Lecture Goals:
A) Triassic Sedimentation (Breakup of Pangaea)
B) Jurassic Sedimentation (Birth of the Atlantic Ocean)
C) Cretaceous Sedimentation (Creation of the Coastal Plain Province)


A) Triassic Sedimentation
The formation of Pangaea was the most important tectonic event in the Paleozoic. It was also instrumental in major paleoclimatic change and evolution. But alas, Pangaea was only a temporary supercontinent. It, like most marriages these days, was doomed to eventual breakup. That separation began in the Triassic and really took off in the Jurassic.

The evidence for initial breakup is now buried beneath the Coastal Plain Province of the Appalachian Mountains or off the east coast of North America (thousands of metres below the surface of the Atlantic Ocean). In order to study these rocks, you need to either drill down to them (e.g., get cores) or use seismic techniques (this is the discipline of geophysics). Fortunately, we have a lot of both types of data because the oil companies have been actively studying the region looking for $$$ (i.e., oil and gas). Seismic profiles of the east coast of Canada and in the Gulf of Mexico reveal fault structures that we have previously discussed in GY 112 (refer back to the Wopmay Orogeny lecture):

The faults are all normal which indicated that the area was experiencing tension during the Triassic. The multiple normal faults are typical of rift valleys which I’m sure you’ll remember, is the initial phase of divergence (divergent plate boundary). As divergence
proceeds, the rift will widen enough to allow new oceanic crust to form, but this takes time. To the best of our knowledge, no new oceanic crust formed until later in the Mesozoic. In the Triassic, all that rifting did was to form linear canyons very much like the East Africa Rift today. Nevertheless, this was a very important event that signaled the eventually breakup of Pangaea and the eventual formation of new oceans. The North Atlantic and Gulf of Mexico started to open first. The Southern Atlantic opened a bit later.

The initial rifting was accompanied by a great deal of sedimentation. The crack that formed developed along the middle of the Appalachian Mountains\(^1\) and produced a steep topographic gradient (see diagram below). As I have said in this class before, holes don’t last very long in geology and this long linear “hole” was no exception. It started to get filled by sediment.

The type of sediment that initially was deposited into the rift was, not surprisingly, coarse grained and relatively “immature” (angular, composed of feldspar and other unstable minerals). It was arkose and breccia (collectively called red beds) and was deposited in alluvial fan-like depositional environments. Sedimentation was occurring simultaneously with rifting so the red beds were also faulted. In Alabama, geologists at the Geological Survey of Alabama named the faulted Triassic siliciclastic unit the Eagle Mills Formation (see the Alabama stratigraphy chart at the end of this lecture).

\(^1\) The rift closely followed the original suture line that marked the junction of Laurentia, Baltica and Gondwanna, but it wasn’t perfect. In some places, the rift developed to the east of the suture line leaving a portion of Gondwanna on North America (e.g., southern Nova Scotia, parts of the Carolinas). Sometimes the rift developed to the west of the suture line leaving a chunk of Laurentia in Europe, Africa or South America.
As rifting continued, the fault blocks continued to sink deeper into the lithosphere. The rift continued to be filled with siliciclastic sediment but in some places, the sediment was starting to become more mature because it was traveling further from its source. Eventually, the fault blocks sunk below sea level and when this occurred, sea water flooded into the depression. Non-marine sedimentation was replaced by “marine” sedimentation. Geological evidence suggests that this started to occur in the southern and northern Appalachians near the end of the Triassic, but things really started to get flooded during the Jurassic.
B) Jurassic Sedimentation

The initial pulse of marine sedimentation in the Atlantic Ocean and the Gulf of Mexico was dominated by carbonate rocks (limestones and dolostones) and evaporite minerals. Thick sequences of halite, gypsum and anhydrite blanketed the rift valleys. The reason why these minerals were deposited is pretty straight-forward. The sea that flooded the rift valleys was initially very shallow and the warm paleoclimate resulted in very intense evaporation (see image to right of the Jurassic “Gulf of Mexico” from http://igp.colorado.edu/hmns and image below left of Death Valley as an example of an evaporite basin from http://ccwf.cc.utexas.edu/~gavenda/images/L8610.91_16.JPG). In some areas of the Gulf, 100’s of metres of halite were deposited during the Jurassic. In coastal Alabama, the evaporite unit is called the Luann Salt Formation and it is over 20,000 feet below the surface of the Earth, at least in most places. The thing about halite is that it is a very ductile material (that means it is capable of “flowing” if there is sufficient overlying pressure), and 20,000 feet of horizontally bedded rock units certainly qualifies as “sufficient”. In some areas, the salt has flowed upward into enormous domes or diapers. The oil companies are well aware of these structures because they are major producers of oil and gas. Some diapers are small structures, but others are very impressive. I know of one that is 18,000 feet thick that has never been completely drilled. A few almost made it to the surface of the Earth (e.g., they are a few hundred feet below the surface). They could be mined for salt, but are instead used by...
chemical companies as a source of brine for production of chlorine gas, bleach and other halide compounds. If the salt diapers get too close to the surface, they encounter groundwater and can dissolve. This leaves a huge hole just below the surface that might collapse into a sinkhole. This happened once before in Louisiana (take my environmental geology class if you want to hear more about this event!).

As the Atlantic Ocean and Gulf of Mexico continued to widen, the evaporite minerals were replaced by shallow marine shelf sedimentary rocks. Fossiliferous and non-fossiliferous limestones (Norphlet and Smackover Formations) were deposited in Alabama. These rocks still contain a few evaporite minerals as well as ooids indicating that the shelf was still shallow and tropical. The Smackover Formation also contains a lot of algae. We haven’t mentioned cyanobacteria for quite some time, but it was still around in the Jurassic (in fact, it is still around today). The Smackover Formation contains a lot of algal clasts and stromatolite-like structures. Some of the algae was extensive enough to be called reefs (these composite structures were 100s of meters long). We actually know a lot about these reefs (even though none are exposed at the surface) because they are excellent reservoirs for oil and natural gas. As a general rule, if there is any money to be made from something in geology (e.g., oil, gas, gold, uranium, water), geologists know a lot about it.

We now need to turn our attention to western North America. When we last discussed the west, we were talking about tectonics. By the Jurassic, the Cordilleran Mountains were a nearly continuous chain from Alaska to Mexico. Sedimentation was still dominated by siliciclastic material derived through erosion. But now there was a difference. In the Jurassic, sea level was substantially higher than it is today. The climate was warmer (there would have been less glacial ice) and warmer water is less dense than cold water (warm water occupies more space than cold water), which also contributed to high a sea level. In addition, there were significant areas where new oceanic crust was being produced which decreased the volume of the ocean basins thereby contributing to even higher sea levels. Enough said. Sea level was high and in North America, this resulted in flooding of
the continent from north to south. It was a shallow epeiric seaway that some people call the **Sundance Sea** (see cartoon at the bottom of the previous page). From western Canada most of the way down to Nevada, Jurassic sedimentation was a mixture of non-marine and shallow marine siliciclastic sedimentation. Great river deposits (lithic sandstone, red shales, conglomerates) pass into equally great deltas (lithic sandstone, coals, black shale), deserts (quartz arenite), beaches (quartz arenite) and shelf sequences (fossiliferous sandstone, green shales, limestones). These sediments are as important to the west as the Smackover Formation is to Alabama from an economical perspective. They produce incredible amounts of oil and gas. There is no need to get into specific formation names for the western Mesozoic sedimentary rocks, but one in particular is worth briefly mentioning. The **Navajo Sandstone** (pictured above right in an excellent photo by Willie Holdman; http://www.willieholdman.com), characterized by spectacular cross-stratification indicative of a coastal desert environment of deposition. It is also the formation most commonly spotted behind the "cowboys and indians" in your typical John Wayne "git along little doggie westerns". However, in GY 112, it is better if you focus on Alabama Stratigraphy instead of the stratigraphy from other parts of the country. Which brings us to the last topic of the day.

C) Cretaceous Stratigraphy

Finally we start to discuss the rocks that actually underlie our part of the world. Yes, it’s time to deal with the Alabama **Coastal Plain**. This is the **post-deformational** province of the Appalachian Mountains. Technically, these rocks include the Triassic and Jurassic rocks we discussed earlier in this lecture, but all of those rocks are deeply buried beneath the younger components of the Coastal Plain. Those younger components include thick sedimentary rock layers of Cretaceous age.

In Alabama, the oldest exposed Cretaceous rocks crop out in a belt right along the edge of the
Appalachian Mountains. The rocks get successively younger in belts from north to south. Were you to draw a cross section from Montgomery to Mobile, you would get the following portrait:

The beds are drawn with a significant vertical exaggeration\(^2\) making the beds appear to have a relatively steep slope. In the cartoon above, the beds look like they are tilted at 20 degrees, but in reality, they dip no more than 2 or 3 degrees. In other words, the Cretaceous strata of the Alabama Coastal Plain are essentially “flat-lying”, exactly what you would predict for a passive continental margin.

The younging trend from north to south in the Alabama Coastal Plain is a classic example of lateral accretion of the continents. As erosion continued to wear down the Appalachian Mountains, the sediment being shed through weathering was transported down gradient. In Alabama, this was to the south. The Coastal Plain formed through erosion of the mountains and became more extensive over time. This is still happening today. The beaches, estuaries, lagoons and bays of the Alabama Gulf Coast are modern environments were the erosional sediment of the Appalachian Mountains is being deposited. If we went back in time 1000 years or 10 million years or 30 million years, we would see the same types of depositional environments, just in a different location. One hundred million years ago, the “beach” was located close to Montgomery. Ten million years from now, it will probably be many dozens of mile south of Dauphin Island. The amazing thing to remember is that in a mere 100 million years, lateral accretion has added 170 miles of new land (coastal plain) to North America in our state alone.

\(^2\) Vertical exaggerations result when the horizontal scale is much larger than the vertical scale. The total thickness of the Coastal Plain sequence in Mobile is 25,000 feet and the distance from Montgomery to Mobile is 900,000 feet or 170 miles. The vertical exaggeration in the cartoon cross section is significant.
The Cretaceous strata deposited in Alabama and other parts of the Coastal Plain (i.e., the eastern side of the Appalachian Mountains in VA, NC, SC, GA and FL) consists of a variety of sedimentary rock types. Much of it is siliciclastic and dominated by non-marine (e.g., rivers), marginal marine (e.g., deltas, lagoons, estuaries, beaches, barrier islands) or shallow marine environments (e.g., shelf). In some areas (and/or at different times), limestones were deposited on the Coastal Plain. In the late Cretaceous (and into the Tertiary), thick sequences of chalk were deposited.

In Alabama, the Cretaceous chalk unit is called the **Selma Chalk Group** and it is truly impressive. The chalk is composed of the remains of exceptionally small beasties called **cocco-lithophoroids** (coccoospheres for short). Coccoospheres are a type of marine algae that is surrounded by small calcitic plates each no more than a few microns across (0.001 mm) called **coccoliths**. It is the coccoliths that are left behind after the algae dies and they are so small that you need an electron microscope to examine them. In fact, paleontologists refer to them as **nannofossils** to distinguish them from “much larger” **microfossils** like foraminifera which compared to coccoliths are relative giants (0.1 mm in size versus 0.001 mm). A colleague of mine at the Geological Survey of Alabama (Dr. Charlie Smith) reckons that each cubic cm of Selma Chalk (e.g., about the size of a sugar cube) contains more than 40 billion coccoliths. When you consider how thick and how extensive the Selma Chalk is, it is absolutely mind boggling how many beasties are contained in this one stratigraphic unit alone. Dr. Smith also did some work to characterize the stratigraphy of the Selma Chalk. The group contains the Cretaceous-Tertiary (K-T)
contact which is the interval that saw the end of the dinosaurs. Perhaps the best outcrop in Alabama (I think so anyway), is a K-T exposure near Moscow Landing on the Tombigbee River (see photo on previous page). I take senior students to this outcrop each fall as part of my GY 344 (Sedimentary Petrology) class.

The Selma Chalk is unusual as far as chalk is concerned. Most chalks today are deposited in fairly deep water (off the edge of the shelf in water greater than 200 m), but the Selma Chalk was deposited in a shelf environment (e.g., less than 200 m water depth). Picture the waters of the Florida Keys, but instead of a clean turquoise color, the waters of Alabama Cretaceous shelf would have been milky due to all of the coccolithophoroids.

Deposition along the Alabama Coastal Plain was eventually replaced by siliciclastic sediment, but not until well into the Tertiary. In other parts of the Coastal Plain (e.g., NC, VA etc.), Cretaceous sediment was siliciclastic rather than carbonate. Siliciclastic sedimentation was also occurring in the epeiric seaway that covered the interior of North America. During the Cretaceous, sea level was as high as it ever was in the Phanerozoic. The seaway (officially called the Western Interior Seaway) was continuous from the Arctic Ocean all the way to the Gulf of Mexico. Thick clastic wedges of sandstone, shale and conglomerate extended eastward from the Cordilleran Mountains into the seaway. Once again, the sediment was deposited in river, beach and shallow shelf environments. Thick coal seams indicate that there were also swamps (commonly associated with deltas) in the area. The middle part of the seaway was pretty deep; perhaps 200 or 250 deep. Roger Walker, one of the best geologists I have ever worked with (in fact he is one of the best sedimentologists of the modern era), spend a good chunk of his career studying the marine sedimentary sequences of the Western Interior Seaway. He determined that the seaway was frequently disturbed by strong storms (including hurricanes), some of which were 100s of times more powerful than what we see today. Scary stuff!

Sediment deposited during the Cretaceous in the Western Interior was thick and since much of it contained organic material, it has ended up being an important petroleum and coal exploration target in Canada, the United States and Mexico. I spend a summer between my sophomore and senior undergraduate years looking for oil in Cretaceous river deposits in the subsurface of Alberta near Calgary. I got to look at cores and geophysical data sets, but alas, I did not strike it rich. While it is true that there is oil in the west, it isn’t everywhere. Moreover, it’s getting harder to find and we are pretty wasteful with the oil we presently have. The moral of this soapbox story is, trade in the Hummer, ride a bicycle to school.

One last attempt to relate sedimentation and tectonics. In the Rocky Mountains, Triassic, Jurassic and Cretaceous sedimentary rocks have been caught up in the compressional events that ultimately formed the mountains. Additional Cretaceous sedimentary rocks have been produced as a "clastic wedge" from the sediment derived from the thrust faults that comprise the mountains, particularly in the Canadian Rockies (see cartoon on next page).
Cross section across the Canadian Rockies showing the clastic wedge passing laterally into Cretaceous marine sediments

Were you to visit the Rockies and like the Grand Canyon, Niagara Falls, New Zealand and Newfoundland, all serious students of geology should do this once or twice in their lives, you would be amazed by the near vertical orientation of some of the sedimentary layers (see image below from http://uregina.ca/~sauchyn/geog323/306.jpg). As I have said previously in this class, mountain building occurs simultaneously with all other geological processes (weathering, erosion, sedimentation, lithification etc). Sometimes you have to see the actual mountains in person to fully appreciate this.

The next two diagrams in today’s lecture (on the next pages) are Mesozoic stratigraphic columns for the Coastal Plain Province of Alabama. The first is for the subsurface. The second is for outcrops exposed at the surface. You will see examples of subsurface and surface rocks in upcoming lab(s).
Alabama Subsurface Stratigraphy (from the Geological Survey of Alabama)
Alabama Mesozoic Surface Stratigraphy (from the Geological Survey of Alabama)

Names and terms to be familiar with from today's lecture

(Google any that you aren't familiar with)

Coastal Plain Province
Cores
Seismic/geophysics
Oceanic crust
Red beds (arkose and breccia)
Eagle Mills Formation
Smackover Formation
Luann Salt Formation
Norphlet Formation
Selma Chalk Formation
Tallahatta Formation
Navajo Formation

Evaporite minerals (halite, gypsum, anhydrite)
evaporite basin
Algae
Reefs
Salt domes/diapers
Petroleum reservoirs
Sundance Sea
Western Interior seaway
Epeiric seaway (again!)
Lateral accretion
Coccolithophoroids/coocliths
Microfossils/nannofossils
This is a set of truly remarkable paleogeography maps of the southwestern portion of the United States that I found on the web (http://jan.ucc.nau.edu/~rcb7/). What I like most about them is the combination of topographic expression (e.g., mountains and valleys), water depth and sedimentation. Note that the Proterozoic is fairly active (tectonically), but that much of the Paleozoic (Cambrian, Devonian, Mississippian) is passive, except for the Antler Orogeny in the Devonian. From the Triassic through the Eocene (more maps on the next page), the area is a convergent plate boundary. The Cordilleran Mountains are being born.