GY 111 Lecture Notes
Thrust Faults and the Appalachian Mountains

Lecture Goals:
A) Thrust Faults
B) The Appalachian Mountains

Reference: Press et al., 2004, Chapters 2, 6, 20; Grotzinger et al., 2007, Chapters xxx-xxx;

A) Thrust Faults,
Several lectures ago, we discussed the major types of faults. Two of these were dip slip faults where movement was along the dip direction of the fault plane. At the time, I hinted that there was a special class of reverse dip slip fault associated with mountain building. They are low angle reverse faults called thrust faults. Thrust faults occur when widespread compression, usually associated with convergent plate boundaries, starts to affect continental rocks.

They are particularly prominent in thick sequences of sedimentary rock. To make a long story short, when sedimentary rock sequences are compressed, a series of thrust faults that dip in the direction that the stress originated from start to develop. Any rock layers that lay above the thrust fault are pushed over top the layers that lay below the thrust fault. This does two things. First of all, it "thrusts" the overlying layers up above the surface of the Earth forming linear trending mountain belts (amazingly called thrust
fault mountains). Seconding, it shortens the original width of the sedimentary succession. If you recall our initial lecture on deformation, shortening is a natural consequence of compressive stress, so the lateral shortening that occurs when thrust faults develop is exactly as predicted. It is, however, staggering just how much compression can occur. There are thrust faults in the Cordilleran Mountains where more than 100 km of lateral displacement has occurred.

Very shortly, you will see a review film on thrust faults and mountain building that will very graphically demonstrate how this compressive process occurs. You will also learn that thrust faults are seldom isolated. They usually occur in sets. As compression continues, successive thrust faults develop. Many branch off from earlier ones. Eventually, you can get very wide mountain belts composed of nothing but thrust faults and the rocks that were faulted. The block diagrams above are from your lab manual and demonstrate just how complex the geology (and the resulting geological map) can be when thrust faulting is extensive.

There are two more terms that need to be introduced at this time. If you look at the previous two diagrams (and if you pay attention to the thrust fault film you will shortly see), you will hear the terms **ramp** and **flat** applied to thrust faults. The ramp is defined as the port of a thrust fault that is relatively steep that cuts up and through sedimentary
layers. The flat is the nearly horizontal part of the thrust fault where rock layers slide over top of other rock layers. Flats are frequently lost from thrust fault mountains because of erosion. You will also notice a new geological symbol on the geological block diagrams on the previous page:

This symbol indicates both the position of a thrust fault and which side of the fault is the overthrown side. The triangles are always placed on the side of the fault that was overthrown. The same symbol is also used for convergent plate boundaries. In the cartoon at the top of the next page, the map symbol indicates that the North American plate overlays the Pacific Plate.

**B) The Appalachian Mountains**

Up until now, we have been using western North America as an example of thrust fault mountains. This is understandable considering that these mountains (especially the Canadian Rockies), contain some of the best examples of thrust faults anywhere in the world. But what about the other mountain range in North America? What about the Appalachians? For the rest of today, I'd like for you to consider the mountain belt in our own back yard. True, the Appalachians are not all that impressive compared to the Cordilleran Mountains. They are less rugged, less high and hence, less intimidating. But remember; they are old. Where we to get in a time machine and travel back to the present location of Mobile some 300 Million years ago, we would be amazed by the Appalachian
Mountains\textsuperscript{1}. We would see mountains as high, and possibly higher, than the Himalayas. They were also much more extensive. They extended from Alabama through what is today the Maritime Provinces of Canada, and into Greenland and Scandinavia. Three hundred million years of erosion can really take a lot out of you!

The origin of the Appalachian Mountains is one of the most interesting Earth history stories, at least as far as North America and Alabama are concerned. In order to understand the events that occurred to form the Appalachians, we need to get back in our time machine and travel further back than 300 Ma. We need to go back to the Cambrian, some 550 million years in to the past.

\textsuperscript{1} We would also not be in Mobile anymore. In fact, we would probably be standing on part of what is today, South America. Plate tectonics – you gotta love it!
The world at this time was very different than the world of today. North America\(^2\) was tilted about 60 degrees from its present orientation and lay across the equator. The continent was drifting more toward the east than toward the northwest as it is today. Were we to step out of our time machine in the present location of Mobile, we would find ourselves in very deep water. The shoreline lay 100's of km to our north. Near Huntsville, the water was shallower. We would see tropical biochemical sediment just about everywhere we looked. Ooids and reefs\(^3\) were wide spread all along the eastern coastline. At the coastline, we would find quartz sand along the beaches, mud in estuaries, lithic sand in delta channels. In other words, the coast of North America 550 Million years ago was very much like it is today, except that the weather was better and the beasties were different.

Well off to our east was another land mass. Today we would call it Europe. Like North America, its coastline was surrounded by largely tropical sediment deposits, beaches etc.

\(^2\) Technically speaking, North America did not exist in the Cambrian. Nor did Europe, Asia, Australia, Africa, South America or Antarctic. These are names that we apply to the continents as they are configured today. Five hundred million years ago, the continents were different, so we give them different names. North America was called \textit{Laurentia}, Europe was called \textit{Baltica}, South America, Africa, Antarctica and Australia were all stuck together into a large continent called \textit{Gondwanna}. Asia was fragmented. Some present day parts of Asia were isolated continents (e.g., Siberia) where as others were stuck to other continents (e.g., India was part of Gondwanna). The oceans were also different. You will have to know all of these names for GY 112 as this is an important component of Earth history, but you are off the hook as far as this nomenclature is concerned for GY 111.

\(^3\) This far in the past it is important to remember that the beasties that comprised reefs were completely different from the ones we see today. Evolution has induced a lot of changes in 500 Ma.
But between the two continents… well that’s where things were very different from today. In today’s world, North America and Europe are moving away from one another. There is a divergent plate boundary (Mid Atlantic Ridge) between the two that is widening the Atlantic Ocean. During the Cambrian, Europe and North America were drifting toward one another and the ocean⁴ between them was getting smaller. Geologists believe that there was a convergent plate boundary where subduction took place somewhere between North America and Europe at this time. There may have been more than one subduction zone. One or more zones of subduction were also occurring between North America and Gondwanna.

Ultimately, the Appalachian Mountains resulted from the convergence and collision of all of these continents. The Appalachian Mountains were formed by 3 distinct pulses of mountain building. Geologists name these events orogenies and give them proper names which you do not have to remember in GY 111. The first phase of mountain building (Taconic Orogeny) occurred during the early to middle Ordovician (about 500 Ma) and affected much of the eastern coastline of North America; however, it was largely focused in the area from present day Newfoundland down to about New York State. In the south, Taconic events mostly involved intrusions (e.g., plutons composed of granite), but in the north, there was significant compressional deformation (e.g., thrust faulting). It is now believed that the Taconic Orogeny and the deformation that occurred with it was induced by the collision of an island arc complex with eastern North America. After God-knows how many years of drift, North America was beginning to experience the collision of land masses and the Taconic Orogeny was simply the first strike.

Perhaps a recap about island arcs is necessary here. Island arcs like the Aleutian Islands of Alaska, or Japan form where oceanic plate is subducted below oceanic plate (see cartoon below). The melting of the subducted plate produces plutons consisting mostly of intermediate composition magma. Eruption of this material at the top of the overriding plate results in a linear series of composite volcanoes that parallel the subduction zone and the deep water trench. If enough lava is erupted, the volcanoes get bigger and bigger as do the islands that they are producing. Japan is a huge island arc composed of numerous separate volcanoes such as Mt. Fuji, Mt. Unzen etc. In contrast, the islands of

⁴ Offically, this ocean was not the Atlantic. The Atlantic Ocean did not develop until the Mesozoic when Pangaea broke up. Like ancient continents, it is desirable to name ancient oceans. The Cambrian Ocean has been called the Proto-Atlantic by some, but the favored name is Iapetus Ocean.
the Aleutians are pretty small with some consisting of little more than a volcanic vent. Island arc volcanoes tend to erupt intermediate lavas (e.g., Andesite, Pumice, Tuff) and can be violently explosive.

So, the first phase of mountain building in what would become the Appalachian Mountains occurred about 500 million years ago when an island arc complex hit North America. Some people regard it as more of a “docking” or an accretionary event. The island arc was simply “glued” to the outside margin of the continent. But with this docking came uplift, thrust faulting, and limited (localized) metamorphism. Many plutons burned their way up through the continental crust at this time too. It may have been a relatively small collision, but it was accompanied by all of the geological consequences that we have come to expect from plate tectonics.
The second phase of mountain building was much more impressive. It occurred during the early Devonian Period (around 400 Ma) and was a follow-up collision to the island arc that hit us during the Taconic Orogeny. This event was a continent-continent collision between North America and Europe and it completely closed the northern portion of the Iapetus Ocean, re-deformed some of the rocks previously affected by the Taconic Orogeny, and would have caused a mountain belt the height of the Himalayas in what is today Newfoundland, Nova Scotia, Maine, New York, England, Ireland, Scandinavia and Greenland. In North America, we call this event the Acadian Orogeny (see next cartoon).

The southern Appalachian Mountains that crop out from Virginia to Alabama resulted from the third and last of the great mountain building events to affect eastern North America during the Paleozoic. The Alleghenian Orogeny occurred during the Pennsylvanian Period and resulted from the collision of Africa/South America (then called Gondwanna) with North America. This was the final straw as far as the Iapetus Ocean was concerned. When the Alleghenian Orogeny was finished, the Iapetus Ocean was gone and the continents were assembled into the most recent of the great supercontinents. Pangaea had just formed.

As you know, Pangaea would eventually break up in the Mesozoic. The Atlantic Ocean began to form about 200 million years ago as North America started drifting to the west. The Cordilleran Mountains would start their major phase of growth about 150 million years ago as land masses began to "dock" with North America. The separation of North America, Europe and Gondwanna occurred almost along the same "suture line" where these continents came together in the Paleozoic. I think it's because the suture line represented a weak surface. When the tectonic forces reversed from compression to tension, the continents slipped along the suture line, but it wasn't perfect. Some parts of Gondwanna stuck to North America (e.g., southern Nova Scotia, parts of South Carolina) whereas parts of North America stuck to Africa or Europe. The last cartoons in today's lecture summarize the major mountain building events responsible for the Appalachian
Mountains as well as their major structural elements. Please note that we recognize five distinct geological "provinces" in the Appalachian Mountains. This is best illustrated in a cartoon transect of the Appalachians from approximately Tuscaloosa to Savannah, GA. This section represents ½ of the original width of the Appalachians (the other half is over in Africa!), but it still demonstrates the increase in deformation and metamorphism that you would predict as you get closer to the area where the suture zone developed during Pangaea's formation. We will spend much more time in GY 112 discussing the formation of the Appalachians. Today's lecture is just meant to tempt you into the wonderful world of Earth History.
The series of cartoons below come from the GY 112 lecture notes and summarize the events responsible for the formation of the Appalachian Mountains. They have been highly simplified and there are bound to be grievous errors in some of them, but they should help you to understand the role of plate tectonics in mountain building.
Terms to be familiar with (refer to Chapters 2, 6 and 20 of your text book for help)

island arc
ramp
flat
thrust faults
orogeny
Pangaea
suture line

optional terms (not needed for GY 111 but pretty cool for general knowledge)
Laurentia
Gondwanna
Baltica
Iapetus