March 2009 Mineral of the Month: Andradite

It has taken thirteen years, but at last we have tracked down a find of exceptional andradite garnet specimens in great enough quantity to be featured in our Club–and just in time for our thirteenth anniversary! We hope this write-up will enhance your appreciation for andradite and its unique properties.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: $Ca_3Fe_2(SiO_4)_3$ Calcium Iron Silicate, often containing aluminum and titanium
Class: Silicates
Subclass: Nesosilicates
Group: Andradite
Crystal System: Isometric (Cubic)
Crystal Habits: Usually as coarse, well-formed, 12-sided dodecahedrons; less commonly as 24-sided trapezohedrons. Also occurs in compact, massive, granular, lamellar, and disseminated forms.
Color: Often red or reddish-brown; also green, greenish-yellow, yellow, yellowish-brown, gray, and black
Luster: Vitreous
Transparency: Usually translucent to nearly opaque; sometimes transparent.
Streak: Colorless
Refractive Index: 1.888-1.889
Cleavage: None
Fracture: Uneven to conchoidal
Hardness: Mohs 6.5-7.2
Specific Gravity: 3.7-4.1
Luminescence: None
Distinctive Features and Tests: Best field marks are isometric crystal form and dodecahedral habit, high specific gravity, hardness, and frequent occurrence in metamorphic environments. Andradite can be easily confused with other garnet-group minerals.
Dana Classification Number: 51.4.3b.1

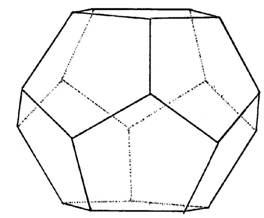

Figure 1. Ideal garnet crystal showing dodecahedral habit.

NAME Andradite is named for Brazilian mineralogist José Bonifácio de Andrada e Silva (1763-1838). The pronunciation in English-speaking countries is AHN-drah-dite; in those where romance language are spoken, the pronunciation is ahn-DRAH-dite. Andradite is a garnet-group mineral. The word “garnet” stems from the Latin *granatus* for pomegranate, a fruit with red seeds that resemble small garnet crystals. Andradite is also known as “allochroite,” “andradite garnet,” “iron garnet,” “aplome,” “jelletite,” “kalkeisentongranate,” “polyadelphine,” and “rothoffite.” Gem varieties include green, chromium-rich “demantoid” (DEH-men-toid); black, titanium-rich “melanite” or “titanium andradite”; greenish-yellow “topazolite”; and iridescent “rainbow garnet.”

COMPOSITION: Andradite’s chemical formula, $Ca_3Fe_2(SiO_4)_3$ shows that it contains calcium (Ca), iron (Fe), silicon (Si), and oxygen (O). Andradite’s atomic weight is made up of 23.66 percent calcium, 21.98 percent iron, 16.58 percent silicon, and 37.78 percent oxygen. As a silicate, andradite consists of silicon and oxygen combined with one or more metals. Because of strong, omnidirectional bonding, andradite is quite hard at Mohs 6.5-7.2 and forms short, blocky crystals with no cleavage. Dense atomic packing and iron’s high atomic weight give andradite a high specific gravity of 3.7-4.1. One of 15 garnet-group minerals, andradite has both igneous and metamorphic origins. Igneous andradite occurs in granitic

Mineral of the Month Club 1770 Orville Avenue Cambria, CA 93428
1-800-941-5594 www.mineralofthemonthclub.org

pegmatites and carbonatites. Most andradite is metamorphic in origin and occurs in contact metamorphic rocks and skarns of hydrothermal metamorphic rocks. Because of its relatively high density, andradite sometimes concentrates as placer deposits in alluvial sediments.

COLLECTING LOCALITIES: Important andradite localities in the United States include Garnet Hill in Calaveras County and the Victor Mine in the New Idria district in San Benito County, both in California. Andradite also occurs at the Stanley district in Graham County, Arizona; and in Cripple Creek, Colorado; Magnet Cove, Arkansas; Lewis County, New York; Franklin, New Jersey; Gettysburg and St. Peters, Pennsylvania; and Alleghany County, North Carolina. Foreign localities include Cadereta, Querétaro, Mexico; Mont Saint-Hilaire, Québec, Canada; Serifos Island, Greece; Kaiserstuhl in Baden-Württemberg, Germany; Söråker in Medelpad, Sweden; Zermatt, Valais, Switzerland; the Somma-Vesuvius complex and the Malenco Valley in Italy; the Kovdor Mine in northern Russia; the Funiushan copper-gold-iron deposit in China; Soghan, Kerman Province, Iran; Badakhshoni-Kuni, Tajikistan; Hotazel, Northern Cape Province, South Africa; and the Karibib district in Namibia.

HISTORY, LORE, & USES: Because of their abundance, hardness, range of attractive colors, and cuttable nature, garnet-group minerals have served as gemstones since antiquity. In medieval times, crusaders wore red garnets for protection in battle and to aid in their safe return, while physicians believed that garnets protected wearers against poisons and helped cure infections and blood-related maladies. Garnets, including andradite, remain popular gemstones today. The most valuable andradite gemstone is the green demantoid variety, which can cost $5,000 per carat. Worldwide, some 400,000 metric tons of garnet are mined each year, mainly for use as industrial abrasives.

ABOUT OUR SPECIMENS: Our specimens come from skarns on Garnet Hill in Calaveras County, California, 60 miles east-southeast of Sacramento. Skarns are zones of calcium-rich silicates that form when silica-rich magma intrudes layers of calcium-rich limestone or shale. The resulting high-temperature, metamorphic contact creates various calcareous silicates and oxides, including andradite, epidote, ferro-axinite, scheelite, and titanite. Garnet Hill was once a minor source of scheelite, an ore of tungsten. Today, commercial specimen collectors lease the old mines to mine andradite and epidote crystals. The Garnet Hill skarns consist of massive andradite with occasional pockets that are filled with well developed, reddish-brown, mostly opaque andradite crystals in the dodecahedral (12-sided) habit.

TEN YEARS AGO IN OUR CLUB: Red Beryl, Violet Claims, Wah Wah Mountains, Beaver County, Utah. Yes, we said Red Beryl! From the same deposit that caused the January-February 1991 *Mineralogical Record* to exclaim: “The talk of the Denver Show this year was beryl . . . To see these in the bright Colorado sunlight is almost a religious experience.” Of course, our Club membership them was less than half of what it is now–we obtained 278 specimens, and sent the majority of them to Club members. People who saw our then-advertisement in *Rock & Gem* were calling, not to join our Club, but to purchase specimens, and of course we turned them away.

At that time, the Red beryl claims had been bought by a group of Canadian investors for several million dollars, and this group subsequently spent millions more to develop the project. It was their intention to market Red Beryl as “Red Emerald” to the high-end gem market, but it was not to be–they went bankrupt soon after, and the claims reverted to the previous owner. The mine is now closed. We had the opportunity to see some of these gorgeous red beryl crystals, on and off matrix, as part of the “American Mineral Treasures” exhibition on display at the 2008 Tucson Gem & Mineral Show–stunning! We also picked out a few choice specimens from the mine geologist’s collection to offer to Club members who want to obtain minerals we have featured in the past. Back in 1999, the matrix on the specimen we kept for our collection broke open to reveal an even better red beryl crystal inside!

March 2009 Mineral of the Month: Andradite

COMPREHENSIVE WRITE-UP

COMPOSITION

Including this month's andradite, we have now featured six garnet-group minerals: almandine in March 1997; spessartine in August 1998 and March 2005; uvarovite in February 2001; and grossular in December 2002. Andradite's chemical formula, $Ca_3Fe_2(SiO_4)_3$ shows that it contains calcium (Ca), iron (Fe), silicon (Si), and oxygen (O). Andradite's atomic weight is made up of 23.66 percent calcium, 21.98 percent iron, 16.58 percent silicon, and 37.78 percent oxygen. All molecules consist of positively charged ions called cations and negatively charged ions called anions. Andradite's compound cation contains three calcium ions ($3Ca^{2+}$) and two iron ions (ferric, $2Fe^{3+}$) that provide a cumulative +12 cationic charge. Andradite's anion consists of three silica radicals $3(SiO_4)^{4-}$, radicals being groups of ions of different elements that act as entities in chemical reactions. Within the $(SiO_4)^{4-}$ radical, one silicon ion Si^{4+} is bonded to four oxygen ions $4O^{2-}$. The three silica ions provide a cumulative -12 anionic charge to balance the +12 cationic charge and thus provide the andradite molecule with electrical stability. Andradite usually contains variable amounts of aluminum and titanium which substitute for iron.

Andradite is a silicate, 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 $(SiO_4)^{4-}$, in which a silicon ion is surrounded by four equally spaced oxygen ions that form the four corners of a tetrahedron. The oxygen ions are bonded to the silicon ion by strong covalent bonding. In silicate minerals, silica anions and metal cations are linked 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).

Andradite and all garnet-group members are nesosilicates, which consist of metal cations packed tightly between silica tetrahedra. These tetrahedra are isolated from each other with no direct silica-silica bonding. In the rigid nesosilicate crystal lattices, silica anions are bound only to metal cations. In the andradite molecule, three calcium ($3Ca^{2+}$) ions and two iron ($2Fe^{3+}$) ions are positioned between three silica tetrahedra $3(SiO_4)^{4-}$. Each calcium ion is closely surrounded by eight oxygen ions, and each iron ion by six oxygen ions. This close atomic packing strengthens the ionic bonding between the silica anions and the metal cations. Because of the strong, omnidirectional ionic and covalent bonding within the lattice, andradite is quite hard at Mohs 6.5-7.2 and forms short, blocky crystals with no cleavage. Dense atomic packing combined with the high atomic weight of iron (55.845) give andradite a relatively high specific gravity of 3.7-4.1.

Mineral color is categorized as idiochromatic (self-colored) or allochromatic (other colored). In idiochromatic minerals, color is caused by essential elemental components, while in allochromatic minerals it is caused by nonessential elemental impurities called chromophores. Andradite does not fall clearly into either category. The essential component iron, a powerful chromophore, creates the common reddish-brown color in andradite. Small amounts of titanium account for the black in the melanite variety, while chromium creates the green in the demantoid variety. Andradite often contains varying amounts of aluminum which, while not a strong chromophore itself, alters the lattice structure to eliminate certain chromophoric effects of iron, thus enabling traces of other chromophoric elements to create a broad range of colors.

Through cationic substitution, andradite forms complete solid-solution series with two other garnet-group minerals—grossular [calcium aluminum silicate, $Ca_3Al_2(SiO_4)_3$] and schorlomite [calcium titanium iron ferrosilicate, $Ca_3(Ti,Fe)_2(Si,Fe)_3O_{12}$]. In the andradite-grossular series, aluminum substitutes for iron, while in the andradite-schorlomite series, titanium substitutes for part of the iron. Andradite's color varies with the degree of gradation within these solid-solution series. Andradite also forms a partial solid-solution series with uvarovite [calcium chromium silicate, $Ca_3Cr_2(SiO_4)_3$] when chromium substitutes for iron.

Andradite can be of igneous or metamorphic origin and occurs in several mineralogical environments. Igneous andradite occurs in granitic pegmatites with albite [sodium aluminum silicate, $NaAlSi_3O_8$] and the biotite mica-group of basic potassium iron magnesium oxysilicates, and also in carbonatites (calcium-rich igneous rocks) with orthoclase [potassium aluminum silicate, $KAlSi_3O_8$], calcite [calcium carbonate, $CaCO_3$], and wollastonite [calcium silicate, $CaSiO_3$]. Most andradite is of metamorphic origin and occurs in contact metamorphic rocks with calcite and hedenbergite [calcium iron silicate, $CaFeSi_2O_6$], and in the skarns of hydrothermal metamorphic rocks with magnetite [iron (ferrous, ferric) oxide, $Fe^{2+}Fe^{3+2}O_4$] and hedenbergite. With its relatively high density, andradite also concentrates as placer deposits in alluvial sediments.

The Dana mineral classification number 51.4.3b.1 first identifies andradite as a nesosilicate with silica groups present only in the $(SiO_4)^{4-}$ configuration (51). Andradite is subclassified (4) as having silica anions present in coordinations of six or less. As seen in its formula $Ca_3Fe_2(SiO_4)_3$, the coordination of andradite's silica anion is three. Andradite is then assigned to the garnet group (3) and to the ugrandite series (b), as the first (1) of four members. For additional information on the classification of the garnet-group minerals, see "Garnets—From Almandine to Uvarovite."

GARNETS—FROM ALMANDINE TO UVAROVITE

Most people are familiar with garnet as a gemstone, but have no idea that, mineralogically speaking, "garnet" refers to a group of 15 closely related, isomorphic (same form) minerals, all of which are nesosilicates. The garnet group is isostructural, with all members crystallizing in the isometric (cubic) system as dodecahedrons or trapezohedrons with rhombic (diamond-shaped) or modified-rhombic faces. Although garnet-group minerals are most familiar in various shades of red, they actually occur in every color except blue.

The garnet-group's general chemical formula is $A_3B_2(SiO_4)_3$, with "A" representing the divalent metallic ions calcium (Ca^{2+}), magnesium (Mg^{2+}), ferrous iron (Fe^{2+}), and manganese (Mn^{2+}), and "B" representing the trivalent metallic ions aluminum (Al^{3+}), chromium (Cr^{3+}), and ferric iron (Fe^{3+}). In some rare garnet minerals, "B" can also represent 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 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 common group members are classed into two subgroups: the "pyralspite" (PYRope, ALmandine, and SPessartine) subgroup and the "ugrandite" (Uvarovite, GRossular, and ANDradite) subgroup. The pyralspite subgroup members share the aluminum ion Al^{3+} as their trivalent cation, while the ugrandite subgroup members share the calcium ion Ca^{2+} as their divalent cation.

Although the classification of garnet-group minerals can seem confusing, it is actually based on simple chemical criteria. The Dana mineral classification system chemically divides the garnet-group members into four series:

March 2009 Mineral of the Month: Andradite

51.4.3a The Pyralspite Series

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 $Mn_3Fe_2(SiO_4)$

51.4.3b The Ugrandite Series

51.4.3b.1 Andradite--calcium iron silicate $Ca_3Fe_2(SiO_4)_3$

51.4.3b.2 Grossular--calcium aluminum silicate $Ca_3Al_2(SiO_4)_3$

51.4.3b.3 Uvarovite--calcium chromium silicate $Ca_3Cr_2(SiO_4)_3$

51.4.3b.4 Goldmanite--calcium vanadium silicate $Ca_3V_2Cr_2(SiO_4)_3$

51.4.3c The Schorlomite-Kimzeyite Series

51.4.3c.1 Schorlomite--calcium titanium iron silicate $Ca_3(Ti,Fe)_2(SiO_4)_3$

51.4.3c.2 Kimzeyite--calcium zirconium titanium alumnoferrisilicate $Ca_3(Zr,Ti)_2(Si,Al,Fe)_3O_{12}$

51.4.3c.3 Morimotoite--calcium titanium iron silicate $Ca_3TiFe(SiO_4)_3$

51.4.3d Hydrogarnets

51.4.3d.1 Hibschite--basic calcium aluminum silicate $Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$

51.4.3d.2 Katoite--basic calcium aluminum silicate $Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}$

With the exception of the aluminoferrisilicate kimzeyite and the two rare hydrogarnets, all garnet-group members adhere to the general chemical formula $A_3B_2(SiO_4)_3$*. The members of each series form mutual, partial or complete, graded, solid-solution series through the substitution of metal cations. The chemical formula of each mineral represents an ideal, exact chemical composition that does not occur in nature. This tendency to form solid-solution series can make differentiating the garnet-group members difficult. Because all members share the same crystal structure and habits, positive identification often requires chemical qualitative analysis.*

COLLECTING LOCALITIES

As one of the common garnet-group minerals, andradite is widely distributed and has many collecting localities. Our specimens were collected at Garnet Hill in Calaveras County, California. Other California andradite sources include the Pacific Limestone Products quarry near Santa Cruz in Santa Cruz County, and the Victor Mine near Clear Creek in the New Idria district in San Benito County. In the western United States, andradite occurs in Arizona at Dripping Springs in the Banner district in the Dripping Springs Mountains of Gila County, and at the Quartzite Mountain garnet deposit in the Stanley district of the Santa Teresa Mountains in Graham County. In Colorado, andradite has been collected in the Cripple Creek district in Teller County. The melanite variety of andradite occurs in Arkansas at the Kimzey Calcite Quarry and Kimzey Magnetite Mine at Magnet Cove in Hot Spring County.

March 2009 Mineral of the Month: Andradite

In the eastern states, andradite is collected in New Hampshire at the United Mine at Springfield in Sullivan County; in New York at the Gouverneur Talc Co. quarry at Harrisville in Lewis County; in New Jersey at the Franklin Mine and Buckwheat Pit at Franklin in Sussex County; in Pennsylvania at Teeter's Quarry at Gettysburg in Adams County and the French Creek mines at St. Peters in Chester County; and in North Carolina at the Bald Knob garnet deposit near Sparta in Alleghany County.

Andradite is found in Mexico at the Negra Mine at Cadereta in Querétaro. Canadian sources include the Marmoraton Mine in Marmora Township, Hastings County, Ontario, and the Poudrette and Sesourdy quarries at Mont Saint-Hilaire in Rouville County, Québec. In Europe, andradite occurs in Greece on Serifos Island in the Kycládes Islands, Kycládes Prefecture in Aiyaíon (Aegean Islands) Department; in Germany at the Fohberg, Neunbrunnen, and Kirchberg quarries at Kaiserstuhl in Baden-Württemberg; in Spain at the Nueva Vizcaya, La Judía, and Monchi mines at Badajoz in Extremadura; in Sweden at Söråker near Timrå in Medelpad; in Switzerland near the Gorner Glacier at Zermatt in the Matt Valley in Valais; and in Italy at the Villa Inglese and Pollena quarries in the Somma-Vesuvius complex, Naples Province, Campania, and the Franscia and Sferlun asbestos mines in the Malenco Valley, Sondrio Province, Lombardy.

Russia is well-known for the demantoid variety of andradite, notably from the Kovdor Mine on the Kola Peninsula in Murmansk Oblast' in the Northern Region, and various sites at Kakodina in the Northern Urals Region. Andradite is found in China at the Funiushan copper-gold-iron deposit in the Ningzhen district, Nanjing Prefecture, Jiangzu Province; in Iran at Soghan in the Baft district of Kerman Province; in Tajikistan near Badakhshoni-Kuni in the Pamir Mountains; in South Africa at the Wessels Mine at Hotazel in the Kalahari manganese fields in Northern Cape Province; in Namibia at the Elliot and Schmimanski claims in the Karibib district in the Erongo Region; in Japan at the Kamioka Mine at Hida in Gifu Prefecture and the Kouse Mine at Tenkana in Nara Prefecture; and in Peru at the Rosario Mabel claims at Pampa Blanca in the Castrovirreyna district, Castrovirreyna Province, Huancavelica Department.

JEWELRY & DECORATIVE USES

Because of its abundance, hardness, durability, range of attractive colors, and cuttable nature, the garnet-group minerals have served as gemstones since antiquity. Garnet cabochons, known as "carbuncles," date to at least 3000 B.C. By 1400 A.D., the red and green garnet varieties, including those of andradite, were popular as faceted gems, due largely to their resemblance to emeralds and rubies. Because individual garnet species were not distinguishable until the 1800s, all garnet-group gemstones were traditionally referred to simply as "garnet." The modern jewelry industry continues this tradition, marketing all red garnet-group gems under the generic name "garnet" rather than by actual species names, which could be almandine, spessartine, pyrope, or andradite. Only non-red garnet gems are marketed under their formal or variety names, such as demantoid.

Demantoid, the chromium-rich, green andradite variety, is by far the most valuable of all garnet-group gems. This rare and beautiful gemstone has a range of green colors that approximate those of peridot, emerald, and the green varieties of grossular, spinel, and tourmaline. Demantoid has an extraordinary diamond-like luster; its name, in fact, stems from *demant*, the Greek word for diamond. Demantoid also has higher dispersion than most other minerals, including diamond. Dispersion refers to a crystal's ability to divide white light into its spectral colors in an optical effect known as "fire." The dispersion of diamond, a gem known for fire, is 0.044, while that of andradite is considerably higher at 0.057. Demantoid and other andradite varieties also have a high index of refraction, a measure of the ability to bend light and create brilliance in cut gems. Demantoid's index of refraction is 1.888-1.889, considerably higher than that of the corundum [aluminum oxide, Al_2O_3] gemstones ruby and sapphire.

March 2009 Mineral of the Month: Andradite

Demantoid was discovered in 1853 in Russia's Ural Mountains and gained favor as an emerald look-alike. Its popularity peaked after 1900 when Russian jeweler-to-the-czar Peter Carl Fabergé (1846-1920) used the stone in his creations. Although other demantoid sources have since been found, notably in Germany and Italy, the current supply is sparse and erratic. Today, most demantoid is seen in expensive antique jewelry. Demantoid gems over two or three carats now cost as much as $5,000 per carat. Some demantoid aficionados prefer the deeper, emerald-green color, while others choose lighter greens that exhibit more of the stone's brilliant fire.

The 2009 Tucson Gem & Mineral Show featured a large collection of red andradite gems from China. In round, oval, trillion, and princess cuts, these gems ranged in weight just over one carat in weight and sold for about $50 per carat. With excellent transparency, the high dispersion of these gems created superb flashes of red, orange, yellow, and green fire.

Melanite, the reddish-black to jet-black, opaque, titanium-rich andradite variety, was extremely popular as mourning jewelry in the nineteenth century Victorian era. It is said that Queen Victoria would wear only black gemstones after the death of her husband and mother. (Another black gemstone that gained prominence during this period was Jet, a type of coal formed from petrified wood found near Whitby, England.) Another attractive andradite variety is greenish-yellow to nearly colorless topazolite. Topazolite crystals have dazzling fire and brilliance, but unfortunately few are large enough to cut into gems. An iridescent form of andradite has recently been discovered and cut into beautiful gems. The iridescent reflections, which are created by thin-film interference on the surface of the andradite, span the entire visible spectrum. A beautiful photograph of iridescent andradite was featured on the cover of the May-June 2008 issue of *Rocks & Minerals*.

Andradite is often cut into collector gems for display purposes. Mineral collectors value andradite for its colors and crystal form in both individual and composite specimens, the latter often in association with white marble or green epidote.

HISTORY & LORE

Archaeologists have recovered andradite amulets and talismans from Egyptian tombs dating to 3100 B.C. and from Swedish cultural sites dating to 2100 B.C. Some historians believe that a cabochon of andradite was one of the 12 gemstones adorning the breastplate worn by high priests of the Hebrews. In medieval times, European crusaders wore red garnets for protection in battle and to aid in their safe return, while physicians believed that red garnet crystals protected wearers from poisons and helped cure infections and blood-related maladies.

Because of their complexity, similar physical properties, and the tendency to form solid-solution series, mineralogists were unable to distinguish individual garnet species until the early 1800s. Improved chemical-analysis techniques enabled mineralogists to distinguish pyrope and almandine in 1803, grossular in 1807, and spessartine and uvarovite in 1832. Andradite was identified as a species in 1868, when it was named in honor of Brazilian naturalist, statesman, professor, and mineralogist José Bonifácio de Andrada e Silva (1763-1838). Andrada e Silva, who visited Europe often to work with Portuguese and Spanish mineralogists, discovered four new minerals, including the closely related lithium-aluminum-silicate minerals spodumene [$LiAlSi_2O_6$] and petalite [$LiAlSi_4O_{10}$]. The introduction of X-ray diffraction analytical techniques in the 1920s improved the ability to differentiate between the known garnet-group species. But the ability to positively distinguish all garnet species awaited the later development of mass-spectrography and other advanced quantitative-analysis methods that could detect subtle differences in chemical composition. Mineralogists only identified the most recent garnet-group mineral in 1996.

March 2009 Mineral of the Month: Andradite

Red garnet-group gems are the birthstone for January. Red garnet (species not specified) is New York's state mineral, while red star almandine is Idaho's state gemstone and red almandine is Connecticut's state gemstone. Garnet-group minerals have been featured on at least six postage-stamp issues. A beautiful specimen of red andradite on a green epidote matrix appeared on the 15-manat stamp of Azerbaijan in 1994.

Metaphysical practitioners believe that garnet-group members generally enhance compassion, love, imagination, and creativity, while teaching patience and strengthening the mind and body in times of need. Andradite is thought to stimulate creativity and help develop close relationships. The demantoid variety is though to enhance vitality and to prevent fear, insecurity, and feelings of loneliness; topazolite protects children and the frail, while eliminating mental, spiritual and emotional chaos; and melanite dispels anger, envy, jealousy, and mistrust, and helps to elevate partnerships to higher levels.

TECHNOLOGICAL USES

Almandine, pyrope, grossular, and to a lesser extent andradite have served as industrial abrasives since the 1880s. Although only as hard as quartz (about Mohs 7.0), they make a superior abrasive. Unlike quartz, garnet abrasives can be reused often. Garnet's relatively high density enables hydraulic recovery, and its grains do not round with wear, but instead fracture into sharp-edged, durable bits that retain their abrasive properties. Garnet abrasives fill an industrial niche between inexpensive sand and costly synthetic abrasives. Garnet grains are the grit on the "garnet paper" that is used to smooth and polish wood, plastic, glass, and metal. The petroleum industry uses large quantities of garnet to scour drilling steel and well casings. Garnet also serves as a sandblasting and water-jet cutting agent, while highly refined garnet dust is the standard polishing agent for fine optics. Garnet has replaced quartz in many industrial-abrasive applications for health reasons; unlike quartz dust which, when inhaled, causes the industrial pulmonary disease silicosis, garnet dust is nontoxic.

Industrial garnet is recovered primarily from alluvial deposits by dredging and sluicing. Lesser amounts are recovered as by-products of certain types of hardrock mining. Nearly 400,000 metric tons of garnet worth $60 million is mined worldwide each year. The leading producers, in order, are Australia, China, India, and the United States. The United States annually produces 61,000 metric tons of garnet from mines in New York, Montana, and Idaho

ABOUT OUR SPECIMENS

Our andradite specimens were collected at Garnet Hill in California. At least 20 "Garnet Hills" (or "Garnet Mountains") exist in the United States, and most are named for occurrences of garnet-group minerals. Garnet Hill near Palm Springs in Riverside County, California, is a popular hiking area where garnet-group minerals are found loose on the surface. Garnet Hill near Ely in White Pine County, Nevada, is a well-known collecting area for spessartine, while Garnet Hill near Raleigh, North Carolina, is a collecting site for almandine.

Our specimens come from Garnet Hill in Calaveras County, California. Garnet Hill is 60 miles east-southeast of Sacramento, 10 miles east of Pioneer (population 800, elevation 3,000 feet) on California Route 88, and 20 miles west of the Bear Valley Ski Area on California Route 4. Overlooking the confluence of the North Fork of the Mokelumne River and Moore Creek, Garnet Hill rises to a 4,491-foot-high summit and is forested with pine at higher elevations and mixed oak-pine growth at its lower elevations. It is reached from California Route 88 by U.S. Forest Service roads that connect with mine access roads.

March 2009 Mineral of the Month: Andradite

Prospectors searched Garnet Hill for gold during the California Gold Rush, but it attracted little mineral interest until 1896, when a state geologist's report cited it as a source of fine crystals of epidote and andradite. Geologists found that these crystals occurred in skarns that outcropped across parts of the hill. Skarns are zones of calcium-rich silicates that form when magma intrudes layers of calcium-rich sediments, usually limestone, a sedimentary rock consisting of at least 50 percent calcite. The Garnet Hill skarns formed when a magmatic mass penetrated overlying strata of limestone and shale to create an intrusion of grandiorite, an igneous rock with a silica content slightly lower than that of granite. The high-temperature metamorphic contact of the silica-rich magma with the calcium-rich marine limestone created marble, slate, and several calcareous silicates and oxides that are typical of skarns. At Garnet Hill, these minerals include andradite, epidote [$Ca_2Al_2(Fe,Al)Si_3O_{12}(OH)$], ferro-axinite [$Ca_2FeAl_2BO(OH)(Si_2O_7)_2$], quartz [$SiO_2$], scheelite [$CaWO_4$], and titanite [sphene, $CaTiOSiO_4$]. The Garnet Hill skarns vary in width and mineralogical character; the skarn outcrops at the summit are 100 feet in width and rich in andradite and quartz, while the smaller outcrops near Moore Creek are richer in epidote.

During World War I, the need for tungsten to manufacture hard, armament-grade steel alloys lured prospectors back to Garnet Hill to search for scheelite. In 1917, miners began shipping scheelite ore—grains of scheelite intermixed with massive, reddish-brown andradite—from small mines near the summit. But production halted when tungsten prices plummeted after the Armistice of 1918. Mining resumed in 1942 when World War II sent tungsten prices soaring, and again in the early 1950s during the Korean War. Despite its lengthy mining history, Garnet Hill was never a major source of tungsten, and mining ended there in 1953. Today, the mining areas are leased to commercial specimen collectors who mine and market andradite and epidote crystals.

Our specimens were collected at the summit mine workings on Garnet Hill, a site that many collectors consider to be a classic North American andradite locality. Garnet Hill andradite is reddish-brown to brown and semi-translucent to opaque. Semi-transparent crystals are rare. The dodecahedral (12-sided) habit is most common. Crystal size is as large as four inches, but the smaller crystals typically show the best development. Many crystal faces are modified, especially in larger crystals. The summit skarns consist mainly of massive or granular andradite with occasional pockets that are filled with well-developed andradite crystals. These pockets are the source of our specimens. Specimen mining at Garnet Hill is not easy, as large amounts of massive andradite must be carefully blasted loose to search for pockets that may or may not be filled with collectible andradite crystals.

Figure 2. Collecting our andradite specimens at Garnet Hill.

As you examine your andradite specimen, compare its physical properties to those detailed at the beginning of this write-up:

Color, transparency, and streak: Crystal form and color are the two most obvious physical properties of any mineral specimen. The uniform, deep, reddish-brown color of our andradite crystals is caused by the essential element iron. Their opacity is also due mainly to their considerable iron content (21.98 percent by weight), as well as to defects in the crystal lattice caused by the presence of trace impurities. Despite the reddish-brown color of our crystals, their streak is colorless. Streak refers to the color of a mineral when it is drawn across a streak plate or ground to a fine powder. Thus, the deep, reddish-brown color of our specimens is due to the reflective properties of the surface of the crystal lattice of *intact* crystals.

March 2009 Mineral of the Month: Andradite

Crystal system and habit: Like all garnets, our andradite crystals are blocky or ball-like, shapes that are characteristic of the isometric system. This system is defined by three axes of symmetry, all of equal length and intersecting at right angles. Observe a well-developed crystal on your specimen and visualize how this isometric axial arrangement would fit within it. Isometric crystals often exhibit cubic (6-sided), octahedral (8-sided), dodecahedral (12-sided), or trapezohedral (24-sided) habits. The habit of our crystals is dodecahedral, meaning that each crystal—in its idealized form—would have 12 faces. Many crystals on our specimens are half-exposed and exhibit about six faces, meaning that the idealized, complete crystal form would exhibit 12 faces. Notice also that many individual crystal faces have a diamond shape or a modified diamond shape that appears as an elongated hexagon by addition of two opposite, parallel sides.

Luster: The manner in which the surface of a mineral crystal reflects light is called "luster." Luster is determined by the surface characteristics of the atomic structure and can be modified by the crystal's degree of transparency. Do not confuse luster with color, as differently colored minerals can have the same luster and vice versa. Luster is best observed from a fresh cleavage surface or a clean crystal face. Our andradite crystals exhibit a bright, vitreous or glass-like luster that is similar to the luster of a polished glass surface.

Fracture and cleavage: The physical properties of fracture and cleavage are also determined by atomic structure. Minerals exhibit cleavage when they break along smooth, flat, lustrous planes, while fracture refers to the irregular breakage of a crystal. Because of the strong, omnidirectional, covalent bonding in its crystal lattice, andradite, like quartz, has no definite cleavage and exhibits an uneven to conchoidal fracture. Study any broken crystals at the edges of your specimen and notice the absence of any flat, smooth cleavage planes (do not confuse crystal faces with cleavage planes). Note also that the broken surfaces of the crystals are generally irregular, but sometimes exhibit conchoidal (concave or shell-like) patterns.

Specific gravity: Density, or weight per unit volume, is measured in specific gravity. Relative density of any object can generally be sensed by its "heft" in the hand. With an average specific gravity of 3.9, andradite is about 50 percent more dense than quartz. This is why our andradite specimens, when compared to quartz specimens of similar size, have noticeably greater heft in the hand.

Now that you have examined your specimen, what stands out in your mind? Andradite and the other common garnet group members are certainly notable for their well-defined crystal forms and faces, which are a joy to examine. Garnets make exceptional gemstones and are indisensable as abrasives. And garnets are widely dispersed around the world so that almost anyone may have a chance to collect them personally. What more could we ask from such an exceptional group of minerals?

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold; *2004 Fleischer's Glossary of Mineral Species*, Joseph Mandarino and Malcolm Back; *The Curious Lore of Precious Stones*, George Frederick Kunz, 1913, Dover Books reprint; *Simon & Schuster's Guide to Gems and Precious Stones*, Cipiani, Borrelli, Lyman, 1999, Simon & Schuster Fireside Books; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold; *Gemstones of North America*, John Sinkankas, Geoscience Press; *Color Encyclopedia of Gemstones*, Joel E. Arem, Van Nostrand Reinhold; *The Complete Guide to Rocks & Minerals*, John Farndon, Hermes House, 2007; "Industrial Garnet," Donald W. Olson, *2007 Minerals Yearbook*, United States Geological Survey; "Colored Gemstones of Africa," Michael Gray, *Rocks & Minerals*, September-October 2001; "Garnet: Featured Mineral Group at the 1993 Tucson Show," Peter Modreski, *Rocks & Minerals*, January-February 1993; "Garnets are Great," Bob Jones, *Rock & Gem*, July 1980; "Garnet," Bob Jones, *Rock & Gem*, January 1999; "Garnet: A Better Abrasive," Steve Voynick, *Rock & Gem*, September 2004; "Large Andradite Collection at GemFair," *Jewelers Circular Keystone*, January 16, 2009; "Iridescent Andradite," David Federman, *Modern Jeweler*, July 2006; "Genesis of the Garnet Hill Skarn, Calaveras County, California," Kenneth J. Brock, *GSA Bulletin*, Geological Society of America, November 1972.