Name: ___________________________

Lab 9: Metamorphic Processes and Rock Identification

Metamorphism is the change in the form of crustal rocks exposed to heat, pressure, hydrothermal fluids, or a combination of these agents in the absence of melting. Rocks undergoing metamorphism will experience changes in both composition and texture. Geologists study metamorphic compositions and textures as evidence of the conditions that formed them: we can infer the temperature and pressure conditions the rock formed in and thereby constrain its history. The occurrence of metamorphic rocks can indicate where ancient mountains once were, where faults lie, or the location of former subduction zones. They are particularly important in unraveling Earth's ancient history, since few rocks survive great lengths of time without becoming metamorphosed.

Metamorphic Processes

Several changes happen to rocks when they are subjected to high temperatures and pressures:

1) Reorientation of mineral grains. Platy, sheetlike, and prismatic mineral grains will rotate or grow in an orientation perpendicular to the applied stresses. The alignment of platy and prismatic grains is called "foliation." Some minerals are not prone to foliation (especially quartz and calcite), so metamorphosed quartz sandstones or limestones will typically not be foliated. Often, though, these non-foliated metamorphic rocks will have a coarser texture than the original rock.
2) Recrystallization of existing minerals. With increasing pressure, very small grains dissolve (while still in solid state) while others grow. This results in coarser grains than were in the original rock.
3) Growth of new minerals. Polymorphs (same chemical composition but different arrangement of atoms) of the original minerals that are more stable at higher temperatures or pressures can develop during metamorphism. New minerals that differ in composition may also form with the introduction of new elements by hydrothermal fluids.
4) Differential melting. Sometimes the temperature increases enough to melt just the felsic minerals, then cools again before the melt can migrate away. Rocks that melt enough to have some igneous features and some metamorphic features are called "migmatites."
5) Segregation of minerals. During crystallization and/or differential melting, some mineral grains of the same type migrate together and form bands or concentrations of the mineral. The alternation of colors due to the separation of mineral layers is called "banding." This is distinct from foliation, which is just concerned with the alignment of the grains.
6) Baking. Temperatures that are not high enough to melt the rock can still alter them through the introduction of heat. Certain minerals and textures form in "baked" zones. These features often form in the country rock near magmatic intrusions.
7) Shearing. The pressures and stresses from tectonic forces can shear, fracture, and pulverize rock. Recrystallization during shearing can produce a special metamorphic texture called mylonite.

Types of Metamorphism
There are five main types of metamorphism, each with a characteristic set of processes.

1) *Regional metamorphism* occurs under increasing temperatures and pressure conditions. The major processes contributing to regional metamorphism are orientation of mineral grains, recrystallization of existing minerals, and segregation of minerals. This takes place in mountain belts and at tectonic plate boundaries.
2) *Contact metamorphism* occurs due to high temperature and interaction with fluids at relatively low pressures. This can occur next to cooling magma bodies. The major processes contributing to contact metamorphism are baking and differential melting.
3) *Burial metamorphism* results from burial of a sedimentary basin with sufficient fluids at relatively low metamorphic temperatures and pressures. The major process resulting from burial metamorphism is growth of new minerals.
4) *Cataclastic metamorphism* occurs as a result of shearing in fault zones or other areas of tectonic activity.
5) *Shock metamorphism* from meteorite impact.

Metamorphic Rock Classification
As with the igneous and sedimentary rocks, metamorphic rocks are classified based on their texture and composition. Metamorphic textures are divided into two major groups: foliated and non-foliated. Non-foliated metamorphic rocks are further classified based on their composition. Foliated textures are described on the basis of the style or degree of foliation as well as composition. The major types of foliation are:

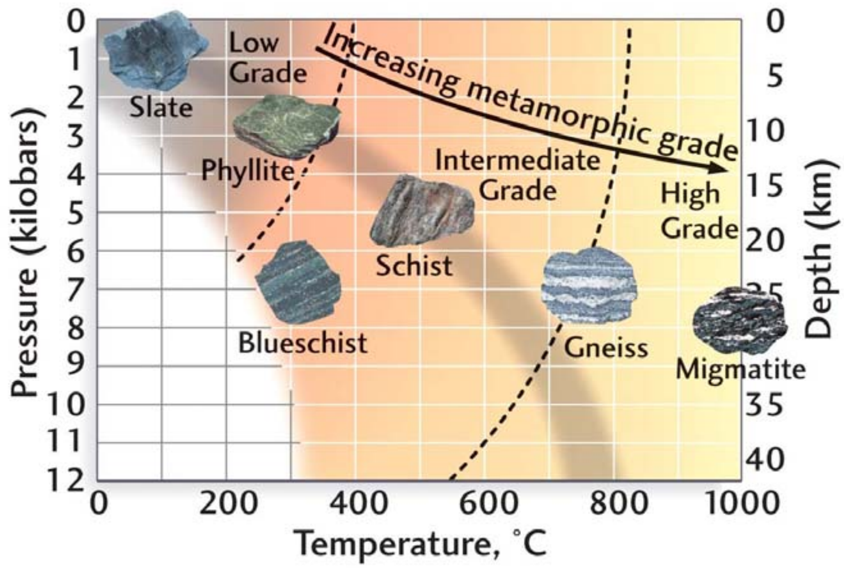
1) Slaty cleavage. Weak foliation that results in breakage along smooth planes, with dull or weakly-reflective surfaces. Similar to a chalkboard, though not restricted in color.
2) Phyllitic. Moderate foliation that produces slightly wavy surfaces that are commonly more reflective (often pearly or waxy).
3) Schistose. Moderate to strong foliation, often with visible growth or recrystallization of mineral grains. Layers often (but not always) appear undulatory.
4) Gneissic banding. Strong foliation of platy minerals and the creation of alternating bands of predominantly light and dark minerals (banding).

It is important to note that foliation occurs as a continuum between these major types. Foliated metamorphic rocks are classified based on the approximate type of foliation and their names modified to indicate prominent minerals visible in the sample. For example, a metamorphic rock with moderate to strong foliation (schistose) and prominent garnet crystals would be classified as a garnet schist. A metamorphic rock with strong foliation including prominent biotite would be classified as a biotite gneiss.

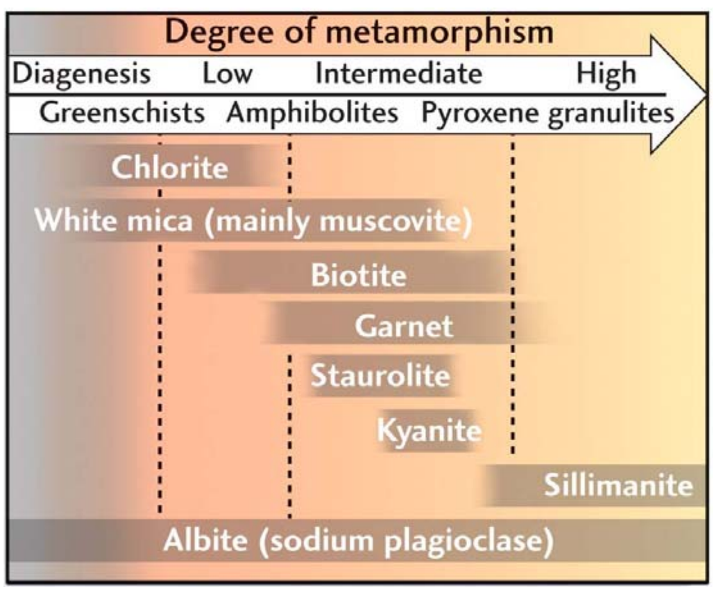
Metamorphic Grade
Metamorphic grade describes the degree to which a rock has been subjected to elevated pressure and temperature. The descriptions of foliation above are listed in order of increasing metamorphic grade. In other words, a slate represents low-grade metamorphism, with little recrystallization and alteration from the original rock. With increasing grade, it will become

phyllite, then schist, then gneiss. Finally, if the rock reaches high enough temperatures, it can partially melt and become a migmatite, the highest grade before the rock melts into magma.

Metamorphic Grade and Foliation



Index Minerals



Classification of Metamorphic Rocks

Texture	Type of foliation	Composition	Rock Name
Non-foliated		Quartz	Quartzite
		Calcite	Marble
		Rock fragments	Metaconglomerate
		Dark-colored (pyroxene, plagioclase most common)	Hornfels
Foliated	Slaty cleavage	Minerals rarely visible, commonly clays and quartz	Slate
	Phyllitic	Minerals not commonly visible, very small mica grains give surfaces a “shimmer”	Phyllite
	Schistose	Some minerals commonly visible, often including micas, garnet, quartz	Schist*
	Gneissic banding	Minerals commonly visible	Gneiss*
Banded	Migmatitic banding	Igneous and metamorphic textures, foliated mafic minerals and veins and pods of melted and recrystallized felsic minerals	Migmatite
* Note that these names are generally modified based on any prominent mineral(s) (e.g. garnet biotite schist or biotite gneiss).			

Part 1. Metamorphic compositions and textures

1. Determine the minerals present in rocks A, B, C, and D.

A

B

C

D

2. Which of the above rocks are foliated?

   a. Based on the degree of foliation, rank these rocks by their metamorphic grade.

Low grade _________ _________ __________ ________ High grade

3. Chlorite (a soft, green, platy mineral) forms as a new mineral during low-grade metamorphism. Similarly, garnets form during medium-grade metamorphism.. Because of this, chlorite and garnet are referred to as index minerals, and their presence can indicate the degree of metamorphism experienced by a rock. Which of the above rocks (A, B, C or D) experienced medium-grade metamorphism, based on its mineralogy?

4. How might one distinguish between sample B and a quartz sandstone?

5. Sample E is metamorphosed basalt. What minerals should be found in basalt? After being squeezed and heated, this rock now contains a different set of minerals. What minerals are in this rock now? What has happened to the grain size of the minerals during metamorphism?

Minerals in protolith (basalt):

Minerals in E after being squeezed and heated:

Change in grain size:

6. Sample F is a metamorphic rock called blueschist. It contains a high abundance of an amphibole called glaucophane, which is bluish gray in color. Glaucophane forms at moderate temperatures (< 400°C) and high to very high pressures—depths greater than 20 km below Earth's surface. The protoliths for blueschist are shales and/or basalt. In what tectonic environments might blueschists form? Explain your reasoning.

7. What difficulty arises when attempting to identify the grade of a monomineralic nonfoliated rock, such as marble or quartzite?

Part 2. Metamorphic Rock Classification

Sample Number	Texture (Foliated vs. Non-foliated)	Type of Foliation	Metamorphic grade (foliated rocks only)	Composition	Rock Name
1					
2					
3					
4					
5					
6					

Sample Number	**Texture (Foliated vs. Non-foliated)**	**Type of Foliation**	**Metamorphic grade (foliated rocks only)**	**Composition**	**Rock Name**
7					
8					
9					