GY 112 Lecture Notes
Evolution of the Chordates

Lecture Goals:
A) The first animals with backbones (conodonts)
B) The fish family tree
C) Other key chordate evolutionary events


A) The conodonts
By now you should realize that there are still a lot of mysteries in Earth history. The same can be said about biology, chemistry and physics. Science does not have all the answers, nor will it ever find all the answers. However, every once in a while, a long standing mystery or problem is solved. I bet you're thinking that in order to do this, a clever scientist had to dedicate his or her entire life to finding the solution. He/She had to work non-stop, day and night, taking a break only to eat, sleep for a few hours, and, occasionally, pee. Yep, sometimes this is what's done. Other times, however, it's just blind luck. Such is the case with a formerly mysterious group of animal remains simply classified as the conodonts. These hard body parts (see scanning electron microscope image to the left from, http://earthnet-geonet.ca/earth/ranges_e.php?s=conodonts) are usually quite small (less than 1 mm), are composed of the mineral apatite [Ca$_5$(PO$_4$)$_3$(OH,F)] and really look like tiny teeth. They have been long used for biostratigraphy and there are many well-know examples of conodont index fossils, but apart from the fact that they look like teeth, and that they are now all extinct, no one really knew what they were. At least up until the 1980’s. Before I explain the solution to the conodont mystery, you might want to know the extent to which paleontologists go to get their data. A former girlfriend of mine (Susannah P.) did her doctorate on these little beasties at Memorial University while I was doing my Masters degree. She took bulk samples of limestone (10 to 20 kg at a time!) and dumped it into a vat of fairly concentrated acetic acid. A dilute form of this substance is used to flavor fish and chips (vinegar), but when concentrated, it is quite capable of dissolving limestone (and smelling up an entire geology laboratory!). Unlike the hydrochloric acid that you use to test for limestone in the GY 112 lab, acetic acid slowing reacts with limestone. Anything consisting of CaCO$_3$ eventually dissolves. Anything within the limestone that is not composed of CaCO$_3$ (e.g., conodonts), do not dissolve but do sink to the bottom of the dissolution vat. Susannah would wait for a week or so, then collect the residue from the bottom of the tank. Then she would clean, dry and
examine each piece of material separating and collecting the conodonts as she went. Hard work. In the end, she was able to come up with a really good story about the paleoenvironment and age of some of the Paleozoic limestones along the west coast of Newfoundland. She received her Ph.D. and is living happily ever after as all geologists eventually do (I hope).

Now back to the conodont mystery. Up until 1982, most geologists assumed that there was a conodont animal, but they could not agree what it was. Yes they looked like teeth, but no fossil had been found with them in the right place (i.e., at the jaw). One geologist reported that he found conodonts in what appeared to be the stomach of an annelid (worm) and suggested that the conodonts might be some sort of a digestive aid in these beasties. Someone else suggested that maybe they were just the remains of an animal that had been eaten by the worm. On and on it went. Then one day, probably a cold, stormy, miserable one, a geologist examining some Paleozoic fossils that had been collected many years before (they had been in storage for decades!), saw a fossil “fish” that contained conodonts within the jaw of the animal. The fact that the animal had eyes (they otherwise looked like eyeless hagfish or lampreys) and cellular bones indicated that they were clearly vertebrates (see artist’s reconstruction to right from http://www.scientific-art.com). Moreover, the conodonts were just teeth rather than anything all that complex. Sometimes your first guess ends up being the correct one.

The conodonts were early examples of vertebrates. The next phase of vertebrate evolution led to more recognizable beasties, including many to day that are delicious in a garlic butter sauce; the fish.

B) The Fish

If you live in Alabama, there are two preferred activities for a Sunday afternoon; (1) watching NFL football with your buddies and (2) fishing with your buddies. Both go better with a cold beverage and a bag of potato chips. As far as fishing goes, I have never seen anything like it. Every stream, pond,
creek, lake, bay and estuary in this state is almost always full of fisher folk. Would you ever eat a fish caught in the Municipal Park Lake? Sewers dump into this body of water. I've even seen people fishing in the pond near the USA Library. I have a small (5 gallon) artificial water feature in my backyard. I'm afraid to tell the neighbors about it in case they start climbing over my fence with fishing rods.

People can be strange, but I do understand the interest with the fish. It is a relaxing sport. From the scientific point of view, the fishes are an incredible group of animals and they have an incredibly long family tree. The earliest fish appears to have evolved in the Late Cambrian to Early Ordovician, but our understanding of this species (*Anatolepis heintzi*) is rather limited, because we only have a few scales (see image to left from http://www.palaeos.com/Vertebrates/) and bone fragments. The real start to fish evolution did not get going until the Silurian and by the Devonian, fish diversification was incredible. In fact, the Devonian is frequently called the **Age of the Fishes** (refer to the evolution diagram at the bottom of the previous page).

We can't go any further until we discuss fish taxonomy. The fish are members of the subphylum **Vertebrata** (as are you, your cat and your dog). There are 5 major fish classes:

- **Phylum:** Chordata
  - **Sub-Phylum:** Vertebrata
    - **Class:** Agnatha (jawless fish, lampreys etc.); Camb-Recent (D)*
    - Acanthodii (spiny sharks); O-P (M-P)
    - Placodermi (armored jawed fish); S-M (D)
    - Chondrichthyes (sharks, rays, skates); S-Recent (J-Recent)
    - Osteichthyes (boney fish); D-Recent (J-Recent)

*The geological periods in black show the entire range of each fish class. The period(s) in red are the times of class domination in the rock record.

The Agnathans (Class: Agnatha) are known as the jawless fish and include a lot of extinct beasties like the ones in the sketch at the top right of the next page (from http://www.mun.ca/biology/scarr/Agnathans.gif). Living agnathans include the thoroughly nasty lampreys which have caused a lot of problems for freshwater fish in the Great Lakes. These fish may not have jaws, but they do (or did) have teeth. Rows of them surrounding a mouth. Lampreys today (see the image at the bottom of the last page) attach

---

1. This website (http://www.palaeos.com/Vertebrates/Units/040Pteraspidomorphi/040.100.html) has an incredible amount of info of a taxonomic and morphological nature. It also has lots of links to scientific publications. It gets one of my highest “visit it” recommendations
The Acanthodians (Class: Acanthodii) are an extinct group of fish. Collectively known as the “spiny sharks” they were predators of the sea. Their most noteworthy characteristic was a series of razor sharp, non moveable fine spines (see image of Climatius sp. (top) and Ischnacanthus sp. (bottom) to right from: http://vivaldi.zool.gu.se).

Climatius sp. was a relatively small fish (20 cm long), but it was a typical acanthodian. It was covered in small and closely fitted scales and may have had an air bladder. It probably swam like an eel. The immobile sharp fins clearly offered an additional layer of protection from other predators in the sea, but it was the development of the jaw that set these and other fishes apart from the agnathans. With a jaw, you can open your mouth wider (eat bigger prey), chop it up into smaller bits before it can escape, and clamp on long enough to make sure it is dead. Jaws gave these vertebrates a pretty big advantage over other sea beasties. Nevertheless, the entire class could not survive the continued evolution of other animals (including other fish). The acanthodians went extinct near by the end of the Permian.

Now we come to the Placoderms (Class: Placodermi), not to be confused with pachyderm which is an elephant. The largest of these (e.g., Dunkleosteus sp.) was the mother of all fish possibly
exceeding 4 meters in length (12 feet), but the typifying genus of the placoderms was the much smaller *Coccosteus* (see image at bottom of the previous page from http://www.btinternet.com). All placoderms had scissor-like cutting jaws but no real teeth. In fact, the characteristic that sets the placoderms apart from all other fish classes is that they were armor-plated (by bone), at least around the head. They were scary looking beasties, especially when seen head on (I included a couple of images of *Dunkleosteus* on this page. The large one below is an artist’s rendition of the beast swimming in a shallow Devonian sea from http://visindavetur.hi.is, the fun one of the diver battling a long extinct *Dunkleosteus* is from the BBC, and the bottom most one which shows the bone structure around the head, is some other site that I forgot to note).

What a freaky vertebrate, huh? They as a class, did not last very long at all. They evolved in the Silurian, peaked in abundance in the Devonian and were gone by the Mississippian. Obviously they were not as well suited to their environment as their fossil remains suggest.
Now for a class of fish that did not go extinct. The chondrichtyes (Class: Chondrichtyes) are those fish with a cartilaginous skeleton. They include the sharks (like those still alive today), the rays and the skates. First evolving in the Silurian, this class of fish have shown remarkable staying power. Lower Devonian beasties like *Cladoselache* sp. (picture right from http://www.fosil.cl/shark06g1.jpg) were scary looking beasties up to 2 m long. Of course the real monsters of this class were *Megalodon* spp. which went extinct at the end of the Pliocene era a mere 1.5 million years ago. Check out the image below from http://www.aloha.com/~lifeguards/jaws.jpg that shows just how big these fish got!

Since these vertebrates have a skeleton composed of cartilage, their bones are never preserved in the rock record. It is only their teeth that are found. *Megalodon* teeth got up to 8 inches in size and when you consider that the average shark had lots of teeth, I think it’s safe to say that you would rather not see one of these things floating behind you while treading water. By the way, the tooth below is one of those 8 inch long varieties.

The most important fish, at least in terms of numbers, are the osteichthyans (Class: Osteichthyans). They are better known as the *bony fish* and have two major subdivisions (essentially sub-classes). The first of these are the most numerous. The *ray-fined fish* literally exploded in terms of numbers from the Mesozoic era to today. Just about every fish you can think of (bass, char, grouper, red snapper, trout, your goldfish) is a member of this class. Why have they been so successful where others (e.g., placoderms or spiny sharks) have not? I didn’t really know the answer, so I turned to some of my colleagues for help. Dr. David Nelson (Biology)
suggests that the flexibility of the fins gave the osteichthyans gave them a competitive advantage. They could swim faster, were more agile and in some situations, modified the fin to do special activities (e.g., like making it a aerofoil shape (e.g., flying fish) to allow them glide through the air to escape slower predators like sharks).

Dr. Robert Shipp (Marine Sciences) who is this regions best authority on all things fishy, also points out that the osteichthyans range in size from really tiny (e.g., minnows) to huge (e.g., blue fin tuna). They could occupy every aquatic niche imaginable (including pitch black caves). They also had a more effective reproduction strategy. Each pair produces lots of offspring that are pretty much uncared for. Sharks tend to produce fewer offspring, but their chance for survival is normally higher that a ray fined fish. So there you have it. Osteichthyes is the most dominant class of fish because they are better suited for the Earth’s aquatic systems than the other classes. By the way, the image to the right is a wonderful family photo of the Class Osteichthyes from http://science.kennesaw.edu/~jdirnber/oceanography/LecuturesOceanogr.

The second subclass of Osteichthyes are the lobe fined fish. (see image below from http://cas.bellarmine.edu/tietjen/images/lungfish.jpg). These fish peaked in importance during the Devonian and are not all that important in numbers today, but they were around at one of the pivotal times in vertebrate evolution. We will spend an entire lecture discussing this details of this event when we get to the lecture on amphibians and reptiles, but for now, we can simply state that it was one or more of the members of this class that moved from water onto the land and that it happened sometime during the Devonian. The lungfish (see image on next page) give clues to how this might have been done. These fish have lungs and gills that allow the fish to breathe underwater and above water when the water has too little oxygen (common in stagnant pools) or if a pond they are living in dries up entirely.
Coupled with the lob fin strength (see the lecture on the reptiles), these fish, and presumably some of their Devonian ancestors, could move from pool to pool whereas other fish could not. A pretty good evolutionary modification if you think about it.

C) Other vertebrate evolutionary events
I don’t want to spend much more time on the evolution of the vertebrates. I know that they are an important group, but there are other equally (actually more) important phyla to consider for geologists. Still, there has been so much work done by biologists and paleontologists that it would be a good idea to include a nice summary diagram that puts everything that we have talked about so far (and will talk about eventually) into context. That diagram is below. It’s from: http://myweb.cwpost.liu.edu/vdivener/gly_302/notes.htm.
Important terms/concepts from today’s lecture  
*Google any terms that you are not familiar with*

- Chordate (chordates)
- Conodonts
- Vertebrata (vertebrates)
- Agnatha
- Acanthodii lacodermi
- Chondrichthyes
- Osteichthyes (bony fish)
- ray-fined, lobe-fined