

# Mineral of the Month Club November 2015

## FLUORITE with CALCITE

This month we are featuring composite specimens of fluorite with calcite from China's Xianghualing Mine. Our write-up discusses the mine's history, the industrial importance of fluorite, and an internationally recognized collector's guidelines for assessing the visual beauty of mineral specimens.

### OVERVIEW

### PHYSICAL PROPERTIES

Chemistry: Calcium Fluoride  $\text{CaF}_2$

Class: Halides

Group: Fluorite

Crystal System: Isometric (Cubic)

Crystal Habits: Usually cubic, often as penetration twins; less frequently octahedral; rarely dodecahedral; also occurs in botryoidal, granular, massive, earthy, and columnar forms.

Color: White, colorless, violet, purple, lilac, blue, green, yellow, brown, amber, bluish-black, pink, and rose-red; the "rainbow" variety is multicolored.

Luster: Vitreous

Transparency: Transparent to translucent

Streak: White

Cleavage: Perfect in four directions, forming octahedrons.

Fracture/Tenacity: Uneven; brittle.

Hardness: 4.0

Specific Gravity: 3.0-3.2

Luminescence: Often fluorescent and phosphorescent, sometimes thermoluminescent and triboluminescent.

Refractive Index: 1.433

Distinctive Features and Tests: Best field indicators are well-developed cubic or octahedral crystals; perfect, four-directional cleavage and a tendency to cleave into octahedrons; relative softness; and occurrence in fluorine-rich, mineralogical environments.

Dana Classification Number: 9.2.1.1

**NAME:** The word "fluorite," pronounced FLOR-ite, stems from the Latin *fluor*, meaning "flow" and alluding to the mineral's ability to reduce the melting temperature of metallurgical smelting mixes. Alternate names for fluorite include "androdamant," "bruiachite," "Derbyshire spar," "fluor," "fluores," "fluoride of calcium," "fluoride of lime," "fluorspar," "fluorspath," "flusse," "flusspat," "liparite," "murrhina," and "spath vitreux." Among fluorite's color-related varieties are "false emerald," "false amethyst," "false ruby," and "fluorite rose." The "rainbow" variety

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exhibits multicolored banding and zoning; “chlorophane” is a thermoluminescent variety. In European mineralogical literature, fluorite appears as *fluorit*, *fluorita*, and *fluorin*.

**COMPOSITION & STRUCTURE:** Fluorite’s chemical formula  $\text{CaF}_2$  shows that it is a simple halide mineral consisting of the elements calcium and fluorine. Calcium accounts for 51.33 percent of fluorite’s molecular weight, fluorine for 48.67 percent. Fluorite crystallizes in the isometric (cubic) system, usually as well-developed cubes and less frequently as octahedrons. The fluorite molecule and crystal lattice are joined entirely by ionic bonding. Because the ionic bonding within the cubic lattice is inherently weak, fluorite has perfect, four-directional cleavage and cleaves easily into octahedrons. It is also relatively soft at Mohs 4.0. Fluorite is an allochromatic or “other-colored” mineral; its colors are due to traces of nonessential elements called chromophores, lattice defects called “color centers,” and exposure to natural geophysical radiation. Because these color-producing mechanisms frequently occur together, fluorite exhibits the broadest color range of all minerals. Fluorite forms in several mineralogical environments. In epithermal (low-temperature) veins, it is associated with calcite, rhodochrosite, and chalcedony. In hydrothermal replacement deposits, fluorite occurs with galena, pyrite, sphalerite, and barite, and is often a gangue mineral with lead, zinc, and silver ores. Fluorite also occurs with albite and pyrite in carbonatites, with calcite and spinel in the hornfels of contact metamorphic rocks, and with albite in granite pegmatites.

**COLLECTING LOCALITIES:** Fluorite is collected in China, England, Norway, Sweden, Spain, Hungary, Germany, Italy, Peru, Bolivia, Australia, Pakistan, Russia, Morocco, Namibia, Zimbabwe, South Africa, Canada, and Mexico. In the United States, fluorite occurs in Illinois, Kentucky, Tennessee, Colorado, New Mexico, Oklahoma, New Hampshire, and Ohio.

**HISTORY, LORE & USES:** Known since antiquity, fluorite has long been used as a gemstone and a decorative stone that is fashioned into faceted gems, spheres, figurines, and other ornamental objects. It has served as a smelting flux since 600 B.C. and remains an important flux material in many modern metallurgical processes. Fluorite was among the first minerals studied in the pioneering X-ray diffraction experiments of 1914. Fluorspar ore consists mainly of fluorite and is the only source of fluorine. About seven million metric tons of fluorspar are mined worldwide each year. Fluorite has numerous direct and indirect industrial uses. It provides the fluorine used to prepare hydrofluoric acid, which is a feedstock for the manufacture of many chemicals and pharmaceuticals. Fluorite is converted to uranium hexafluoride ( $\text{UF}_6$ ), an intermediate chemical step in the gas-diffusion concentration of uranium-235 for the production of nuclear fuel rods and nuclear weapons. Large amounts of fluorite are also converted into aluminum fluoride and synthetic cryolite for use as an aluminum-smelting flux. Metaphysical practitioners believe that fluorite calms the spirit and mind to prepare for meditation, clarifies the decision-making process, and enhances objectivity and concentration. Because individual fluorite colors are assigned specific metaphysical properties, multicolored “rainbow” fluorite is considered an especially useful stone. With its wide range of colors, well-developed crystals, and interesting mineralogical associations, fluorite is among the most widely collected of all minerals.

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**ABOUT OUR SPECIMENS:** Our specimens of fluorite with calcite were collected at the Xianghualing Mine in the Xianghualing polymetallic ore field in Linhu County, Chenzhou Prefecture, Hunan Province, China. Located 250 miles north-northwest of the coastal city of Hong Kong, this region has a humid, subtropical climate; its terrain is consists of low, wooded ridges separating valleys where rice is cultivated. The highly mineralized Xianghualing polymetallic ore field is an important source of tin, lead, zinc, copper, tungsten, and other metals. The Xianghualing mineral deposit was first mined for tin and copper in the 10<sup>th</sup> century A.D. By the time the modern People's Republic of China was founded in 1949, mining at the Xianghualing deposit had yielded some 10,000 tons of tin and left the hillsides scarred with old pits and tunnels. The Xianghualing Mine, operated by the provincially owned Xianghualing Tin Co., Ltd., began production in 1982. The mine now yields 3,000 tons of tin per year, along with significant quantities of lead, zinc, copper, molybdenum, tungsten, beryllium, and rare-earth metals. Since the 1990s, the Xianghualing Mine has been an important source of fluorite specimens, which occur in vugs within altered limestone. These vugs range in size from small cavities only inches in width to large, "walk-in" openings that are sometimes completely covered with well-developed, lustrous crystals of fluorite and calcite.

## COMPREHENSIVE WRITE-UP

### *COMPOSITION & STRUCTURE*

Over the past 19 years, fluorite has been featured as a Mineral of the Month in a variety of habits and colors, including cubic, octahedral, and botryoidal forms and purple, blue, dark-green, pink, and "rainbow" colors. This month we are featuring pale-green, octahedral fluorite as composite specimens with calcite from a new locality—China's Xianghualing Mine.

Fluorite [calcium fluoride, CaF<sub>2</sub>] is a simple halide mineral that consists of the elements calcium (Ca) and fluorine (F), which respectively account for 51.33 percent and 48.67 percent of its molecular weight. The fluorite molecule consists of a single cation (positively charged ion) and a single anion (negatively charged ion) joined together entirely by ionic bonding, which is the attractive force between positively charged ions of distinctly metallic elements and negatively charged ions of distinctly nonmetallic elements. In fluorite, the calcium ion Ca<sup>2+</sup> has a +2 charge and is ionically bound to two fluorine ions 2F<sup>1-</sup> with a collective -2 charge. This balance of anionic and cationic charges provides the fluorite molecule with electrical stability.

Within fluorite's crystal lattice, eight fluorine ions surround each calcium ion, while four calcium ions surround each fluorine ion. In this arrangement, alternating rows of calcium ions and fluorine ions are oriented in four axial directions to create cubic structures with calcium ions occupying the eight corners of each cube and the centers of its six faces. Because of weak ionic bonding, fluorite exhibits perfect, four-directional cleavage and cleaves easily into octahedrons. Fluorite is relatively soft at Mohs 4.0; its moderately high density (specific gravity 3.0-3.2) is due to close atomic packing within its rigid, well-organized cubic structure.

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Fluorite exhibits the widest color range of all minerals. It is an allochromatic or “other-colored” mineral, with colors caused by elemental impurities, defects in the crystal lattice, unbound fluorine ions, or by combinations of some or all of these factors. Most fluorite colors are produced by traces of nonessential elements called chromophores (color-causing agents). Pure fluorite is colorless or white, but traces of iron or the rare-earth elements yttrium and cerium alter the light-absorption properties of the lattice. Iron imparts green and yellow colors to fluorite; yttrium and cerium create pink and rose colors; lanthanum also produces green colors. Purple, blue, and violet colors are usually due to lattice defects called “color centers,” which result from abnormal crystal growth or exposure to natural geophysical radiation. In fluorite, color centers form when fluorine ions are displaced from their normal lattice positions to create voids that trap electrons. White light boosts these trapped electrons to higher energy levels; to return to normal levels, the trapped electrons release excess energy as purple, blue, or violet light. Fluorite is sometimes multicolored, with bands and zones of different colors and color intensities within the same crystal.

Fluorite is often fluorescent, phosphorescent, thermoluminescent, or triboluminescent. These forms of luminescence occur when fluorite absorbs mechanical, thermal, or various forms of electromagnetic energy that boost the electrons within the crystal lattice from their normal inner orbits to high-energy outer orbits. They return to their normal orbits by releasing excess energy as visible light. In fluorescence, ultraviolet light energizes electrons, which immediately release excess energy as purple, blue, or violet light. The word “fluorescence” is derived from fluorite, the first mineral in which this phenomenon was observed. Phosphorescent minerals continue to emit visible light even after input energy has ceased. Thermoluminescent minerals, including fluorite, emit light when heated; triboluminescent minerals emit light when mechanically stressed.

Fluorite is a relatively abundant, widely distributed mineral that forms in several mineralogical environments. In epithermal (low-temperature) veins, fluorite is associated with calcite [calcium carbonate,  $\text{CaCO}_3$ ], rhodochrosite [manganese carbonate,  $\text{MnCO}_3$ ], and chalcedony [microcrystalline quartz, silicon dioxide,  $\text{SiO}_2$ ]. In hydrothermal replacement deposits, it occurs with galena [lead sulfide,  $\text{PbS}$ ], pyrite [iron disulfide,  $\text{FeS}_2$ ], sphalerite [zinc sulfide,  $\text{ZnS}$ ], and barite [barium sulfate,  $\text{BaSO}_4$ ], and is a common gangue mineral in many lead, zinc, and silver ores. Fluorite also occurs with albite [sodium aluminum silicate,  $\text{NaAlSi}_3\text{O}_8$ ] and pyrite in carbonatites (calcium-rich igneous rocks); with calcite and spinel [magnesium aluminum oxide,  $\text{MgAl}_2\text{O}_4$ ] in hornfels (fine-grained, altered silicate rocks) of contact metamorphic zones; and occasionally with albite in granite pegmatites.

The Dana mineral-classification number 9.2.1.1 identifies fluorite as a halide mineral (9). It is subclassified (2) as an anhydrous halide with the general formula  $\text{AX}_2$ , in which “A” can be calcium, barium, or the rare-earth element yttrium, and “X” is any halogen element. Fluorite then falls into the fluorite group (1) as the first (1) of three members. The other two group members are the physically similar minerals frankdicksonite [barium fluoride,  $\text{BaF}_2$ ] and tveitite-(Y) [calcium yttrium fluoride,  $\text{Ca}_{14}\text{Y}_5\text{F}_{43}$ ].

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Although elemental fluorine, one of fluorite's two essential elements, is extremely poisonous and corrosive, fluorite specimens are stable, safe, and require no special handling or storage. However, be sure never to heat fluorite or treat it with any acid that might release fluorine gas.

### *COLLECTING LOCALITIES*

Our specimens of fluorite with calcite are from the Xianghualing Mine in the Xianghualing polymetallic ore field in Linhu County, Chenzhou Prefecture, Hunan Province, China. Fluorite also occurs at the nearby Huangshaping, Yaogangxian, Dongpo, Chashan, and Xianghuapu mines. Other noted Chinese fluorite localities are the Jiuling Shan Mountains in Jiangxi Province; and the Tongbai fluorite mine in Tongbai County, Gaoxin District, Nanyang Prefecture, Henan Province.

In England, fluorite occurs at the Rogerley Mine in the Weardale district near Frosterly, North Pennines County, Durham; and the Blue John and Old Tor mines and Treak Cliff Cavern at Castleton, Derbyshire, Cornwall. Other European localities include the Lassedalen fluorite deposit and the Kongsberg silver mines near Kongsberg, Buskerud, Norway; the Manhem, Kårvet, and Finnbo mines at Falun, Dalarna, Sweden; the La Florina and Gloria mines at Hornachuelos near Córdoba, Andalusia, Spain; the Bella Mine at Pákozd in the Velencei Mountains, Fejér County, Hungary; the Badenweiler lead-mining district in Baden-Württemberg, Germany; and the Carrara marble quarries in the Apuan Alps, Massa-Carrara Province, Tuscany, Italy.

Fluorite occurs in the Huaron district in Pasco Department, and the Pasto Buena district in Ancash Department, both in Peru; and the Mururata and Chojilla mines in Sud Yungas Province, La Paz Department, Bolivia. Australian sources include the Sandy Creek fluorite deposit at Walwa, Victoria; the Cannington silver-lead-zinc deposit in the Mount Isa-Cloncurry area, Queensland; and the Gulf fluorite mine at The Gulf, New South Wales.

In Pakistan's Northern Areas, fluorite is collected at Nagir and Chumar Bakhoor in the Hunga Valley in the Gilgit District, and at Baha and Apo Ali Gun in Baltistan. Russian specimens come from the Pouvyva and Dodo mines at Tyumenskaya Oblast' in the Polar Urals, Western-Siberian Region; and the Aunik deposit at Buriatia in Transbaikalia, Eastern-Siberian Region. Other sources are the El Hammam Mine at Meknès, Meknès-Tafilalet Region, Morocco; the Okoruso Mine in the Otjiwarongo District and the Kombat Mine in the Grootfontein District, both in Otjozondjupa Region, Namibia; the Hwange lead-zinc district in Matabeleland, North District, Zimbabwe; and the Aladdin Mine at Sinkwazi in KwaZulu-Natal Province, and the Marico Fluorspar Mine in the Marico district in Northwest Province, both in South Africa.

Canadian fluorite specimens are collected at the Rogers fluorspar mine at Madoc, Huntingdon Township, Hastings County, Ontario; the Poudrett, Uni-Mix, and Desourdy quarries at Mont Saint-Hilaire, Rouville County, Québec; and the Penobsquis potash mines, Kings County, New Brunswick. Mexican sources include the Navidad Mine near El Rodeo; the China, Ojuela, and

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Reina mines at Mapimí, both in Durango; and the Cantera and Asturiana mines near the city of Zacatecas, Zacatecas.

Fluorite sources in the United States include the Cave-in-Rock and Ozark-Mahoning subdistricts of the Illinois-Kentucky Fluorspar District in Hardin County, Illinois; and the Babb, Commodore, and Dike-Eaton subdistricts of Crittenden and Caldwell counties, Kentucky. Among Colorado's sources are the Sweet Home Mine at Alma, Park County; the Barstow Mine near Ouray, Ouray County; and the Browns Canyon Fluorspar District, Chaffee County. In New Mexico, fluorite occurs at Fluorite Ridge, Luna County; the Hansonburg district at Bingham, Socorro County; and Pine Canyon near Tyrone in Grant County. Fluorite is also collected at the Capital and Ten-Acre quarries, Johnston County, Oklahoma; the William Wise Mine in Westmoreland, Cheshire County, New Hampshire; the Elmwood Mine at Carthage, Smith County, Tennessee; and the quarries at Clay Center, Ottawa County, Ohio.

## *JEWELRY & DECORATIVE USES*

Cleaved and crudely faceted fluorite gems were popular in Europe in the 1600s, when such color varieties as “false emerald,” “false ruby,” and “false amethyst” were substituted for more valuable gems. Among fluorite's many excellent gemological properties are good transparency, a wide range of pleasing colors, a vitreous luster, and large crystals suitable for cutting into sizeable gems. Unfortunately, a low refractive index of 1.433 limits the brilliance of fluorite gems. Also, fluorite's perfect, four-directional cleavage makes cutting difficult, while its softness (Mohs 4.0) is not suitable for everyday jewelry use. Nevertheless, fluorite cabochons and faceted gems are sometimes mounted in pendants and brooches. Collectors' gems of 100 carats or more are popular for display purposes. The Smithsonian Institution in Washington, D.C., exhibits several spectacular fluorite gems, including one of 492.1 carats. Massive, translucent fluorite is fashioned into spheres, vases, figurines, and other ornamental objects.

As both individual and composite specimens, fluorite is widely collected for its large crystal size, excellent crystal development, availability, affordability, broad range of colors, and interesting mineralogical associations. Fluorite collections, which often focus on specific colors and crystal habits, are a favorite among museum curators. In composite specimens, fluorite is usually associated with calcite [calcium carbonate,  $\text{CaCO}_3$ ], galena [lead sulfide,  $\text{PbS}$ ], rhodochrosite [manganese carbonate,  $\text{MnCO}_3$ ], and quartz [silicon dioxide,  $\text{SiO}_2$ ].

## *HISTORY & LORE*

The earliest known fluorite artifacts were recovered from 4,000-year-old Egyptian tombs. By 600 B.C., Greek metalworkers were using fluorite as a smelting flux to remove impurities from, and lower the melting temperature of, silver ores. Later, the Romans mined fluorite extensively in Spain and England, also to serve as a smelting flux. Medieval physicians prescribed the ingestion of powdered fluorite to treat kidney disease, and placed fluorite crystals against arthritic joints to alleviate pain. By the 15<sup>th</sup> century, the Chinese were carving beautiful figurines

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from massive, blue and green fluorite that resembled jade. European metallurgists of the same period were using fluorite, which they called “flusse” or “flusspat,” as a smelting flux. In his classic *De re Metallica*, German scholar Georgius Agricola (Georg Bauer, 1494-1555) called fluorite “*lapides igni liquiscentes*,” literally “stones that become liquid in fire,” and extolled the value of fluorite as a metallurgical flux. Agricola later referred to “flusspat” by the Latin word *fluor*, meaning “flow,” which became the root of the modern word “fluorite.” The mineral form of calcium fluoride was formally named “fluorite” in 1868. In 1914, fluorite was one of the first minerals to have its atomic structure defined through X-ray diffraction analysis.

Fluorite, the official state mineral of Illinois, has appeared on Switzerland’s 10-centime stamp of 1961, Namibia’s 2-cent stamp of 1991, Kyrgyzstan’s 80-tyiyn stamp of 1994, Kenya’s 80-cent stamp of 1977, France’s 5-franc stamp of 1986, and Algeria’s 2.40-dinar stamp of 1983. Fluorite is popular among modern metaphysical practitioners, who believe it calms the spirit and mind to prepare for meditation, enhances objectivity and concentration, and clarifies the decision-making process. Individual fluorite colors are assigned specific metaphysical properties: White accesses the spiritual world; greens energize the heart and mind; blues provide inner peace; purples focus the mind; and yellows facilitate group communication. Multicolored “rainbow” fluorite is considered especially valuable for metaphysical purposes.

### *TWO EXPERTS’ GUIDELINES FOR ASSESSING MINERAL BEAUTY*

Many people are drawn to minerals by their beauty, a point that no one has expressed better than Peter Bancroft, author of the classic book *The World’s Finest Minerals and Crystals*. “Throughout history, man has been captivated by eye-catching minerals,” Bancroft writes. “The concentration of vibrant colors and the perfection of crystal forms create a singular beauty rivaled only by such masterpieces of nature as a butterfly’s wing or a sunset.”

Because it appeals to our sense of aesthetics, beauty is a critical factor in determining the value of mineral specimens, especially the high-end specimens that can cost thousands of dollars each and are displayed at museums and gem-and-mineral shows. The ability to judge mineral beauty requires the recognition and appreciation of several related factors, including color, color contrast, luster, form, proportional relationships, artistic balance, degree of transparency, and physical perfection. But because beauty is in the eye of the beholder, a determination of mineral beauty is subjective. In comparing two specimens, collectors often disagree on which one is more beautiful—and why.

For insight into assessing the visual appeal of mineral specimens, we spoke with world-class mineral collector Keith Proctor, a widely acclaimed judge of mineral beauty. Together with his wife Mauna, Proctor has assembled spectacular collections of mineral crystals and crystallized gold. In 1976, the couple paid \$100,000 for a stunning, gem-quality crystal of the pink morganite variety of beryl [beryllium aluminum silicate,  $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ] on a prism of the red, tourmaline-group mineral elbaite [basic sodium lithium aluminum borosilicate,  $\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ ]. At the time, this was the highest price ever paid for a mineral crystal that would not be cut into gems. The Proctors later traveled again to Brazil to

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acquire a 14-inch-long, 5-inch-wide, gemmy prism of transparent, raspberry-red elbaite on a gleaming matrix of snow-white albite [sodium aluminum silicate,  $\text{NaAlSi}_3\text{O}_8$ ]. Known as the “Rose of Itatiaia,” it was the first million-dollar mineral specimen ever brought to the United States. The exceptional value of both these superb specimens was derived not from mineralogical rarity, but from their exceptional beauty.

Drawing upon their personal philosophies of mineral and crystal aesthetics, the Proctors cite the following nine factors that contribute to the visual appeal of both individual crystals and composite specimens of crystals on matrix.

1/ Because many collectors consider elegant crystal form the most exciting and pleasing aspect of minerals, crystals should exhibit sharp, architectural lines and be complete in form.

2/ Crystals should preferably be gem-like in their transparency or translucency. The most beautiful crystals exhibit the same qualities that are admired in gems—brilliance, clarity, and symmetry.

3/ Crystal faces should be glassy and mirror-like. The most attractive crystals display natural faces that appear to have been faceted and polished. Crystals should transmit or reflect most of the light that strikes them to create a luminescent, glowing effect. Crystals with smooth, glassy faces exhibit a vibrant quality; those with rough faces that absorb light tend to appear dull.

4/ Colors should be as desirable and appealing as possible. Because the eye is always drawn to color, color intensity and color purity are primary elements in mineral beauty. Bright colors are the most desirable. It is not coincidental, all other factors being equal, that brightly colored crystals have greater appeal and value than those that are white, colorless, gray, or black.

5/ In composite specimens—specimens in which two or more mineral species are prominent—overall composition becomes critical. Composition, which is the visual relationship between the crystal and the matrix, must be balanced and properly proportioned. We judge all composite objects, from flower arrangements to paintings, by the sum of their parts. Truly beautiful objects have a definite sense of balance and a harmony of form. A crystal that appears “misplaced” on its matrix upsets visual balance. Overall symmetry and pleasing composition depend not only upon the relationship between the size of the crystal and matrix, but also upon shapes and relative positions. Composition is also influenced by relief, or physical separation, which should exist between the crystal and the matrix. Crystals lying flat on a matrix are never as interesting as those that project outward.

6/ Crystals and matrix should have a pleasing size relationship. In composite specimens of crystals on matrix, neither the crystals nor the matrix should dominate in size or importance. Ideally, the matrix should “present” the crystals, while the crystals should counterbalance the matrix.

7/ Color contrast between crystals and matrix should be intense and pleasing. While similarly colored crystals and matrices may exhibit beauty of form, the most eye-catching and valuable

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specimens present a sharp contrast of colors, such as red rhodochrosite on white quartz, or green emeralds on white calcite.

8/ Ideally, crystals should not be clustered, but separated or isolated on the matrix in a manner that facilitates the study and observation of both crystal shape and matrix texture. It is easier to observe and study well-formed crystals that stand alone on the matrix as opposed to those that are tightly clustered.

9/ Both crystals and matrix must be essentially intact. The eye is easily drawn to imperfections or damaged areas, which seriously detract from a specimen's overall beauty and value. As in all objects of fine art, physical perfection in crystals is critical.

“These nine points must always be considered when acquiring or appraising fine mineral specimens,” Keith Proctor concludes. “Taken together, they enable collectors to build great collections with assured value.”

While few collectors have the opportunity or the means to acquire the finest and most valuable mineral specimens, anyone can build a fine collection which, while more modest and of lesser monetary value than, for example, the Proctors' collection is nevertheless beautiful. The basic points of judging mineral beauty hold true, whether applied to million-dollar specimens or to perfectly formed crystals of such eminently affordable minerals as quartz.

## *TECHNOLOGICAL USES*

Fluorspar ore consists primarily of fluorite and is the only commercial source of fluorine. Fluorite mining is a billion-dollar-per-year global industry, with more than seven million metric tons of fluorspar mined each year. China accounts for two-thirds of the world's output. Other major fluorspar sources are, in order of production, Mexico, Morocco, South Africa, and Spain. The United States relies entirely upon foreign sources for its supply. Fluorspar is mined from both open-pit and underground mines, then crushed and concentrated by hydraulic, gravitational separation. Concentrated fluorspar is classified into three grades: Metallurgical grade contains 60-85 percent fluorite; ceramic grade, 86-96 percent fluorite; and acid grade, at least 97 percent fluorite. Depending upon grade, fluorspar concentrate sells for between \$250 and \$600 per metric ton.

Because of fluorine's extreme chemical reactivity, fluorite is an ideal metallurgical flux. Fluorine combines with impurities to form volatile fluorides, which are removed as vapors, while the calcium combines with silicates into an easily removable slag. Metallurgical-grade fluorspar is used extensively in steelmaking; six pounds of metallurgical-grade fluorspar are needed to produce one metric ton of high-quality steel. Ceramic-grade fluorspar is converted to aluminum fluoride and synthetic cryolite [sodium aluminum fluoride,  $\text{Na}_3\text{AlF}_6$ ] for use in smelting aluminum. It is also used to manufacture ceramics, glass, fiberglass, welding-rod coatings, and uranium hexafluoride ( $\text{UF}_6$ ), the latter an intermediate compound in the gas-diffusion concentration of the uranium-235 for the production of nuclear fuel rods and the fission

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components of nuclear weapons. Most acid-grade fluorite is converted to hydrofluoric acid (HF) for use in etching glass and in the manufacturing of numerous chemical and pharmaceutical products.

Before synthetic, optical-grade fluorite became available in the 1960s, flawless, transparent, natural fluorite crystals were cut into aberration-free, apochromatic lenses for specialized infrared and ultraviolet optical uses. Today, synthetic fluorite is doped with uranium and rare-earth elements for use as laser rods. Various fluoride compounds are added to municipal drinking-water supplies and toothpastes as dental-cavity preventatives.

## *ABOUT OUR SPECIMENS*

Our specimens of fluorite with calcite were collected at the Xianghualing Mine in Linhu County, Chenzhou Prefecture, Hunan Province, China. Hunan Province, located in south-central China, has 72 million residents and is the size of the American state of Kansas. Chenzhou Prefecture, one of Hunan's 14 prefectures, is located in southern Hunan and has 4.5 million residents. The city of Chenzhou, population 600,000, is the prefecture capital. The Xianghualing Mine is located 60 miles south of Chenzhou city, and 250 miles north-northwest of the coastal city of Hong Kong. This region has a humid, subtropical climate; its terrain is dominated by wooded ridges that separate valleys where rice is cultivated.

The Xianghualing (literally translated as "flower-that-smells-good hill") Mine is one of the major mines in the Xianghualing polymetallic ore field, an important source of tin, lead, zinc, tungsten, molybdenum, copper, beryllium, and rare-earth metals. This multimetal mineralization was emplaced about 170 million years ago in the massive crustal deformation that accompanied the Jurassic-Cretaceous Yanshanian Orogeny (mountain-building episode). As tectonic stresses uplifted and fractured the crust, granitic magma surged upward into carbonate sedimentary rocks. At Xianghualing, this magma was accompanied by acidic, hydrothermal solutions rich in fluorine, tin, lead, zinc, and other metals. As the carbonate rocks decreased the acidity of the solutions, metal-ore minerals and fluorite precipitated to form complex vein- and replacement-type deposits.

Outcrops of the Xianghualing multimetal deposit were first mined for tin and copper during China's Tang and Five-Dynasty periods in the 10<sup>th</sup> century A.D. By the time the modern People's Republic of China was founded in 1949, centuries of mining had yielded an estimated 10,000 tons of tin and left the hillsides pockmarked with pits and tunnels. During China's first national economic development program in 1965, drill-core sampling at Xianghualing revealed large volumes of remaining ore that contained some 90,000 tons of tin, 19,000 tons of lead, and 90,000 tons of zinc, along with economic concentrations of several other metals.

After years of planning and development, the Xianghualing Mine began production in 1982. Today, the mine and its concentration mill, operated by the provincially owned Xianghualing Tin Co., Ltd., recovers 3,000 tons of tin per year, along with significant quantities of lead, zinc, copper, molybdenum, tungsten, beryllium, and rare-earth metals. The mill has recently installed

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a circuit to recover by-product fluorite for use as a smelting flux (see “Technological Uses”). Of its 2,400 employees, 2,000 work underground in conditions of very high heat and humidity, using outdated, labor-intensive mining methods. Numerous hillside portals and adits access the various mine levels, which are connected by internal shafts and declines. Like most Chinese mines and mills, Xianghualing operates with few environmental restraints. Subsequently, randomly discarded mine waste and mill tailings have created a severe water-pollution problem.

The complex mineralization at Xianghualing represents at least three distinct periods of deposition. The primary ore minerals are cassiterite [tin dioxide,  $\text{SnO}_2$ ], scheelite [calcium tungstate,  $\text{CaWO}_4$ ], galena [lead sulfide,  $\text{PbS}$ ], sphalerite [zinc sulfide,  $\text{ZnS}$ ], chalcopyrite [copper iron sulfide,  $\text{CuFeS}_2$ ], stannite [copper iron tin sulfide,  $\text{Cu}_2\text{FeSnS}_4$ ], tetrahedrite [copper iron zinc antimony arsenic sulfide,  $\text{Cu}_{10}(\text{Fe,Zn})_2(\text{Sb,As})_4\text{S}_{13}$ ], and ferberite [iron tungstate,  $\text{FeWO}_4$ ]. Gangue minerals include quartz [silicon dioxide,  $\text{SiO}_2$ ] and calcite [calcium carbonate,  $\text{CaCO}_3$ ]. Xianghualing is the type locality for two rare fluorosilicate minerals: hsianghualite [lithium calcium beryllium fluorosilicate,  $\text{Li}_2\text{Ca}_3(\text{Be}_3\text{Si}_3\text{O}_{12})\text{F}_2$ ], which is not found elsewhere; and balipholite [basic magnesium lithium barium aluminum fluorosilicate,  $\text{Mg}_2\text{LiBaAl}_3(\text{Si}_2\text{O}_6)_2(\text{OH,F})_8$ ].

Since the late 1980s, the Xianghualing Mine has been a noted source of fluorite specimens, which are collected from vugs in altered limestone. The walls of the vugs, which range in size from tiny cavities to large “walk-in” openings, are sometimes completely covered with lustrous, well-developed crystals of fluorite and calcite. Most crystals are shades of pale green, but bluish-green, grayish-green, grayish-blue, and lilac colors are also present. The Xianghualing fluorite crystals are usually an inch or two in size, but several have measured three feet on a side and weighed one-half ton each. In some vugs, three phases of crystallization have created superposed layers of fluorite crystals with distinctly different habits and colors.

At Xianghualing, fluorite is often associated with calcite, which crystallizes in the trigonal subdivision of the hexagonal system, and has a Mohs hardness of 3.0 and a specific gravity of 2.7-3.0. This calcite, which is colorless or white and occurs as scalenohedrons, grows atop the fluorite, which was the first of the two minerals to crystallize.

Your specimen is a composite of two minerals—fluorite and calcite. Fluorite is the primary or most visually prominent mineral; calcite is the secondary mineral. The fluorite is present as octahedrons; some specimens may also exhibit fluorite in the cubic habit. The fluorite crystals are transparent and have lightly frosted faces. Their pale-green color is due to traces of iron. The calcite occurs atop the fluorite as colorless, transparent, scalenohedral crystals with terminations, sharp edges, and lustrous faces. Your composite specimen of fluorite with calcite from China’s Xianghualing Mine offers an excellent opportunity for side-by-side comparisons of the color, luster, and form of two different mineral species.

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