

May 2009 Mineral of the Month: Okenite

This month's mineral, okenite, was collected from quarries near Mumbai, India. Despite its zeolite-like appearance, okenite only masquerades as a zeolite. Our write-up explains okenite's unusual structural properties and why its namesake, German naturalist Lorenz Oken, is among the few individuals with two minerals named in his honor.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$ Hydrous Calcium Silicate, often containing small amounts of strontium, sodium, potassium, and iron.

Class: Silicates

Subclass: Phyllosilicates

Group: Tobermorite

Crystal System: Triclinic

Crystal Habits: Acicular and hairlike in "cotton ball" forms; fibrous; also as rounded, hemispherical aggregates of tightly packed, radiating crystals; rarely as individual, bladed crystals.

Color: White, yellowish-white, bluish-white

Luster: Vitreous, pearly

Transparency: Transparent to translucent

Streak: White

Cleavage: Perfect in one direction

Fracture: Conchoidal; acicular crystals are elastic and flexible.

Hardness: 4.5-5.0

Specific Gravity: 2.3

Luminescence: Fluorescent

Refractive Index: 1.51-1.54

Distinctive Features and Tests: Best field-identification marks are hairlike, elastic, or flexible crystals; occurrence in cavities in basaltic rocks; and association with zeolite-group minerals.

Dana Classification Number: 72.3.2.5

NAME Okenite, pronounced OH-ken-ite, is named after German naturalist and philosopher Lorenz Oken (1779-1851). Okenite has previously been known as "bordite" and "disclasite"; in European mineralogical literature, the name appears as *okenit* and *okenita*.

COMPOSITION: The chemical formula $\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$ shows that okenite contains the elements calcium (Ca), silicon (Si), oxygen (O), and hydrogen (H). Okenite's molecular weight consists of 20.37 percent calcium, 25.71 percent silicon, 52.07 percent oxygen, and 1.85 percent hydrogen. Okenite is a hydrous mineral, with nine molecules of water of hydration attached to each molecule. Although okenite is classified as a "sheet" silicate or phyllosilicate, it also exhibits certain structural properties of inosilicates or chain silicates. Okenite's weakly bound, layered structure explains its perfect, one-directional cleavage, elasticity, flexibility, and hardness of Mohs 4.5-5.0 (soft for most silicate minerals). As a secondary mineral, okenite forms at low temperatures and pressures from the alteration of basalt and occurs almost exclusively in cavities of basaltic rocks in association with quartz, prehnite, and zeolite minerals. Because of its zeolite-like appearance and occurrence, it is often erroneously thought to be a zeolite mineral itself. See our February 2009 Heulandite write-up for a fascinating discussion of the zeolite mineral group.

COLLECTING LOCALITIES: Okenite is collected in quarries in the Mumbai, Puna, Nasik, and Ahmed Nagar districts in the state of Maharashtra in west-central India. Okenite also occurs at Strond and

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Nordoyni on Bordhoy Island in Denmark's Faeroe Islands; in Germany at the Bramberg Quarry at Göttingen in Lower Saxony; in Russia at the Vuoriyarvi alkaline-ultrabasic massif on the Kola Peninsula in Murmansk Oblast', Northern Region; and in Greenland at the type locality at Qeqertarsuag (Disko) Island in Kitaa Province. Notable collecting areas in the United States include Horseshoe Dam, Maricopa County, Arizona; the Crestmore quarries in Riverside County, California; the Skookumchuck highway cut in Idaho County, Idaho; the Georgetown mining district in Grant County, New Mexico; several road cuts at Goble in Columbia County, Oregon; the Fairfax Quarry at Centreville in Fairfax County, Virginia; and the Durham Quarry at Durham in Durham County, North Carolina.

HISTORY, LORE, & USES: Although mineralogists initially classified okenite as a zeolite mineral, it was correctly recognized as a non-zeolite species in 1828. Okenite and other basic, hydrous, and basic-hydrous calcium-silicate minerals have been studied in depth to determine their chemical interactions with alkaline water to improve the qualities of modern Portland-type cements. Metaphysical practitioners believe that okenite provides a comforting energy that purifies one's physical, spiritual, emotional, and intellectual condition. Okenite has no use in jewelry.

ABOUT OUR SPECIMENS: Our specimens were collected at the Khandivali Quarry in the northern suburbs of the city of Mumbai (formerly Bombay) in the Mumbai District of the state of Maharashtra on the west-central coast of the Republic of India. Mumbai and the entire state of Maharashtra are located within the Deccan Traps, a huge volcanic province that consists of basalt formations as thick as 6,000 feet. Again, see our February 2009 Heulandite write-up for more on the Deccan Traps, including a discussion of its formation and how that event may be linked to the extinction of the dinosaurs. Email us if you don't have the write-up, and we'll be happy to send it to you.

Our specimens were collected from cavities or vesicles that formed from gas bubbles within the original magma. Later, these cavities filled with mineral-rich groundwater that precipitated crystals of okenite, quartz, calcite, prehnite, fluorapophyllite, and zeolite-group minerals. Our specimens were recovered as a by-product of quarrying basalt and consist of okenite in association with prehnite, quartz, gyrolite, and calcite atop a basalt matrix. **The acicular, hairlike okenite crystals that have a "fuzzy" or "cotton ball" appearance are fragile and should not be touched with the fingers.**

10 YEARS AGO IN OUR CLUB: Stilbite, Jalgaon District, Maharashtra, India. Coincidentally, stilbite is a zeolite group mineral, the second we had featured, after scolecite in May 1997. Other minerals from India's Deccan Traps we had featured to that point are cavansite in April 1996 (our second month of operation), apophyllite in July 1996, and okenite for the first time in January 1998. The write-up highlighted a form of crystal twinning common to stilbite--cruciform penetration twins, and explained what it is and how it occurs. Looks like we should feature stilbite again in the future!

COMPREHENSIVE WRITE-UP

COMPOSITION

Okenite's chemical formula $\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$ shows that its elemental constituents are calcium (Ca), silicon (Si), oxygen (O), and hydrogen (H). The molecular weight of okenite consists of 20.37 percent calcium, 25.71 percent silicon, 52.07 percent oxygen, and 1.85 percent hydrogen. All molecules are made up of an electrically balanced mix of positively charged cations and negatively charged anions. The simple cation in the okenite molecule consists of five calcium ions 5Ca^{2+} and has a collective cationic charge of +10. Okenite's anion is a radical, which is a group of atoms of different elements that behave as single entities in chemical reactions. Okenite's anion is the silica radical $(\text{Si}_9\text{O}_{23})^{10-}$, in which 9 silicon ions 9Si^{4+} are

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covalently bonded to 23 oxygen ions 23O^{2-} . The +36 charge of the 9 silicon ions 9Si^{4+} and the -46 charge of the 23 oxygen ions 23O^{2-} provide a cumulative -10 anionic charge. This balances the cationic +10 charge to provide the okenite molecule with electrical stability.

The “ $9\text{H}_2\text{O}$ ” in okenite’s chemical formula means that it is a hydrous (or hydrated) mineral with nine molecules of water (H_2O) attached to each parent molecule. Attached water molecules, called “water of hydration,” consist of electrically neutral water molecules and do not affect the electrical balance of the parent molecule. The water molecule is configured with two hydrogen ions (2H^{1+}) grouped closely together on one side of a large oxygen ion (O^{2-}). These grouped hydrogen ions retain a small positive charge, while the opposite side of the molecule, dominated by the large oxygen ion, retains a small negative charge. The resulting polarity enables the water molecules to behave as tiny dipole magnets that can attach themselves to other molecules by a weak attraction called “hydrogen bonding.”

Okenite is a member of the silicates, a large group of minerals formed by the combination of silicon and oxygen with one or more metals. The basic silicate structural unit is the silica tetrahedron (SiO_4)⁴⁻, in which a silicon ion is surrounded by four equally spaced oxygen ions positioned at the four corners of a tetrahedron (a four-faced polyhedron). In the silicates, silica anions and metal cations join together in repeating chains to form seven types of structures: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); framework silicates (tectosilicates); and sheet silicates (phyllosilicates).

Okenite is classified as a sheet silicate or phyllosilicate, the latter word derived from the Greek *phyllon*, or “leaf.” In most sheet silicates, each silica tetrahedron shares three oxygen ions with adjacent tetrahedra to create thin, sheet-type structures that extend indefinitely in two directions. The sheets consist of a checkerboard-like system of alternating “strips” of three tetrahedra each that are linked at their corners. In okenite, the tetrahedra within these flat sheets form five-member rings. This arrangement electrically satisfies three of the oxygen ions in each tetrahedron, leaving one remaining, negatively charged oxygen ion at the apex of each tetrahedron that attracts water molecules. Drawn by their dipolar positive charge, water molecules fill the spaces between the apices of the silica tetrahedra to partially satisfy the remaining tetrahedral negative charge. These water molecules are attached only by hydrogen bonds, a very weak form of bonding between the faintly positive poles of the water molecules and the negative charge of the single oxygen in each tetrahedron. Stacks of these hydrated silica sheets are then bound together by layers of positive metal ions which satisfy the remaining negative charge of the sheets.

Phyllosilicates are subclassified structurally into two- or three-layer groups. Okenite exhibits a three-layer or “2:1” structure with an octahedral layer of metal ions bonded ionically between two hydrated silica sheets. In the okenite structure, the middle layer consists of calcium ions “sandwiched” between two tetrahedral silica layers. Within each of these three-layer sheets, a combination of ionic and strong covalent bonding creates cohesive sheet units. But the ionic attraction *between* the three-layer groups is so weak that the sheets slip and separate even under light mechanical pressure. This explains okenite’s perfect, one-directional cleavage; its hardness of Mohs 4.5-5.0, which is soft for most silicate minerals; and its elasticity and flexibility. Elasticity is defined as the ability to bend under stress and return to the original form; flexibility is the ability to bend under stress but not return to the original form. Okenite’s acicular crystals can exhibit both qualities. Under mechanical pressure, these hairlike crystals will bend, but may not always return to their original form—the reason they should not be unnecessarily touched. Okenite’s low specific gravity of 2.3 is explained by its loose atomic packing and the relatively low atomic weights of its elemental components (calcium 40.08, silicon 28.09, oxygen 16.00, and hydrogen 1.01).

As a phyllosilicate (sheet silicate), okenite is unusual in that it also exhibits certain structural properties of inosilicates (chain silicates). Phyllosilicates are best represented by muscovite [basic potassium aluminum

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silicate, $\text{KAl}_2\text{AlSi}_3\text{O}_{10}(\text{OH})_2$] and other mica-group minerals that form infinite, two-directional sheet structures. But unlike the micas, okenite has the inosilicate characteristic of forming infinite chain structures in only *one* direction, which accounts for its long, acicular, hairlike crystals. The elasticity and flexibility of these hairlike crystals is due to the phyllosilicate characteristic of slippage between the silica sheets along the one direction of perfect cleavage.

The Dana classification number 72.3.2.5 first identifies okenite as a phyllosilicate with layers consisting of other than six-member silica rings (72). Okenite is then subclassified as a phyllosilicate with five- or eight-member rings (3). Finally, okenite is assigned to the tobermorite group (2) as the fifth (5) of eight closely related members. The following list compares the formulas of okenite to several other tobermorite-group members. Note the similar chemistries that differ only in the configuration of the silica radicals, a quantitative variation in water of hydration, and the presence of hydroxyl ions $(\text{OH})^{-1}$ in certain members. Because of these subtle differences in chemistry, mineralogists were unable to recognize several tobermorite-group members as distinct mineral species until the 1980s.

Okenite	hydrous calcium silicate	$\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$
Tobermorite	basic hydrous calcium oxysilicate	$\text{Ca}_{4.5}\text{Si}_6\text{O}_{15}(\text{O},\text{OH})_2\cdot 5\text{H}_2\text{O}$
Riversideite	basic calcium silicate	$\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2$
Nekoite	hydrous calcium silicate	$\text{Ca}_3\text{Si}_6\text{O}_{15}\cdot 7\text{H}_2\text{O}$

Okenite forms in conditions of low temperature and pressure as a secondary mineral from the alteration of basalt and occurs almost exclusively in cavities of basaltic rocks. It is associated with quartz [silicon dioxide, SiO_2], prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$], and such zeolite minerals as mesolite [hydrous sodium calcium aluminosilicate, $\text{Na}_2\text{Ca}_2(\text{Al}_6\text{Si}_9\text{O}_{30})\cdot 8\text{H}_2\text{O}$], heulandite-Ca [hydrous calcium sodium potassium aluminosilicate, $(\text{Ca}_{0.5},\text{Na},\text{K})_9(\text{Al}_9\text{Si}_{27}\text{O}_{72})\cdot \sim 24\text{H}_2\text{O}$], mordenite [hydrous sodium calcium potassium aluminosilicate, $(\text{Na}_2,\text{Ca},\text{K}_2)_4(\text{Al}_8\text{Si}_{40}\text{O}_{96})\cdot 28\text{H}_2\text{O}$], and stilbite-Ca [hydrous calcium potassium sodium aluminosilicate, $(\text{Ca}_{0.5},\text{K},\text{Na})_9(\text{Al}_9\text{Si}_{27}\text{O}_{72})\cdot 28\text{H}_2\text{O}$].

Because of its zeolite-like appearance and occurrence, okenite is often erroneously thought to be a zeolite mineral. Zeolites are hydrous aluminosilicates that can lose and regain their water of hydration without altering their crystal structures. Okenite fails to qualify as a zeolite on two counts. First, aluminum is not one of its essential elemental components. Second, when heated, okenite will lose its water of hydration and transform into the mineral wollastonite [CaSiO_3], but it cannot regain its water of hydration.

As an idiochromatic or self-colored mineral, okenite's basic white color is caused by its essential elemental components and the nature of its crystal lattice. Impurities play only a minor role in shifting this basic color. The common impurities in okenite are strontium, sodium, potassium, and ferrous (Fe^{2+}) iron, of which only ferrous iron is a chromophore (color-causing agent). Traces of ferrous iron are responsible for the slight yellowish and bluish shifts in okenite's basic white color seen in some specimens.

COLLECTING LOCALITIES

Okenite is a relatively rare mineral that, although widely distributed, has few sources of fine specimens. Our okenite specimens were collected at the Khandivali Quarry (also called the Khandivali-Damupada Quarry) in the northern suburbs of the city of Mumbai in the Mumbai District of the state of Maharashtra in the Republic of India. Other okenite sources in Maharashtra include quarries at Vanidindori in the Nasik District, Gunjale in the Ahmed Nagar District, and Puna in the Puna District.

In Europe, okenite occurs at Strond and Nordoyri on Bordhoy Island in the Danish Faeroe Islands; in Germany at the Bramberg Quarry at Göttinger in Lower Saxony and at the Zeilberg Quarry at Franconia in

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Bavaria; in Hungary at the Kőszárhegy Quarry at Szár Hill in Fejér; in Italy in the basalt of the Schio-Valdagno Tunnel in Vicenza Province, Veneto; in Norway at the Sulitjelma Mine at Fauske in Nordland; in Austria at the Kirchdoff Tunnel at Frohnleiten, Styria; and in Northern Ireland at Scawt Hill at Larne in Antrim County. In Russia, okenite occurs in the Vuoriyarvi alkaline-ultrabasic massif on the Kola Peninsula in Murmansk Oblast' in the Northern Region. Okenite is also collected at its type locality at Qeqertarsuag (Disko) Island in Kitaa Province, Greenland.

Other okenite localities include Mt. Stormont in the Moina District of Tasmania, Australia; the Nunatak Battlements in Victoria Land, Antarctica; the Aranga Quarry at Northland on North Island, New Zealand; Río Putagan in Linares Province in the Maule Region of Chile; Pedernal at Bajo Chacones in San José Province, Costa Rica; the Noche Buena Mine at Mazapil in Zacatecas, Mexico; and the Hatrurim basalt formation in the Negev Desert in Israel.

In the United States, most okenite localities are in the western states and include Horseshoe Dam, Maricopa County, Arizona; the Crestmore quarries at Crestmore in Riverside County, California; the Skookumchuck highway cut in Idaho County, Idaho; the Georgetown mining district in Grant County, New Mexico; the Neer and Jaquish road cuts at Goble in Columbia County, Oregon; the East Tintic District in the East Tintic Mountains of Utah County, Utah; and the Rock Island Dam at Bucoda in Thurston County, Washington. In the eastern states, okenite occurs at the Fairfax Quarry at Centreville in Fairfax County, Virginia; and the Durham Quarry at Durham in Durham County, North Carolina.

JEWELRY & DECORATIVE USES

Because of its softness and flexibility, okenite has no use in jewelry. Collectors value okenite, both as individual and composite specimens with quartz and zeolite-group minerals for its rarity and unusual crystal form. In perfect condition, cabinet specimens with two-inch okenite "cotton balls" can sell for more than \$1,000 each. In recent years, some brightly colored lavender, green and pink okenite from China and India has sold for premium prices, but these specimens have been chemically dyed. Natural okenite is always white with only occasional yellowish or bluish tinges.

HISTORY & LORE

After wollastonite [calcium silicate, CaSiO_3] was discovered in 1818, okenite was the second calcium-silicate mineral to be identified. Mineralogists discovered okenite after studying specimens collected at Qeqertarsuag (Disko) Island off the coast of Kitaa Province in west-central Greenland, but initially classified it as a zeolite. It was initially classified as a zeolite until 1827, when German mineralogist Franz Ritter von Kobell (1803-1882) performed a blowpipe analysis of the specimens and found them devoid of aluminum, an essential element of the zeolite-group minerals. In 1828, German mineralogist August Johann Friedrich Breithaupt (1791-1873) published the first formal description of okenite and correctly classified it as a new, non-zeolite mineral species. Von Kobell then named the new mineral in honor of German naturalist and philosopher Lorenz Oken (1779-1851, see "Lorenz Oken and Others Honored Twice in Minerals Names"), whose writings on biology were then attracting widespread attention.

Mineralogists believed wollastonite and okenite to be the only calcium-silicate minerals until 1858, when they identified plombièreite [basic hydrous calcium silicate, $\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2 \cdot 7\text{H}_2\text{O}$]. The true complexity and diversity of the basic, hydrous, and basic-hydrous suite of calcium silicates became apparent with the discovery of tobermorite [basic hydrous calcium oxysilicate, $\text{Ca}_{4.5}\text{Si}_6\text{O}_{15}(\text{O},\text{OH})_2 \cdot 5\text{H}_2\text{O}$] in 1880. Later, newly developed X-ray-diffraction analytical methods later enabled mineralogists to identify riversideite [basic calcium silicate, $\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2$] in 1917 and afwillite [basic hydrous calcium silicate, $\text{Ca}_3(\text{SiO}_3\text{OH})_2 \cdot 2\text{H}_2\text{O}$] in 1925.

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In 1955, British researchers were studying specimens of a mineral thought to be okenite collected from the Crestmore quarries at Crestmore in Riverside County, California. Using both X-ray diffraction and spectrographic analysis methods, they determined that the specimens, while nearly identical in both physical and chemical properties to okenite, were actually those of a new mineral. They named this new species "nekoite," a name derived from the reverse spelling of Oken, thus making Lorenz Oken one of the few individuals to have two minerals named in their honor. Nekoite [hydrous calcium silicate, $\text{Ca}_3\text{Si}_6\text{O}_{15}\cdot 7\text{H}_2\text{O}$] differs from okenite only in the configuration of its silica radicals and the number of attached molecules of water of hydration. The ability to distinguish okenite from nekoite subsequently led to the discovery of jennite [basic hydrous calcium hydrogen silicate, $\text{Ca}_9\text{Si}_6\text{O}_{18}\text{H}_2(\text{OH})_8\cdot 6\text{H}_2\text{O}$] in 1966 and clinotobermorite [basic hydrous calcium oxysilicate, $\text{Ca}_5\text{Si}_6(\text{O},\text{OH})_{18}\cdot 5\text{H}_2\text{O}$] in 1986. Mineralogists believe that additional basic, hydrous, or basic-hydrous calcium-silicate minerals are still awaiting discovery. The atomic structure of okenite was defined in the early 1980s, when mineralogists also identified okenite as the first mineral known to share structural characteristics of both phyllosilicates and inosilicates.

Modern-day metaphysical practitioners believe that okenite provides a comforting energy that purifies one's physical, spiritual, emotional, and intellectual sides, and improves circulation, reduces fevers, and alleviates stomach disorders.

LORENZ OKEN AND OTHERS HONORED TWICE IN MINERAL NAMES

Okenite is named for German naturalist and philosopher Lorenz Oken (1779-1851). Born as Lorenz Ockenfuss into a farming family in the village of Bohlsbach (now part of Offenbach, Hessen, Germany), Oken studied natural science, medicine, and philosophy at the universities of Freiburg, Wurzburg, and Göttingen. At Göttingen, where he changed his name to Oken, he developed interests in subjects ranging from biology and minerals to optics and military history. Oken also became an adherent of the German naturphilosophie (physio-philosophical) school of thought that mixed natural history with philosophy and romanticism with science. His academic pursuits suffered when he involved himself with several government-suppressed, revolutionary youth movements. Nevertheless, in 1803, at age 24, he published Naturphilosophie (Natural Philosophy), a book that described the fundamental units of all living organisms as tiny, primal, living animals called "infusoria" or "animalcules." Oken believed that infusoria fused together to form higher organisms—a concept leading to the development of modern biological cell theory. Oken later extended his thoughts on basic units to minerals, theorizing that different minerals contained many common units—a concept that touched upon the basis of modern atomic theory.

At the time okenite was named in his honor in 1828, Oken was a prominent lecturer and well-known biological theorist at the University of Zurich in Switzerland. In 1955, more than a century after his death, the new mineral nekoite [$\text{Ca}_3\text{Si}_6\text{O}_{15}\cdot 7\text{H}_2\text{O}$] also honored Oken by spelling his name in reverse, earning him the rare distinction of having two unrelated minerals named for him. Today, about one-third of the approximately 4,400 recognized mineral species are named for individuals, but less than two dozen have two minerals named for them. Among them are:

Aleksandr Evgenevich Fersman (1883-1945), eminent Russian mineralogist, geochemist and gemologist: fersmanite [calcium sodium titanium niobium oxyfluorosilicate, $(\text{Ca},\text{Na})_2(\text{Na},\text{Ca})_2(\text{TiNb})_2(\text{Si}_2\text{O}_7)\text{O}_4\text{F}$] and fersmite [basic calcium cesium sodium niobium tantalum titanium oxyfluorosilicate, $(\text{Ca},\text{Ce},\text{Na})(\text{Nb},\text{Ta},\text{Ti})_2(\text{O},\text{OH},\text{F})_d$].

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Andor von Semsey (1833-1923), Hungarian nobleman and prominent amateur mineralogist: andorite [lead silver antimony sulfide, $PbAgSb_3S_6$] and semseyite [lead antimony sulfide, $Pb_9Sb_8S_{21}$].

Arthur Edward Ian Montagu Russell (1878-1964), British mineralogist: arthurite [hydrous basic copper iron arsenate, $CuFe_2(AsO_4)_2(OH)_2 \cdot 4H_2O$] and russellite [bismuth tungstate, Bi_2WO_6]. Arthurite is co-named with British mineralogist Arthur William Gerald Kingsbury (1906-1968).

Brian Harold Mason (1917-), New Zealand-born mineralogist, pioneer in the study of meteorites, and Curator Emeritus of the meteorite collection of the Smithsonian Institution: brianite [sodium calcium magnesium phosphate, $Na_2CaMg(PO_4)_2$] and stenhuggarite [calcium iron antimony arsenate, $CaFe(AsO_2)(AsSbO_5)$]. Stenhuggarite is derived from stenhuggar, Swedish for "stonemason," and honors Mason's classical studies at Sweden's Långban mineral deposit.

Caleb Wroe Wolfe (1908-1980), American crystallographer and professor of mineralogy at Boston University: wolfeite [basic iron phosphate, $Fe_2(PO_4)(OH)$] and wroewolfeite [basic hydrous copper sulfate, $Cu_4(SO_4)(OH)_6 \cdot 2H_2O$].

Charles Locke Key (1935-), American mineral dealer: keyite [hydrous copper zinc cadmium arsenate, $Cu_3(Zn,Cu)_4Cd_2(AsO_4)_6 \cdot 2H_2O$] and ludlockite [lead iron arsenate, $PbFe_4As_{10}O_{22}$]. Ludlockite is co-named with American mineral dealer F. Ludlow Smith III.

Clifford Frondel (1907-2002), American mineralogist and author of two editions of Dana's System of Mineralogy: cliffordite [uranium tellurium oxide, UTe_3O_9] and frondelite [basic manganese iron phosphate, $MnFe_4(PO_4)_3(OH)_5$].

Eugen Friedrich Stumpfl (1931-), Austrian professor of mineralogy at the Mining University in Loeben, Austria: eugenite [silver mercuride, $Ag_{11}Hg_2$] and stumpflite [platinum antimonide, $PtSb$].

Gabriel Auguste Daubrée (1814-1896), French mineralogist and geologist: daubréeite [basic bismuth oxychloride, $BiO(OH,Cl)$] and daubréelite [iron chromium sulfide, $FeCr_2S_4$].

Jöns Jacob Berzelius (1779-1848), Swedish baron and chemist, and a founder of modern chemistry: berzelianite [copper selenide, Cu_2Se] and berzeliite [calcium sodium magnesium manganese arsenate, $(Ca,Na)_3(Mg,Mn)_2(AsO_4)_3$].

Kin-ichi Sakurai (1912-1993), Japanese mineral collector, amateur mineralogist, and author: kinichilite [hydrous magnesium manganese iron tellurate, $Mg_{0.5}(Mn,Fe)(TeO_3)_3 \cdot 4.5H_2O$] and sakuraiite [copper zinc indium iron tin sulfide, $(Cu,Zn,In,Fe,Sn)S$].

Leo Neal Yedlin (1908-1997), American micromount mineral collector: nealite [hydrous lead iron arsenochloride, $Pb_4Fe(AsO_3)Cl_4 \cdot 2H_2O$] and yedlinite [basic lead chromium oxychloride, $Pb_6CrCl_6(O,OH)_8$].

Toshio Sudo (1911-), Japanese crystallographer and professor of mineralogy at the University of Tokyo: sudoite [basic magnesium aluminum oxysilicate, $Mg_2Al_3(Si_3Al)O_{10}(OH)_8$] and the clay mineral tosudite [basic hydrous sodium aluminum magnesium oxysilicate, $Na_{0.5}(Al,Mg)_6(Si,Al)_8O_{18}(OH)_{12.5} \cdot 5H_2O$].

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Marie Curie-Sklodowska (1867-1934), Polish-born French chemist, Nobel Prize winner, and researcher of radioactivity: curite [hydrous lead uranate, $Pb_2U_5O_{17} \cdot 4H_2O$] and sklodowskite [hydrous magnesium uranium oxysilicate, $Mg(UO_2)_2Si_2O_7 \cdot 6H_2O$]. Curite is co-named with her husband, French chemist Pierre Curie. Cuprosklodowskite [$Cu(UO_2)_2Si_2O_7 \cdot 6H_2O$] is named for its similarity to sklodowskite.

Neil Alden Armstrong (1930-), American astronaut and the first human to set foot on the moon: armalcolite [magnesium iron titanium oxide, $(Mg,Fe)Ti_2O_5$] and armstrongite [hydrous calcium zirconium silicate, $CaZr(Si_6O_{15} \cdot 3H_2O)$]. The acronym "armalcolite" honors ARMstrong and the other two Apollo 11 astronauts, Edwin "Buzz" ALdrin and Michael COLlins.

Pierre Berthier (1782-1861), French geologist: berthierine [basic iron aluminum oxysilicate, $(Fe,Al)_3(Si,Al)_2O_5(OH)_4$] and berthierite [iron antimony sulfide, $FeSb_2S_4$].

TECHNOLOGICAL USES

Since the 1950s, industrial researchers have studied okenite and other calcium-silicate minerals in depth to determine the precise nature of the chemical interaction of basic, hydrous, and basic-hydrous calcium silicates in order to improve the qualities of modern Portland-type cements. Okenite has been synthesized in laboratories and researchers are assessing the possible use of synthetic okenite as a catalyst in dehydrogenation (cracking) processes for petrochemical and other hydrocarbon feedstocks.

ABOUT OUR SPECIMENS

Our specimens were collected at the Khandivali Quarry (also called the Khandivali-Damupada Quarry) near the city of Mumbai in the Mumbai District of the Maharashtra state of the Republic of India. The city of Mumbai (formerly Bombay), located in west-central India on the coast of the Arabian Sea, is India's leading commercial and cultural center. Mumbai has one of the world's finest deepwater ports and a population in the city proper of 14 million, giving it a population density of 57,000 per square mile—more than twice that of New York City. Mumbai's northern suburbs are home to an additional six million residents. The Khandivali Quarry is 25 miles north of the center of Mumbai in the Damupada section of the suburb city of Khandivali. The Khandivali Quarry, one of several local basalt (traprock) quarries, opened in the 1860s to supply building stone for Bombay. The quarries near the suburbs of Khandivali and Malad are famed for their "Malad stone," a very fine-grained, durable basalt that was used to construct many of old Bombay's largest and most impressive buildings. Since the Mumbai suburbs began an ongoing period of rapid growth in the 1980s, quarry operations have been increasingly restricted to reduce dust and noise in the encroaching residential and business areas.

The entire state of Maharashtra falls within the Deccan Traps, a huge volcanic province that covers much of west-central India. The eruptions that created the Deccan Traps began about 68 million years ago and continued for 8 million years. During that time, they extruded an estimated 300,000 cubic miles of basaltic magma onto the surface in multiple phases of massive lava floods that formed countless superposed layers of basalt ranging in thickness from 3 to 400 feet. Today, the Deccan volcanic formations cover some 200,000 square miles to a depth of as much as 6,000 feet. Basalt is an extrusive igneous rock that forms directly from the solidification of magma. Volcanic rocks usually cool quickly and have generally smooth textures with no visible crystals (aphanitic texture, which is typical of Deccan basalts) or only very small crystals scattered through a dense matrix (porphyritic texture). Basalt is a low-silica rock in which large amounts of iron and magnesium minerals impart a dark color. Hard, durable, and dense, basalt is widely used throughout west-central India as a building stone and cement additive, and as ballast-fill material for construction of roads, railroads, and building foundations.

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The collectible minerals of the Deccan Traps occur in cavities or vesicles within the basalt that formed from gas bubbles when the original magma solidified. These vesicles range in size from less than an inch to many feet and were initially devoid of secondary mineralization. But fissures and fractures enabled alkaline, mineral-rich groundwater to circulate through the basalt, where it filled many vesicles and precipitated such minerals as quartz, calcite, prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$], and many zeolite-group minerals. Vesicles that are filled with these secondary minerals are known as “amygdules.”

Since commercial mineral-specimen collecting at India’s basalt quarries became a business in the 1960s, the Khandivali Quarry has supplied many fine crystals of okenite, prehnite, calcite, quartz, gyrolite [basic hydrous sodium calcium aluminosilicate, $(\text{NaCa})_2\text{Ca}_{14}(\text{Si}_{23}\text{Al})\text{O}_{60}(\text{OH})_8 \cdot (14+x)\text{H}_2\text{O}$], fluorapophyllite [basic hydrous potassium calcium fluorosilicate, $\text{KCa}_4\text{Si}_8\text{O}_{20}(\text{F},\text{OH}) \cdot 8\text{H}_2\text{O}$], the zeolite mineral laumonite [hydrous calcium aluminum silicate, $\text{Ca}_2(\text{Al}_8\text{Si}_{16}\text{O}_{25}) \cdot 25\text{H}_2\text{O}$], and pseudomorphs of prehnite-after-laumonite. At Khandivali and many other Indian basalt quarries, commercial collectors contract with quarry managers for permission to collect specimens when they are exposed by quarrying operations. Specimens are then passed along to buyers in Mumbai who in turn export them to world markets. Because of continuing population growth and residential and business construction in Mumbai’s northern suburbs, operations at Khandivali will soon be phased out completely, and the quarry will no longer be a source of specimens.

Okenite is often confused with zeolite minerals not only because of its similar appearance and occurrence, but because Indian exporters have traditionally included okenite specimens in zeolite shipments and sometimes even mislabeled okenite as a zeolite mineral, an error that is unknowingly perpetuated by some foreign specimen dealers. Our Indian exporters must be credited for their fine work of carefully and individually packing our specimens to prevent damage to the delicate, hairlike okenite crystals.

The Mumbai region has a generally flat topography except for Gilbert Hill. Located a few miles south of the Khandivali Quarry, Gilbert Hill is a 200-foot-high, sheer-faced, monolithic column of black basalt. It was formed some 65 million years ago during the height of the Deccan eruptions when thickening lava was “squeezed” upward from a rapidly cooling and contracting lava flood to form a ridge. Slow weathering of this ridge-like mass of basalt eventually created distinctive, hexagonal, columnar jointing (parallel fracturing with no relative movement) along sheer cliffs. Over time, this ridge proved considerably more erosion-resistant than did the surrounding lava formations. A century of quarrying at Gilbert Hill has reduced the original, long ridge into a roughly circular, monolithic column of basalt. In 2007, the Greater Mumbai Municipal Corporation declared the hill a heritage area which prohibits any further nearby quarrying. The flat summit of the hill, accessible by a stairway carved into the cliffs, offers a panoramic view of Mumbai to the south. At the top, the Gaodevi and Durgamata Hindu temples are set amid terraced gardens. Gilbert Hill is geologically similar to other jointed basalt “tower” formations located in the U.S. at Wyoming’s Devils Tower National Monument and California’s Devils Postpile National Monument.

When handling and examining your okenite specimen, remember that the thin, hairlike okenite crystals that create the distinctive “fuzzy” or “cotton ball” appearance are very fragile and should not be touched unnecessarily. Also, when storing or transporting the specimen, be sure to wrap it in a manner that completely protects its surface. The okenite in our specimens appears as white, hemispherical structures covered with delicate, hairlike crystals. The hemisphere itself is a solid, radial fibrous mass of tightly packed okenite crystals; the hairlike protrusions are individual okenite crystals. The elasticity and flexibility of these crystals can be demonstrated by touching them gently with a needle or toothpick. (Oil or dirt from our fingers may baffle the okenite, and there is no way to clean it without damaging the hairlike crystal fibers. So if you want your specimen to stay clean and intact, keep all fingers away!) These long, elastic, flexible crystals reflect the combined structural characteristics of both the phyllosilicates (sheet silicates) and the inosilicates (chain silicates).

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Our Gold-level and Platinum-level okenite specimens are composites which may include several other interesting minerals. The thin, white or greenish-white layer directly atop the basalt is prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$]. The thin layer atop the prehnite is drusy quartz that appears as a glittering, sugary coating; inspection with a 10x loupe will reveal the hexagonal prisms with pyramidal terminations that are characteristic of quartz. The smooth, white hemispherical structures (without the hairlike okenite crystals) are gyrolite [basic hydrous sodium calcium aluminosilicate, $(\text{NaCa})_2\text{Ca}_{14}(\text{Si}_{23}\text{Al})\text{O}_{60}(\text{OH})_8 \cdot (14+x)\text{H}_2\text{O}$]. Occasionally present are quarter-inch, colorless, transparent crystals of calcite that are actually pseudomorphs after fluorapophyllite [basic hydrous potassium calcium fluorosilicate, $\text{KCa}_4\text{Si}_8\text{O}_{20}(\text{F},\text{OH}) \cdot 8\text{H}_2\text{O}$]. These calcite-after-fluorapophyllite crystals can appear at first glance to be cubic, but they are actually elongated along one axis—the tetragonal-prism habit of the original fluorapophyllite crystals. Black calcite crystals are occasionally seen, and the okenite cotton balls often crystallize on top of these!

The okenite and the other minerals in our specimens rest atop a base of dark, fine-grained basalt and is actually a small section of a cavity wall. Because this basalt is very hard and durable, the extraction of intact specimens of okenite and associated minerals within the cavities is exceedingly difficult. The commercial collectors who gather these specimens employ such special tools as electric or pneumatic rock drills and hydraulic splitters. They first drill three-quarter-inch-diameter holes into the basalt around a partially exposed, crystal-filled cavity, then insert a three-piece splitter rod consisting of two half-rod sections and a center wedge into the drill hole. They then hydraulically drive the center wedge between the half-rod sections to exert outward pressure that splits the adjacent basalt. This job requires considerable experience, because the placement, number, and depth of the drill holes are critical for the recovery of “plates” of basalt with intact cavity crystals. As you examine your okenite specimen, remember that a great deal of work went into its recovery!

Twice in this write-up we have recommended you try to resist touching your okenite cotton balls, difficult as it may be to fight the urge to touch. This reminds us of a common problem we encounter when displaying okenite and other very delicate minerals at shows. It is not practical for us to bring huge showcases so as to keep delicate specimens behind glass, and we like to have our minerals where they can easily be seen (but hopefully not touched) by show attendees. We have several “Do Not Touch” signs throughout our booth, but in the excitement of the show, it is easy for people to get carried away. At some of the larger Gem & Mineral Club-sponsored shows, field trips are arranged to bring in hundreds of schoolchildren to visit the shows, a wonderful way to encourage their natural interest in rocks and minerals. However, in their youthful exuberance, despite our gentle reminders to the contrary, some seem to want to touch every single specimen in the booth. We try to direct their attention to our tumbled stones and small quartz crystals, which are not damaged by handling, and this generally solves the problem. We also encourage parents and teachers to more closely supervise the young ones, and we want to commend all our young Club members who respectfully examine minerals at shows without touching (or at least asking the dealer’s permission first). Keep up the good work!

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