

## ***November 2009 Mineral of the Month: Wulfenite***

Our specimens of this month's mineral, wulfenite, were collected at the historic Ojuela Mine, Mexico's most prolific source of mineral specimens. Our write-up explains wulfenite's unusual chemistry and why it ranks as one of the most collectible of all minerals.

### **OVERVIEW**

### **PHYSICAL PROPERTIES**

Chemistry:  $\text{PbMoO}_4$  Lead Molybdate, often containing 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 cube-like; crystal faces can be slightly curved; rarely in massive, coarse, and granular forms.

Color: Yellow, yellow-gold, yellow-orange, orange, orange-red, reddish-brown, yellowish-gray, tan, and whitish; 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: Brilliant yellow and orange colors, tabular habit, and occurrence in oxidized zones of lead-rich deposits. Wulfenite is difficult to mistake for other minerals.

Dana Classification Number: 48.1.3.1.1

**NAME** Wulfenite, pronounced WOOL-feh-nite, is named in honor of Austrian Jesuit mineralogist Franz Xavier von Wulfen (1728-1805). Wulfenite has also been known as "yellow lead spar," "yellow lead ore," "molybdate of lead," "molybdenated lead ore," and "carinthite." The names of wulfenite varieties are based on contained impurities and include "calcium wulfenite," "chromian wulfenite," "vanadian wulfenite," and "tungstenoan wulfenite" or "chillagite." In European mineralogical literature, wulfenite appears as *wulfenita* and *wulfenit*. Wulfenite can be phonetically confused with wolframite, the name of a tungstate-mineral series consisting of hübnerite [manganese tungstate,  $\text{MnWO}_4$ ] and ferberite [iron tungstate,  $\text{FeWO}_4$ ].

**COMPOSITION:** Wulfenite's chemical formula  $\text{PbMoO}_4$  identifies its elemental components as lead (Pb), molybdenum (Mo), and oxygen (O). Its molecular weight consists 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  $(\text{MoO}_4)^{2-}$ , which forms a distorted (flattened) tetrahedral structure with four oxygen ions occupying the four tetrahedral corners around a 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 forms in the oxidation zones of lead-rich, replacement deposits and is often associated with barite [barium sulfate,  $\text{BaSO}_4$ ], sphalerite [zinc sulfide,  $\text{ZnS}$ ], galena

## ***November 2009 Mineral of the Month: Wulfenite***

[lead sulfide, PbS] and molybdenite [molybdenum disulfide, MoS<sub>2</sub>]. Wulfenite most often forms in arid climates where oxidation has extended deeply below the surface.

**COLLECTING LOCALITIES:** The best wulfenite specimens are found in the arid climates of Mexico and Arizona. Mexican sources include the Ojuela Mine at Mapimí in the Mapimí district, Durango; the Erupción and Ahumaca mines at Los Lamentos and the León and León-Congreso mines at Casas Grandes, Chihuahua; the Bilbao Mine at Ojo Caliente, Zacatecas; and the Montezuma Mine at Montezuma, Sonora. Among Arizona's localities are the Mystery and Defiance mines at Gleeson in the Turquoise district, Cochise County; the Mammoth-St. Anthony Mine at Tiger in the Mammoth district, Pinal County; the Red Cloud and Pure Potential mines in the Silver district in the Trigo Mountains, La Paz County; and the Rawley Mine at Theba in the Painted Rock district, Maricopa County. Other notable sources include the type locality of Bad Bleiberg in the Bleiberg district in the Gailtaler Alpen-Karnischer Alpen region of Carinthia, Austria; the Tsumeb Mine at Tsumeb in the Otjikoto Region of Namibia; the Toussit Mine in the Toussit district, Oujda-Angad Province, Oriental Region, Morocco; the Kabwe Mine at Kabwe in the Central Province of Zambia; and the Santa Rosa Mine in the Santa Rosa-Huantajaya district, Iquique Province, Tarapacá Region, Chile.

**HISTORY, LORE, & USES:** Austrian Jesuit mineralogist Franz Xavier von Wulfen (1728-1805) made the first specific historical mention of wulfenite in 1785. After studying specimens collected at the Bad Bleiberg lead-mining district in Carinthia, Austria, von Wulfen published *Vom Kärntnerischen Bleispat*, his 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. According to modern metaphysical practitioners, wulfenite helps to get in touch with one's emotions, harmonizes emotional forces, and alleviates emotional blockages. Wulfenite is also said to heal the reproductive system and to encourage general healing. Although wulfenite is too soft for general jewelry use, nicely colored, uncut crystals are sometimes wrapped in silver wire for wear as pendants. Despite being brittle and difficult to cut, wulfenite is faceted into collector's gems that exhibit unusual colors and extraordinary brilliance and luster. As an eminently collectible mineral, wulfenite specimens are in high demand among mineral collectors.

**ABOUT OUR SPECIMENS:** Our wulfenite specimens were collected at the Ojuela (pronounced oh-HWAY-la) Mine at Mapimí in the Mapimí district, Durango, Mexico. One of Mexico's most historic mines, the Ojuela Mine is located in north-central Mexico northwest of the city of Torreón. Spanish prospectors discovered the Ojuela silver-lead deposit in 1598 and within 50 years had developed it into a major source of silver for the Spanish Crown. Over its 410-year operating life, Ojuela has produced seven million tons of ore that contained on average 15 troy ounces of silver, 15 percent lead, 12 percent zinc, and small amounts of gold and copper. The mine has an estimated 200 miles of underground workings, many of which is now flooded, inactive, or abandoned. Several sections of the mine are currently operated primarily as a source of mineral specimens.

**10 YEARS AGO IN OUR CLUB:** Tektite, Maoming, Guangdong Province, China. This was the first time we had featured a nonmineral—tektites lack a crystal structure and therefore are classified as natural glass—so the heading of our write-up read "November 1999 Rock of the Month." The Chinese word for tektite is lei-gong-mo, meaning "Ink-Black Stone from the Thunder God." Australian Aborigines called them "Blackfellow's Buttons" in allusion to the disc-like form they sometimes take. In Thailand, they are called Chant Khant, "Eclipse of the Moon." All these countries are part of the same strewnfield, as tektite localities are called, the Australasian Strewnfield, which ranges from southeast Asia to Australia. The write-up explains the various theories of tektite formation. The lot we picked needed cleaning, which we did here with a brush after heating the tektites in a crock pot. It was a lot of fun—we should do it again!

# ***November 2009 Mineral of the Month: Wulfenite***

## **COMPREHENSIVE WRITE-UP**

### *COMPOSITION*

We're very proud to be able to feature wulfenite this month—its rarity and the beauty of its colors and crystal forms give it a prominent place in collectors' eyes, which means it generally is hard to find and expensive! Fortunately, a large quantity has been coming from Ojuela these past couple of years, through a source who believes in affordable mineral prices, so we were only too glad to pick out a large lot. This is not to suggest that Ojuela wulfenite is inexpensive—the choicest pieces still sell for hundreds and thousands of dollars, as a quick Internet search will attest.

Wulfenite now becomes our second featured mineral containing the element molybdenum, after molybdenite [MoS<sub>2</sub>] from Australia in February 2005. We've featured several lead-containing minerals, including galena [PbS] in July 2005, crocoite [PbCrO<sub>4</sub>] in October 1996 and October 2006, pyromorphite [Pb<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>Cl] in July 2002, and vanadinite [Pb<sub>5</sub>(VO<sub>4</sub>)<sub>3</sub>Cl] in November 2001 and December 2007.

Wulfenite's chemical formula PbMoO<sub>4</sub> identifies its elemental components as 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 consists of a lead ion Pb<sup>2+</sup> with its +2 charge. The compound anion (negatively charged ion) is the molybdate radical (MoO<sub>4</sub>)<sup>2-</sup>. Radicals are groups of atoms that act as entities in chemical reactions. The molybdate radical consists of a molybdenum ion Mo<sup>6+</sup> covalently bound to four oxygen ions 4O<sup>2-</sup>. This provides a collective -2 anionic charge, which 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 molybdates and tungstates subclass and the 26-member basic and hydrous molybdates and tungstates subclass. As an anhydrous molybdate, wulfenite contains neither hydroxyl ions [(OH)<sup>1-</sup>] nor attached water molecules (H<sub>2</sub>O). The core of the wulfenite molecule is the molybdate radical (MoO<sub>4</sub>)<sup>2-</sup>, which forms a distorted (flattened) tetrahedral structure with four oxygen ions occupying the four tetrahedral corners around a molybdenum ion. Because the four oxygen ions collectively share the resulting -2 charge, the molybdate radical can bond ionically (opposite charges attract) with various metal cations. In wulfenite, the molybdate radical bonds with the lead ion Pb<sup>2+</sup>. 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. Its ionic bonding is weakest between the lattice layers where the ionic distance is greatest, thus explaining wulfenite's distinct cleavage in one direction.

Wulfenite crystallizes in the tetragonal system, which is characterized by three mutually perpendicular axes, two of which are of equal length. Minerals that crystallize in the tetragonal crystal system generally form prisms, pyramids, and dipyramids. In wulfenite, however, the flattened shape of the molybdate tetrahedrons manifests itself into one very short axis, which can distort the usual tetragonal shapes into the thin, tabular crystals often seen in wulfenite.

As an allochromatic (other-colored) mineral, wulfenite's colors are caused not by its essential elemental components or the nature of its crystal structure, but by trace amounts of nonessential elements called chromophores. When nearly pure, wulfenite is colorless or white. But wulfenite virtually always contains sufficient amounts of chromophoric elements that impart pale to fairly intense colors. These elements, which are most often vanadium, manganese, chromium, and titanium, have strong chromophoric properties and are all divalent (having a +2 oxidation state) transition metals with roughly the same ionic

## ***November 2009 Mineral of the Month: Wulfenite***

radius as lead. This similarity of charge and ionic size enables these ions to readily substitute for lead in the wulfenite crystal lattice. The presence of these chromophores usually alters the light absorption-reflection characteristics of the crystal lattice in a manner that causes it to absorb the violet, blue, and green end of the visible spectrum, and to reflect the yellows and reds that are the most common wulfenite colors.

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 metallic components lead (207.2) and molybdenum (95.9). Wulfenite's 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. Wulfenite's index of refraction means that light travels that many times faster in air than it does passing through a wulfenite crystal. The higher its index of refraction, the greater is the ability of a crystal to refract or bend light. Wulfenite's index of refraction is considerably higher than that of almost all other gemstones and minerals and approaches that of diamond (2.417 – 2.419).

Wulfenite is a secondary mineral that forms in the oxidation zones of lead-rich, hydrothermal replacement deposits where it is often associated with barite [barium sulfate, BaSO<sub>4</sub>], sphalerite [zinc sulfide, ZnS], galena [lead sulfide, PbS] and molybdenite [molybdenum disulfide, MoS<sub>2</sub>]. Most wulfenite is found in arid climates in areas where low water tables enable oxidation to extend deeply below the surface. Smaller amounts of wulfenite are found in carbonatites (carbonate-rich igneous rocks), where it is frequently associated with molybdenite, barite, and calcite [calcium carbonate, CaCO<sub>3</sub>]. Quartz [silicon dioxide, SiO<sub>2</sub>] sometimes forms pseudomorphs after wulfenite, whereas wulfenite is known to form pseudomorphs after such minerals as calcite, cerussite [lead carbonate, PbCO<sub>3</sub>], mimetite [lead chloroarsenate, Pb<sub>5</sub>(AsO<sub>4</sub>)<sub>3</sub>Cl], and pyromorphite [lead chlorophosphate, Pb<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>Cl].

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<sub>4</sub>, 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 of this group is stolzite [lead tungstate, PbWO<sub>4</sub>]. Stolzite forms a solid-solution series with wulfenite through anionic substitution when the molybdate radical (MoO<sub>4</sub>)<sup>2-</sup> replaces the tungstate radical (WO<sub>4</sub>)<sup>2-</sup>. This solid-solution series is not complete because neither wulfenite nor stolzite occur as pure end-members. The stolzite end of this series tends to have pronounced brownish colors, while the wulfenite end usually exhibits yellow-orange colors. Increasing brownish color in wulfenite specimens indicates the increasing substitution of tungstate ions.

### ***COLLECTING LOCALITIES***

Although it is an uncommon mineral, wulfenite has quite a few occurrences. Most localities, however, yield only small crystals. Our specimens were collected at the Ojuela Mine at Mapimí in the Mapimí district, Durango, Mexico. This prolific locality has blessed us with two previously featured minerals: adamite [Zn<sub>2</sub>(AsO<sub>4</sub>)(OH)] in May 1998 and May 2008, and conichalcite [CaCu<sup>2+</sup>(AsO<sub>4</sub>)(OH)] in September 2002. The Mexican state of Chihuahua also has a number of wulfenite sources, most notably 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 the United States, most wulfenite sources are located in the arid Southwest, especially in 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

## ***November 2009 Mineral of the Month: Wulfenite***

include the Mammoth-St. Anthony Mine at Tiger in the Mammoth district, and the Silver King Mine in the Pioneer district, both in the Pinal Mountains. Arizona's most acclaimed wulfenite specimens are collected at the Red Cloud, Pure Potential, Black Rock, Hamburg, and Papago mines in the Silver district in the Trigo Mountains of La Paz County. Other notable 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 of Maricopa County.

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

In Europe, wulfenite occurs at the type locality of Bad Bleiberg in the Bleiberg district in the Gailtaler Alpen-Karnischer Alpen region of Carinthia, Austria; the Les Farges Mine at Ussel in 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 Grootfontain district in the Otjozondjupa Region, both in Namibia; the Sandia Mine at Mindouli in the Poole Region of the Republic of Congo; the Toussit Mine in the Toussit district, Oujda-Angad Province, Oriental Region, Morocco; the Shinkolobwe Mine in the Central Area of the Katanga Copper Crescent, Katanga, Democratic Republic of Congo; and the Kabwe Mine at Kabwe in the Central Province of Zambia. In Australia, wulfenite occurs at Whim Creek in Roeburne Shire and at Ledge in Ashburton Shire, both in the Pilbara Region of Western Australia. Most Canadian specimens come from Québec, where sources include the Moly Hill molybdenum mine at Abitibi in the Abitibi-Temiscaminque region; the Poudrette Quarry at Mont St.-Hilaire in Rouville County; and the Demix-Varennés Quarry at Varennés & St.-Amable in Verchères County. Chinese specimens come from the Jianshan Mine in Ruoqing County, Bayin'qholin Prefecture, Xinjiang Province; and from the Maoniuping rare-earth mine in Mianning County, Liangshan Prefecture, Sichuan Province. Chilean specimens come from the Santa Rosa Mine in the Santa Rosa-Huantajaya district, Iquique Province, Tarapacá Region. You might get the impression from this extensive listing that you could hardly turn around at a mineral show without knocking over a couple of wulfenite pieces, but that is not all the case—we have seen very few specimens from any of these localities at shows!

### ***JEWELRY & DECORATIVE USES***

At Mohs 3.0, wulfenite is too soft for general jewelry use, but nicely colored, uncut crystals are occasionally wrapped in silver wire for wear as pendants. Although wulfenite is brittle and difficult to cut, it is nevertheless faceted into collectors' gems that are quite popular because of their unusual colors and extraordinary brilliance and luster. High indices of refraction and dispersion (see "Composition") approaching that of diamond make faceted wulfenite one of the most dazzling of all colored, collector gems. Wulfenite collector gems, which are comparable in brilliance and general appearance to colored diamond gems, have been cut to sizes as large as 10 carats.

## ***November 2009 Mineral of the Month: Wulfenite***

Wulfenite is among the most collectible of all minerals (see “Collectible Species, Collectible Specimens”) and specimens have long been in high demand among mineral collectors. Wulfenite specimens are featured prominently at many museums and mineral shows. Some mineral collectors specialize in wulfenite, building suites of wulfenite specimens based upon specific localities, colors, and crystal habits.

### ***HISTORY & LORE***

Austrian Jesuit mineralogist Franz Xavier von Wulfen (1728-1805) made the first specific historical mention of wulfenite in 1785. After studying specimens collected at the Bad Bleiberg lead-mining district near Kärnten in Carinthia, Austria, von Wulfen published *Vom Kärntnerischen Bleispat*, a treatise on the local lead ores in which he described wulfenite crystals. Von Wulfen also accurately sketched crystals of wulfenite and other minerals at a time when few 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, when he used improved analytical methods to prove that its chemical composition was different from that of the closely related, rare mineral stolzite [lead tungstate,  $PbWO_4$ ]. Haidinger named the new mineral for von Wulfen in recognition of his earlier contributions to mineralogy. In 1918, wulfenite was among the first minerals to have its crystal structure defined by X-ray diffraction techniques.

According to modern metaphysical practitioners, wulfenite helps to get in touch with one's emotions, harmonizes emotional forces, and alleviates emotional blockages. Wulfenite is also said to heal the reproductive system and to encourage general healing.

In testimony to its great collector appeal, wulfenite has been featured on the cover of the prestigious *Mineralogical Record* eight times. Wulfenite crystals have also appeared on the 45-cent stamp of South West Africa (now Namibia) in 1989, the 1.50-rand postage stamp of Namibia in 1991, the 1125-franc stamp of the Comoros Islands in 1998, the 13-dinar stamp of Yugoslavia in 1980, and the 29-cent stamp of the United States in 1992.

### ***COLLECTIBLE SPECIES, COLLECTIBLE SPECIMENS***

*Mineral dealers, collectors, and museum curators describe wulfenite as an especially “collectible” mineral, and with good reason. Wulfenite specimens enjoy high collector demand, prominence in private collections and in the collections of institutions and museums, and great popularity in competitive exhibits at mineral shows. But before looking at the factors that make wulfenite a collectible mineral, let's first consider the term itself. In its mineralogical context, “collectible” can refer either to mineral species or to mineral specimens, and thus the word has different meanings.*

***Collectible Mineral Species:*** *When it comes to general desirability, not all mineral species are equal. Some inherently have great collector appeal, while others have relatively little. Most collectible mineral species stand out in color and form, tending to form large, well-developed crystals with bright, distinctive, eye-catching colors. Good examples of collectible minerals are rhodochrosite, which forms cherry-red rhombohedrons, and pyrite, most familiar as brassy-colored, near-perfect cubes with a shiny metallic luster. Other minerals which often show brilliant colors and remarkable crystals include tourmaline, garnet, varieties of beryl, apatite, diopside, cavansite, azurite, fluorite—really, the list goes on and on. We have thought many times how interesting it would be to survey collectors as what they consider the most*

## ***November 2009 Mineral of the Month: Wulfenite***

beautiful minerals. Such research could lead to a "Collector's Top 10," "Top 50," "Top 100," "Top 200," or whatever size list was desired. What would you put on your list?

But many other minerals have nondescript "light" or "dark" colors, or rarely form well-developed or large crystals, and thus have little visual appeal. Years ago, a mineral store owner gave us a bit of advice he has gone by: don't purchase white or black minerals and expect them to sell quickly. They lack the visual punch many collectors are looking for! Of course, there are many exceptions, such as lustrous black tourmaline. And there are a significant number of collectors looking for "rare uglies": extremely rare species, with little concern for their size or appearance.

Mineralogical associations also play a role in mineral desirability. Some species occur in associations that produce beautiful composite (composed of two or more species) specimens that are visually enhanced by contrasting colors or textures. Granite pegmatites are well-known as a source of such spectacular composite specimens as pink crystals of the tourmaline-group mineral pink elbaite [basic sodium aluminum lithium borosilicate,  $\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$ ] in a snow-white, sugary matrix of the feldspar-group mineral albite [sodium aluminum silicate,  $\text{NaAlSi}_3\text{O}_8$ ].

Another factor in species desirability is rarity. Many minerals are too rare to be collectible. Of the approximately 4,400 currently recognized mineral species, more than three-quarters are so rare that specimens are simply not available to instill appreciation or generate demand among large numbers of collectors. While specimens of these species are needed for specialized scientific, rare-mineral, or locality collections, they have little interest among general collectors. On the other hand, the abundance of a particular species can also affect its desirability. Quartz [silicon dioxide,  $\text{SiO}_2$ ] is a good example of a mineral known for its abundance of large, well-developed crystals. Crystals of such size and quality in other, less-common species would be quite valuable and desirable, but the sheer abundance of quartz makes only its rarest colors, most unusual and most perfect crystal forms truly collectible. Mineral collectors usually focus on no more than 100 species, many of which are uncommon. Wulfenite is inherently collectible not only because of its distinctive colors and forms, but also because it is not abundant enough to flood the market with specimens, nor so rare as to make specimens unavailable or unaffordable. This combination of color, form, and the "right" degree of rarity makes wulfenite one of the eminently collectible mineral species.

**Collectible Mineral Specimens:** Now let's consider what makes individual specimens of any given species collectible. Ideally, a collectible mineral specimen will exhibit the colors and forms that typify the particular species—or the colors and forms that are atypical, meaning unusual or rare, for that species.

Regarding specimen form, crystals should be as well-developed as possible, with smooth faces that intersect at clean, well-defined, sharp edges and terminations that are typical or atypical for the species. The combination of color and form are the primary factors that determine a specimen's overall aesthetic appeal, that is, the beauty we perceive in a specimen and the enjoyment we derive from viewing it.

Factors that contribute to the overall appeal of composite specimens are the contrast in colors and the balance in size and ratio between the primary and the matrix species.

Other factors also contribute to the desirability of a particular specimen. Given similarity of color and form, specimens from famed or classic localities are always more collectible, as are specimens from mines and other sources that have closed or that have an unusual or interesting history. The physical condition of a specimen also determines desirability. Because most specimens must be separated from their host rock to be collected, some broken edges and other physical alterations are inevitable. But in specimens that

## ***November 2009 Mineral of the Month: Wulfenite***

*have been properly collected and trimmed by professionals, broken edges are “positioned” in a manner that does not significantly detract from the beauty of the specimens. Fine specimens should never exhibit crushed surfaces and other damage that reflects improper collecting, trimming, shipping, or storage.*

*Obviously, there is a personal, human side to these evaluations. Each individual collector will tend to favor some minerals over others. A mineral considered by many collectors to be especially desirable may not have a similar appeal to everyone. Certain colors, forms, groups, or composites may affect one collector more than other, which is as we might expect and as it should be. We often advise new collectors at shows to choose pieces that appeal most to them—if they continue in the hobby, their tastes will develop naturally and their eye will be trained to seek specimens that fit the criteria we’re discussing here. While it is true that a well-preserved, well-chosen, well-organized mineral collection will usually appreciate in value over time (and sometimes appreciate greatly if kept for many years), the main reason for building a collection should be the joy and satisfaction it brings to the individual collector!*

*Our wulfenite specimens are collectible both for their species and as specimens. First, wulfenite, an uncommon mineral with distinctive colors and crystal forms, has great collector appeal. Collector demand, coupled with limited supply of quality wulfenite specimens, creates a tight market and supports high specimen prices. Second, our specimens have been professionally collected and trimmed. Although somewhat atypical in crystal form for the species, our specimens are characteristic of those coming from the Ojuela Mine, one of Mexico’s most historic and storied silver mines (see “About Our Specimens”).*

### **TECHNOLOGICAL USES**

Wulfenite has at various times served as a minor ore of lead.

### **ABOUT OUR SPECIMENS**

As noted, our wulfenite specimens were collected at the Ojuela (pronounced oh-HWAY-la) Mine at Mapimí in the Mapimí district, Durango, Mexico. Ojuela, one of Mexico’s most historic and productive mines, is located in the north-central part of the country northwest of the city of Torreón. From Torreón, it is reached by taking Mexico Route 49 north for 25 miles to Bermejillo, turning west on Mexico Route 30 for 12 miles, then following the signs to the small 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 western foothills of the Sierra Madre Occidental.

Spanish prospectors discovered the Ojuela silver-lead deposit in 1598. By 1640, miners had developed it into a major source of silver for the Spanish Crown. After being mined from underground workings, the ore was crushed and reduced to lead-silver alloys in adobe smelting furnaces. Smelter workers then separated the silver from the lead with a simple cupellation (selective oxidation) process. By the time the Spanish colonial era was nearing its end in the early 1800s, the Ojuela Mine had produced about 100 million troy ounces of silver (about 3,200 metric tons) along with huge amounts of lead. But the Mexican war of independence soon curtailed production and the mine was largely abandoned. Although the mine reopened in the 1820s, production remained sporadic for decades. The mine was modernized in the 1890s and 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. The mine was upgraded once more during the 1920s, only to have its production curtailed by the Great Depression. After World War II, the mine owner, Compañía Minera de Penoles, leased sections of the mine to independent cooperatives of miners, a system that still survives today. Over its 410-year operating life, Ojuela has produced seven million tons



## ***November 2009 Mineral of the Month: Wulfenite***

of ore with an average content of 15 troy ounces of silver, 15 percent lead, 12 percent zinc, and small amounts of gold and copper. The mine has an estimated 200 miles of underground workings, many of which are now flooded, inactive, or abandoned. Sections of the mine are now operated primarily as a source of mineral specimens. A core-drilling exploration program is currently underway to determine if the mine can be reopened.

The Ojuela deposit is one of many carbonate-replacement deposits that occur 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 between 150 and 65 million years ago. These sediments eventually lithified into limestone and dolomite, sedimentary rocks that consist primarily, and respectively, of calcite [calcium carbonate,  $\text{CaCO}_3$ ] and dolomite [calcium magnesium carbonate,  $\text{CaMg}(\text{CO}_3)_2$ ]. Later, tectonic stresses folded and deformed these formations into the contorted strata typical 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 solutions dissolved sections of the limestone and dolomite, replacing them with precipitated sulfide and silicate minerals rich in silver, lead, and zinc, along with lesser amounts of gold and copper. For a detailed account of the history, geology, and mineralogy of the Ojuela Mine, refer to our May 2008 write-up on adamite. We have posted it to our web site at [www.mineralofthemonthclub.org](http://www.mineralofthemonthclub.org). Just click on the "Sample Write-up" on the left to find it.

In testimony to its extraordinarily complex mineralogy, 126 individual mineral species have been identified at Ojuela, which is the type locality for six of these species. Ojuela's fame as an extraordinary source of specimens is due to two factors: a very large volume of oxidized mineralization and an unusual chemistry. Unlike most mineral deposits, Ojuela's extremely deep water table has enabled huge volumes of sulfide minerals to oxidize into colorful, uncommon-to-rare secondary minerals. Ojuela also has an unusually complex chemistry because of its abundance of arsenic and because it is a polymetallic deposit that contains significant quantities of silver, lead, zinc, molybdenum, and copper. These metals, originally present as sulfides, became oxidized into a wide variety of secondary minerals, one of which is wulfenite, which formed after erosion had exposed the upper sections of the original sulfide deposit to atmospheric oxygen and groundwater. This triggered the processes of chemical oxidation and physical weathering to create numerous voids that later provided space for the growth of well-developed crystals of secondary minerals. Mineral-rich groundwater 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.

Collectors first became aware of Ojuela's wealth of fine mineral specimens shortly after World War II, when miners found large vugs filled with beautiful crystals of adamite. As the interest of dealers in the United States grew, Ojuela's miners soon learned that collecting and selling specimens could be more lucrative than mining ore. Through the 1960s, 1970s, and 1980s, Ojuela established an international reputation as an extraordinary source of mineral specimens. Finally, in 1996, Tucson, Arizona-based Top Gem Minerals contracted with the mine owner and the miners' cooperatives to become the exclusive authorized buyer and distributor of Ojuela specimens.

Our wulfenite specimens were collected in May 2008 from the Santo Domingo Stope on the sixth level of the Ojuela Mine. For centuries, Ojuela miners had extracted ore from a series of seven massive, vertical mineralized veins or "chimneys" to create open stopes—huge voids between walls of barren host rock. The miners traditionally named many of these stopes after saints—San Juan, San Ignacio, San Nicolás, San Vicente, etc.—in the hope that these saints would keep them safe in their dangerous work. The Santo Domingo Stope, nearly 1,800 feet below the surface and just above the level of the water that now floods the lowest workings, was opened during a period of booming production in the early 1900s.

## ***November 2009 Mineral of the Month: Wulfenite***

In examining your specimen, notice first the host rock of orange-brown limonite, an indeterminate mixture of hydrous iron oxides that forms only in oxidation environments. Limonite is a product of the oxidation or alteration of such primary iron sulfide minerals as pyrite [iron disulfide, FeS<sub>2</sub>, cubic], marcasite [iron disulfide, FeS<sub>2</sub>, orthorhombic], and arsenopyrite [iron arsenic sulfide, FeAsS], all of which are abundant at Ojuela. In our specimens, several habits of limonite can be observed, including, earthy, massive, columnar, and botryoidal.

The wulfenite crystals in our specimens are recognized by their bright luster and distinctive yellow-gold color that some collectors refer to “honey-yellow,” “caramel,” or “butterscotch.” Wulfenite at Ojuela tends to form in two habits: as elongated prisms with rounded terminations and as blocky, four-sided, prismatic crystals. Your specimen will show one of these habits. (You could always contact us if you would like to purchase a second piece showing the other habit.) These forms are actually atypical for the species, but are characteristic of wulfenite from the Ojuela Mine. On the blocky, four-sided crystals, the terminations are flat and the double terminations create a pseudo-cubic form, which is quite fascinating. All the crystals of both habits are well-developed with sharp edges, smooth faces, and a bright luster. Luster, which is dependent upon atomic structure, is determined by the amount of light that is directly reflected from a crystal surface. Luster is not a function of color, but simply of the amount of reflected white light. Wulfenite is known for its bright, adamantine-to-vitreous luster. (“Adamantine” is named after the typical luster of diamond crystals, and is often part silvery in character, while “vitreous” means bright, like the surface of freshly broken glass.) Now study the crystals closely in strong light (such as direct sunlight) to observe the color zoning that is typical of Ojuela wulfenite specimens. The crystals clearly exhibit two types of color: one section of the prism is a translucent yellow, while the other is a more transparent orange. This color zoning is believed to have been caused by a change in the chemistry of the precipitating solutions during the time of crystal growth.

The crystal form typical of wulfenite that is so pleasing to collectors is that of a simple rectangle, sometimes with modified faces so that it looks like a picture frame with beveled edges. Such specimens are known from the Red Cloud mine in the Silver district of the Trigo Mountains, La Paz County, Arizona, and from other localities, but rarely if ever at Ojuela. Combine the simple symmetry and remarkable proportions of such crystals with lustrous red or orange colors, and it is easy to see why wulfenite ranks in the highest echelon of sought-after minerals!

Some of our pieces contain small green botryoidal crystals of mimetite [Pb<sub>5</sub>(AsO<sub>4</sub>)<sub>3</sub>Cl] that appear on the surface of the limonite host rock. Composite specimens of wulfenite and mimetite are particularly desirable to discerning collectors. We hope to feature in the future other minerals from the Ojuela Mine—Mexico’s most prolific and noted source of mineral specimens. And who knows, maybe we will feature wulfenite again, in another fascinating form!

References: *Dana’s New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Co.; *2004 Fleischer’s Glossary of Mineral Species*, Joseph Mandarino and Malcolm Back, The Mineralogical Record Company; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Co.; *Manual of Mineralogy*, Cornelius Hurlbut and Cornelia Klein, Twenty-first Edition, John Wiley & Sons; *Gemstones of the World*, Walter Schumann, Sterling Publishing, 1977; *Gems and Jewelry*, Joel E. Arem, Geoscience Press, 1992; *The World’s Finest Minerals and Crystals*, Peter Bancroft, Viking Press, 1973; “Mapimi: Mineral Collectors’ Capital of Mexico,” P. W. Johnson, *The Mineralogist*, May-June 1962; *Mines and Minerals of Mexico, Volume Two: The Ojuela Mine*, Thomas Moore and Peter Megaw, The Mineralogical Record Company, 2003; “Tales from Mexico (Parts I and II),” B. Smith and C. Smith, editors, *Rocks & Minerals*, January-February and March-April 1999; “High-Temperature, Carbonate-Hosted Lead-Zinc-Silver Massive Sulfide Deposits of Mexico,” Peter Megaw and Juan Ruíz, *Economic Geology*, Volume 83, 1988; “Mexico’s Greatest Wulfenite Mines,” Bob Jones, *Rock & Gem*, November 2008; “The Frugal Collector: Wulfenite,” Bob Jones, *Rock & Gem*, December 2003; “Connoisseur’s Choice: Wulfenite,” Robert B. Cook, *Rocks & Minerals*, March-April 1999; “Wulfenite, The Desert Mineral,” Richard A. Bideaux, *Rocks & Minerals*, January-February 1990.