Lesson Seven: Metamorphic Rocks

Background Reading: Metamorphic Rocks

Metamorphic Rocks – These are rocks that have been changed from pre-existing rock due to heat and or pressure, without melting.

Parent Rock (or protolith): These are both names for the rock that existed prior to metamorphism. For example, limestone is a protolith that changes to marble due to metamorphism. The igneous rock peridotite is a protolith that changes to serpentinite (the California State rock!).

Grade: The grade of a metamorphic rock refers to the degree of change during metamorphism and ultimately to the conditions present during metamorphism. We will consider three general categories of grade: low, medium, and high grade. Low grade rocks have been subjected to low degrees of heat and/or pressure, whereas high grade rocks have been subjected to high degrees of heat and pressure.

Metamorphic Process include heat, pressure and fluid migration through the rock. All three of these can cause ions (atoms that are in the pre-existing rock) to migrate to new locations where they form new minerals. One of the changes we will see is the presence of new (often shiny or sparkling) minerals. Micas are often formed during metamorphism and these can give the rocks a shine or sparkle depending on the size of the mica crystals.

Something to keep in mind – minerals that were stable (were not changing) in the pre-existing rock become unstable under the new heat and pressure conditions. Therefore the atoms (ions) in the pre-existing minerals leave the mineral structure and migrate to new positions to form new minerals. This is how the rock changes. These changes can be very obvious when conditions allow for big, new, sparkly minerals to be formed, or they can be subtle when the mineral changes only produce minor changes in the texture or hardness of the rock.

Heat: this is the energy that drives ion migration and recrystallization. The new crystals are stable at higher temperatures. Example: clays will often recrystallize to form muscovite and biotite (micas).
Pressure: this causes compaction and the **differential stress** (more pressure in one direction than another) can cause squeezing in a preferred direction. This occurs in tectonically active areas. In these cases the minerals grow perpendicular to stress direction and cause a texture known as **foliation** (see changes listed below).
Fluids – hot fluids facilitate migration of ions. Water in pore space of sedimentary rocks provides often provide the fluids involved in this process.

Metamorphic Changes: We will consider the following types of changes that occur during metamorphism: Texture changes and Mineralogical changes (changes in the mineral composition of the pre-existing rocks.

Changes in Texture

Foliation – a preferred orientation of minerals is developed due to differential stress (see pressure discussion). Foliation includes Slaty Cleavage, Schistocity, Gneissic Banding. We will see example of these in the lab. In general you can think of foliation as a "grain" or "fabric" in the same way that wood or cloth has a preferred orientation that makes it easier to split or tear in a particular direction.

Crystalline Texture (non foliated) – quartz and calcite are equal-dimensional crystals, so they do not align in a preferred direction to produce foliation. Instead the crystals just tend to get larger with higher grades of metamorphism.

Porphyroblastic – Some minerals tend to grow more rapidly in the metamorphic environment than others. Consequently large crystals can be formed within a smaller crystalline rock. Garnets are good examples of crystals that form large crystals and give a metamorphic rock a porphyroblastic texture (this texture is similar to the porphyritic texstures of igneous rocks).

Mineral Changes in Metamorphic Rocks

During metamorphism, new minerals form which are stable in the new metamorphic environment. Some minerals are good indicators of a specific grade of metamorphism. These are called **index minerals.**

Index Minerals include chlorite (low grade), muscovite and biotite (med. grade), garnet (med. to high grade)

Quartz, Calcite, Feldspars are stable in a variety of temperatures and pressures; consequently, they are **not** good index minerals.

The new metamorphic minerals that are produced reflect the protolith (or parent rock)

Chlorite – forms from the ferromagnessium minerals in basalt

Micas – form from clays that are in sedimentary protoliths

Talc– forms from mafic minerals that are in ultramafic rocks such as peridotite

Serpentine –forms from the metamorphism of peridotite in the presence of water.

Metamorphic Environments: A metamorphic environment is the geologic/tectonic settings where a metamorphic rock is formed. There are several ways of categorizing these environments. The categorization presented below is similar to the one presented in the textbook. However, I have lumped the environments under two big subdivisions: Localized, and Larger Areas.

Localized (although some of these can occur over large areas)

Contact / Thermal: this environment exists when the intense heat of magma "bakes" the surrounding rock. Contact metamorphic rocks are typically not foliated. Batholiths can produce contact metamorphic zones that are several km wide.

Hydrothermal: this occurs due to the hot fluids associated with geothermal activity. These rocks are typically not foliated and they may be associated with contact/thermal metamorphic environments. The presence of water can cause more intense ion migration and development of unique minerals. This environment is common at mid ocean ridges (divergent boundaries). It may result in concentrations of metals, such as those seen at "black smokers" under the ocean.

Fault Zones: this environment is produced from the pressure (low heat) associated with faulting. Rocks formed in this environment develop a foliation that is usually parallel to the fault plane. This is sometimes called ***Dynamic Metamorphism***

Larger Areas – these categories include environments that are not related to specific sources of heat or pressure, but rather to a larger geologic or tectonic setting.

Burial Metamorphism – rocks formed in this environment are usually not foliated. This environment results from the confining pressure generated at 8 or more km deep; however, the stress is not differential so foliation is not produced. These are usually low grade metamorphic rocks with only subtle changes.

Dynamothermal or Regional Metamorphism – This environment is associated with mountain building and the tectonic activity of a convergent plate boundary (subduction zone). This environment is capable of producing both differential stress and heat present. Consequently the rocks are usually foliated. The variation of heat and pressure within these environments can produce a variety of metamorphic grades. This results in metamorphic that range from slates to schists to gneiss. Most of our lab rocks are examples of rocks formed in a Dynamothermal environment.

Subduction zones are unique environments where high pressures but relatively low temperatures exist. When basaltic ocean crust (what is being subducted) is subjected to these conditions (high pressure, low heat) it results in something called **blueschist metamorphism.** The name comes from a bluish colored amphibole that develops when the mafic rock (basalt) changes in this high pressure/low temperature dynamothermal environment.

Metamorphic Rocks

Metamorphic Terms:

Protolith (or precursor or parent rock): the preexisting rock (prior to metamorphism).

Grade: The degree of metamorphism; the amount of heat and pressure required to produce the rock.

Foliation: parallel planar orientation of minerals.

Textures: Textures developed during metamorphism can be used to determine the grade (degree) of metamorphism and, in some cases, the protolith

There are two main types of textures: foliated and nonfoliated.

Foliated Textures:

Slaty Cleavage: near perfect, planar foliation of very fine-grained minerals

Phyllitic Texture: a "sheen" due to alignment of fine-grained (too small to see) platy minerals

Schistosity: new metamorphic minerals are visible. They often create a "sparkly" appearance.

Gneissic Texture: alternating layers of parallel to subparallel foliation of medium- to coarse-grained platy minerals.

Nonfoliated Textures:

crystalline: mass of crystals

Some Low-grade metamorphism of basalt, conglomerate, sandstone, or other coarse-grained/crystalline rocks.

Minerals (these are in addition to minerals we have already studied in previous labs):

Chlorite: green platy mineral (think of this as a green mica)

Garnets: red-brown, spherical (polyhedral), glassy mineral

Serpentine: mineral group that includes greenish white minerals (actinolite, lizardite)

Metamorphic Rocks:

Foliated Metamorphic Rocks (distinguished by grade and foliation):

Slate,
Phyllite,
Schist,
Gneiss

Nonfoliated Rocks (distinguished by the minerals present):

Quartzite,
Marble,
Greenstone (low grade basalt)

Foliated or nonfoliated:

Serpentinite (low-med. grade)
Metaconglomerate (low-med grade)

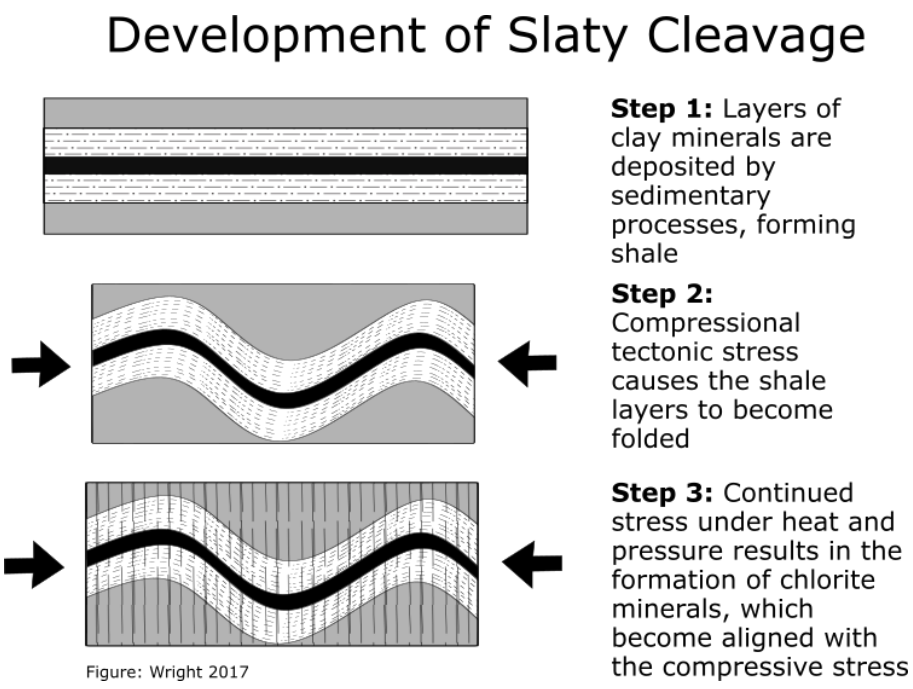
Typical transition in mineralogy during progressive metamorphism of shale

	Increasing Metamorphism →
	Low Grade — **Intermediate Grade** — **High Grade**
Mineral Composition	**Chlorite** (Low Grade to Intermediate Grade) **Muscovite (mica)** (Low Grade to Intermediate Grade) **Biotite (mica)** (Intermediate Grade to High Grade) **Garnet** (Intermediate Grade to High Grade) **Quartz** (Low Grade to High Grade) **Calcite** (Low Grade to High Grade)
Metamorphic Rock Type	**Shale** (no alteration) - **Slate** - **Phyllite** — **Schist** — **Gneiss**

Metamorphic Rock Classification

Foliated Metamorphic Rocks			**Non-Foliated Metamorphic Rocks**			**Sometimes foliated**		
Name	**Grade**	**Protolith**	**Name**	**Grade**	**Protolith**	**Name**	**Grade**	**Protolith**
Slate	**Low**	**Shale**	**Quartzite**	**Variable**	**Quartz-rich Sandstone, Chert**	**Serpentinite**	**Low**	**Peridotite**
Phyllite	**Low/Med**	**Shale**	**Marble**	**Variable**	**Limestone**	**Metaconglomerate**	**Low/Med**	**Conglomerate**
Schist	**Med –High**	**Variable**	**Greenstone**	**Low grade**	**Basalt**			
Gneiss	**High**	**Variable**						

Worksheet 7.1: Metamorphic Rocks



1. The diagram above provides an example of how metamorphic foliation develops. To help clarify the difference between sedimentary bedding and metamorphic foliation, use this example to fill out the table below with the orientation of each structure in each step of the diagram above. ***The orientation can be horizontal, vertical, angled or not present (if the structure does not exist at that step).***

Orientation of structure:	Step 1	Step 2	Step 3
Sedimentary Bedding			
Metamorphic Foliation			

2. Use the following vocabulary to fill in the blanks in the paragraph.
   Atoms
   Minerals
   Rocks

In most cases (except where rocks are highly altered by hydrothermal fluids), _____ do not significantly change overall chemical composition during metamorphism, so the _____ in the metamorphic rock will essentailly be the same as the _____ in the protolith. However, the _____ can combine in new ways under heat and pressure creating new _____ that were not present in the protolith.

3. Use the letter L, I, H to show which of the following minerals indicates a Low, Intermediate, or High grade metamorphic rock. Write "All" if the mineral does not provide evidence of a specific grade. Refer to the information on page 65.
   a. garnets _____ b. chlorite _____
   c. quartz _____ d. muscovite and biotite_____

The diagram below shows the theoretical pressure-temperature space of the crust. The lines with arrows represent possible paths that a metamorphic rock might take though the pressure and temperature space. The letters A-D represent points along those paths.

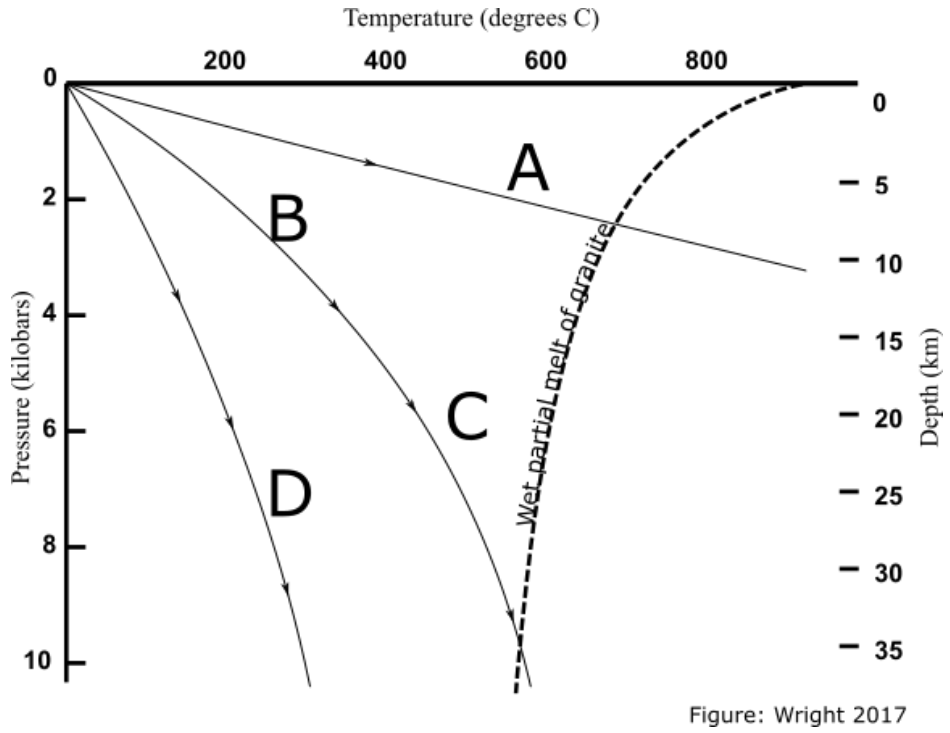
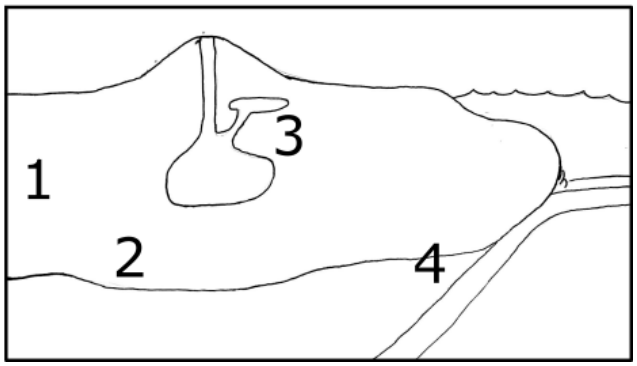


Figure: Wright 2017

4. Match each of the letters A-D in the diagram above with the number in the cross section below that corresponds to the location where the pressure temperature conditions would occur.



5. Label each of the lines with arrows on the pressure-temperature diagram on page 67 with one of the following descriptions:
   Mountain Belt Metamorphism
   Contact Metamorphism
   Subduction Metamorphism

6. Read each of the following rock descriptions. After each rock description write the letter corresponding to the zone in the pressure-temperature diagram where the rock would most likely form.

   _____ **Blueschist:** This rock gets its name from the mineral Gluacaphane, a bluish colored amphibole that is stable at high pressure and low temperature.

   _____ **Gneiss:** High grade, foliated metamorphic rock. Minerals separate into bands of minerals with similar chemistry.

   _____ **Hornfels:** A non-foliated metamorphic rock that varies in mineral composition, but is often quite hard and may contain high-grade metamorphic minerals.

   _____ **Phyllite:** A low grade metamorphic rock that often contains graphite, chlorite and muscovite. It has a shimmery appearance.

Lab 7.2: Metamorphic Minerals and Known Metamorphic Rocks

Minerals: Use the samples provided to answer these questions

Describe how to distinguish chlorite from mica (muscovite and biotite)

Describe three properties that help one distinguish quartz from calcite.

Describe the rock sample made of the serpentine group of minerals

Describe amphibole

Describe garnet

Known Metamorphic Rocks, use the labeled specimens to determine:

Rock Set 1:
How can you distinguish Quartzite from Marble?

Rock Set 2:
How can you distinguish Slate from Phyllite?

How can you distinguish Phyllite from Schist?

How can you distinguish Schist from Gneiss?

Rock Set 3:
How can you distinguish Chlorite Schist from Serpentinite?

How can you distinguish Greenstone from Serpentinite?

Rock Set 4:
How can you distinguish Gneiss from Quartzite?

Rock Set 5:
How could you tell a metaconglomerate from a conglomerate (sedimentary rock)?

Lab 7.3: Unknown Metamorphic Rocks:

Provide the metamorphic textures, minerals, grade, protolith and the rock name for each of these specimens. Only list the minerals you observed. * Grade and Protolith may be indeterminate for some rock types. Write NA in these sections if grade or protolith cannot be determined.

Specimen	Foliated or Non-foliated?	Minerals (if visible)	Acid Test (if it applies)	Metamorphic Rock Name	Grade* (if it applies)	Protolith* (if it applies)
A						
B						
C						
D						
E						
F						
G						

Specimen	Foliated or Non-foliated? (For foliated, list the type of foliation)	Minerals (if visible)	Acid Test (if it applies)	Metamorphic Rock Name	Grade* (if it applies)	Protolith* (if it applies)
H						
I						
J						
K						
L						
M						
N						

Sedimentary and Metamorphic Rock Lab Quiz - Study Guide

You may use a sheet of notes (two sides of 8.5x11 inch paper). Computer generated text is OK, but no photocopies are allowed. You will **not** be able to use your labs. You may, however, transfer lab information to your sheet of notes.

Sedimentary Rocks – Be able to identify and describe the properties of:

Clastic Sedimentary Rocks:

Conglomerate,
Breccia,
Quartz-Rich Sandstone (Arenite),
Feldspar-Rich Sandstone (Arkose),
Mud-Rich Sandstone (Graywacke),
Mudstone (Shale),

Chemical/Biochemical Sedimentary Rocks

Fossiliferous Limestone,
Crystalline Limestone,
Micrite
Chert
Diatomite
Chalk

Sample Sedimenatary Rock Questions

List the sedimentary rock name

What is a distinguishing characteristic in this rock?

List the name of the mineral that makes up most of this rock

List a distinguishing characteristic of this rock

What mineral is common in this rock

Explain your criteria for assigning this rock name.

Photos of Sedimentary and Metamorphic Rock Specimens can be found on the course Canvas web site. They are also at the following URLs:

Sedimentary Rock Photos:
http://tinyurl.com/g1sedrocks

Metamorphic Rock Photos:
http://tinyurl.com/g1metrocks

Metamorphic Rocks– Study Guide

Terminology:
Protolith, Grade, and Foliation. Be able to list these (if appropriate) for a given sample.

Minerals
Be able to identify distinguishing minerals: quartz, calcite, muscovite, biotite, chloritie, amphibole, garnet

Know the characteristics and rock names of the following rock types:

Foliated Metamorphic Rocks:
Slate
Phyllite
Schist
Gneiss

Non-foliated Metamorphic Rocks
Marble
Quartzite
Greenstone

Foliated and non-foliated varities
Serpentinite.
Metaconglomerate

Sample Questions for Metamorphic Rocks:

List the protolith for this rock.

List the name of this metamorphic rock

List the metamorphic grade

List one of the metamorphic minerals present in this rock (<u>other than quartz</u>)

List the metamorphic <u>texture</u> of this sample

Identify the rock sample using the specific rock name (this may be a igneous, sedimentary, or metamorphic rock).

There will be one or two samples that can be any rock type (igneous, sedimentary, metamorphic)