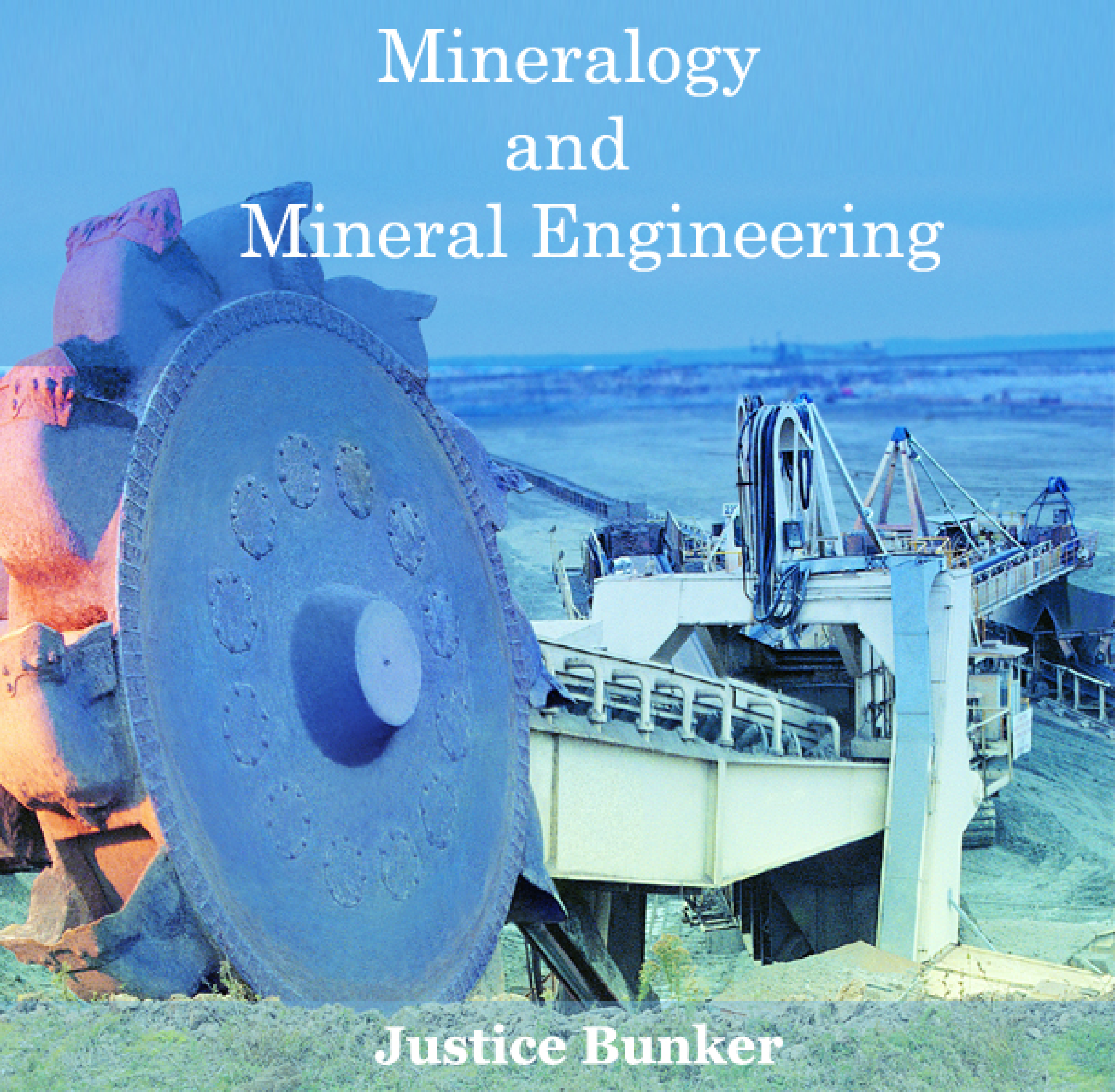
Mineralogy and Mineral Engineering



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First Edition, 2012

ISBN 978-81-323-3495-8

Published by:
Research World
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter-1

Mineralogy

Mineralogy is the study of chemistry, crystal structure, and physical (including optical) properties of minerals. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

History

Early writing on mineralogy, especially on gemstones, comes from ancient Babylonia, the ancient Greco-Roman world, ancient and medieval China, and Sanskrit texts from ancient India and the ancient Islamic World. Books on the subject included the Naturalis Historia of Pliny the Elder, which not only described many different minerals but also explained many of their properties, and Kitab al Jawahir (Book of Precious Stones) by Muslim scientist Al Biruni. The German Renaissance specialist Georgius Agricola wrote works such as *De re metallica* (*On Metals*, 1556) and *De Natura Fossilium* (*On the Nature of Rocks*, 1546) which begin the scientific approach to the subject. Systematic scientific studies of minerals and rocks developed in post-Renaissance Europe. The modern study of mineralogy was founded on the principles of crystallography (the origins of geometric crystallography, itself, can be traced back to the mineralogy practiced in the eighteenth and nineteenth centuries) and to the microscopic study of rock sections with the invention of the microscope in the 17th century.

Modern mineralogy

Chalcocite, a copper ore mineral.

Historically, mineralogy was heavily concerned with taxonomy of the rock-forming minerals; to this end, the International Mineralogical Association is an organization whose members represent mineralogists in individual countries. Its activities include managing the naming of minerals (via the Commission of New Minerals and Mineral Names), location of known minerals, etc. As of 2004 there are over 4,000 species of mineral recognized by the IMA. Of these, perhaps 150 can be called "common," another 50 are "occasional," and the rest are "rare" to "extremely rare."

More recently, driven by advances in experimental technique (such as neutron diffraction) and available computational power, the latter of which has enabled extremely accurate atomic-scale simulations of the behaviour of crystals, the science has branched out to consider more general problems in the fields of inorganic chemistry and solid-state physics. It, however, retains a focus on the crystal structures commonly encountered in rock-forming minerals (such as the perovskites, clay minerals and framework silicates). In particular, the field has made great advances in the understanding of the relationship between the atomic-scale structure of minerals and their function; in nature, prominent examples would be accurate measurement and prediction of the elastic properties of minerals, which has led to new insight into seismological behaviour of rocks and depth-related discontinuities in seismograms of the Earth's mantle. To this end, in their focus on the connection between atomic-scale phenomena and macroscopic properties, the **mineral sciences** (as they are now commonly known) display perhaps more of an overlap with materials science than any other discipline.

Physical mineralogy

Physical mineralogy is the specific focus on physical attributes of minerals. Description of physical attributes is the simplest way to identify, classify, and categorize minerals, and they include:

- crystal structure
- crystal habit
- twinning
- cleavage
- luster
- color
- streak
- hardness
- specific gravity

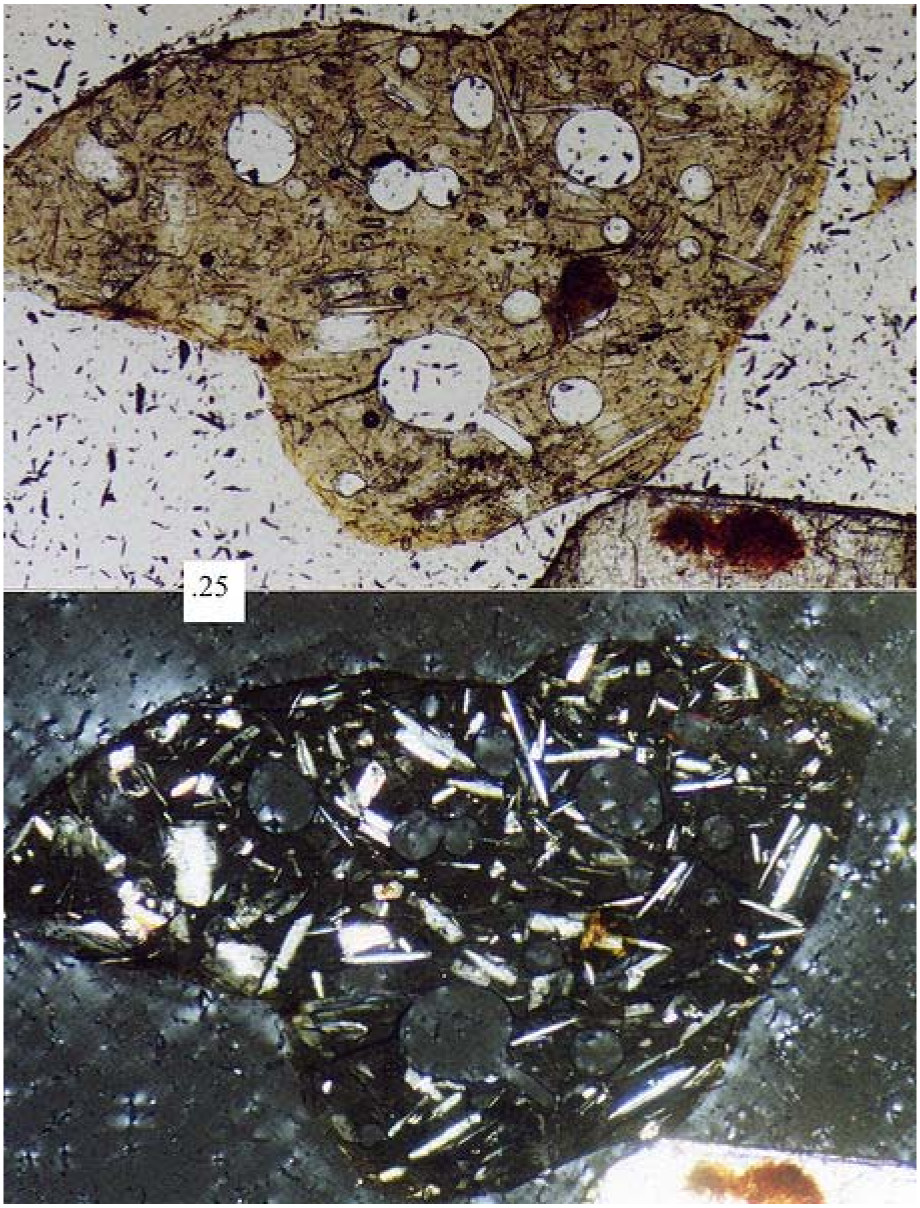
Chemical mineralogy

Chemical mineralogy focuses on the chemical composition of minerals in order to identify, classify, and categorize them, as well as a means to find beneficial uses from them. There are a few minerals which are classified as whole elements, including sulfur, copper, silver, and gold, yet the vast majority of minerals are chemical compounds, some more complex than others. In terms of major chemical divisions of minerals, most are placed within the isomorphous groups, which are based on analogous chemical composition and similar crystal forms. A good example of isomorphism classification would be the calcite group, containing the minerals calcite, magnesite, siderite, rhodochrosite, and smithsonite.

Biomineralogy

Biomineralogy is a cross-over field between mineralogy, paleontology and biology. It is the study of how plants and animals stabilize minerals under biological control, and the sequencing of mineral replacement of those minerals after deposition. It uses techniques from chemical mineralogy, especially isotopic studies, to determine such things as growth forms in living plants and animals as well as things like the original mineral content of fossils.

Optical mineralogy



Photomicrograph of a volcanic lithic fragment (sand grain); upper picture is plane-polarized light, bottom picture is cross-polarized light, scale box at left-center is 0.25 millimeter.

Optical mineralogy is a specific focus of mineralogy that applies sources of light as a means to identify and classify minerals. All minerals which are not part of the cubic system are double refracting, where ordinary light passing through them is broken up into two plane polarized rays that travel at different velocities and refracted at different angles. Mineral substances belonging to the cubic system pertain only one index of refraction. Hexagonal and tetragonal mineral substances have two indices, while orthorhombic, monoclinic, and triclinic substances have three indices of refraction. With opaque ore minerals, reflected light from a microscope is needed for identification.

Crystal structure

X-rays are used to determine the atomic arrangements of minerals and so to identify and classify them. The arrangements of atoms define the crystal structures of the minerals. Some very fine-grained minerals, such as clays, commonly can be identified most readily by their crystal structures. The structure of a mineral also offers a precise way of establishing isomorphism. With knowledge of atomic arrangements and compositions, one may deduce why minerals have specific physical properties , and one may calculate how those properties change with pressure and temperature.

Formation environments

The environments of mineral formation and growth are highly varied, ranging from slow crystallization at the high temperature and pressures of igneous melts deep within the Earth's crust to the low temperature precipitation from a saline brine at the Earth's surface.

Various possible methods of formation include:

- sublimation from volcanic gases
- deposition from aqueous solutions and hydrothermal brines
- crystallization from an igneous magma or lava
- recrystallization due to metamorphic processes and metasomatism
- crystallization during diagenesis of sediments
- formation by oxidation and weathering of rocks exposed to the atmosphere or within the soil environment.

Descriptive mineralogy

Descriptive mineralogy summarizes results of studies performed on mineral substances. It is the scholarly and scientific method of recording the identification, classification, and categorization of minerals, their properties, and their uses. Classifications for descriptive mineralogy includes:

- native elements
- sulfides
- oxides and hydroxides
- halides
- carbonates, nitrates and borates
- sulfates, chromates, molybdates and tungstates
- phosphates, arsenates and vanadates
- silicates
- organic minerals

Determinative mineralogy

Determinative mineralogy is the actual scientific process of identifying minerals, through data gathering and conclusion. When new minerals are discovered, a standard procedure of scientific analysis is followed, including measures to identify a mineral's formula, its crystallographic data, its optical data, as well as the general physical attributes determined and listed.

Uses

Minerals are essential to various needs within human society, such as minerals used as ores for essential components of metal products used in various commodities and machinery, essential components to building materials such as limestone, marble, granite, gravel, glass, plaster, cement, etc. Minerals are also used in fertilizers to enrich the growth of agricultural crops.

Collecting

Mineral collecting is also a recreational study and collection hobby, with clubs and societies representing the field. Museums, such as the Smithsonian National Museum of Natural History Hall of Geology, Gems, and Minerals and the Natural History Museum of Los Angeles County, have popular collections of mineral specimens on permanent display.

Chapter-2

Antimony Minerals

Berthierite

Berthierite	
 Berthierite	
General	
Category	Mineral
Chemical formula	$FeSb_2S_4$
Strunz classification	02.HA.20
Identification	
Color	steel grey
Crystal system	Orthorhombic
Cleavage	poor/indistinct
Mohs scale hardness	2-3
Luster	metallic

Diaphaneity	opaque
Specific gravity	4.64

Berthierite is a mineral, a sulfide of iron and antimony with formula $FeSb_2S_4$. It is steel grey in colour with a metallic lustre which can be covered by an iridescent tarnish. Because of its appearance it is often mistaken for stibnite.

It was discovered in France in 1827 and named for the French chemist, Pierre Berthier.

Boulangerite

Boulangerite	
	
Boulangerite, found in Romania	
General	
Category	Sulfosalt minerals
Chemical formula	$Pb_5Sb_4S_{11}$
Strunz classification	02.HC.15

Boulangerite is a sulfosalt mineral, lead antimony sulfide, formula $Pb_5Sb_4S_{11}$. It was named in 1837 in honor of French mining engineer Charles Boulanger. It forms metallic grey monoclinic crystals. Sometimes the crystals form a fine feathery mass which has been called plumosite.

Bournonite

Bournonite	

Bournonite and baryte

General	
Category	Sulfosalt mineral
Chemical formula	$PbCuSbS_3$
Strunz classification	02.GA.50
Dana classification	3.4.3.2

Identification	
Color	Steel-gray to iron-black
Crystal habit	Crystals short prismatic to tabular, typically striated; commonly as subparallel aggregates. Also massive, granular to compact
Crystal system	Orthorhombic
Twinning	On {110}, commonly forming cross or cogwheel aggregates
Cleavage	[010] Imperfect

Fracture	Subconchoidal to uneven
Mohs scale hardness	2.5 - 3.0
Luster	Brilliant to dull
Streak	Steel-gray to iron-black
Diaphaneity	Opaque
Specific gravity	5.7 - 5.9
Pleochroism	Very weak

Bournonite is a sulfosalt mineral species, a sulfantimonite of lead and copper with the formula $PbCuSbS_3$.

It was first mentioned by Philip Rashleigh in 1797 as an ore of antimony and was more completely described in 1804 by French crystallographer and mineralogist Jacques Louis de Bournon (1751–1825), after whom it was named. The name given by Bournon himself (in 1813) was **endellione**, since used in the form **endellionite**, after the locality in Cornwall where the mineral was first found.

The crystals are orthorhombic, and are generally tabular in habit owing to the predominance of the basal pinacoid; numerous smooth bright faces are often developed on the edges and corners of the crystals. Usually, however, the crystals are twinned, the twin-plane being a face of the prism (m); the angle between the faces of this prism being nearly a right angIe (86 20), the twinning gives rise to cruciform groups and when it is often repeated the group has the appearance of a cog-wheel, hence the name *Rdelerz* (wheel-ore) of the Kapnik miners. The repeated twinning gives rise to twin-lamellae, which may be detected on the fractured surfaces, even of the massive material.

It is a mineral in medium temperature hydrothermal vein deposits. It commonly occurs with galena, tetrahedrite, sphalerite, chalcopyrite, pyrite, stibnite, zinkenite, siderite, quartz, rhodochrosite, dolomite and barite.

It was first described for an occurrence in Wheal Boys in the parish of St Endellion in Cornwall, it was found associated with jamesonite, sphalerite and siderite. Later, still better crystals were found in another Cornish mine, namely, Herodsfoot mine near Liskeard, which was worked for argentiferous galena. Fine crystals of large size have been found with quartz and siderite in the mines at Neudorf in the Harz, and with sphalerite and tetrahedrite at Cavnic near Baia Mare in Romania. It has been reported from a large number of other localities.

Cylindrite

Cylindrite	
	
Trinacria Mine, Callipampa, Poopó Province, Oruro Department, Bolivia	
General	
Category	Sulfosalt minerals
Chemical formula	$Pb_3Sn_4FeSb_2S_{14}$
Strunz classification	02.HF.25a

Cylindrite is a sulfosalt mineral containing tin, lead, antimony and iron with formula: $Pb_3Sn_4FeSb_2S_{14}$. It forms triclinic pinacoidal crystals which often occur as tubes or cylinders which are in fact rolled sheets. It has a black to lead grey metallic colour with a Mohs hardness of 2 to 3 and a specific gravity of 5.4.

It was first discovered in the Santa Cruz mine, Oruro Department, Bolivia in 1893. The name arises from its curious cylindrical crystal form it almost unique among mineral kingdom.

Franckeite

Franckeite	
	
Franckeite var. Potosíite, San José Mine, Cercado Province Bolivia. Field of view about 10mm.	
General	
Category	Sulfosalt mineral
Chemical formula	$(Pb,Sn^{2+})_6Fe^{2+}Sn_2Sb_2S_{14}$
Strunz classification	02.HF.25b
Dana classification	03.01.04.02
Identification	
Color	Grayish black
Crystal habit	Typically in spherical, rosette aggregates of thin plates; commonly massive, radiated, or foliated
Crystal system	Triclinic - Pinacoidal H-M Symbol (1) Space Group: P1
Twinning	Complex
Cleavage	{010}, perfect
Tenacity	Flexible, inelastic; slightly malleable

Mohs scale hardness	2.5 - 3
Luster	Metallic
Streak	Grayish black
Diaphaneity	Opaque
Specific gravity	5.88 – 5.92
Pleochroism	Weak

Franckeite, chemical formula $Pb_5Sn_3Sb_2S_{14}$, belongs to a family of complex sulfide minerals. Franckeite is a sulfosalt. It is closely related to cylindrite.

It was first described in 1893 for an occurrence in Chocaya, Potosí Department, Bolivia. It is named after the mining engineers, Carl and Ernest Francke. It can be found in Bolivia at Poopó in Oruro and at Las Aminas, southeast of Chocaya, in Potosi. Franckeite has an average density of 5.7 and can be both grayish black, blackish gray in color.

It occurs in hydrothermal silver-tin deposits in Bolivia and in contact metamorphosed limestone deposit in the Kalkar quarry in California. It occurs with cylindrite, teallite, plagionite, zinkenite, cassiterite, wurtzite, pyrrhotite, marcasite, arsenopyrite, galena, pyrite, sphalerite, siderite and stannite.

Kermesite

Kermesite	
	
General	
Category	Oxysulfide
Chemical formula	(Sb_2S_2O)
Strunz classification	02.FD.05
Dana classification	02.13.01.01
Identification	
Color	Red to cherry red
Crystal habit	Acicular, fibrous, radial
Crystal system	Triclinic Pinacoidal 1
Cleavage	Perfect {100}, parting on {010}
Fracture	Brittle
Tenacity	Sectile
Mohs scale hardness	1 - 2
Luster	Adamantine to semimetallic
Streak	Brownish red
Diaphaneity	Translucent, Opaque
Specific gravity	4.5 - 4.8+
Optical properties	Biaxial (+)

Refractive index nα = 2.720 nβ = 2.740 nγ = 2.740

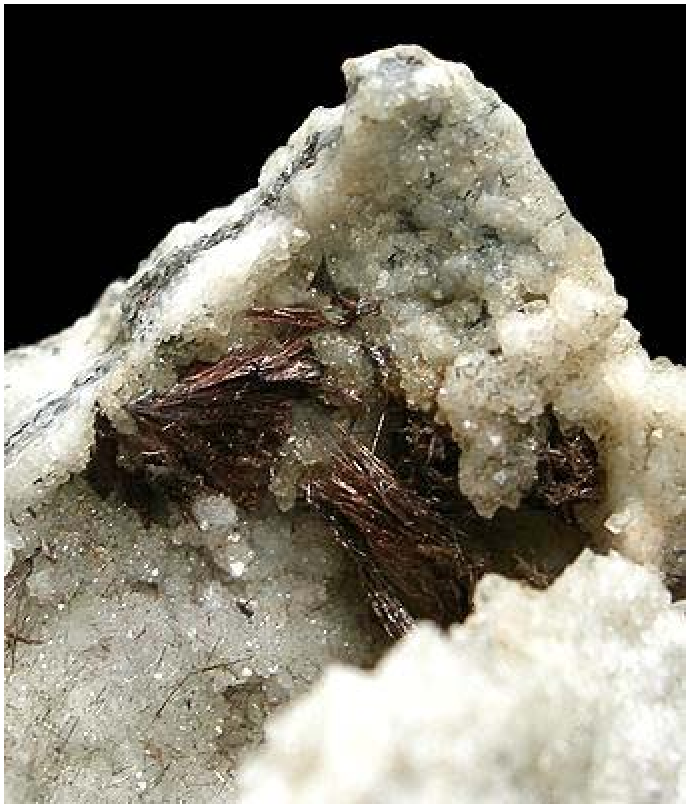
Pleochroism None

Kermesite or antimony oxysulfide is also known as **red antimony** (Sb_2S_2O) . The name kermesite is a name derived from the Persian *qurmizq* (قرمز), which later became "crimson" and was given to the mineral's color which ranges from cherry red to a deep red bordering on black. Kermesite is the result of partial oxidation between stibnite (Sb_2S_3) and other antimony oxides such as valentinite (Sb_2O_3) or stibiconite ($Sb_3O_6(OH)$). Under certain conditions with oxygenated fluids the transformation of all sulfur to oxygen would occur but kermesite occurs when that transformation is halted.

Lustrous, acicular, deep wine-red kermesite crystals, up to 4 cm.long, on massive sulfide matrix, from Pezinok, Malé Karpaty Mts, Bratislava Region, Slovakia.

Mining and specimens

Deposits of this mineral have been found all over the world, however notable deposits have been found in Braunsdorf, near Freiberg, Saxony, Germany; Pernek, Pezinok, and Pribram, Czechoslovakia; the Lac Nicolet mine, South Ham Township, Wolfe County, Quebec, Canada; Sombrerete, Zacatecas, Mexico; Santa Cruz and San Francisco mines, Poopo, Oruro, Bolivia; Que Que, Zimbabwe; Djebel Haminate, Algeria; Broken Hill, New South Wales, Australia; Mohave, Kern County, California and Burke, Shoshone County, Idaho.



History and uses

Kermesite or red antimony has been used as early as the Old Kingdom's 6th Dynasty in ancient Egypt (c.2345-2181 BCE) in lip cosmetics and in the 18th Dynasty Queen Hatshepsut (Maatkare) (1498-1483 BCE) negotiated with the Land of Punt for it s colored antimony deposits. Besides stibnite which was used for eye liner red antimony is one of the oldest minerals used in cosmetics. Further archaeological evidence indicates that antimony levels were higher in ancient Egyptian female remains which had exposure to both antimony compounds (Bencze, 1994). Because of its color, the precipitate of kermesite was used as a coloring agent and in alchemy. Because of alchemy's focus on material transformation as evidenced by color, red antimony was used to produce the red state. Kermesite is the mineral state for Kermes mineral which was used extensively in the medical field for centuries

Presently, kermesite is collected for the beauty of its crystal metallic structure and not used in either cosmetics or the medical field any longer due to the toxic affects that it shares with antimony; less harmful substitutes have been found using both organic and pharamceutical production.

Miargyrite

Miargyrite	
 **Miargyrite**, Flint district, Idaho	
General	
Category	Mineral
Chemical formula	$AgSbS_2$
Strunz classification	02.HA.10
Identification	
Crystal system	Monoclinic
Mohs scale hardness	2-2.5
Streak	red
Specific gravity	5.2

Miargyrite is a mineral, a sulfide of silver and antimony with the formula $AgSbS_2$. It is a dimorph of Cuboargyrite. Originally discovered in the Freiberg district of Germany in 1824, it has subsequently been found in many places where silver is mined. It usually occurs in low temperature hydrothermal deposits. and forms black metallic crystals which may show a dark red internal reflection. The streak is also red.

Miargyrite is named from the Greek *meyon*, "smaller" and *argyros*, "silver," as its silver content is lower than most silver sulfides.

Miargyrite, San Genaro Mine, Castrovirreyna District, Peru. Size 6.1 x 4.2 x 2.7 cm.

Polybasite

Polybasite	
	
Locality: Arizpe, Sonora, Mexico. Scale bar is one inch (2.5 cm.)	
General	
Category	Sulfosalt minerals
Chemical formula	$[(Ag,Cu)_6(Sb,As)_2S_7][Ag_9CuS_4]$
Strunz classification	02.GB.15

Polybasite is a sulfosalt mineral of silver, copper, antimony and arsenic. Its chemical formula is $[(Ag,Cu)_6(Sb,As)_2S_7][Ag_9CuS_4]$.

It forms black monoclinic crystals (thin, tabular, with six corners) which can show dark red internal reflections. It has a Mohs hardness of 2.5 to 3. It is found worldwide and is an ore of silver. The name comes from the number of base metals in the mineral.

Unusual polybasite specimen from Mayo Mining District, Yukon Territory, Canada. Size 3.0 x 2.2 x 1.3 cm.

Pyrargyrite

Pyrargyrite	
	
General	
Category	Mineral

Chemical formula	silver antimony sulfide: Ag_3SbS_3
Strunz classification	02.GA.05
Identification	
Color	dark red to red-black
Crystal habit	Include prismatic crystals with rhombohedral and scalenohedral faces forming terminations. There is no perpendicular mirror plane and therefore a hemimorphic crystal can be seen, in some rare examples, with differing terminations at the top and bottom of the crystal. Typical crystals are poorly formed and modified heavily by secondary faces. Also found massive.
Crystal system	trigonal; 3m
Cleavage	Sometimes distinct in three directions forming rhombohedrons
Fracture	conchoidal
Mohs scale hardness	2.5
Luster	adamantine
Streak	dark cherry red
Specific gravity	approximately 5.8
Refractive index	translucent to nearly opaque
Other characteristics	darkens upon exposure to light; crystals are frequently striated

Pyrargyrite is a sulfosalt mineral consisting of silver sulfantimonide, Ag_3SbS_3. Known also as dark red silver ore or ruby silver, it is an important source of the metal.

It is closely allied to, and isomorphous with, the corresponding sulfarsenide known as proustite or light red silver ore. Ruby silver or red silver ore (German *Rotgiiltigerz*) was mentioned by Georg Agricola in 1546, but the two species so closely resemble one another that they were not completely distinguished until chemical analyses of both were made.

Both crystallize in the ditrigonal pyramidal (hemimorphic-hemihedral) class of the rhombohedral system, possessing the same degree of symmetry as tourmaline. Crystals are perfectly developed and are usually prismatic in habit; they are frequently attached at one end, the hemimorphic character being then evident by the fact that the oblique striations on the prism faces are directed towards one end only of the crystal. Twinning according to several laws is not uncommon. The hexagonal prisms of pyrargyrite are usually terminated by a low hexagonal pyramid or by a drusy basal plane.

The color of pyrargyrite is usually greyish-black and the lustre metallic-adamantine; large crystals are opaque, but small ones and thin splinters are deep ruby-red by transmitted light, hence the name, from the Greek *pyr* and *argyros*, "fire-silver" in allusion to color and silver content, given by E. F. Glocker in 1831. The streak is purplish-red, thus differing markedly from the scarlet streak of proustite and affording a ready means of distinguishing the two minerals. The Mohs hardness is 2.75, and the specific gravity 5.85. The refractive indices ($n\omega$=3.084 $n\varepsilon$=2.881) and birefringence (δ=0.203) are very high. There is no very distinct cleavage and the fracture is conchoidal. The mineral occurs in metalliferous veins with calcite, argentiferous galena, native silver, native arsenic, &c. The best crystallized specimens are from Sankt Andreasberg in the Harz, Freiberg in Saxony, and Guanajuato in Mexico. It is not uncommon in many silver mines in the United States, but rarely as distinct crystals; and it has been found in some Cornish mines.

Pyrargyrite silver ore from the Comstock Lode, Storey Co., Nevada, USA

Although the red silver ores afford a good example of isomorphism, they rarely form mixtures; pyrargyrite rarely contains as much as 3% of arsenic replacing antimony, and the same is true of antimony in proustite. Dimorphous with pyrargyrite and proustite respectively are the rare monoclinic species pyrostilpnite or fireblende (Ag_3SbS_3) and xanthoconite (Ag_3AsS_3): these four minerals thus form an isodimorphous group.

Stibnite

Stibnite	
	
Stibnite in the Carnegie Museum of Natural History	
General	
Category	Sulfide mineral
Chemical formula	Sb_2S_3
Strunz classification	02.DB.05a
Crystal symmetry	Orthorhombic 2/m 2/m 2/m
Unit cell	a = 11.229 Å, b = 11.31 Å, c = 3.8389 Å; Z = 4
Identification	
Color	Lead-gray, tarnishing blackish or iridescent; in polished section, white
Crystal habit	Massive, radiating and elongated crystals. Massive and granular
Crystal system	Orthorhombic, Dipyramidal
Cleavage	Perfect and easy on {010}; imperfect on {100} and {110}
Fracture	Subconchoidal
Tenacity	Highly flexible but not elastic; slightly

	sectile
Mohs scale hardness	2
Luster	Splendent on fresh crystals surfaces, otherwise metallic
Streak	Similar to color
Diaphaneity	Opaque
Specific gravity	4.63
Solubility	decomposed with hydrochloric acid
Other characteristics	Anisotropism: Strong
Major varieties	
Metastibnite	Earthy, reddish deposits

Stibnite, sometimes called **antimonite**, is a sulfide mineral with the formula Sb_2S_3. This soft grey material crystallizes in an orthorhombic space group. It is the most important source for the metalloid antimony. The abbreviation for antimony, Sb, is taken from stibnite.

Structure

Crystals from Henan Province, China (size: 16.8 x 5.4 x 5.4 cm)

Stibnite has a structure similar to that of arsenic trisulfide, As_2S_3. The Sb(III) centers, which are pyramidal and three-coordinate, are linked via bent two-coordinate sulfide ions. It is grey when fresh, but can turn superficially black due to oxidation in air.

Uses

Pastes of Sb_2S_3 powder in fat or in other materials have been used since 3000 BC as eye cosmetics in the Middle East and farther afield; in this use, Sb_2S_3 is called kohl. It was used to darken the brows and lashes, or to draw a line around the perimeter of the eye.

Antimony trisulfide finds use in pyrotechnic compositions, namely in the glitter and fountain mixtures. Needle-like crystals, "Chinese Needle", are used in glitter compositions and white pyrotechnic stars. The "Dark Pyro" version is used in flash powders to increase their sensitivity and sharpen their report. It is also a component of modern safety matches. It was formerly used in flash compositions, but its use was abandoned due to toxicity and sensitivity to static electricity.

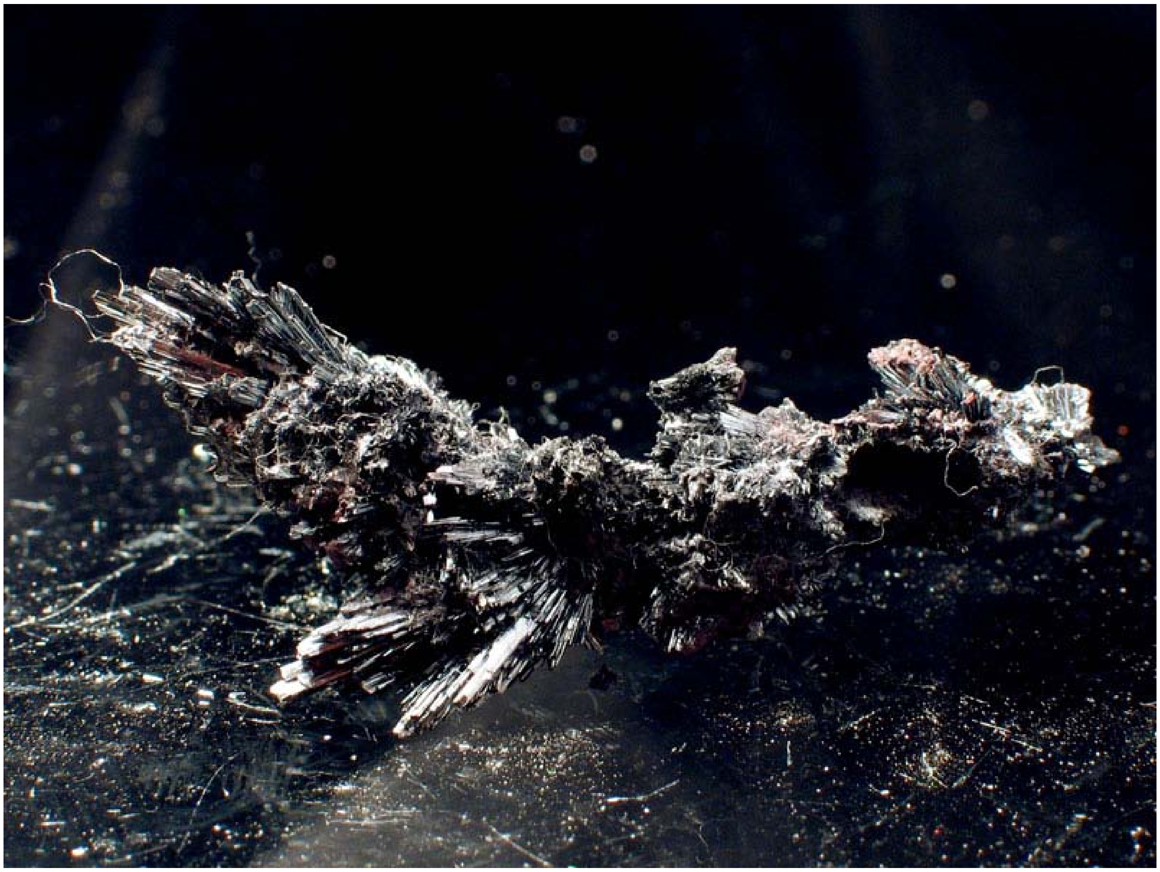
The natural sulfide of antimony, stibnite, was known and used in Biblical times, as a medication and in Islamic/pre-Islamic times as a cosmetic. The Sunan Abi Dawood reports, “prophet Muhammad said: 'Among the best types of collyrium is antimony (ithmid) for it clears the vision and makes the hair sprout.'”

Occurrence

Needles of stibnite within a transparent crystal of calcite (size: 4.5 x 3.5 x 1.8 cm)

Small deposits of stibnite are common, but large deposits are rare. It occurs in Canada, Mexico, Peru, Japan, China, Germany, Romania, Italy, France, England, Algeria, and Kalimantan, Borneo. In the United States it is found in Arkansas, Idaho, Nevada, California, and Alaska.

As of May 2007, the largest specimen on public display (1000 pounds) is at the American Museum of Natural History. The largest documented single crystals of stibnite measured ~60x5x5 cm^3 and originated from different locations including Japan, France and Germany.



Chapter-3

Barium Minerals

Barytocalcite

Barytocalcite	
	
Barytocalcite from England	
General	
Category	Carbonate minerals
Chemical formula	$BaCa(CO_3)_2$
Strunz classification	05.AB.45

Barytocalcite is a barium calcium carbonate mineral with chemical formula: $BaCa(CO_3)_2$. It crystallizes in the monoclinic crystal system typically as massive to druzey accumulations of transparent white to yellow to grey aggregates of slender prismatic crystals. It has a Mohs hardness of 4 and a specific gravity of 3.64 to 3.66.

It was first described in 1824 for an occurrence in Blagill Mine in North Pennines, Cumbria (Cumberland), England.

Celsian

Celsian	
	
celsian (transparent/gray in photo) in sanbornite (white) matrix—Incline, Maricopa County, California	
General	
Category	Feldspar
Chemical formula	$BaAl_2Si_2O_8$
Identification	
Color	usually colorless and transparent
Crystal habit	adularia, larger, snout crystals, and long, slender to acicular.
Crystal system	monoclinic
Twinning	manebach twins on (001), baveno twins (021), rare lamellar twinning
Cleavage	c(001) perfect cleavage and a b(010) good cleavage
Mohs scale hardness	6

Luster	pearly to non-fluorescent
Diaphaneity	usually colorless and transparent
Density	3.31 to 3.33 g/cm³
Optical properties	2V angle which is approximately 880
Refractive index	moderate relief
Birefringence	0.014, biaxial -

Celsian is an uncommon feldspar mineral, **barium aluminosilicate**, $BaAl_2Si_2O_8$. The mineral occurs in contact metamorphic rocks with significant barium content. Its crystal system is monoclinic, and it is white, yellow, or transparent in appearance. In pure form, it is transparent. Synthetic barium aluminosilicate is used as a ceramic in dental fillings and other applications.

The mineral is named after Anders Celsius.

Composition

Celsian is a barium feldspar with a chemical composition $BaAl_2Si_2O_8$. It forms part of the feldspar group and belongs to the celsian-hyalophane series and the celsian-orthoclase series. It has some resemblance to anorthite, and it has four distinct polymorphs. The essential elements are Si,Al,O and Ba. Some common impurities in the mineral are Fe, Ti, Mg,K and Ca. Celsian is stable from room temperature up to 1590 °C (Lin and Foster,1968) .The most common trace elements are potassium and calcium, in an analysis of the approximate chemical composition of celsian the following wt% were found: • SiO_2—35.1 • Al_2O_3---26.8 • BaO----35.8 • K_2O-----2.3 Total:100.0 (Newham and Megaw,1960).

Geologic occurrence

Celsian is of limited occurrence. Most of the barium feldspars are associated with exhalative hydrothermal processes and low-and medium-grade metamorphism (Moro and Cembranos and Fernandez, 2001). It is also associated with sedimentary and meta sedimentary rocks, manganese, ferromanganese and barite deposits. Barium is rarely found in its pure form since it quickly oxidizes with air, it is more commonly found and extracted from barite, in other cases the barium may be present due to metamorphic events.

Celsian can be found in places like Wales, Zamora (Spain), Alaska, California, Sweden and Japan, also with hendricksite on the Franklin mines in New Jersey (N.J), others locations of Celsian are showned in figure 1.

Structure

The symmetry in celsian is somewhat different from the symmetry normally found in feldspars. It is monoclinic with a body centered lattice similar to those of anorthite. Not sufficient evidence has been found to suggest that celsian lacks a center of symmetry, so its space group is I 2/c (Newnham and Megaw, 1960). The space group differs from others of its group like orthoclase, albite and body center anorthite are C2/m, C1bar and I1bar.

X-ray analysis shows that the values for the lattice parameters *a*, *b*, *c* axes and angles are approximately a=863 pm, b=131.0 pm, c=1400 pm and β=116°, θ=90°(Gay, 1956).

There are 8 formula units per cell, and the general position is eightfold, so all atoms can lie in general positions (Newnham and Megaw,1960). This structure is very similar to that of orthoclase and sanidine but differs in a couple of ways: 1. The distribution of Si and Al. 2. The coordinates of all the atoms. The distribution of silicon and aluminum along the tetrahedral sites mixed with the nature of the barium atom makes an impact on the surrounding silicate framework (Newham and Megaw,1960). The Si-Al bonds are partially ordered, and in some cases the aluminum substitute's silicon.

The order in celsian is very simple, each aluminum tetrahedron is surrounded by four silicon tetrahedral, and vice versa (Newham and Megaw,1960). Also there is another type of transformation besides aluminum-silicon, where silicon-poor goes into a silicon-rich network that involves having to simultaneously be a replacement of Al, and Si at other sites.

The barium ion has an irregular configuration close to the one in potassium in the feldspars. Each barium has an oxygen close, and thanks to this configuration it has a strong effect on the silicon-oxygen-silicon bond angles.

Polymorphism of Celsian

There are four distinctive polymorphs of Celsian, two of them are the natural minerals and the other two are synthetic products. The first are paracelsian and celsian, the second ones are hexacelsian and the other one is related to the mineral cymrite (Lin and foster, 1967). The order of increasing stability is paracelsian→hexacelsian→celsian in a temperature range between 500C to the 1000C.

As temperature rises from the 1,600 °C to 1,760 °C it goes from celsian to a reversible form of hexacelsian. Paracelsian is less stable than the other two and Celsian is the most stable.

TwiningBarium feldspars occur in optically uniform crystals where the twining is poorly developed, except on coarse crystals. Eighteen crystals forms have been identified; eleven of them coincide with those known for the orthoclase. On this structures it was found manebach twins on (001), baveno twins (021). Some samples of celsian were found to have a rare lamellar twinning (Spencer, 1941). Figure 5 : Celsian crystals from Benalt mine, Carnavoshire. (Spencer, 1941)

Physical properties

Celsian shows a c(001) perfect cleavage and a b(010) good cleavage, which marks the difference with its polymorph paracelsian which has a [110] indistinct cleavage.There are different crystals habits like adularia, larger, snout crystals (spencer, 1941), and long, slender to acicular. It is usually colorless and transparent with a pearly to non-fluorescent luster.

The density is about 3.31 to 3.33 g/cm³. This might be the case due to some impurities in the structure of the mineral. It has a hardness of 6 on the Moh's scale, this hardness is due to the short length of the bond in the structure, since is relative short tends to be harder. Some optical properties

Some other optical properties are the 2V angle which is approximately 880 with a maximum birefringence of 0.014, biaxial with a negative sign (Newnham and Megaw, 1960). It has a moderate relief.

Uses

Celsian has very attractive features such as chemical stability and high mechanical resistance, which can be favourably exploited in order to obtain enhanced-performance composites with respect to bulk glass. (Cannillo, Carlier, Manfredini, Montorsi, and Siligardi 2006). Many studies shows that by increasing the amount of celsian phases in the glasses results in increased bulk of crytaslization.(Khater and Idris, 2004)

The uses of celsian are mostly related to glass and ceramics. This uses are usually achieved by the preparation of pure monoclinic celsian.

Harmotome

Harmotome	
 Harmotome	
General	
Category	zeolites
Chemical formula	$(Ba_{0.5},Ca_{0.5},Na,K)_5Al_5,Si_{11}O_{32}\cdot 12(H_2O)$

Harmotome is a mineral, one of the rarer zeolites; a hydrated barium silicate with formula: $(Ba_{0.5},Ca_{0.5},Na,K)_5Al_5,Si_{11}O_{32}\cdot 12(H_2O)$. It forms vitreous white well defined monoclinic crystals, often associated with calcite and other zeolites. It has a Mohs hardness of 4 to 5 and a specific gravity of 2.44 to 2.5.

Name and discovery

Named from the greek words *harmos* (I combine) and *temseis* (I cut) because the pyramid divides parallel to the plane that passes through the terminal edges. It was first described in 1801 from an occurrence in the Harz Mountains, Lower Saxony, Germany.

Psilomelane

Psilomelane	
 A native sample of psilomelane	
General	
Category	Mineral
Chemical formula	The general formula $Ba(Mn^{2+})(Mn^{4+})_8O_{16}(OH)_4$ or as $(Ba,H_2O)_2Mn_5O_{10}$

	Barium Manganese Oxide Hydroxide
Identification	
Molar mass	590.03 gm
Color	black with gray pyrolusite bands
Crystal habit	Botryoidal, Mammillary, Reniform
Crystal system	monoclinic
Cleavage	none
Fracture	conchoidal and uneven
Mohs scale hardness	5.0 - 6.0
Luster	Sub-Metallic, Dull
Streak	brownish black
Diaphaneity	Opaque
Specific gravity	3.7 - 4.7
Polish luster	vitreous to subadamantine
Solubility	in hydrochloric acid
Other characteristics	hard black manganese oxides such as hollandite and romanechite

Polished specimen of manganese ore from the Batesville, Arkansas district. Slab of manganese ore showing an intimate mixture of hausmannite and psilomelane in a roughly zonal arrangement and a radiating mass of white barite at the center. The light steel-gray mineral and the black mineral immediately adjacent to the barite are **psilomelane**. The rest of the black mineral is **hausmannite.** Natural size.

Psilomelane, also known as **black hematite**, is a group name for hard black manganese oxides such as hollandite and romanechite. Psilomelane consists of hydrous manganese oxide with variable amounts of barium and potassium.

Formula

Generalized formula may be represented as $Ba(Mn^{2+})(Mn^{4+})_8O_{16}(OH)_4$ or as $(Ba,H_2O)_2Mn_5O_{10}$. It is sometimes considered to be a hydrous manganese manganate, but of doubtful composition. The amount of manganese present corresponds to 70-80% of manganous oxide with 10-15% of available oxygen.

Characteristics

Psilomelane is amorphous and occurs as botryoidal and stalactitic masses with a smooth shining surface and submetallic lustre. The mineral is readily distinguished from other hydrous manganese oxides (manganite and wad) by its greater hardness 5 to 6; the specific gravity varies from 3.7 to 4.7. The streak is brownish black and the fracture smooth. Owing to its amorphous nature, the mineral often contains admixed impurities, such as iron hydroxides. It is soluble in hydrochloric acid with evolution of chlorine gas.

History and occurrence

The name has reference to this characteristic appearance, from the Greek for (naked, smooth) and (black); a Latinized form is calvonigrite, and a German name with the same meaning is **Schwarzer Glaskopf**. It is a common and important ore of manganese, occurring under the same conditions and having the same commercial applications as pyrolusite. It is found at many localities; amongst those which have yielded typical botryoidal specimens may be mentioned the Restormel iron mine at Lostwithiel in Cornwall, Brendon Hills in Somerset, Hoy in Orkney, Sayn near Coblenz, and Crimora in Augusta county, Virginia. With pyrolusite it is extensively mined in Vermont, Virginia, Arkansas, and Nova Scotia.

Psilomelane is also cut, shaped, and polished for a variety of jewelry applications.

Romanèchite

Romanèchite	

Romanèchite, La Negrita Mine, Rio Negro, Argentina

General	
Category	Oxide minerals
Chemical formula	$(Ba,H_2O)_2(Mn^{+4},Mn^{+3})_5O_{10}$
Strunz classification	04.DK.10

Romanèchite ($(Ba,H_2O)_2(Mn^{+4},Mn^{+3})_5O_{10}$) is the primary constituent of psilomelane, which is a mixture of minerals. Most psilomelane is not pure romanechite, so it is incorrect to consider them synonyms. Romanèchite is a valuable ore of manganese, which is used in steelmaking. It has a monoclinic crystal structure, a hardness of 6 and a specific gravity of 4.7-5. It is associated with hematite, barite, pyrolusite, quartz and other manganese oxide minerals. It has been found in France, Germany, England, Brazil and various parts of the United States, including Arizona, Virginia and Michigan.

Witherite

Witherite	
	
Witherite from Cave-in-Rock (size: 4.9 x 3.7 x 3.2 cm)	
General	
Category	Carbonate mineral
Chemical formula	$BaCO_3$
Strunz classification	05.AB.15
Crystal symmetry	Orthorhombic dipyramidal (2/m 2/m 2/m)
Unit cell	a = 5.31 Å, b = 8.9 Å, c = 6.43 Å; Z = 4
Identification	
Color	Colorless, white, pale gray, with possible tints of pale yellow, pale brown, or pale green
Crystal habit	Striated short prismatic crystals, also botryoidal to spherical, columnar fibrous, granular, massive.
Crystal system	Orthorhombic
Twinning	On {110}, universal
Cleavage	Distinct on {010} poor on on {110}, {012}

Fracture	Subconchoidal
Mohs scale hardness	3.0 - 3.5
Luster	Vitreous, resinous on fractures
Streak	White
Diaphaneity	Subtransparent to translucent
Specific gravity	4.3
Optical properties	Biaxial (-)
Refractive index	$n_\alpha = 1.529$ $n_\beta = 1.676$ $n_\gamma = 1.677$
Birefringence	$\delta = 0.148$
2V angle	Measured: 16°, calculated: 8°
Dispersion	Weak
Ultraviolet fluorescence	Fluorescent and phosphorescent, short UV=bluish white, long UV=bluish white

Witherite is a barium carbonate mineral, $BaCO_3$, in the aragonite group. Witherite crystallizes in the orthorhombic system and virtually always is twinned. The mineral is colorless, milky white, grey, pale yellow, green, to pale brown. The specific gravity is 4.3, which is high for a translucent mineral. It fluoresces light blue under both long and short-wave UV light, and is phosphorescent under short-wave UV light.

Two sharp pseudohexagonal crystals of witherite on calcite from Hardin County, Illinois (size: 6.4 x 5.4 x 3.4 cm)

Witherite forms in low-temperature hydrothermal environments. It is commonly associated with fluorite, celestine, galena, barite, calcite and aragonite. Witherite occurrences include: Cave-in-Rock, Illinois, USA; Alston Moor, Cumbria, Anglezarke, Lancashire and Burnhope, County Durham, England; Thunder Bay area, Ontario, Canada, Germany and Poland (Tarnowskie Góry and Tajno at Suwałki Region).

Witherite was named for William Withering (1741-1799) an English physician and naturalist.

Risk to Human Health

The 18th century naturalist Dr. Leigh recorded its lethal effects after the death of a farmer's wife and child. James Watt Jnr. experimented with the mineral on animals and he recorded the same lethal properties. Until the 18th century farmers at Anglezarke used the mineral as rat poison.

Industrial Use

Another experiment was conducted by Josiah Wedgwood who used it in his 'Jasper ware', the mineral had previously been considered as worthless.

Chapter-4

Silver Minerals

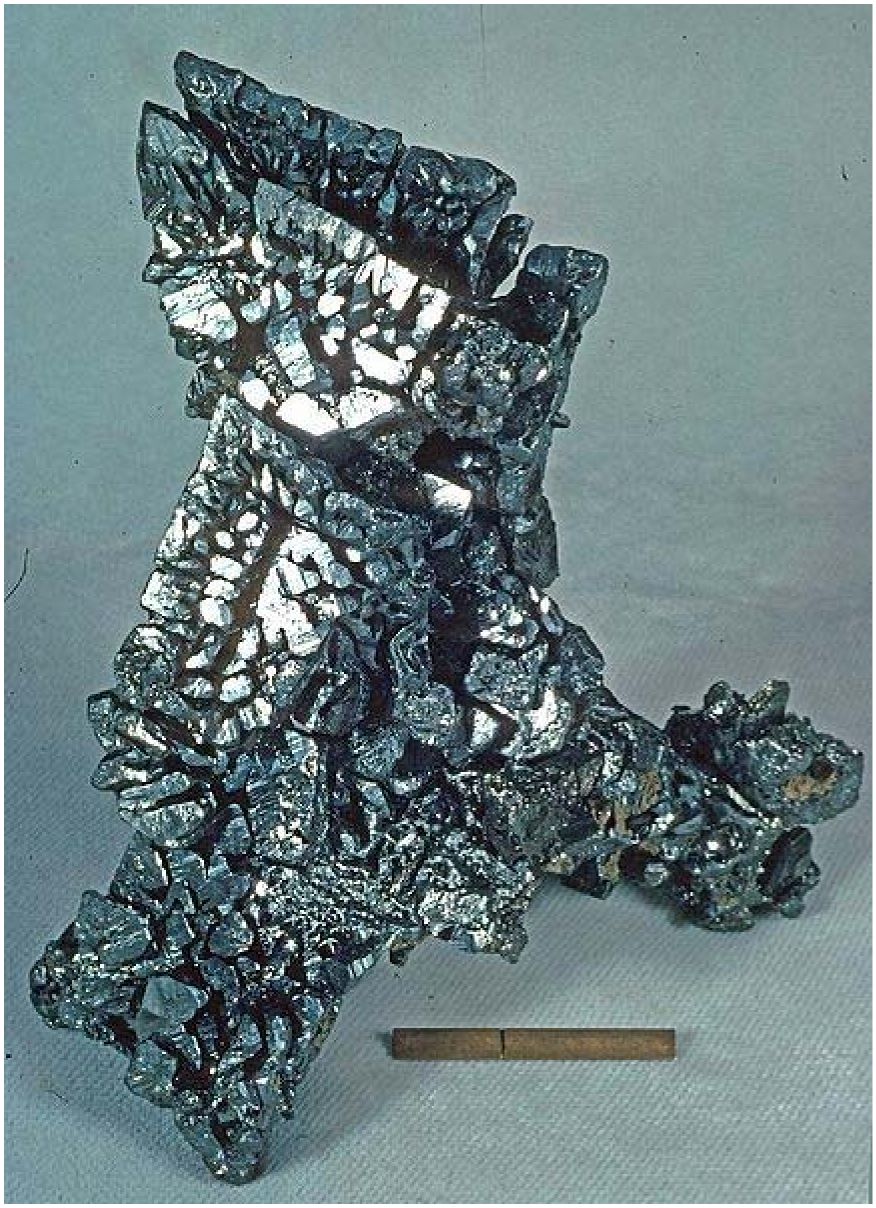
Acanthite

Acanthite	
	
Acanthite on calcite - Locality: Freiberg District, Erzgebirge, Saxony, Germany - Scale is one inch with a rule at one cm	
General	
Category	Sulfide mineral
Chemical formula	Ag_2S

Strunz classification	02.BA.30a
Crystal symmetry	Monoclinic 2/m
Unit cell	a = 4.229 Å, b = 6.931 Å, c = 7.862 Å; β = 99.61°; Z = 4
Identification	
Color	Iron-black
Crystal habit	Primary crystals rare, prismatic to long prismatic, elongated along [001], may be tubular; massive. Commonly paramorphic after the cubic high-temperature phase ("argentite"), of original cubic or octahedral habit
Crystal system	Monoclinic prismatic
Twinning	Polysynthetic on {111}, may be very complex due to inversion; contact on {101}
Cleavage	Indistinct
Fracture	Uneven
Tenacity	Sectile
Mohs scale hardness	2.0 - 2.5
Luster	Metallic
Streak	Black
Diaphaneity	Opaque
Specific gravity	7.20 - 7.22

Acanthite, Ag_2S, crystallizes in the monoclinic system and is the stable form of silver sulfide below 173 °C. Argentite is the stable form above that temperature. As argentite cools below that temperature its cubic form is distorted to the monoclinic form of acanthite. Below 173 °C acanthite forms directly. Acanthite is the only stable form in normal air temperature.

Occurrence



Acanthite - Locality: Chispas Mine, Arizpe, Mun. de Arizpe, Sonora, Mexico - Scale is one inch with a rule at one cm

Acanthite is a common silver mineral in moderately low-temperature hydrothermal veins and in zones of supergene enrichment. It occurs in association with native silver, pyrargyrite, proustite, polybasite, stephanite, aguilarite, galena, chalcopyrite, sphalerite, calcite and quartz.

Acanthite was first described in 1855 for an occurrence in the Jáchymov (St Joachimsthal) District, Krušné Hory Mts (Erzgebirge), Karlovy Vary Region, Bohemia, Czech Republic. The name is from the Greek "akantha" meaning thorn or arrow, in reference to its crystal shape.

Chlorargyrite

Chlorargyrite	
	
Bromian chlorargyrite (embolite), Chañarcillo, Copiapó Province, Chile. Size: 5.0 x 4.7 x 1.0 cm.	
General	
Category	Halide
Chemical formula	AgCl
Strunz classification	03.AA.15

Chlorargyrite is the mineral form of silver chloride (AgCl). Chlorargyrite occurs as a secondary mineral phase in the oxidation of silver mineral deposits. It crystallizes in the isometric - hexoctahedral crystal class. Typically massive to columnar in occurrence it also has been found as colorless to variably yellow cubic crystals. The color changes to brown or purple on exposure to light. It is quite soft with a Mohs hardness of 1 to 2 and dense with a specific gravity of 5.55. It is also known as **cerargyrite** and, when weathered by desert air, as **horn silver**. Bromian chlorargyrite (or embolite) is also common. Chlorargyrite is water insoluble.

It was first described in 1877 for occurrences in the Broken Hill district, New South Wales, Australia. The name is from the Greek, chloros for "pale green" and Latin for silver, argentum.

Dyscrasite

Dyscrasite	
	
Twinned dyscrasite crystals from the Czech Republic (size: 4.5 x 4.5 x 3.3 cm)	
General	
Category	Antimonide mineral
Chemical formula	Ag_3Sb
Strunz classification	02.AA.35
Crystal symmetry	Orthorhombic pyramidal *mm*2
Unit cell	a = 3.008 Å, b = 4.828 Å, c = 5.214 Å; Z = 1
Identification	
Color	Silver-white (tarnishes to lead-gray, yellowish, or black)
Crystal habit	Pyramidal crystals also cylindrical, prismatic to platy, striated; granular, foliated or massive

Crystal system	Orthorhombic
Twinning	On {110} produces pseudohexagonal forms
Cleavage	Distinct on {001} {001}, imperfect on {110}
Fracture	Irregular or uneven
Tenacity	Sectile
Mohs scale hardness	3½ - 4
Luster	Metallic
Streak	Silver-white
Diaphaneity	Opaque
Specific gravity	9.4 - 10
Birefringence	Very Weak
Pleochroism	Very Weak

The silver antimonide mineral **dyscrasite** has the chemical formula Ag_3Sb. It is an opaque, silver white, metallic mineral which crystallizes in the orthorhombic crystal system. It forms pyramidal crystals up to 5 cm and can also form cylindrical and prismatic crystals.

Crystallography and properties

Dyscrasite demonstrates weak anisotropism. Anisotropism occurs when a mineral has two different indexes of refraction. Dyscrasite's color under plane polarized light is most likely dark grey/black. When spun on a rotatable stage of a microscope (under plane polarized light), dyscrasite's color should slightly change shades. This property is called pleochroism. Dyscrasite exhibits very weak pleochroism.

Dyscrasite belongs to the orthorhombic crystal class, meaning all three of its axes (a, b, and c) are unequal in length and are 90° to each other.

Discovery and occurrence

It was first described for an occurrence in 1797 in the Wenzel Mine, Black Forest, Germany. The name dyscrasite comes from the Greek word δυσκράσις, meaning "a bad alloy."

It occurs as a hydrothermal mineral in silver bearing veins in association with native silver, pyrargyrite, acanthite, stromeyerite, tetrahedrite, allemontite, galena, calcite and baryte.

Hessite

Hessite	
	
Hessite and Quartz specimen from Botés, Alba County, Romania, featuring unusually thick and stout crystals of this rare silver telluride mineral. Size 3.6 x 2.2 x 1.5 cm.	
General	
Category	Sulfide minerals
Chemical formula	Ag_2Te
Strunz classification	02.BA.30c

Hessite is a mineral form of disilver telluride (Ag_2Te). It is a soft, dark grey telluride mineral which forms monoclinic crystals.

It is named after Germain Henri Hess (1802–1850).

Hessite is found in the USA in Eagle County, Colorado and in Calaveras County, California and in many other locations.

Stützite (Ag_7Te_4) and empressite (AgTe) are related silver telluride minerals.

Proustite

Proustite

Proustite on matrix, crystal size: 1 cm, Chañarcillo district, Chile

General	
Category	Sulfosalt mineral
Chemical formula	Ag_3AsS_3
Strunz classification	02.GA.05 Neso-sulfarsenites
Dana classification	03.04.01.01 Proustite group
Crystal symmetry	H-M Symbol (32/m)
Unit cell	a = 10.79 Å, c = 8.69 Å Z = 6
Identification	
Color	Scarlet-vermilion
Crystal habit	Crystals prismatic and scalenohedral, massive, compact
Crystal system	Trigonal - Hexagonal Scalenohedral Space Group: R 3c
Twinning	Common
Cleavage	Distinct on {1011}
Fracture	Conchoidal to uneven
Tenacity	Brittle
Mohs scale hardness	2 – 2.5
Luster	Adamantine
Streak	Vermilion
Diaphaneity	Translucent, darkens when exposed to light
Specific gravity	5.57 measured, 5.625 calculated
Optical	Uniaxial (-)

properties

Refractive index	n_ω = 3.087 - 3.088 n_ε = 2.792
Birefringence	δ = 0.295 - 0.296
Pleochroism	Moderate; cochineal-red to blood-red

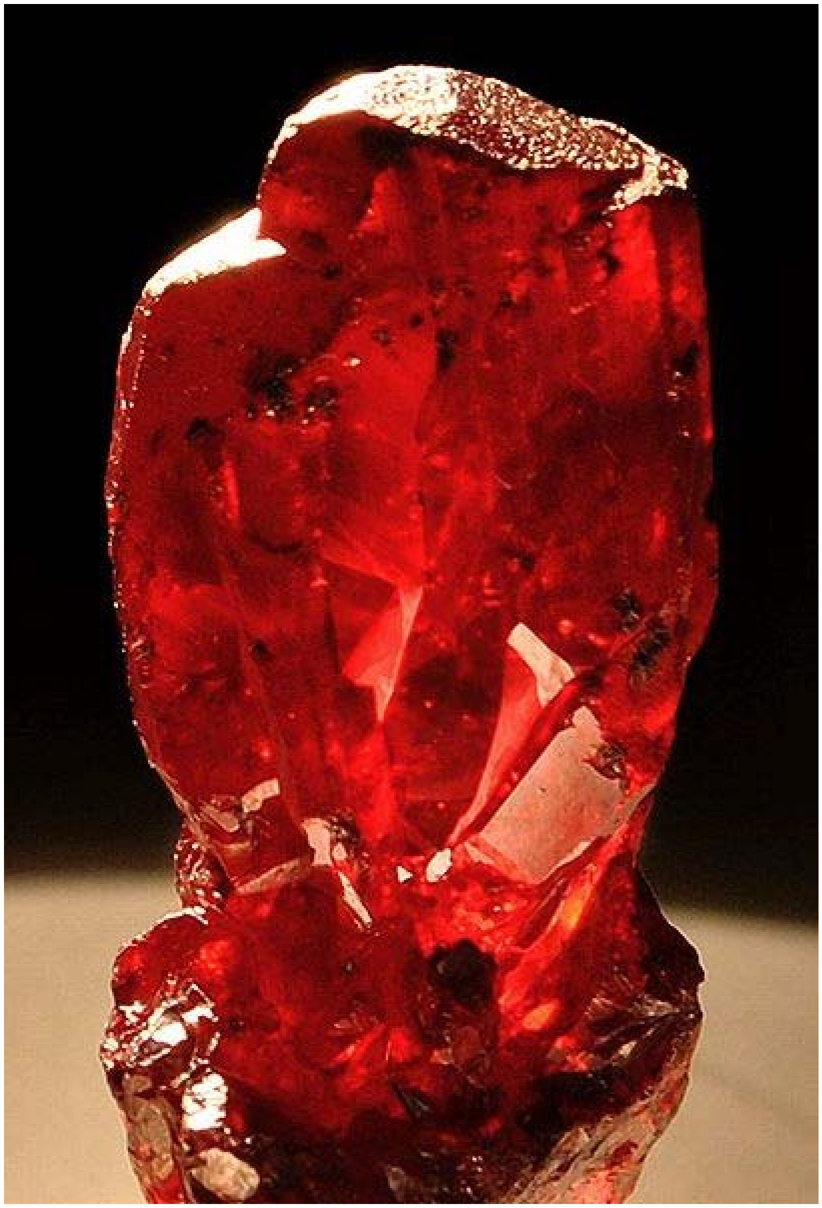
Proustite is a sulfosalt mineral consisting of silver sulfarsenide, Ag_3AsS_3, known also as **light red silver** or **ruby silver ore**, and an important source of the metal. It is closely allied to the corresponding sulfantimonide, pyrargyrite, from which it was distinguished by the chemical analyses of Joseph L. Proust (1754-1826) in 1804, after whom the mineral received its name.

The prismatic crystals are often terminated by the scalenohedron and the obtuse rhombohedron, thus resembling calcite (dog-tooth-spar) in habit. The color is scarlet-vermilion and the lustre adamantine; crystals are transparent and very brilliant, but on exposure to light they soon become dull black and opaque. The streak is scarlet, the hardness 2.5, and the specific gravity 5.57.

Proustite occurs in hydrothermal deposits as a phase in the oxidized and supergene zone. I is associated with other silver minerals and sulfides such as native silver, native arsenic, xanthoconite, stephanite, acanthite, tetrahedrite and chlorargyrite.

Magnificent groups of large crystals have been found at Chañarcillo in Chile; other localities which have yielded fine specimens are Freiberg and Marienberg in Saxony, Joachimsthal in Bohemia and Markirch in Alsace.

Proustite (long prismatic crystal) - Chañarcillo, Copiapo Province, Chile. Specimen height is 4 cm.



Chapter-5

Lead Minerals

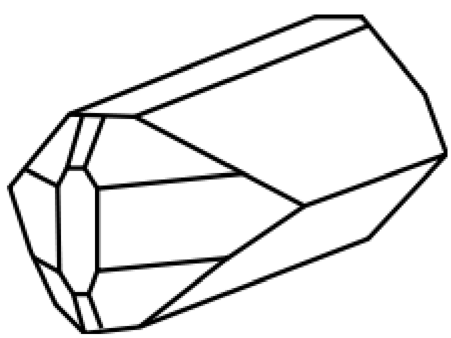
Anglesite

Anglesite	
	
Anglesite Touizit Morroco	
General	
Category	Sulfate minerals
Chemical formula	$PbSO_4$
Strunz classification	07.AD.35
Identification	
Color	Colorless to white, commonly tinted gray; orange, yellow, green, blue, rarely violet
Crystal habit	Granular, banded, nodular to stalactitic
Crystal system	Orthorhombic - Dipyramidal (2/m 2/m

	2/m)
Cleavage	[001] good, [210] distinct
Fracture	Brittle to conchoidal
Mohs scale hardness	2.5 - 3.0
Luster	Adamantine crystals, dull when massive earthy
Streak	White
Diaphaneity	Transparent to translucent
Specific gravity	6.3
Optical properties	Biaxial (+)
Refractive index	$n\alpha = 1.878$ $n\beta = 1.883$ $n\gamma = 1.895$
Fusibility	1.5

Anglesite is a lead sulfate mineral, $PbSO_4$. It occurs as an oxidation product of primary lead sulfide ore, galena. Anglesite occurs as prismatic orthorhombic crystals and earthy masses, and is isomorphous with barite and celestine. It has a high specific gravity of 6.3 due to its lead content, 74% by mass; its hardness is 2.5 - 3. Color is white, gray with pale yellow streaks. It may be dark gray if impure.

Anglesite crystal from Touissit District, Morocco (size: 2.8 x 1.6 x 0.5 cm)



Anglesite diagram illustrating its orthorhombic crystalline form

Beudantite

Beudantite	
	
Large brown crystals of Beudantite.	
General	
Category	Arsenate minerals
Chemical formula	$PbFe_3(OH)_6SO_4AsO_4$
Strunz classification	08.BL.10
Dana classification	43.4.1.1
Crystal symmetry	Trigonal 3 2/m
Unit cell	a = 7.32 Å, c = 17.02 Å; Z = 3
Identification	
Color	black, dark green, brown, yellowish, red, greenish yellow, brown

Crystal habit	tabular, acute rhombohedral, pseudo-cubic, pseudo-cuboctahedral
Crystal system	Trigonal Hexagonal Scalenohedral
Cleavage	distinct; good on {0001}
Mohs scale hardness	3.5-4.5
Luster	vitreous, resinous
Streak	grayish yellow to green
Diaphaneity	transparent, translucent
Specific gravity	4.48
Optical properties	Uniaxial (-)
Refractive index	$n_\omega = 1.957$ $n_\varepsilon = 1.943$
Birefringence	$\delta = 0.014$
Pleochroism	visible
Other characteristics	Soluble in HCl

Beudandite is a secondary mineral occurring in the oxidized zones of polymetallic deposits. It is a lead, iron, arsenate, sulfate with endmember formula: $PbFe_3(OH)_6SO_4AsO_4$.

Beudantite is in a subgroup of the alunite group. It is the arsenate analogue of the phosphate corkite. Beudantite also forms a solid-solution with segnitite and plumbojarosite.

It crystallizes in the trigonal crystal system and shows a variety of crystal habits including tabular, acute rhombohedral, pseudo-cubic and pseudo-cuboctahedral.

It occurs in association with carminite, scorodite, mimetite, dussertite, arseniosiderite, pharmacosiderite, olivenite, bayldonite, duftite, anglesite, cerussite and azurite.

Discovery

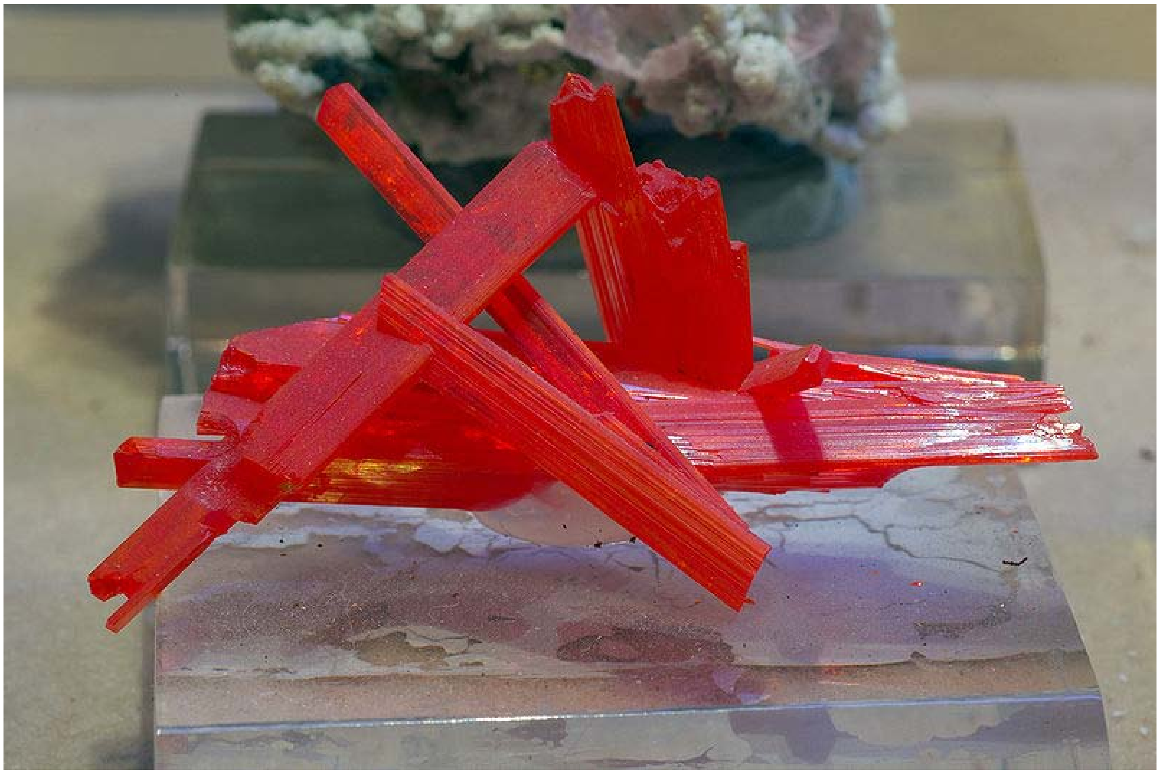
Beudantite was first described in 1826 for an occurrence in the Louise Mine, Wied Iron Spar District, Westerwald, Rhineland-Palatinate, Germany. It was named after French mineralogist François Sulpice Beudant (1787-1850).

Crocoite

Crocoite	
	
Crocoite from Dundas, Tasmania.	
General	
Category	Chromate mineral
Chemical formula	Lead Chromate $PbCrO_4$
Strunz classification	07.FA.20
Identification	
Color	Orange, red, yellow
Crystal habit	Coarsely crystalline to acicular
Crystal system	Monoclinic prismatic (2/m)
Cleavage	Distinct on {110} indistinct on {001} and {100}
Fracture	Conchoidal to uneven
Tenacity	Sectile
Mohs scale hardness	2.5–3
Luster	Adamantine
Streak	Yellowish orange
Diaphaneity	Transparent to translucent

Specific gravity	5.9–6.1
Optical properties	Biaxial (+)
Refractive index	nα = 2.290(2) nβ = 2.360(2) nγ = 2.660(2)
Birefringence	δ = 0.370
Pleochroism	Weak

Crocoite is a mineral consisting of lead chromate, $PbCrO_4$, and crystallizing in the monoclinic crystal system. It is sometimes used as a paint, being identical in composition with the artificial product chrome yellow. It was discovered at Berezovsky deposit near Ekaterinburg in the Urals in 1766; and named crocoise by F. S. Beudant in 1832, from the Greek κροκος, saffron, in allusion to its color, a name first altered to crocoisite and afterwards to crocoite. It is found as well-developed crystals, although these are usually poorly terminated. Crystals are of a bright hyacinth-red color, translucent, and have an adamantine to vitreous lustre. On exposure to light much of the translucency and brilliancy is lost. The streak is orange-yellow; Mohs hardness is 2.5–3; and the specific gravity is 6.0. In the Urals the crystals are found in quartz-veins traversing granite or gneiss. Other localities which have yielded good crystallized specimens are Congonhas do Campo near Ouro Preto in Brazil, Luzon in the Philippines, and Mutare in Mashonaland.



Crocoite specimen from the Red Lead Mine, Tasmania, Australia

Gold is often found associated with this mineral. Exceptional examples of crocoite crystals have been found in the Adelaide Mine at Dundas, Tasmania; they are long slender prisms, 3 or 4 inches in length, with a brilliant lustre and color. Crocoite is also the official Tasmanian mineral emblem.

Associated with crocoite at Berezovsk are the similar minerals phoenicochroite and vauquelinite. The former is a basic lead chromate, Pb_2CrO_5, and the latter a lead and copper phosphate-chromate, $Pb_2CuCrO_4PO_4OH$. Vauquelinite forms brown or green monoclinic crystals, and was named after L. N. Vauquelin, who in 1797 discovered (simultaneously with and independently of M. H. Klaproth) the element chromium in crocoite.

Crystal intergrowth of the secondary lead mineral crocoite

Relative rarity of crocoite is connected with specific conditions required for its formation: an oxidation zone of lead ore bed and presence of ultramafic rocks serving as the source of Cr (in chromite). Oxidation of Cr^{3+} into CrO_4^{2-} (from chromite) and decomposition of galena (or other primary Pb minerals) are required for crocoite formation.

Crocoite on pyromorphite - Berezovsk - Deposit Topotype

Descloizite

Descloizite	
	
Descloizite specimen from Berg Aukas (Berg Aukus), Namibia, 9.5 x 8.9 x 4.9 cm]]	
General	
Category	Vanadate mineral
Chemical formula	$(Pb,Zn)_2VO_4OH$
Strunz classification	08.BH.40
Crystal symmetry	Orthorhombic (2/m 2/m 2/m) - dipyramidal
Unit cell	a = 7.593 Å, b = 6.057 Å, c = 9.416 Å; Z = 4
Identification	
Color	Brownish red, red-orange, reddish to blackish brown, nearly black
Crystal habit	Zoned tabular crystals common, encrustations and plumose aggregates
Crystal system	Orthorhombic
Cleavage	None

Fracture	Irregular, sub-conchoidal
Tenacity	Brittle
Mohs scale hardness	3 - 3.5
Luster	Greasy
Streak	Orange to brownish red
Diaphaneity	Transparent to opaque
Specific gravity	6.1 - 6.2
Optical properties	Biaxial (-)
Refractive index	$n_\alpha = 2.185$ $n_\beta = 2.265$ $n_\gamma = 2.350$
Birefringence	$\delta = 0.165$
Pleochroism	Visible
2V angle	85° to 90°
Dispersion	Strong $r > v$ rarely $r < v$

Descloizite is a rare mineral species consisting of basic lead and zinc vanadate, $(Pb,Zn)_2(OH)VO_4$, crystallizing in the orthorhombic system and isomorphous with olivenite.

The color is deep cherry-red to brown or black, and the crystals are transparent or translucent with a greasy lustre; the streak is orange-yellow to brown; specific gravity 5.9 to 6.2; hardness 31/2. A variety known as cuprodescloizite is dull green in color; it contains a considerable amount of copper replacing zinc and some arsenic replacing vanadium. Appreciable gallium and germanium may also be incorporated into the crystal structure.

Discovery and occurrence

Superb spear-point bladed crystals of Descloizite, Berg Aukas, Namibia. Size 3.6 x 3.1 x .9 cm.

It was discovered in the Sierra de Córdoba deposit in Córdoba, Argentina in 1854 and named in honor of the French mineralogist Alfred Des Cloizeaux. It occurs as small prismatic or pyramidal crystals, usually forming drusy crusts and stalactitic aggregates; also as fibrous encrusting masses with a mammillary surface.

Descloizite occurs in oxidised portions of veins of lead ores in association with pyromorphite, vanadinite, wulfenite, mottramite, mimetite and cerussite.

The Otavi Mountainland of northern Namibia was once considered home to the greatest vanadium deposits in the world, including those at Berg Aukas, Abenab, Baltika and Uitsab. Descloizite and mottramite were the main ore minerals in each of these deposits, which are now exhausted. Other localities are the Sierra de Cordoba in Argentina; Lake Valley in Sierra County, New Mexico; Arizona; Phoenixville in Pennsylvania and Kappel (Eisen-Kappel) near Klagenfurt in Carinthia.

Duftite

Duftite	
	
Duftite from Benahadux, Almeria, Andalusia, Spain. Specimen size 2.4 cm	
General	
Category	Arsenate minerals
Chemical formula	$PbCuAsO_4(OH)$
Strunz classification	08.BH.35
Dana classification	41.5.1.4
Crystal symmetry	Orthorhombic 222
Unit cell	a = 7.768(1) Å, b = 9.211(1) Å, c = 5.999(1) Å; Z=4
Identification	
Molar mass	426.67 g
Color	Green, olive green or grey green.

	Generally zoned due to compositional variations
Crystal habit	Tiny crystals elongated along [001] with curved and rough faces, aggregated into crusts. Crystals may be pseudo-octahedral.
Crystal system	Orthorhombic 222 disphenoidal
Cleavage	Indistinct
Fracture	Uneven to conchoidal
Mohs scale hardness	4.5
Luster	Vitreous on fracture surfaces and dull on crystal faces
Streak	Pale green or white
Diaphaneity	Crystals are transparent to translucent
Specific gravity	6.4 (measured), 6.60 (calculated)
Optical properties	Biaxial (-)
Refractive index	n_α = 2.03 to 2.04, n_β = 2.06 to 2.08, n_γ = 2.08 to 2.10
Birefringence	δ = 0.0600
2V angle	Large
Dispersion	r > v, perceptible
Other characteristics	Decrepitates on heating. Not radioactive.

Duftite is a relatively common arsenate mineral with the formula $CuPb(AsO_4)(OH)$, related to conichalcite. It is green and often forms botryoidal aggregates. It is a member of the Adelite-Descloizite Group, Conichalcite-Duftite Series. Duftite and conichalcite specimens from Tsumeb are commonly zoned in colour and composition. Microprobe analyses and X-ray powder-diffraction studies indicate extensive substitution of Zn for Cu, and Ca for Pb in the duftite structure. This indicates a solid solution among conichalcite, $CaCu(AsO_4)(OH)$, austinite, $CaZn(AsO_4)(OH)$ and duftite

$PbCu(AsO_4)(OH)$, all of them belonging to the adelite group of arsenates. It was named after Mining Councilor G Duft, Director of the Otavi Mine and Railroad Company, Tsumeb, Namibia. The type locality is the Tsumeb Mine, Tsumeb, Otjikoto Region, Namibia.

Structure

The structure is composed of chains of edge-sharing CuO_6 distorted octahedra parallel to the c axis. The chains are linked by AsO_4 tetrahedra and Pb atoms.

Environment

Duftite is an uncommon product of weathered sulfide ore deposits. It is associated with azurite at the type locality, and with bayldonite, segnitite, agardite and gartrellite at the Central Cobar Mines, New South Wales, Australia, where some pseudomorphs of duftite after mimetite have also found. It occurs in association with olivenite, mottramite, azurite, malachite, wulfenite and calcite in the Tsumeb, Namibia deposite. It occurs with bayldonite, beudantite, mimetite and cerussite in the Cap Garonne mine, France.

Duftite on cerussite, Tsumeb mine, Namibia. Size: 6 x 5 x 3 cm.

Distribution

Reported from Argentina, Australia, Austria, Chile, the Czech Republic, France, Germany, Greece, Italy, Japan, Mexico, Namibia, Poland, Portugal, Russia, South Africa, Spain, Switzerland, the UK, the USA and Zimbabwe.

Mimetite

Mimetite	
	
General	
Category	Arsenate minerals
Chemical formula	$Pb_5(AsO_4)_3Cl$ lead chloro-arsenate
Strunz classification	08.BN.05
Identification	
Color	Yellow, Brown, Orange, Red, White
Crystal habit	Reniform, botryoidal, globular, prismatic
Crystal system	Hexagonal
Cleavage	[1011] Imperfect
Fracture	Brittle, conchoidal
Mohs scale hardness	3.5 - 4
Luster	Resinous, adamantine
Streak	White

Diaphaneity	Subtransparent to translucent
Specific gravity	7.1 - 7.24
Refractive index	2.129 - 2.144

Mimetite, whose name derives from the Greek Μιμητής *mimethes*, meaning "imitator", is an arsenate mineral which forms as a secondary mineral in lead deposits, usually by the oxidation of galena and arsenopyrite. The name is a reference to mimetite's resemblance to the mineral pyromorphite. This resemblance is not coincidental, as mimetite forms a mineral series with pyromorphite ($Pb_5(PO_4)_3Cl$) and with vanadinite ($Pb_5(VO_4)_3Cl$). The most notable occurrences are Mapimi, Durango, Mexico and Tsumeb, Namibia.

Uses of mimetite

Mimetite from Namibia

Industrially, mimetite is a minor ore of lead, especially when found in relatively large quantities. The chief use of mimetite is as a collector's specimen, often creating very attractive botryoidal crusts on the surface of the specimen. Though mimetite is also found in prismatic crystal forms, it is not used as a gemstone due to its softness. The best of these prismatic forms have been found in Johanngeorgenstadt in Saxony and Wheal Unity in Cornwall, England.

Associated minerals

Mimetite is found in association with lead and arsenic minerals, including those minerals with which it forms a series. Some associated minerals include:

- Bellite
- Calcite, $CaCO_3$
- Galena, PbS
- Pyromorphite, $Pb_5(PO_4)_3Cl$
- Smithsonite, $ZnCO_3$
- Vanadinite, $Pb_5(VO_4)_3Cl$
- Wulfenite, $PbMoO_4$

Alternative names

Alternative names of mimetite include arsenopyromorphite, mimetesite, and prixite. Campylite is the name for a variety with barrel shaped crystals of a brownish-red or orange-yellow color and containing a considerable proportion of phosphoric acid.

Notes for identification

Useful information pertaining to the field identification of mimetite include its habit, color, and high density. However, this mineral's similarity to pyromorphite can be problematic, especially since these minerals are known to share colors. Pyromorphite is typically green, and mimetite is typically yellow, but specimens of each are known in the other's colors. As a result, some identification may require lab analysis.

Mimetite, Pingtouling Mine, Guangdong Province, China. Size: 2.2 x 2.1 x 1.8 cm.

Mimetite, Santa Eulalia, Chihuahua, Mexico. Size: 5.4 x 3.9 x 1.5 cm.

Mimetite, Bilbao mine, Zacatecas, Mexico. Size: 7.9 x 5.8 x 3.4 cm.

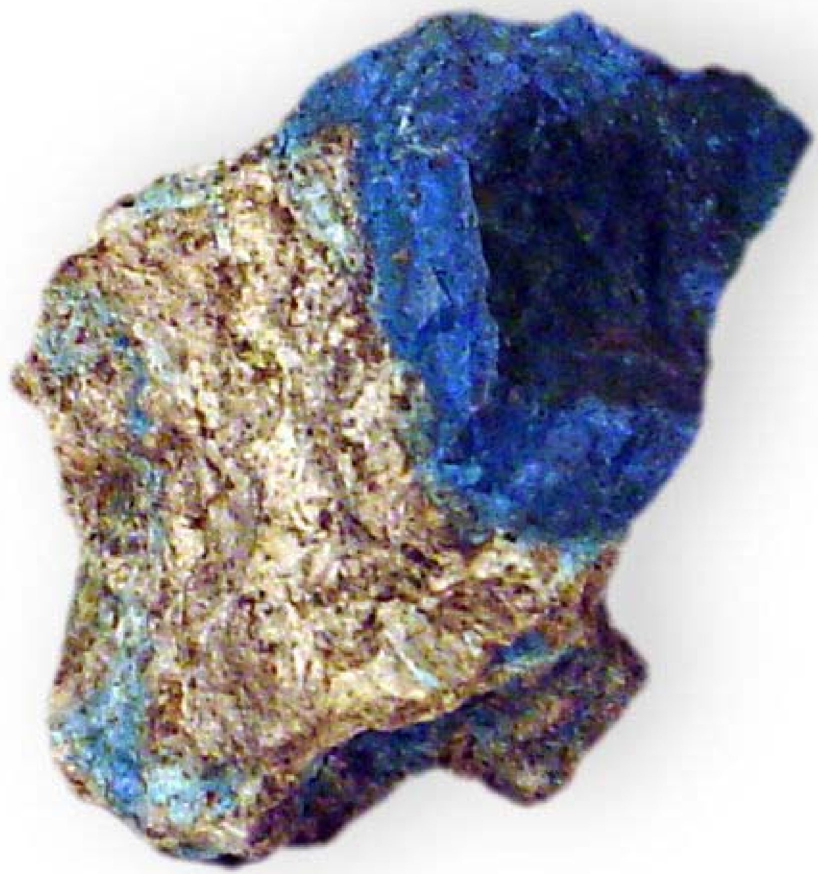
A thumbnail sample of mimetite.

Chapter-6

Magnesium Minerals

Aerinite

Aerinite from Spain



Aerinite from Spain

Aerinite ($Ca_4(Al,Fe,Mg)_{10}Si_{12}O_{35}(OH)_{12}CO_3 \cdot 12H_2O$) is a bluish-purple inosilicate mineral. It crystallizes in the monoclinic system and occurs as fibrous masses and coatings. It has a dark, vitreous luster, a specific gravity of 2.48 and a Mohs hardness of 3.

It is a low temperature hydrothermal phase occurring in zeolite facies alteration of mafic rocks. Associated minerals include prehnite, scolecite and mesolite.

Its name comes from a Greek root "aerinos," meaning "atmosphere" or "sky".

Anthophyllite

Anthophyllite	
	
General	
Category	Inosilicates Amphibole
Chemical formula	Hydrous Magnesium Iron silicate $(Mg,Fe)_7Si_8O_{22}(OH)_2$
Identification	
Color	gray to green, brown, and beige
Crystal habit	Rarely as distinct crystals. Commonly lamellar or fibrous.
Crystal system	orthorhombic; *2/m2/m2/m*
Cleavage	{210} perfect 55°
Mohs scale hardness	5.5 - 6
Luster	Vitreous
Specific gravity	2.85 - 3.2
Refractive	Optically (-) α=1.60 - 1.69, β=1.61 - 1.71,

index	γ=1.62 - 1.72; 2V = 70° - 100° Indices increase with Fe content
Diagnostic features	Characterized by clove brown color, but unless in crystals, difficult to distinguish from other amphiboles without optical and/or X-ray tests

Anthophyllite is an amphibole mineral: $(Mg, Fe)_7Si_8O_{22}(OH)_2$, magnesium iron inosilicate hydroxide. Anthophyllite is polymorphic with cummingtonite. Some forms of anthophyllite are lamellar or fibrous and are used as asbestos. The name is derived from the Latin word *anthophyllum*, meaning *clove*, an allusion to the most common color of the mineral.

Occurrence

Anthophylite is the product of metamorphism of magnesium-rich rocks especially ultrabasic igneous rocks and impure dolomitic shales. It also forms as a retrograde product rimming relict orthopyroxenes and olivine, and as an accessory mineral in cordierite-bearing gneisses and schists. Anthophyllite also occurs as a retrograde metamorphic mineral derived from ultramafic rocks along with serpentinite.

Geographically, it occurs in Pennsylvania, southwestern New Hampshire, central Massachusetts, Franklin, North Carolina, and in the Gravelly Range and Tobacco Root Mountains of southwest Montana.

Occurrence in ultramafic rocks

Anthophyllite is formed by the breakdown of talc in ultramafic rocks in the presence of water and carbon dioxide as a prograde metamorphic reaction. The partial pressure of carbon dioxide (XCO_2) in aqueous solution favors production of anthophyllite. Higher partial pressures of CO_2 reduces the temperature of the *anthophyllite-in* isograd.

Ultramafic rocks in purely hydrous, CO_2-free environments will tend to form serpentinite-antigorite-brucite-tremolite assemblages (dependent on MgO content) or at amphibolite to granulite metamorphic grade, metamorphic pyroxene or olivine. Thus, metamorphic assemblages of ultramafic rocks containing anthophyllite are indicative of at least greenschist facies metamorphism in the presence of carbon dioxide bearing metamorphic fluids.

The typical metamorphic assemblage reactions for low-magnesian (<25% MgO) and high-magnesian (>25% MgO) ultramafic rocks are;

- Olivine + Tremolite + Talc → Olivine + Tremolite + Anthophyllite (low MgO, >550°C, XCO2 <0.6)
- Talc + Tremolite + Magnesite → Tremolite + Anthophyllite + Magnesite (High MgO, >500°C, XCO2 >0.6)
- Talc + Magnesite + Tremolite → Anthophyllite + Tremolite + Magnesite (Low MgO, >500°C, XCO2 >0.6)

Anthophyllite in serpentinised komatiite, Maggie Hays Ni Mine, Western Australia

Retrogressive anthophyllite is relatively rare in ultramafic rocks and is usually poorly developed due to the lower energy state available for metamorphic reactions to progress and also the general dehydration of rock masses during metamorphism. Similarly, the need for substantial components of carbon dioxide in metamorphic fluid restricts the appearance of anthophyllite as a retrograde mineral. The usual metamorphic assemblage of retrograde-altered ultramafic rocks is thus usually a serpentinite or talc-magnesite assemblage.

Retrograde anthophyllite is present most usually in shear zones where fracturing and shearing of the rocks provides a conduit for carbonated fluids during retrogression.

Biotite

Biotite	
 thin tabular Biotite aggregate (Image width: 2.5 mm)	
General	
Category	Silicate mineral
Chemical formula	$K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$
Identification	
Molar mass	433.53 g
Color	Dark brown, greenish brown, blackish brown, yellow, white
Crystal habit	massive to platy
Crystal system	Monoclinic (2/m) Space Group: C 2/m
Twinning	common on the [310], less common on the {001}
Cleavage	Perfect on the {001}
Fracture	Micaceous
Tenacity	Brittle to flexible, elastic
Mohs scale hardness	2.5–3.0
Luster	Vitreous to pearly

Streak	White
Diaphaneity	transparent to translucent to opaque
Specific gravity	2.7–3.1
Density	2.8–3.4
Optical properties	Biaxial (-)
Refractive index	n_α = 1.565–1.625 n_β = 1.605–1.675 n_γ = 1.605–1.675
Birefringence	δ = 0.03–0.07
Pleochroism	strong
Dispersion	r < v (Fe rich); r > v weak (Mg rich)
Ultraviolet fluorescence	None

Biotite is a common phyllosilicate mineral within the mica group, with the approximate chemical formula $K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$. More generally, it refers to the dark mica series, primarily a solid-solution series between the iron-endmember annite, and the magnesium-endmember phlogopite; more aluminous endmembers include siderophyllite. Biotite was named by J.F.L. Hausmann in 1847 in honour of the French physicist Jean-Baptiste Biot, who, in 1816, researched the optical properties of mica, discovering many unique properties.

Biotite is a sheet silicate. Iron, magnesium, aluminium, silicon, oxygen, and hydrogen form sheets that are weakly bond together by potassium ions. It is sometimes called "iron mica" because it is more iron-rich than phlogopite. It is also sometimes called "black mica" as opposed to "white mica" (muscovite) – both form in some rocks, in some instances side-by-side.

Properties

Like other mica minerals, biotite has a highly perfect basal cleavage, and consists of flexible sheets, or lamellae, which easily flake off. It has a monoclinic crystal system, with tabular to prismatic crystals with an obvious pinacoid termination. It has four prism faces and two pinacoid faces to form a pseudohexagonal crystal. Although not easily seen because of the cleavage and sheets, fracture is uneven. It appears greenish to brown or black, and even yellow when weathered. It can be transparent to opaque, has a vitreous to pearly luster, and a grey-white streak. When biotite is found in large chunks, they are called "books" because it resembles a book with pages of many sheets.

Under cross polarized light biotite can generally be identified by the gnarled bird's eye extinction.

Occurrence

Biotite is found in a wide variety of igneous and metamorphic rocks. For instance, biotite occurs in the lava of Mount Vesuvius and in the Monzoni intrusive complex of the western Dolomites. It is an essential phenocryst in some varieties of lamprophyre. Biotite is occasionally found in large cleavable crystals, especially in pegmatite veins, as in New England, Virginia and North Carolina. Other notable occurrences include Bancroft and Sudbury, Ontario. It is an essential constituent of many metamorphic schists, and it forms in suitable compositions over a wide range of pressure and temperature.

The largest documented single crystals of biotite were approximately 7 m^2 (75 sq ft) sheets found in Iveland, Norway.

Uses

biotite: Topotype deposit

Biotite is used extensively to constrain ages of rocks, by either potassium-argon dating or argon-argon dating. Because argon escapes readily from the biotite crystal structure at high temperatures, these methods may provide only minimum ages for many rocks. Biotite is also useful in assessing temperature histories of metamorphic rocks, because the partitioning of iron and magnesium between biotite and garnet is sensitive to temperature.

Chondrodite

Chondrodite	
	
Chondrodite from Franklin, New Jersey, USA	
General	
Category	Nesosilicates
Chemical formula	$Mg_5(SiO_4)_2F_2$
Strunz classification	8/B.04-20 or 9.AF.45
Dana classification	52.3.2b.2
Identification	
Molar mass	351.6 g
Color	Yellow, orange, red or brown, rarely colorless
Crystal habit	Typically anhedral masses or grains, or as plates flattened on {010}, {001} or {100}.
Crystal system	Monoclinic 2/m Prismatic
Twinning	Simple or multiple twinning common on {001}, also reported on {105} and {305}.
Cleavage	Poor to good on (001)

Fracture	Conchoidal to Uneven
Tenacity	Brittle
Mohs scale hardness	6 to 6.5
Luster	Vitreous to Greasy
Streak	Grey or Yellow
Diaphaneity	Translucent
Specific gravity	3.1 to 3.26
Optical properties	Biaxial(+)
Refractive index	n_α = 1.592 - 1.643, n_β = 1.602 - 1.655, n_γ = 1.619 - 1.675,
Birefringence	0.027 - 0.032
Pleochroism	X golden yellow to orange, Y and Z light yellow to almost colorless
Solubility	Soluble in HCl and H_2SO_4
Other characteristics	Some specimens fluoresce orange yellow under shortwave and orange under longwave UV. Not radioactive.

Chondrodite is a nesosilicate mineral with formula $(Mg,Fe)_5(SiO_4)_2(F,OH,O)_2$. Although it is a fairly rare mineral, it is the most frequently encountered member of the humite group of minerals. It is formed in hydrothermal deposits from locally metamorphosed dolomite. It is also found associated with skarn and serpentinite. It was discovered in 1817 on Mt. Somma, part of the Vesuvius complex in Italy, and named from the Greek for "granule", which is a common habit for this mineral.

Formula

$Mg_5(SiO_4)_2F_2$ is the end member formula as given by the International Mineralogical Association, molar mass 351.6 g. There is usually some OH in the F sites, however, and Fe and Ti can substitute for Mg, so the formula for the naturally occurring mineral is better written $(Mg,Fe,Ti)_5(SiO_4)_2(F,OH,O)_2$.

Structure

The chondrodite structure is based on a slightly distorted hexagonal close packed array of anions O, OH and F with metal ions in the octahedral sites resulting in zigzag chains of $M(O,OH,F)_6$ octahedra. Chains are staggered so that none of the independent tetrahedral sites occupied by Si has OH or F corners. Half of the octahedral sites are filled by divalent cations, principally Mg, and one tenth of the tetrahedral sites are filled by Si. There are three distinct octahedra in the array: Fe is ordered in the M1 sites but not in the larger M2 and smaller M3 sites. Ti is ordered in the M3 positions, which are the smallest, but Ti concentration appears never to exceed 0.5 atoms Ti per formula unit in natural specimens. In the humite series Mg^{2+} is replaced by Fe^{2+}, Mn^{2+}, Ca^{2+} and Zn^{2+} in that order of abundance, though Mg^{2+} always predominates.

Unit cell

Space Group: $P2_1/b$
Unit Cell Parameters:
Synthetic F end member a=7.80 Å, b=4.75 Å, c=10.27 Å, beta=109.2^o.
Synthetic OH end member a=7.914 Å, b=4.752 Å, c=10.350 Å, beta=108.71^o.
Natural chondrodite has a=7.867 to 7.905 Å, b=4.727 to 4.730 Å, c=10.255 to 10.318 Å, beta=109.0^o to 109.33^o. Z=2.

Color

Chondrodite with magnetite, Tilly Foster mine, Brewster, New York, USA

Chondrodite is yellow, orange, red or brown, or rarely colorless, but zoning of different color intensity is common, and intergrown plates of chondrodite, humite, clinohumite, forsterite and monticellite have been reported.

Optical properties

Chondrodite is biaxial(+), with refractive indices variously reported as n_α = 1.592 - 1.643, n_β = 1.602 - 1.655, n_γ = 1.619 - 1.675, birefringence = 0.025 - 0.037, and 2V measured as 64° to 90°, calculated: 76° to 78°. Refractive indices tend to increase from norbergite to clinohumite in the humite group. They also increase with Fe^{2+} and Ti^{4+} and with $(OH)^-$ substituting for F^-. Dispersion: r > v.

Environment

Chondrite is found largely in metamorphic contact zones between carbonate rocks and acidic or alkaline intrusions where fluorine has been introduced by metasomatic processes. It is formed by the hydration of olivine, $(Mg,Fe^{2+})_2SiO_4$, and is stable over a range of temperatures and pressures that include those existing in a portion of the uppermost mantle.

Titanian chondrodite has been found as inclusions in olivine in serpentinite in West Greenland, where it is associated with clinohumite, olivine, magnesite, magnetite and Ni-Co-Pb sulfides in a matrix of antigorite.

Cordierite

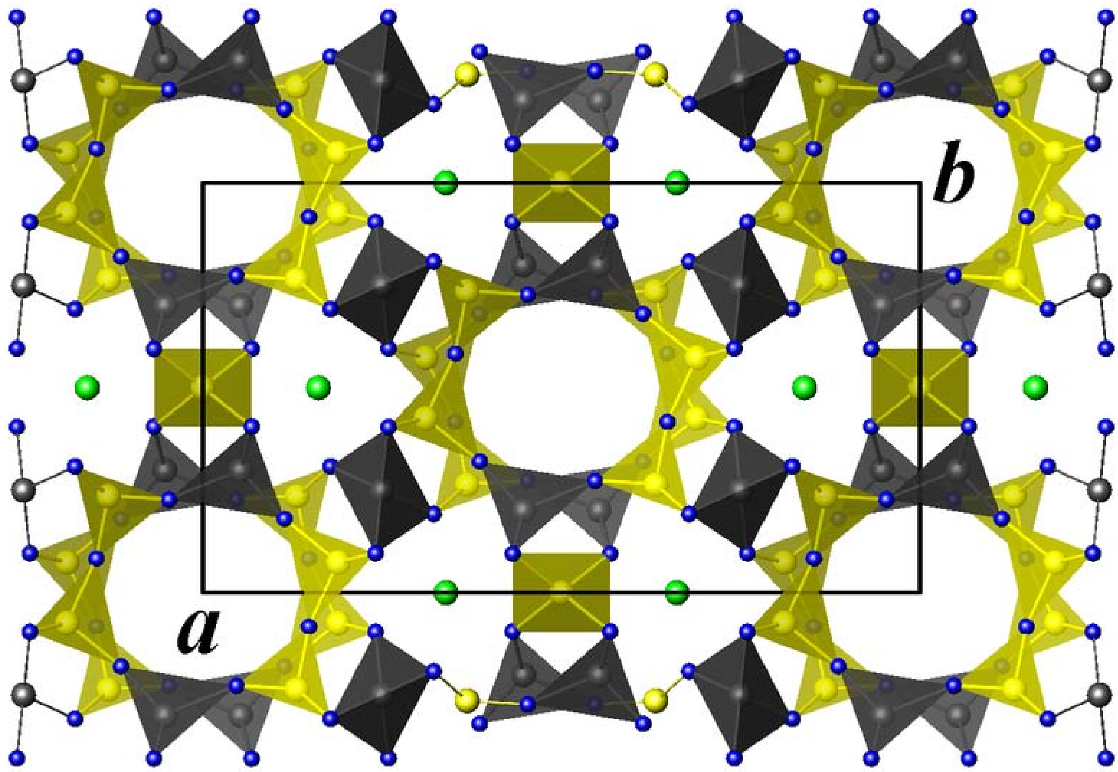
Cordierite

Cordierite from Madagascar

General	
Category	Silicate mineral
Chemical formula	$(Mg,Fe)_2Al_4Si_5O_{18}$
Strunz classification	09.CJ.10
Dana classification	61.02.01.01 Cordierite group
Crystal symmetry	2/m 2/m 2/m Orthorhombic - Dipyramidal
Unit cell	a = 17.079 Å, b = 9.730 Å, c = 9.356 Å; Z = 4

Identification	
Color	Blue, smoky blue, bluish violet; greenish, yellowish brown, gray; colorless to very pale blue in thin section
Crystal habit	Pseudo-hexagonal prismatic twins, as imbedded grains, and massive
Crystal system	Orthorhombic - Dipyramidal Space Group: C ccm
Twinning	Common on {110}, {130}, simple, lamellar, cyclical
Cleavage	Fair on {100}, poor on {001} and {010}
Fracture	Subconchoidal
Tenacity	Brittle
Mohs scale hardness	7 - 7.5
Luster	Greasy or vitreous
Streak	White
Specific gravity	2.57 - 2.66
Optical properties	Usually optically (-), sometimes (+); 2V = 0-90°
Refractive index	n_α = 1.527 - 1.560 n_β = 1.532 - 1.574 n_γ = 1.538 - 1.578 Indices increase with Fe content.
Pleochroism	X = pale yellow, green; Y = violet, blue-violet; Z = pale blue
Fusibility	on thin edges
Diagnostic features	Resembles quartz can be distinguished by pleochroism. Can be distinguished from corundum by its lower hardness

Cordierite (mineralogy) or **iolite** (gemology) is a magnesium iron aluminium cyclosilicate. Iron is almost always present and a solid solution exists between Mg-rich cordierite and Fe-rich sekaninaite with a series formula: $(Mg,Fe)_2Al_3(Si_5AlO_{18})$ to $(Fe,Mg)_2Al_3(Si_5AlO_{18})$. A high temperature polymorph exists, indialite, which is isostructural with beryl and has a random distribution of Al in the $(Si,Al)_6O_{18}$ rings.



Crystal structure of Cordierite

Name and discovery

Cordierite is named after the French geologist Louis Cordier (1777–1861). Discovered in 1813.

Occurrence

Cordierite typically occurs in contact or regional metamorphism of argillaceous rocks. It is especially common in hornfels produced by contact metamorphism of pelitic rocks. Two common metamorphic mineral assemblages include sillimanite-cordierite-spinel and cordierite-spinel-plagioclase-orthopyroxene. Other associated minerals include garnet (cordierite-garnet-sillimanite gneisses) and anthophyllite. Cordierite also occurs in some granites, pegmatites, and norites in gabbroic magmas. Alteration products include mica, chlorite, and talc. Cordierite occurs in the granite contact zone at Geevor Tin Mine in Cornwall.

Commercial use

Catalytic converters are commonly made from ceramics containing a large proportion of cordierite. The manufacturing process deliberately aligns the cordierite crystals to make use of the very low thermal expansion seen for one axis. This prevents thermal shock cracking from taking place when the catalytic converter is used.

Gem variety

Left: rough specimen showing dichroism; *right*: cut stone

Facet cut Iolite gemstone

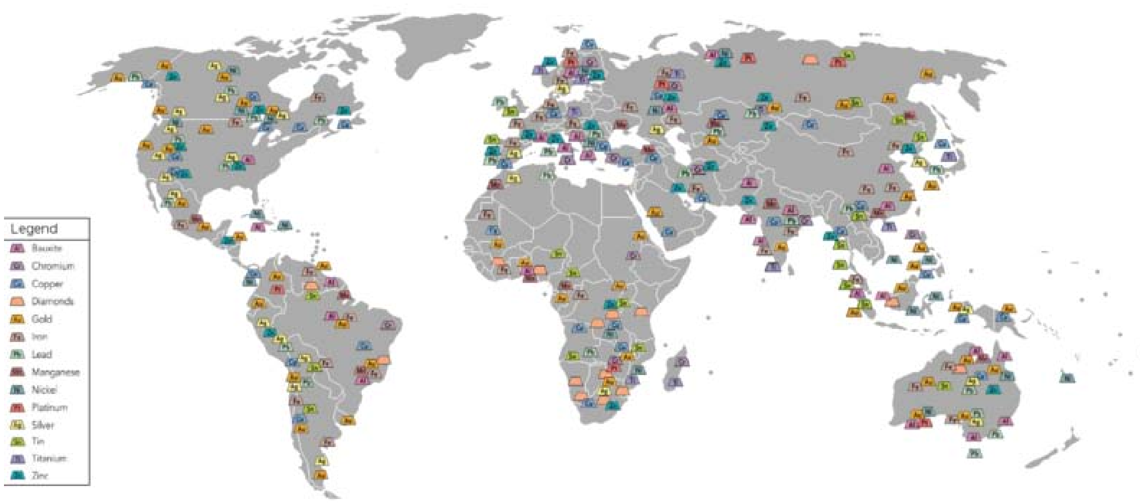
Pleochroism of Cordierite

As the transparent variety iolite, it is often used as a gemstone. The name "iolite" comes from the Greek word for violet. Another old name is *dichroite*, a Greek word meaning "two-colored rock", a reference to cordierite's strong pleochroism. It has also been called "water-sapphire" and "Vikings' Compass", because of its ability to determine the direction of the sun on overcast days. This works by determining the direction of polarization of the sky overhead. Light scattered by air molecules is polarized, and the direction of the polarization is at right angles to a line to the sun, even when the sun's disk itself is obscured by dense fog or lies just below the horizon.

Gem quality iolite varies in color from sapphire blue to blue violet to yellowish gray to light blue as the light angle changes. Iolite is sometimes used as an inexpensive substitute for sapphire. It is much softer than sapphires and is abundantly found in Sri Lanka, India, Burma, Australia's Northern Territory, Namibia, Brazil, Tanzania, Madagascar, Connecticut, and the Yellowknife area of the Northwest Territories of Canada.

Chapter-7

Mining



Simplified world active mining map

Chuquicamata, Chile, site of the largest circumference and second deepest open pit copper mine in the world.

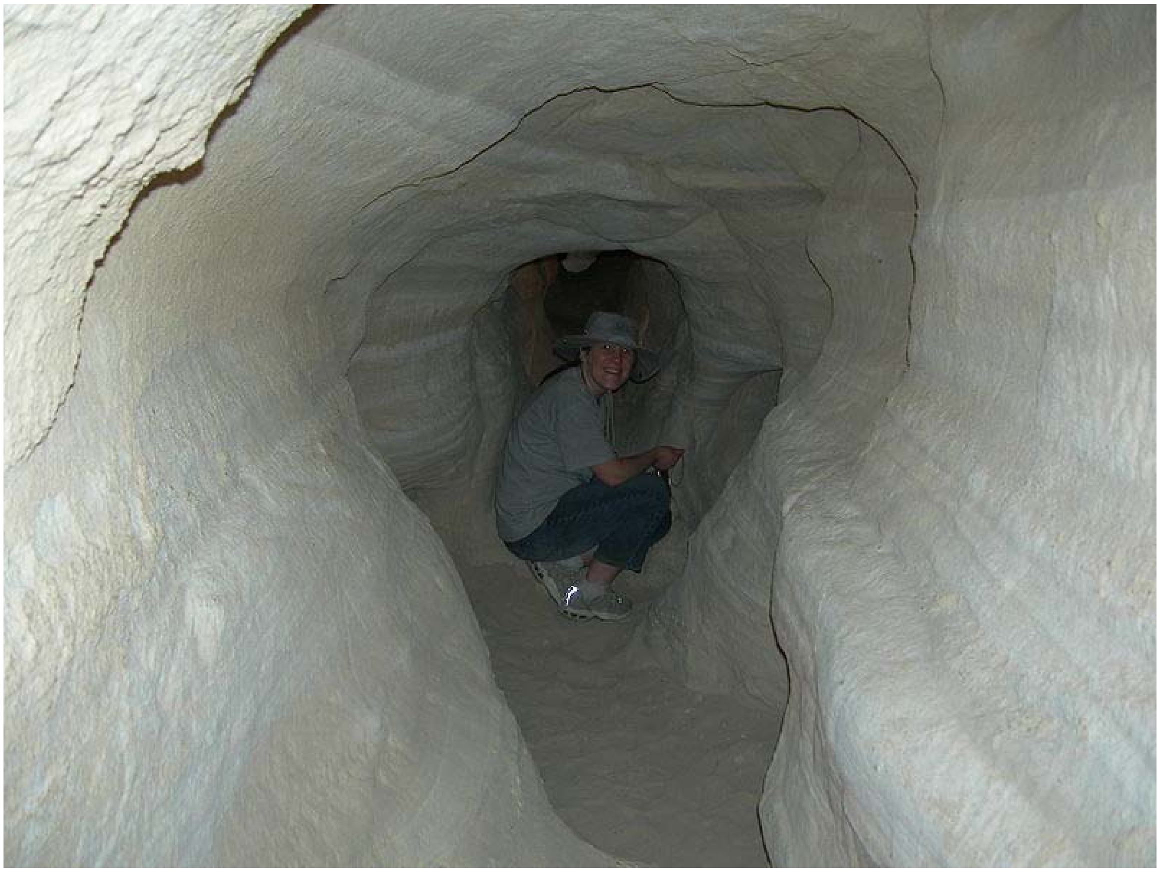
Mining is the extraction of valuable minerals or other geological materials from the earth, from an ore body, vein or (coal) seam. The term also includes the removal of soil. Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash. Any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory, is usually mined. Mining in a wider sense comprises extraction of any non-renewable resource (e.g., petroleum, natural gas, or even water).

Mining of stone and metal has been done since pre-historic times. Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed.

The nature of mining processes creates a potential negative impact on the environment both during the mining operations and for years after the mine is closed. This impact has led to most of the world's nations adopting regulations to moderate the negative effects of mining operations. Safety has long been a concern as well, though modern practices have improved safety in mines significantly.

History

Prehistoric mining



Chalcolithic copper mine in Timna Valley, Negev Desert, Israel.

Since the beginning of civilization, people have used stone, ceramics and, later, metals found on or close to the Earth's surface. These were used to manufacture early tools and weapons, for example, high quality flint found in northern France and southern England were used to create flint tools. Flint mines have been found in chalk areas where seams of the stone were followed underground by shafts and galleries. The mines at Grimes Graves are especially famous, and like most other flint mines, are Neolithic in origin (ca 4000 BC-ca 3000 BC). Other hard rocks mined or collected for axes included the greenstone of the Langdale axe industry based in the English Lake District.

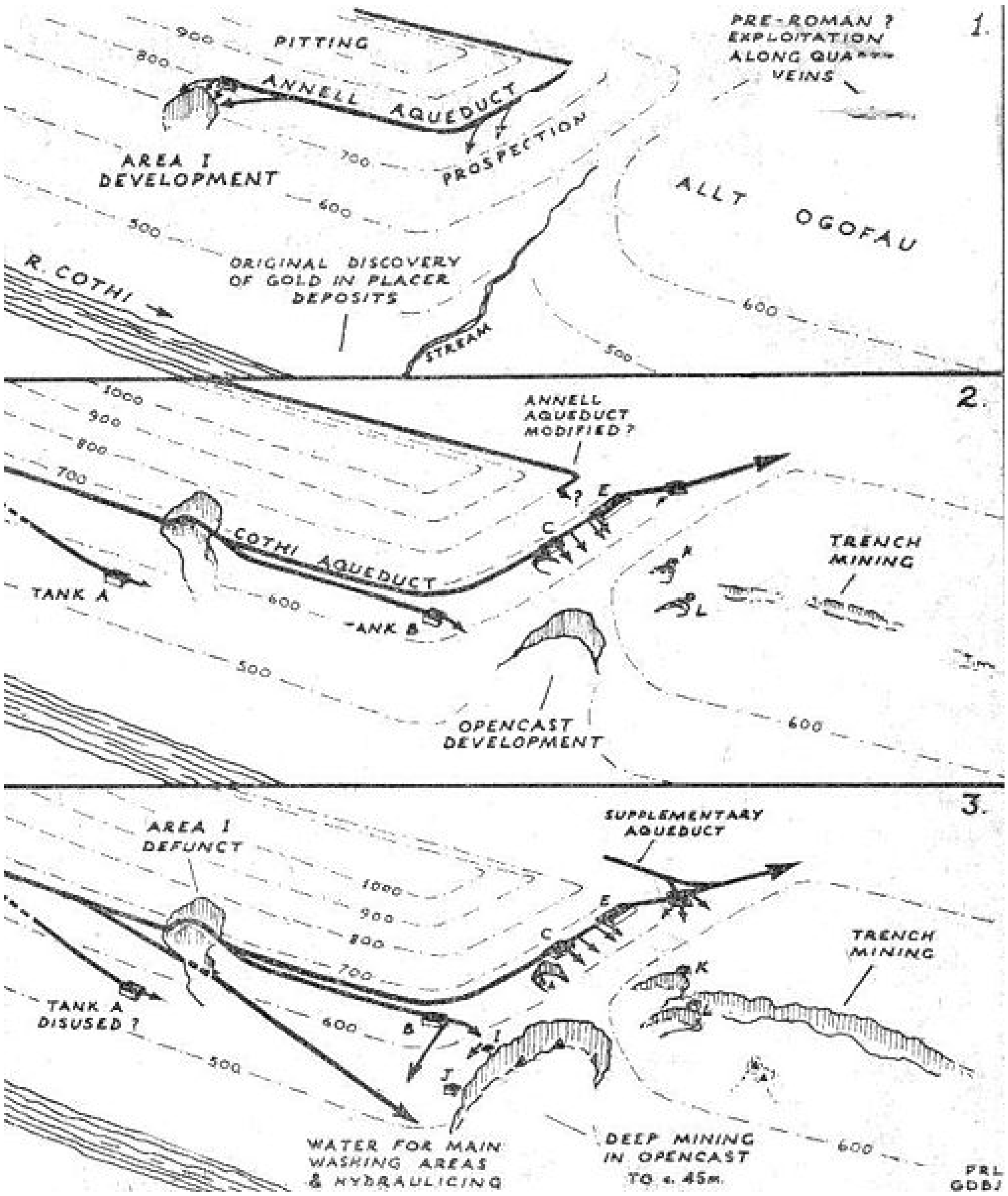
The oldest known mine on archaeological record is the "Lion Cave" in Swaziland , which radiocarbon dating show to be about 43,000 years old,. At this site paleolithic humans mined mineral hematite, which is Iron oxide (similar to rust), was ground to produce the red pigment ochre. Mines of a similar age in Hungary are believed to be sites where Neanderthals may have mined flint for weapons and tools.

Ancient Egypt

Ancient Egyptians mined malachite at Maadi. At first, Egyptians used the bright green malachite stones for ornamentations and pottery. Later, between 2,613 and 2,494 BC, large building projects required expeditions abroad to the area of Wadi Maghara in order "to secure minerals and other resources not available in Egypt itself." Quarries for turquoise and copper were also found at "Wadi Hamamat, Tura, Aswan and various other Nubian sites" on the Sinai Peninsula and at Timna.

Mining in Egypt occurred in the earliest dynasties, and the gold mines of Nubia were among the largest and most extensive of any in Ancient Egypt, and are described by the Greek author Diodorus Siculus. He mentions that fire-setting was one method used to break down the hard rock holding the gold. One of the complexes is shown in one of earliest known maps. They crushed the ore and ground it to a fine powder before washing the powder for the gold dust.

Ancient Greece and Rome



Ancient Roman development of the Dolaucothi Gold Mines, Wales.

Mining in Europe has a very long history, examples including the silver mines of Laurium, which helped support the Greek city state of Athens. However, it is the Romans who developed large scale mining methods, especially the use of large volumes of water brought to the minehead by numerous aqueducts. The water was used for a variety of purposes, including using it to remove overburden and rock debris, called hydraulic mining, as well as washing comminuted or crushed ores, and driving simple machinery.

The Romans used hydraulic mining methods on a large scale to prospect for the veins of ore, especially a now obsolete form of mining known as hushing. It involved building numerous aqueducts to supply water to the minehead where it was stored in large reservoirs and tanks. When a full tank was opened, the wave of water sluiced away the overburden to expose the bedrock underneath and any gold veins. The rock was then attacked by fire-setting to heat the rock, which would be quenched with a stream of water. The thermal shock cracked the rock, enabling it to be removed, aided by further streams of water from the overhead tanks. They used similar methods to work cassiterite deposits in Cornwall and lead ore in the Pennines.

The methods had been developed by the Romans in Spain in 25 AD to exploit large alluvial gold deposits, the largest site being at Las Medulas, where seven long aqueducts were built to tap local rivers and to sluice the deposits. Spain was one of the most important mining regions, but all regions of the Roman Empire were exploited. They used reverse overshot water-wheels for dewatering their deep mines such as those at Rio Tinto. In Great Britain the natives had mined minerals for millennia , but when the Romans came, the scale of the operations changed dramatically.

The Romans needed what Britain possessed, especially gold, silver, tin and lead. Roman techniques were not limited to surface mining. They followed the ore veins underground once opencast mining was no longer feasible. At Dolaucothi they stoped out the veins, and drove adits through barren rock to drain the stopes. The same adits were also used to ventilate the workings, especially important when fire-setting was used. At other parts of the site, they penetrated the water table and dewatered the mines using several kinds of machine, especially reverse overshot water-wheels. These were used extensively in the copper mines at Rio Tinto in Spain, where one sequence comprised 16 such wheels arranged in pairs, and lifting water about 80 feet (24 m). They were worked as treadmills with miners standing on the top slats. Many examples of such devices have been found in old Roman mines and some examples are now preserved in the British Museum and the National Museum of Wales.

Medieval Europe

Agricola, author of *De Re Metallica*

Mining as an industry underwent dramatic changes in medieval Europe. The mining industry in the early Middle Ages was mainly focused on the extraction of copper and iron. Other precious metals were also used mainly for gilding or coinage. Initially, many metals were obtained through open-pit mining, and ore was primarily extracted from shallow depths, rather than though the digging of deep mine shafts. Around the 14th century, the demand for weapons, armor, stirrups, and horseshoes greatly increased the demand for iron. Medieval knights for example were often laden with up to 100 pounds of plate or chain link armor in addition to swords, lances and other weapons. The overwhelming dependency on iron for military purposes helped to spur increased iron production and extraction processes.

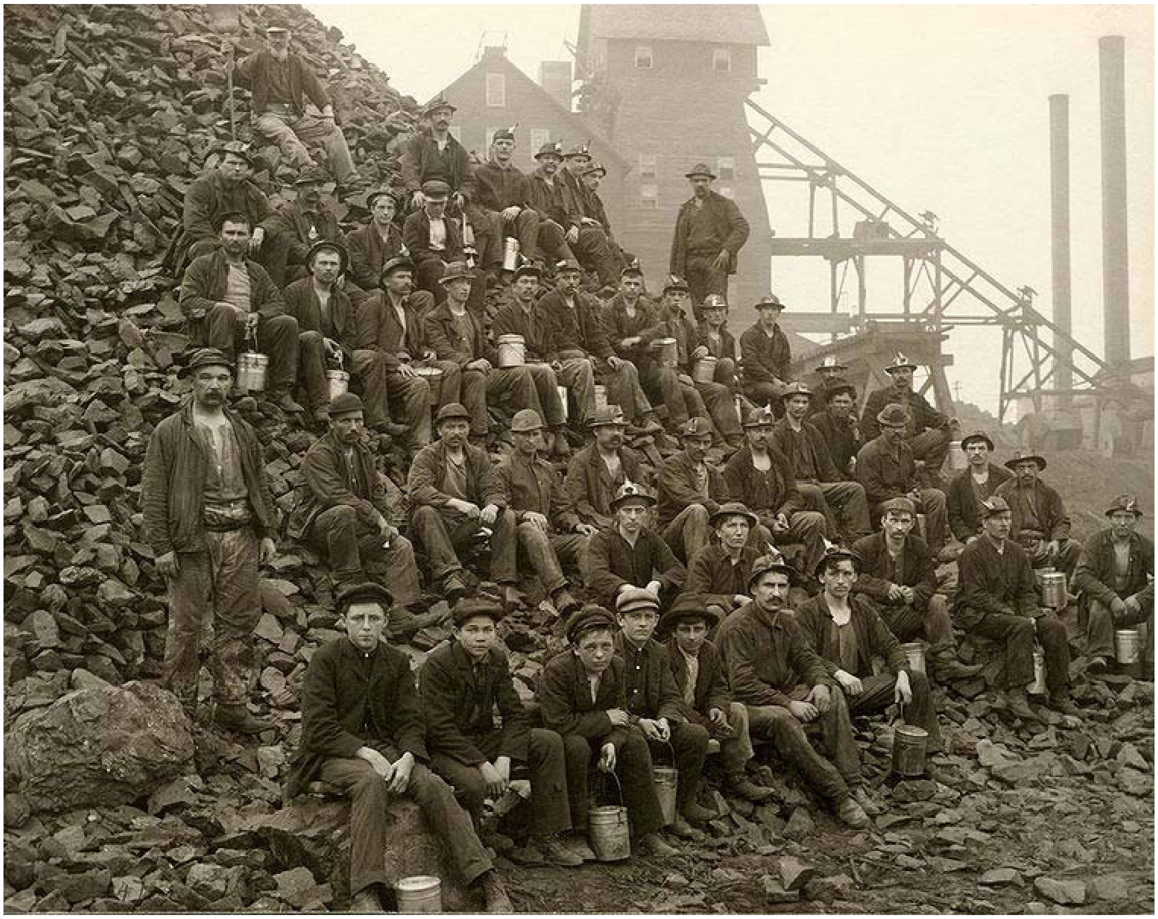
These new military applications coincided with a population explosion throughout Europe in the 11th-14th centuries which enriched the demand for precious metals in order to fill a currency shortage. The silver crisis of 1465 occurred when the mines had all reached depths at which the shafts could no longer be pumped dry with the available technology. Although the increased use of bank notes and the use of credit during this period did decrease the dependence and value of precious metals, these forms of currency still remained vital to the story of medieval mining. Use of water power in the form of water mills was extensive; they were employed in crushing ore, raising ore from shafts and ventilating galleries by powering giant bellows. Black powder was first used in mining in Selmecbánya, Kingdom of Hungary (present-day Banská Štiavnica, Slovakia) in 1627. Black powder allowed blasting of rock and earth to loosen and reveal ore veins, which was much faster than fire-setting, in which rock was exposed to heat and then doused with cold water. Black powder allowed the mining of previously impenetrable metals and ores. In 1762, the world's first mining academy was established in the same town.

The widespread adoption of agricultural innovations such as the iron plowshare, as well as the growing use of metal as a building material, was also a driving force in the tremendous growth of the iron industry during this period. Inventions like the arrastra were often used by the Spanish to pulverize ore after being mined. This device employed animal power and utilized mechanical principles similar to that of the ancient Middle Eastern technology of grain threshing.

Much of our knowledge of Medieval mining techniques comes from books such as Biringuccio’s *De la pirotechnia* and probably most importantly from Georg Agricola's *De re metallica* (1556). These books detail many different mining methods used in German and Saxon mines. One of the prime issues confronting medieval miners (and one which Agricola explains in detail) was the removal of water from mining shafts. As miners dug deeper to access new veins, flooding became a very real obstacle. As a result the mining industry became dramatically more efficient and prosperous as the use of various mechanical and animal driven pump systems were implemented.

North and South America

Lead mining in the upper Mississippi River region of the U.S., 1865.



Miners at the Tamarack Mine in Copper Country, Michigan, U.S. in 1905.

In North America there are ancient, prehistoric copper mines along Lake Superior. "Indians availed themselves of this copper starting at least 5000 years ago," and copper tools, arrowheads, and other artifacts that were part of an extensive native trade network have been discovered. In addition, obsidian, flint, and other minerals were mined, worked, and traded. While the early French explorers that encountered the sites made no use of the metals due to the difficulties in transporting it, the copper was eventually traded throughout the continent along major river routes. In Manitoba, Canada, there also are ancient quartz mines near Waddy Lake and surrounding regions.

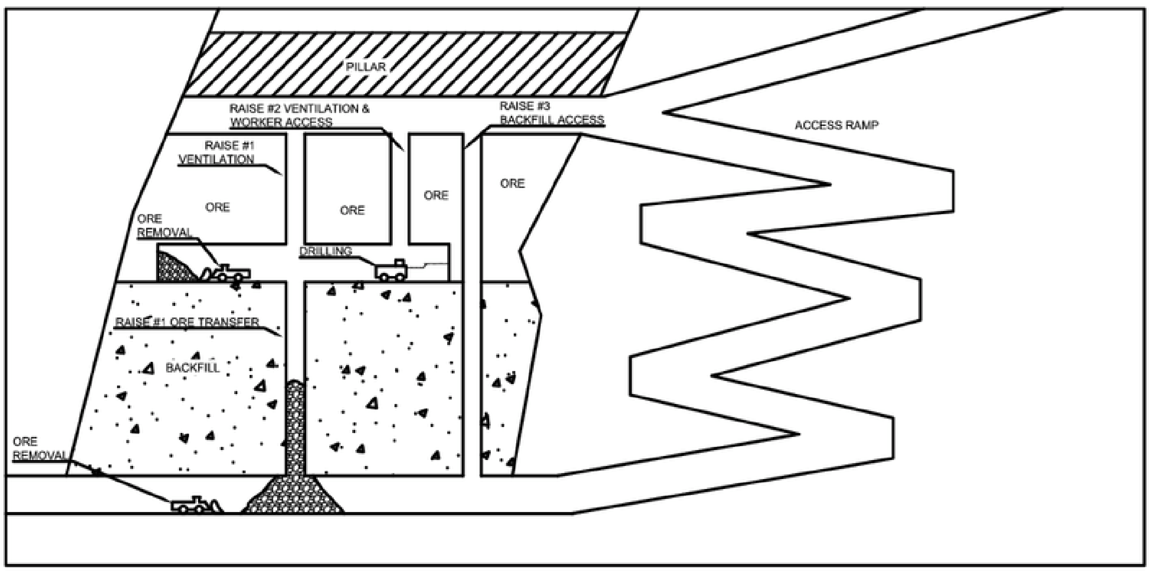
In the early colonial history of the Americas, "native gold and silver was quickly expropriated and sent back to Spain in fleets of gold- and silver-laden galleons" mostly from mines in Central and South America. Turquoise dated at 700 A.D. was mined in pre-Columbian America; in the Cerillos Mining District in New Mexico, estimates are that "about 15,000 tons of rock had been removed from Mt Chalchihuitl using stone tools before 1700."

Mining in the United States became prevalent in the 19th century, and the General Mining Act of 1872 was passed to encourage mining of federal lands. As with the

California Gold Rush in the mid 19th century, mining for minerals and precious metals, along with ranching, was a driving factor in the Westward Expansion to the Pacific coast. With the exploration of the West, mining camps were established and "expressed a distinctive spirit, an enduring legacy to the new nation;" Gold Rushers would experience the same problems as the Land Rushers of the transient West that preceded them. Aided by railroads, many traveled West for work opportunities in mining. Western cities such as Denver and Sacramento originated as mining towns.

Mining methods and procedures

Steps of mine development



Schematic of a cut and fill mining operation in hard rock.

The process of mining from discovery of an ore body through extraction of minerals and finally to returning the land to its natural state consists of several distinct steps. The first is discovery of the ore body, which is carried out through prospecting or exploration to find and then define the extent, location and value of the ore body. This leads to a mathematical resource estimation to estimate the size and grade of the deposit.

This estimation is used to conduct a pre-feasibility study to determine the theoretical economics of the ore deposit. This identifies, early on, whether further investment in estimation and engineering studies is warranted and identifies key risks and areas for further work. The next step is to conduct a feasibility study to evaluate the financial viability, technical and financial risks and robustness of the project.

This is when the mining company makes the decision to develop the mine or to walk away from the project. This includes mine planning to evaluate the economically recoverable portion of the deposit, the metallurgy and ore recoverability, marketability and payability of the ore concentrates, engineering concerns, milling and infrastructure costs, finance and equity requirements and an analysis of the proposed mine from the initial excavation all the way through to reclamation. The proportion of a deposit that is economically recoverable is dependent on the enrichment factor of the ore in the area.

Once the analysis determines a given ore body is worth recovering, development begins to create access to the ore body. The mine buildings and processing plants are built and any necessary equipment is obtained. The operation of the mine to recover the ore begins and continues as long as the company operating the mine finds it economical to do so. Once all the ore that the mine can produce profitably is recovered, reclamation begins to make the land used by the mine suitable for future use.

Mining techniques

Underground Longwall mining.

Mining techniques can be divided into two common excavation types: surface mining and sub-surface (underground) mining. Surface mining is much more common, and produces, for example, 85% of minerals (excluding petroleum and natural gas) in the United States, including 98% of metallic ores. Targets are divided into two general categories of materials: *placer deposits*, consisting of valuable minerals contained within river gravels, beach sands, and other unconsolidated materials; and *lode deposits*, where valuable minerals are found in veins, in layers, or in mineral grains generally distributed throughout a mass of actual rock. Both types of ore deposit, placer or lode, are mined by both surface and underground methods.

Processing of placer ore material consists of gravity-dependent methods of separation, such as sluice boxes. Only minor shaking or washing may be necessary to disaggregate (unclump) the sands or gravels before processing. Processing of ore from a lode mine, whether it is a surface or subsurface mine, requires that the rock ore be crushed and pulverized before extraction of the valuable minerals begins. After lode ore is crushed, recovery of the valuable minerals is done by one, or a combination of several, mechanical and chemical techniques.

Uranium mine near Moab, Utah.

Some mining, including much of the rare earth elements and uranium mining, is done by less-common methods, such as in-situ leaching: this technique involves digging neither at the surface nor underground. The extraction of target minerals by this technique requires that they be soluble, e.g., potash, potassium chloride, sodium chloride, sodium sulfate, which dissolve in water. Some minerals, such as copper minerals and uranium oxide, require acid or carbonate solutions to dissolve.

Surface mining is done by removing (stripping) surface vegetation, dirt, and if necessary, layers of bedrock in order to reach buried ore deposits. Techniques of surface mining include; Open-pit mining which consists of recovery of materials from an open pit in the ground, quarrying or gathering building materials from an open pit mine, strip mining which consists of stripping surface layers off to reveal ore/seams underneath, and mountaintop removal, commonly associated with coal mining, which involves taking the top of a mountain off to reach ore deposits at depth. Most (but not all) placer deposits, because of their shallowly buried nature, are mined by surface methods. Landfill mining, finally, involves sites where landfills are excavated and processed.

Sub-surface mining consists of digging tunnels or shafts into the earth to reach buried ore deposits. Ore, for processing, and waste rock, for disposal, are brought to the surface through the tunnels and shafts. Sub-surface mining can be classified by the type of access shafts used, the extraction method or the technique used to reach the mineral deposit. Drift mining utilizes horizontal access tunnels, slope mining uses diagonally sloping access shafts and shaft mining consists of vertical access shafts.

Other methods include shrinkage stope mining which is mining upward creating a sloping underground room, long wall mining which is grinding a long ore surface underground and room and pillar which is removing ore from rooms while leaving pillars in place to support the roof of the room. Room and pillar mining often leads to retreat mining which is removing the pillars which support rooms, allowing the room to cave in, loosening more ore. Additional sub-surface mining methods include hard rock mining which is mining of hard materials, bore hole mining, drift and fill mining, long hole slope mining, sub level caving and block caving

Machinery

The Bagger 288 is a bucket-wheel excavator used in strip mining.

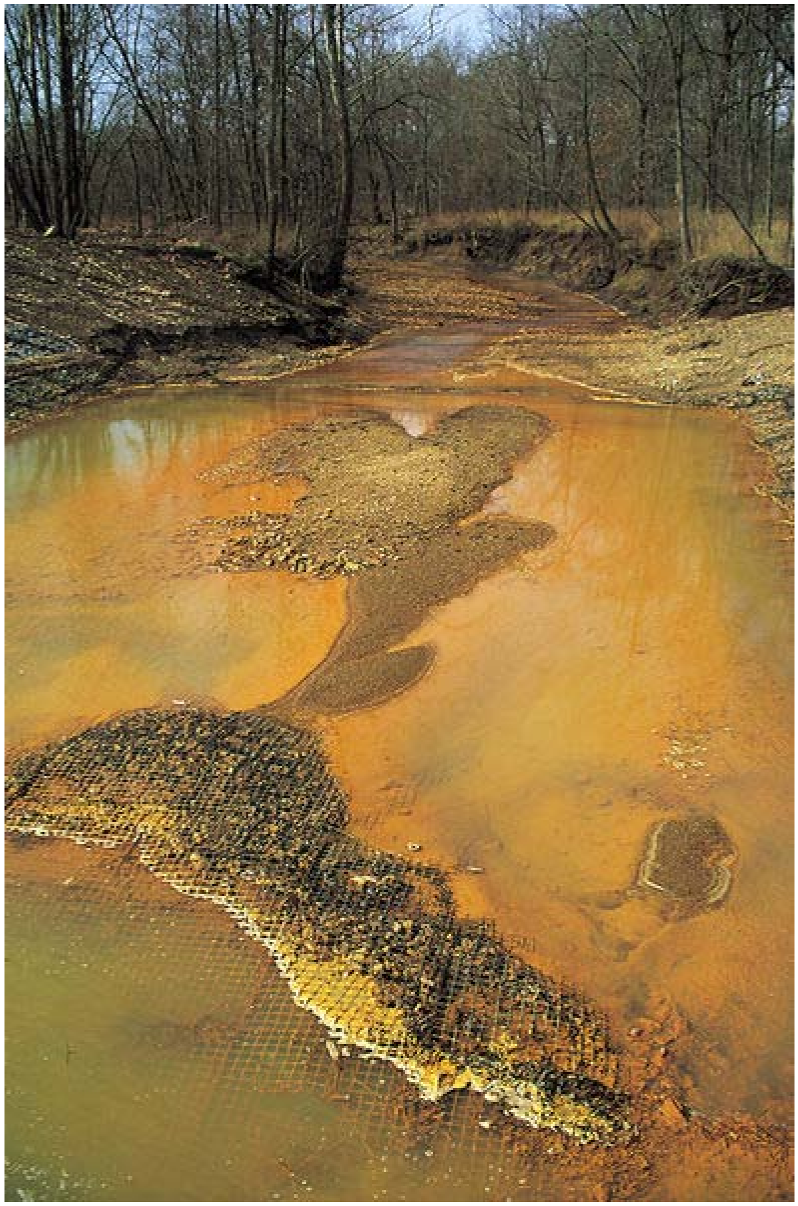
Heavy machinery is needed in mining for exploration and development, to remove and stockpile overburden, to break and remove rocks of various hardness and toughness, to process the ore and for reclamation efforts after the mine is closed. Bulldozers, drills, explosives and trucks are all necessary for excavating the land. In the case of placer mining, unconsolidated gravel, or alluvium, is fed into machinery consisting of a hopper and a shaking screen or trommel which frees the desired minerals from the waste gravel. The minerals are then concentrated using sluices or jigs.

Large drills are used to sink shafts, excavate stopes and obtain samples for analysis. Trams are used to transport miners, minerals and waste. Lifts carry miners into and out of mines, as well as moving rock and ore out, and machinery in and out of underground mines. Huge trucks, shovels and cranes are employed in surface mining to move large quantities of overburden and ore. Processing plants can utilize large crushers, mills, reactors, roasters and other equipment to consolidate the mineral-rich material and extract the desired compounds and metals from the ore.

Extractive metallurgy

The science of extractive metallurgy is a specialized area in the science of metallurgy that studies the extraction of valuable metals from their ores, especially through chemical or mechanical means. Mineral processing (or mineral dressing) is a specialized area in the science of metallurgy that studies the mechanical means of crushing, grinding, and washing that enable the separation (extractive metallurgy) of valuable metals or minerals from their gangue (waste material). Since most metals are present in ores as oxides or sulfides, the metal needs to be reduced to its metallic form. This can be accomplished through chemical means such as smelting or through electrolytic reduction, as in the case of aluminum. Geometallurgy combines the geologic sciences with extractive metallurgy and mining.

Environmental effects



Iron hydroxide precipitate stains a stream receiving acid drainage from surface coal mining.

Environmental issues can include erosion, formation of sinkholes, loss of biodiversity, and contamination of soil, groundwater and surface water by chemicals from mining processes. In some cases, additional forest logging is done in the vicinity of mines to increase the available room for the storage of the created debris and soil. Contamination resulting from leakage of chemicals can also affect the health of the local population if not properly controlled.

Mining companies in most countries are required to follow stringent environmental and rehabilitation codes in order to minimize environmental impact and avoid impacts on human health. These codes and regulations all require the common steps of Environmental impact assessment, development of Environmental management plans, Mine closure planning (which must be done before the start of mining operations), and Environmental monitoring during operation and after closure. However, in some areas, particularly in the developing world, regulation may not be well enforced by governments.

For major mining companies, and any company seeking international financing, there are however a number of other mechanisms to enforce good environmental standards. These generally relate to financing standards such as Equator Principles, IFC environmental standards, and criteria for Socially responsible investing. Mining companies have used this financial industry oversight to argue for some level of self-policing. In 1992 a Draft Code of Conduct for Transnational Corporations was proposed at the Rio Earth Summit by the UN Centre for Transnational Corporations (UNCTC), but the Business Council for Sustainable Development (BCSD) together with the International Chamber of Commerce (ICC) argued successfully for self-regulation instead.

This was followed up by the Global Mining Initiative which was initiated by nine of the largest metals and mining companies, and led to the formation of the International Council on Mining and Metals to "act as a catalyst" for social and environmental performance improvement in the mining and metals industry internationally. The mining industry has provided funding to various conservation groups, some of which have been working with conservation agendas that are at odds with emerging acceptance of the rights of indigenous people - particularly rights to make land-use decisions.

Ore mills generate large amounts of waste, called tailings. For example, 99 tons of waste are generated per ton of copper, with even higher ratios in gold mining. These tailings can be toxic. Tailings, which are usually produced as a slurry, are most commonly dumped into ponds made from naturally existing valleys. These ponds are secured by impoundments (dams or embankment dams). In 2000 it was estimated that 3,500 tailings impoundments existed, and that every year, 2 to 5 major failures and 35 minor failures occurred for example, in the Marcopper mining disaster at least 2 million tons of tailings were released into a local river. Subaqueous tailings disposal is another option. The mining industry has argued that submarine tailings disposal (STD), which disposes of tailings in the sea, is ideal because it avoids the risks of tailings ponds; although the practice is illegal in the United States and Canada, it is used in the developing world.

Certification of mines with good practices occurs through the International Organization for Standardization (ISO) such as ISO 9000 and ISO 14001, which certifies an 'auditable environmental management system'; this certification involves short inspections, although it has been accused of lacking rigor. Certification is also available through Ceres' Global Reporting Initiative, but these reports are voluntary and unverified. Miscellaneous other certification programs exist for various projects, typically through nonprofit groups.

Regulations and World Bank relationship

The World Bank has been involved in mining since 1955, mainly through grants from its International Bank for Reconstruction and Development, with the Bank's Multilateral Investment Guarantee Agency offering political risk insurance. Between 1955 and 1990 it provided about $2 billion to fifty mining projects, broadly categorized as reform and rehabilitation, greenfield mine construction, mineral processing, technical assistance, and engineering. These projects have been criticized, particularly the Ferro Carajas project of Brazil, begun in 1981. The bank established mining codes intended to increase foreign investment, in 1988 solicited feedback from 45 mining companies on how to increase their involvement.

In 1992 the bank began to push for privatization of government-owned mining companies with a new set of codes, beginning with its report *The Strategy for African Mining*. In 1997, Latin America's largest miner Companhia Vale do Rio Doce (CVRD) was privatized. These and other movements such as the Philippines 1995 Mining Act led the World Bank to publish a third report (*Assistance for Minerals Sector Development and Reform in Member Countries*) which endorsed mandatory environment impact assessments and attention to the locals. The codes based on this report are influential in the legislation of developing nations. The new codes are intended to encourage development through tax holidays, zero custom duties, reduced income taxes, and related measures. The results of these codes were analyzed by a group from the University of Quebec, which concluded that the codes promote foreign investment but "fall very short of permitting sustainable development". The observed negative correlation between natural resources and economic development is known as the resource curse.

Mining industry

Mining exists in many countries but Australia and Canada have a reputation for domestic mining expertise, and London is known as the capital of global "mining houses" such as Rio Tinto, BHP Billiton, and Anglo American PLC. The US mining industry is also large but it is dominated by the coal and nonmetal minerals, and the various regulations have worked to reduce the significance of mining in the United States. In 2007 the total market cap of mining companies was reported at US$962 billion, which compares to a total global market cap of publicly traded companies of about US$50 trillion in 2007.

While exploration and mining can sometimes be conducted by individual entrepreneurs or small business, most modern-day mines are large enterprises requiring large amounts of capital to establish. Consequently, the mining sector of the industry is dominated by large, often multinational companies, most of them publicly listed. It can be argued that what is referred to as the 'mining industry' is actually two sectors, one specializing in exploration for new resources, the other specializing in mining those resources. The exploration sector is typically made up of individuals and small mineral resource companies ("juniors") dependent on venture capital. The mining sector is typically large and multi-national companies sustained by mineral production from their mining operations. In addition to these two sectors, various other industries such as equipment manufacture, environmental testing and metallurgy analysis also rely on and support the mining industry throughout the world. Canadian stock exchanges have a particular focus on mining companies, particularly junior exploration companies through the TSX Venture Exchange; Canadian companies raise capital on these exchanges and then invest the money in exploration globally. Some have argued that below juniors there exists a substantial sector of illegitimate companies primarily focused on manipulating stock prices.

Mining operations can be grouped into five major categories in terms of their respective resources. These are, oil and gas extraction, coal mining, metal ore mining, nonmetallic mineral mining and quarrying, and support activities for mining. Out of all these categories, oil and gas extraction remains one of the largest in terms of its global economic importance. Prospecting potential mining sites, a vital area of concern for the mining industry is now done using sophisticated new technologies such as seismic prospecting and remote-sensing satellites.

Corporate classifications

Mining companies can be classified based on their size and financial capabilities:

- **Major** companies are considered to have an adjusted annual mining-related revenue of more than US$500 million, with the financial capability to develop a major mine on its own.

- **Intermediate** companies have at least $50 million in annual revenue but less than $500 million.

- **Junior** companies rely on equity financing as their principal means of funding exploration. Juniors are mainly pure exploration companies, but may also produce minimally, and do not have a revenue of US$50 million.

Safety

Abandoned mine entrance in Yorkshire, England, United Kingdom

Safety has long been a controversial issue in the mining business especially with sub-surface mining. While mining today is substantially safer than it was in the previous decades, mining accidents are often very high profile, such as the Quecreek Mine Rescue saving 9 trapped Pennsylvania coal miners in 2002. The Courrières mine disaster, Europe's worst mining accident, caused the death of 1,099 miners (including many children) in Northern France on 10 March 1906. It seems that this disaster was surpassed only by the Benxihu Colliery accident in China on April 26, 1942, which killed 1,549 miners. Government figures indicate that 5,000 Chinese miners die in accidents each year, while other reports have suggested a figure as high as 20,000. Mining ventilation is a significant safety concern for many miners. Poor ventilation of the mines causes exposure to harmful gases, heat and dust inside sub-surface mines. These can cause harmful physiological effects, including death. The concentration of methane and other airborne contaminants underground can generally be controlled by dilution (ventilation), capture before entering the host air stream (methane drainage), or isolation (seals and stoppings).

Ignited methane gas is a common source of explosions in coal mines, or, the more violent coal dust explosions. Gases in mines can also poison the workers or displace the oxygen in the mine, causing asphyxiation. For this reason, the MHSA requires that workers have gas detection equipment in groups of miners. It must be able to detect common gases, such as CO, O_2, H_2S, and % Lower Explosive Limit. Additionally, further regulation is being requested for more gas detection as newer technology such as nanotechnology is introduced.

High temperatures and humidity may result in heat-related illnesses, including heat stroke which can be fatal. Dusts can cause lung problems, including silicosis, asbestosis and pneumoconiosis (also known as miners lung or black lung disease). A ventilation system is set up to force a stream of air through the working areas of the mine. The air circulation necessary for the effective ventilation of a mine is generated by one or more large mine fans, usually located above ground. Air flows in one direction only, making circuits through the mine such that each main work area constantly receives a supply of fresh air.

Miners utilize equipment strong enough to break through extremely hard layers of the Earth's crust. This equipment, combined with the closed workspace that underground miners work in, can cause hearing loss. For example, a roof bolter (commonly used by mine roof bolter operators) can reach sound power levels of up to 115 dB. Combined with the reverberant effects of underground mines, a miner without proper hearing protection is at a high risk for hearing loss.

Since mining entails removing dirt and rock from its natural location creating large empty pits, rooms and tunnels, cave-ins are a major concern within mines. Modern techniques for timbering and bracing walls and ceilings within sub-surface mines have reduced the number of fatalities due to cave-ins, but accidents still occur. The presence of heavy equipment in confined spaces also poses a risk to miners, and despite modern improvements to safety practices, mining remains dangerous throughout the world.

Abandoned mines

Abandoned mine in Nevada.

Warning sign near Jerome, Arizona

There are upwards of 560,000 abandoned mines on public and privately owned lands in the United States alone. Abandoned mines may be dangerous to anyone who attempts to explore them without proper knowledge and safety training. Old mines are often dangerous and can contain deadly gases. Standing water in mines from seepage or infiltration poses a significant hazard as the water can hide deep pits and trap gases below the water. Additionally, since weather may have eroded the earth and rock surrounding it, the entrance to an old mine in particular can be very dangerous. Old mine workings, caves, etc. are commonly hazardous simply due to the lack of oxygen in the air, a condition in mines known as blackdamp.

Records

As of 2008, the deepest mine in the world is TauTona in Carletonville, South Africa at 3.9 kilometers, replacing Savuka Mine in the North West Province of South Africa at 3,774 meters. East Rand Mine in Boksburg, South Africa briefly held the record at 3,585 meters, and the first mine declared the deepest in the world was also TauTona when it was at 3,581 meters. The deepest mine in Europe is Bergwerk Saar in Saarland, Germany at 1,750 meters. The second deepest mine in Europe is Pyhäsalmi Mine in Pyhäjärvi, Finland at 1,444 meters. The third deepest mine in Europe is Boulby Mine England at 1,400 meters (shaft depth 1,100 meters).

The deepest open pit mine in the world is Bingham Canyon Mine in Bingham Canyon, Utah, United States at over 1,200 meters. The largest and second deepest open pit copper mine in the world is Chuquicamata in Chuquicamata, Chile at 900 meters, 940,600 tons of copper and 17,700 tons of molybdenum produced annually.

The deepest open pit mine with respect to sea level is Tagebau Hambach in Germany, where the ground of the pit is 293 meters below sea level.

The largest underground mine: El Teniente, in Rancagua, Chile, 2,400 kilometers of underground drifts, 418,000 tons of copper yearly. The deepest borehole in the world is Kola Superdeep Borehole at 12,262 meters. This, however, is not a matter of mining but rather related to scientific drilling.