

April 2011 Mineral of the Month: Kyanite

This month's mineral is an unusual, polymorphic silicate mineral from Brazil. Our write-up explains its industrial and gemological uses, how our specimens were recovered as a by-product of gemstone mining, and why kyanite and other lesser-known gemstones are becoming increasingly popular in jewelry.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: Al_2SiO_5 Aluminum Silicate, often containing iron and chromium.

Class: Silicates

Subclass: Nesosilicates (Independent Tetrahedral Silicates)

Group: Subsaturate Nesosilicates (Nesosilicates with one or more oxygen ions in addition to those in the silica tetrahedra.)

Subgroup: Kyanite

Crystal System: Triclinic

Crystal Habits: Usually as tabular or bladed, prismatic crystals elongated on the main axis and rarely terminated; often folded or wavy in bladed aggregates; also massive. Twinning common; well-developed, transparent crystals rare.

Color: Primarily blue; also colorless and white; trace elements create shades of gray, green, brown, and occasionally pale pinks, oranges, and yellows. Exhibits pronounced, irregular color zoning.

Luster: Vitreous to pearly

Transparency: Transparent to translucent

Streak: White

Cleavage: Perfect in one direction, good in a second direction

Fracture: Splintery to fibrous, brittle

Hardness: 4.5-5.0 parallel to crystal length; 7.0 perpendicular to crystal length.

Specific Gravity: 3.55-3.66

Refractive Index: 1.715-1.732

Luminescence: Weakly fluorescent

Distinctive Features and Tests: Blue color; vitreous luster; bladed habit; perfect one-directional cleavage; splintery fracture; substantial variation in directional hardness; and occurrence in metamorphic environments with quartz [SiO_2]; garnet-group member almandine [$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$]; staurolite [$(\text{Fe},\text{Mg},\text{Zn})_{3-4}(\text{Al},\text{Fe})_{18}(\text{Si},\text{Al})_8\text{O}_{48}\text{H}_{2-4}$]; biotite micas (a group of basic potassium iron magnesium aluminosilicates); and the polymorphic minerals andalusite and sillimanite [both Al_2SiO_5].

Dana Classification Number: 52.2.2c.1

NAME The name "kyanite" (pronounced KYE-an-ite) stems from the Greek *kyanos*, meaning "blue," alluding to the mineral's primary color. Kyanite is also known as "disthene," from a French word meaning "double hardness," referring to its varying directional hardness. Other names are "rhaeticite," "cyanite," "munkrudite," and "blue mullite." In European literature, kyanite appears as *Kyanit*, *disthène*, and *kianita*.

COMPOSITION: Kyanite, which is made up of 33.30 percent aluminum, 17.33 percent silicon, and 49.37 percent oxygen, is a member of the silicates, the largest and most abundant class of minerals. As a nesosilicate, kyanite consists of aluminum cations packed tightly between silica tetrahedra that are insular or isolated and have no mutual bonding. Kyanite is further described as a subsaturate nesosilicate with one or more oxygen ions in addition to those forming the silica tetrahedra. Kyanite crystallizes in the triclinic system, which has three axes of different lengths, none perpendicular to the others. Like many triclinic crystals, those of kyanite are generally flattened with sharp edges and thin cross sections, exhibit no right angles on faces or edges, and are elongated along the central axis. As an allochromatic or "other-

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colored” mineral, kyanite’s color is due to the presence of traces of nonessential elements. Pure kyanite is colorless, but iron and chromium ions often replace the aluminum ions within the crystal lattice to produce its characteristic blue color. Kyanite is polymorphic and one of three mineral species that consist of aluminum silicate (Al_2SiO_5). Polymorphs are minerals with the same chemical composition, but different crystal structures. The other two polymorphs of aluminum silicate are sillimanite and andalusite. Kyanite forms primarily in aluminous rocks that have been altered by high-pressure, regional metamorphism.

COLLECTING LOCALITIES: A relatively abundant mineral, kyanite occurs worldwide. Important sources are located in Brazil, Italy, Austria, Switzerland, Russia, Zimbabwe, Tanzania, Namibia, Greenland, Canada, China, India, and Australia. In the United States, notable deposits are found in Georgia, Virginia, North Carolina, South Carolina, Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Alabama, California, and South Dakota.

HISTORY, LORE, & GEMSTONE/TECHNOLOGICAL USES: Known since antiquity, kyanite was recognized as a distinct mineral species in 1789. Kyanite is a raw material for the manufacture of refractory materials with high melting points and resistance to thermal shock. These include furnace and insulating brick and firebrick; ceramic molds for metallurgical, plastic, glass, and cement applications; automotive brake shoes and pads; electrical porcelains; and floor and wall tiles. After mining, raw kyanite is crushed, finely ground, concentrated by flotation-separation, then calcined or heated to 1380°C . to drive off volatile matter such as water, carbon, and sulfur and to decompose the kyanite into the synthetic aluminosilicate mullite. In 2009, the United States, the world’s largest kyanite producer, mined 72,000 tons of kyanite worth \$11 million from open-pit mines in Virginia. Kyanite has recently gained popularity in jewelry. Kyanite gems are faceted into rectangular and oval cuts; semi-transparent to translucent kyanite is fashioned into beads for necklaces and bracelets or into cabochons for mounting in pendants. Modern metaphysical practitioners believe that kyanite enhances creativity, broadens perspective, and promotes mutual understanding. It is also considered a stone of attunement that brings calmness and tranquility to enhance meditation.

ABOUT OUR SPECIMENS: Our kyanite specimens were collected at the Capelinha Mine near Capelinha in the Jequitinhonha Valley in the Brazilian state of Minas Gerais, which is one of the world’s premier sources of mineral crystals and gemstones. Our specimens were obtained as a by-product of mining pegmatite gemstones. In the early Paleozoic Era some 490 million years ago, the present-day surface of Minas Gerais was buried to a depth of about 12,000 feet. The basement rock, which consisted of highly metamorphosed gneiss, schist, and quartzite, was intruded by granitic magma that created gemstone-bearing pegmatites and provided the pressures that formed our kyanite crystals in the adjacent schist. Capelinha has three pegmatite gemstone mines, the Capelinha, Campo do Boa and Fazenda Rubin Pimenta mines, which are worked by both open-pit and underground methods. These mines yield crystals of topaz, titanite, and the tourmaline mineral elbaite. In their search for gemstones, pegmatite miners remove large quantities of surrounding schist, which sometimes contains well-developed, blue kyanite crystals. Miners collect these crystals and sell them to specimen buyers in nearby towns.

10 YEARS AGO IN OUR CLUB: Smithsonian, San Antonio Mine, Santa Eulalia District, Chihuahua, Mexico. Our specimens consisted of a botryoidal layer of lovely light green translucent crystals of this zinc carbonate mineral (ZnCO_3) on an earthy brown matrix. If you were a member then, hang onto your piece, for it no doubt has increased in value, as we have not seen this exceptional material offered at shows in years! Our write-up explained that the mineral was named in honor of British mineralogist and chemist James Smithson (1765-1829), who left a legacy of \$508,318.46 to the United States in the 1800’s for the founding of “an Establishment for the increase and diffusion of knowledge,” to be named the “Smithsonian Institution.” Amazingly, James Smithson had never visited the United States!

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COMPREHENSIVE WRITE-UP

COMPOSITION

This is the third time we have featured kyanite. The first time was in May 1996, our third month of operation, when we had only about twenty-five members. We sent them similar specimens from Minas Gerais, Brazil, larger specimens than this time around, though membership cost only \$20 month then. (Of course, a gallon of gas was only \$1.30 in 1996.) In October 2004, we again featured kyanite, this time from Khit Island, near the prolific Kola Peninsula, Russia, source of a number of our previously featured minerals. The Russian kyanite was quite different in appearance from this month's specimen, consisting of a single blade of blue kyanite in a matrix of kyanite-garnet-biotite gneiss (pronounced "nice.") We will put the write-up on our web site under "Sample Write-ups" in case you would like to read it. There are several other past write-ups to be found there too, if you would like to check them out.

Kyanite's chemical formula Al_2SiO_5 indicates that it contains the elements aluminum (Al), silicon (Si), and oxygen (O) in the proportions of 33.30 percent aluminum, 17.33 percent silicon, and 49.37 percent oxygen. Like all molecules, those of kyanite consist of a cation (positively charged ion) and an anion (negatively charged ion). Kyanite's simple cation consists of two aluminum ions 2Al^{3+} , each with a +3 charge to provide a total cationic charge of +6. Kyanite's compound anion includes a radical (a group of atoms that acts as an entity in chemical reactions) and an isolated oxygen ion. The radical is the silica radical $(\text{SiO}_4)^{4-}$, in which four oxygen ions 4O^{2-} surround one silicon ion Si^{4+} and provide a collective -4 charge. The compound anion also has a single oxygen ion O^{2-} , which is not attached to the silica radical. To indicate that one oxygen ion is not part of the silica radical, kyanite's chemical formula Al_2SiO_5 is sometimes expressed as Al_2OSiO_4 . In this formula, the total -6 anionic charge of the $[\text{OSiO}_4]^{6-}$ anion balances the cationic +6 charge to provide the kyanite molecule with electrical stability.

Kyanite 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 at the four corners of a tetrahedron. The oxygen ions are bonded to the silicon ion by strong covalent bonding. In silicate minerals, silica anions and metal cations are linked together like polymers (repeating chains) to form seven types of structures: double tetrahedral silicates (sorosilicates); framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); sheet silicates (phyllosilicates); and independent tetrahedral silicates (nesosilicates).

Kyanite is a nesosilicate that consists of aluminum cations packed tightly between silica tetrahedra. These tetrahedra are insular or isolated and have no direct silica-silica bonding. In the rigid, nesosilicate crystal lattices, silica anions bond only to metal cations and never to each other. Kyanite is subclassified as a subsaturate nesosilicate—a nesosilicate having one or more oxygen ions in addition to those in the silica tetrahedron. In the kyanite lattice, aluminum ions Al^{3+} alternate with silica ions Si^{4+} to form flat layers of silica radicals and thin layers of aluminum ions. In this arrangement, each aluminum center is surrounded by four silica tetrahedra, a configuration known as "four coordination." The aluminum ions are bound ionically to both non-tetrahedral and tetrahedral oxygen ions.

Unlike the strong oxygen-oxygen bonds between adjacent silica tetrahedra in other silicates such as quartz, in which tetrahedra are linked into chain- or framework-type structures, the kyanite-type combination of ionic and covalent bonding forms linear structures with great directional variations in strength. Kyanite's highly directional bonding, which is primarily ionic and to a lesser degree covalent, provides excellent mechanical strength in one direction, but relatively little in others. Weak ionic bonding

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dominates along the longest crystal axis, while much stronger covalent bonding prevails in the perpendicular plane. This arrangement accounts for two of kyanite's most important diagnostic properties: its perfect, one-directional cleavage along the plane of weak ionic bonding and a great directional or vectorial variation in hardness. When abraded parallel to the crystal length, that is, along the direction of perfect cleavage and the weak ionic-bonding plane, kyanite has a Mohs hardness of just 4.5 to 5.0. But when abraded perpendicular to the crystal length along the plane of strong covalent bonding, kyanite has a much greater hardness of Mohs 7.0 (equal to that of quartz). Kyanite's extreme range of directional variation in hardness is the greatest of any mineral. Yet despite its great one-directional hardness, kyanite is also brittle because its weak ionic-bonding is vulnerable to mechanical stress. Kyanite's lattice structure also makes possible very close atomic packing. Although kyanite consists only of elements with relatively light atomic weights (aluminum 26.98, silicon 28.09, and oxygen 16.00), its close atomic packing creates a surprisingly high density (specific gravity 3.55-3.66). Kyanite crystallizes in the triclinic system with three axes of different lengths, none being perpendicular to the others. As seen in kyanite, triclinic crystals are generally flattened, have sharp edges and thin cross sections, exhibit no right angles on faces or edges, and are elongated along the central axis.

As a polymorphic mineral, kyanite is one of three distinct mineral species that consist of aluminum silicate (Al_2SiO_5). Polymorphs are minerals that have the same chemical composition, but different crystal structures. The other two polymorphic forms of aluminum silicate are the minerals sillimanite and andalusite. All form primarily in aluminous metamorphic rocks, but under different pressures. Pressure affects the size of atomic radii and thus determines which trimorph of aluminum silicate will crystallize under specific conditions. Note the relationships between formation pressure and specific gravity that exist in kyanite, sillimanite, and andalusite:

Kyanite forms in high pressure, crystallizes in the triclinic system, and has a specific gravity of 3.56-3.67.

Sillimanite forms in medium pressure, crystallizes in the orthorhombic system, and has a specific gravity of 3.23-3.27.

Andalusite forms in low pressure, crystallizes in the orthorhombic system (with a different lattice structure than sillimanite), and has a specific gravity of 3.13-3.21.

Note that kyanite forms in the highest pressure and is the most dense, while andalusite forms in low pressure and is the least dense. In aluminum silicate, density is a function of atomic packing, which is determined by the pressure that existed at the time of crystallization. Because of its closer atomic packing, kyanite has the strongest bonding and thus the greatest chemical stability. Andalusite, with much looser atomic packing, has the weakest bonding and the least chemical stability. This explains why andalusite often alters structurally into sillimanite or kyanite.

As an allochromatic or "other-colored" mineral, kyanite's color is due to the presence of traces of nonessential elements. Pure kyanite is colorless, but the trivalent forms of iron and chromium commonly replace the aluminum ions within the crystal lattice to produce its characteristic blue color. Kyanite crystals are strongly pleochroic, exhibiting different color intensities when viewed along different axes. These color shifts are usually from colorless to light blue, or from light blue to dark blue. (For a detailed explanation of pleochroism, see "Composition" in our write-up on axinite-(Fe), our Mineral of the Month for March 2011.)

Kyanite most often forms through high-pressure, regional metamorphism of aluminum-rich rocks in associated with such other silicate minerals as quartz [silicon dioxide, SiO_2]; muscovite [hydrous potassium aluminum silicate, $(\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$]; almandine [garnet group, iron aluminum silicate,

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$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$]; biotite micas (a group of basic potassium iron magnesium aluminosilicates); staurolite [basic iron magnesium zinc oxyaluminosilicate, $(\text{Fe,Mg,Zn})_{3-4}(\text{Al,Fe})_{18}(\text{Si,Al})_8\text{O}_{48}\text{H}_{2-4}$]; corundum [aluminum oxide, Al_2O_3]; and the aluminum silicate polymorphs andalusite and sillimanite. Kyanite also occurs in kimberlite pipes with pyrope [garnet group, magnesium aluminum silicate, $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$] and has a distinctive, light-blue color caused by traces of chromium.

The Dana mineral-classification number 52.2.2c.1 first identifies kyanite as a nesosilicate with insular $(\text{SiO}_4)^{4-}$ silica groups with oxygen (O^{2-}), hydroxyl [$(\text{OH})^{1-}$], or fluorine (F^{1-}) ions or attached water molecules (52). It next defines kyanite as having silica anions in coordinations of four or less (2). Kyanite is then assigned to the kyanite subgroup (2c) as the first and only member (1). In the Dana mineral-classification system, the kyanite polymorphs sillimanite (52.2.2a.1) and andalusite (52.2.2b.2) are assigned to their own subgroups to reflect their different crystal structures.

COLLECTING LOCALITIES

As a relatively abundant mineral with important industrial uses, kyanite is found and mined worldwide. Our specimens were collected at the Capelinha Mine near Capelinha in the Jequitinhonha Valley, Minas Gerais, Brazil. Other Minas Gerais sources are São José da Safira in the Doce Valley near Governador Valadares, the Barras do Salinas Mine at Araçuaí, and the Tripuí Mine at Ouro Preto. Other Brazilian localities include the mines at Anagé and Serra da Mangobeira near Paramirim, both in Bahia; and the Zacharias Mine at Mara Rosa in Goiás.

European specimens come from Monte Folgarito near Pietrasanta in the Alpuan Alps, Lucca Province, Tuscany, Italy; Mt. Greiner near Zillertal, Tyrol, Austria; and Mt. Campione near Uri and Sponda Alp-Pizzo Forno in the Chironico Valley near Leventina, both in Ticino, Switzerland. Russian specimens come from Ol'khaniskiye Voroto near Lake Baikal, Irutskaya Oblast', Eastern-Siberian Region. Ukrainian specimens are found in the Volodarsk-Volynskii area of Zhytomyr Oblast'. In Africa, kyanite specimens come from the Prylin kyanite deposit, Rushingo District, Mashonland Central, Zimbabwe; the Merelani Hills section of the Lelatema Mountains, Arusha region, Tanzania; and Sultan Hamad in the Uмба Valley, Makueni District, Eastern Province, Kenya. Namibian localities include the Gorob Mine, Swakopmund District, Erongo Region; Kyanite Kop, Windhoek District, Khomas Region; and the Abenab Mine, Grootfontein District, Otjozondjupa Region.

Kyanite is also collected at Kangerdluarssuq Firth in the Ilimassug Metamorphic Complex near Narsaq, Kitaa (Western Greenland), Greenland; the Anderson and Stall Lake mines in the Snow Lake district of Manitoba, and the Narco deposit at Tèmiscamingue, Abiti-Tèmiscamingue, Québec, both in Canada; the Qingshuitang iron deposit, Zongyang County, Anqing Prefecture, Anhui Province, China; the Lepso Mine at Singhbhum, Singhbhum District, Jharkhand, India; and the O'Connell kyanite district at Broken Hill, Yancowinna County, New South Wales, Australia.

In the United States, the highly metamorphosed rock of the Appalachians hosts many kyanite deposits. These include Graves Mountain in Lincoln County and the F. M. Cagle Mine in Pickens County, both in Georgia; the Willis Mountain Mine at Willis Mountain in Buckingham County, and the Baker Mountain kyanite deposit in Prince Edward County, both in Virginia; the Jefferson Mountain kyanite locality at Gaffney, Cherokee County, South Carolina; the Cook Road staurolite locality at Windham, Cumberland County, Maine; Signal Hill at Lebanon and Pond Hill at Lisbon, both in Grafton County, New Hampshire; the Pike Hill mines at Corinth in Orange County and the Bemis Soapstone Quarry at Townshend in Windham County, both in Vermont; the Chesterfield kyanite locality at Chesterfield, Hampshire County, Massachusetts; the Becker Quarry at Willington, Toland County, Connecticut; and the Heavy Mineral Placer district, Montgomery County, Alabama. North Carolina's many sources include the Parkway kyanite

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locality at Asheville in Buncombe County; the J. C. Mills Mine at Brindletown in Burke County; and the Celo Mine in the Spruce Pine district in Yancey County. Kyanite is also collected at the Ogilby kyanite deposit in the Cargo Muchacho Mountains, Imperial County, California; the Consolidated Mine in the Silver District, Trigo Mountains, La Paz County, Arizona; the Goat, Marble Creek, and Freezeout areas of Shoshone County, Idaho; the Tin Queen Mine in the Hill City district, Pennington County, South Dakota; and the Range and Powell kyanite localities in Iron County, Wisconsin. Do you live near one of these American localities? Perhaps you could arrange to visit the mine and give us a report!

JEWELRY & DECORATIVE USES

In recent years, kyanite has joined the lesser-known gemstones that are gaining popularity in jewelry markets (see “The Growing Popularity of Lesser-Known Gemstones”). The classic kyanite color is a rich blue similar to that of quality blue sapphire, while kyanite’s refractive index of 1.715-1.732, nearly that of the corundum gemstones sapphire and ruby, is sufficient to provide brilliance in properly cut gems. But cutting kyanite is difficult because of its irregular color zoning, variation in directional hardness, and perfect, one-directional cleavage. Nevertheless, kyanite is faceted as rectangular and oval cuts that maximize cutting retention in its long, prismatic crystals. Because of their directional softness, brittleness, and perfect, one-directional cleavage, kyanite gems are suitable only in low-wear jewelry items such as pendants, necklaces, bracelets, brooches, and earrings. Kyanite gems of 2.5 carats sell for about \$150; 6-carat gems can cost \$400. Although some kyanite gems weigh as much as 20 carats, only those of five carats or less are free of inclusions and color zoning. In rare, cat’s-eye kyanite gems, inclusions of fibrous, needle-like crystals of rutile [titanium dioxide, TiO_2] produce a chatoyant effect. Semi-transparent to translucent kyanite is fashioned into beads for necklaces and bracelets, and into cabochons for mounting in pendants.

Collectors value kyanite specimens for their color and long, bladed crystals, as both individual and composite specimens. In composite specimens, kyanite is usually associated with muscovite [basic potassium aluminum silicate, $\text{KA}_3\text{Si}_3\text{O}_{10}$], staurolite [basic iron magnesium zinc oxyaluminosilicate, $(\text{Fe},\text{Mg},\text{Zn})_{3-4}(\text{Al},\text{Fe})_{18}(\text{Si},\text{Al})_8\text{O}_{48},\text{H}_{2-4}$], quartz, or the metamorphic rock schist. Cabinet specimens in which five- or six-inch-long, bladed crystals of blue kyanite contrast against light-colored matrices of quartz or muscovite are quite popular with both collectors and museum curators.

HISTORY & LORE

Kyanite has been collected since antiquity for its attractive long, blue crystals. Medieval physicians administered potions containing powdered kyanite to alleviate sinus congestion and muscular pain. In 1789, German mineralogist Abraham Gottlieb Werner (1747-1817), studying specimens obtained primarily from Mt. Greiner near Zillerthal in Austria’s Tyrol, established their chemical composition as aluminum silicate and recognized them as a new mineral species which he named *Zyanit*, a German word derived from the Greek *kyanos*, or “blue.” Mt. Greiner was long considered to be the type locality for kyanite, but because Werner had also worked with specimens from other sources, this type locality has been recently discredited. In 1794, the name *Zyanit* was anglicized to “kyanite.” However, the popular French spelling *kyanite* remained in use until the mid-20th century. Kyanite was assumed to be the only mineral form of aluminum silicate until 1798, when French philosopher and scientist Jean Claude Delametherie (1743-1817) identified a polymorphic form which he named “andalusite” after Andalusia, the Spanish province where he had obtained his specimens. In 1801, the prominent French chemist and crystallographer René-Just Häuy (1743-1822) proposed renaming kyanite “*disthène*,” a French word stemming from the Greek *di* or “two” and *stenos* or “hardness” that literally means “double hardness,” in allusion to its directionally variable hardness. Although not formally accepted by mineralogists, “disthene” nevertheless became a

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popular alternative name for kyanite. In 1824, American mineralogist George T. Bowen (1803-1825) identified sillimanite, the last of the aluminum silicate polymorphs, and named it in honor of Yale University professor of mineralogy Benjamin Silliman (1779-1864). Mineralogists used X-ray diffraction methods in the 1930s to define and differentiate the structures of the three polymorphic aluminum silicate minerals kyanite, sillimanite, and andalusite.

Kyanite crystals have appeared on Kenya's 30-cent stamp of 1977 and the 1980 Malawi one-kwacha stamp to recognize the kyanite-mining industries of both nations. Modern metaphysical practitioners believe that kyanite enhances creativity, broadens perspective, and promotes mutual understanding. It is also thought to be a stone of attunement, bringing calmness and tranquility to enhance meditation.

TECHNOLOGICAL USES

Kyanite, sillimanite, and andalusite serve as indicator minerals that further the understanding of metamorphic processes. The relative proportions of these three polymorphic minerals in such rocks as gneiss and schist enable geologists to estimate the degree of pressure (and thus burial depth) that existed during metamorphism.

Kyanite (and sillimanite and andalusite) are raw materials for the manufacture of refractory materials. The term "refractory," which literally means "stubborn," describes materials with high melting points and resistance to thermal shock. Kyanite's use in refractory materials dates to the early 1900s when a special ceramic material was needed for automotive spark-plug porcelain that had excellent electrical-insulation properties, high thermal resistance, good casting properties, and the ability to withstand the stresses of expansion and contraction that accompanied repetitive heating and cooling. The kyanite-mining industry began about 1910 in the southern Appalachian region when kyanite proved to be exceptionally well-suited for automotive refractory ceramic use. Mined kyanite is crushed, finely ground, then concentrated by flotation-separation. The refined kyanite is calcined or heated to about 1380° C. to drive off volatile matter and to decompose the kyanite into synthetic mullite, an aluminosilicate compound that takes its name from natural mullite [aluminum silicate, $Al_{4+2x}Si_{2-2x}O_{10-x}$], a rare mineral with a variable aluminosilicate composition. Calcined kyanite is used to manufacture furnace and firebrick for the iron and steel industries; ceramic molds for metallurgical, plastic, glass, and cement applications; automotive brake shoes, brake pads, and electrical porcelains; and floor and wall tiles. In 2009, the United States, the world's largest kyanite producer, mined 72,000 tons of kyanite worth \$11 million from two open-pit mines in Virginia.

THE GROWING POPULARITY OF LESSER-KNOWN GEMSTONES

Kyanite is one of a number of unusual minerals that are gaining popularity as gemstones in mainstream jewelry markets. In the case of kyanite, transparent crystals are faceted into gems, while semi-transparent or translucent material is fashioned into cabochons, beads, and free-form shapes (see "Jewelry & Decorative Uses"). Kyanite gems have long been available in limited quantities through rare-gem dealers, custom gem cutters, and specialty-jewelry retailers. Now kyanite is being utilized by mass jewelry manufacturers and is appearing in retail display cases alongside traditional gemstones.

Familiar, traditional gemstones include diamond [C]; emerald, the green variety of beryl [$Be_3Al_2Si_6O_{18}$]; and the ruby and sapphire varieties of corundum [Al_2O_3]. Other less costly, but no less beautiful, traditional gemstones are aquamarine, the blue-green beryl variety; topaz [$Al_2SiO_4(F,OH)_2$]; amethyst, the purple variety of quartz; peridot, the gem variety of forsterite [Mg_2SiO_4]; several members of the garnet group of

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complex silicates; turquoise [$\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$]; and the tourmaline-group member elbaite [$\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$].

Although traditional gemstones will always retain their appeal, many jewelers and jewelry-makers now recognize the public's growing interest in unusual, rare, and exotic gemstones. Some customers are interested in unusual gemstones that resemble traditional stones in colors and patterns, while others seek out non-traditional gemstones that have their own distinctive qualities. Aside from their beauty and appeal, lesser-known gemstones can make different and memorable gifts, become conversation pieces, or simply offer new and innovative directions in jewelry. Some jewelers even suggest that the increased popularity of unusual gemstones reflects a growing public appreciation and awareness of the basics of mineralogy and gemology. Hundreds of minerals and natural materials such as mineraloids and fossils can be fashioned into attractive gem forms and beads for use in exotic jewelry. Some of the newer, unusual gemstones and materials now appearing in mainstream jewelry markets include:

Kunzite: A pale, pink-to-lavender gem variety of spodumene [lithium aluminum silicate, $\text{LiAlSi}_2\text{O}_6$], this pegmatite mineral has a substantial harness of Mohs 6.0-7.0 and a moderately high refractive index that provides sparkle to cut gems.

Prehnite: Prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$] has a substantial hardness of Mohs 6.5 and colors that range from brownish to green and yellow. Transparent crystals of prehnite (our Mineral of the Month for September 2005) are faceted into attractive gems, while sub-transparent material is cut and polished as cabochons.

Variscite: A translucent to opaque stone, variscite [hydrous aluminum phosphate, $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$] has a hardness of Mohs 4.0-5.0 and a basic green color that ranges to bluish-green and yellowish-green. It is fashioned into cabochons and beads that have a similar appearance to turquoise and amazonite. Our featured mineral in April 2000.

Feldspars: The feldspar group of aluminosilicates consists of abundant, rock-forming minerals with a substantial hardness of about Mohs 6.5. The alkali-feldspar subgroup includes the minerals anorthoclase, sanidine, orthoclase (our Mineral of the Month for March 2010), and microcline; the plagioclase-feldspar subgroup includes albite and anorthite, as well as the intermediate phases oligoclase, andesine, labradorite, and bytownite. Translucent albite, microcline, or labradorite (our April 1997 featured mineral) is moonstone, which exhibits a soft, blue-white sheen and is fashioned into cabochons and beads. Transparent crystals of orthoclase and bytownite are faceted into champagne-colored gems. Amazonite (our Mineral of the Month for March 2007), the blue-green, gem variety of microcline, is polished into cabochons and used in jewelry in the manner of turquoise.

Cordierite: Also known as "iolite," cordierite [magnesium aluminum silicate, $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$] has a hardness of Mohs 7.0-7.5 and a soft blue to blue-purple color. Transparent crystals are faceted into gems that resemble pale, blue sapphires.

Apatite: Correctly known as fluorapatite [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$], "apatite" gems have a Mohs hardness of 5.0 and a basic yellow to greenish-yellow color. Fluorapatite (featured by us from three different localities in October 1998, May 2003, and May 2006) is faceted into gems for pendants and brooches. Opaque blue apatite from Madagascar is now coming onto the market.

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Stichtite-in-Serpentinite: *Stichtite [basic hydrous magnesium chromium carbonate, $Mg_6Cr_2(CO_3)(OH)_{16} \cdot 4H_2O$], our Mineral of the Month for July 2008, is an opaque, purple mineral that contrasts nicely with its green serpentinite host rock. Although relatively soft, stichtite-in-serpentinite is worked into distinctive, colorful cabochons for use in pendants.*

*Other interesting and unusual gem materials appearing in mainstream jewelry outlets are purple **sugilite** [potassium sodium iron manganese aluminum lithium silicate, $KNa_2(Fe,Mn,Al)_2LiSi_{12}O_{30}$], an opaque stone that is cut into cabochons and beads; **ammolite**, the beautifully iridescent, fossilized shell material of Cretaceous Period ammonoids, which is mounted in pendants and brooches; and **Moldavite**, a bottle-green, amorphous natural glass of meteor-impact origin that is cut into both gems and cabochons. This list could go on and on, and no doubt includes minerals you are particularly fond of! With hundreds of minerals and other natural materials that can be fashioned into attractive gems, together with remarkably creative modern jewelry-makers, we can expect to see an ever-increasing array of distinctive jewelry featuring rare and unusual gem materials.*

ABOUT OUR SPECIMENS

Our kyanite specimens are from the Capelinha Mine near Capelinha in the Jequitinhonha Valley, Minas Gerais, Brazil. One of Brazil's 26 states, Minas Gerais is nearly the size of Texas and has a population of 18 million. Minas Gerais, which includes most of the Planalto Central (Brazilian Highlands), has the highest average elevation of any Brazilian state, with more than half of its area higher than 2,000 feet above sea level. In the 1700s, Brazil, then a Portuguese colony, was the world's largest gold producer, with most mines located in Minas Gerais (Portuguese for "General Mines"). Today, Minas Gerais has one of Brazil's most vibrant economies, thanks to the rapid growth of its mining (gold, gemstones, iron, manganese, zinc, and aluminum), agricultural (coffee, sugarcane, cotton, and oranges), and industrial sectors. Belo Horizonte, the capital of Minas Gerais, is a booming city with two million residents.

Minas Gerais is one of the world's premier sources of mineral crystals and gemstones, and our kyanite specimens are a by-product of gemstone mining. The Minas Gerais pegmatite belt, an area of gemstone-rich granite pegmatites, extends 170 miles east-west and 360 miles north-south in the northeast part of the state. Granite pegmatites are bodies of very coarse-grained granite that originate as pockets of residual magma that cooled slowly and crystallized on a fractional, or mineral-by-mineral, basis into irregular pods, lenses, veins, and dikes. Residual magma is often enriched with accessory or rare minerals, while mariolitic cavities produced by gases sometimes provide space for the growth of large and well-developed crystals. Minas Gerais is noted for extraordinary specimens of topaz [basic aluminum fluorosilicate, $Al_2SiO_4(F,OH)_2$]; cat's-eye chrysoberyl [beryllium aluminum oxide, $BeAl_2O_4$]; beryl [beryllium aluminum silicate, $Be_3Al_2Si_6O_{18}$], including its many color varieties; quartz, especially purple amethyst; spodumene [lithium aluminum silicate, $LiAlSi_2O_6$], including yellow-green hiddenite and pink kunzite; spinel [magnesium aluminum oxide, $MgAl_2O_4$]; greenish-yellow brazilianite [basic sodium aluminum phosphate, $NaAl_3(PO_4)_2(OH)_4$]; and elbaite [tourmaline group, basic sodium aluminum lithium borosilicate, $Na(Al_{1.5}Li_{1.5})Al_6(BO_3)_3(Si_6O_{18})(OH)_4$].

The Minas Gerais pegmatites were formed some 490 million years ago in the early Paleozoic Era when the present-day surface was buried to a depth of about 12,000 feet. The basement rock then consisted of highly metamorphosed gneiss, quartzite, and schist. As bodies of granitic magma surged upward, they were initially capped by these metamorphic rocks. But as these lower intrusions cooled and the overlying metamorphic "roof" fractured, columns of residual magma surged upward into fissures in schist to form granite pegmatites and to further metamorphose the schist to create cell-developed crystals of kyanite.

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Later surges of non-residual magma then penetrated the fractured metamorphic basement rock to solidify into large, rounded, loaf-like, vertical intrusions. Hundreds of millions of years of geological uplifting and erosion eventually exposed these subterranean formations as today's bedrock. The highly-resistant, loaf-shaped, granitic intrusions have become the distinctive, domed hills that are peculiar to eastern Brazil, the best example being the monolithic Sugar Loaf Mountain that towers over Rio de Janeiro's harbor. Erosion also exposed many pegmatites, which support a major gemstone-mining industry.

Capelinha, the source of our kyanite specimens, is located in the upper Jequitinhonha Valley at an elevation of 3,400 feet in northeast Minas Gerais about 500 miles north-northeast of the coastal city of Rio de Janeiro. The greater Jequitinhonha Valley, the size of the state of Maine, is populated by one million people living in 80 towns. One of the least developed parts of Minas Gerais, the Jequitinhonha Valley is still plagued by endemic yellow fever. Nevertheless, the area is known for its colonial-era towns, unique handicrafts, and the gemstones and crystals that are recovered by pegmatite miners. Capelinha, one of the larger regional towns, has 35,000 residents and an economy based on coffee, cattle, and related processing industries.

Capelinha also has three nearby pegmatite mines—the Capelinha, Campo do Boa and Fazenda Rubim Pimenta mines—where open-pit and underground mining methods yield gem-quality crystals of the tourmaline mineral elbaite, topaz, and titanite [calcium titanium oxysilicate, CaTiOSiO_4], the latter also known as “sphene.” In their work, pegmatite miners blast and remove large quantities of the surrounding schist. The schist that is immediately adjacent to the pegmatites sometimes contains well-developed, blue kyanite crystals, which miners collect and sell to buyers from the cities of Teófilo Otoni, 60 miles to the east, and Governador Valadares, 80 miles to the south. These buyers pass the kyanite on to foreign dealers who bring it to international specimen markets.

As you examine your kyanite specimen, note first its considerable “heft” or weight in the hand. Close atomic packing gives kyanite a relatively high specific gravity of 3.55-3.66, meaning it weighs 25 percent more than a piece of quartz of equal size. Your specimen is an aggregate of long, bladed crystals with few, if any, terminations, a habit that is characteristic of kyanite. Your specimen's soft blue color, which is also typical of kyanite, is caused by the presence of small amounts of iron and possibly chromium that replace aluminum in the crystal lattice. To note kyanite's pleochroism, study a single, larger crystal as you rotate the specimen in your hand and observe the shifts in intensity of the blue color. Your specimen has been professionally prepared to remove other minerals in order to expose the kyanite crystals. Traces of these minerals can still be seen, including paper-thin, sheet-like crystals of silvery muscovite and bits of massive, gray-white quartz.

Kyanite was one of the first minerals we encountered when we started visiting and selling at gem and mineral shows bank in 1995. Gradually, we became more and more intrigued by its beautiful blue color. How gratifying it is to see it now being utilized as a gemstone!

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