

## ***February 2013 Mineral of the Month: Vanadinite***

### **VANADINITE**

Our featured mineral this month is vanadinite, an uncommon, vanadium-containing mineral from a classic locality in Morocco. Our write-up explains vanadinite's mineralogy and history, and also provides an overview of the element vanadium.

### **OVERVIEW**

### **PHYSICAL PROPERTIES**

Chemistry:  $\text{Pb}_5(\text{VO}_4)_3\text{Cl}$  Lead Chlorovanadate, usually containing some calcium, phosphorus, and arsenic.

Class: Phosphates, Arsenates, and Vanadates

Group: Pyromorphite

Crystal System: Hexagonal

Crystal Habits: Usually as small, prismatic crystals with hexagonal cross sections, occasionally hopper-shaped or hollow (skeletal); also fibrous, incrusting, compact, nodular, and globular aggregates of needle-like prisms.

Color: Ruby-red, orange-red, orange, orange-brown, yellow, and brown; color zoning common; individual crystals can be multicolored.

Luster: Adamantine to resinous

Transparency: Transparent to translucent

Streak: Pale yellow to light brownish-yellow

Cleavage: None

Fracture: Uneven to subconchoidal

Hardness: 2.8-3.0

Specific Gravity: 6.7-7.1

Luminescence: None

Refractive Index: 2.350-2.412

Distinctive Features and Tests: Best field marks are orange-red colors, bright luster, softness, and hexagonal shape of the crystal cross section. Pyromorphite [lead chlorophosphate,  $\text{Pb}_5(\text{PO}_4)_3\text{Cl}$ ] and mimetite [lead chloroarsenate,  $\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$ ] have many similar physical properties, but are usually green and yellow respectively, while bright-red crocoite [lead chromate,  $\text{PbCrO}_4$ ] crystals are striated.

Dana Classification Number: 41.8.4.3

**NAME:** Vanadinite, pronounced vah-NAY-dinn-ite, is named for the essential elemental component vanadium. Vanadinite has also been known as “brown lead,” “johnstonite,” “lead vanadate,” “vanadium lead,” and “red vanadium lead.” An arsenic-rich variety is called “endlichite.” In European mineralogical literature, vanadinite appears as *vanadinit* and *vanadinita*.

**COMPOSITION:** Vanadinite is one of the nearly 300 members of the phosphates, arsenates, and vanadates class of minerals. Vanadinite's chemical formula  $\text{Pb}_5(\text{VO}_4)_3\text{Cl}$  shows that it

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contains four essential elemental components: lead (Pb), vanadium (V), oxygen (O), and chlorine (Cl). Its molecular weight is made up of 73.15 percent lead, 13.56 percent oxygen, 10.79 percent vanadium, and 2.50 percent chlorine. Vanadinite is an uncommon, secondary mineral that develops in the alteration zones of massive hydrothermal-replacement and vein deposits following the oxidation of primary lead minerals. It forms mainly in arid climates in shallow environments with restricted circulation of acidic groundwater. Vanadinite is often associated with such minerals as galena [lead sulfide, PbS], barite [barium sulfate, BaSO<sub>4</sub>], wulfenite [lead molybdate, PbMoO<sub>4</sub>], and calcite [calcium carbonate, CaCO<sub>3</sub>]. It is an idiochromatic (self-colored) mineral in which its basic, ruby-red to orange-red colors are created by vanadate radicals that cause the lattice to absorb the lower end of the visible spectrum and to reflect only light in the yellow-to-red wavelengths.

**COLLECTING LOCALITIES:** Vanadinite specimens are collected in Morocco, Zambia, Namibia, Mexico, Australia, Chile, Argentina, Scotland, England, and Austria. Sources in the United States are located in Arizona, Nevada, New Mexico, Texas, California, and South Dakota.

**HISTORY, LORE AND GEMSTONE / TECHNOLOGICAL USES:** Vanadinite was recognized as a new mineral species in 1801 and formally named “vanadinite” in 1838. Vanadinite was the only known source of vanadium until metallurgists succeeded in extracting the metal from vanadiferous (vanadium-containing) iron ores in 1870, after which vanadinite was no longer served as an ore of vanadium. Vanadinite was also once a minor ore of lead. Because of its softness (Mohs 2.8-3.0), vanadinite has only limited use as a gemstone and is usually fashioned into beads for necklaces. Transparent vanadinite crystals are occasionally faceted into collector’s gems to display their striking orange-red colors. Because of its combination of bright colors, the rarity of good specimens, its unusual chemistry, and a number of interesting mineralogical associations, vanadinite is one of the most collectible of all minerals for both study and display purposes. Modern metaphysical practitioners believe that vanadinite helps to bring emotional sensitivity to analytically minded people who tend to over-intellectualize their feelings. Vanadinite is also thought to enhance sensitivity, help clear confusion and feelings of purposelessness, and assist in grounding and centering.

**ABOUT OUR SPECIMENS:** Our specimens are from a classic vanadinite locality—the Mibladen Mining District near Midelt, Khénifra Province, Meknès-Tifalalet Region, Morocco. Midelt, population 45,000, is located in the northern foothills of the Middle Atlas Mountains about 100 miles southeast of the national capital and coastal city of Rabat. Midelt was founded in the 1920s as a government administrative center at a time when Morocco was still a French colony. Midelt grew quickly, largely because of the development of lead-zinc mines at Mibladen, seven miles to the northeast. By 1949, the Mibladen district had over 600 shafts, most of which had operated only briefly and were no deeper than 40 feet. At its peak, the Mibladen district employed about 350 miners. After Morocco received its independence in 1956, production mining declined and finally ended in the 1970s. Mineralization at Mibladen was emplaced during the second uplifting of the Middle Atlas Mountains some 80 million years ago, when mineral-rich, hydrothermal fluids deposited veins of lead and lead- and zinc-sulfide minerals. After erosion later exposed these deposits, the sulfides oxidized into arsenates, molybdates, and sulfates. In this alteration process, acidic groundwater dissolved small amounts

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of vanadium from the adjoining host rock and percolated downward to dissolve lead minerals. This mineral-laden groundwater then filled voids and seams where vanadinite crystallized out of solution to cover the cavity walls. Today, hundreds of private miners manually sink narrow, 10-foot-deep shafts, then dig radiating, three-foot-high, horizontal tunnels in search of vanadinite-filled vugs. Although most miners earn only a subsistence living, striking one “good” vug can yield vanadinite specimens worth several thousand dollars—an entire year’s salary for the average Moroccan worker. Our specimens were recovered by private specimen miners, then sold to dealers in Midelt who exported them to international markets.

### **COMPREHENSIVE WRITE-UP**

#### *COMPOSITION*

This is the third time we have featured vanadinite as our Mineral of the Month. It was first featured it in 2001 and again in 2007. Vanadinite is an uncommon mineral that is widely collected because of its distinctive orange-red color and unusual chemistry. Because the supply of vanadinite specimens is erratic and uncertain, it is difficult to acquire specimens in the quantity necessary to provide to our members. Fortunately, however, we were able to take advantage of an opportunity offered by a dealer in fall 2012. These specimens are quite different from those we featured earlier. In 2007, our vanadinite specimens were from the Pure Potential Mine in the Silver district of La Paz County, Arizona. In 2001, our specimens also came from Morocco’s Mibladen district, but they were from a different mine and had a different appearance from those we are featuring now.

Vanadinite’s chemical formula  $\text{Pb}_5(\text{VO}_4)_3\text{Cl}$  shows that it contains four essential elemental components: lead (Pb), vanadium (V), oxygen (O), and chlorine (Cl). Vanadinite’s molecular weight is made up of 73.15 percent lead, 13.56 percent oxygen, 10.79 percent vanadium, and 2.50 percent chlorine. To understand vanadinite’s chemistry and structure, remember that all molecules consist of cations (positively charged ions) and anions (negatively charged ions). In vanadinite, the cation consists of five lead ions  $5\text{Pb}^{2+}$  with a collective +10 charge. Anions often take the form of radicals, which are groups of different atoms that act as entities in chemical reactions. Vanadinite’s compound anion consists of three vanadate radicals  $3(\text{VO}_4)^{3-}$  and a chlorine ion  $\text{Cl}^{1-}$ . These provide a collective anionic -10 charge to balance the cationic +10 charge and thus provide the vanadinite molecule with electrical stability.

Vanadinite is among the nearly 300 members of the phosphates, arsenates, and vanadates class of minerals. The basic building blocks of this mineral class are the phosphate radical  $(\text{PO}_4)^{3-}$ , the arsenate radical  $(\text{AsO}_4)^{3-}$ , and the vanadate radical  $(\text{VO}_4)^{3-}$ . All form tetrahedral structures in which four oxygen ions  $4\text{O}^{2-}$  surround the ion of a metal or semimetal (vanadium is a metal; arsenic and phosphorus are semi-metals). In the vanadate radical  $(\text{VO}_4)^{3-}$ , four oxygen ions surround and covalently bond to a single, pentavalent vanadium ion  $\text{V}^{5+}$ . This resulting -3 charge is spread evenly over the four oxygen ions and enables the vanadate radical to bond ionically with various metal ions. In vanadinite, three vanadate radicals  $3(\text{VO}_4)^{3-}$  bond ionically to five lead ions  $5\text{Pb}^{2+}$  to form the intermediate, octahedral-shaped, lead-vanadate radical

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$[\text{Pb}_5(\text{VO}_4)_3]^{1-}$ . The spaces between these octahedra provide the necessary room for one chlorine ion  $\text{Cl}^{1-}$  to bond ionically to every fifth lead ion, thus completing and electrically balancing the vanadinite molecule.

Within the vanadinite lattice, each structural unit consists of a chlorine ion surrounded by six lead ions, with one lead ion provided by an adjacent molecule. Because vanadate radicals shield the lead ions, and oxygen ions within the radicals shield the vanadium ions, vanadinite exhibits no metallic properties. This structural arrangement in which six lead ions surround a single chlorine ion causes vanadinite to crystallize in the hexagonal system. The hexagonal system is defined by four axes, three of equal length and lying in a common plane with angles of  $60^\circ$  between them. The fourth axis, which is unique to the hexagonal system, is perpendicular to the plane of the other three and of variable length. Hexagonal crystals have a clearly defined, six-fold symmetry, which is apparent in the six prismatic faces of vanadinite's hexagonal crystals.

Both covalent and ionic bonding exist within the vanadinite crystal lattice. Strong, electron-sharing, covalent bonding is limited to the vanadate radical. Much weaker ionic bonding, which joins the lead ions to the vanadate radicals and the chlorine ions to the lead ions, dominates throughout the lattice and explains vanadinite's brittleness and softness (Mohs 2.8-3.0). Because ionic-bonding strength is omnidirectional, vanadinite has no cleavage planes. Vanadinite has an extremely high density (specific gravity 6.7-7.1) for a transparent-to-translucent mineral. This high density is due to the essential component lead (atomic weight 207.2), which accounts for 73.15 percent of vanadinite's molecular weight. Vanadinite's great density also explains its very high index of refraction of 2.350-2.412, which is nearly that of diamond.

As an uncommon, secondary mineral, vanadinite develops in the alteration zones of massive hydrothermal-replacement and vein deposits and follows the oxidation of primary lead minerals. It forms mainly in arid climates in environments with restricted circulation of acidic groundwater. Vanadinite is associated with such minerals as galena [lead sulfide,  $\text{PbS}$ ], barite [barium sulfate,  $\text{BaSO}_4$ ], wulfenite [lead molybdate,  $\text{PbMoO}_4$ ], and calcite [calcium carbonate,  $\text{CaCO}_3$ ].

The Dana mineral classification number 41.8.4.3 first identifies vanadinite as an anhydrous phosphate, arsenate, or vanadate containing a hydroxyl or halogen ion (41). The subclassification (8) then defines it by the general formula  $\text{A}_5(\text{XO}_4)_3\text{Z}_q$ , in which "A" is a divalent metal ion, " $\text{XO}_4$ " is a phosphate, arsenate, or vanadate radical, and "Z" is a hydroxyl ion  $[(\text{OH})^{1-}]$  or a halogen ion. Halogens fall under group VII A of the periodic table of elements and include fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). The "q" notation denotes a variable quantity. Finally, vanadinite is a member of the pyromorphite group (4) as the third (3) of the following, closely related members:

pyromorphite	lead chlorophosphate	$\text{Pb}_5(\text{PO}_4)_3\text{Cl}$	(hexagonal)
mimetite	lead chloroarsenate	$\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$	(monoclinic)
vanadinite	lead chlorovanadate	$\text{Pb}_5(\text{VO}_4)_3\text{Cl}$	(hexagonal)

Chemically, these minerals vary only in their anionic radicals. The phosphate, arsenate, and vanadate radicals have the same electrical charge and similar ionic radii, enabling them to easily

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substitute for each other to form mutual, graded, solid-solution series. Because of the nearly identical ionic radii of the vanadate and phosphate radicals, vanadinite and pyromorphite are isomorphic, meaning that they have identical crystal structures despite their different chemistries. In these solid-solution series, species identity is determined by the radical that makes up the greatest molecular weight. Cationic substitution also takes place in vanadinite, with divalent calcium ions  $\text{Ca}^{2+}$  partially substituting for divalent lead ions  $\text{Pb}^{2+}$ . Vanadinite therefore rarely occurs pure because of the frequency of both cationic and anionic substitution.

As an idiochromatic (self-colored) mineral, vanadinite's color is caused by its essential elemental components and the nature of its crystal structure. Vanadinite's basic, ruby-red to orange-red colors are created by its vanadate radicals, which cause the lattice to absorb the lower end of the visible spectrum and reflect only light in the yellow-to-red wavelengths. Frequent cationic and anionic substitution, along with the presence of other impurities, alter the light-absorption properties of the lattice to impart colors that range from ruby-red to brown. Variations in the chemistry of the crystallizing solutions during crystal growth sometimes create multi-coloration, with reds, yellows, and browns appearing in the same crystal.

Of the 56 vanadium-containing minerals, only vanadinite and four others are common enough or form sufficiently large crystals to interest collectors. These include descloizite [basic lead zinc vanadate,  $\text{PbZnVO}_4(\text{OH})$ ], mottramite [basic lead copper vanadate,  $\text{PbCuVO}_4(\text{OH})$ ], patrónite [vanadium disulfide,  $\text{V}(\text{S}_2)_2$ ], and carnotite [hydrous potassium uranium vanadate,  $\text{K}_2(\text{UO}_2)_2(\text{VO}_4)_2 \cdot 3\text{H}_2\text{O}$ ].

### *COLLECTING LOCALITIES*

The finest vanadinite specimens come from Morocco, notably from the Mibladen district in Khénifra Province and the Four Man Mine at Taouz in El Rachidia Province, both in the Meknès-Tafilalet Region. Other African sources include the Kabwe (Broken Hill) Mine at Kabwe, Central Province, Zambia; and the Abenab Mine at Grootfontein, Grootfontein district, Otjozondjupa Region, Namibia.

Mexican specimens come from the type locality at Zimapán in Hidalgo; and Villa Ahumada in the Sierra Los Lamentos district and the San Carlos Mine at San Carlos near Manuel Benavides, both in Chihuahua. Australian specimens are collected at the Iron Monarch open pit in the Middleback Range on the Eyre Peninsula, South Australia. Other localities include the Presidente Mine at San Antonio, Copiapó Province, Antofagasta Region, Chile; the Río Agrio Mine at Neuquen, Picunches Department, Argentina; the Belton Grain vein at Wanlockhead in the Leadhills-Wanlockhead district, Dumfriesshire, Scotland; the Old Pots Gill and Brandy Gill mines at Caldbeck Fells in Cumbria, England; and the Alt-Stefanie Mine at Heiligengeist, Bleiberg district, Carinthia, Austria.

In the United States, vanadinite is collected in Arizona at the Pure Potential (formerly North Geronimo) Mine in the Silver district of the Trigo Mountains, La Paz County; the Apache Vanadium Mine in the Globe-Miami district in Gila County; the Old Yuma Mine at Jaynes, Amole district, Pima County; the J. C. Holmes Mine in Temporal Gulch near Patagonia in the

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Patagonia Mountains, Santa Cruz County; and the Mammoth-St. Anthony Mine at Tiger, Mammoth district, Pinal County. Other localities include the Carlin Gold Mine in the Lynn district and the Gold Quarry Mine in the Maggie Creek district, both in Eureka County, Nevada; the Groundhog Mine at Vanadium, Central district, Grant County, New Mexico; the Dukes, Lonestar, and Purple Sage mines in the Indio Mountains, Hudspeth County, Texas; the El Dorado Mine near Indio, Riverside County, California; and the Spokane Mine at Iron Mountain, Custer County, South Dakota.

### *JEWELRY & DECORATIVE USES*

Because of its softness (Mohs 2.8-3.0), vanadinite has only limited use as a gemstone and is usually fashioned into beads for wear in necklaces. Transparent vanadinite crystals in bright, orange-red hues are occasionally faceted into collector's gems to display their striking colors and the unusual brilliance that is due to their very high index of refraction (2.350-2.412). Vanadinite collector's gems are costly because their brittleness and softness make faceting and polishing difficult.

Because of the combination of bright colors, the rarity of good specimens, its unusual chemistry, and a number of interesting mineralogical associations, vanadinite is one of the most collectible of all minerals for both study and display purposes.

### *HISTORY & LORE*

Spanish naturalist and mineralogist Andrés Manuel del Río (1764-1849) recognized vanadinite as a new mineral species in 1801 after studying specimens collected at the silver-lead mines in Zimapán, Hidalgo, Mexico. At that time, vanadium had not yet been identified as an element. Aware that lead was the major elemental component of his specimens, del Río referred to the new mineral as "brown lead," but also believed that a previously undiscovered element was present. When chemists recognized vanadium as a new element in 1830 (see "A View of Vanadium"), their attention returned to "brown lead," which was formally named "vanadinite" in 1838. Vanadinite was the sole source of vanadium until metallurgists succeeded in extracting the metal from vanadiferous (vanadium-containing) magnetite [iron (ferrous-ferric) oxide,  $\text{Fe}^{2+}\text{Fe}_2^{3+}\text{O}_4$ ] iron ores in 1870. Researchers used X-ray diffraction methods to determine the basic atomic structure of vanadinite in 1926. The detailed crystal structure of vanadinite was not satisfactorily described until 1966.

According to modern metaphysical beliefs, vanadinite helps to bring emotional sensitivity to analytically minded people who tend to over-intellectualize their feelings. Vanadinite is also thought to enhance sensitivity in general, help clear confusion and feelings of purposelessness, and assist in grounding and centering. Vanadinite was featured on the 132-metical postage stamp of Mozambique in 2007.

### *TECHNOLOGICAL USES*

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Until 1870, vanadinite was the only known source of vanadium; it has also occasionally served as a minor ore of lead.

### *A VIEW OF VANADIUM*

Vanadium, pronounced vah-NAY-dee-um, is an element that is rarely seen in pure form. Elemental vanadium is a silver-white metal with excellent properties of ductility, hardness, structural strength, and corrosion resistance. The physical properties of vanadium are often compared with those of iron. Its atomic weight of 50.94 is similar to that of iron, but its density (specific gravity 5.96) is considerably less than iron (specific gravity 7.86). Vanadium's melting point of 3434° F. (1890° C) exceeds that of iron (2795° F., 1535° C.). Vanadium forms four oxidation states: +2, +3, +4, and most commonly +5. All are powerful chromophores or coloring agents. Compounds of vanadium in its +2 oxidation state are lilac in color, +3 are green, +4 are blue, and +5, the oxidation state of vanadium in the mineral vanadinite, are yellow to red. Ranking 19<sup>th</sup> among the elements in crustal abundance, vanadium is roughly as common as chromium and nickel. Vanadium occurs in about 56 minerals and is also frequently associated with iron minerals and ores. Because of its high level of chemical activity and especially its chemical affinity for oxygen, vanadium does not occur as a native metal.

The discovery of vanadium was surrounded by 30 years of scientific confusion. When Spanish mineralogist Andrés Manuel del Río proposed the recognition of “brown lead” as a new mineral species in 1801 (see “History & Lore”), he also suggested that the mineral contained a previously undiscovered metallic element that was chemically similar to chromium. Noting the colorful compounds he produced from this element, Del Río first named it “panchromium,” literally “all colors,” from the Greek *pan*, meaning “all” or “every,” and *chrōma*, meaning “color.” He later changed this name to “erythronium,” from the Greek *erythros*, or “reddish.” But from the beginning, many scientists confused del Río's predicted new element with chromium, an element that had been discovered only four years earlier. When French chemist Hippolyte Victor Collet-Desotils (vita uncertain) contested del Río's findings, claiming that “erythronium” was a form of chromium and that “brown lead” was actually crocoite [lead chromate,  $\text{PbCrO}_4$ ], del Río withdrew his claim of having discovered a new element.

Del Río's proposed new element was largely forgotten until 1830, when German chemist and mineralogist Friedrich Karl Wöhler (1800-1882) reexamined specimens of “brown lead.” Wöhler concluded that del Río had been correct in predicting the existence of a new metallic element. But sudden illness and subsequent death prevented Wöhler from publishing his findings and crediting himself and del Río with co-discovering a new element. In 1831, Swedish chemist Nils Gabriel Sefström (1787-1845), working independently of Wöhler, experimented with ores from Sweden's Taberg iron mine and produced the oxide of a new metallic element. From this oxide, Sefström then produced several other brightly colored red and yellow compounds. Although he failed to isolate the new metal, his calculations proved that it was the same element that del Río had found in “brown lead” decades earlier. Sefström named the new element “vanadium,” after Vanadīs, the Old Norse goddess of beauty, in allusion to its colorful

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compounds. The European scientific community rejected suggestions to name it “rionium,” in honor of del Río.

Scientists were unable to isolate vanadium for another 36 years. Finally in 1867, British chemist Sir Henry Enfield Roscoe (1835-1915) succeeded in chemically reducing vanadium chloride to produce elemental vanadium. Vanadium was then considered rare and obtainable only in small quantities from the uncommon mineral vanadinite or as a by-product of processing vanadiferous iron ores. The inability to obtain vanadium in quantity was not a concern at that time, because the metal was little more than a laboratory curiosity with no practical uses. But in the late 1890s, French metallurgists learned that adding 0.1 to 5.0 percent vanadium to steel refined the grain of the steel and enhanced its tensile strength, toughness, ductility, and corrosion resistance. It also combined with any carbon present to form vanadium carbides that hardened the steel. As European industrial demand for vanadium increased, the first primary vanadium mine opened in Peru in 1901, exploiting a deposit of patrónite [vanadium sulfide,  $V(S_2)_2$ ]. Several years later, carnotite [hydrous potassium uranium vanadate,  $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ ], originally an ore of uranium, became another source of vanadium.

While European steelmakers experimented with the new vanadium-steel alloys, their North American counterparts steadfastly clung to traditional carbon steels. American acceptance of vanadium steels came about largely through the initiative of automaker Henry Ford (1863-1947). In 1913, Ford sought out advanced steels to improve his wildly successful Model T. Examining a European racing car that had crashed at the new Indianapolis Motor Speedway, Ford found that the impact had demolished virtually every engine and power-train component. The notable exception was the undamaged crankshaft, which Ford learned consisted of a new, Swedish, vanadium-steel alloy. After testing these alloys, Ford specified them for critical parts in his Model T power trains. Vanadium-steel alloys went into millions of the legendary Model Ts, substantially improving their durability and service life, while demonstrating to American steelmakers and the world the great value of the new vanadium-steel alloys.

Vanadium is no longer obtained from primary vanadium ores, but as a by-product of processing the uranium ore carnotite [hydrous potassium uranium vanadate,  $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ ], and vanadiferous iron and titanium ores, slags, and petroleum residues. About 62,000 tonnes (metric tons) of contained vanadium are now recovered each year, mainly in China, South Africa, and Russia. One pound of vanadium, as contained in vanadium pentoxide ( $V_2O_5$ ), now sells for \$15 per pound. The United States is the largest consumer of vanadium, but imports 95 percent of its supply.

More than 85 percent of the global vanadium supply goes to alloys, especially vanadium-steels for pipelines, high-speed tool steels, and structural girders. Vanadium-chrome steels are used in automotive suspension springs, transmission gears, and high-stress engine components. Lightweight, heat-resistant, vanadium-aluminum-titanium alloys serve as components of high-performance jet and rocket engines. Vanadium pentoxide, the metal's most important compound, is a catalyst in the production of sulfuric acid and maleic anhydride, the latter the primary feedstock for the manufacture of polyester resins, fiberglass, and fiber optics. Vanadium pentoxide is also used in the massive “load-leveling” batteries that maximize the efficiency of commercial power grids, as well as in coin-sized, rechargeable, lithium batteries for clocks,



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computers, watches, and cameras. Demand for vanadium is rapidly growing, largely because of new uses in the batteries of hybrid and rechargeable electric vehicles.

### *ABOUT OUR SPECIMENS*

Our specimens were collected at a classic vanadinite locality—the Mibladen Mining District near Midelt, Khénifra Province, in the Meknès-Tifalalet Region of Morocco. The Kingdom of Morocco is located on Africa's northwest shoulder, directly south of the Strait of Gibraltar. The Atlantic Ocean is to Morocco's northwest, the Mediterranean Sea to the north, Tunisia to the northeast, Algeria to the east and south, and Western Sahara (territory claimed and administered by Morocco) to the southwest. Covering 172,413 square miles, Morocco is a bit larger than the state of California. The country is roughly bisected by the southwest-northeast-trending Atlas Mountains, which include the High (Haut, Grand) Atlas, Middle Atlas, and Anti Atlas sub-ranges. Population, industrial, and agriculture centers are concentrated north and west of the Atlas Mountains along the Mediterranean and Atlantic coasts. Midelt, population 45,000, is located in the northern foothills of the Middle Atlas Mountains about 100 miles southeast of the national capital of Rabat.

At an elevation of nearly 5,000 feet, Midelt is one of the highest of Morocco's large towns and the trading center of a large agricultural area. It was founded in the 1920s, when Morocco was a French colony, as a government administrative center. Midelt grew quickly with the development of lead-zinc mines at Mibladen, seven miles to the northeast. Mining spurred construction of a railroad between Midelt and the Mediterranean coast in 1934. Two years later, Midelt became the second Moroccan city, after Casablanca, to receive electrical power.

In the 1920s, French engineers had opened the Mibladen Mining District, which is part a large mineralized zone called the Upper Moulouya Lead District, and developed both open-pit and underground workings. By 1949, the Mibladen district had over 600 shafts, most of which only operated briefly and were no deeper than 40 feet. Only a few shafts were deeper than 200 feet. Over the decades the Mibladen district and adjacent mines produced more than 35,000 tons of lead and 15,000 tons of zinc. At their peak, the district's mines employed 350 workers. After France granted Morocco its independence in 1956, production mining slowed before eventually ending in the early 1970s.

Mineralization at Mibladen is traced back to the Atlas Mountains Orogeny, which occurred in two major uplifts. The first took place 300 million years ago when crustal stresses associated with the rifting of the Pangaeian supercontinent uplifted huge blocks of sandstone and limestone. Long after erosion had nearly leveled these mountains, the collision of the African and Eurasian plates some 80 million years ago generated a second uplift. As the crust fractured, magma forced its way upward to form igneous intrusions beneath overlying formations of rhyolite, limestone, and dolomite. Within these overlying formations, accompanying surges of mineral-rich, hydrothermal fluids emplaced thin veins of galena [lead sulfide, PbS] along with smaller amounts of zinc, copper, and silver minerals. After lengthy periods of erosion eventually exposed the uppermost parts of these deposits, groundwater and atmospheric oxygen oxidized the sulfides into arsenates, molybdates, vanadates, and sulfates. In the alteration process that

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created our vanadinite specimens, acidic groundwater dissolved small amounts of vanadium from the adjoining rhyolite and percolated downward to contact lead ions. This mineral-laden groundwater then filled voids and seams within the rhyolite where vanadinite crystallized out of solution to cover the cavity walls.

The colorful vanadinite crystals attracted immediate attention when the Mibladen mines were first developed. These specimens were then acquired mainly by mineralogists, geologists, engineers, and museum curators, as no broad-based collectors' market yet existed. During the 1960s, Mibladen specimens began attracting attention at the newly established, international gem-and-mineral shows. Ironically, just as Mibladen vanadinite gained popularity among collectors in the 1970s, production mining at Mibladen ended, cutting off the supply of specimens. But within a few years, an influx of "diggers" arrived and, with the approval of local authorities, reopened many old workings and sank shallow shafts in a search for valuable vanadinite specimens.

Because of the production of these freelance miners, the Mibladen district has earned recognition as a classic vanadinite locality and the source of the world's finest vanadinite specimens. Today, hundreds of private miners manually sink narrow, 10-foot-deep shafts, then dig branching systems of three-foot-high, horizontal tunnels. Most miners follow veins of barite [barium sulfate,  $\text{BaSO}_4$ ] in the hope that they will open into vugs filled with vanadinite crystals. The work is dangerous, and the conditions difficult: the average January low temperature is 32° F. (0° C.), while the average July high temperature is 93° F. (34° C.). Because vanadinite-filled vugs are few and far between, most miners earn only a subsistence living at best. But a single "good" vug can yield vanadinite specimens worth several thousand dollars—an entire year's salary for the average Moroccan worker. The largest find, made in 2000, yielded hundreds of superb crystals and crystal plates that rekindled worldwide collector interest in vanadinite. Smaller, but still impressive, recoveries were also made again 2007 and 2009. Several mineral dealers maintain offices in Midelt and purchase specimens directly from the miners, then move them along to international specimen markets. The ready availability of vanadinite specimens in Midelt is an attraction that has helped to boost tourism.

The Mibladen district mines also yield a number of other specimens. Cerrusite [lead carbonate,  $\text{PbCO}_3$ ] is common in the oxidized zones throughout the district, sometimes forming sharp, lustrous, translucent, white crystals as long as three or four inches. The most common gangue mineral at Mibladen is barite, which occurs in a wide variety of colors as tabular crystals up to one inch in size. Plates of white barite blades in association with orange-red vanadinite crystals make up Mibladen's most striking composite specimens. Wulfenite [lead molybdate,  $\text{PbMoO}_4$ ] is also collected, usually as yellow to deep-yellow bipyramidal crystals approaching one inch in size, as is anglesite [lead sulfate,  $\text{PbSO}_4$ ], which occurs as microcrystalline crusts on barite or rhyolite.

As you examine your vanadinite specimen note first the matrix of fine-grained rhyolite, which is a high-silica, volcanic rock. The black discoloration and staining on the surface of the rhyolite is a mixture of manganese-oxide and iron-oxide minerals. The portion of the rhyolite that is covered with vanadinite crystals was originally a vug wall and part of a fissure-seam system. The color of the translucent-to-near-transparent vanadinite crystals is a rich orange-red, the

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classic and most desirable color for vanadinite specimens. Using an intense backlight, study the crystals closely to see their near-transparency and frequent color-zoning. Notice, too, that the crystal development is exceptional, with sharp edges and smooth, vitreous faces. The hexagonal cross section of each vanadinite crystal is readily apparent; many of these hexagonal cross sections are geometrically perfect, while others show only slight modification. The vanadinite crystals rest atop the secondary, manganese-oxide and iron-oxide coatings and thus represent the final stage of mineral deposition. In testimony to the skill and patience of the Moroccan miners who collected these specimens, the vanadinite crystals are completely intact. Your vanadinite specimen is a souvenir of a classic African collecting locality, an almost-perfect mineralogical environment for crystal development, and a former colonial-era mining district that is now a world-class source of mineral specimens.

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Co.; *2008 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 Cornelius Klein, Twenty-first Edition, John Wiley & Sons; "Arsenate, Phosphates, and Vanadates," J. Anthony, R. Bideaux, K. Bladh, and M. Nichols, *Handbook of Mineralogy*, Mineral Data Publishing, 2000; "Vanadinite, Carnotite . . . Vanadium," Steve Voynick, *Rock & Gem*, June 2002; "The Frugal Collector: Arsenates and Vanadates," Bob Jones, *Rock & Gem*, April 2006; "The Structure of Vanadinite," J. Trotter and W. Barnes, *The Canadian Mineralogist*, June 1958; "Vanadium," Désirée E. Polyak, *2011 Minerals Yearbook*, United States Geological Survey; "Morocco Mineralogy," Anne Voileau, *The Mineralogical Record*, September-October 1976; "Sainte-aux-Marie Mines Show," William F. Larson, *The Mineralogical Record*, November-December 2001; "Munich Show," William F. Larson, *The Mineralogical Record*, May-June 2002.

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