

# Minerals explained IV—Some ore minerals

**Craig Barrie**

*Minerals Explained* editor

## Overview

While most of the minerals discussed in the previous releases in the *Minerals Explained* online event could mostly be classified as rock formers, the minerals discussed in parts IV and V will deal with those minerals that occur in small concentrated pockets within Earth's crust. So far the series has examined in detail some of the most common, and well known, silicate, carbonate, sulphate and halide minerals; in contrast this release will look at a few of the most notable and common sulphide, oxide and carbonate ore minerals. Ores are basically rocks that contain an appreciable concentration of metallic and non-metallic minerals of importance to human society. Therefore, as a rule of thumb, concentrations of sphalerite (ZnS) or hematite ( $\text{Fe}_2\text{O}_3$ ) in the crust would be classified as ore deposits, while concentrations of quartz ( $\text{SiO}_2$ ) or olivine ( $\text{FeSiO}_3$ ) would, in general, not.

The concentration of an ore mineral in Earth's crust, the grade of that concentration as well as its form (i.e. porphyry, replacement, volcanic massive sulphide, VMS), directly influences the ore's value and whether extraction will be economic. Ores that are too low a grade, too small in size, or too difficult to mine (i.e. too deep in the crust, unsuitable geology, unsuitable access) will not be extracted unless prices are sufficiently high to overcome these economic barriers. For example, metal prices are never stable but fluctuate through time with the result that small or low concentration mines may be economic while prices are high (i.e. as gold and many other metals are experiencing at the moment) but find themselves uneconomic if prices drop. Metallic ores cannot be used immediately after their extraction, needing some form of processing to remove the non-metallic component (i.e. the sulphide, oxide, carbonate component, leaving the metal behind). Ore processing can be done in a number of ways and is highly dependent upon the mineral extracted and the metal to be concentrated. For example, the concentration of Zn and Pb ores from sulphide minerals often involves the ore being ground to a fine powder in industrial grinders prior to the different Zn and Pb metals being separated through a series of chemically controlled flotation tanks.

Iron is the fourth most abundant element in the Earth's crust and yet the occurrence of pure Fe at the Earth's surface is virtually unknown (although it does occur). Instead, the majority of Fe is bound into minerals of silicate (i.e. ferromagnesian silicates) as well as smaller amounts in the carbonates, oxides and sulphides. Iron ore minerals are those in which Fe can be extracted economically and are dominated by the oxide minerals, primarily hematite ( $\text{Fe}_2\text{O}_3$ ) but also magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{FeO}(\text{OH})$ ) and a few others. The majority of mined Fe ore (some estimates suggest ~98%) is used in the manufacture of steel, and Fe is by far the most important metal in the expansion of human populations. Fe mineralization is widespread in the geological record, although the most well known occurrences, the banded iron formations (BIF), are exclusively restricted to the Precambrian. BIFs (Fig. 1A) are sedimentary rocks composed of > 15% Fe, generally locked up in the form of intercalated layers of Fe-oxides (e.g. hematite, magnetite), Fe-carbonates (e.g. siderite) and Fe-silicates (e.g. grunerite).

Sulphides comprise all of the minerals that contain an anion of sulphide ( $\text{S}^{2-}$ ) as a major component of their chemical composition. Although some sulphide minerals provide economically important metals (i.e. sphalerite (ZnS), galena (PbS), chalcopyrite ( $\text{CuFeS}_2$ )) others are considered, at the present day, as gangue (i.e. pyrite ( $\text{FeS}_2$ )). The sulphide class of minerals also incorporates a number of other mineral groupings including the tellurides (i.e. calaverite ( $\text{AuTe}_2$ )) that are important sources of Au and Ag. Sulphide minerals can form in a range of geological settings and at the present day they are commonly found forming along spreading centres in the oceans at so-called 'black smokers' (Fig. 1B). These vent settings are generally thought to be analogous to the origins of sedimentary exhalative (SEDEX) and volcanic hosted massive sulphide (VMS) deposits which are a major source of the world's copper, zinc and lead.

## Mineral details

**Hematite** (Fig. 2A) is a mineral with the chemical formula  $\text{Fe}_2\text{O}_3$  and also a member of both the Fe-oxide class and the hematite group of minerals. The hematite group has the general formula  $\text{X}_2\text{O}_3$  and includes, amongst others, the minerals corundum ( $\text{Al}_2\text{O}_3$ ) and eskolaite ( $\text{Cr}_2\text{O}_3$ ). Hematite is one of the most common Fe-minerals in Earth's crust and along with magnetite ( $\text{Fe}_3\text{O}_4$ ) represents the primary source of Fe within the Precambrian BIF deposits. Hematite can form in a range of colours, but generally appears either silvery or reddish-brown

to black. Crystal habit of hematite is variable with prismatic and tabular varieties a possibility but the most common habit, to students of geology, will be the classic 'reniform' or kidney ore texture (Fig. 2B). Hematite can precipitate at hot springs and within standing waters or may be generated from volcanic magmas. Goethite (FeO(OH)) (Fig. 2C) can also potentially act as a precursor stage mineral to hematite (Fe<sub>2</sub>O<sub>3</sub>) forming, one from the other, as a result of weathering in soils and Fe-rich bogs. Important hematite mining districts include Lake Superior in North America, Minas Gerais in Brazil and Cerro Bolivar in Venezuela.

**Did you know that while hematite is not magnetic in nature it does become so if you heat it?**

**Galena** is a sulphide mineral with the chemical formula (PbS) and is by far the most important source of lead in the Earth's crust. Galena is one of the most abundant and widespread of the sulphide minerals and is one of the easiest to identify due to its characteristic silvery-grey colour, excellent well-formed cubic or octahedron crystals and density (7.57 g/cm<sup>3</sup>). As with many of the sulphide minerals galena is cubic and is commonly thought of as occurring as characteristic cubes (Fig. 3A), yet more exotic habits including skeletal or 'hoppered' overgrowth textures are reported to occur (Fig. 3B). Galena rich ore deposits and regions are found globally, often forming in close association with zinc (sphalerite), copper (chalcopyrite) and iron (pyrite) rich-sulphides. Two characteristic regions associated with abundant lead deposits are the Mississippi Valley Type (MVT) deposits in Missouri, USA and the Irish-Type or SEDEX deposits in Ireland. Both of these regions are type localities for lead ores and contain some of the largest mines in the world (i.e. the Navan Zn-Pb deposit). Exhalative processes at mid-ocean ridges at the present day, and throughout geological history (as stated above) also favour the precipitation of sulphide minerals, and galena is a prominent component of the VMS deposits of Norway, Japan, Spain and the USA.

**Did you know that although dense, galena is not the heaviest known mineral, with native platinum taking the honour with a density of 21.4 g/cm<sup>3</sup>?**

**Sphalerite** is a sulphide mineral with the chemical formula ZnS, although it is rarely pure, with Fe often substituting into the crystal lattice along with Zn. Other elements that can substitute into the sphalerite lattice, albeit in minor or trace amounts, are cadmium (Cd), chlorine (Cl) and silver (Ag). Sphalerite (Fig. 4A) can precipitate in an array of colours and hues, with browns and yellows as well as pinks, reds and greens all possible and widespread. Where sphalerite is particularly rich in Fe it will be much darker in colour and black sphalerite is known by the name 'marmatite' (Fig. 4B). Other names for different coloured sphalerite varieties include 'cleiophane' for white sphalerite and 'ruby blende' for rich red, translucent sphalerites (Fig. 4C). Sphalerite, as with galena, is a member of the cubic crystal system but unlike galena where crystals show a good habit, which is not that common, they appear as hexatetrahedrals. Sphalerite is also a polymorph with the mineral wurtzite (Fig. 4D), a less common hexagonal structured variety of sphalerite that often forms in low temperature environments. It is possible to find sphalerite and wurtzite forming together in hydrothermal ore deposits but distinguishing between the two will be a challenge at best!

For the most part, sphalerite precipitated in ore deposits tends to have poor crystal shape often forming characteristic microcrystalline, colour-banded layers known as 'colloform' textures. Gem quality examples (Fig. 4C) of sphalerite are possible but considering the softness of the mineral (3.5–4 on Mohs scale) these are rarely set into jewellery, as they are liable to scratching. Sphalerite is the world's primary source of Zn (~95% of mined Zn comes from sulphide ores, although not necessarily all as sphalerite) and its formation and distribution is closely tied to that of galena. Indeed, most of the world's major Zn mines also contain a considerable percentage of Pb and potentially a number of other metals locked up within the sulphides (i.e. appreciable concentrations of Ag are well known). The world's largest known deposit of Zn is the Mehdiabad Zn-Pb deposit in Central Iran, although it is not yet in production, and the largest currently producing Zn mines are Century in Australia and Red Dog and Greens Creek in Alaska. Sphalerite forms in similar settings and environments to galena, predominantly being mined from carbonate hosted MVT and SEDEX deposits and VMS regions world-wide.

**Did you know that Tara Mines in Ireland, also known as the Navan Zn-Pb deposit, produces over 200 000 tonnes of Zn and 40 000 tonnes of Pb annually making it the 5th largest Zn Mine in the world?**

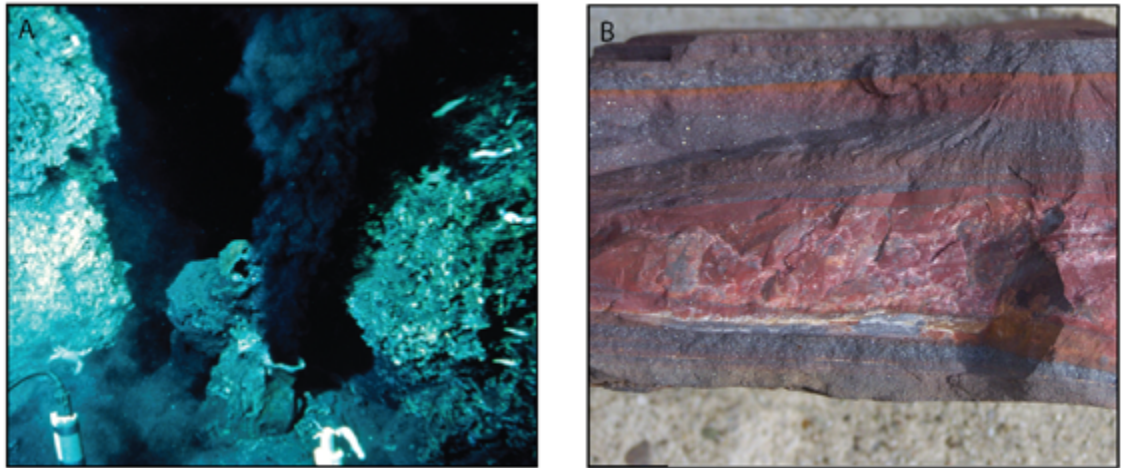
**Pyrite** is a sulphide mineral with the chemical formula FeS<sub>2</sub> and a characteristic brassy-yellow, metallic appearance that has earned it the pseudonym 'fools gold'. Pyrite is by far the most common of the sulphide minerals being found in virtually every rock type on Earth as well as meteorites and growing within nanobacteria. Pyrite is a cubic mineral, often forming characteristic cube shaped crystals varying from micrometres to metres in size (Fig. 5A). Pyrite cubes are commonly found in slate quarries (Fig. 5B), coal beds, estuarine environments and Fe-rich bogs all forming through the breakdown of organic matter. In ore deposits, pyrite is often found associated with the other common sulphide minerals (galena, sphalerite, chalcopyrite) but, unlike the rest, it is generally considered to be at best gänge, and at worst either a hindrance to profits or a mining hazard. Pyrite

dusts are known to have caused explosions, via the combustion of fine particulate pyrite, in mines and some can behave exothermically when oxidized, potentially risking mine wall collapses. Pyrite is also the primary source of acid mine drainage (AMD) in waterways; for these reasons, pyrite itself is therefore, not generally an economically important mineral. However, it is often an economically important **carrier mineral** and known to host considerable quantities of invisible gold in some deposits. Furthermore, some studies suggest that pyrite may hold the key to understanding the initial evolutionary spark that gave rise to life on Earth!

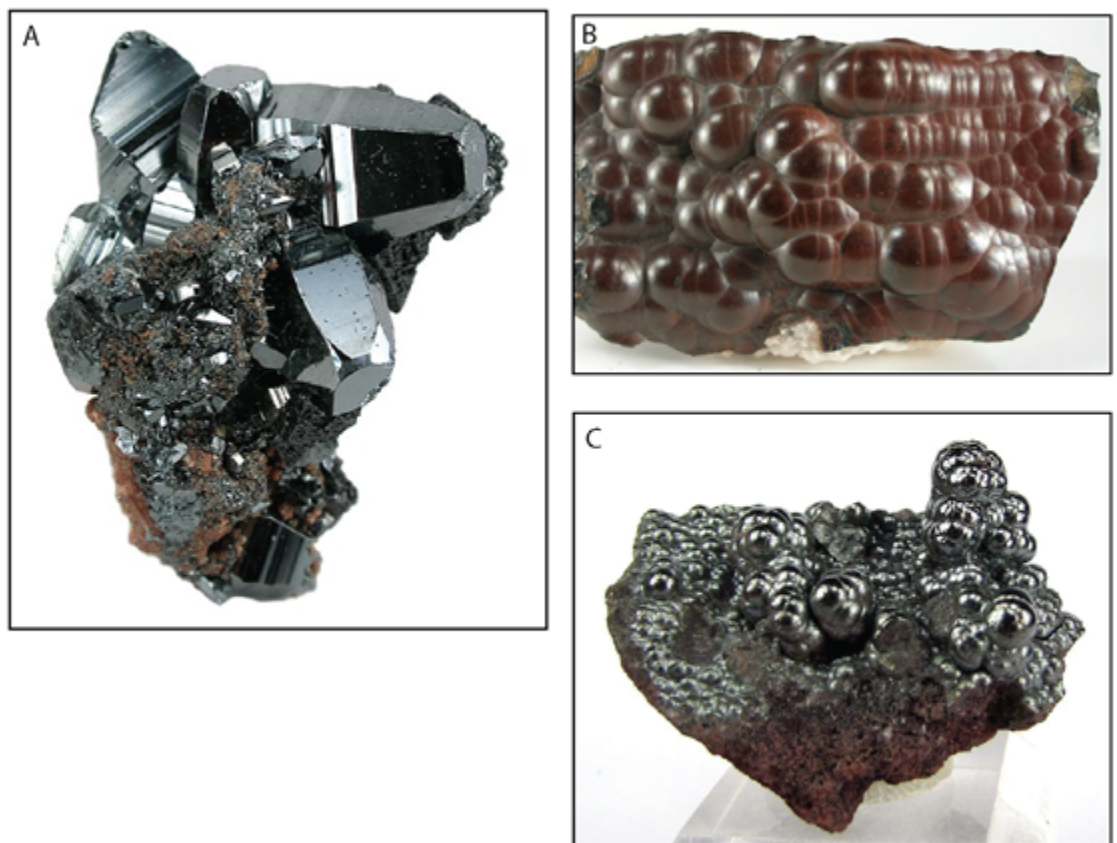
**Did you know that although pyrite is not generally considered a commercial mineral it is still used to produce large quantities of both SO<sub>2</sub> and sulphuric acid?**

**Azurite and malachite** are both copper carbonate minerals, with the formulae  $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$  and  $\text{Cu}_2\text{CO}_3(\text{OH})_2$  respectively. Both minerals contain  $\text{Cu}^{2+}$  ions, and simple Cu is not known to precipitate under natural conditions. Both of these minerals are monoclinic and can form in a range of different habits, commonly precipitating in massive, stalactitic and prismatic forms, although characteristic botryoidal specimens are probably the most well known examples, if not the most common. The primary distinguishing feature between these two minerals is their colour: azurite (Fig. 6A) generally precipitates in a range of blues (i.e. azure blue) while malachite (Fig. 6B) generally precipitates in a mixture of dark greens. Except for this difference in colour the two minerals share very similar properties. Malachite is the more common of the two Cu carbonate ores, although they can generally be found together (Fig. 6C, D), often associated with carbonate host rocks. This difference in abundance is related to the fact that azurite, relative to malachite, is metastable at Earth's surface and is often pseudomorphed by malachite. Both minerals are primarily formed via weathering of copper ores and while not major ores of copper themselves, the presence of malachite and azurite at Earth's surface is a useful indicator of the presence of deeper, potentially economic, copper sulphide ores. Malachite is mined in a number of localities worldwide, often associated with other copper ores, including Broken Hill, Australia, where there is one of the world's largest Zn-Pb-Ag deposits, as well as in the copper mines of the Timna Valley, Israel.

**Did you know azurite is sometimes called 'chessylite' a name derived from the type locality for the mineral 'Chessy-les-Mines' in France?**

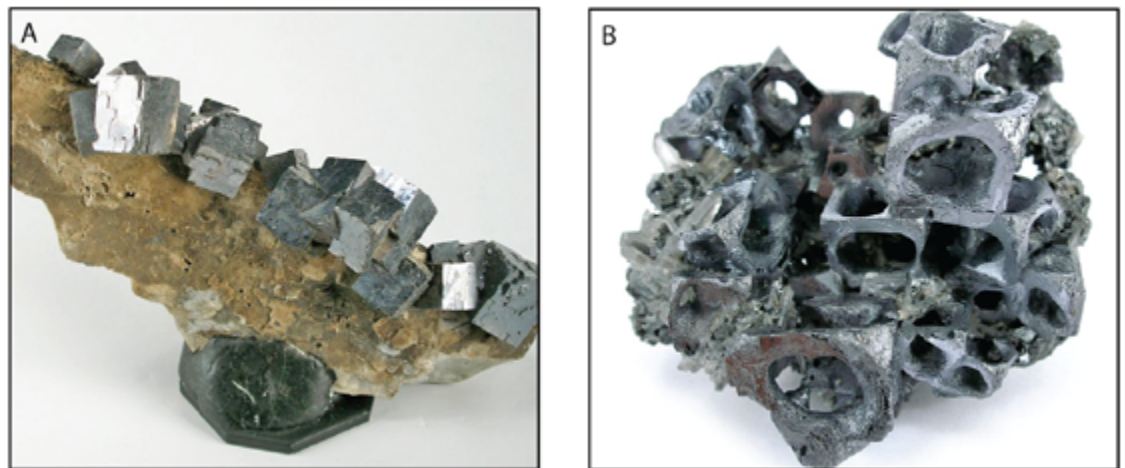


**Fig. 1.** **A.** The base of a black smoker chimney; locality: East Pacific Rise, 21° North. **B.** Rock sample from a banded Iron Formation (BIF); locality Moories Group, South Africa.

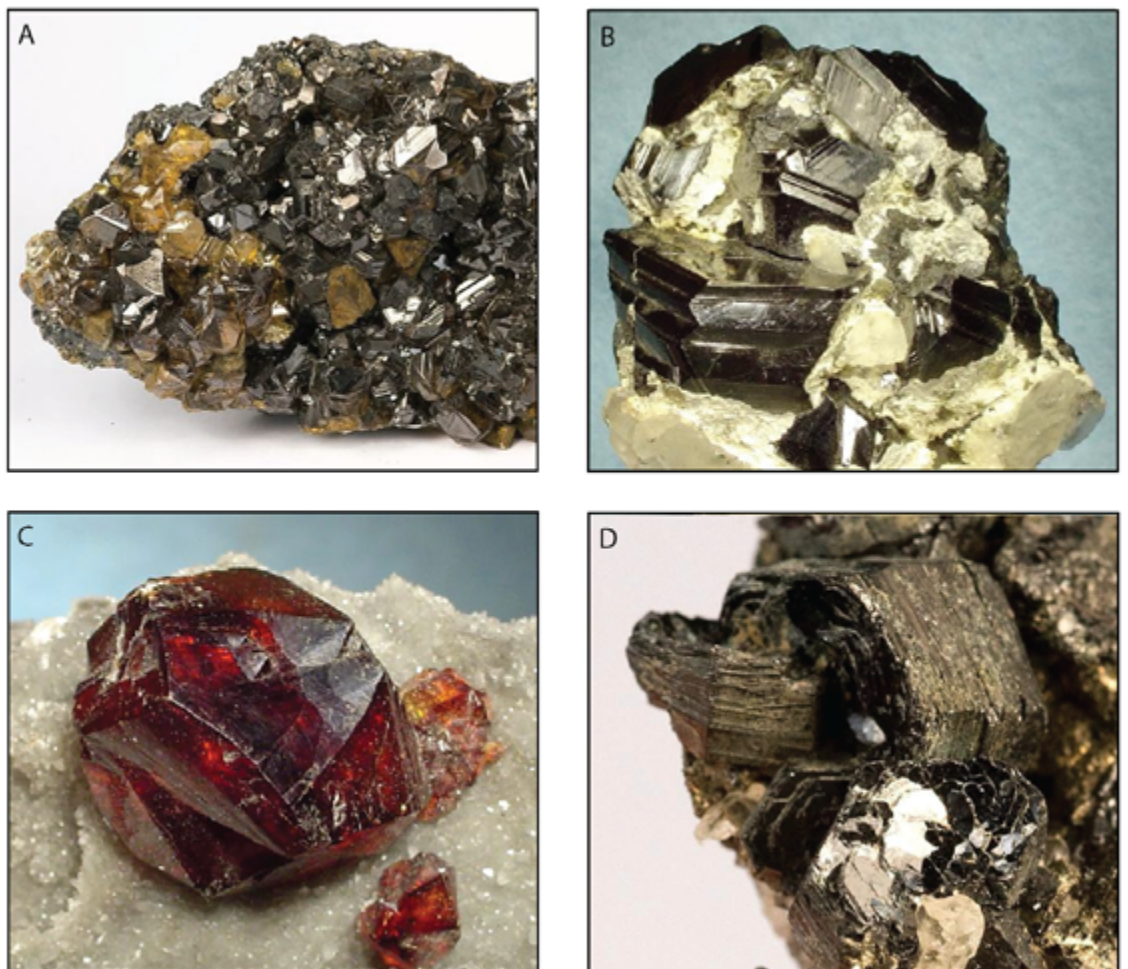


**Fig. 2.** **A.** Jewel-like crystals of hematite up to 2 cm in size; locality: Wessels Mine, Northern Cape Province, South Africa. **B.** Highly lustrous, rust-red banded, botryoidal or 'kidney stone' texture hematite; locality: Wisconsin, USA. **C.** Intergrown smoke-gray goethite balls (size: 4.4 × 2.8 cm); locality: Bisbee, Arizona, USA.

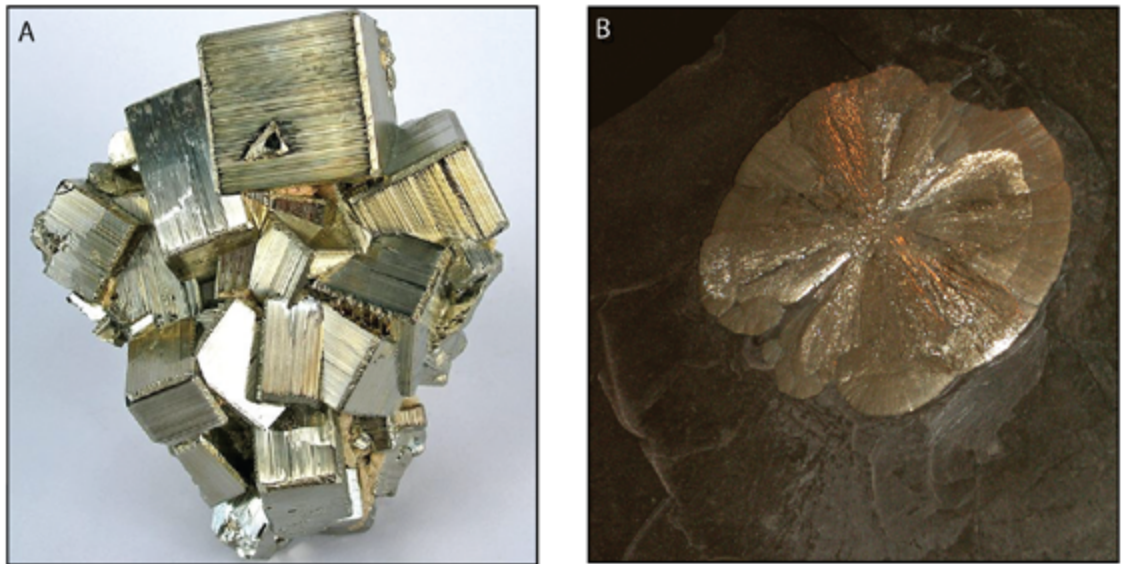




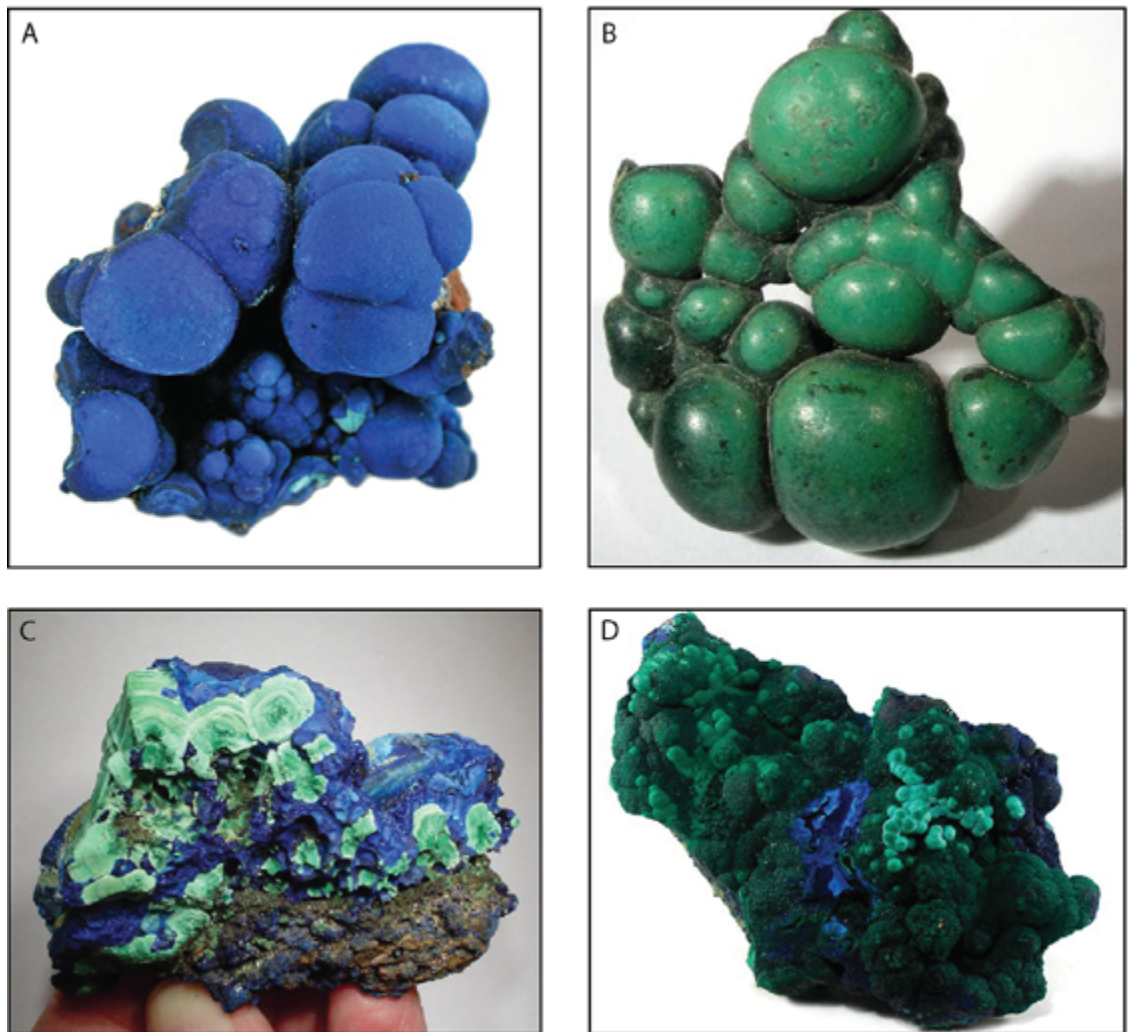
**Fig. 3. A.** Pristine, lustrous galena cubes (up to 2.2 cm in size) on a matrix of chert; locality: Joplin Field, Missouri, USA. **B.** Cluster of all-hoppered galenas (up to 1.3 cm in size); locality: Bulgaria.



**Fig. 4. A.** Combination plate of golden-yellow sphalerite crystals, brassy chalcocopyrite crystals and a few, scattered galena crystals (size  $11.9 \times 5.7 \times 3.0$  cm); locality: Commodore Mine, Colorado, USA. **B.** Jet-black, twinned crystals of sphalerite (var. marmatite) (size:  $6.4 \times 5.4 \times 2.5$  cm); locality: Trepča complex, Kosovo. **C.** 1.8 cm cherry-red crystal of sphalerite on a matrix of drusy quartz; locality: Kangjiwan Pb-Zn-Ag-Au deposit, Hunan Province, China. **D.** Booklets of sharp, hexagonal submetallic wurtzite crystals within a quartz matrix (size:  $3.0 \times 2.2 \times 2.1$  cm); locality Siglo Veinte Mine, Bolivia.



**Fig. 5. A.** Intricate cubes of pyrite showing excellent striations (size:  $9.2 \times 8.2 \times 3.4$  cm); locality: Huaron Mining District, Peru. **B.** Pyrite 'sun' or 'flower' bedded within layers of slate; locality: Ascaro Mining Company.



**Fig. 6. A.** Specimen of bright blue azurite (size:  $3.7 \times 3.3 \times 2.6$  cm); locality: Dixie Mine, Utah, USA. **B.** Cluster of lustrous malachite spheres (size:  $3.4 \times 3.1 \times 1.0$  cm); locality: Kolwezi, Katanga, Democratic Republic of Congo. **C.** Banded and botryoidal azurite and malachite (size:  $7.8 \times 5.4 \times 5.0$  cm); locality: Bisbee, Arizona, USA. **D.** Three generations of botryoidal malachite are present in this specimen, indicated by the change in colour hues. In the centre of the specimen is a druse of light and dark blue azurite (size:  $17.7 \times 11.8 \times 5.5$  cm); locality: Dixie Mine, Utah, USA.



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