, pure forsterite consists of 34.55 percent magnesium, 19.96 percent silicon, and 45.49 percent oxygen. Pure fayalite would consist of iron, silicon, and oxygen in the ratio of 54.90 percent iron, 13.86 percent silicon, and 31.24 percent oxygen. In nature, both end members always exhibit some degree of cationic substitution. Technically, forsterite becomes fayalite when the weight of the iron exceeds the weight of the magnesium. Because of its higher magnesium content, forsterite has a lower index of refraction, less density (lower specific gravity), and a much lighter color then does fayalite. Beyond such physical differences, however, forsterite and fayalite are difficult to distinguish precisely. For this reason, the forsterite-fayalite series is often referred to simply as "olivine."

The forsterite-fayalite series is ideochromatic, or "self colored," meaning its color is due primarily to an essential elemental component. The gemmy grades of forsterite are the gemstone peridot. Even in magnesium-rich forsterite, ferrous iron (Fe^{++}) is nevertheless the primary element responsible for peridot's characteristic green colors. In fayalite, the higher iron content creates brown colors that have little gemstone appeal. The classic peridot lime-green colors are usually found in forsterite that contains less than 15 percent iron. Trace amounts of ferric iron (Fe^{+3}), nickel (Ni^{+2}), and titanium (Ti^{+2}) and chromium (Cr^{+2}) also modify the basic ferrous iron color.

Silicates, which include olivine, are the largest and most common class of minerals. The basic building block of all silicates is the silica tetrahedron $(SiO_4)^{-4}$, in which one silicon atom is surrounded by four equally spaced oxygen atoms that occupy the four corners of the tetrahedron. There are seven different silicate structures, each categorized by the number and type of atomic bonds between the tetrahedra. As a nesosilicate, or independent tetrahedral silicate, olivine's tetrahedra are not directly joined, but are linked only by relatively weak ionic bonds between ions of magnesium or iron. This is unlike other silicates in which tetrahedra are directly joined by strong oxygen bonding in chain-type or framework-type structures. Olivine's weaker ionic bonding makes it softer and less chemically stable than, for example, quartz, which is a tectosilicate, or framework silicate. While quartz is largely impervious to chemical weathering, olivine's weaker bonds cause it to break down into various clay minerals when exposed to water over very long periods of time– the reason why many peridot sources are located in arid regions. Peridot is also mined in wet climates, but always from recently deposited rock formations that have not had time to weather.

Olivine is a common constituent of gabbro, basalt, and other rocks that are derived from mafic and ultra-mafic magmas (silica-poor magmas high in magnesium and iron). Because of its high melting point of 1890˚ C., the forsterite end member crystallizes very early in the crystallizing sequence of mafic magmas. Interestingly, fayalite has a significantly lower melting point of only 1205˚ C. Because the magnesium in forsterite has a much smaller ionic radius than does the iron in fayalite, it can position itself much closer to

the oxygens in the silica ions, thus forming stronger bonds than does iron.

Many basaltic magmas already contain solid grains of olivine. These grains can settle by gravity through the magmatic melt to concentrate in layers which eventually solidify into such rocks as dunite and peridotite, in which olivine sometimes makes up half the overall weight of the rock. Concentrated masses of olivine grains are sometimes ejected from volcanoes as volcanic bombs. Although olivine is abundant, it rarely occurs as well-developed crystals, in sizes larger than tiny grains, or as unshattered phenocrysts (prominent embedded crystals in porphyry) in its host rock.

Small amounts of forsterite also form in metamorphic environments from the thermal alteration of dolomite, or calcium magnesium carbonate ($CaMgCO_3$). Gemmy olivine also occurs as glassy grains in stony meteorites and as crystals in iron-nickel meteorites, and can account for half the meteorite's weight.

COLLECTING LOCALITIES

Olivine is abundant in small grains in many formations of basalt and other mafic volcanic rocks. Sizes large enough to be faceted, however, have been found in only a few locations. Throughout history, there have been five major sources of peridot, all from olivine-rich basalt formations: Egypt, the United States, Myanmar (formerly Burma), Pakistan, and the People's Republic of China.

The earliest source was Zirbirget or Zebirget Island (also known as St Johns Island or Zagbargat, Arabic for peridot), a barren, volcanic island of peridot-rich basalt in the Red Sea 34 miles off the Egyptian coast, as described in our opening quote. Zirbirget peridot is emerald-green due to its high nickel content. Mining on Zirbirget began about 1500 B.C. and continued until recent times. Its production peaked in the early 1900s and again in the 1930s, when the island produced millions of dollars worth of what many gemologists believe is the finest peridot ever mined. Production ceased in 1956 after the Egyptian government nationalized the mines. The government continues to restrict access to Zirbirget today.

The leading source of peridot in the United States is Peridot Mesa on the San Carlos Apache Reservation in Gila County, Arizona, where our specimens originated. We'll discuss this more fully in *About Our Specimens*. Peridot also comes from Buell Park, Apache County, Arizona, about eight miles north of Fort Defiance. Localities in New Mexico producing gem-quality peridot include the Buell Park area, McKinley County, and the Kilbourne Hole, the Potrillo Mar depression, and other spots in the Potrillo Mountains, Doña Ana County, southwestern New Mexico, near the Mexican border. This latter area extends into the Mexican state of Chihuahua, and the potential exists for tremendous production, more so on the Mexican side. The New Mexico localities evidently are open for collecting should any of us visit the area.

The Pyaung Gaung district in the Mogok Valley of Myanmar, famed for its rubies, has produced peridot since antiquity and remains a commercial, although erratic, source of large, high-quality peridot in which tiny mica inclusions often create a distinctive, velvety appearance. In the 1980s, in the Kohistan and Suppatt regions of northern Pakistan, miners opened commercial deposits of fine peridot with a pleasing olive-green color and extraordinary brilliance. Since the 1990s, newly discovered deposits in the Hunan region of the People's Republic of China have been producing large quantities of peridot which, while large in size, is somewhat lacking in color intensity.

Smaller quantities of peridot have been collected in Minas Gerais, Brazil; Eifel, Germany; Chihuahua, Mexico; and at the Altemark talc mine at Nordland, Norway, which produces clean peridot that has become a favorite of European faceters. In the United States, peridot has come from the volcanic formations in Park County in central Colorado; the Salt Lake Crater on the island of Oahu, Hawaii; Crater of Diamonds State Park near Murfreesboro, Arkansas; the Leucite Hills District of Sweetwater County,

Wyoming; and the Worthington Claims in Okanogan County, Washington. In Canada, peridot occurs in the Atlin Mining District near Ruby Creek, British Columbia. Other worldwide localities include Finland, Ethiopia, Australia, and even Antarctica.

JEWELRY & DECORATIVE USES

Peridot's attractive range of greens is among the most pleasing of all mineral colors. With a Mohs hardness of 6.5-7.0, peridot is a bit softer than quartz, and thus best suited for use in pendants, earrings, necklaces, bracelets, and pins rather than mounted in rings. Peridot's refractive index of 1.65-1.69, roughly that of beryl, topaz, and tourmaline, is sufficient to put brilliance into properly faceted stones. Although treatment is not the rule, larger stones are sometimes oiled and dyed to enhance their appearance, and dark stones have been successfully heated to reduce color intensity. Peridot is faceted, usually into table or emerald cuts, cut *en cabochon*, or tumble-polished and drilled to fashion beads. Traditionally, most peridot has been set in gold. Because its green color tends to intensify in the lower light of evening, peridot has been called "evening emerald." Generally, the more intense lime-greens are the preferred peridot colors. While peridot is generally considered a relatively inexpensive gemstone, top-quality stones in large sizes are rare and costly. Chatoyant peridot is sometimes cut into cat's-eyes. Imitations for peridot include colored glass, synthetic corundum, and synthetic spinel. Peridot has been synthesized, but the abundance of natural material and the relatively low value of peridot gems have put a damper on production.

One of the largest faceted peridot gems is an oval stone of 430.47 carats in the Colorado School of Mines Museum, while another, weighing 310 carats, is displayed at the National Museum of Natural History (Smithsonian Institution) in Washington, D.C. A yellow-green gem of 192.75 carats, once owned by the Russian czars, is in the Diamond Treasury collection in Moscow. The geology collection of the British Museum in London displays a deep-green, 146-carat, step-cut peridot gem, as well as a crystal section measuring about 2½ x 2 x 1 inch, but the largest known gemmy peridot crystal, nearly six inches tall, is in the collection of the Natural History Museum of Los Angeles County in California.

Collectors value specimens of peridot-rich basalt and individual peridot crystals for display purposes. Thinly cut slices of olivine-rich, nickel-iron meteorites are polished into very unusual and attractive display pieces, in which the polished steel-gray of the iron-nickel contrasts with the green of the peridot in patterns reminiscent of stained-glass art. Some peridot has been recovered from meteorites and faceted into what are the first gems ever to have come from space. Meteorites containing olivine are known as pallasites, and have been found in the U.S. at Glorieta, New Mexico, Eagle Station, Kentucky, and most notably, Brenham, Kansas. A famous meteorite expert procured a peridot crystal from a pallasite found near Brenham, had it faceted, and with great excitement delivered to a jeweler to be set into a ring for his wife. Imagine his disappointment when the jeweler later reported to him that it had broken during setting!

HISTORY & LORE

Peridot has been valued as a gemstone for at least 3,500 years. At Zirbirget in the Red Sea, slaves were forced to break the tough basalt to recover the peridot. Peridot was a favorite gemstone of the Egyptian pharaohs, and Cleopatra's fabled "emeralds" were probably peridot. Faceted stones over 300 carats have come from Zirbirget! Ancient Egyptian miners believed that peridot glowed so brightly that it was difficult to see in the midday desert sunlight. In his natural-history writings, the Roman scholar Pliny the Elder (A.D. 23?-79) mentioned the peridot of Zirbirget Island.

Crusaders brought peridot to Europe in the Middle Ages where it was often used in religious objects. Even today, many historic European cathedrals have spectacular peridot collections. Peridot gained great

popularity in the baroque jewelry styles of 17th- century Europe. During their six-century reign that began in 1300 A.D., the Ottoman sultans amassed what historians consider to be the greatest collection of peridot gems ever assembled. Hawaiian natives believed that the small peridot grains that weathered from basalt formations and which sometimes accumulated in quantity as beach-gravel deposits were the teardrops of their goddess Pele.

Chrysolite = Peridot

The green gemstone we now call peridot has gone through a number of name changes over the years. As mentioned, it was first discovered on an Island in the Red Sea, which also has gone through its share of name changes. Its first known name meant "Serpent Isle," perhaps for good reason. By the time of the aforementioned Pliny, it was known as the Island of Topazos, from a Greek word meaning "to seek," and the green gemstone found there was known as topazos or topazion, a name which persisted until the 18th century when the British began using the name peridot. Of course, this allowed for the use of the name "Topaz" for the beautiful gem mineral we know it as today.

The Greeks also used the term "chrysolite," from *chrysos*, meaning "gold," and *lithos*, "stone," to describe a yellow or green stone, now thought to be peridot. The word chrysolite is rarely used today, denoting peridot with a more yellowish-green color, though writers throughout the centuries used "chrysolite" when referring to what we now call peridot. Chrysolite is used once in the Christian Greek portion of the Bible, in Revelation, as the seventh foundation of the walls of New Jerusalem.

The Hebrew word *tarshiysh* is used as a gemstone name several places in the Old Testament, and is believed to be peridot. Some translations call it chrysolite, beryl, or topaz. *Tarshiysh* was used as one of the 12 gemstones that represented the 12 tribes of Israel in the breastplate of the Jewish high priest, the first gemstone in the fourth row. The Shullamite girl of the Song of Solomon used it when describing the hands of her shepherd lover, the prophet Ezekiel as one of the precious stones that served as a covering for the king of Tyre, and the prophet Daniel in describing the body of a man seen in a vision.

Although olivine has been known since antiquity, mineralogists did not identify forsterite as a separate mineral until 1824 after studying specimens from its type locality at Mt. Somma, Vesuvius, Italy. In 1840, mineralogists identified fayalite as a mineral from specimens collected at its type locality in the Azores.

During the Middle Ages, physicians used powdered peridot as a cure for asthma and placed peridot beneath patients' tongues to alleviate thirst. Peridot mounted in gold was thought to dispel curses. When drilled, strung on donkey hair, and worn on the left arm, peridot was believed to dispel evil spirits. According to modern metaphysicists, peridot attracts love and enhances both eloquence and the metaphysical powers of other stones. Today, peridot is the birthstone for August and the symbolic gift for the 16th wedding anniversary.

TECHNOLOGICAL USES

Forsterite is among the very few silicates that have served as metal ores. Because of its weak ionic bonding that permitted inexpensive chemical reduction, forsterite was once a minor ore of magnesium. With its high melting point, forsterite is also used in refractory sand and brick in high-temperature, metal-casting operations. Since the early 1990s, synthetic forsterite has been used as a laser medium. And with its low coefficient of thermal expansion almost identical to that of silicon, synthetic forsterite is a fine

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electronic substrate for microprocessor chips and circuit boards.

Knowledge of olivine's properties is even aiding space exploration. Remote imagers aboard orbiting planetary spacecraft have determined that about three percent of the soil and rock over a million-square-mile area of the Martian surface consists of olivine as both forsterite and fayalite. The olivine originated in basalt formations emplaced long ago when Mars was volcanically active. But the presence of large amounts of olivine casts doubt on the prevailing theories that Mars later had large oceans and a warm, wet, life-sustaining paleoclimate. With prolonged contact with water, olivine breaks down into various clay minerals, none of which have been detected on the Martian surface. Some scientists now believe that the large quantities of unweathered olivine (and possibly peridot) on the Martian surface indicate that the red planet's water may have been locked up as underground ice and in polar ice caps.

ABOUT OUR SPECIMENS

Our wonderful specimens come from Peridot Mesa, north of the town of Peridot, Arizona, which is 19 miles east of Globe, Arizona, on U.S. 70. Only Native Americans are allowed to collect peridot here, though collecting tours can sometimes be arranged through the San Carlos Apache Tribal Cultural Center in Peridot, Arizona. This mesa is a massive basalt flow containing fractured masses of olivine that make up some 20 percent of the rock volume. Tribal members have mined Peridot Mesa since the early 1900s, using hand tools to break the basalt and screen out the peridot fragments. Most recovered fragments are small and are tumble-polished for use as beads. At Peridot Mesa, the flow of vesicular basalt contains a peridot-rich layer ranging in thickness from 10 feet to more than 100 feet. The United States Geological Survey estimated that in the early 1990s, Peridot Mesa produced 80 to 95 percent of the world's peridot– and that only 20% of the peridot-bearing rock had currently been mined! Heavy equipment and drilling and blasting are occasionally used to open new sections of the peridot-rich basalt layer. Almost all the peridot found here is as small grains, suitable for use in gem trees and the like or for faceting into stones of only a few carats or less. The development of ultrasonic drilling machines with the ability to drill holes into beads in a fraction of the time that hand-drilling used to take is what has made this peridot so valuable. Although large stones are rare, spectacular specimens do turn up occasionally. The largest known stone from Peridot Mesa is a 100-carat piece dubbed Geronimo's Secret.

Our pieces consist of forsterite as numerous small grains that form in vesicles in the gray basalt. Some specimens also show bright green crystals of chrome diopside [$CaMgSi_2O_6$] and black crystals of an unknown member of the orthopyroxene subgroup of the pyroxenes, such as enstatite [$Mg_2Si_2O_6$].

"What's in a name?" asked Shakespeare. "That which we call a rose by any other name would smell as sweet." We might add: "That which we call peridot, olivine, or forsterite, variety peridot, would look as beautiful," and "that which we call St Johns Island, Zirbirget, Zebirget, Zagbargad, Zagbargat, or Topazos would an ancient source of a beautiful gemstone/mineral!"

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *1999 Glossary of Mineralogical Species*, J. A. Mandarino; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Gems and Jewelry*, Joel Arem, Geoscience Press; *Rocks and Minerals,* Joel Arem, Geoscience Press; *Gemstone and Mineral Data Book*, John Sinkankas, Geoscience Press; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; *Gem and Crystal Treasures*, Peter Bancroft, Western Enterprises; *Gemstones of North America, Volume 3*, John Sinkankas, Geoscience Press; *Gem & Lapidary Materials,* June Culp Zeitner, Geoscience Press; *Insight on the Scriptures,* Watchtower Bible & Tract Society of New York, Inc.; "The Prized Peridot," Bob Jones, *Rock & Gem*, June, 2001; "Colorado Peridot," Steve Voynick, *Rock & Gem*, August 2000; "Kilbourne Hole Peridot," Leslie Wagner, *Rock & Gem*, May 1994

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