

Native elements

Copper Cu

Copper may contain Ag, As or Bi.

Crystals

Copper is cubic. $D = 8.95$, $H = 3$.

Polished section

Copper is bright metallic pink but tarnishes and darkens rapidly. $R \approx 75\%$, it is isotropic, but with incomplete extinction, and fine scratches may cause false anisotropy. $VHN = 80-100$.

Occurrence

Copper occurs as small flakes, granular aggregates, porous masses or dendrites. Zonal texture is rare, and lamellar twinning may be revealed by etching. It is associated with cuprite Cu_2O and $Cu + Fe + S$ minerals, often in deposits associated with basic extrusives. Copper is common in the oxidation zone, where it results from the oxidation of copper sulphides.

Distinguishing features

Compared with copper: gold is brighter and coloured yellow or white.

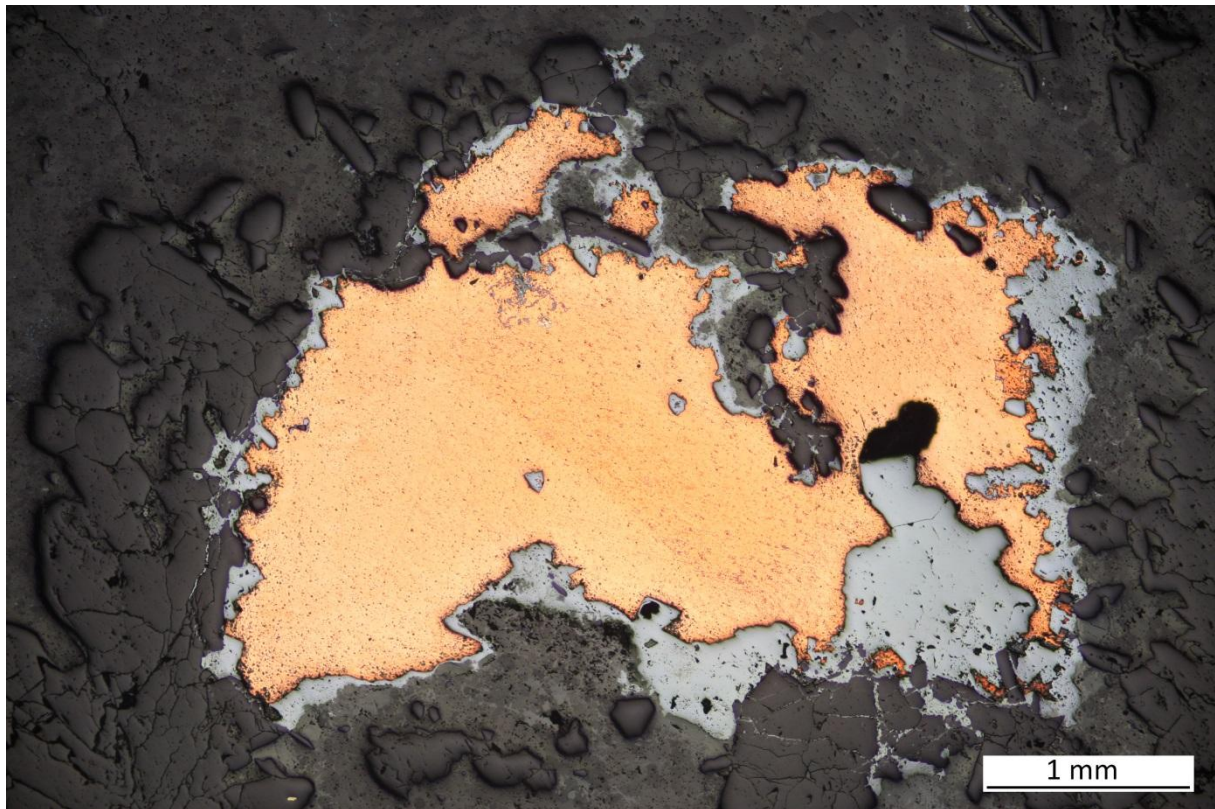


Fig. 1. Copper (pink) covered by cuprite (grey), sample Borovec u Štěpánova, PPL

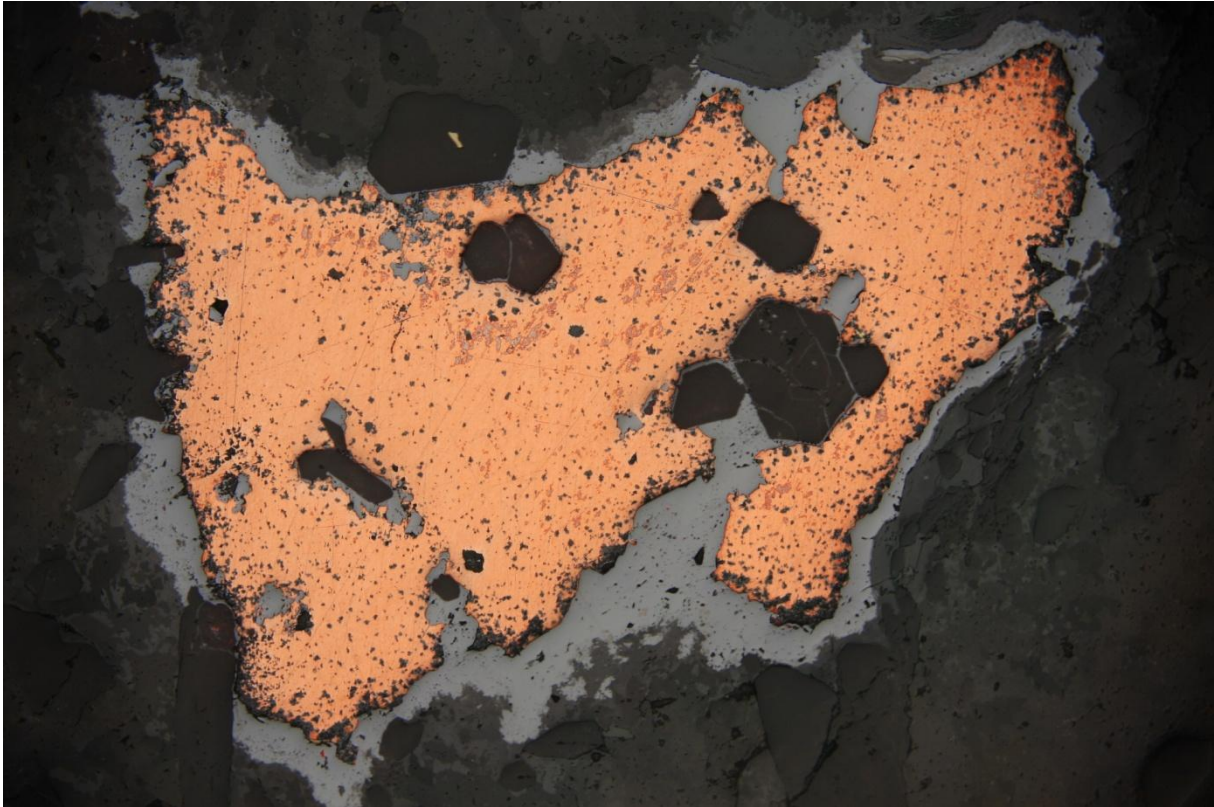


Fig. 2. Cooper (pink) covered by cuprite (grey), sample Borovec u Štěpánova, PPL

Gold Au

Gold may contain Ag, Cu, Pd or Rh. Electrum (Au, Ag) contains 30-45% Ag.

Crystals

Gold is cubic and can rare occur as cubic, dodecahedral or octahedral crystals, but repeated twinning on {111} often gives reticulated and dendritic aggregates. $D = 19.3$, $H = 2$.

Polished section

Gold is bright yellow. Argentiferous gold is whiter and cupriferous gold is pinker. $R \approx 76\%$, making gold much brighter than pyrite and chalcopyrite. Electrum is brighter ($R \approx 85\%$) and whiter than pure gold. It is isotropic, but with incomplete extinction, when a greenish colour is observed. Gold does not tarnish, but large grains scratch easily and may be difficult to polish.

Gold occurs as irregular grains, blebs or veinlets, often in sulphides as pyrite or arsenopyrite. The various forms of gold are often intergrown with each other or with Au + Bi + Te and Sb + As-containing minerals. Gold can occur as very fine coatings which may easily be lost on polishing. $VHN = 30-35$.

Occurrence

Gold is found in hydrothermal deposits, often associated with igneous rocks; in auriferous quartz veins. It seems to be present throughout the temperature range of vein mineralization.

In placers deposit, gold appears to be chemically mobile, resulting in nugget growth.

Gold often occurs as very small grains, even in economic gold deposits.

Distinguishing features

Compared with gold: chalcopyrite is less yellow, darker and weakly anisotropic.

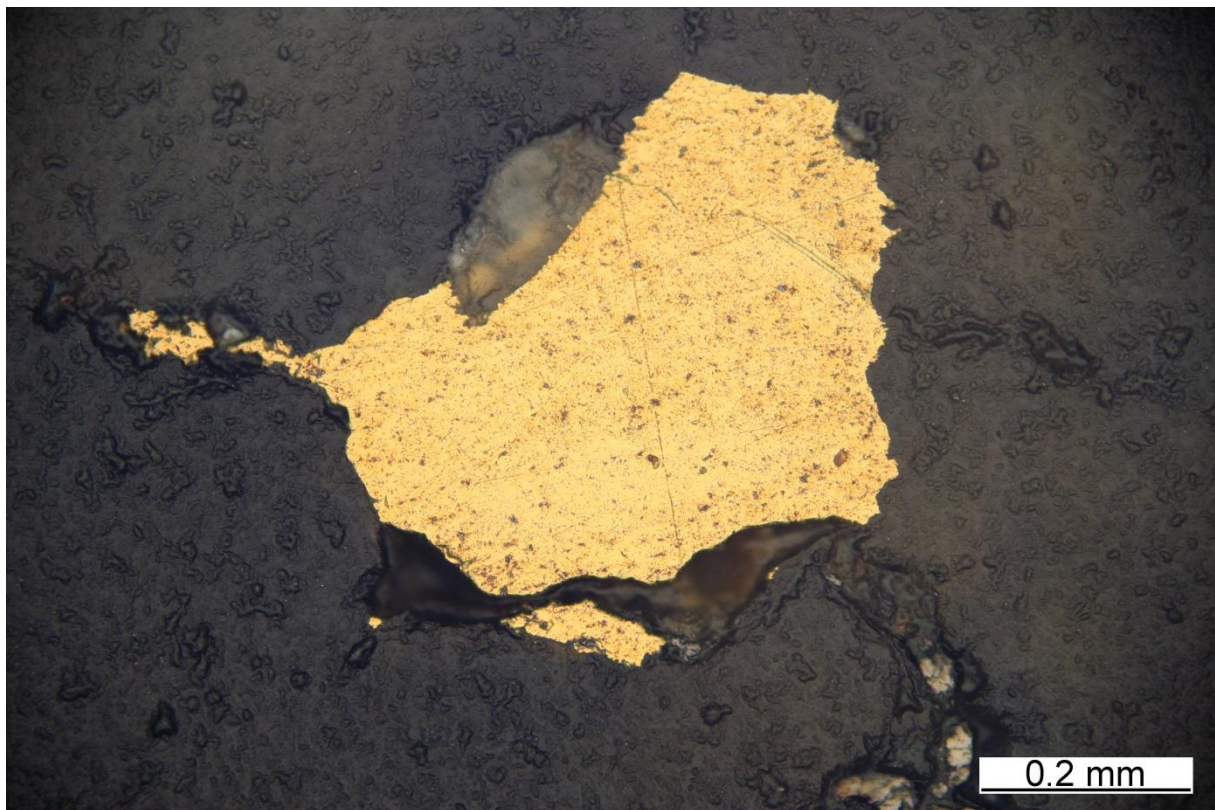


Fig. 3. Gold, sample Zlatý chlum, PPL

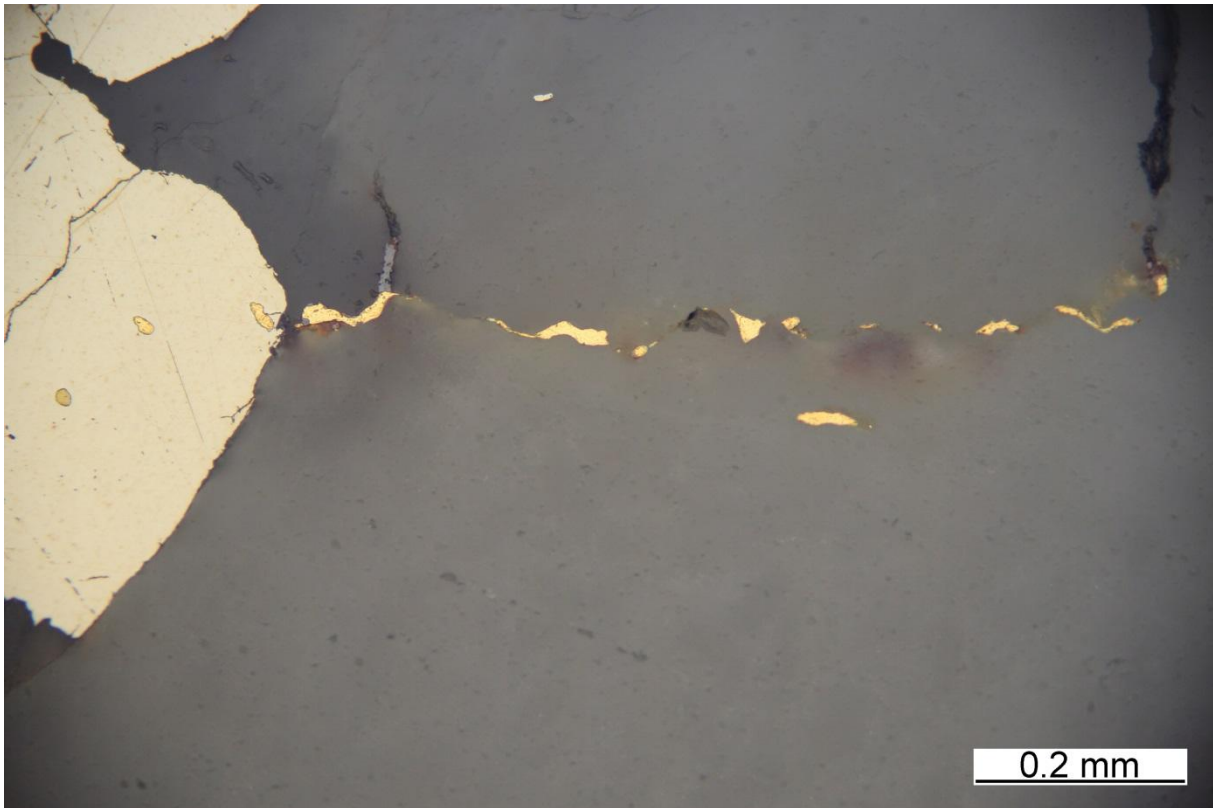


Fig. 4. Gold (yellow) in pyrite and quartz, sample Suchá Rudná, PPL

Silver Ag

Silver may contain minor amounts of Au, Hg, As, Sb, Pt, Ni, Pb or Fe.

Crystals

Silver is cubic. $D = 10.5$, $H = 2,5$.

Polished section

Silver is white but it soon tarnishes. It is much brighter ($R \approx 95\%$) than the common ore minerals. Silver is isotropic, but false anisotropy may result from fine polishing scratches.

Silver occurs in dendritic or irregular masses and as inclusions. Often in silver-bearing sulphides or sulphur-poor minerals. $VHN = 46-118$.

Occurrence

Silver is found with Co + Ni + Fe arsenides, usually associated with basic igneous rocks. It also occurs in the oxidation zones of galena-bearing veins. Many veins recorded as “silver veins” are in fact argentiferous galena veins, the silver being produced as a byproduct of lead recovery. Silver is associated with native copper, and often with carbonate.

Distinguishing features

Compared with silver: gold is less brighter and coloured yellow.

Sulphides

In the structures of sulphide minerals, sulphur atoms are usually surrounded by metallic atoms (e.g. Cu, Zn or Fe) or the semi-metals (Sb, As or Bi). The chemical bonding is usually considered to be essentially covalent. Although sulphur has a preference for fourfold tetrahedral coordination, it is found in a large variety of coordination polyhedra which may be quite asymmetric.

Non-stoichiometry, i.e. a variable metal: sulphur ratio, is a feature of many sulphide structures, especially at high temperatures; complex ordering may result on cooling of a non-stoichiometric phase leading, at low temperature, to minerals with only slightly different compositions but different structures. A good example is that of high-temperature cubic digenite, Cu_{2-x}S ($x \leq 0.2$), which is represented at low temperatures by orthorhombic chalcocite Cu_2S , orthorhombic djurleite $\text{Cu}_{1.97}\text{S}$ and $\text{Cu}_{1.8}\text{S}$.

Two further possible complexities in sulphide structures are the existence of sulphur-sulphur bonds, exemplified by the S_2^{2-} pair in pyrite FeS_2 , and the existence of structures that can be considered as resulting from a replacement by a semi-metal of half the sulphur in such pairs, e.g. arsenopyrite FeAsS .

Most sulphides are opaque but some (e.g. sphalerite when pure zinc sulphide) are transparent. Some are transparent for red light (e. g. pyrargyrite Ag_3SbS_3) or only in the infrared (e.g. stibnite Sb_2S_3). Many are semiconductors, which means they conduct electricity at a high temperature but not at a low temperature. In fact, the optical and physical properties of many sulphides are best understood if the band model of semiconductors is applied (see Shuey 1975).

Sulphide structures can be classified – as are the silicates – into structures based on chains, sheets, networks and so on. Although such a classification is of less value than for the silicates, consideration of structures in such a way helps to explain the crystal morphology, cleavage directions etc. of some sulphides.

The sulphosalts are one group of sulphides which are very diverse chemically and structurally. They contain a semi-metal as well as a metal and sulphur in their structures; the semi-metal is typically bonded to sulphur in trigonal pyramidal coordination, but there is no semi-metal to metal bonds as in arsenopyrite FeAsS . Two examples of sulphosalts which are relatively common are pyrargyrite Ag_3SbS_3 and tetrahedrite $(\text{Cu,Ag})_{10}(\text{Zn,Fe})_2(\text{Sb,As})_4\text{S}_{13}$.

Useful reviews on sulphide mineralogy are given by Gribble and Hall (1992), Vaughan and Craig (1978), Ribbe (1974) and Nickless (1968).

Arsenopyrite FeAsS

Arsenopyrite is commonly non-stoichiometric and may have Fe replaced by Co.

Crystals

Pseudo-orthorhombic (monoclinic) with axial ratios $a:b:c = 1.6833:1:1.1400$. Crystals are commonly prismatic [001] with twinning on {101} and {001} giving pseudo-orthorhombic crystals; {101} giving penetration twins; or {012} giving cruciform twins. Cleavage {101} is distinct. $D = 6.1$, $H = 6$.

Polished section

Arsenopyrite is white, with $R \approx 52\%$, about the same as pyrite. Bireflectance is weak but anisotropy is usually quite distinct, the colours being dark blues and browns, and extinction is poor. The anisotropy is easier to observe than that of pyrite but weaker than that of marcasite.

Grain sections are often idiomorphic rhomb or lozenges (FIG. 3.23) or rather elongate skeletal porphyroblasts. Zonation of extinction is common, and simple or hourglass twins are frequently observed. Lamellar twinning is reported. $VHN = 1048-1127$.

Occurrence

Arsenopyrite is considered to be typical of relatively high-temperature hydrothermal veins, where cassiterite, wolframite, chalcopyrite, pyrrhotite and gold are common associates. It is also found in most types of sulphide deposits.

Distinguishing features

Compared with arsenopyrite, pyrite is yellowish and cubic in morphology and marcasite is much more anisotropic.

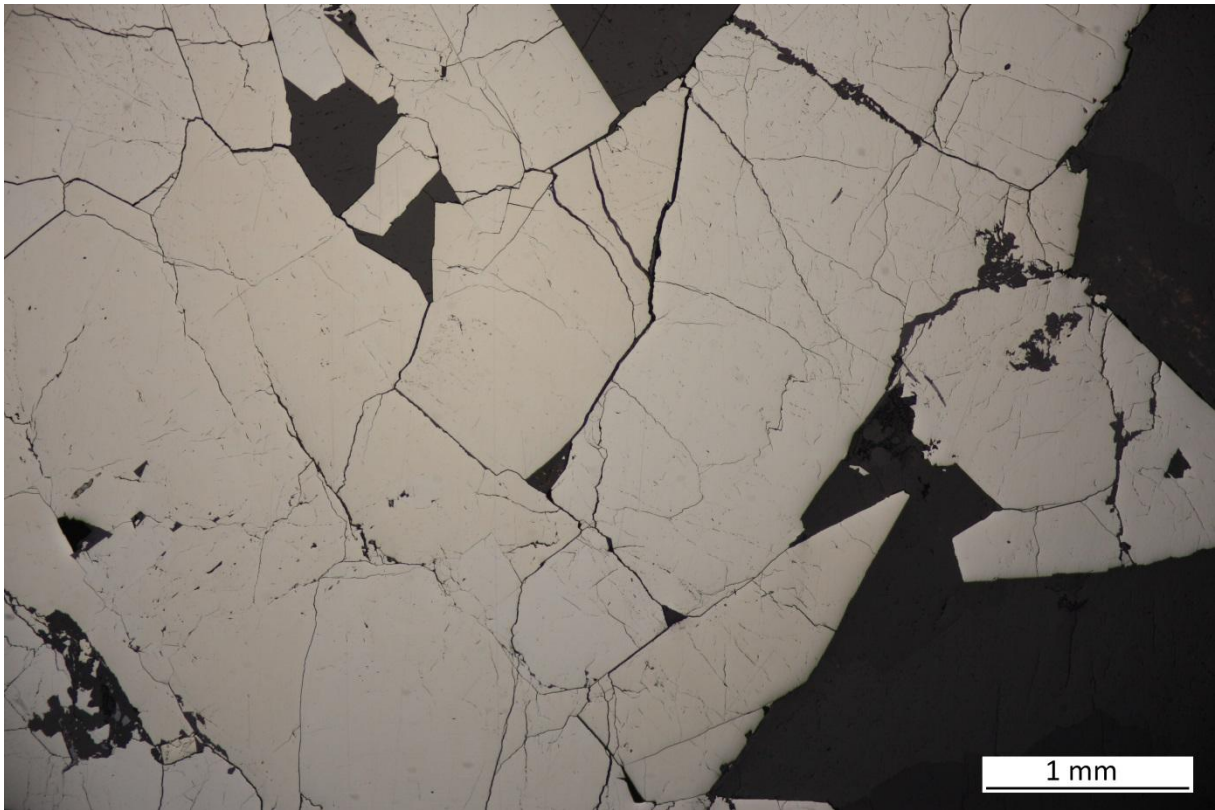


Fig. 5. Arsenopyrite aggregate (yellow-white) with weak bireflection, sample 8, PPL

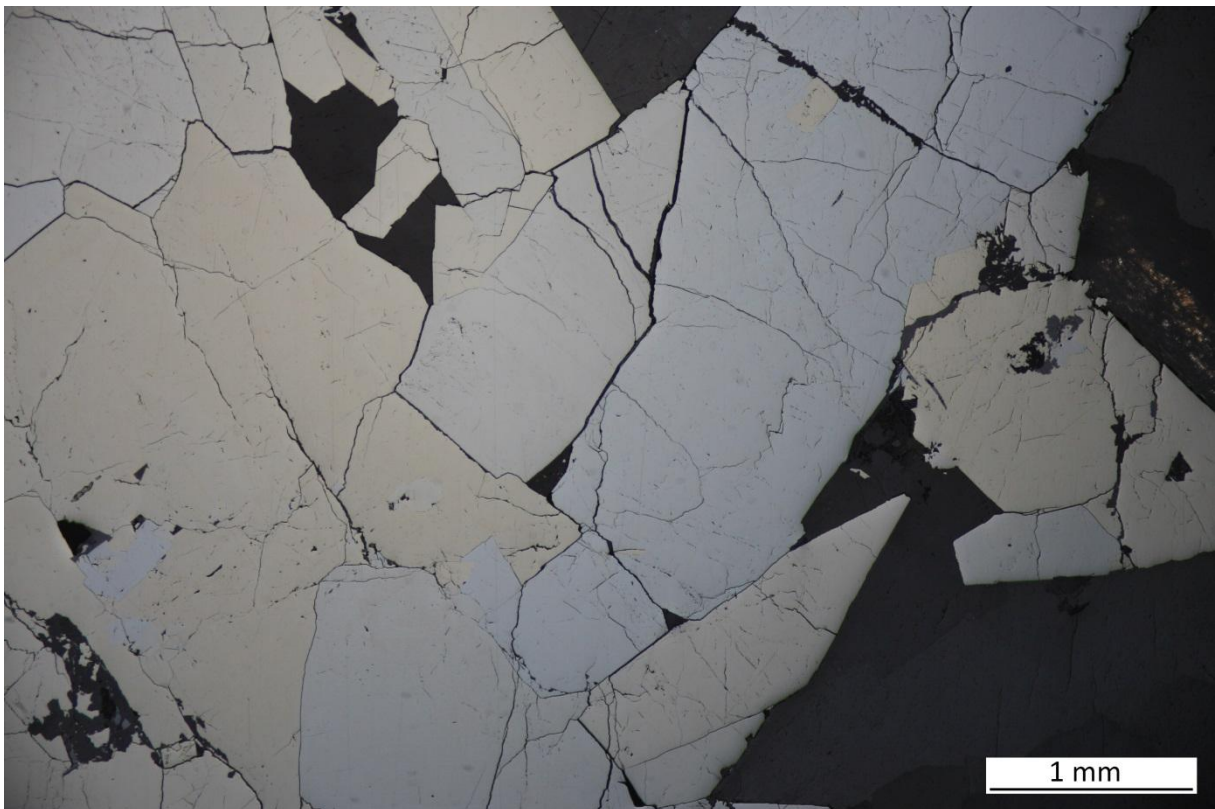


Fig. 6. Arsenopyrite aggregate with distinct anisotropy, sample 8, PPL

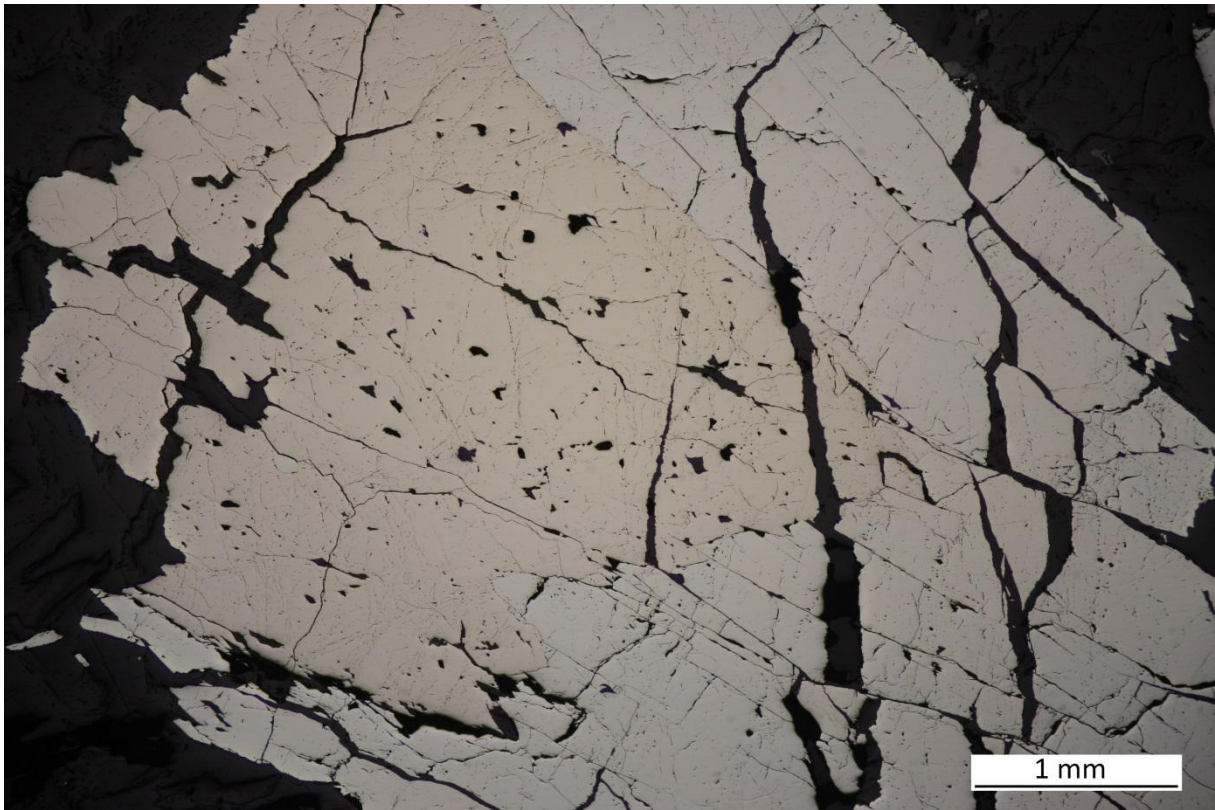


Fig. 7. Arsenopyrite (yellow-white), sample 8, PPL

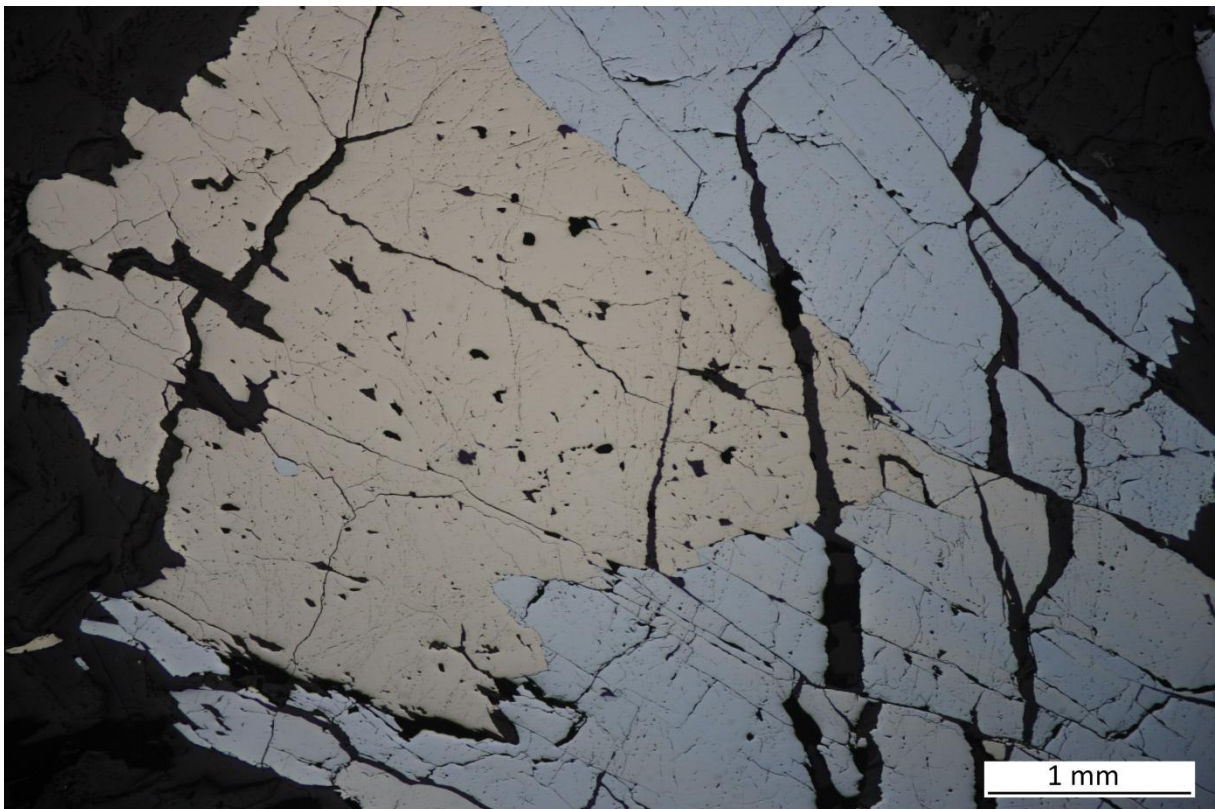


Fig. 8. Arsenopyrite with distinct anisotropy, sample 8, PPL

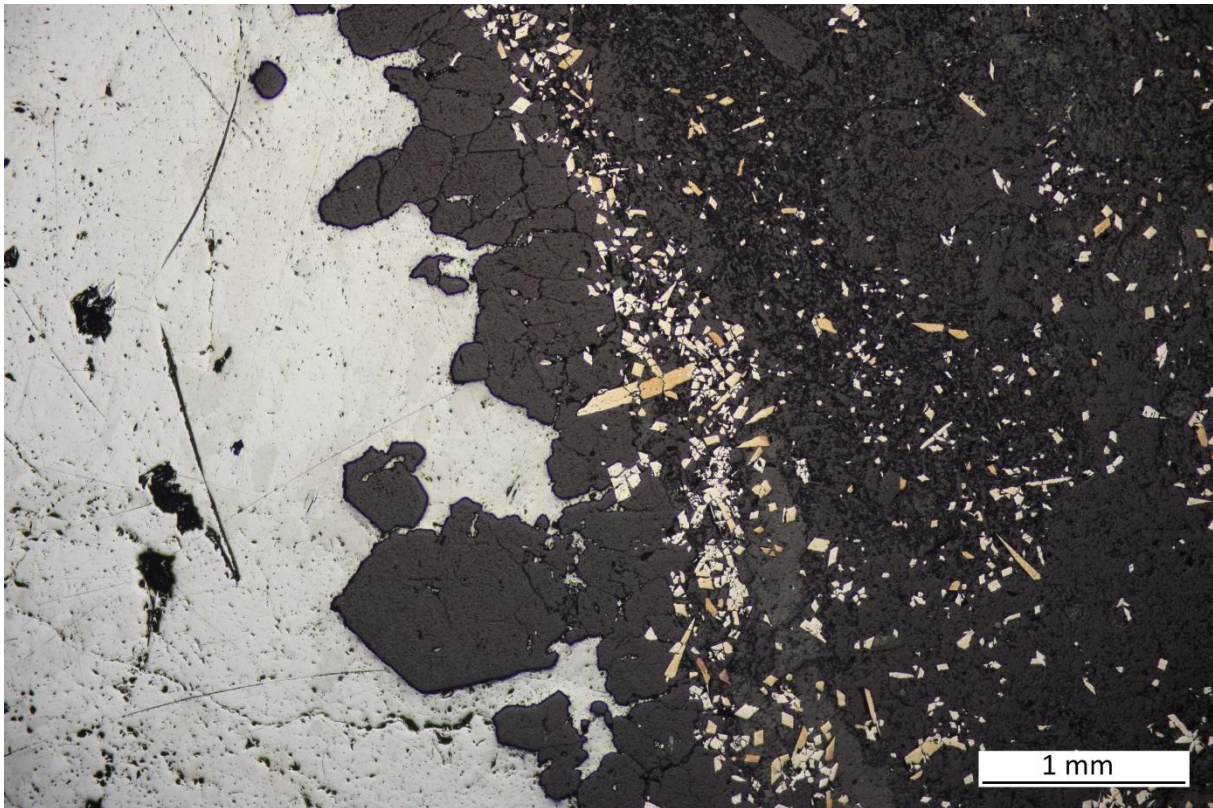


Fig. 9. Euhedral rhomb-shape arsenopyrite crystals (yellow-white) with stibnite (white), sample Hynčice, PPL

Bornite Cu_5FeS_4

Crystals

Bornite is tetragonal (pseudo-cubic). Crystals are rare as cubes, dodecahedra or octahedral. Twinning on $\{111\}$ is also a cleavage orientation. $D = 5.1$, $H=3$.

Polished section

Bornite is pinkish brown when fresh, but soon tarnishes to purple or iridescent blue. With $R \approx 22\%$ it is brighter than sphalerite. Both bireflectance and anisotropy, with dark brown and grey tints, are very weak. Very fine granular aggregates appear isotropic. There is often a colour variation or zonation due to tarnishing. Multiple twinning is reported and cleavage traces in two directions are common. Chalcopyrite is commonly present as myrmekitic intergrowths or lamellae. Chalcopyrite commonly occurs along fractures.

Occurrence

Bornite is usually associated with other $\text{Cu} + \text{Fe} + \text{S}$ minerals in the “secondary environment”. It can result from unmixing of high-temperature $\text{Cu} + \text{Fe} + \text{S}$ solid solutions on cooling.

Distinguishing features

Compared with bornite, pyrrhotite is lighter brown and distinctly anisotropic; they rarely occur together.

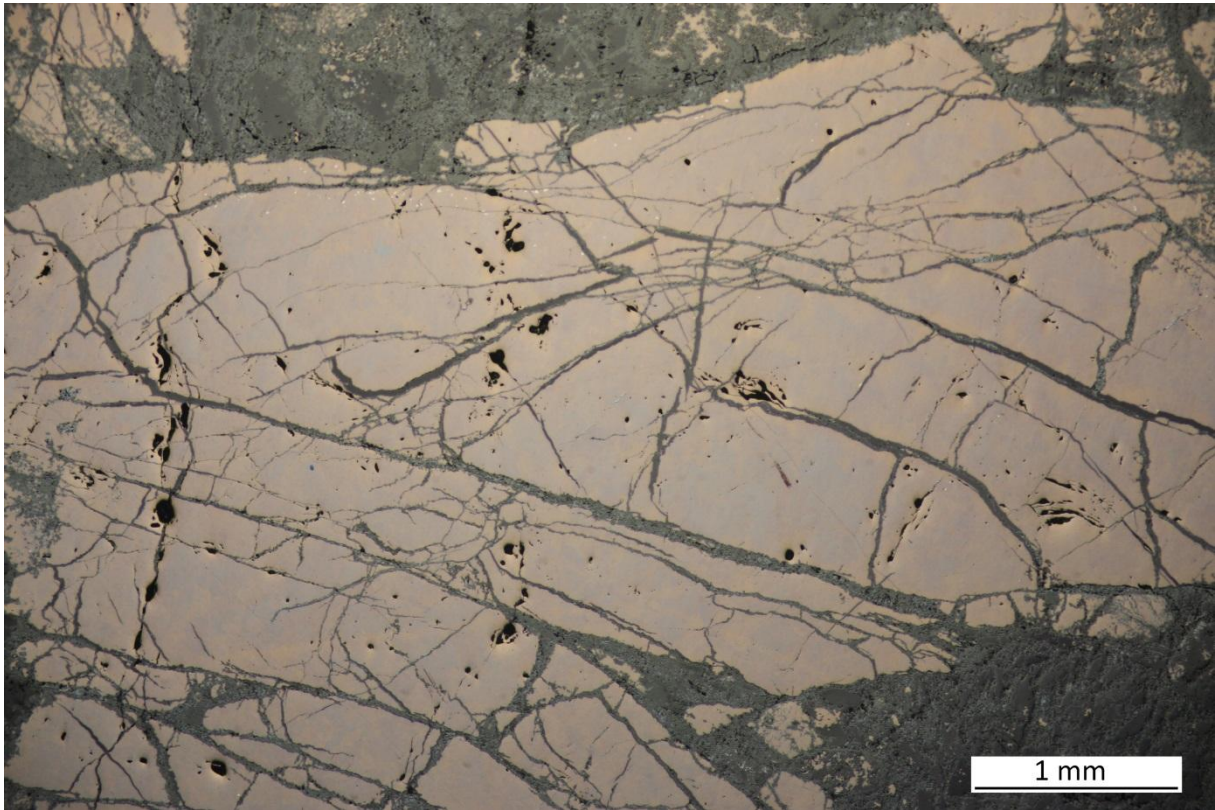


Fig. 10. Bornite, sample 10 - Rybice (PL), PPL

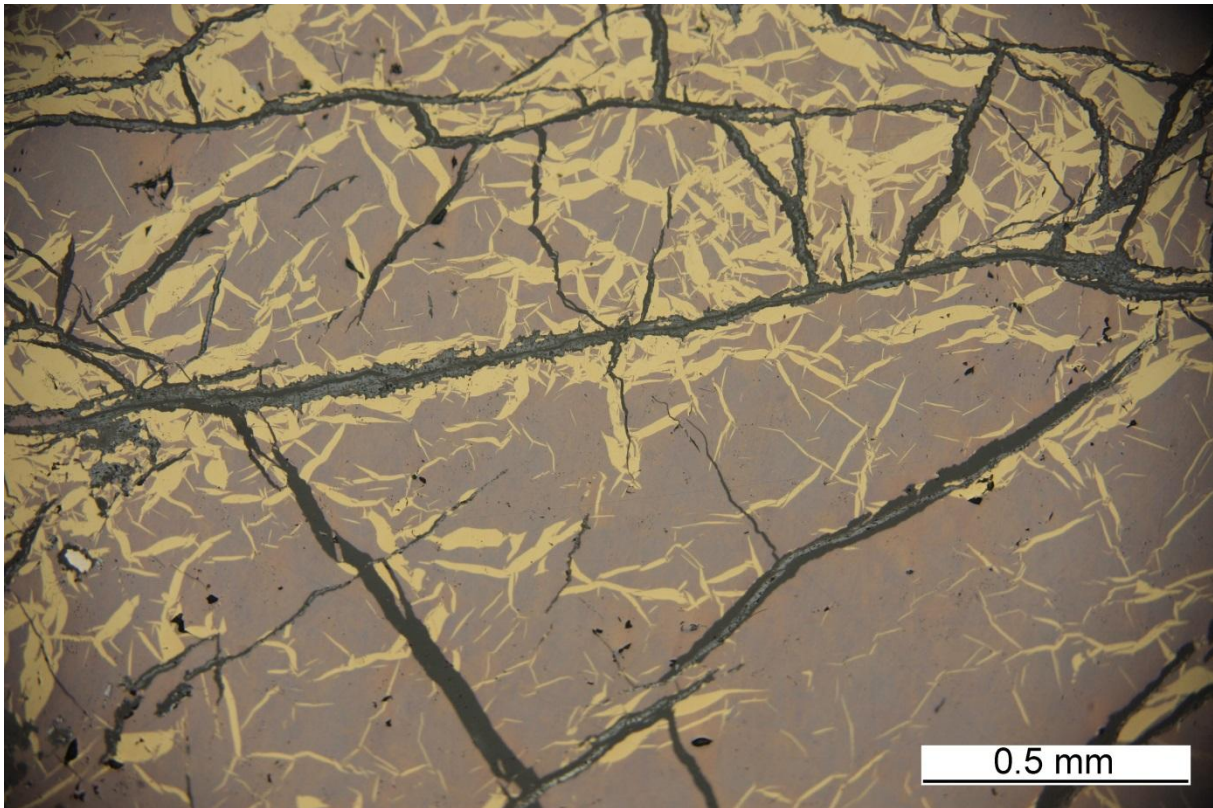


Fig. 11. Bornite with chalcopyrite as product of its decomposition, sample 10 - Rybice (PL), PPL

Chalcocite Cu_2S (chalcocite)

Digenite Cu_9S_5

Ramdohr (1969) states that “what has hitherto been considered as chalcocite with the formula Cu_2S is a great number of semi-independent minerals and solid solutions, whose relationships are not yet fully understood and for which there are diverse interpretations”. Care must therefore be taken, when examining samples reportedly containing chalcocite.

Crystals

Chalcocite Cu_2S is orthorhombic, $a:b:c = 0.5822 : 1 : 0.9701$. Digenite Cu_9S_5 is cubic. Both minerals are usually massive. $D=5.77$, $H=2.5$.

Polished section

Chalcocite appears bluish light grey with $R \approx 33\%$, whereas digenite is light grey to bluish grey, with $R \approx 21\%$. Chalcocite is weakly anisotropic, with pinkish, greenish-grey or brownish tints. Digenite is isotropic.

Both minerals occur in granular aggregates, and are commonly in intergrowths with each other or other $\text{Cu} + \text{Fe} + \text{S}$ minerals. Lancet-shaped inversion twinning indicates cooling from

the high-temperature hexagonal polymorph through 103°C to the orthorhombic polymorph. Cleavage traces may be observed and are enhanced on weathering. VHN= 80-90 (chalcocite), 80-110 (digenite).

Occurrence

Digenite is indicative of higher temperatures and higher sulphur activity than chalcocite. Both minerals are associated with other copper and iron sulphides, especially covellite, in low-temperature hydrothermal veins and in the “secondary environment”. They occur in cupriferous, red-bed sedimentary rocks and are widespread as replacement minerals.

Distinguishing features

Compared with chalcocite, djurleite $\text{Cu}_{1.96}\text{S}$ (orthorhombic) is very similar; sphalerite is slightly darker, isotropic and often shows internal reflections; and tetrahedrites are less blue, harder and isotropic.

Notes

Cu-sulphide minerals are complex owing to the variation in crystallographic and optical properties with slight changes in the Cu : S ratio. Their colour changes readily, owing to surface damage during polishing as well as to tarnishing.

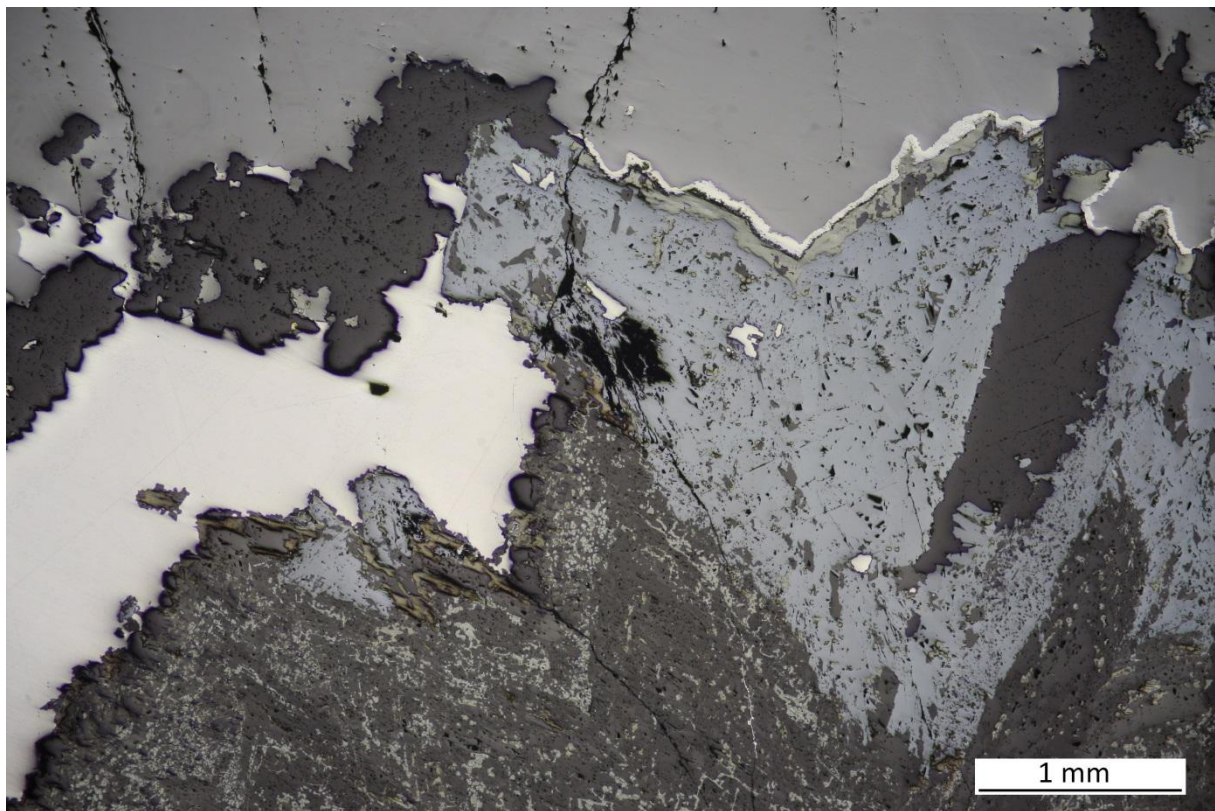


Fig. 12. Chalcocite aggregate (bluish grey), sphalerite (darker grey) and galena (white), sample 6, PPL

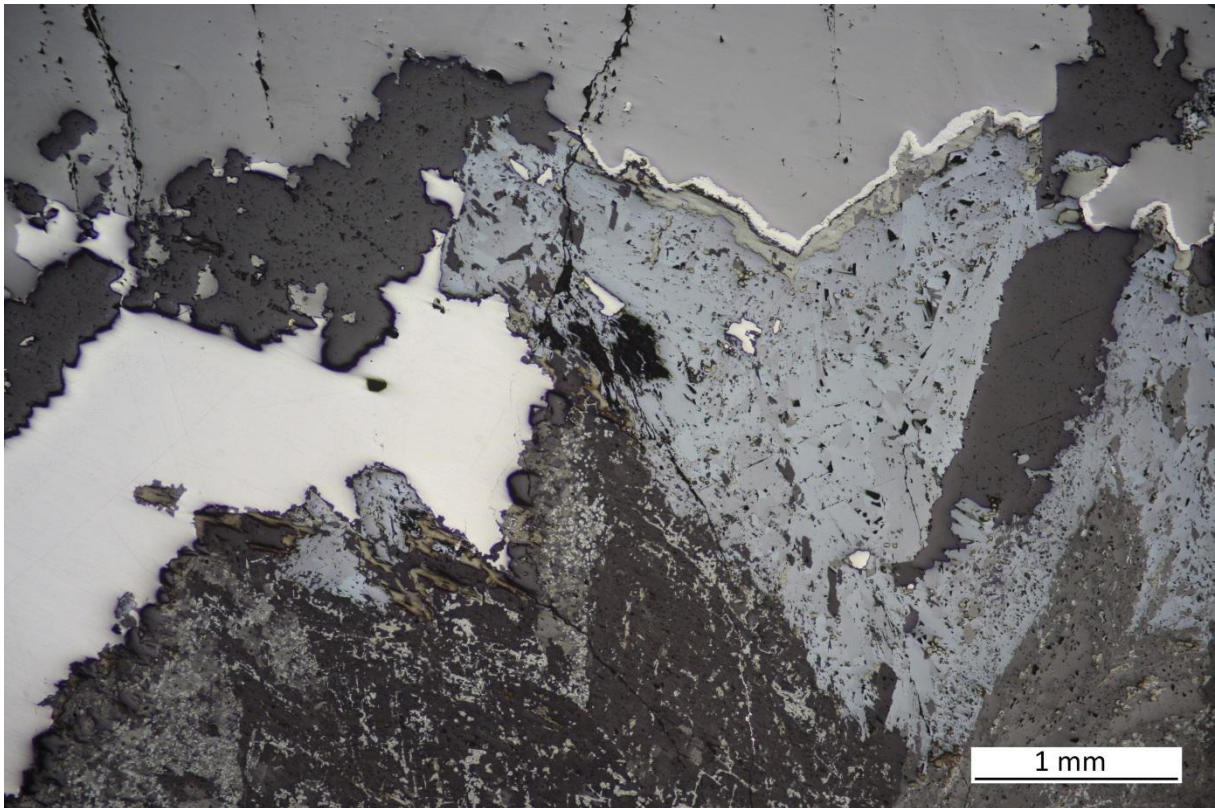


Fig. 13. Chalcocite aggregate (bluish grey with distinct anisotropy), sphalerite (darker grey) and galena (white), sample 6, XPL

Chalcopyrite CuFeS_2

Incorporation of many other elements (e.g. Ni, Zn or Sn) is possible at high temperatures in the cubic polymorph, which has a range in composition in the Cu + Fe + S system. Unmixing occurs on cooling, resulting in inclusions in chalcopyrite.

Crystals

Chalcopyrite is tetragonal, $a:c = 1:1.9705$. Crystals are commonly scalenohedral or tetrahedral in appearance. Twinning is common on $\{112\}$ and $\{012\}$ and cleavage is $\{011\}$. $D = 4.28$, $H = 4$.

Thin section

Chalcopyrite is opaque, but alteration leads to associated blue-green staining or associated secondary hydrous copper carbonates, which are blue to green in colour.

Polished section

Chalcopyrite is yellow and it tarnishes to brownish yellow. $R = 44-46\%$, slightly less than pyrite and similar to galena. Anisotropy is weak, with dark brown and greenish-grey tints, and is often not visible.

Chalcopyrite usually occurs as irregular or rounded grains. It is common as rounded inclusion or in fractures in other sulphides, especially pyrite and sphalerite. Colloform masses of chalcopyrite have been reported. Simple and multiple twinning is common, and cleavage traces are sometimes observed. Several phases may be present in chalcopyrite as exsolved blebs, lamellae or stars (e.g. ZnS) and indicate a high-temperature origin. VHN = 180–200.

Occurrence

Chalcopyrite is a common mineral in most types of ore deposit, as well as in igneous and metamorphic rocks. It is the major primary copper mineral in porphyry copper deposits and is occurs, with bornite, in the stratiform sulphide deposits of the Copperbelt. Chalcopyrite appears to be a relatively mobile mineral in ore deposits, and commonly replaces and veins other minerals, especially pyrite.

Distinguishing features

Compared with chalcopyrite, pyrite is white, much harder and commonly idiomorphic, and gold is much brighter but may be yellower or whiter. Small isolated grains of pyrite and chalcopyrite can be very similar in appearance.

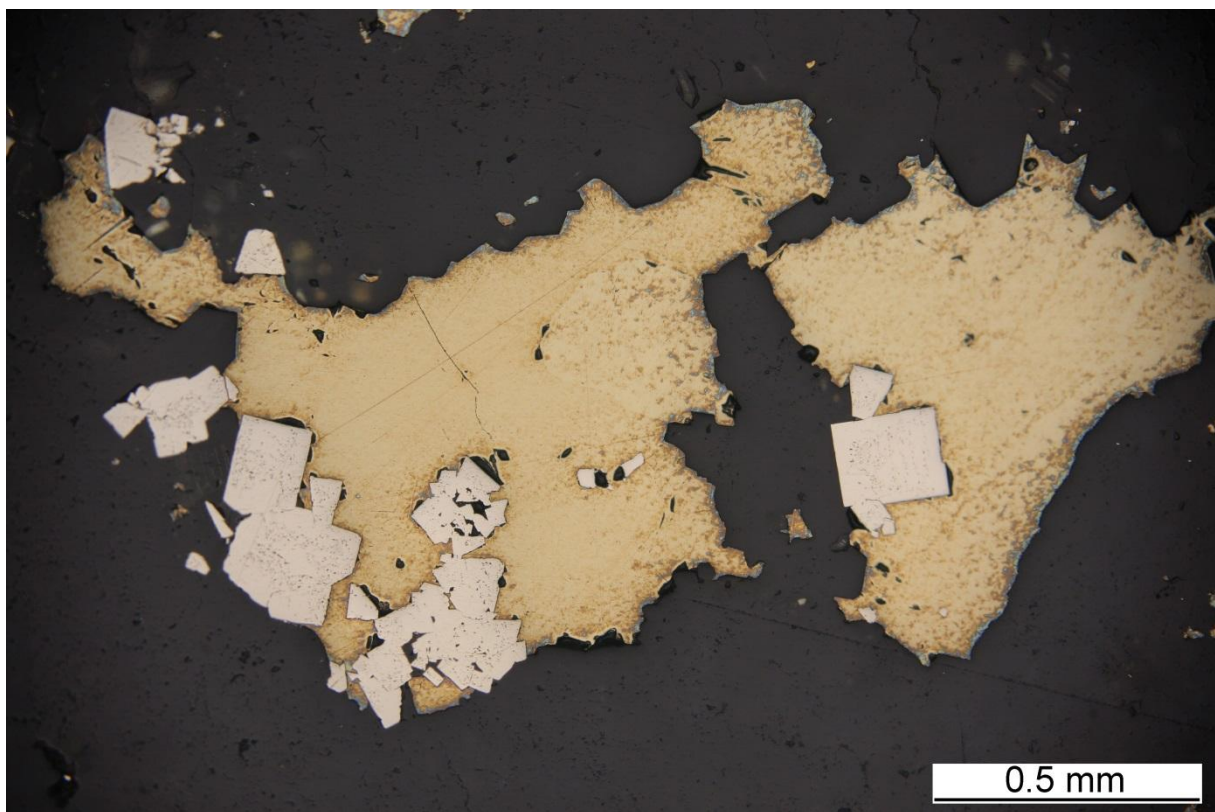


Fig. 14. Chalcopyrite (yellow) with euhedral cubic pyrite (white), sample 64, PPL

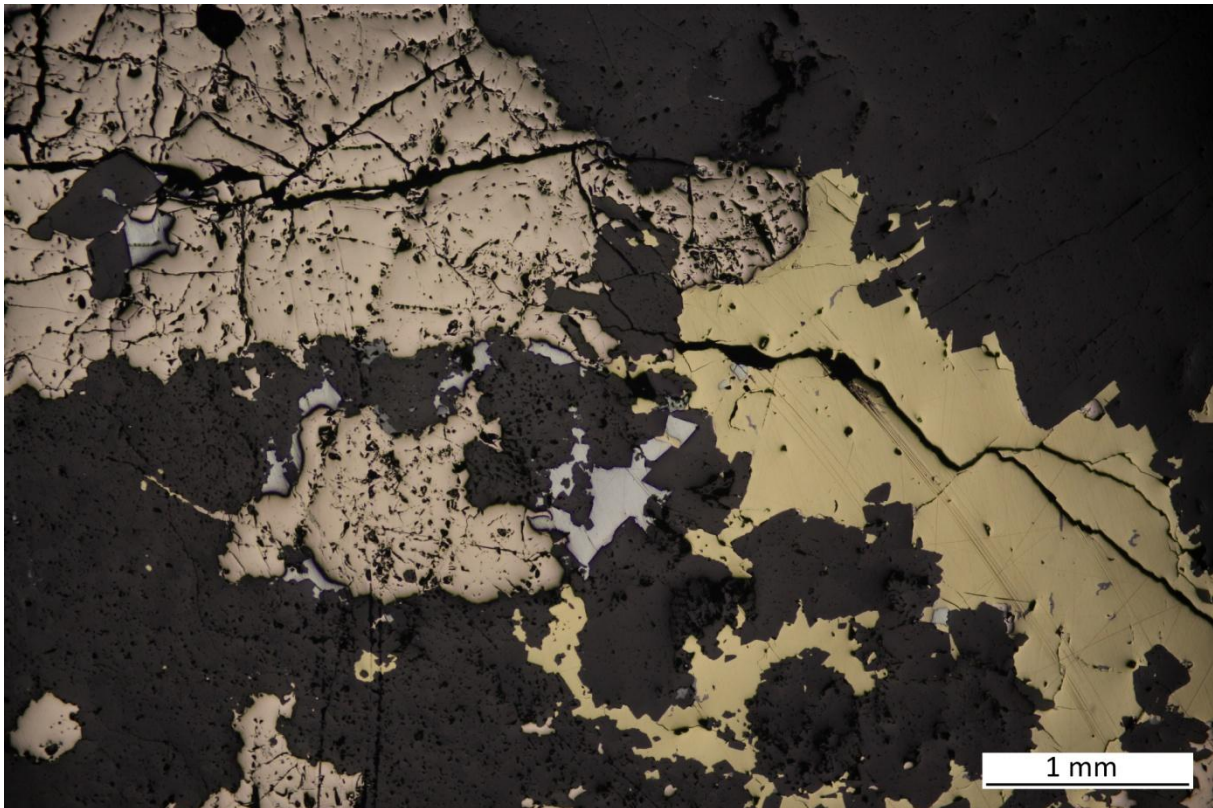


Fig. 15. Chalcopyrite (yellow), pyrrhotite (brownish pink) and galena (white), sample Zlaté Hory, PPL

Cinnabar HgS

Crystals

Cinnabar is trigonal, $a:c = 1:2.2905$, and it occurs as thick tabular $\{0001\}$ or prismatic $[1011]$ crystals. There is a $\{0001\}$ twin plane and perfect $[1011]$ cleavage. $D= 8.09$, $H= 2.5$.

Thin Section

Cinnabar is deep red. Refractive index values ($\lambda = 598$ nm) are $n_0= 2.905$ and $n_e= 3.256$.

Polished section

Cinnabar (Plates 4e and f) is light grey to bluish light grey, weakly pleochroic, with $R_0 = 24\%$, and $R_e = 29\%$. Anisotropy is moderate with greenish-grey tints, but these are often marked by abundant deep red internal reflections.

Cinnabar occurs as granular aggregates and idiomorphic crystals. Deformation multiple twinning may be present. As a result of variation in polishing hardness with orientation, granular aggregates may resemble a two-phase intergrowth at first glance.

Occurrence

Cinnabar is rare, occurring in low-temperature hydrothermal veins, impregnations and replacement deposits often associated with native mercury, mercurian tetrahedrite–tennantite, stibnite, pyrite and marcasite in siliceous gangue. VHN = 80–160.

Distinguishing features

Compared with cinnabar, hematite is brighter, harder and has very rare internal reflections; pyrargyrite is very similar, but with less intense internal reflections; and cuprite (Cu_2O) is bluish grey, harder and usually associated with native copper.

Notes

Metacinnabarite is a high-temperature cubic polymorph of HgS . It occurs as grains within cinnabar and is slightly darker; it is isotropic, lacks internal reflections and is softer than cinnabar.

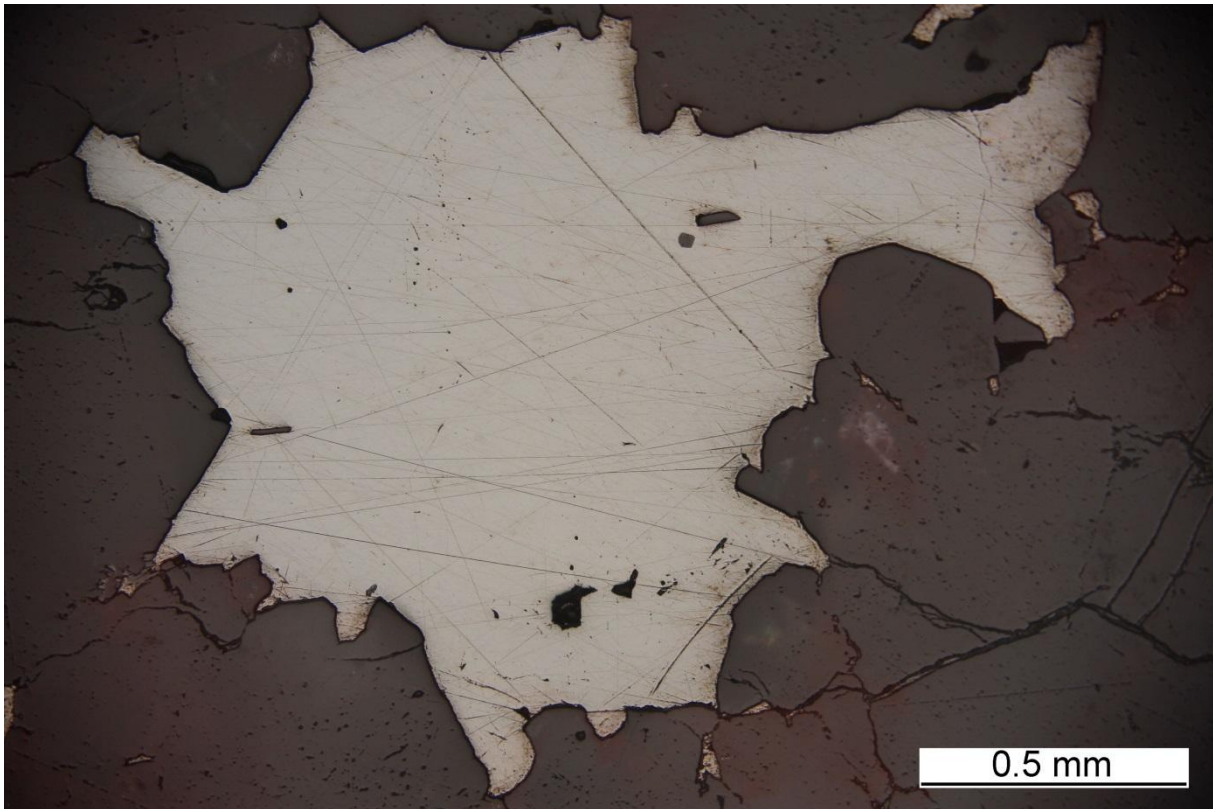


Fig. 16. Cinnabar, sample 65, PPL

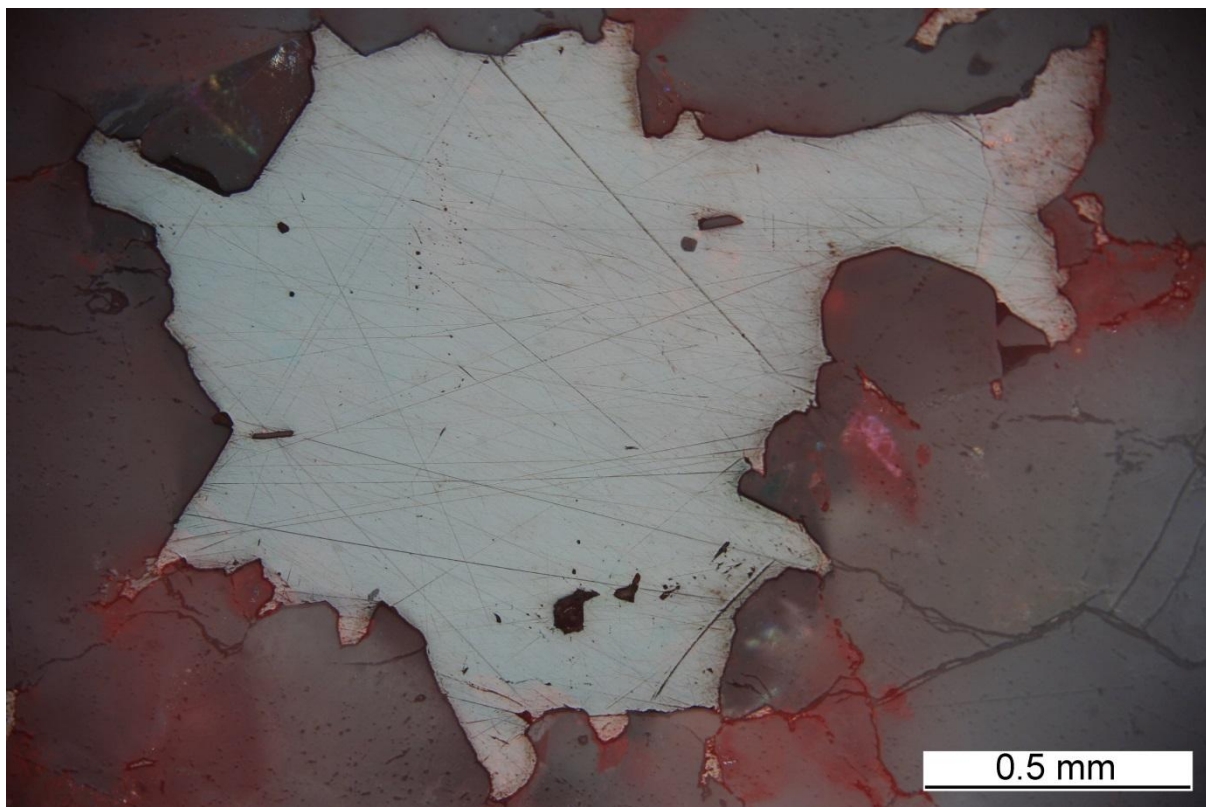


Fig. 17. Cinnabar with typical red internal reflexes, sample 65, XPL

Cobaltite CoAsS

Cobaltite may contain significant amounts of Fe and Ni in solid solution.

Crystals

Cobaltite is orthorhombic (pseudo-cubic). It commonly occurs in cubes or pyritohedrons, but may be octahedral. There is perfect {001} cleavage. D=6.0-6.3, H= 6.5.

Polished section

Cobaltite is pinkish white with $R \approx 51\%$, slightly less than pyrite. Both bireflectance and anisotropy, with brownish to bluish tints, are weak. Cobaltite is often idiomorphic and of “cubic” morphology. It may be granular or skeletal. Colour zonation has been observed, and complex fine lamellar twinning and cleavage traces may be present. VHN =1100–1350.

Occurrence

It is associated with Cu + Fe + S and Co + Ni + As minerals in high- to medium-temperature deposits in veins and as disseminations.

Distinguishing features

Compared with cobaltite, pyrite is yellowish and harder.

Covellite CuS

Covelline is an alternative name recommended by the International Mineralogical Association.

Crystals

Hexagonal, $a:c=1:1.43026$. It occurs as platy {0001} crystals with a perfect {0001} basal cleavage. $D = 4.6$, $H = 2$.

Thin section

Greenish in very thin flakes.

Polished section

Blue and strongly pleochroic, from blue to bluish light grey, except in basal sections which remain blue. $R_o = 7\%$ and $R_e = 24\%$. $R_o =$ reddish purple, $R_e =$ bluish grey. Anisotropy is very strong, with bright “fiery” orange colours. Covellite occurs as idiomorphic platy crystals and flakes. As well as rather “micaceous” aggregates. The good basal cleavage, parallel to the length of grains, is often deformed. $VHN = 50-140$.

Occurrence

Covellite commonly occurs as a “secondary” mineral after Cu + Fe + S minerals, often in the zone of secondary enrichment.

Distinguishing features

Covellite is easy to identify. Digenite is blue, but neither pleochroic nor anisotropic.

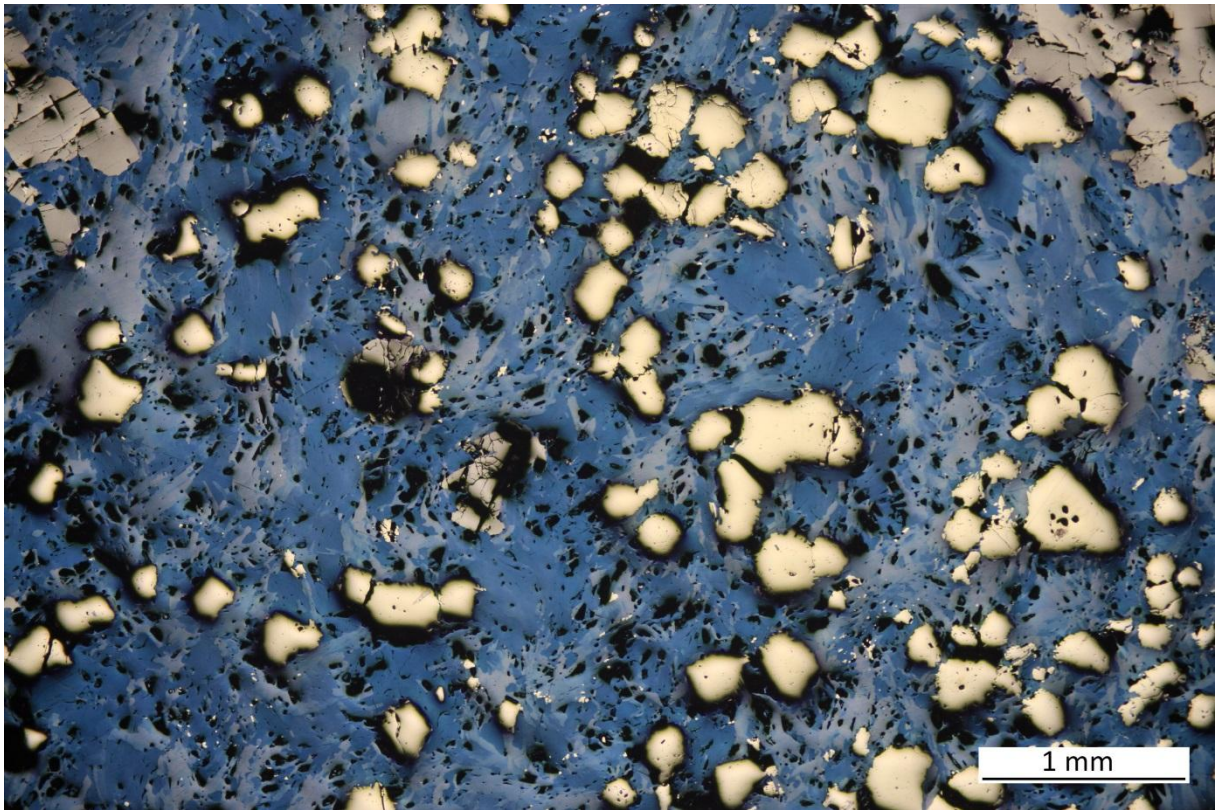


Fig. 18. Covellite (blue and strongly pleochroic, from blue to bluish light grey) with pyrite (yellow-white) and bornite (pinkish brown), sample Bor, PPL

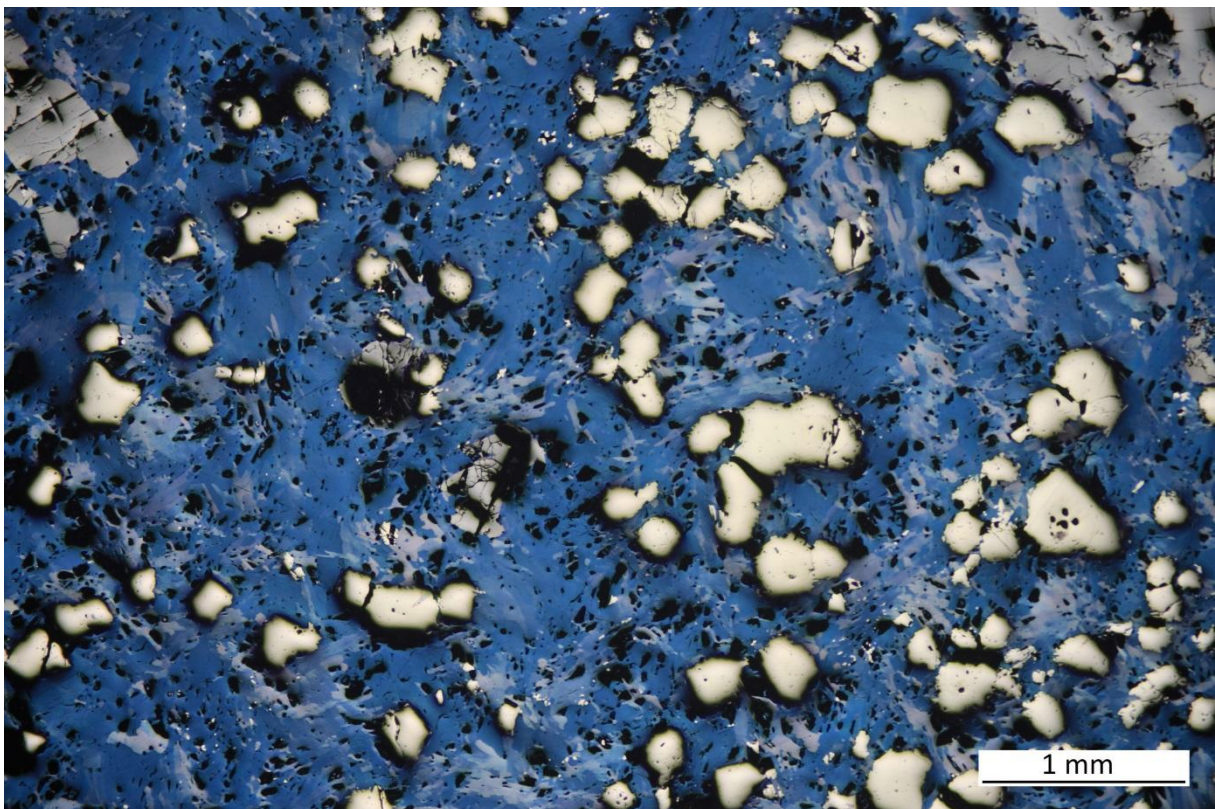


Fig. 19. Covellite (blue with strong anisotropy, from blue to bluish light grey) with pyrite (yellow-white) and bornite (pinkish brown), sample Bor, XPL

Galena PbS

Galena may possibly contain some Se, Te, **Ag**, Sb, Bi, or As in solid solution, but usually only in trace amounts.

Crystals

The crystallographic symmetry of galena is cubic and crystals are commonly cubic, cubo-octahedral and (less often) octahedral in shape. Twinning on {111} is common, and lamellar twinning may occur on {114}. There is a perfect {001} cleavage. $D = 7.58$, $H = 2.5$.

Polished section

Galena is white, sometimes with a very slight bluish tint. $R = 43\%$, which makes it darker than pyrite. It is isotropic but sometimes very weakly anisotropic.

Galena commonly has cubic morphology in vein and replacement deposits. It is often interstitial to other sulphides and occurs in microfractures. Internal grain boundaries of granular aggregates are enhanced by excessive polishing. Triangular cleavage pits are characteristic of galena and it is often altered along cleavage traces. Many minerals occur as inclusions, but especially sulphosalts of Pb, Ag with Sb or As. $VHN=60-100$.

Occurrence

Galena is common in hydrothermal vein and replacement deposits in many rock types, especially limestones. It is also common in some young (Proterozoic and Phanerozoic) stratiform massive sulphide deposits. Sphalerite is a common associate.

Distinguishing features

Compared with galena, some Pb + Sb + S minerals are similar, but these are usually distinctly anisotropic.

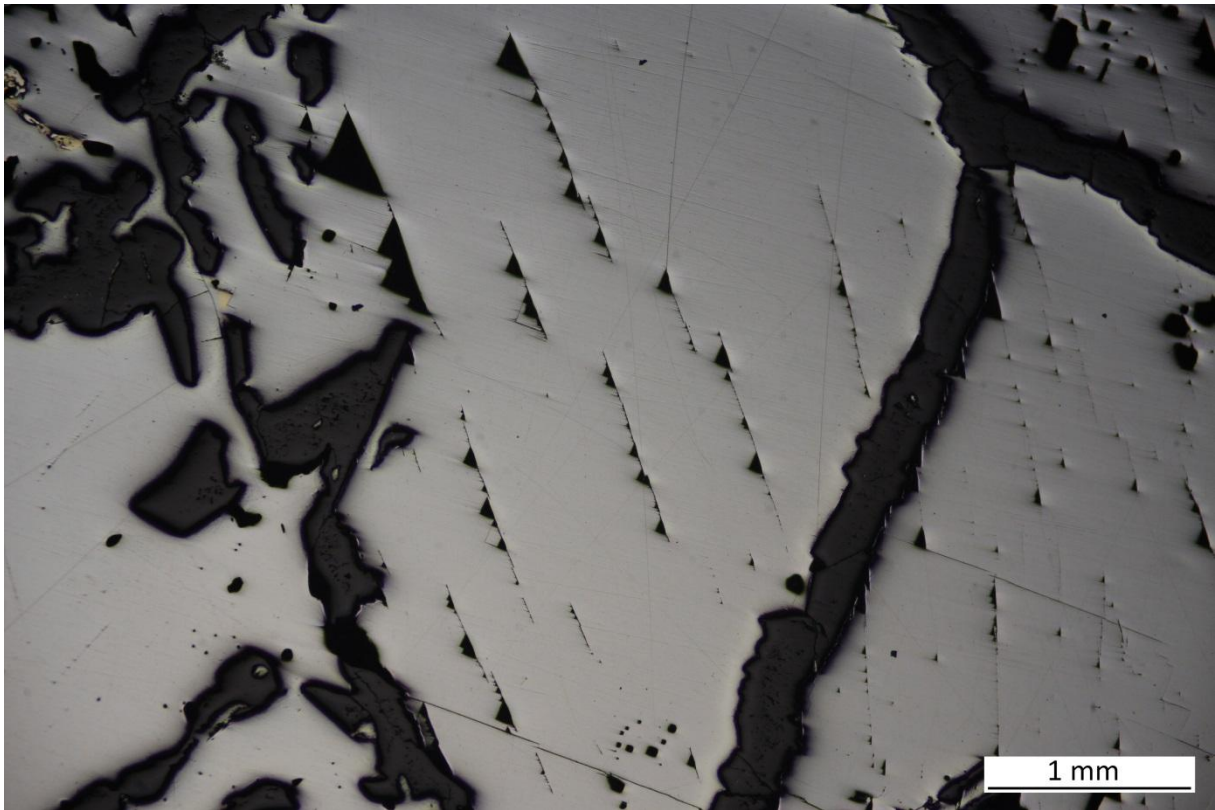


Fig. 20. Galena including the characteristic triangular cleavage pits, sample 64, PPL

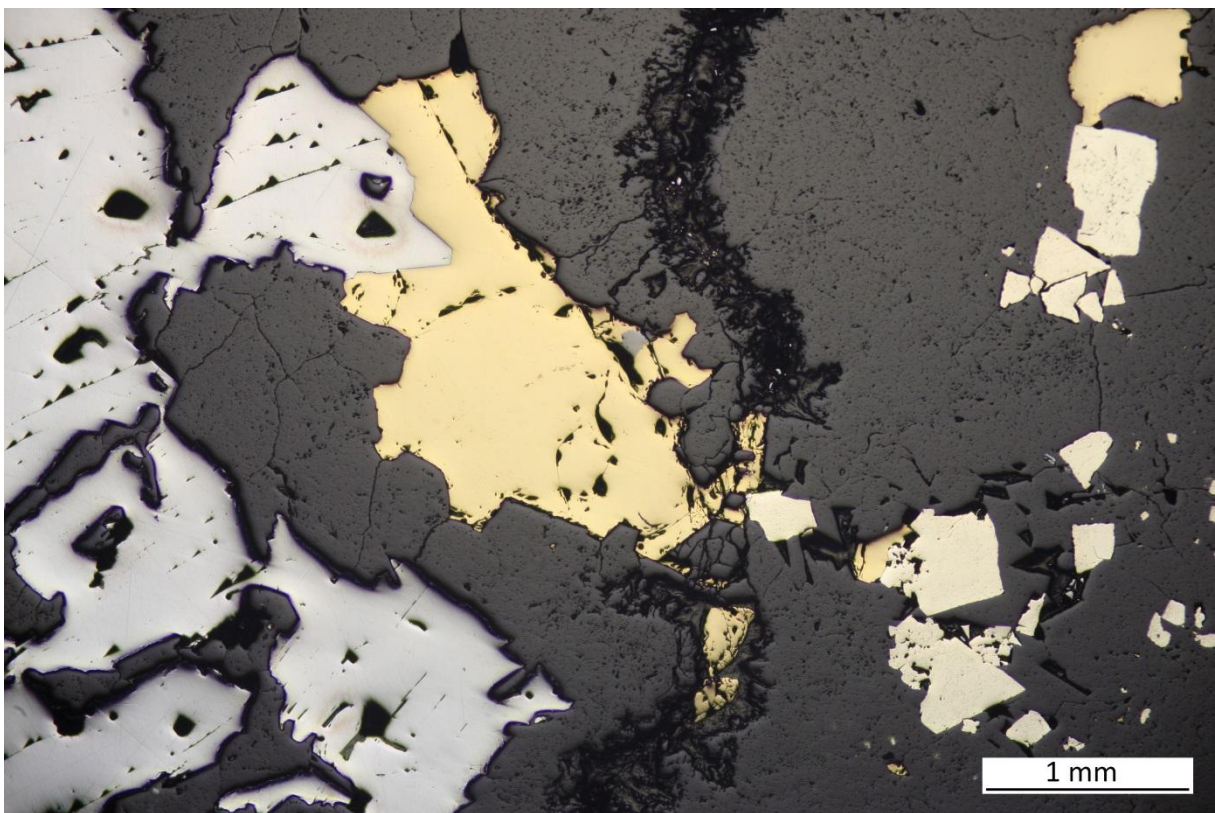


Fig. 21. Galena (white) with chalcopyrite (yellow) and euhedral pyrite (yellow-white), sample 64, PPL

Marcasite FeS₂

Crystals

Marcasite is orthorhombic, $a:b:c = 0.8914 : 1 : 0.6245$. It is commonly tabular {010} but may be pyramidal. Aggregates are often globular or stalactitic. Twinning on {101} is common, often repeated, producing cockscomb pseudo-hexagonal shapes. Cleavage on {101} is distinct. $D = 4.88$, $H = 6.5$.

Thin section

Marcasite is opaque, but because of ready oxidation a brown staining of limonite is often associated with it.

Polished section

Marcasite is white or slightly yellowish (Plate 4c). There is a weak pleochroism Ila pinkish white IIb and IIc yellowish white. $R = 49-55\%$, very close to pyrite. The strong anisotropy of marcasite in very bright bluish and greenish greys and browns is one of the most distinctive features.

Occurrence

Marcasite often appears as lath-shaped crystals in radiating aggregates of twins. Colloform aggregates with pyrite are common. Lamellar twinning and cleavage pits may be present. $VHN = 901-1100$.

Distinguishing features

Marcasite often occurs as concretions in sedimentary rocks. It is usually associated with pyrite in low-temperature sulphide deposits.

Compared with marcasite, pyrite is yellower slightly softer and weakly anisotropic or isotropic; pyrrhotite is darker, brownish, softer and has a weaker anisotropy; and arsenopyrite is whiter, brighter and has a weaker anisotropy.

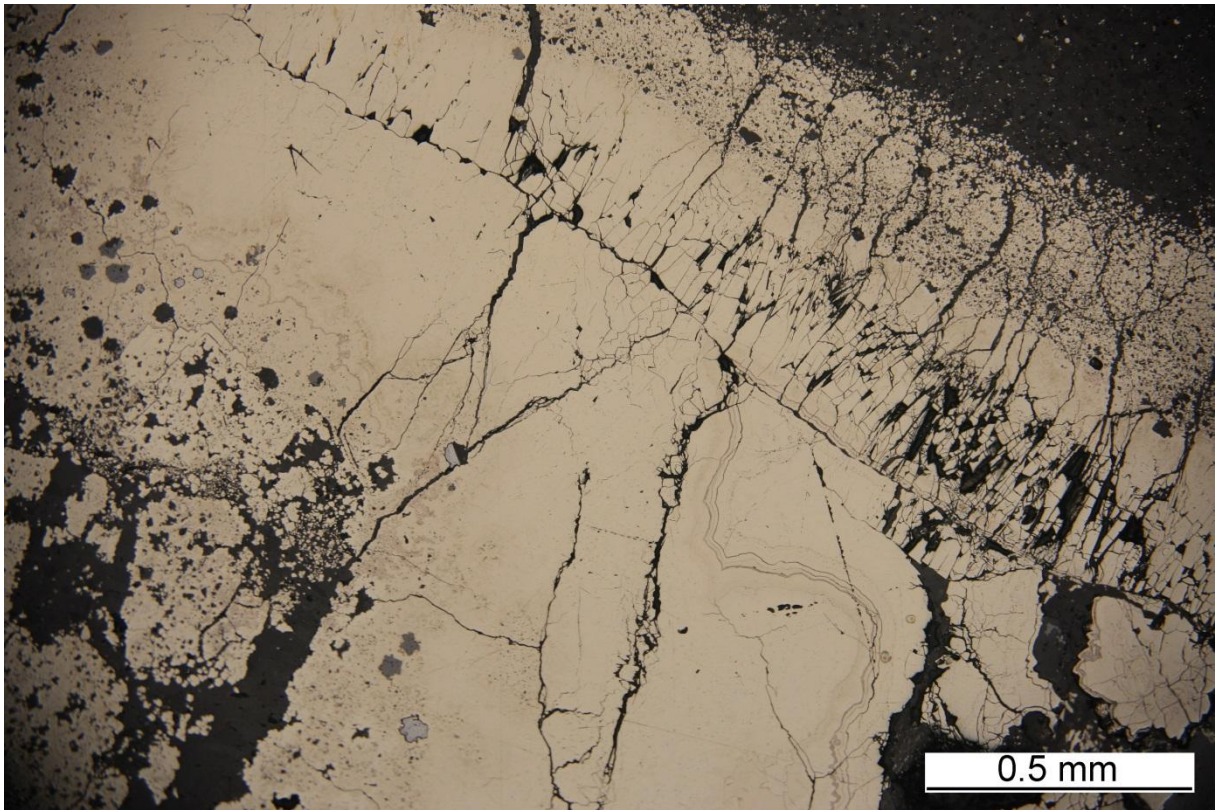


Fig. 22. Colloform marcasite aggregate (yellow-white), sample 104, PPL

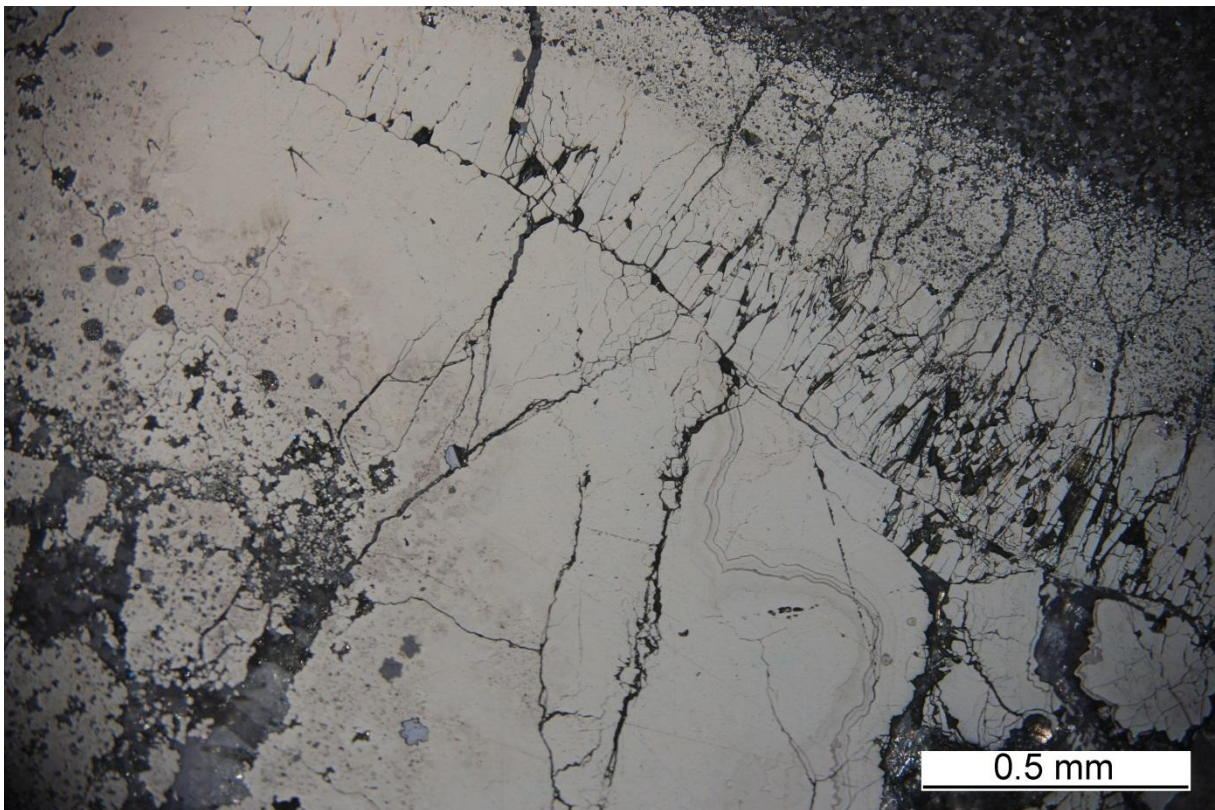


Fig. 23. Colloform marcasite aggregate, sample 104, XPL

Molybdenite MoS₂

Molybdenite may contain Rh.

Crystals

Molybdenite is hexagonal, $a:c = 1:3.815$. Having a layer structure, it commonly has a hexagonal tabular or a short barrel-shaped prismatic habit. It is commonly foliated massive or in scales. There is a perfect basal $\{0001\}$ cleavage. $D = 4.7$, $H = 1.5$.

Thin section

Molybdenite is opaque in the visible light but it is transparent and uniaxial negative in the infrared.

Polished section

Molybdenite is bireflecting, with $R_0 = 39\%$ (white, less bright than galena) and $R_e = 19\%$ (grey similar to sphalerite). Anisotropy is very strong, with slightly pinkish white tints. Extinction is parallel to cleavage (the brighter R_0 orientation) but is often undulatory because of deformation.

Molybdenite occurs as flakes or platelets with hexagonal basal sections. Well-developed basal cleavage often results in a poor polish, especially on grains which have their cleavage parallel to the polished surface. A deformation twinning-like structure is related to buckling of the cleavage. $VHN = 16-19$ (perpendicularly to cleavage), $21-28$ (parallel to cleavage).

Occurrence

Molybdenite is found in high-temperature hydrothermal veins and quartz pegmatites, with Bi, Te, Au, Sn and W minerals. It also occurs in porphyry copper style deposits. It is an accessory mineral in acid igneous rocks, and is occasionally a detrital mineral.

Distinguishing features

Compared with molybdenite, tungstenite WS_2 is very similar; graphite is morphologically similar but much darker; and tetradyrite Bi_2Te_2S is brighter. Molybdenite polishes poorly because of smearing.

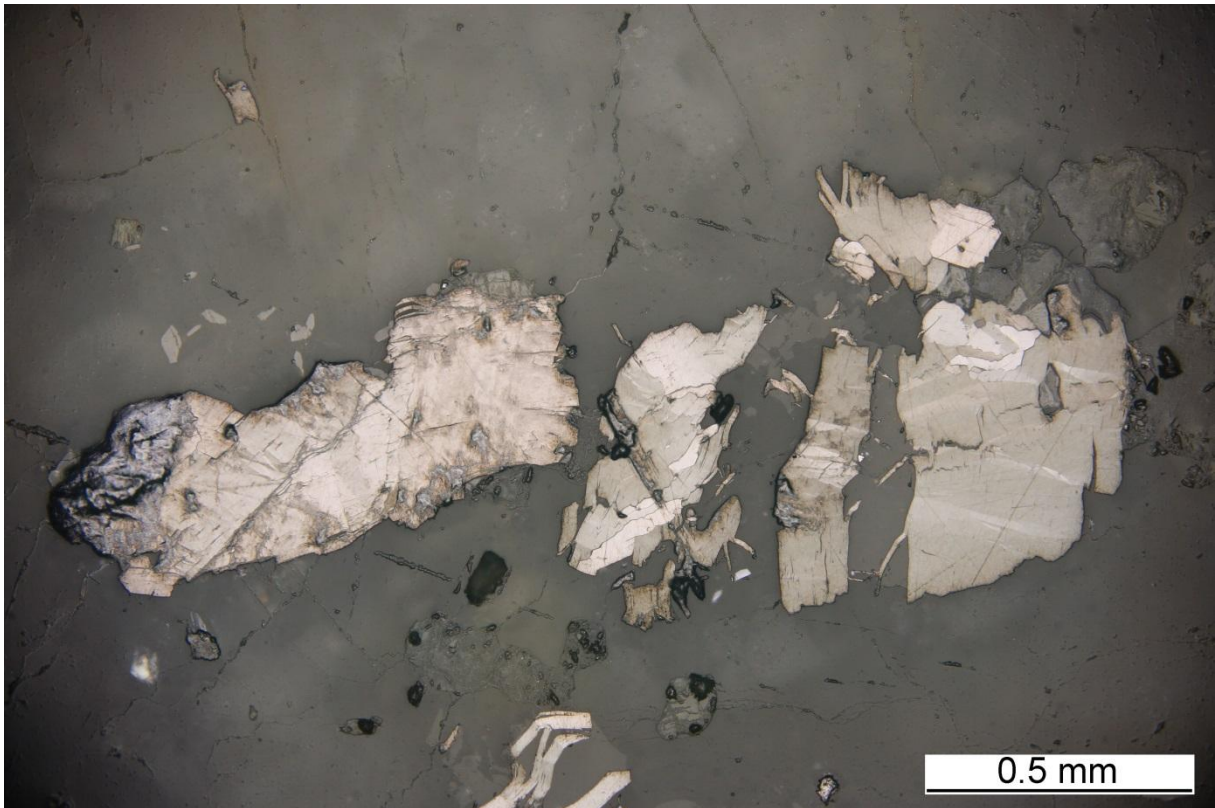


Fig. 24. Molybdenite (white-grey) with strong bireflection, sample 16, PPL

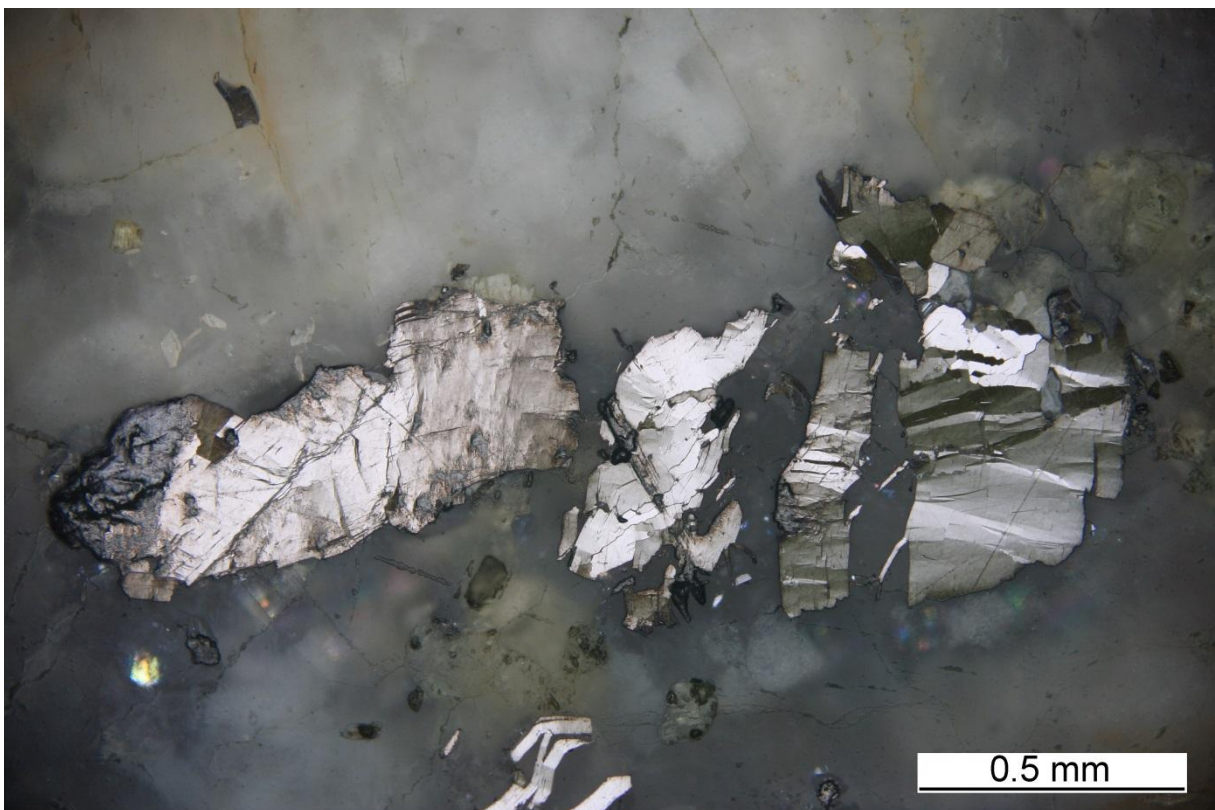


Fig. 25. Molybdenite (white-grey) with very strong anisotropy, and visible pressure twinning, sample 16, XPL

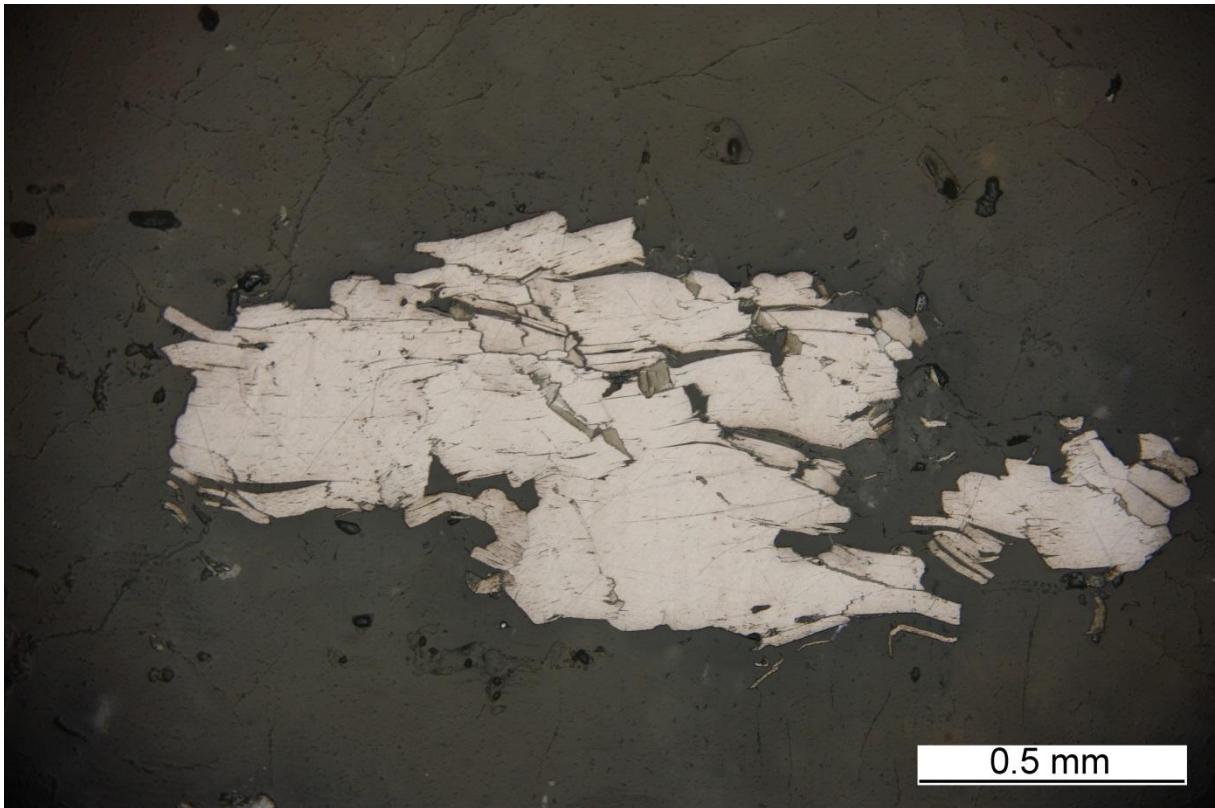


Fig. 26. Molybdenite (white-grey) with distinct bireflection, sample 16, PPL

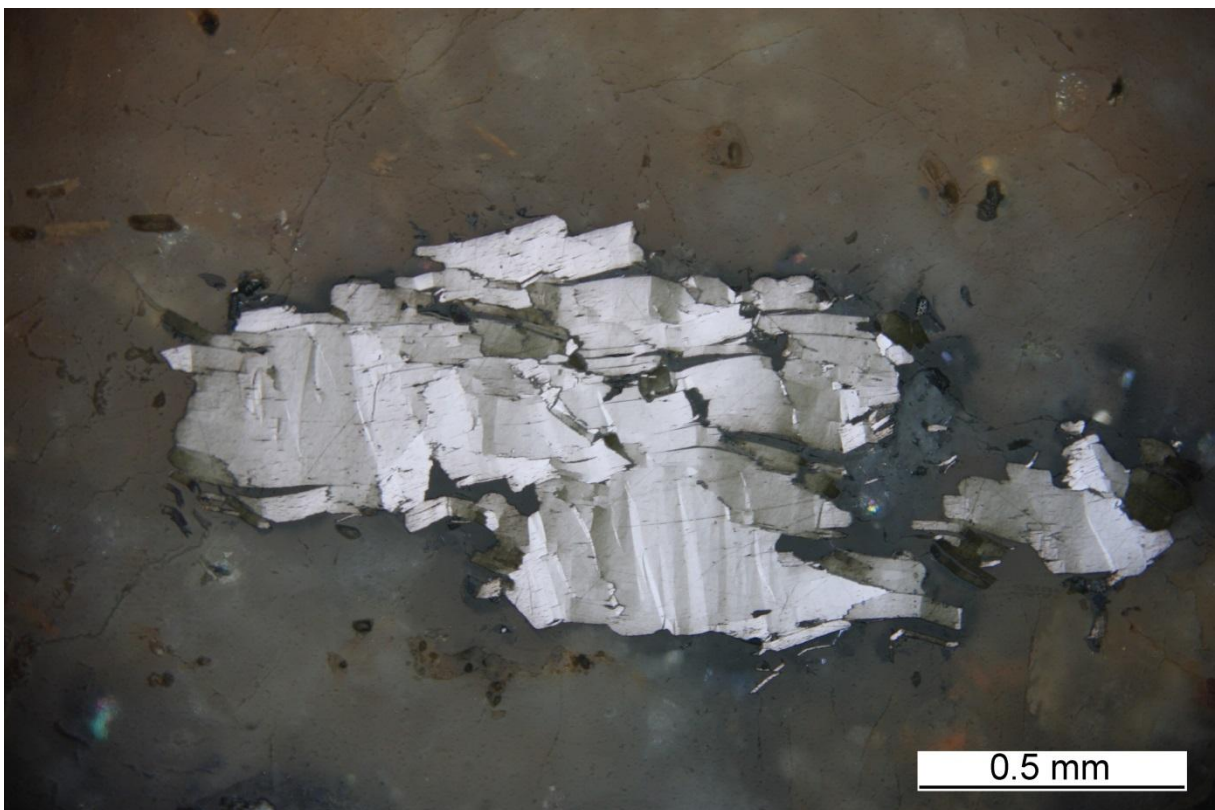


Fig. 27. Molybdenite (white-grey) with strong anisotropy, sample 16, XPL

Pentlandite (Fe,Ni)₉S₈

Pentlandite usually contains about equal amounts of Fe and Ni. It often contains Co and sometimes Cu or Ag in solid solution.

Crystals

Pentlandite is cubic, but rarely occurs as well shaped crystals. There is no cleavage, but a parting on {111}. D = 5.0, H = 4.

Polished section

Pentlandite is very slightly yellowish white (cream) with R = 47%. It is isotropic.

It occurs commonly as „flame“ lamellae in pyrrhotite and as veinlets or xenomorphic grains associated with pyrrhotite. The octahedral parting {111} is often well developed, resulting in triangular cleavage pits. Alteration also takes place along this parting. VHN=270–290.

Occurrence

Pentlandite, usually associated with pyrrhotite and other Cu + Ni + Fe + S phases is common mafic igneous rocks, e.g. norites and some massive sulphide deposits.

Distinguishing features

Compared with pentlandite, pyrite is yellowish, often weakly anisotropic and harder, and pyrrhotite is darker, brownish, anisotropic and slightly harder.

Pyrrargyrite Ag₃SbS₃ and proustite Ag₃AsS₃

Pyrrargyrite and proustite are known as “ruby silvers” because they are translucent, with a deep red colour. Extensive solid solution occurs between the two minerals.

Crystals

Pyrrargyrite is trigonal, a:c = 1:0.7892, and proustite is trigonal, a:c = 1:0.8039. Both minerals are commonly prismatic [0001] with twinning, sometimes complex, on {1014}. There is a distinct {1011} cleavage. D = 5.85 (pyrrargyrite), D = 5.57 (proustite), H = 2.5.

Thin section

Both minerals are deep red, and uniaxial negative.

Polished section

Both minerals are lightly grey, often slightly bluish. R = 28–30% (pyrrargyrite) and R = 25–28% (proustite), which makes them similar in brightness to tetrahedrite. Bireflectance is distinct and anisotropy strong in greys. Red internal reflections are common and are more abundant in proustite.

Both minerals occur as isolated crystals but are common as inclusions in galena. Simple and multiple twinning may be present. VHN: pyrrargyrite 50–97 perpendicularly to cleavage, 97–126 parallel to cleavage, proustite VHN: 70–110.

Occurrence

Pyrrargyrite is more common than proustite. They are associated with other sulphosalts, especially tetrahedrite-tennantite, in low-temperature Pb + Zn mineralization and Ag + Ni + Co veins. The ruby silvers and similar Ag minerals may be significant silver carriers in base metal mineralization.

Distinguishing features

There are some rare complex sulphides which resemble the ruby silvers. Cinnabar is quite similar, but the anisotropy tints are greenish grey.

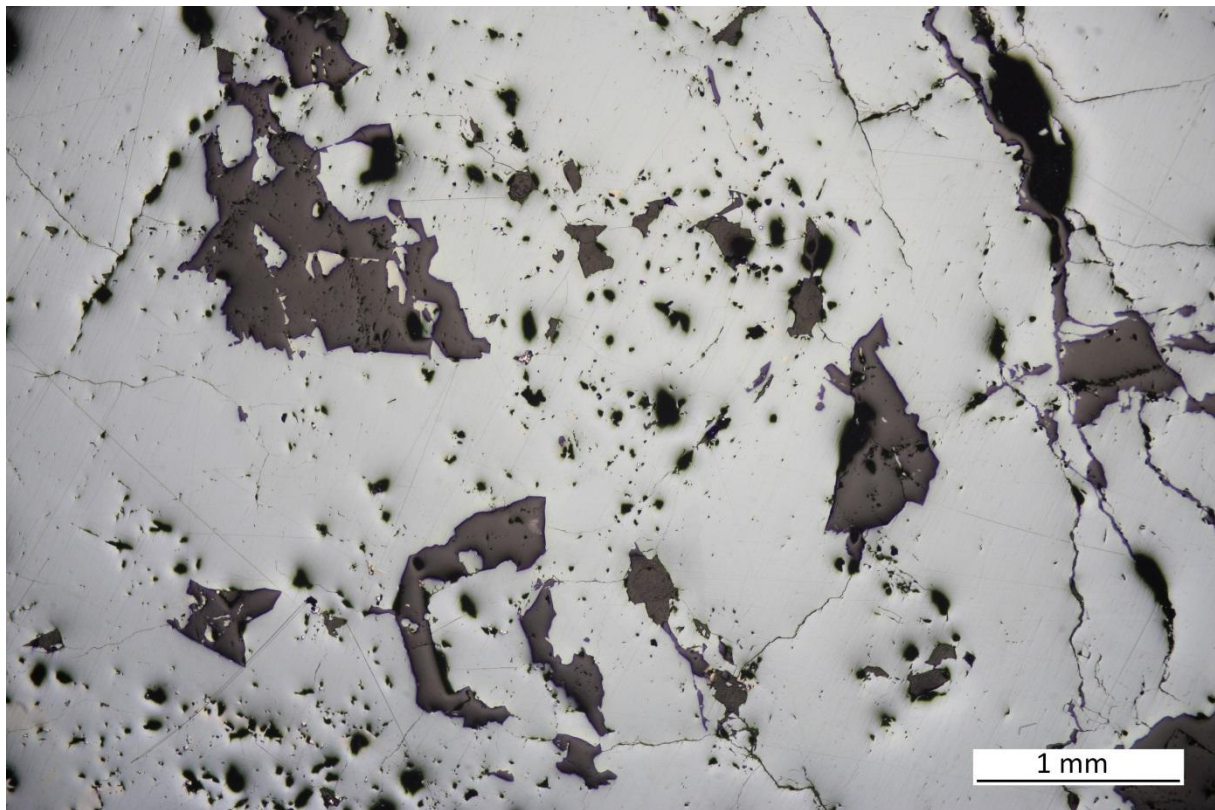


Fig. 28. Proustite (lightly grey), sample Měděnec, PPL

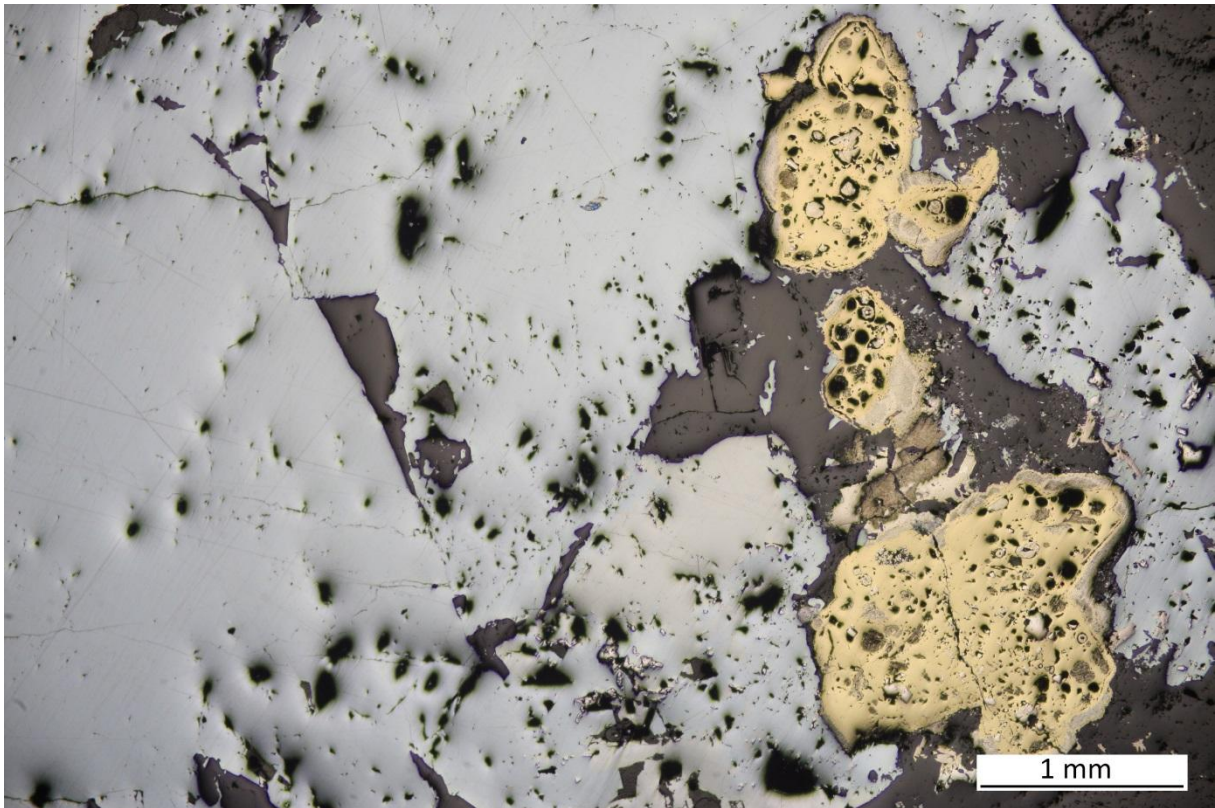


Fig. 29. Proustite (lightly grey) with aggregates of pyrite and marcasite (yellow), sample Měděnec, PPL

Pyrite FeS_2

Pyrite may contain some Ni or Co. auriferous pyrite probably contains inclusions of native gold, and cupriforous pyrite probably contains inclusions of chalcopyrite.

Crystals

Pyrite is cubic, crystals most commonly being modifications of cubes. The $\{011\}$ twin plane and $[001]$ twin axis produces penetration twins. There is a poor $\{001\}$ cleavage. $D = 5.01$, $H = 6.5$.

Thin sections

Pyrite is opaque, often occurring as euhedral crystals or aggregates of small rounded grains. Alteration to limonite results in brownish or reddish coloured rims or brown staining.

Polished section

Pyrite is white, often with a slight yellowish tint, especially in small grains. $R = 54\%$, resulting pyrite usually appearing very bright. It is only ideally isotropic in (111) sections, and the weak anisotropy in very dark green and brown can usually be seen in well polished grains.

Pyrite is usually idiomorphic but is occasionally intergrowth with other sulphides, e. g. sphalerite. Grains are often cataclased. Framboidal pyrite is common in sedimentary rocks. Growth zoning in pyrite is enhanced by etching. Zonation of inclusions is common. Inclusions of other sulphides, e.g. chalcopyrite or pyrrotite, are common. Fractures in pyrite often contain introduced sulphides, e. g. chalcopyrite or galena. VHN = 1000–2000.

Occurrence

Pyrite is a common sulphide, occurring in most rocks and ores. Organic material, carbonate and quartz are all readily replaced by pyrite.

Distinguishing features

Compared with pyrite, marcasite is whiter and strongly anisotropic; chalcopyrite is distinctly yellow and much softer; arsenopyrite is whiter and tends to form rhomb shapes; and pentlandite is whiter, softer and often shows alterations along octahedral partings.

Notes

Melnikovite is poorly crystallized colloform iron sulphide which appears brownish and porous. It probably consists of FeS_2 . It tarnishes rapidly.

Bravoite is nickeliferous pyrite $(\text{Fe,Ni})\text{S}_2$ often with some Co. It is similar to pyrite but brownish, slightly darker and anisotropic. It usually occurs as idiomorphic centres or as layers in zoned pyrite.

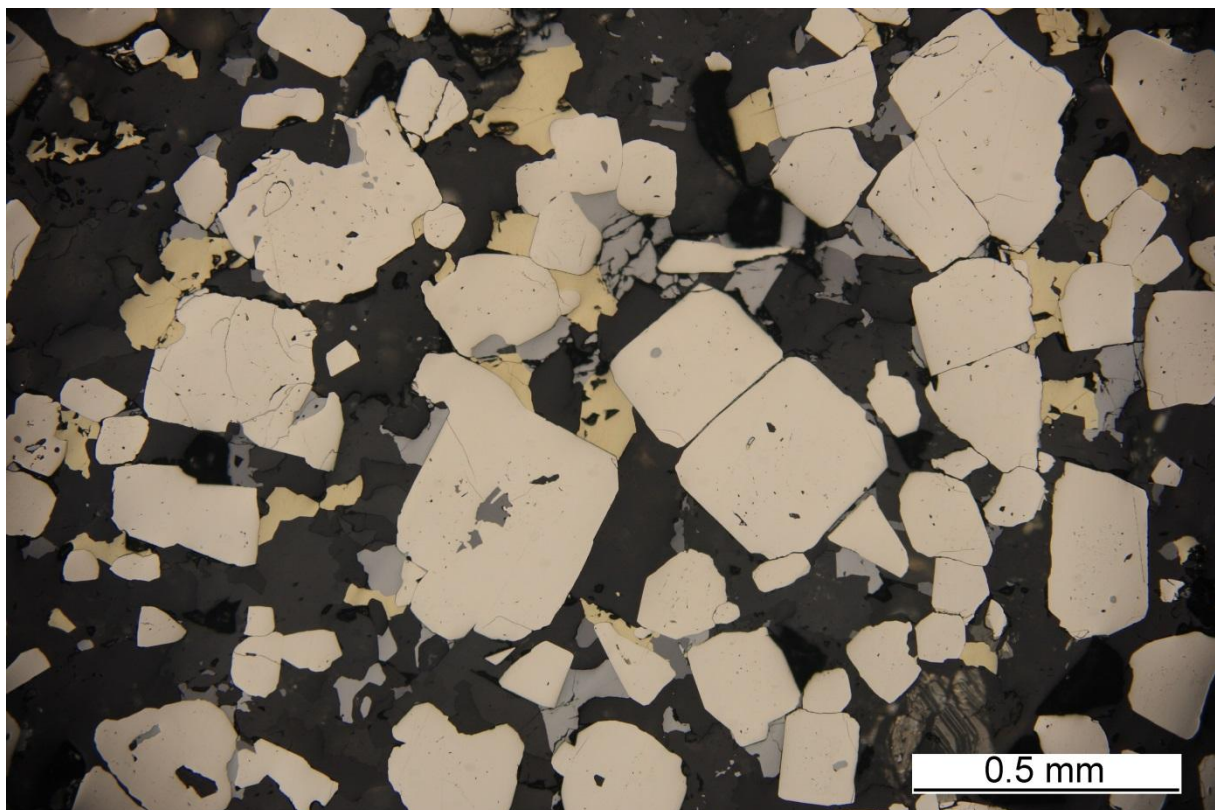


Fig. 30. Euhedral pyrite cubes (yellow-white) with chalcopyrite (yellow) and tennantite (grey), sample 59, PPL

Pyrrhotite $Fe_{1-x}S$

Pyrrhotite may contain some Ni, Co or Mn. It contains deficient relative to the stoichiometric mineral troilite FeS. Nickeliferous pyrrhotite probably contains pentlandite.

Pyrrhotine is an alternative name recommended by the International Mineralogical Association.

Crystals

Both monoclinic and hexagonal $a:c = 1:1.6502$, varieties of pyrrhotite occur, and these are commonly intergrown. Crystals are commonly tabular to platy with twinning on $\{1012\}$. There is no cleavage. $D = 4.6$, $H = 4.5$.

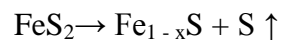
Polished section

Pyrrhotite is brownish or pinkish white with a weak but usually visible pleochroism. $R = 35\text{--}40\%$ with R_0 being darker and R_e being lighter in the case of hexagonal pyrrhotite. Anisotropy is strong with yellowish, greenish or bluish-grey tints.

Pyrrhotite is usually xenomorphic, often occurring as polycrystalline aggregates or as inclusions in pyrite. Multiple twinning, often spindle-shaped due to deformation, is common. Exsolved lamellae (or flames) of white pentlandite are common. $VHN = 370\text{--}410$.

Occurrence

The presence of pyrrhotite indicates a relatively low S availability. It is common in igneous rocks, metamorphic rocks and stratiform massive $Cu + Fe + S$ deposits. It forms by the reaction



in contact metamorphic aureoles. In veins, it is usually taken to indicate precipitation from relatively high-temperature, acid, reducing solutions.

Distinguishing features

Hexagonal and monoclinic pyrrhotite are not easily distinguished in polished section. A magnetic colloid may be used to stain monoclinic pyrrhotite (Craig and Vaughan 1981). Compared with pyrrhotite, ilmenite is darker and harder; bornite is browner (soon tarnishing to purple) and essentially isotropic; and chalcopyrrhotite (rare) is isotropic and browner than pyrrhotite.

Notes

Pyrrhotite alters readily along irregular fractures to a mixture of iron minerals, including marcasite, pyrite, magnetite and limonite. Although rare in sedimentary rocks and common in metamorphosed equivalents, especially near synsedimentary stratiform sulphide deposits, pyrrhotite is not thought to be necessarily a metamorphic mineral formed by breakdown of pyrite. It may be of hydrothermal exhalative origin, and could persist in seafloor sediments provided that the sulphur availability is low.

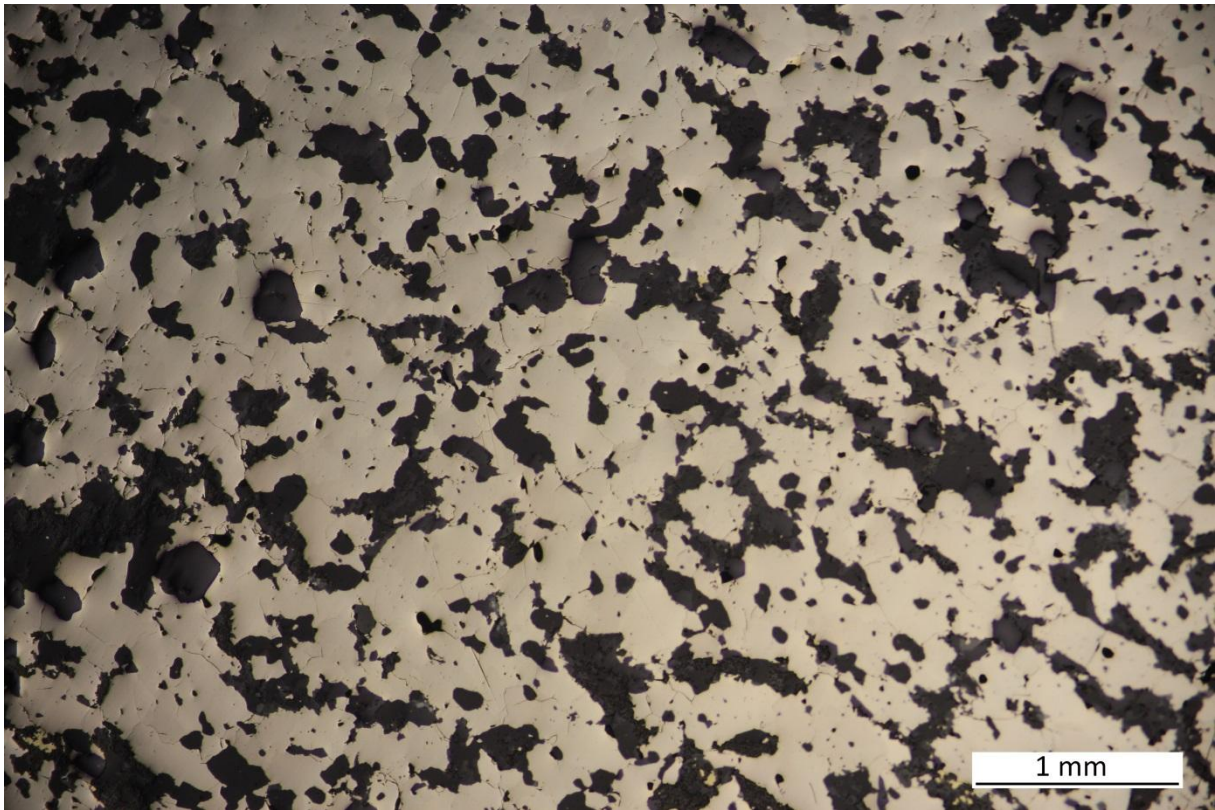


Fig. 31. Granular pyrrhotite aggregate (brownish to pinkish), sample 67, PPL

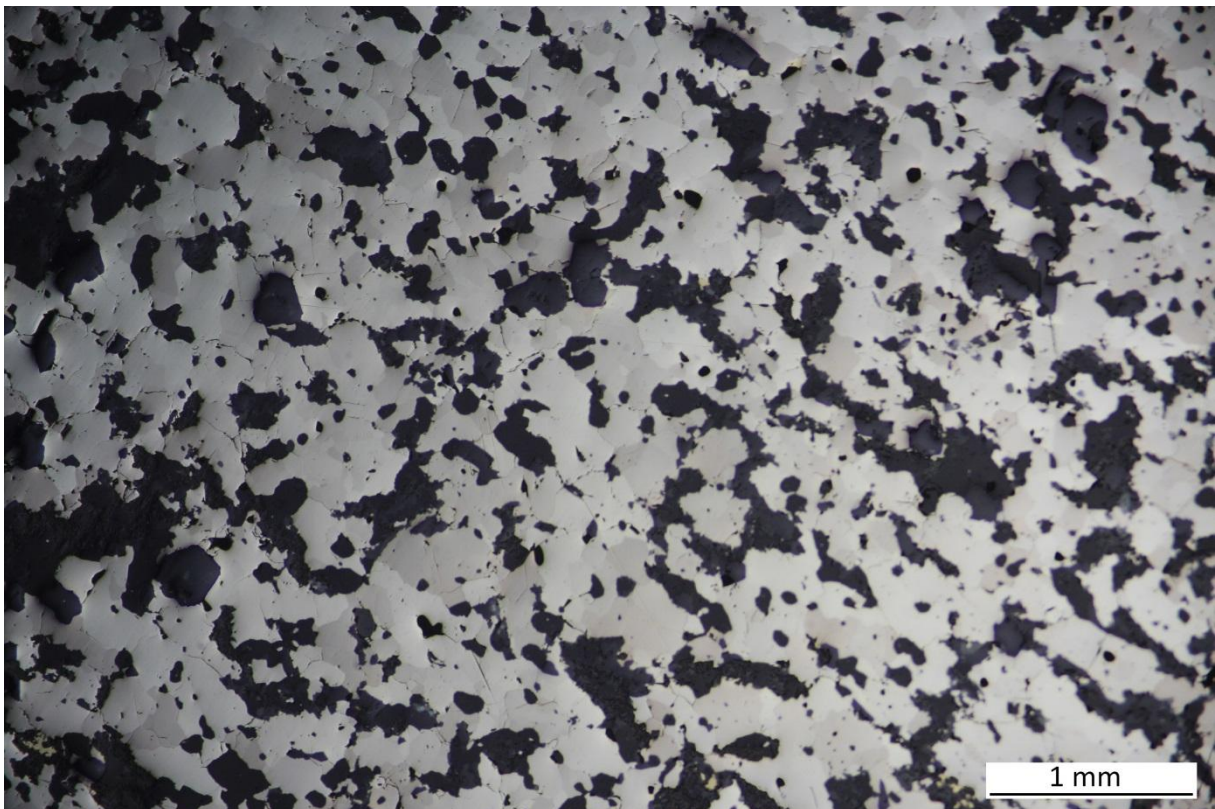


Fig. 32. Granular aggregate of pyrrhotite with visible anisotropy, sample 67, XPL

Sphalerite ZnS

Sphalerite usually contains Fe and sometimes Cd, Mn or Hg in solid solutions. Wurtzite (hexagonal ZnS) is very similar to sphalerite in polished section, but it is rare.

Crystals

Sphalerite is cubic. It has the diamond structure but is more complex than one might suspect: there are many polytypes. Crystals are commonly tetrahedral and dodecahedral. Twinning about the [111] axis leads to simple and complex twins. There is a perfect {011} cleavage. $D = 3.9$, $H = 4$.

Thin section

Pure ZnS is transparent and colourless, but sphalerite is opaque when iron rich. It has very high relief and is usually yellow to brownish in colour, with dark brown bands due to Fe zonation. Oxidation of iron-bearing varieties leads to brown staining, especially in fractures. Sphalerite is isotropic but is sometimes anomalously anisotropic, revealing fine lamellar twinning probably due to stacking polytypes. At $\lambda = 589$ nm, $n = 2.369$ (pure ZnS), 2.4 (5.46% Fe), 2.43 (10.8% Fe) and 2.48 (17.06 % Fe).

Polished section

Sphalerite is grey, with $R = 17\%$. It is darker than most ore minerals but brighter than the gangue minerals. It is isotropic. Pure ZnS has abundant internal reflections but, with increasing Fe content, opacity increases and internal reflections become fewer and brownish or reddish.

Sphalerite is rarely idiomorphic. It usually occurs as rounded grains in aggregates. It also is found as zoned colloform masses. Irregular fractures are common and the cleavage often results in severe pitting. Multiple twinning is often visible. Zonation of iron, seen as brown bands in transmitted light or by internal reflection, does not visibly change brightness. Sphalerite usually contains inclusions especially of chalcopyrite, as blebs or lamellae. $VHN = 200-220$.

Occurrence

Sphalerite is common in stratabound, vein and massive sulphide deposits. Sphalerite, typically very low in Fe content, also occurs with galena, pyrite and chalcopyrite in calcareous nodules or veinlets, probably of diagenetic origin. Fe-rich sphalerite often occurs with pyrrhotite, as it is the activity of FeS rather than the abundance of Fe that controls the iron content of sphalerite. Sphalerite is often associated with galena.

Distinguishing features

Compared with sphalerite, magnetite is often pinkish, harder and never has internal reflections; limonite is bluish grey, usually has reddish internal reflections and is usually replacing iron-bearing minerals; and tetrahedrite is brighter, greenish or bluish grey and only very rarely shows internal reflections.

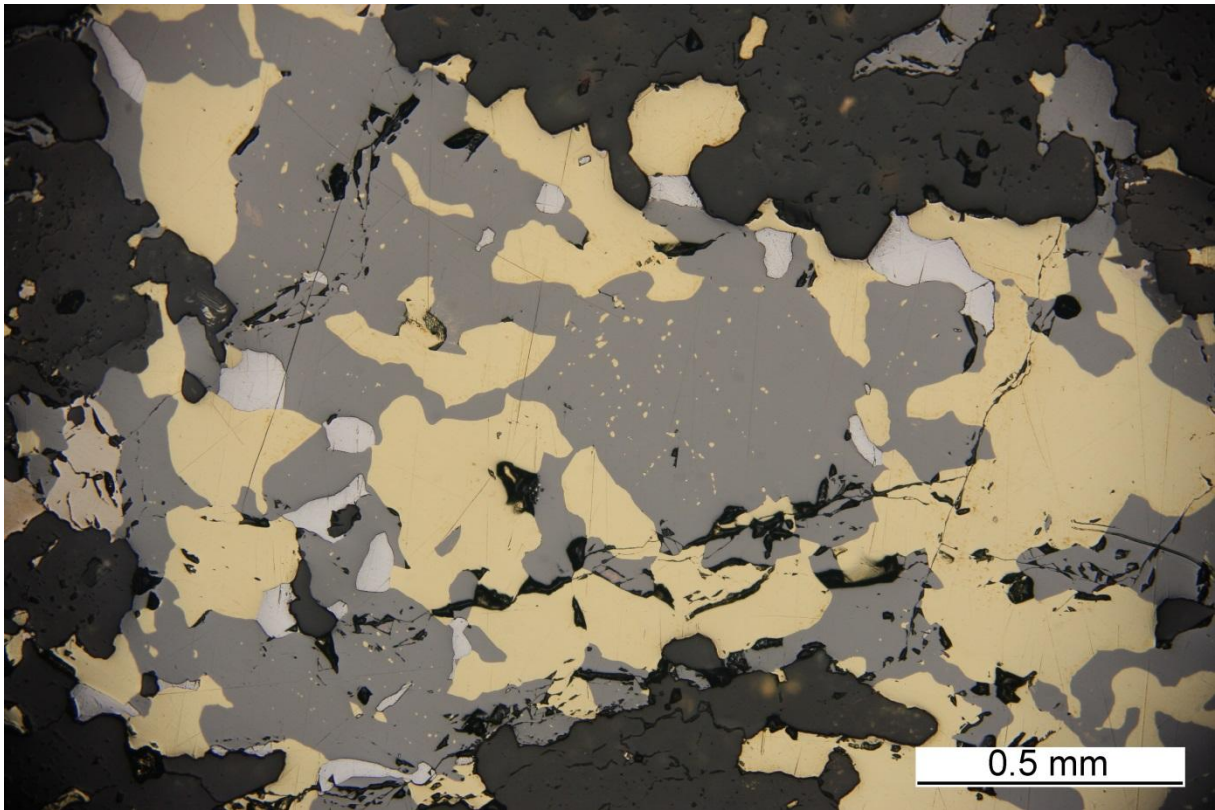


Fig. 33. Sphalerite (grey) with chalcopyrite (yellow), galena (white) and pyrrhotite (cream-brownish), sample 21, PPL

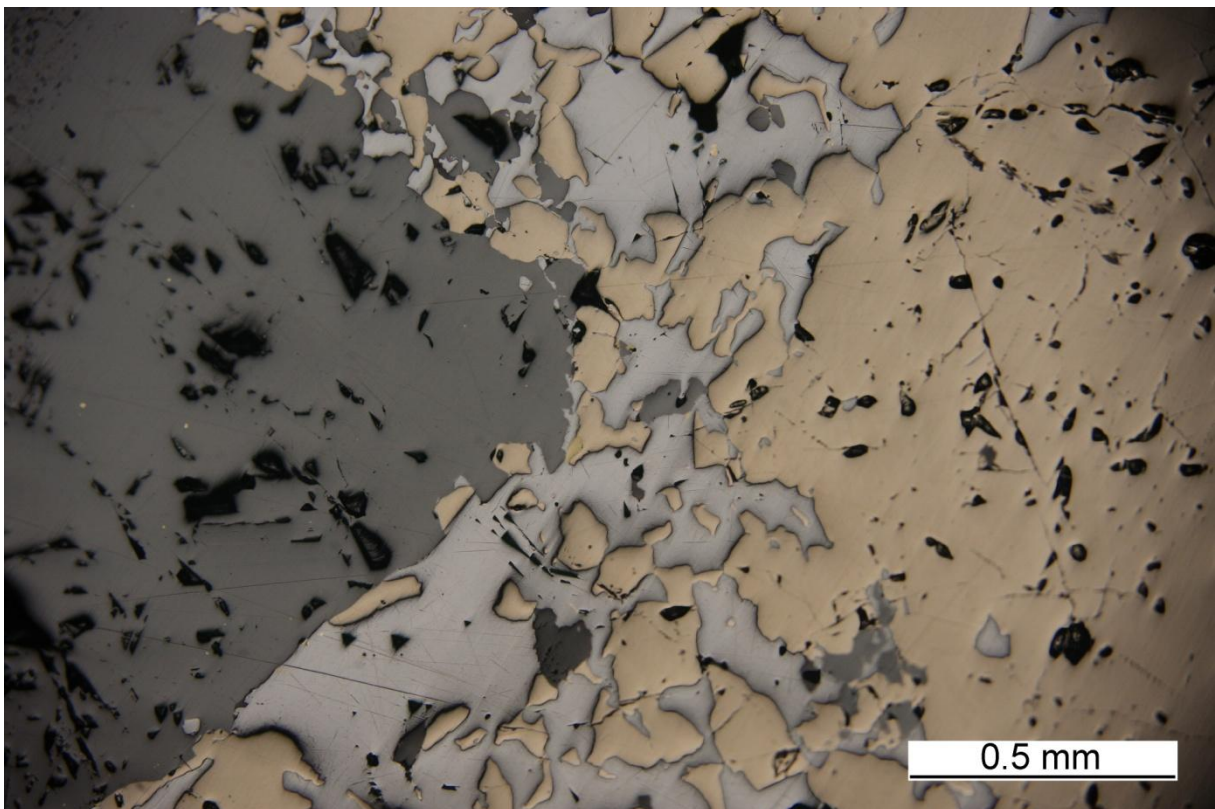


Fig. 34. Sphalerite (dark grey) with pyrrhotite (cream-brownish) and galena (white), sample 21, PPL

Stibnite Sb_2S_3

Crystals

Orthorhombic, with $a:b:c = 0.9926 : 1 : 0.3393$. Crystals are usually prismatic [001], often slender to acicular. Twinning on {130} is rare. There is a perfect {010} cleavage and imperfect {100} and {110} cleavages. $D = 6.63$, $H = 2.5$.

Thin section

Stibnite is opaque. However, it is transparent using infrared transmitted light.

Polished section

Stibnite has a pronounced bireflectance, with $R = 30\text{--}47\%$. It is light grey Ila, brownish light grey IIb and white IIc. The anisotropy is very strong, with tints ranging from light bluish grey to brown. Extinction is straight.

Stibnite often occurs as acicular or bladed crystals (fig. 3.37) or granular aggregates. The usually well developed cleavage traces are deformed, and deformation twinning is common. $VHN = 70\text{--}90$.

Occurrence

Stibnite is found in low-temperature hydrothermal veins, usually with quartz. It is associated with complex Sb-bearing and As-bearing sulphides, pyrite, gold and mercury.

Distinguishing features

Compared with stibnite, hematite has a smaller bireflectance, weaker anisotropy, is harder and lacks cleavage. Some lead antimony sulphides are very similar to stibnite.

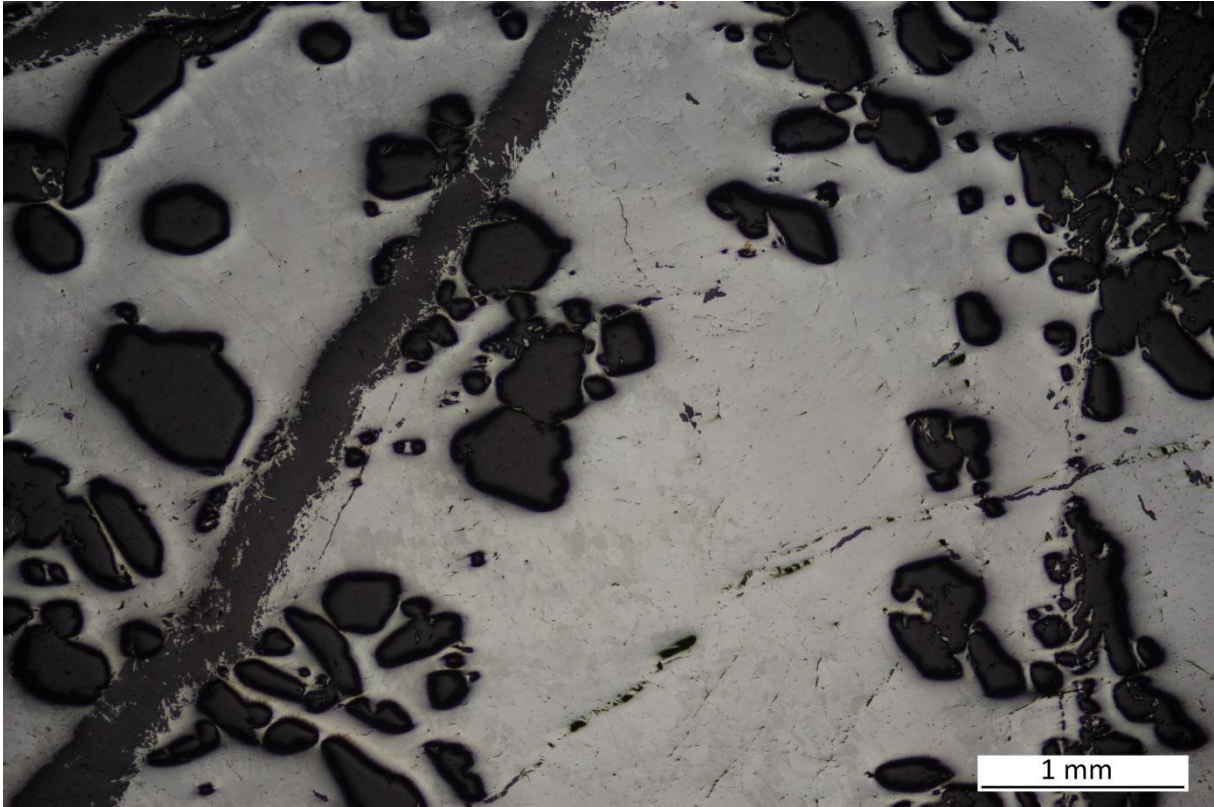


Fig. 35. Stibnite aggregate with distinct birefractance, sample 18, PPL

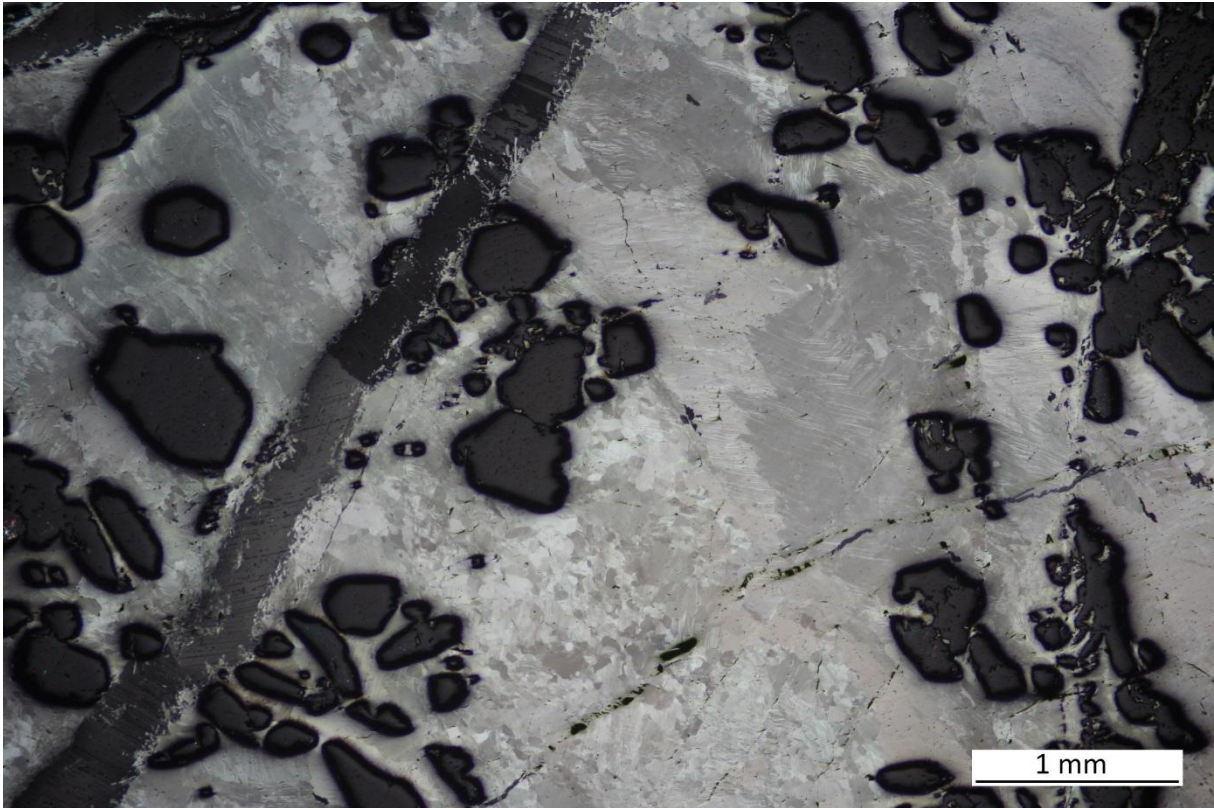


Fig. 36. Stibnite aggregate with strong anisotropy, sample 18, XPL

Tetrahedrite $\text{Cu}_{10}(\text{Zn,Fe})_2\text{Sb}_4\text{S}_{13}$

Tetrahedrite (see Fig. 3.22) exhibits extensive chemical substitution and often contains Ag, Hg and As, but only rarely Cd, Bi and Pb. The arsenic end member is tennantite $\text{Cu}_{10}(\text{Zn,Fe})_2\text{As}_4\text{S}_{13}$. Silver rich tetrahedrite is known as freibergite. Tetrahedrite-tennantite were often formerly called fahlerz.

Crystals

Tetrahedrite is cubic and occurs as modified tetrahedra. Twinning on the axis [111] is often repeated. There are also penetration twins. There is no cleavage. $D \approx 5.0$, $H \approx 4.5$.

Thin section

Tetrahedrites are usually opaque, but iron-free and arsenic-rich varieties transmit some red light.

Polished section

Tetrahedrite is light grey, sometimes appearing slightly greenish, bluish or brownish. With $R \approx 32\%$ it is darker than galena but brighter than sphalerite. It is usually isotropic but may be weakly anisotropic. Very scarce red internal reflections have been reported from tennantite.

Tetrahedrite is rarely idiomorphic. It is usually in the form of rounded grains of polycrystalline aggregates. It forms myrmekitic intergrowths with other sulphides, e.g. galena or chalcopyrite. Zonation of Sb/As and Fe/Zn is commonly detected on microanalysis, but is not visible in polished section. Irregular fracturing is common. Inclusions, especially of chalcopyrite, are common. $VHN = 240\text{--}370$.

Occurrence

Tetrahedrite commonly occurs associated with galena in lead + zinc deposits, although it is inexplicably abundant in some and absent in others. Tennantite is common in porphyry copper mineralization.

Distinguishing features

Compared with tetrahedrites, sphalerite is darker, harder, has a good cleavage and usually shows internal reflections. Many complex sulphides (sulphosalts) are similar at first glance to tetrahedrite, but most of these are anisotropic.

Notes

The various chemical varieties of tetrahedrite cannot be identified with any certainty in polished section without resorting to micro-analysis.

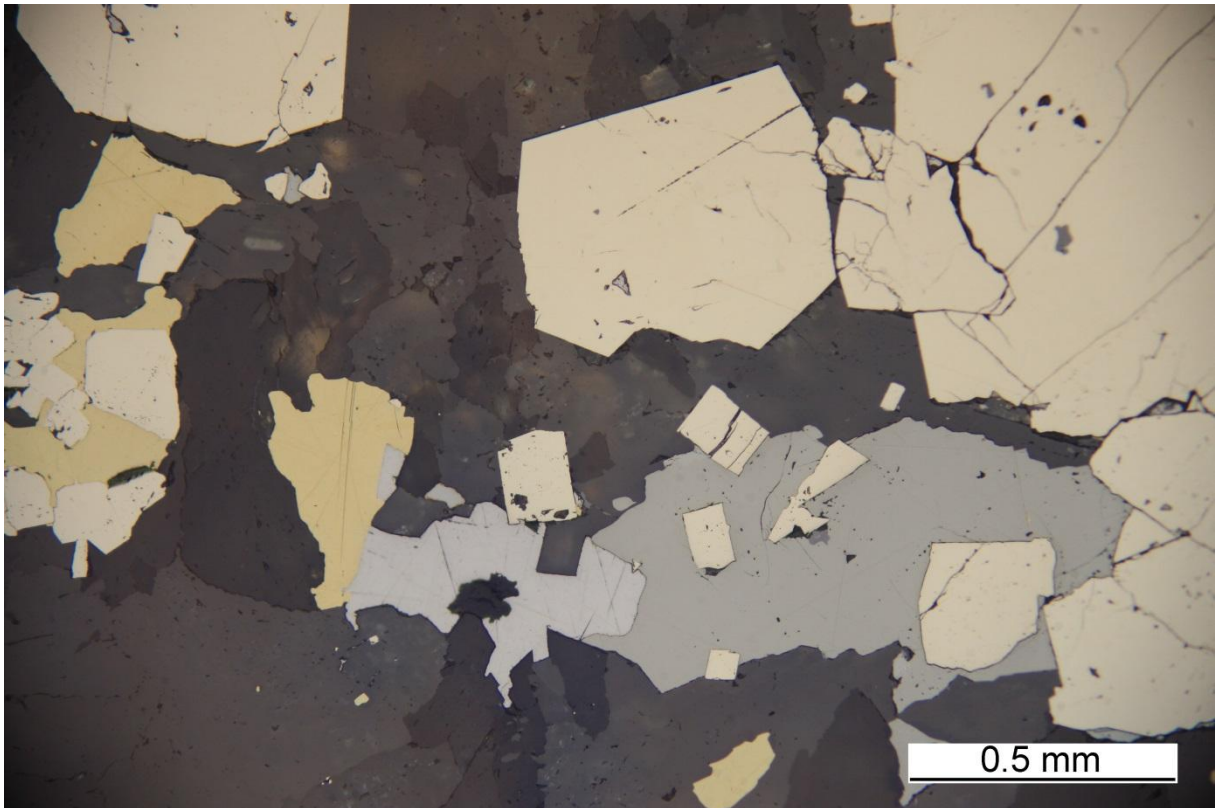


Fig. 37. Euhedral pyrite (yellow-white), surrounded by younger tetraedrite (grey), chalcopyrite (yellow) and galena (white), sample 22, PPL

Arsenides

Niccolite (nickeline) NiAs

Niccolite may contain some Fe or Co.

Crystals

Niccolite is hexagonal, $a:c = 1 : 1.3972$. Crystals are rare. It is usually massive, reniform with columnar structure. Repeated twinning occurs on $\{10\bar{1}1\}$, there is no cleavage. $D = 7.8$, $H = 4.5$.

Polished section

Nicolite is pinkish or orange white with a pronounced pleochroism, with $R_0 = 52\%$ (lighter, orange or yellowish) and $R_e = 48\%$ (darker, pinkish). The reflectance is similar to pyrite. Anisotropy is very strong, the tints being bright bluish and greenish greys.

Nicolite usually occurs in xenomorphic or concentric, botryoidal masses with other Co + Ni + As + S minerals. Grains are often cataclased. Growth zonation is common, and botryoidal masses often contain radiating intergrown irregular lamellae. VHN = 328-455.

Occurrence

Nicolite occurs in Ni + Co + Ag + As + U deposits, which are probably low-temperature hydrothermal veins and replacements. Such deposits are often associated with basic igneous rocks and organic-rich sedimentary rocks.

Distinguishing features

Compared with niccolite: marcasite is whiter, and arsenopyrite is whiter and has a weaker anisotropy.

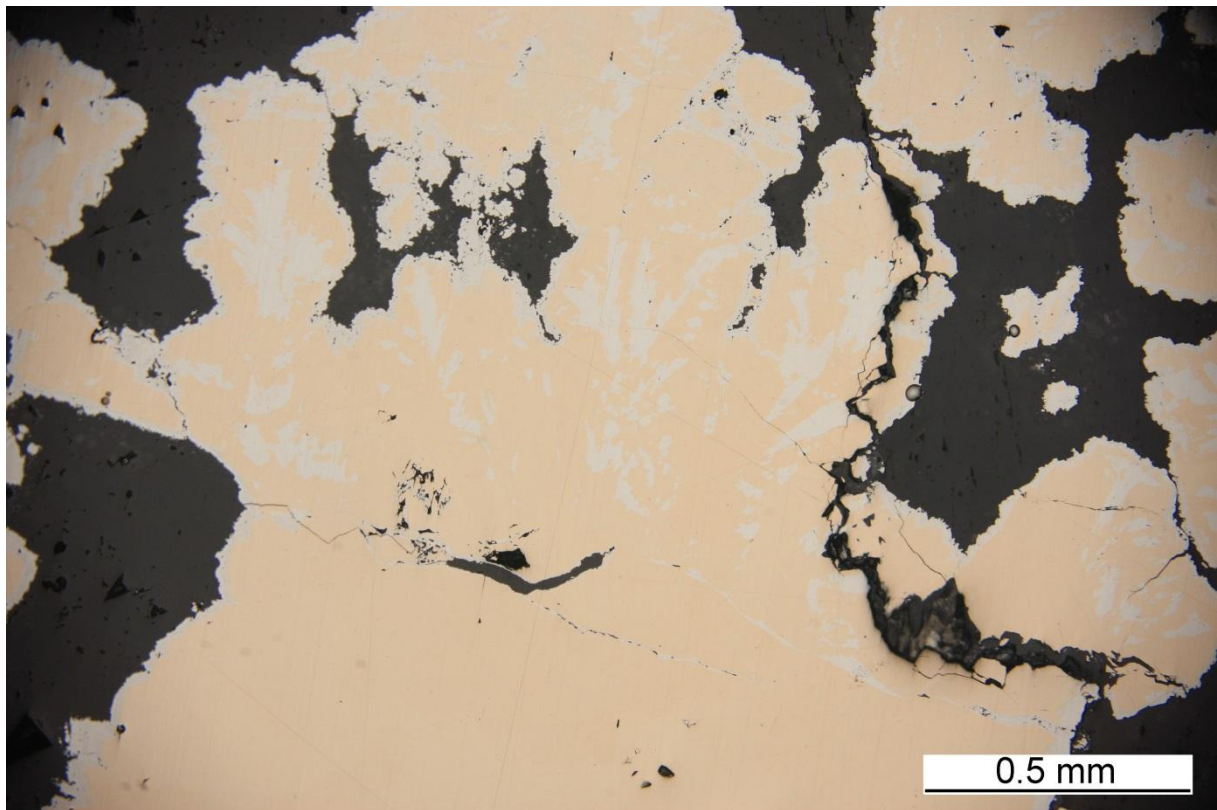


Fig. 38. Niccolite (pinkish to orange white), surrounded by other arsenides (white), sample Zálesí u Javorníka, PPL

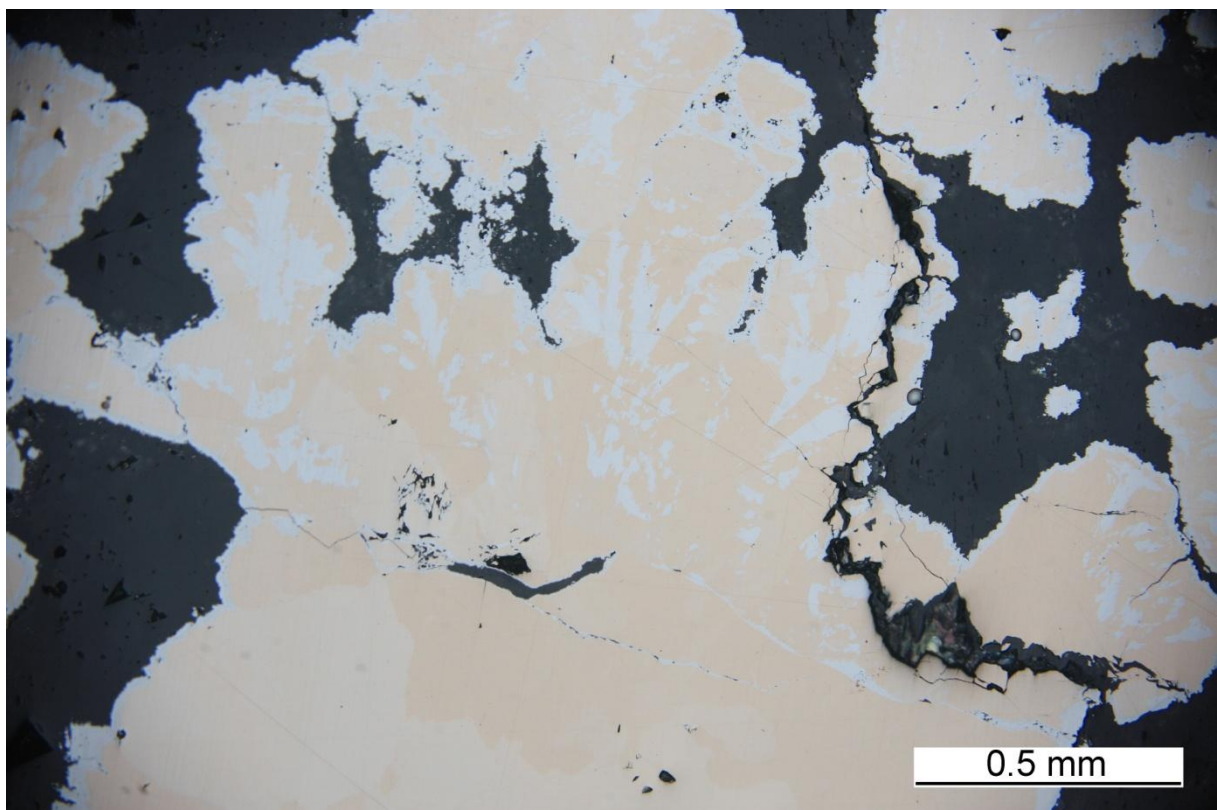


Fig. 39. Niccolite (pinkish to orange white), surrounded by other arsenides (white), sample Zálesí u Javorníka, XPL