

Mineral of the Month Club April 2015

GYROLITE with APOPHYLLITE-(KF)

Gyrolite, an uncommon, complex aluminosilicate, occurs with zeolites, although it is not a zeolite mineral itself. Our specimens were collected in India, and our write-up explains gyrolite's mineralogy and history, and also discusses the causes of mineral density and how it is expressed numerically in terms of specific gravity.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $(\text{NaCa}_2)\text{Ca}_{14}(\text{Si}_{23}\text{Al})\text{O}_{60}(\text{OH})_8 \cdot (14+x)\text{H}_2\text{O}$ Basic Hydrous Sodium Calcium Aluminosilicate (Basic Hydrous Sodium Calcium Aluminum Silicate)

Class: Silicates

Subclass: Phyllosilicates (Sheet Silicates)

Group: Reyerite

Subgroup: Gyrolite

Crystal System: Triclinic

Crystal Habits: Usually as groups of radiating, lamellar crystals that form spherules, nodular aggregates, or concretions; sometimes granular, compact, or as platy, mica-like masses.

Color: Usually colorless or white; sometimes pale shades of brown, green, or yellow.

Luster: Vitreous to dull

Transparency: Transparent to translucent, occasionally opaque.

Streak: White

Cleavage: Perfect in one direction

Fracture: Uneven, brittle.

Hardness: 2.5-3.5

Specific Gravity: 2.4-2.5

Luminescence: Often fluoresces white under shortwave and long-wave ultraviolet light

Refractive Index: 1.535-1.549

Distinctive Features and Tests: Frequent occurrence as spherules in vesicles of hydrothermally altered basalt and basaltic tuffs; association with apophyllite-(KF) [basic hydrous potassium calcium fluorosilicate, $\text{KCa}_4\text{Si}_8\text{O}_{20}(\text{F},\text{OH}) \cdot 8\text{H}_2\text{O}$], okenite [hydrous calcium silicate, $\text{Ca}_5\text{Si}_9\text{O}_{23} \cdot 9\text{H}_2\text{O}$], and such zeolite minerals as stilbite-Ca [hydrous calcium sodium potassium aluminum silicate, $\text{Ca}_{0.5}\text{K},\text{Na}_9(\text{Al}_9\text{Si}_{27}\text{O}_{72}) \cdot 28\text{H}_2\text{O}$]. Unlike other similar-looking minerals such as prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$] and smithsonite [zinc carbonate, ZnCO_3], gyrolite forms individual spherules rather than continuous, botryoidal or crustal growths. Gyrolite loses water when mildly heated.

Dana Classification Number: 73.2.2c.1

NAME: The name "gyrolite," pronounced JYE-row-lite, stems from the Greek word *gyros*, meaning "circular" and alluding to the mineral's frequently spherical form. Gyrolite was also

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known as “centrallasite.” The former names “glimmer zeolite” and “round zeolite” were used in the 1800s, when gyrolite was mistakenly thought to be a zeolite-group mineral. In European mineralogical literature, gyrolite appears as *gurolite*, *gyrolita*, *Gyrolit*, and *Centrallasit*.

COMPOSITION: Gyrolite’s molecular weight is made up of 0.64 percent sodium, 17.88 percent calcium, 0.75 percent aluminum, 18.01 percent silicon, 58.90 percent oxygen, and 3.82 percent hydrogen. It is a member of the silicates, the largest of all mineral groups, in which oxygen and silicon combine with one or more metals. The structural and chemical foundation of all silicate minerals is the silica tetrahedron (SiO_4)⁴⁻, in which four equally spaced oxygen ions surround a silicon ion. Gyrolite is a phyllosilicate or sheet silicate, specifically a two-layer, sheet silicate consisting of alternating sheets of aluminosilicate tetrahedra and octahedral, along with sheets of metal cations. The tetrahedral sheets and octahedral sheets are grouped in units and separated by layers of sodium and calcium ions and attached water molecules. Gyrolite is an allochromatic (other-colored) mineral, meaning that its colors are caused by traces of nonessential elements. It is colorless or white when pure or nearly pure, but trace impurities impart a range of pale colors. Most gyrolite is white or colorless. Subtle green hues are caused by traces of iron or nickel that substitute for calcium. Iron creates pale yellows and browns, while manganese creates pale pinks. Gyrolite is a secondary mineral that primarily forms at low temperatures in vesicular (gas-formed) cavities of basaltic rock. Mineral-rich groundwater eventually fills some of the vugs and precipitates such minerals as gyrolite; quartz [silicon dioxide, SiO_2]; calcite [calcium carbonate, CaCO_3]; an array of zeolite minerals (a group of hydrous aluminosilicates); prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$]; and apophyllite-(KF) and other apophyllite-group minerals. Gyrolite also occurs, to a lesser extent, in cavities within metamorphic contact zones where igneous rock has intruded limestone.

COLLECTING LOCALITIES: The finest gyrolite specimens are collected in the basalt quarries of several districts in Maharashtra, India. Other sources are in Canada, China, Australia, Costa Rica, Czech Republic, Denmark, Iceland, Italy, Japan, Norway, Romania, Russia, Slovakia, Northern Ireland, Ukraine, Greenland, and the United States (Arizona, California, Idaho, New Jersey, North Carolina, Utah, Virginia, Wyoming, and Oregon).

HISTORY, LORE & USES: Dr. Thomas Anderson, a Scottish medical doctor and professor of chemistry at Glasgow University, identified gyrolite as a new mineral species in 1861, after studying specimens collected at Isle of Skye, Scotland. Although the structure of gyrolite was first generally defined by X-ray diffraction methods in 1926, the details of its lattice structure were not understood until the 1950s. Because of its softness and relative rarity, gyrolite has very limited use in jewelry. Small spherules of gyrolite are occasionally wire-wrapped and worn as pendants, usually for metaphysical purposes. Metaphysical practitioners believe that gyrolite positively affects the metaphysical properties of other crystals by activating and cleansing them. Gyrolite is thought to connect the physical body with spiritual realms, enhance meditation, and provide access to the wisdom, insight, and willpower of ancient civilizations. It also promotes self-confidence and overcomes excessive introversion and addictive behaviors. Physically, gyrolite is thought to stimulate the assimilation of calcium, help align the spine, enhance bone structure, and promote cellular maintenance. Gyrolite is also used to assist in acupuncture therapy by stimulating the flow of energy through the nervous system. Although gyrolite has no technological uses, it has served as the chemical model for its own laboratory synthesis.

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Gyrolite's chemistry and structure are studied extensively because of their similarity to the chemistry and structure of certain calcium-silicate compounds in portland cement. Gyrolite is collected for its relative rarity, complex chemistry, and generally spherical shapes. It is popular both as individual specimens and as composite specimens with other minerals.

ABOUT OUR SPECIMENS: Our gyrolite with apophyllite-(KF) specimens were collected from basalt quarries near the city of Mumbai (formerly Bombay) in the Mumbai District, Maharashtra, Republic of India. Maharashtra is located entirely within the Deccan Traps, a huge volcanic province that covers much of west-central India. The Deccan Traps were created by massive, prolonged, volcanic eruptions that began some 68 million years ago. In the Deccan Traps, collectible minerals occur in cavities or vesicles within basalt that formed from gas bubbles when magma was extruded and solidified. These vesicles, which range from less than an inch to many feet in size, were initially devoid of mineralization. Fissures and fractures later enabled mineral-rich, alkaline groundwater to circulate through the basalt to fill the vesicles and precipitate gyrolite, apophyllite-(KF), and other minerals. The Mumbai District quarries have provided many fine crystals of gyrolite, apophyllite-(KF), okenite, prehnite, calcite, quartz, and a host of zeolite minerals. At the Mumbai quarries, commercial collectors contract with quarry managers for permission to collect specimens when they become exposed by quarrying operations. Because of continuing population growth and development in the Mumbai area, many basalt quarries are closing and will no longer be sources of mineral specimens.

COMPREHENSIVE WRITE-UP

COMPOSITION

Our Mineral of the Month specimens are composites of gyrolite and apophyllite-(KF). Composite specimens consist of two minerals that are more-or-less equally prominent. Because we have already featured apophyllite-(KF) as our Mineral of the Month in December 2013, we have chosen gyrolite—a mineral not previously featured—as our primary mineral for this write-up. While describing gyrolite in detail, we also include an account of the chemical and physical properties of apophyllite-(KF) (see “About Our Specimens”).

Gyrolite's standard chemical formula $(\text{NaCa}_2)\text{Ca}_{14}(\text{Si}_{23}\text{Al})\text{O}_{60}(\text{OH})_{8 \cdot (14+x)}\text{H}_2\text{O}$ shows that it is a basic hydrous sodium calcium aluminosilicate consisting of the elemental components sodium (Na), calcium (Ca), aluminum (Al), silicon (Si), oxygen (O), and hydrogen (H). Its molecular weight is made up of 0.64 percent sodium, 17.88 percent calcium, 0.75 percent aluminum, 18.01 percent silicon, 58.90 percent oxygen, and 3.82 percent hydrogen. Gyrolite's standard chemical formula is written to reflect its structure as an aluminosilicate. Gyrolite's formula can also be written as $(\text{NaCa}_2)\text{Ca}_{14}\text{Al}(\text{Si}_{23}\text{O}_{60})(\text{OH})_{8 \cdot (14+x)}\text{H}_2\text{O}$ to more clearly express its composition as a silicate mineral.

All molecules are composed of positively charged cations and negatively charged anions. Gyrolite's triple cation consists of the linked sodium-calcium unit $(\text{NaCa}_2)^{5+}$ with its collective +5 charge, 14 calcium ions 14Ca^{2+} with their +28 charge, and a single aluminum ion Al^{3+} with its +3 charge. This gives the gyrolite cation a cumulative +36 charge. Gyrolite's double anion

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consists of the silicate radical $(\text{Si}_{23}\text{O}_{60})^{28-}$ with its -28 charge and eight hydroxyl ions $8(\text{OH})^{1-}$ with their collective -8 charge. Expressed ionically, the complete gyrolite cation is $[(\text{NaCa}_2)\text{Ca}_{14}\text{Al}]^{28+}$, while the complete anion is $(\text{Si}_{23}\text{O}_{60})^{28-}$. This balance of cationic and anionic charges imparts electrical stability to the gyrolite molecule.

In gyrolite's chemical formula, the " $\cdot(14+x)\text{H}_2\text{O}$ " indicates that the gyrolite molecule has at least 14 attached water molecules that are collectively called "water of hydration." Water of hydration is bound to the parent molecule as integral water molecules that retain their characteristic composition and structure. Because these attached water molecules are electrically neutral, they function neither as cations nor anions and do not affect the electrical balance of the molecule. In water molecules, each oxygen ion O^{2-} is bound covalently by shared electrons to two hydrogen ions 2H^{1+} . The two small hydrogen ions are grouped together on one side of the large oxygen ion. This creates a dipolar effect, with the two grouped hydrogen ions retaining a small positive charge and the opposite side of the molecule, dominated by the large oxygen ion, retaining a small negative charge. Water of hydration is attached to the parent molecule by hydrogen bonding (also called "polar bonding"), in which the water molecules' faintly positive poles are attracted to negative charges.

Gyrolite is a member of the silicates, the largest of all mineral groups, in which oxygen and silicon are combined with one or more metals. The structural and chemical foundation of all silicate minerals is the silica tetrahedron $(\text{SiO}_4)^{4-}$, which consists of a silicon ion surrounded by four equally spaced oxygen ions. Silicate minerals consist of silica anions bound to metal cations in repeating structural units that form seven general 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).

The phyllosilicates, which include gyrolite, are also known as "sheet silicates," a term that describes their crystal structure. In phyllosilicates, each silica tetrahedron shares three oxygen ions with adjacent tetrahedra. This inter-molecular arrangement forms very thin, sheet-like structures that extend indefinitely in two directions. Within these flat sheets, the silica tetrahedra are arranged in three-, four-, five-, six-, or eight-membered rings. Gyrolite has alternating four-membered (tetrahedral) rings and eight-membered (octahedral) rings. Sheet silicates are subclassified structurally into two-layer and three-layer groups. As a two-layer sheet silicate, gyrolite consists of alternating sheets of aluminosilicate tetrahedra and octahedra, along with those of metal cations. The tetrahedral and octahedral sheets are grouped in units and separated by a complex layer of sodium ions, calcium ions, and attached water molecules. Ionic bonding holds these alternating aluminosilicate and metal-cation sheets together. The gyrolite lattice thus has three distinct types of atomic bonds: covalent bonds within the silica tetrahedra; ionic bonds between the metal-cation sheets and aluminosilicate sheets; and hydrogen bonds that attach the water of hydration.

Gyrolite crystallizes in the triclinic system, which has three axes of different lengths, none being perpendicular to the others. This arrangement results in a low symmetry that produces poorly developed crystals, as is the case with gyrolite, which rarely, if ever, forms distinct, individual

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crystals. Chemically complex compounds, such as gyrolite, often crystallize in the triclinic system.

The dominant, weak ionic bonding between the stacked sheets gives gyrolite a low Mohs hardness of 2.5-3.5 and also accounts for its perfect, one-directional cleavage. Gyrolite's low specific gravity of 2.4-2.5, roughly 10 percent less than that of quartz [silicon dioxide, SiO₂], is primarily caused by the low atomic weights of its essential elemental components (sodium, 22.99; calcium, 40.00; aluminum, 26.98; silicon, 28.09; oxygen, 16.00; hydrogen, 1.01) and, to a lesser extent, by loose atomic packing. One of gyrolite's diagnostic properties is its tendency to lose its water of hydration when heating separates the hydrogen bonds that attach the water of hydration. Higher levels of heat will break all the hydrogen bonds, dehydrating the crystal completely, disrupting all the ionic bonding, and causing it to deteriorate into amorphous particles.

Because of their close association with zeolite minerals and their occurrence in the same mineralogical environments, both gyrolite and apophyllite-(KF) are often erroneously assumed to be zeolite minerals. Zeolites are hydrous aluminosilicates that are structurally classified as tectosilicates (framework silicates). Zeolites have the unusual ability to lose and regain water of hydration without altering their crystal structure. Although gyrolite and apophyllite-(KF) are both phyllosilicates, they do have certain zeolitic properties and can lose *some* of their water of hydration without altering their crystal structure. However, unlike the zeolite minerals, gyrolite and apophyllite-(KF) cannot regain their water of hydration.

As an allochromatic (other-colored) mineral, the colors in gyrolite are caused by traces of nonessential elements. When pure or nearly pure, gyrolite is colorless or white, but trace impurities impart a limited range of pale colors. Green hues are caused by traces of iron or nickel that substitute for calcium. Traces of iron create subtle-yellow hues, while traces of manganese create pale shades of pink.

The Dana classification number 73.2.2c.1 first identifies gyrolite as a phyllosilicate consisting of tetrahedral sheets with a two-dimensional, infinite sheet structure. The subclassification (2) defines it as a phyllosilicate with both single and double layers. Finally, gyrolite is assigned to the gyrolite subgroup (2c) of the reyerite group as the only member (1). The four reyerite subgroups have only nine members; with the single exception of gyrolite, all are rare.

Gyrolite is a secondary mineral that primarily crystallizes primarily at low temperatures in vesicular (gas-formed) cavities of basaltic rock. In this process, when magma is extruded, gas bubbles form as pressure is reduced. As magma cools and solidifies, these gas bubbles create vugs or cavities. Over time, the circulation of mineral-rich groundwater through the basalt partially or completely fills these vugs and precipitates such minerals as gyrolite; quartz [silicon dioxide, SiO₂]; calcite [calcium carbonate, CaCO₃]; an array of zeolite minerals (a group of hydrous aluminosilicates); prehnite [basic calcium aluminum silicate, Ca₂Al₂Si₃O₁₀(OH)₂]; and apophyllite-(KF) and other apophyllite-group minerals. Gyrolite also occurs, to a lesser extent, in cavities within metamorphic contact zones where igneous rock has intruded limestone.

COLLECTING LOCALITIES

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Our gyrolite specimens were collected at quarries in the basalt formations of the Deccan Traps near the city of Mumbai, Mumbai District, Maharashtra state, Republic of India. Other collecting localities in Maharashtra include basalt quarries at Pashan in Pune District; Nashik and Mahadari in Nashik District; and Rahuri and Gunjalin in Ahmadnagar District.

In Canada, gyrolite is collected at the Lac d'Amiante Mine, Saint-Joseph-de-Coleraine, Chaudière-Appalaches, Québec; the Chipman Brook and Black Rock areas on the Bay of Fundy, Kings County, Nova Scotia; and Horse Lake in the Cariboo Mining District, British Columbia. Other localities worldwide include the Fushan Mine, She County, Handan Prefecture, Hebei Province, China; the Upper Mersey Valley, Tamar Valley, Marrawah, Central Plateau, and Bumie district, all in Tasmania, Australia; La Garita, Alajuela Province, Costa Rica; Provodín-Puchavec, Liberec Region, Bohemia, Czech Republic; the Vágur, Streymoy, and Eysturoy islands, Faroe Islands, Denmark; Suður-Múlasýsla, Reydarfjörður, and Neskaupsúður areas, Eastern Region, Iceland; the San Marco basalt quarry at Gambellara in Vicenza Province and Contrada Baggatei at Vestenanuova in Verona Province, both in Italy; the Kamagawa Mine, Awa-gun, Chiba Prefecture, Kanto Region, Honshu Island, Japan; the Charlotta Mine at Sulitjelma, Fauske, Nordland, Norway; Valea Arsului, Crișcior, Brad, Hunedoara County, Romania; Noris'lk, Taimyr Peninsula, Taymyrskiy Autonomous Okrug, Eastern-Siberian Region, Russia; Vechec, Vranov nad Top'lou County, Prešov Region, Slovakia; the Pervomaiskiy Quarry, Trudolyubovka, Crimea Peninsula, Crimea Oblast', Ukraine; and Qaasut on the Nuussug Peninsula on Greenland's west-central coast. In Northern Ireland, gyrolite is collected at quarries at Squires Hill, Roughfort, Broughshane, Belfast, Ballymana, and Ballyclare, all in County Antrim.

In the United States, gyrolite occurs in the Tombstone district mines, Cochise County, Arizona; the Crestmore quarries, Crestmore, Riverside County, California; Pinehurst, Adams County, Idaho; Laurel Hill, Secaucus, Hudson County, New Jersey; Durham Quarry, Durham County, North Carolina; the Bingham Canyon copper mine in the Oquirrh Mountains, Salt Lake County, Utah; the Manassas quarries in Fairfax County and the Chantilly quarry at Chantilly in Loudoun County, both in Virginia; and Upper Geyser Basin, Yellowstone National Park, Park County, Wyoming. In Oregon, gyrolite is found at the Newberry Caldera, East Lake, Deschutes County; the Ritter Quarry at Ritter, Grant County; Harper Mountain near Spray, Wheeler County; Oceanside, Tillamook County; and the Green Peter Dam at Sweet Home, Linn County.

JEWELRY & DECORATIVE USES

Gyrolite's use in jewelry is very limited because of its pale colors, softness (Mohs 2.5-3.5), the somewhat fibrous nature of its poorly developed crystals, and its sensitivity to heat generated during the cutting and soldering processes. Small spherules of gyrolite are occasionally wire-wrapped and worn as pendants, usually for metaphysical purposes.

Gyrolite is popular among mineral collectors because of its relative rarity, unusual and complex chemistry, and generally spherical shapes. It is most popular in composite specimens with such minerals as apophyllite-(KF) [basic hydrous potassium calcium fluorosilicate,

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$\text{KCa}_4\text{Si}_8\text{O}_{20}(\text{F},\text{OH})\cdot 8\text{H}_2\text{O}$]; prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$]; okenite [hydrous calcium silicate, $\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$], and many zeolite minerals such as stilbite-(Ca) [hydrous calcium sodium potassium aluminum silicate, $\text{Ca}_{0.5}\text{K},\text{Na})_9(\text{Al}_9\text{Si}_{27}\text{O}_{72})\cdot 28\text{H}_2\text{O}$], all of which provide attractive and interesting contrasts in color, crystal form, and degrees of transparency.

HISTORY & LORE

Dr. Thomas Anderson, a Scottish medical doctor and professor of chemistry at Glasgow University, identified gyrolite as a new mineral species in 1851, after studying specimens collected at Isle of Skye, Scotland. Anderson named the new mineral “gyrolite” after the Greek word *gyros*, meaning “circular” and alluding to its spherical form. Anderson published his findings in 1861 in *Philosophical Magazine*, one of the oldest English-language, scientific journals. The type locality for gyrolite is Portree, Trotternish, Isle of Skye, North West Highlands, Scotland. Initially, gyrolite was erroneously thought to be a zeolite mineral. Gyrolite’s crystallography was first studied using X-ray diffraction methods in 1926, but the details of its complex structure were not determined until the 1950s.

Metaphysical practitioners believe that gyrolite positive affects the metaphysical properties of other crystals by activating and cleansing them. It is thought to connect the physical body with spiritual realms, enhance meditation, and provide access to the wisdom, insight, and willpower of ancient civilizations. It also promotes self-confidence and overcomes excessive introversion and addictive behaviors. Physically, gyrolite is believed to stimulate the assimilation of calcium, help align the spine, enhance bone structure, and promote cellular maintenance. Gyrolite is also used in acupuncture therapy to stimulate the flow of energy through the nervous system.

TECHNOLOGICAL USES

Unlike other, more abundant zeolite minerals, gyrolite has no technological uses. Gyrolite has, however, served as the chemical model for its own laboratory synthesis. Its chemistry and structure have been studied extensively because of their similarity to the chemistry and structure of certain calcium-silicate compounds in portland cement.

MINERAL DENSITY AND SPECIFIC GRAVITY

Our write-ups always state the specific gravity of each Mineral of the Month specimen. In this month’s write-up, we note that the specific gravity of gyrolite is 2.4-2.5, while that of apophyllite-(KF) is only slightly lower 2.3-2.4. Specific gravity is a measurement of density, which is defined as weight per unit volume. Specific gravity is a measurement that refers to a mineral’s density relative to the density of water. It is derived by dividing a mineral’s density by the density of water. The density of water equals one gram per cubic centimeter (at a specific temperature). Mineral density is also expressed in grams per cubic centimeter. As an example, the common mineral quartz [silicon dioxide, SiO_2] has a density of 2.65 grams per cubic

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centimeter. The specific gravity of quartz is therefore 2.65 ($2.65/1.0 = 2.65$). Another way to express this relationship is to say that quartz is 2.65 times heavier than an equal volume of water.

Precise specific gravity is determined by laboratory methods in which a mineral sample is weighed twice—once in air, and once while suspended in water. The difference between the two weights equals the volume (and thus the weight) of the displaced water. The specific gravity can then be easily calculated by dividing the weight of the mineral by the weight of the displaced water. Such exact measurements require specialized laboratory equipment.

Specific gravity is a diagnostic property that is valuable in mineral identification. As an example, it is possible to visually confuse colorless, cubic crystals of halite [sodium chloride, NaCl] with colorless, pseudocubic crystals of apophyllite-(KF). But the specific gravities for these minerals differ significantly, which is helpful in identification. The specific gravity of halite is 2.16, while that of apophyllite-(KF) is 2.3-2.4. Apophyllite-(KF) thus has about 10 percent greater density than halite, which is easily detectable in laboratory tests.

Experienced mineral collectors, prospectors, and field geologists can often make surprisingly accurate estimates of specific gravity by simply gauging a mineral's "heft" in the hand. These relative estimates depend, of course, upon familiarity of the specific gravities of a number of familiar minerals.

Density in minerals is determined by elemental composition, atomic packing, and crystal structure. Minerals composed of dense elements always have greater densities than those containing "lighter" elements. Each element has an atomic weight, which is a relative measure of mass compared to the carbon-12 isotope of the element carbon (C). Natural carbon has an atomic weight of 12.01. In comparison, the element iron has an atomic weight of 55.85, making it roughly 4.5 times more dense than carbon. Thus, minerals containing significant amounts of iron always have a substantially greater density than those consisting largely of such lighter elements as carbon. As another example, pyrite [iron disulfide, FeS₂], with its high iron content, has a substantial specific gravity of 5.0. Galena [lead sulfide, PbS] has an even higher specific gravity of 7.5 because it consists largely of lead, a much heavier metal.

Impurities, or accessory elements, also help to determine density. Consider calcite [calcium carbonate, CaCO₃] which, when pure, is colorless and has a specific gravity of 2.7. When manganese (atomic weight 54.94) replaces some of the calcium (atomic weight 40.08), calcite takes on a pinkish hue and is known as manganoan calcite. The presence of manganese can increase the specific gravity of manganoan calcite to more than 3.0. When manganese completely replaces the calcite, the mineral becomes rhodochrosite, which has an even higher specific gravity of 3.7.

Gold [native element, Au] provides another example of how accessory elements affect specific gravity. The specific gravity of pure gold, which is very dense, is 19.3. But native gold never occurs in a pure state. Because it is always alloyed with other metals, often such lighter metals as silver and copper, the specific gravity of native gold averages only about 17.0 and can be as low as 15.0.

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Atomic packing and crystal structure are other factors that affect mineral density. Atomic packing is a function of bonding strength within the crystal lattice. The four types of atomic bonding are covalent, metallic, ionic, and hydrogen. Ionic and hydrogen bonds are relatively weak, while metallic and covalent bonds are much stronger. Stronger atomic bonds hold ions closer together to create greater density. Crystal structure also can affect density. Consider diamond and graphite, two important polymorphs of carbon. Both consist entirely of covalently bonded carbon. But diamond's cubic structure creates much closer atomic packing than does graphite's hexagonal structure. These differences in atomic packing are reflected in densities. The specific gravity of diamond is a substantial 3.5, while that of graphite is only 2.2. Both minerals consist only of carbon, yet diamond has a 50 percent greater density.

In general, metallic minerals have substantially higher specific gravities than do nonmetallic minerals. The following scale provides a relative comparison of the specific gravities of *nonmetallic* minerals, meaning minerals that do not contain transition metals or other heavy, metallic elements:

Specific Gravity	Relative Weight
1.0-2.0	very light
2.0-2.5	light
2.5-3.0	average
3.0-3.5	slightly above average
3.5-4.0	above average
4.0-5.0	heavy
5.0-7.0	very heavy
7.0+	extremely heavy

The following general scale provides a relative comparison of specific gravities for *metallic* minerals, meaning those that contain transition metals or other heavy metals:

Specific Gravity	Relative Weight
1.0-3.0	very light
3.0-4.0	light
4.0-5.0	average
5.0-6.0	slightly above average
6.0-7.0	above average
7.0-10.0	heavy
10.0+	very heavy

The mineral with the least density is flagstaffite [terpin hydrate, $C_{10}H_{22}O_3$], which has a specific gravity of just 1.1, meaning that it is only slightly more dense than water. It is a rare mineral found only in certain environments within fossilized logs. The mineral with the greatest density is iridium [native element, Ir], one of the platinum-group metals, which has an extremely high specific gravity of 22.7.

Density, expressed numerically as specific gravity, is one of the physical properties of minerals that make their study so fascinating. As an interesting exercise, look back over your previous

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Minerals of the Month. “Heft” each specimen in your hand and estimate its relative density. Then refer back to the write-ups to see the actual specific gravity of each mineral. You may be surprised how accurate your estimates can be.

ABOUT OUR SPECIMENS

Our gyrolite specimens were collected from basalt quarries near the city of Mumbai in the Mumbai District, Maharashtra state, Republic of India. Covering 118,000 square miles, Maharashtra is roughly half the size of the state of Texas. 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 14 million residents and an excellent deepwater port. The Mumbai quarries are about 25 miles north of the center of Mumbai near the suburb city of Khandivali. These quarries were first mined in the 1860s as a source of basalt for building stone used in the construction of many prominent buildings in Bombay.

The state of Maharashtra is located entirely within the Deccan Traps, a huge volcanic province that covers much of west-central India. The Deccan Traps were created by massive, prolonged, volcanic eruptions that began some 68 million years ago, lasted for 8 million years, and extruded an estimated 300,000 cubic miles of basaltic magma. These eruptions occurred in repetitive lava floods that formed superposed layers of basalt, each from 3 to 400 feet thick. Today, even after eons of substantial erosion, the Deccan basalt still covers 200,000 square miles to a depth of 6,000 feet. As an extrusive igneous rock, basalt forms from the solidification of magma. Volcanic rocks usually cool quickly and have a smooth or aphanitic texture with no visible crystals. But some Deccan basalts have a porphyritic texture and exhibit very small crystals scattered through a dense matrix. 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 roads, building foundations, and rail beds.

In the Deccan Traps, collectible minerals occur in cavities or vesicles within the basalt that formed from gas bubbles in the original magma when it was extruded and solidified. These vesicles, which range in size from less than an inch to many feet, were initially devoid of mineralization. But as mineral-rich, alkaline groundwater circulated through the basalt’s fissures and fractures, it filled the vesicles and precipitated such minerals as gyrolite; apophyllite-(KF); quartz [silicon dioxide, SiO_2]; calcite [calcium carbonate, CaCO_3]; prehnite [basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$]; and numerous zeolite-group minerals. Vesicles filled with these secondary minerals are called “amygdules.”

Commercial specimen collecting in India’s basalt quarries began in the 1960s. Since then, the Mumbai quarries have yielded countless fine specimens of gyrolite; apophyllite-(KF); okenite [hydrous calcium silicate, $\text{Ca}_5\text{Si}_9\text{O}_{23}\cdot 9\text{H}_2\text{O}$]; prehnite; quartz; calcite; 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. Commercial collectors contract with Mumbai quarry managers for permission to collect specimens when they are exposed by quarrying operations, then sell them to buyers in Mumbai for export to world markets.

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Gyrolite was often erroneously thought to be a zeolite mineral because of its similar appearance and occurrence, and also because many Indian exporters traditionally mislabeled gyrolite as a zeolite mineral. Because of continuing population growth and development in the Mumbai area, many quarries are closing and will no longer be sources of mineral specimens.

Our specimens are composites of gyrolite and apophyllite-(KF) [basic hydrous potassium calcium fluorosilicate, $\text{KCa}_4\text{Si}_8\text{O}_{20}(\text{F},\text{OH})\cdot 8\text{H}_2\text{O}$]. Apophyllite-(KF), our Mineral of the Month for December 2013, is a phyllosilicate like gyrolite. However, unlike gyrolite, which crystallizes in the triclinic system, apophyllite-(KF) crystallizes in the tetragonal system. It occurs as well-formed, cube-like or tabular crystals with rectangular, longitudinally striated prisms, square cross sections, and steep, diamond-shaped, pyramidal termination faces. Pseudo-cubic prisms, as seen in our gyrolite-with-apophyllite-(KF) specimens, have flat terminations with beveled, distinctly triangular corners. Apophyllite-(KF) is usually colorless or white, but occasionally exhibits pale shades of green, yellow, red, blue, or violet. It is transparent to translucent, with a vitreous-to-pearly luster and occasional flashes of iridescence. Apophyllite-(KF) has perfect cleavage in one direction, an uneven fracture, a Mohs hardness of 4.5-5.0, and a specific gravity of 2.3-2.4. It occurs as a secondary mineral in vesicles within altered basalt and basaltic tuff, usually in association with gyrolite and various zeolite minerals.

Your composite specimen of gyrolite with apophyllite-(KF) provides an interesting comparison of many of the physical properties of these two minerals. The gyrolite appears as well-formed spherules and nodular aggregates that consist of radiating, lamellar, internal crystals. These spherules are white in color, indicating a high chemical purity. The spherules exhibit varying degrees of translucency, which becomes apparent when the specimen is backlighted using an intense light source. Some smaller spherules may appear to be nearly opaque. The spherule surfaces have a ridged texture somewhat similar to that of micaceous aggregates, a texture that is common among many phyllosilicates. The colorless, transparent apophyllite-(KF) crystals contrast nicely with the white gyrolite spherules. The transparent sections are exceptionally clear, which is typical of the species. The apophyllite-(KF) crystal faces have a bright, vitreous luster and their square or rectangular cross sections reflect the pseudo-cubic habit. Many have flat terminations with sharply beveled corners that form triangles—another diagnostic feature of apophyllite-(KF).

In your specimen, notice that the gyrolite spherules have grown on and around the apophyllite-(KF) crystals. This shows that the apophyllite-(KF) crystals formed first, because of their higher temperature of crystallization. The gyrolite, which has a lower temperature of crystallization, was able to crystallize only after the apophyllite-(KF) had already formed and after further cooling. Your composite specimen of gyrolite with apophyllite-(KF) is a fine example of sequential crystallization and of the fine mineral specimens that come from India's Deccan Traps.

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