

## Metamorphic Minerals

Metamorphism means Change

Rocks Change as Conditions Change

- When changes in conditions of Sedimentary Rocks are not too dramatic, we call changes in the rock **diagenesis** (up to about 200°C)
- When new minerals, which are never observed to form at Earth's surface, form, we call the changes **metamorphism**

Metamorphism is: changes in a rock's mineralogy, texture or composition without melting (in the solid state)

Any kind of rock can become a Metamorphic Rock

- Meta-igneous rocks
- Originally igneous, have been changed
- Meta-sedimentary rocks
- Originally sedimentary, have been changed
- Poly-metamorphic rocks (meta-metamorphic rocks)
- Already metamorphic, changed again

## What causes Metamorphism?

- Increase in temperature (T)
- T increases with depth in the Earth
- Increase in pressure (P)
- P increases with depth (from the load of overlying rock)
- Deformation (changes rock texture)
- Movement of fluids (like water vapor)

## Two main types of Metamorphism

- Contact Metamorphism
- Caused by heat from a nearby pluton
- Forms narrow "contact aureole"
- Regional Metamorphism
- Over large regions
- Usually associated with mountain building

## Metamorphic Minerals

The two most important factors controlling mineralogy of metamorphic rocks are the composition of the rock and the grade of metamorphism.

We account for rock composition by grouping rocks into general compositional classes

- Pelitic rocks            clay-rich sediments, shales
- Psammites             sandstones
- Mafic rocks            basalts and gabbros
- Carbonates            limestones
- Ultramafic            mantle rocks, composed entirely of mafic minerals
- Granitic                granites

We'll consider important minerals in each of these rock types separately

Psammites            meta-sandstones

- start with Quartz and Feldspar
- metamorphic rock has Quartz and Feldspar
- coarser grain size
- rock may be foliated
- called Quartzite or Quartzofeldspathic Gneiss
- Not much change with metamorphism

Metamorphosed Granites

- Start with Quartz, Feldspar and Micas
- Metamorphic rock has Quartz, Feldspar, and Micas
- Rock may be foliated (gneissic layering)
- Metamorphic rocks called granitic gneiss

- Again not much change with metamorphism

## Metamorphosed Shales, Pelitic Rocks

- Sedimentary protolith has Quartz silt and Clay minerals
- Clays contain K, Fe, Mg, Ca, and especially Al in addition to SiO<sub>2</sub>
- These elements can make many new and interesting minerals
- Their mineralogy also changes dramatically with metamorphic grade or intensity

## Some Minerals we already talked about occur in Pelitic Metamorphic Rocks

- Quartz
- Plagioclase
- K-feldspar
- Muscovite
- Biotite

## What are the new and interesting minerals?

- Garnet  $(\text{Ca,Mg,Fe,Mn})_3\text{Al}_2\text{Si}_3\text{O}_{12}$
- Staurolite  $\text{Fe}_2\text{Al}_9\text{Si}_4\text{O}_{23}(\text{OH})$
- Andalusite  $\text{Al}_2\text{SiO}_5$
- Sillimanite  $\text{Al}_2\text{SiO}_5$
- Kyanite  $\text{Al}_2\text{SiO}_5$
- Notice the essential Al, which comes from clays
- All of these minerals are isolated tetrahedral Silicates

- All are porphyroblastic (big, visible crystals!)

## Garnet Structure

## Garnet Properties

## More Garnet Examples

## Garnet Porphyroblasts in thin section

## Staurolite

## Twinned Prismatic Staurolite

## Optical Properties of Staurolite

- High relief
- Low birefringence, max. 1st order yellow
- Clear, yellow or light brown color
- Pleochroic
- Commonly exhibits a sieve-like texture due to abundant quartz inclusions

## Staurolite in a Thin Section

## The Aluminosilicate Polymorphs, $\text{Al}_2\text{SiO}_5$

- Andalusite
- Sillimanite

- Kyanite

View Andalusite Movie

<http://socrates.berkeley.edu/~eps2/wisc/geo360/andalusite.mov>

The  $\text{Al}_2\text{SiO}_5$  Phase Diagram - see handout

### Kyanite Properties

- Blue, bladed crystals (can be clear or white)
- $H=5$  along blades,  $H=7$  across blades
- $SG = 3.60$
- One perfect cleavage
- Luster vitreous, pearly

### Kyanite Optical Properties

- Typically colorless in thin section, may be blue
- High relief, low birefringence, but higher birefringence than andalusite
- Monoclinic, inclined extinction
- Bladed shape and one perfect, one good cleavage characteristic

Kyanite in thin section

Andalusite Properties (Low pressure form of  $\text{Al}_2\text{SiO}_5$ )

- Luster vitreous
- Color pink or white
- $H=7.5$ ,  $SG=3.18$
- Stubby, square prisms
- May show a crossed pattern of graphite inclusions, called Chiastolite
- Optically lower relief and lower birefringence than kyanite

## Andalusite

The  $Al_2SiO_5$  Phase Diagram - see handout

## Sillimanite Properties (hi T polymorph)

- Acicular to thin prismatic
- Clear, colorless and vitreous
- May form mats of fine fibers, called fibrolite
- Optically, sillimanite has high relief, moderate birefringence, and parallel extinction
- Clear needles, thin prisms or fibers

## Sillimanite in thin section

## Sillimanite (Fibrolite)