May 2010 Mineral of the Month: Staurolite

For this month's mineral, we are pleased to feature dark, reddish-brown, twinned staurolite crystals in a white schist matrix from northern Russia's Kola Peninsula. Our write-up explains the high-grade, metamorphic origin and the rich lore of twinned staurolite crystals, while providing insight into one of Russia's most mineralogically fascinating regions.

OVERVIEW

PHYSICAL PROPERTIES

Figure 1. Staurolite with nearly 90° twinned crystals, plus untwinned single crystal.

Chemistry: $(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}$ Basic Iron Magnesium Zinc Oxyaluminosilicate (Iron Magnesium Zinc Aluminum Oxysilicate Hydroxide), often containing titanium, chromium, manganese, and lithium.
Class: Silicates
Subclass: Nesosilicates
Group: Staurolite
Crystal System: Monoclinic
Crystal Habits: Single or twinned crystals: single crystals are prismatic with six-sided, pseudohexagonal cross sections; twinned crystals common as penetration intergrowths of two individual crystals at angles of nearly 60 degrees or nearly 90 degrees.
Color: Yellowish-brown, reddish-brown, and brownish-black; rarely bluish; weathers to gray.
Luster: Vitreous to dull
Transparency: Usually translucent to opaque; rarely transparent.
Streak: White to grayish-white
Refractive Index: 1.736-1.762
Cleavage: Distinct in one direction
Fracture: Uneven to subconchoidal, brittle
Hardness: 7.0-7.5
Specific Gravity: 3.7-3.8
Luminescence: None
Distinctive Features and Tests: Best field marks are color; occurrence in metamorphic environments; and frequent, distinctive "crossed" twinning.
Dana Classification Number: 52.2.3.1.1

NAME Pronounced STORE-uh-lite, the name stems from the late Greek word *stauros*, "cross," and *lithos*, "stone," literally "stone cross." Interestingly, the Greek word *stauros* as used in the classical Greek of epic poems like the *Iliad* and the *Odyssey*, meant "upright stake" or "pale." When *stauros* came to mean "cross" is debated be scholars. In the Bible, the word *stauros* is used for the instrument upon which Jesus Christ was executed. Some scholars believe that when the New Testament was written, *stauros* still meant "upright stake," and that it was in later centuries that *stauros* took on the meaning of "cross."

Staurolite has been known as "croisette," "angel cross," "faith cross," "stone cross," "fairy cross," and "fairy stone," in allusion to its cross-like, twinned crystals or to their mythical origin. Other names for staurolite are "grenatite" and "staurotide." Zinc-rich staurolite is the mineral zincostaurolite; magnesium-rich staurolite is the mineral magnesiostaurolite. A cobalt-rich variety is called "cobaltoan staurolite" or "lusakite." In European mineralogical literature, "staurolite" appears as *staurolit*, *staurolith*, and *estaurolita*.

COMPOSITION: The general chemical formula $(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}$ shows that staurolite contains the elements iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), silicon (Si), oxygen (O), and hydrogen (H). Because of the quantitative variables within its complex composition, no precise molecular weight or composition can be stated. Staurolite consists approximately of 50 percent oxygen, 20 percent aluminum, 12 percent silicon, 11 percent iron, 5 percent zinc, 2 percent magnesium, and a fractional percentage of hydrogen. As a silicate-class mineral in the nesosilicate subclass, staurolite consists of metal cations and hydroxyl ions packed tightly between silica tetrahedra. The most common staurolite shape is the single crystal, but an estimated 35 percent of all staurolite crystals are twinned. Twinned crystals are rational, symmetrical intergrowths of two or more individual crystals of the same mineral species. Staurolite is a metamorphic mineral produced by the medium- to high-grade metamorphism of shale. Its primary host rock is schist, a medium-to-coarse-grained, silvery-gray-brown, metamorphic rock with prominent, parallel mineral orientation (foliation) consisting mainly of muscovite. The three basic types of staurolite twins are the “St. Andrew’s” cross, in which two individual crystals of similar size and shape penetrate each other at their midpoints to form opposing, acute angles of 60 degrees; and the Roman and Maltese crosses, in which two individual, stubby crystals penetrate each other at their approximate midpoints to form an angle of nearly 90 degrees.

COLLECTING LOCALITIES: Although staurolite is widely distributed, not all localities produce collectible twinned crystals. Good specimens come from Russia, Ukraine, Turkey, Japan, China, Switzerland, Spain, Mexico, and Canada. The best specimens in the United States are found from Maine to Georgia in the highly metamorphosed schists of the Appalachian Mountains.

HISTORY, LORE, & USES: Known since antiquity, staurolite was identified as a distinct mineral species in 1792. Twinned staurolite crystals, both loose and in matrix, have been collected for display and talismanic and jewelry uses since antiquity. After the cross was adopted as a symbol of Christendom, twinned staurolite crystals gained great popularity as “natural crucifixes,” with “floaters” (twinned crystals free of matrix) worn as pendants or strung on rosaries. Today, twinned staurolite crystals are worn as pendants and brooches; smaller twins are made into earrings. Staurolite is occasionally recovered by hydraulic gravitational separation as a by-product of mining titanium-bearing sands. Finely ground staurolite is used as a sandblasting medium when an abrasive slightly harder than quartz is required. Medieval physicians believed that twinned staurolite crystals alleviated the pain of aching joints and aided the healing of wounds. According to modern metaphysical practitioners, staurolite twins enhance overall physical health and well-being, invigorate the body, and counteract the effects of aging.

ABOUT OUR SPECIMENS: Our twinned staurolite crystals are from the Keivy Mountains on the Kola Peninsula in Murmanskaya Oblast’ in Russia’s Northern Region. Located in Russia’s far northwest, the Kola Peninsula, part of traditional Lapland, is bordered by Finland to the west, the Barents Sea on the north, the White Sea on the east, and the White Sea and Kandalaksha Gulf on the south. One of the world’s richest and most diverse mineralogical regions, the Kola Peninsula consists of ancient, highly metamorphosed rock and is an important source of kyanite, apatite, and other minerals. The topography is dominated by rocky hills, low mountains, lakes, taiga, and tundra, all drained by numerous, fast-flowing rivers. Despite its Arctic location, the influence of the Atlantic Drift, an Arctic arm of the warm-water Gulf Stream, gives the Kola Peninsula a relatively mild climate. The average annual January temperature is 14˚ F. (-10˚ C.), while the average July temperature is 50˚ F. (10˚ C.) Our twinned staurolite crystals were collected by kyanite miners in the Keivy Mountains who supplement their income by providing specimens to mineral dealers.

10 YEARS AGO IN OUR CLUB: Staurolite–from the same locality and the same supplier! We normally wait ten years to feature a mineral for a second time, when it is from the same locality as the first. How many of you remember when we first featured staurolite in May 2000? If you do, you have our deepest gratitude for being a longtime member! Thank you very, very much!

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COMPREHENSIVE WRITE-UP

COMPOSITION

The general chemical formula $(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}$ shows that staurolite contains the elements iron (Fe), magnesium (Mg), zinc (Zn), aluminum (Al), silicon (Si), oxygen (O), and hydrogen (H). Our write-ups usually provide an ideal molecular weight and a precise balance of molecular anionic and cationic charges. But because of its quantitative variables (indicated by commas in the formula), staurolite has no precise molecular weight or composition. An approximate molecular weight of staurolite consists of 50 percent oxygen, 20 percent aluminum, 12 percent silicon, 11 percent iron, 5 percent zinc, 2 percent magnesium, and a fractional percentage of hydrogen. In the staurolite molecule, the complex cation or positively charged ion $[(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8]^{\approx ?100+}$ has an approximate charge of +100. The staurolite anion or negatively charged ion $[O_{48}H_{2-4}]^{\approx ?100-}$ has a charge of about -100. The balance of these approximate anionic and cationic charges provides the staurolite molecule with electrical stability.

Staurolite is a member of the silicates, the largest and most abundant class of minerals. Silicates consist of silicon and oxygen combined with one or more metals. The basic silicate structural unit is the silica tetrahedron $(SiO_4)^{4-}$, 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: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); and sheet silicates (phyllosilicates).

Staurolite, subclassified as a nesosilicate, consists of metal cations packed tightly between silica tetrahedra. These tetrahedra are isolated, with no direct silica-silica bonding. In the rigid, nesosilicate crystal lattices, silica anions bond only to metal cations, never to each other. The staurolite lattice is actually based on the modified aluminosilica tetrahedral structure $(AlSiO_5)^{3-}$, in which aluminum ions Al^{3+} alternate with silica ions Si^{4+}. The structure is closely related to that of kyanite [aluminum silicate, Al_2SiO_5]. The staurolite lattice consists of flat layers of kyanite alternating with thin layers of iron, magnesium, zinc, aluminum, oxygen, and hydroxyl ions. In this arrangement, each aluminum center is surrounded by four tetrahedra, a configuration known as "four coordination." To visualize this structure and to show why staurolite is classified as a silicate, we rewrite the standard staurolite formula as an empirical formula:

$(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}$ (standard)
$(Fe,Mg,Zn)_{3-4}(Al,Fe)_{18}(AlSiO_5)_8O_4(OH)_4$ (empirical)

The empirical formula shows the aluminosilicate structure, the hydroxyl ions that make staurolite a basic mineral, and the presence of structural oxygen ions that are not covalently bonded within the aluminosilica tetrahedra. These "free" oxygen ions, along with non-tetrahedral aluminum ions, other metal ions, and hydroxyl ions, are instead bonded ionically to the aluminosilica tetrahedra. Strong covalent bonding throughout the lattice explains staurolite's considerable hardness of 7.0-7.5 (harder than quartz). But because weak ionic bonding prevails between the flat structural layers, staurolite exhibits distinct, one-directional cleavage. Although staurolite consists primarily of elements with light atomic weights (oxygen, 16.00; aluminum, 26.96; silicon 28.09), close atomic packing produces a high specific gravity of 3.7-3.8. Crystallizing in the monoclinic system, staurolite has three axes of different lengths, two of which are perpendicular. The third axis is not perpendicular to the plane of the other two, but intersects at an angle to give crystals a deformed, orthorhombic appearance. Minerals with complex chemistry and complex bonding arrangements, such as staurolite, often crystallize in the monoclinic or orthorhombic systems.

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Although most staurolite occurs as single crystals, twinned crystals are so common as to be diagnostic. About 35 percent of all staurolite crystals are twinned. Twinned crystals are rational, symmetrical intergrowths of two or more individual crystals of the same mineral species. In crystallography, the term “rational” means that twinned crystals share common lines, planes, or points; “symmetrical” means that twins are related by definite rules of crystallographic symmetry. Crystallographers define “symmetry” as the correspondence of size, shape, and position of parts on opposite sides of a dividing line or median plane or around an axial center. The crystallographic term “individual” or “component” refers to one crystal unit of a twinned-crystal arrangement. (See “The Twinning of Mineral Crystals” in our April 2010 write-up on orthoclase for details.) Twinned crystals form from errors or interruptions in the normal sequence of crystal growth. Crystals grow by adding layers of atoms or molecules in orderly, repetitive sequences so that each subsequent layer replicates the structure of the previous layer. The unusual frequency of staurolite twinning is caused by complex chemistry, the variable composition of several essential elements, and significant amounts of impurities that disrupt normal crystal-lattice growth.

Staurolite forms penetration-type twins, with one individual prism appearing to penetrate the other. The most common staurolite twin is the “St. Andrew’s” cross, in which two individual crystals of similar size and shape penetrate each other at their midpoints to form two opposing, acute angles of 60 degrees and two opposing, obtuse angles of 120 degrees. In the Maltese cross, two stubby, individual crystals penetrate each other at their approximate midpoints to form an angle of nearly 90 degrees. In the Roman cross, longer prisms penetrate each other at their approximate midpoints, also forming an angle of nearly 90 degrees. Occasionally, three individual prisms penetrate each other at the same point and in the same plane to produce blunt, six-rayed stars and flower-shaped rosettes. Staurolite twinned crystals exhibit many other variations of angle, thickness, length, and intersection points. A couple of years ago, a new habit of twinning in staurolite was recognized in a Russian mineral publication! Most staurolite twins are less than one inch in size; four-inch crystals are uncommon and six-inch crystals are rare. The size and shape of staurolite twins varies greatly among localities.

As an idiochromatic (self-colored) mineral, staurolite’s basic yellowish-brown, reddish-brown, and brownish-black colors are produced by the essential components iron and zinc and by the nature of the crystal structure. The varying amounts of iron and zinc account for staurolite’s color range. Trace amounts of the accessory elements chromium and manganese influence color only slightly. Impurities make staurolite quite porous and subject to surface staining, particularly from the iron minerals hematite [iron oxide, Fe_2O_3] and limonite (an indeterminate mixture of iron oxides and hydroxides).

As a metamorphic mineral, staurolite forms from the high-grade metamorphism of shale. Its primary host rock is schist, a medium-to-coarse-grained, silvery-gray-brown metamorphic rock with prominent, parallel mineral orientation (foliation). Its composition varies, but muscovite [basic potassium aluminum silicate, $KAl_3Si_3O_{10}(OH)_2$] and the complex silicates of the biotite and chlorite groups are usually present. In schist, staurolite is associated with albite [sodium aluminum silicate, $NaAlSi_3O_8$]; biotite minerals (dark micas, basic potassium magnesium iron aluminum silicates); the garnet-group mineral almandine [iron aluminum silicate, $Fe_3Al_2(SiO_4)_3$]; and quartz [SiO_2]. Staurolite is also associated with kyanite, sillimanite, and andalusite, the three polymorphic forms of aluminum silicate [Al_2SiO_5]. The high density of staurolite enables crystals that weather free of their host rock to concentrate gravitationally in placer deposits.

The Dana mineral classification number 52.2.3.1 identifies staurolite as a nesosilicate with insular (unbound) silica-tetrahedra groups and containing oxygen, hydroxyl and/or fluorine ions and/or water molecules (52). Staurolite is subclassified (2) by the four-or-less coordination of its silica anions. Staurolite is then assigned to the staurolite group (3) as the first (1) of three members along with magnesiostaurolite [basic magnesium iron zinc oxyaluminosilicate $(Mg,Fe,Zn)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}$] and zincostaurolite [basic zinc iron magnesium oxyaluminosilicate $[(Zn,Fe,Mg)_{3-4}(Al,Fe)_{18}(Si,Al)_8O_{48}H_{2-4}]$.

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COLLECTING LOCALITIES

Although staurolite is fairly common, not all localities yield collectible twinned crystals. Our crystals were collected in the Keivy Mountains on the Kola Peninsula in Murmanskaya Oblast' in Russia's Northern Region. Other Russian sources include the Lovozero Massif schists, also on the Kola Peninsula; and the Aldan Shield schists in the Sakha Republic, Eastern-Siberian Region. Staurolite is also found at Volovarsk-Volyskii in Ukraine; the Sivrihisar Massif in Tavşanli, Central Anatolia Region, Turkey; Unasaki, Toyama Prefecture, Chubu Region, Honshu Island, Japan; the Balangoda gem gravels at Ratnappura, Sabaragumura, Sri Lanka; and the Xiafangshen magnesite deposit in Fengcheng County, Dandong Province, Liaoning Province, China.

Europe's sources include the Pizzo-Forno staurolite locality at Leventina, Chironico, Ticino, Switzerland; Pistil Ogo on the Lizard Peninsula, Cornwall, England; the Grønnøya area near Meloyfjørden in Meløy, Nordland, Norway; and the Otivar schist outcrops near Salobreña, Granada, Andalusia, Spain. Other localities are the Serra de Mangabeira gem gravels near Paramirim, Bahia, Northern Region, Brazil; the Gorob Mine in the Swakopmund District, Erongo Region, Namibia; the Tarkwa Mine at Tarkwa in the Ashanti Gold Belt, Western Region, Ghana; the Lusaka schist outcrops in the Central Region of Zambia; the San Carlos Mine at San Carlos, Manuel Benavidas, Chihuahua, Mexico; and the Anderson Lake Mine in the Snow Lake District of Manitoba, Canada.

In the United States, many staurolite sources are hosted by the heavily metamorphosed rock of the Appalachian Mountains between Maine and Georgia. Notable sites include the Cook Road staurolite locality at Windham, Cumberland County, Maine; the Ruggles Mine at Grafton and the Franconia iron mine at Sugar Hill in Grafton County, and the Cat Hole staurolite locality at Charlestown, Sullivan County, both in New Hampshire; the Ely Mine at Vershire, Orange County, Vermont; and the Blandfield mica mines at Blandfield, Hampden County, Massachusetts. Among Connecticut's sources are the Interstate-84 road cuts at Newtown in Fairfield County; the Rossi Road cuts at Litchfield, Litchfield County; and the Collins Hill Quarry at Portland in Middlesex County. Other sites are the Crugers Emery Mine at Montrose, Westchester County, New York; the Foote Lithium Mine in the Kings Mountain district, Cleveland County, North Carolina; and the Gaffney monazite placer deposits in Cherokee County, South Carolina. Staurolite is also found in Virginia near Martinsville in Henry County and at the Alta Vista andalusite locality in Campbell County. Georgia has numerous sources in its northern counties.

Other notable localities in the United States are the Champion Mine at Champion in the Marquette Iron Range, Marquette County, Michigan; the Sedalia Mine in the Sedalia district, Chaffee County, Colorado; the Stillwater platinum-group-metals complex in Stillwater County, Montana; the Shoshone County schist outcrops in Idaho; and the Ballarat staurolite occurrence in the Panamint district, Death Valley National Park, Inyo County, California.

JEWELRY & DECORATIVE USES

Twinned staurolite crystals, both loose and in matrix, have been collected for display, talismanic value, and use in jewelry since antiquity, gaining in popularity after the crucifix was adopted by the early Catholic Church as its symbol in the fifth century. In our day, loose staurolite twins are worn as pendants or brooches, while smaller twins are made into earrings. The value of staurolite twins is dependent upon perfection of the cross shape, degree of exposure or "relief" from the matrix rock, definition of crystal faces, and color contrast with the matrix. Although twinned staurolite is common, nearly perfect, cross-shaped twins are uncommon. Staurolite is often associated with the garnet-group mineral almandine, and tiny, reddish almandine crystals embedded in staurolite can increase its value. The price of staurolite twins ranges from as little as $10 for crude cross shapes to $300 and up for exceptional specimens.

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Rounded, transparent-to-opaque, brownish-pink staurolite pebbles found in the alluvial gem gravels of Brazil and Sri Lanka are sometimes fashioned into beads for necklaces and bracelets. Rare, transparent crystals with a rich reddish-brown color similar to that of spessartine [garnet-group, manganese aluminum silicate, $Mn_3Al_2(SiO_4)_3$] are faceted into small, but unusual and quite valuable collector gems. A zinc-rich, transparent staurolite variety from Switzerland is faceted into collector gems that appear yellow-green in daylight and reddish-brown in incandescent light. We'll be on the lookout for these gems!

Because of the rarity and value of perfectly formed, cross-shaped staurolite twins, treated and imitation staurolite is common. Near-perfect floaters (crystals free of matrix) are imitated by firing clay casts in ovens or by molding mixtures of mica flakes and brown cement or plaster. Natural staurolite twins are frequently dyed or oiled to deepen their basic brown color and enhance contrast with the matrix. Imitations are also made by carving schist into cross shapes and applying linseed oil to create a dark, staurolite-like color. Imitations are passed off on unsuspecting buyers as true staurolite crosses. But true staurolite will easily scratch glass or a stainless-steel knife blade; the imitations will not.

Collectors seek fine specimens of twinned staurolite crystals, both floaters and matrix specimens, for display and study purposes. Some have amassed extensive, specialized collections of staurolite twins based on locality, different cross shapes, and mineralogical associations with such other minerals as kyanite and almandine.

HISTORY & LORE

In 1792, French mineralogist and naturalist Jean-Claude Delamétherie (1743-1817) identified staurolite as a distinct mineral species and assigned its name. Mineralogists used improved analytical methods to generally define its chemical composition in the 1840s. By the 1880s, staurolite was one of the minerals that figured into the new theories of metamorphism proposed by Scottish geologist George Barrow (1853-1932). While studying schist formations, Barrow observed that certain zones were subjected to sequential degrees of metamorphism and were characterized by the presence of specific minerals. He compiled a list of "index" minerals to represent progressive zones, noting that almandine formed at lower temperatures and pressures (see "About our Specimens"), while staurolite, kyanite, and sillimanite formed at the highest temperatures and pressures. Barrow's observations furthered the understanding of metamorphic processes. Mineralogists used X-ray diffraction analysis to define the complex atomic structure of staurolite in 1929.

Staurolite would be an obscure mineral were it not for the frequent occurrence of cross-shaped twinned crystals. The use of the two-beamed cross as a religious symbol dates back long before Christ, according to *An Expository Dictionary of New Testament Words*, to ancient Chaldea, where it was used as the symbol of the god Tammuz, in the shape of the mystic Tau, the initial of his name. Objects decorated with designs of crosses of various forms have been found in India, Syria, Persia, and Egypt. Emperor Constantine (C. 272-337) was instrumental in popularizing veneration of the cross, after he claimed in 312 AD to have seen a vision of a cross of light above the sun with the words "by this, conquer." Contact us if you would like additional information about the origin of the use of the cross as a religious symbol.

Much of the mythic lore that emerged to explain the origin of staurolite focuses on fairies who, upon hearing of the execution of Jesus Christ, shed teardrops that fell to Earth as staurolite twins. By medieval times, twinned staurolite crystals had also assumed secular significance as "good-luck" charms. Medieval physicians used twinned staurolite crystals to treat joint pain and to help heal wounds. In one legend, twinned staurolite crystals are said to have cured Richard the Lionhearted (Richard Plantagenet, Richard I of England, 1157-1199) of a malaria-like ailment during the Third Crusade. Germans knew staurolite as *baseler Taufstein* ("baptismal stone") and used it in baptismal rites.

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In the United States, Spanish missionaries in northern New Mexico in the 1700s observed that Pueblo Indians collected twinned staurolite crystals. The Penitentes, a secretive, regional Catholic sect of northern New Mexico and southern Colorado, still wear twinned staurolite crystals as crucifixes. In southeastern American folklore, twinned staurolite crystals were important to the Cherokees and other Native American cultures. The Cherokees who lived in the staurolite-rich, southern Appalachian region used staurolite in ceremonies to beseech the spirits for ample rain, good harvests, and safe traveling. At Jamestown, Virginia, the Powhatan (Tenakomakah) Indian maiden Pocahontas (Mataoka, ca. 1595-1617) gave English colonist John Smith (ca. 1580-1631) a staurolite-cross pendant for good luck. Much later, President Theodore Roosevelt (1858-1919) carried a small staurolite cross for good luck, as did presidents Woodrow Wilson (1856-1924) and Warren Harding (1865-1923). By the early 1900s, staurolite crosses had become popular souvenirs of the southern Appalachians. In the 1930s, Virginia established the 4,500-acre Fairy Stone State Park near Martinsville, which is named for a nearby staurolite source. The Stone Cross Mountain Museum on U.S. Highway 58 west of Martinsville has superb displays of twinned staurolite crystals. In 1976, the Georgia legislature named staurolite as its official state mineral.

Modern metaphysical practitioners believe that twinned staurolite crystals enhance overall physical health and well-being, invigorate the body, and counteract the effects of aging.

TECHNOLOGICAL USES

Staurolite is sometimes recovered by hydraulic gravitational separation as a by-product of titanium-sand mining. Finely ground staurolite is used as a sandblasting medium when an abrasive slightly harder than quartz is required. The powdered, blue, cobalt-rich lusakite variety of staurolite from Lusaka, Zambia, is used as a pigment.

Geologists use staurolite as a metamorphic index mineral. By determining the ratio of kyanite to staurolite in schists, geologists can estimate absolute temperatures and pressures of metamorphism and depth of burial.

THE KOLA PENINSULA

Russia's Kola Peninsula is a classic source of twinned staurolite crystals, a remarkable mineralogical province, and one of Russia's most interesting regions. Other minerals we have featured from this locality include Astrophyllite in July 2001, Glendonite (calcite pseudomorphs after ikaiite) in September 2003, Kyanite in October 2004, and Ruby in December 2006.

The name "Kola," an anglicization of the Russian Kol'skij, derives from the Saami (Lapp) word Guoladat. The Kola Peninsula is part of the Baltic (Fennoscandian) Shield, the exposed northwestern section of the East European Craton. The Baltic Shield, an ancient continent that grew through repeated collisions with adjacent crustal fragments, consists of one-to-three-billion-year-old, intensely metamorphosed rocks. Complex fault systems within the Kola region hosted at least five major intrusions of granitic magma, each characterized by very unusual chemistries. Most were deficient in aluminum and silica, but rich in the alkali metals, and in titanium, zirconium, phosphorus, manganese, zinc, lead, uranium, barium, and such rare-earth elements as yttrium, niobium, cerium, lanthanum, and neodymium. Deep burial of existing sediments, along with continuing intrusive activity and tectonic stresses, provided the heat and pressure necessary for the intensive regional and contact metamorphism that formed the highly mineralized Khibiny, Lovozero, and Keivy massifs—names that are familiar to all mineralogists and mineral collectors. Much later, parts of these massifs were thrust upward to form the Khibiny, Lovozero, and Keivy mountains. Erosion has since reduced these mountains nearly to their bases. Between 100,000 and

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20,000 years ago, five major phases of Pleistocene glaciation scoured the Baltic Shield clean of overlying sediments, exposing the highly mineralized massifs and shaping the modern topography as a generally flat region of rocky hills and low mountains, areas of flat taiga and tundra, and many lakes and rivers.

Although geologists first noted unusual mineralization in the Kola Peninsula in the 1840s, the region's remoteness and inaccessibility precluded development for nearly a century. The indigenous Saami culture continued its traditional, reindeer-herding lifestyle until the outbreak of World War I, when the blockading of Russia's Baltic and Black Sea ports created an urgent need for a secure port to unload wartime supplies. The best site was on the Barents Sea along the northwest coast of the Kola Peninsula. In 1914, Russia began constructing an 800-mile-long, standard-gauge rail line from St. Petersburg (Petrograd) almost to the shore of the Barents Sea. The project, which required building 1,200 bridges and dikes, was completed in just 18 months and enabled the hastily constructed port of Murmansk to open in September 1916. Sadly, this remarkable achievement was made possible by the forced labor of thousands of political prisoners and Austrian prisoners-of-war, most of whom died during construction.

In 1920, the emerging Soviet Union embarked on a crash program of resource development and ordered geological expeditions into remote areas. One primary target, now that it was rail-accessible, was the Kola Peninsula and its unusual mineral deposits. Mineralogist Aleksandr Evgenievich Fersman (1883-1945) led several surveys into the Kola Peninsula. In 1924, Fersman discovered an enormous apatite deposit in the Khibiny Massif just east of the Murmansk rail line. Apatite [fluorapatite, calcium fluorophosphate, $Ca_5(PO_4)_3F$] is the primary component of phosphate rock, the only commercial source of phosphorus and its compounds that are vital for agricultural fertilizers and industrial chemicals. Subsequent surveys found large deposits of copper-nickel, iron, and kyanite [aluminum silicate, Al_2SiO_5], the latter a raw material for ceramics and refractory firebrick. The Soviet government immediately developed these resources, building a spur rail line east into the Khibiny Mountains and forcibly relocating 250,000 people to work the railroads, mines, and processing facilities, and to fill the ranks of the supporting labor camps.

During World War II, the Kola Peninsula contributed greatly to the survival of the Soviet Union, both as the site of the Murmansk port and as a mineral source. In the Cold War that followed, Russia constructed nickel-copper smelters, nuclear power plants, and dozens of nuclear-missile launching sites in the Kola Peninsula, while turning Murmansk into a nuclear-submarine base. Today, the Kola Peninsula is a prime example of rapid resource and industrial development under state socialism that achieved high production quickly, but only at the expense of severe environmental degradation and dismal social conditions.

Aided by a rudimentary but functional network of gravel roads, geological exploration and mineralogical investigation of the Kola Peninsula is continuing. Mineralogists have now identified more than 400 distinct minerals species on the Kola Peninsula and recognize about 120 type localities—places where new minerals were first discovered. No other place on Earth of similar size can boast such mineralogical variety or so many type localities.

The Kola Peninsula is also the site of the Kola Superdeep Borehole, the world's deepest borehole. Under government supervision, drilling commenced in 1970; when it ended in 1989, the borehole had reached a depth of 40,226 feet (7.6 miles). Drilling was stopped when ambient rock temperatures reached 356˚ F. (180˚ C.), much higher than the anticipated temperature of 212˚ F. (100˚ C.). The borehole had penetrated one-third of the way through the Baltic Shield, providing geophysicists with valuable data about the deep shield structure, seismic discontinuities, and the physical, thermal, and chemical nature of the deep crust.

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ABOUT OUR SPECIMENS

As noted, our twinned staurolite crystals are from the Keivy Mountains on the Kola Peninsula in Murmanskaya Oblast' in Russia's Northern Region. The Kola Peninsula, in the Russia's far northwest and part of traditional Lapland, is bordered by the Barents Sea on the north, the White Sea on the east, and the White Sea and Kandalaksha Gulf on the south. The western limit of the Kola Peninsula (a peninsula is a body of land surrounded on three sides by water) is a line from the Kola Gulf near Murmansk extending south through Imandra Lake to the Kandalaksha Gulf, about 100 miles east of the borders of northern Finland and Norway. The Kola Peninsula is almost entirely above the Arctic Circle, covers 39,000 square miles, and is roughly equal in area to the state of Tennessee. Its topography is dominated by rocky hills, low mountains, lakes, taiga, and tundra drained by numerous, fast-flowing rivers. Despite its Arctic location, the influence of the Atlantic Drift, an Arctic arm of the warm-water Gulf Stream, gives the Kola Peninsula its relatively mild climate. The average annual January temperature is 14˚ F. (-10˚ C.), while the average July temperature is 50˚ F. (10˚ C.).

Rising some 1,500 feet above the surrounding taiga and tundra, the Keivy Mountains are part of the Keivy Massif (Pestsoyve Keivy), a large, alkaline, igneous geological province consisting of six peralkaline (low in silica, rich in magnesium and iron) granite intrusions with an exposed area of nearly 1,000 square miles. The ancient rock of the Keivy Massif has been dated to more than 2.5 billion years. (For a detailed discussion of regional geology and history, see "The Kola Peninsula.") The mineralogy of the Keivy Mountains is extremely varied, with seven type localities and about 120 different mineral species reported. Both the intruded rock and sediments within the massif have undergone at least four different metamorphic events caused by a combination of heat and pressure resulting from secondary intrusions, deep burial, and tectonic stresses.

Metamorphism or recrystallization is a process in which heat and pressure cause changes, often dramatic, in the chemistry, structure, and properties of rock. Our specimens of twinned staurolite crystals in schist are a classic example of high-grade metamorphism. They originally consisted of ancient shale, a fine-grained sedimentary rock. Over eons of metamorphism, this shale was transformed first into phyllite, a micaceous (containing mica-group minerals), partially foliated rock. Continued metamorphism at higher temperatures next transformed the phyllite into mica schist, a foliated rock composed primarily of mica-group minerals. Subjected to even higher temperatures, the schist then became plastic in consistency as new minerals crystallized from the components of the original shale. Picturing the rock in a plastic state as the elements recrystallize is an excellent way of understanding the process of metamorphism. These "index" minerals enable geologists to determine the grade of metamorphism that has taken place.

Grade of Metamorphism Index Minerals

Low-grade up to 250˚ C. (480˚ F.)	Chlorite group [hydrous magnesium iron aluminum silicates] Albite [$NaAlSi_3O_8$]
Medium-Grade up to 450˚ C. (840˚ F.)	Almandine [garnet group, [$Fe_3Al_2(SiO_4)_3$] Epidote [$Ca_2Al_2(Fe,Al)(Si_3O_{12})(OH)$]
High-Grade up to 700˚ C. (1290˚ F.)	Staurolite Kyanite [aluminum silicate, Al_2SiO_5] Sillimanite [aluminum silicate, Al_2SiO_5]

This table indicates that staurolite is an index mineral for high-grade metamorphism. Kyanite is also a high-grade index mineral and crystallizes at temperatures slightly higher than does staurolite. The Keivy

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Mountains host huge deposits of kyanite, a mineral used to manufacture firebrick and other refractory materials. Kyanite is mined from large open pits and trucked 80 miles east to the railhead and apatite-mining city of Kivorsk, population 30,000.

Our twinned-staurolite crystals were collected by kyanite miners who supplement their income by providing specimens to mineral dealers. The Keivy Mountains have many outcrops of a staurolite-rich, mica schist, called "Keivy schist," that weathers into large talus slopes. Miners collect staurolite by searching the fragmented talus for uniformly sized, nicely crossed crystals visible within the schist. Specimens are then prepared by "reliefing"—removing some schist to better expose the twinned crystals. Miners "relief" the specimens in mine machine shops using wire wheels to abrade away the schist, which is softer than staurolite. Dealers from St. Petersburg or Moscow periodically visit the Keivy Mountain kyanite mines to purchase prepared staurolite specimens for export to the international markets.

Figure 2. Staurolite "equation" as displayed at 2009 Tucson Gem & Mineral Show by the Fersman Mineralogical Museum of Moscow, Russia.

As you examine your specimen, first note the sharp contrast between the light-colored, glittery, schist matrix and the much darker, twinned-staurolite crystals. This degree of contrast is rarely found in staurolite specimens from other localities. Our specimens are known as penetration-type twins, in which one individual crystal appears to penetrate the other, even though the second crystal grew out of the first crystal. These crystals have the six-sided (pseudohexagonal) cross section; the diagnostic, deep reddish-brown color; and the vitreous luster that are all typical of staurolite. Smaller, single staurolite crystals may also be visible within the matrix. The matrix consists of Keivy schist, a highly metamorphosed, medium-grained, mica schist with muscovite [basic potassium aluminum silicate, $KAl_3Si_3O_{10}(OH)_2$] making up more than 50 percent of the rock. The muscovite appears as tiny, flat, glittery flakes of white mica aligned in parallel foliation. Also visible in the schist are small crystals of jet-black, biotite-group micas (basic potassium magnesium iron aluminum silicates). Finally, notice how your specimen has been prepared by abrading away the schist to expose the twinned staurolite crystals in high relief. To avoid fragmenting the staurolite, do not attempt to remove the twinned staurolite crystals from the schist matrix. Your specimen represents a remarkable story of mineralogical creation and an unusual tale of collection in one of Russia's most mineralogically rich and diverse regions.

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