Metamorphic Rocks

I. Metamorphism - definition:

transformation of pre-existing rocks by heat, pressure, and chemically active fluids.

The term means "changed form".

A. Metamorphic Occurrence:

a few kms below the earth's surface to 10-30 km(the crust-mantle boundary),

at these depths, increases in heat and pressure and changes in the chemical environment result in changes in the mineral compositions and crystalline textures of sedimentary and igneous rocks, which remain solid all the while.

II. Metamorphism - settings:

1) Mountain building - rock is subjected to the intense stresses and temperatures associated with large-scale deformation. Extensive areas undergo **regional metamorphism**.

accounts for the greatest volume of metamorphic rock.

2) Contact metamorphism - rock is changed by contact with a magma.

The high temperature of the molten material "bakes" the surrounding rock.

III. Types of metamorphism:

Low-grade metamorphism - involves only slightly higher temperatures and pressures than sediments exposed to lithification. Formed in shallow crustal regions.

High-grade metamorphism - involves extreme conditions closer to those in which rocks melt. Formed at deeper zones of high temperature and pressures.

IV. Agents of Metamorphism

1) Heat

Heat provides energy to drive chemical reactions resulting in the recrystallization of minerals.

As rock adjusts to its new temperature, its atoms and ions recrystallize into new arrangements, creating new mineral assemblages.

Many crystals will grow larger, and the rock may become banded as the minerals segregate into separate planes.

For example - In upper crust, geothermal gradient is between $20^{o}C$-$30^{o}C/km$. Clays can be transformed into micas.

2) Pressure

Pressure increases with depth.

Pressure change a rock's texture as well as its mineralogy.

Directed pressure guides the shape and orientation of the new metamorphic crystal.

e.g. During recrystallization of micas, the crystals grow with the planes of their sheet-silicate structures aligned perpendicular to the directed stress.

3) Chemically Active Fluids

Chemically active fluids, most commonly water containing ions in solution, also enhance the metamorphic process. When deep burial occurs, water is forced out of the mineral structures and is then available to aid in the chemical reaction. Further, as heat is applied, the dehydration of minerals releases water. Water that surrounds the crystal acts as a catalyst by aiding ion migration.

V. Textural and Mineralogical Changes

The degree of metamorphism is reflected in the texture and mineralogy of metamorphic rocks.

Low grade metamorphism - rocks become more compact and more dense.

e.g. shale becomes slate when subjected to low grade metamorphism. Clay minerals in shale realign into more compact arrangement found in slate.

High grade metamorphism - under more extreme conditions minerals recrystallize (through the aid of water), forming larger crystals.

Results in a *foliation*- or preferred mineral alignment usually perpendicular to the principal stress.

A. Types of foliation

depends on degree of metamorphism and the mineralogy of the parent rock.

During the transformation of shale to slate, clay minerals recrystallize into mica flakes, which are more stable at higher temperatures and pressures. Further, these fine-grained mica crystals become aligned during recrystallization so that their flat surfaces are nearly parallel.

Slate can be easily split along these layers- called rock cleavage or slaty cleavage.

Under more extreme temperature - pressure regimes, the fine mica flakes in slate will grow larger. This gives rock a platy or scaly appearance. This type of foliation is called **schistosity**, and the rock is called a schist.

The most abundant schist is mica schist - contains muscovite and biotite.

During high grade metamorphism, minerals can segregate. The dark and light minerals separate giving the rock a banded appearance. The rock with this texture is called a **gneiss**.

Progressive metamorphism of a shale:

shale → slate → phyllite→ schist → gneiss

VI. Common Metamorphic Rocks

A. Foliated Rocks (in order of metamorphic grade):

Slate - very fine grained foliated rock composed of minute mica flakes.
excellent rock cleavage.
formed from the low grade metamorphism of shale.
Slate - black (carbonaceous), red or purple (iron oxides), and green (chlorite).

Phyllite -
a metamorphic grade above slate.
its platy minerals are a little larger than slate.
it has a glossy sheen which distinguishes it from slate.
composed of fine grained muscovite or chlorite.

Schists -
strongly foliated rocks formed by regional metamorphism
can be easily split into thin flakes or slabs.

contain more than 50% platy and elongated minerals that commonly include muscovite, biotite, and amphibole. Can also contain quartz and feldspar.

Schist describes: 1) the texture of the rock -coarse, wavy, pervasive foliation.
2) can also include dominant mineralogy (e.g. mica schist).

<u>Gneiss</u> -

banded metamorphic rock that contains mostly elongated and granular minerals.

contains quartz, potassium feldspar, and sodium feldspar.

segregation of light (quartz and feldspar) and dark (amphibole and other mafic) minerals gives a banded texture.

Gneiss represents the last rock in the sequence of shale, slate, phyllite, schist, and gneiss.

B. Nonfoliated Rocks:

<u>Marble</u>

coarse, crystalline rock - parent rock was limestone or dolomite.

Pure marble is white and composed essentially of the mineral calcite.

Impurities can make marble pink, gray, green and black.

<u>Quartzite</u> -

very hard metamorphic rock formed from quartz sandstone.

Under moderate - high grade metamorphism the quartz grains in sandstone fuse.

typically white, although iron oxide may produce reddish and pinkish stains.

VII. Regional Metamorphism

takes place at considerable depths over an extensive area and is associated with the process of mountain building.

geologists can use index minerals to distinguish different zones of regional metamorphism.

For example, shale may grade into a slate, and then chlorite when temperatures are relatively low (~200^{o}C). As progressive effects are felt, biotite, garnet, staurolite, kyanite, sillimanite forms in extreme conditions when temperatures exceed ~600^{o}C.

Also, foliations become more extreme in this sequence from shale to slate to phyllite to schist to gneiss.