

# Mineral of the Month Club February 2015

## WULFENITE

This month our featured mineral is wulfenite, an uncommon lead molybdate from Mexico's historic Ojuela Mine. Our write-up discusses wulfenite's unusual chemistry and collector appeal, and explains the differences between type localities and classic localities.

### OVERVIEW

### PHYSICAL PROPERTIES

Chemistry:  $\text{PbMoO}_4$  Lead Molybdate, often containing small amounts of tungsten, calcium, vanadium, arsenic, manganese, chromium, and titanium.

Class: Molybdates and Tungstates

Subclass: Anhydrous Molybdates and Tungstates

Group: Wulfenite

Crystal System: Tetragonal

Crystal Habits: Usually as square, tabular crystals, often extremely thin; sometimes elongated or pyramidal; occasionally stubby prismatic and pseudo-cubic; crystal faces can appear slightly curved. Wulfenite almost always occurs as crystals, and rarely in massive or granular forms.

Color: Yellow, yellow-gold, yellow-orange, orange, orange-red, reddish, yellowish-gray, tan, and gray; rarely colorless.

Luster: Bright adamantine and sub-adamantine to resinous

Transparency: Transparent to translucent

Streak: White

Refractive Index: 2.283-2.405

Cleavage: Distinct in one direction

Fracture: Subconchoidal to uneven

Hardness: 3.0

Specific Gravity: 6.5–7.0

Luminescence: None

Distinctive Features and Tests: Often-brilliant, yellow-to-reddish colors; tabular crystal habit; high specific gravity; and occurrence in oxidized zones of lead-rich deposits.

Wulfenite can be confused with few other minerals.

Dana Classification Number: 48.1.3.1

**NAME:** Wulfenite, pronounced WOOL-fen-ite, is named for Austrian mineralogist and Jesuit priest Franz Xavier von Wulfen (1728-1805). Wulfenite has also been known as "Gelbbleierz," "yellow lead spar," "yellow lead ore," "molybdate of lead," "molybdenated lead ore," "chillagite," and "carinthite." Wulfenite varieties are named for contained impurities and include "calcium wulfenite," "chromian wulfenite," "vanadian wulfenite," and "tungstenoan wulfenite." In European mineralogical literature, wulfenite appears as *wulfenita* and *wulfenit*. Wulfenite is

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sometimes phonetically confused with wolframite, a tungstate-mineral series consisting of hübnerite [manganese tungstate,  $MnWO_4$ ] and ferberite [iron tungstate,  $FeWO_4$ ].

**COMPOSITION:** Wulfenite's chemical formula  $PbMoO_4$  identifies its elemental components as lead (Pb), molybdenum (Mo), and oxygen (O). Its molecular weight is made up of 56.44 percent lead, 26.13 percent molybdenum, and 17.43 percent oxygen. Wulfenite is one of 49 members of the molybdates and tungstates mineral class. Its crystal lattice is built around the molybdate radical  $(MoO_4)^{2-}$ , which forms a flattened, tetrahedral structure with oxygen ions occupying each of the four tetrahedral corners surrounding a single molybdenum ion. Because the four oxygen ions collectively share the resulting -2 charge, the molybdate radical can bond ionically with various metal cations. In wulfenite, the molybdate radical bonds with a lead ion. As a secondary mineral, wulfenite occurs in the oxidation zones of lead-rich replacement deposits in association with barite [barium sulfate,  $BaSO_4$ ], sphalerite [zinc sulfide,  $ZnS$ ], galena [lead sulfide,  $PbS$ ], and molybdenite [molybdenum disulfide,  $MoS_2$ ]. Wulfenite most often forms in arid conditions where oxidation extends to considerable depths below the surface. As an allochromatic (other-colored) mineral, wulfenite's colors are caused by trace amounts of nonessential elements called chromophores. When pure, which is rare, wulfenite is colorless. But wulfenite usually contains small amounts of chromophoric elements such as vanadium, manganese, chromium, and titanium that impart pale-to-intense, yellow-orange colors.

**COLLECTING LOCALITIES:** Wulfenite is collected in Mexico, Austria, France, Italy, Namibia, Morocco, Democratic Republic of Congo, Zambia, Australia, Canada, China, and Chile. In the United States, wulfenite occurs in Arizona, New Mexico, California, Nevada, Colorado, Idaho, Montana, South Dakota, Texas, and Utah.

**HISTORY, LORE & USES:** After studying specimens collected in 1785 at the Bad Bleiberg lead-mining district in Carinthia, Austria, Austrian mineralogist and Jesuit priest Franz Xavier von Wulfen (1728-1805) published *Vom Kärntnerischen Bleispat*, a treatise on local lead ores, in which he accurately described wulfenite crystals. Austrian geologist Wilhelm Karl Ritter Haidinger (1795-1871) recognized wulfenite as a distinct mineral species in 1845. Although wulfenite is too soft for general jewelry use, nicely colored, uncut crystals are sometimes wrapped in silver wire for use as pendants. Despite being brittle and difficult to cut, wulfenite is also faceted into collector's gems that exhibit unusual colors and extraordinary brilliance and luster. According to modern metaphysical practitioners, wulfenite helps to get in touch with one's emotions, harmonizes emotional forces, alleviates emotional blockages, and increases the energy needed to communicate with other realms. Wulfenite is also thought to heal the reproductive system and to encourage general healing. Wulfenite specimens are in high demand among mineral collectors for their unusual colors, well-developed crystals, and rarity.

**ABOUT OUR SPECIMENS:** Our wulfenite specimens are from the the Ojuela Mine at Mapimí in the Mapimí district, Durango, Mexico. The Ojuela Mine is in north-central Mexico, northwest of the city of Torreón at an elevation of 6,800 feet in the eastern foothills of the Sierra Madre Occidental. In this arid desert region, rugged, low mountain ranges separate broad plains.

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Ojuela is one of the major carbonate-replacement deposits in the Mexican Fold Belt, a 900-mile-long zone of folded carbonate rocks. The Fold Belt sediments, laid down by a shallow sea 150-to-65 million years ago, later lithified into limestone and dolomite. From 40-to-25 million years ago, regional volcanism and magmatic intrusions forced mineral-laden hydrothermal solutions into the circulation systems within the Fold Belt. Mineralization occurred by replacement when superheated, acidic, saline solutions dissolved sections of the limestone and dolomite. These deposits, rich in silver, lead, and zinc with lesser amounts of gold and copper, were originally emplaced far below the surface, then later exposed by erosion. Spanish prospectors discovered the Ojuela deposit in 1598. Over its long life, Ojuela has produced more than seven million tons of ore containing on average 15 troy ounces of silver, 15 percent lead, 12 percent zinc, 0.1 troy ounces of gold, and small amounts of copper. When regular operations ended after World War II, total production amounted to more than 100 million troy ounces of silver, 700,000 troy ounces of gold, and roughly 200,000 tons of lead and zinc. Although the Ojuela Mine has not produced ore in decades, it is still mined for mineral specimens and is being explored for possible future ore production.

### COMPREHENSIVE WRITE-UP

#### *COMPOSITION & STRUCTURE*

As shown by the chemical formula  $\text{PbMoO}_4$ , wulfenite's elemental components are lead (Pb), molybdenum (Mo), and oxygen (O). Wulfenite's molecular weight consists of 56.44 percent lead, 26.13 percent molybdenum, and 17.43 percent oxygen. The cation (positively charged ion) of the wulfenite molecule is a lead ion  $\text{Pb}^{2+}$  with its +2 charge. The anion (negatively charged ion) is the molybdate radical  $(\text{MoO}_4)^{2-}$ . Radicals are groups of atoms that act as entities in chemical reactions. The molybdate radical consists of a molybdenum ion  $\text{Mo}^{6+}$  that is covalently bound to four oxygen ions  $4\text{O}^{2-}$ . The collective -2 anionic charge balances the +2 cationic charge to provide the wulfenite molecule with electrical stability.

Wulfenite is one of 49 members of the molybdates and tungstates mineral class. This class is divided into the 23-member anhydrous subclass and the 26-member basic-and-hydrous subclass. As an anhydrous molybdate, wulfenite contains neither hydroxyl ions  $[(\text{OH})^1-]$  nor attached water molecules ( $\text{H}_2\text{O}$ ). Within the wulfenite molecule the molybdate radical  $(\text{MoO}_4)^{2-}$  forms a flattened, tetrahedral structure in which four oxygen ions occupy the four tetrahedral corners surrounding a molybdenum ion. Because the four oxygen ions collectively share the resulting -2 charge, the molybdate radical can bond ionically with various, positively charged metal cations. In wulfenite, the molybdate radical bonds with the lead ion  $\text{Pb}^{2+}$ . Repetitive bonding forms a layered, lattice structure held together by ionic bonds. Because ionic bonds are relatively weak, wulfenite is quite soft at Mohs 3.0. Wulfenite exhibits distinct, one-directional cleavage along the plane of the weakest ionic bonding.

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Wulfenite crystallizes in the tetragonal system, which is defined by three mutually perpendicular axes, two of which are of equal length. Minerals that crystallize in the tetragonal crystal system usually form prisms, pyramids, and dipyrramids. In the wulfenite crystal lattice, however, the flattened shape of the molybdate tetrahedrons create one very short axis, which modifies the usual tetragonal-system shapes into wulfenite's diagnostic, thin, tabular crystals.

Wulfenite is among the densest of all transparent-to-translucent minerals. Its high specific gravity of 6.5-7.0 is due to the high atomic weights of its essential, metallic components lead (207.2) and molybdenum (95.9). This great density imparts a very high index of refraction of 2.283-2.405. The index of refraction of any transparent or translucent object is the ratio of the speed of light in air to the speed of light in the crystal. This means that light travels 2.283-2.405 times faster in air than it does when passing through a wulfenite crystal. Crystals with high refractive indices have a great ability to refract or bend light. Wulfenite's refractive index is considerably higher than that of almost all other minerals and approaches that of diamond (2.417 – 2.419).

Wulfenite is an allochromatic (other-colored) mineral, meaning that its colors are caused not by essential elemental components or the nature of its crystal structure, but by trace amounts of nonessential elements called chromophores. When nearly pure, which is rare, wulfenite is colorless or white. But wulfenite almost always contains small amounts of chromophoric impurities that impart pale to fairly intense colors. These elements, usually vanadium, manganese, chromium, and titanium, have strong chromophoric properties. All are divalent (having a +2 oxidation state) transition metals with roughly the same ionic radius as lead. The common +2 charge and similarity of ionic size enables these ions to readily substitute for lead in the wulfenite crystal lattice. These chromophores alter the light absorption-reflection characteristics of the crystal lattice, causing it to absorb the violet, blue, and green wavelengths of white light, and to reflect the only the yellows and reds commonly seen in wulfenite crystals.

The Dana mineral-classification number 48.1.3.1 identifies wulfenite as an anhydrous molybdate or tungstate (48). Its subclassification places it in the wulfenite series (1), which is defined by the general formula  $AXO_4$ , in which "A" is lead and "X" can be either molybdenum or tungsten. Wulfenite is then assigned to the wulfenite group (3) as the first (1) of two members. The other member is stolzite [lead tungstate,  $PbWO_4$ ], which forms a partial solid-solution series with wulfenite through anionic substitution in which the tungstate radical  $(WO_4)^{2-}$  replaces the molybdate radical  $(MoO_4)^{2-}$ . This solid-solution series is not complete because neither wulfenite nor stolzite form pure end-members. The stolzite end of this series has brownish colors, while the wulfenite end usually has yellow-orange colors.

As a secondary mineral, wulfenite forms in the oxidation zones of lead-rich, hydrothermal replacement deposits in association with barite [barium sulfate,  $BaSO_4$ ], sphalerite [zinc sulfide,  $ZnS$ ], galena [lead sulfide,  $PbS$ ], and molybdenite [molybdenum disulfide,  $MoS_2$ ]. Wulfenite most often forms in arid conditions where deep water tables enable oxidation to extend far below the surface. Small amounts of wulfenite also occur in carbonatites (carbonate-rich igneous

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rocks) in association with molybdenite, barite, and calcite [calcium carbonate,  $\text{CaCO}_3$ ]. Wulfenite forms pseudomorphs after calcite, cerussite [lead carbonate,  $\text{PbCO}_3$ ], mimetite [lead chloroarsenate,  $\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$ ], and pyromorphite [lead chlorophosphate,  $\text{Pb}_5(\text{PO}_4)_3\text{Cl}$ ]. Quartz [silicon dioxide,  $\text{SiO}_2$ ] sometimes forms pseudomorphs after wulfenite.

### *COLLECTING LOCALITIES*

Although uncommon, wulfenite is widely distributed. However, most occurrences yield only very small crystals. Our specimens are from the Ojuela Mine at Mapimí, Mapimí district, Durango, Mexico. Wulfenite also occurs in the adjacent Mexican state of Chihuahua, notably at the San Carlos Mine at Manuel Benevides; the León and León-Congreso mines at Casas Grandes; and the Erupción and Ahumaca mines at Los Lamentos. Other Mexican sources are the Bilbao Mine at Ojo Caliente, Zacatecas; and the Montezuma Mine at Montezuma, Sonora.

In Europe, wulfenite occurs at the type locality of Bad Bleiberg in the Bad Bleiberg district, Gailtaler Alpen-Karnischer Alpen region, Carinthia, Austria; the Les Farges Mine at Ussel, Limousin, France; and the Graveglia Valley at Ne, Genova Province, Liguria, Italy. African specimens come from the Tsumeb Mine at Tsumeb in the Otjikoto Region and the Kombat Mine in the Grootfontein district in the Otjozondjupa Region, both in Namibia; the Sandia Mine at Mindouli, Poole Region, Republic of Congo; the Toussit Mine, Toussit district, Oujda-Angad Province, Oriental Region, Morocco; the Shinkolobwe Mine in the Katanga Copper Crescent, Katanga, Democratic Republic of Congo; and the Kabwe Mine at Kabwe, Central Province, Zambia. In Australia, wulfenite occurs at Whim Creek in Roeburne Shire and at Ledge in Ashburton Shire, both in Western Australia's Pilbara Region. Canadian sources include the Moly Hill molybdenum mine at Abitibi in the Abitibi-Temiscamisque region; the Poudrette Quarry at Mont St.-Hilaire in Rouville County; and the Demix-Varennes Quarry at Varennes & St.-Amable in Verchères County, all in Québec Province. Chinese specimens come from the Jianshan Mine in Ruoqing County, Bayin'qholin Prefecture, Xinjiang Province; and the Maoniuping rare-earth mine in Mianning County, Liangshan Prefecture, Sichuan Province. Wulfenite is also collected at the Santa Rosa Mine in the Santa Rosa-Huantajaya district, Iquique Province, Tarapacá Region, Chile.

The leading wulfenite source in the United States is Arizona, where localities include the Mystery and Defiance mines at Gleeson in the Turquoise district, and the Cole and Campbell mines at Bisbee in the Warren district, both in Cochise County. Pinal County sources include the Mammoth-St. Anthony Mine at Tiger in the Mammoth district, and the Silver King Mine in the Pioneer district. Fine specimens are found at the Red Cloud, Pure Potential, Black Rock, Hamburg, and Papago mines in the Silver district in La Paz County. Other Arizona sources are the Purple Passion Mine in the Red Pacheco district of Yavapai County, and the Rawley Mine at Theba in the Painted Rock district, Maricopa County.

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In the United States, wulfenite is collected in New Mexico at the Stephenson-Bennett Mine in the Organ District, Doña Ana County; the Lucky Bill Mine in the Central district, Grant County; and the Mahoney mines in the Tres Hermanas district, Luna County. California's localities include the St. Charles and Thompson mines in the Darwin District, Inyo County; the Lodi No. 4 Mine in the Last Chance district, Plumas County; and the Blue Bell claims at Baker, San Bernadino County. In Nevada, wulfenite occurs at the Chalk Mountain Mine, Churchill County; and at the Ruby Hill Mine in the Ruby Hill-Eureka district, Eureka County. Among Colorado's sources are the Sherman Tunnel in the Leadville district, Lake County; the Bankers and Slide mines in the Paquin district, Ouray County; and the Bandora Mine in the Silverton district, San Juan County. Other western localities are the Hercules mine at Canyon Creek and the Sherman Mine at Burke in the Coeur d'Alene district, Shoshone County, Idaho; the Hidden Treasure Mine in the Ophir district, Tooele County, Utah; the Gar Mine in the Elkhorn district, Beaverhead County, Montana; the Grants Mine in the Lead district, Lawrence County, South Dakota; and the Bonanza and Red Chief mines in Hudspeth County, Texas.

### *JEWELRY & DECORATIVE USES*

With a hardness of Mohs 3.0, wulfenite is too soft for general jewelry use. Nevertheless, intensely colored, uncut crystals are occasionally wrapped in silver wire for wear as pendants. Despite being brittle and difficult to cut, wulfenite is often faceted into collectors' gems that are quite popular because of their unusual yellow-orange and reddish colors and extraordinary brilliance and luster. Very high indices of refraction (see "Composition & Structure"), and a high dispersion approaching those of diamond, make faceted wulfenite one of the most dazzling of all colored collectors' gems. Wulfenite rarely exhibits a water-clear transparency, but instead has a "soft" clarity that complements its exceptional brilliance. Because wulfenite usually occurs as thin tabs, few crystals are thick enough to cut. Although rarely exceeding one carat in weight, wulfenite collectors' gems cost about \$400. Intensely colored, yellow-orange wulfenite gems as large as two carats can cost about \$400 per carat. Among the largest known wulfenite gems is a 50-carat orange stone on display at the National Museum of Natural History (Smithsonian Institution) in Washington, D.C.

Collectors rank wulfenite among the most desirable of all minerals because of its rarity, well-formed crystals, distinctive orange-reddish colors, and unusual lead-molybdenum chemistry. Wulfenite specimens, especially those from the classic localities of Mexico, Morocco, and Arizona, are featured prominently at many museums and gem-and-mineral shows. Some mineral collectors specialize in amassing suites of wulfenite specimens based upon specific localities, crystal habits, and colors.

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### *HISTORY & LORE*

The Austrian mineralogist, botanist, zoologist, and Jesuit priest Franz Xavier von Wulfen (1728-1805) made the first historical mention of wulfenite in 1785. After studying specimens collected at the Bad Bleiberg lead-mining district near Kärnten, Carinthia, Austria, von Wulfen published *Vom Kärntnerischen Bleispat*, a treatise on the local lead ores in which he described wulfenite crystals in detail. Von Wulfen also accurately sketched crystals of wulfenite and other minerals decades before other scientists recognized the importance of crystal shape in mineral classification. In 1800, German geologist and mineralogist Abraham Gottlob Werner (1750-1817) applied the term *Gelbbleierz* (yellow lead ore) to wulfenite, describing it as an uncommon, yellowish-brown ore occurring at Bad Bleiberg and several other European lead-mining districts. Austrian geologist Wilhelm Karl Ritter Haidinger (1795-1871) recognized wulfenite as a distinct mineral species in 1845, after using advanced analytical methods to prove that its chemical composition differed from that of the closely related, rare mineral stolzite [lead tungstate,  $PbWO_4$ ]. Haidinger named the new mineral in honor of von Wulfen in recognition of his earlier contributions to mineralogy. In 1918, wulfenite was among the first minerals to be crystallographically analyzed with X-ray diffraction techniques.

Because of its great popularity among mineral collectors, the prestigious *Mineralogical Record* has featured photographs of fine wulfenite specimens on its cover eight times. Wulfenite crystals have also appeared on the 45-cent stamp of South West Africa (now Namibia) in 1989, the 1.50-rand stamp of Namibia in 1991, the 1125-franc stamp of the Comoros in 1998, the 13-dinar stamp of Yugoslavia in 1980, and the 29-cent stamp of the United States in 1992.

Metaphysical practitioners believe that wulfenite crystals help to get in touch with emotions, harmonize emotional forces, alleviate emotional blockages, and increase the energy necessary to communicate with other realms. Wulfenite is also thought to heal the reproductive system and to encourage general healing.

### *TYPE LOCALITIES, CLASSIC LOCALITIES*

A Mineral of the Month Club member recently asked us to explain the difference between a mineral's type locality and its classic locality. This month's featured mineral, wulfenite, presents an excellent opportunity to address this topic. Wulfenite's type locality is Austria's Bad Bleiberg lead-mining district (see "History & Lore"). Our specimens were collected at Mexico's Ojuela Mine, which is one of the classic localities for wulfenite.

A type locality, designated as "TL" in mineralogical literature, is defined as the source of the specific specimens that provided data used to describe a new mineral species. The first specimens of the mineral that would later be named "wulfenite" were collected at the Bad Bleiberg lead-mining district near Kärnten, Carinthia, Austria, in 1785. Sixty years later, these

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same specimens were studied again and determined to represent a new mineral species. Austria's Bad Bleiberg district is therefore recognized as the type locality for wulfenite.

Botanist and zoologists began documenting type localities in the late 1700s, making the place of discovery a standard addition to the descriptive literature for new plant and animal species. In the early 1800s, mineralogists drew upon these botanical and zoological precedents to make type localities part of the formal descriptions of all new mineral species.

Mineralogists now recognize approximately 4,800 mineral species. Of these, only about 160 have no assigned type locality. In modern mineralogical literature, the absence of a type locality is noted as "type locality uncertain." Generally, the minerals without designated type localities are abundant species that have been mined and utilized since ancient times. Most of these were recognized as distinct mineral species by the late 1700s, prior to the addition of type localities in new-mineral descriptions. Examples of minerals with no assigned type localities include gold [native metal, Au], diamond [carbon, C], galena [lead sulfide, PbS], halite [sodium chloride, NaCl], quartz [silicon dioxide, SiO<sub>2</sub>], and pyrite [iron disulfide, FeS<sub>2</sub>].

With its considerable geographic size, richness, and variety of mineralization, extensive mining history, numerous mineralogical surveys, and excellent research capabilities, the United States, with 16 percent of all type localities, ranks first among nations in number of type localities. Russia is second with 13 percent, largely for the same reasons. Next in line are Germany at 6.7 percent; Italy, 5.0 percent; Canada, 4.6 percent; and Sweden, 3.9 percent. Despite the smaller geographic sizes of the European nations, most are richly mineralized and have long mining histories and capable research institutions. The area with the most type localities is the Lovozero Mountains on Russia's Kola Peninsula, an area with many diverse alkaline rocks and unique mineralogical environments. Most of the record number of minerals first identified there—nearly 100—have only been described in recent decades. Mexico's Ojuela Mine, the source of our wulfenite specimens, is the type locality for six mineral species.

The related term "type specimen" refers to the specific reference sample(s) that were collected and studied to define a new mineral species. With wulfenite, the type specimens, collected in 1785, are stored in a mineralogical repository at the Freiberg Mining Academy in Freiberg, Germany. Because the practice of preserving type specimens in mineralogical repositories became common practice only after 1900, the preservation of wulfenite's type specimens is somewhat unusual. Type specimens now exist for more than 4,000 of the approximately 4,800 recognized mineral species. Today, type specimens are usually preserved within the nation of origin at a museum or a university nearest to the type locality.

Type specimens fall into four categories: holotypes, cotypes, neotypes, and topotypes. Holotypes are specimens that provide all the data required for an original mineral description. Cotypes are specimens from the same type locality that are studied to obtain additional data for the original mineral description. Neotypes are specimens designated to represent a species when



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it must be redefined, or when the original holotype or cotype has been lost. Topotypes are specimens obtained from the type locality that correspond to the original holotype description.

Type specimens play an important role in the process of mineral-species *discreditation*. Once described and accredited, most mineral species remain valid. But because species are continuously restudied using more and more advanced analytical methods, new data occasionally indicates that the original description of certain minerals is invalid. It then becomes necessary to restudy the original type specimens.

While type localities and type specimens are primarily of scientific value, they also have financial significance. Mineral specimens collected from their type localities command premium prices on collectors' markets because of their added historical and scientific interest.

Type localities may or may not be classic localities. The phrase "classic locality" appears widely in mineralogical literature and has two general meanings. In one usage, it refers to a mineral locality that has produced an unusually large number of different mineral species. Such localities include the Broken Hill Mining District, New South Wales, Australia; the Lovozero and Khibiny massifs, Kola Peninsula, Russia; and the Tsumeb Mine, Tsumeb, Namibia, each of which have yielded specimens of hundreds of species. Mexico's Ojuela Mine, where 126 individual mineral species have been identified, is a classic locality in this usage of the term.

But in its primary usage, the term "classic locality" refers to a site that produces specimens that best exemplify the aesthetic appeal and physical properties of a particular mineral species. The Ojuela Mine is recognized as a classic locality for wulfenite, as well as legrandite [basic hydrous zinc arsenate,  $Zn_2(AsO_4)(OH)\cdot H_2O$ ]; austenite [basic calcium zinc arsenate,  $CaZn(AsO_4)(OH)$ ]; conichalcite [basic calcium copper arsenate,  $CaCu(AsO_4)(OH)$ ]; adamite [basic zinc arsenate,  $Zn_2(AsO_4)(OH)$ ]; hemimorphite [basic hydrous zinc silicate,  $Zn_4Si_2O_7(OH)_2\cdot H_2O$ ]; rosasite [basic copper zinc carbonate,  $(Cu,Zn)_2(CO_3)(OH)_2$ ]; and aurichalcite [basic zinc copper carbonate,  $(Zn,Cu)_5(CO_3)_2(OH)_6$ ]. Specimens of these minerals from the Ojuela Mine rank among the world's best.

Some minerals, especially the abundant species, have several classic localities, each representing a specific physical property such as color, crystal size, or crystal habit. As an example, the classic locality for blue barite [barium sulfate,  $BaSO_4$ ] is Stoneham, Weld County, Colorado, while the classic locality for colorless barite is the Palos Verdes Hills, Los Angeles County, California. Pyrite [iron disulfide,  $FeS_2$ ] has different classic localities for specific crystal habits. The classic locality for nearly perfect, individual pyrite cubes is Navajún, La Rioja, Spain (our Mineral of the Month for March 2006), while the classic locality for pyrite-crystal clusters is the Huanzalá Mine, Dos de Mayo Province, Huanaco Department, Peru (our Mineral of the Month for October 2003). In collectors' markets, specimens from classic localities tend to command higher values than those from lesser-known sources.

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### *TECHNOLOGICAL USES*

Wulfenite has in the past served as a minor ore of lead.

### *ABOUT OUR SPECIMENS*

Our wulfenite specimens were collected at the Ojuela (pronounced oh-HWAY-la) Mine at Mapimí in the Mapimí district, Durango, Mexico. Ojuela, one of the Western Hemisphere's richest and most historic mines, is in north-central Mexico northwest of the city of Torreón in the neighboring state of Coahuila. From Torreón, Ojuela is reached by taking Mexico Route 49 north for 25 miles to Bermejillo, then turning west on Mexico Route 30 for 12 miles, and proceeding to the village of Mapimí four miles to the south. The mine is located in the arid Chihuahuan desert at an elevation of 6,800 feet in the eastern foothills of the Sierra Madre Occidental.

Spanish prospectors discovered the Ojuela silver-lead deposit in 1598. Within 50 years, it had become a major source of silver. By the time the Spanish colonial era was nearing its end in the early 1800s, the Ojuela Mine had produced an estimated 100 million troy ounces of silver (about 3,200 metric tons) along with huge amounts of lead. The mine was largely inactive during the Mexican war of independence in the early 1820s and subsequent production remained sporadic for decades. After modernization in the 1890s, Ojuela again became a major producer, with 1,200 miners turning out one million troy ounces of silver per year, along with large quantities of lead and zinc. After World War II, the mine owner, Compañía Minera de Panoles, ceased regular ore production and leased mine sections to independent cooperatives of miners.

Over four centuries of operation, Ojuela has produced seven million tons of ore with an average content of 15 troy ounces of silver, 15 percent lead, 12 percent zinc, 0.1 troy ounces of gold, and small amounts of copper. The mine has about 200 miles of underground workings, most now flooded, inactive, or abandoned. The upper mine sections are now operated only as a source of mineral specimens. A core-drill exploration program is currently underway to determine if the mine can be reopened in the future for regular ore production.

The Ojuela deposit is one of the carbonate-replacement deposits in a 900-mile-long belt of carbonate rocks called the Mexican Fold Belt. The basement rock within this belt consists of marine sediments that were deposited 150-to-65 million years ago. These sediments eventually lithified into limestone and dolomite rock, sedimentary rocks that consist primarily of calcite [calcium carbonate,  $\text{CaCO}_3$ ] and the mineral dolomite [calcium magnesium carbonate,  $\text{CaMg}(\text{CO}_3)_2$ ]. Tectonic stresses later folded and deformed these formations into the contorted strata of the Mexican Fold Belt. Finally, in mid-Tertiary time some 40-to-25 million years ago, regional volcanism and associated, deep, magmatic intrusions forced mineral-laden, hydrothermal solutions into the folded, carbonate host rocks. These saline, superheated, acidic

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solutions dissolved sections of the limestone and dolomite, replacing them with precipitated metal-sulfide minerals.

Ojuela is an extraordinary source of specimens because of its unusual and complex chemistry, and large volume of oxidized mineralization. Unlike most mineral deposits, an extremely deep water table has enabled huge volumes of sulfide minerals to oxidize into colorful, uncommon-to-rare, secondary minerals. Ojuela's complex mineralization has an abundance of the semimetal arsenic and such metals as silver, lead, zinc, molybdenum, and copper. These metals, originally present as sulfides, oxidized into an array of secondary minerals after erosion had exposed them to atmospheric oxygen and groundwater. Subsequent chemical oxidation and physical weathering created numerous voids that provided space for the growth of well-developed crystals of secondary minerals. Mineral-rich groundwater then circulated through the oxidized portion of the deposit and eventually filled the voids where, in an oxygen-rich environment and conditions of low temperature and low pressure, the solutions precipitated wulfenite and other secondary minerals.

Ojuela first impacted international specimen markets shortly after World War II, when miners found vugs filled with beautiful adamite [basic zinc arsenate,  $Zn_2(AsO_4)(OH)$ ] crystals. As the interest of dealers in the United States grew, Ojuela's miners began selling specimens as a source of secondary income. Throughout the 1960s, 1970s, and 1980s, Ojuela steadily established an international reputation as an extraordinary source of fine mineral specimens.

As you study your wulfenite specimen, notice that the host rock or matrix consists of orange-brown limonite and dark brown goethite [basic iron oxide,  $FeO(OH)$ ]. Limonite is not a mineral, but an indeterminate mixture of hydrous iron oxides that forms in oxidation environments. Limonite is a product of the oxidation or alteration of such primary iron-sulfide minerals as pyrite [iron disulfide,  $FeS_2$ , cubic], marcasite [iron disulfide,  $FeS_2$ , orthorhombic], and arsenopyrite [iron arsenic sulfide,  $FeAsS$ ], all of which are abundant at Ojuela. In our specimens, limonite is present in earthy, massive, columnar, and botryoidal habits.

Wulfenite crystals are easily recognized by their blocky shape, sharp edges, bright luster, and distinctive yellow-orange color that some collectors refer to as "honey-yellow" or "butterscotch." These blocky, four-sided, prismatic crystals, although atypical for the species, are characteristic of Ojuela wulfenite. The crystal terminations are flat; in doubly terminated crystals, this creates a pseudo-cubic form. These crystals have a bright, adamantine luster. "Luster" is the manner in which a surface reflects light. It is dependent upon a mineral's atomic structure, and is determined mainly by the amount of light that is directly reflected from a crystal surface. To observe the color-zoning that is typical of Ojuela wulfenite specimens, study the crystals closely in direct sunlight or under a high-intensity lamp. The crystals exhibit two types of color: one section of the prism is a translucent yellow, the other a more transparent orange. This color zoning is due to a change in the chemistry of the precipitating solutions during the time of crystal growth. Finally, some specimens will have small, green-gray, botryoidal crystals that appear on

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## WULFENITE

the surface of the host rock with the wulfenite crystals. These are crystals of adamite, one of the uncommon arsenate minerals for which Ojuela is well-known. Composite specimens of wulfenite and adamite are unusual at any locality other than Ojuela.

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