# *February 2005 Mineral of the Month: Molybdenite*

Although it feels greasy like graphite and is as heavy as lead, this month's featured mineral is unique in many ways. It's the primary ore of the rare element molybdenum, melts at some 2,000˚ F. higher than most steels and 1,000˚ F. higher than most rocks and is crucial for hardening steel, although it itself does not make it harder. You'll be amazed by the properties of this singular mineral!

*PHYSICAL PROPERTIES*

Chemistry: $MoS_2$ Molybdenum Sulfide (Molybdenum Disulfide)
Class: Sulfides Group: Molybdenite
Crystal System: Hexagonal
Crystal Habits: Tabular as thin, platy, hexagonal crystals terminated by pinacoidal faces, also as tapering, six-sided pyramids foliated in flat, platy forms; crystals are fairly common but usually distorted and misshapen because of their thin, foliated nature and tendency to bend easily; also occurs as scales and foliated masses, and occasionally in fine, granular masses with uniformly indistinguishable crystals.
Color: Bluish lead-gray
Luster: Metallic
Transparency: Opaque
Streak: Grayish-black; greenish-gray on unglazed, white porcelain
Cleavage: Perfect in one direction
Fracture: Sectile; thin flakes are flexible and have a greasy feel. Scraping with a knife blade produces curved shavings.
Hardness: 1.0-1.5
Specific Gravity: 4.6-5.1
Luminescence: None
Distinctive Features and Tests: Perfect cleavage and flexible laminae. May be confused with graphite (C) which has a similar greasy feel, but is blacker and much lighter in weight.
Dana Classification Number: 2.12.10.1

*NAME*

The name "molybdenite" (pronounced mo-LIBB-den-ite) derives from the element molybdenum (pronounced mo-LIBB-den-um), which in turn stems from the Greek *molybdos*, meaning "lead," and *molybdaena*, the Greek word for molybdenite which, because of its similar color, was erroneously thought to be a form of lead. Other names for molybdenite are "molybdenglans," "eutomglanz," "rhenian molybdenite" (a rhenium-rich variety), and "femolite" (an iron-rich variety). In the vernacular of the American mining and metallurgical industries, both molybdenite and molybdenum are commonly referred to as "moly" (rhymes with "holly").

*COMPOSITION*

We're very pleased and excited to close our ninth year with our first mineral containing the element molybdenum, our second featured mineral from Australia (after crocoite from the island of Tasmania back in October 1996), and our third sulfide mineral containing one of the rarer elements, after cinnabar [HgS] in February 2004, and carrollite [$CuCo_2S_4$], which we hope to feature later this year. We never thought we'd be able to find molybdenite crystals in sufficient quantity or quality, until we met a couple of collectors who had spent time in the Australian Outback!


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Molybdenite's chemical formula, $MoS_2$, indicates that it contains the elements molybdenum (Mo) and sulfur (S). The atomic weight of each molybdenite molecule is comprised of 59.94 percent molybdenum and 40.06 percent sulfur. Within the molybdenite molecule, the +4 charge of the molybdenum cation ($Mo^{4+}$) balances the collective -4 charge of the double sulfur anion ($S^{2-}$).

Molybdenite is a member of the large sulfide class of minerals that includes the many metal-sulfide ores together with the rarer selenides, tellurides, arsenides, and antimonides, all of which share similar physical properties. Molybdenite's Dana classification number, 2.12.10.1, first identifies molybdenite as a sulfide (2). The subclassification (12) next defines it as a mineral with the general formula $A_mB_nX_p$, in which the ratio of m + n:p is 1:2. This 1:2 cation-anion relationship is reflected in the single molybdenum cation and double sulfur anion in the molybdenite molecule. In more detailed classification, molybdenite falls into its own group (10), in which it is the first (1) of three other minerals. The other molybdenite-group minerals include drysdallite, or molybdenum diselenide ($MoSe_2$), and tungstenite, or tungsten disulfide ($WS_2$).

Molybdenite's perfect, one-directional cleavage, softness, and greasy feel are explained by the complex bonding within its crystal lattice. The molybdenite molecule consists of a molybdenum atom bound to two sulfur atoms by strong covalent bonds. But the molecules within the crystal lattice are joined by two different types of bonds. The first of these is a weak, metallic-type bond between molybdenum atoms which consists of pooled electrons and accounts for molybdenite's metallic luster and weak electrical conductivity.

The second type of bond within the molybdenite lattice is a form of electrostatic attraction known as "van der Waals forces." Named for the Dutch physicist Johannes van der Waals (1837-1923), these are weak attractive forces between neutral atoms and molecules. Originating from very small residual charges on the surfaces of neutral atoms or molecules, van der Waals forces are similar to static-electrical charges. Van der Waals forces are generated by the electric polarization induced in each particle by the proximity of adjacent particles. To understand the effect of van der Waals forces in molybdenite, consider first that the molybdenite crystal structure consists of repetitive layers. Within these layers, each molybdenum atom is surrounded by six sulfur atoms. These sulfur atoms form the corners of right trigonal prisms, thus leaving each sulfur atom surrounded by three molybdenum atoms. Although the combined covalent and metallic bonding within the layers is strong, the bonding *between* the layers is very weak. Because each layer is electrically neutral, the adjacent sheets are joined not by any strong, shared-electron bonds, but only by van der Waals forces.

Within the molybdenite lattice, van der Waals forces act on the sulfur atoms on the outside of each molecular layer. These very weak electrostatic forces give molybdenite perfect, one-directional cleavage along the planes between the layers. This ability to separate easily along these planes imparts a characteristic slippery or greasy feel. Even the slightest physical force from abrading, indenting, or scratching will overpower the van der Waals forces, causing the sheets to displace, or "slip." This accounts for molybdenite's softness and its effectiveness as a lubricant. Van der Waals forces weakly bind similar sheet-type structures to account for the great softness and greasy feel of two other familiar minerals—the sheet-silicate talc, a hydrous magnesium silicate with the chemical formula $Mg_3Si_4O_{10}(OH)_2$, and graphite, a form of elemental carbon (C) which, like molybdenite, crystallizes in the hexagonal system.

Molybdenite is the most abundant molybdenum-bearing mineral. It occurs with quartz (silicon dioxide, $SiO_2$), cassiterite (tin dioxide, $SnO_2$), and chalcopyrite (copper iron sulfide, $CuFeS_2$) in high-temperature, hydrothermal veins. Hydrothermal emplacement sometimes forms massive, disseminated deposits of great commercial importance. Molybdenite also occurs with pyrite (iron disulfide, $FeS_2$), scheelite (calcium tungstate-molybdate, [$Ca(WO_4,MoO_4)$]), and garnet (a group of complex metal silicates) in skarn (contact

zones between igneous intrusions and limestone) of hydrothermal metamorphic rocks; with pyrite and barite (barium sulfate, $BaSO_4$) in carbonitites (carbonate-rich igneous rocks); and in granite pegmatites. Molybdenite outcrops tend to oxidize slowly to molybdite, or molybdenum trioxide ($MoO_3$), forming a dust-like, bright yellow powder. Yellowish outcrops of molybdite are often a clue to the existence of lower deposits of molybdenite.

Molybdenum, the metallic element in molybdenite, is a silvery-white metal that never occurs as a native metal. With an atomic number of 42 and an atomic weight of 95.94, molybdenum is roughly as heavy as lead, but much harder and less common. Ranking 56$^{th}$ in crustal abundance, molybdenum is about as common as tungsten. Molybdenum has a very high melting point of 4,730˚ F., the fifth highest melting temperature among all elements. Molybdenum melts at some 2,000˚ F. higher than most steels and 1,000˚ F. higher than most rocks. Molybdenum has a chemical affinity for many metals, notably iron, and small amounts have a remarkable ability to toughen steel alloys. In nature, molybdenum associates readily with copper and rhenium. Copper-sulfide ores always contain some molybdenum, and molybdenite almost always contains some copper. Some molybdenite ores are processed to recover small, by-product quantities of rhenium.

*COLLECTING LOCALITIES*

**Figure 1** Wolfram Camp Portal.

Many localities have provided molybdenite specimens. Specimens are still collected at molybdenite's type locality at Bispberg Klack, Säter, Dalarna, Sweden, and at the mineral's first commercial source, the Kven Mine at Knaben in southern Norway. Mines at Tilama, Coquimbo, Chile, have yielded molybdenite inclusions in quartz. Nice molybdenite specimens have recently been collected at the Tae Hwa Mine in Angsang-gu, Chung-ju, Korea. The Shap district in Cumbria, England, has yielded molybdenite in association with pyrite and quartz. Perhaps the finest molybdenite specimens, usually associated with white quartz, have come from Australia, notably from the Queensland localities of Walsh River and Wolfram Camp in the Bamford mining center, and from the Kingsgate mines at Glenn Innes in the Deepwater mining center of New South Wales.

Fine molybdenite specimens have come from many North American localities. Among them are the major molybdenite deposits at the Climax Mine near Leadville, Colorado; the Henderson Mine near Empire, Colorado; the Questa Mine near Questa, New Mexico; and the Thompson Creek Mine near Challis, Idaho. Another interesting molybdenite locality is the Pine Creek Mine near Bishop in Inyo County, California. In Arizona, nice specimens have come from the Helvetia district in Pima County and from the Morenci Mine near Morenci in Greenlee County. In Washington, molybdenite has been found in the Washington Pass area of Okanogan County and at the Crown Point Mine near Holden in Chelan County. In Mexico, the Naica Mine at Saucillo, Chihuahua, has yielded excellent molybdenite specimens, as has La Trinidad, Sahuaripa district, Sonora, where it is found in groups on galena and sphalerite. Canada is also a prolific source of molybdenite specimens. In Quebec, specimens have been collected at Aldfield in Pontiac County, the Moly Hill Mine near Preissac in Abitibi County, and the Mont Saint-Hilaire district in Rouville County. Nice specimens have also come from the Desmont Mine at Faraday Hill at Bancroft, Ontario; the Bay d'Espair area of southern Newfoundland; and the Endako Mine, Canada's largest molybdenite producer, near Prince George, British Columbia.

# *February 2005 Mineral of the Month: Molybdenite*

*JEWELRY & DECORATIVE USES*

Molybdenite's great softness and tendency to leave greasy streaks on fingers and clothing precludes its use in jewelry. However, collectors value fine molybdenite specimens for mineralogical and display purposes.

*HISTORY & LORE*

Known since antiquity, molybdenite has long been confused with lead. After studying a 14th-century A.D. Japanese sword that contained molybdenum, anthropologists believe that Japanese metalworkers may have been first to alloy the metal with iron. Confusion about lead, graphite, and molybdenite persisted until the late 1700s. In 1778, the Swedish chemist Carl Wilhelm Scheele (1742-1786), working with molybdenite specimens from the type locality at Bispberg Klack, Säter, Dalarna, Sweden, showed how nitric acid ($HNO_3$) could convert molybdenite—but not graphite—to an acidic, white powder he named molybdic acid. Scheele then produced the same compound by roasting molybdenite in oxygen to drive off a gas he recognized as sulfur dioxide. From his observations, Scheele correctly concluded that molybdenite was the sulfide form of a previously unknown element that he named "molybdenum."

Four years later, Scheele's colleague, Swedish mineralogist Peter Jacob Hjelm (1746-1813), isolated the metal by heating a mixture of molybdic acid and carbon in an oxygen-free environment to produce carbon dioxide and a heavy, dark powder of nearly pure molybdenum. But the metal's very high melting point made it impossible to fuse the powder into a metallic mass suitable for metallurgical study. Because it was assumed to be rare in nature and was so difficult to work with, molybdenum would remain an obscure laboratory curiosity without value or use for the next century.

Confusion about the true natures of molybdenite and molybdenum lingered until the late 1800s. After an American prospector, Charles J. Senter (1846-1926), discovered a huge, low-grade molybdenite deposit at Climax, Colorado, assayers and chemists took 15 years to positively identify the samples as molybdenite. By then, French chemist Henri Moisson (1852-1907) had used an electric furnace to prepare the purest molybdenum yet isolated, which greatly aided other researchers in determining the metal's true chemical and physical properties. Also during the 1890s, European metallurgists, working with molybdenite obtained from the only known commercial source, a small, high-grade, vein-type deposit at Knaben in southern Norway, discovered molybdenum's ability to toughen steel. Finally, molybdenum attracted international attention when World War I erupted in 1914 and Germany unveiled an arsenal of unexpectedly superior weaponry and armor. When British analysis of captured weaponry revealed that the German steels were molybdenum alloys, soaring molybdenum prices triggered a rush to Climax, Colorado, and the start of one of America's great mining adventures.

The Climax Molybdenum Company began mining and milling molybdenite ore at Climax in February 1918. Molybdenum quickly proved its value in American armor, weapons-grade steels, and the famous NC-4 "Liberty" aircraft engine. But the molybdenum market quickly collapsed with the Armistice of November 1918. Owning a mountain filled with millions of tons of again-worthless molybdenite ore, the Climax Molybdenum Company set out to develop a market by promoting the peacetime uses of tough, molybdenum-steel alloys. The company even advertised "Mo-*lyb*-den-um" alloys in such mainstream publications as *The Saturday Evening Post*, always hyphenating the word to assist in the pronunciation of the name of the unfamiliar metal. The company attracted the interest of Childe Harold Wills, a renegade engineer who had left the Ford Motor Company to build his own automobile, the Wills Sainte Claire. Built largely of heavily publicized "Mo-*lyb*-den-um Steel," the extraordinarily durable Wills Sainte Claire

dominated the competition in the grueling, early cross-country auto races. Production of the pricey car soon halted, but not before molybdenum-steel alloys caught the attention of American industry.

Realizing that only mass mining could make their low-grade molybdenite ore profitable, the Climax Molybdenum Company gambled everything on the development of a massive, block-cave mining system. Engineers designed a sprawling, 30-mile-long maze of underground, rail-haulage tunnels beneath the huge ore body. Workings were then driven upward at an angle of 45 degrees, causing the ore body—which comprised most the mountain—to collapse and crush itself under its own great weight. The crushed ore was then removed by gravity and pneumatic scrapers and loaded onto long lines of electric-powered ore trains.

By 1934, block-cave mining enabled Climax to begin mining 6,000 tons of molybdenite ore daily. With mining costs plummeting and production soaring, Climax controlled 90 percent of the now-booming world molybdenum market. Its shares, which traded for pennies in 1928, split three times and rocketed to $42 per share. That stock appreciation, together with a huge net profit, marked the best financial performance of any American company in the Depression era. During World War II, the Climax Mine, classified as the top-priority mine in the United States, worked at an emergency production rate of 24,000 tons per day to supply virtually all the molybdenum needed for the combined Allied war effort. After the war, Climax researchers found many new applications for molybdenum and its compounds. By 1957, with more than 100 miles of underground workings and a daily production of 36,000 tons of molybdenite ore, Climax ranked as the world's largest underground mine. But a dramatic restructuring of the molybdenum market in the early 1980s then shifted the emphasis of molybdenum production from primary molybdenum mines like Climax to by-product recovery circuits at copper mines.

Despite its great industrial importance, molybdenite has appeared on only one postage stamp--the 250-dram stamp of Armenia in 2000. Interestingly, perhaps because of its greasy feel and tendency to "streak" fingers and clothing, molybdenite is one of the few important minerals that has not been assigned metaphysical significance.

*TECHNOLOGICAL USES*

Molybdenite is the primary ore of molybdenum. As an alloying agent, molybdenum enhances the toughness and durability of steel and improves its strength at high temperatures. While molybdenum does not harden steel per se, it does increase its *hardenability*, that is, its ability to become hardened by other alloying agents such as manganese and tungsten. Sixty percent of world molybdenum output is alloyed to make stainless steels, molybdenum steels, and specialty and "super" alloys. These alloys are used in the manufacture of heat-resistant components in jet engines and rocket motors, high-temperature tool steels, oil-well drilling steels and casings, military armor and weaponry, corrosion-resistant structural steels, and high-stress automotive parts.

Metallic molybdenum is also an effective catalyst in removing sulfur during the "cracking" of crude oil and in manufacturing the propylene and acrylic compounds needed for the production of plastics and synthetic fibers. Because of its very high melting point, metallic molybdenum and high-molybdenum alloys are ideal materials for high-temperature electric-furnace parts, metalworking dies, and filament supports in electric lightbulbs. Various molybdate [$(MoO_4)^{2-}$] compounds are valuable as red-orange pigments for plastics, ceramics, and corrosion-resistant metal paints. Molybdenum disulfide (highly refined molybdenite) makes an excellent high-pressure, high-temperature metal lubricant that is stable and effective at temperature levels that would decompose regular hydrocarbon-based lubricating oils.

# *February 2005 Mineral of the Month: Molybdenite*

Annual world mine production of molybdenum stands at 125,000 metric tons, half of which is recovered from molybdenite ore and half as a by-product of copper mining. The United States, with three primary molybdenite mines and copper mines that produce by-product molybdenum, is the leading source and accounts for one-quarter of world production. China and Chile rank second and third in molybdenum production. The current price of refined molybdenum is about $7 per pound.

*ABOUT OUR SPECIMENS*

As mentioned, our specimens come from the Australian Outback, namely the Bamford mining center near the little village of Dimbulah in northeastern Queensland, inland from Cairns. Dimbulah is a first-day whistlestop of the great overnight Queensland rail journeys aboard the *Savannahlander*. Coffee growing is the major industry in the area, while mining for tungsten and molybdenite ores has been done on an irregular basis over the years. Gold was discovered nearby in the Tyreconnell area in the 1880's and lead to a mining boom, with copper and silver also being produced in quantity.

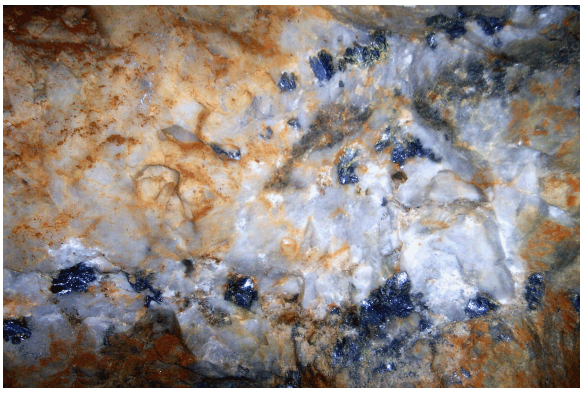

**Figure 2** Moly crystals on quartz– do you see your piece?

At Wolfram Camp, a molybdenum-bearing ore vein many kilometers long has been worked from various points under different mine names. The portal seen in Figure 1 enters what was known in the 1980's as the Mount Arthur Mine, but has had other names over the years. The tungsten/molybdenum minerals formed in an alteration zone on the edge of a porphyry system rich in volatile elements like fluorine, bismuth, tungsten, and molybdenum, and as we might expect, tungsten-containing minerals such as scheelite [$CaWO_4$] and members of the wolframite group are occasionally found here. (Wolfram is the German word for tungsten, and according to 16$^{th}$ century mineralogist Agricola, comes from *volf*, "wolf," and *rahm*, "cream," in allusion to a disgusting scum that formed during the smelting of ores containing tungsten. "W" is the elemental symbol for tungsten.)

Some of our specimens were still attached to the milky quartz matrix they originally formed on, a real treat. No doubt you noticed the greasy feel of your specimen, and noticed how it lingered on your fingers, helping you appreciate why moly is such an effective lubricant. Handle your specimen carefully, as it can be scratched by fingernails and comes apart easily, as explained earlier. (As we've mentioned before, hand-washing after handling your specimens is always a good idea.) Truly this month's mineral "Moly" is a delight to examine and its unique properties are a pleasure to consider!

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