

## ***December 2005 Mineral of the Month: Clinochlore***

Most who know this month's beautiful chatoyant green and white mineral know it as "seraphinite," rather than by its true mineral name, clinochlore. Named for its crystal shape and predominant green color, clinochlore has an interesting and complex three-layer structure and is among the softest minerals ever used as a gemstone. We'll also try to determine where the name "seraphinite" originates.

### *PHYSICAL PROPERTIES*

Chemistry:  $(\text{Mg,Al})_6(\text{Si,Al})_4\text{O}_{10}(\text{OH})_8$  Magnesium Aluminum Silicate Hydroxide (Basic Magnesium Aluminum Silicate), often containing significant amounts of iron, sometimes containing small amounts of chromium and calcium

Class: Silicates      Subclass: Phyllosilicates (Sheet Silicates)      Group: Chlorite (also Clay Minerals)

Crystal System: Monoclinic

Crystal Habits: Pseudohexagonal tabular crystals with tapering pyramidal terminations; commonly foliated, fibrous, granular, earthy, or massive. Twinning occasionally on larger crystals.

Color: Usually green to emerald-green, often streaked with white; also olive-green, blackish-green, and bluish-green; impurities sometimes impart red, brown, yellow, tan, and white hues.

Luster: Vitreous to pearly

Transparency: Transparent to translucent

Streak: White to greenish-white

Cleavage: Perfect in one direction

Fracture: Uneven; thin cleavage flakes are flexible.

Hardness: 2.0-2.5

Specific Gravity: 2.6-2.8

Luminescence: None

Refractive Index: 1.57-1.59

Distinctive Features and Tests: Best field indicators are green color, softness, crystal habit, and perfect one-directional cleavage. Laboratory analysis is often needed to positively distinguish clinochlore from other chlorite-group minerals.

Dana Classification Number: 71.4.1.4

### *NAME*

Correctly pronounced "KLINE-oh-kloar" (rhymes syllabically with "dinosaur"), this month's mineral takes its name from the Greek *klino*, meaning "inclined" or "oblique," a reference to the crystal's tapering pyramidal terminations, and *chlōros*, meaning "green," after the mineral's predominant color. Other names for clinochlore include "clinochlorite," "clinochlorita," "grasit," and "lofoit." Clinochlore and the other chlorite-group minerals are often generally referred to simply as "chlorite." The industrial term for commercial, finely ground clinochlore is "sheridanite." When fashioned into jewelry items and decorative objects, clinochlore is usually sold under the names "seraphinite" or "seraphina." The names "kaemmererite" and "chromium clinochlore" refer to a chromium-rich variety of clinochlore; "nickeloan clinochlore" to a nickel-rich variety; "ripidolite" or "prochlorite" to an iron-rich variety; "pennine" to a pseudotrigonal variety; and "leuchtenbergite" to an iron-deficient variety.

### *COMPOSITION*

From its chemical formula  $(\text{Mg,Al})_6(\text{Si,Al})_4\text{O}_{10}(\text{OH})_8$ , we see that clinochlore contains the elements magnesium (Mg), aluminum (Al), silicon (Si), oxygen (O), and hydrogen (H). The theoretical molecular weight of clinochlore, which reflects the complete absence of iron, is made up of 16.31 percent magnesium, 36.23 percent aluminum, 13.45 percent silicon, 34.00 percent oxygen, and 0.01 percent

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hydrogen. In clinochlore's empirical formula, the +58 cationic charge does not even approximate the -28 anionic charge. This imbalance infers an electrical instability in the single molecule which is satisfied only by atomic bonding within a multi-molecular lattice. The practical formula  $(\text{Mg}_{10}\text{Al}_2)(\text{Si}_6\text{Al}_2)\text{O}_{20}(\text{OH})_{16}$  reflects clinochlore's complex lattice bonding and subsequent electrical balance, with the +56 cationic charge equaling the -56 anionic charge.

Clinochlore is a member of the silicates, the largest and by far the most abundant class of minerals. Silicates are combinations of silicon and oxygen with one or more metals. The basic structural feature of all silicate minerals is the silica tetrahedron  $(\text{SiO}_4)^{4-}$ , which consists of a silicon atom surrounded by four equally spaced oxygen atoms at the corners of a tetrahedron. Silicate minerals consist of silica anions and metal cations bonded together in repeating structural units to form seven distinct and complex groups: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); and sheet silicates (phyllosilicates).

Clinochlore is a member of the phyllosilicates, in which the alternative term "sheet silicate" aptly describes the crystal structure. In the sheet silicates, each silica tetrahedron shares three oxygen ions with adjacent tetrahedra. This inter-molecular arrangement satisfies the unstable, single-molecule electrical charge as discussed above, while forming a very thin, sheet-type structure that extends indefinitely in two directions. Although the charges of the three shared oxygen ions are neutralized, the remaining, unshared oxygen on the apex of each tetrahedron still carries a -1 charge. Hydroxyl ions  $[(\text{OH})^-]$  occupy the holes between the apices of the tetrahedra. Stacks of these sheets are then held together by positive metal ions which satisfy the collective negative charges of the tetrahedra and hydroxyl ions.

Sheet silicates are subclassified structurally into two-layer and three-layer groups. As a three-layer sheet silicate, clinochlore exhibits a typical three-layer structure. Within the thin sheets, silica tetrahedra are arranged in two-dimensional, six-membered rings. In the three-layered structure, two of these silica tetrahedral layers, with their apices pointed toward each other, sandwich an octahedral layer consisting of ions of such metals as magnesium, aluminum, and often iron. The positive charges of these metal ions satisfy the negative charges of the two adjacent tetrahedral layers, forming strong, internal ionic bonds that hold together as cohesive sheet units. But the ionic attraction *between* the individual three-layer sheets is very weak, so weak, in fact, that the sheets will slip and separate under even moderate mechanical pressure. This explains both clinochlore's softness (Mohs 2.0-2.5) and its perfect one-directional cleavage.

The three-layer silicates are further subdivided by the nature of their atomic bonding into seven groups: talc, mica, brittle micas, montmorillonites, chlorites, vermiculites, and sepiolites. Clinochlore is a member of the chlorite group. The term "chlorite" refers not to an individual mineral, but to a group of similar minerals that are usually difficult to distinguish. Chlorites are generally green in color, crystallize in the monoclinic system, and exhibit perfect, one-directional cleavage.

The Dana classification number 71.4.1.4 first identifies clinochlore as a phyllosilicate with a sheet structure consisting of six-membered rings. The subclassification (4) next defines it as a three-layer silicate with an octahedral center layer. Finally, clinochlore is a member of the chlorite group (1), of which it is the fourth (4) of 10 members. All chlorite-group members are basic silicates with very similar physical and chemical properties. The primary chemical difference is in cationic substitution, in which atoms of magnesium, aluminum, ferric iron ( $\text{Fe}^{3+}$ ), ferrous iron ( $\text{Fe}^{2+}$ ), zinc, manganese, lithium, and nickel replace each other in various combinations.

A complete solid-solution series exists between clinochlore  $[(\text{Mg},\text{Al})_6(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH})_8]$  and the chlorite-

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group member chamosite  $[(\text{Fe}, \text{Al}, \text{Mg})_6(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_8]$ . As the formulas indicate, the end-member clinochlore has no iron at all, while the end-member chamosite is iron-rich. The complete solid-solution series that exists between these two end-members is based upon the gradation of iron content. With increasing amounts of iron, colors grade from clinochlore's lighter greens to chamosite's less-transparent and darker grays, browns, and blackish-greens. Because solid-solution series exist to lesser degrees among all chlorite group members, laboratory analysis is often required for positive differentiation.

Clinochlore and the other chlorite-group minerals are common worldwide and are often found in igneous rocks as alteration products of such mafic (iron- and magnesium-rich) minerals as pyroxenes, amphiboles, and biotite. The chlorites are also associated with quartz (silicon dioxide,  $\text{SiO}_2$ ) and epidote [basic calcium aluminum iron silicate,  $\text{Ca}_2\text{Al}_2(\text{Fe}^{3+}, \text{Al})\text{Si}_3\text{O}_{12}(\text{OH})$ ] in hydrothermal replacement deposits. Chlorites, the diagnostic species of the greenschist facies, can form from low-grade metamorphism in association with quartz, albite (sodium aluminum silicate,  $\text{NaAlSi}_3\text{O}_8$ ), and garnet-group minerals in pelitic schists (schists metamorphosed from fine-grained sedimentary rocks). Chlorite minerals also occur with calcite (calcium carbonate,  $\text{CaCO}_3$ ) and zeolites (a group of hydrated aluminosilicates) in cavities in basalt formations, in schists of contact metamorphic zones, and in the gneisses of regional metamorphic rocks.

Mineralogists sometimes include chlorites in the clay group of minerals. Clays, the weathering products of preexisting rock, are defined as any soft sediment or deposit that exhibits plasticity (the ability to be molded when wet) and consists of very fine-grained (two microns or less), mica-like minerals that are mainly complex, basic aluminum silicates. Chlorites have some, but not all, the characteristics of clays. Like clays, chlorites typically weather into flaky, microscopic crystals, but unlike other clay minerals, chlorites sometimes form large crystals. Clay minerals are divided into four major groups: kaolinite, montmorillonite-smectite, illite (clay-mica), and chlorite. All clays have a sheet-type structure and are capable of containing water molecules between individual sheets. Most clay-group minerals have major industrial applications, but do not occur in large, concentrated deposits useful as commercial clay sources.

### *COLLECTING LOCALITIES*

Because clinochlore and other chlorite-group minerals are widely distributed in small quantities, they have numerous collecting localities. Clinochlore is a common gangue mineral at the Lord Brassey Mine at Heazlewood, Tasmania, Australia. In Italy, clinochlore is a common fracture filling in chert deposits in the Graveglia Valley, Ne, Genova Province, and in the Gilba Valley, Val Varaita, Cuneo Province. Brightly colored light-green clinochlore is found at La Combe de la Selle, Isère, France. Similar specimens are collected at the Greystone Quarry at Lezant, Cornwall, England. Fine clinochlore specimens occur at several localities in Russia, most notably at the Korshunovskoe mine, Irkutskaya Oblast', Siberia, where our specimens originated, and outstanding pleochroic red-green crystals are found at the Saranovskii Mine near Saranui in the Ural Mountains. Nice crystals have recently been collected at the Gardiner Geologic Complex at Kangerlussuaq Firth, Tunu, Greenland. Platy clinochlore crystals to one-half inch in size occur at the Palaboro Mine at Loolekop, Limpopo Province, South Africa.

In North America, sharp, platy clinochlore crystals as large as one-half inch are collected in Canada's Ontario Province at Elliot Lake in the Algoma District and at the Kidd Creek Mine at Timmons in the Cochrane District. The best Mexican clinochlore crystals come from the El Potosí Mine in the Santa Eulalia District at Aquiles Serdán, Chihuahua.

Fine clinochlore crystals also occur at numerous localities in the United States. In the East, these include the New England and Allyndale quarries at East Canaan in Litchfield County, Connecticut; the Millington Quarry at Millington in Morris County, New Jersey, which yields clinochlore rosettes; the Hunting Hill

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Quarry, Rockville, Montgomery County, Maryland; the Tilly Foster Mine at Brewster, Putnam County, New York; the Berkshire Talc Co. mines at Hinsdale in Berkshire County and the Rowe mines in Franklin County, both in Massachusetts; and at Brinton's Quarry, at West Chester, Chester County, Pennsylvania, which is the clinochlore type locality. In northern Michigan, sharp, platy clinochlore crystal clusters occur at the Republic Mine at Republic and the Beacon Mine at Champion, both in Marquette County.

In the western United States, nice clinochlore specimens have come from the Yellow Cat Mine in the New Idria District, San Benito County, California; the Dallas and Cole mines at Bisbee in Cochise County and the United Verde Mine at Jerome in Yavapai County, both in Arizona; and the Treasure Falls locality near Wolf Creek Pass in Mineral County and the Camp Bird Mine at Ouray, Ouray County, Colorado. The Little Falls Claim near Sheridan in Sheridan County, Wyoming, has provided limited amounts of clinochlore (sheridanite) for industrial use.

### *JEWELRY & DECORATIVE USES*

Despite clinochlore's considerable softness (Mohs 2.0-2.5), it is surprisingly popular in jewelry because of its pleasing, silky-green appearance when polished. Although clinochlore crystals are not faceted because of their softness and perfect, one-directional cleavage, the massive material we are featuring from Korshunovskoe is primarily fashioned into cabochons for use in pendants and bracelets, as well as polished decorative objects such as eggs, spheres, detailed carvings, and display slabs. When used in this fashion, Korshunovskoe clinochlore is usually marketed under the name "seraphinite" or "seraphina."

Clinochlore crystals are valued by mineral collectors for mineralogical and display purposes. Collectors consider clinochlore in association with garnet-group members to be a classic mineral collectible.

### *HISTORY & LORE*

That clinochlore has been known since antiquity is shown through stone carvings recovered from a 3,600-year-old, early Bronze Age archaeological site in China's Sichuan Province. The first of these eight-inch-high carvings depicting human figures was excavated in the 1920s for the illegal artifacts trade and initially was thought to be made of jade. But when a dozen similar figures were excavated from the same site in 2001, laboratory analysis proved they were actually clinochlore.

The earliest documented work with clinochlore is attributed to William Phipps Blake (1826-1910), a Yale University mineralogist and geologist best known for his work with the U.S. Government's transcontinental railroad surveys of the 1850s. In 1851, after studying specimens obtained from Brinton's Quarry at West Chester in Chester County, Pennsylvania, Blake identified them as a new and distinct mineral species which he named "clinochlore" for their crystal shape and green color. Today, the name "clinochlore" is somewhat of a departure from the norm in mineral names, as it somehow escaped the mineralogical movement of the early 1900s that assigned or reassigned most minerals names ending in "-ite."

According to modern metaphysical belief, clinochlore enhances personal creative expression, reduces stress, provides peace of mind, helps adjust to higher states of awareness, and aids in recalling dreams.

### *TECHNOLOGICAL USES*

Natural clinochlore has served as the model for its laboratory synthesis. Small amounts of finely-powdered, synthetic clinochlore, marketed under the commercial name "sheridanite," is added to glass mixtures to adjust melting temperatures and to enhance chemical resistance.

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Natural clinochlore is a valuable tool in two diverse fields of geological study. The chemical composition of clinochlore is very similar to that of other chlorite-group minerals that originate in the Earth's upper mantle. Clinochlore is often studied to determine the rate at which it loses oxygen and hydrogen (as water) when subjected to extreme pressure. These studies, which employ a technique known as vibrational spectroscopy, have aided geologists both in creating realistic models of the physical behavior of mantle rocks and in explaining how the breakdown of iron-bearing chlorites in hot subduction zones releases water into the overlying mantle wedge.

Clinochlore also has a high affinity for uranium, which binds onto the clinochlore molecule's magnesium ion. Measuring the rates at which clinochlore will adsorb uranium has been helpful in assessing the overall permeability properties of rocks in future deep geological repository sites for radioactive waste.

### ***ABOUT OUR SPECIMENS***

Another of the many remote localities in Siberia, Russia, is the source of this month's glorious specimens. You'll find the city of Zheleznogorsk (Russian for "Iron City") about 100 miles east of Bratsk and 100 miles west of the tip of Lake Baikal in Irkutskaya Oblast', southeastern Siberia, Russia. With a population of 90,000, Zheleznogorsk was known by its code name Krasnoyarsk-26 until 1994, and is the site of one of Russia's three remaining weapons-grade plutonium-producing reactors, scheduled to be shut down by next year. The reactor is set so deeply into a granite mountain that it was thought it could continue to produce despite a nuclear strike!

Near to Zheleznogorsk are two enormous iron deposits, the Korshunovskoe and the Rudnogorskoe. Our specimens come from the Korshunovskoe deposit, whose total iron ore reserves down to a depth of 1700 meters are estimated at 1.5 billion tons. Korshunovskoe is a huge open pit mine, and there is a zone of clinochlore enrichment in the upper part of the corner of the deposit. Approximately every seven to ten years, the mine is expanded through this zone, and as much beautiful chatoyant green-white clinochlore as possible is carefully removed to be sold to lovers of beautiful gemstones. An expansion must have taken place in the last few years, as we are seeing greater amounts of this beautiful mineral at shows in the form of polished slices, cabochons, jewelry, carved eggs and spheres and the like.

The Korshunovskoe deposit, located in Proterozoic age rocks (approximately 2.5 billion to 570 million years), is a large skarn iron ore deposit that has undergone metamorphism. Korshunovskoe has been a rich source for other exceptional minerals over the years. In addition to clinochlore, excellent specimens of drusy hematite, amethyst, diopside, magnetite, epidote, orthoclase, and thaumasite have been dug here. It is also the type locality for three rare minerals: ekaterinite, shabnyite, and the aptly-named korshunovskite. We'll inquire with our Russian contacts to try to obtain nice specimens of these other minerals to offer you in the future.

It seems that our lovely gem-grade clinochlore from Korshunovskoe did not hit the American mineral and gem markets until the mid 1990's. We found several references to the deposit along with photos of the lovely chatoyant clinochlore in the Russian magazine "World of Stones," but no mention of when the discovery was made. With the collapse of the Soviet Union in 1991, the Russian gem and mineral market really opened to the world, and its bounty became available to lovers of exquisite gems and minerals.



**Figure 1.** Zheleznogorsk's old name: Krasnoyarsk 26. Image courtesy of Nuclear Cities Initiative.

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The excellent reference book *Gems and Lapidary Materials* by June Culp Zeitner, published in 1996, makes no mention of this find, although it does mention charoite, the beautiful purple gemstone discovered in another remote region of Siberia in the 1960's. Ms Zeitner mentions the mineral group chlorite as one of the causes for the green color of the cryptocrystalline quartz variety prase, and as one of the minerals commonly found in quartz phantoms.

An update of *Love Is in the Earth* published in 1996 does mention "Serefina" as a new type of chlorite available from Russia, but unfortunately does not give the origin of the name. Was it a Russian mineral dealer looking for a pretty name to go with a pretty new stone? (An example of this practice is taking place right now, with regard to a lovely blue richterite from near Lake Baikal that Russian dealers are calling "Dianite" in honor of the late princess.) Or could it have been a metaphysically-minded dealer who wished to try to link this stone in people's minds with the angelic realms? Either way, when we see this marvelous mineral at shows, it is almost always called "seraphinite" rather than clinochlore, and pronounced either with the accent on the second or third syllables.

The magazine *Gems & Gemology*, published by the Gemological Institute of America, also took note of this exceptional new find, as reported in the Summer 1996 issue under Gem News: "Chatoyant clinochlore from Russia. One of the interesting 'phenomenal' materials seen at the 1995 and 1996 Tucson shows was a chatoyant chlorite-group mineral from Russia. Gemological properties were as follows: color-green; diaphenity-semi-translucent; color distribution-uneven (mottled, fibrous); pleochroism (visible in some more transparent areas)-yellow-green; optic character-doubly refractive with an aggregate structure. Individual fibrous crystals in the aggregates appeared chatoyant, with a pearly luster." The GIA had obtained specimens from Heaven and Earth, a promoter of crystals and minerals for metaphysical purposes—likely they were the ones who appointed the name "seraphinite."

Our specimens highlight one of clinochlore's common crystal forms: a radial fibrous structure. This means that the clinochlore crystals form as hairlike, fibrous crystals, radiating out from a central axis. This results in the formation of little spherules (small spheres of sphere-like bodies) of clinochlore, which we were able to observe in some of our larger specimens, and in our unpolished Junior-size pieces. Polishing reveals the intricacy of the radiating crystals and brings out the color and chatoyancy that make this find unique and highly desirable. The term "chatoyant" comes from a French word meaning "shine like a cat's eyes," and means "having a changeable luster or color with an undulating narrow band of white light." This definition perfectly fits our specimens, which are outstanding for their chatoyant, pearly luster when polished. A few pieces also show some areas of black magnetite. This material is always expensive, sold by the gram weight. When we first started doing shows in the mid 1990's it was very scarce and very expensive. We have noticed a large upsurge in the amount available in the last couple of years, evidence that another large pocket has been mined at Korshunovskoe and made its way into the market. The price has gone down, but only slightly. We are delighted to be able to procure this large lot so we all can add this beautiful new find from a remote iron-ore locality to our collections!

References: *Dana's New Mineralogy*, Eighth Edition; 2004 *Fleischer's Glossary of Mineral Species*, J. A. Mandarino and M. E. Back, The Mineralogical Record, Inc.; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *Manual of Mineralogy*, 21st Edition, Cornelius Klein and Cornelius S. Hurlburt, Jr., John Wiley & Sons; *Western Massachusetts Mineral Localities*, Alan Plante, Valley Geology Press, 1992; *The Mystical Lore of Precious Stones*, George Frederick Kunz, Newcastle Publishing Company, 1986 (reprint of 1913 original); *Clay Mineralogy*, Ralph E. Grim, McGraw-Hill, 1968; *Gems and Lapidary Materials*, June Culp Zeitner, Geoscience Press; *Love Is in the Earth*, Melody, Earth-Love Publishing House; "Minerals of the Hunting Hill Quarry," Fred Parker, *The Mineralogical Record*, September-October 2005; "Zeolites and Associated Minerals of the Wolf Creek Pass Area, Mineral and Archuleta Counties, Colorado," Arnold G. Hampson, *Rocks & Minerals*, September-October 2004; "Siberia and Far East: A Brief Mineralogical Guide," Alexander A. Evseev, *World of Stones*, No. 4/94; "Siberia's Crystals and Symmetry in the Distribution of Occurrences of Minerals," Alexander A. Evseev, *World of Stones*, 1/93.