

Minerals explained V—Some ore minerals

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Minerals Explained editor

Overview

This final release for the *Minerals Explained* online event deals with some of the rarest and most unusual minerals in Earth's crust. I say unusual not because the minerals are exotic combinations of rare elements, or mixtures of vibrant colours and unusual habits but, because they are pure, or very nearly-pure, native elements. All of the minerals discussed so far have been composed of combinations of elements (i.e. in the form of silicates, carbonates, sulphides, etc); however, here elements that occur naturally uncombined (i.e. gold (Au), silver (Ag), graphite (C), etc.) are discussed.

There are well over 4000 individual mineral species, with between 50–100 new minerals recognized every year, and one or two either discredited or downgraded. Of these 4000 minerals, only around 20 (it depends how stringent the criteria for defining a native mineral is) occur as native minerals, consisting of only a single element. One interesting native mineral is Fe, for although it can be found in pure form in the Earth's crust, or as an alloy with nickel (Ni), the majority is extra-terrestrially sourced from meteorites! Most Fe in the crust is bound with silicates, sulphides or oxides and only one known major deposit of native Fe or 'telluric Fe' is known to exist, which is near Disko Bay in Greenland; again this Fe forms an alloy with Ni (Fig. 1A).

Native minerals can be separated out into three groups; the native metals, semi-metals and non-metals. The metals are by far the largest and most common group of native minerals with gold, silver and copper by far the most abundant, with three still of sufficient size to be mined, if not far more when gold is considered, worldwide. Rarer native metals, those not known to be currently mined as ore deposits on their own, include the platinum group minerals (i.e. platinum, palladium), lead, tantalum, tin and zinc. Despite their name, the famous tin mines of Cornwall were not actually extracting native tin, but rather an oxide called cassiterite (SnO_2), which had to be smelted to generate pure Sn (Fig. 1B). The semi-metal native minerals include arsenic, tellurium and selenium, all of which are generally uncommon in their native form, more commonly found as sulphide minerals. The non-metal native minerals only really include two elements: sulphur and carbon, the latter taking numerous forms, most commonly, graphite and diamond. In this release five of the most widespread and abundant native minerals are discussed, including three metals: copper, silver and gold and two non-metals: sulphur and graphite.

Mineral details

Copper is an element and native mineral and while it can and does occur in pure form, it is most commonly extracted from Earth's crust as a sulphide (i.e. chalcopyrite; CuFeS_2 chalcocite; Cu_2S , covellite; CuS etc.), or oxide (i.e. cuprite; Cu_2O) minerals. Native copper is a cubic mineral that can occur in cubes and dodecahedra; but these are rare and it is most commonly found as flattened, dendritic growths or distorted strand like formations (Fig. 2A). Its colour is generally brownish-orange to a very deep red when a fresh surface is exposed; however, it will often appear green resulting from weathering to copper carbonate (i.e. malachite). This weathered upper surface is also known as a patina. Native copper, as with its oxide and sulphide forms, is relatively soft at only 2.5–3 on Mohs scale of hardness. Native copper was a vastly important source of copper in antiquity, and remained so through to the nineteenth and early twentieth centuries before copper porphyry deposits, including the world's largest pit mine, Chuquibambilla in Chile (Fig. 2B), came online, and when chalcopyrite (CuFeS_2) (Fig. 2C) became the world's primary source of Cu. Native copper is still mined in small quantities around the world but, all of the major mines, dominant up until the early twentieth century, and in some cases later, are now closed.

Did you know that the statue of liberty in the USA is made from copper with the characteristic green colour resulting from surface oxidation?

Silver is an element and native mineral that can also occur naturally as an alloy with gold, known as electrum (commonly known as 'white gold'; Fig. 3A), or and bound with sulphur and other elements as a silver mineral ore (argentite; Ag_2S). Silver is an extremely rare element in Earth's crust, accounting for ~0.07 ppm, contrast that with copper which is ~785 times more prevalent and its rarity becomes apparent! Silver, as the name suggests, is generally silvery-white in colour, although where exposed to the atmosphere weathered surfaces

can appear black (Fig. 3B). This black coating, much like with copper, is a result of tarnishing of the mineral surface to acanthite (Ag_2S).

Native silver is a cubic mineral and while individual crystals are rarely seen they can occur as cubes or dodecahedrons. Other habits include subhedral disseminated grains and blebs with or even within other minerals but, as with copper, distorted wires and dendritic growths as well as plates are generally considered characteristic, particularly 'ram's horns textures' (Fig. 3C). Native silver is a relatively soft mineral at only ~2.5–3 on Mohs scale. Two of the world's principle sources of silver are the Cannington Ag-Pb Mine in Australia which is the world's largest Ag mine, producing over 38 million ounces of Ag in 2010 and the Rudna-Lubin Ag Mine in Poland the world's second largest Ag mine at just 38 million ounces of Ag in 2010. In 2010 Peru was the world's primary producer of Ag at 4000 tonnes, 18% of the total output! None of these mines are extracting native silver, in any significant quantity if at all, but instead silver sulphides of acanthite (Ag_2S) and other species (Fig. 3D).

Did you know that in 2010 around 7% of the Ag produced annually (~72 million ounces) was used in photography, this might seem a lot but in 2001 prior to the digital revolution the figure was >24%?

Gold is an element and native mineral and while it can occur as nuggets and flakes of pure Au it generally occurs as an alloy with Ag (i.e. electrum). Compared with Ag and Cu, gold has an even rarer crustal abundance accounting for a mere 0.001 ppm of all of the elements in Earth's crust. Gold characteristically appears as a metallic, rich yellow colour, although with increasing Ag content this changes to white. As with the other native metals discussed gold is a cubic mineral, yet rarely does it ever form good crystals instead tending to forms rounded nuggets and blebs (Fig. 4A), as well as plates and dendritic or distorted strands (Fig. 4B). Unlike the other native metals which have a preference to occur as sulphides, oxides or in another form the primary mineral of gold, is in fact, the native metal itself, as well as electrum. Tellurides such as calaverite (AuTe_2) and sylvanite (Ag,AuTe_2) are also sources of gold ore, but not to the same extent as the native metal (Fig. 4C, D). Native gold tends to occur as microscopic, or at least very small, particles locked up within host rocks of quartz and within sulphide minerals, including pyrite. The Grasberg Mine (Fig. 5) in Indonesia is the world's largest gold mine, producing over 33 tonnes of Au and 230 tonnes of Ag in 2009 alone! Of the nearly 2060 tonnes of Au produced in 2010, 50% of it was used in the jewellery industry and nearly 750 tonnes (~36% of the market) was sold to India!

Did you know that the purite of gold is measured in 'carats'? Pure, 100% gold is designated as 24 carats, whereas an alloy of 50% Au and 50% other materials would be 12 carats.

Sulphur is an element and native that often forms around volcanic and hydrothermal springs world-wide. Native sulphur generally precipitates as yellow to yellowish-brown crystals often forming dipyrramids, although 50 known habits have been reported but are less common (Fig. 6A, B). Native sulphur is very soft (~1.5–2 on Mohs scale) and brittle such that it can be scratched easily with a fingernail. It is usually precipitated via volcanic activity at Earth's surface, sublimating from volcanic gasses associated with the formation of realgar (Fig. 6C) or 'ruby sulphur' (As_4S_4), cinnabar (HgS) (Fig. 6D) and other sulphide minerals. Native sulphur can also be found within Earth's crust, generated by two methods: firstly as a result of alteration of sulphide minerals hosted within vein deposits; and secondly as a decomposition product of calcium sulphate (i.e. gypsum) within deep-seated salt domes. Note that both of these formation processes are not generating primary but, instead, secondary native sulphur. Although mining for native sulphur was of considerable importance through antiquity and into the nineteenth and early twentieth centuries this, as with mining of most of the other native minerals (excluding gold), is generally no longer the case. However, a few concentrations of native sulphur are still currently mined with probably the best example being the Kawah Ijen volcano, Indonesia (Fig. 7A, B).

Did you know that the 'rotten eggs' odour often associated with native sulphur is not emitted from this mineral? Native sulphur is odourless, the distinctive odour comes from H_2S generated when H_2O reacts with the surface of the mineral!

Graphite is an element and native mineral and is one of a number of allotropes of carbon, each of which has widely differing properties. At Earth's surface graphite (Fig. 8A) is the most stable form of carbon while at the high pressures and temperatures in the shallow mantle (>140 km depth) the mineral diamond (Fig. 8B) is the most stable form of carbon. The precursor material to graphite is coal or organic-rich limestones, which, when metamorphosed to conditions between prehnite-pumpellyite and greenschist facies during regional metamorphism, generate graphite. Graphite can also form during igneous processes and is also commonly reported in meteorites, specifically the polycrystalline variety cliftonite. The debate is still open as to whether cliftonite is indeed a new mineral or allotrope of carbon or whether it is simply a pseudomorph of diamond. While the graphite form of carbon is one of the softest minerals with a value of between 1.5 on Mohs scale

of hardness, the diamond form of graphite is one of the hardest, topping off the scale at a value of 10, hence their excellent use as gemstones (Fig. 8C). Current world extraction of native graphite was over 1 million tones, with mining restrictive to only a handful of countries, with China extracting over 70% of the annual total. Graphite can also be produced artificially, through the treatment of petroleum coke leftover from the refinement of crude oil in an oxygen-free oven. This artificial graphite is more expensive than native graphite but can form many applications of more a suitable quality.

Did you know that graphite can be classed as the highest grade of coal, with the name 'meta-anthracite', it is not normally used as a fuel however as it can be very difficult to ignite?

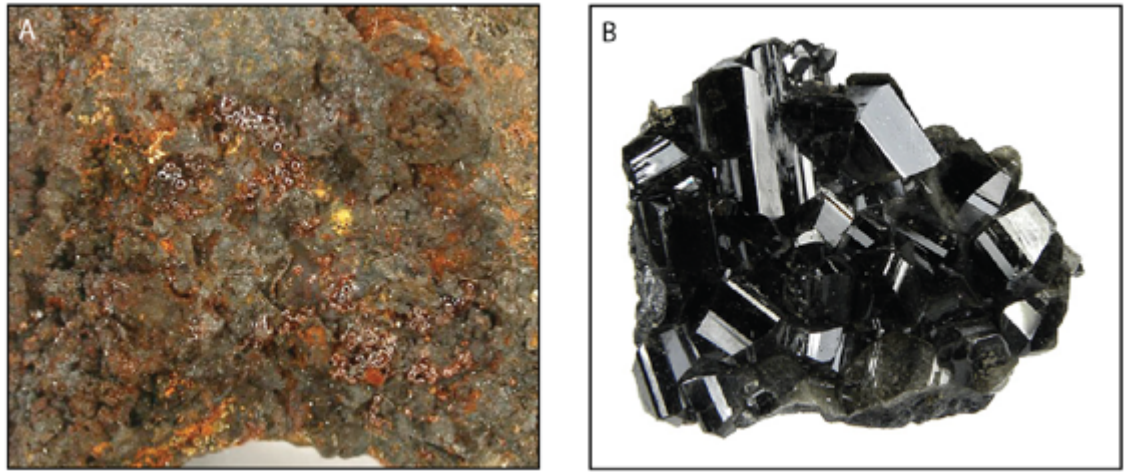


Fig. 1. **A.** Rare mass of terrestrial native iron, metallic crystals, in a matrix of basalt from the remote Disko Island, Greenland. **B.** Cluster of several sharp, lustrous, mostly black cassiterite crystals (size: 4.1 × 3.7 × 2.1 cm); locality: Viloco Mine, Bolivia.

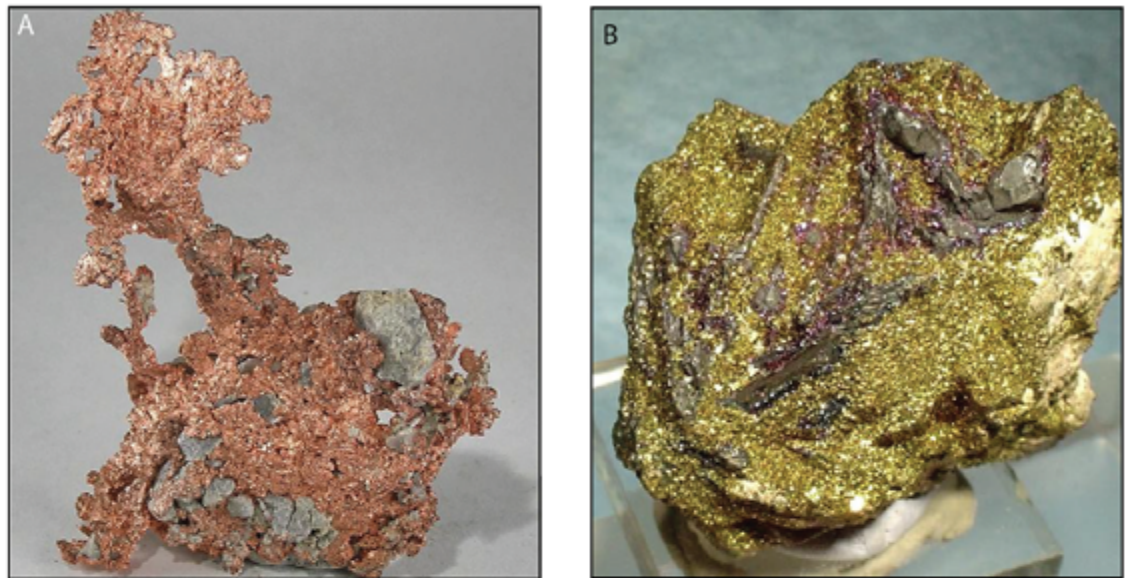


Fig. 2. **A.** Large, leaf or platy specimen of penny-bright native copper (size: 12.4 × 8.8 × 4.5 cm); locality: Morenci, Arizona, USA. **B.** Golden-yellow chalcopyrite microcrystals covering a matrix of solid, bladed polybasite (size: 3.9 × 3.6 × 3.3 cm); locality: San Juan de Rayas Mine, Mexico. **C.** The open pit at the Chiquimita copper mine with a large mine transport truck in the right hand corner for scale.

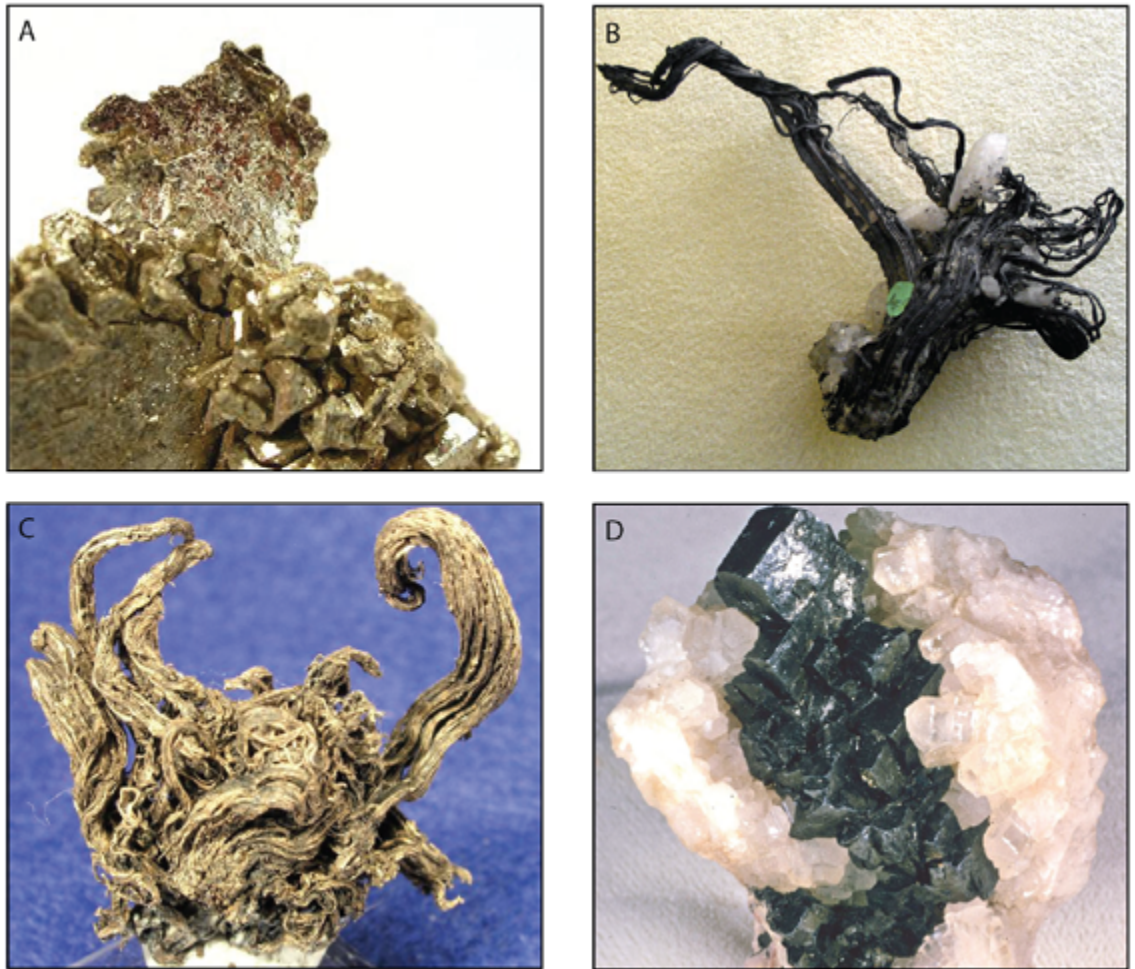


Fig. 3. **A.** Crystalline specimen of electrum, comprised of cubes and crudely developed octahedrons exhibiting hopper growth (size: $3.0 \times 2.5 \times 1.3$ cm); locality Round Mountain Mine, Nevada, USA. **B.** Thread like growth of native silver on a matrix of calcite; locality: Kongsberg, Norway. **C.** Thick 'rams head' texture of native silver (size: $2.5 \times 1.5 \times 1.5$ cm) locality: Kings Mine, North Carolina, USA. **D.** Acanthite crystals within a matrix of calcite; locality: Freiberg District, Saxony, Germany.



Fig. 4. **A.** Large nugget of river-worn gold (size: $1.6 \times 1.1 \times 0.3$ cm); locality: Mother Lode, California, USA. **B.** Thin, fragile, specimen of crystallized leaf gold on a crystal of calcite (size: $4.1 \times 2.4 \times 1.8$ cm); locality: Bronzewing Mine, Australia. **C.** Sharp, highly splendid, tabular, striated crystals of the rare calaverite which have a brassy hue and are sitting against frosted grey quartz matrix. The largest calaverite crystal measures a full 9 mm in length (size: $2.6 \times 2.1 \times 1.1$ cm); locality: Cresson Mine, Colorado, USA. **D.** Specimen of metallic sylvanite crystals up to 8 mm in size (size: $5.7 \times 4.0 \times 1.9$ cm); locality: Cripple Creek District, Colorado, USA.



Fig. 5. The Grasberg Gold Mine in Papua, Indonesia.



Fig. 6. **A.** Lemon coloured, translucent crystals of native sulphur on a druse of calcite, the largest crystal, is 3 cm across. **B.** Yellowish-green crystals of native sulphur (size: 17.5 × 8.8 × 6.8 cm); locality: El Desierto Mine, Bolivia. **C.** Cluster of cherry-red realgar crystals (size: 2.2 × 1.1 × 0.8 cm); locality: Royal Reward Mine, USA. **D.** Three drill-bit twinned crystals of cinnabar set within a matrix of quartz needles and dolomite crystals (size: 7.3 × 4.1 × 1.9 cm); locality: Tongren Mine, China.



Fig. 7. A/B. Sulphur mining operations at the Kawah Ijen Volcano, Java, Indonesia. (pictures by Justin Blethrow).

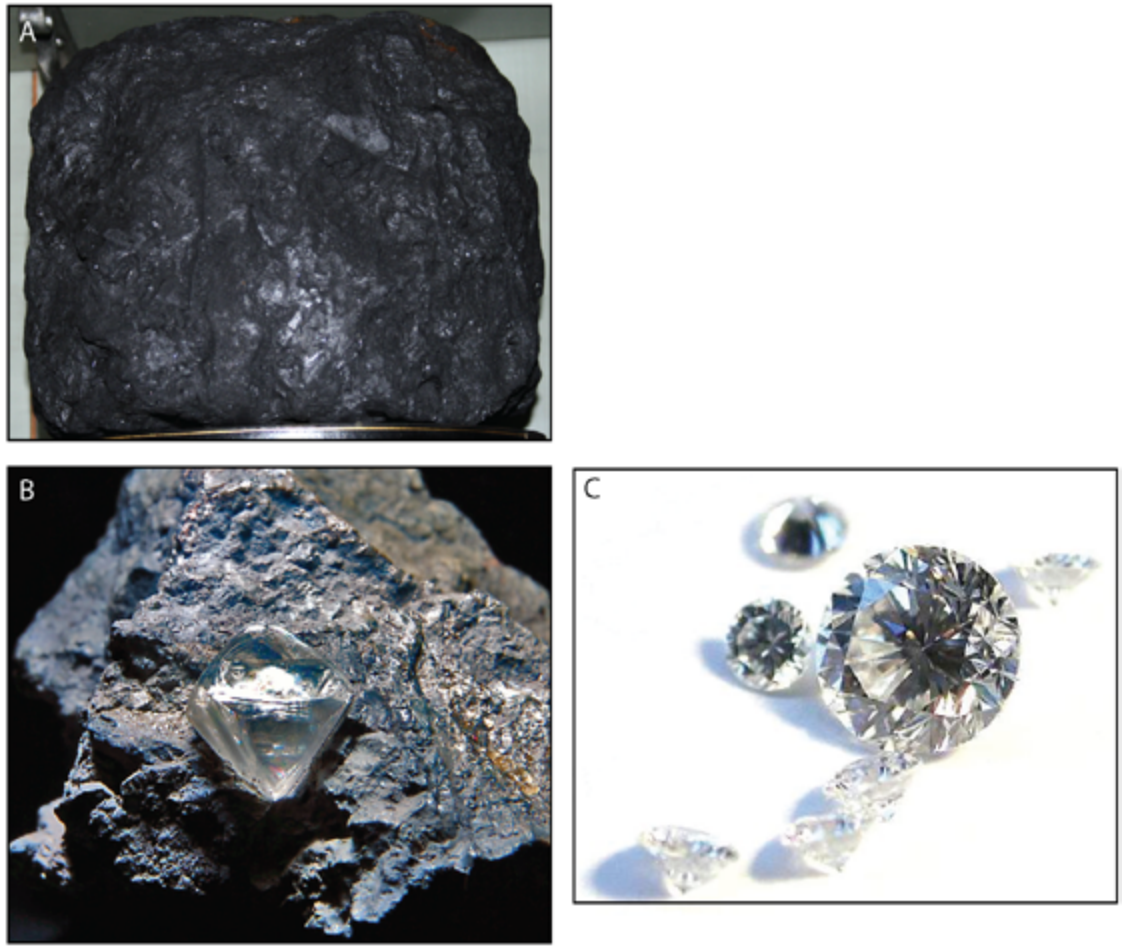


Fig. 8. A. Specimen of graphite from the National Museum of Prague. B. Specimen of rough diamond from the Senckenberg Museum, Frankfurt, Germany. C. Selection of 'brilliant' cut diamonds.

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