

3. Properties observed using reflected light

Most of the ore minerals have a heading polished section. The properties presented under this heading are in particular sequence, and the terms used are explained briefly below. Not all properties are shown by each mineral, so only properties which might be observed are given in Chapters 4.1 and 4.2.

Properties observed using plane polarized light (PPL)

The analyser is taken out of the optical path to give a bright image.

Colour

Most minerals are only slightly coloured when observed using PPL, and the colour sensation depends on factors such as the type of microscope, the light source and the sensitivity of an individual's eyes. Colour is therefore usually described simply as being a variety grey or white, e. g. bluish –grey rutile or pinkish –white cobaltite.

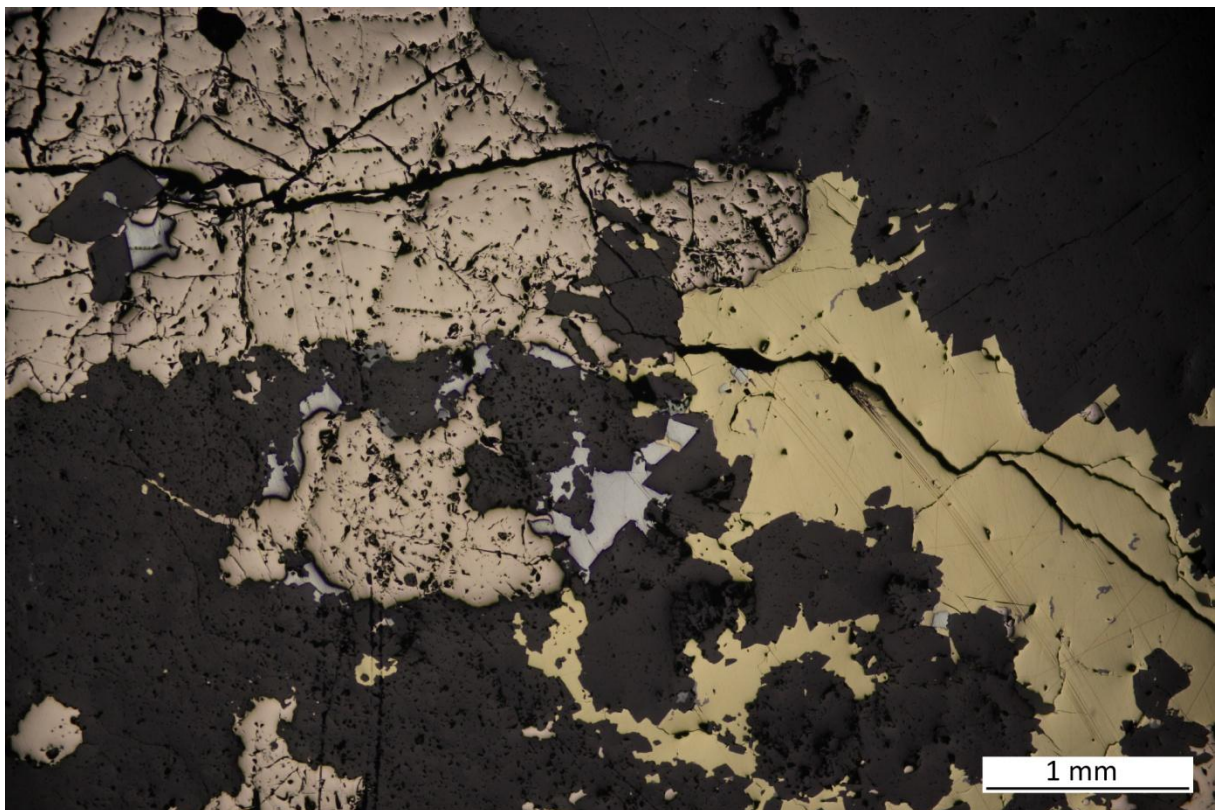


Fig. 1. Chalcopyrite (yellow), pyrrhotite (brownish pink) and galena (white), sample Zlaté Hory, PPL

Pleochroism

If the colour of mineral varies from grain to grain and individual grains change in colour on rotation of the stage, then the mineral is pleochroic. The colours for different crystallographic orientations are given when available. Covellite, for example, shows two extreme colours, blue and bluish light grey. Pleochroism can often be observed only by careful examination of groups of grains in different crystallographic orientations. Alternatively, the pleochroic mineral may be examined adjacent to a non-pleochroic mineral, e.g. ilmenite against magnetite.

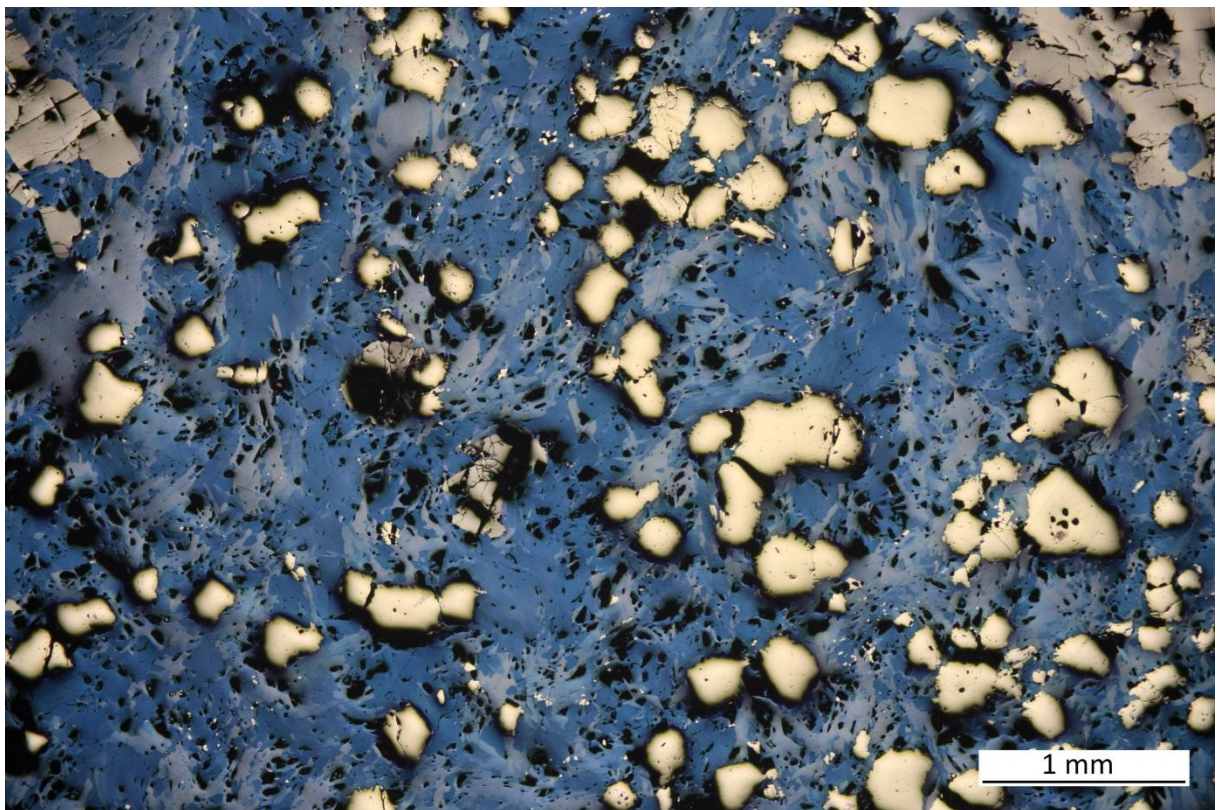


Fig. 2. Covellite (blue and strongly pleochroic, from blue to bluish light grey) with non-pleochroic pyrite (yellow-white) and bornite (pinkish brown), sample Bor, PPL

Reflectance

This is the percentage of light reflected from the polished surface of the mineral and, where possible, values are given for each crystallographic orientation. The eye is not good at estimating absolute reflectance but is a good comparator. The reflectance values of the minerals should therefore be used for the purpose of comparing minerals. Reflectance can be related to a grey scale of brightness in the following way (however, although followed in this book it is not a rigid scale). A mineral cca 15 % (e.g.

sphalerite) may appear to be light grey or white compared with a low-reflectance mineral (such as quartz) or dark grey compared with a bright mineral (such as pyrite):

R (%)	Grey scale
0-10	Dark grey
10-20	Grey
20-40	Light grey
40-60	White
60-100	Bright white

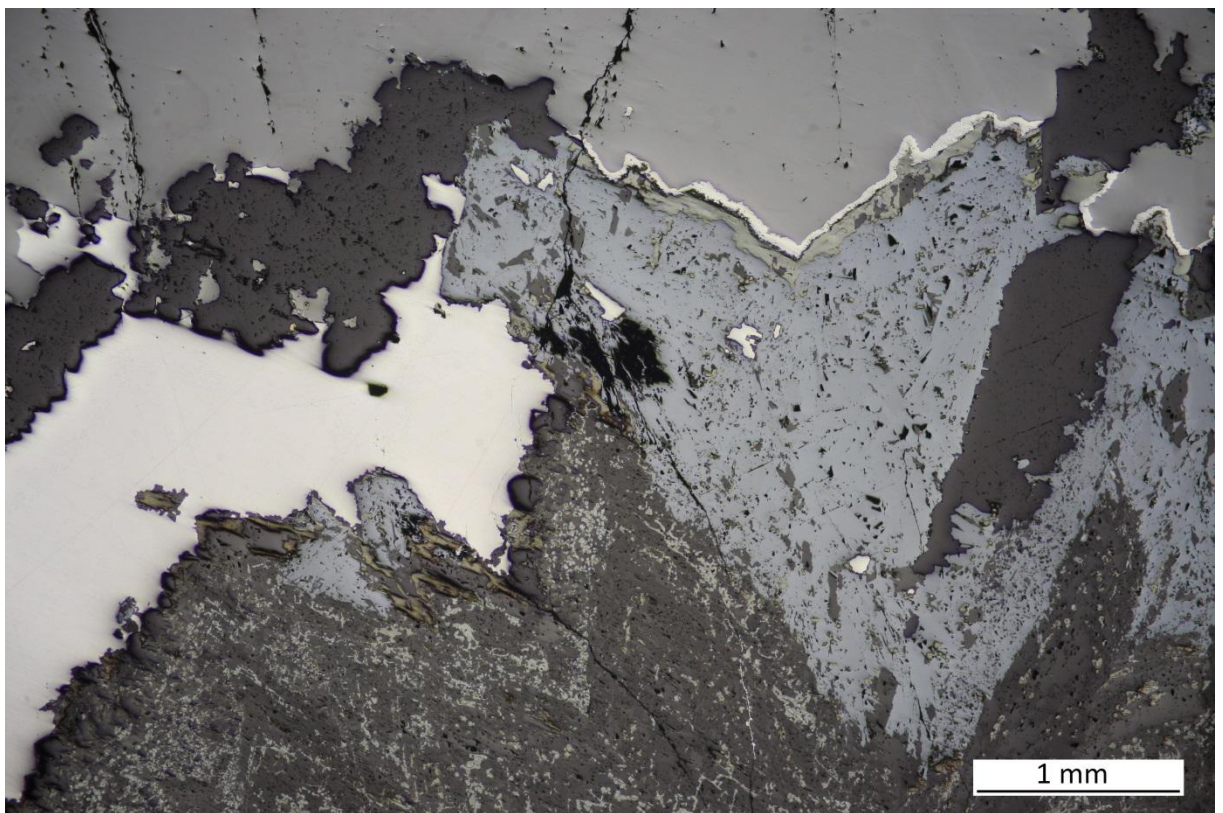


Fig. 3. Chalcocite aggregate (bluish grey), sphalerite (darker grey with R=15%) and galena (white with R=43%), sample 6, PPL

Bireflectance

Bireflectance is a quantitative value, and for an anisotropic grain it is a measure of the difference between the maximum and minimum values of reflectance. However, bireflectance is usually assessed qualitatively, e.g.: weak: observed with difficulty, $\Delta R < 5\%$ (e.g. hematite)

Distinct: easily observed, $\Delta R > 5\%$ (e.g. stibnite)

Pleochroism and bireflectance are closely related properties; the term pleochroism is used to describe change in tint or colour intensity, whereas bireflectance is used for a change in brightness.

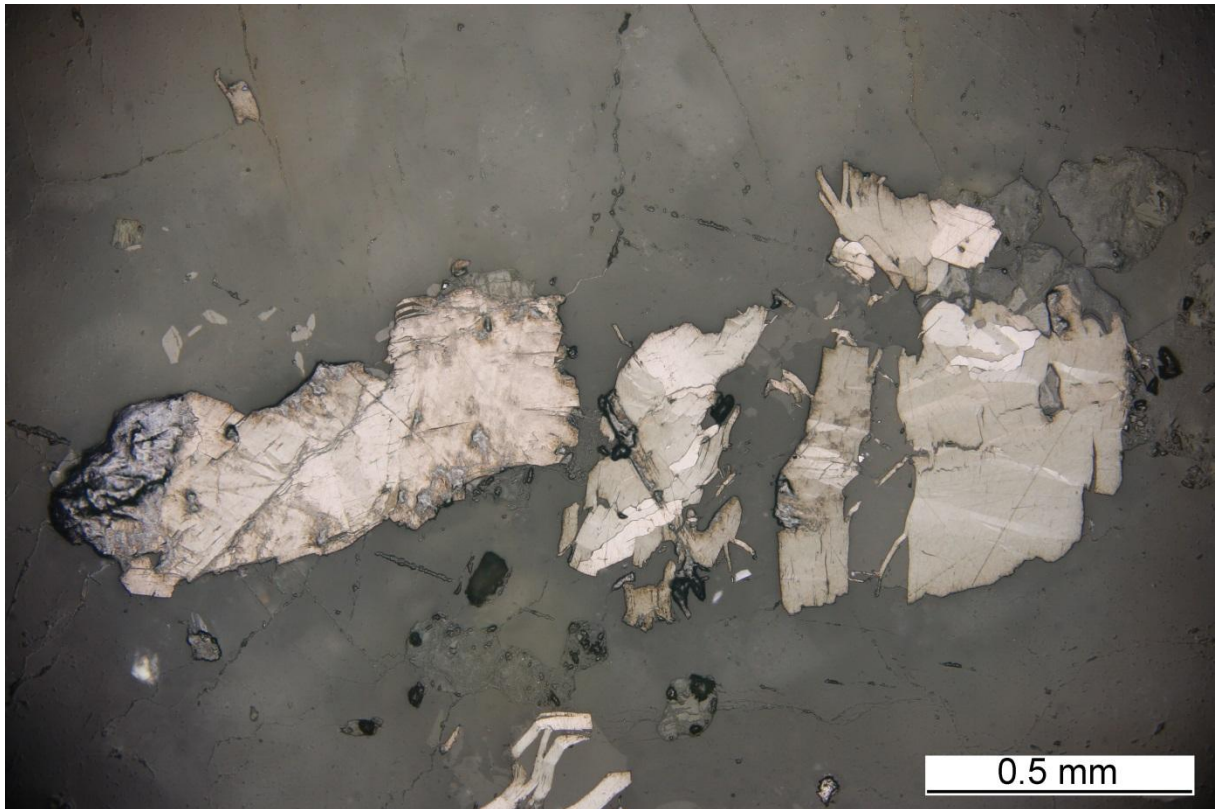


Fig. 4. Molybdenite (white-grey) with very strong bireflection, sample 16, PPL

Properties observed using crossed polars

The analyser is inserted into the optical path to give a dark image.

Anisotropy

Anisotropy varies markedly with the crystallographic orientation of a section of a non-cubic mineral. It is assessed as follows:

- a) Isotropic mineral: all grains remain dark on rotation of the stage, e.g. magnetite
- b) Weakly anisotropic mineral: slight change on rotation, seen only on careful examination using slightly uncrossed polars. e.g. ilmenite
- c) Strongly anisotropic mineral: pronounced change in brightness and possible colour seen on rotating the stage when using exactly crossed polars, e.g. hematite.

Note - Some cubic minerals (e.g. pyrite) can appear to be anisotropic, and weakly anisotropic minerals (e.g. chalcopyrite) may appear to be isotropic. Anisotropy and birefractance are related properties; an anisotropic grain is necessarily birefracting, but the birefractance in PPL is always much more difficult to detect than the anisotropy in crossed polars.

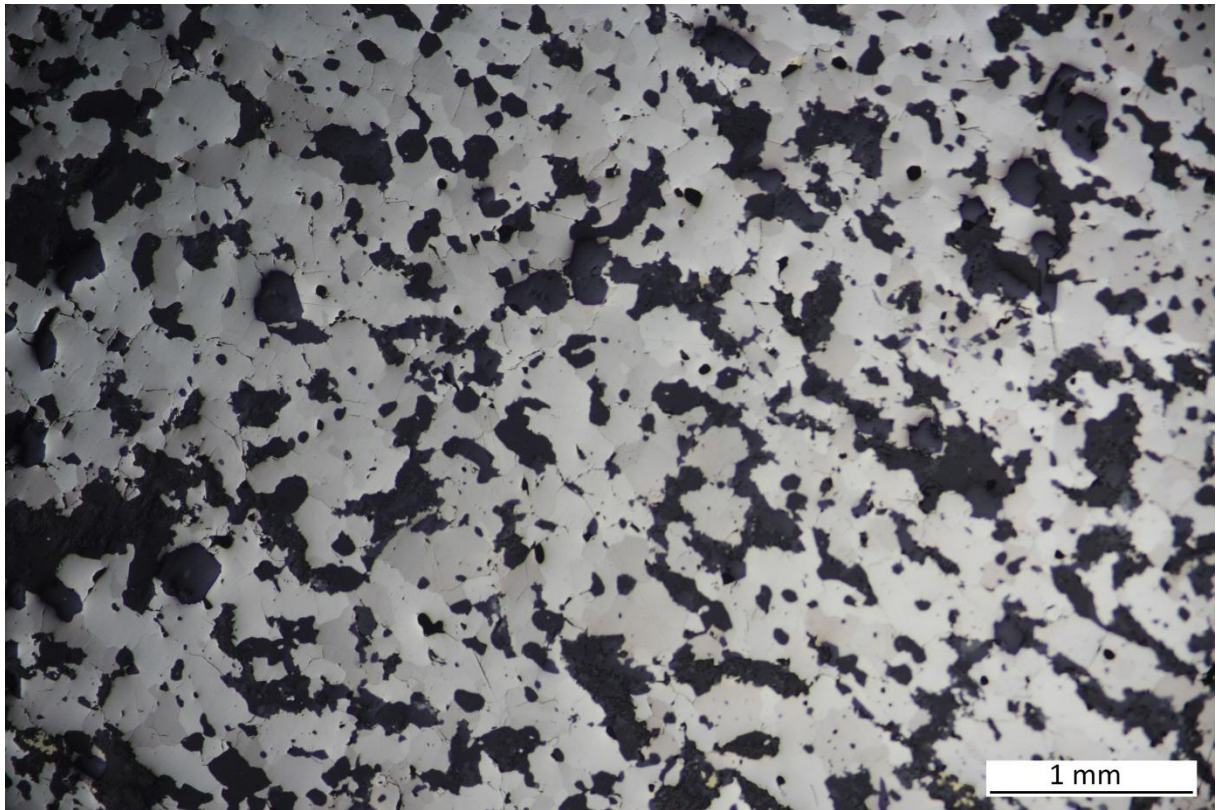


Fig. 5. Granular aggregate of pyrrhotite with visible anisotropy, sample 67, XPL

Internal reflections

Light may pass through the polished surface of a mineral and be reflected back from below. Internal reflections are therefore shown by all transparent minerals. When one is looking for internal reflections, particular care should be paid to minerals of low to moderate reflectance (semi-opaque minerals), for which internal reflection might be

defected only with difficulty and near grain boundaries or fractures. Cinnabar, unlike hematite which is otherwise similar, shows spectacular red internal reflections.

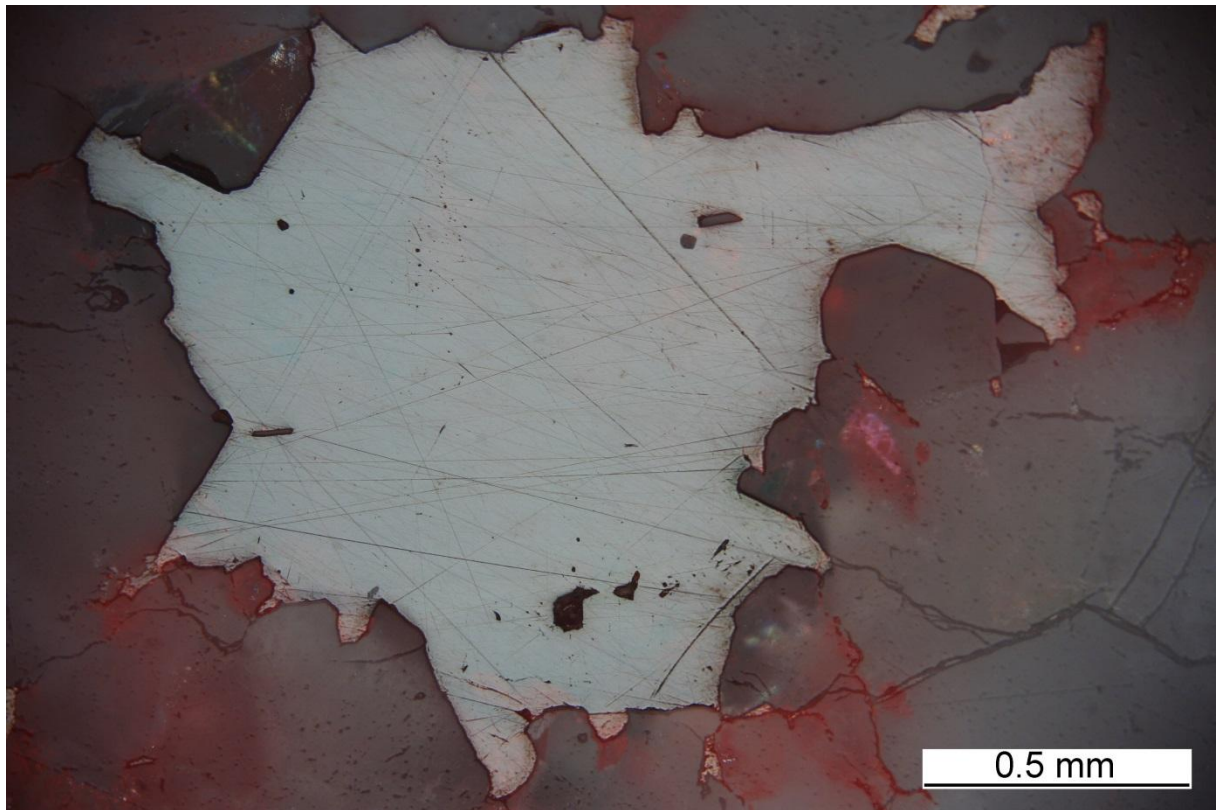


Fig. 6. Cinnabar with typical red internal reflexes, sample 65, XPL

The external nature of grains

The grain shapes of minerals are determined by complex variables acting during deposition and crystallization, and subsequent recrystallization, replacement or alteration. Idiomorphic (a term used by reflected-light microscopists for well shaped or euhedral) grains are unusual, but some minerals in a polished section will be found to have a greater tendency towards a regular grain shape than others. In the ore mineral descriptions in chapter 3, the information given under the heading crystals is intended to be an aid to recognizing minerals on the basis of grain shape. Textural relationships are sometimes also given.

Internal properties of grains

Twining is best observed using crossed polars, and is recognized when areas with differing extinction orientations have planar contacts within a single grain. Cassiterite is commonly twinned.

Cleavage is more difficult to observe in reflected light than transmitted light, and is usually indicated by discontinuous alignments of regularly shaped or rounded pits. Galena is characterized by its triangular cleavage pits. Scratches sometimes resemble cleavage traces.

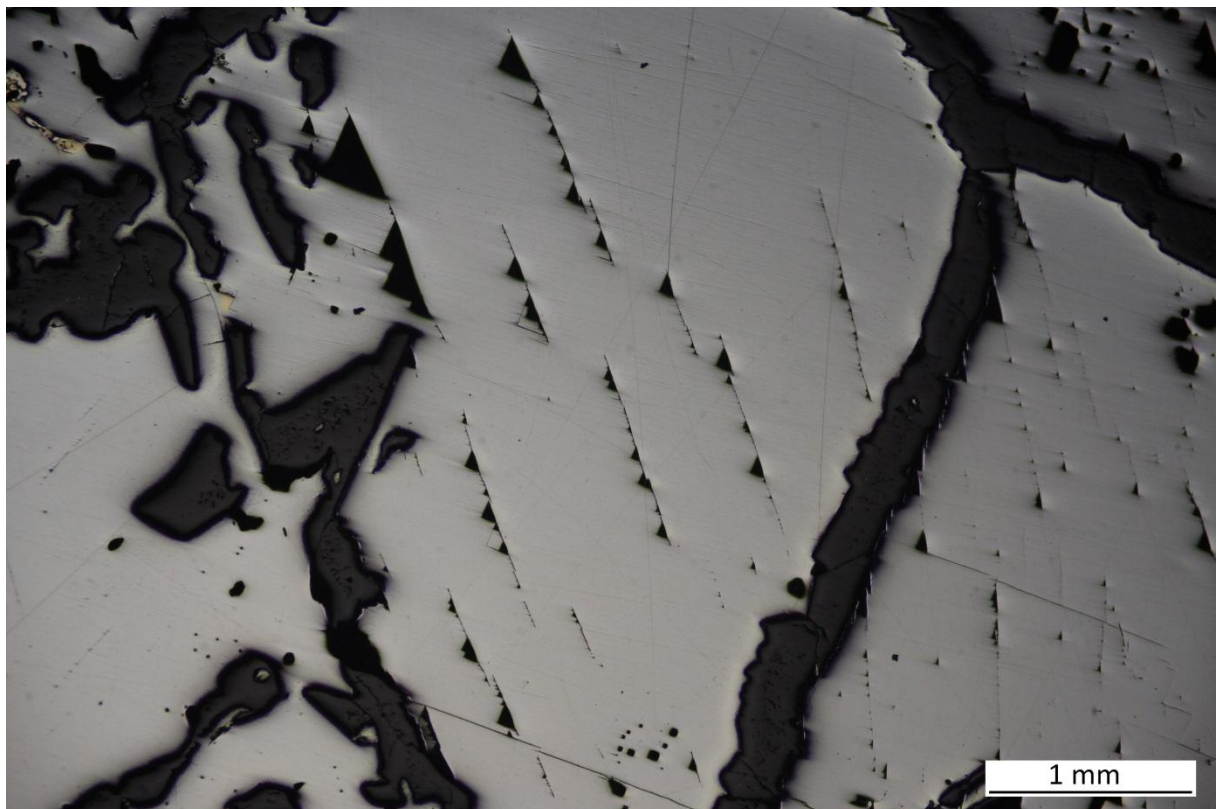


Fig. 7. Galena including the characteristic triangular cleavage pits, sample 64, PPL

Zoning Compositional zoning of chemically complex minerals, such as tetrahedrite, is probably very common but rarely gives observable effects such as colour banding. Zoning of micro-inclusions is more common.

Inclusions The identity and nature of inclusions commonly observed in the mineral are given, as this knowledge can be an aid to identification. Pyrrhotite, for example, often contains lamellas inclusions of pentlandite.

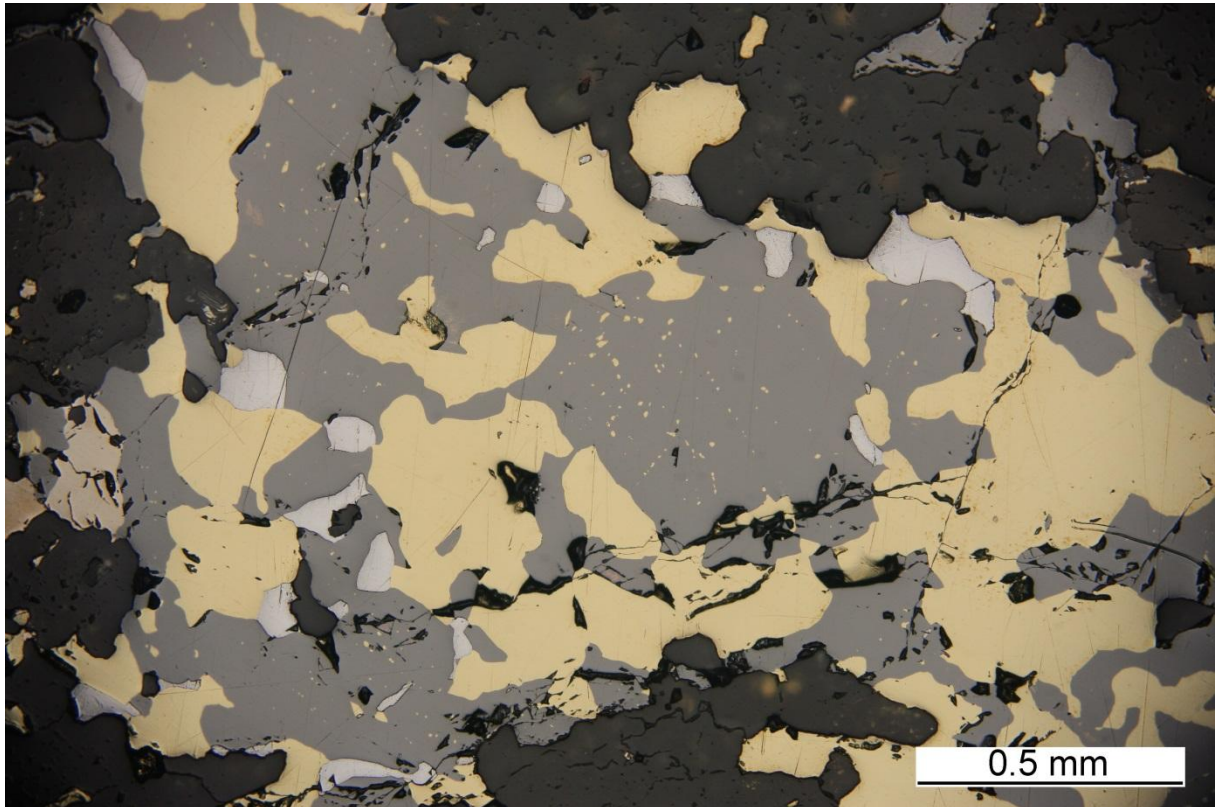


Fig. 8. Sphalerite (grey with yellow chalcopyrite inclusions), chalcopyrite (yellow), galena (white) and pyrrhotite (cream-brownish), sample 21, PPL

Vickers hardness number (VHN)

The Vickers hardness number is a quantitative value of hardness, knowledge of which is useful when comparing the polishing properties of minerals.

Distinguishing features

Distinguishing features are given for the mineral compared with other minerals or similar appearance. The terms harder or softer refer to comparative polishing hardness.

Observations using oil immersion in reflected-light studies

Preliminary observations on polished sections are always made simply with air (RI=1.0) between the polished surface and the microscope objective, and for most purposes this suffices. However an increase in useful magnification and resolution can be achieved by using immersion objectives which require oil (use the microscope manufacturer's recommended oil, e.g. Cargille oil type A) between the objective lens and the section surface. A marked decrease in glare is also obtained with the use of immersion objectives further reason for using oil immersion is that the ensuing change appearance of a mineral may aid its identification. Ramdohr (1969) states: It has to be emphasized over and over again that whoever shuns the use of oil immersion misses an important diagnostic tool and will never see hundreds of details described in this book.

Oil immersion nearly always results in a decrease in reflectance of a mineral to its optical properties and to the refractive index (N) of the immersion medium. Because it is the $n-N$ and $n + N$ values in the equation that are affected, the decrease in reflectance resulting from the increase in N is greater for minerals with a lower absorption coefficient.

The colour of a mineral may remain similar or may change markedly from air to oil immersion. The classic example of this is covellite, which changes from blue in the air to red in oil, whereas the very similar blaubleibender covellite remains blue in both air and oil. Other properties, such as bireflectance and anisotropy, may be enhanced or diminished by the use of oil immersion.

To use oil immersion, lower the microscope stage so that the immersion objective is well above the area of interest on the horizontal polished section. Place a droplet of the recommended oil on the section surface, and preferably also on the objective lens. Slowly raise the stage using the coarse focus control, viewing from the side, until the two droplets of oil just coalesce. Continue to raise the stage very slowly using the fine focus looking down the eyepiece until the image comes into focus. Small bubbles may drift across the field, but they should not cause any inconvenience. Larger bubbles, which tend to be caused by moving the sample too quickly may be removed satisfactorily only by complete cleaning.

To clean the objective, lower the stage and immediately wipe the end of the objective with a soft tissue. Alcohol on a tissue may be used, but not a solvent such as acetone, which may result in loosening of the objective lens. The polished section can be carefully lifted from the stage and cleaned in the same way.

Most aspect of qualitative ore microscopy can be undertaken without recourse to oil immersion, and oil immersion examination of section which are subsequently to be carbon coated for electron-beam micro-analysis should be avoided. The technique is most profitably employed in the study of small grains of low reflectance materials such as graphite or organic compounds, where the benefits are a marked increase in resolution and image quality at high magnification.

Polishing hardness

During the polishing process, polished sections inevitably develop some relief (or topography) owing to the differing hardness of the component minerals (see Fig. 9). soft minerals tend to be removed more easily than hard minerals. Also, the surfaces of hard grains tend to become convex, whereas the surfaces of soft grains tend to become concave. One of the challenges of the polishing technique is totally to avoid relief during polishing, because of the detrimental effect of polishing relief on the appearance of the polished section, as well as the necessity for optically flat polished surfaces for reflectance measurements. As some polishing relief is advantageous in qualitative mineral identifications, it is often beneficial to enhance the polishing relief by buffing the specimen for a few minutes using a mild abrasive such as gamma alumina on a soft nap.

Polishing relief results in a phenomenon known as the Kalb light line, which is similar in appearance to a Becke line. A sharp grain contact between a hard mineral such as pyrite and a soft mineral specimen is exactly in focus. On defocusing slightly by increasing the distance between the specimen and objective, a fine line of bright light should appear along the grain contact in the softer mineral.

The origin of this light line should easily be understood on examination of Fig. 9. Ideally the light line should move away from the grain boundary as the specimen is further defocused. On defocusing in the opposite sense the light appears in the harder mineral, and defocusing in this sense is often necessary, as the white line is difficult to

see in a bright white soft mineral. The light line is best seen using low-power magnification and an almost closed-aperture diaphragm.

The Kab light line is used to determine the relative polishing hardness of minerals in contact in the same polished section. This sequence can be used to confirm optical identification of the mineral set, or as an aid to the identification of individual minerals, by comparison with published lists of relative polishing hardness (e.g. Uytebogaard and Burke 1971).

Relative polishing hardness can be value in the study of micro-inclusions in an identified host phase; comparison of the hardness of an inclusion and its surround may be used to estimate the hardness of the inclusion, or to eliminate some possibilities resulting from optical properties. Similarly, if optical properties cannot be used to identify a mineral with certainty, comparison of polishing hardness with an identified coexisting mineral may help. For example, pyrrhotite is easily identified and may be associated with pyrite or pentlandite, which are similar in appearance; however, pyrite is harder than pyrrhotite, whereas pentlandite is softer.

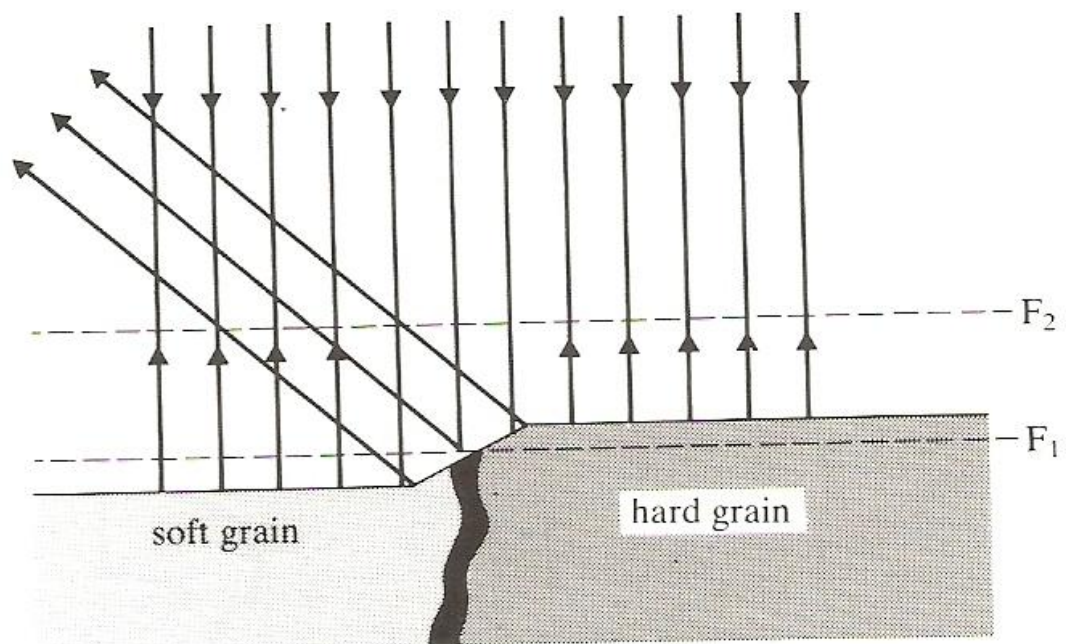


Fig. 9. Relative polishing hardness. The position of focus is first at F_1 . If the specimen is now lowered away from the objective, the level that is in focus will move to F_2 so that a light line (the Kab light line) appears to move into the softer substance.

According to Gribble and Hall (1992).

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