EENS 1110	Physical Geology
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Metamorphism and Metamorphic Rocks

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Definition of Metamorphism

The word "***Metamorphism***" comes from the Greek: Meta = change, Morph = form, so metamorphism means to change form. In geology this refers to the changes in mineral assemblage and texture that result from subjecting a rock to pressures and temperatures different from those under which the rock originally formed.

The original rock that has undergone metamorphism is called the ***protolith***. Protolith can be any type of rock and sometimes the changes in texture and mineralogy are so dramatic that is difficult to distinguish what the protolith was.

- Note that diagenesis and weathering are also a changes in form that occur in rocks. In geology, however, we restrict diagenetic processes to those which occur at temperatures below 200°C and pressures below about 300 MPa (MPa stands for Mega Pascals), this is equivalent to about 3,000 atmospheres of pressure.

- Metamorphism therefore occurs at temperatures and pressures higher than 200°C and 300 MPa. Rocks can be subjected to these higher temperatures and pressures as they become buried deeper in the Earth. Such burial usually takes place as a result of tectonic processes such as continental collisions or subduction.

- The upper limit of metamorphism occurs at the pressure and temperature of wet partial melting of the rock in question. Once melting begins, the process changes to an igneous process rather than a metamorphic process.

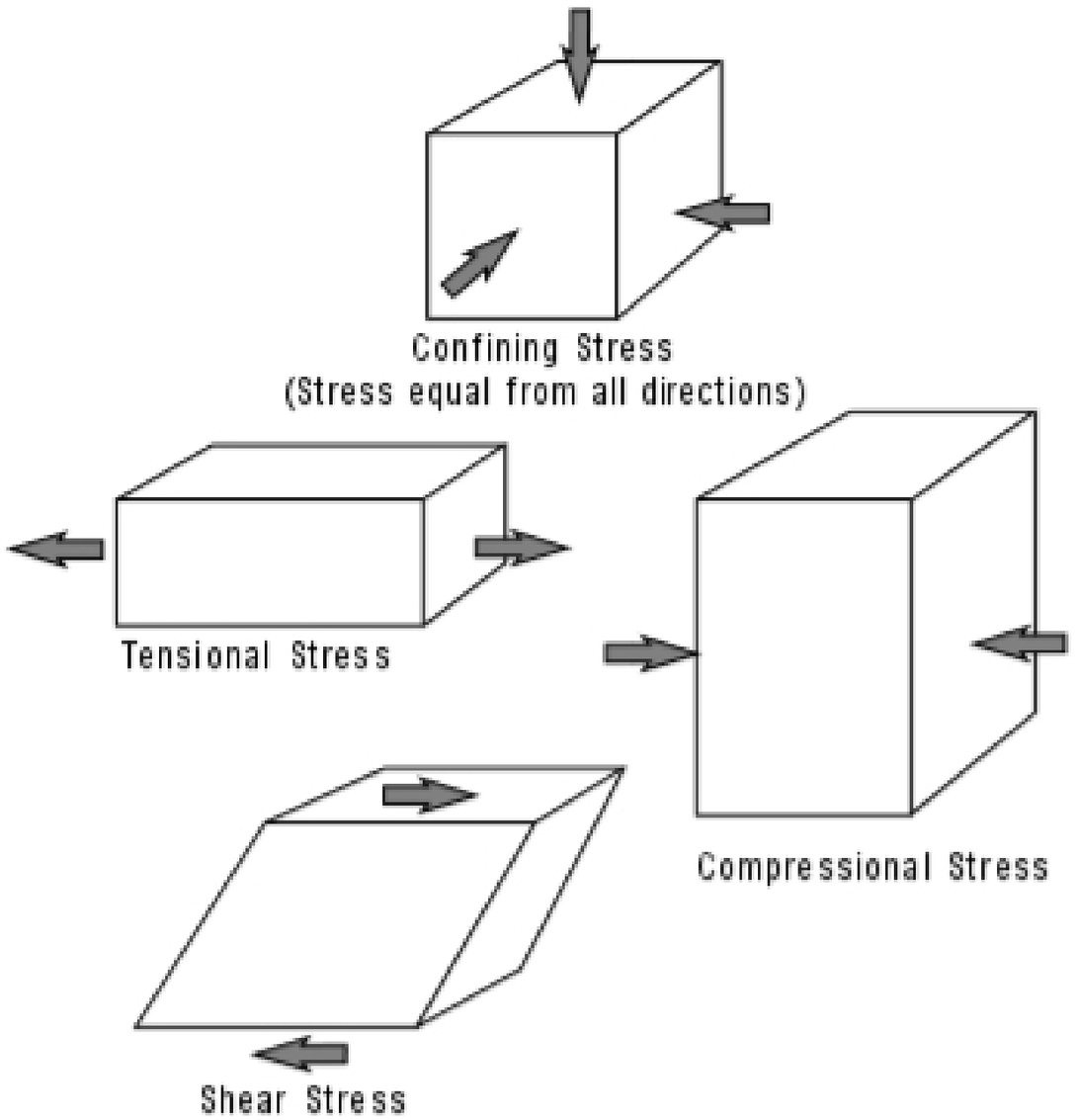
During metamorphism the protolith undergoes changes in texture of the rock and the mineral make up of the rock. These changes take place mostly in the solid state and are caused by changes in physical or chemical conditions, which in turn can be caused by such things as burial, tectonic stress, heating by magma or interactions with fluids.

Factors that Control Metamorphism

Metamorphism occurs because rocks undergo changes in temperature and pressure and may be subjected to differential stress and hydrothermal fluids. Metamorphism occurs because some minerals are stable only under certain conditions of pressure and temperature. When pressure and temperature change, chemical reactions occur to cause the minerals in the rock to change to an assemblage that is stable at the new pressure and temperature conditions. But, the process is complicated by such things as how the pressure is applied, the time over which the rock is subjected to the higher pressure and temperature, and whether or not there is a fluid phase present during metamorphism.

- Temperature
    - Temperature increases with depth in the Earth along the Geothermal Gradient. Thus higher temperature can occur by burial of rock.
    - Temperature can also increase due to igneous intrusion.
- Pressure increases with depth of burial, thus, both pressure and temperature will vary with depth in the Earth. Pressure is defined as a force acting equally from all directions. It is a type of ***stress***, called ***hydrostatic stress***, or ***uniform stress.***

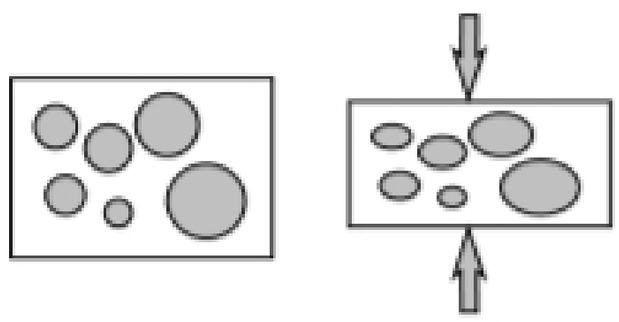
  If the stress is not equal from all directions, then the stress is called a ***differential stress.***



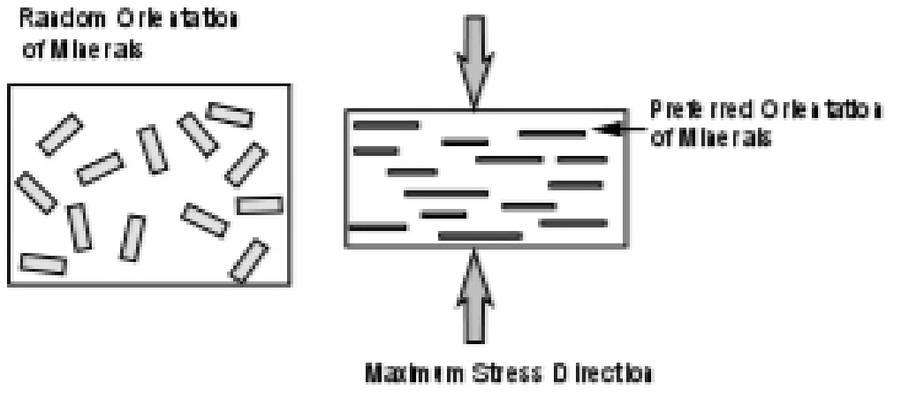
There are two kinds of differential stress. ***Normal stress*** causes objects to be compressed in the direction of maximum principal stress and extended in the direction of minimal stress. If differential stress is present during metamorphism, it can have a profound effect on the texture of the rock. ***Shear stress*** causes objects to be smeared out in the direction of applied stress.

Differential stress if acting on a rocks can have a profound affect on the appearance or texture of the rock.

Rounded grains can become flattened in the direction of maximum stress.



Minerals that crystallize or grow in the differential stress field can have a preferred orientation. This is especially true of the sheet silicate minerals (the micas: biotite and muscovite, chlorite, talc, and serpentine).



These sheet silicates will grow with their sheets orientated perpendicular to the direction of maximum stress. Preferred orientation of sheet silicates causes rocks to be easily broken along approximately parallel sheets. Such a structure is called a ***foliation***.

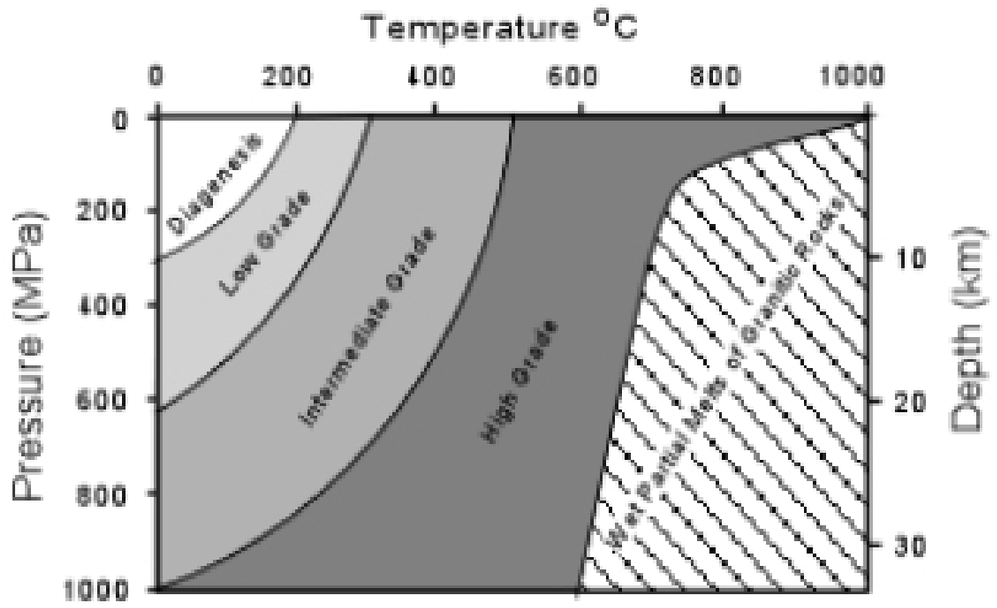
- Fluid Phase.- Any existing open space between mineral grains in a rock can potentially contain a fluid. This fluid is mostly H_2O, but contains dissolved ions. The fluid phase is important because chemical reactions that involve changing a solid mineral into a new solid mineral can be greatly speeded up by having dissolved ions transported by the fluid. If chemical alteration of the rock takes place as a result of these fluids, the process is called ***metasomatism***.

- Time - Because metamorphism involves changing the rock while it is solid, metamorphic change is a slow process. During metamorphism, several processes are at work. Recrystallization causes changes in minerals size and shape. Chemical reactions occur between the minerals to form new sets of minerals that are more stable at the pressure and temperature of the environment, and new minerals form as a result of polymorphic phase transformations (recall that polymorphs are compounds with the same chemical formula, but different crystal structures.

  Laboratory experiments suggest that the the sizes of the mineral grains produced during metamorphism increases with time. Thus coarse grained metamorphic rocks involve long times of metamorphism. Experiments suggest that the time involved is tens of millions of years.

Grade of Metamorphism

Metamorphic grade is a general term for describing the relative temperature and pressure conditions under which metamorphic rocks form. As the temperature and/or pressure increases on a body of rock we say that the rock undergoes ***prograde metamorphism*** or that the grade of metamorphism increases.



- Low-grade metamorphism takes place at temperatures between about 200 to 320°C, and relatively low pressure. Low grade metamorphic rocks are characterized by an abundance of ***hydrous minerals*** (minerals that contain water, H_2O, in their crystal structure).