

Mineral of the Month July 2014

FLUORITE var. "RAINBOW"

This month our featured mineral is the beautiful "rainbow" variety of fluorite from China. Our write-up explains the origin of its multicolored bands and discusses the development of X-ray diffraction and its importance in mineralogy and other sciences.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: Calcium Fluoride 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, columnar, and earthy forms, and as cleavage masses.

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

Luster: Vitreous

Transparency: Transparent and translucent to nearly opaque

Streak: White

Cleavage: Perfect in four directions, forming octahedrons.

Fracture: 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 cubic crystal form and well-developed crystals; perfect, four-directional cleavage; relative softness; and occurrence in fluorine-rich, mineral environments.

Dana Classification Number: 9.2.1.1

NAME: The word "fluorite," pronounced FLOR-ite, stems from the Latin *fluere*, meaning "flow" and alluding to fluorite's ability to reduce the melting temperatures of metals in smelting processes. Alternative names include "androdamant," "bruiachite," "Derbyshire spar," "fluor," "fluores," "fluoride of calcium," "fluoride of lime," "fluorspar," "fluorspath," "flusse," "flussspat," "liparite," "murrhina," and "spath vitreux." Color-related variety names are "false emerald," "false amethyst," "false ruby," and "fluorite rose." "Rainbow" fluorite has multicolored banding. "Chlorophane" is a thermoluminescent variety. In European mineralogical literature, fluorite appears as *fluorit*, *fluorita*, and *fluorin*.

Mineral of the Month July 2014

COMPOSITION & STRUCTURE: The chemical formula CaF_2 shows that fluorite is a simple halide mineral containing the elements calcium (Ca) and fluorine (F). Calcium accounts for 51.33 percent of fluorite's molecular weight, fluorine for 48.67 percent. The fluorite molecule and crystal lattice are held together entirely by ionic bonding. Because ionic bonding is inherently weak, fluorite has perfect, four-directional cleavage and readily cleaves into octahedrons. It is relatively soft at Mohs 4.0. Due to colors caused variously by traces of nonessential elements called chromophores, lattice defects called "color centers," and exposure to natural geophysical radiation, fluorite has 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, it 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 a relatively common and widely distributed mineral with collecting localities in China, England, Russia, Pakistan, Namibia, Morocco, South Africa, Zimbabwe, Norway, Sweden, Spain, Germany, Italy, Peru, Bolivia, Australia, Hungary, Canada, Mexico, and the United States (Illinois, Kentucky, Oklahoma, Ohio, New Mexico, Tennessee, New Hampshire, Colorado).

HISTORY, LORE & USES: Known since antiquity, fluorite is a gemstone and decorative stone that is carved into spheres, figurines, and other ornamental objects. It has served as a smelting flux since around 600 B.C. and is used in metallurgical processes today. Fluorite was one of the first minerals studied in pioneering X-ray diffraction experiments in 1914. It has many direct and indirect industrial uses and is mined extensively. Fluorite is the primary source of fluorine for the manufacture of hydrofluoric acid, an important feedstock for chemical and pharmaceutical manufacturing. It is converted into uranium hexafluoride (UF_6) for use in the gas-diffusion concentration of the uranium-235 isotope needed for production of nuclear fuel rods and nuclear weapons. Large amounts of fluorite are processed into aluminum fluoride and synthetic cryolite for use as an aluminum-smelting flux. According to metaphysical practitioners, fluorite calms the spirit and mind when preparing 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 powerful and useful stone. Because of its wide range of colors and habits, well-developed crystals, and many interesting mineralogical associations, fluorite is among the most widely collected of all minerals.

ABOUT OUR SPECIMENS: Our specimens of "rainbow" fluorite were collected in the Jiuling Shan Mountains of Jiangxi Province in southeastern China. Jiangxi Province is about the size of the American state of Washington and has a population of 45 million. It has a humid, subtropical climate and a terrain consisting of hills, low mountains, and broad river basins. Jiangxi Province is an important producer of tea and rice. Mining is conducted in northern Jiangxi's Jiuling Shan Mountains for coal, copper, lead, zinc, kaolin clay, and fluorite. These mountains have a complex geologic origin that began when tectonic stresses fractured 400-million-year-old limestone formations to enable fluorine-rich, hydrothermal solutions associated with deep magmatic intrusions to penetrate the faulted limestone. Our specimens of "rainbow"

Mineral of the Month July 2014

fluorite formed when hydrothermal solutions rich in calcium and fluorine ions filled horizontally oriented seams between the limestone strata to deposit fluorite. Crystallization then occurred in sequential layers to create banding patterns with different colors and thicknesses. Open-pit and underground mines in northern Jiangxi Province are a major source of both industrial fluorspar and fluorite specimens. Fluorite specimens are sent to the city of Changsha, 250 miles to the southwest in neighboring Hunan Province, where lapidaries carve “rainbow” fluorite into decorative objects, cabochons, and beads, or cut and polish selected pieces into quarter-to-half-inch-thick slabs to display the multicolored bands.

COMPREHENSIVE WRITE-UP

COMPOSITION & STRUCTURE

This is the seventh time in our 18-year history that our Club has featured fluorite as its Mineral of the Month—but the first time that we are presenting the “rainbow” variety. Our previous fluorite specimens have included cubic and octahedral crystals and a botryoidal form in colors ranging from purple to blue, green and pink. Our fluorite specimens this month are distinctly different than any that we had previously featured because they are multicolored, with five or more distinct colors appearing in sharply differentiated bands. Our transparent specimens of “rainbow” fluorite have been specially slabbed and polished to display this unusual coloration.

Fluorite is a simple halide mineral composed 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) that are held together entirely by ionic bonding. Ionic bonding is the attractive force that joins the positively charged ions of metallic elements to the negatively charged ions of nonmetallic elements. In fluorite, the calcium ion Ca^{2+} with its +2 charge is attracted to, and ionically bonded with, two fluorine ions 2F^{1-} with their 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. This arrangement results in alternating rows of calcium ions and fluorine ions that are oriented in four axial directions to create cubic structures with calcium ions occupying the eight corners of each cube and the centers of the six faces. Because of the inherent weakness of ionic bonding, fluorite exhibits perfect, four-directional cleavage and cleaves easily into octahedrons. It is also relatively soft at Mohs 4.0. Fluorite has a higher-than-expected density (specific gravity 3.0-3.2). While the atomic weights of fluorite’s essential elements calcium (40.08) and fluorine (19.00) would indicate a lesser density of about 2.8, close atomic packing within a rigid, well-organized cubic structure imparts significantly higher density.

Most fluorite specimens are fluorescent; many are also phosphorescent, thermoluminescent, or triboluminescent. These forms of luminescence occur when certain minerals absorb mechanical, thermal, or various forms of electromagnetic energy. This energy excites electrons, boosting them from their normal inner orbits to high-energy outer orbits. To return to their normal orbits,

Mineral of the Month July 2014

they release excess energy as visible light. In fluorescence, electromagnetic energy in the form of ultraviolet light energizes electrons, which then release excess energy by emitting visible light. In the case of fluorite, the emitted light is usually in the blue wavelengths. The word “fluorescence” is derived from fluorite, the first mineral in which this phenomenon was observed. Phosphorescent minerals continue to emit visible light for a period of time even after the input energy source has been removed. Thermoluminescent minerals emit light when heated; triboluminescent minerals emit light when subjected to mechanical stress.

Fluorite’s extraordinary color range, the broadest of all minerals, is attributed to three causes: elemental impurities, defects in the crystal lattice, and unbound fluorine ions. Fluorite is an allochromatic or “other-colored” mineral, meaning that its colors are created by factors not related to its essential elements or the basic nature of its crystal lattice. Fluorite’s colors are most often caused 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 can alter the light-absorption properties of the lattice. Iron imparts green and yellow colors to fluorite; traces of yttrium and cerium provide pink and rose colors; and lanthanum produces green colors. Purple, blue, and violet colors, however, 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 which then trap electrons. White light boosts these trapped electrons to higher energy levels; when returning to normal levels, this excess energy is released as purple, blue, or violet light.

Fluorite that formed through single-phase precipitation is usually has a single color and exhibits minimal color-zoning. Multiple-phase crystallization, however, can often produce extreme color-zoning, distinct color-banding, and multicoloration. Our specimens of “rainbow” fluorite were created by changes in the chemistry of the crystallizing solutions during slow precipitation (see “About Our Specimens”).

Fluorite is a relatively common, widely distributed mineral that forms in several mineralogical environments. In epithermal (low-temperature) veins, fluorite is associated with calcite [calcium carbonate, CaCO_3], rhodochrosite [manganese carbonate, MnCO_3], and chalcedony [microcrystalline quartz, silicon dioxide, SiO_2]. In hydrothermal replacement deposits, it occurs with galena [lead sulfide, PbS], pyrite [iron disulfide, FeS_2], sphalerite [zinc sulfide, ZnS], and barite [barium sulfate, BaSO_4], and is a common gangue mineral in many lead, zinc, and silver ores. It 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, MgAl_2O_4] in hornfels (fine-grained, altered silicate rocks) in 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 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 members are the physically similar minerals frankdicksonite [barium fluoride, BaF_2] and tveitite-(Y) [calcium yttrium fluoride, $\text{Ca}_{14}\text{Y}_5\text{F}_{43}$].

Mineral of the Month July 2014

Although elemental fluorine is extremely poisonous and corrosive, fluorite specimens are stable, safe, and require no special handling or storage. However, never attempt to heat fluorite specimens or treat them with any acid that might release hazardous fluorine gas.

COLLECTING LOCALITIES

Our specimens of “rainbow” fluorite were collected in Jiangxi Province, China. Other Chinese localities include the Tongbai fluorite mine in Tongbai County, Gaoxin District, Nanyang Prefecture, Henan Province; and the Huangshaping, Yaogangxian, Dongpo, Xianghualing, Chashan, and Xianghuapu lead-zinc mines in Chenzou Prefecture, Hunan Province.

Among Europe’s fluorite localities are 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, all in England; the Lassedalen fluorite deposit and the Kongsberg silver mines near Kongsberg, Buskerud, Norway; the Manhem, Kåravet, 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 the Black Forest region of Baden-Württemberg, Germany; and the Carrara marble quarries in the Apuan Alps, Massa-Carrara Province, Tuscany, Italy.

In the Northern Areas of Pakistan, fluorite is collected at Nagir and Chumar Bakhoo in the Hunga Valley in the Gilgit District, and at Baha and Apo Ali Gun near Baltistan. Russian specimens come from the Pouvyá and Dodo mines at Tyumenskaya Oblast’ in the Polar Urals of the Western-Siberian Region, and the Aunik rare-metals deposit at Buriatia in Transbaikalia in the 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 the Otjozondjupa Region, Namibia; the Hwange lead-zinc district in Matabeleland, North District, Zimbabwe; and the Aladdin Fluorite Mine at Sinkwazi in KwaZulu-Natal Province, and the Marico Fluorspar Mine in the Marico district in Northwest Province, both in South Africa.

Fluorite occurs in the Huaron district at Cerro del Pasco 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 in Victoria; the Cannington silver-lead-zinc deposit in the Mt. Isa-Cloncurry area of Queensland; and the Gulf fluorite mine at The Gulf in New South Wales.

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

Mineral of the Month July 2014

The primary source of fluorite in the United States is the Illinois-Kentucky Fluorspar District, notably the Cave-in-Rock and Ozark-Mahoning subdistricts of Hardin County, Illinois; and the Babb, Commodore, and Dike-Eaton subdistricts of Crittenden and Caldwell counties, Kentucky. The Elmwood Mine at Carthage in Smith County, Tennessee, has yielded fine specimens. Colorado sources include 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; and Clay Center, Ottawa County, Ohio.

JEWELRY & DECORATIVE USES

Because fluorite crystals cleave easily into octahedrons, fluorite may have been the first “faceted” gemstone. Cleaved and crudely faceted fluorite gems were popular in Europe in the 1600s when color varieties known as “false emerald,” “false ruby,” and “false amethyst” were used to imitate more valuable gems. While fluorite exhibits many excellent gemological properties—good transparency, a range of pleasing colors, a vitreous luster, and crystals suitable for cutting into large gems—its low refractive index of 1.433 reduces brilliance. Also, its perfect, four-directional cleavage makes cutting difficult and, at Mohs 4.0, fluorite gems are too soft for everyday jewelry use. Nevertheless, fluorite cabochons and faceted gems are occasionally mounted in pendants and brooches. Collectors’ gems in sizes exceeding 100 carats are popular for both display and study purposes. The Smithsonian Institution in Washington, D.C., exhibits several spectacular fluorite gems, the largest weighing 492.1 carats. As a decorative stone, large quantities of massive fluorite are fashioned into spheres, vases, and figurines.

Fluorite, as both individual and composite specimens, is one of the most widely collected of all minerals because of its large crystal size, excellent crystal development, availability, affordability, broad range of colors, and interesting mineralogical associations. Extensive fluorite-exclusive collections have been assembled that are specifically based on colors and crystal forms. Fluorite specimens are a favorite display among museum curators. In composite specimens, fluorite is often associated with galena, rhodochrosite, and quartz. Colorful, well-developed, cubic or octahedral fluorite crystals can greatly enhance both the value and the visual appeal of composite mineral specimens.

HISTORY & LORE

Fluorite artifacts have been recovered from 4,000-year-old Egyptian tombs. As early as 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 ancient Romans mined fluorite extensively in Spain and England as a smelting flux for lead, silver, and copper ores. Medieval physicians prescribed the ingestion of powdered fluorite to treat kidney disease, and also placed fluorite crystals against joints to alleviate arthritic pain. By 1500 A.D., when the Chinese were

Mineral of the Month July 2014

carving beautiful, jade-like figurines from massive, blue-and-green fluorite, European metallurgists were also using fluorite, which they called *flusse* or *flusspat*, as their standard smelting flux. In his classic *De re Metallica*, German scholar Georgius Agricola (Georg Bauer, 1494-1555) described the use of *flusspat*, which he called “*lapides igni liquiscentes*,” literally “stones that become liquid in fire.” Agricola also renamed *flusspat* using the Latin word *fluere*, meaning “flow,” a word that was later anglicized to “fluor,” the root of the word “fluorite.”

The mineral form of calcium fluoride was formally named “fluorite” in 1868. In 1914, fluorite was one of the first minerals to be studied with X-ray diffraction analysis (see “X-ray Crystallography: Exploring the Secrets of Atomic Structure”).

Fluorite is the official state mineral of Illinois. It 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.

According to modern metaphysical practitioners, fluorite calms the spirit and mind to prepare for meditation, enhances objectivity and concentration, and clarifies the decision-making process. Metaphysical healers assign specific powers to individual fluorite colors: White is thought to help access the spiritual world, green energizes the heart and mind, blue provides inner peace, purple focuses the mind, and yellow facilitates group communication. Because of its multicoloration, “rainbow” fluorite is considered especially valuable for metaphysical purposes.

X-RAY CRYSTALLOGRAPHY: EXPLORING THE SECRETS OF ATOMIC STRUCTURE

As noted in “History & Lore,” fluorite, our Mineral of the Month, played an important role in the development of one of science’s greatest analytical tools—X-ray diffraction analysis, a method of determining the positions of atoms in minerals, metals, and other crystalline materials. During the first experimental application of X-ray diffraction analysis in 1914, the father-son team of British physicists Sir William Henry Bragg (1862-1942) and Sir William Lawrence Bragg (1890-1971) selected two crystalline minerals for testing. Both were chosen for their high chemical purity, simple chemical compositions, and nearly perfect, cubic crystals. The minerals were halite [sodium chloride, NaCl] and fluorite [calcium fluoride, CaF₂].

The Braggs bombarded small crystals of halite and fluorite with microsecond pulses of high-frequency X rays. The X rays passed through the crystals and emerged to be recorded on photographic film. The crystals were then slightly rotated and the process repeated many times. The resulting photographs showed “scatter patterns” that revealed how the X rays had been diffracted by varying electron densities within the crystal lattices. Plotting and measuring the scatter patterns showed that they represented atoms that were aligned in precise, cubic structures. The Braggs could then assign specific positions to the chlorine and sodium atoms in the halite, and to the fluorine and calcium atoms in the fluorite. These experiments provided the first glimpse ever into the world of atomic structure and marked the birth of a specialized branch of physics called X-ray crystallography which would revolutionize mineralogy, chemistry, physics, and materials science.

Mineral of the Month July 2014

The X-ray diffraction experiments of 1914 had been preceded by centuries of scientific debate about crystal structure. In 1610, German astronomer Johannes Kepler (1571-1630) suggested that the regular, hexagonal symmetry of snowflakes was due to the regular packing of spherical water particles. In 1784, French mineralogist René-Just Haüy (1743-1822), who would become known as the father of crystallography, theorized that crystals consist of tiny, individual units arranged in orderly, repeating, internal structures that were reflected in the angles and shapes of external crystal faces.

But proving these theories about internal crystal structure would require two landmark achievements in physics. The first came in 1895 when German physicist Wilhelm Conrad Röntgen (1845-1923) discovered X rays, a type of penetrating electromagnetic radiation with wavelengths shorter than those of visible light. The second was the emergence of quantum theory in the early 1900s, which postulated that matter consisted of atomic and subatomic particles that interacted with energy and with each other according to precise physical laws.

The theoretical groundwork for X-ray diffraction was laid in 1912 by German physicist Max Theodore Felix von Laue (1879-1960). While studying how microscopic slits called “gratings” diffracted visible light, von Laue found that diffraction occurred only when the grating size corresponded closely to the wavelength of the light. He proposed that the internal atomic planes of crystals could also function as diffraction gratings—not for visible light, but for X-ray beams with much shorter wavelengths. Von Laue then bombarded a small crystal of bright-blue chalcantite [hydrous calcium sulfate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$] to prove that the crystal’s internal structure did indeed diffract X rays into circular patterns.

Applying von Laue’s discovery subsequently became the work of William Henry Bragg and William Lawrence Bragg. After their successful analysis of halite and fluorite in 1914, the Braggs used X-ray diffraction to define the cubic structure of pyrite [iron disulfide, FeS_2]. Next, they succeeded in mathematically expressing photographic scatter patterns to simplify their interpretations. William Lawrence Bragg then proved that the angle of diffraction for specific X-ray wavelengths was governed by the distance between the atomic planes within the crystal lattice, a relationship now known as “Bragg’s Law.” Finally, the Braggs demonstrated that atomic positions within crystal structures indicated the type of atomic bonding present.

The Braggs used X-ray diffraction to reveal the cubic structure of diamond [carbon, C] and the tetrahedral arrangement of its carbon-carbon bonding. Turning to more chemically and structurally complex minerals, they defined the structure of spinel [magnesium aluminum oxide, MgAl_2O_4] and explained the structural difference between the anatase and rutile polymorphs of titanium dioxide [TiO_2]. Although they initially worked with single, nearly perfect mineral crystals, the Braggs soon learned how to analyze the structures of polycrystalline samples, a technique now known as “powder diffraction,” which they used to define the hexagonal structures of graphite [carbon, C] and iron. For their work, the Braggs were awarded the 1916 Nobel Prize for physics. In the 1920s, X-ray diffraction literally rewrote mineralogy textbooks by defining the internal structures of the garnet-group minerals, revealing the seven basic silicate structures, and showing how aluminum substituted for silicon in certain silicates to create the zeolite-group minerals.

Mineral of the Month July 2014

Single-crystal diffraction remains the most commonly used method of X-ray diffraction. For this method, sample crystals must have high chemical purity, a non-deformed structure with no twinning or significant internal defects, and a three-dimensional size of at least 100 micrometers (millionths of a meter). As the sample crystals are rotated and bombarded with X-rays, scatter patterns are recorded on sensitized electrostatic surfaces. A single data “set” produced from a one-half crystal rotation contains tens of thousands of individual scatter points, which are processed using the same computerized-axial-tomography (CAT) techniques used in medical CAT and magnetic-resonance-imaging (MRI) scans. Today, data bases containing X-ray diffraction data for every known mineral are available for the use of mineralogists, chemists, and crystallographers worldwide.

TECHNOLOGICAL USES

Fluorite, and the fluorine and fluorine compounds derived from it, are major industrial commodities. Fluorite is the primary component of fluorspar ore, the only commercial source of fluorine. 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 by fluorite content. Metallurgical grade contains 60-85 percent fluorite, ceramic grade 86-96 percent, and acid grade at least 97 percent.

Because of fluorine’s extreme chemical reactivity, it is an ideal metallurgical flux. Most metallurgical-grade fluorspar is used as a flux in steelmaking; the fluorine component readily combines with impurities to form volatile fluorides, which are removed as vapors, while the calcium component combines with silicate impurities to produce easily removable slag. Six pounds of metallurgical-grade fluorspar are needed to produce one metric ton of high-quality steel. Most ceramic-grade fluorspar is converted to aluminum fluoride (AlF_3) and synthetic cryolite [sodium aluminum fluoride, Na_3AlF_6] for use in smelting aluminum. Small amounts of ceramic-grade fluorspar are used in the manufacture of ceramics, glass, fiberglass, and welding-rod coatings. Ceramic-grade fluorspar is also converted to uranium hexafluoride (UF_6), a vital, intermediate chemical step in the gas-diffusion concentration of the uranium-235 isotope that is used in nuclear fuel rods and fission components for nuclear weapons. All acid-grade fluorspar is used to manufacture hydrofluoric acid (HF), which is used extensively in glass-etching and as the feedstock for the manufacture of a wide array of consumer, chemical, and pharmaceutical products.

Fluorite and fluoride compounds have many interesting, specialized uses. Flawless, transparent fluorite crystals were once cut into apochromatic lenses free of chromatic and spherical aberrations for infrared and ultraviolet optical uses, a purpose now served by synthetic fluorite. Synthetic fluorite is also doped with uranium and rare-earth elements for use in lasers. For more than 60 years, fluoride compounds have been extensively used for dental purposes. To prevent cavities, sodium fluoride is routinely added to most public drinking-water supplies, and stannous fluoride to most toothpastes.

Fluorite mining is a billion-dollar-per-year global industry. More than seven million metric tons of fluorspar were mined in 2012. China was the leading producer, accounting for two-thirds of

Mineral of the Month July 2014

the total output. Other important sources, in order of production, are Mexico, Morocco, South Africa, and Spain. With no domestic fluorspar production, the United States relies completely upon foreign sources for its supply. Depending upon grade, fluorspar concentrates sell for between \$230 and \$600 per metric ton.

ABOUT OUR SPECIMENS

Our specimens of “rainbow” fluorite were collected in the Jiuling Shan Mountains of Jiangxi Province, China. Located in southwestern China, Jiangxi Province is bordered by the provinces of Zhejiang to the northeast, Fujian to the east, Guangdong to the south, Hunan to the west, Hubei to the northwest, and Anhui to the north. Covering 64,400 square miles, Jiangxi is about the size of the American state of Washington and has 45 million residents. Jiangxi has a humid, subtropical climate. The southern half of the province has low mountains, the north-central area is a flat river basin, and the far north is an area of rugged mountains. Tea is grown in the south, while rice is produced in the river basins. The Jiuling Shan Mountains in the north of Jiangxi, the source of our specimens, are heavily mineralized, with numerous mines producing coal, copper, lead, zinc, kaolin clay, and fluorite.

The complex geology of the Jiuling Shan Mountains can be traced to marine sediments that were laid down by a shallow Devonian Period sea some 400 million years ago. After deep burial, these sediments eventually became lithified into massive strata of limestone and siltstone. Beginning about 200 million years ago, the regional crust became severely deformed by repeated orogenies or mountain-building episodes, most recently the Himalayan Orogeny about 40 million years ago. During the Himalayan Orogeny, tectonic stresses generated by the collision of the South China and North China cratons (stable sections of continental crust) uplifted the calcareous, or calcite-rich, basement rock to form the Jiuling Shan Mountains. Uplifting fractured the formations, enabling fluorine-rich, hydrothermal solutions associated with deep magmatic intrusions to penetrate the faulted limestone. These solutions first dissolved existing calcite to form voids within the limestone, then precipitated calcium and fluorine ions as replacement deposits of fluorite. Erosion later reduced the surface to expose the fluorite veins.

Our specimens of “rainbow” fluorite formed as veins within the Jiuling Shan Mountains limestone when hydrothermal solutions rich in calcium and fluorine ions filled seams between the horizontal limestone strata. With very slow cooling, massive, crystalline fluorite completely filled the seams. The distinctive, multicolored banding of our specimens is the result of hydrothermal solutions that were in a constant state of chemical flux, meaning that the chromophores present at any given time varied in type and concentration. Crystallization progressed from the bottom of the voids upward. The type and concentration of chromophores within the solutions continuously deposited successive layers of fluorite that varied in color, color intensity, and thickness.

China is the world’s leading producer of fluorspar (see “Technological Uses”), and the Jiuling Shan Mountains of northern Jiangxi Province are a major source. Fluorite mining began in the region in the early 1980s, during a major expansion of China’s mining industry. Today, two of the most important Jiangxi mines are the De’an fluorite mine at Wushan in Jiujiang Prefecture

Mineral of the Month July 2014

and the Yongfeng fluorite ore field in Ji'an Prefecture. These two mines, which have both open-pit and underground workings, produce an estimated 100,000 metric tons of fluorspar each year. Both mines are also major sources of fluorite specimens. Fluorite specimens are sent to dealers in the city of Changsha, 250 miles to the southwest in neighboring Hunan Province. Lapidary factories in Changsha carve this “rainbow” fluorite into cabochons, beads, and a variety of decorative objects like paperweights, figurines, and spheres.

Your specimen of “rainbow” fluorite was specially selected and slabbed into a quarter-to-half-inch thickness and polished to display its colors and banding. Be sure to view your specimen with transmitted light, that is, with a primary light source of moderate intensity behind the specimen. Your specimen is transparent, with a honey-hued base color. The colors of the individual bands range from purple and violet to blue, green, yellow, and pink. As you view your specimen, rotate it slowly until your line of sight is parallel with the banding. Some color bands appear as thin as hairlines, while others are relatively thick; the colors of the bands also vary in intensity. These variations in thickness and intensity reflect the random variations in chemical composition that existed in the solutions during the crystallization process. Under ultraviolet light, your specimen will exhibit a purplish-white fluorescence. Your specimen also has a noticeable “heft” in the hand. This is due to its specific gravity of 3.0-3.2, which means it would weigh 15 percent more than a similar volume of quartz. Your specimen is a fine example of banded, multicolored, “rainbow” fluorite from the world’s leading fluorite source—China.

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Mineral of the Month July 2014



The locality for the Rainbow Fluorite is the Jiangxi Province, which you will see on the lower right corner of the above map.