

ECONOMIC MINERALS: A REVIEW OF THEIR CHARACTERISTICS AND OCCURRENCE

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Summary

This article presents a description of the main minerals of economic interest (metalliferous minerals, industrial minerals, and gemstones), emphasizing their principal chemical and physical properties, the geological environments where they occur, and their main practical uses.

1. Introduction

The purpose of this article is to provide a brief summary of the characteristics and modes of occurrence of the main mineral species that have an economic interest, that is, those that can be profitably mined for some practical application. This definition is obviously strictly dependent on the market demand, in turn related to a specific stage of industrial development. For instance, until the nineteenth century metals such as aluminum, zinc, and uranium were essentially of no practical use, therefore their minerals had no economic interest. Economic minerals have been traditionally divided into two main categories, metalliferous minerals (that are mined to extract a metal), and industrial minerals (that either have some direct practical use, or take part in some industrial process). Gems and precious stones could be considered as special cases of industrial minerals, as they do have a direct “practical” application; however, in the literature they are generally dealt with separately from industrial minerals.

The term “ore minerals” has been used by some authors as a synonym for economic minerals, and by others in the more restrictive sense of metalliferous minerals. As a further complication, because many metalliferous minerals are opaque (see *Ore Mineralogy*), in optical mineralogy there is a tendency to define “ore minerals” all opaque minerals, independently of their economic interest. Finally, several minerals are, or have been, used both to extract a metal and as industrial minerals (for instance, chromite), or as industrial minerals and gemstones (for instance, diamond). For all these reasons, I personally prefer the less specific, but less ambiguous, definition of “economic minerals.”

In the following description, minerals will be arranged according to the 1997 classification scheme of Gaines et al., except for silicates, which were grouped together; for each mineral or mineral group, the corresponding class in Gaines et al.’s scheme is specified. The data reported in this article were compiled from various sources, but again, the main source was Gaines et al. The main metalliferous and industrial minerals (including gemstones) are listed in Tables 1 and 2 respectively. (Additional information on some of the minerals mentioned here, especially metalliferous minerals, can be found in *Ore Mineralogy*.)

2. Native Elements: Class 1

Gold (Au): Gold is a metal with a distinctive yellow color. It crystallizes in the cubic system. In nature, it may be quite pure, or form alloys with Cu, Ag, Hg, and others. Silver-bearing gold is known as *electrum*.

Gold occurs in a variety of hydrothermal deposits, including volcanogenic massive sulfides, skarn, mesothermal lodes in orogenic settings, and epithermal deposits. Because of its chemical inertia and high density, it can be concentrated in placer deposits, where it may form large nuggets.

Since ancient times, the main uses of gold have been for capitalization, including the establishment of reserves for national state banks, and for jewelry. Gold also has some industrial uses, mainly in the electronic industry; this use may rapidly expand in the future.

PGE minerals: Platinum-group elements (PGE), or platinoids, is the collective name for metals of the second and third rows of the VIIIb group in the periodical table—ruthenium, rhodium, palladium, osmium, iridium, and platinum. Platinum is the best known, and along with palladium the most widely used, mainly for catalyzers. While these elements may occur in sulfide and arsenide minerals, they are most commonly found as native elements/alloys. As primary minerals, they occur in mafic to ultramafic igneous rocks, where they could be of direct magmatic formation, or deposited by high-temperature hydrothermal fluids. Because of their very high density and high chemical inertia, platinum and its allies may be concentrated in placer deposits.

Sulfur (S): Sulfur occurs in two polymorphs, of which the orthorhombic form is by far the most common in nature. It is a light, yellow substance with a resinous luster. The most important deposits are associated with evaporites, and subordinately of volcanic

(fumarolic) nature. Sulfur is used in the chemical industry (mostly for the production of sulfuric acid), and in agriculture. Nowadays, native sulfur is being increasingly replaced by sulfur obtained as a byproduct of the oil industry.

Diamond and graphite (C): The element carbon occurs in nature in two main polymorphs, *diamond* (cubic) and *graphite* (hexagonal). Their properties, arising from a different hybridization of electronic orbitals, are dramatically different.

Diamond, when pure, is a perfectly transparent, colorless material, with a distinctive (adamantine) luster. It is the hardest known substance (hardness 10), and an electric insulator. Diamond is the most famous and valuable gem, but most mined diamonds are in fact used as abrasives or for cutting tools. Because of its stability field, diamond can be formed only at very high pressures, at depths > 200 km. From there, it is carried up to Earth's surface by ultramafic volcanic rocks (kimberlites and lamproites). Because of its comparatively high density, diamond can be concentrated in alluvial deposits.

Graphite is a black, soft (hardness 1.5) material, with a metallic luster. It is an excellent electrical conductor. This property warrants a number of applications in manufacturing electrical equipment. However, the main uses of graphite are as a refractory and a lubricant. An additional use is for pencil leads. Graphite typically occurs in medium to high-grade metamorphic rocks.

3. Sulfides and Related Compounds

Argentite (Ag₂S): Class 2: The compound Ag₂S occurs in two polymorphs. Argentite, cubic, is stable above 167 °C (at atmospheric pressure). Below this temperature, the monoclinic form, *acanthite*, is stable. Silver sulfide typically occurs in epithermal precious and base metal deposits. In most of these occurrences, argentite was the primary mineral formed, but only acanthite can be observed at room temperature, because the transformation is very rapid. Argentite (acanthite), along with other sulfides and sulfosalts, is a major silver mineral.

Pentlandite [(Ni, Fe)₉S₈]: Class 2: This mineral is cubic. The Fe:Ni ratio is variable, but in general not far from 1. Cobalt-rich varieties are also known. The most common occurrence is as microscopic inclusions within pyrrhotite in deposits of mafic-ultramafic magmatic affiliation. Such mixtures are usually described as “nickeliferous pyrrhotite,” and represent the main source of nickel.

Cinnabar (HgS): Class 2: Cinnabar, trigonal, is a mineral with a distinctive red color, and in fact its first use by humankind was as a pigment. It occurs in low-temperature hydrothermal deposits. A less common cubic polymorph, *metacinnabar*, is found in deposits in metamorphic rocks. Being exceedingly insoluble, cinnabar is one of the few sulfides that is comparatively resistant to weathering, and therefore may occur in placer deposits. Cinnabar is the main source of mercury. However, because of its high toxicity, this element is increasingly being replaced in most industrial applications.

Chalcopyrite (CuFeS₂): Class 2: Chalcopyrite, tetragonal, (hardness 4), has a bright yellow color and a metallic luster. It is the main copper mineral. It occurs in some

magmatic deposits associated with mafic–ultramafic rocks, and in a variety of hydrothermal deposits, including volcanogenic massive sulfides, porphyry copper deposits, and skarn.

Galena (PbS): Class 2: Galena is cubic, comparatively soft (hardness 2.5), dark gray with a faint blue nuance, and a bright metallic luster. It is the main mineral of lead, but is often associated with economic amounts of silver. This element may replace lead in the lattice, usually coupled with bismuth or antimony, but in many “argentiferous galenas” silver is in fact present as micro-inclusions of separate minerals. Galena is a typical hydrothermal mineral. The main deposit types include massive sulfide deposits (both volcanic- and sediment-hosted), and low-temperature deposits in carbonate rocks (the so-called Mississippi Valley type deposits).

Sphalerite (ZnS): Class 2: Sphalerite is cubic, slightly harder (3.5) than galena. Color and luster vary significantly in response to chemical composition. Natural sphalerite invariably contains iron. Iron-poor varieties are transparent, and have a yellow color and a resinous luster. With increasing iron content the mineral becomes progressively opaque, of darker colors (brown to almost black), with a submetallic luster. In addition to iron, many natural sphalerites contain other trace elements, such as Cd, Hg, In, and Ge that may be of economic interest. Sphalerite is in any case the main mineral of zinc. It occurs in the same type of hydrothermal deposits as galena. The two minerals in fact are often closely associated.

Bismuthinite (Bi₂S₃): Class 2: Crystallizes in the orthorhombic system. It is isostructural with stibnite (see below), with which it forms a continuous solid solution; may contain Se. Its physical properties are also similar to stibnite. It occurs in hydrothermal deposits, usually of relatively high temperature. It is the main mineral of bismuth.

Stibnite (antimonite- Sb₂S₃): Class 2: Orthorhombic, isostructural with bismuthinite. The color is gray, with a distinct metallic luster, a low hardness (2), and a perfect cleavage. The crystal habit is typically acicular. Occurs in hydrothermal deposits, usually of low temperature. It is the main mineral of antimony.

Arsenopyrite (FeAsS): Class 2: Arsenopyrite is monoclinic, comparatively hard, with a yellowish gray color and a metallic luster. The As/S ratio is variable (from about 0.85 to about 1.15) as a function of physicochemical parameters (sulfur fugacity, temperature, and to a lesser extent pressure). It may contain additional elements such as Co, Ni, and Sb. Some arsenopyrites are auriferous: gold may occur as microscopic to submicroscopic inclusions, but at least in some cases it is bound in the arsenopyrite structure. Arsenopyrite is a fairly common mineral in several hydrothermal deposits, usually of medium to high temperature. It may have an economic interest for arsenic and gold.

Molybdenite (MoS₂): Class 2: Molybdenite is hexagonal, quite soft (hardness 1.5), lead gray with a metallic luster, and a greasy feeling on touching; it may contain some Re. It is the main mineral of molybdenum and rhenium. It is also used as a lubricant.

Typical occurrences are high-temperature hydrothermal deposits, including greisens and porphyry systems.

Pyrite (FeS₂): Class 2: Pyrite, cubic, is among the hardest sulfides (hardness 6 to 6.5). It has a pale yellow color, and a metallic luster. It may contain several additional elements, including Co, Ni, Cu, and As. It may be auriferous, but is unclear whether gold is bound in the structure, or occurs as submicroscopic inclusions. It is by far the most common sulfide. It is ubiquitous in hydrothermal deposits. It is also formed in sedimentary environments under anoxic conditions. Pyrite was fairly important in the past as a starting material for the production of sulfuric acid, but it is now increasingly being replaced by sulfur obtained as a byproduct of the oil industry. Exceptionally, it was also used as an iron mineral. The polymorph marcasite, orthorhombic, is less common, and has no practical importance.

Tetrahedrite-tennantite [Cu₁₂(Sb,As)₄S₁₃]: Class 3: Tetrahedrite and tennantite are the end-members of a series that has been collectively indicated as “fahlores.” They are cubic, dark gray, with a metallic luster. While they form a continuous solid solution, in nature intermediate terms are uncommon, and either Sb-rich or As-rich terms prevail; Sb-rich members are more widespread. On the other hand, fahlores usually contain one or more of a cohort of additional elements, including Fe, Zn, Hg, Ag, Bi, and Te. Fahlores are the most common minerals of the sulfosalt class. They are found in a wide variety of hydrothermal deposits, usually at moderate temperatures. They may be valuable copper minerals; Ag-rich varieties (typically Sb-rich freibergite) are excellent silver minerals.

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Biographical Sketch

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