Lecture Notes - Metamorphism Introduction

- **Metamorphism** is a change of form that includes the growth of new minerals, typically in response to a rise in temperature and normally without the involvement of a magma. If the temperature of metamorphism is high enough for **partial melting** of the rock to occur, the changes would still be called metamorphism until the melt is separated from it's source. Not all changes of form are considered to be metamorphism. **Weathering**, which takes place at or near the earth's surface at low temperature is not included. **Digenesis**, which includes all the changes that occur to sediment after deposition leading to and following lithification, is also not included, but the boundary between diagenesis and metamorphism is fuzzy.

- By far the most common is **regional metamorphism**, which extends over large areas and involves deformation and high pressure as well as high temperature. Growth of metamorphic minerals while the rock is under stress produces the foliation that is characteristic of most regional metamorphic rocks. Intermediate pressure (4-12 kb - **Barrovian**) regional metamorphism is a result of the burial and heating that accompanies the collision of two pieces of continental crust, as is occurring the Himalayas today. Low pressure (0-4 kb - **Buchan**) regional metamorphism is a result of many intrusions in a region undergoing a continental collision. This may be called **regional contact metamorphism**, because of the many intrusions. High pressure (10-25 kb blueschist), low temperature (<500°C) regional metamorphism occurs in subduction zones.

- **Contact metamorphism** occurs when the rocks that are intruded or covered by magma are heated by the magma. The resulting contact metamorphic rocks form a **contact aureole** around the magma source with the temperature of metamorphism increasing toward the contact with the igneous rock, in some cases at quite low pressure. Contact metamorphism can occur without penetrative deformation, producing metamorphic rocks without foliation. Ocean floor or ocean ridge metamorphism occurs at or near mid-ocean ridges and is the result of circulating sea water heated by circulation through hot volcanic rocks. **Cataclastic metamorphism** occurs along faults due to the frictional heating and deformation associated with the faulting.

- Metamorphism is nearly **isochemical** with only limited changes in whole rock chemical composition. Volatiles, such as water and carbon dioxide, are generally lost during metamorphism. Other elements may be redistributed within the rock by chemical diffusion but are not likely to leave or enter the rock because of the limited scale of diffusion through rocks. Fluids flowing through fractures and pores in rocks may lead to changes in chemical composition. Where such changes have been observed, the chemical change is called **metasomatism**.

- **Metamorphic grade** is "the extent or rank of metamorphism, measured by the amount of degree of difference between the parent rock and the metamorphic rock" according to the AGI *Glossary of Geology*. Generally, metamorphic grade is closely associated with the maximum temperature of metamorphism so that higher-grade rocks have experienced higher temperatures.

- Metamorphic rocks experience a range of pressures and temperatures as they are buried and exhumed, a **P-T path**. The mineral assemblage in a metamorphic rock typically reflects the highest temperature (and associated pressure) that occurs along the P-T path. Metamorphic rocks retain their high temperature mineral assemblages because the water (and carbon dioxide) needed for the low temperature minerals is no longer present in the rock. When water is present or is added during cooling, the high-grade minerals may be partially to completely replaced. This **retrograde metamorphism** is typically patchy or local in scale, reflecting the access of water.

- The **mineral assemblage** of a metamorphic rock is the set of minerals that occur in contact with one another. Because the minerals are in contact, it is believed that they may have been in chemical equilibrium during metamorphism. The mineral assemblage of a rock depends on its bulk composition and on the conditions of metamorphism. One outcrop may contain a number of different mineral assemblages if it includes layers of different chemical composition.

- **Metamorphic facies** is the entire suite of mineral assemblages that occur in a local area. The facies includes all possible mineral assemblages for all bulk compositions at a given set of physical conditions (P, T, a_{H2O}). It is based on the assumption that metamorphic rocks represent a close approach to equilibrium. The metamorphic facies of a rock is a more precise concept than its metamorphic grade. If you know to what facies an outcrop belongs, you can say (in principle) what the mineral assemblage should be for any bulk composition. However, since rocks have a P-T history, not just a maximum temperature, the metamorphic facies will apply only to one part of the P-T path.

- A **metamorphic isograd**, a line of "constant grade", is a line on a map (a surface in three dimensions) that separates rocks that appear to be at different grade. Most commonly, isograds mark the first appearance (when traveling up grade) of a mineral, such as garnet, in a particular terrain. Because the growth of a mineral can depend on bulk composition as well as temperature and pressure, isograds must be considered in their full context.

- Metamorphism generally includes a number of **textural changes**. Indeed, for some rocks the primary changes that occur during metamorphism are textural. These rocks are composed of minerals that are stable both in the original rock and in the metamorphic product. Examples include: sandstone --> quartzite; limestone --> marble. Commonly observed textural changes are:

  - **coarsening** of grain size
  - **evening** of grain size (among all grains of the same mineral)
  - tendency to develop "**mosaic texture**" (120 degrees grain junctions -<)
  - the elimination of porosity (holes)
  - the parallel growth of minerals (**foliation**, **schistosity**) or the axes of mineral prisms (**lineation**), due to growth under stress. This is manifested by a tendency for the rock to break parallel to these minerals.
  - the development of **folds**
  - the **stretching** of mineral grains as in "stretched pebble conglomerates"

- the **rolling** of mineral grams as in John Rosenfeld's rolled garnets
- the **crushing** of mineral grains as in cataclastic rocks

Many of these changes are related to the principle of minimizing surface or interface area.

- Names for metamorphic rocks tend to be simpler and more descriptive than names for igneous rocks. In general, name is based on a texture plus mineralogic modifiers. Some common names are:

slate - a fine-grained metamorphic rock with a slatey cleavage. The mineralogic composition of a slate may be difficult to determine even under a microscope
phyllite - a very fine-grained schist. There are sufficiently coarse micas in a phyllite to impart a good sheen to its surface.
schist - a relatively coarse-grained metamorphic rock that exhibits a good schistosity (ease of splitting) due to the parallel orientation of coarse, visible micas.
gneiss - a relatively coarse-grained metamorphic rock that exhibits a coarse foliation and commonly a compositional banding parallel to that foliation.
granulite - a metamorphic rock in which the minerals are roughly equant and all about the same size - a sugary texture.

These names are used with mineralogical modifiers such as: hornblende granulite, staurolite-biotite-garnet schist, and andalusite phyllite. Other names are in use for specific rock types that have a principal mineral or texture. These include:

amphibolite - predominantly amphibole
pyroxenite - predominantly pyroxene
marble - predominantly carbonate
quartzite - predominantly quartz
serpentinite - predominantly serpentine
greenschist - a metabasalt that is green from chlorite, epidote, and/or actinolite
greenstone - a fine-grained metabasalt that is green in color, but lacks schistosity
blueschist - a metamorphic rock containing abundant glaucophane
eclogite – a metabasalt consisting principally of omphacite and garnet
hornfels - a very fine-grained, even-textured rock that may be splintery on impact (some have been used for arrowheads), commonly produced by contact metamorphism

If the protolith is known, a metamorphic rock can be named after the protolith with a "meta-" prefix. Examples include **metabasalt**, **metapelite**, and **metacarbonate**.