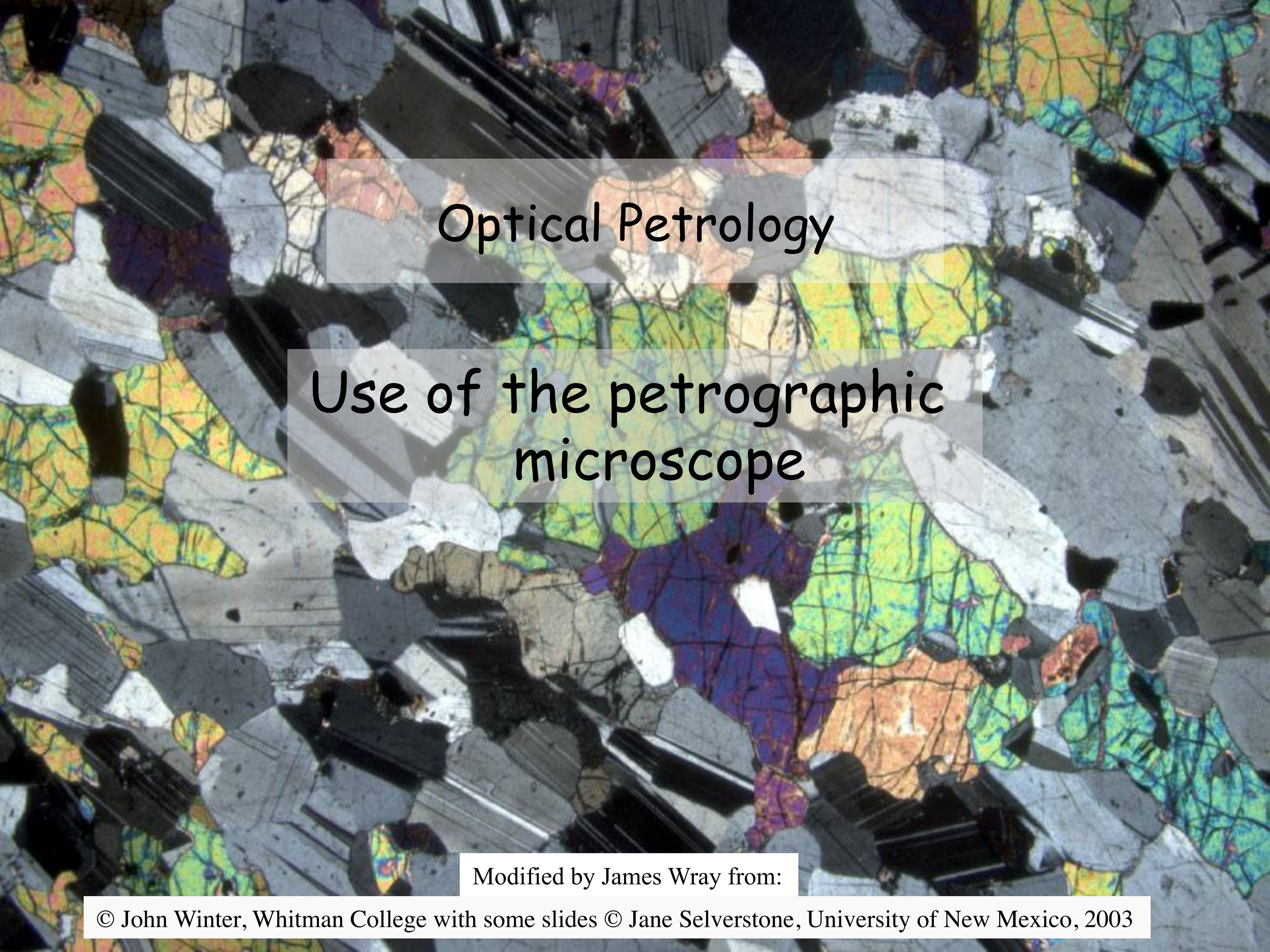
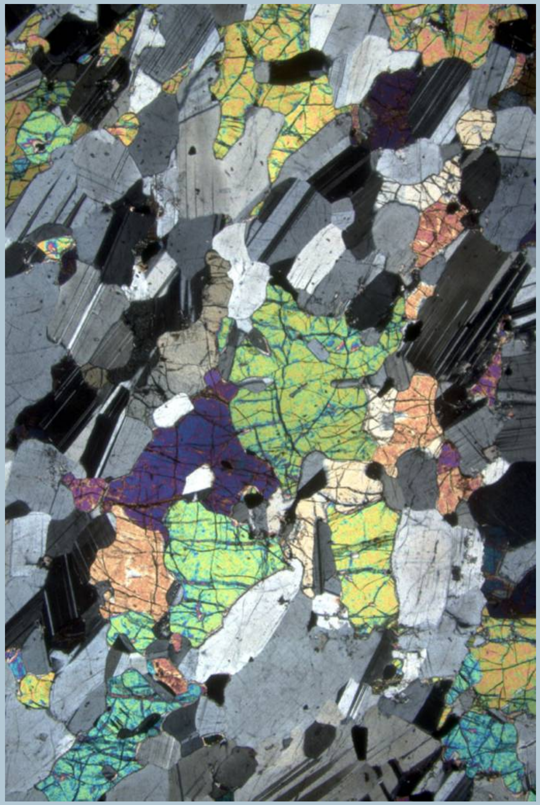


Optical Petrology

Use of the petrographic microscope

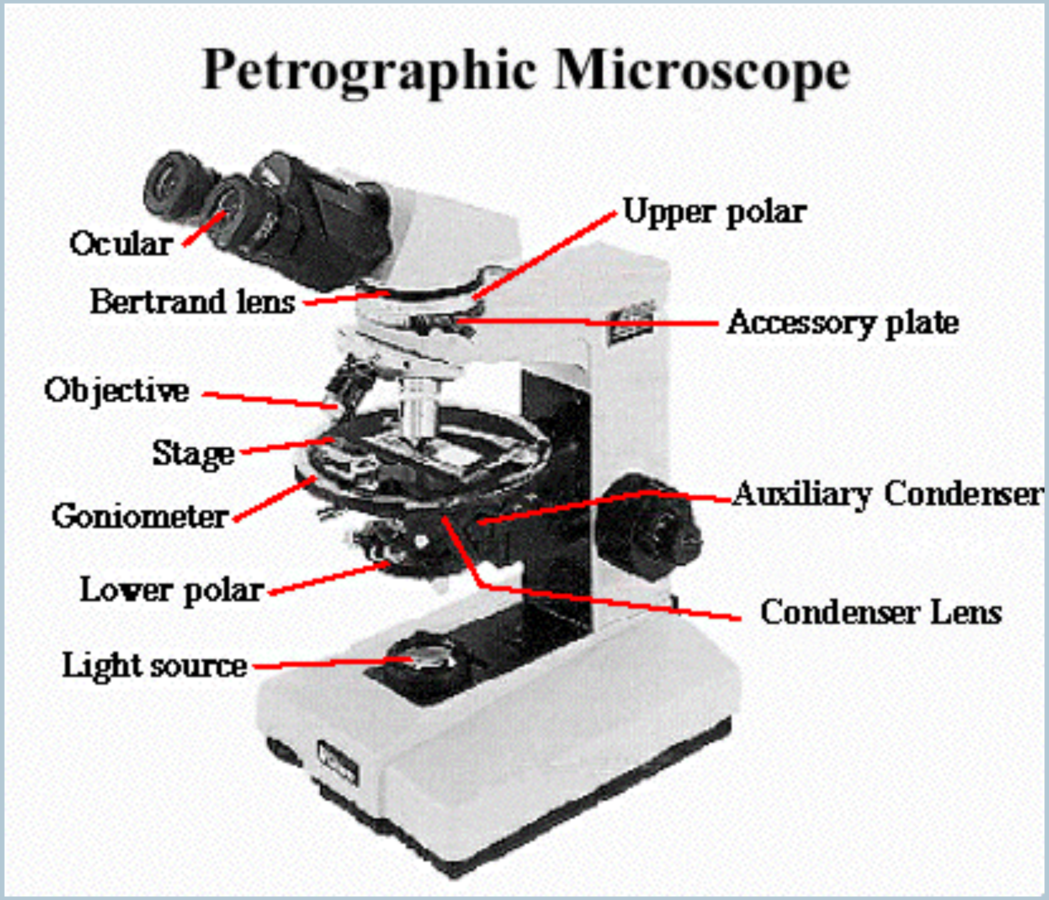
Modified by James Wray from:

Why use the microscope??



- Identify minerals
- Determine rock type
- Determine crystallization sequence
- Observe frozen-in reactions
- Document deformation history
- Constrain P-T history
- Note weathering/alteration

The petrographic microscope

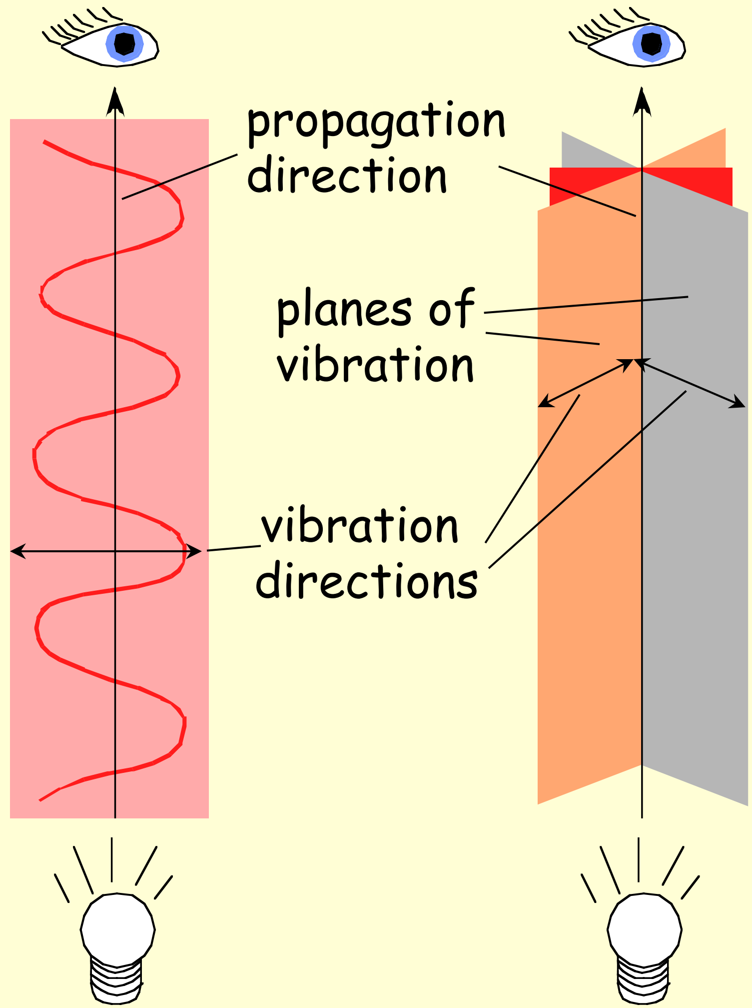


Also called a polarizing microscope

In order to use the scope, we need to understand a little about the **physics of light**

What happens as light moves through the scope?

Each photon vibrates as a wave form in a single plane



Light beam = numerous photons, all vibrating in the same plane

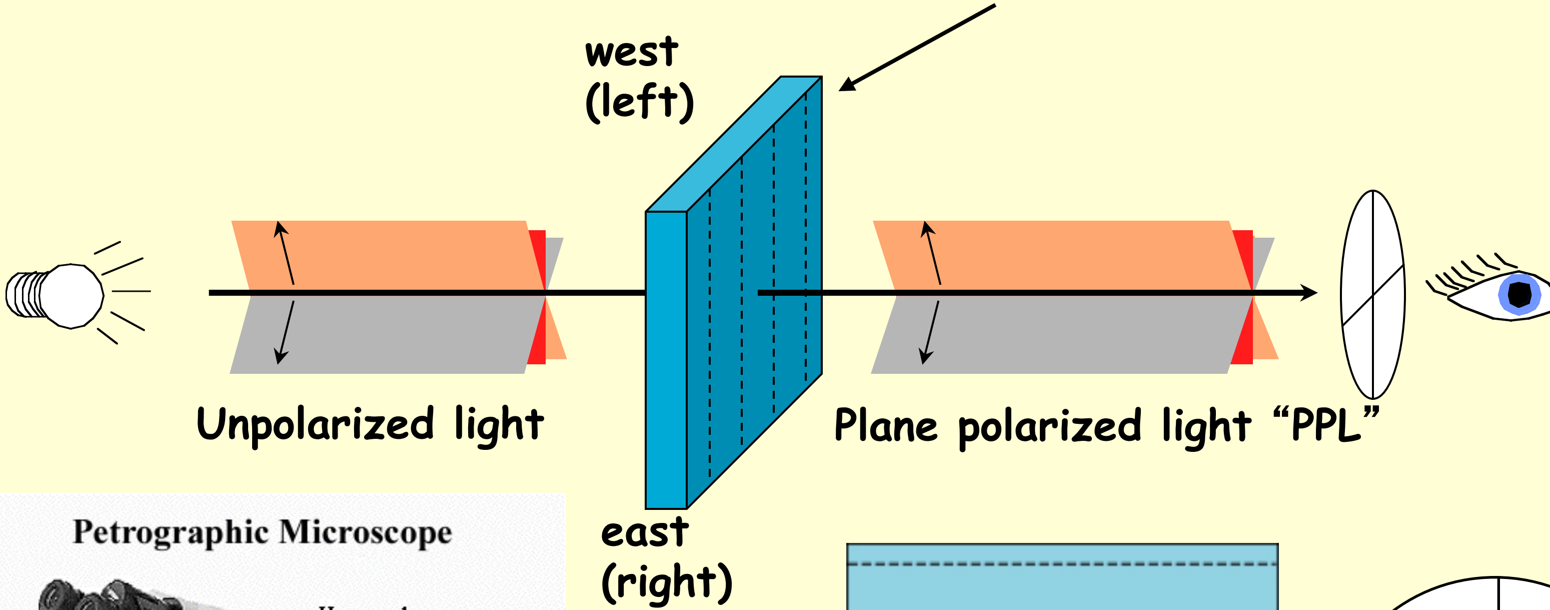
Light beam = numerous photons, each vibrating in a different plane

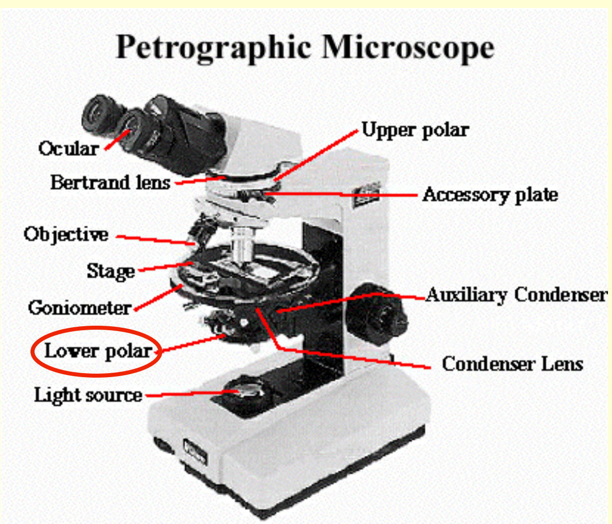
Vibration in all directions ~ perpendicular to propagation direction

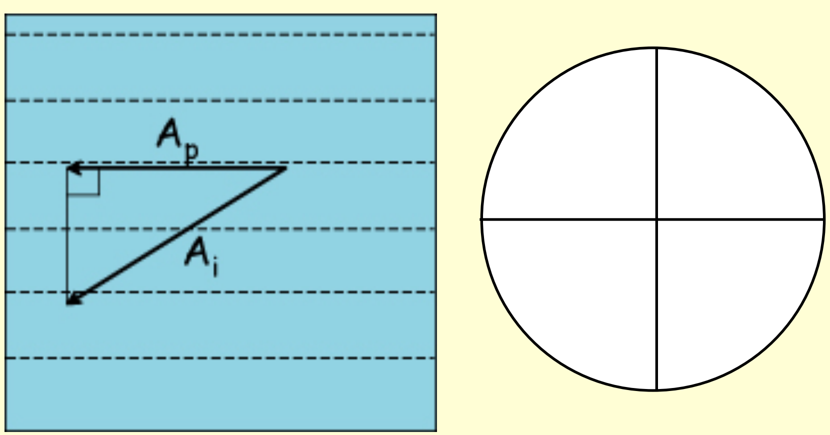
Polarized Light

Unpolarized Light

1) Light passes through the **lower polarizer**

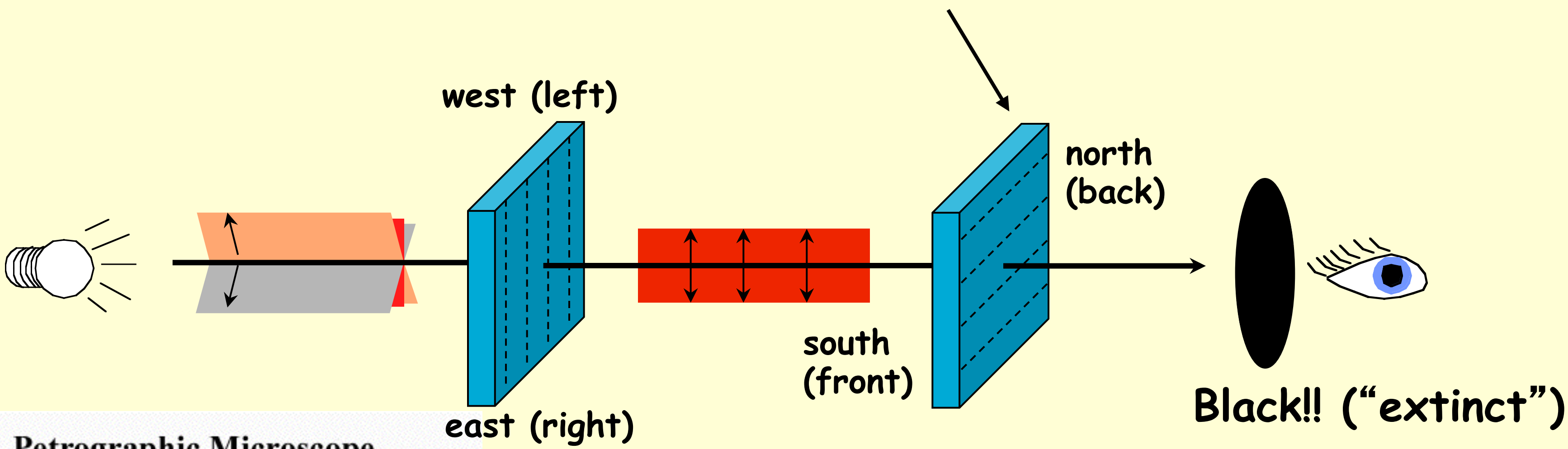


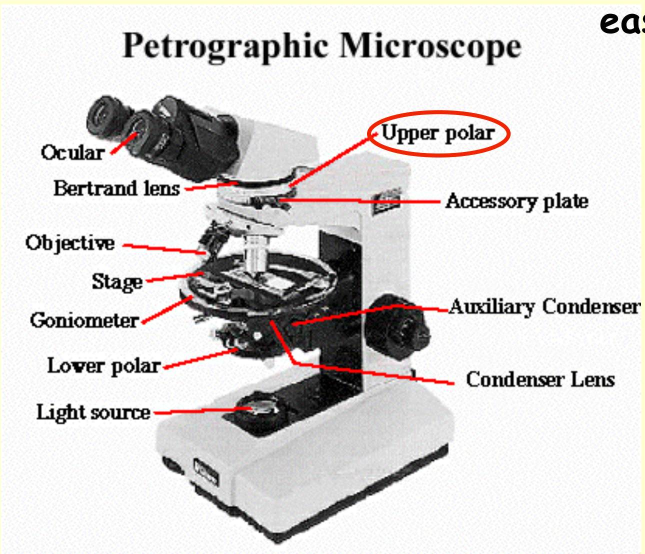




Only the component of light vibrating in E-W direction can pass through lower polarizer – light intensity decreases

2) Insert the **upper polarizer**



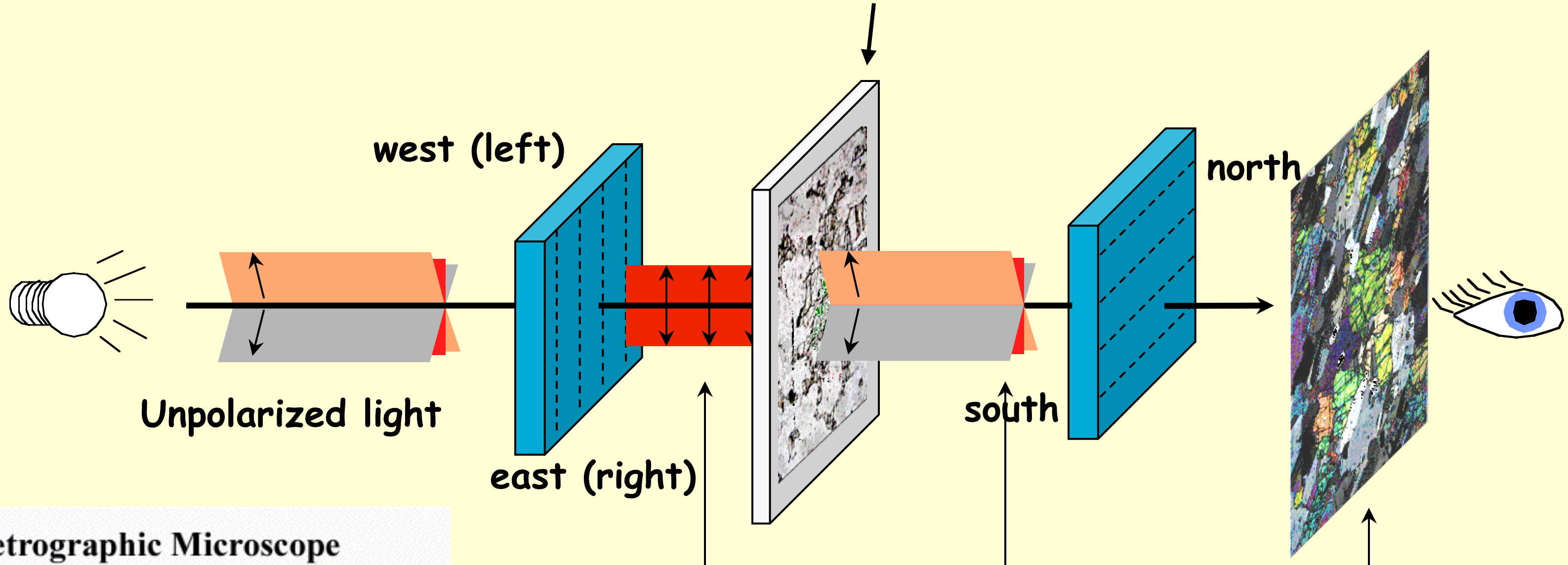


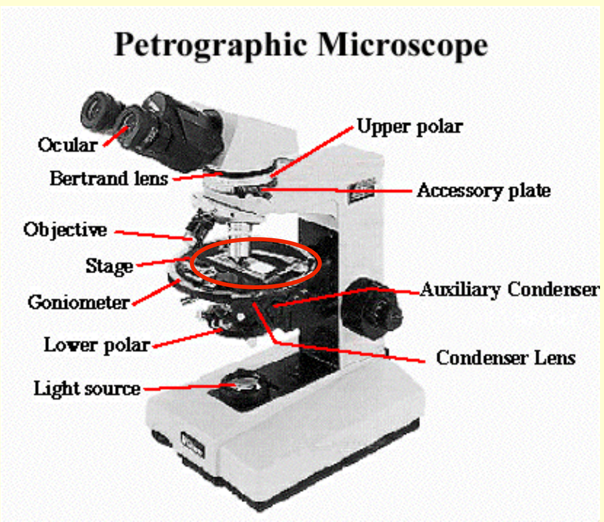
XPL=crossed nicols
(crossed polars)

Now what happens?
What reaches your eye?

Why would anyone design a microscope that prevents light from reaching your eye???

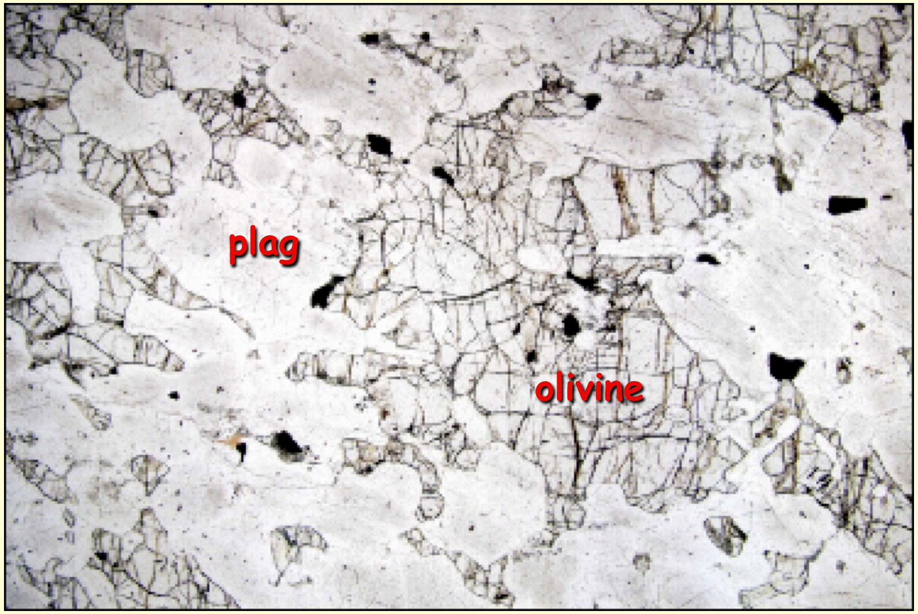
Now insert a **thin section** of a rock in XPL



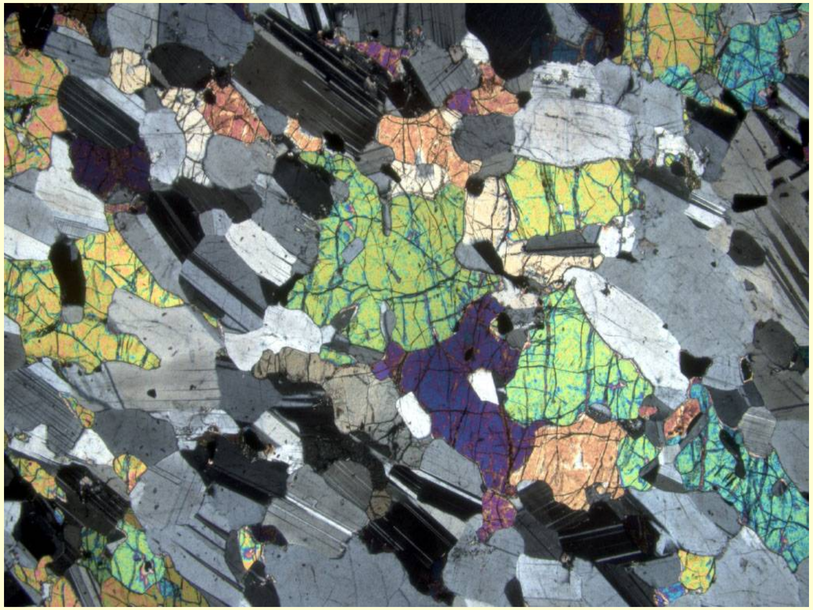


How does this work??

Conclusion has to be that minerals somehow **reorient** the planes in which light is vibrating; some light passes through the upper polarizer



PPL



XPL

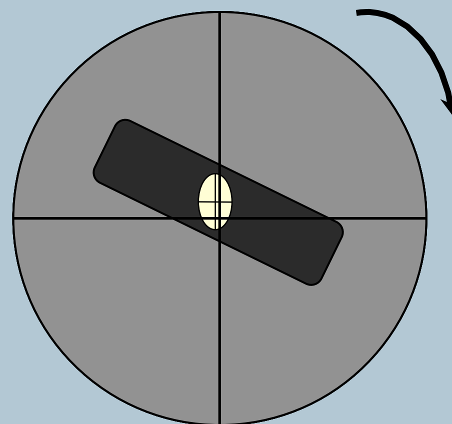
But, note that some minerals are better at this than others (i.e., some grains stay dark and thus can't be reorienting light)

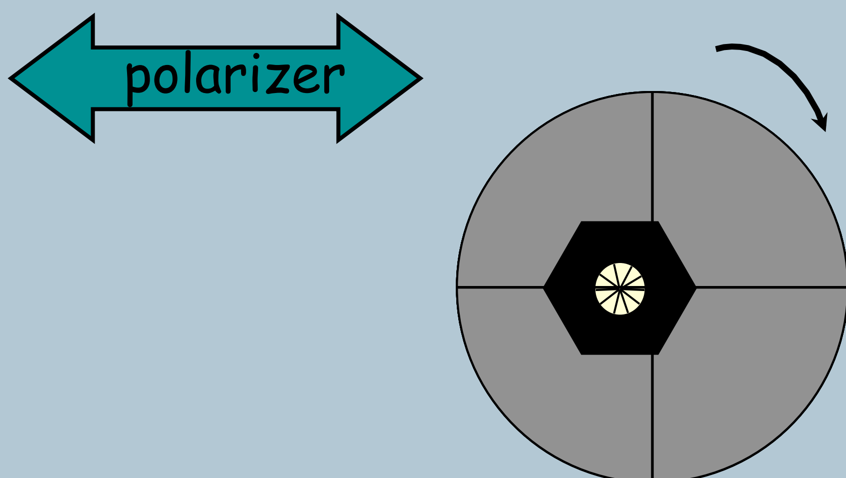
Some generalizations and vocabulary

- Amorphous materials and isometric minerals (e.g., *garnet*) are **isotropic** – they cannot reorient light. These minerals are always extinct in crossed polars (XPL).
- All other minerals are **anisotropic** – they are all capable of reorienting light.
- All **anisotropic** minerals contain one or two special *propagation* directions that do **not** reorient light.
  - Minerals with **one** special direction are called **uniaxial** (hexagonal, tetragonal)
  - Minerals with **two** special directions are called **biaxial** (orthorhombic, monoclinic, triclinic)

Rotating the stage

Anisotropic minerals change color as the stage is rotated; these grains go black 4 times in 360° rotation- **exactly every 90°**





Isotropic: glass or isometric minerals or look down optic axis of anisotropic minerals

Transmission by the Analyzer

Determined by:

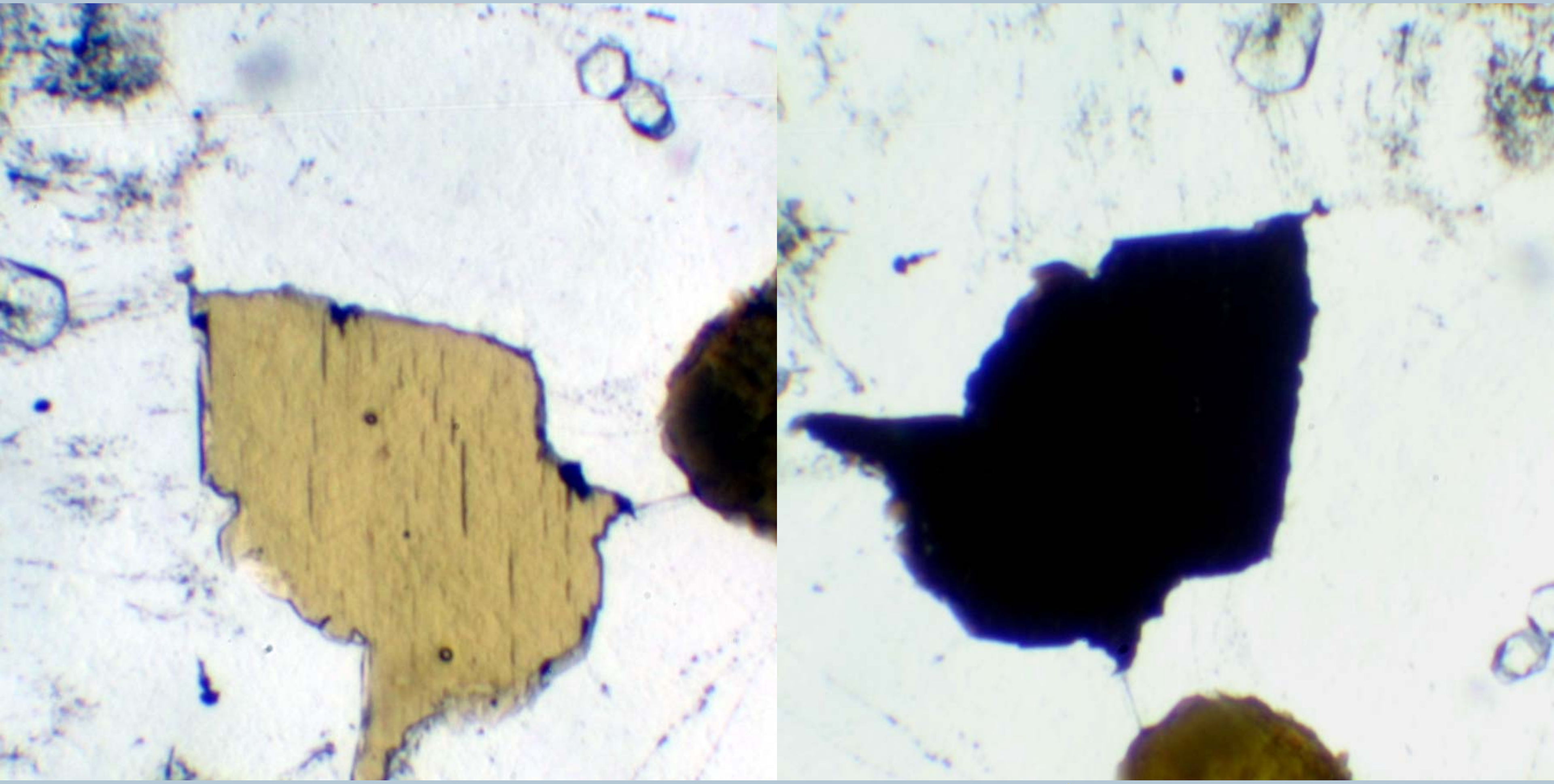
a) **Angle between analyzer and polarizer** (fixed at 90°)

b) **Angle between polarizer and closest privileged direction of xl**

- When polarizer || either privileged vibration direction → extinct, since only one ray & it's cancelled
- Every crystal goes extinct 4 times in 360° rotation (unless isotropic)

Pleochroism

- Changes in **absorption color in PPL** as rotate stage (common in biotite, amphibole…)

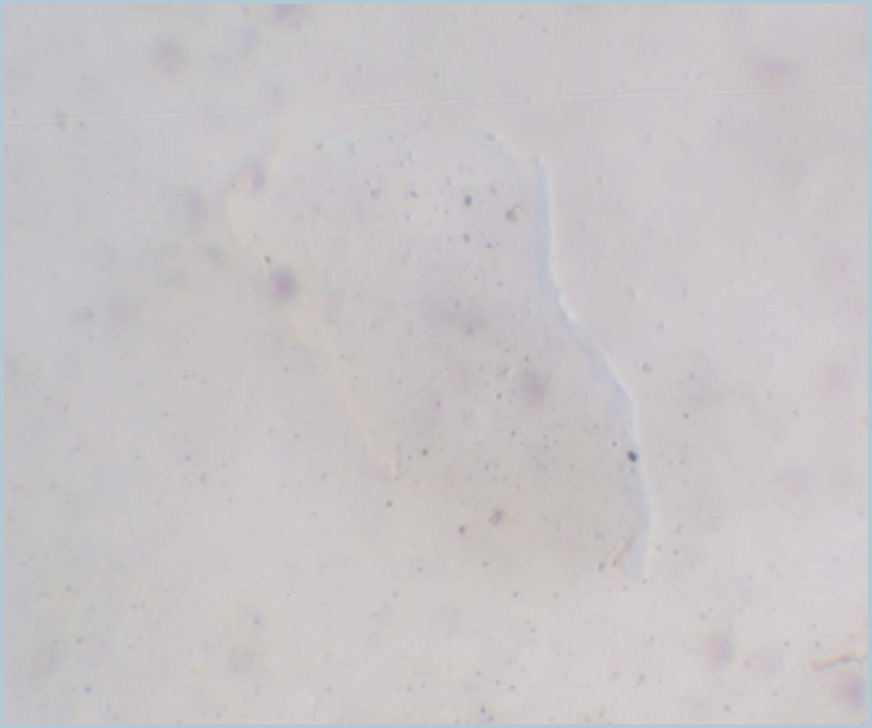


Biotite as stage is rotated

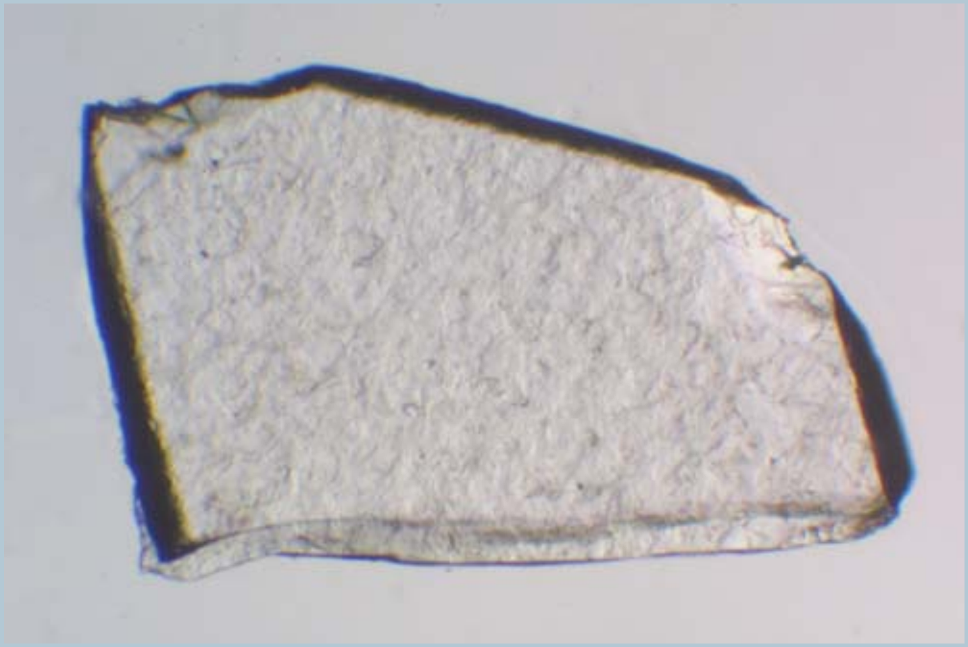
Mineral properties in PPL: **relief**

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n

garnet:	n = 1.72-1.89
quartz:	n = 1.54-1.55
epoxy:	n = 1.54



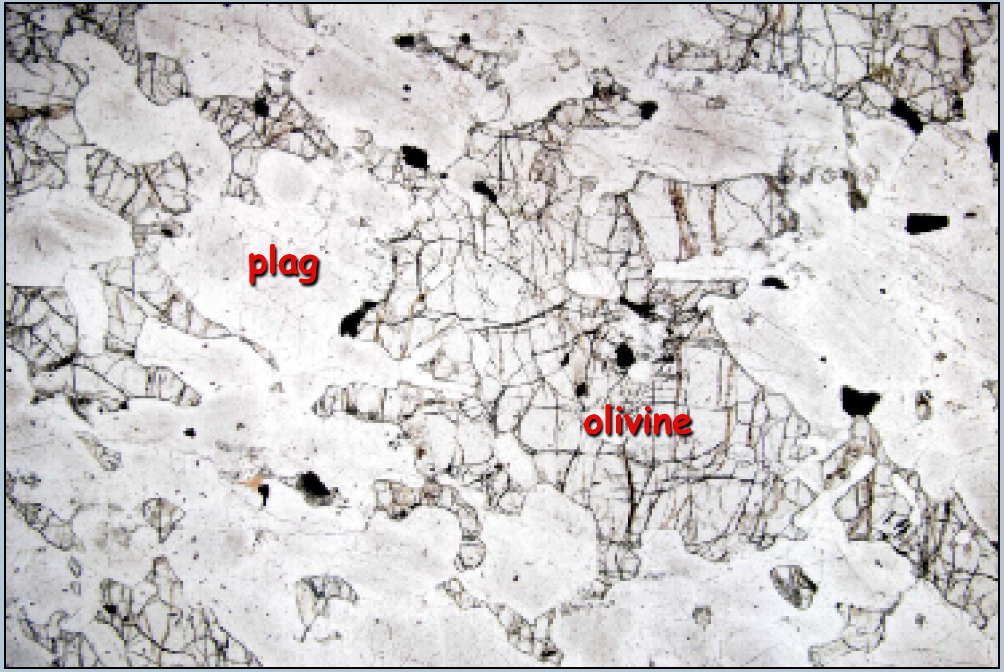
Quartz has low relief



Garnet has high relief

Mineral properties in PPL: **relief**

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n



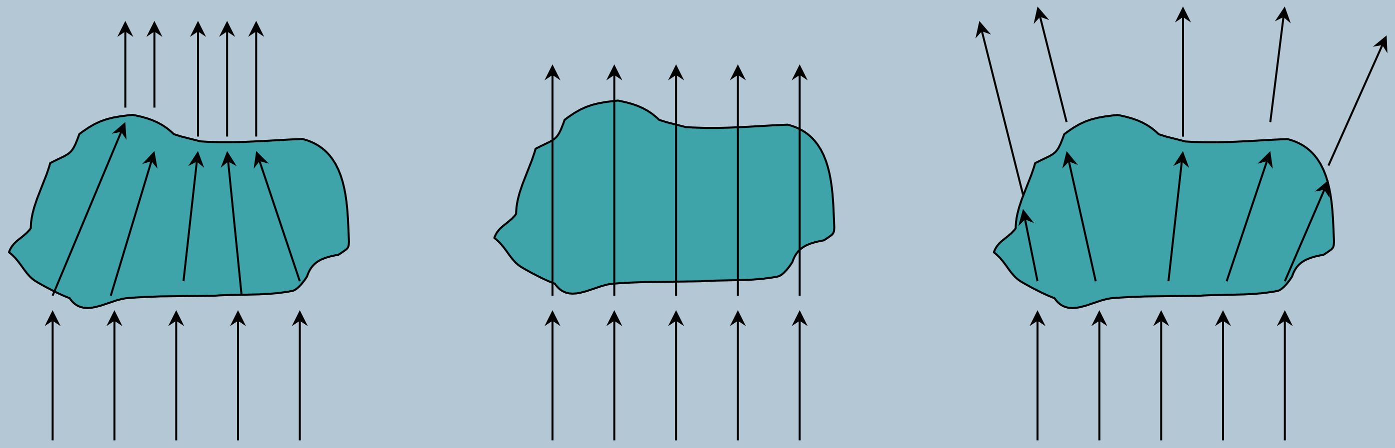
- Olivine has high relief
- Plagioclase has low relief

olivine:	n = 1.64-1.88
plag:	n = 1.53-1.57
epoxy:	n = 1.54

What causes relief?

Difference in speed of light (n) in different materials causes refraction of light rays, which can lead to focusing or defocusing of grain edges relative to their surroundings

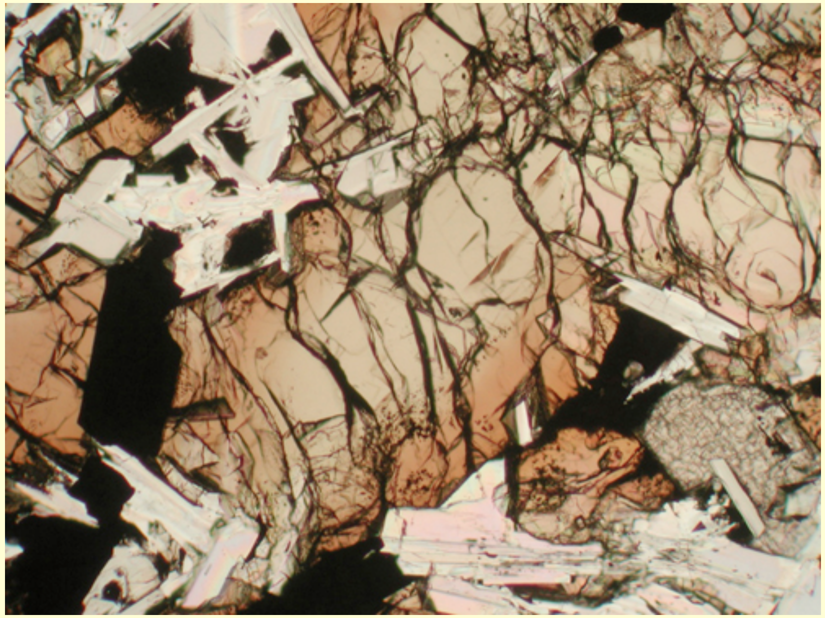
Hi relief (+) | Lo relief (+) | *Hi relief (-)*



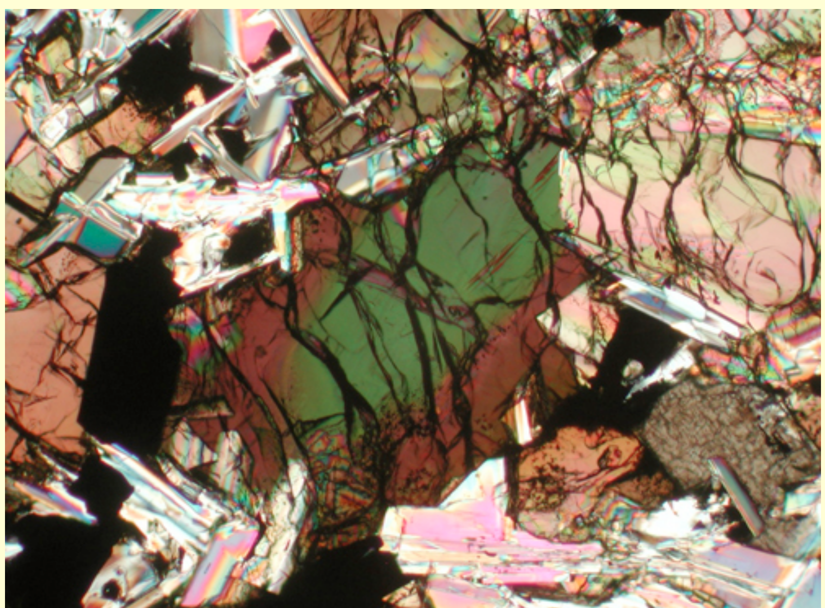
$n_{xtl} > n_{epoxy}$ | $n_{xtl} = n_{epoxy}$ | $n_{xtl} < n_{epoxy}$

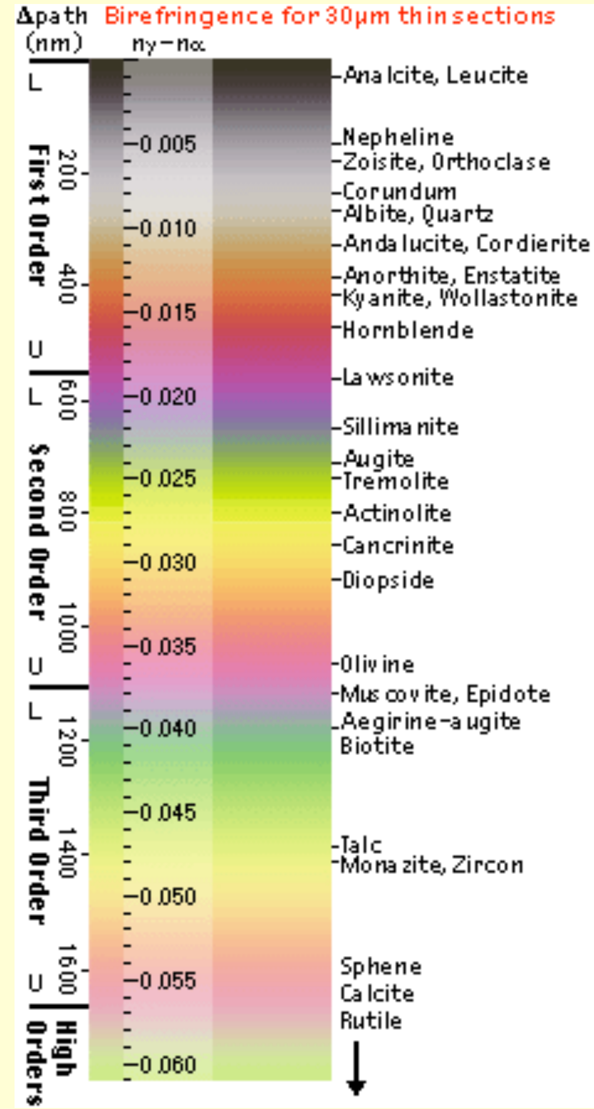
Birefringence (in lunar basalt)

Plane-polarized ("normal") illumination



Cross-polarized view





A few additional properties of individual minerals

Cleavage – number and orientation of cleavage planes

Twinning – type of twinning, orientation

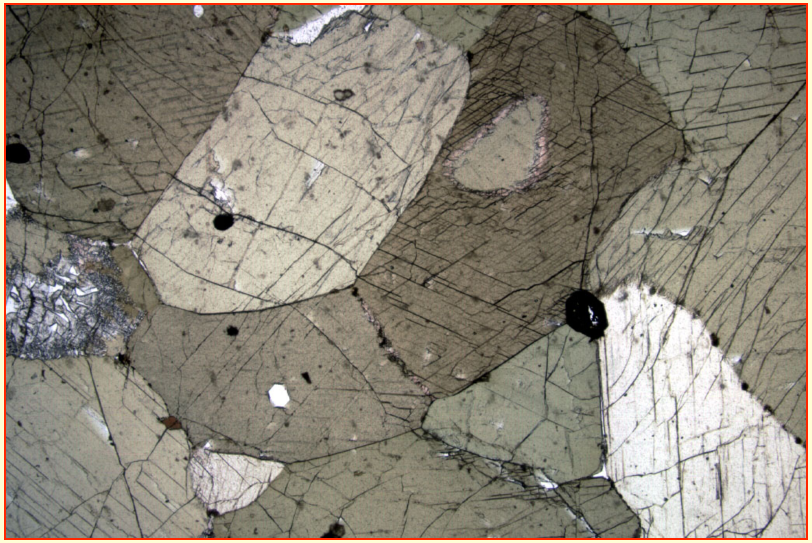
Extinction angle – parallel or inclined? Angle?

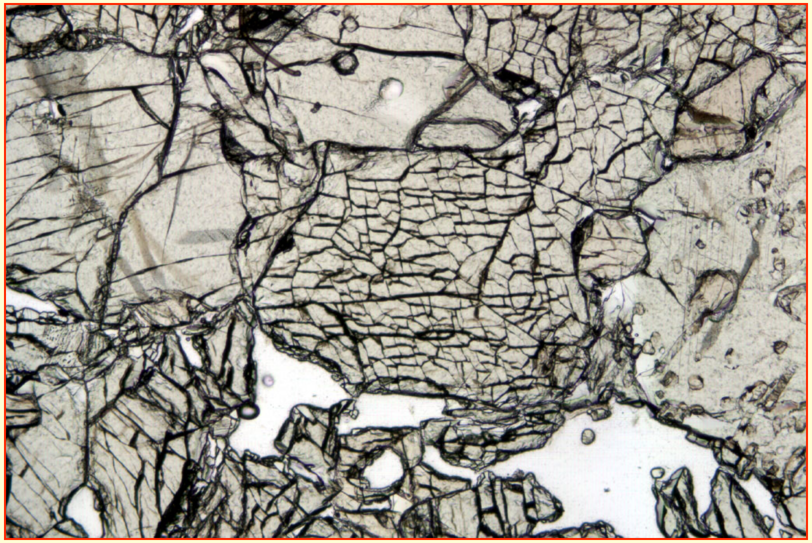
Habit – characteristic form of mineral

Cleavage

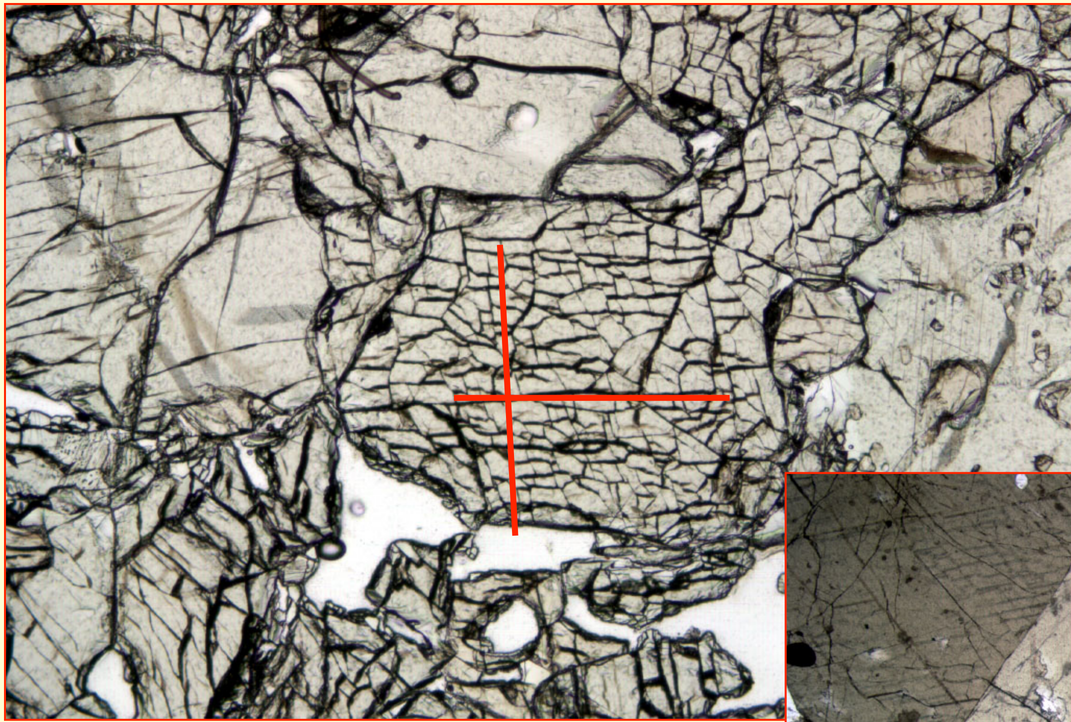
Most easily observed in PPL (upper polarizer out), but visible in XN as well

- No cleavages: quartz, olivine
- 1 good cleavage: micas
- 2 good cleavages: pyroxenes, amphiboles

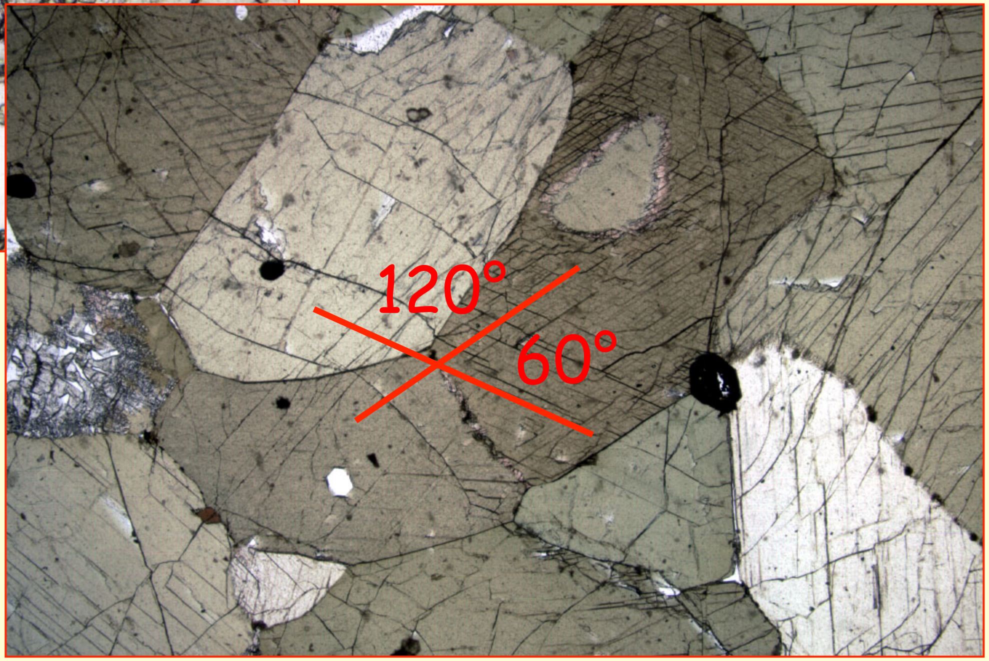




Cleavage

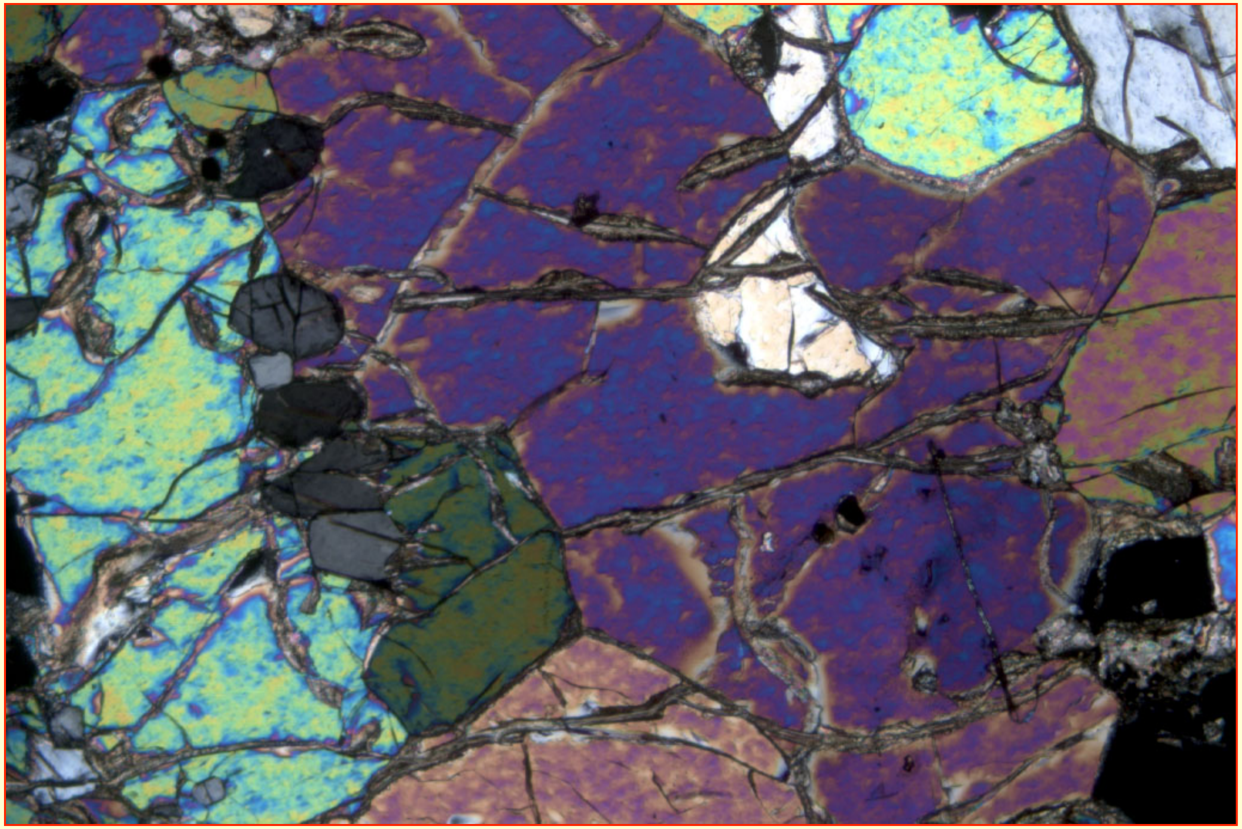


2 cleavages intersecting at ~90°
pyroxene



2 cleavages intersecting at 60°/120°:
amphibole

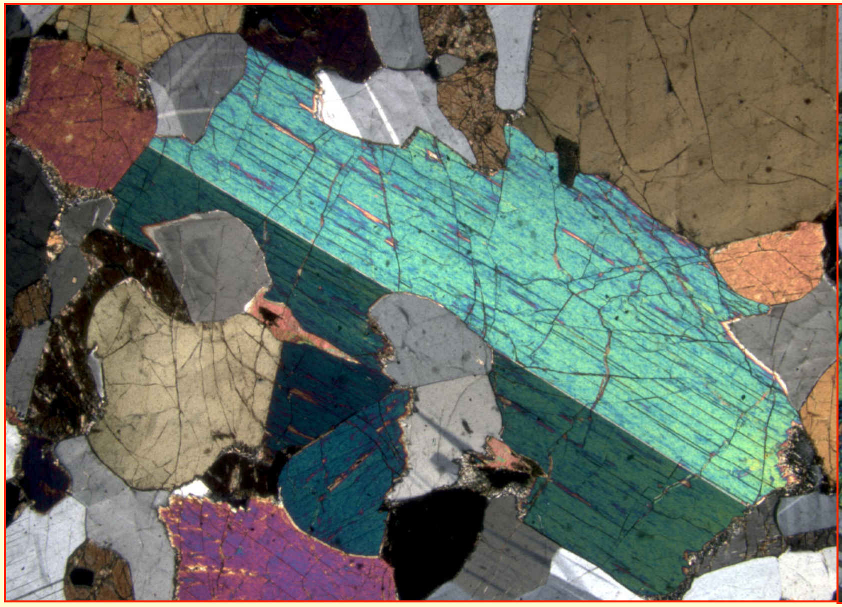
Cleavage

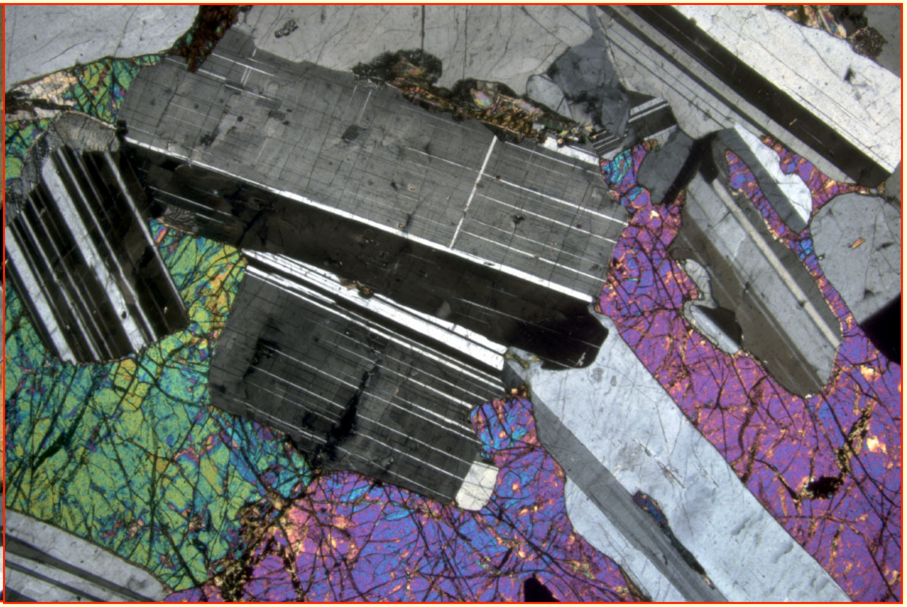


random fractures, no cleavage: olivine

Twinning

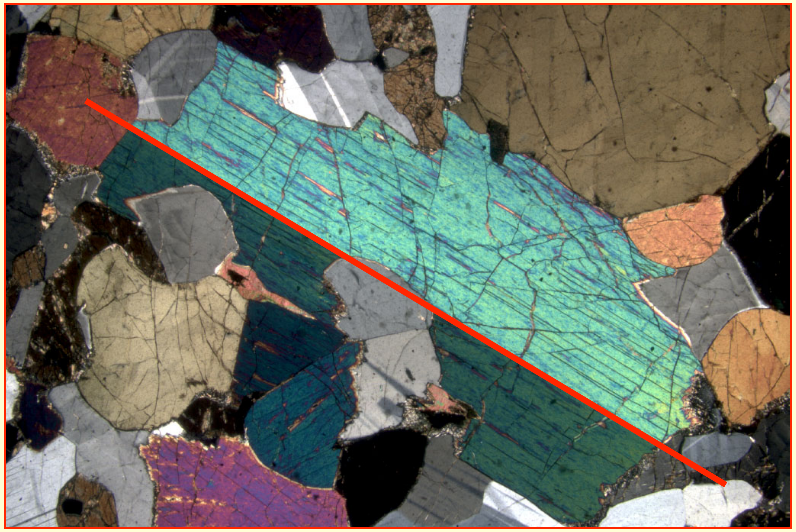
Presence and style of twinning can be diagnostic





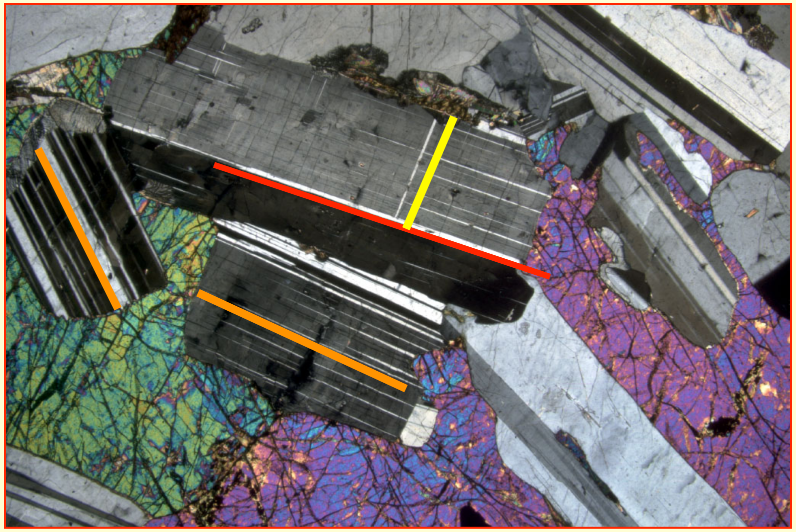
Twins are usually most obvious in XN (upper polarizer in)

Twinning - some examples



Clinopyroxene (augite)

- Simple twin on {100}



Plagioclase

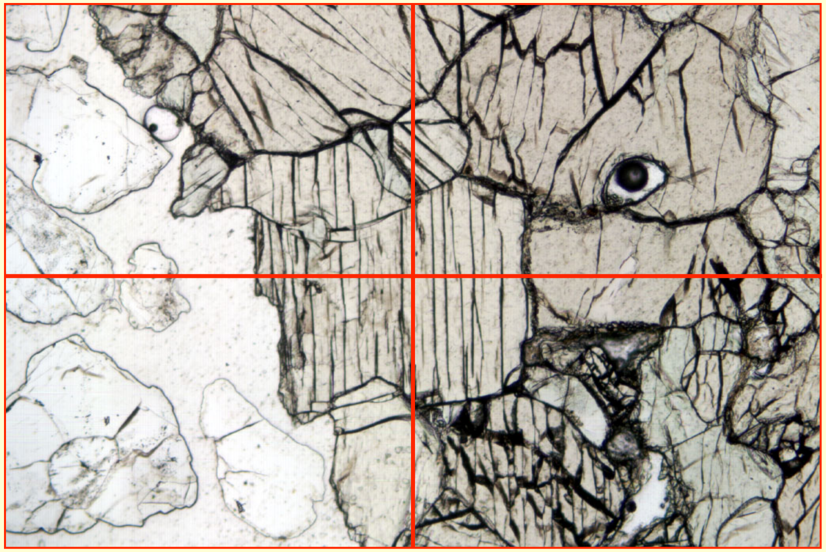
- Simple (Carlsbad) twinning
- Polysynthetic albite twinning
- Pericline twinning

Extinction angle – parallel extinction

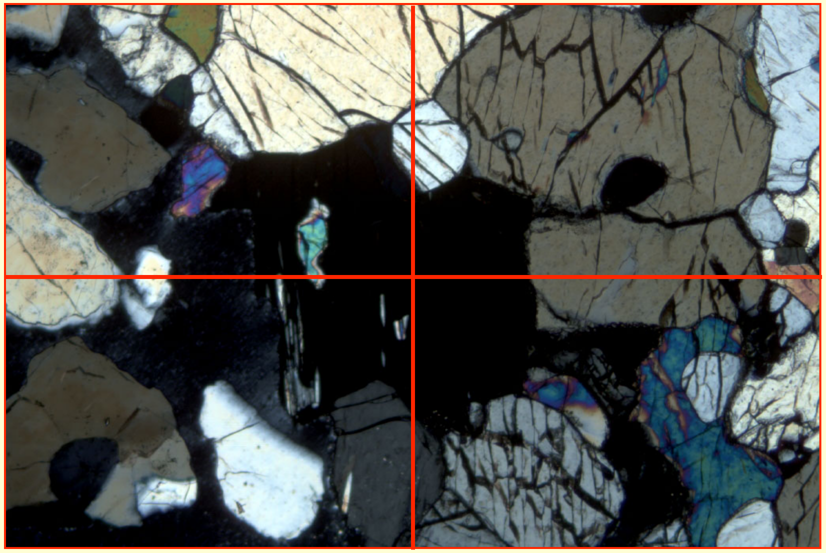
- All uniaxial minerals show parallel extinction
- Orthorhombic minerals show parallel extinction

(this is because the crystal axes and indicatrix axes coincide)

orthopyroxene



PPL

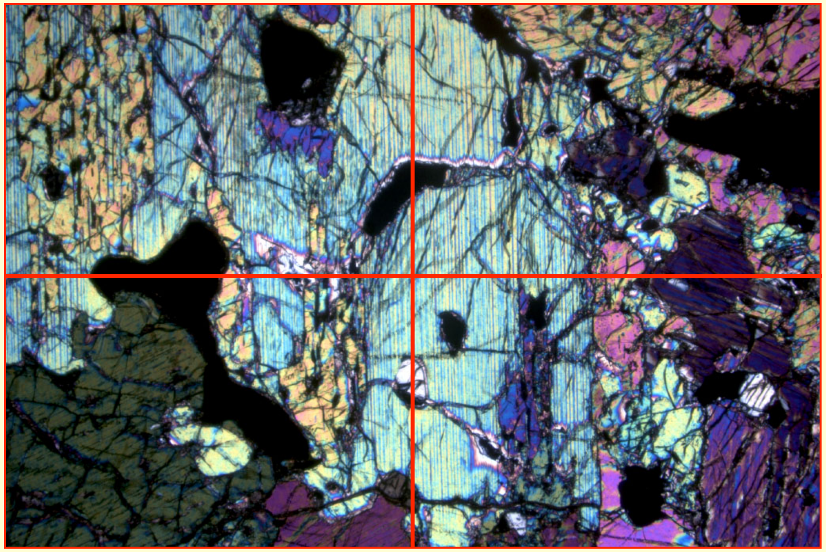


XN

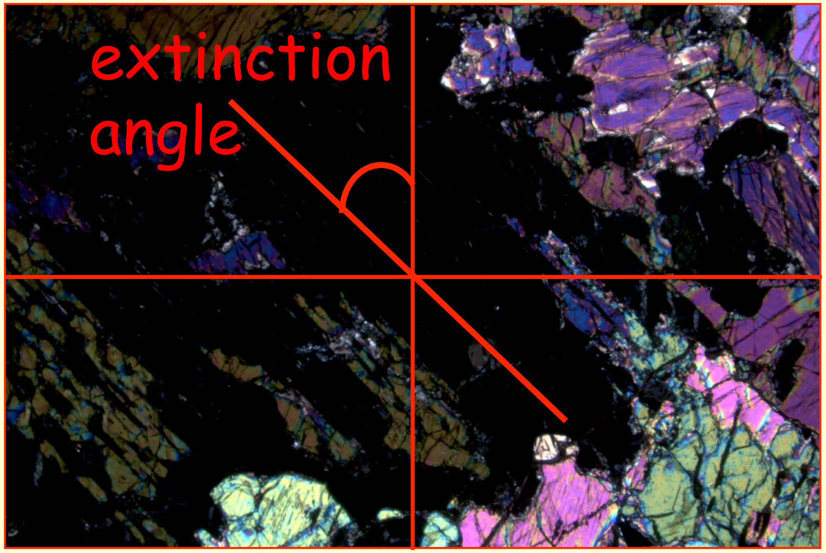
Extinction angle - inclined extinction

Monoclinic and triclinic minerals have inclined extinction

(and extinction angle helps to identify them)

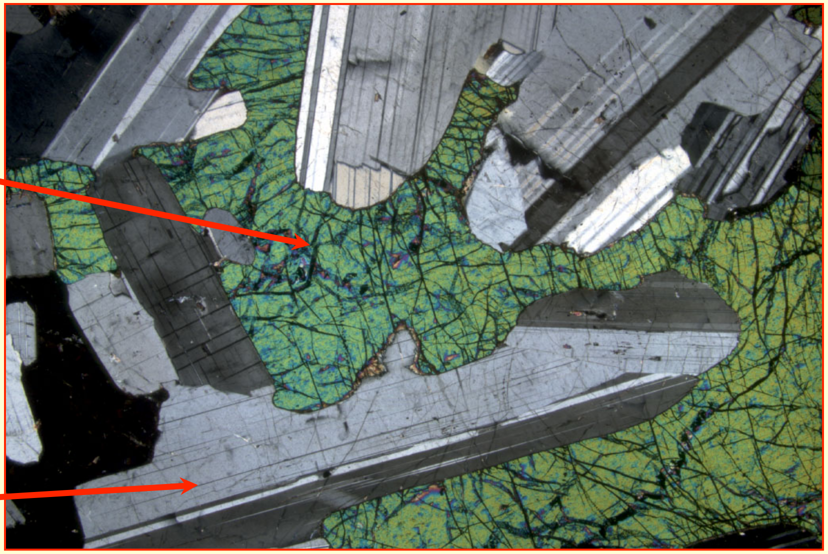


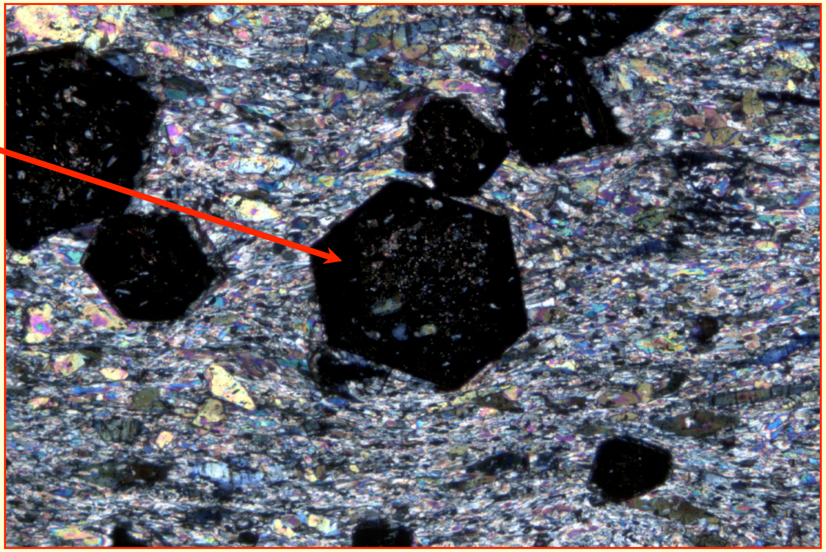
clinopyroxene



Habit or form

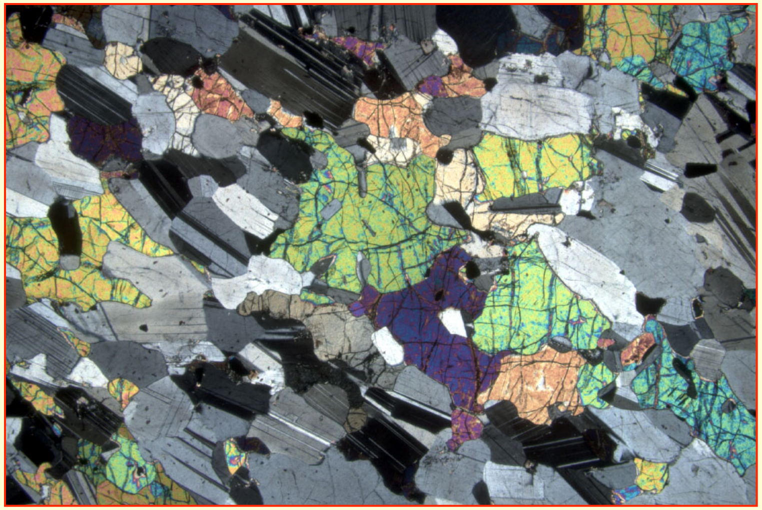
- acicular
- anhedral/irregular
- bladed
- blocky
- elongate
- euhedral
- fibrous
- prismatic
- rounded
- tabular





Review – techniques for identifying unknown minerals

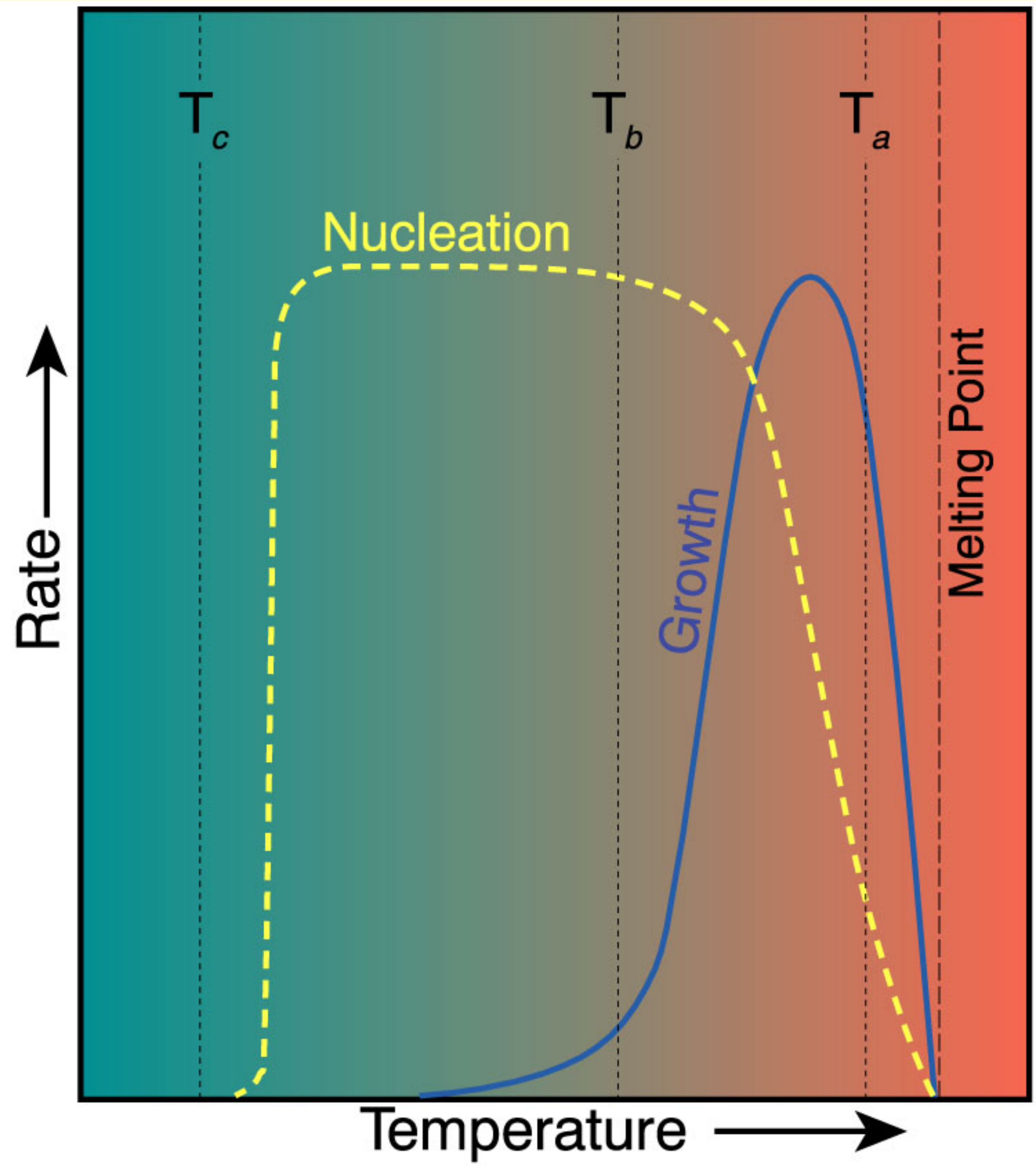
Start in PPL:
- Color/pleochroism
- Relief
- Cleavages
- Habit



Then go to XPL:
- Birefringence
- Twinning
- Extinction angle
- Uniaxial or biaxial?
- Additional info from accessory plates

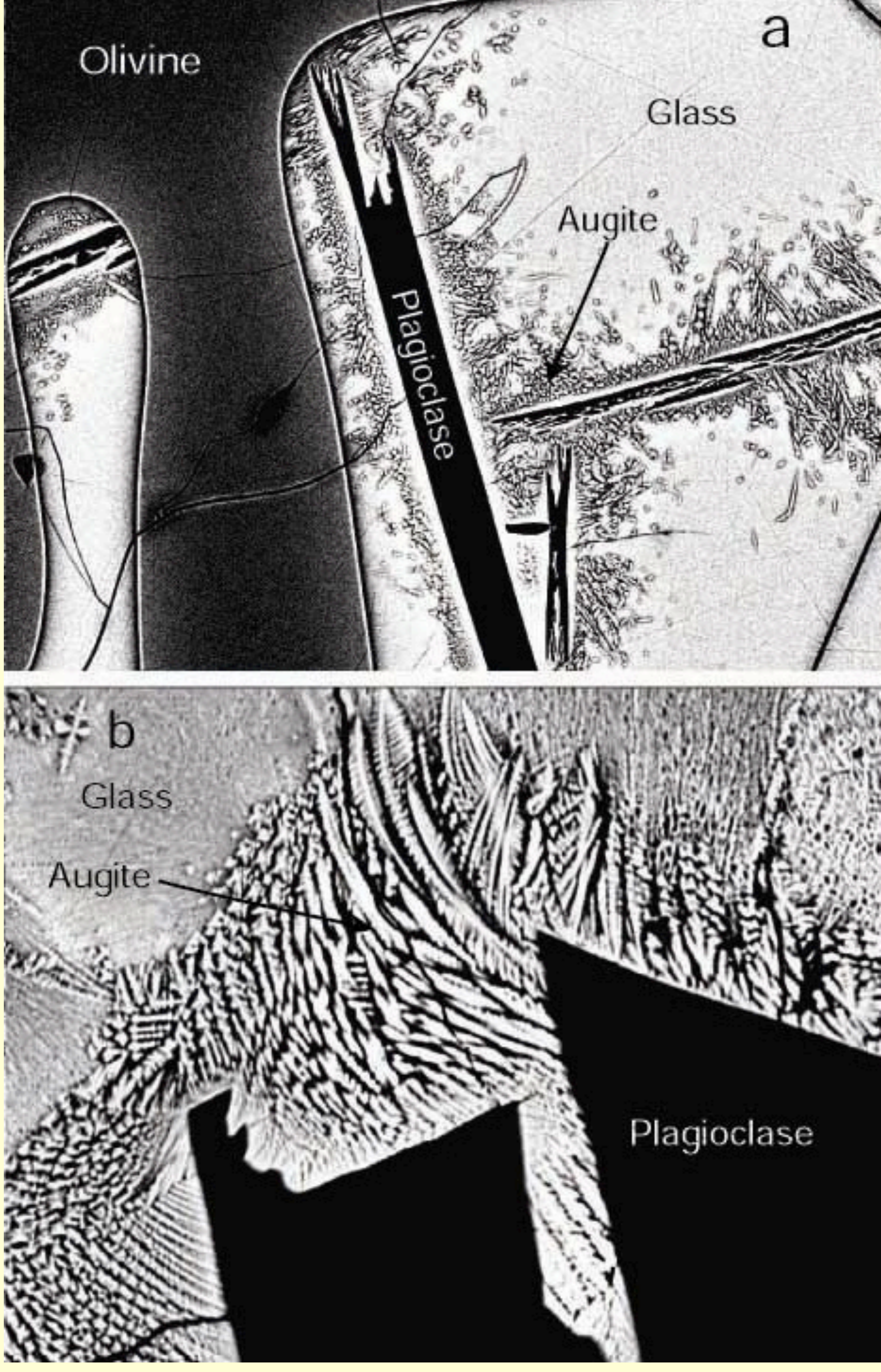
Chapter 3: Igneous Textures

Figure 3.1. Idealized rates of crystal nucleation and growth as a function of temperature below the melting point. Slow cooling results in only minor undercooling (T_a), so that rapid growth and slow nucleation produce fewer coarse-grained crystals. Rapid cooling permits more undercooling (T_b), so that slower growth and rapid nucleation produce many fine-grained crystals. Very rapid cooling involves little if any nucleation or growth (T_c) producing a glass.



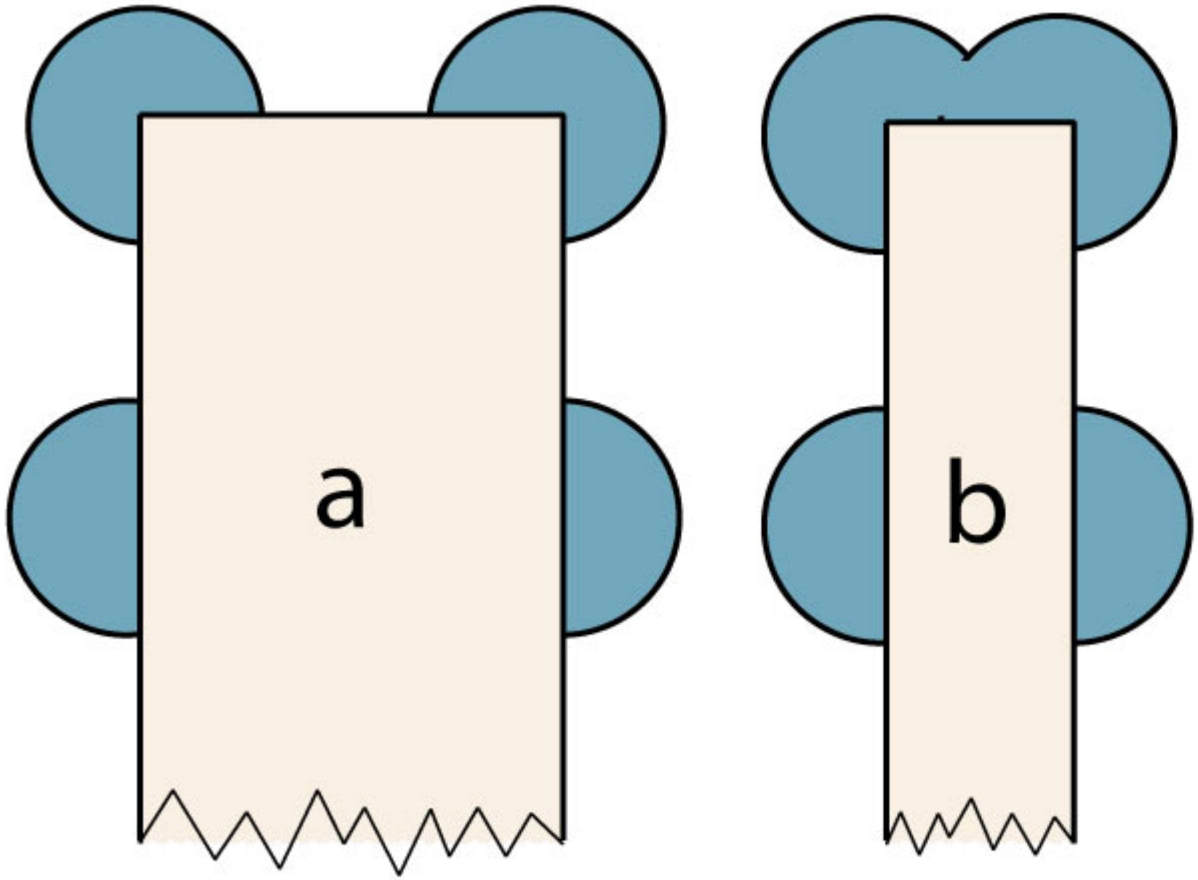
Igneous Textures

Figure 3.2. Backscattered electron image of quenched "blue glassy pahoehoe," 1996 Kalapana flow, Hawaii. Black minerals are felsic plagioclase and gray ones are mafics. **a.** Large **embayed** olivine phenocryst with smaller plagioclase laths and clusters of feathery augite nucleating on plagioclase. Magnification ca. 400X. **b.** ca. 2000X magnification of feathery quenched augite crystals nucleating on plagioclase (black) and growing in a dendritic form outward. Augite nucleates on plagioclase rather than pre-existing augite phenocrysts, perhaps due to local enrichment in mafic components as plagioclase depletes the adjacent liquid in Ca, Al, and Si.



Igneous Textures

Figure 3.3. a. Volume of liquid (green) available to an edge or corner of a crystal is greater than for a side. **b.** Volume of liquid available to the narrow end of a slender crystal is even greater. After Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.



Igneous Textures

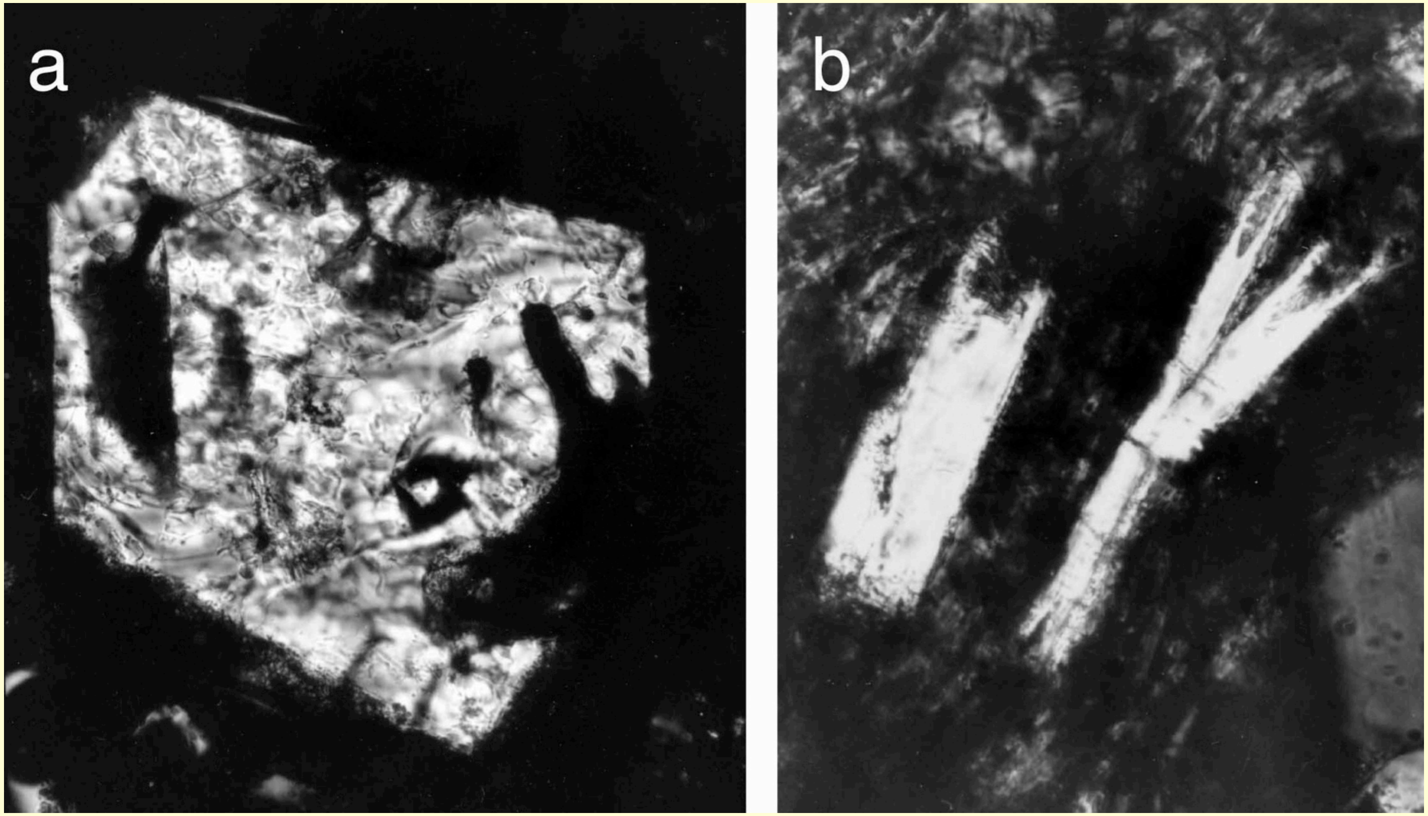
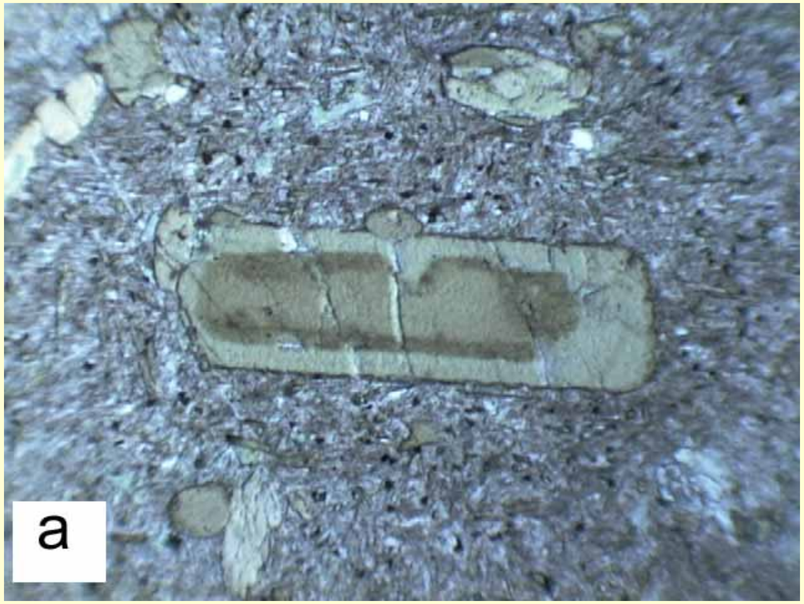


Figure 3.4. a. Skeletal olivine phenocryst with rapid growth at edges enveloping melt at ends. Taupo, N.Z. **b. "Swallow-tail"** plagioclase in trachyte, Remarkable Dike, N.Z. Length of both fields ca. 0.2 mm. From Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.

Igneous Textures



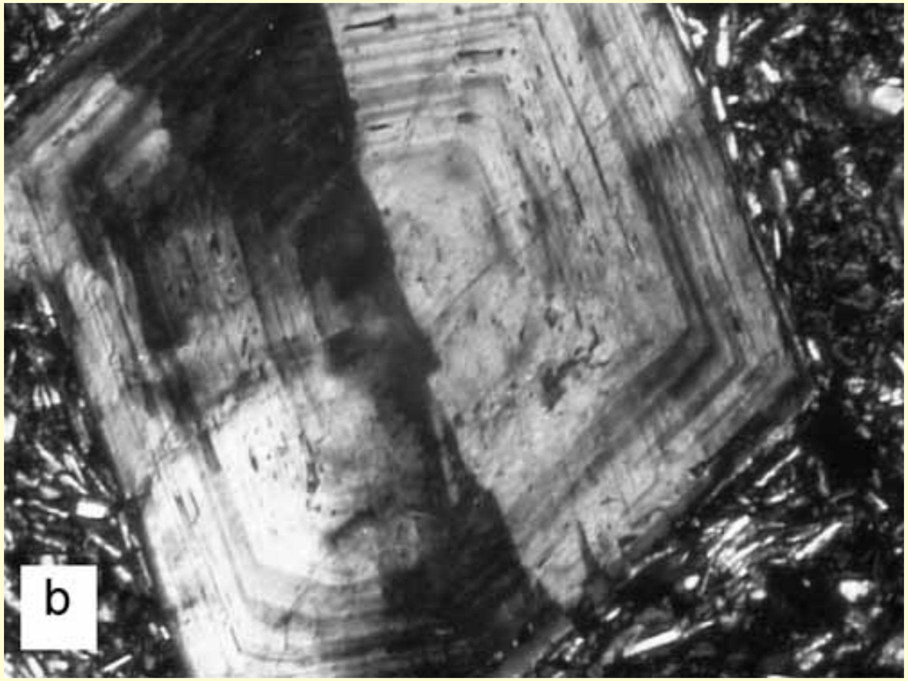


Figure 3.5. a. Compositionally zoned hornblende phenocryst with pronounced color variation visible in plane-polarized light. Field width 1 mm. **b.** Zoned plagioclase twinned on the carlsbad law. Andesite, Crater Lake, OR. Field width 0.3 mm. © John Winter and Prentice Hall.

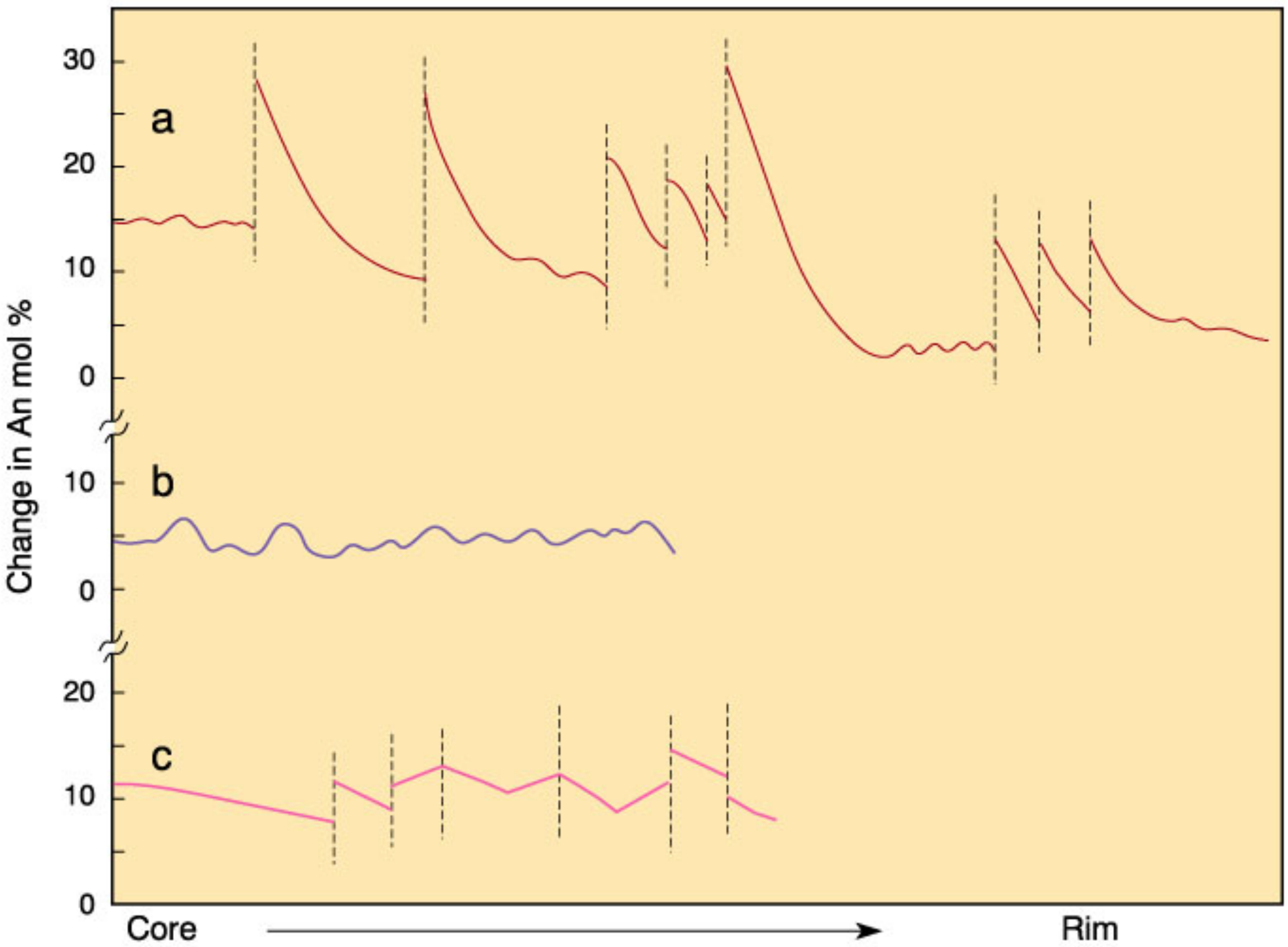


Figure 3.6. Examples of plagioclase zoning profiles determined by microprobe point traverses.

a. Repeated sharp **reversals** attributed to magma mixing, followed by **normal** cooling increments.

b. Smaller and irregular oscillations caused by local disequilibrium crystallization.

c. Complex oscillations due to combinations of magma mixing and local disequilibrium.

From Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.

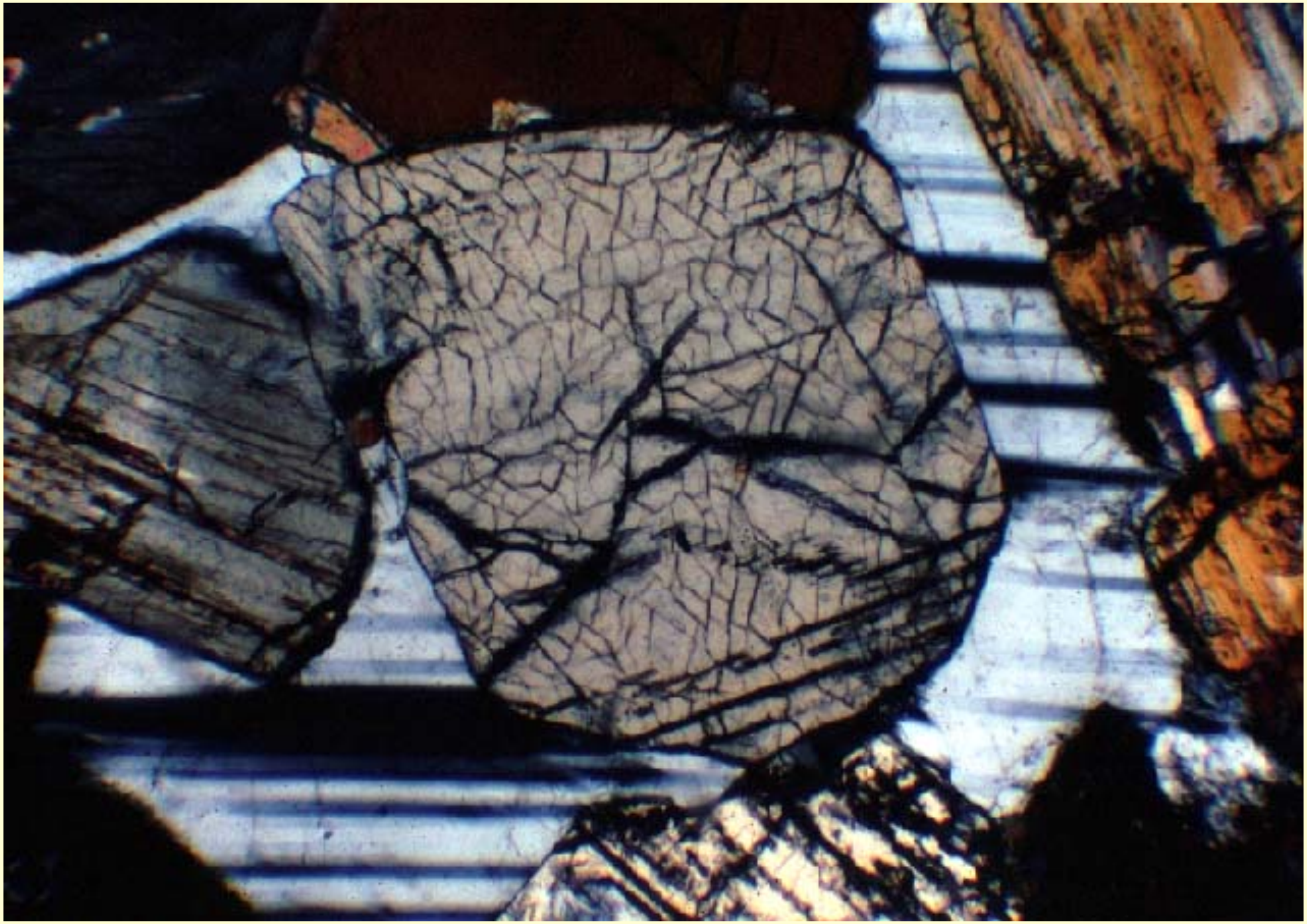


Figure 3.7. Euhedral early pyroxene with late **interstitial** plagioclase (horizontal twins). Stillwater complex, Montana. Field width 5 mm. © John Winter and Prentice Hall.

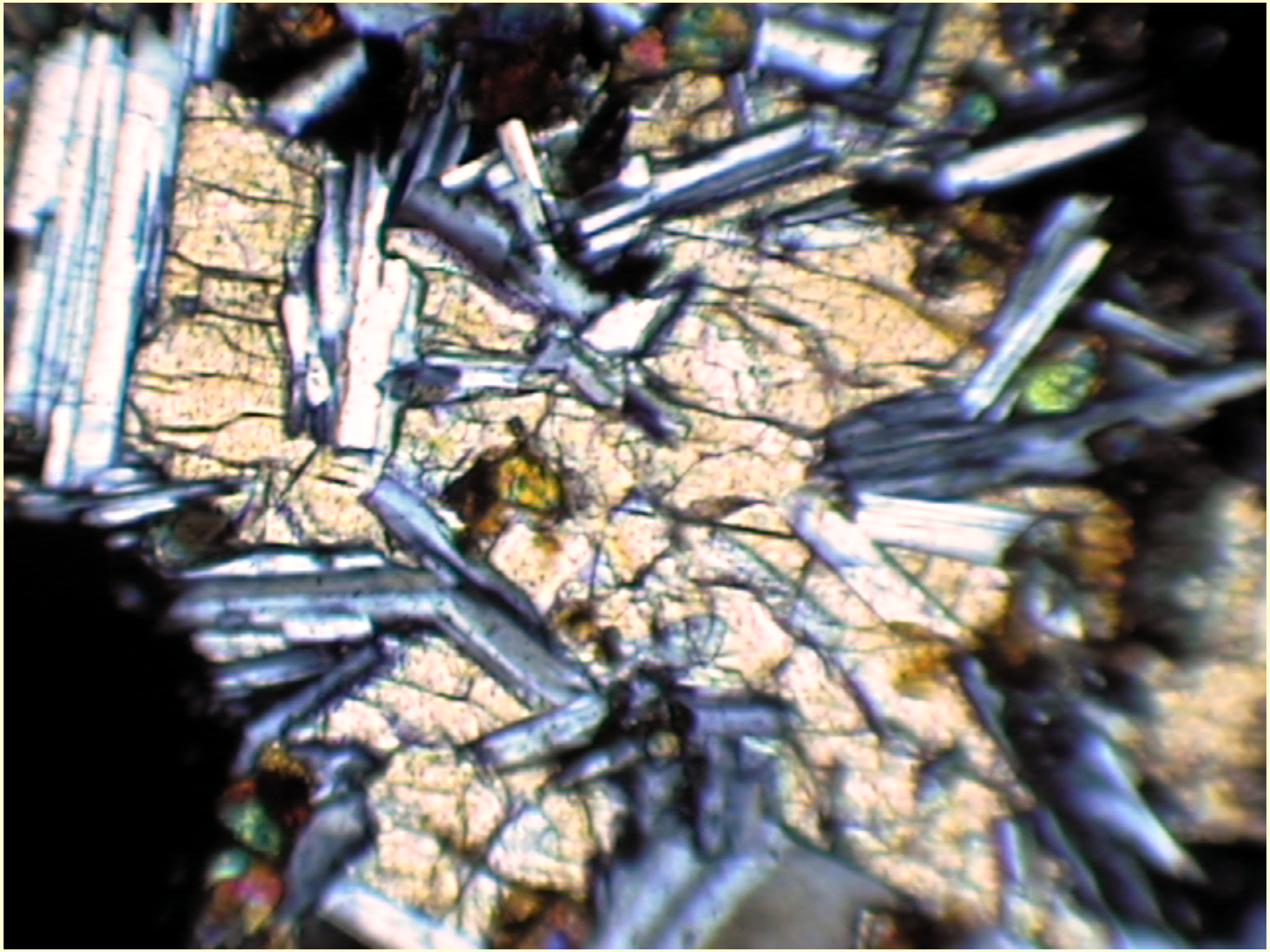
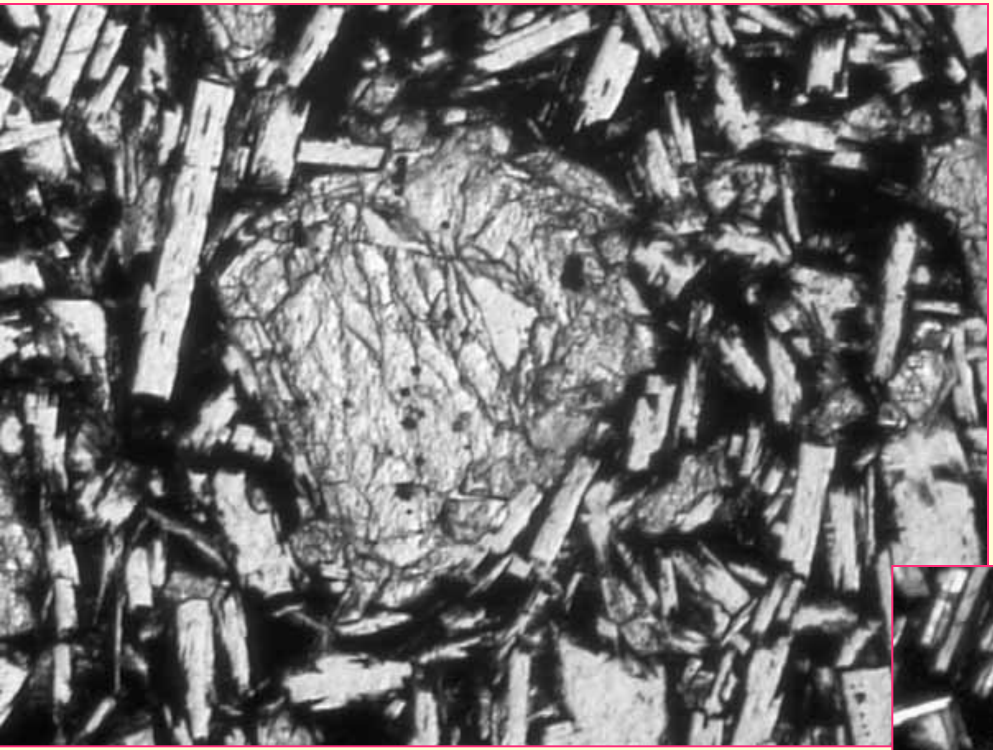


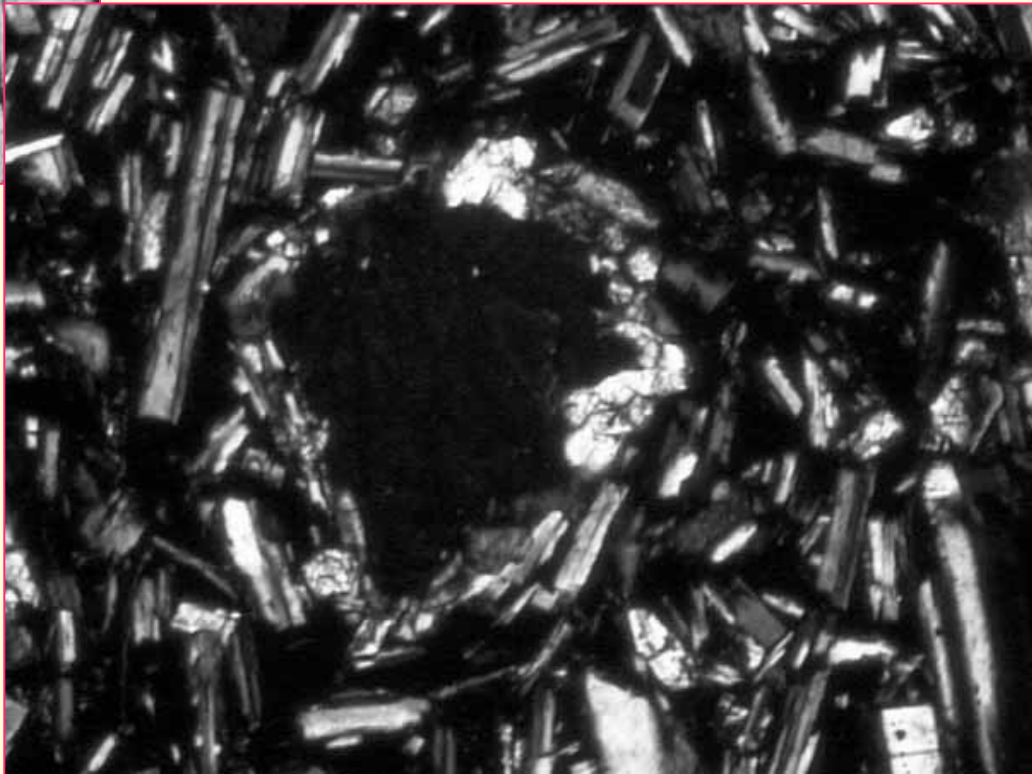
Figure 3.8. Ophitic texture. A single pyroxene envelops several well-developed plagioclase laths. Width 1 mm. Skaergård intrusion, E. Greenland.

Figure 3.10. Olivine mantled by orthopyroxene



(a) plane-polarized light

(b) crossed nicols: olivine is extinct and the pyroxenes stand out clearly.



Basaltic andesite, Mt. McLaughlin, Oregon.

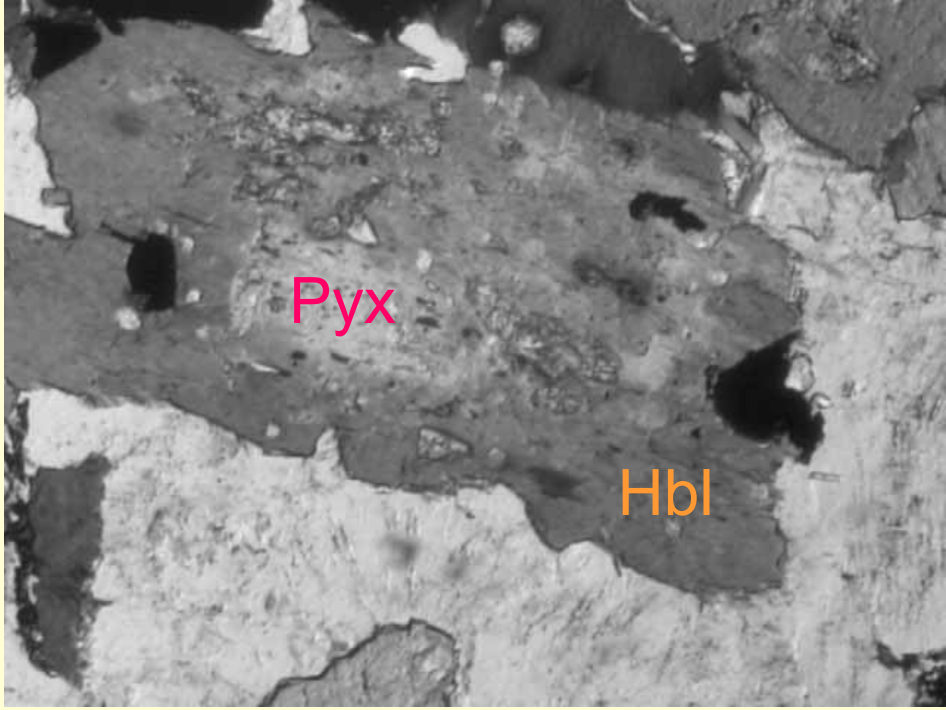
Width ~ 5 mm.

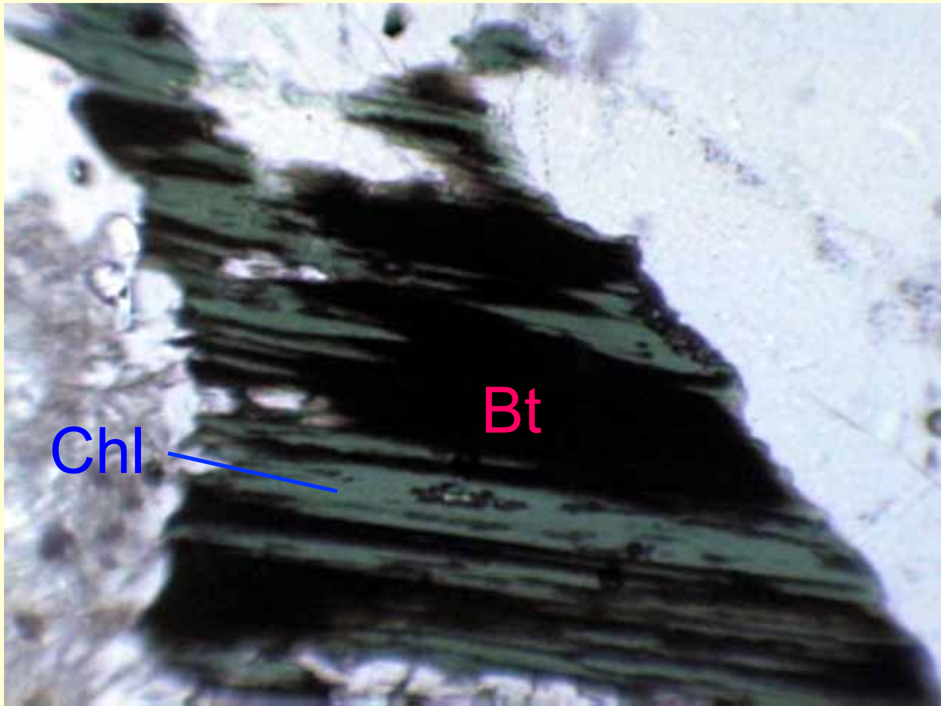
Figure 3.13. **Flow banding** in andesite. Mt. Rainier, WA. © John Winter and Prentice Hall.

Figure 3.12a. **Trachytic** texture in which microphenocrysts of plagioclase are aligned due to flow. Note flow around phenocryst (P). Trachyte, Germany. Width 1 mm. From MacKenzie *et al*. (1982). © John Winter and Prentice Hall.

Figure 3.18. (c-d) Tartan twins in microcline. Field widths ~1 mm. © John Winter and Prentice Hall.

Figure 3.20. a. Pyroxene largely **replaced** by hornblende. Some pyroxene remains as light areas (Pyx) in the hornblende core. Width 1 mm. **b.** Chlorite (green) replaces biotite (dark brown) at the rim and along cleavages. Tonalite. San Diego, CA. Width 0.3 mm.





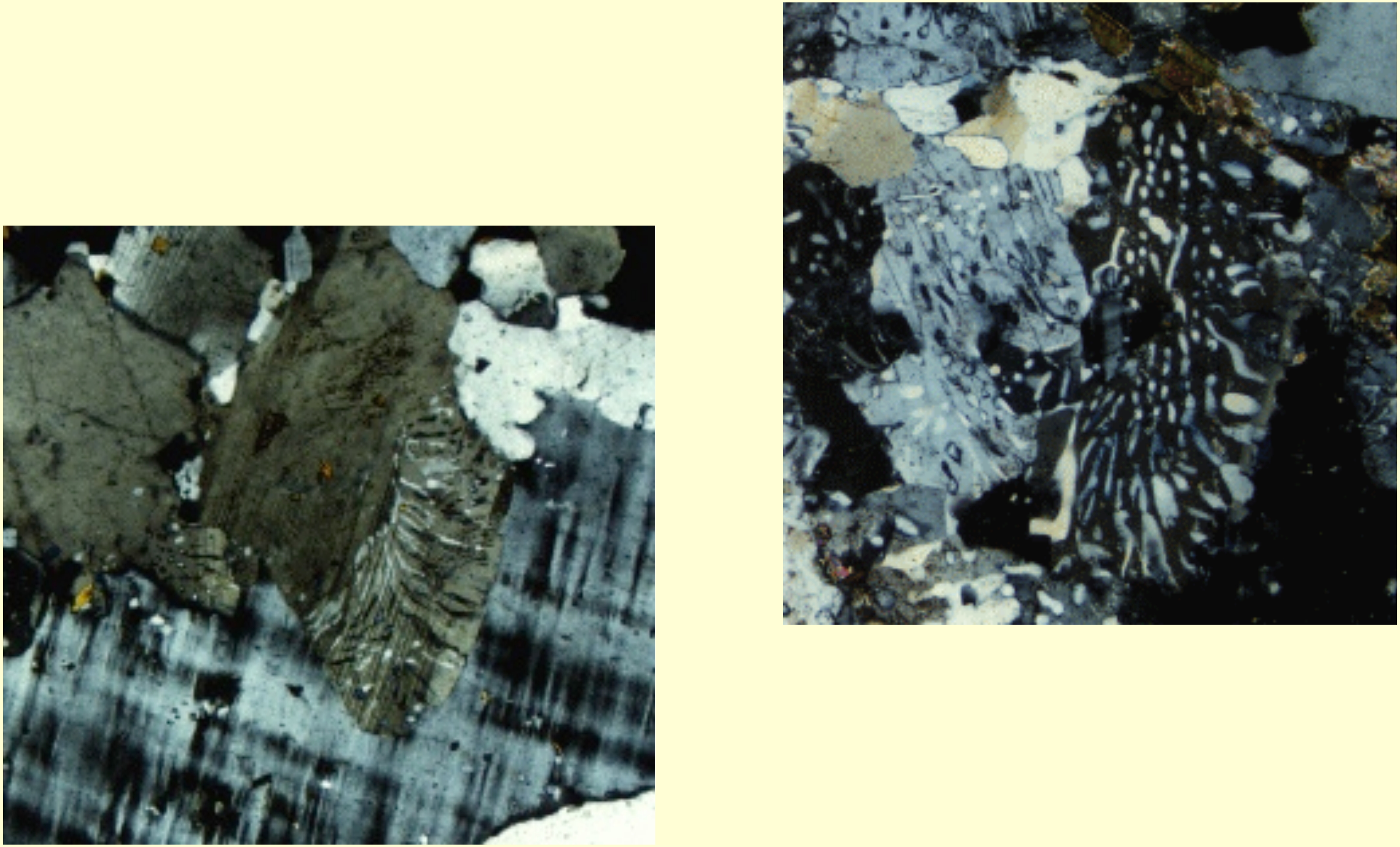


Figure 3.21. **Myrmekite** (dendritic quartz) formed in plagioclase at the boundary with K-feldspar. Photographs courtesy © L. Collins. http://www.csun.edu/~vcgeo005