

Mineral of the Month Club June 2016

FLUORAPATITE

This month we are featuring fluorapatite, or calcium fluorophosphate, from a classic locality—Mexico's Cerro de Mercado mine. Our write-up explains fluorapatite's dual mineralogical and biological origins and why it is vital to all life forms. Fluorapatite is the only ore of phosphorus, and our special section discusses the properties and uses of this unusual element.

OVERVIEW

PHYSICAL PROPERTIES:

Chemistry: $\text{Ca}_5(\text{PO}_4)_3\text{F}$ Calcium Fluorophosphate (Calcium Phosphate Fluoride), usually containing small amounts of manganese, cerium, and strontium.

Class: Phosphates, Chromates, Arsenates, and Vanadates

Subclass: Anhydrous Phosphates

Group: Apatite

Crystal System: Hexagonal

Crystal Habits: Usually as short-to-long, hexagonal prisms with pyramidal terminations; sometimes as thick, tabular-to-pyramidal crystals with complex faces; also in massive, coarse, granular, compact, and earthy forms, as well as globular, radial, and stalactitic growths, and as nodular concretions.

Color: Usually yellow, green, or yellowish-green; sometimes colorless. Impurities create pale shades of pink, brown, blue, purple, and violet.

Luster: Vitreous to resinous, sometimes oily.

Transparency: Transparent to translucent, rarely opaque.

Streak: White

Refractive Index: 1.632-1.646

Cleavage: Poor in one direction crosswise.

Fracture/Tenacity: Subconchoidal to uneven/brittle.

Hardness: Mohs 5.0 (Fluorapatite is the reference mineral for the "5.0" ranking on the Mohs hardness scale.)

Specific Gravity: 3.1-3.2

Luminescence: Often fluorescent or phosphorescent

Distinctive Features and Tests: Best field mark is the distinctive, hexagonal cross section. Can be confused with beryl, which is much harder; tourmaline, which forms striated prisms with rounded, triangular cross sections; and green forsterite (peridot), which crystallizes in the orthorhombic system. Fluorapatite is difficult to differentiate from the chemically and physically similar minerals chlorapatite and hydroxylapatite, with which it forms mutual solid-solution series. Fluorapatite reacts readily with hydrochloric acid.

Dana Classification Number: 48.8.1.1

NAME: The word "fluorapatite," pronounced flor-APP-a-tite, is a combination of "fluor," referring to its essential element fluorine, and "apatite," the name of its mineral group. The word

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“apatite” stems from the Greek *apatē*, meaning “deceit” and alluding to the difficulty in distinguishing apatite-group minerals from beryl and certain other minerals. Fluorapatite is often referred to as “apatite.” Other names are “apatite-(CaF),” “fluoro-apatite,” “fluorine apatite,” “apatit,” “agustit,” and “wilkeite.” “Asparagus stone” is a green variety; “mangano-fluorapatite” or “mangano-apatite” is a manganese-rich variety; “saamite” or “strontian-fluorapatite” is a strontium-rich variety. “Collophane,” “collophanite,” and “staffelite” refer to botryoidal, microcrystalline varieties. In European mineralogical literature, fluorapatite appears as *Fluorapatit* and *fluorapatita*. In 2008, the International Mineralogical Association officially changed the name of fluorapatite to “apatite-(CaF),” but reinstated the name “fluorapatite” in 2010.

COMPOSITION & STRUCTURE: The molecular weight of fluorapatite is made up of 39.74 percent calcium, 18.43 percent phosphorus, 38.06 percent oxygen, and 3.77 percent fluorine. Fluorapatite is one of the nearly 300 members of the Phosphates, Chromates, Arsenates, and Vanadates class of minerals. The basic building block of the phosphates is the phosphate ion $(\text{PO}_4)^{3-}$, a tetrahedral structure in which four oxygen ions surround a phosphorus ion. Fluorapatite crystallizes in the hexagonal system, which has four axes, three of equal length and lying on a plane; the fourth axis, which is unique to the hexagonal system, is perpendicular to the plane of the other three and varies in length. The most common fluorapatite habit is the hexagonal (six-sided) prism, in which all six prismatic faces are parallel to the unique axis. Fluorapatite crystals usually have pyramidal terminations. Fluorapatite is an idiochromatic (self-colored) mineral, meaning that its basic yellow, green, and yellowish-green colors are caused by its essential chemical components and the nature of its crystal structure. However, impurities or exposure to natural geophysical radiation can cause fluorapatite to be colorless or to exhibit a range of pale colors. Fluorapatite is a minor accessory mineral in many igneous and metamorphic rocks. It forms by both mineralogical and biological processes. Biogenic fluorapatite is abundant in a microcrystalline form called collophane, which occurs in certain sedimentary rocks, notably those deposited by ancient, shallow seas that supported large populations of plankton and other tiny, invertebrate organisms. The phosphorus-rich remains of these organisms mixed with sea-bottom sediments and eventually lithified into phosphate rock, a variable mixture of cryptocrystalline fluorapatite and lesser amounts of other apatite-group minerals.

COLLECTING LOCALITIES: Fluorapatite specimens are collected in Mexico, Canada, Brazil, Colombia, Bolivia, Germany, Portugal, Russia, Namibia, Morocco, Democratic Republic of the Congo, Rwanda, Pakistan, Afghanistan, and Australia. In the United States, fluorapatite is collected in Maine, California, Colorado, New Jersey, New York, Connecticut, Massachusetts, Utah, and New Hampshire.

HISTORY, USES & LORE: When German mineralogist Abraham Gottlob Werner (1749-1817) began studying the apatite-group minerals in 1788, he assumed that “apatite” was a single mineral species. But in 1826, German mineralogist and chemist Gustav Rose (1798-1873) determined that several “varieties” existed. Finally, in 1860, German mineralogist Karl Friedrich Rammelsberg (1813-1899) demonstrated that apatite was actually three distinct minerals based upon the dominance of fluorine, chlorine, or hydroxyl anions. Rammelsberg named the fluorine-rich species “fluorapatite.” Although fluorapatite has a range of attractive, pale colors and a

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refractive index of 1.632-1.646 (similar to that of the gemstones peridot and tourmaline), its moderate hardness of Mohs 5.0 limits its use in jewelry. Faceted fluorapatite is occasionally mounted in brooches, pendants, and other low-wear types of jewelry. Most fluorapatite gems are tumbled, drilled, and strung into necklaces and bracelets. The most desirable fluorapatite gems are cut from bright-yellow crystals from the Cerro de Mercado Mine in Durango, Mexico. Medieval physicians prescribed powdered apatite-group minerals as appetite suppressants for overweight patients (the words “apatite” and “appetite” are not related). Modern metaphysical practitioners believe that crystals of fluorapatite and other apatite-group minerals enhance insight, learning abilities, and creativity; increase self-confidence; and help achieve deeper states of meditation. Apatite-group minerals are also thought to enhance the metaphysical properties of other minerals.

ABOUT OUR SPECIMENS: Our fluorapatite specimens were collected at the Cerro de Mercado Mine near the city of Durango in the state of Durango, Mexico. Geologists believe that the Cerro de Mercado deposit was mineralized either by direct intrusion of iron-rich magma, circulation of associated, iron-rich hydrothermal fluids, or a combination of both. The deposit is one mile long and one-third of a mile wide, and has four main ore bodies. Its iron mineralization was emplaced 30 million years ago in the form of magnetite [iron oxide, Fe_3O_4]. This magnetite has since altered into hematite [iron oxide, Fe_2O_3], much of which is present in the pseudomorphic form of hematite-after-magnetite. The Cerro de Mercado iron deposit was discovered in 1552 by Capitan Ginés Vázquez de Mercado who investigated vague reports of a rich silver deposit within a reddish-colored mountain. Upon reaching the site, Mercado recognized the reddish ridge that now bears his name as a major iron deposit. In the 1700s, residents of the nearby settlement of Durango built crude furnaces to smelt small amounts of iron with which to fashion tools and farm implements. In 1828, a British company built an ironworks at Cerro de Mercado that operated for ten years. In the 1880s, several foreign-owned companies established open-pit mines and built smelters. Despite the ore's very high grade, these operations all failed because of lack of rail transportation and the high price of hauling in wagon-loads of coal for the furnaces. Only after the railroad arrived in Durango in 1905 did Cerro de Mercado become a major source of iron. Today, Cerro de Mercado is a modern open-pit mine and mill that produces 1,500 tons of iron concentrate per day.

COMPREHENSIVE WRITE-UP

COMPOSITION & STRUCTURE

Before discussing fluorapatite, it is important to understand the relationship of the words “fluorapatite” and “apatite,” and the term “apatite group.” Apatite was the original name applied to a mineral known as fluoro-chloro-hydroxylapatite with the chemical formula $\text{Ca}_5(\text{PO}_4)_3(\text{F},\text{Cl},\text{OH})$. Citing wide variations in the amounts of fluorine, chlorine, and hydroxyl ions present, mineralogists later reclassified “apatite” as three separate minerals—fluorapatite [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$], chlorapatite [calcium chlorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$], and hydroxylapatite [basic calcium phosphate, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$]. The general term “apatite” now refers to the mineral group that includes these three and eleven other closely related and

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physically similar minerals, all of which form mutual, graded, solid-solution series. Differentiating these minerals often requires laboratory analysis.

Fluorapatite, [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$] contains the elements calcium (Ca), phosphorus (P), oxygen (O), and fluorine (F). Fluorapatite's ideal molecular weight is made up of 39.74 percent calcium, 18.43 percent phosphorus, 38.06 percent oxygen, and 3.77 percent fluorine. These percentages vary somewhat with the substitution of fluorine, chlorine, and hydroxyl ions.

Fluorapatite is one of the nearly 300 members of the Phosphates, Chromates, Arsenates, and Vanadates class of minerals. The basic building blocks of these minerals are the phosphate ion $(\text{PO}_4)^{3-}$, chromate ion $(\text{CrO}_4)^{3-}$, arsenate ion $(\text{AsO}_4)^{3-}$, and vanadate ion $(\text{VO}_4)^{3-}$, all of which form tetrahedral structures with four oxygen ions surrounding the ion of a metal or semi-metal (chromium and vanadium are metals; phosphorus and arsenic are semi-metals). In the phosphates, four oxygen ions 4O^{2-} surround and covalently bond to a single phosphorus ion P^{5+} . The resulting -3 collective charge is distributed evenly over the four oxygen ions, enabling the phosphate ion $(\text{PO}_4)^{3-}$ to bond with many different, positively charged metal cations. In fluorapatite, three phosphate anions $3(\text{PO}_4)^{3-}$ bond ionically to five calcium cations 5Ca^{2+} . The resulting collective +1 charge is satisfied by addition of a fluorine ion (F^{1-}). Within the fluorapatite molecule, the combined +10 charge of the 5Ca^{2+} cation balances the combined -10 charge of the $[3(\text{PO}_4)\text{F}]^{10-}$ anion to provide electrical stability.

All apatite-group minerals are amenable to substitution by foreign ions. In the solid-solution series between fluor-, chlor-, and hydroxylapatite, fluorine, chlorine, and hydroxyl ions readily substitute for each other because of their similar electrical charges and ionic sizes. Fluorapatite and hydroxylapatite also enter into other solid-solution series when carbonate ions $(\text{CO}_3)^{3-}$ substitute for phosphate ions $(\text{PO}_4)^{3-}$ to form calcium carbonate-fluorapatite $[\text{Ca}_5(\text{PO}_4, \text{CO}_3)_3\text{F}]$ and calcium carbonate-hydroxylapatite $[\text{Ca}_5(\text{PO}_4, \text{CO}_3)_3\text{OH}]$. In fluorapatite, cerium, strontium, and manganese ions also substitute for calcium ions.

Fluorapatite crystallizes in the hexagonal system, which has four axes. Three are of equal length and lie on a plane; the fourth, which is unique to the hexagonal system, is perpendicular to the plane of the other three and is of variable length. The most common fluorapatite crystal habit is the hexagonal (six-sided) prism, in which all six prismatic faces are parallel to the unique axis. Prismatic fluorapatite crystals typically have well-developed, pyramidal terminations.

Within fluorapatite's crystal lattice, strong, three-dimensional, covalent bonding between adjacent phosphate ions explains its poor cleavage and substantial hardness of Mohs 5.0. Fluorapatite is the reference mineral for the 5.0 ranking on the Mohs hardness scale. The Mohs reference minerals include talc (1, softest), gypsum (2), calcite (3), fluorite (4), fluorapatite (5), microcline (6), quartz (7), topaz (8), corundum (9), and diamond (10, hardest). These minerals were chosen as Mohs reference species because of their abundance, familiarity, and minimal variation in hardness.

As the most abundant of all phosphates, fluorapatite is a minor accessory mineral in many igneous and metamorphic rocks, and is the major component of certain sedimentary rocks. It

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occurs with magnetite [iron oxide, Fe_3O_4] and titanite [calcium titanium oxysilicate, CaTiSiO_4] in plutonic rocks; with muscovite [basic potassium aluminum silicate, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$] and albite [sodium aluminum silicate, $\text{NaAlSi}_3\text{O}_8$] in granite pegmatites; with nepheline [sodium potassium aluminum silicate, $(\text{Na,K})\text{AlSiO}_4$] in nepheline-syenite pegmatites; and with andradite [garnet group, calcium iron silicate, $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$] in hornfels of contact-metamorphic rocks. Fluorapatite forms by both mineralogical and biological processes. Biogenic fluorapatite is abundant in a microcrystalline form called collophane (also collophanite), which is common in certain sedimentary rocks, notably marine sediments deposited by ancient, shallow seas that supported a profusion of plankton and other tiny, invertebrate organisms. Their phosphorus-rich remains mixed with sea-bottom sediments to later lithify into phosphate rock, a variable mixture of silica and cryptocrystalline fluorapatite with lesser amounts of other apatite-group minerals.

Fluorapatite is often luminescent, exhibiting both fluorescence and phosphorescence. Luminescence occurs when minerals absorb electrical, mechanical, or electromagnetic energy which excites and elevates their electrons to higher orbital levels. To return to their normal orbits, these electrons release their excess energy as visible light. In fluorescence, this energy is released immediately; in phosphorescence, a delayed release occurs after the input of incidental energy has ceased. Fluorine causes fluorapatite's luminescence. Fluorine is highly reactive and its single outer electron readily absorbs, then releases, excess energy as visible light.

Fluorapatite is technically an idiochromatic (self-colored) mineral, meaning that its basic yellow, green, and yellowish-green colors are caused by its essential chemical components and the nature of its crystal structure. However, fluorapatite also exhibits certain properties of allochromatic (other-colored) minerals. Traces of nonessential minerals, notably rare-earth elements such as cerium that modify the crystal lattice can cause fluorapatite to be colorless or to exhibit other colors that mask its basic yellows and greens. Traces of manganese create pale-pink colors. Exposure to natural irradiation also influences fluorapatite color.

The Dana mineral-classification number 48.8.1.1 first identifies fluorapatite as an anhydrous phosphate containing halogen or hydroxyl ions (48). It is then subclassified (8) by the formula $\text{A}_5(\text{XO}_4)_3\text{Z}_q$, in which "A" can be divalent ions of calcium, strontium, cerium, sodium, boron, or lead; (XO_4) is the phosphate ion $(\text{PO}_4)^{3-}$; "Z" is a halogen or hydroxyl ion; and "q" is a quantifier. Fluorapatite is assigned to the apatite group (1) as the first (1) of 14 members. After fluorapatite, the most abundant members are chlorapatite [calcium chlorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$], and hydroxylapatite [basic calcium phosphate, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$]. The remaining members are rare.

COLLECTING LOCALITIES

Our fluorapatite specimens were collected at the Cerro de Mercado Mine at the city of Durango in the state of Durango, Mexico. Another Mexican source is the Llario Mine at Mapimí, also in the state of Durango. Canadian fluorapatite localities include the Yates Mine at Otter Lake, Pontiac Regional County Municipality, Outaouais, Québec; Bear Lake in Monmouth Township and the Richardson Mine in Cardiff Township, both in Haliburton County, Ontario; and the Rapid Creek and Big Fish areas in the Dawson Mining District, Yukon. Brazilian specimens

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come from Pedras Altas in the Ipirã Complex, Capim Grosso, Bahia; and the Sapo and Golconda mines near Ferruginha in the Doce Valley near Conselheiro Lafaiete, Minas Gerais. Other Latin American localities are the La Marina Mine, Pauna, Boyacá Dept, Colombia; and the Siglo Veinte Mine, Llallagua, Rafael Bustillo Province, Potosí Department, Bolivia.

In Europe, fluorapatite is collected in Germany at the type locality near Ehrenfriedersdorf, Erzgebirge, Saxony; and at Panasqueira, Covilhã, Castelo Branco District, Portugal. Russian specimens come from the Slyudyanka marble quarries near Lake Baikal, Irutskaya Oblast', Eastern-Siberian Region; and Seidozero Lake in the Lovozero Massif, Kola Peninsula, Murmanskaya Oblast', Northern Region. African specimens are collected in Namibia at the Van der Made pegmatite on Brabant Farm, Karibib District, Erongo Region; at Imilchil, Er Rachidia Province, Meknès-Tafilalet Region, Morocco; the Shinkolobwe Mine, Katanga Copper Belt, Katanga Province, Democratic Republic of the Congo; and the Buranga Pegmatite near Gatumba, Gisenyi, Rwanda. Other localities include the Hunza Valley pegmatites at Gilgit and Dassu in the Braidu Valley, Skardu District, Baltistan, Northern Areas, Pakistan; the Mawi Pegmatite in the Nilaw-Lolum pegmatite field, Du Ab District, Nuristan Province, Afghanistan; and the Lake Boga granite quarry at Swan Hill, Victoria, Australia.

In the United States, fluorapatite occurs in Maine at the Mt. Mica, Pulsifer, and Mt. Apatite pegmatite quarries near Auburn in Androscoggin County; and the Emmons and Harvard quarries near Greenwood in Oxford County. Other localities are the Himalaya Mine in the Mesa Grande district, San Diego County, California; the Fulbright district, Eagle County, Colorado; Franklin, Ogdensburg (Sterling Hill), and Hamburg in Sussex County, New Jersey; the quarries at Amity, Orange County, New York; the Strickland Quarry, Portland, Middlesex County, Connecticut; the Acushnet Quarry at Acushnet, Bristol County, Massachusetts; the Iron Springs Mining District, Iron County, Utah; and the Palermo No. 1 Mine at Groton, Grafton County, New Hampshire.

JEWELRY & DECORATIVE USES

Despite fluorapatite's range of attractive, pale colors and moderately high refractive index of 1.63-1.64 (similar to that of the peridot gem variety of forsterite [magnesium silicate, Mg_2SiO_4] and the sodium aluminum borosilicate minerals of the tourmaline group minerals, its medium hardness of Mohs 5.0 somewhat limits its gem uses. Faceted fluorapatite is occasionally mounted in brooches, pendants, and other low-wear types of jewelry, but most fluorapatite gems are tumbled, drilled, and strung in necklaces and bracelets. The most desirable fluorapatite gems are cut from bright-yellow crystals from the Cerro de Mercado Mine in Durango, Mexico. Although some of these gems have exceeded 100 carats in weight, most weigh less than 20 carats. Fluorapatite gems from other localities, especially those in the rarer shades of blue and violet, usually weigh less than two carats. Maine's pegmatites provide the most intensely colored violet and purple fluorapatite gems. The National Museum of Natural History (Smithsonian Institution) in Washington, D.C., displays a spectacular, two-inch, gemmy, intense-purple fluorapatite crystal from Maine's Pulsifer Quarry. Fluorapatite gems are often heat-treated to intensify their colors.

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As both singular and composite specimens, fluorapatite is valued by collectors for its unusual colors; well-developed, hexagonal prisms; and frequent association with other interesting minerals.

HISTORY & LORE

Apatite (fluorapatite) was first studied in 1788 by German mineralogist Abraham Gottlob Werner (1749-1817), who named it after the Greek *apatē*, meaning “deceit” and alluding to its visual similarity to beryl [beryllium aluminum silicate, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$] and certain other minerals. Given the limited analytical methods of his time, Werner assumed “apatite” to be a single mineral species. But in 1826, German mineralogist and chemist Gustav Rose (1798-1873) determined that both chlorine and fluorine “varieties” existed. In 1860, German mineralogist Karl Friedrich Rammelsberg (1813-1899), using both spectrographic and chemical techniques to analyze specimens from the type locality at Ehrenfriedersdorf, Saxony, Germany, demonstrated that “apatite” was actually three minerals based upon dominance of either fluorine, chlorine, or hydroxyl ions. Rammelsberg named the fluorine-rich species “fluorapatite.” In 2008, the International Mineralogical Association renamed fluorapatite “apatite-(CaF),” but reinstated the name “fluorapatite” in 2010. This name change and subsequent reversal is causing some confusion among mineral collectors, because of the time that is required for mineralogical literature, textbooks, and field-collecting guides to respond to such changes.

Medieval physicians prescribed powdered apatite-group minerals as appetite suppressants for overweight patients (the words “apatite” and “appetite” are not related). Modern metaphysical practitioners believe that crystals of fluorapatite and other apatite-group minerals enhance insight, learning abilities, and creativity; increase self-confidence; and help achieve deeper states of meditation. Apatite-group minerals are also thought to enhance the metaphysical properties of other minerals.

Fluorapatite is most often represented on postage stamps by phosphate rock. Phosphate-rock mining is featured on the 4.50-dirham stamp of Morocco of 1947, and on the 25-Australian cent stamp of the central-Pacific nation of Republic of Nauru of 1982. These stamps commemorated the 25th and 100th anniversaries, respectively, of the founding of phosphate-mining industries in these nations. In 2014, purple fluorapatite crystals appeared on the 2500-West African Franc stamp of the Togolese Republic.

FLUORAPATITE AND PHOSPHORUS

Fluorapatite is the most abundant phosphate mineral and the only ore of phosphorus. Phosphorus, the 13th element to be discovered and the first to be identified that was not known since ancient times, was found by German alchemist Hennig Brand (1630-1710) in 1669. Brand heated evaporite residues from urine to produce glowing fumes and a flammable liquid. When captured and covered, this liquid solidified into a glowing, white, waxy solid (elemental phosphorus). Brand named his discovery *phosphorus mirabilis* (“miraculous bearer of light”) after *phōsphoros*, the Greek word for “light-bearing.” In 1777, French chemist Antoine-Laurent

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Lavoisier (1743-1794) isolated the same material from bone ash and confirmed that it was indeed a new element. By the 1840s, commercial quantities of phosphorus were being obtained from bat and bird guano. Phosphate rock became the leading source of phosphorus in the 1880s.

Because of its extreme chemical reactivity, phosphorus does not occur in native form. Phosphorus, a nonmetal, is the 11th most common element in the Earth's crust. Of its five allotropic forms, white phosphorus is the most abundant. White phosphorus has an atomic weight of 30.97 and a very low specific gravity of 1.82. It is a waxy solid at room temperature and melts at the low temperature of 111.5 F. (44.1 C). Because white phosphorus ignites spontaneously in air, it is stored underwater.

Phosphorus, as fluorapatite, is essential to all plant and animal life. As a vital component of genes, teeth, bones, and muscles, phosphorus makes up roughly one percent of the weight of the human body. The body of a 150-pound adult contains about 1.5 pounds of elemental phosphorus in the form of four pounds of fluorapatite. The average adult dietary requirement for elemental phosphorus is slightly more than one gram per day, or about one pound per year. Because phosphorus is common in many foods, deficiencies are rare.

Fluorapatite and lesser amounts of chlorapatite and hydroxylapatite are the primary components of teeth in all vertebrate animals. Of these three minerals, fluorapatite is the hardest and most durable. Various fluoride compounds are routinely added to drinking water and toothpaste to increase the hardness and durability of teeth by converting some of their chlorapatite and hydroxylapatite in the teeth into more decay-resistant fluorapatite.

Phosphate rock is a major industrial commodity (see "Technological Uses"). After mining, it is concentrated, crushed, ground to a powder, and treated with acid to convert the fluorapatite into a concentrated, hydrated calcium phosphate called "superphosphate." Most superphosphate is used to manufacture nitrogen-phosphorus-potassium (N-P-K) agricultural fertilizers. Superphosphate is also the feedstock to produce elemental phosphorus and phosphoric acid (H_3PO_4), which are used to manufacture insecticides, herbicides, matches, pyrotechnics, nutritional supplements, food additives, and many other products.

TECHNOLOGICAL USES

Most fluorapatite occurs as microcrystalline collophane, which is found in sedimentary rocks, notably marine sediments that were deposited by ancient, shallow seas with prolific populations of plankton and other tiny, invertebrate organisms. Their phosphorus-rich remains mixed with sea-bottom sediments and later lithified into phosphate rock, which consists primarily of microcrystalline fluorapatite with lesser amounts of chlorapatite and hydroxylapatite. Phosphate rock is the only commercial source of phosphorus. Phosphate-rock mining is \$7.5-billion-per-year industry. Some 220 million tonnes (metric tons) of phosphate rock are mined worldwide each year from open pits. China is the leading producer with 93 million tonnes (metric tons) annually and is followed by the United States with 32 million tonnes, Morocco with 28 million tonnes, and Russia with 11 million tonnes. The United States has six major phosphate-rock mines in Florida, North Carolina, Utah, and Idaho.

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Fluorapatite is the raw material for the production of elemental phosphorus and all phosphorus compounds (see “Fluorapatite and Phosphorus”). It is also used as an entombment material for radioactive-waste products of atomic-fission reactions, and has served as the chemical model for its own laboratory synthesis. Crystals of synthetic fluorapatite are used as laser-rod material. Titanium alloys impregnated with synthetic fluorapatite graft easily onto human bone and are state-of-the-art, joint-replacement, tooth-implant, and prosthetic-implant materials.

Geophysicists consider chemically pure fluorapatite to be a crystallographic record of the thermal history of sedimentary and hydrothermal deposits. The unusually pure fluorapatite from Cerro de Mercado in Durango, Mexico, is the base of a geo-dating technique called fission-tracking. When fluorapatite is formed, atomic particles emitted by traces of uranium isotopes create “tracks” within its crystal lattice. The annealing or “healing” rate of these tracks indicates the thermal conditions that existed when the crystals formed.

ABOUT OUR SPECIMENS

Our fluorapatite specimens were collected at the Cerro de Mercado Mine near the city of Durango in the state of Durango, Mexico. Located in northwestern Mexico, the state of Durango is one of the nation’s 31 states. It is bordered by Chihuahua on the north, Coahuila on the northeast, Zacatecas on the southeast, Nayarit on the southwest, and Sinaloa on the west. Durango has an average elevation of 6,600 feet; the peaks, ravines, and forests of the Sierra Madre Occidental occupy the central and western parts of the state. The climate is pleasant and semi-arid, with most rain falling in the summer months. Farming, logging, ranching, and mining support the regional economy. The city of Durango is the state capitol and has a population 520,000. Its beautiful colonial architecture and colorful festivals draw more than one million visitors annually. Located at the city’s northern limit, the Cerro de Mercado iron mine has 500 workers and is major regional employer.

Three major mountain systems dominate Mexico’s topography—the Sierra Madre Occidental in the northwest, the Sierra Madre Oriental in the northeast, and the Sierra Madre Sur in the south. The nation’s mineral wealth is concentrated in the Sierra Madre Occidental, where mineral deposits extend from the states of Sonora and Chihuahua in the north to just beyond Mexico City in the south. This geologically complex region has hosted virtually all of Mexico’s mining activity. Its rich mineralization is due to its position near the junction of several tectonic plates. The stresses caused by the collision of these plates have weakened the regional crust, leaving it susceptible to magmatic intrusion and volcanism. The Sierra Madre Occidental formed some 65 million years ago during the Laramide Orogeny, a mountain-building episode that uplifted huge blocks of limestone and dolomite basement rock. The Laramide Orogeny also created the Rocky Mountains in the United States and Canada; geologists consider the Sierra Madre Occidental to be the southern limit of Rocky Mountains.

Following the uplifting of the Sierra Madre Occidental, magma surged into the fractured crust to form granitic intrusions and formations of rhyolitic and dacitic volcanic rock, while associated surges of hydrothermal solutions emplaced numerous mineral deposits. Some 30 million years

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ago, a volcanic event emplaced iron mineralization at Cerro de Mercado either by direct intrusion of iron-rich magma, circulation of associated, iron-rich hydrothermal fluids, or a combination of both. The Cerro de Mercado iron deposit is one mile long and one-third of a mile wide, and has four main ore bodies. This iron was originally emplaced as magnetite [iron oxide, Fe_3O_4]. Millions of years of weathering have since altered the magnetite into hematite [iron oxide, Fe_2O_3]. The ore body has yielded fine specimens of hematite-after-magnetite pseudomorphs as large as two inches that consist of hematite with the exterior shape of the original, octagonal magnetite crystals.

The Cerro de Mercado iron deposit was discovered in 1552 by Ginés Vázquez de Mercado (? – 1553), while investigating a report of a reddish-colored mountain that was supposedly rich in silver. Upon reaching the site, Mercado recognized the reddish-colored ridge that now bears his name not as a source of silver, but as a major iron deposit. Earlier Spanish prospectors, aware that iron often accompanied silver mineralization, had assumed erroneously that the ridge was also rich in silver. On his return to Mexico City, de Mercado was killed in an Indian attack. A decade later, the Spanish explorer Francisco de Ibarra (1539-1575) founded the settlement of Durango at the southern foot of Cerro de Mercado.

In the 1700s, Durango settlers built crude furnaces to smelt iron to fashion into tools and farm implements. In 1828, shortly after Mexico won its independence from Spain, a British company built a small ironworks that operated for ten years. By the 1880s, after Mexico had liberalized its mining laws to attract development capital, three foreign companies were mining and smelting iron ore. But despite the very high grade of the ore, all failed because of lack of rail transportation and the high cost of hauling in wagon-loads of coal for the furnaces. Cerro de Mercado became a major source of iron only after the railroad arrived in Durango in 1905. In 1993 a new mill began concentrating 1,500 tons of ore per day by both flotation and hydraulic-separation methods. Today, the Cerro de Mercado Mine is owned by MINOSA (Minera del Norte, S.A.), a branch of Altos Hornos de Mexico, S.A. (AHMSA), Mexico's largest iron-and-steel company.

Minerals associated with hematite ore at Cerro de Mercado include calcite [calcium carbonate, CaCO_3]; titanite [calcium titanium oxysilicate, CaTiSiO_4]; the chalcedony variety of quartz [silicon dioxide, SiO_2]; and fluorapatite. Cerro de Mercado is a classic locality for fluorapatite and one of the world's premier sources of fluorapatite specimens. Fluorapatite crystals from this locality have an extraordinarily high degree of chemical purity and occur as well-developed, elongated, hexagonal prisms. Most crystals are smaller than three-quarters of an inch and have excellent transparency, a glassy luster, and a distinctive, honey-yellow color. Larger crystals as long as three or four inches are usually fractured and translucent. Crystals typically contain visible inclusions of magnetite, hematite, and gas bubbles.

Your specimen of fluorapatite from the Cerro de Mercado Mine consists of individual crystals of fluorapatite in a complex matrix of altered limestone, particulate and crystalline hematite, and calcite. The fluorapatite is present as well-developed, hexagonal prisms with pyramidal terminations. They exhibit a yellow color with a slight hint of green, and are transparent to translucent. The crystal faces are glassy and smooth; fractured surfaces appear oily or resinous with no apparent cleavage. The matrix consists of heavily altered rhyolite. Hematite is present

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in both a red, particulate form and a black, crystalline form. Some black hematite in your specimen may be pseudomorphic hematite-after-magnetite and exhibit the octahedral shape of the original magnetite crystals. The crusty, white coating in your specimen is calcite of relatively recent origin.

References: *Dana's New Mineralogy*, Eighth Edition, Richard Gaines, Catherine Skinner, et al, Wiley-Interscience, 1997; *Encyclopedia of Minerals*, Second Edition, William Roberts, Thomas Campbell, Jr., and George Rapp, Van Nostrand Reinhold Company, 1990; *2014 Fleischer's Glossary of Mineralogical Species*, Malcolm E. Back; The Mineralogical Record Company; *Mineralogy*, John Sinkankas, Springer-Verlag, 1993; *Gem and Crystal Treasures*, Peter Bancroft, Western Enterprises and Mineralogical Record, 1984; *Gemstones of the World*, Fifth Edition, Walter Schumann, Sterling Publishing Company, 2013; "Apatite and Phosphate Rock," Steve Voynick, *Rock & Gem*, February 2003; "The Geology and Minerals of Cerro de Mercado, Durango, Mexico," Peter Megan and Mark Barton, *Rocks & Minerals*, January-February 1999; "The Mineral Industry of Mexico," Alberto Alexander Perez, *2012 Minerals Yearbook*, United States Geological Survey; "Iron Ore," Christopher A. Tuck, *2013 Minerals Yearbook*, United States Geological Survey; "Volcanogenic Iron-Oxide Deposits, Cerro de Mercado and Vicinity, Durango, Mexico," James L. Lyons, *Economic Geology*, Volume 83, No. 8, 1988; "Mineral Resources of Durango, Mexico," Manuel Rangel and Alberto Terrones, *Engineering & Mining Journal*, Volume 112, No. 5, 1921; "Mineralogy and Geochemistry of Fluorapatite from Cerro de Mercado, Durango, Mexico," E. J. Young, A. T. Myers, et al, *Professional Paper 650-C*, United States Geological Survey, 1969; "What's New in Minerals," Thomas P. Moore, *The Mineralogical Record*, January-February 2002; "Phosphate Rock," Stephen Jasinski, *February 2014 Mineral Commodity Summaries*, United States Geological Survey.

