Geology and Art, Fall 2004
Review and Metamorphism, Lecture 7
Dynamic Earth, Chapter 8

Metamorphism

Metamorphic rocks: formed under the temperatures and pressures higher than those of diagenesis (200 C) and below the "melting zone". Metamorphic rocks are created by solid state changes in the rock. Because metamorphism occurs at depth, this is a processes that is continuously occurring but can not be observed. The only way to see metamorphic rocks is after significant uplift and erosion.

Any rock can be metamorphosed: igneous, sedimentary or metamorphic

Low-grade metamorphism: occurs at temperatures between 200 and 500 degrees C.
High-grade metamorphism: occurs at temperatures above 500 degrees C.

Contact Metamorphism: when a magma comes into contact with a parent rock, the heat will initiate metamorphism. The change in mineralogy is due to the heat and the circulation of fluids, pressure is not a significant factor.

Regional Metamorphism: this process alters rocks over a very large area (regional).

Burial Metamorphism: occurs when rocks are overlain by more than 10 kms of overburden. Confining pressure and heat combine to recrystallize the minerals. Differential pressure is not a factor and so burial metamorphic rocks are generally nonfoliated.

Recrystallization of minerals (confining and directed)
Dissolution in high-pressure sites
Crystallization in low-pressure sites

Dyamothermal (dynamic) Metamorphism: occurs along convergent plate margins (mountain building). Heat, confining pressure, and differential stress drive recrystallization and produce foliated ("leaf" like) metamorphic rock.

In the case of directed pressure, recrystallization normal to principal strain produces foliation

Cataclastic Metamorphism: dominated by mechanical deformation. Mineral grains elongate and a foliation develops.

Conditions Promoting Metamorphism

Minerals (and rocks) are most stable in the environment that they form and tend to break down when placed in a new temperature and pressure situation. During metamorphism minerals of the parent rock recrystallize to stable minerals while staying in solid form. The circulation of ion-rich fluids helps in this recrystallization process.

$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_25(OH)_4 + 4H_4SiO_4 + 2K^+$
K-feldspar Kaolinite clay silicic acid

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Heat: speeds up the rate of chemical reactions. Since the geothermal gradient of the continent is about 10-20 degrees C/km, metamorphism starts around 10-20 kms deep.

Pressure: metamorphism requires more than 1 kbar of pressure. This would be approximately equal to 3 kms beneath the surface (lithostatic pressure). Frequently pressure is differential (directed pressure) during metamorphism (plate collisions).

> **Foliation**: the systematic orientation of crystals (micas) perpendicular to the primary stress creates a texture (layering) distinctive to metamorphic rocks.

Fluids (water): fluids (liquid or gas) facilitates the transportation of ions and acts as a catalyst to recrystallization. Most rocks, particularly sedimentary rocks contain significant pore space that contain intergranular fluid (pore water). Water is also produced during dehydration reactions. Veins can be produced during metamorphism

> **Prograde metamorphism**: changes occur as temperature and pressure increase. Mineralogy tends to be in equilibrium with pressure and temperature conditions because water is present.
>
> **Retrograde metamorphism**: changes occur as temperature and pressure decrease. This process is usually retarded because fluid has been expelled (that's why we can find high-grade metamorphic rocks on the Earth surface).

Parent Rock: the composition of the parent rock determines what metamorphic rock and minerals will form.

> A monomineralogic rock, such as quartz sandstone will metamorphose to a quartz arenite and a limestone will metamorphose to a marble (no change in chemical composition)

Time: since metamorphism is rate dependent, time is an important factor in the production of metamorphic rock. Time is needed to reach equilibrium. Time also allows larger crystals to grow (similar to igneous textures).

Metamorphic Rock Types:

Foliated rocks are produced when multi-mineral rock is subjected to progressively greater heat and differential pressure.

Folidated Rock:

Low-grade: slaty cleavage and fine-grained (foliation)

	Parent Rock	Key Minerals
slate	shale, mudstone	clay, micas, chlorite
phyllite	shale, mudstone	larger mica, chlorite

High-grade: schistosity and coarse-grained texture, metammorphic differentiation

schist	shale, mudstone, basalt, greywacke, sandstone, dirty limestone
gneiss	

Unfoliated Rock:

Marble: metamorphosed limestone

Quartzite: metamorphosed quartz sandstone

migmatite (600° - 800°C) partial melt of felsic gneiss bands (water-rich pocket melt)

Metamorphic Facies:

The major element composition of a rock tends to remain constant during metamorphism (volatiles can be added and lost), thus there is a change in the mineral composition, not the chemical composition of a rock.

The mineral composition is determined by the composition of the original rock, pressure and temperature.

Metamorphic facies define temperature and pressure conditions in which metamorphic rocks formed, despite differences chemical composition.