

July 2012 Mineral of the Month: Corundum (Ruby)

CORUNDUM (var. RUBY)

This month's featured mineral, the ruby variety of corundum, was collected in India. Our write-up explains ruby's rich history and lore, the origin of its vibrant red color, and the efforts to synthesize this beautiful gemstone.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: Al_2O_3 Aluminum Oxide, containing traces of chromium and sometimes of iron and titanium

Class: Oxides

Subclass: Simple Oxides

Group: Corundum-Hematite

Crystal System: Hexagonal (Trigonal)

Crystal Habits: Usually as three- or six-sided tabular, pyramidal, or tapering prismatic crystals, commonly in rounded barrel shapes; often striated; also as granular masses.

Color: Red or pinkish-red, sometimes with hints of brown, orange, blue, or purple. Color zoning common.

Luster: Adamantine to vitreous

Transparency: Usually transparent to translucent.

Streak: White

Cleavage: None, sometimes exhibits three-directional parting.

Fracture: Conchoidal to uneven; brittle.

Hardness: 9.0

Specific Gravity: 3.9-4.1

Luminescence: Fluoresces red under shortwave and long-wave ultraviolet light.

Refractive Index: 1.757-1.778

Distinctive Features and Tests: Red color, extreme hardness, moderately high density, striated crystal faces, and frequent occurrence in syenite rock. Can be confused with red spinel [magnesium aluminum oxide, MgAl_2O_4], but is much harder.

Dana Classification Number: 4.3.1.1

NAME: The word "corundum," pronounced coh-RUN-dum, derives from the ancient Sanskrit word for ruby, *kuruvinda*. Alternative names for corundum include "alumina crystal," "alundum," "adamantine spar," "corindin," "corindon," "corundite," "dementspath," "soimonite," and "zircolite." The variety name "ruby" stems from the Latin *rubeus*, meaning "reddish," in allusion to its color. In European mineralogical literature, corundum appears as *corundit* and *corundita*, ruby as *rubin*, *rubino*, and *rubí*.

COMPOSITION: Corundum, one of nearly 400 members of the oxide class of minerals

July 2012 Mineral of the Month: Corundum (Ruby)

in which metals or semimetals combine with oxygen, consists of 52.93 percent aluminum and 47.07 percent oxygen. Corundum crystallizes in the hexagonal (or trigonal) system, which has four axes, three of which are of equal length and lie in a common plane with angles of 60° between them. The fourth axis, which is unique to the hexagonal system, is perpendicular to the plane of the other three and is of variable length. As an allochromatic (other-colored) mineral, corundum's colors are caused by traces of nonessential elements called chromophores (color-causing agents). Pure corundum is colorless. The diagnostic red color of ruby is due to traces of chromium and to distortions in the crystal lattice, both of which act to absorb all non-red wavelengths of white light and reflect only the red wavelengths. Corundum forms in pegmatites of syenite, nepheline-syenite, and other silica-poor rocks; in hornfels (fine-grained silicate rocks) in contact metamorphic zones; and in gneiss and hornfels of regional metamorphic rock. The ruby variety of corundum is most common in syenite and nepheline-syenite rocks. After weathering free of their host rocks, ruby and other corundum varieties have sufficient density (specific gravity 3.9-4.1) to concentrate in secondary alluvial deposits (placers) that can be of economic importance.

COLLECTING LOCALITIES: Gem-quality ruby comes from Myanmar, Afghanistan, Thailand, India, Sri Lanka, Cambodia, and Tanzania. Other sources are in Malawi, Kenya, Madagascar, Mozambique, Australia, Pakistan, Norway, Nepal, Greenland, China, and Russia. In the United States, ruby is found in North Carolina, Wyoming, and Montana.

HISTORY, LORE & GEMSTONE/TECHNOLOGICAL USES: With its great hardness, durability, relatively high index of refraction, and vibrant red color, ruby has been valued as a precious gemstone since antiquity. Ruby value depends primarily upon transparency and color. The most desirable color, called "pigeon's blood," is an intense, "pure" red with only slight hints of blue. All natural rubies have imperfections, including color zoning and inclusions of tiny rutile needles that create a soft translucency known as "silk." Transparent ruby is faceted, usually in square or round cuts; translucent ruby of the "star" type is cut into cabochons. Because of their rarity, untreated, fine ruby gems are more costly than diamonds of comparable size and quality and can sell for more than \$250,000 per carat. All but the highest grades of gem-quality ruby are heat-treated to enhance clarity and transparency, reduce color-zoning, intensify red colors, and remove purple overtones. Ruby gems are widely imitated and commercially synthesized. Shortly after 1800, researchers learned that corundum was aluminum oxide, and that both ruby and sapphire were color varieties of corundum. Ruby and other forms of corundum are used as abrasives and are fashioned into jewel bearings for fine watches and similar precision instruments. Ruby crystals, both natural and synthetic, were used to develop solid-state ruby lasers in 1961. Modern metaphysical practitioners believe that ruby inspires love and spirituality, enhances creativity and wisdom, imparts confidence and courage, and stimulates leadership abilities.

ABOUT OUR SPECIMENS: Our ruby specimens were collected at Madikeri in the

July 2012 Mineral of the Month: Corundum (Ruby)

Mysore District of the state of Karnāṭaka in the Republic of India. Geologically, the Mysore District is part of the Dharwad Craton, the stable southern section of the Indian Plate, which consists of granite, gneiss, and schist basement rocks more than two billion years old. In the Mysore District, the richest sources of ruby are veins of coarsely textured syenite, an igneous rock generally similar to granite, but containing less quartz. The occurrence of ruby in these syenite outcrops was known in ancient times. Most Mysore rubies are translucent; many are of the star type, which are cut into cabochons for gem use. Until the 1960s, sporadic mining in the Mysore region produced only small quantities of gem-quality, star ruby. But after worldwide demand for mineral specimens grew rapidly, ruby-in-syenite specimens from Mysore became quite valuable. In the late 1970s, these specimens received great attention at major gem-and-mineral shows in Europe and the United States. Ruby mining has since revived in the Mysore region, where Indian miners now lease and operate five sites where they blast syenite exposures, then inspect the broken rock for rubies. Recovered rubies are then sorted into three categories: gem-quality star ruby; industrial grade ruby for abrasive use; and ruby-in-matrix for sale to specimen dealers.

COMPREHENSIVE WRITE-UP

COMPOSITION

Before discussing the composition and structure of the ruby variety of corundum, it is helpful to define the terms “corundum,” “ruby,” and “sapphire.” Corundum, the mineral form of aluminum oxide (Al_2O_3), occurs in all colors. Ruby and sapphire are color varieties of corundum. In its mineralogical context, ruby refers to red corundum, while all non-red colors are known as sapphire. In its gemological usage, ruby refers to gem-quality, red corundum.

Corundum is one of nearly 400 members of the oxide class of minerals in which metals or semimetals combine with oxygen. The oxide class includes both simple oxides (one metal combined with oxygen) and compound oxides (two or more metals combined with oxygen). Corundum is a simple oxide that contains the elements aluminum (Al) and oxygen (O) in the proportions of 52.93 percent aluminum and 47.07 percent oxygen. Corundum’s simple cation, or positively charged ion, consists of two trivalent aluminum ions 2Al^{3+} with a collective +6 charge. Its simple anion, or negatively charged ion, has three divalent oxygen ions 3O^{2-} with a collective -6 charge. These balanced cationic and anionic charges provide the corundum molecule with electrical stability.

Bonding within the corundum molecule and lattice is exclusively covalent, with two aluminum ions sharing electrons with three oxygen ions. This bonding arrangement creates a three-dimensional lattice with six oxygen ions surrounding each aluminum ion, an arrangement that explains corundum’s hexagonal crystal structure and many of its physical properties. Because its aluminum ions are completely shielded by oxygen ions,

July 2012 Mineral of the Month: Corundum (Ruby)

corundum exhibits no metallic properties. Strong, omnidirectional, covalent bonding produces no distinct cleavage planes. Close atomic packing within its lattice explains corundum's high density, extreme hardness, and relatively high index of refraction. Although corundum consists of two light elements, aluminum (atomic weight 26.98) and oxygen (atomic weight 16.0), close atomic packing creates a surprisingly high density (specific gravity 3.9-4.1). This high density, in turn, results in a high index of refraction (1.757-1.778), which is one of ruby's important gem qualities. Close atomic packing also makes corundum's covalent bonding unusually strong, which accounts for its great hardness. At Mohs 9.0, corundum is second in hardness only to diamond [carbon, C] at Mohs 10. Because the Mohs hardness scale is based loosely on a logarithmic, rather than an arithmetic, base, diamond is actually 140 times harder than corundum, while corundum is 7 times harder than the next hardest mineral, topaz [basic aluminum fluorosilicate, $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$], at Mohs 8.0.

As an allochromatic (other-colored) mineral, corundum's colors are caused by traces of nonessential elements called chromophores (color-causing agents). Pure corundum is colorless. Colors are created when other metal ions of similar ionic radii and electrical charge substitute for aluminum ions. In the case of ruby, these metallic ions are chromium (Cr^{3+}), iron (ferric, Fe^{3+}), and vanadium (V^{3+}). The trivalent chromium ion Cr^{3+} is the primary cause of the diagnostic red color of ruby. As a transition metal, chromium has valence electrons (the electrons that combine with other elements) in more than one orbital shell. Electrons usually move about in energy-sharing pairs, but transition-metal ions, such as those of chromium, often have a lone electron in a valence orbital. When a chromium atom, which has an even number of electrons, loses three electrons to form a Cr^{3+} ion, it retains one unpaired electron. To satisfy its normal "paired" energy level, this single electron absorbs the non-red portions of the visible spectrum, transmitting and reflecting only the vivid red color that we perceive in ruby. Trace amounts of iron and vanadium ions can modify this basic red color. Iron imparts brownish hues, while vanadium imparts purplish hues. Many mineralogists believe that lattice distortion also plays a role in creating ruby's vibrant red color. The trivalent chromium ions that replace aluminum ions in the ruby crystal lattice are 20 percent larger in radius than those of aluminum. This distorts the corundum lattice, enabling it to absorb all wavelengths of white light while reflecting only pure red., thus reinforcing the red color created by the trivalent chromium ions.

Inclusions, notably those of rutile [titanium dioxide, TiO_2], can also alter the color of ruby (and sapphire). Random inclusions of fiber-like rutile crystals can scatter light to soften the red color and create a "silky" effect. The phenomenon of asterism—the reflection of a six-rayed "star"—occurs when these rutile inclusions are aligned with the basic hexagonal morphology of the corundum crystal. These stones, known as star rubies, have gem value and are cut as cabochons to best display the reflected star pattern.

Corundum crystallizes in the hexagonal (or trigonal) system, which is characterized by four axes, three of equal length and lying in a common plane with angles of 60° between

July 2012 Mineral of the Month: Corundum (Ruby)

them. The fourth axis, which is unique to the hexagonal system, is perpendicular to the plane of the other three and is of variable length. Hexagonal crystals have a six-fold symmetry, while trigonal crystals, such as those of corundum, have a three-fold symmetry. The ruby and sapphire varieties of corundum differ somewhat in crystal habits. While both occur as barrel-shaped and pyramidal prisms, ruby more often forms tabular crystals, which are rare in sapphire. This difference in habit is due to traces of trivalent chromium that, apart from creating the red color of ruby, also distorts and slightly elongates the ruby lattice to create tabular crystals.

The Dana classification number 4.3.1.1 identifies corundum as a simple oxide (4). The subclassification (3) is defined by the general formula $A^{3+}_2O_3$, in which “A” is a trivalent metal such as aluminum (Al^{3+}), iron (ferric, Fe^{3+}), chromium (Cr^{3+}), or vanadium (V^{3+}), while “O” is divalent oxygen (O^{2-}). Corundum is included in the corundum-hematite group (1) as the first (1) of five members. The other group members are hematite [iron oxide, Fe_2O_3], eskolaite [chromium oxide, Cr_2O_3], karelianite [vanadium oxide, V_2O_3], and tistarite [titanium oxide, Ti_2O_3].

Corundum occurs with albite [sodium aluminum silicate, $NaAlSi_3O_8$] in pegmatites of syenite, nepheline-syenite, and other silica-poor rocks; with andalusite [aluminum silicate, Al_2SiO_5] and cordierite [magnesium aluminum silicate, $Mg_2Al_4Si_5O_{18}$] in hornfels (fine-grained silicate rocks) in contact-metamorphic zones; and with muscovite [basic potassium aluminum silicate, $KAl_3Si_3O_{10}(OH)_2$], almandine [garnet group, iron aluminum silicate, $Fe_3Al_2(SiO_4)_3$], and anorthite [calcium aluminum silicate, $CaAl_2Si_2O_8$] in gneiss and hornfels of regional metamorphic rock. Ruby can form in all these environments, but is most common in syenite and nepheline-syenite rocks. After weathering free from its host rock, ruby has sufficient density (specific gravity 3.9-4.1) to concentrate in secondary alluvial deposits (placers) that can be of economic importance.

COLLECTING LOCALITIES

Sources of gem-quality ruby are rare; non-gem-quality ruby is uncommon but widely distributed. The leading historical source of gem-quality ruby is Myanmar (formerly Burma), where localities include the Thabeikkyn, Mogok, and Madaya townships of Pyin-Oo-Lwin District in Mandalay state; the Mu Se and Loilem districts in Shan state; and the Moynyin mines at Namya in Kachin state. Other sources include the Jegdalek metamorphic deposit in the Surobi District in Kabul Province and Ab-i-Panja in the Shighan District of Badakhshan Province, both in Afghanistan; the Bang Kha Cha mines in Chatthaburi Province, Thailand; and Madikeri, Mavinhalli, and Nuggihalli in the Mysore District, Karnātaka state, India. In Sri Lanka (formerly Ceylon), ruby is mined at Ratnapura, Pelmadulla, and Avissawella in Sabaragamuwa Province; Pollonnaruwa in North-Central Province; and Munwatte and Elahera in Central Province. Among Cambodia’s localities are the Ba Key, Bo Kham, and Andaung districts, Rattanakiri Province; and the Bo Pie Rin Mine (Hills of Precious Stones Mine) in Palain District,

July 2012 Mineral of the Month: Corundum (Ruby)

Batdambang Province. Tanzanian gem-quality ruby comes from Songea in Rumuva Region, Mundarara in Kilimanjaro Region, and Naenda and Kisumba in Rukwa Region.

Sources of common (non-gem-quality) ruby include Chimwadzulu Hill in the Ntcheu district of Malawi; the Voi and Taita mines at Taveta in Coast Province, Kenya; the Manombo Voavboa deposit, Ranohira District, Fianarantsoa Province, Madagascar; Nanhumbir, Cabo Delgado District, Montpuez, Mozambique; the Gloucester Ruby Mine at Barrington Tops, New South Wales, Australia; Aliabad and Hassanbad Nala in the Hunza Valley, Northern Areas, Pakistan; the Kleggåsen ruby quarry at Froland, Aust-Agder, Norway; the Ruyil Mine, Dhading District, Bagmati Zone, Nepal; and the Bjørnesund corundum deposit Nuuk, Kitaa (West Greenland) Province, Greenland. Chinese sources include the Yuanjiang ruby mine in Yuanjiang County, Yuxi Prefecture, Yunnan Province; and the Aozilike corundum deposit at Beicheng County, Akasu Prefecture, Xinjiang Autonomous Region. Among Russia's sources are the Lovozero, Kovdor, and Khibiny massifs on the Kola Peninsula in Murmansk Oblast; and the Khit Ostrov, Diadina Gora, Varatskoe, Nigrozerskoe, and Notozerskoe localities in the Lukailaisvaara Massif in the Republic of Karelia.

In the United States, ruby occurs in the heavily metamorphosed rocks of the southern Appalachian Mountains, notably in North Carolina at the Old Cardinal Mine in Franklin County, the Chunky Gal Mine in Clay County, and the Cowee Valley mines in Macon County. Ruby also occurs at Tin Cup Mountain and in the Granite Mountains of Fremont County, Wyoming; and at the Rock Creek Sapphire Mine at Rock Creek in Granite County, Montana.

JEWELRY & DECORATIVE USES

With its extreme hardness (Mohs 9.0), durability, relatively high index of refraction (1.757-1.778), and vibrant red colors, ruby is a superb gemstone for all jewelry uses. Ruby value depends primarily upon color. The most desirable color, called "pigeon's blood," is an intense, "pure" red with only slight hints of blue. Value decreases as color intensity lessens and hints of brown, blue, or purple become more prominent. All rubies have imperfections such as color zoning and inclusions of tiny rutile needles that create a soft translucency called "silk." Transparent ruby with very little, if any, silk is faceted, usually in square or round cuts to maximize cutting retention of the tabular crystals. Translucent, heavily included crystals of the star type are cut as cabochons. All but the highest grades of transparent ruby are heat-treated to enhance clarity and transparency, reduce color-zoning, intensify red colors, and remove purple overtones. Fractures in ruby gems are often filled with leaded, red glass to enhance transparency. Ruby is widely synthesized (see "Replicating the Ruby"). Imitations include red-foil-backed quartz, red glass, and red spinel [magnesium aluminum oxide, $MgAl_2O_4$].

Because of their rarity, untreated, fine ruby gems are more costly than diamonds of

July 2012 Mineral of the Month: Corundum (Ruby)

comparable size and quality, and often sell for more than \$250,000 per carat. When the jewelry collection of the late actress Elizabeth Taylor was auctioned in 2011, a beautiful, 8.24-carat ruby sold for \$4.2 million, setting a new price record for ruby of \$512,925 per carat. One of the world's finest rubies, a spectacular, 23.1-carat gem from Myanmar, can be seen at the National Museum of Natural History (Smithsonian Institution) in Washington, D.C., which also displays the 138.7-carat Rosser Reeves ruby, the world's finest star ruby. The largest-known, rough gem-quality ruby, found in Myanmar, weighed more than 400 carats and was fashioned into three spectacular gems. Other famous rubies include the 167-carat Edward ruby of the British Museum in London. The American Museum of Natural History in New York City displays the 100-carat De Long star ruby and the 43-carat, round-brilliant Peace ruby (named for its discovery shortly after World War I). The irregularly cut, 105-carat Anne of Brittany ruby can be seen at the Musée de Louvre in Paris.

Mineral collectors value ruby specimens, usually as crystals in matrix, for their rarity, color, crystal habit, and mineralogical associations.

HISTORY & LORE

Ruby was one of the first precious gemstones ever mined. Based on Neolithic stone tools recovered from ruby placers in Myanmar, archaeologists believe that mining was underway there by 8000 B.C. By 200 B.C., rubies were a regular trading commodity on the Silk Road that linked China and the Middle East. Ruby was especially prized by ancient Hindu royalty, who knew it as *ratnaraj*—literally “the king of precious stones.” Oriental legends say that ruby contains the “spark of life” and is “a drop of the blood from the heart of Mother Earth.” Burmese cultures once believed that rubies ripened with age, that sapphires were “unripe” rubies, and that silky rubies were “overripe.”

Ruby may have been one of the jewels in the breastplate of Aaron, the first high priest of the ancient Hebrews. As described in Exodus 28:17-20, this breastplate had 12 gems that represented the twelve tribes of Israel. However, some biblical scholars question whether the “ruby” of this breastplate was actually corundum. Nevertheless, ruby later became associated with many religious beliefs. During the Middle Ages, rubies were worn to bring good health and guard against wicked thoughts. Physicians of that era, who associated the red color of ruby with blood, prescribed potions of powdered ruby to treat ailments of the heart and circulatory system.

Throughout most of history, the term “ruby” referred generally to any red gemstones, especially pyrope [garnet group, magnesium aluminum silicate, $Mg_3Al_2(SiO_4)_3$] and spinel. The term was not specifically applied to red corundum until after 1800, when mineralogists learned that corundum was aluminum oxide, and that both ruby and sapphire were color varieties of corundum. During the 1800s in the United States, the enduring tradition of referring to all red gemstones as “ruby” led to numerous “Ruby

July 2012 Mineral of the Month: Corundum (Ruby)

Mountain,” “Ruby Hill”, and “Ruby Creek” place names—most of which actually designate garnet occurrences.

Modern metaphysical practitioners believe that ruby inspires love and spirituality, enhances creativity and wisdom, imparts confidence and courage, and stimulates leadership abilities. Ruby is the birthstone for July and the symbolic gemstone for the 40th wedding anniversary. Star ruby is the gem for the 52nd wedding anniversary.

Seven nations, five of which are major commercial sources of gem-quality ruby, have featured rough crystals and cut gems of ruby on their postage stamps. These include the 75-stang stamp of Thailand of 1972, the 5-rupee stamp of Sri Lanka of 1976, the 20-shilling stamp of Kenya of 1977, the 30-shilling stamp of Tanzania of 1986, the 40-afghani stamp of Afghanistan of 1988, the 50-pyas stamp of Myanmar of 1991, and the 375-franc stamp of Comoros of 1998.

TECHNOLOGICAL USES

Corundum has long served as an important industrial abrasive for grinding and polishing metal and softer gemstones. In the 1890s, increasing production of fine watches and similar precision instruments created a huge demand for jewel bearings—tiny, donut-shaped jewels about one millimeter in diameter that function as weight-bearing and friction surfaces. With its hardness and ability to take a fine polish, corundum became the preferred jewel-bearing material. Ruby was especially in demand, because red jewel bearings were easier on watchmakers’ eyes than those of other colors. By 1900, ruby had been classified into three commercial categories: gem-quality ruby for faceting into gems; bearing ruby, stones too small or too poorly colored for gem use, but suitable for jewel bearings; and industrial-grade ruby for abrasive purposes. In 1900, 20 million natural, ruby jewel bearings were used to manufacture fine watches and other precision instruments. Today, all jewel bearings are fashioned from flame-fusion, synthetic ruby (see “Replicating the Ruby”).

Natural and synthetic ruby crystals were used to develop solid-state ruby lasers in 1961. “Laser” is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. In ruby lasers, electrons within the ruby corundum crystal lattice are energized by a microwave energy source, then stimulated by a photon source (light) that causes them to emit their excess energy as additional photons in the form of intense, directional, and spectrally pure beams of red light with many scientific and industrial applications.

REPLICATING THE RUBY

Ruby’s beauty, rarity, and unusually intense, vibrant red color has always set it apart from other gemstones and made it extremely valuable. During the Middle Ages,

July 2012 Mineral of the Month: Corundum (Ruby)

alchemists, seeking to create precious metals and diamonds, also tried to replicate the ruby. In that pre-scientific time, alchemists had two basic approaches. One was to transfer the red colors of natural mineral and organic pigments into common, colorless crystals such as those of quartz. The other was to employ heating and various solvents to enhance the transparency, hardness, and color of such common red gemstones as pyrope and rhodochrosite [manganese carbonate, MnCO_3]. Although alchemists failed to create ruby and other valuable materials, their work did help to establish the foundation of modern mineralogy.

Synthesizing ruby became possible only after the early 1800s when mineralogists learned that both ruby and sapphire were color varieties of corundum, and that corundum itself consisted of aluminum oxide (Al_2O_3). The first step in eventually replicating rubies was taken in 1817, when the French chemist and physicist Joseph Louis Gay-Lussac (1778-1850) heated ammonium alum [hydrous ammonium aluminum sulfate, $\text{NH}_4\text{Al}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$] to produce synthetic aluminum oxide. By then, mineralogists had also learned that traces of chromium in aluminum oxide produced the red color of ruby, while iron and titanium created the classic blue of sapphire. In 1837, French chemist Marc Antoine Auguste Gaudin (1804-1880) created the first synthetic rubies by mixing synthetic aluminum oxide with chromium oxide (Cr_2O_3), then melting the mixture and allowing it to slowly solidify. However, Gaudin's synthetic ruby was not gem quality.

In 1866, French chemists devised the flame-fusion method of ruby synthesis by dropping fine particles of aluminum oxide and chromium oxide through a hot oxy-hydrogen flame. The particles melted and collected in a receptacle below the flame where they crystallized as synthetic ruby. The best crystals, which were indistinguishable from natural ruby, were faceted and shown in the Paris gem markets where they created a minor panic. But the process proved too unreliable for commercial use.

Commercializing flame-fusion ruby synthesis became the work of French chemist Auguste Victor Louis Verneuil (1856-1913), who began developing advanced flame-fusion techniques in 1878. During the 1890s, he discovered how to pass pure, powdered aluminum oxide that had been "doped" with chromium oxide through a stream of oxygen and into a hot gas flame. Below the flame, the molten aluminum oxide collected and crystallized on the tip of a revolving rod as a pencil-shaped crystal called a "boule," which was transparent, deep ruby-red in color, and nearly perfect in crystal structure. Initially, Verneuil "grew" gem-quality, 15-carat ruby boules in three hours, then faceted into each boule into 8 carats of synthetic ruby gems that were comparable in quality and appearance to costly natural ruby gems.

Because of Verneuil's limited production, his synthetic rubies were initially little more than curiosities at gem expositions. But in 1907, after learning to produce two-foot-long, ruby boules in just eight hours, Verneuil opened a commercial laboratory. That year, he turned out 1,000 kilograms (2,205 pounds) of gem-quality, synthetic ruby and within four years had tripled his production. After other European companies began synthesizing

July 2012 Mineral of the Month: Corundum (Ruby)

rubies, millions of carats of “Verneuil ruby,” all indistinguishable from natural ruby, flooded jewelry stores and created a full-scale panic in the North American and European gem markets. Most ruby-mining companies were forced to close, including the world’s greatest source of natural rubies, British-owned Burma Ruby Mines, Ltd., in Burma’s fabled Mogok Stone Tract.

Verneuil then began synthesizing sapphire, using the same basic process, but with iron and titanium oxides as chromophores to produce blue colors. By 1913, the year of Verneuil’s death, the world sapphire markets were immersed in a full financial panic. Fortunately, World War I closed most gem markets, allowing time for the panics to subside and for gemologists to fully assess the situation. Shortly after the war, gemologists learned to recognize the subtle “growth rings” and swirls of microscopic gas bubbles that characterized flame-fusion gems. Although gem markets quickly stabilized, the mining of natural rubies and sapphires never fully recovered.

During World War II, the focus of ruby and sapphire synthesis shifted from gem production toward scientific and industrial applications. To meet the huge, emergency wartime demand for abrasives and mechanical jewel bearings, American manufacturers began mass-producing flame-fusion ruby. Following the war, companies began synthesizing flame-fusion star ruby and sapphire by adding rutile [titanium dioxide, TiO_2] to the aluminum-oxide powder. During the 1950s, flame-fusion ruby and sapphire gems became enormously popular, filling the huge jewelry-market gap between cheap imitations and costly natural gems. Synthetic star rubies and sapphires became a fashion phenomenon, while transparent synthetic corundum gems became the preferred stones for countless millions of school-graduation rings each year.

In the late 1980s, researchers developed the flux method of ruby synthesis, in which aluminum oxide and chromophores are dissolved in a metallic flux, then cooled and seeded to induce crystallization—a process that closely replicates the manner in which natural rubies are formed. Today, the highest quality synthetic ruby is produced by the flux process and requires expert analysis to distinguish it from natural ruby.

ABOUT OUR SPECIMENS

Our ruby specimens were collected at Madikeri in the Mysore District of the state of Karnāṭaka in the Republic of India. Karnāṭaka, located in southwestern India, is bordered by the Arabian Sea on the west, Maharashtra state on the northwest and north, Andhra Pradesh state on the east, and Tamil Nādu and Kerala states on the south. Karnāṭaka, population 60 million, covers 74,059 square miles, an area roughly equal to that of North Dakota (population less than 700,000). The Mysore administrative district has a population of 2.6 million and is about the size of the state of Delaware. The district capital is the city of Mysore, population 900,000. Madikeri, the source of our specimens, is 60 miles west of Mysore at coordinates 12°42’ north latitude and 75°73’ east longitude.

July 2012 Mineral of the Month: Corundum (Ruby)

At an elevation of 5,000 feet in the Western Ghats, a 900-mile-long mountain range on India's west coast, Madikeri enjoys a pleasant, nearly temperate climate. It is one of India's "hill station" towns, so named in the early 1800s by British colonial administrators who flocked to Madikeri and other high-elevation towns for relief from the oppressive lowland heat. Madikeri, population 30,000, has an economy based on tourism and the production of sugar, rice, and peanuts.

Geologically, the Mysore District rests on the Dharwad Craton, the stable southern section of the Indian tectonic plate where the basement rocks consist of granite, gneiss, and schist more than two billion years old. The Western Ghats were formed some 50 million years ago by tectonic stresses generated by the breakup of the Gondwana supercontinent. Uplifting accelerated erosion and eventually exposed many of the basement rocks. Near Madikeri, the exposed granite was crisscrossed with veins of syenite, a rock similar to granite, but containing much less silica. The essential light-colored minerals in syenite are potash and plagioclase feldspars (complex potassium sodium calcium aluminum silicates); the essential dark-colored components include the biotite- and hornblende-group minerals of complex basic silicates. Syenite's accessory minerals include muscovite [basic potassium aluminum silicate, $KAl_3Si_3O_{10}(OH)_2$], apatite-CaF [calcium fluorophosphates, $Ca_5(PO_4)_3F$], and corundum. In the Mysore syenite, corundum is present as ruby in sizes ranging from tiny granules to three-inch crystals. Geologists believe that syenitic magma was injected into fractures in existing granite, where it cooled slowly into coarse-textured, pegmatitic syenite rock. The corundum crystallized first, followed by the feldspar, biotite, and hornblende minerals. This solidification sequence created veins of coarse syenite rock containing scattered ruby crystals.

The Mysore syenite was a source of ruby in ancient times. Over the centuries, these deposits yielded significant quantities of translucent, star gemstones that were fashioned into cabochons. British geologists first documented the Mysore ruby occurrences in the 1830s. In the 1880s, British miners began recovering ruby from the placer deposits that had formed below weathered syenite outcrops. Most of this ruby was used as abrasives; smaller quantities were fashioned into jewel bearings. British miners also occasionally recovered gem-quality star rubies. British ruby mining at Mysore ended when synthetic corundum (see "Replicating the Ruby") was introduced shortly before World War I.

When worldwide demand for mineral specimens began to grow rapidly in the 1960s, Indian specimen miners first focused on zeolite minerals in Maharashtra state to the north. In the mid-1970s, a number of zeolite miners shifted their operations to Mysore and began recovering and exporting specimens of ruby-in-syenite. These specimens soon received considerable attention at major gem-and-mineral shows in Europe and the United States and in 1978 earned mention in *The Mineralogical Record*. Since then, continued strong demand for Mysore ruby-in-syenite specimens has helped to revive regional ruby mining. Indian miners now operate five ruby-mining leases in the Mysore District where they blast syenite exposures, then sort the broken rock. The recovered

July 2012 Mineral of the Month: Corundum (Ruby)

ruby from the Mysore District is classified as gem-quality, star ruby for fashioning into cabochons; industrial-grade ruby for abrasive uses; and ruby-in-matrix for sale to specimen dealers. The Madikeri area is noted for its unusually large and well-developed prismatic and tabular ruby crystals.

As you study your ruby specimen, note first the “salt-and-pepper” appearance of the syenite matrix rock that consists of light- and dark-colored silicate minerals. The light-colored minerals are potash and plagioclase feldspars (complex potassium sodium calcium aluminum silicates); the black or dark-colored minerals are complex basic silicates of the biotite and hornblende groups. In your ruby-in-syenite specimen, the ruby crystallized first and became encased by the later crystallization of the light- and dark-colored silicates of the syenite. Smaller ruby crystals may also be visible within the coarse texture of the syenite. Many crystals clearly exhibit a six-sided hexagonal structure. The purplish tinge of your ruby crystal is caused by traces of vanadium and is typical of almost all Indian rubies. To best observe the translucency and purplish-red color of your ruby crystal, place it close to an intense light source. Note also the striated crystal faces, which are a diagnostic feature of corundum. To see the unusual triangular striations that reflect the trigonal (three-fold) character of corundum, rotate the specimen while viewing it to change the angle of reflection from the crystal faces.

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