GY 111 Lecture Notes
Metamorphism 2: Regional Metamorphism

Lecture Goals:
A) Foliated rocks part 1
B) Foliated rocks part 2
C) Non-foliated rocks

Reference: Press et al., 2004, Chapter 9; Grotzinger et al., 2007, Chapter 6;
GY 111 Lab manual Chapter 4

A) Foliated Rocks part 1
If you recall the last lecture, you will realize that regional metamorphism involves the combination of heat and pressure. Pressure is the agent that is responsible for the development of foliation in many of the metamorphic rocks that develop during mountain building. Foliation can be defined as a near parallel alignment of "platy" minerals in metamorphic rocks. Platy minerals are those minerals that have a sheet-like crystallographic structure. Remember this from our discussion of the silicate minerals? The sheet silicates (phyllosilicates) included the common mica group minerals biotite, muscovite and chlorite. It is also necessary to include another mineral group of silicate minerals to the phyllosilicates if we are going to be able to explain the origin of foliation in regionally metamorphosed rocks. The clay group of minerals includes kaolinite, which I know all of you will recall is one of the major chemical weathering products of hydrolysis. Kaolinite and most other clays like biotite, muscovite and chlorite, have a sheet structure; however, unlike the mica minerals, the clay minerals are exceeding tiny (less than 10 microns or 0.01 mm in size), and the only way that you can see their platyness is via an electron microscope (see scanning electron microscope photo of kaolinite to right from: http://www.ktgeo.com).

The reason for resurrecting mineralogy at this stage in the class is because it is the clay minerals in parent rocks that ultimately develop foliation in regionally metamorphosed rocks. In order to understand this process, a rather complex diagram is required. Moreover, we need to first consider the composition of a platy-mineral rich parent rock.

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1 One of the most confusing things about geology is the double meaning of some geological terms. Clay minerals are a group of very fine-grained phyllosilicates. This is a mineralogical term. Clay-sized sediments are a group of very fine-grained particles. This is a sedimentological term. If it helps, most clays are clay sized sedimentary particles.
Which platy mineral-rich rock we choose is largely a matter of personal preference. We could choose a mica-rich igneous rock like granite or diorite or andesite, but since we just finished the sedimentary rocks, and considering that your humble instructor is a sedimentologist\(^2\), let's instead consider a shale. The colour of the shale doesn't matter, but just to be sure that we are as precise as possible, let's make it a red shale.

Were you to examine a red shale under a powerful microscope (see cartoon at the top of this page), you would discover that the rock is composed of a variety of small silt and clay-sized grains. The silt fraction is mostly composed of silicate minerals like quartz and feldspar. The clay component is mostly composed of platy clay minerals. Note that the orientation of the clay minerals is relatively random. This is because the shale was produced through the action of minimal compaction during the lithification stage. I know that when we were talking about the role of compaction in dewatering of wet mud I implied that a lot of horizontal confining or burial pressure was required to convert mud into shale. But this is still only a fraction of what is experienced during regional metamorphism. Burial of mud and lithification into shale squeezes the water out of the sediment but doesn't really have the "oomph" to squish the clay particles. The directed pressure or compressive stress of regional metamorphism does.

The first stage of regional metamorphism (equivalent to the lowest grade) occurs when pressure flattens out the platy minerals into a more stable orientation. This is always perpendicular to the direction of compressive stress (see cartoon at the top of the next page). Apart from this induced orientation change, the composition of the red shale has not really changed. Yet the rock can no longer be called a "shale". It is no longer a sedimentary rock, but a low grade metamorphic rock. It is called **slate**. Since the parent rock was a red shale, the slate will also be red in colour\(^3\). Careful examination of the red slate, and more importantly, direct comparison between the red slate an a red shale will reveal that the surface of the slate is subtly "shinier" that the parent rock was. It is never a good idea to mix up terms in a science class, but this may be one time where it will help

\(^2\) This means that he considers sedimentary rocks to be the most important types of rocks on the Earth. You should too if you want to pass GY 111.

\(^3\) Had we started with a black shale, we would have produced a black slate. A green shale would have produced a green slate etc.
you to spot the difference between a slate and a shale. If you recall our section on minerals, you will remember that minerals have different lusters. Some are glassy, some are waxy, some are earthy etc. If you look at the surface of the red shale, it will look "dull" or "earthy". In comparison, the red slate has more of a sheen to it. It almost looks like a thin layer of wax was smeared on it. Another difference between the slate and the shale is the nature of the layering that characterizes the rocks. The layering of a shale is sedimentary in origin. Fine grained silt and clay was deposited out of water resulting in a fine horizontal lamination. Dewatering and compaction during the conversion from mud to shale tends to emphasize this layering resulting in the "fissility" that characterizes shale. The layering in slate is due to directed pressure. It could have come in from any direction. In fact, some slates have 2 layering patterns. One is the original horizontal bedding. The other is the alignment of the platy minerals due to compression. This parallel alignment of clay minerals can cause the rock to break or cleave in almost perfectly parallel slices a property that is called rock cleavage⁴.

⁴ It's actually just called cleavage, but I think it best to refer to it as rock cleavage to avoid confusion with other uses of the term (e.g., mineral cleavage).
If the amount of stress (and now we must include heat) was higher than that needed to form slate (but still in the “low grade” metamorphism range), there will be more changes to the parent rock than just realignment of the platy clay minerals. Now there will be mineral changes. In the same way that some minerals formed under certain igneous conditions (e.g., olivine forms from the melt over a specific temperature range), some minerals start to form when metamorphic conditions reach a critical point. The first minerals that appear are members of the phyllosilicates. The include (in order of formation), chlorite, muscovite and biotite. The materials required for the growth of these minerals were already in the parent rock. They include clay minerals like kaolinite, and iron oxide minerals like hematite and limonite. As chlorite, muscovite and biotite grow, the clay and iron oxide content remaining in the parent rock decrease. There are actually two varieties of metamorphic rock that can be produced this way. If the metamorphic grade was relatively low, the growth of the phyllosilicates may not have been sufficient to produce visible crystals of mica. There will be a colour change to the rock (for example, the red colour of a red shale would not be preserved), but you won’t be able to identify specific mica minerals in the resulting rock. There will, however, be a change in the surface "luster" of the rock. Compared to slate, this rock has a much glossier surface. Think of a frosted donut. This low grade metamorphic rock is called phyllite.

Had the metamorphic grade been a bit higher (call it medium grade), the mica minerals would have grown sufficiently large for you to identify what they were. You would see chlorite and/or muscovite and/or biotite, as well as a host of other metamorphic minerals. If you can see and identify these minerals, the rock is called schist. We will discuss the various types of schists later during the lab introduction to the metamorphic minerals.

By the way, I need to re-introduce an important metamorphic term at this point in the lecture. The growth of the platy minerals is the reason why regionally metamorphic rocks are foliated. The degree of foliation depends upon the amount of mica minerals in the rock, so it stands to reason that schists are the most foliated rocks and slates the least
foliated. In fact, most geologists don’t even consider slates to be foliated (they area characterized by rock cleavage). But is it as simple as this? Is schist as foliated as you can go? The answer is yes and no.

The highest grades of metamorphism induce a different type of layering to metamorphic rocks. Under these conditions, the minerals that form separate into distinct (or near distinct) band. It is not truly foliation anymore because the mica minerals do not comprise the majority of the rock. Instead what you see are bands of mica (usually biotite) interspersed with layers of quartz (white/grey), Na-plagioclase (white) and/or orthoclase (pink). Does this combination of minerals ring a bell? Does it remind you of granite or diorite? It should. Under the highest grades of metamorphism, it is possible to convert a shale into a rock that has the same overall composition as granite. This might come as a surprise to you, but remember, the shale might have ultimately been derived from the weathering of a granite in the first place. All the raw elements and chemicals of a granite were still there, just in a different mineral form. All that metamorphism did was to reassemble them back into minerals that had originally formed through igneous processes. Yet another example of the rock cycle.

The rock that resembles granite that has the nice parallel band in it is called granite gneiss or just gneiss. It is the highest grade of metamorphic rock that can form from a shale or felsic\textsuperscript{5} igneous parent rock. Beyond this, metamorphism is so intense that partial melting occurs. In GY 111, we regard any melting as an igneous process, but metamorphic geologists frequently classify partially melted metamorphic rocks as migmatites. You'll learn more about these rocks in the next lecture. In the meantime, why not ponder the summary cartoon on the top of this page. If all went as planned in today's lecture, we produced something very much like it on the chalk board.

\textsuperscript{5} In case you forgot, felsic igneous rocks include rhyolite, granite, most tuffs, pumice and volcanic ash.
Examples of the major foliated metamorphic rocks. Clockwise from upper left; slate, phyllite, garnet muscovite schist and gneiss (source of all images on this page: http://www.uwm.edu)

B) Foliated Rocks part 2
Alright. You get a foliated rock if you metamorphose a shale or a felsic igneous rock. The question arise, what happens if the parent rock was something else? What if it was, say, a mafic igneous rock like gabbro or basalt or scoria? What would you get if you metamorphosed one of these rocks?

The metamorphic rock that you ultimately get again depends upon the grade of metamorphism that the rock experiences. If it is relatively low grade, you wouldn't notice many changes in the rock. You might see a bit of chlorite formation (the rock turns a bit greenish in colour), but no distinct foliation or rock
cleavage develops. In situations like this, adding the prefix "meta" to the rock name (e.g., meta-basalt, meta-gabbro) is commonly employed by geologists. If, however, the grade of metamorphism is medium to high (the range where a schist would form), you do start to see a type of foliation. It is not as good as the one that develops when mica minerals form in a schist because this foliation is produced from the alignment of amphibole crystals. Under medium to high grade metamorphism, the rock that forms from a mafic igneous parent rock is an amphibole rich schist which is conveniently named amphibole schist or amphibolite. The rock is foliated, but because amphibole is not a platy mineral, the foliation is less distinct (see cartoon below and photo at the bottom of the previous page).

C) Non-foliated rocks
Okay. Last questions of the day. If foliation in rocks is caused by compressive stress in a play mineral-rich parent rock, what would you get if the parent rock did not have any platy minerals to begin with? What if you started off with a pure quartz arenite sandstone (100% quartz) or a pure limestone (100% calcite). Neither quartz, nor calcite, are platy. If you metamorphose parent rocks containing only them, the resulting parent rock (regardless of grade), would be non-foliated. The effects of pressure on these parent rocks simply squishes the quartz or calcite grains into an interlocking mosaic of crystal:

The resulting metamorphic rocks lose virtually all of the original sedimentary character of the parent rock. Most importantly, you no longer see individual sedimentary grains. The colour of these metamorphic rocks are also highly variable. A metamorphosed quartz arenite is called quartzite and a metamorphosed limestone is called marble. The two of these rocks frequently look identical. That being the case, you might ask yourself how can I distinguish the two in a lab setting? Think about it before we get to the lab later this week.

6 Choose any limestone you wish. Oolite, fossiliferous, non-fossiliferous, chalk etc. Even travertine (cave-produced calcium carbonate) would give you the same result.
There is one other non-foliated regionally metamorphosed rock to mention before we call it quits today. A metamorphosed conglomerate is called **metaconglomerate**. It looks very much like a normal conglomerate with two important exceptions. The first is that the pebbles are frequently flattened, a result of the compressive stress of regional metamorphism. The second exception is that unlike conglomerates which break *around* the gravel sized particles when the rock is broken, metaconglomerates break *through* gravel sized particles. Metamorphism tends to homogenize the conglomerate so that quartz gravel and the cement that held the pebbles together end up being equally strong. In a sedimentary conglomerate, quartz gravel is usually much stronger than the cement. Hence, conglomerates break at the cement rather than through the grains.
Important terms/concepts from today’s lecture

(Google any terms that you are not familiar with)

foliation (foliated)
mica (mica group)
clay group
kaolinite
cleave
rock cleavage
slate
phyllite
schist
(granite) gneiss
muscovite
chlorite
biotite
amphibolite
quartzite
marble
meta
metabasalt
metaconglomerate
migmatites
non-foliated rocks
foliated rocks