Metamorphic Rocks **12.001 – 9/19/2012**

Metamorphism can happen in many ways: burial of rocks to various depths, local heating of rocks by magma, extreme heat and pressure during asteroid impacts, shearing and heating along faults, even percolation of water through fractures in rocks. However, broadly speaking, and certainly for our purposes, there are two main types of metamorphism:

Contact metamorphism. This is caused by the heating of surrounding rocks by magma passing through or cooling in the crust. The result is high temperatures but no change in pressure. As a result, the rocks do not typically form the nice textures that we often associate with metamorphic rocks.

Regional metamorphism. This is caused by the burial of rocks, which results in increasing pressure and temperature. More specifically, regional metamorphism typically refers to this happening on a large-scale, typically during mountain building events. We will see many regionally metamorphosed rocks on our field trip, caused by the collision of various bits of microcontinents with the supercontinent Laurentia. This pressure has a direction (typically downward…you know, gravity and all that), and so causes existing minerals to align and new minerals to grow perpendicular to that direction. This creates what is called a **foliation** – a plane or set of planes of weakness in the rock - we can talk more about this in class and you will instantly see it in the rocks, but note that this only happens if the crystals are elongate or platy; stubby, equant crystals do not gain much from re-orienting themselves in this new pressure field.

Regionally metamorphosed rocks can give us an extraordinary amount of detail about the history of the Earth because the minerals and mineral compositions found in these rocks are very sensitive to pressure and temperature, so from analyzing a sequence of rocks, we can learn about precisely what happened in that place. In order to understand this, the first thing we need is to know how to identify and interpret the rocks we see with our naked eyes, and to help us we need a classification scheme in which to put these observations.

There are two major schemes used to describe metamorphic rocks. One is based on metamorphosed mudstones (**metapelites**) and one is based on metamorphosed basalts (**metabasites**).

Both mudstones and basalts produce mineral assemblages (groups of minerals that are characteristically found together) that are highly indicative of the pressure and temperature conditions that the rock has experienced. However, the mineral assemblages produced in mudstones and basalts at exactly the same temperature and pressure are very different because of the difference in bulk composition between mudstones (high Si, low Mg+Fe, high Fe:Mg) and basalts (low Si, high Mg+Fe, low Fe:Mg). This is why we have two separate classifications, developed by different people at different times, working on different types of rocks! If we can find both metapelites and metabasites of the same age in the same place, we can learn even more about the conditions that area experienced.

NOTE: Metamorphic "grade" refers to the temperature and pressure conditions a rock has experienced. A "high grade" rock has been to higher temperatures and pressures than a "low grade" rock. As a rock gets buried, it will become a progressively higher-grade metamorphic rock.

Metapelites (metamorphosed mudstones/shales)

Because mudstones are rich in H_2O, silica, alumina and clay minerals, metapelites are often rich in micas, quartz, garnet and aluminosilicate minerals (Al_2SiO_5 has three polymorphs – info in class).

Metapelites are typically given a two-part name, with the first part giving the diagnostic minerals that give the most information about the pressure and temperature conditions (e.g. staurolite, which is stable over a relatively small range of conditions compared to quartz, which is stable almost everywhere). The second part of the name is textural. The textural definitions are, from low-pressure to high-pressure:

Slate – very fine-grained. Foliation is caused by clay minerals.

Phyllite – slightly coarser grained. They have a sheen that is caused by the alignment of very small crystals of muscovite and chlorite.

Schist – much coarser grained. Most schists have crystals that are large enough to identify with a hand lens. Rocks of this metamorphic grade are typically very rich in platy minerals, mostly muscovite and biotite. The abundance and larger grain size (up to mms) of these minerals results in thicker foliations that can be slightly wavy and deformed – this is called *schistosity*.

Gneiss – as the pressure gets really high, the rock separates into light and dark bands! The reason for this is that it is energetically favorable for the elongate and platy minerals to form in discrete bands as opposed to lying all over the place, and all the dark minerals are either elongate or platy, so these bands tend to be dark in color. In metapelites, the most common mineral that is not elongate or platy is typically quartz, which forms the light regions between the dark bands.

In metapelites, the idea of "index minerals" was proposed long ago based on metamorphic rocks in Scotland. The idea is that certain minerals are only found in rocks that have experienced conditions above a certain temperature (and often pressure). There are two progressions of index minerals based on the pressure-temperature range experienced by the rocks. The best-known is the Barrovian sequence, which is commonly found in mountain ranges. From low temperature (and pressure) to high temperature (and pressure), the sequence goes:

Chlorite – biotite – garnet – staurolite – kyanite – sillimanite

So if we had a rock with biotite and garnet in it, with a clear schistosity, we might call it a garnet-mica schist. Or if we had a gneiss with sillimanite in it, we might call it a sillimanite gneiss. You get the idea.

Metabasites (metamorphosed basalts)

Metabasites are classified according to "facies" - these are ranges in temperature and pressure over which characteristic sets of minerals occur together in metamorphosed basalts. The figure later in this handout nicely shows how these facies fit into temperature-pressure space. But why are the facies named this way, and what are these mineral assemblages that are so distinctive?

Zeolite – This facies is named for the fact that the rock is full of zeolites! We won't see much of this.

Hornfels – This facies only usually forms during contact metamorphism (high temperatures, low pressures), and is named after "hornfels", a rock type defined by its texture rather than its composition, simply referring to the fact that the rock gets baked at such hot temperatures that it becomes very hard and splintery.

Greenschist – This facies is named for the presence of a number of green minerals! Chlorite, epidote and often actinolite (a green amphibole) form in basalts metamorphosed at these conditions. Sodium-rich plagioclase feldspar (albite) is also common.

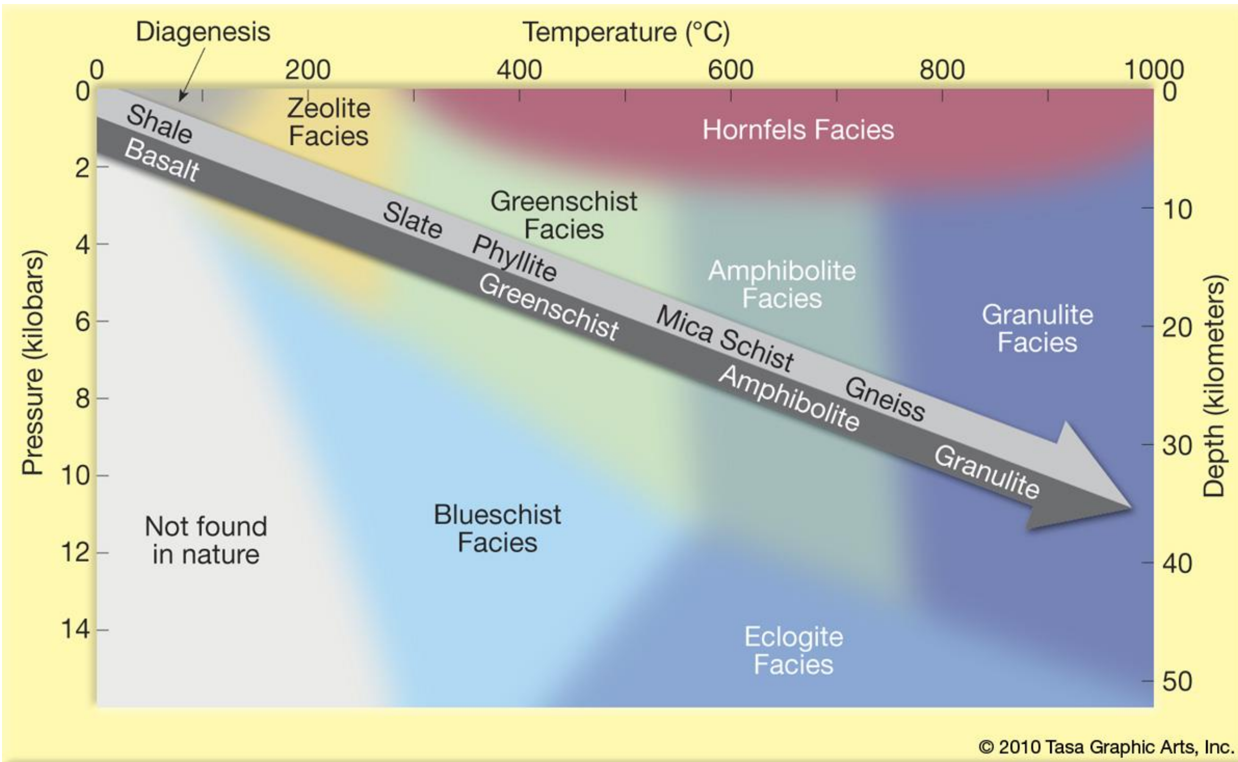
Blueschist – This facies is named for the presence of the blue amphibole glaucophane. Other distinctive minerals can include the minerals lawsonite, epidote, phengite (a silvery white mica) and jadeite (a sodium-rich pyroxene).

Amphibolite – This facies is named for the presence of hornblende (an amphibole), which is typically black in these rocks. Plagioclase feldspar is also abundant.

Granulite – This facies is named for the fact that the rocks have a granular texture (large (often >1 mm) crystals with no foliation) due to the absence of any platy or elongate minerals. Diagnostic minerals are one or two types of pyroxene, plagioclase feldspar, and sometimes garnet (only if pressure is high enough).

Eclogite – This root of this word is Greek via. German in origin but is not helpful! The classic eclogite mineral assemblage is garnet and a green clinopyroxene called omphacite. Other common minerals include quartz, rutile and phengite.

The following diagram conveniently displays information about the two classification schemes in one diagram. The colored regions represent facies used to describe metabasites. The arrow shows the temperature-pressure range that you might find as you go deeper inside a mountain belt, which represents the increase in temperature and pressure that a rock might experience as it is progressively buried during mountain building. The dark grey represents the metabasite facies you would find, and the light grey represents the corresponding types of metapelites you might find. Because the facies are technically descriptions of pressure-temperature ranges, not rock names, a metabasite at amphibolite facies might be called an amphibolite but it might also be called a hornblende schist. Confusing, I know, but you will get used to it! To put some more geologic context in the picture, subducting oceanic plates experience temperatures in blueschist and eclogite facies while contact-metamorphosed rocks are largely confined to zeolite and hornfels facies.



The table below provides a nice comparison of mineral assemblages produced in metapelites and metabasites at the same facies.

Table 6.2 Major Minerals of Metamorphic Facies Produced from Parent Rocks of Different Composition

Facies	Minerals Produced from Shale Parent	Minerals Produced from Basalt Parent
Greenschist	Muscovite, chlorite, quartz, albite	Albite, epidote, chlorite
Amphibolite	Muscovite, biotite, garnet, quartz, albite, staurolite, kyanite, sillimanite	Amphibole, plagioclase feldspar
Granulite	Garnet, sillimanite, albite, orthoclase, quartz, biotite	Calcium-rich pyroxene, calcium-rich plagioclase feldspar
Eclogite	Garnet, sodium-rich pyroxene, quartz/coesite, kyanite	Sodium-rich pyroxene, garnet

And here's a table just to help you out with textural classification of rocks. Most of the information in it is in the previous pages of this handout, but this is a (relatively) user-friendly guide.

Table 6.1 Classification of Metamorphic Rocks by Texture

Classification	Characteristics	Rock Name	Typical Parent Rock
Foliated	Distinguished by slaty cleavage, schistosity, or gneissic foliation; mineral grains show preferred orientation	Slate Phyllite Schist Gneiss	Shale, sandstone
Granoblastic (nonfoliated)	Granular, characterized by coarse or fine interlocking grains; little or no preferred orientation	Hornfels Quartzite Marble Argillite Greenstone Amphibolite[a] Granulite[b]	Shale, volcanics Quartz-rich sandstone Limestone, dolomite Shale Basalt Shale, basalt Shale, basalt
Porphyroblastic	Large crystals set in fine matrix	Slate to gneiss	Shale

[a]Typically contains much amphibole, which may show alignment of long, narrow crystals.
[b]High-temperature, high-pressure rock.