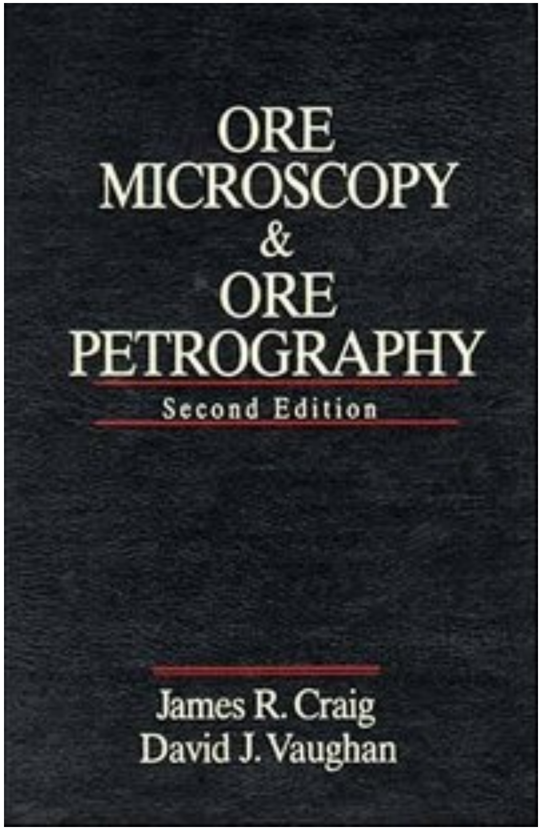
EARTH 471
Mineral Deposits

Ore minerals,
reflected light microscopy,
textures
and alteration

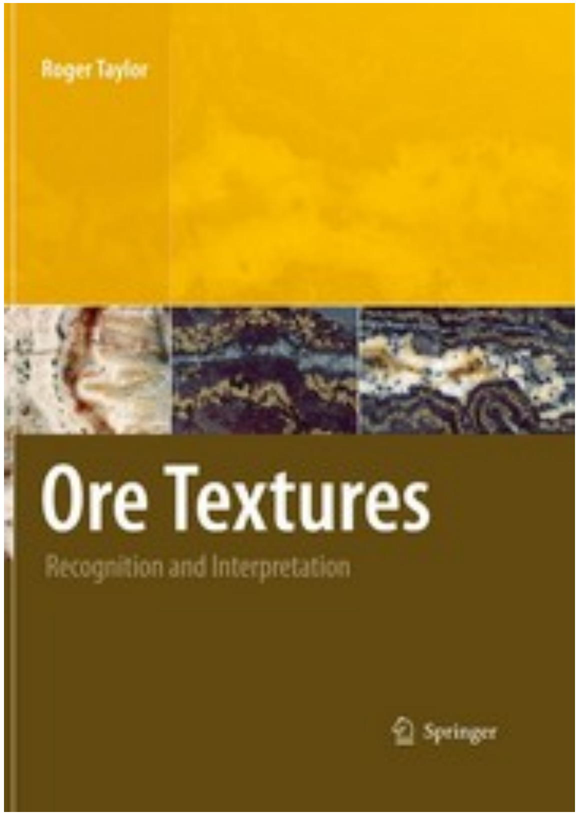
Resources

http://www.atlas-of-ore-minerals.com



CV94 Chapter 7
Free online

http://www.minsocam.org/msa/OpenAccess_publications/Craig_Vaughan/



Taylor 2009
Free online through library

http://www.springer.com/earth+sciences+and+geography/geology/book/978-3-642-01782-7

Important Ore Minerals

(all photos from webmineral.com)

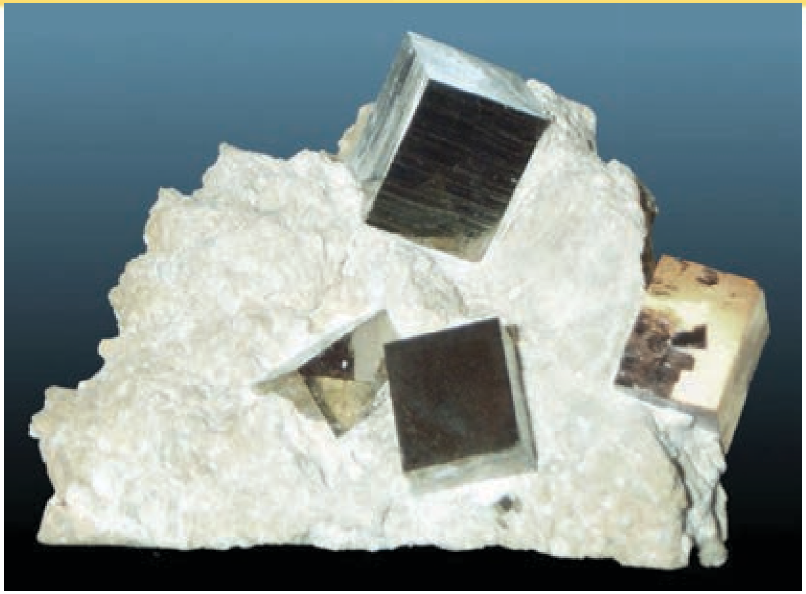
Iron oxide ore minerals

Hematite – Fe_2O_3

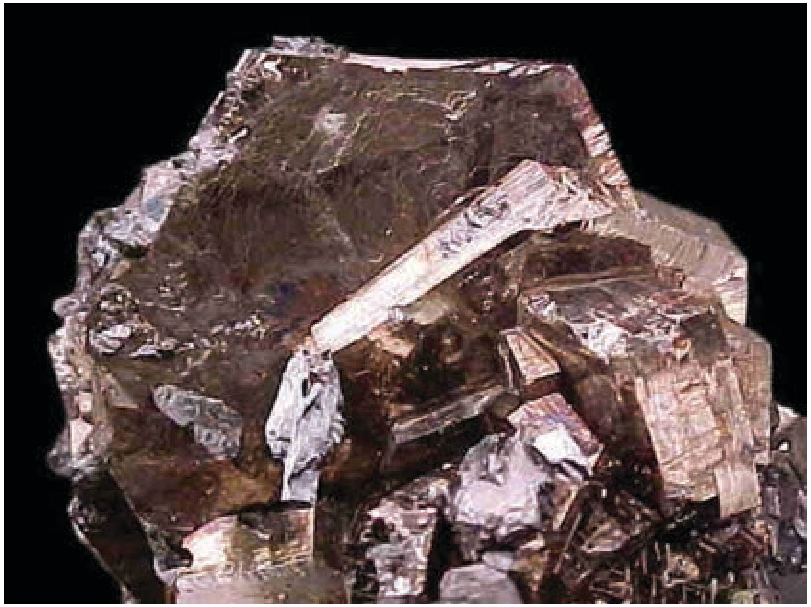
Magnetite – Fe_3O_4

Note the oxidation state of Fe

Iron sulphide ore minerals



Pyrite – FeS_2



Pyrrhotite – $Fe_{(1-x)}S$ $x=0–0.17$

Copper ore minerals I

Chalcopyrite – $CuFeS_2$
(most important ore mineral for Cu)

Bornite – Cu_5FeS_4

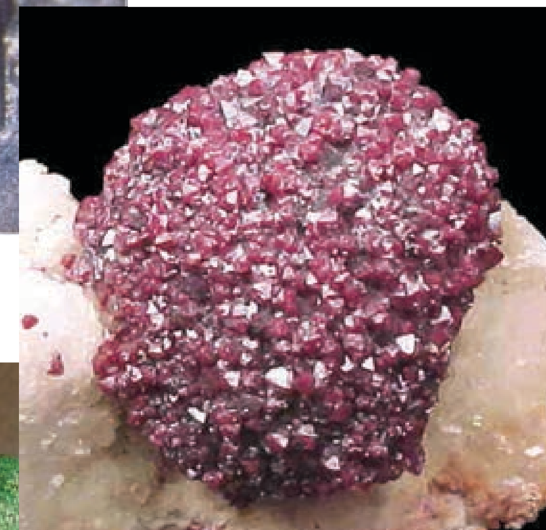
Chalcocite – Cu_2S

Covellite – CuS

Copper ore minerals II

Digenite – Cu_9S_5

Cuprite – Cu_2O



Malachite – $Cu_2CO_3(OH)_2$

Azurite – $Cu_3(CO_3)_2(OH)_2$

Other sulphide ore minerals I

Galena – PbS

Stibnite – SbS_3

Sphalerite – ZnS

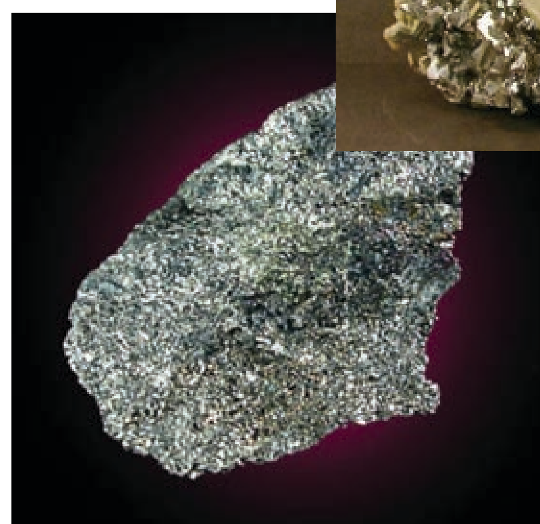
Molybdenite – MoS_2

Other sulphide ore minerals II

Cassiterite – SnO_2

Arsenopyrite – FeAsS

Pentlandite – $(Fe,Ni)_9S_8$

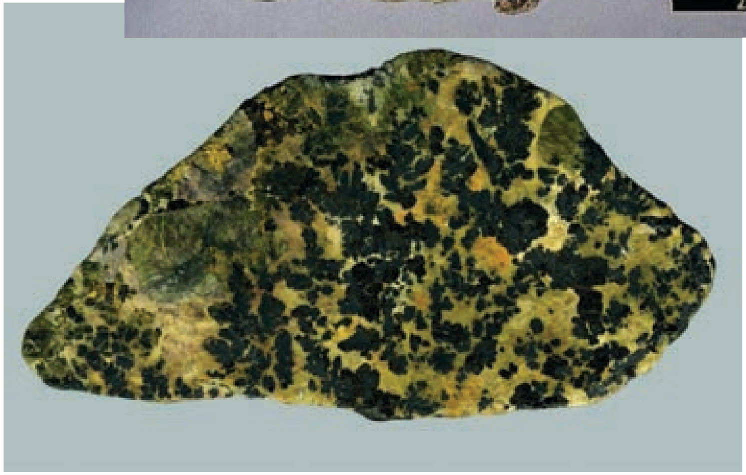


Other ore minerals

Pyrolusite – MnO_2

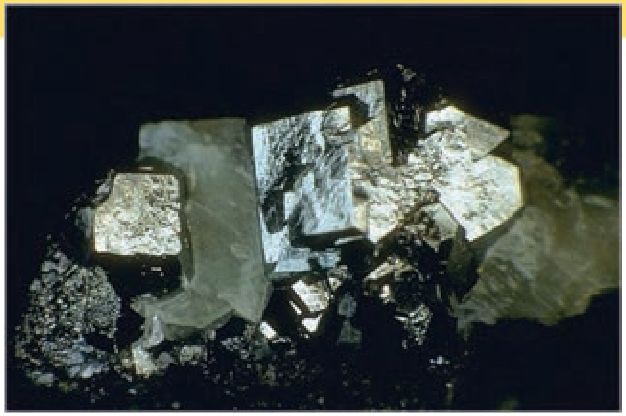
Chromite – $FeCr_2O_4$

Uraninite – UO_2



Other ore minerals

Skutterudite – $(Co,Ni,Fe)As_3$



Wolframite – $(Fe,Mn)WO_4$

Cobaltite – $CoAsS$

Carbon bearing stuff

Coal – a complex mixture of (C,H,S,O)

http://www.vancouverobserver.com

Graphite – C (an easy one!)

Other minerals you already know:

Rutile
Ilmenite
Tourmaline
Epidote
Chlorite
Magnesite
Calcite

Ankerite
Apatite
Halite
Sylvite
Quartz
Feldspars
Micas
Amphiboles

Sulphide ore minerals

Pyrite – FeS_2
Marcasite – FeS_2
Pyrrhotite – $Fe_{(1-x)}S$ (x=0–0.17)

Chalcopyrite* – **<u>Cu</u>**FeS_2
Bornite – Cu_5FeS_4
Chalcocite – Cu_2S
Covellite – CuS

Galena* – **<u>Pb</u>**S
Sphalerite* – **<u>Zn</u>**S
Molybdenite* – **<u>Mo</u>**S_2
Arsenopyrite – FeAsS

Oxide ore minerals

Hematite* – $\underline{\mathbf{Fe}}_2O_3$
Magnetite* – $\underline{\mathbf{Fe}}_3O_4$

Cuprite – Cu_2O

Chromite* – $Fe\underline{\mathbf{Cr}}_2O_4$

Uraninite* – UO_2

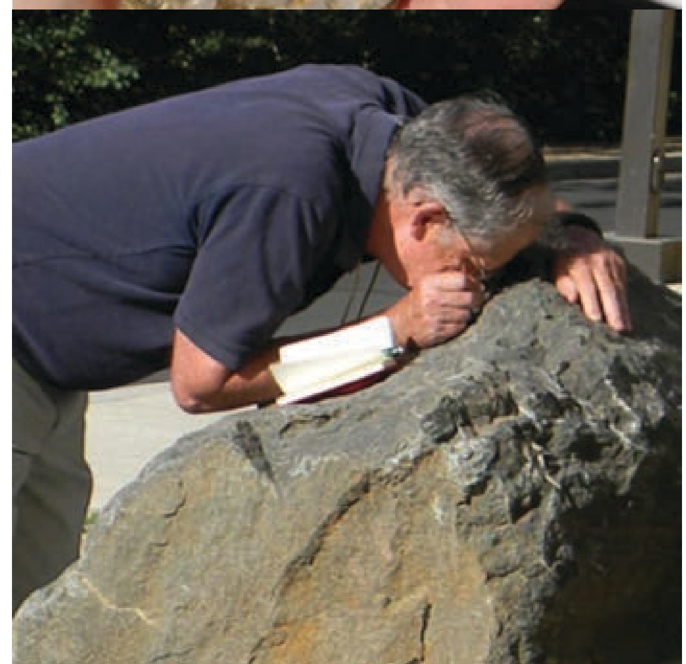
Wolframite* – (Fe,Mn)**W**O_4

Ore mineral identification

- Cleavage
- Streak
- Colour
- Hardness
- Density (specific gravity)

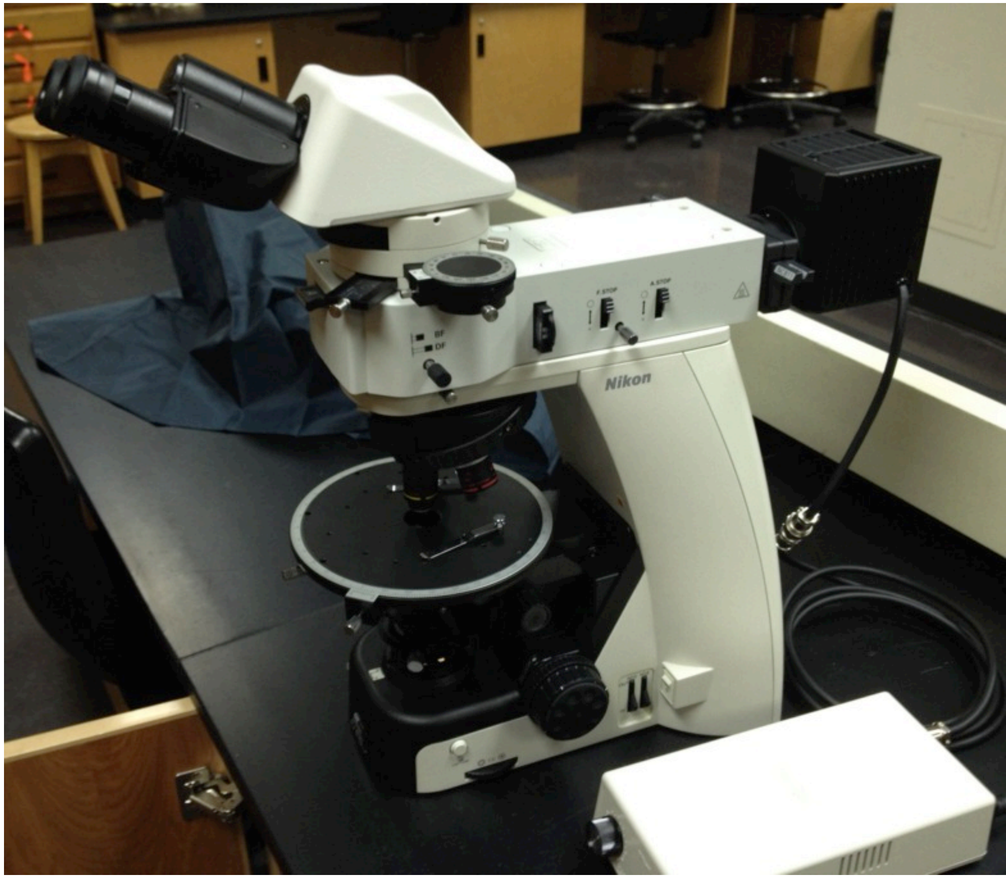
Unless you have a pristine and large minerals, these properties are very difficult to determine!

We need a better way to identify small ore minerals in rock samples…



Reflected light microscopy

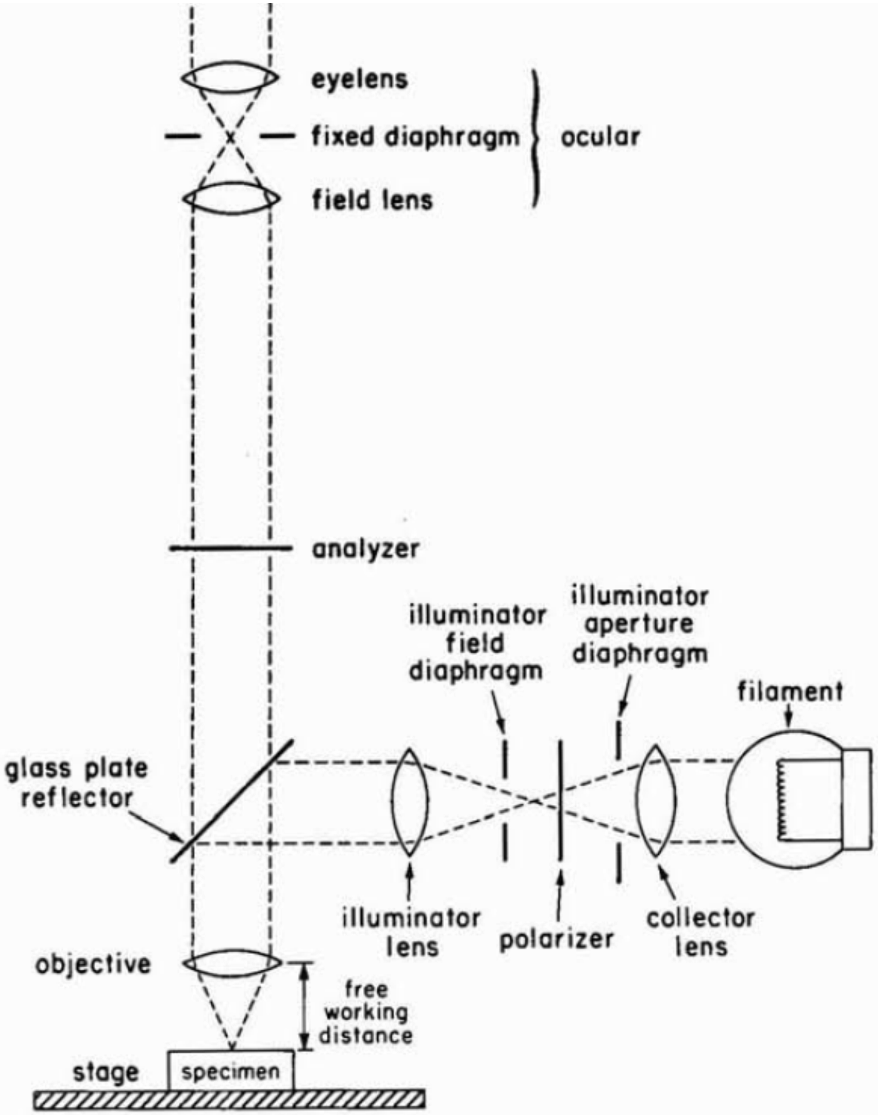
Many ore minerals are opaque in transmitted light.



Reflected light used for:

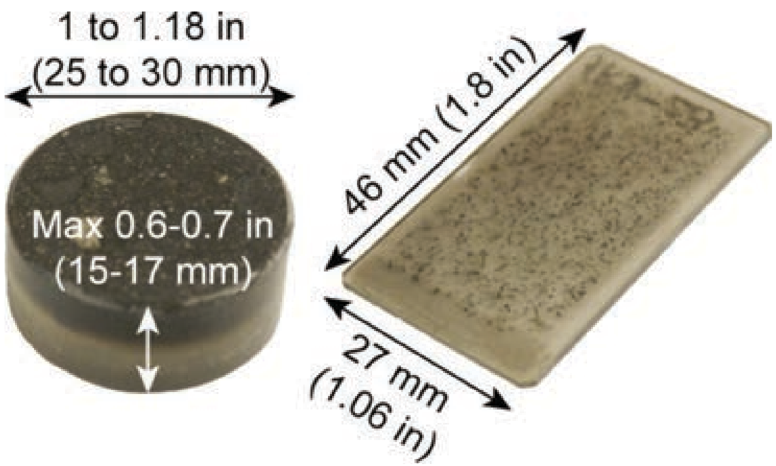
- Mineral identification, associations and textures
- Ore genesis
- Ore reserve estimation
- Grade control
- Metallurgy and metal recovery
- Environmental assessment

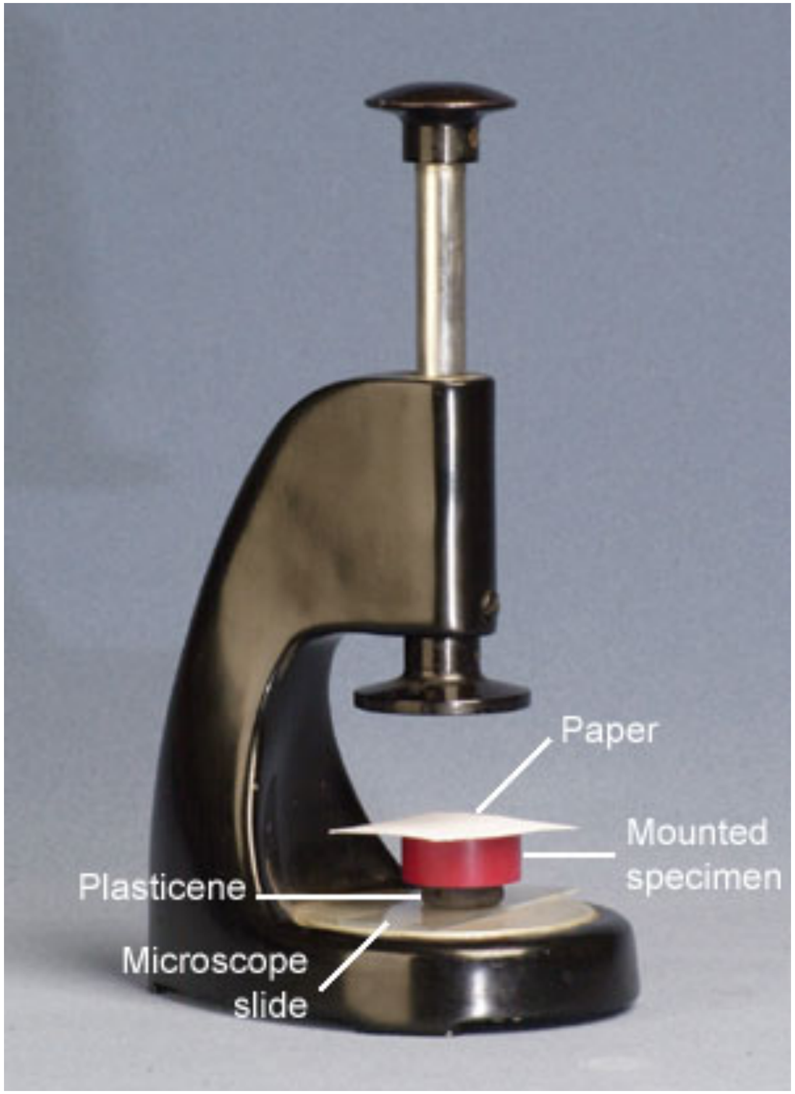
Reflected light microscopy



Mount preparation

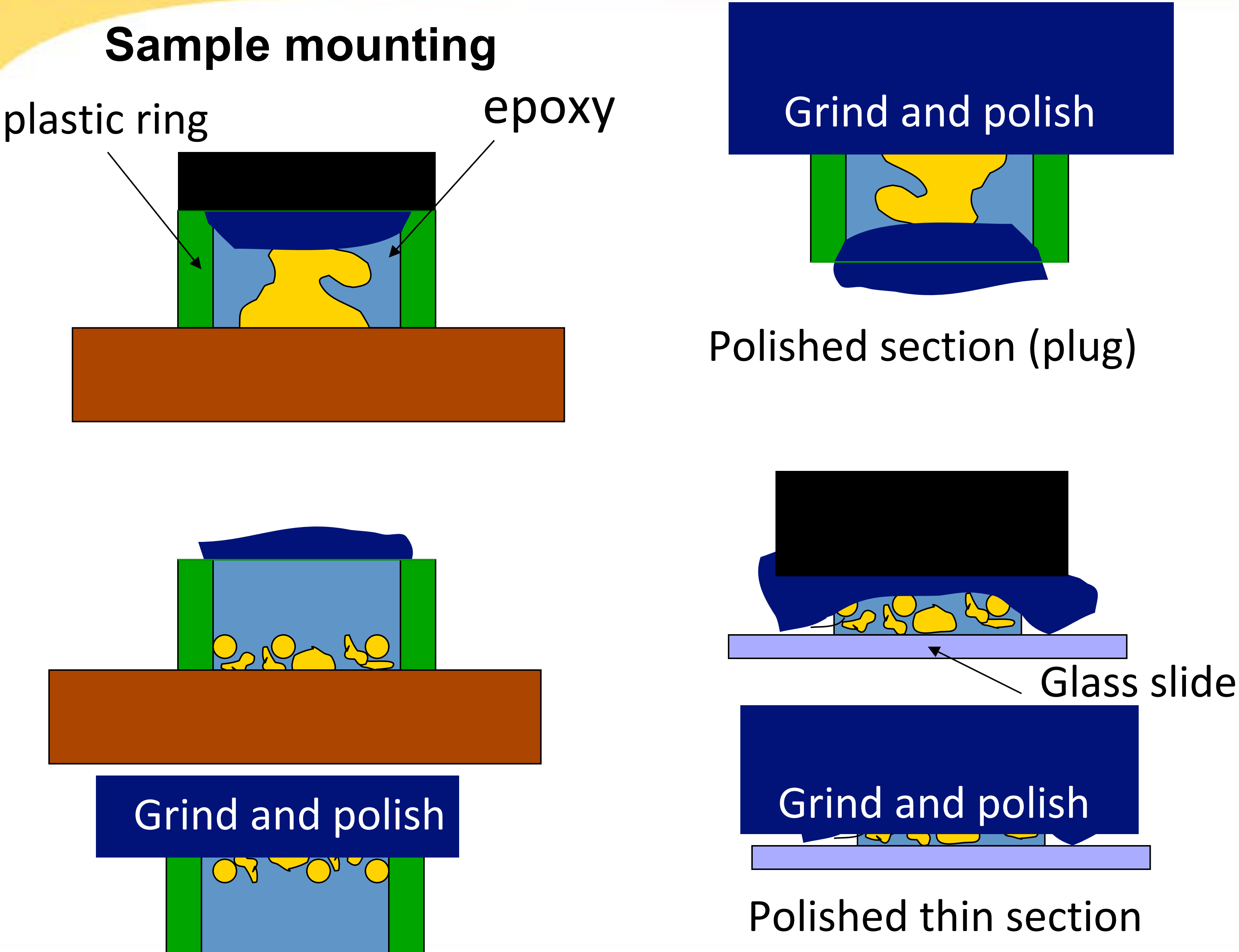
- Thin sections and pucks
- Polished surface needs to be flat for reflective light microscopy



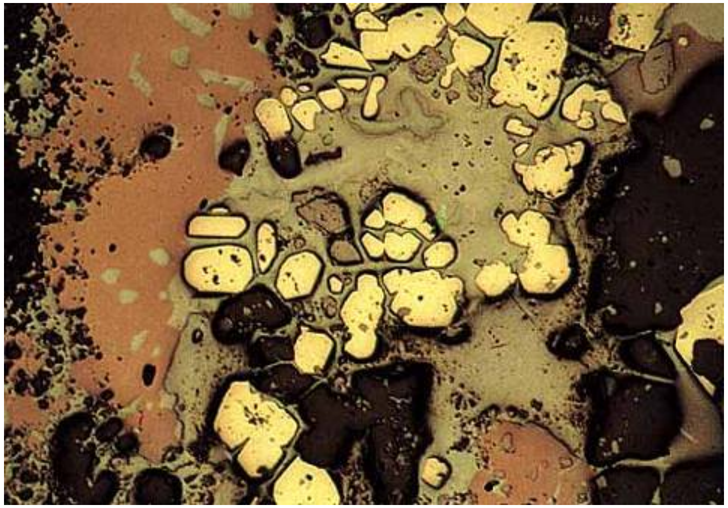


Specimen levelling press

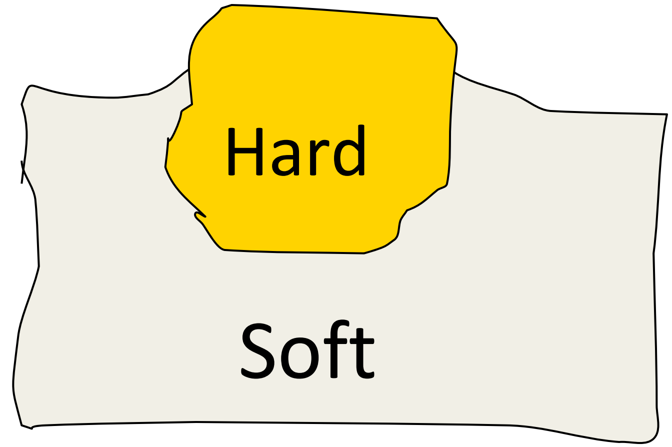
Sample mounting



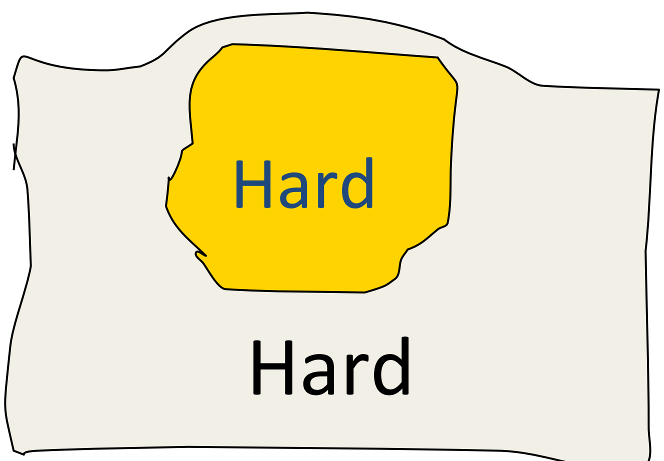
Polishing

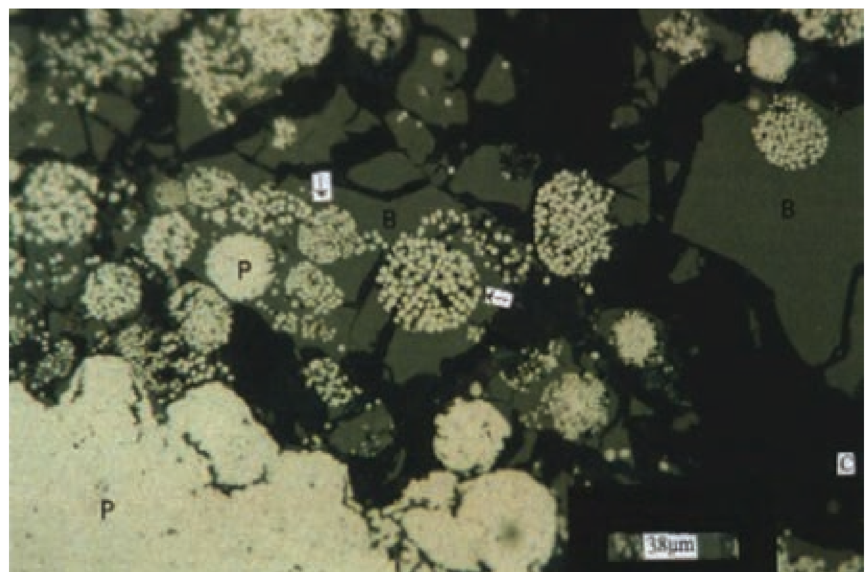


High Relief

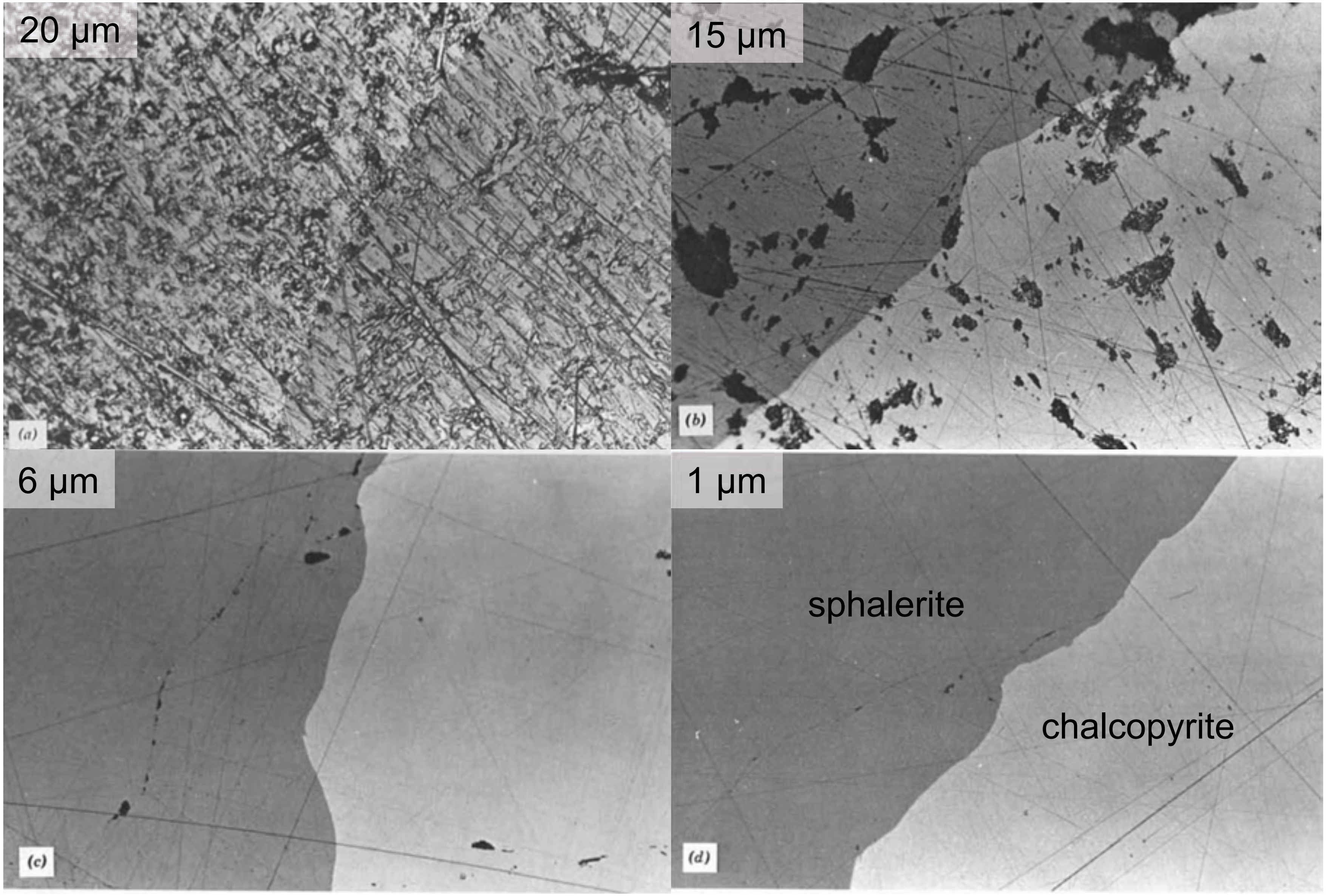


Low Relief





The importance of a good polish



Ore mineral identification

Important properties

Without analyzer (plane polarized light)

- Colour
- Reflectance
- Shape or Habit
- Zoning
- Cleavage
- Hardness
- Bireflectance

With analyzer (crossed polarizers)

- Anisotropic v. isotropic
- Polarization colours
- Internal reflections

Important properties

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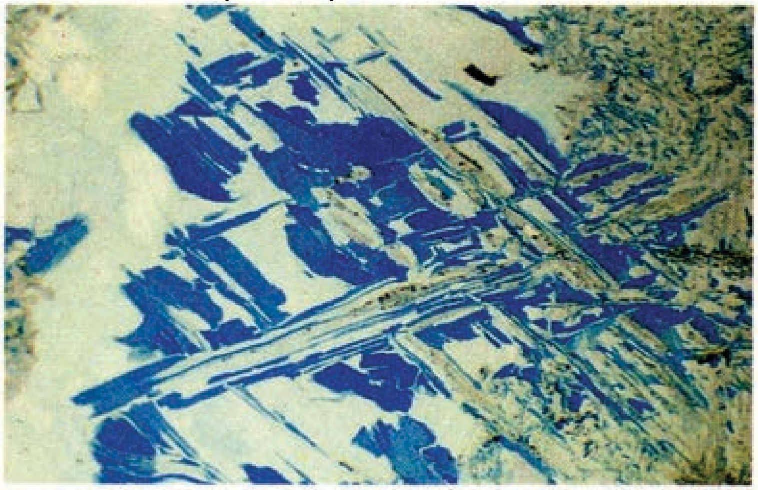
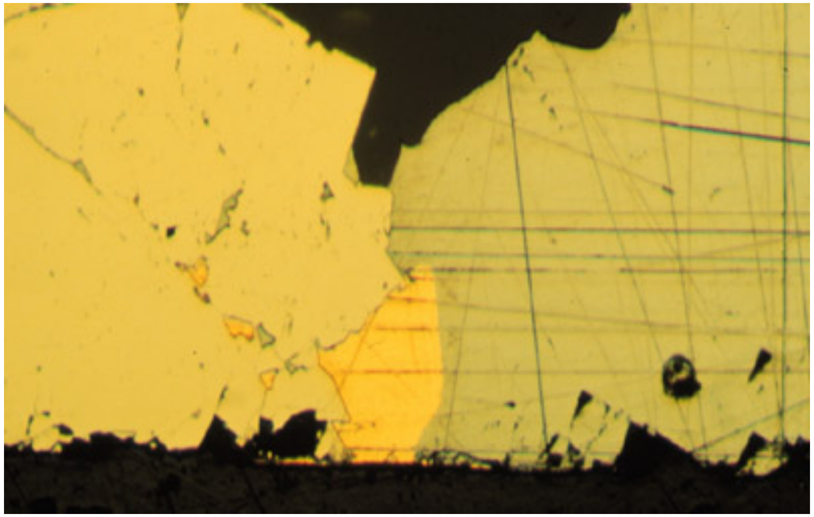
Covellite (Blue)



Lamelles de covellite (bleu) dans un mélange chalcocite-digenite — Tizert (Maroc) — L.N. — Obj. 5,6.

Gold (brilliant yellow)



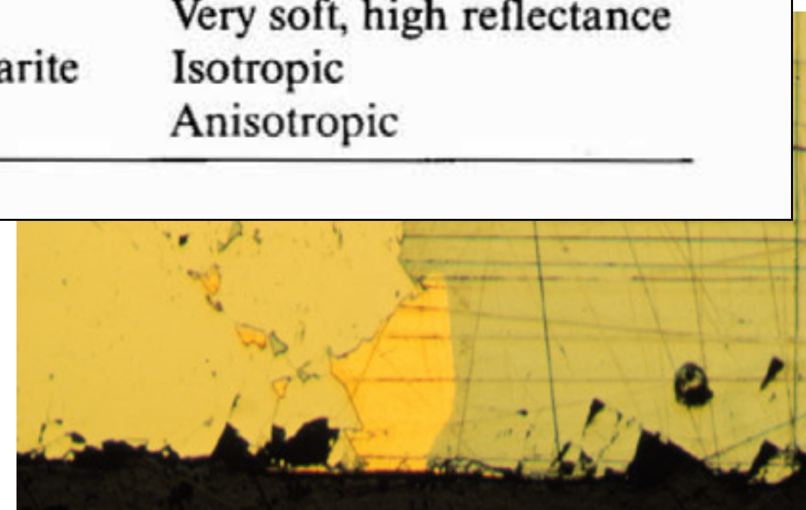
Important properties

Without analyzer

Covellite (Blue)

TABLE 3.1 Minerals Distinctly Colored in Reflected Light

Color	Mineral Phases	Other Observations
Blue	Covellite	Intense pleochroism
	Chalcocite, Digenite	Weakley anisotropic
Yellow	Gold	Very high reflectance
	Chalcopyrite	Very weak anisotropy
	Millerite, Cubanite	Strong anisotropy
	Mackinawite, Valleriite	Strong pleochroism
Red-brown to brown	Bornite	Weak anisotropy
	Copper	Very soft, high reflectance
	Nickeloan Pyrite, Violarite	Isotropic
	Breithauptite	Anisotropic



- Internal reflections

Important properties

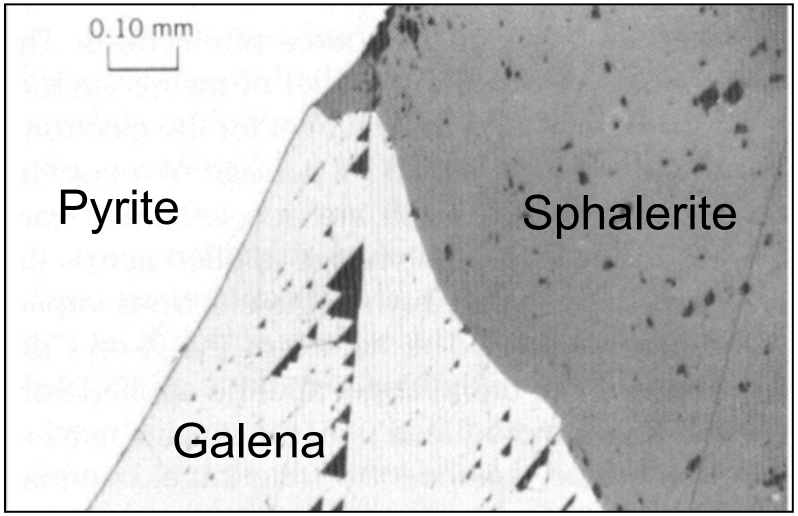
Without analyzer

- Colour
- **Reflectance**
- Shape or Habit
- Zoning
- Cleavage
- Hardness
- Bireflectance

With analyzer

- Anisotropic v. isotropic
- Polarization colours
- Internal reflections

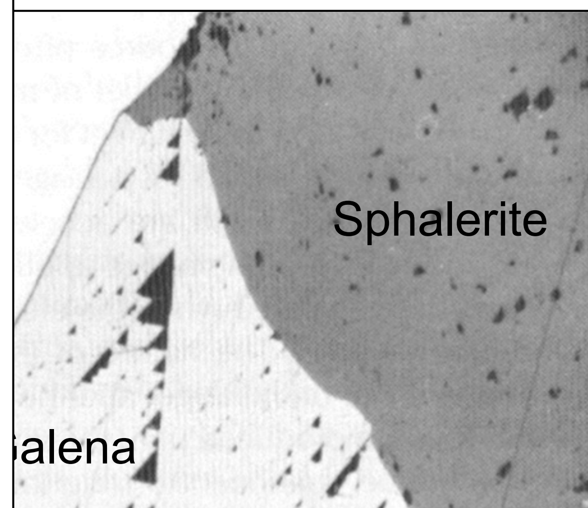
When most light is reflected a mineral is termed highly reflective. Most opaque minerals have intermittent reflectivities (oxides, many sulfides) and reflectivity drops as more and more light passes into the mineral and is either transmitted (most silicates) or absorbed (minerals like graphite).



Klein Fig. 7-30 (in gray scale)

When most light is reflected a mineral is
reflective. Most opaque
intermittent reflectivities
sulfides) and reflectivity drops
nore light passes into the
either transmitted (most
osorbed (minerals like graphite).

Relatively high reflectance:		Relatively low reflectance:	
Native silver	85 %	Rutile	23.5 %
Gold	72	Ilmenite	19.5
Native iron	59	Sphalerite	17
Arsenopyrite	52	Graphite	16
Marcasite	52 (46)	Titanite	11
Pyrite	51	Zircon	10
Chalcopyrite	45	Barite	7
Galena	43	Calcite	6
Hematite	29	Quartz	5
Covellite	23	Fluorite	3
Bornite	23	Coal	0.5 - 5



Klein Fig. 7-30 (in gray scale)

Important properties

Without analyzer

- Colour
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- Bireflectance

With analyzer

- Anisotropic v. isotropic
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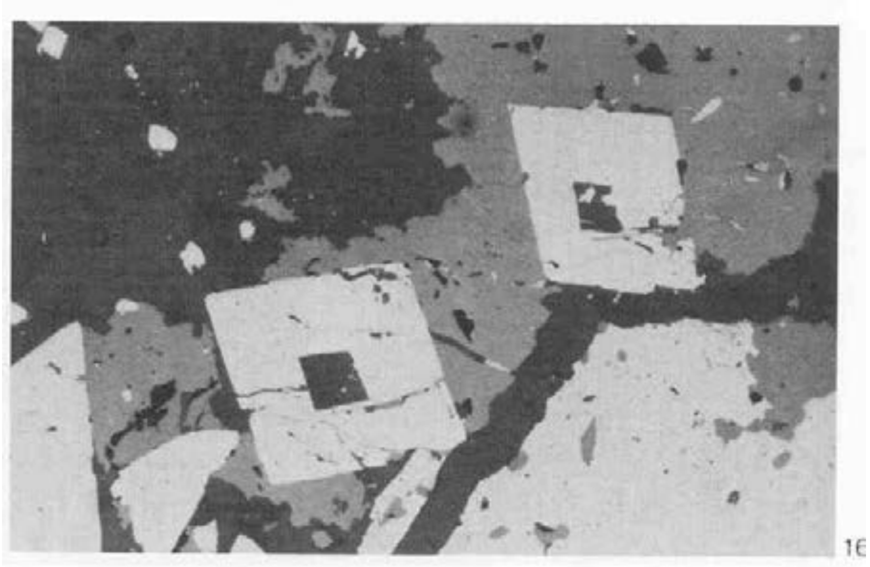
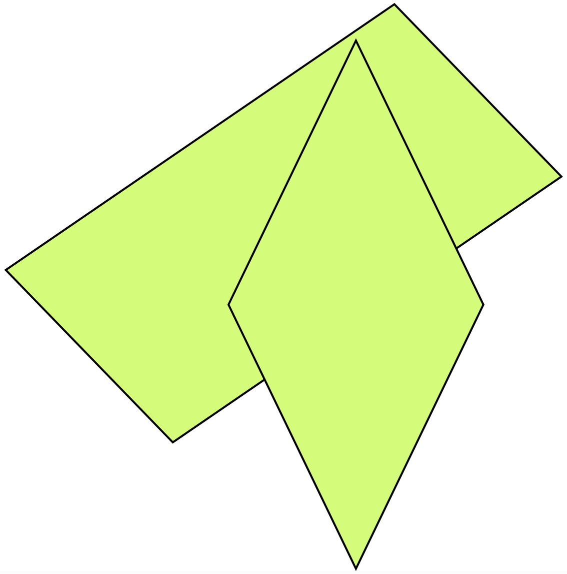
- Internal reflections

Arsenopyrite





Important properties

Without analyzer

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With analyzer

- Anisotropic v. isotropic
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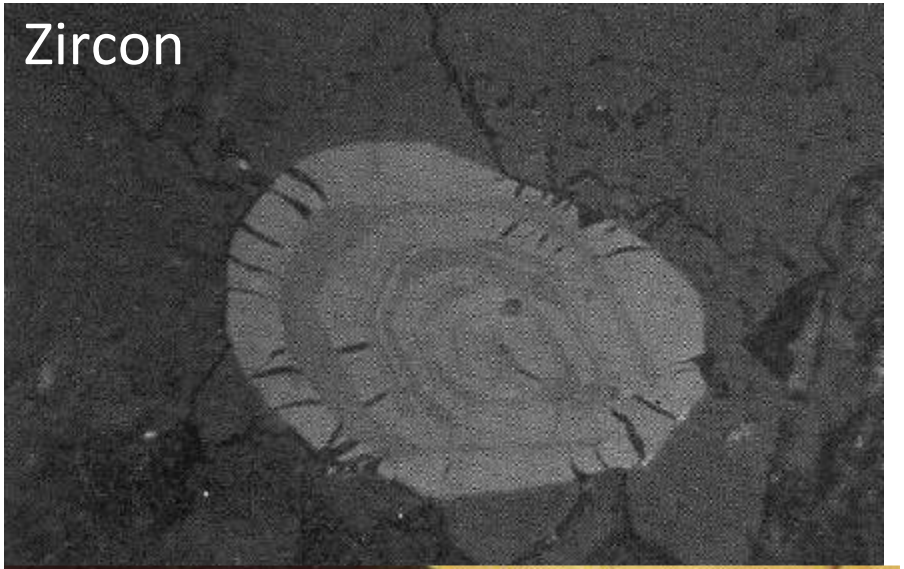

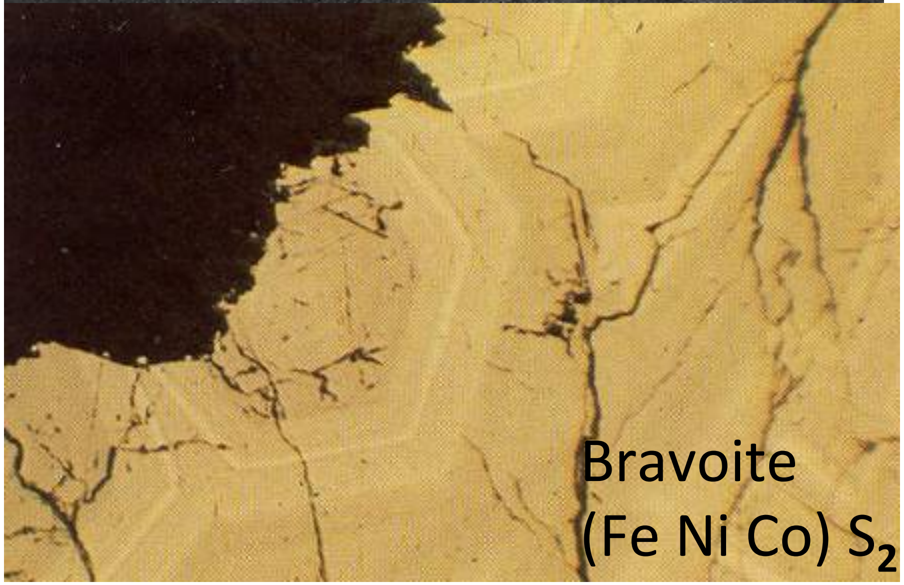

Important properties

Without analyzer

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- **Cleavage**
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With analyzer

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- Polarization colours
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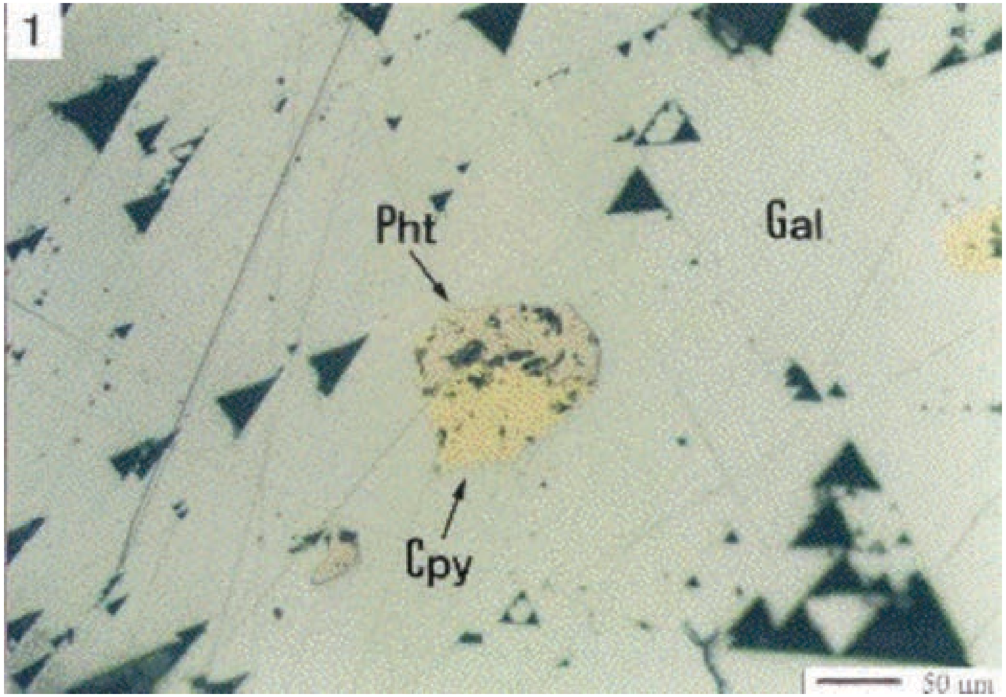
Triangular pits as typically seen in galena (PbS). These are manifestations of the perfect cubic cleavage of galena where small bits are plucked during sample preparation (think of the corners of cubes).



http://www.geo.arizona.edu/geo3xx/geo306_mdbarton

Important p

Without ana

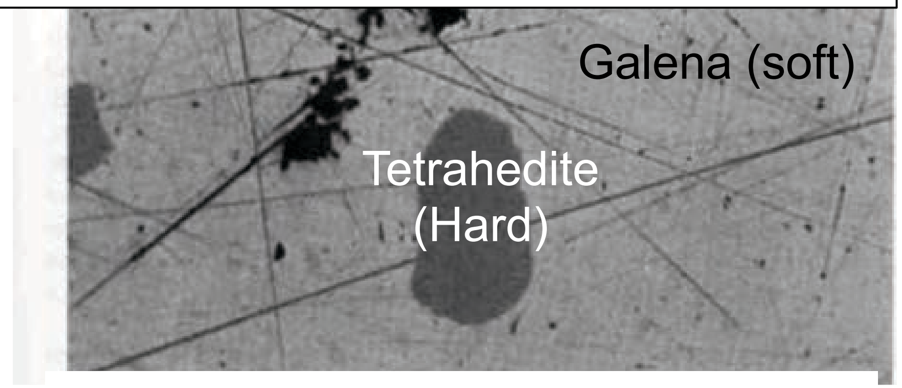
- Colour
- Reflectan
- Shape or
- Zoning
- Cleavage
- **Hardness**
- Bireflectance

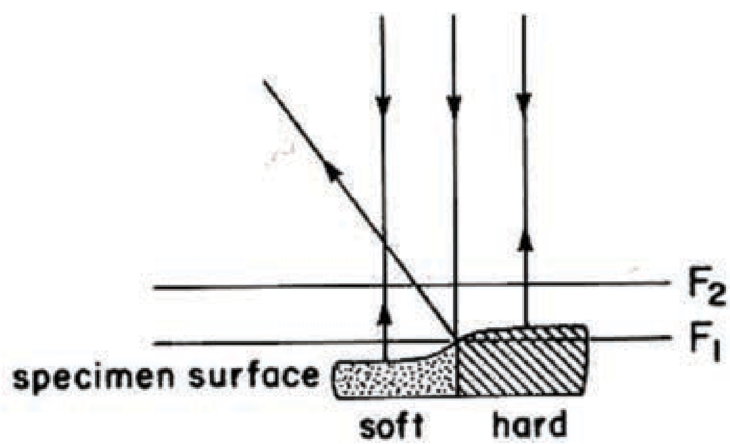
With analyzer

- Anisotropic v. isotropic
- Polarization colours
- Internal reflections

Differences in hardness result in polishing relief. We can use the Kalb line to see which mineral is in positive relief (harder).

-Focus on a grain boundary between 2 minerals
-Lower the stage
-Observe the "line" of light (similar to Becke line). As you lower the stage, it moves toward the softer mineral.





Important properties

Without analyzer

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With analyzer

- Anisotropic v. isotropic
- Polarization colours
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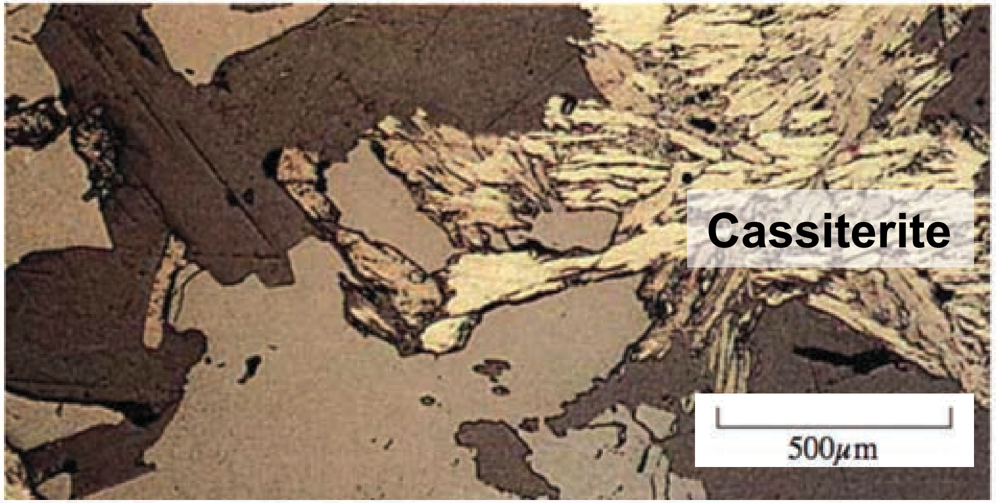
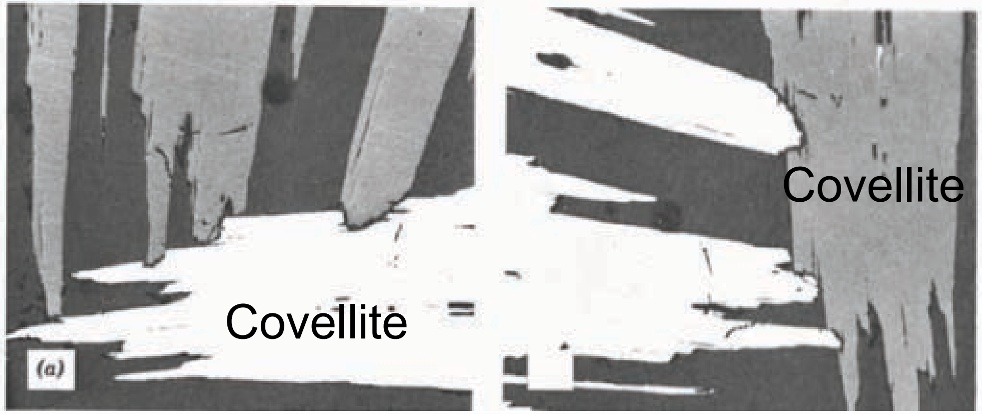
Bireflectance: reflectivity change ***in plane polarized light*** as the stage is rotated and the crystallographic axes change their positions relative to the polarizaton direction.





Important properties

Without analyzer

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With analyzer

- Anisotropic v. isotropic
- Polarization colours
- Internal reflections

Under crossed-polars, isotropic minerals remain extinct when rotating the stage.

Anisotropic minerals will reflect some light under specific orientations, and some will even change color.

It is useful to change the angle between the polarizer and the analyzer.

hematite replacing magnetite

Important properties

Without analyzer

- Colour
- Reflectance
- Shape or Habit
- Zoning
- Cleavage
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- Bireflectance

With analyzer

- Anisotropic v. isotropic
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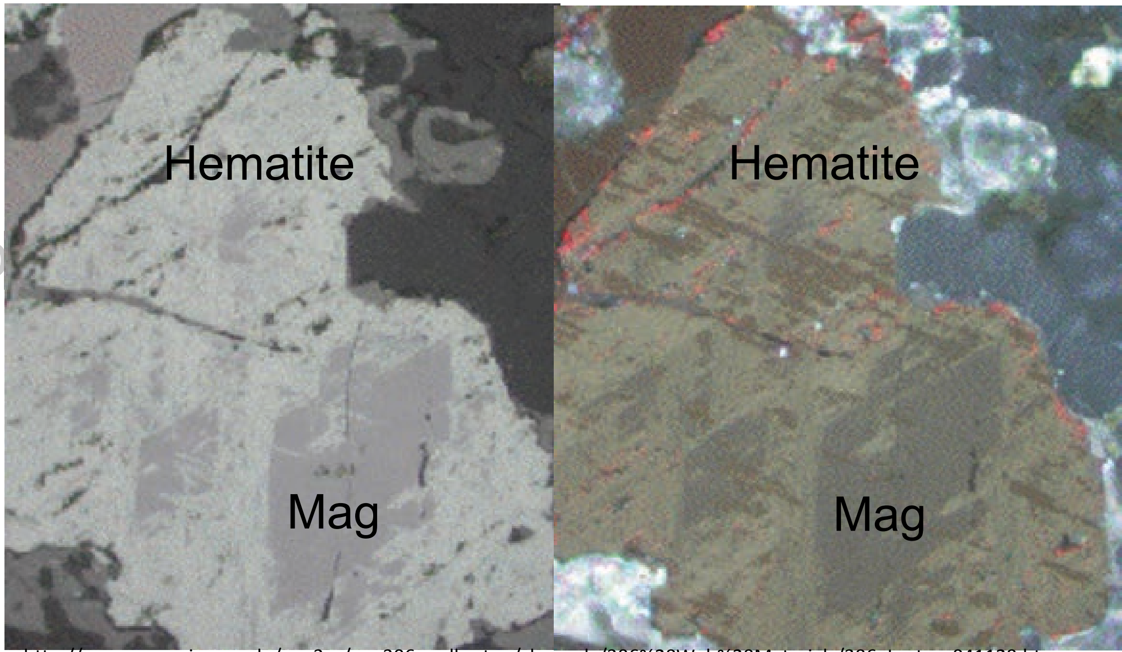
- Internal reflections

Some minerals show different colours under cross polarized light.

Below, magnetite has similar colours whereas hematite changes colour.

Reflected PPL | Crossed polarizers



http://www.geo.arizona.edu/geo3xx/geo306_mdbarton/classonly/306%20Web%20Materials/306_Lecture041129.htm

Important properties

Without analyzer

- Colour
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With analyzer

- Anisotropic v. isotropic
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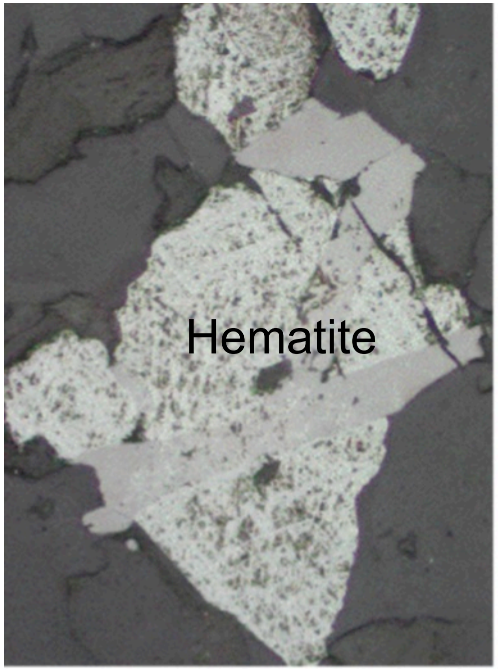
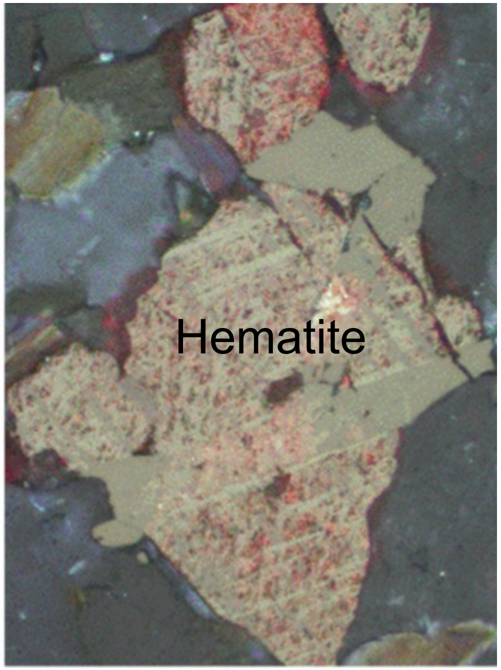
- Internal reflections

Internal reflections: faint to prominent colored patches that result from light being reflected back after passing into the crystal. They are most common in partly transparent minerals such as sphalerite, rutile, and (in many cases) hematite.

Polarizer : in
Analyzer : out



Polarizer : in
Analyzer : in



Ore textures

"*The interpretation of textures is simultaneously one of the most difficult and important aspects of the study of rocks and ore*" (Barton, 1991)

Textures (a.k.a. microstructures) represent the spatial relationships within and between grains

Textures provide evidence of processes such as:

- Initial ore deposition
- Post-depositional re-equilibration
- Metamorphism
- Deformation
- Annealing
- Weathering

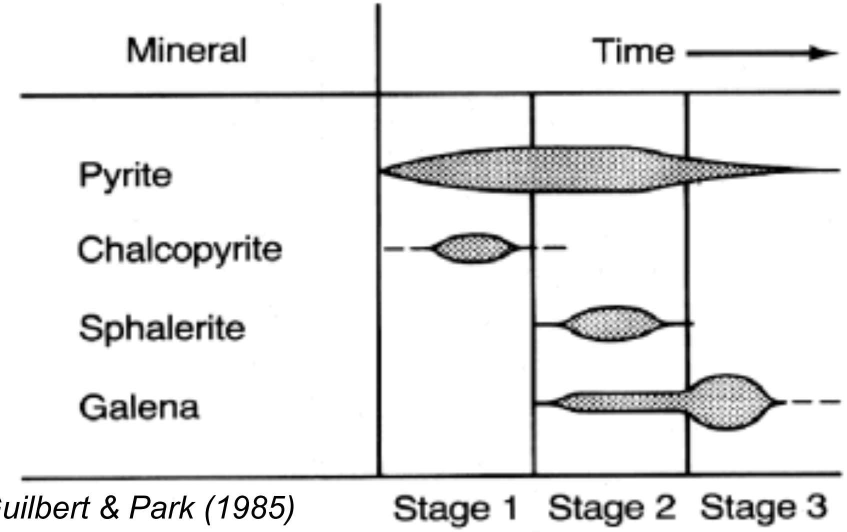
Textures are used to infer the **paragenesis** of a mineral assemblage.

Paragenetic sequence*

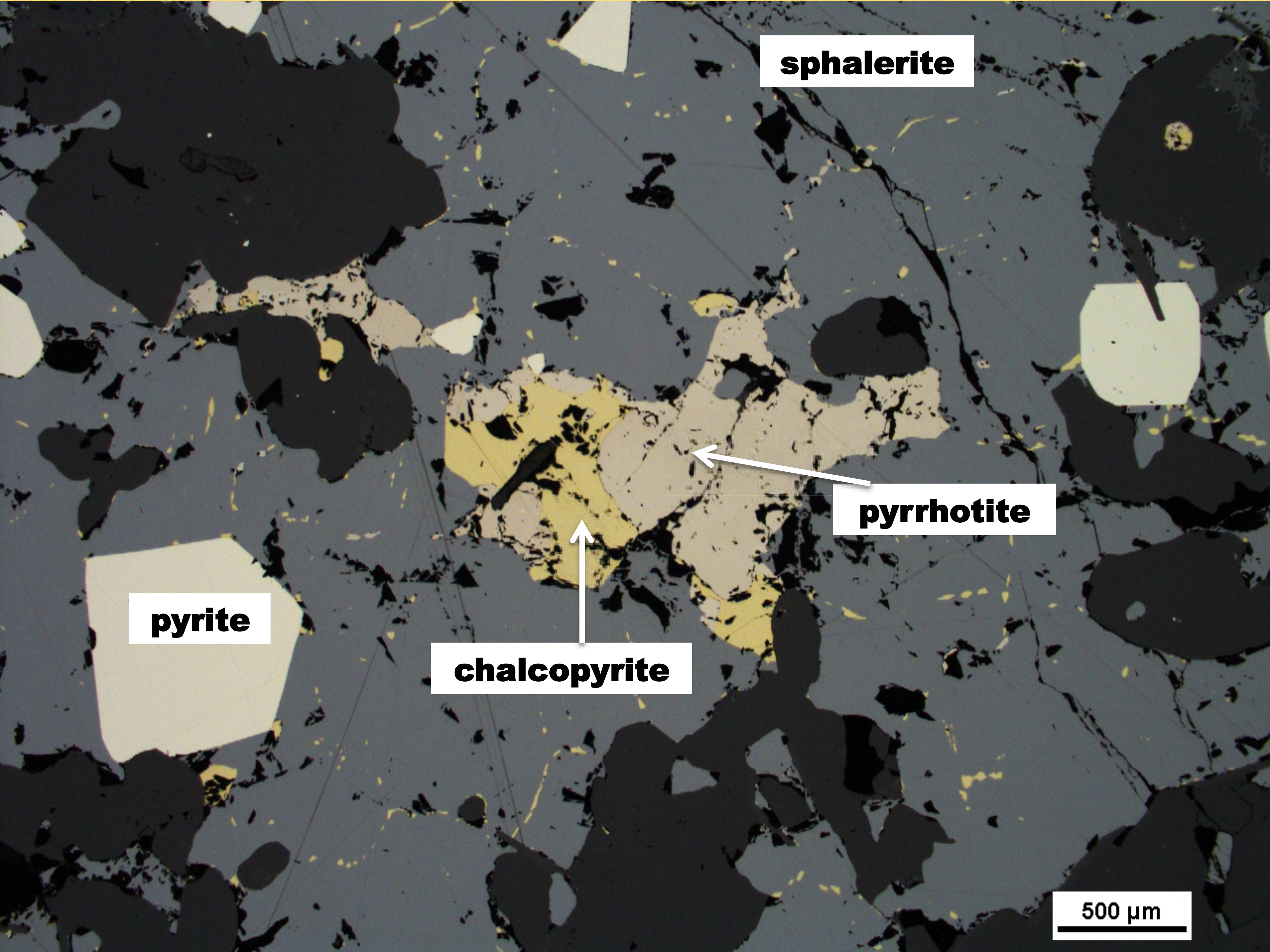
Relative sequences of ore mineral growth.

Textures are used to determine the paragenetic sequence:

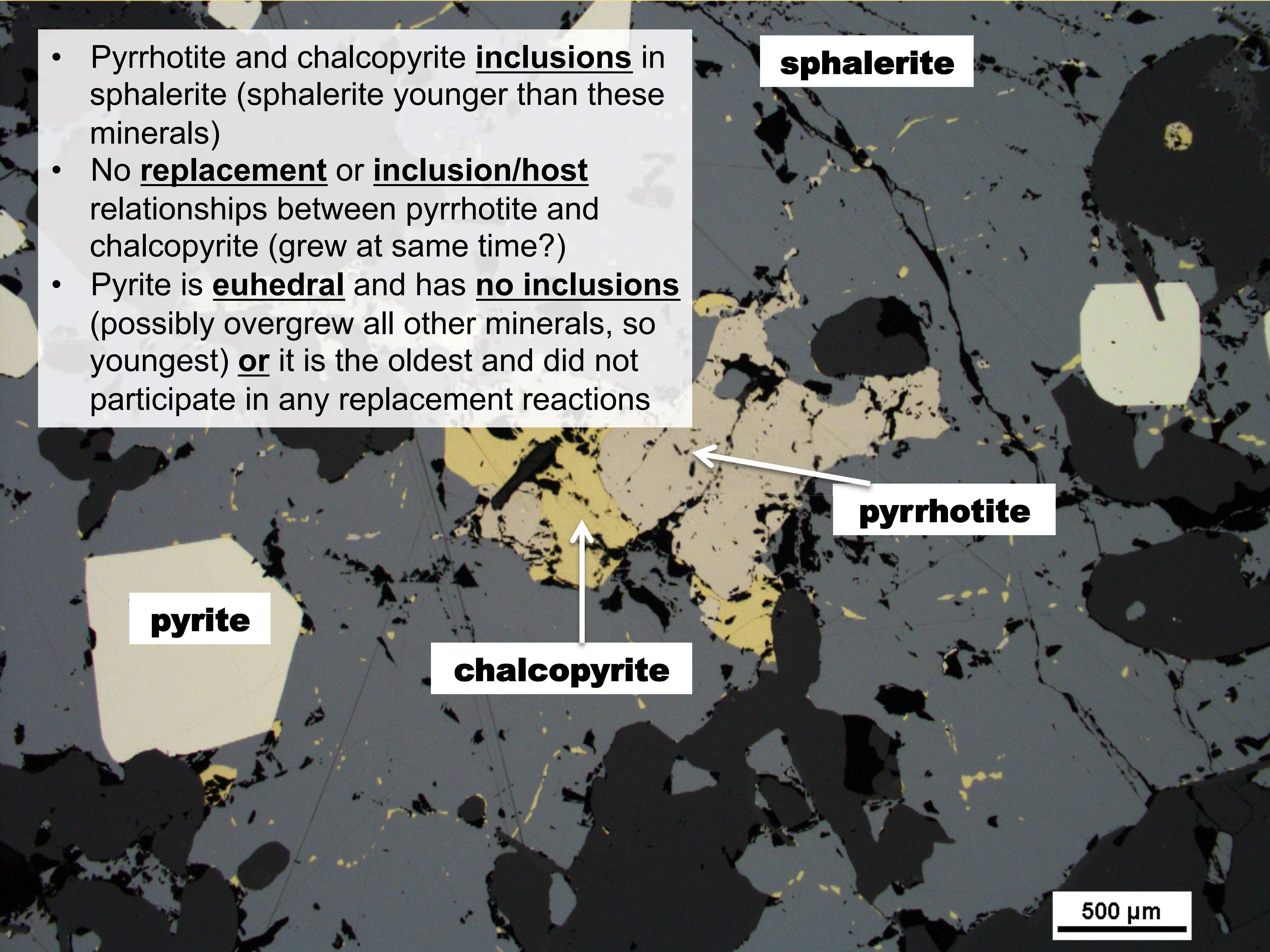
- **Inclusion/host relationships**
- **Replacement textures**
- Deformation textures
- Metamorphic textures

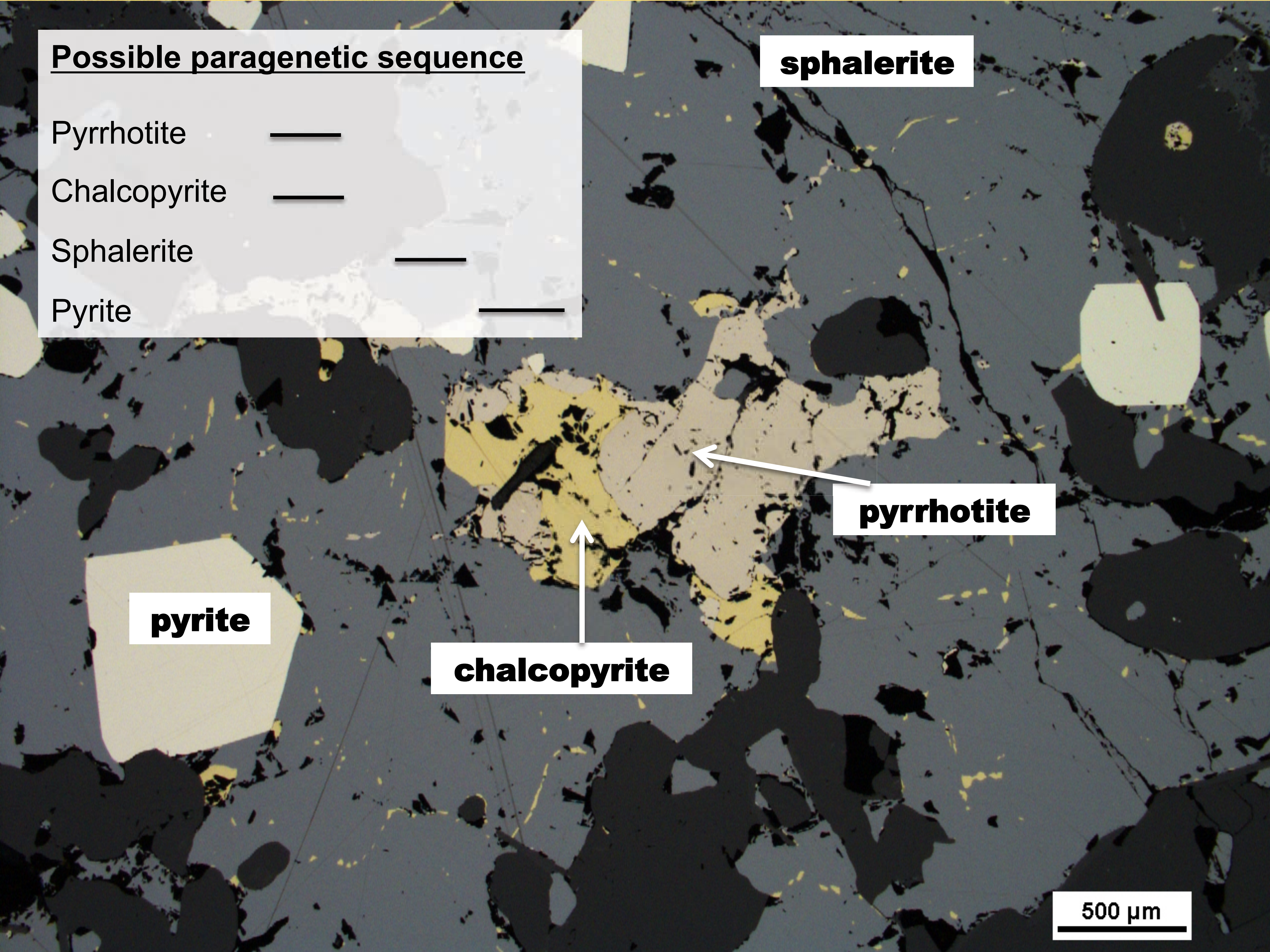


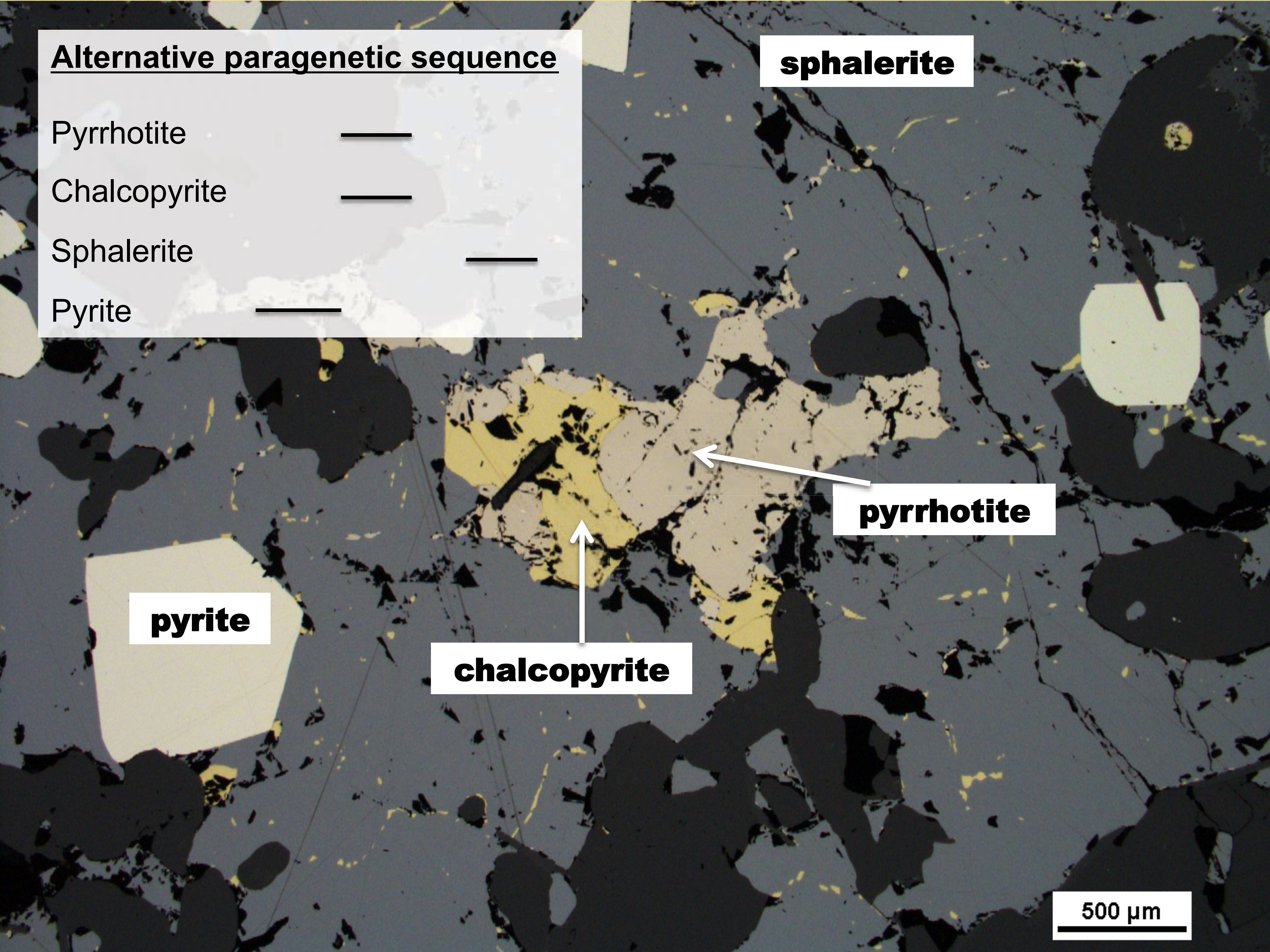
Guilbert & Park (1985)


sphalerite
pyrrhotite
pyrite
chalcopyrite
500 µm

- Pyrrhotite and chalcopyrite **inclusions** in sphalerite (sphalerite younger than these minerals)
- No **replacement** or **inclusion/host** relationships between pyrrhotite and chalcopyrite (grew at same time?)
- Pyrite is **euhedral** and has **no inclusions** (possibly overgrew all other minerals, so youngest) **or** it is the oldest and did not participate in any replacement reactions




Possible paragenetic sequence
Pyrrhotite
Chalcopyrite
Sphalerite
Pyrite
sphalerite
pyrrhotite
chalcopyrite
pyrite
500 µm


Alternative paragenetic sequence
Pyrrhotite
Chalcopyrite
Sphalerite
Pyrite
sphalerite
pyrrhotite
chalcopyrite
pyrite
500 µm

A list of important textures

Primary
Liquid: magmatic
Hydrothermal: Open-space deposition (Infill textures)

Secondary:
Replacement:
- Hydrothermal
- Weathering

Cooling:
- Recrystallisation
- Exsolution

Deformation:
- Twinning
- Kinking
- Pressure lamellae
- Breccia

Metamorphism
- Annealing and new growth

Sedimentary
- Rounding, scratching

Primary magmatic textures

Crystal grows from liquid:

- No obstruction to growth
- Euhedral or subhedral grains

Refractory minerals will retain magmatic textures:

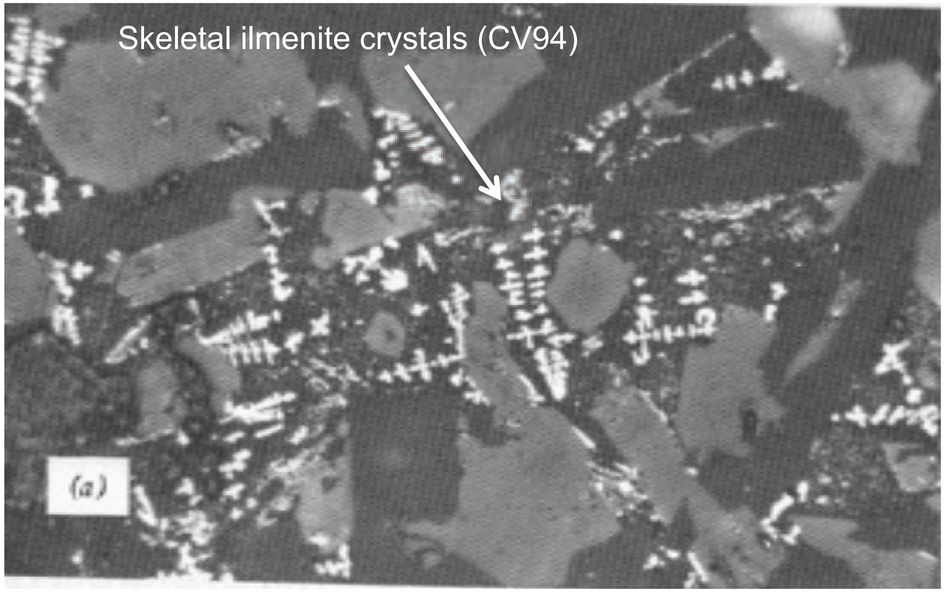
- Chromite, magnetite, ilmenite

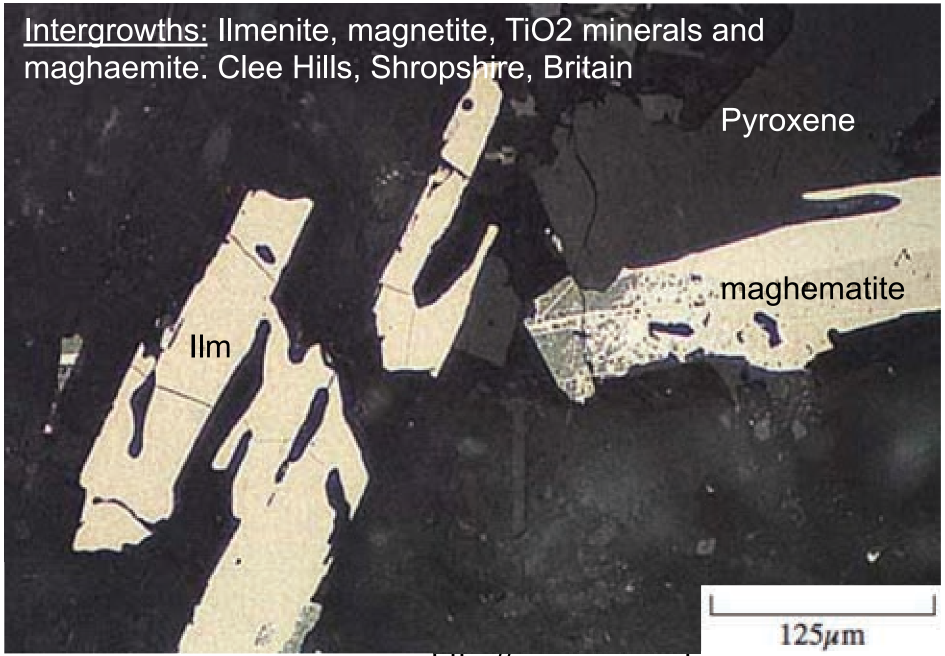
Rapid cooling:

- Skeletal crystals, droplets

Slow cooling:

- Poikilitic, intergrowths





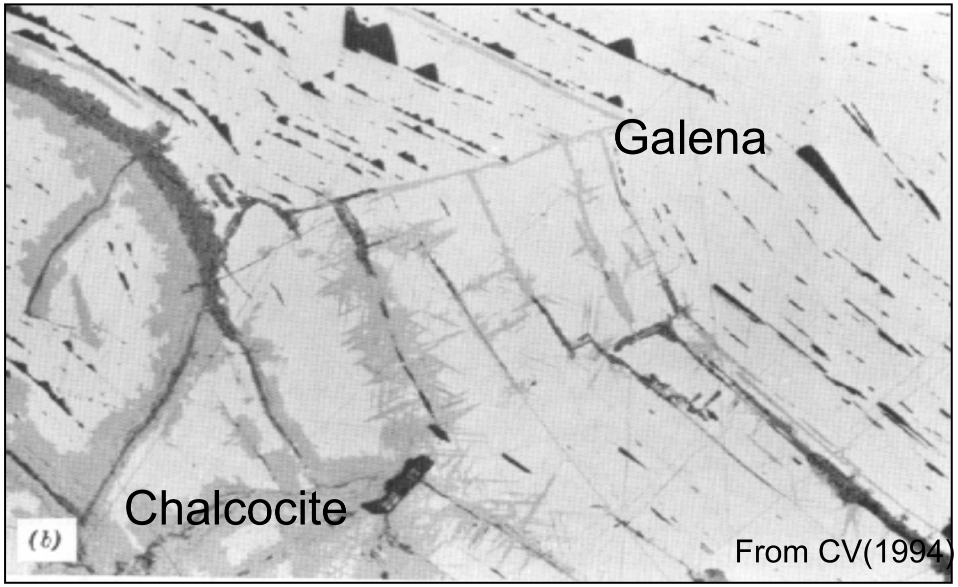
http://www.smenet.org/opaque-ore/

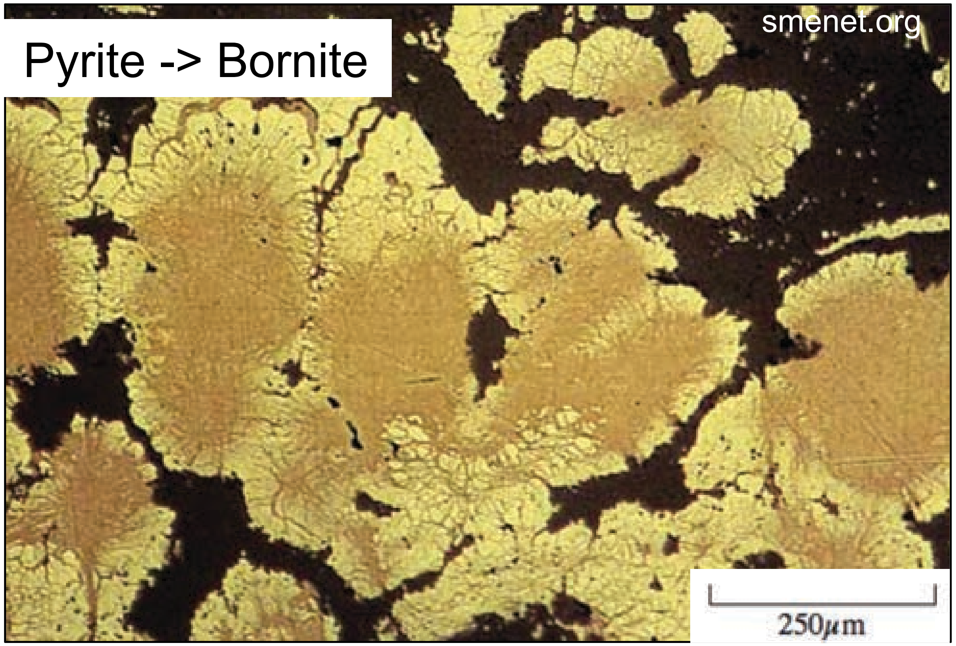
Secondary – Replacement textures

Replacement processes:

1. Dissolution and reprecipitation
2. Oxidation
3. Solid state diffusion

Complete replacement is called pseudomorphing





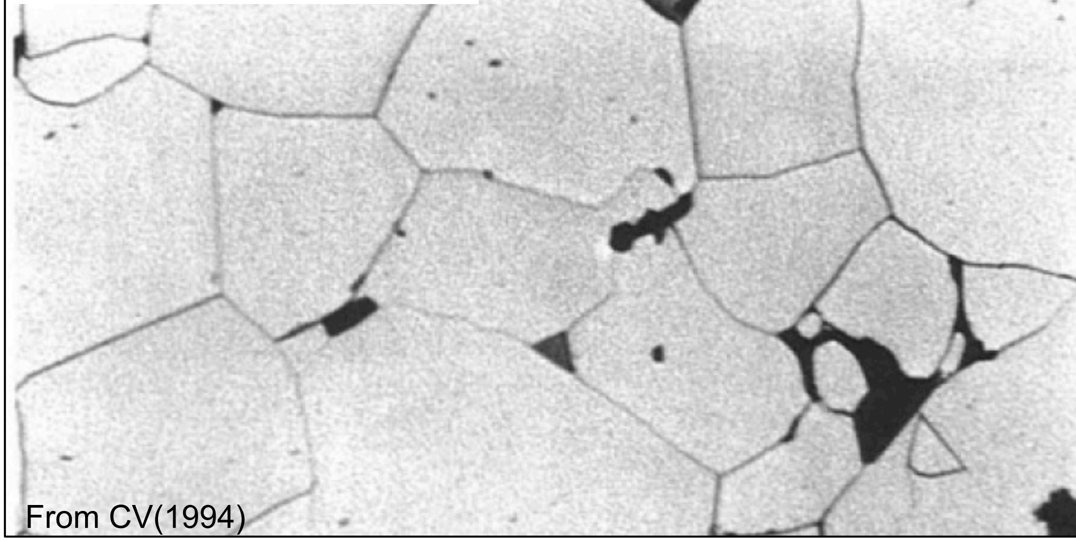
Secondary – Cooling textures

Some mineral deposits form at high T and cooling causes the minerals to reequilibrate at lower T:

Recrystallization: Grain boundaries migrate to minimize surface energy

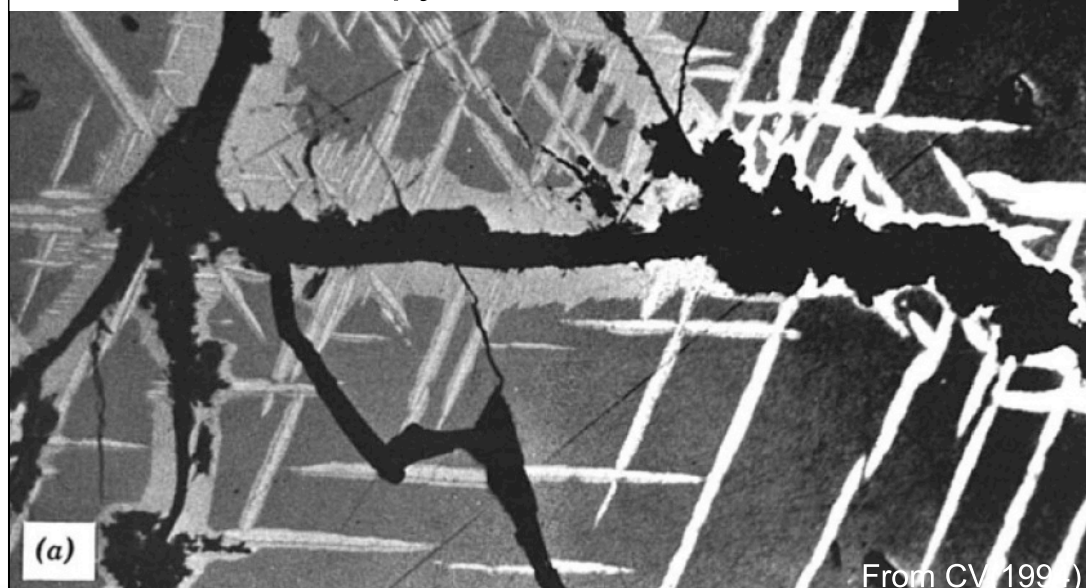
Exsolution: Separation of a solid solution into multiple phases (often the exsolved phase follows crystallographic planes)

Recrystallized pyrite



From CV(1994)

Bornite -> chalcopyrite exsolution lamellae



From CV(1994)

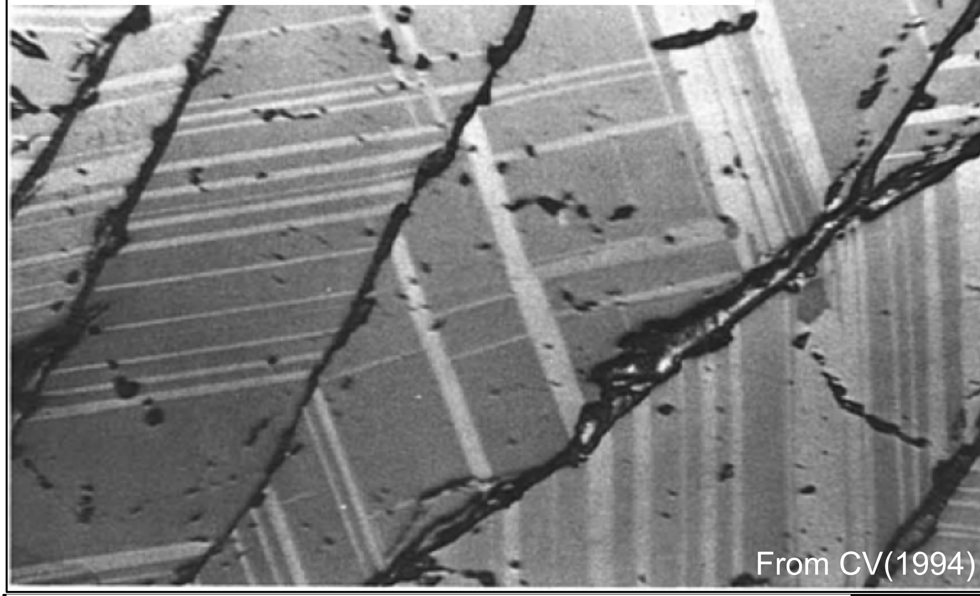
Secondary – Deformation textures

Some minerals will preserve deformation textures and some will not:

Deformation twinning:
- Think of it as local bending of the crystal structure
- Terminate in brittle fractures
- Lamellae of similar thickness

Pressure lamellae:
- "crumpled lamellae"
- Not necessarily parallel
- Still poorly understood

Deformation twinning in hematite



From CV(1994)

Complex pressure lamellae in stibnite

From CV(1994)

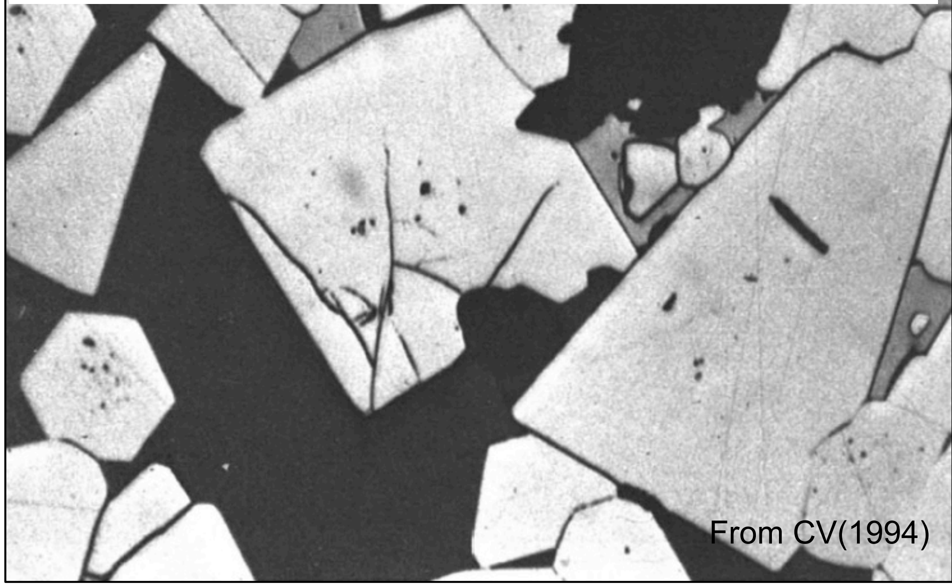
Secondary – Metamorphic textures

Metamorphism generally leads to an increase in grain size through:

- Annealing
- Crystal growth (producing porphyroblasts)

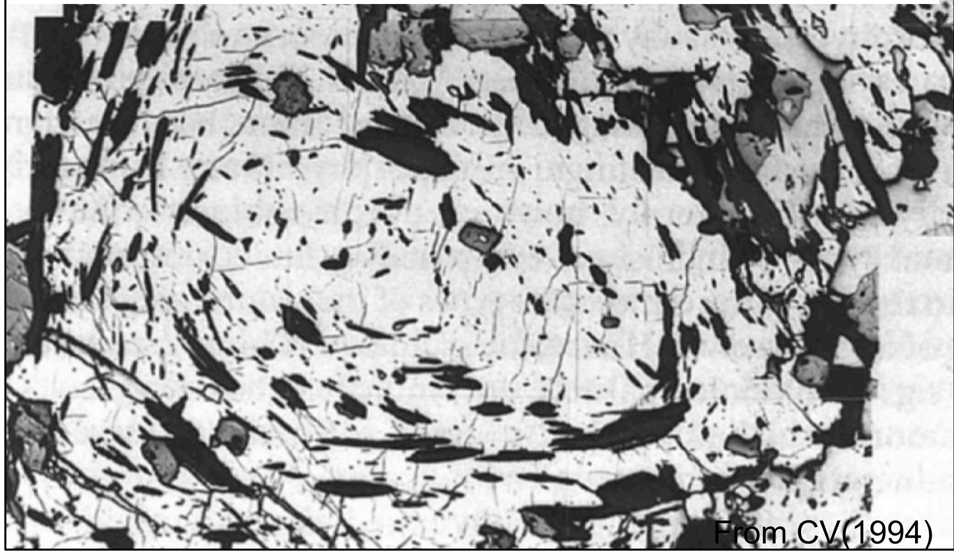
Annealing vs growth rate will influence if primary textures are preserved

Annealed pyrite within sphalerite and chalcopyrite



From CV(1994)

Pyrite porphyroblast with amphibole inclusion trail



From CV(1994)

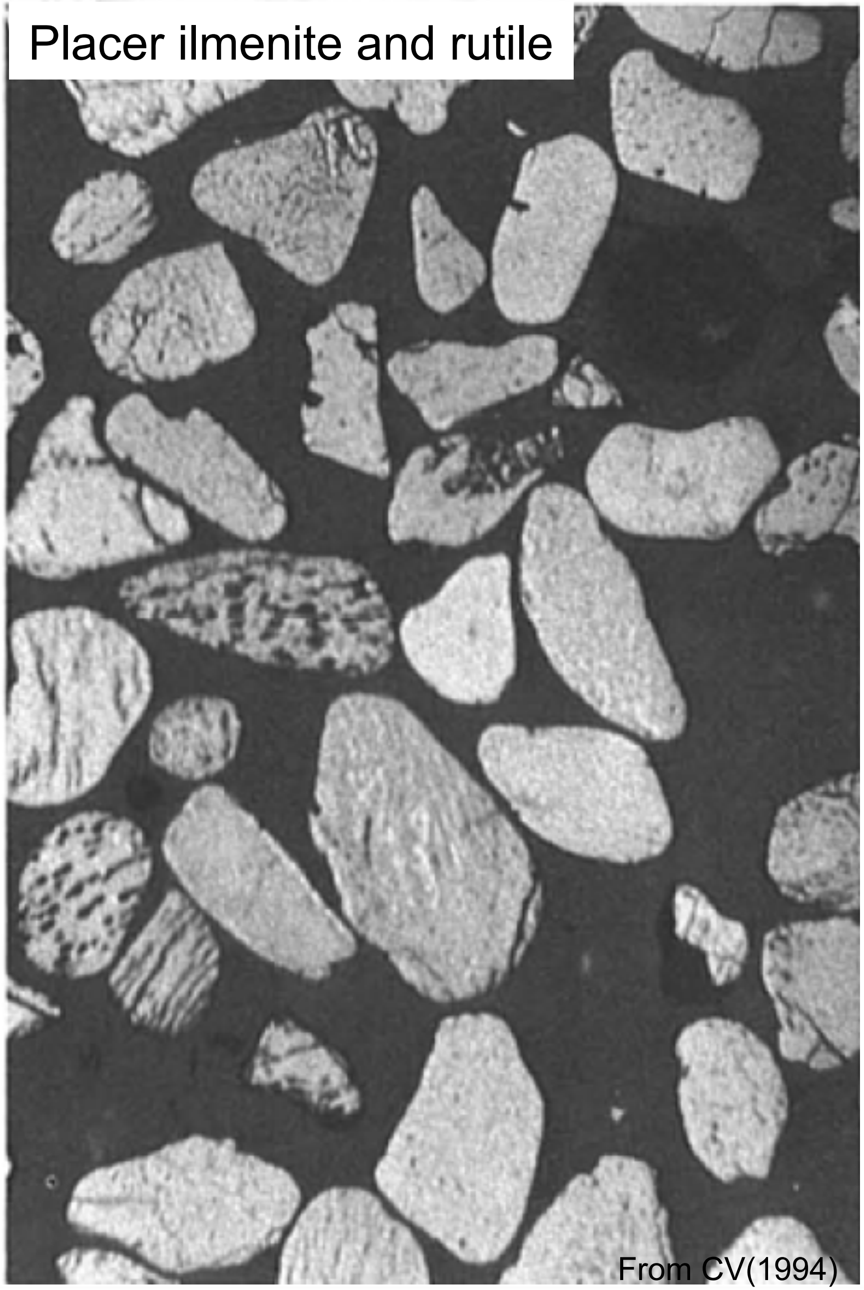
Secondary – sedimentary textures

Placer deposits contain detrital grains of ore minerals that are the products of weathering

Detrital grains :

- Have internal textures that reflect their origins
- Have external textures that reflect the weathering process
- Oxidation is common (except in some Archean deposits)
- Commonly rounded in shape

Placer ilmenite and rutile



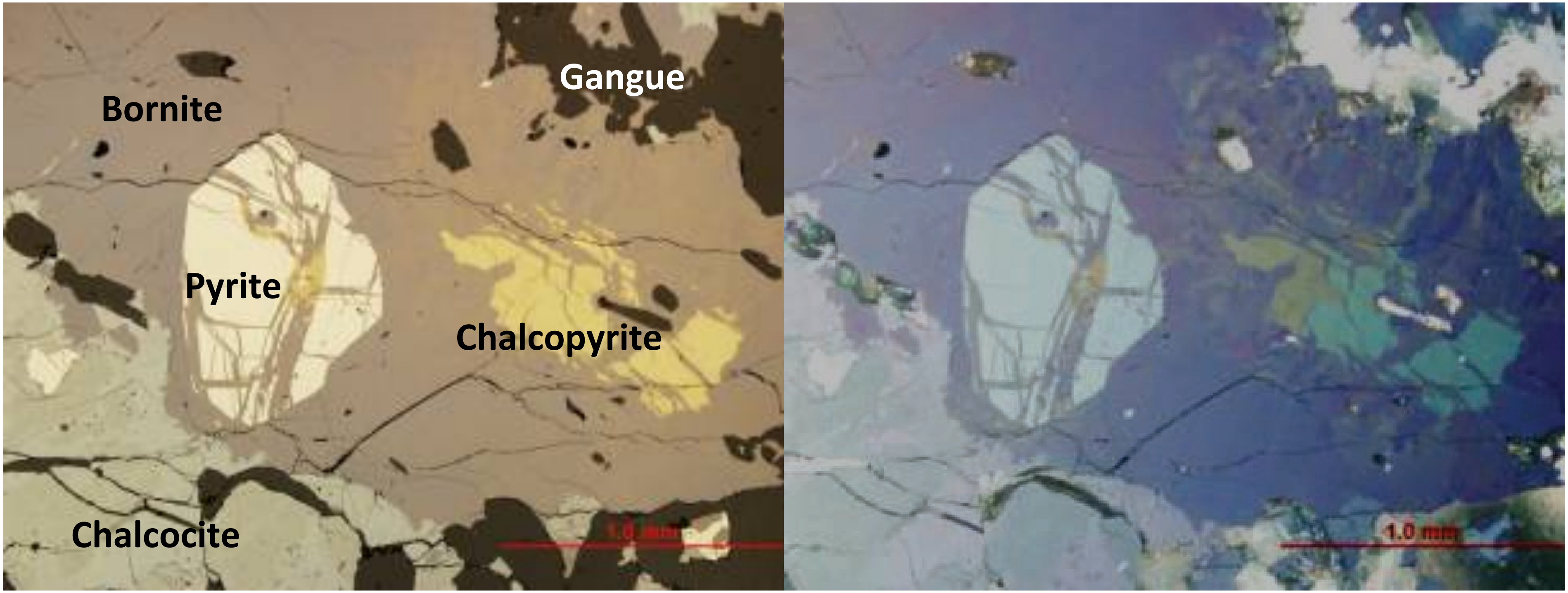
From CV(1994)

Ore minerals under the microscope

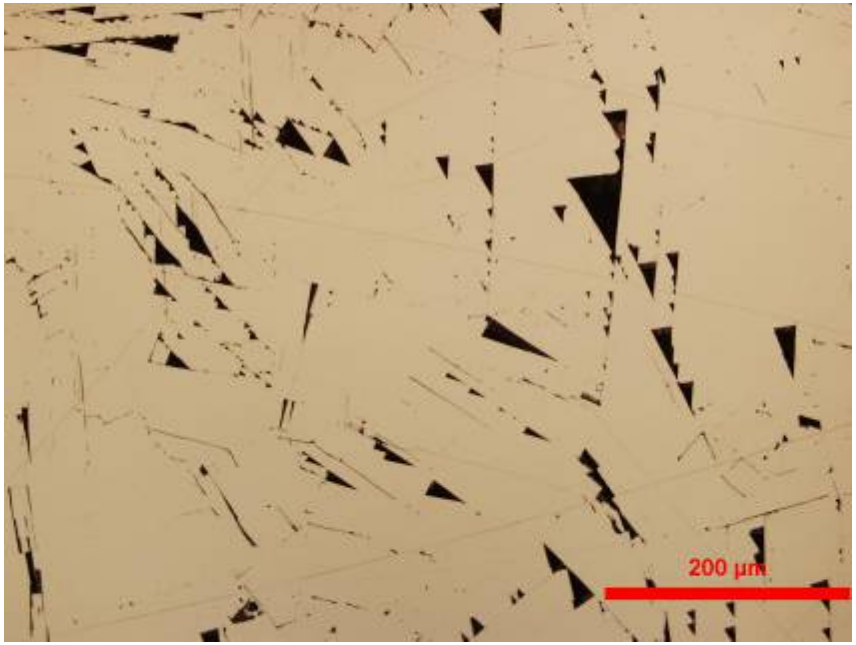
(photos from Y. Kettannah)

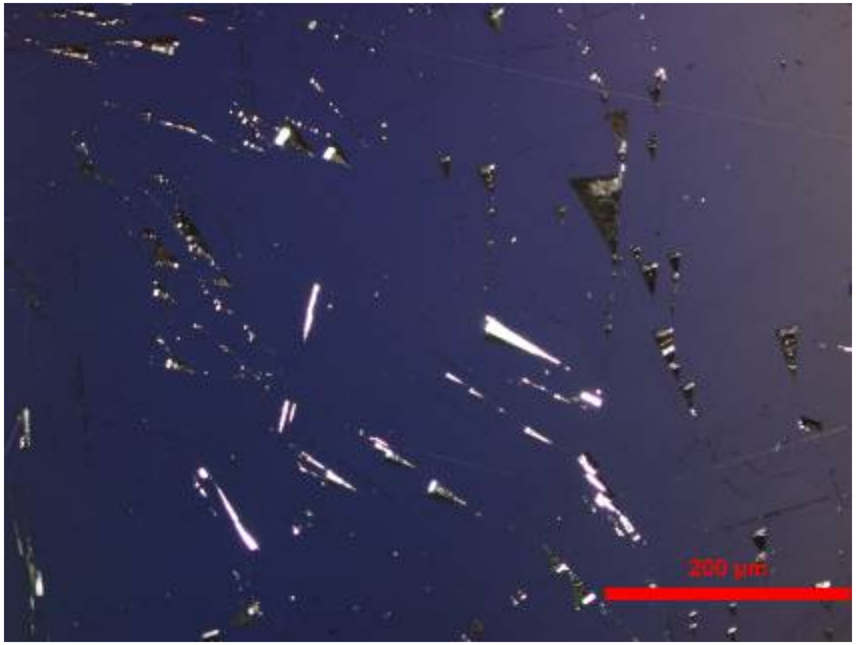
Bornite (Cu_5FeS_4)
Chalcopyrite ($CuFeS_2$)
Chalcocite (Cu_2S)
Pyrite (FeS_2)

PPL **Cross polarization**

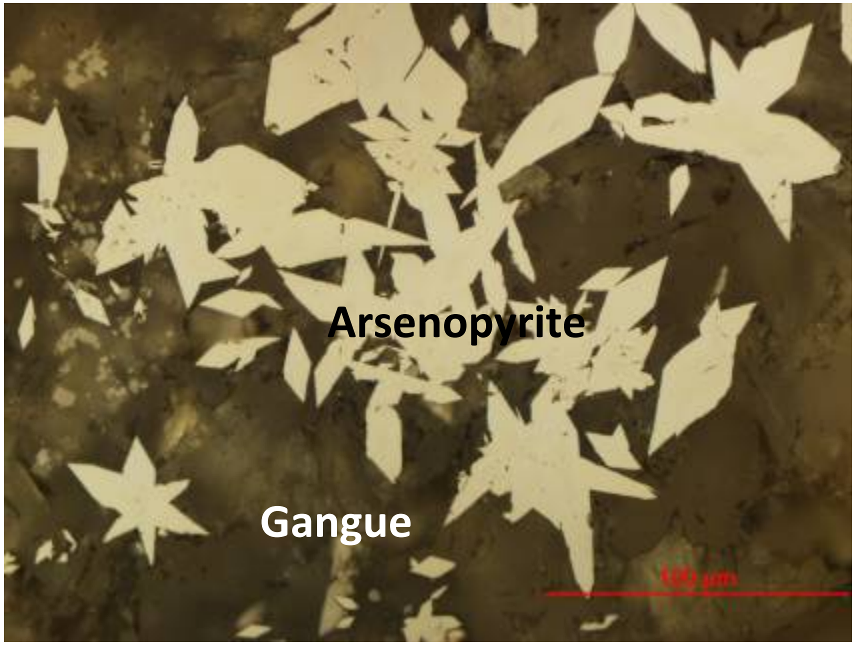


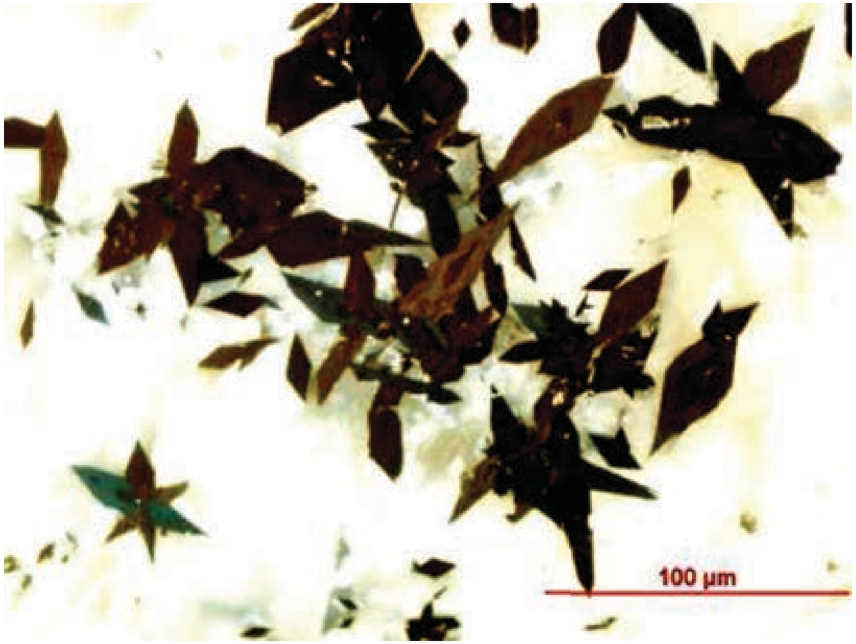
Galena (PbS)
(Showing triangular pits)



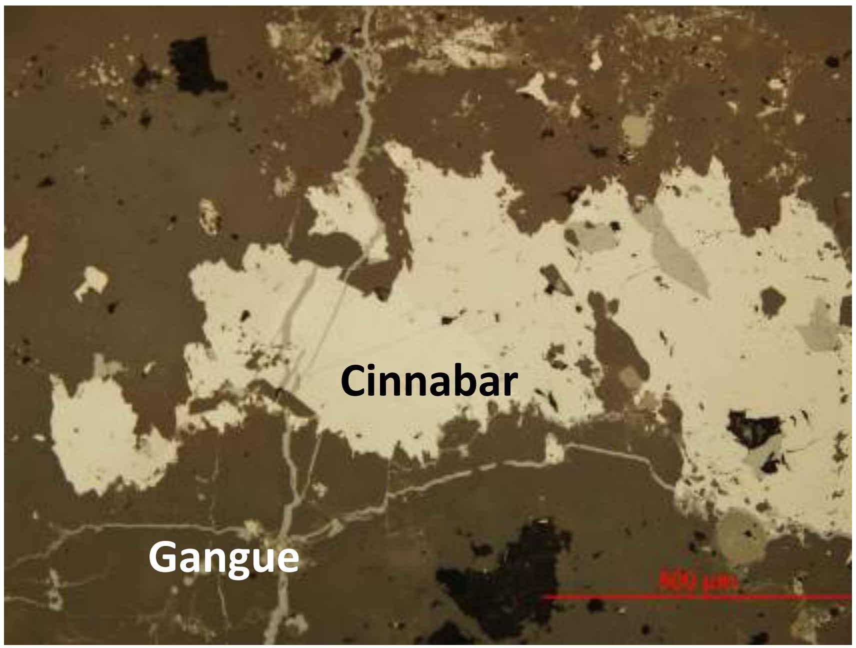


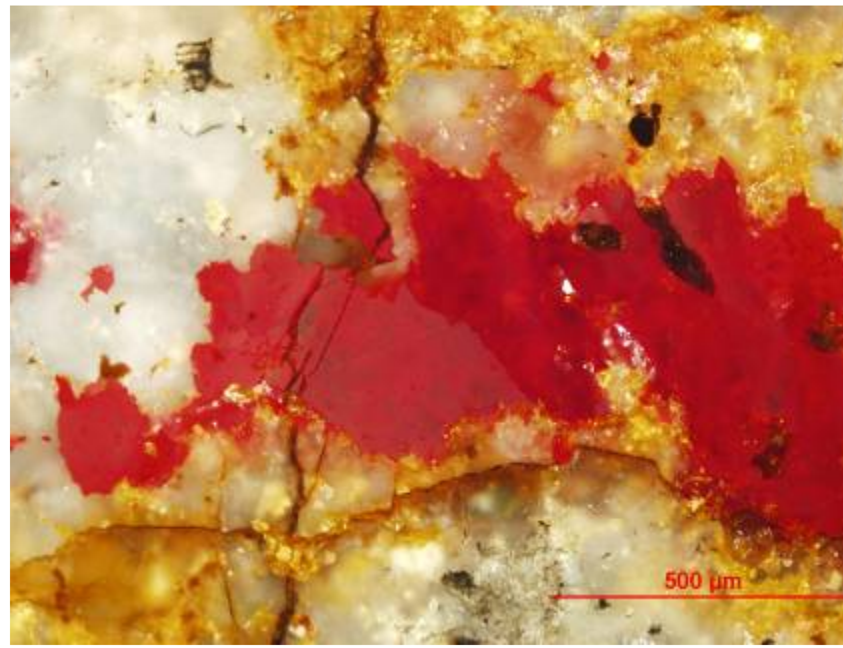
Arsenopyrite (FeAsS)



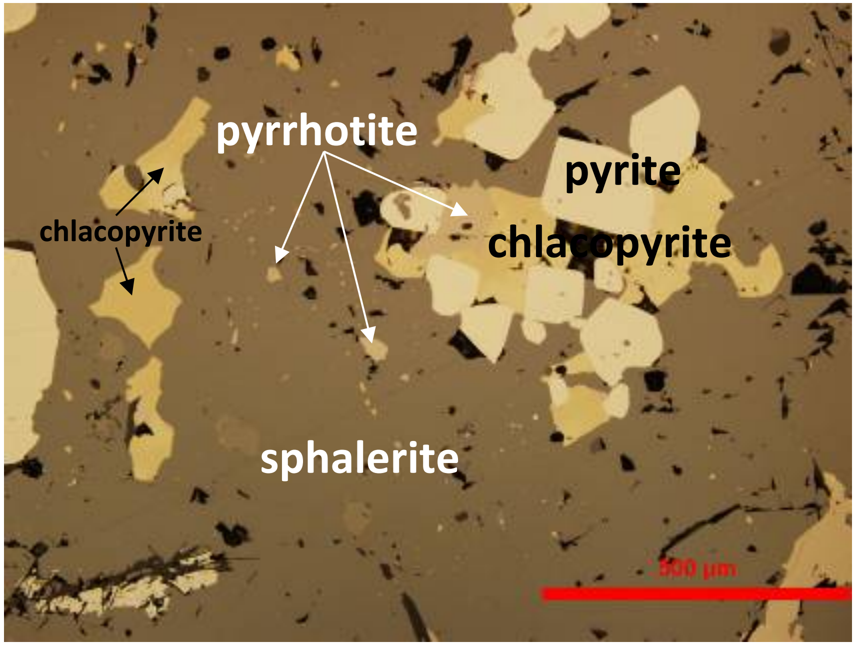


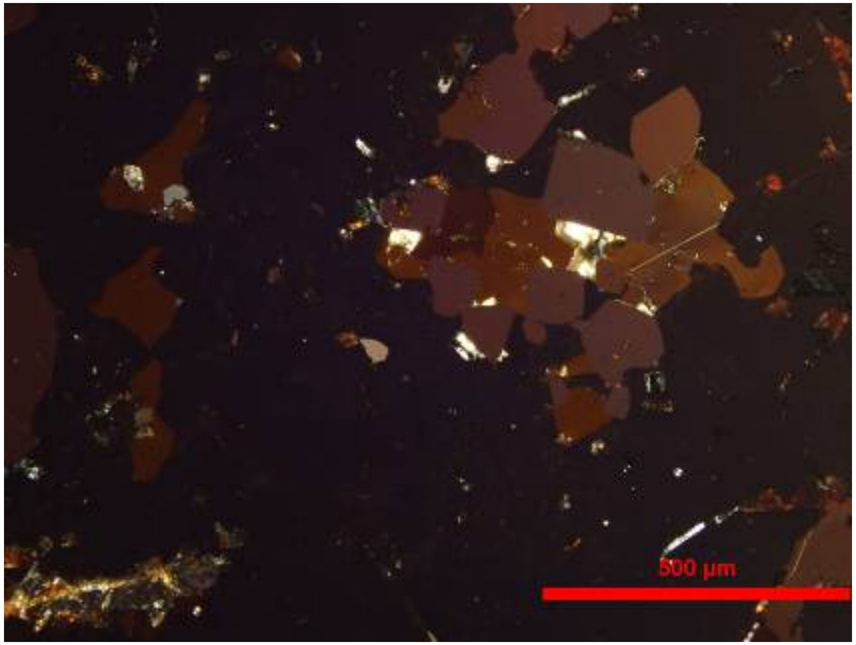
Cinnabar (HgS)



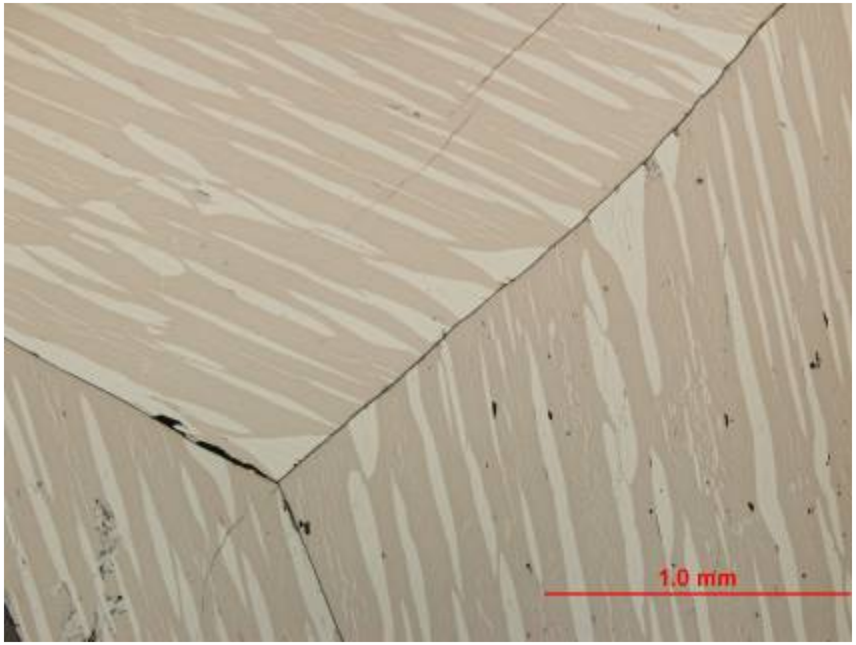


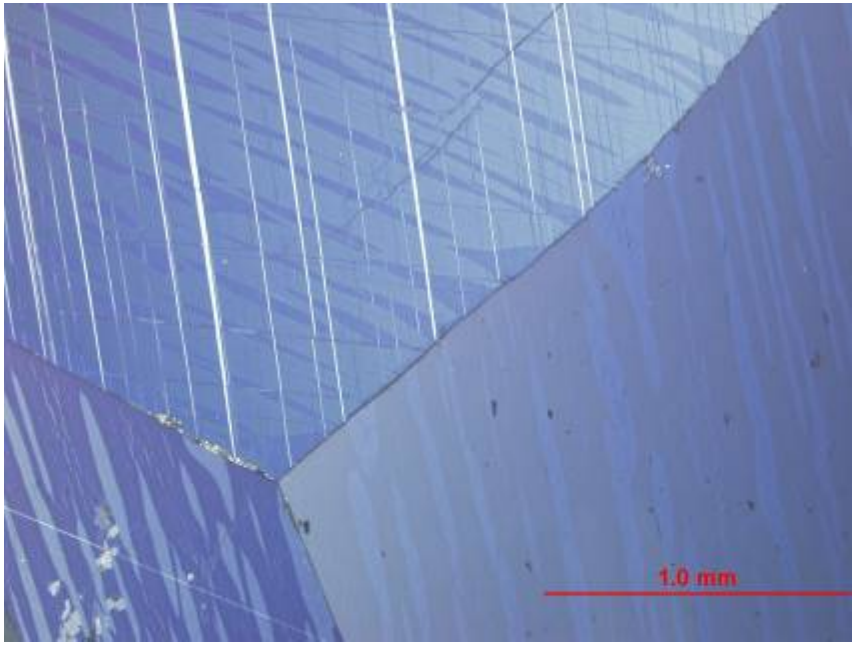
Sphalerite(ZnS)
Pyrrhotite ($Fe_{1-x}S$)
Pyrite (FeS_2)
Chalcopyrite ($CuFeS_2$)



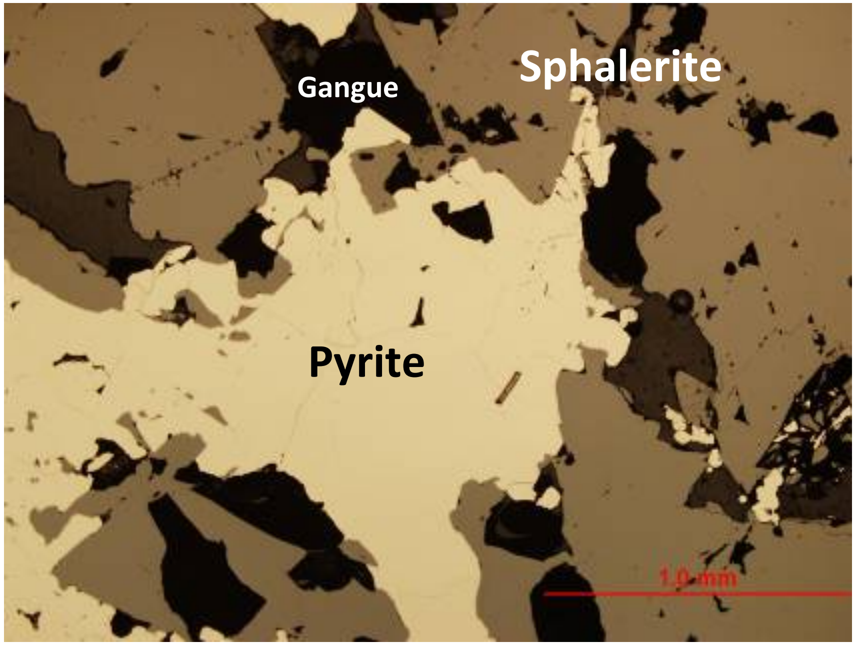


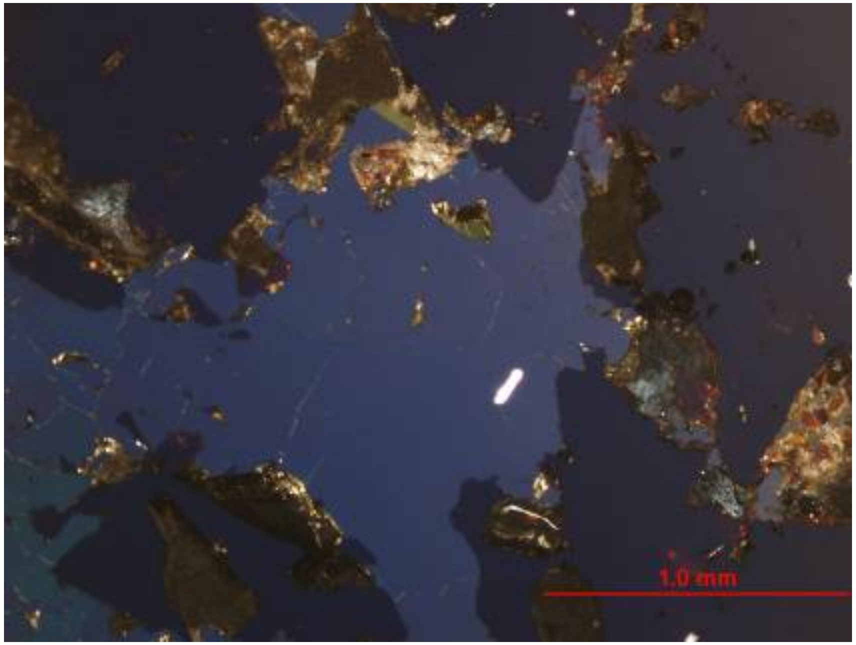
Ilmenite ($FeTiO_3$)



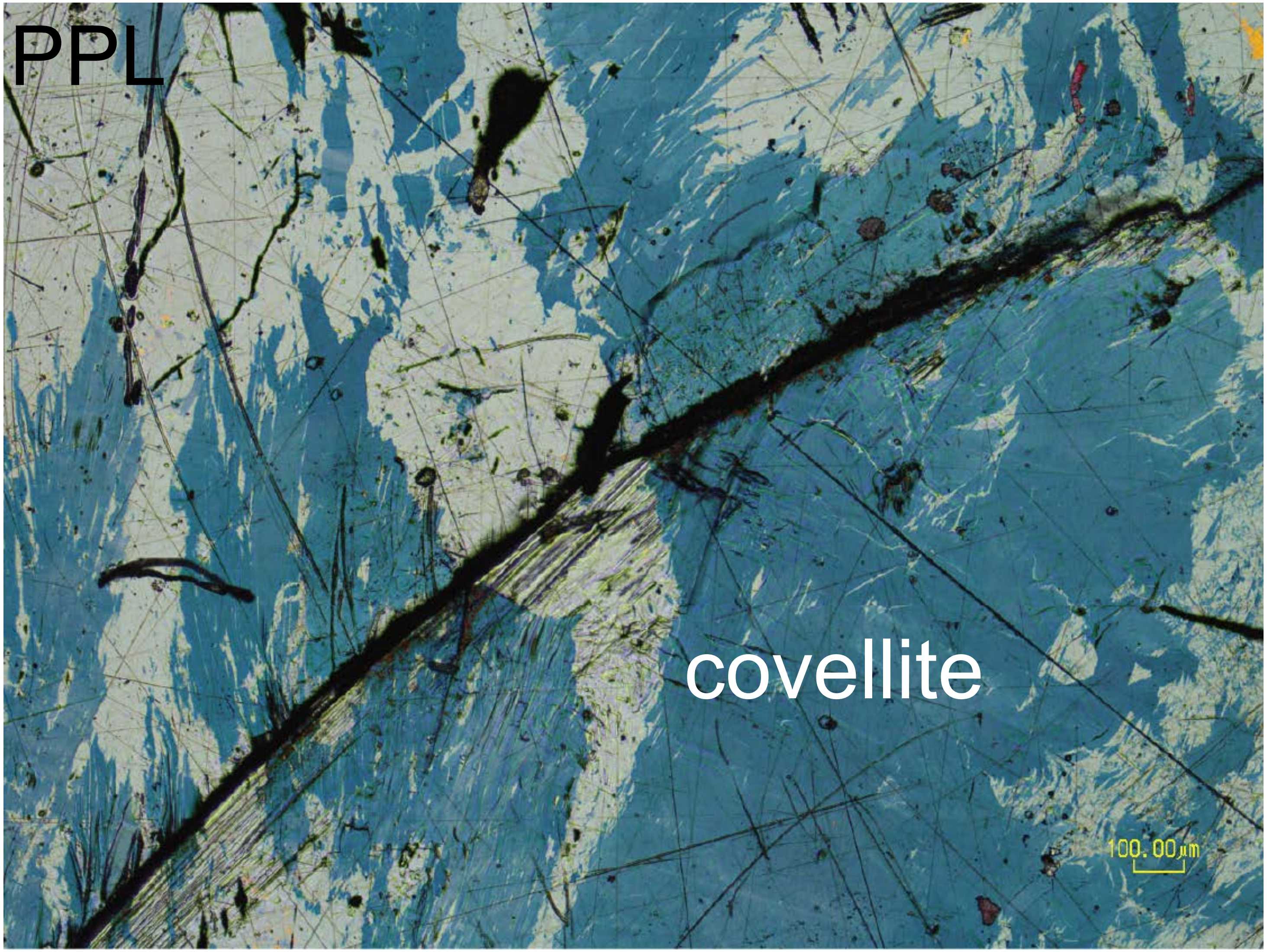


Pyrite (FeS_2)
Sphalerite (ZnS)

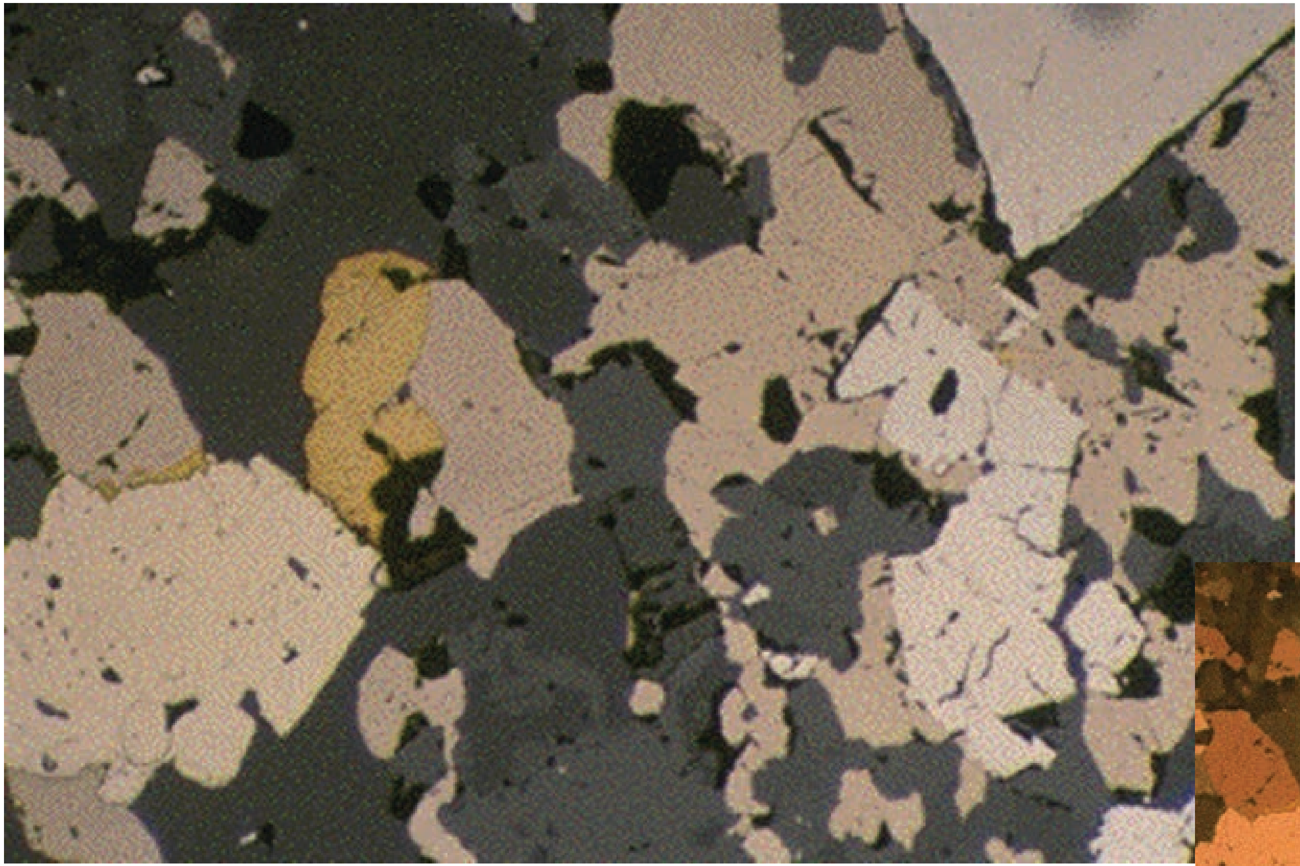


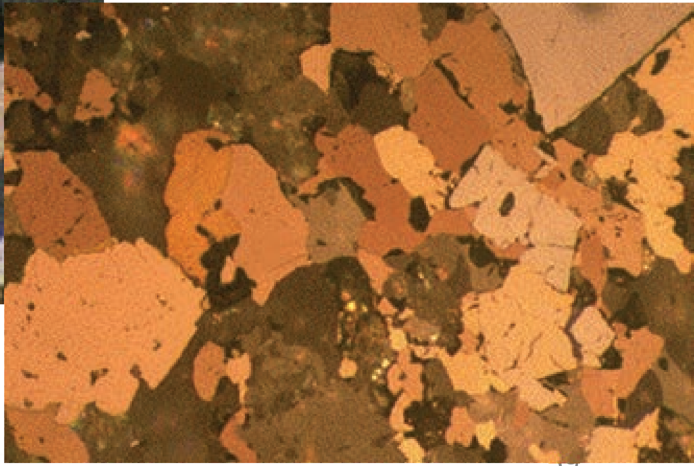


Covellite – CuS



Pyrrhotite ($Fe_{1-x}S$)
Pyrite (FeS_2)
Chalcopyrite ($CuFeS_2$)



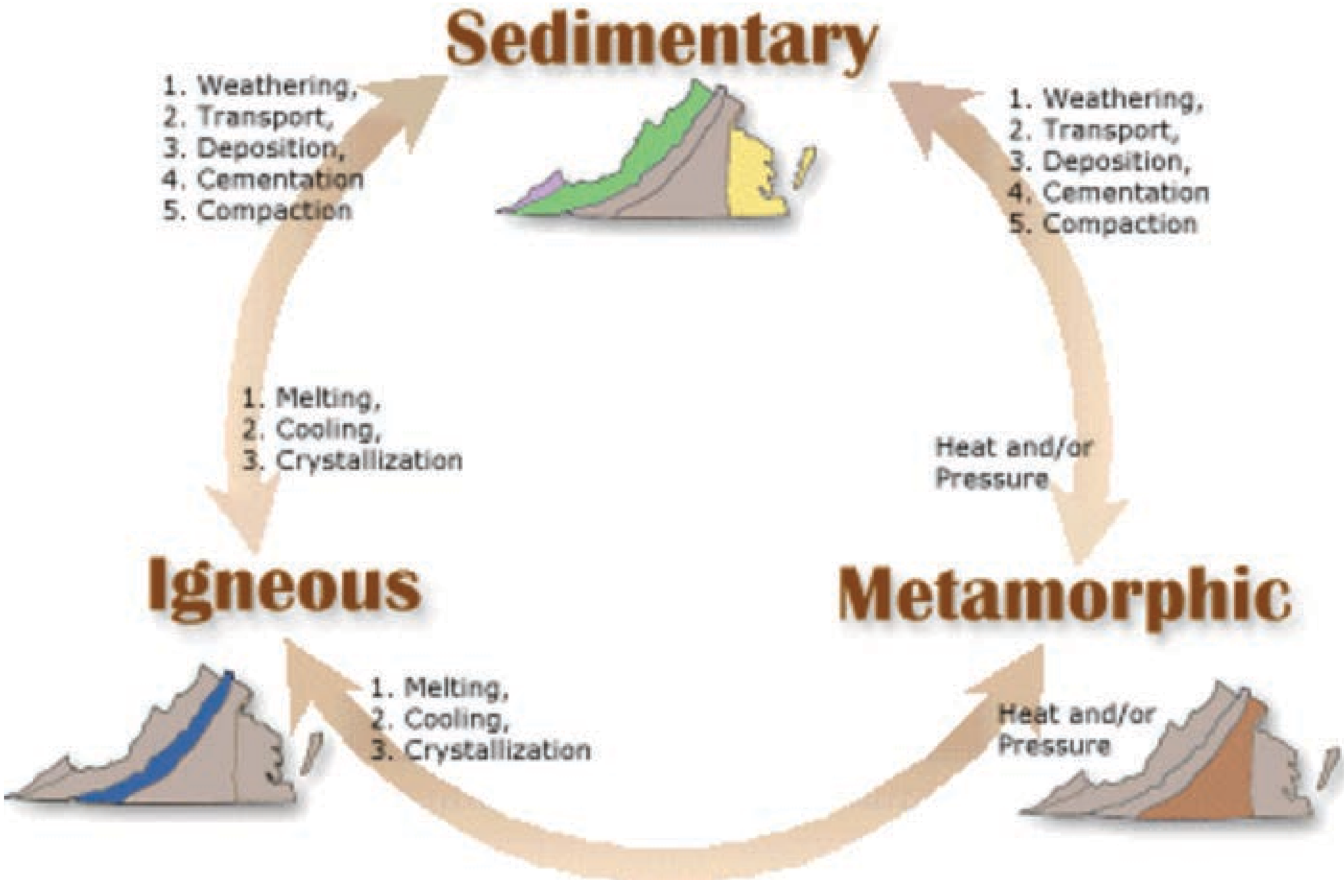


http://www.geo.arizona.edu/geo3xx/geo306_mdbarton

Hydrothermal Alteration

(an introduction)

Hydrothermal rocks – where do they fit?

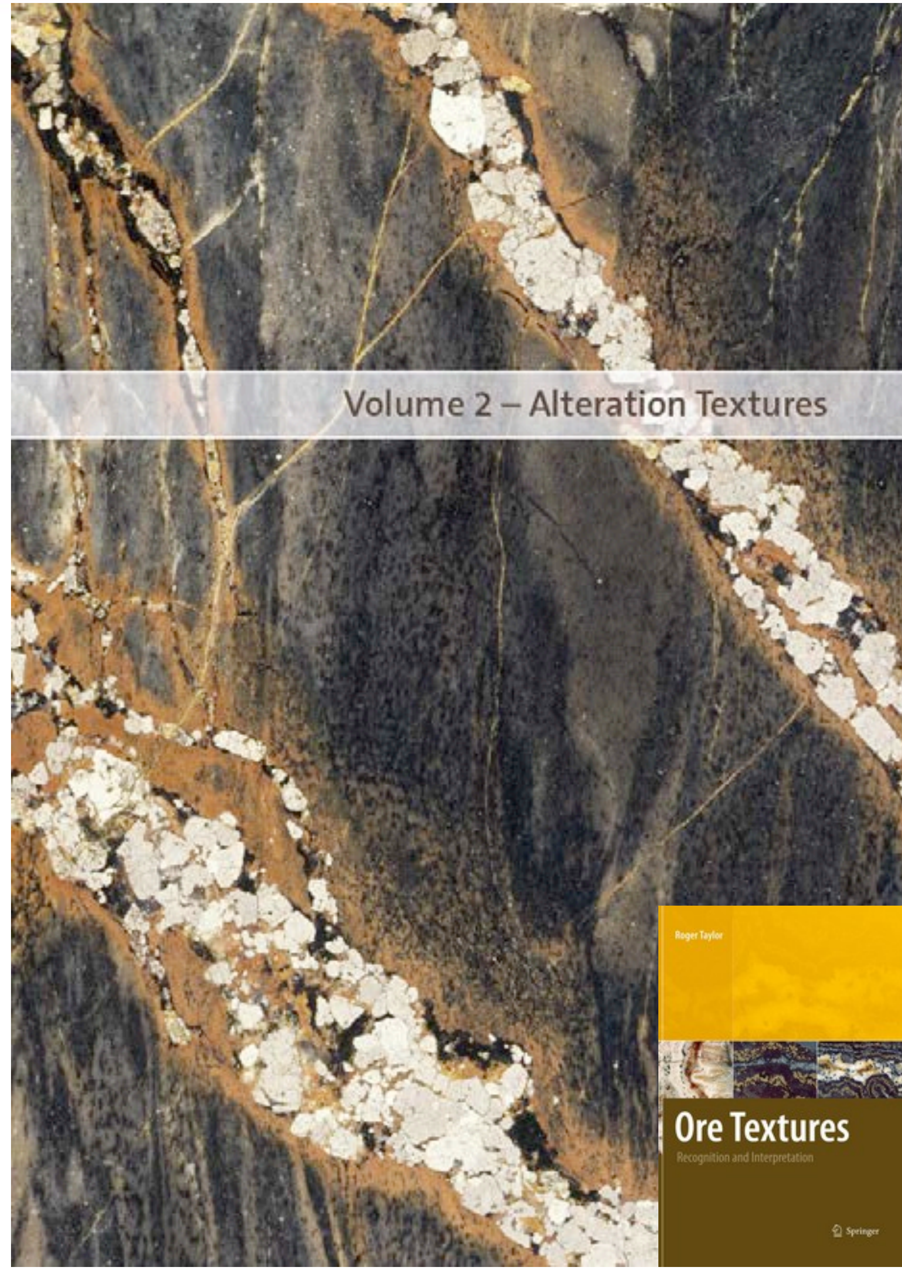


http://web.wm.edu/geology/virginia/provinces/rockcycle.html

Alteration: a change in mineralogy or chemistry of rock resulting from chemical interactions with <u>hydrothermal fluids</u>.

<u>VERY IMPORTANT</u> in mineral exploration since hydrothermal fluids often carry and deposit the elements of economic interest.

Hydrothermal alteration zones commonly surround ore bodies but NOT ALWAYS.

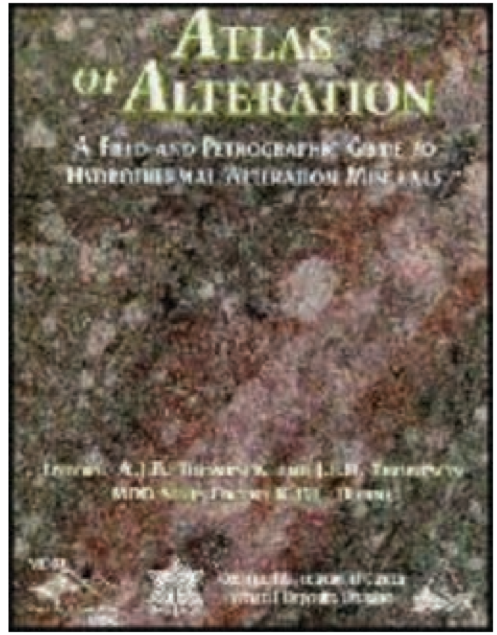


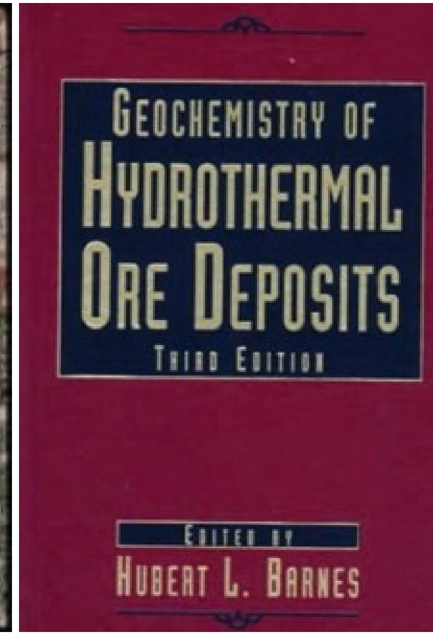
Alteration is a HUGE subject.

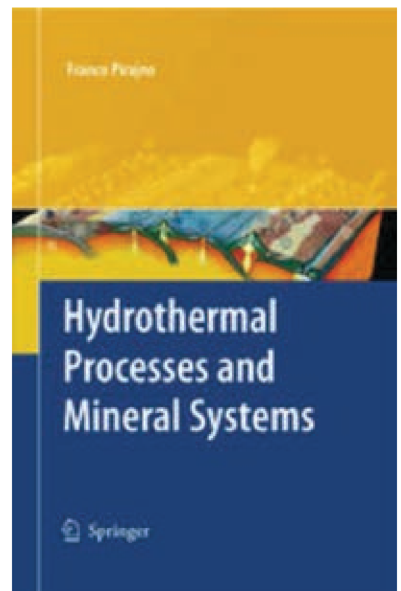
There are many textbooks written solely on the subject of hydrothermal processes and alteration.

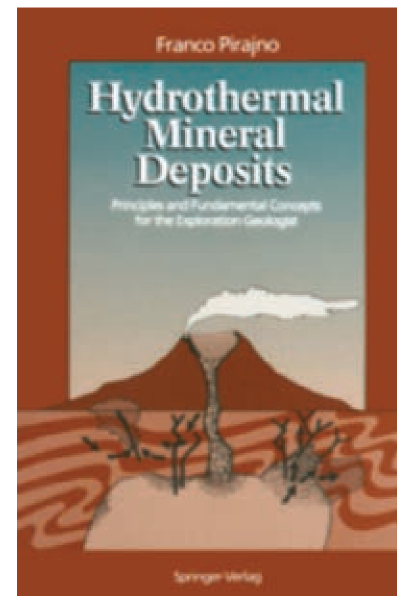
Today, we will take a brief look at the minerals associated with alteration.

Later in the course, we will discuss hydrothermal processes in more detail.









Hydrothermal alteration:

- Common around ore bodies
- Zoning is common
- May appear simple (colour change) or more complex (chemical changes)
- May be mm or km scale
- May be observed in some rock types and not others

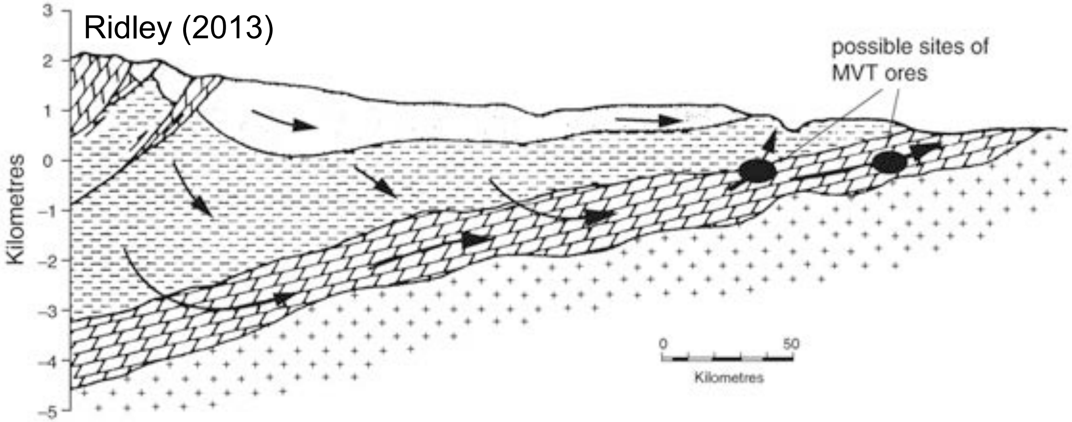
Twin peaks gold deposit, WA, Australia

calcite + chlorite	dolomite + chlorite + sericite	dolomite + sericite
No bleaching	Some bleaching	complete bleaching

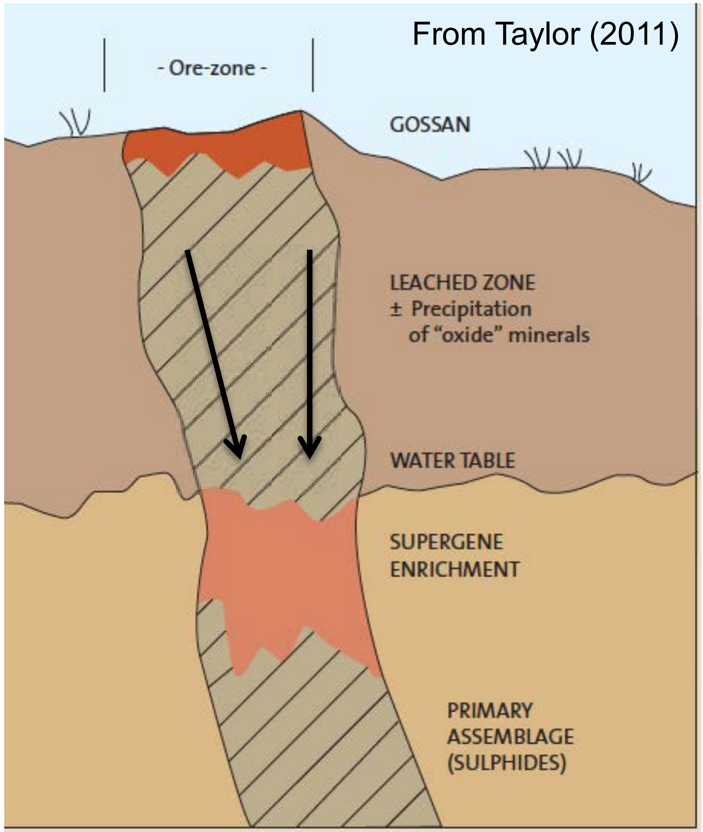
Alteration increasing →

Hydrothermal alteration:

Hypogene: caused by ascending hydrothermal fluids



Supergene: caused by descending hydrothermal fluids (we will return to this later in the course)



Alteration as an exploration tool – surface processes

<u>Gossan</u>: rusty-coloured alteration zone resulting from the breakdown of pyrite and other Fe-sulphides to Fe-oxides/ hydroxides (such as limonite) at the surface

- a.k.a. "leeched capping" or "ironstone"
- Acid waters can kill vegetation
- Obvious candidates for further exploration

Alteration as an exploration tool – subsurface processes

Hydrothermal fluids require conduits for focussing and transportation.

The fluids interact with wall rock around these conduits, resulting in hydrothermal alteration

There is a gradient from the alteration front to the source of the fluid.

From Taylor (2009)

Extent of alteration depends on:

Composition of the fluid(s)

- Ions in solution
- H_2O v. CO_2 rich
- Redox state (fO_2)
- pH
- P and T

Nature of the host rock

- Mineralogy and grain size
- Temperature
- Porosity and permeability

Fluid / rock ratio

- How much fluid
- Duration of interaction

From Taylor (2009)

Important alteration minerals:

Sericite (fine grained white mica)
Chlorite
Epidote
Quartz
Feldspars (K-feldspar, plagioclase, adularia)
Tourmaline
Clays (kaolinite, montmorillonite)
Hematite
Magnetite
Sulphides
Topaz
Carbonates (calcite, siderite, dolomite, ankerite)

Sericite

$KAl_2(Al\ Si_3O_{10})(OH)_2$
Very fine grained white mica
Unable to see with a hand lens

Color (pale-buff greenish) and luster (silky) are characteristic but can vary...

Sericite after plagioclase

http://minerva.union.edu/hollochk/c_petrology/ig_minerals/sericite1-X-100x.JPG

Commonly produced through the break down of feldspars:
Kfs + H_2O = Sericite + Qtz
Plag+ H_2O + K^+ = Sericite + Qtz + Ca^{2+}

Easy to recognize under the microscope

Chlorite

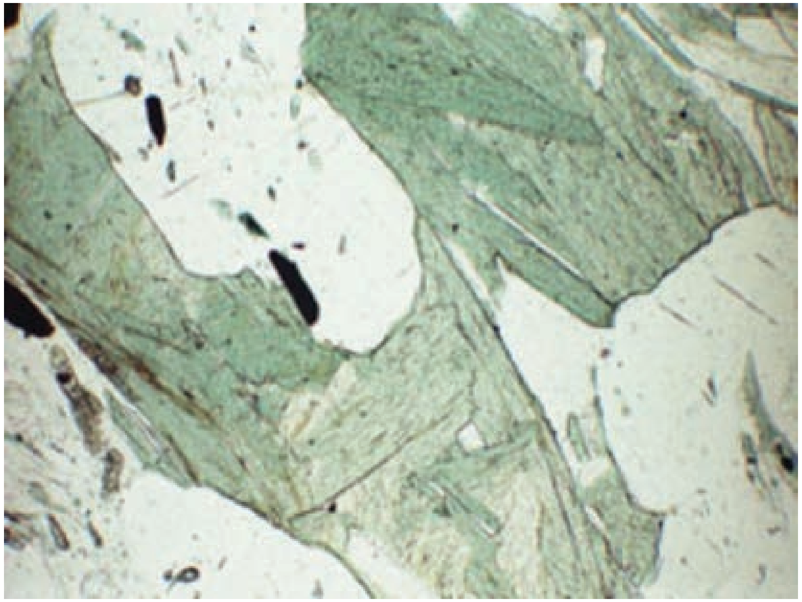
$(Mg, Fe^{2+}, Fe^{3+})_6 Al Si_3O_{10} (OH)_8$

Very Common

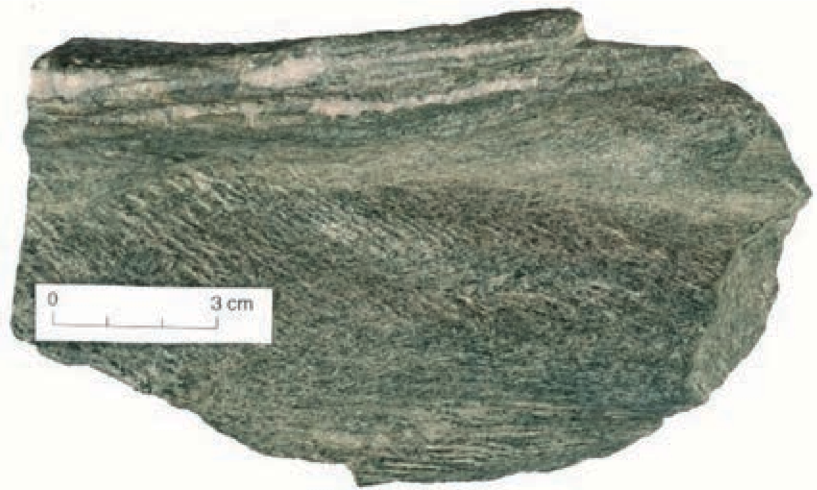
Deep green colour

Hydration of mafic minerals like Amphiboles and Pyroxenes

Soft and green powder when scratched



http://web2.ges.gla.ac.uk/~minerals/Images/Chlorite1.jpg



http://www.earth.ox.ac.uk/~oesis/rocks/met2.html

Epidote

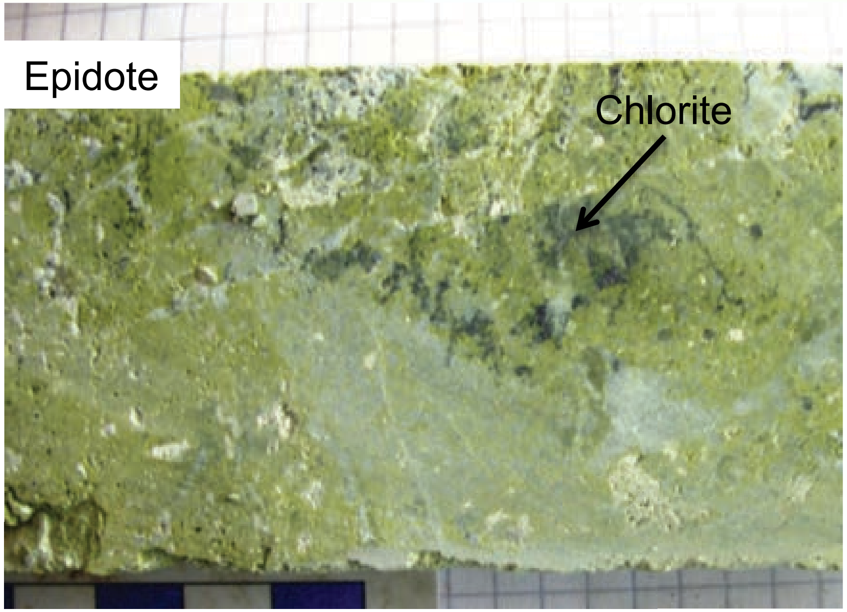
$Ca_2 (Al\ Fe)_3\ Si_3\ O_{12}\ (OH)$

Common

Characteristic 'pistachio' green color

Replaces plagioclase

Commonly associated with chlorite



http://pasinex.com/wp-content/uploads/2012/11/Fig-8 TGSJ18_90.50_cc_epidote.jpg

http://americanpistachios.co.uk/sites/uk/files/APG-Pistachio_Close_Up.jpg

Quartz

SiO_2
Very common
Easily dissolve in fluids -> quartz veins

K-feldspar

$KAlSi_3O_8$
Common
White to pink
High T alteration by K-rich fluids

Albite

$NaAlSi_3O_8$
Very common
Milky/creamy coloured
Sodic fluid

From Taylor (2009)

Tourmaline

Na $Fe^{3+}{}_3 Al_6 (Si_6O_{18})(BO_3)_3 (OH)_4$

From a Boron-bearing fluid

Associated with Quartz

Black with triangular sections

Associated with many tin and gold deposits

Quartz-tourmaline veins and tension gashes in a felsic dyke (6737526N, 2470868E)

http://minerva.union.edu/hollochk/c_petrology/fieldtrips/2002/pet-monadnock-2002-19.jpg

Clays

Kaolinite - $Al_2Si_2O_5(OH)_4$
Pyrophyllite - $Al_2\ Si_4O_{10}\ (OH)_2$

Common

Low-temperature

Alteration or Weathering?

- Alteration is penetrative
- Weathering is at the surface

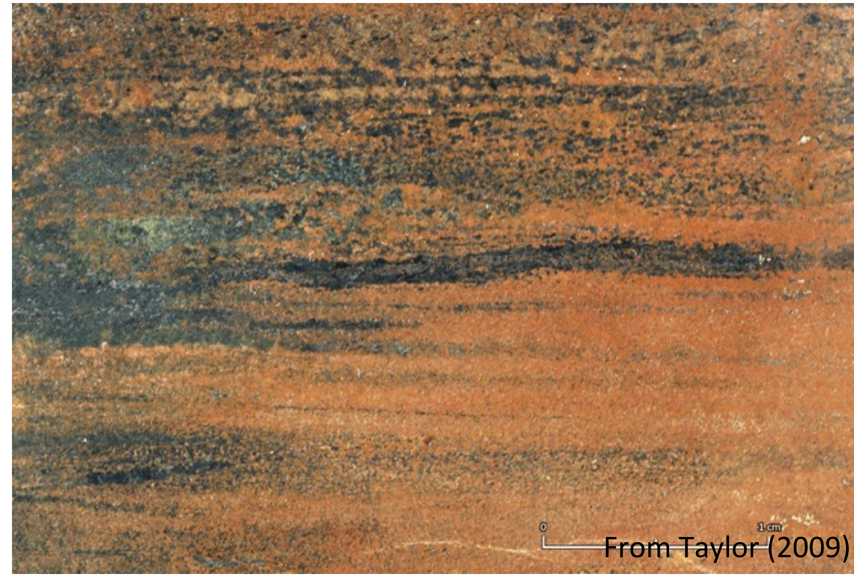
Hematite

Fe_2O_3

Very Common

High fO_2 (oxidizing conditions)

Red colour



Magnetite

Fe_3O_4

Common

Lower fO_2 than hematite

Magnetic!!!

http://www.mirasolresources.com/i/maps/Rubi/Corner_Zone_target-stockwork_of_quartz.jpg

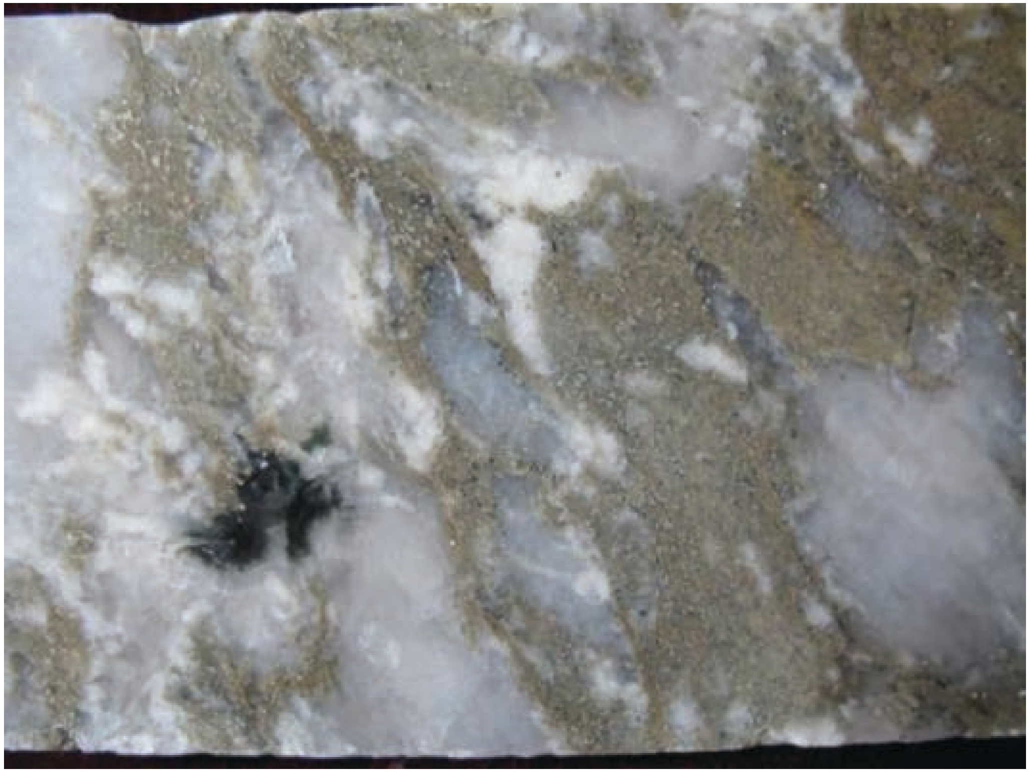
Carbonates

Calcite: $CaCO_3$
Ankerite: $Ca(Mg, Fe, Mn) (CO_3)_2$
Siderite: $FeCO_3$
Dolomite: $CaMg(CO_3)_2$

Very Common

CO_2-rich fluids

Ankerite is brownish



http://www.pcgold.ca/vm/newvisual/attachments/805/Media/IMG0085.jpg

Hydrothermal Alteration

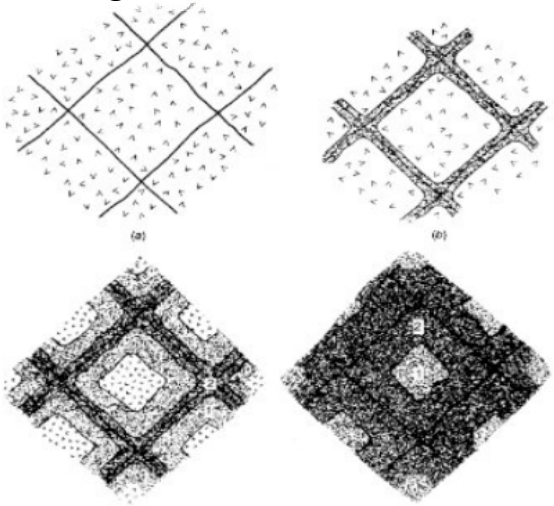
- Lots of jargon and loosely used terminology

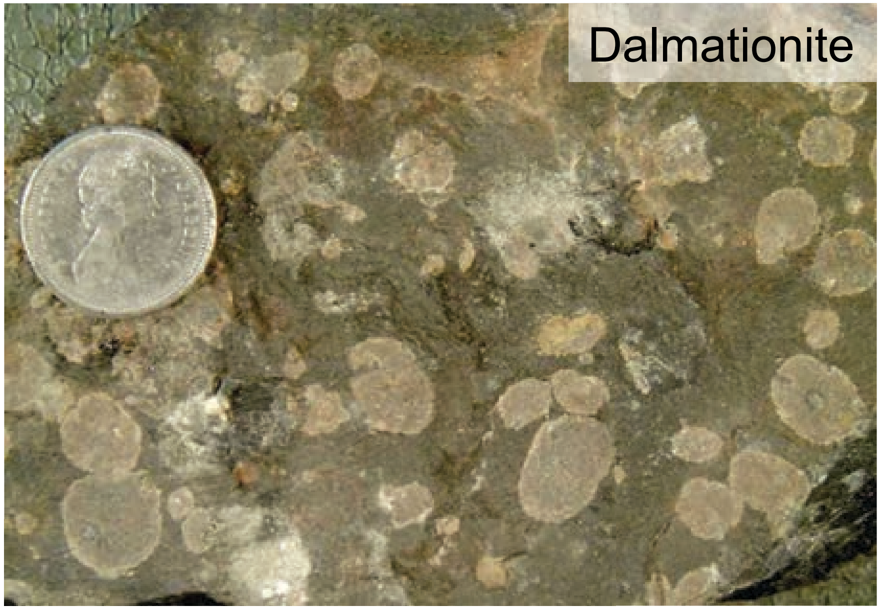
Alteration names:

- May be regional (dalmationite)
- Field terms
- May be named after minerals (albitic, sericitic)
- May be named after the important elements in solution (potassic, calcic)

Let's take a brief look at a few important types of alteration…

Progressive alteration





http://instruct.uwo.ca/earth-sci/200a-001/archprotorig/dscf0243.jpg

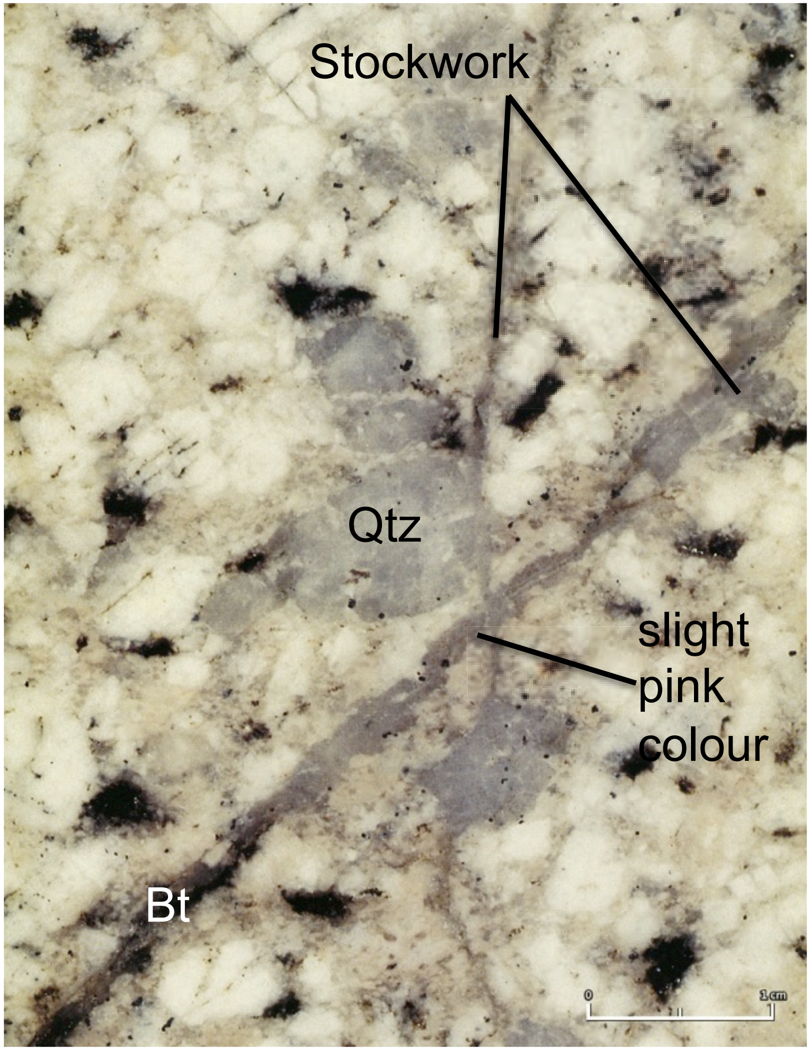
Potassic alteration

- 450–600°C
- Fluid with high K^+/H^+
- Fsp -> K-Fsp
- Mafic minerals -> biotite

Common in porphyry deposits associated with:

- Chalcopyrite
- Bornite
- Chalcocite
- Molybdenite
- Gold

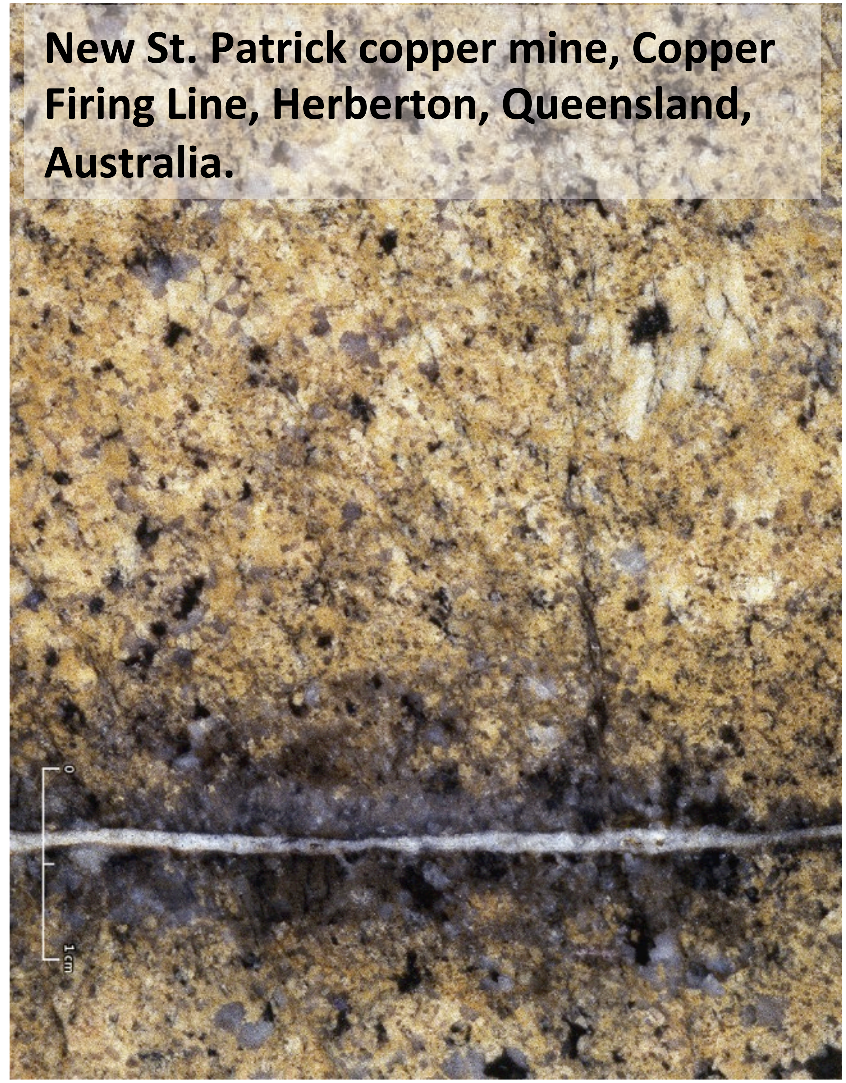
Chuqui Norte, Chuquicamata copper mine, Chile



From Taylor (2009)

Sericitic (aka Phyllic)
- K introduced
- Primary quartz unchanged
- K-feldspar -> sericite (e.g. fine-grained white mica)
- Biotite -> chlorite
- Intermediate T (200–350°C)

Common in porphyry deposits associated with:
- Chalcopyrite
- ± Molybdenite
- ± Gold



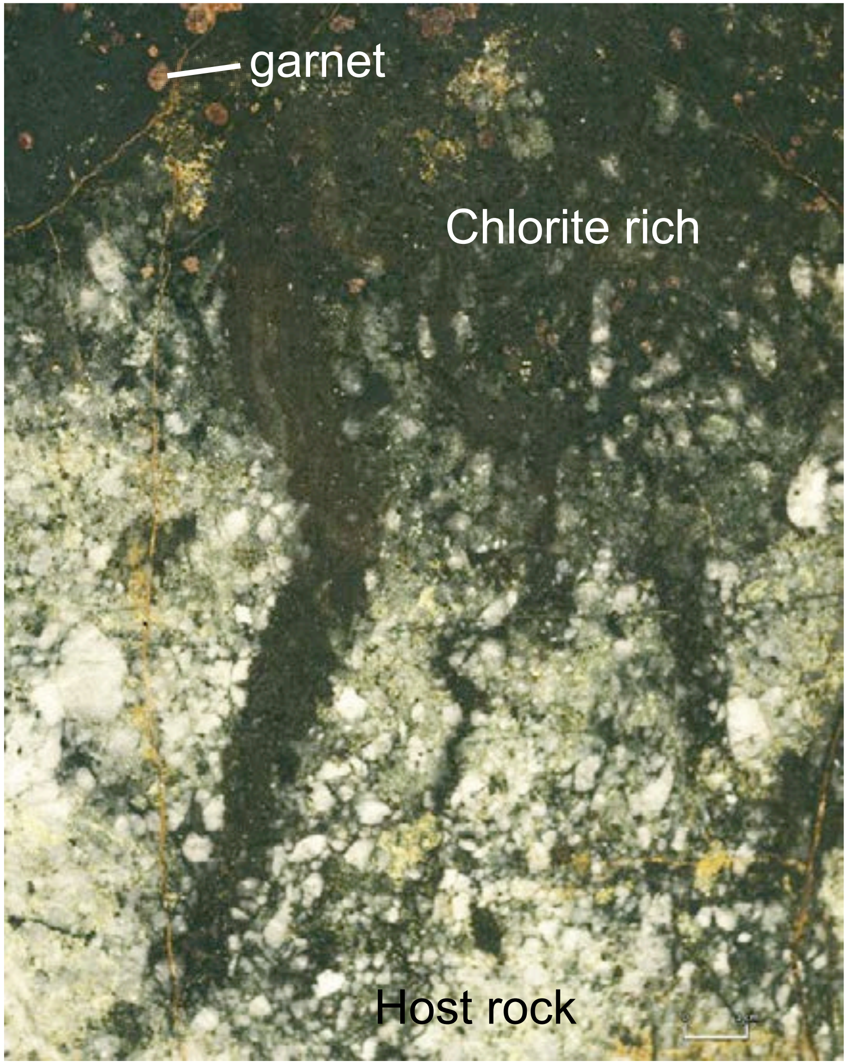
From Taylor (2009)

NOTE : mainly K-spar being hydrated and turning to sericite + biotite

Propylitic

- Green colour!!
  - Chlorite, epidote, actinolite
- Resembles greenschist facies metamorphism
- 200–350°C
- Widespread
- Chlorite may be from alteration of mafic minerals or introduction of Fe and/or Mg
- Very common surrounding seafloor massive sulphide deposits

Jumna tin mine, Irvinebank, Queensland, Australia



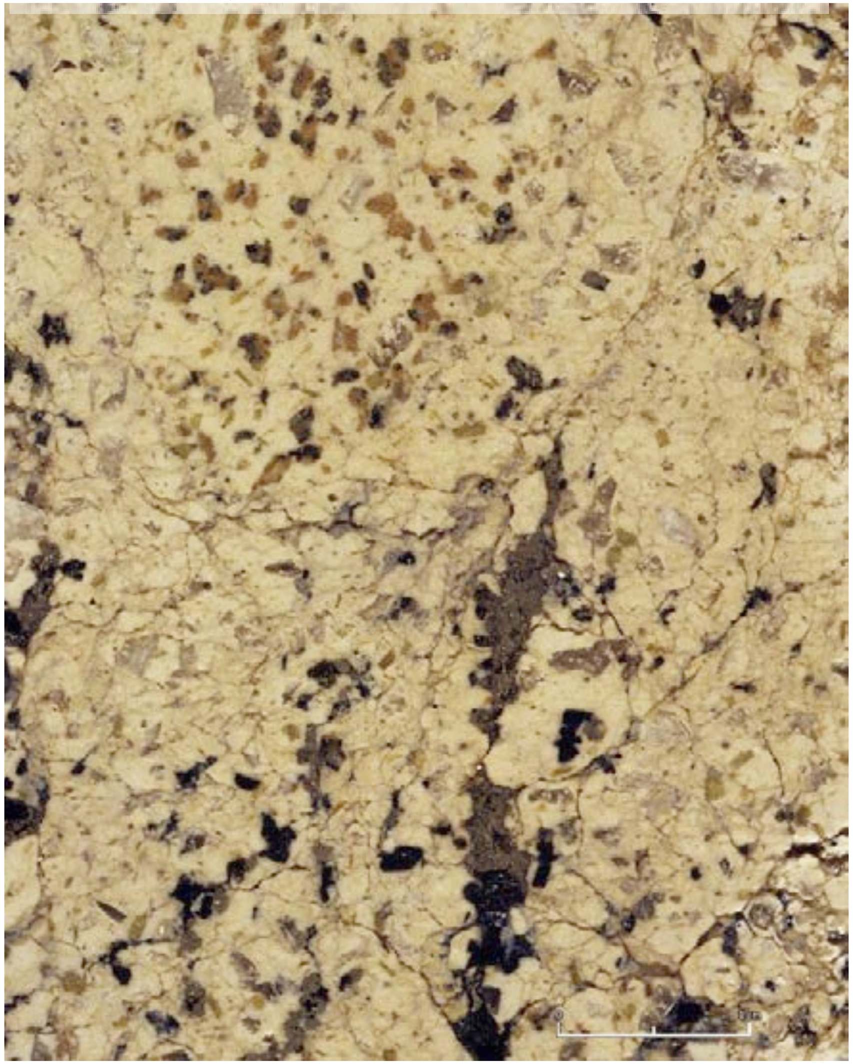
From Taylor (2009)

Argillic (e.g. clay)

- Shallow and relatively cool
- <250°C
- Clay minerals (montmorillonite and kaolinite)
- H^+ added
- Commonly subdivided into intermediate and advanced
- Mainly affects plagioclase:
  Plag + H_2O -> clays

Note that if plagioclase is absent, it may be difficult to detect.

Mine porphyry, Mt Leyshon gold mine, Queensland, Australia



From Taylor (2009)

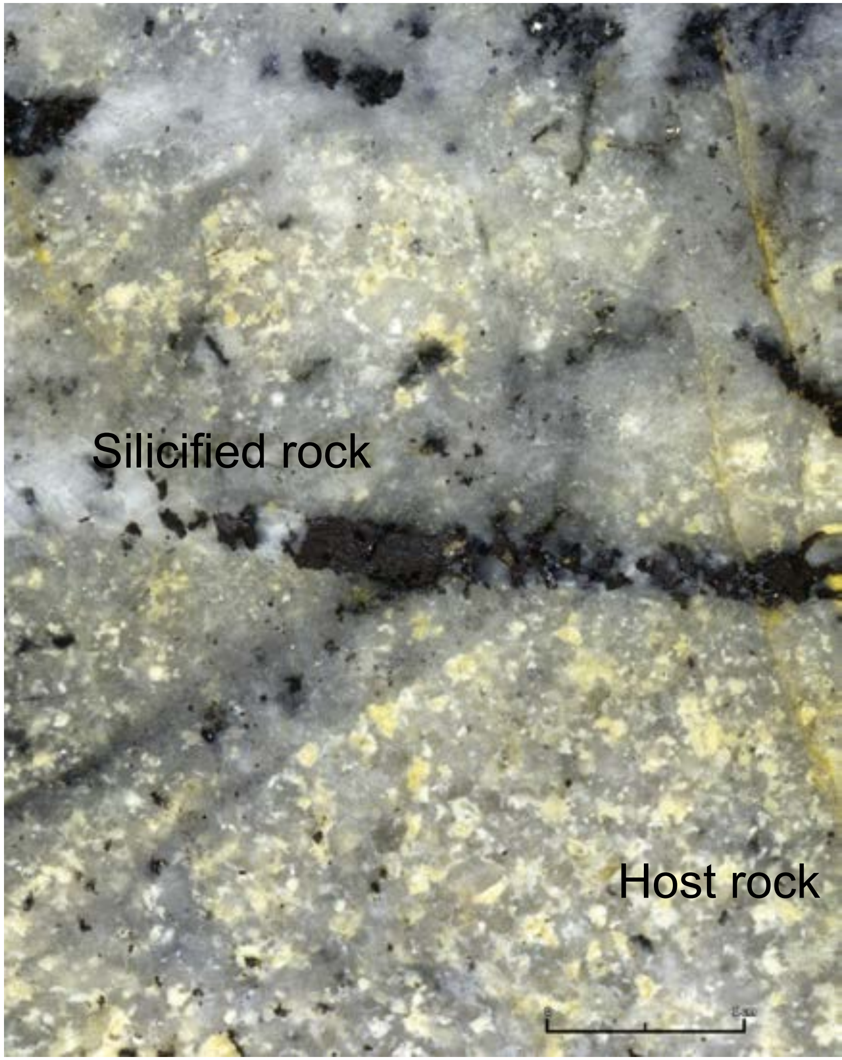
Silicification

- SiO_2 is a by product of hydrolysis reactions:

Plag + H^+ -> Pyrophl + Qtz + Na^+

- SiO_2 scavenged from country rock during fluid infiltration
- Si^{4+} taken into solution and commonly deposited as infill
- Look for infill textures!
- Common product of shallow ore forming processes (epithermal)

Isobella (silver, lead, zinc) mine, Herberton, Queensland, Australia



From Taylor (2009)

Greisenization

Hydrothermal alteration assemblage of granite (Qtz–Musc.) rock with one or more F- or B-bearing minerals

Coarse grained Musc

Commonly with:
Topaz ($Al_2SiO_4(OH,F)_4$) ± Tourmaline ± fluorite

Sn and W mineralization

Si rich

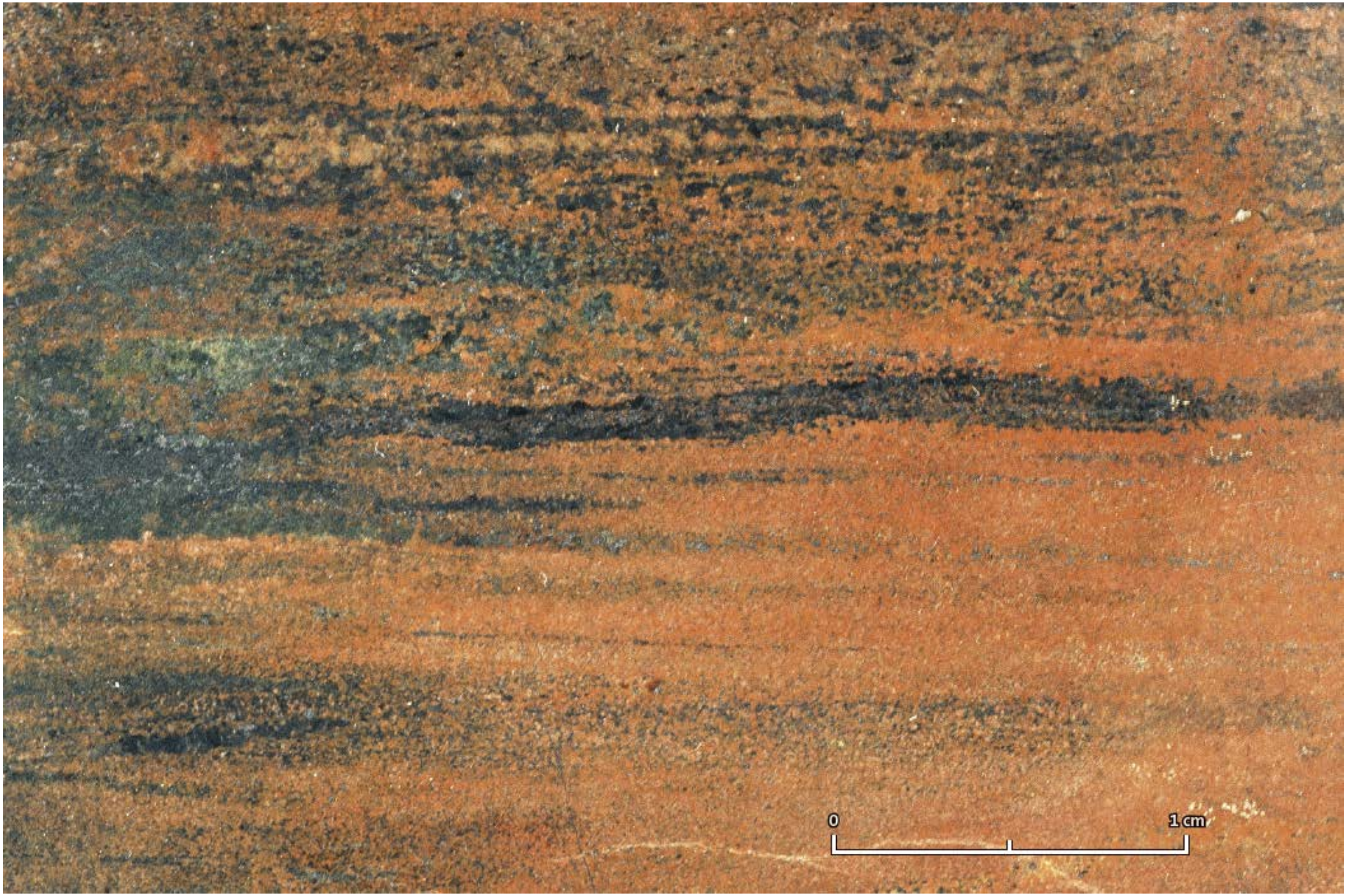
Musc. Rich (appear dark on slab surface here)

Ms+Qtz+K fs (pink)

Ollera Creek tungsten mine, Paluma District, Queensland, Australia.

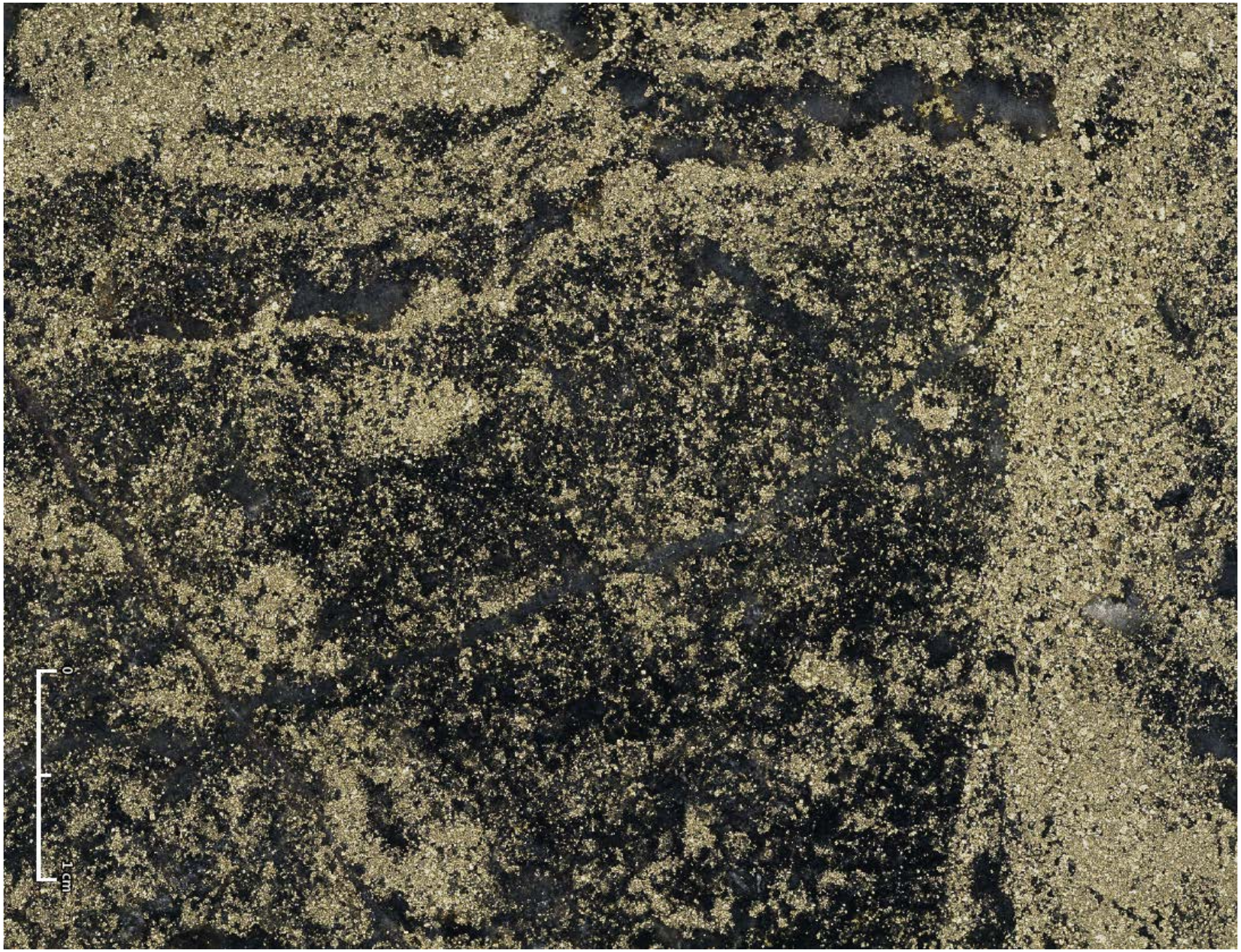
Hematite alteration

Altered gneiss



From Taylor (2009)

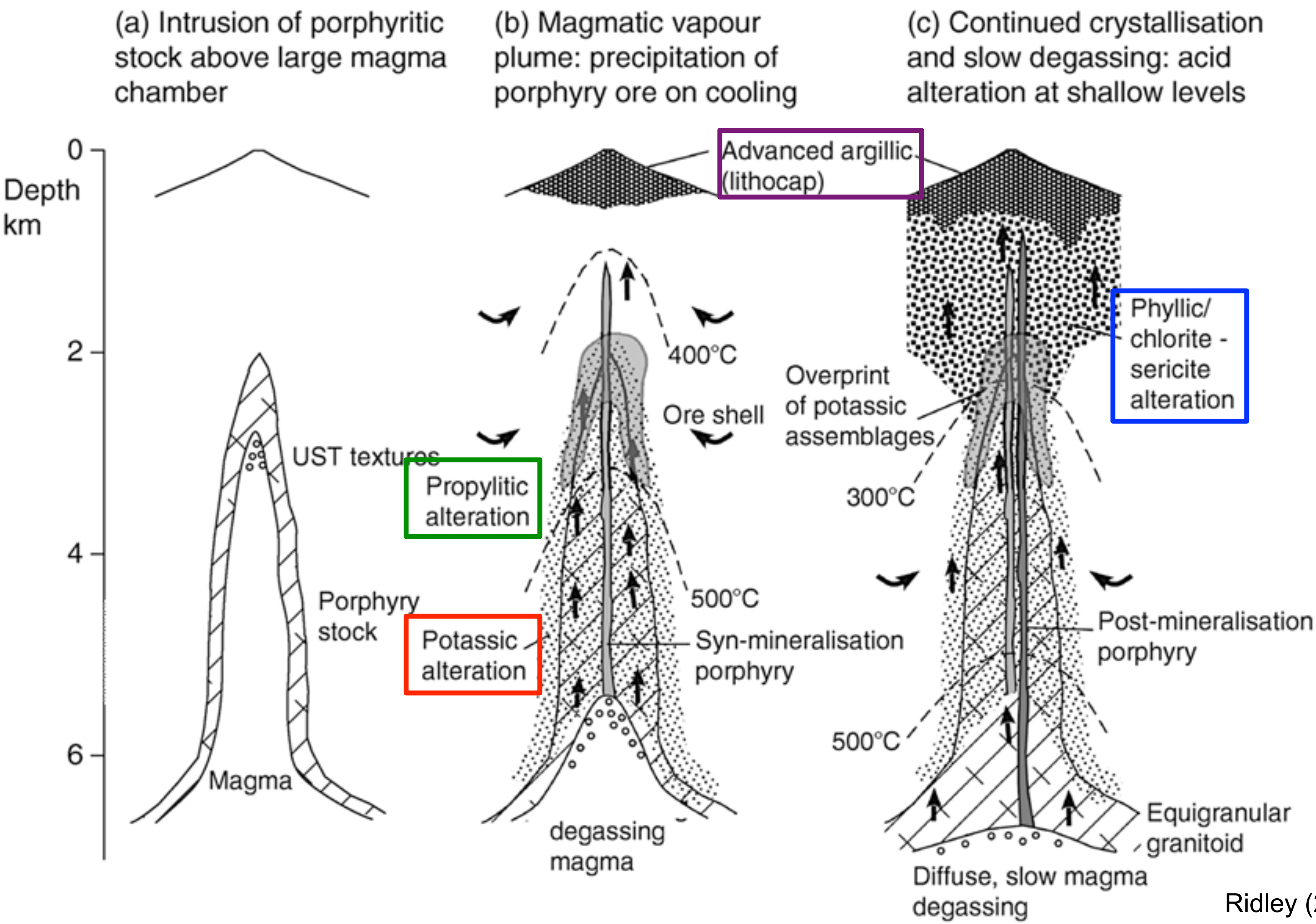
Pyrite alteration (pyritization)



Volcanic Breccia

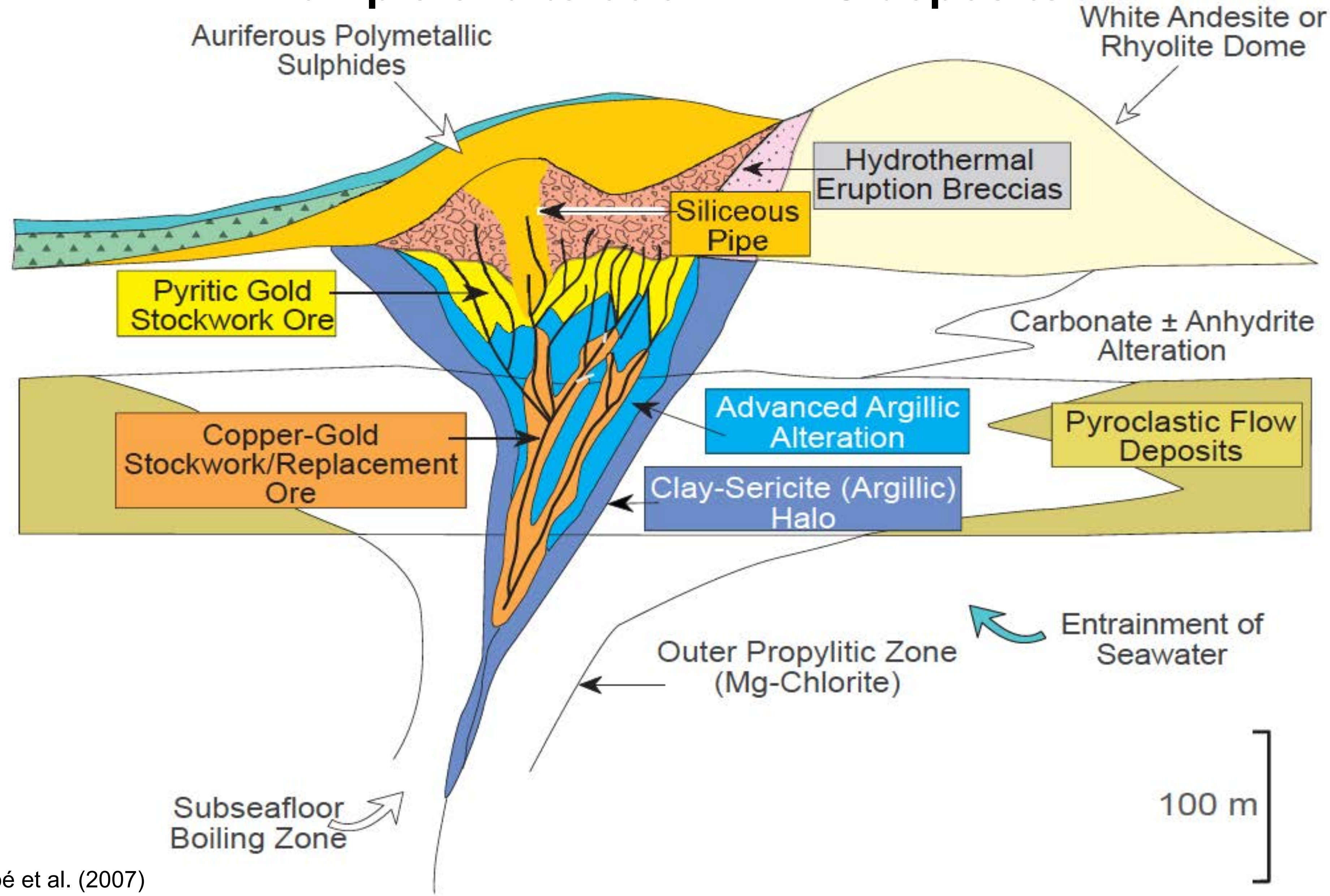
From Taylor (2009)

Example of alteration



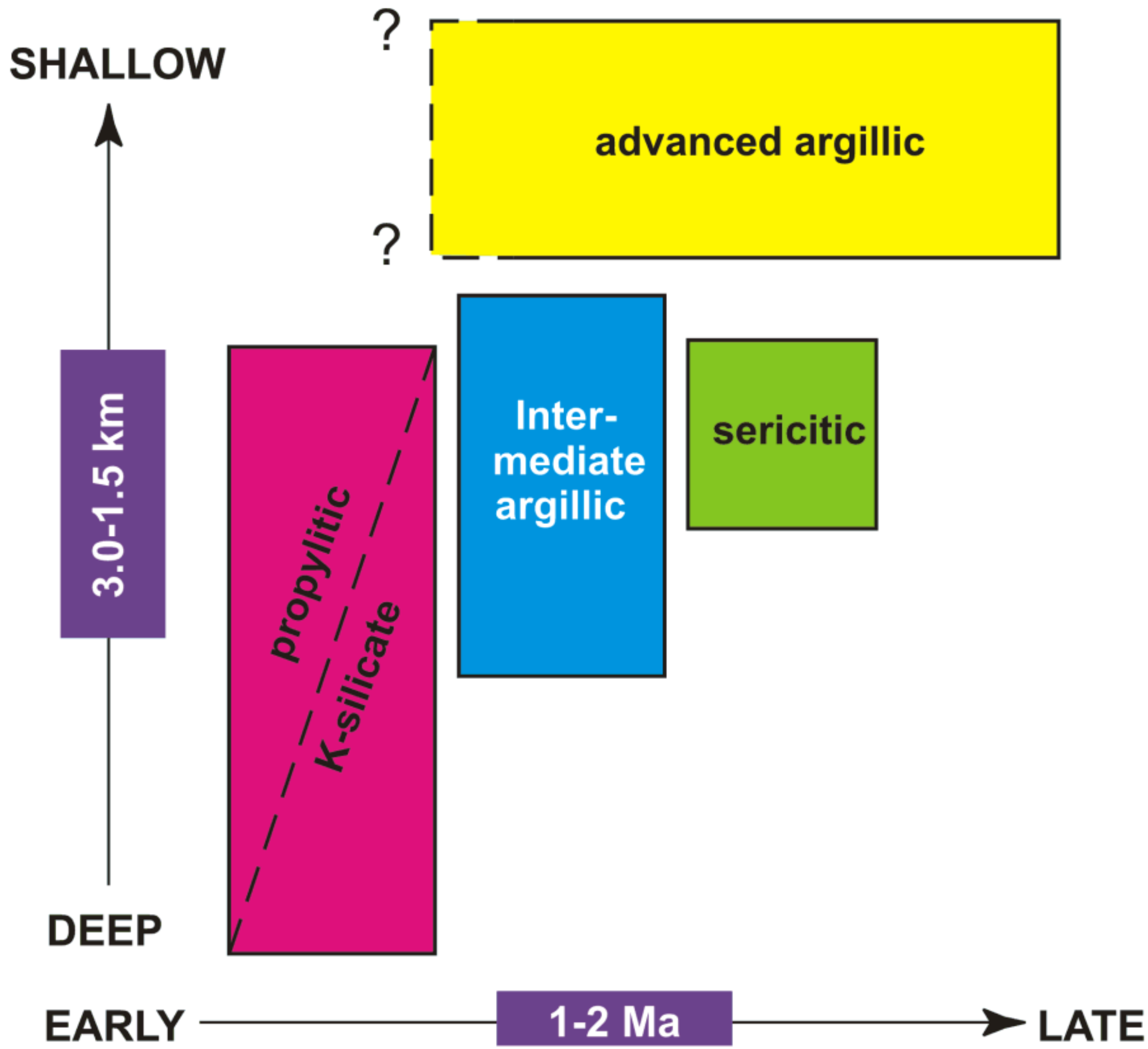
Ridley (2013)

Example of alteration – VMS deposits



Dubé et al. (2007)

Example of alteration – Porphyry Cu



from Sillitoe, 1993

Things to think about when describing an altered rock:

1. Determine what minerals are present along with their mineralogical and textural characteristics (e.g. evidence of primary or secondary origin)
2. Determine the distribution of minerals at multiple scales (outcrop, hand sample, thin section). Is the alteration pervasive or selective?
3. Define the relationship between main minerals (e.g. **paragenetic sequence**). Is there evidence of textural equilibrium or replacement?
4. What is the distribution of the mineral assemblages at the map scale?

Take home messages:

- Textures provide clues to the processes of ore formation
- Alteration is a *vector* towards mineralization (points you in the right direction in space and time)
- Important to compare unaltered and altered rock to determine type and extent of alteration
- It can take years to get your 'eye in' on the different alteration types

"Geoscientists who work with hydrothermal alteration learn through practical experience"

– Thompson et al., *Atlas of Alteration*