March 2004 Mineral of the Month: "Cactus Quartz" Quartz, variety Amethyst

What makes this quartz particularly appealing is the habit—elongate crystals with a myriad of tiny, secondary overgrowth crystals all along the prism faces like thorns on a cactus, hence the name "cactus quartz." --*Bruce Cairncross and Uli Bahmann, Rand Afrikaans University, 2003*

PHYSICAL PROPERTIES

Chemistry: SiO_2 Silicon Dioxide (always with traces of iron and sometimes of manganese)
Class: Silicates Subclass: Tectosilicates Group: Quartz (variety amethyst)
Crystal System: Hexagonal (Trigonal)
Crystal Habits: Usually long, prismatic crystals, striated crosswise and frequently terminated by double rhombohedrons shaped like hexagonal pyramids; less frequently short prisms to nearly bipyramidal; sometimes distorted. Twinning common. Also occurs in geodes.
Color: Light to dark purple; lavender; violet, with shades ranging from reddish violet to bluish violet; sometimes with pink or reddish flashes.
Luster: Vitreous to slightly greasy
Transparency: Transparent to translucent
Streak: White
Refractive Index: 1.55
Cleavage: Generally none, occasionally exhibits indistinct rhombohedral parting
Fracture: Conchoidal to subconchoidal
Hardness: Mohs 7.0
Specific Gravity: 2.65
Luminescence: Triboluminescent (luminescence caused by friction)
Distinctive Features and Tests: Best field marks are purple color, vitreous to greasy luster, crosswise-striated hexagonal crystals, and hardness.
Dana Classification Number: 75.1.3.1

NAME

The English word "amethyst" derives from the Greek *amethystos*, literally "remedy against drunkenness." Color-zoned amethyst with distinct color banding is known as "chevron amethyst," while stones with the paler shades of purple have been called "rose de France." The darkest purple amethyst is known as "royal amethyst" or "Siberian amethyst."

"Cactus" quartz is named for the distinctive visual appearance of its crystal habit—an overgrowth of tiny, secondary crystals atop a primary crystal. "Cactus" quartz is also known as "spirit," "angel," and "porcupine" quartz.

COMPOSITION

As a color variety of quartz, amethyst quartz has the chemical formula, SiO_2, indicating that it consists of the elements silicon and oxygen, with only a trace presence of iron and other elements. In the quartz molecule, a cationic silicon ion (Si^{+4}) is drawn to the combined -4 charge of two oxygen (O^{-2}) ions. In atomic weight, quartz consists of 46.74 percent silicon and 53.26 percent oxygen. Silicon and oxygen are the most abundant elements in the earth's crust, together comprising 75 percent of all crustal material by weight. Silicates are the largest class of minerals and quartz itself, in various macrocrystalline and microcrystalline forms, accounts for 12 percent of all crustal minerals.

Quartz is a tectosilicate, or "framework" silicate. Its fundamental structural unit is silica (SiO^4) in a tetrahedral configuration. Each silica tetrahedron shares its corner oxygen ions with adjacent tetrahedrons to form a repeating, rigid, compact, three-dimensional framework. The silicon ions lie on interpenetrating hexagonal lattices and are surrounded by oxygen ions in a tetrahedral configuration. This results in a very closely packed, hexagonal crystal lattice that actually fills three-quarters of the space within the lattice. Despite this compact structure, the relative lightness of quartz's elemental components, silicon and oxygen, provides a low density and a specific gravity of only 2.65. Quartz has great resistance to abrasion because, like non-crystalline glass, most of which is also composed of silica, its lattice has neither centers of symmetry nor significant planes of weakness (cleavage planes). The inherent rigidity of the quartz crystal lattice explains quartz's considerable hardness of Mohs 7.0.

Quartz crystals, including those of amethyst, form as a component of crystallizing magma in intrusive and extrusive formations; by the crystallization of silica-rich, hydrothermal fluids; and by the downward percolation of silica-rich meteoric (ground) water. The largest and best-formed quartz crystals originate in granite pegmatites and hydrothermally emplaced veins. Pegmatites form from the very slow cooling of pockets of residual, rare-mineral-enriched, granitic magmas which sometimes develop hollow center voids that provide space for the unrestricted growth of large, well-formed crystals. In hydrothermal emplacement, pressure forces superheated, aqueous, silica-rich solutions upward into fractured country rock. In the cooler temperatures and reduced pressures of near-surface rock, and in the space of voids, these silica-rich hydrothermal solutions can solidify into large, well-developed quartz crystals.

AMETHYST "CACTUS QUARTZ"

The amethyst-cactus variety of quartz is quite rare because its formation depends on two specific chemical and physical conditions. The chemical composition of the crystallizing solutions must enable the creation of amethystine color, while physical conditions must make possible a secondary crystallizing event to create the "cactus" structure.

Minerals are classified either as idiochromatic (self-colored) or allochromatic (other-colored). In idiochromatic minerals, the essential chemical composition and crystal structure create a characteristic and diagnostic color. An example of an idiochromatic mineral is rhodochrosite (magnesium carbonate, $MnCO_3$). Although varying somewhat with impurities, the color of pure rhodochrosite is always rose-red.

The colors of allochromatic minerals are created by the trace presence of elements which act as coloring agents, or chromophores. The basic mineral chromophores are transition metals (metals with valance electrons in their two outer orbitals) such as copper, iron, manganese, chromium, nickel, cobalt, vanadium, and titanium. Quartz is an allochromatic mineral. Pure quartz is colorless and forms the variety known as rock crystal, our December 1997 featured mineral. But trace amounts of chromophores create a number of color varieties including pink rose quartz, which has a titanium chromophore, and yellow citrine and purple amethyst, both with iron chromophores in different oxidation states. The primary chromophore in citrine is ferrous iron (Fe^{+2}), while the amethyst chromophore is ferric iron (Fe^{+3})

The purple color of amethyst is produced by the phenomenon of "color centers." Color centers are imperfections in the crystal lattice that create perceived color by altering light-absorption characteristics. In amethyst, very small quantities of ferric iron—only about 40 parts per million—are distributed in layers parallel to the rhombohedral lattice interfaces. The ferric iron ions substitute for silicon ions, and under certain conditions can give up another electron, thus producing Fe^{+4} ions. These free electrons then migrate to vacant sites in the lattice called "electron traps" where they impart a local, negative charge that alters the absorption of visible light. In amethyst, these electron traps absorb the yellow portion of the visible spectrum, thus transmitting and reflecting the combined red and blue portions which create a purple color.

While manganese ions can also contribute to amethyst color, the primary amethyst chromophore is always ferric iron. Natural or artificial heat, in varying degrees of intensity and duration, can alter the oxidation states of the iron in amethyst and thus radically change its color. Because heat can intensify the amethyst color by spinning off more free electrons, heat treatment is a common color-enhancement process. But different levels of heat treatment can also recombine the free electrons with iron ions to create ferrous ions (Fe^{+2}), which cause the purple color of amethyst to shift to the yellow-orange color of citrine. Irradiation can often reverse this process by spinning off free electrons from the iron ions, which migrate to color centers to recreate the amethyst color.

Amethyst commonly exhibits pronounced color banding, or color zoning, in which the purple color is concentrated in certain sections of the crystal. Color zoning reflects changes in the chemical composition of the silica solutions in which the crystals grew. Sections of amethyst crystal that are intensely colored represent a growth solution relatively rich in ferric iron, while the paler or nearly colorless sections grew from solutions very low in ferric iron. Many amethyst crystals display repetitive color banding which indicates a sequential enrichment and depletion of the ferric iron content in the silica solutions during the crystal-growth process.

The creation of "cactus" quartz requires two separate phases of crystal growth. The initial phase begins when a minute crystal, called a seed crystal, forms from solution. Continued cooling of silica-rich fluids causes more silica to come out of solution and form new tetrahedra on the growing crystal lattices. Given slow cooling, physical space for free growth, and a steady supply of silica fluids, the quartz crystals grow into a basic hexagonal crystal form. "Cactus" and other unusual forms develop when this normal, continuous growth process is interrupted by a dramatic change in the mineral environment. Such changes can be caused by nearby volcanic activity or igneous intrusions, tectonic stresses, or fault movements that vary the temperature, pressure, and mineral-nutrient mix of the silica solution.

In "cactus" quartz, the original silica solutions actually withdraw, leaving behind typical, hexagonal quartz prisms. The distinctive "cactus" covering forms when hydrothermal solutions later resurge to begin a second phase of crystallization under a completely different set of temperature, pressure, and mineral-nutrient conditions. Some mineralogists believe that evenly dispersed, tiny impurities on the surface of the original quartz crystal faces act as seed points for the growth of small, secondary crystals that create the distinctive "cactus" appearance. When the secondary hydrothermal fluids have different mineral compositions, "cactus" quartz specimens will consist of two distinct quartz varieties. Typical combinations in "cactus" quartz include secondary amethyst growth atop primary crystals of citrine or milky quartz. (Milky quartz, a white, translucent quartz variety, is not colored by chemical chromophores, rather by countless, tiny disseminated gas- or liquid-filled bubble inclusions.)

COLLECTING LOCALITIES

March 2004 Mineral of the Month: "Cactus Quartz" Quartz, variety Amethyst

Amethyst occurs worldwide and varies greatly in color saturation, size, and transparency. Sources in Russia's Ural Mountains, now largely exhausted, once supplied the deep-purple "Siberian" amethyst favored in jewelry. Sites in Italy and Germany have yielded large, pale amethyst crystals. The best-known South America amethyst sources are in the Brazilian states of Minas Gerais, Rio Grande do Sul, and Bahia where amethyst often occurs in crystal-lined vugs and geodes in volcanic rock and has pale-to-medium color and pronounced zonation. In Uruguay, intensely colored amethyst with relatively little zonation occurs in volcanic vugs. Bolivian amethyst is similar to that of Uruguay, but crystal sizes are larger. In Mexico, color-saturated and strongly zoned amethyst comes from sites in the state of Guerrero, while paler shades in crystals of exceptional transparency are produced by mines in the state of Veracruz. In Canada, Ontario's Thunder Bay area produces small, intensely colored amethyst crystals with unusual reddish inclusions. Amethyst occurrences in the United States are numerous, with fine crystals coming from Maine, Rhode Island, Connecticut, North Carolina, Pennsylvania, Arizona, and Montana. In Colorado, nicely colored amethyst was actually the primary gangue mineral in the silver ores of the great mining camp of Creede. African amethyst, primarily from sites in Zambia and Namibia, generally occurs in small crystals with deep color and excellent clarity.

JEWELRY & DECORATIVE USES

Amethyst, the most familiar and highly valued of all quartz varieties, has served as a gemstone since antiquity. Deeply colored stones have traditionally had the greatest value, although paler, "rose de France" lilac shades enjoyed great popularity in Victorian-era jewelry. A hardness of Mohs 7.0 suits amethyst gems for use in all types of jewelry, including rings. Amethyst is most often faceted in square, emerald, or rectangular cuts and in sizes ranging from one to six carats. Exceptional faceted gems can weigh 10 carats or more. Amethyst's pronounced color zoning tends to limit gem size, as most stones must be cut in a manner that minimizes the visual effects of zoning. Amethyst cabochons are also fashioned, mainly for use in bracelets and necklaces. Most amethyst gems on today's market have been heat-treated to intensify their color.

In London, the British Museum exhibits a superb 343-carat amethyst gem, while the collection of the National Museum of Natural History (Smithsonian Institution) in Washington, DC, displays a 1,362-carat amethyst gem from Brazil and a 202.5-carat gem from North Carolina. Because large amethyst crystals are fairly common, spectacular collector's gems are surprisingly affordable. Amethyst gems in the 100-carat to 200-carat range are available for less than $1,000.

Amethyst is sometimes carved into decorative objects, often miniature wine goblets that reflect the stone's significance in Greek mythology (see *History and Lore*). Fine amethyst crystal clusters and sections of geode walls are highly valued by collectors. In recent decades, large sections of amethyst-lined geode walls have become popular as display pieces for interior decoration.

HISTORY & LORE

With its beauty, abundance, and availability, amethyst has accumulated an especially rich lore. Because of its wine-like color, the ancient Greeks associated amethyst with wine and its inebriating effects. According to Greek legend, amethyst originated with Dionysus (Bacchus), the god of wine and joviality, and Artemis, the goddess of the moon and the hunt. Insulted by a mortal, Dionysus swore revenge on the next mortal to cross his path and created fierce tigers to carry out his wish. The unlucky mortal who approached was a young maiden named Amethyst, on her way to pay homage to the goddess Artemis. Attacked by Dionysus' tigers, Amethyst cried out to Artemis for help. To protect the maiden, Artemis turned her into a statue of pure, colorless quartz. Awed by the statue's beauty and shamed by his own ruthlessness, Dionysus remorsefully wept tears of wine which colored the quartz purple to create the gemstone amethyst. How imaginative! Ancient Greeks and Romans who enjoyed wine often wore amethyst jewelry or amulets to protect them from the intoxicating effects of alcohol. Some drank from carved amethyst wine goblets, believing that since these goblets retained their purple color after the wine had been consumed, the wine's intoxicating effects remained with the goblet.

Amethyst was among the 12 stones in the jeweled breastplate of Aaron, worn by the high priests of the Temple of Jerusalem. In the first century A.D., the Roman scholar Pliny the Elder (Gaius Plinius Secundus, A.D. 23-79) noted that amethyst had been named for its wine-like color. By then, amethyst was also thought to aid in hunting, to protect soldiers from harm in battle, and to protect wearers from the intoxication of love. Medieval physicians believed that amethyst helped remove toxins from the body, dulled the pain of arthritis, and alleviated certain disorders of the digestive and circulatory systems. Because amethyst symbolized piety and was also thought to encourage celibacy, it became important in the personal jewelry of Catholic clergymen during the Middle Ages. Amethyst became the stone of bishops, who still wear amethyst rings today. Later, amethyst's beauty also earned it a place in the British Crown Jewels amid gemstones of far greater monetary value.

According to modern metaphysical theory, amethyst brings serenity and calm, enhances the ability to assimilate new ideas, provides mental strength and stability, and balances one's physical, intellectual, and emotional states. Metaphysicists believe that the energy in "cactus" quartz is directly proportional to the number of small, secondary crystals that cover the primary crystal.

Amethyst crystals appear on the postage stamps of fourteen nations, and it is the official gemstone of the state of North Carolina and of the Canadian province of Ontario. It is also the birthstone for February and the symbolic gemstone gift for the seventeenth wedding anniversary.

TECHNOLOGICAL USES

Although pure quartz crystals have many commercial uses in electronic filters, frequency controls, and timers, natural amethyst has no technological uses itself. Nevertheless, it has served as the model for the laboratory creation of hydrothermally grown synthetic amethyst. In the early 1990s, synthetic amethyst gems enjoyed limited market popularity under the name "Japanese amethyst." Although the price difference between synthetic and natural amethyst gems is very little, synthetic amethyst has none of the color zoning that characterizes natural crystals.

ABOUT OUR SPECIMENS

We might wonder how such an exceptional new find could remain hidden in the ground for so long. Especially when it's in an area, about 70 km northeast of Pretoria, containing the Bushveld Complex, famous for having the world's largest deposits of platinum and chrome, and the Houtenback district, producer of molybdenum, copper, gold, nickel, and tin. It seems that the villagers had found quartz crystals in the vicinity of their small village on Boekenhout Farm, but they were of milky quartz, not terribly desirable, and no one showed much interest. In 1986, a local man digging the foundation for his

March 2004 Mineral of the Month: "Cactus Quartz" Quartz, variety Amethyst

home uncovered quartz veins containing beautifully colored amethyst crystals. He quickly removed the crystals, and a friend brought them to the Pretoria Gem Club to see if they were worth anything. (Don't you wish you were at that Club meeting?) They were immediately purchased by South African collectors, but collecting in Boekenhout was forbidden by the local mayor, and no specimens appeared on the market until 2000.

Figure 1. Extracting Cactus quartz. Can you imagine doing this with simple hand tools?

As so often happens, the first collectors attempted to hide the locality, saying the specimens were from the Magaliesberg Mountains, and later from the town of Marble Hall. Both misleading names have subsequently been repeated, even in the mineral magazines. But honest investigators have discovered that the specimens are coming from two farm villages, Boekenhout and Mathys Zyn Loop, and from the neighboring Kwaggafontein, in an old apartheid-era homeland called Kwandebele. Here the crystals are dug by the local women, as most of the men are away working for long periods in the large cities. They use only simple hand tools, sometimes finding crystals in their own gardens! Because of the huge interest in these wonderfully colored pieces, the women have engaged in the backbreaking work, and the hillsides are dotted by with holes of various sizes, as seen in the photos, posing a threat to livestock. The villagers have learned that undamaged specimens are more valuable, and have learned to be more careful in extracting them, and due to the number of dealers visiting the area, are now receiving a good price for their efforts. (Before you rush over to purchase a nice lot, remember that dealers have been mugged and carjacked, and one shot at and almost killed by local brigands.)

Figure 2. Crystals were discovered while harvesting corn!

The locals have given fitting names to the different colors and habits they find. "Cactus Quartz" is used because the secondary growth of small quartz crystals resembles cactus thorns, and has become the name attached to all specimens found here. They call intensely colored amethyst pieces "Spirit Quartz," in allusion to the color of the chemical substance known as methylated spirits that they use for heating. Our specimens they call "Autumn Quartz," because they show fall colors. Some of our specimens show orangish- and yellowish-brown colors on the surfaces, caused by inclusions of iron in the form of hematite [a-Fe_2O_3] and goethite [a-$Fe^{3+}O(OH)$, pronounced GER-tite, in honor of German poet and naturalist Johann Wolfgang von Goethe (1749-1832)]. Such are sometimes mistakenly referred to as citrine, but true citrine has not been found here as yet. Other fanciful names include "Ice Cream Quartz," "Fairy Quartz, " and "Sunshine Quartz." Fine Japan-law twin and intensely black smoky quartz are also found here, as are distorted curved crystals and healed crystals. All are found in veins on massive quartz, making removal of undamaged pieces difficult. Occasionally, small crystals of pyrite and of cubic fluorite coated with drusy quartz are found. We will be watching to see what wonderful new finds come from this area!

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company;

March 2004 Mineral of the Month: "Cactus Quartz" Quartz, variety Amethyst

1999 Glossary of Mineralogical Species, J. A. Mandarino; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Gems and Jewelry*, Joel Arem, Geoscience Press; *Gemstone and Mineral Data Book*, John Sinkankas, Geoscience Press, *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; *Gem and Crystal Treasures*, Peter Bancroft, Western Enterprises; *Color Encyclopedia of Gemstones*, Joel Arem, Van Nostrand Reinhold Company; "New Data on the Cause of Smoky and Amethystine Color in Quartz," A. J. Cohen, *The Mineralogical Record*, September-October 1989; "Amethyst Occurrences of the Eastern United States," J. S. White and R. B. Cook, *The Mineralogical Record*, May-June 1990; "Maine Amethyst," Steve Voynick, *Rock & Gem*, May 1994; "Amethyst, Agate, and Calcite 'Skunks,'" R. Currier, *Rocks & Minerals*, March-April 1997; "Amethyst Discovery on Deer Hill, Stowe, Oxford County, Maine," W. B. Thompson, *Rocks & Minerals*, January-February 1994; Special thanks to Uli & Anka Bahmann