

## ***October 2004 Mineral of the Month: Kyanite***

This month we feature another wonderful example of a mineral that is not only attractive, but of great importance in diverse ways: to the geologist, it is an indicator of heat and pressure during metamorphism, crucial in research; to the auto manufacturer, its low electrical conductivity, high thermal resistance, and ability to withstand the stresses of heating and cooling makes it the perfect material for use in spark plugs; collectors and jewelry makers love it for its color. The write-up elaborates on all these aspects.

### *PHYSICAL PROPERTIES*

Chemistry: Aluminum Silicate  $\text{Al}_2\text{SiO}_5$  (Also  $\text{Al}_2\text{OSiO}_4$ )  
Class: Silicates  
Subclass: Neosilicates (Independent Tetrahedral Silicates)  
Group: Subsaturate Neosilicates (Neosilicates having in their structure one or more oxygen ions in addition to those forming the silica tetrahedra.)  
Subgroup: Kyanite  
Crystal System: Triclinic  
Crystal Habits: Commonly as tabular, prismatic crystals elongated on the main axis and rarely terminated; often folded or wavy in bladed aggregates; sometimes massive. Twinning common; well developed, transparent crystals rare.  
Color: Most often blue; also white, gray, green, brown, black, or colorless, depending on the presence of trace elements. Often shows irregular, pronounced color zoning.  
Luster: Vitreous to pearly  
Transparency: Transparent to translucent  
Streak: White  
Cleavage: Perfect in one 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: Large variation in directional hardness; typical blue color; vitreous luster; bladed habit; perfect one-directional cleavage, and splintery fracture.  
Dana Classification Number: 52.2.2c.1

### *NAME*

The name "kyanite" (correctly pronounced KYE-an-ite) originated from the Greek word for "blue," *kyanos*, in reference to the mineral's predominant color. Kyanite is also known as "disthene," "cyanite," "munkrudite," and "blue mullite."

### *COMPOSITION*

Kyanite, in the form of clusters of long, thin blue blades frozen in a white quartz matrix from Minas Gerais, Brazil, was the third mineral we featured in our Club, way back in May 1996. At that time, we had approximately twenty members or so, and the specimens we sent were on the large side. We distinctly remember a phone call from a new member in Texas, who sounded a little uncertain about joining, perhaps not sure he would be satisfied with the size and quality of the specimens he would receive. Well, he called us after he received the kyanite piece to let us know how impressed he was with the specimen, and he has been an active member ever since!

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Our kyanite write-up was just two pages long then, as we were still getting a feel for how deeply to go into the aspects of the mineral properties, but followed the same format as now. Our first six-page write-up was on amethyst in December 1996, and most write-ups have been about the same length since.

From its chemical formula,  $\text{Al}_2\text{SiO}_5$ , we see that kyanite contains the elements aluminum (Al), silicon (Si), and oxygen (O). The atomic weight of kyanite is made up of 33.30 percent aluminum, 17.33 percent silicon, and 49.37 percent oxygen. Within the kyanite molecule, the +6 cationic charge of the two aluminum ions balances the -6 anionic charge of the silicate radical ( $\text{SiO}_5$ ).

Kyanite's chemical formula may also be written as  $\text{Al}_2\text{OSiO}_4$ , a variation which specifically indicates the placement of the oxygen atoms within the molecule. To understand this placement, consider that the silica tetrahedron ( $\text{SiO}_4$ )<sup>-4</sup> is the basic building block of all silicates. In this configuration, one silicon atom is surrounded by four equally spaced oxygen atoms occupying the four corners of the tetrahedron. There are seven different silicate structures, each categorized by the number and type of atomic bonds that link the tetrahedra together to form a lattice. As a neosilicate, or independent tetrahedral silicate, kyanite's tetrahedra are not directly joined, but are linked only by ionic and covalent bonds involving aluminum ions. Unlike the strong oxygen-oxygen bonds in most other silicates that link tetrahedra into chain-type or framework-type structures, this combination of ionic and covalent bonding forms linear structures with great directional variations in strength.

Within the kyanite lattice, balance is achieved by positive aluminum ions positioned among the negatively charged tetrahedra in such a way that each aluminum ion is shielded by surrounding oxygen ions that are not part of the silica tetrahedra. This attraction holds the crystal lattice together and determines its symmetry. It is also the reason that kyanite's chemical formula is sometimes written as  $\text{Al}_2\text{OSiO}_4$ , reflecting the placement of the single, non-tetrahedral oxygen atom. In this formula, the combined +4 cationic charge of the two aluminum ions and the one cationic oxygen ion equals the -4 anionic charge of the silica tetrahedron ( $\text{SiO}_4$ )<sup>-4</sup>.

The nature of atomic bonding explains many of the physical properties of minerals. In the case of kyanite, the bonding, which is primarily ionic and to a lesser degree covalent, gives the crystal lattice great mechanical strength in one direction, but relatively little in others. Covalent bonding dominates on the longest crystal axis, while ionic bonding dominates perpendicular to that axis. This arrangement accounts for two of kyanite's most important diagnostic properties. The first is its perfect cleavage in one direction, made possible by the ease of parting along the weakest bonding planes. The second is a great directional, or vectorial, variation in hardness within the same kyanite crystal. When abraded parallel to the crystal length, that is, along the direction of perfect cleavage and the direction of the weakest bonding planes, kyanite has a low Mohs hardness of 4.5 to 5.0. But when the crystal is abraded perpendicular to the crystal length, kyanite has a Mohs hardness of 7.0 and is quite scratch-resistant. This feature is the basis for an alternative name for kyanite—*disthene*, which comes from the association of two ancient Greek words, *di*, or "two," and *stenos*, meaning "hardness." Appropriately, "disthene" thus literally means "two hardnesses." Kyanite is the best example of directional variations in mineral hardness. Yet despite its great one-directional hardness, kyanite is still quite brittle because its weaker bonding planes are susceptible to mechanical stress.

Both ionic and covalent bonds withstand heat and are therefore commonly found in materials with high melting points or high limits of thermal stability. In kyanite, the considerable strength of the ionic and covalent aluminum-oxygen bonds explains its unusually high limit of thermal stability of nearly 1510° C (2750° F.). In many minerals, the upper limit of thermal stability is also the melting point. This is not true in kyanite, however, which actually decomposes rather than fuses (see "Technological Uses").

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Kyanite is an allochromatic or “other-colored” mineral, meaning its color is due to the presence of trace amounts of nonessential elements. Pure kyanite is colorless, but iron and chromium commonly replace aluminum within the crystal lattice to produce its characteristic blue and blue-green colors. In contrast, the colors of ideochromatic, or “self-colored,” minerals are inherent to their chemical and physical make-up. Kyanite is also strongly pleochroic, exhibiting different color hues when viewed along different crystal axes. The color shifts are usually from light blue to colorless, or from dark to light blue.

Kyanite is an excellent example of a polymorphic mineral. Polymorphs are minerals that have the same chemical composition, but different crystal structures. Kyanite is actually a trimorph, since it one of three polymorphs of aluminum silicate,  $\text{Al}_2\text{SiO}_5$ . The other two minerals are sillimanite and andalusite. All form in aluminous metamorphic rocks, but under different conditions of temperature and pressure. The specific combination of temperature and pressure affects atomic radii and thus determines which trimorph will crystallize. During the crystallization sequence, high pressure pushes atoms closer together, providing a more densely packed crystal structure. On the other hand, higher temperatures cause atoms to vibrate more and thus to maintain their atomic space. Generally, andalusite forms in conditions of low temperature and over a broad pressure range, kyanite in low temperature and high pressure, and sillimanite in high temperature and over a broad pressure range.

Because of their formation in different conditions, kyanite crystallizes in the triclinic system, while sillimanite and andalusite both crystallize in the orthorhombic system, but with different lattice structures. The three aluminum silicate trimorphs also have decreasing specific gravities that reflect the relative pressures at the time they crystallized. Kyanite is the densest of the aluminum-silicate trimorphs. The specific gravity of kyanite, which crystallizes at the highest pressure, is 3.55-3.66. The specific gravity of sillimanite is 3.23-3.27, and the specific gravity of andalusite, which crystallizes at the lowest pressures, has the lowest density of all the trimorphs, as shown in its specific gravity of 3.13-3.16.

Kyanite is most often formed from high-pressure regional metamorphism, sillimanite from high-temperature regional metamorphism, and andalusite from the relatively low pressures generated by contact metamorphism. Kyanite is usually found in association with a number of other silicate minerals, including quartz, or silicon dioxide,  $\text{SiO}_2$ ; muscovite, or hydrous potassium aluminum silicate,  $(\text{KAl}_2\text{AlSi}_3\text{O}_{10}(\text{OH})_2)$ ; almandine garnet, or iron aluminum silicate,  $\text{Fe}^{2+}_3\text{Al}_2(\text{SiO}_4)_3$ ; biotite, or potassium magnesium aluminum silicate, formerly expressed as  $\text{K}(\text{Mg},\text{Fe}^{2+})_3(\text{Al},\text{Fe}^{2+})\text{Si}_3\text{O}_{10}(\text{OH},\text{F})_2$ , but now designated as meaning dark micas with a trioctahedral crystal structure and without lithium; staurolite, or iron magnesium aluminum silicate,  $(\text{Fe},\text{Mg},\text{Zn})_{3-4}(\text{Al},\text{Fe})_{18}(\text{Si},\text{Al})_8\text{O}_{48}\text{H}_{2-4}$ ; and corundum, or aluminum oxide,  $\text{Al}_2\text{O}_3$ . Kyanite also occurs in kimberlite pipes where it is associated with pyrope garnet, or magnesium aluminum silicate,  $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ . In this occurrence, kyanite has a characteristic light-blue color due to the trace presence of chromium.

### *COLLECTING LOCALITIES*

Kyanite and the other aluminum-silicate trimorphs are relatively abundant and are found and mined worldwide. Localities near Mt. Campione, Uri, Switzerland, continue to yield long, deeply colored, blue blades of kyanite. Even after two centuries of collecting, kyanite's type locality, Mt. Greiner, near Zillerthal, Austria, remains another source of fine specimens. Exceptional specimens are found elsewhere in Europe, including Pizzo Forno, Monte Camplone, St. Gotthard region, Switzerland, and the Tyrol of Italy and Zillerthal, Austria. Large gorgeous gem crystals are found at Karai, Zimbabwe, Africa. The Barras do Salinas Mine at Araçuaí, Minas Gerais, Brazil, provides excellent specimens of kyanite in association with white muscovite. Many fine kyanite specimens now reaching the United States, especially gem-quality, transparent crystals, come from the Lepso Mine in the Singhbhum District of India.

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In the United States, the greatest concentration of kyanite deposits is in the greater Appalachian mountain chain, especially the section from Georgia to Virginia, which has massive formations of highly metamorphosed rock. Many collectors consider the classic American kyanite locality to be Graves Mountain, in Lincoln County, Georgia. Other noted American collecting localities are the garnet-kyanite schist formations near Durham, North Carolina, and Willis Mountain in Buckingham County, Virginia. Nice kyanite specimens have also come from the mica-schist layers near Chesterfield, Hampshire County, Massachusetts, and from the Cargo Muchacho Mountains in Imperial County, California.

### *JEWELRY & DECORATIVE USES*

The greatest non-industrial use of kyanite is as mineral specimens for the collector market. Kyanite is especially popular in the form of long, blue, bladed crystals in both individual and composite specimens, the latter most often in association with muscovite and staurolite.

Transparent, deeply colored, blue and blue-green kyanite crystals are also cut into gems that are similar to blue sapphires or to intensely colored aquamarines. Kyanite's refractive index is 1.715-1.732, nearly that of the corundum gemstones sapphire and ruby, and thus sufficient to assure brilliance in a properly cut gem. Cutting, however, is difficult because of kyanite's irregular color zoning and its variable directional hardness. Because of their relative softness and perfect, one-directional cleavage, kyanite gems cannot be mounted in rings, but only in pendants, brooches, and earrings. Kyanite gems are popular among collectors, with prices ranging roughly from \$150 to \$400 for gems in the 2.5 to 6.0-carat range. Although the largest kyanite gems approach 20 carats in weight, only gems that are five-carats or smaller tend to be free of inclusions or color zoning. In the few catseye kyanite gems that have been cut, the chatoyant catseye effect is due to the inclusion of many fibrous, needle-like crystals of rutile, or titanium dioxide (TiO<sub>2</sub>). Transparent to semi-transparent kyanite is also fashioned into beads for stringing in necklaces and bracelets, and into cabochons for mounting in pendants.

### *HISTORY & LORE*

Kyanite has been known since antiquity when it was collected for the pleasing appearance of its long, blue, bladed crystals. In 1789, German mineralogist Abraham Gottlieb Werner (1749-1819), working with specimens collected from the type locality at Mt. Greiner, Zillertal, Austria, confirmed kyanite's composition as aluminum silicate and gave the mineral its name, for its characteristic blue color. In 1801, the prominent French chemist and crystallographer Rene-Just Hauy proposed renaming the mineral disthene, in reference to its directionally variable hardness. Although "kyanite" became the generally accepted name, some French writers continue to use "disthene" even today.

Although kyanite had been identified in 1789 as a distinct mineral species, its relationship to the other two aluminum-silicate trimorphs remained unclear. In 1798, French philosopher and scientist Jean Claude Delametherie (1743-1817) identified the second trimorph, naming it andalusite after Andalusia, a province in southern Spain where the mineral occurred. Then in 1824, American mineralogist George T. Bowen (1803-1828) identified the third aluminum-silicate trimorph, sillimanite, naming it in honor of Yale University professor of mineralogy Benjamin Silliman (1779-1864). Kyanite has been featured on postage stamps in both Kenya and Malawi to honor the kyanite-mining industries of both African nations.

Medieval physicians believed that kyanite alleviated sinus congestion and aided the treatment of muscular disorders. Modern metaphysicists believe that kyanite enhances creativity, broadens perspectives, and promotes mutual understanding, and is thought to be a stone of attunement, bringing calmness and tranquility to enhance meditation.

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### *TECHNOLOGICAL USES*

Kyanite, sillimanite, and andalusite are widely used to manufacture refractory materials. In material engineering, the term “refractory,” which literally means “stubborn,” refers to materials with high melting points and resistance to thermal shock, but especially to heat-resistant ceramic materials. Kyanite’s refractory properties were known by 1824, but had no applications at the time. Then, when production of gasoline engines boomed in the early 1900s, a special ceramic material was needed for spark-plug porcelain, a use which demanded very low electrical conductivity, high thermal resistance, good casting properties, and an ability to withstand mechanical stresses induced by the expansion and contraction that accompanied repetitive heating and cooling. After testing many refractory materials, engineers found that kyanite had near-ideal properties. By 1910, growing automotive demand for kyanite had started the kyanite-mining industry in the southern Appalachians.

Kyanite may be used in its “raw,” or unaltered, form or in a calcined form called mullite. To produce raw kyanite, the mineral is mined, crushed, ground to a powder, then concentrated by a flotation-separation process. Mullite is produced by calcining raw kyanite. “Calcining” means heating a material nearly to its melting point or to the limit of its thermal stability to drive off volatile matter. Calcining converts kyanite, sillimanite, and andalusite (remember that all share the same formula,  $\text{Al}_2\text{SiO}_5$ ) to silica ( $\text{SiO}_2$ ) and mullite ( $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ). Synthetic mullite takes its name from a rare mineral with the same chemical composition. Whether natural or synthetic, mullite has the refractory properties of kyanite and in addition is thermally stable at even higher temperatures. Mullite may also be synthesized by heating mixtures of alumina ( $\text{Al}_2\text{O}_3$ ) and silica ( $\text{SiO}_2$ ).

When raw kyanite is incorporated into ceramic mixtures, it converts to mullite during the firing process. During this conversion, kyanite undergoes an irreversible physical expansion of 16-18 percent in volume. Addition of the appropriate amount of kyanite to ceramic mixes can thus offset the shrinkage normally incurred during the firing process—a big advantage in the manufacture of many types of ceramics.

Raw kyanite and calcined mullite are used in the manufacture of many products including insulating brick and firebrick, virtually all types of ceramic molds for metallurgical applications, automotive brake shoes and pads, electrical and automotive porcelains, floor and wall tiles, and special glasses, plastics, and cements. The United States is the world’s largest kyanite producer, mining 90,000 tons worth \$13 million each year. Virginia is the leading kyanite-producing state. Although raw kyanite has many uses in industry, most is converted to mullite before use. Geologists and mineralogists also consider the presence of kyanite, sillimanite, and andalusite in metamorphic rocks as indicators of the nature of the metamorphism that formed the rocks.

### *ABOUT OUR SPECIMENS*

Care to travel to the Arctic Circle to collect some kyanite? First step would be a flight to St. Petersburg, former capital of Russia (for more than two centuries), the “Venice of the North,” one of Europe’s most beautiful cities. Located in northwestern Russia, at the head of the Gulf of Finland (an arm of the Baltic Sea), St. Petersburg is the second largest city in Russia, and its largest port. After taking in the sights, such as the Hermitage Museum, housed in the former Winter Palace, head north about 450 miles, across the Russian republic of Karelia, until you reach the little town of Karelsky, in the Chupa fjord district, right where the Arctic Circle cuts across the republic, which is bordered by Finland to the west, the White Sea to the east, and Lakes Ladoga and Onega to the south. The population of approximately 780,000 people is of Russian and Karelian (a Finnish people) descent. It is a land of lakes and trees, as seen in Figure 1, with a very long but surprisingly mild winter, by Russian standards.

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From here, it's only five kilometers to Khit Island (in Russian, Khit-ostrov or Khitostrov), which sits among the peaceful waters of lake Pulongskoye, or Verkhne-Pulongskoe. This locality is best known for the rubies currently being found there, called "Rose Corundum" in the defunct Russian



**Figure 1** The Khitostrov landscape. Photo by O. Oganov, courtesy of World of Stones magazine.

mineral magazine "World of Stones." (We are working on accumulating enough ruby specimens from this locality to feature it in the future.)

The article speaks of kyanite-garnet-biotite gneisses as the host rock here, which perfectly describes our specimens—"gneiss," pronounced "nice" as in "Have a nice day," is a term for coarsely foliated (banded) rock formed by regional metamorphism. The banding is usually caused by the segregation of quartz and feldspar into layers alternating with layers of dark minerals. Our specimens contain white plagioclase feldspar alternating with layers of black "biotite" mica, whose flat faces catch and reflect light, giving off the pretty sparkle. (Much information on biotite can be found in our July 2004 write-up.) The Russian article describes the color of the garnets as akin to rhodolite, while the composition is closer to almandine, though with a significantly higher than normal magnesium content, which perhaps account for the pleasing color. Together, this contrast sets off the blue kyanite blades most attractively, don't you think? With a hand lens, you can readily discern the crystals of garnet and mica, and also notice the color zoning common to kyanite. (With our UV lamp, we saw no evidence of the weak fluorescence sometimes found in kyanite.) Certainly, this is a mineral we can appreciate both for its beauty and its many important uses!

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; *Color Encyclopedia of Gemstones*, Joel Arem, Van Nostrand Reinhold Company; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; "Rose Corundum From the Khitostrov Locality of North Karelia," Alexander V. Gromov, *World of Stones* No. 2/1993; "Large Andalusite Crystals from Campbell County, Virginia: Their Alteration to Kyanite and Sillimanite and Other Associated Minerals," Richard Mitchell, William Giannini, and D. Allen Pendrick, Jr., *Rocks & Minerals*, November-December 1988; "Kyanite and Related Materials," Michael J. Potter, *2003 Minerals Yearbook*, United States Geological Survey; *Ore Deposits of the United States, 1933-1967*, American Institute of Mining Engineers, 1968; *Andalusite, Kyanite, and Sillimanite*, Ernest Varley, Chemical Publishing, New York, 1968; *Handbook of Industrial Refractories*, Stephen Carniglia and Gordon Barna, Noyes Publications, 1992.

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