



ORE GRADE PETROLOGY

**Guide to Reflected
Light Petrography
and Textural
Relationships**

Reflected Light Properties:

Colour: Arguably the most important property observed in reflected light petrography is the colour of the mineral. This property is simple, what colour is the mineral in the sample?

Pleochroism: Does the colour of mineral varies from grain to grain and individual grains change in colour upon rotation of the stage? If so, then the mineral is pleochroic. Pleochroism can often be observed only by careful examination of groups of grains in different crystallographic orientations. For example, covellite has a strong pleochroism that varies from light blue to dark blue often within the same grain.

Reflectance: Essentially, this is the amount of light that is bounced back from the polished mineral surface back into the objective lens of the microscope (the brightness of the mineral). The eye is not good at estimating reflectance percent, but it can be a useful property to separate minerals with similar colours such as pyrite and pyrrhotite.

Birerectance: This property is the measure of how much the reflectance varies in a mineral (does the brightness in a single mineral vary?). This is not a measure of colour change (which is pleochroism), but the change of intensity of colour within a single mineral. Molybdenite is a great example of a mineral with a high degree of bireflectance.

Anisotropy: This property is directly related to bireflectance.

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

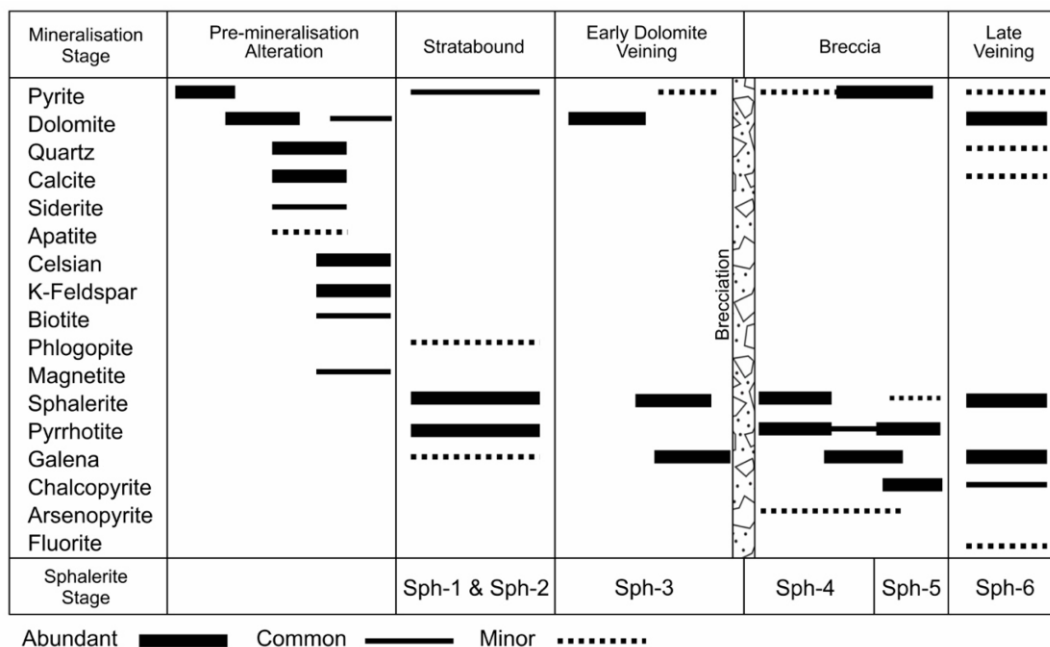
Hardness: This property has pronounced affect on the final polished surface and relates the size of the “borders” that surrounds the minerals. Hard minerals (such as pyrite) will often have thicker borders than relatively softer minerals (such as galena). This is due to small-scale differences in topography caused when polishing the sample (causing light to reflect away from the objective lens). However, this property relies on polishing quality and minerals with relatively different harnesses being in contact.

Habit/Morphology: Just like identifying a mineral in hand specimen or in transmitted light petrography, different minerals have different habits. For example, pyrite will preferentially exhibit a cubic habit. Fine-grained hematite often exhibit a micaceous morphology.

Diagnostic Features: These are features that are common for the specific mineral. For example, sphalerite allows transmitted light to pass through and galena often exhibits diagnostic triangular pits as a result of polishing.

Paragenesis:

This refers to the sequence of mineral formation as deduced from textural relationships. This can be applied to multiple minerals within a single vein, or a variety of minerals within an deposit. Often, complex paragenesis are developed within ore deposits that incorporate multiple mineral assemblages/alteration assemblages. A paragenesis is typically presented in a table form that outlines the minerals present in each stage (in the order of early to late) and where they fit into the paragenetic sequence of the ore deposit. Often, the thickness of the lines in the table refer to the relative abundance of each mineral within a specific stage. The paragenesis of an ore deposit directly reflects the evolution of the ore-bearing fluid, which is often subject to a variety of external processes such as changes in temperature (or possibly pressure if the deposit is being actively exhumed) and reactions with the wall rock. Unless detailed geochronology is completed with paragenetically constrained mineral phases, the timing between mineral phases of unknown. An example of a paragenesis is given below and is that of the Hilton Zn-Pb-Ag-Cu deposit, NW Queensland.



Paragenesis of the Hilton Zn-Pb-Ag-Cu deposit, NW Queensland. Paragenesis from Cave et al (2020).

Paragenetic Stages: Different paragenetic stages may represent differences in time periods that vary from kyrs to myrs. Paragenetic stages may be differentiated to convey important characteristics of the ore deposit (such as a separate Zn to Cu-rich stages that reflect different zones within a single ore deposit), or to reflect a significant change in mineral assemblages (for example, from an earlier carbonate stage to a sulphide stage as above). Typically distinct and obvious textural relationships are used to divide paragenetic stages. For example, the presence of cross-cutting veins or distinct changes in mineralogy can be readily be used to divide paragenetic stages.

Textural Relationships:

As previously mentioned, the paragenesis of a deposit is built on the ability to identify textural relationships between minerals. The main textural relationships that can be used to construct a paragenesis are outlined below.

Intergrowth: Ex-solution intergrowths are commonly used as definitive proof that the ore-minerals of interest have co-crystallised. However, in most ore deposits cooling of the ore-bearing fluid has been sufficiently slow to allow the unmixing and segregation of the ore minerals precipitated in solid-solution.

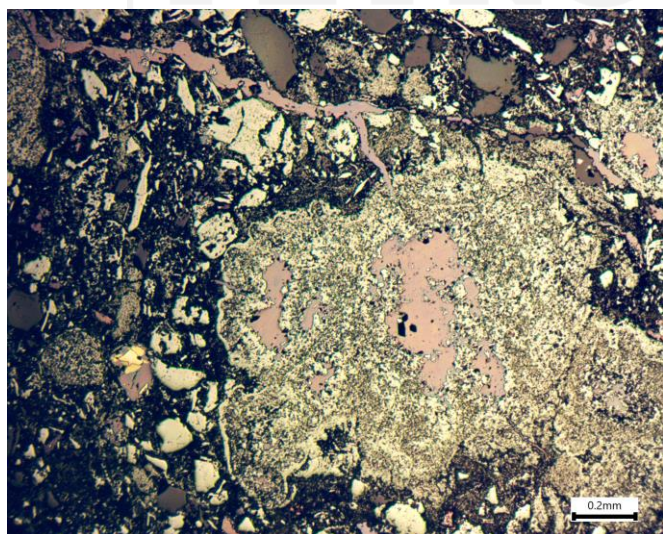
Mutual Boundaries: This texture can often be difficult to assess. It is consistent with grain boundaries showing regular and smooth contacts. Occasionally, triple junctions at an angle of 120° are used to suggest co-crystallisation of sulphide minerals.

Overgrowth: This is used as evidence to suggest that two minerals did not co-crystallise. In this case, the paragenetically earlier mineral is often enveloped/overprinted by a subsequent, paragenetically later mineral phase.

Replacement: Replacement occurs when a pre-existing (paragenetically earlier) mineral phase is consumed either partially or completely by a subsequent (paragenetically later) mineral phase. Replacement of a mineral phase is often concentrated around its rims, within intragranular cracks/fractures, or along its cleavage planes (if a cleavage is present).

Veining: This is the easiest textural relationship to identify and is a very robust relationship. If a variety of minerals occur in a vein that is cross-cutting a previous mineral phase, then it is definitively occurs later in the paragenesis. Often, veins can be a handy tool to differentiate paragenetic stages (if they are present).

Contrasting Textural Relationships: There is little doubt that there is often overlap between the precipitation of the multiple mineral phases within a single paragenetic stage. If there is contrasting textural relationships exhibited by a variety of mineral phases, it can be used as evidence to suggest that the minerals co-crystallised.



Fine-grained hematite replacing bornite. Location of sample is unknown.

Table of Common Ore Minerals:

Mineral	Formula	Colour	Pleochroism	Reflectance	Birefringence	Anisotropy	Hardness	Other
Chalcopyrite	CuFeS ₂	Brassy-yellow	No	34-51%	Weak, occasionally observable	Typically weak. Grey-clue to greenish-yellow.	3.5	Most common-Cu mineral. Its brassy-yellow colour is very distinct in reflected light petrography.
Galena	PbS	Bright-white	No	43-47%	No	Isotropic	2.5	Triangular pits developed along cleavage planes as the result of polishing are very common and distinct.
Pyrite	FeS ₂	Yellowish-white	No	46-55%	No	Weak. Blue-green to orange-red.	6.5	Rectangular or square outlines are often present and result from its relatively high hardness. Pyrite often develops fractures when deformed.
Pyrrhotite	Fe _{1-x} S	Cream with pink-brown tint	Weak	30-42%	Very distinct. Reddish-brown to brown-cream.	Very strong. Yellow to grey	3.5-4	Does not any regular crystal shape. Commonly exhibits an irregular morphology.
Sphalerite	ZnS (+Fe)	Grey	No	17-20%	No	Isotropic	3.5-4	Sphalerite can be viewed in transmitted light (plane polarized). The colour of sphalerite in PPL often reflects its Fe-content. Dark = High, Light = Low.
Tetrahedrite	Cu ₃ SbS _{3.25}	Grey	No	31-32%	No	Isotropic	3.5-4	May have inclusions of sphalerite, chalcopyrite, stannite or pyrrhotite due to exsolution. Similar colour to sphalerite but slightly lighter.
Magnetite	Fe ₂ O ₄	Grey with brownish tint	No	20-21%	No	Isotropic	5.5-6	Magnetic, even in thin section. Often forms euhedral football-shaped crystals.
Hematite	Fe ₂ O ₃	Grey-white	No	22-31%	Weak	Very distinct, greyish blue to greyish yellow.	6.5	Alters to goethite. Often occurs as idiomorphic crystals or aggregates. Slightly brighter & whiter than magnetite.
Bornite	Cu ₅ FeS ₄	Pinkish-brown	Weak	16-25%	Very Slight	Very Weak. No details given on colour.	3	Commonly occurs as aggregates of rounded-grains. Distinct bronze to pinkish-brown colour in thin section.
Cassiterite	SnO ₂	Brownish-grey	Weak to Strong	10-12%	Moderate	Very distinct, grey to dark-grey.	6-7	Often occurs as coarse-grained zoned crystals.
Chalcocite	Cu ₂ S	Blueish-white	Weak to No	~30%	Very Weak	Weak to distinct. Emerald green to light-pink.	2.5-3	Lamellar twinning very common.

Mineral	Formula	Colour	Pleochroism	Reflectance	Birefringence	Anisotropy	Hardness	Other
Ilmenite	FeTiO ₃	Light to dark brown.	No	16-20%	No	Strong. Light-greenish grey to brownish grey.	5.6-6	Often displays a distinct lamellar twinning and/or exsolutions.
Bismuthinite	Bi ₂ S ₃	White with blueish-grey tint.	Weak	40-50%	Weak	Very strong. Slate-grey to yellowish brown or grey violet.	2-2.5	Forms solid solution with stibnite. Usually radial-fibrous developed.
Wolframite	(Fe, Mn)WO ₄	Grey or greyish white.	Weak	15-19%	Weak	Weak to distinct. Yellow to dark-grey.	4-4.5	Forms tabular idiomorphic crystals. Cleavage often distinct in two directions. Twinning is very common. Refers to solid solution between Ferberite (Fe) and Huebnerite (Mn) endmembers.
Rutile	TiO ₂	Grey. Sometimes faint blue tint.	Weak	19-24%	Distinct	Strong. White, yellowish, brown, reddish brown. Depends on content of the admixed elements.	6-6.5	Characterised by very high relief and extreme birefringence. Rutile can be observed in PPL.
Chromite	(Fe, Mg) (Cr, Al, Fe) ₂ O ₄	Dark grey to brownish grey. Varies with composition.	No	11-14%	No	Isotropic	4.5	Usually forms homogenous rounded idiomorphic crystals or crystalline aggregates. Cataclastic texture very common. Often zoned reflecting differences in chemical composition.
Cobaltite	(Co, Fe)As ₂	White with a distinct pinkish, violet or brown tint.	No	20-21%	Weak, white to pinkish white.	Weak to distinct. Blue-grey and brown coloured shades.	5.5-6	Commonly occurs as idiomorphic crystals. Cleavage in coarse-grains distinct. Twinning lamellae often distinct.
Molybdenite	MoS ₂	White	Very Strong	~50%	Extremely High	Very Strong. White with pinkish tinge.	1	Often forms curved plates with undulatory extinction.
Arsenopyrite	FeAs _{0.9} S _{1.1}	White to light-cream	Weak	45-50%	Weak, but noticeable.	Strong. Blue, green, reddish-brown, yellow.	5	Characteristic rhomb-shaped sections with a distinct white-colour.
Uraninite	UO ₂	Grey with brownish tint.	No	10-15%	No	Isotropic	5-6	Occurs in a variety of forms. Highly mobile and reactive to fluids.
Covellite	CuS	Indigo-blue	Strong	11-28%	Extremely High	Extremely High. Fiery orange to reddish-brown.	1.5-2	Common alteration product of Cu-sulphides. Distinct indigo-blue colour and high birefringence/anisotropy.