Earth's Rocks 3:
Metamorphic Rocks and Environments

Metamorphic Rocks

Metamorphic rocks are formed by the transformation of pre-existing rocks in the solid state under the influence of high temperatures (T) and/or pressures (P) and chemically reactive fluids. The temperature range is higher that that under which diagenesis occurs, but lower than that at which the rocks will melt. All types of rocks (Igneous, Sedimentary, Metamorphic) may be metamorphosed. The overall chemical composition of the rock may or may not change as a result.

There are three basic types of metamorphism:

Contact/Thermal metamorphism (high T conditions)

Regional metamorphism (high T and P conditions)

Metasomatism (alteration by chemically reactive fluids)

Metamorphic alterations

Metamorphic processes may result in the following changes:

1) Textural alterations (most common)

2) Mineralogical alterations

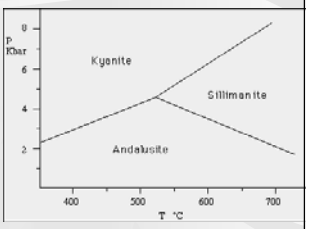
3) Changes in bulk chemistry (composition) of the rock (least common)

Note: Mineralogical changes may occur without the addition or loss of chemical elements/compounds (i.e. without compositional changes). Mineralogical change without compositional change is mainly due to equilibration of the rock material with the new temperature and/or pressure conditions.

As you already know, different minerals are stable (at equilibrium) at different temperatures. The same holds true for minerals under different pressure regimes.

A Classic Case: Kyanite, Andalusite and Sillimanite (Al_2SiO_5)

The minerals Kyanite, Andalusite, and Sillimanite have the same chemical composition (Al_2SiO_5), but different crystal structures. Such minerals are referred to as "polymorphs" of one another.



These minerals are stable under different ranges of temperature (T) and pressure (P) as shown in this diagram.

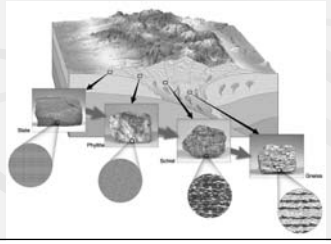
Andalusite is stable under lower pressures, while Sillimanite and Kyanite reflect generally higher pressure regimes.

As the P and T conditions under which these minerals are stable are well known, their presence in metamorphic rocks can reveal a considerable amount of information about the conditions of metamorphism.

Types of Metamorphism

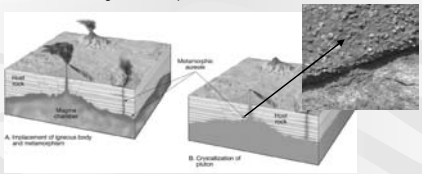
Regional metamorphism (most extensive form): occurs when pre-existing rock is subjected to heat and pressure on a regional scale.

Commonly associated with mountain building events in which rocks are buried to great depths and squeezed by compressive forces.



Contact metamorphism: occurs when a pre-existing rock is subjected to high temperatures under a relatively low pressure regime.

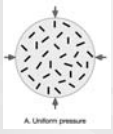
This commonly occurs when country rock is heated by an igneous intrusion, forming a metamorphic halo or "aureole" of local extent.



Due to high heat flow and low pressures, the mineral grains recrystallize in random orientations. The overall composition of the rock basically remains the same, though the altered texture is generally coarser (larger crystals). Other changes (e.g. colour) may also be noted due to various minor chemical effects.

Metamorphism: Foliation

In contact metamorphism, pressure is generally uniform in all directions. As a result, grains of platy minerals such as micas, and elongate minerals such as pyroxenes and amphiboles retain a random orientation.



Regional metamorphism generally occurs in areas where two lithospheric plates are pressing against one another. The rocks here are consequently subjected to differential stress.

In response to this stress, platy/elongate minerals line up (perpendicular to direction of maximum compression) to produce a ***foliated*** texture (*folium* = leaf)

Common Metamorphic Rocks

Non-foliated rocks

Some metamorphic rocks, whether formed by contact or regional metamorphism always have a non-foliated (also called granoblastic) texture. This is because they lack platy/elongate minerals required to define a foliation.

Such rocks include quartzite (formed via metamorphism of quartz sandstone), and marble (formed via metamorphism of limestone).

In both cases, the mineral crystals grow in size and form an interlocking texture. Fossils once present in the original sedimentary rock are obliterated due to this recrystallization.

Common Metamorphic Rocks

Foliated rocks

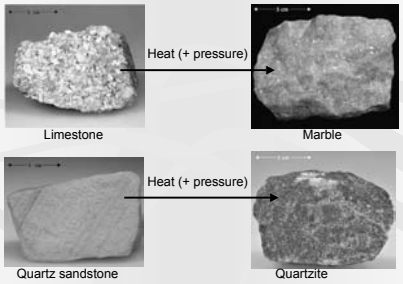
Rocks containing platy/elongate minerals which are subjected to regional metamorphism will typically produce metamorphic rocks which are foliated.

Increasing intensity of metamorphism (in terms of T and P conditions; known as "metamorphic grade") results in the production of larger mineral crystals and the development of several distinct foliation textures.

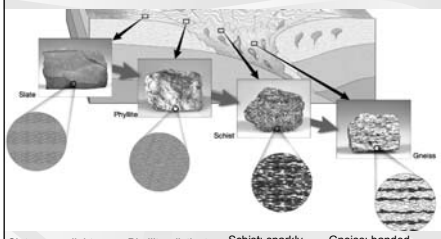
With increasing metamorphic grade (prograde metamorphism), shale (made of up clay minerals) changes into the following rocks: Shale → Slate → Phyllite → Schist → Gneiss

In addition to textural changes, changes in mineralogy are also observed relating the changing stability conditions.

Common non-foliated (granoblastic) metamorphic rocks



Common foliated rocks



Slate: very slight sheen due to growth of platy mica grains. Clay minerals present.

Phyllite: distinct sheen due to continued growth of platy mica grains. Clays still present.

Schist: sparkly appearance due to presence of large mica grains. Clays largely gone.

Gneiss: banded appearance due to partial transformation of micas to dark and light granular minerals (K feldspars, amphiboles).

Typical characteristics of foliated metamorphic rocks

Slate: Microcrystalline, well-foliated and fissile (breaks into thin plates). Fossils and other primary features may be preserved. Lustre, dull, to satin-like on cleavage surfaces.

Phyllite: Very finely crystalline (grains just visible at 10X magnification) and well foliated. Somewhat fissile. Minerals present (as in slates) include muscovite (mica), chlorite and graphite as well as clays. Lustre clearly satin-like, usually somewhat glossy.

Schist: Medium to coarsely crystalline and well-foliated (flaky) though not truly fissile. A diversity of minerals may be present, however platy minerals (micas) predominate over granular minerals. Typically highly lustrous due to high content of macroscopic mica crystals.

Gneiss: Texturally similar to Schist, though granular minerals are more abundant than platy minerals. Micas and chlorite typically occur in small quantities. Granular minerals such as K feldspars, quartz and ampiboles (hornblende) are most common.

Migmatites

At the uppermost end of the highest metamorphic grade, the rocks may begin to melt.

The result of this may be a "mixed rock" or "migmatite" containing both relict regional metamorphic textures as well as some igneous intrusive textures.

These rocks typically show evidence of plastic deformation due to high heat flow

During these transformation, however, most of the volume of the rock remains in the solid state.

Foliation and Aesthetics

The aesthetically pleasing appearance of foliated rocks are often featured prominently in many works in *Suiseki* (the Japanese art of selecting, presenting and appreciating natural stone).

The eye is drawn to the schistose foliation of this rock

Much of the beauty in the rock rock lies in color contrasts inherent in gneissic foliation.

Metasomatism: occurs when chemically reactive fluids (often hydrothermal fluids-hot water and dissolved materials) react with a pre-existing rock and alter the chemical composition of minerals within the rock. In some cases, the solvent (water) itself is involved. In others, materials dissolved in the fluid are involved.

For example, the mineral olivine (which occurs in blocky crystals) reacts with water to form the mineral serpentine (with platy to fibrous crystals).

$2Mg_2SiO_4$ + $2H_2O$ → $Mg_3Si_2O_5(OH)_4$ + MgO

olivine — water — serpentine — (in solution)

Metasomatism, cont'd:

Serpentine can then react with quartz (in solution) to form talc. Soapstone, a rock made primarily of talc is a metamorphic rock that is formed in the process.

Soapstone is used widely as an artistic medium by Aboriginal peoples of the Canadian Arctic.

$Mg_3Si_2O_5(OH)_4$ + $2SiO_2$ → $Mg_3Si_4O_{10}(OH)_2$ + H_2O

serpentine (in solution) talc water

Soapstone

END OF LECTURE