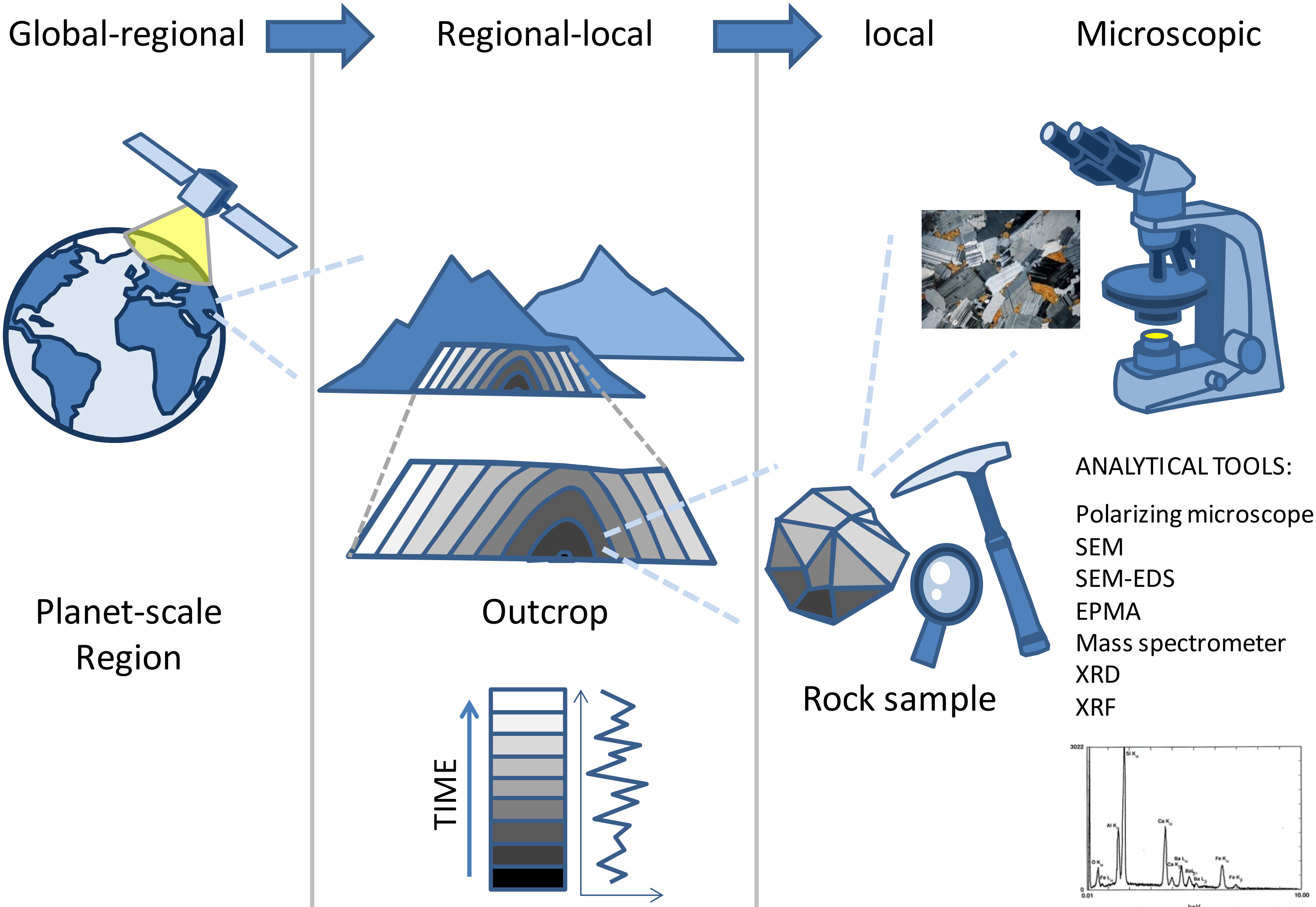
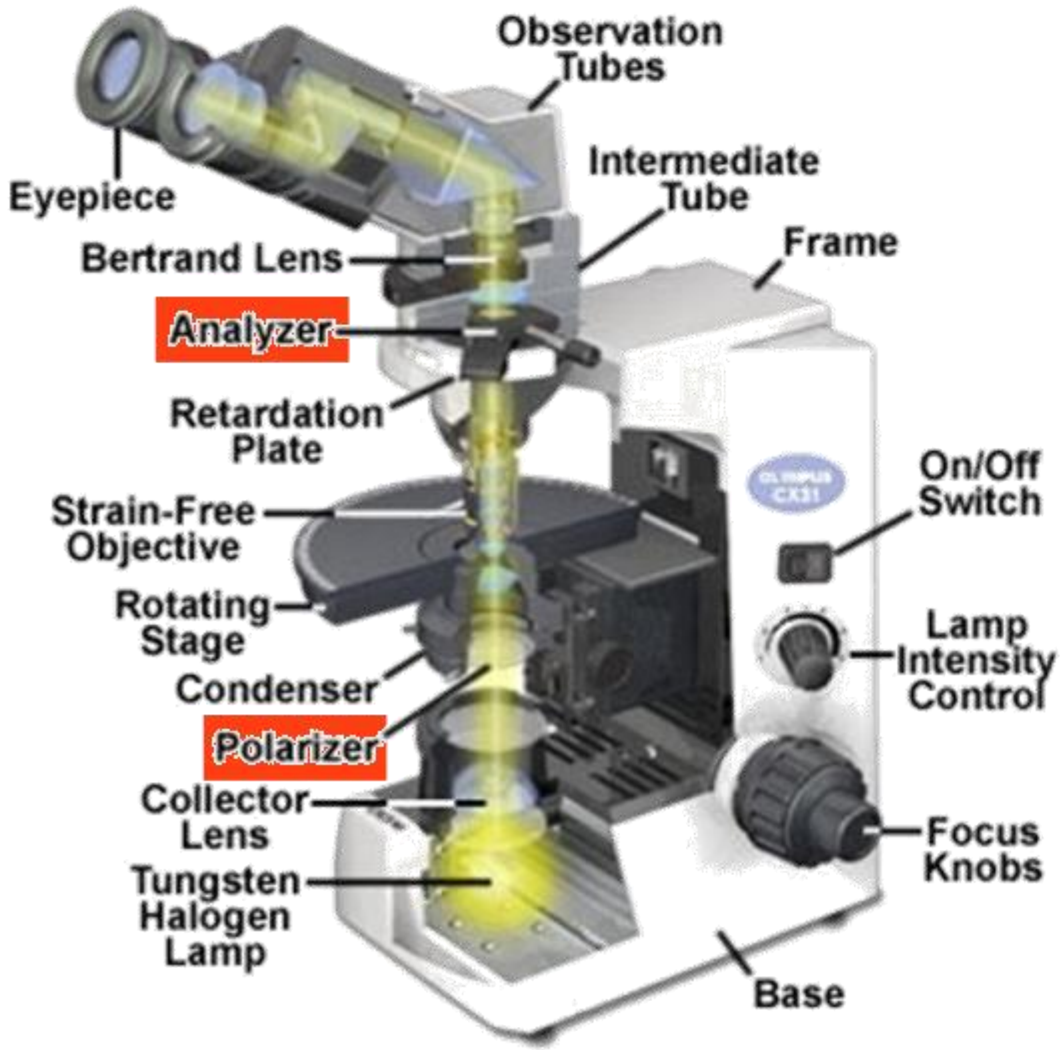
ES1-LAB SESSION


Global-regional
Regional-local
local
Microscopic
Planet-scale
Region
Outcrop
TIME
Rock sample
ANALYTICAL TOOLS:
Polarizing microscope
SEM
SEM-EDS
EPMA
Mass spectrometer
XRD
XRF
3022
keV
0.01
10.00

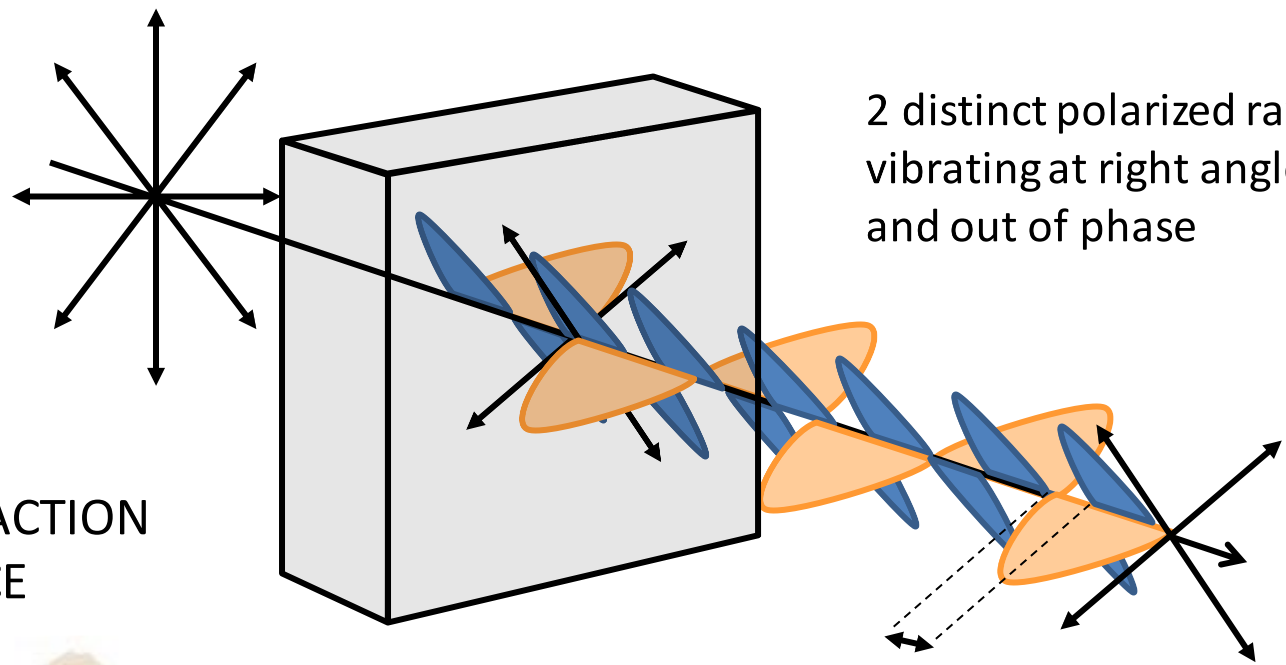
POLARIZING MICROSCOPY



http://www.olympusmicro.com/

ANISOTROPIC MINERAL

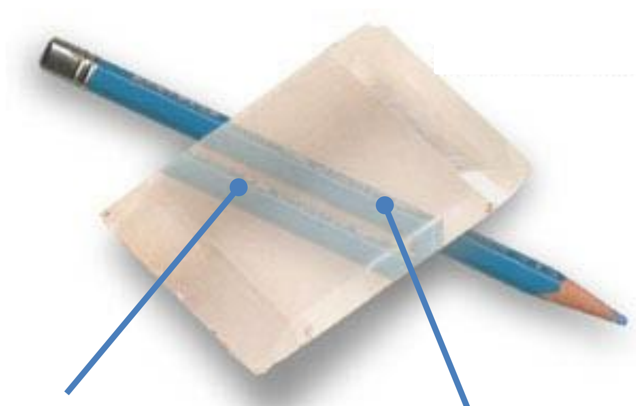
Incident white light (unpolarized)



2 distinct polarized rays vibrating at right angle and out of phase

The slow ray lags behind the fast ray (**retardation**).

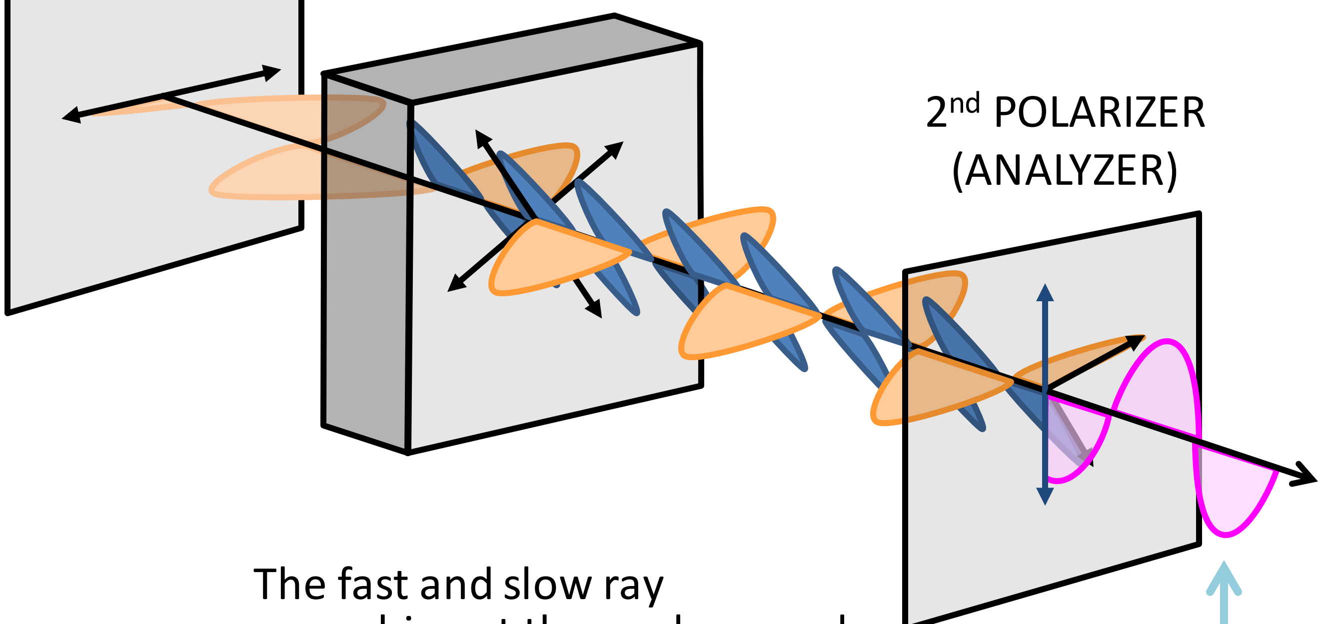
DOUBLE REFRACTION
BIREFRINGENCE

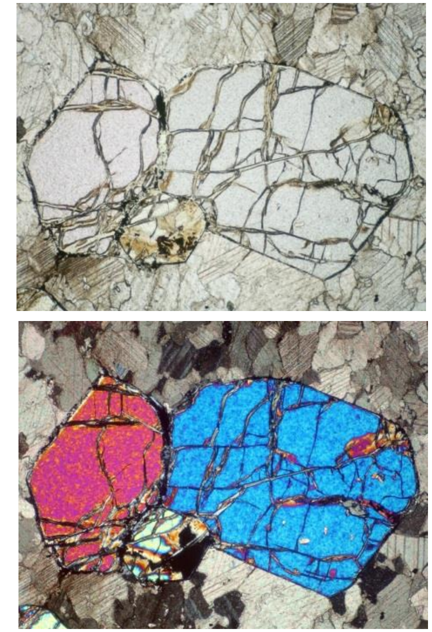


Based on Imperial College Rock Library

1st POLARIZER

In the sample light is split into a fast and slow ray with vibration directions determined by the orientation of the mineral sample



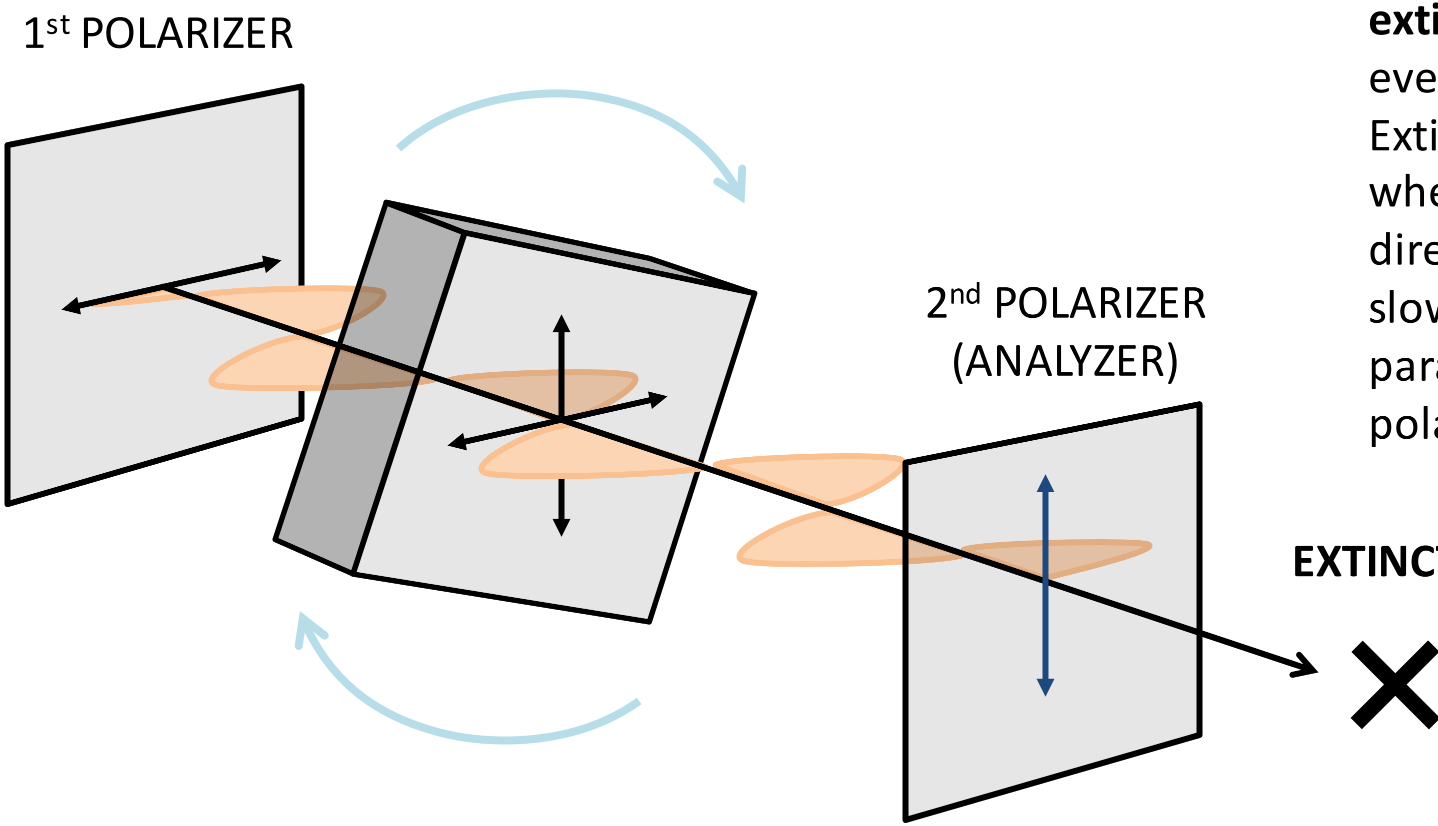


The fast and slow ray recombine at the analyzer and interfere→ **Interference colors**

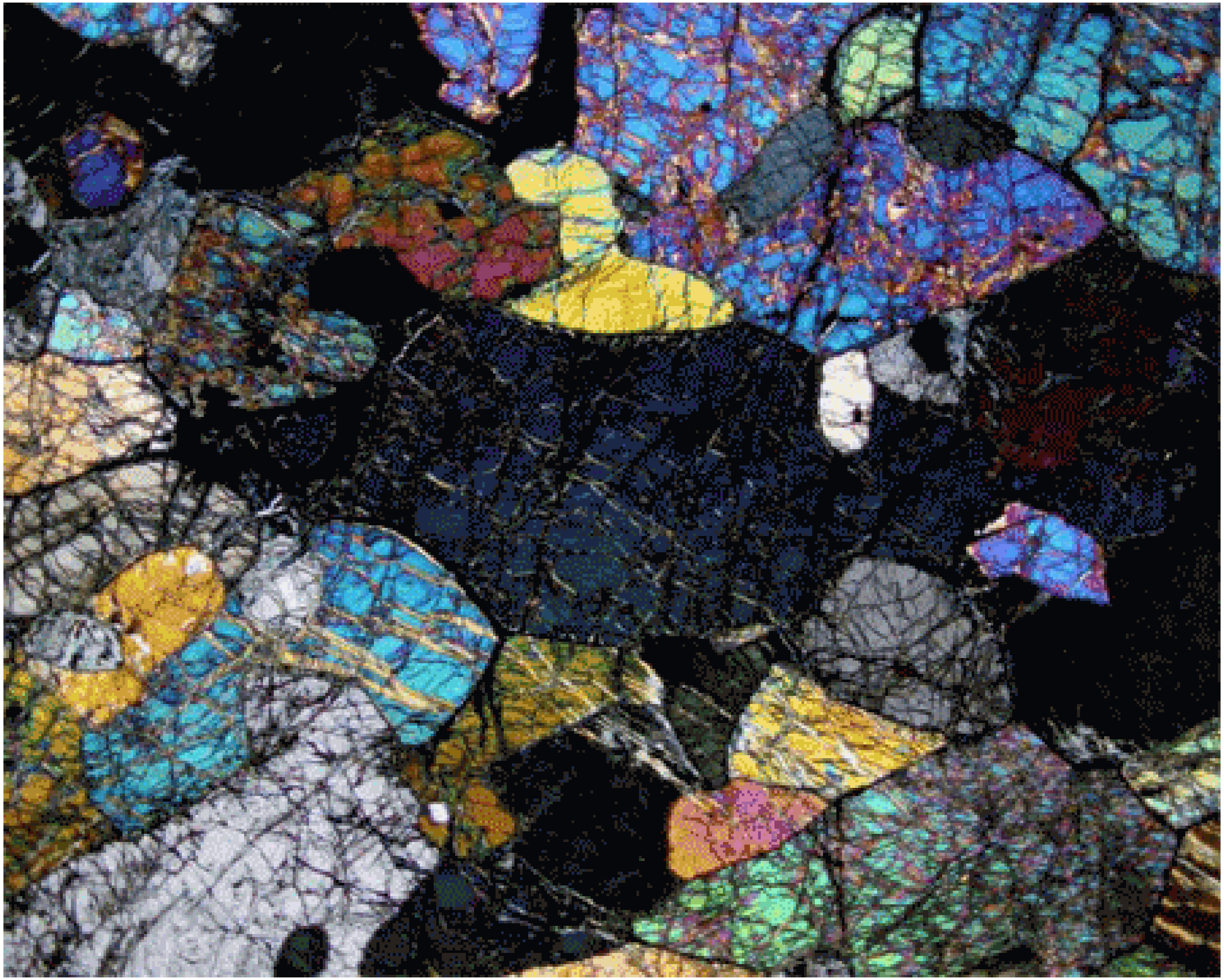
Interference colors depend on

(1) Mineral optical properties (retardation, wavelengths of fast and slow ray)
(2) Crystal orientation
(3) Crystal thickness

Based on Imperial College Rock Library
http://www.earth.ox.ac.uk/~oesis/atlas/metmins/



When the mineral rotates, it becomes **extinct** (black) every 90º. Extinction occurs when the vibration direction of the slow and fast ray is parallel to the polarizers.

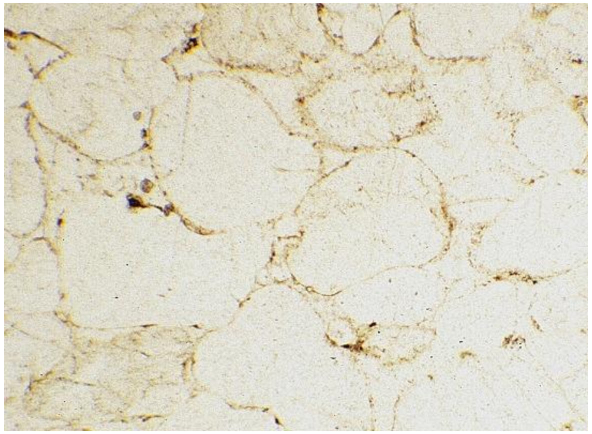


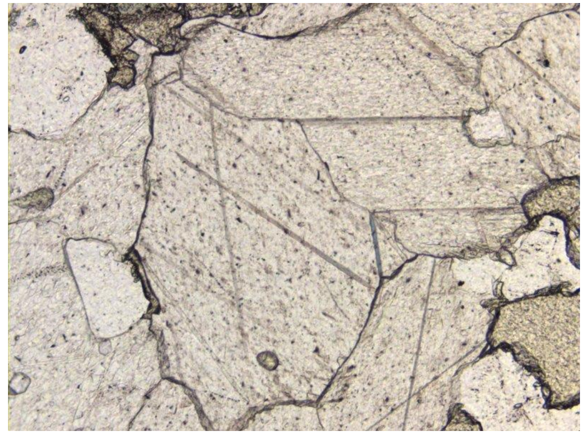
https://www.ig.cas.cz/en/structure/departments/tectonics-and-geodynamics/microstructural-analysis

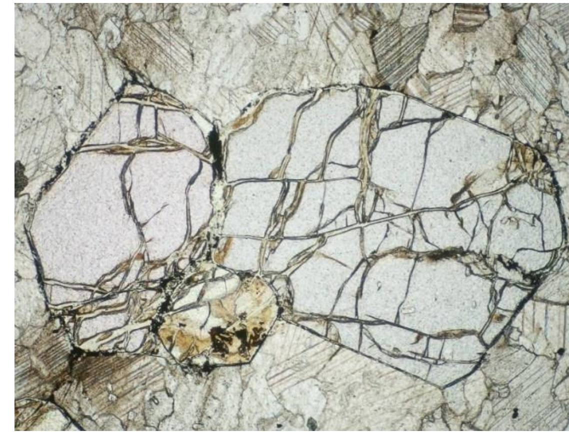
Quartz (SiO_2) | Calcite ($CaCO_3$) | Fosterite (Mg_2SiO_4)

Plane polarized light (PPL)

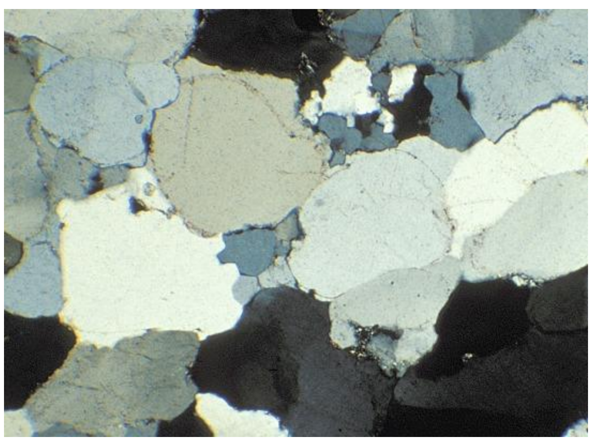
Mg-rich Olivine

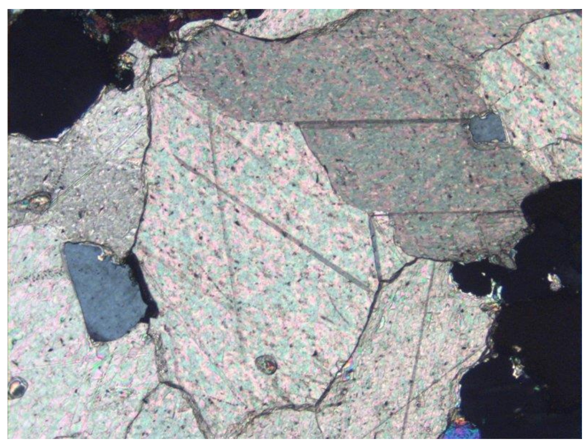


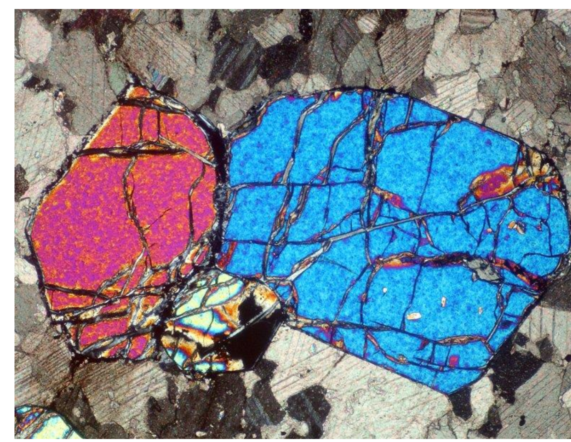




Crossed polarized light (CPL)

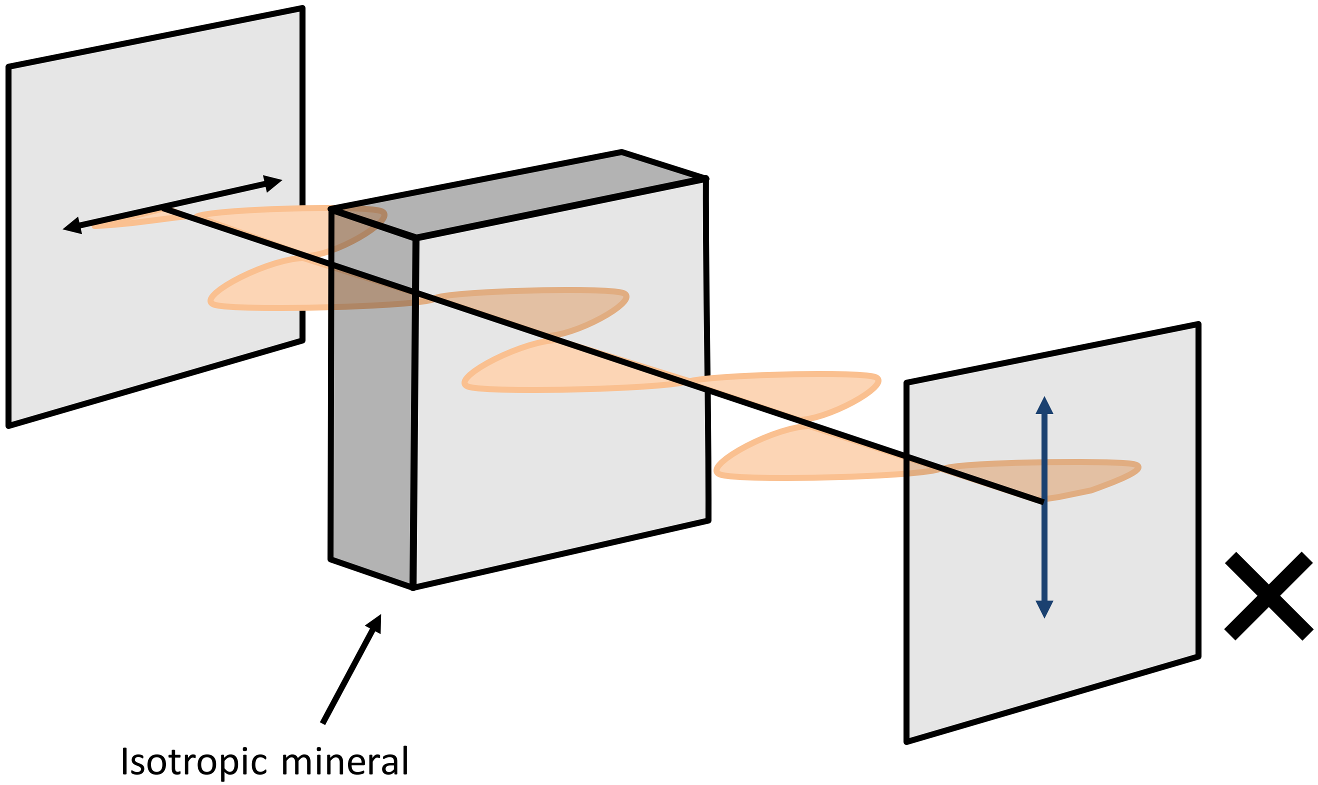






http://www.earth.ox.ac.uk/~oesis/nws/nws-a98-16.html
http://www.earth.ox.ac.uk/~oesis/atlas/metmins/

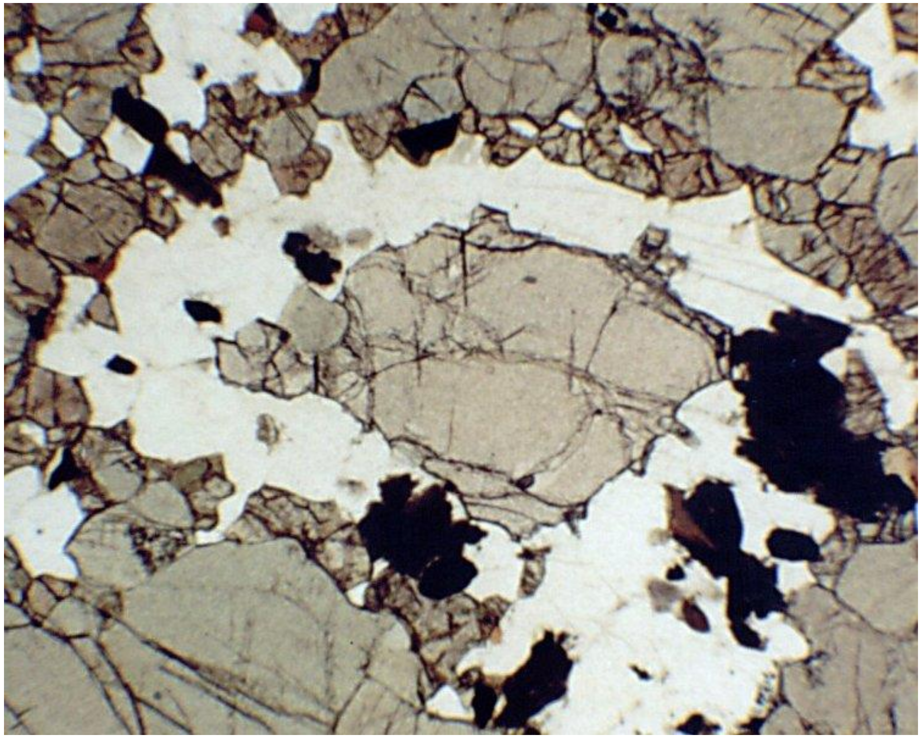
ISOTROPIC MINERAL (e.g. garnet)



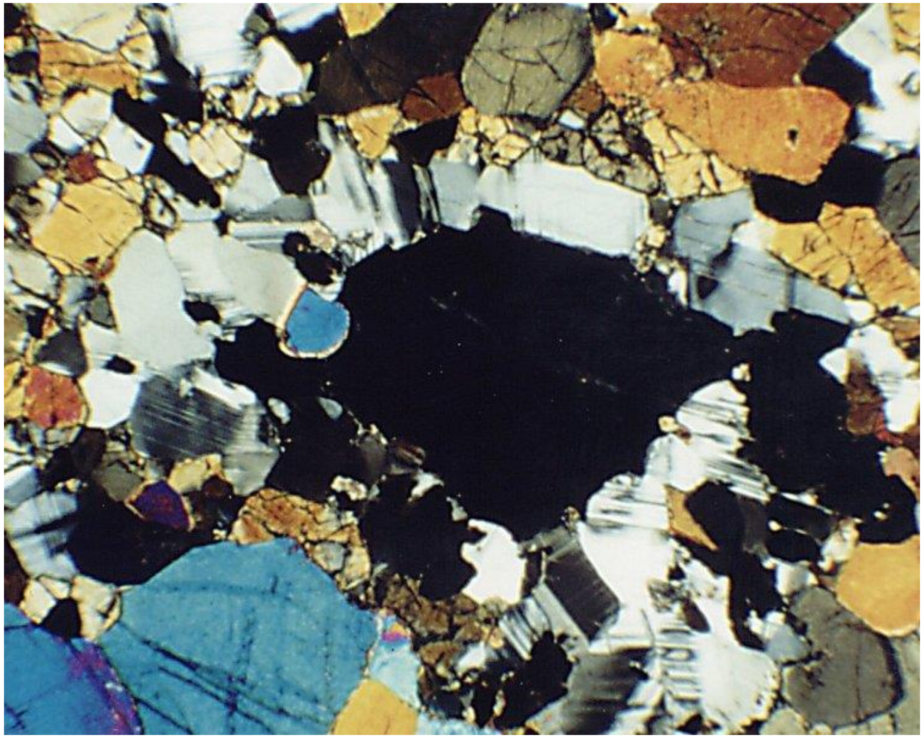
Rotating an isotropic mineral does not affect the outgoing light because the physical properties of the mineral is the same in all direction.

Garnet

Plane polarized light (PPL)



Crossed polarized light (CPL)



SCANNING ELECTRON MICROSCOPE (SEM)

High-energy
electron beam

Electron-sample interactions produce a number of signals:
- Secondary e^-
- Backscattered e^- (BSE)
- Diffracted backsc. e^- (DBSE)
- X-rays
- Visible light (Cathodolumin.)
- Heat

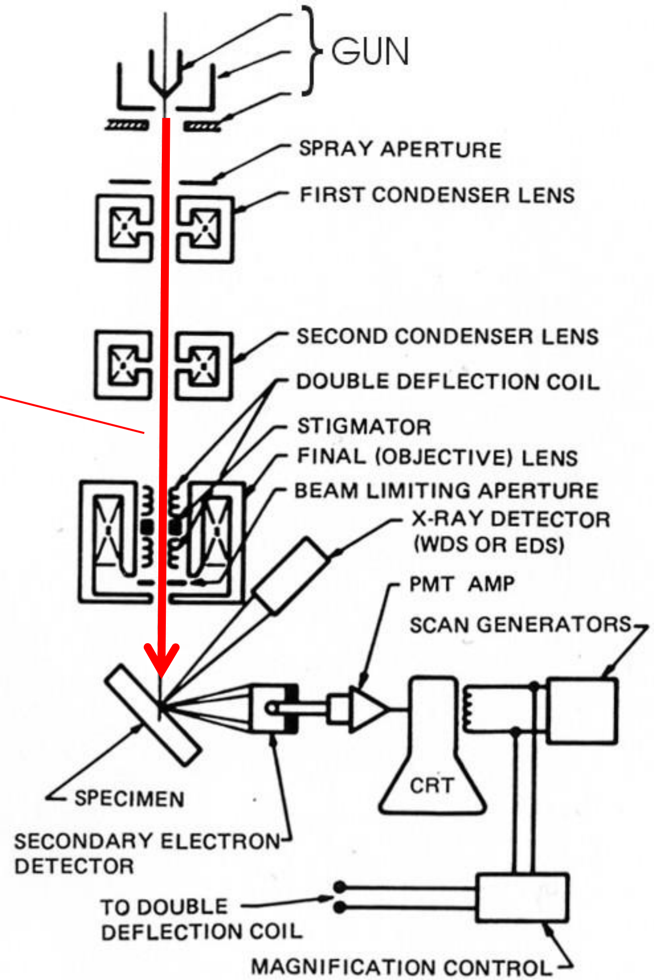


Figure 1.11. Schematic drawing of the electron and x-ray optics of a combined SEM–EPMA.

Secondary electrons
→ sample image

BSE and **DBSE**
→ Structure and orientation of minerals

X-rays (EDS)
→ Chemical composition

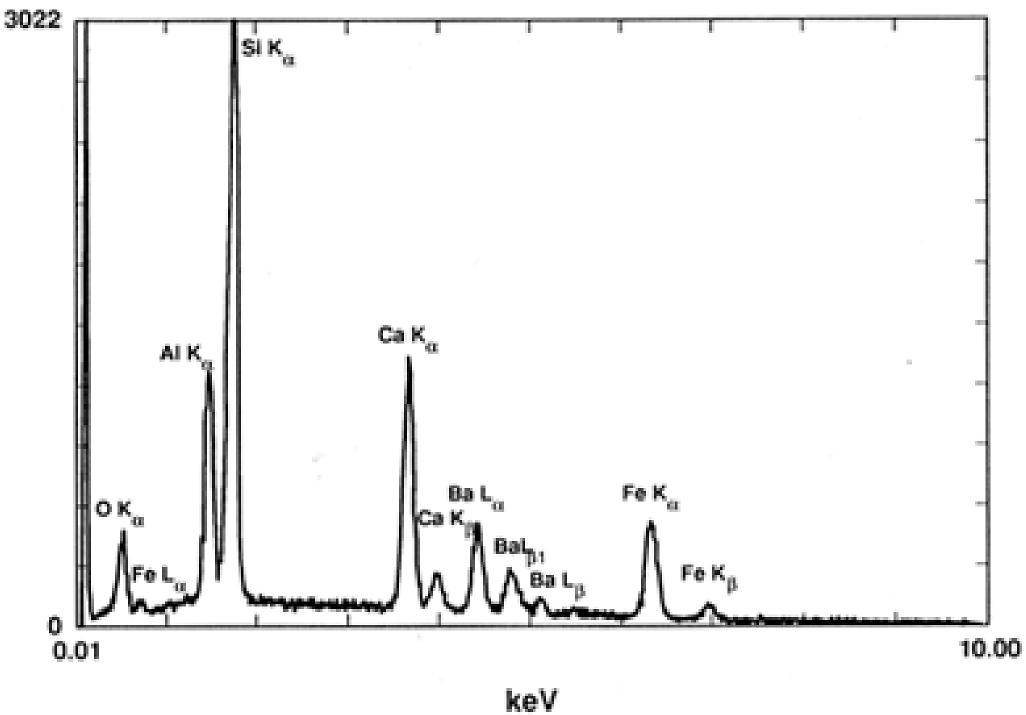
Visible light (cathodo.)
→ Chemical composition

http://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html

Energy-Dispersive X-Ray Spectroscopy (EDS)

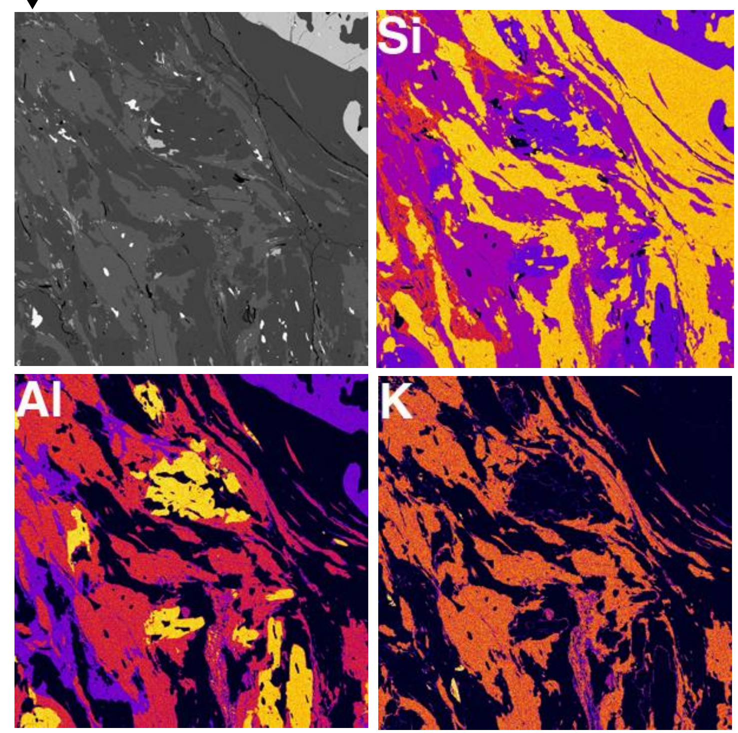
X-rays of different energies characteristic of different elements are separated. Results can be displayed as graphs (A) or elemental maps (B)

(A)



(B)

BSE image of a schist



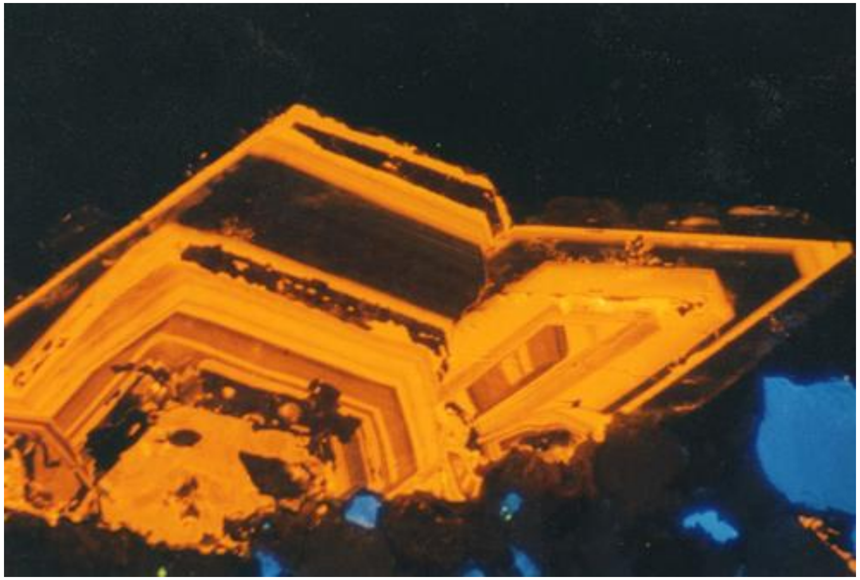
http://serc.carleton.edu/research_education/geochemsheets/eds.html

Cathodoluminescence microscopy

"Cathodoluminescence (CL) is the emission of photons of characteristic wavelengths from a material that is bombarded by high-energy electrons. The electron beam is typically produced in an electron microprobe (EPMA) or scanning electron microscope (SEM-CL) or in a cathodoluminesce microscopy attachment to a petrographic microscope (Optical-CL)."

Darrell Henry, Louisiana State University (http://serc.carleton.edu/research_education/geochemsheets/CLTheory.html)

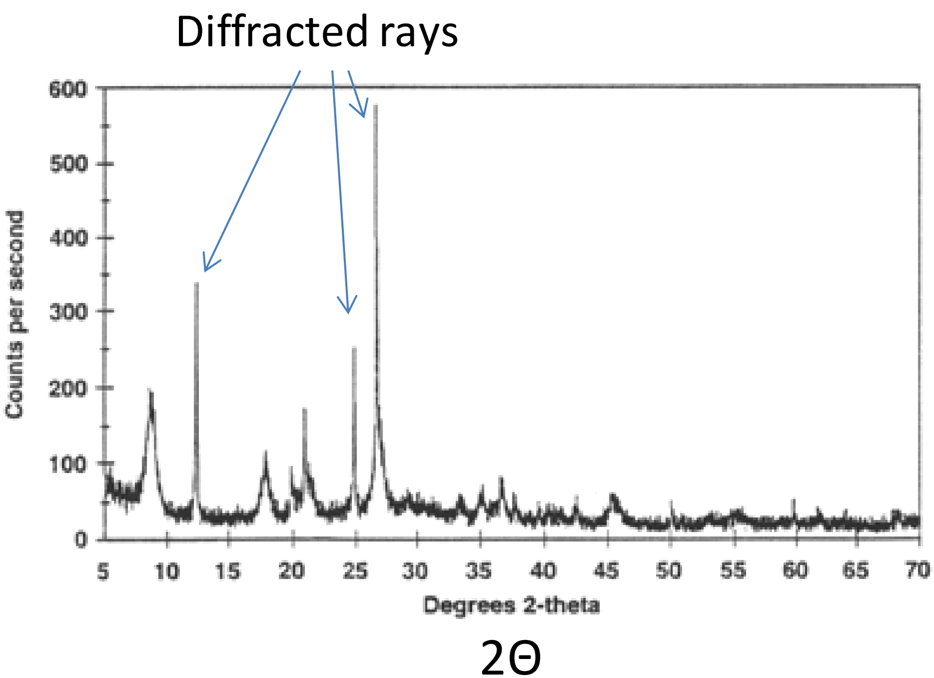
Trace elements promoting CL: Mn^{2+}, Cr^{3+}, Fe^{3+}, Ti^{4+}, rare earth elements (REEs).



http://www.bgs.ac.uk/scienceFacilities/laboratories/mpb/cathodo.html

X-ray powder diffraction (XRD)

X-rays are produced and directed at a rotating sample. The angle at which X-rays are diffracted depend on the spacing between atoms in the crystal lattice of a mineral.



Bragg's law

$$n\lambda = 2d \sin \Theta$$

n: integer

λ: wavelength of incident X-rays

d : spacing of atomic planes

Θ : angle of incidence

This technique is used for mineral identification and reconstruction of mineral structures.

http://serc.carleton.edu/research_education/geochemsheets/techniques/XRD.html

X-ray fluorescence (XRF)

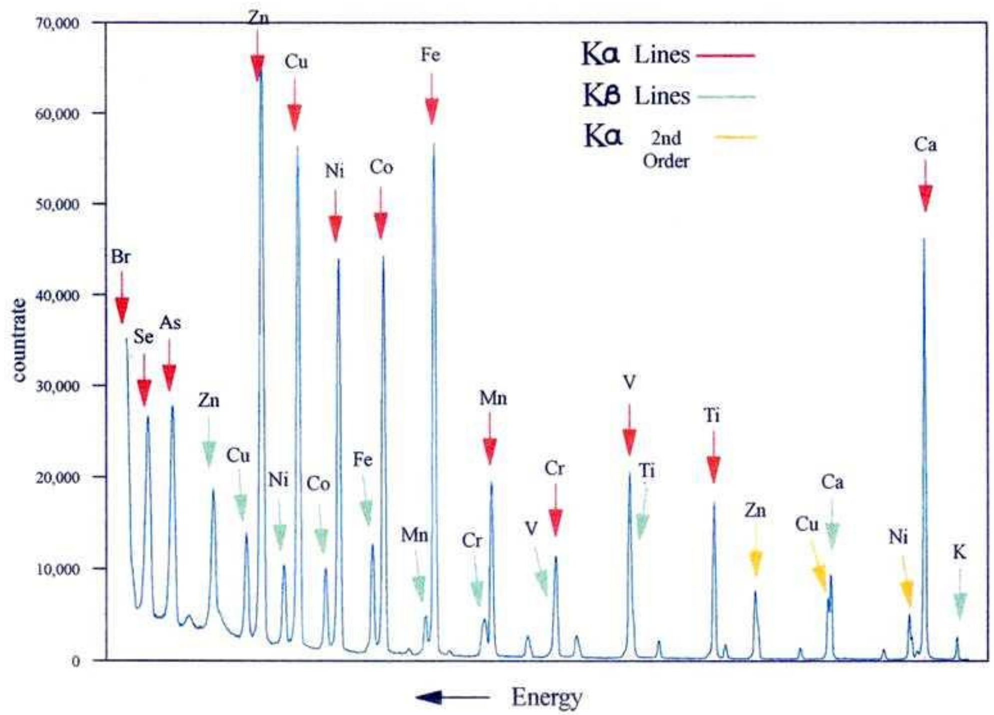
An intense X-ray beam is directed at a sample. Some of the energy is absorbed by the sample and used to dislodge electrons of lower energy levels (usually K and L) = ionization. These electrons are replaced by electrons from outer orbitals, a process accompanied by the emission of radiations in a range of wavelengths. The emitted wavelengths are characteristic of the atoms present in the sample.

The wavelength is given by Planck's law:

$$E = hc/\lambda$$

E = energy
h = Planck constant
λ = wavelength
c = speed of light in a vacuum

This technique is used to determine the abundance of major and trace elements in geological samples.



Wikipedia

http://serc.carleton.edu/research_education/geochemsheets/techniques/XRF.html