

Mineral of the Month Club July 2016

ALMANDINE

This month we are featuring the garnet-group mineral almandine, or iron aluminum silicate. Our specimens are from Paraíba, Brazil, and our write-up discusses the chemistry and structure of almandine, its history, and its uses as both as a gemstone and an industrial abrasive.

PHYSICAL PROPERTIES:

Chemistry: $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ Iron Aluminum Silicate, usually containing some manganese and magnesium.

Class: Silicates

Subclass: Nesosilicates

Group: Garnet

Crystal System: Cubic (Isometric)

Crystal Habits: Forms well-developed, 12-sided dodecahedrons or 24-sided trapezohedrons, or combinations of these habits. Also occurs in granular, lamellar, compact, and disseminated forms.

Color: Usually red to orange-red, purple-red, or brownish-red; typically dark in tone; occasionally pink or purple.

Luster: Greasy to vitreous

Transparency: Transparent to opaque

Streak: Colorless

Refractive Index: 1.780-1.810

Cleavage: None

Fracture and Tenacity: Uneven to conchoidal; brittle.

Hardness: 7.0-7.5

Specific Gravity: 3.7-4.1

Luminescence: None

Distinctive Features and Tests: Best field identification marks are dodecahedral or trapezohedral crystal forms, relatively high specific gravity, reddish colors, and hardness greater than that of quartz. Almandine can be confused with other red, garnet-group minerals.

Dana Mineral-Classification Number: 51.4.3a.2

NAME: The name almandine, pronounced ALL-mahn-deen, is a linguistic corruption of Alabandicus, a ancient city and gem-cutting center in Asia Minor (present-day Alaband, Turkey). Almandine has also been known as “Adelaide ruby,” “almandite,” “almandine garnet,” “almandite garnet,” “oriental garnet,” “iron garnet,” and “hard garnet.” The word “garnet” stems from the Middle French *pomme grenat*, or pomegranate, referring to that fruit’s pulpy, crimson arils that resemble small garnet crystals. In European mineralogical literature, almandine appears as *almandina*, *almandita*, *almandino*, and *almandin*.

COMPOSITION & STRUCTURE: Almandine consists of 33.66 percent iron (Fe), 10.84 percent aluminum (Al), 16.93 percent silicon (Si), and 38.57 percent oxygen (O). Almandine is

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a member of the silicates, the largest class of minerals. Silicates consist of silicon and oxygen combined with one or more metals; their basic structural unit is the silica tetrahedron (SiO_4)⁴⁻, in which four equally spaced oxygen ions positioned at the corners of a tetrahedron (a four-faced polygon) surround a single silicon ion. Almandine and all garnet-group minerals are nesosilicates in which metal cations are packed tightly between isolated silica tetrahedra with no direct silica-silica bonding. Because of its close atomic packing and unusually strong ionic and covalent bonding, almandine has a substantial hardness of Mohs 7.0-7.5 and is the hardest of all garnet-group minerals. Close atomic packing and the high atomic weight of iron (55.85) give almandine a relatively high specific gravity of 3.7-4.1. Almandine crystallizes in the cubic or isometric system, which has three axes of symmetry, all of equal length and at right angles to each other. Isometric crystals are usually blocky in shape, with many similar, symmetrical faces. Almandine is an idiochromatic (self-colored) mineral in which the essential element iron, a powerful chromophore (color-causing agent), creates its basic red color. Traces of manganese and other elements alter this basic red color to orange-red, purplish-red, and brownish-red, and occasionally to purple and pink. Almandine is of igneous or metamorphic origin and occurs in granitic pegmatites, carbonatites, contact metamorphic rocks, and skarns. After weathering free from its igneous or metamorphic host rocks, almandine has enough density to concentrate in placer deposits.

COLLECTING LOCALITIES: Almandine is collected in Brazil, Austria, Norway, Russia, Australia, Ethiopia, China, Japan, Thailand, Turkey, Pakistan, Sri Lanka, Canada, and India. In the United States, almandine is found in Colorado, North Carolina, Alaska, Pennsylvania, New York, New Mexico, South Dakota, Maryland, New Hampshire, Connecticut, Maine, Idaho, Montana, and Nevada.

HISTORY, LORE & GEMSTONE/TECHNOLOGICAL USES: Because of their abundance, wide distribution, hardness, range of attractive colors, and excellent workability, garnet-group minerals have been valued as gemstones since antiquity. Archaeologists have recovered almandine amulets and talismans from 5,000-year-old Egyptian tombs and from 3,000-year-old Swedish cultural sites. In medieval times, European crusaders wore red garnets for protection in battle and to ensure their safe return; physicians of that era believed that red garnets offered protection from poisons and helped cure infections and blood-related maladies. Because of their chemical complexity, similar physical properties, and tendency to form solid-solution series, mineralogists were unable to differentiate garnet species until the early 1800s. Improved chemical-analysis techniques then enabled them to distinguish pyrope and almandine in 1803, grossular in 1807, and spessartine and uvarovite in 1832. Red garnet-group gems are the birthstone for January. “Red garnet” (which is not a proper mineral name) is New York’s state mineral; star almandine is Idaho’s state gemstone; and almandine is Connecticut’s state gemstone. Modern metaphysical practitioners believe that garnet generally enhances compassion, love, imagination, and creativity, while teaching patience and strengthening the mind and body in times of need. Almandine is thought to help inspire love and devotion in romantic partners, to enable one to see things through with clarity and compassion, and to stay calm and focused during stressful times. Almandine and other garnet-group minerals have served as industrial abrasives since the 1880s. Because of its abundance and superior hardness, almandine is the preferred garnet for all industrial uses. Some 1.7 million tonnes (metric tons) of

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garnet concentrate worth about \$300 million are recovered worldwide each year. The United States annually produces 50,000 tonnes of garnet concentrate worth \$9 million. Most red garnet gemstones, which are mined on a much smaller scale, are intermediate members of the pyrope-almandine solid-solution series and are called “rhodolite” in the jewelry trade. Top-quality rhodolite gems of about three carats sell for \$50 to \$100 depending upon color and transparency; ten-carat gems sell for about \$250.

ABOUT OUR SPECIMENS: Our almandine specimens were collected in the Borborema Pegmatite Province at Serrote Redondo, Pedra Lavrada, Paraíba, Brazil. Located in northeastern Brazil, the state of Paraíba, population 3.9 million, is roughly the size of the American state of South Carolina; its economy is based on tourism, service industries, light manufacturing, cattle ranching, and farming. The Borborema Pegmatite Province is a geologic zone of metamorphosed rock consisting largely of mica-rich schist that has been intruded by at least 750 granite pegmatites. The pegmatite province is 50 miles wide and 95 miles long, and trends from Paraíba northeast into Rio Grande do Norte. The Borborema pegmatites formed some 490 million years ago when the present-day surface was buried to an estimated depth of 12,000 feet. The basement rock then consisted of metamorphosed schist. As granitic magma surged upward, it was initially capped by these metamorphic rocks. But as the main magmatic mass cooled and the overlying “roof” fractured, columns of residual magma penetrated the schist to solidify into pegmatites. This residual magma further metamorphosed the schist and created well-developed crystals of almandine, which were then enclosed within nodules of massive quartz. Erosion eventually reduced the surface to expose the garnet-rich schist and its pegmatites. The Borborema Pegmatite Province was first mined during World War I for mica. During World War II, its pegmatites yielded the rare-earth metals tantalum and niobium. Later, the pegmatites provided feldspar minerals for Brazil’s ceramics industries and also became a source of fine specimens of many rare minerals.

COMPREHENSIVE WRITE-UP

COMPOSITION & STRUCTURE

This is the seventh time we have featured a garnet-group mineral as our Mineral of the Month. We first featured almandine in March 1997 with specimens from Wrangell Island, Alaska. Our other featured garnet-group minerals were spessartine in August 1998 and March 2005, uvarovite in February 2001, grossular in December 2002, and andradite in March 2009.

Almandine, chemical formula $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$, consists of iron (Fe), aluminum (Al), silicon (Si), and oxygen (O). Almandine’s molecular weight is made up of 33.66 percent iron, 10.84 percent aluminum, 16.93 percent silicon, and 38.57 percent oxygen. Like all molecules, those of almandine consist of positively charged ions called cations and negatively charged ions called anions. Almandine’s compound cation is made up of three divalent iron (ferrous) ions 3Fe^{2+} and two aluminum ions 2Al^{3+} that provide a cumulative +12 charge. Almandine’s anion consists of three silica radicals $3(\text{SiO}_4)^{4-}$. Radicals are groups of ions of different elements that act as entities in chemical reactions. Within the $(\text{SiO}_4)^{4-}$ radical, one silicon ion Si^{4+} bonds to four

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oxygen ions 4O^{2-} . Almandine's cumulative -12 anionic charge from its three silica ions balances the +12 cationic charge from its iron and aluminum ions to provide electrical stability. Almandine usually contains variable amounts of magnesium and manganese that substitute for iron.

Almandine is a member of the silicates, the largest and most abundant class of minerals. Silicates consist of silicon and oxygen combined with one or more metals. The basic silicate structural unit is the silica tetrahedron $(\text{SiO}_4)^{4-}$, in which four equally spaced oxygen ions are positioned at the corners of a tetrahedron (a four-faced polygon) surrounding a single silicon ion. The oxygen ions are bonded to the silicon ion by strong covalent bonding. In silicate minerals, silica anions and metal cations link together like polymers (repeating chains) to form seven types of structures: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); framework silicates (tectosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); and sheet silicates (phyllosilicates).

Almandine and all garnet-group minerals are nesosilicates, which consist of metal cations packed tightly between isolated silica tetrahedra that have no direct silica-silica bonding. In the rigid nesosilicate crystal lattices, the silica anions are bound only to metal cations. In the almandine molecule, three iron ions 3Fe^{2+} and two aluminum ions 2Al^{3+} are positioned between three silica tetrahedra $3(\text{SiO}_4)^{4-}$. Eight oxygen ions closely surround each iron ion, and six oxygen ions surround each aluminum ion. This close atomic packing greatly strengthens the ionic bonding between the silica anions and the metal cations. Strong ionic and covalent bonding give almandine a substantial hardness of Mohs 7.0-7.5 to make it the hardest of all garnet-group minerals. Close atomic packing and the high atomic weight of iron (55.85) explain almandine's relatively high specific gravity of 3.7-4.1.

All garnet-group minerals crystallize in the cubic or isometric system, which has three axes of symmetry, all of equal length and at right angles to each other. Isometric crystals are usually blocky in shape, with many similar, symmetrical faces. Common cubic-system habits are 6-sided cubes, 8-sided octahedrons, 12-sided dodecahedrons, and 24-sided trapezohedrons, either as singular or combined habits. Minerals that crystallize in the isometric system are usually chemically simple, such as pyrite [iron disulfide, FeS_2] and halite [sodium chloride, NaCl]. The garnet-group minerals, with their moderate level of chemical complexity, are an exception and are among the few silicate minerals that crystallize in the cubic system.

Minerals are categorized either as idiochromatic (self-colored) or allochromatic (other-colored). In idiochromatic minerals, color is caused by essential elemental components and/or the nature of the crystal lattice; the color of allochromatic minerals is caused by nonessential elemental impurities called chromophores (color-causing agents). Almandine is an idiochromatic mineral with the essential element iron, a powerful chromophore, creating its basic red color. Small amounts of manganese and other elements often alter this color to orange-red, purplish-red, and brownish-red, and occasionally to shades of purple and pink.

Almandine typically has many inclusions which decrease transparency. These inclusions often consist of tiny, well-developed crystals of fluorapatite [calcium fluorophosphate, $\text{Ca}(\text{PO}_4)_3\text{F}$],

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zircon [zirconium silicate, ZrSiO_4], spinel [magnesium aluminum oxide, MgAl_2O_4], and rutile [titanium dioxide, TiO_2]. Some almandine crystals exhibit “feather” and bubble inclusions, which are called “fingerprints” because they are source-unique. A particularly common inclusion is tiny, needle-like crystals of rutile. When these are of proper length and thickness and are aligned with the crystallographic axes, they create the phenomenon of asterism, in which light is reflected as a four-rayed (or sometimes a six-rayed) star. These valuable gemstones are known as “star” garnets.

Through cationic substitution, almandine forms two complete solid-solution series with the garnet-group minerals pyrope [magnesium aluminum silicate, $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$] and spessartine [manganese aluminum silicate, $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$]. In the almandine-pyrope series, iron and magnesium substitute for each other; in the almandine-spessartine series, the substitution is between iron and manganese. Almandine’s color varies with the degree of gradation within these solid-solution series. Because almandine almost always contains some magnesium and/or manganese, mineralogists sometimes refer to almandine as “almandine-pyrope” or “almandine-spessartine.”

Almandine can be of igneous or metamorphic origin. In granite pegmatites, it occurs with albite [sodium aluminum silicate, $\text{NaAlSi}_3\text{O}_8$] and the biotite-group of basic potassium iron magnesium oxysilicates; in carbonatites (carbonate-rich igneous rocks), it is associated with orthoclase [potassium aluminum silicate, KAlSi_3O_8], calcite [calcium carbonate, CaCO_3], and wollastonite [calcium silicate, CaSiO_3]. Most almandine is metamorphic and occurs in contact-metamorphic rocks with calcite and hedenbergite [calcium iron silicate, $\text{CaFeSi}_2\text{O}_6$], and in skarns of hydrothermal metamorphic rocks with magnetite [iron oxide, Fe_3O_4] and hedenbergite. Almandine that weathers free from its igneous or metamorphic host rocks has sufficient density (specific gravity 3.7-4.1) to concentrate in placer deposits.

The Dana mineral-classification number 51.4.3a.2 first identifies almandine as a nesosilicate with silica groups present in the $(\text{SiO}_4)^{4-}$ configuration (51). Almandine is subclassified (4) by silica anions in coordinations of six or less. As seen in its formula $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$, almandine’s silica-anion coordination is three. Almandine is then assigned to the garnet group (3) and the pyrospite series (a) as the second (2) of six members (see “The Garnet-Group Minerals”).

COLLECTING LOCALITIES

Our almandine specimens are from the Borborema Pegmatite Province at Serrote Redondo, Pedra Lavrada, Paraíba, Brazil; almandine is also collected at the nearby Itajubatiba Mine at Catigueira. Another Brazilian locality is the Sapucaia Mine at Galiléia, Doce Valley, Minas Gerais.

In Europe, almandine occurs in Austria at Hochgurgl in the Otztal Valley, North Tyrol, Tyrol, and in Norway at Tiltvika, Hamarøy, Nordland. In Russia it is found at the Lakkulaisvaaka ultrabasic massif in the Oulanka plutonic complex, Northern Karelia, Karelia Republic, Northern Region. Other localities include Mt. Riddick Station, the Entia Valley, and the Carrara Mine in

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Hart's Range, Central Desert District, Northern Territories, Australia; the Kenticha Mine in the Kenticha Pegmatite Field, Sidamo-Borana Province, Ethiopia; Jianchang, Donghai County, Lianyungang Prefecture, Jiangsu Province, China; the Noda-Tamagawa Mine, Kunohe-gun, Iwate Prefecture, Honshu Island, Japan; the Kathu District, Phuket Province, Thailand; Alabanda, Aydin Province, Aegean Region, Turkey; the Swat Valley, Swat District, North-West Frontier Province, Pakistan; and the Ratnapura gem gravels, Ratnapura District, Sabaragamuwa, Sri Lanka. Canadian specimens come from the Page and McDonald prospects in Loughrin Township, and from the Elizabeth Mine and Wanup Quarry in Dill Township, both in Sudbury District, Ontario. In India, almandine is found at the Sargipalli mines, Sundargarh District, Orissa; and at the Dunka Gem Mine, Ajmer District, Rajputana.

Localities in the United States include the Sedalia Mine, Sedalia district, Chaffee County, Colorado; Buck Creek in Clay County and the Fanny Gorge Mine in the Spruce Pine district in Yancey County, North Carolina; Garnet Ledge at Wrangell, Wrangell Island, Wrangell-Petersburg Borough, Alaska; the Behr Garnet Mine at Chelsea and the Chester Heights quarries in Delaware County, Pennsylvania; the Barton mines at North River and Willsboro, Warren County, New York; the Harding Mine, Picuris district, Taos County, New Mexico; the Keystone pegmatite quarries, Pennington County, South Dakota; the Bare Hills copper mine, Baltimore County, Maryland; and the Turner Mine at Marlow in Cheshire County and the Wasau Abrasives Co. mine at Wilnot in Merrimack County, both in New Hampshire. Among Connecticut's localities are the Anderson Nos. 1 and 2 mica mines, and the Clark Hill and Hog Hill quarries at East Hampton, Middlesex County; Becker's Quarry at Willington, Tolland County; and the Redding Glen quarries at Redding, Fairfield County. In Maine, almandine is found at Topsham in Sagadahoc County; at Albany, Buckfield, Greenwood, and Newry in Oxford County; and at the Pulsifer Quarry at Auburn in Androscoggin County. Idaho localities include Emerald, Carpenter, and Meadow creeks near Fernwood in Benewah County; the Purdue Creek gravels in Latah County; the gravels of the North and Little North forks of the Clearwater River in Clearwater County; and alluvial gravels at Avery in Lemhi County. Montana specimens are collected at the Missouri River bars near Helena in Lewis and Clark County; and in the Alder Gulch gravels in the Ruby River Valley in Madison County. Nevada localities include Garnet Hill and the Hampton Creek Canyon gravels near Ely in White Pine County.

JEWELRY & DECORATIVE USES

Because of their abundance, wide distribution, hardness, durability, ease of workability, and range of attractive colors, the garnet-group minerals have served as gemstones since antiquity. Red garnet cabochons, called "carbuncles," were fashioned as early as 4000 B.C. Archaeologists have recovered almandine amulets and talismans from 5,000-year-old Egyptian tombs and from 3,000-year-old Swedish cultural sites. By 1400 A.D., red garnets, including almandine, were popular as faceted gems because of their resemblance to rubies. Because individual garnet species were not differentiated until the 1800s, all garnet-group gemstones were traditionally referred to simply as "garnet." The modern jewelry industry continues this tradition, marketing red garnet-group gems under the generic name "garnet," rather than actual species names. Only non-red garnet gems, such as the green demantoid variety of andradite [calcium iron silicate,

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$\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$], are marketed under their mineral or variety names. Garnets are among the few gemstones that are never treated to enhance their colors.

Most garnet gemstones are mined from alluvial deposits by sluicing or hydraulic separation. The value of gem-garnet production in the United States is poorly documented, but the United States Geological Survey estimates that about \$250,000 worth of rough gem garnets are mined each year. Most red garnet gemstones are part of the pyrope-almandine solid-solution series and are known as “rhodolite” in the jewelry trade. Faceted rhodolite gems of about three carats sell for \$50 to \$100 depending upon color; top-quality, ten-carat rhodolite gems sell for about \$250. “Star” rhodolite is included with needle-like crystals of rutile [titanium dioxide, TiO_2]. When oriented along the crystal axes, these inclusions reflect light as a four-rayed (or occasionally a six-rayed) star. Star rhodolite is translucent and cut into cabochons to display its star-like reflections. Star-garnet cabochons in the 100-carat range sell for about \$400.

Almandine crystals are popular among mineral collectors for their well-developed crystal forms and saturated colors. Various types of transparent garnet, including almandine, can be faceted into collector gems exceeding 100 carats in weight.

HISTORY & LORE

Some historians believe that an almandine cabochon was among the 12 gemstones of the biblical breastplate of Aaron, the high priest of the Hebrews. In medieval times, European crusaders wore red garnets for protection in battle and to ensure their safe return; physicians of that era believed that red garnets offered protection from poisons and helped cure infections and blood-related maladies. The name almandine is a linguistic corruption of Alabandicus, a city and ancient gem-cutting center in Asia Minor (present-day Alaband, Turkey). The Roman scholar Pliny the Elder (Gaius Plinius Secundus, A.D. 23-79) referred to almandine as *alabandina*. The German scholar and scientist Agricola (Georg Bauer, 1495-1555) used the term *alemaundine* in *De Re Metallica*, his classic work on mining and extractive metallurgy that was published in 1556. *Alemaundine* later entered the English language as “almandine.”

Because of their chemical complexity, similar physical properties, and tendency to form solid-solution series, mineralogists were unable to distinguish between individual garnet species until the early 1800s. Improved chemical-analysis techniques then enabled them to distinguish pyrope and almandine in 1803, grossular in 1807, and spessartine and uvarovite in 1832. But the ability to positively distinguish all garnet species required the later development of mass-spectrography and other advanced quantitative-analysis methods that could detect subtle differences in chemical composition. Mineralogists most recently described a new garnet-group mineral in 1996.

Red garnet-group gems are the birthstone for January. “Red garnet” (although that term is not a formal mineral name) is New York’s state mineral, star almandine is Idaho’s state gemstone, and almandine is Connecticut’s state gemstone. At least six garnet-group minerals have been

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featured on postage stamps. Almandine appeared on the 10-leva stamp of Bulgaria in 1995 and on the 1.00-franc stamp of the French Southern and Antarctic Territories in 1993.

Modern metaphysical practitioners believe that garnet enhances compassion, love, imagination, and creativity, teaches patience, and strengthens the mind and body in times of need. Almandine is specifically thought to help to inspire love and devotion in romantic partners, to enable one to see things through with clarity and compassion, and to stay calm and focused during stressful times.

THE GARNET-GROUP MINERALS

The word “garnet” is not a species name, but a group name for 15 closely related, isomorphic (same form), nesosilicate minerals. The garnet group is isostructural, with all members crystallizing in the cubic (isometric) system as dodecahedrons or trapezohedrons with rhombic (diamond-shaped) or modified-rhombic faces. Garnet-group minerals are most familiar in shades of red, but occur in every color except blue.

In the Dana Mineral-Classification System, the general formula for garnet-group minerals is $A_3B_2(SiO_4)_3$, with “A” representing the divalent metal ions calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (ferrous, Fe^{2+}), and manganese (Mn^{2+}), and “B” representing the trivalent metallic ions aluminum (Al^{3+}), chromium (Cr^{3+}), and iron (ferric, Fe^{3+}). In some garnet minerals, “B” also represents the trivalent ions vanadium (V^{3+}), titanium (Ti^{3+}), and zirconium (Zr^{3+}). In the rare hydrogarnets, the hydroxyl ion (OH)¹⁻ substitutes for some of the silica ions.

Only 6 of the 15 garnet-group minerals are common. In order of abundance, these are almandine, pyrope, andradite, grossular, spessartine, and uvarovite. These six minerals are classed into two subgroups: the “pyralspite” (PYRope, ALmandine, and SPessartine) subgroup and the “ugrandite” (Uvarovite, GROSSular, and ANDradite) subgroup. The pyralspite subgroup members have the aluminum ion Al^{3+} as their trivalent cation; the ugrandite subgroup members have the calcium ion Ca^{2+} as their divalent cation.

The Dana Mineral-Classification System chemically divides the garnet-group members into four subgroups:

51.4.3a Pyralspite Subgroup

51.4.3a.1 pyrope	magnesium aluminum silicate	$Mg_3Al_2(SiO_4)_3$
51.4.3a.2 almandine	iron aluminum silicate	$Fe_3Al_2(SiO_4)_3$
51.4.3a.3 spessartine	manganese aluminum silicate	$Mn_3Al_2(SiO_4)_3$
51.4.3a.4 knorringite	magnesium chromium silicate	$Mg_3Cr_2(SiO_4)_3$
51.4.3a.5 majorite	magnesium iron aluminum silicate	$Mg_3Fe_2(SiO_4)_3$
51.4.3a.6 calderite	manganese iron silicate	$Mn_3Fe_2(SiO_4)_3$

51.4.3b Ugrandite Subgroup

51.4.3b.1 andradite	calcium iron silicate	$Ca_3Fe_2(SiO_4)_3$
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51.4.3b.2	grossular	calcium aluminum silicate	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$
51.4.3b.3	uvarovite	calcium chromium silicate	$\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$
51.4.3b.4	goldmanite	calcium vanadium silicate	$\text{Ca}_3\text{V}_2\text{Cr}_2(\text{SiO}_4)_3$
51.4.3c Schorlomite-Kimzeyite Subgroup			
51.4.3c.1	schorlomite	calcium titanium iron silicate	$\text{Ca}_3(\text{Ti,Fe})_2(\text{SiO}_4)_3$
51.4.3c.2	kimzeyite	calcium zirconium titanium alumnoferrisilicate	$\text{Ca}_3(\text{Zr,Ti})_2(\text{Si,Al,Fe})_3\text{O}_{12}$
51.4.3c.3	morimotoite	calcium titanium iron silicate	$\text{Ca}_3\text{TiFe}(\text{SiO}_4)_3$
51.4.3d Hydrogarnet Subgroup			
51.4.3d.1	hibschite	basic calcium aluminum silicate	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_{3-x}(\text{OH})_{4x}$
51.4.3d.2	katoite	basic calcium aluminum silicate	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_{3-x}(\text{OH})_{4x}$

The formulas of these garnet-group members represent ideal chemical compositions that are unlikely to occur in nature. With the exception of kimzeyite and the two rare hydrogarnets, all garnet-group members adhere to the general chemical formula $\text{A}_3\text{B}_2(\text{SiO}_4)_3$. The members of each subgroup form mutual, partial or complete, graded solid-solution series by substituting metal cations. Because of their tendency to form solid-solution series and their similar crystal structure and habits, positive identification of the garnet-group members often requires laboratory analysis.

Classification of the garnet-group minerals is still being debated. The 2014 *Fleischer's Glossary of Mineral Species*, the most recent edition of this standard reference that we use in our write-ups, has reclassified the garnet-group minerals and now recognizes an expanded "Garnet Supergroup" which includes a 14-species "Garnet Group." Listed within the Garnet Supergroup are 32 minerals, all of which share the basic garnet structure regardless of which elements occupy the molecule's structural sites.

TECHNOLOGICAL USES

Almandine, pyrope, grossular, and andradite have served as industrial abrasives since the 1880s. Because of its abundance and greater hardness, almandine is the preferred garnet for industrial uses. Although only slightly harder than quartz (Mohs 7.0), garnet is a superior abrasive. Unlike quartz abrasives, garnet abrasives can be reused many times; their density enables them to be inexpensively recovered by hydraulic separation. And unlike quartz, garnet does not smooth with wear, but fractures into sharp-edged, durable bits that retain their abrasive properties. Garnet abrasives fill an economic niche between inexpensive quartz sand and costly synthetic abrasives. Garnet is the grit in "garnet paper" that is used to smooth and polish wood, plastic, glass, and metal; highly refined garnet dust is a polishing agent for fine optics. Garnet also serves as a water-jet cutting agent. The petroleum industry uses large quantities of garnet abrasives to scour drill steel and well casings. And garnet has replaced quartz in many abrasive applications for health reasons: Inhaling quartz dust causes the industrial pulmonary disease silicosis, but garnet dust does not damage lung tissues.

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Although garnet is relatively abundant, commercial deposits are scarce. Most industrial-grade garnet is recovered from alluvial deposits by dredging and sluicing. Lesser amounts are obtained as by-products of certain types of feldspar mining. About 1.7 million tonnes (metric tons) of crude garnet concentrate worth approximately \$300 million are recovered worldwide each year. The leading producers are Australia, China, and India. The United States annually produces about 50,000 tonnes of crude garnet concentrate valued at about \$9 million. Crude garnet concentrate costs \$180 per tonne; industrial garnet that has been sized and cleaned sells for \$280 per tonne. Four American companies account for all domestic production of industrial garnet, which comes from mines in Montana, Idaho, and New York. In the United States, 35 percent of the garnet supply is used as abrasives for water-jet cutting, 30 percent as abrasive blasting agents, 20 percent as water-filtration material, and 10 percent as abrasive and polishing powders. The remaining five percent is used as a polishing grit for fine optics and metal surfaces, and to manufacture abrasive papers and coated abrasives. Much smaller quantities of garnet are mined as gemstones (See “Jewelry & Decorative Uses”).

ABOUT OUR SPECIMENS

Our almandine specimens were collected in the Borborema Pegmatite Province at Serrote Redondo, Pedra Lavrada, Paraíba, Brazil. The state of Paraíba, located in northeastern Brazil, is bordered by the state of Rio Grande do Norte to the north, Ceará to the west, Pernambuco to the south, and the Atlantic Ocean to the east. Paraíba's Cape Branco marks the easternmost point of the Americas. Covering 21,847 square miles, Paraíba, population 3.9 million, is the size of the American state of South Carolina and has an economy based on service industries, tourism, cattle ranching, and farming. Paraíba's capital is the coastal city of João Pessoa, population 700,000, which is known for its pleasant, year-round climate, festivals, and miles of beautiful beaches.

The Borborema Pegmatite Province is a 50-mile-wide, 95-mile-long geologic zone of metamorphosed rock that trends northeast from Paraíba into Rio Grande do Norte. It consists mainly of mica-rich schist that is intruded by more than 750 granite pegmatites. Granite pegmatites, which are bodies of very coarse-grained granite, originated as pockets of residual magma that cooled slowly and crystallized on a fractional, or mineral-by-mineral, basis to form irregular pods, lenses, veins, and dikes. Residual magma is often enriched with accessory or rare minerals; within pegmatites, mariolitic cavities produced by gases sometimes provide space for the growth of unusually large, well-developed crystals.

When the Borborema pegmatites formed some 490 million years ago, the present-day surface was buried to an estimated depth of 12,000 feet. As granitic magma surged upward, it was initially capped by basement rock of metamorphic schist. But as the magma cooled, the overlying metamorphic “roof” fractured, enabling columns of residual magma to penetrate the schist to form granite pegmatites. This residual magma also further metamorphosed the schist and created well-developed crystals of almandine, which were then enclosed by nodules of massive quartz. Erosion eventually reduced the surface to expose the garnet-rich schist and its granite pegmatites.

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The Borborema Pegmatite Province was first mined during World War I for the mica-group mineral muscovite [basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$]. During World War II, these pegmatites were a critical source of the rare metals tantalum and niobium. After the 1960s, the Borborema pegmatites provided feldspar minerals for Brazil's ceramics industry; a by-product of feldspar mining was fine specimens of rare minerals for the international collectors' market. Borborema most recently gained attention for its "Paraíba tourmaline," a variety of elbaite [tourmaline group, basic sodium aluminum lithium borosilicate, $\text{Na}(\text{Li}_{1.5}\text{Al}_{1.5})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18}(\text{OH})_4)$], in which traces of copper create a distinctive, neon-like, blue-green color.

Our specimens consist of almandine crystals within nodules of massive quartz [silicon dioxide, SiO_2]. When the schist host rock was still undergoing metamorphism in a plastic state, hydrothermal fluids rich in silica, iron, and aluminum accumulated in pockets. With gradual cooling, almandine crystallized first as clusters of dodecahedrons and trapezohedrons. With further cooling, massive quartz then crystallized around the almandine to create nodules. Erosion eventually exposed the schist, which weathered and decomposed to free the quartz-almandine nodules. Pegmatite miners in parts of the Borborema Pegmatite Province collect these nodules from river gravels to sell as specimens. The miners break each nodule open to determine if it contains almandine crystals.

As you examine your specimen, note first the shape of the almandine crystals. Like all garnets and most minerals that crystallize in the isometric system, almandine forms blocky or ball-like crystals. The almandine crystals in your specimen exhibit dodecahedral, trapezohedral, and combined dodecahedral-trapezohedral habits. Dodecahedral and trapezohedral crystals usually have somewhat distorted, four-sided, diamond-shaped, trapezoidal faces. In the combined habit, two additional, parallel edges make the crystal faces appear as elongated hexagons. The deep, reddish color and the translucency of your almandine crystals are caused by the essential element iron, along with traces of manganese and other elements, and defects in the crystal lattice. The crystal faces have a bright, vitreous luster similar to that of polished glass. Because almandine has no cleavage planes, broken crystal surfaces exhibit irregular or conchoidal fracture patterns. The matrix surrounding the almandine is massive quartz. In some specimens, this quartz is white and essentially pure; in others it contains silvery flakes of the mica-group mineral muscovite and has a reddish color caused by particulate hematite [iron oxide, Fe_2O_3] and tiny crystals of almandine.

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