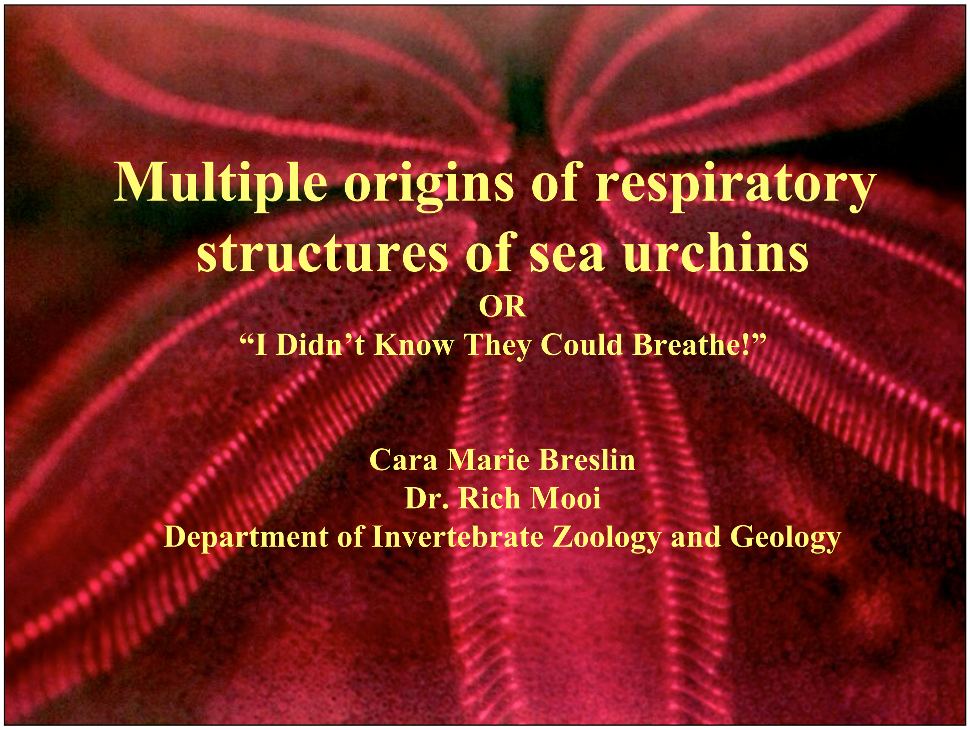
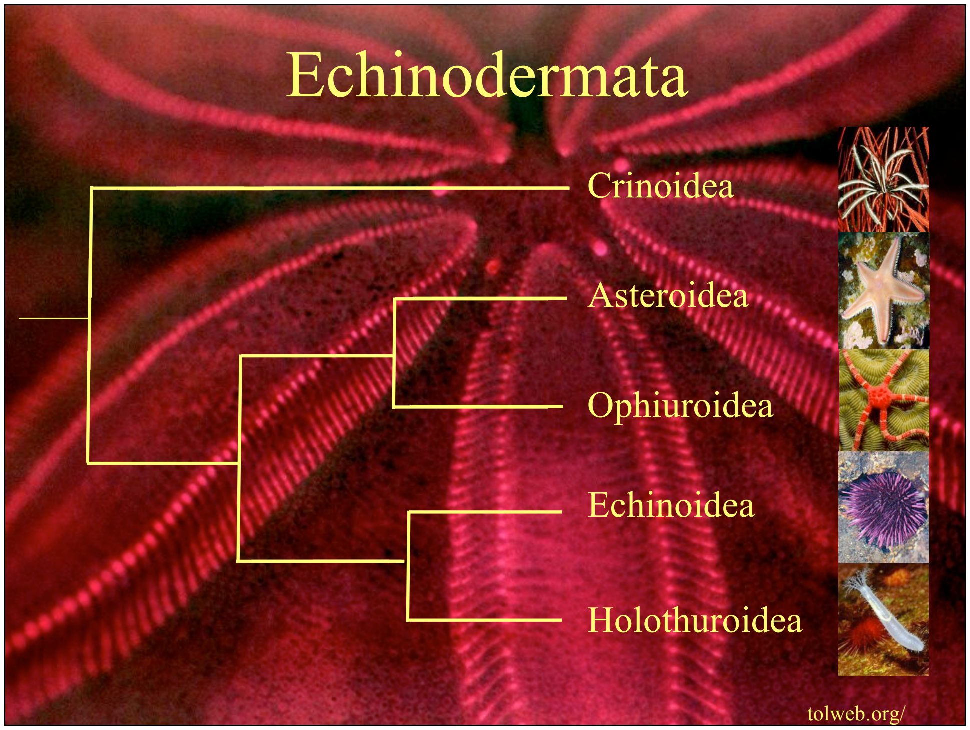


Slide 1: Title and introduction.

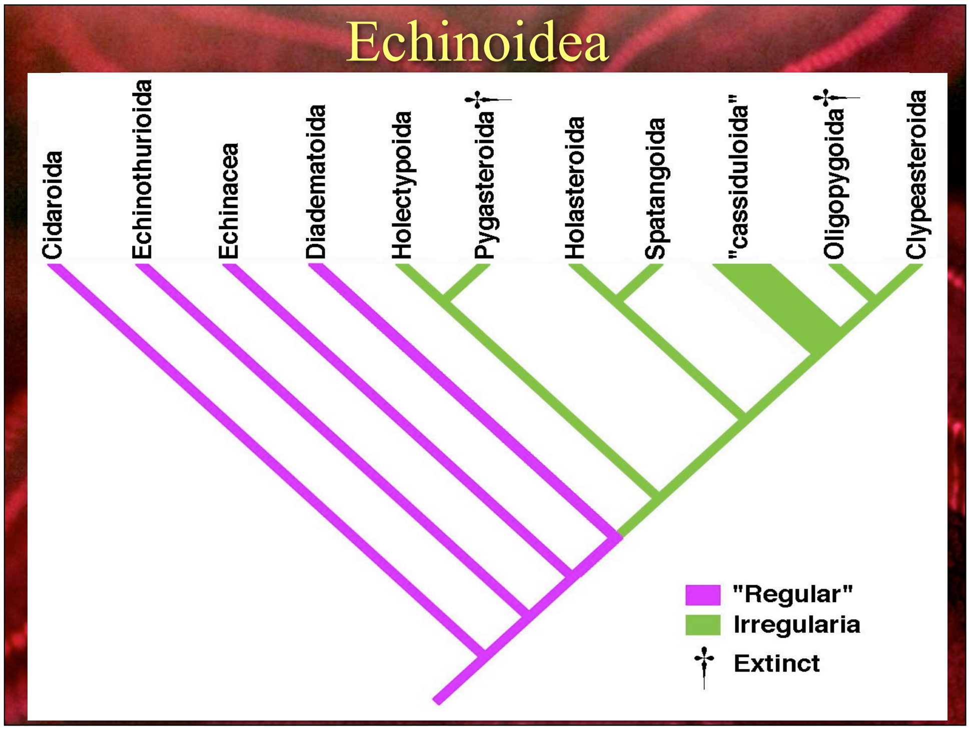
Hi, my name is Cara Marie Breslin and I’m from UCSC Santa Cruz. I’m here today to talk to you about my project that I did with Dr. Rich Mooi in the Department of Invertebrate Zoology and Geology that is titled “Multiple origins of respiratory structures of sea urchins” OR “I didn’t know they could breathe.” Which is what my mother said to me when I first told her what my project was going to be about.

I chose this project after Rich had spent some time explaining to me the morphology sea urchins, and it was their respiratory structures that intrigued me the most. I knew that, unlike my mother, they could breathe, I just didn’t know how, but I wanted to find out. I also though that the specialized respiratory structures that I was going to be studying, called petaloids, were rather pretty.



Slide 2: Echinoderm phylogeny.

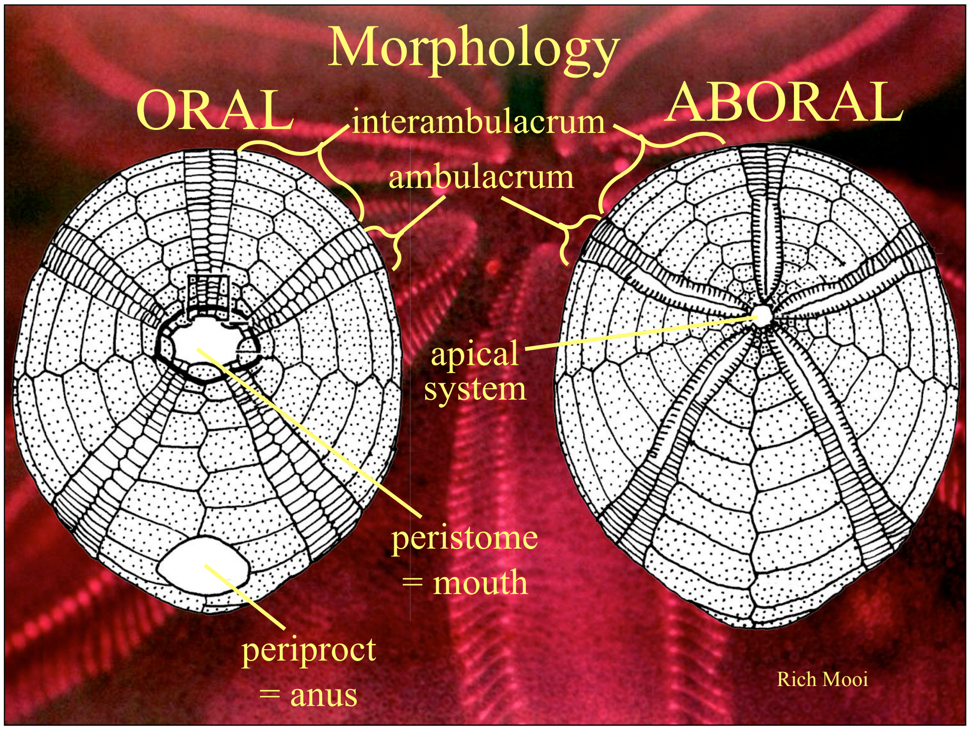
So a little phylogenic background information on sea urchins. Sea urchins are part of the clade, echinodermata, which also include sea stars, sea cucumbers, and brittle stars. Sea urchins are part of Echinoidea.



Slide 3: Echinodea phylogeny.

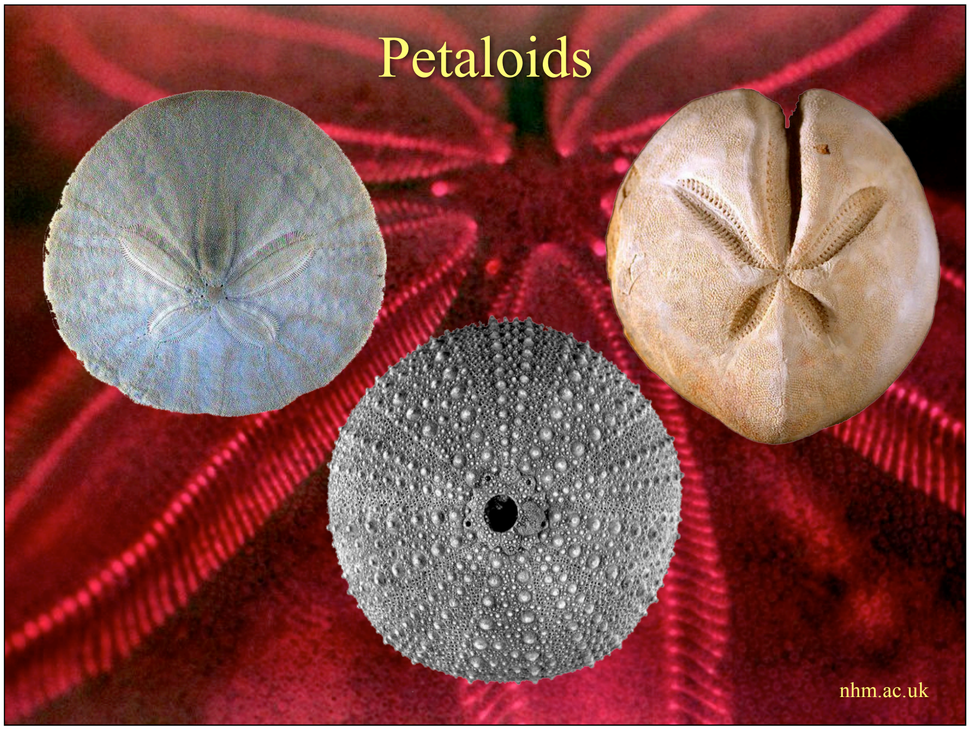
The purple indicates the “regular” sea urchins, a clade that is not monophyletic. The green indicates the clade Irregularia, or irregular sea urchins.The Irregularia include taxa such as Spatangoida, which are heart urchins, Cassiduloida, also called lamp urchins, and Clypeasteroida, or sand dollars. The reason for the thick branch for the cassiduloids is because they are a non monophyletic group. The daggers next to Pygasteroida and Oligopygoida indicate that they are extinct.

For my project, I only studied irregular sea urchins. Shall we see how they’re put together?



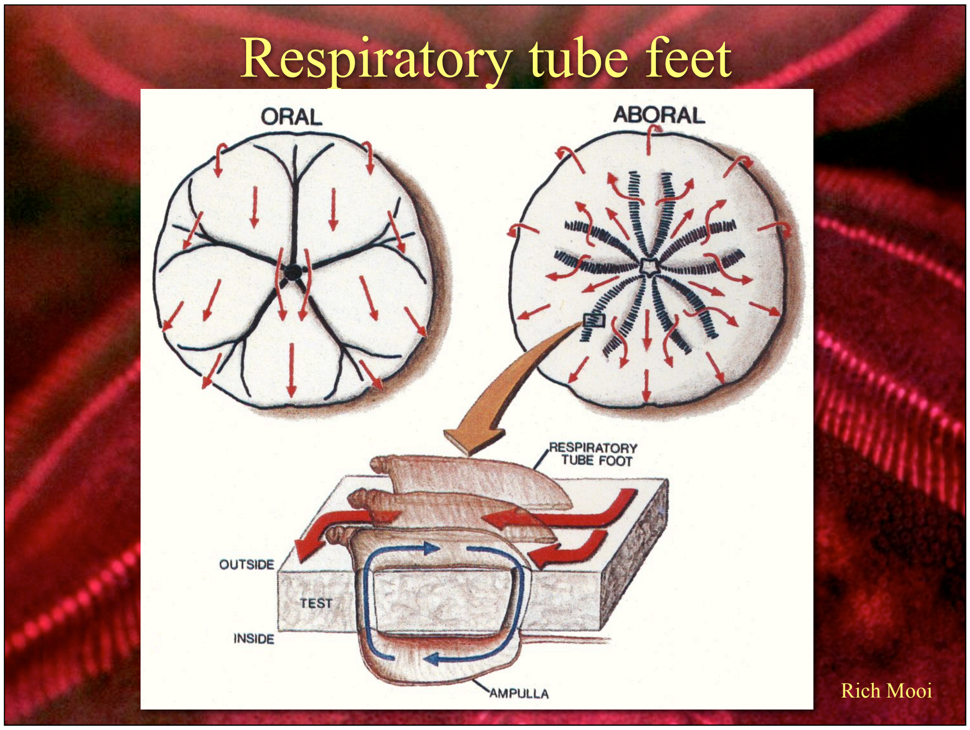
Slide 4: Echinoderm morphology.

So here we have the test of am irregular sea urchin, which is the hard outer body that is completely composed of plates sutured together by collagen. This area here is the interambulacrum, where the spines of the urchin are mostly found. This area here is called the apical system, which is composed of two different kinds of specialized plates, ocular and genital. On the oral side, we have the peristome, where the mouth of the sea urchin is located, and the periproct, where the anus is located. Sometimes, the periproct lies on the edge, or ambitus, of the animal. But these -- these are very special. They are called the ambulacra. The ambulacra are composed of two columns of plates that radiate from peristome up towards the apical system, and mounted on each plate is a tube foot, or podia. On the oral side, the tube feet are usually long and cylindrical, and with a sucker on the end of each one. Those kind of tube feet are used for movement and feeding. But on the aboral side, tube feet take on a new function.



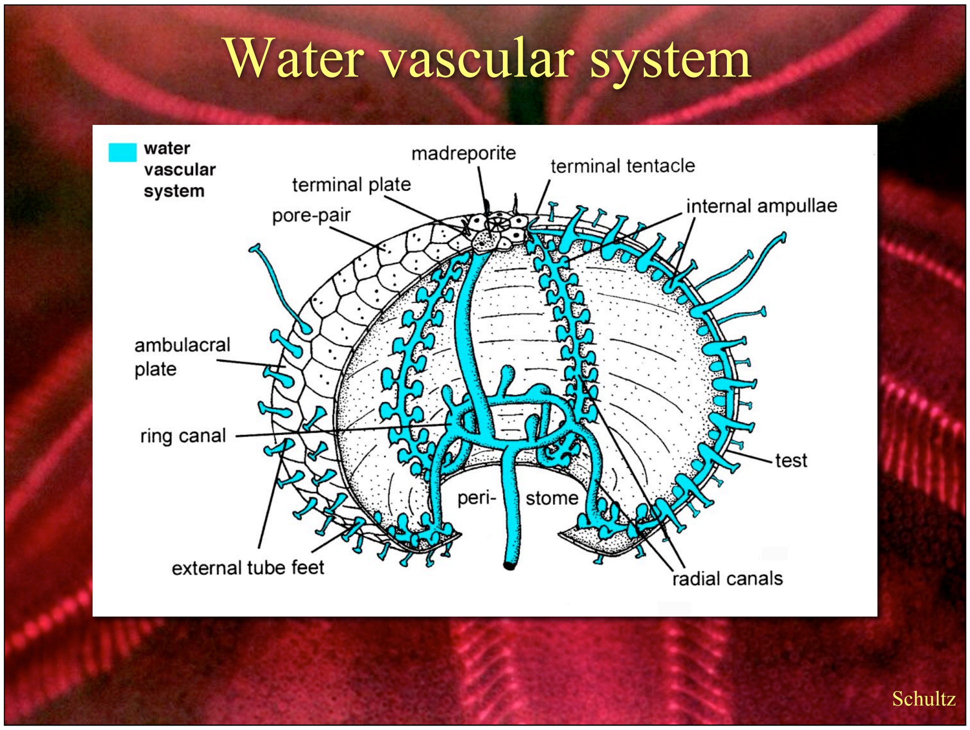
Slide 5: Petaloids.

All sea urchins have ambulacra, but not all sea urchins have petaloids. Petaloids are specialized ambulacra, found only on the aboral side of the animal, found only in the Irregularia. They are called petaloids for their flower petal-like shape. In these specimens here, (this is Schizaster and a Dendraster) the petaloids are very distinctive; you can't miss them, as it were. But here, in this little Stronglyocentrotus, a regular sea urchin, it's hard to even distinguish the ambulacra from the rest of the test. A clear morphological different between non-specialized ambulacra and petaloids is the type of tube feet that reside on them. On the aboral side of the test, tube feet are mostly used for gas exchange. In irregular sea urchins, the respiratory tube feet are much different than the tube feet used for feeding and motion.



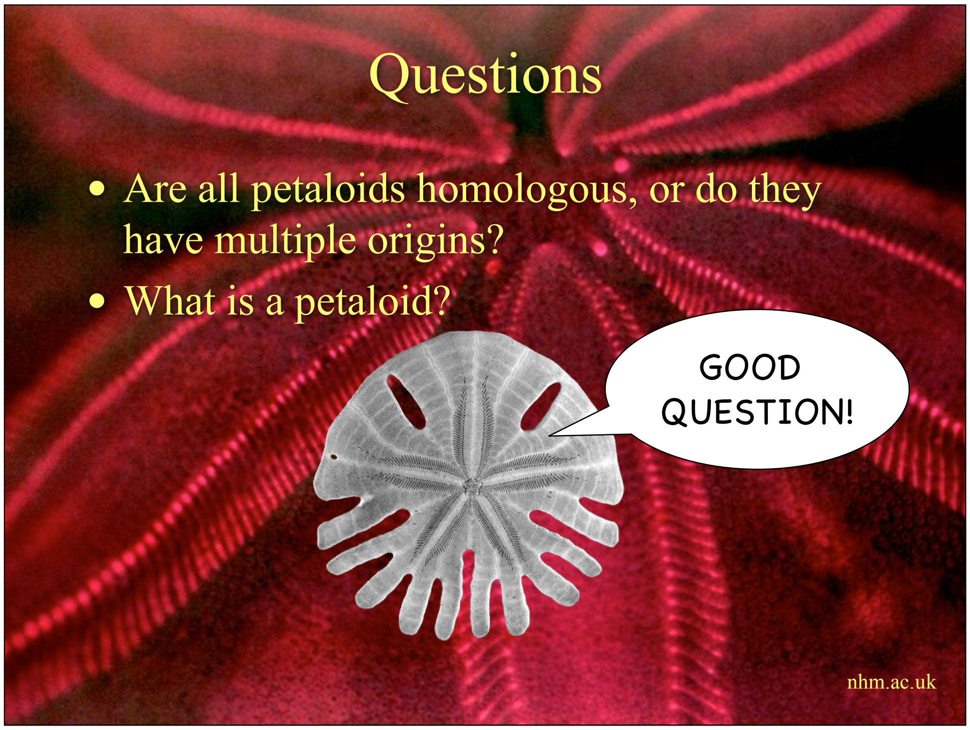
Slide 6: Respiratory tube feet.

Down here we have the respiratory tube feet. They are flatter and wider than the suckered tube feet, and almost look like gills. The podia is connected to the ampulla through a pair of pores. Water from the ampulla travels into the tube foot through the outer pore, and exits back into the ampulla through the inner pore. By using cilia on their spines, sea urchins create currents across their test so that water flows countercurrently to the water flowing through the tube feet. Water that is low in oxygen and high in carbon dioxide travels in one direction inside the tube foot, while water rich in oxygen and low in carbon dioxide travels in the opposite direction outside the tube foot. Oxygen diffuses across the membrane and into the tube foot, and carbon dioxide diffuses out of the tube foot into the ocean. The now oxygen rich water travels back into the ampulla, which is connected to the water vascular system of the animal. The now oxygen rich water “bathes” the organs

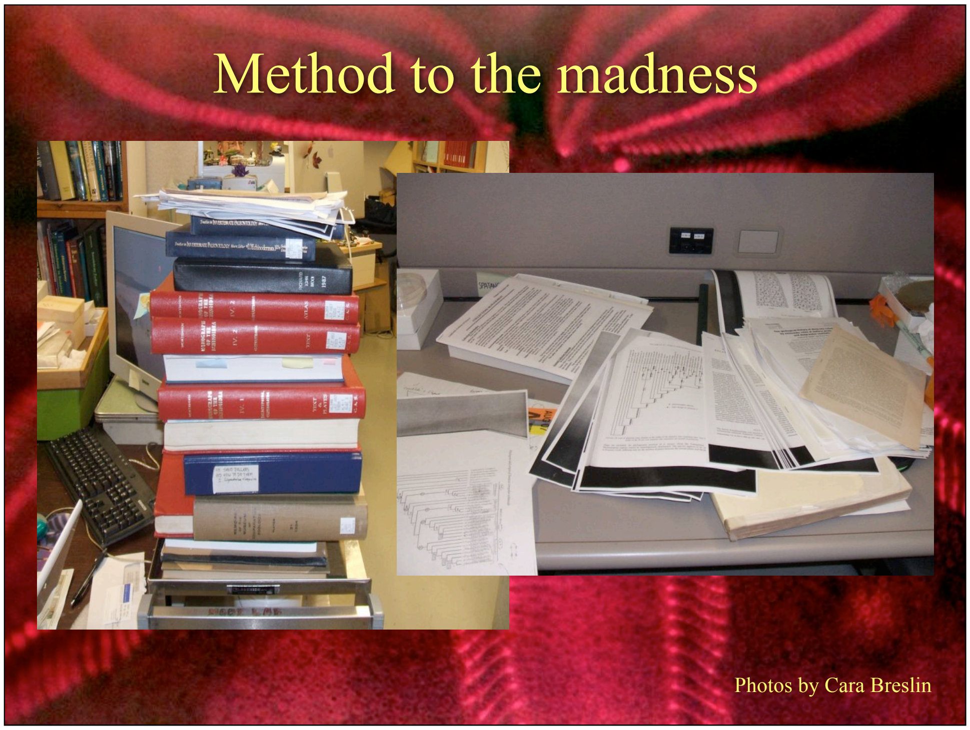


Slide 7: Water vascular system.

Water vascular system. Because the system is under a slight amount of pressure, water in the tube feet is lost due to osmosis. The water vascular system replaces the lost water.

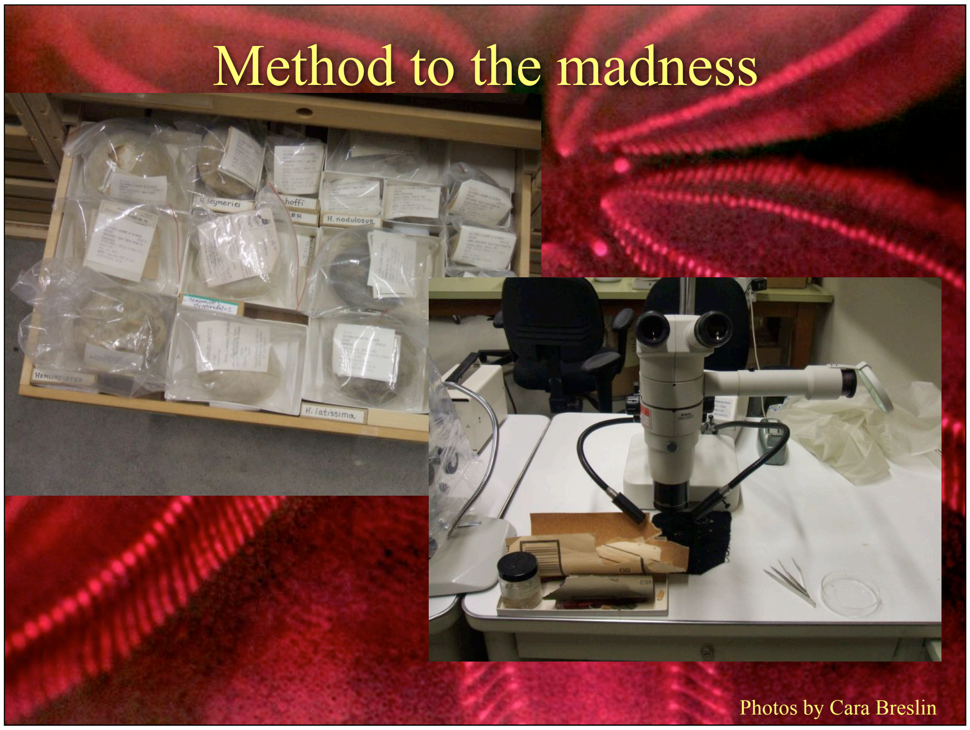


Slide 8: The questions for my project.



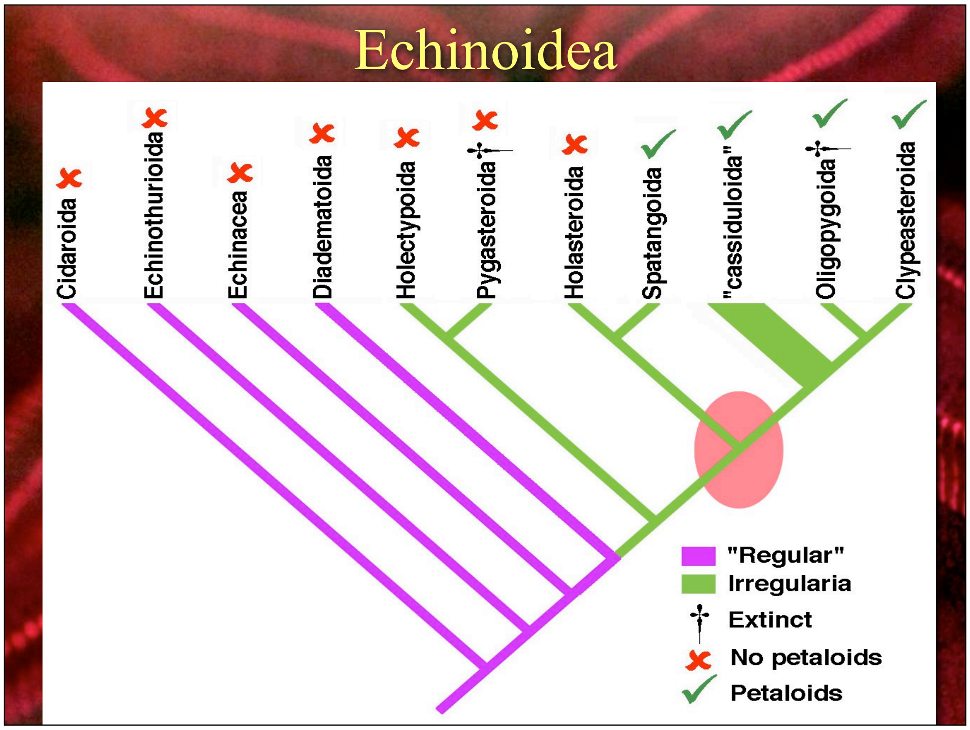
Slide 9: Methods.

How we did our research. Stacks of books, piles of papers



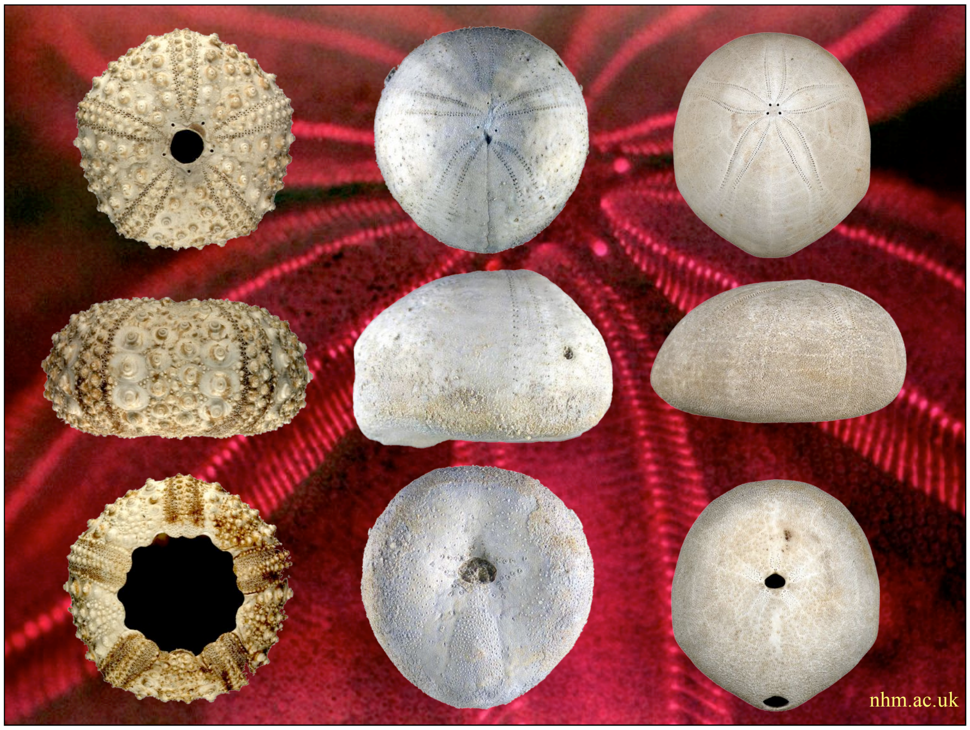
Slide 10: Methods (II).

Dead things and rocks from collections, a microscope to get a closer look at the dead things and rocks. My little cleaning kit is next to the microscope. I used sand paper to scrape off gunk off of fossils and rub off spines of extant taxa.



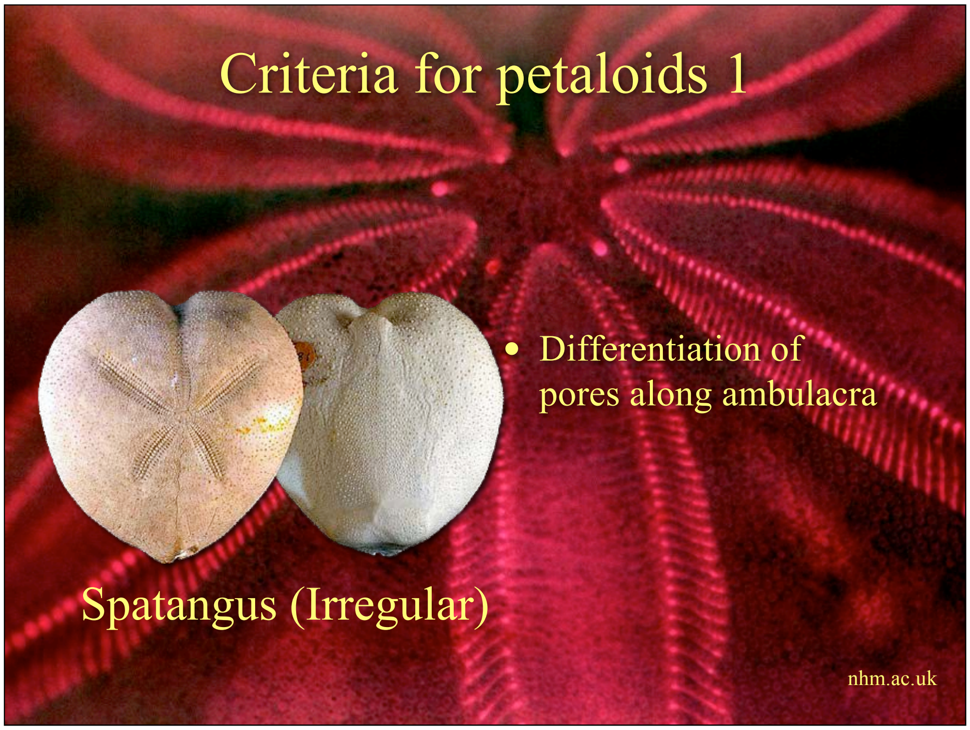
Slide 11: Echinoidea tree.

Here's an overview of the echinoidea clade again, and from previous knowledge, we knew which groups had petaloids and which didn't. It was easy to tell in the modern taxa, but the basal taxa, specifically the ones found in that pink oval, were difficult to determine.



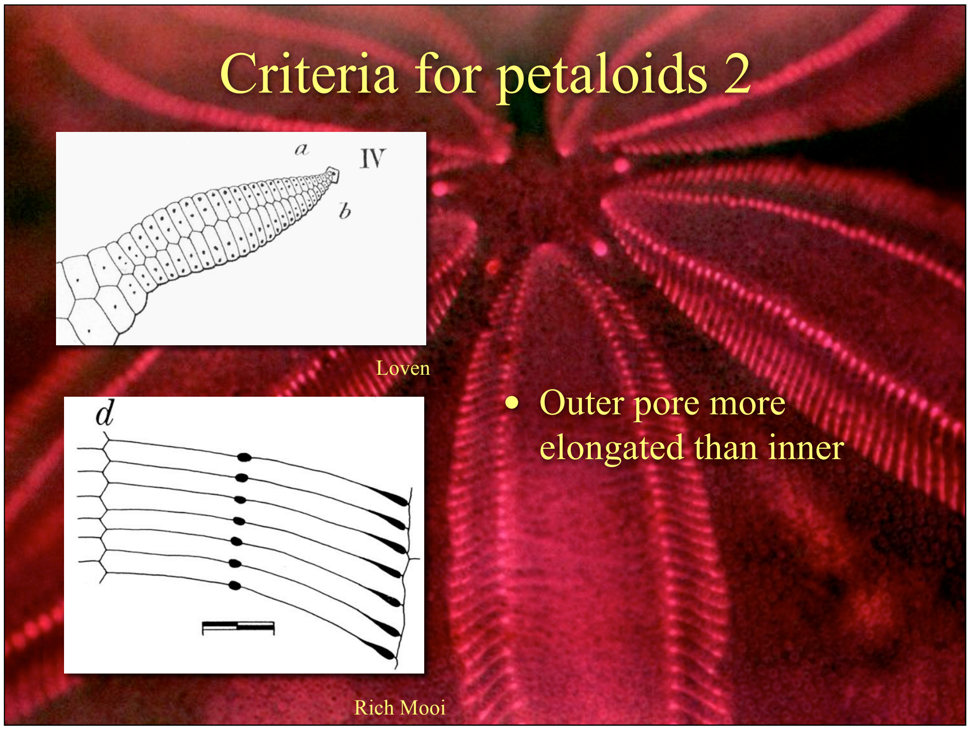
Slide 12: Why we needed to define petaloid criteria.

The sea urchin in the middle, Corystus, is one of those basal taxa. On the aboral surface, the ambulacra of Corystus looks like Diadema; very straight, not petal shaped like Echinolampas. Down the side Corystus, you can see the ambulacra continuously, but then the tube feet start to trail off. Diadema's tube feet travel continuously down the side, and Echinolampas' tube feet trail off almost immediately after the petaloid ends. On the oral side, the tube feet pores can't even be seen on Echinolampas and Corystus, but on Diadema it's the opposite. So Corystus seems to have ambulacra that is across between a regular sea urchin and an irregular sea urchin with petaloids. So petaloids wasn't going to be a simple "yes/no" characteristic, we would need to define some criteria for what makes a petaloid.



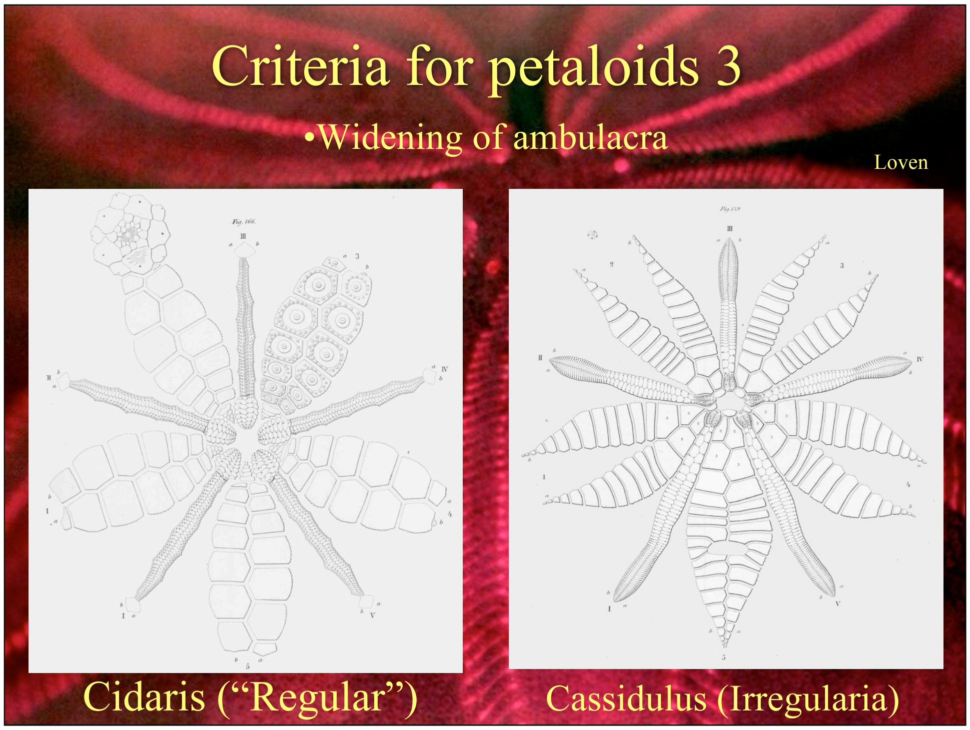
Slide 13: First petaloid criterion.

The pores on the aboral side looks different than pores on the oral side.



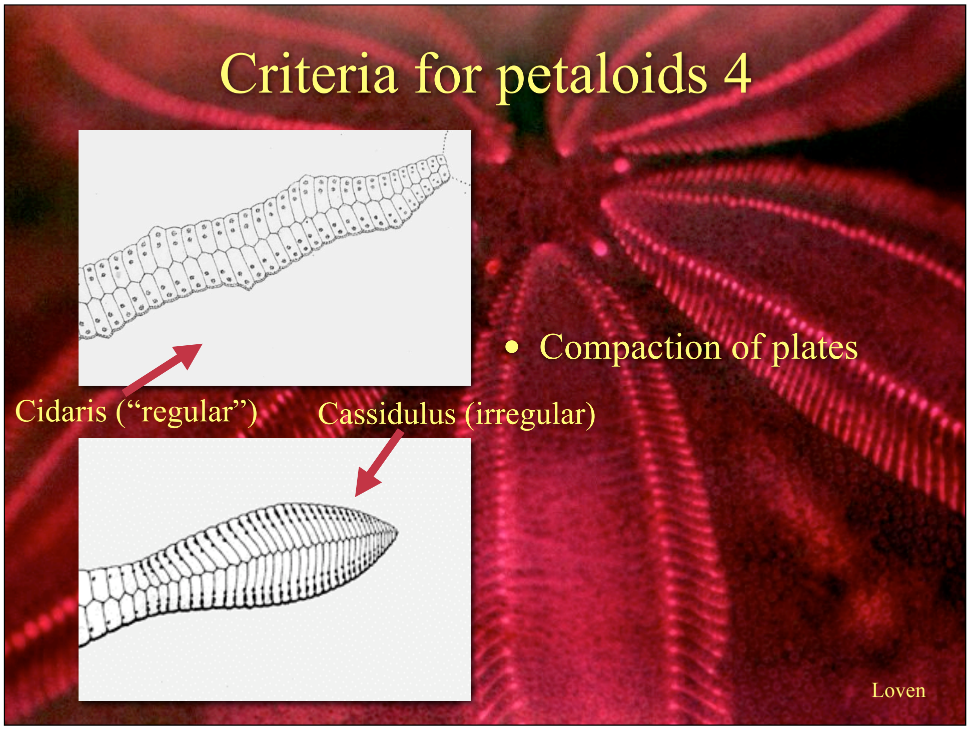
Slide 14: Second criterion.

In regular sea urchins and petaloid-less irregular sea urchins, they have a tendency to have round pores, while sea urchins with petaloids have an elongated outer pore.



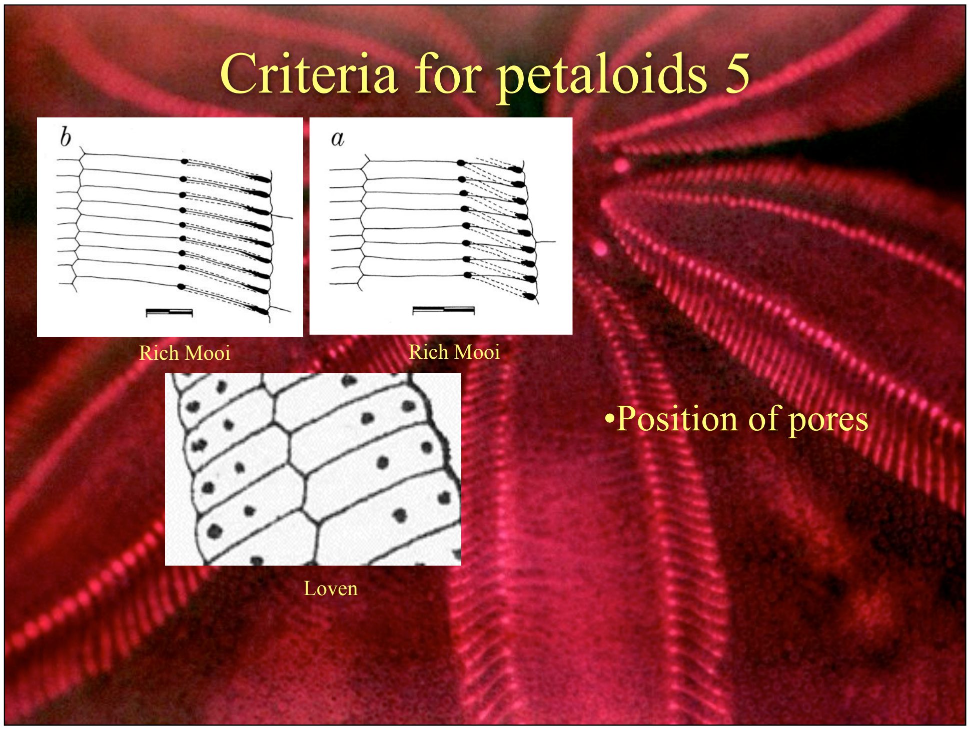
Slide 15: Third criterion.

Petaloids have a noticeably lyrated (lyre like the instrument) shapes to them. Regular sea urchins have straight ambulacra.



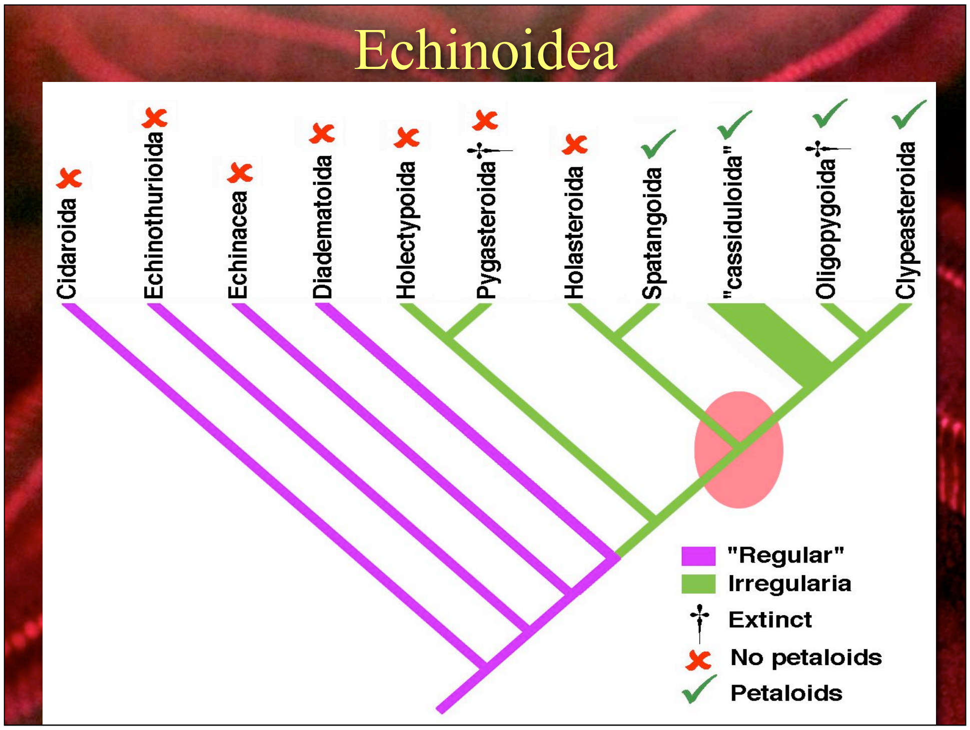
Slide 16: Fourth criterion.

Regular sea urchins have plates that are evenly spaced out. Sea urchins with petaloids have plates that are smashed, or compacted together.



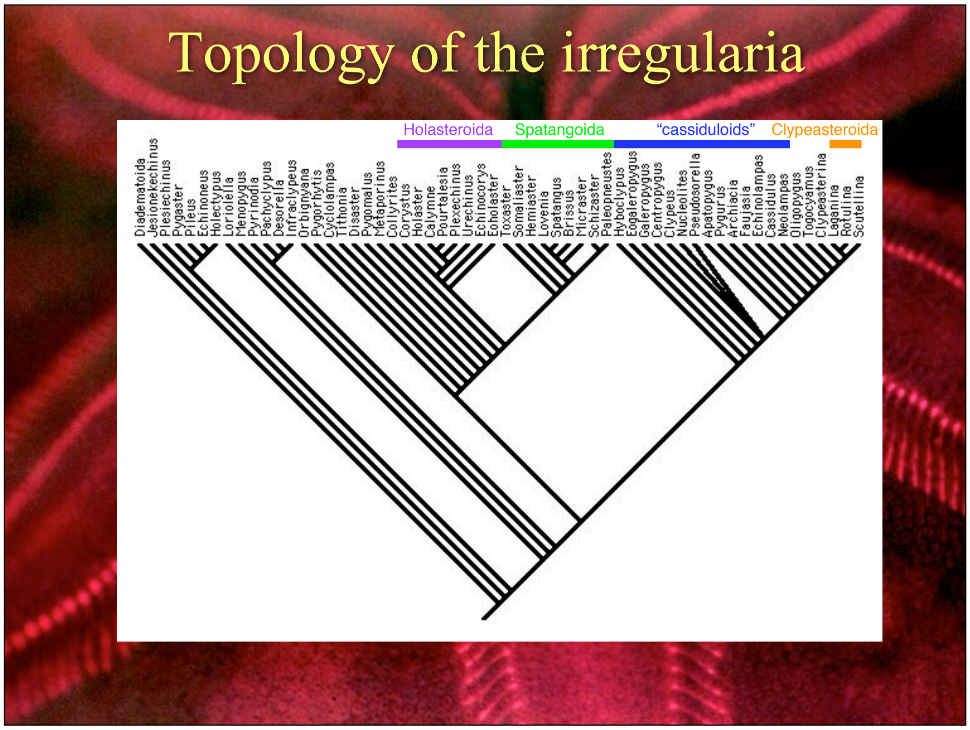
Slide 17: Fifth criterion.

Tube feet on petaloids can show up in different places. They can be in the middle of the plate or on the sutures between the plates. The outer pores can also “swing” between the two sutures, while the inner pores stay on the suture. In some taxa, the inner pore would be on the suture, but the outer pore would be some times near the suture, but not on it, or closer to the middle of the plate. Sometimes, the outer pore can even cross the entire length of the plate and can be found on the opposite suture, resulting in the tube foot lying diagonally across the plate.



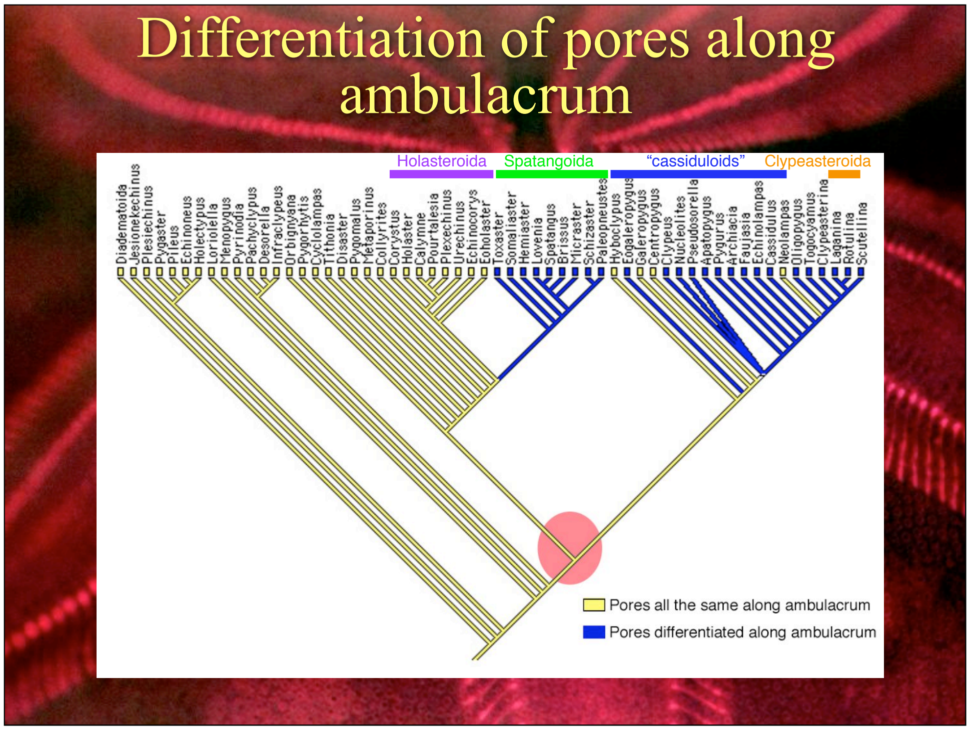
Slide 18: Echinoidea tree.

Again, here is the Echinoidea. The heart urchins (Spatangoida), lamp urchins (“cassiduloida”), oligopygoids, and sand dollars (Clypeasteroida) all have petaloids, remember that. Once we had looked at all our taxa, we had to apply it to clade Irregularia, but there had never been a tree made that ever went beyond this level of detail. So after we read a bunch of papers, we put together a bunch of previously published trees, which made the following.



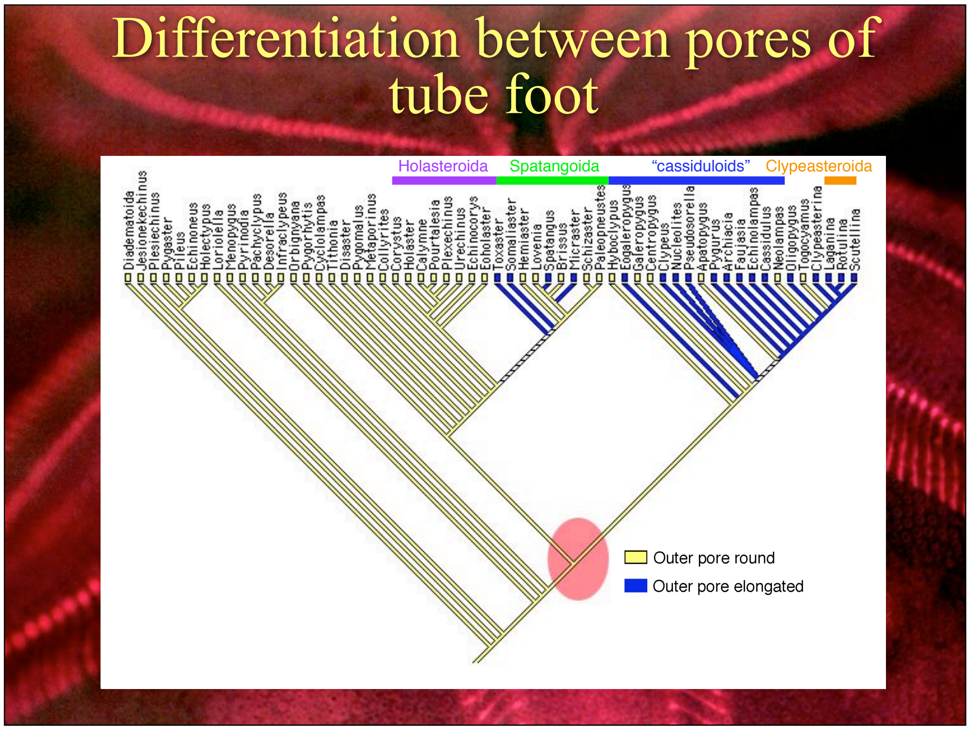
Slide 19: Detailed tree.

And this is what we got. Again, we can see all our old friends, holasteroids, spatangoids, cassiduloids, clypeasteroids.



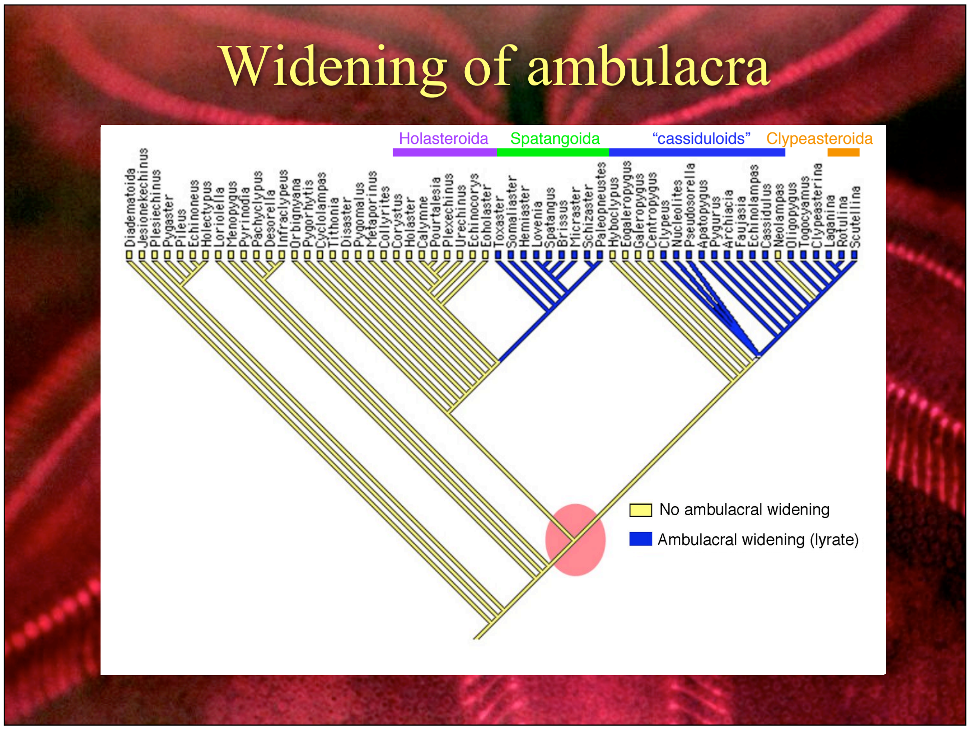
Slide 20: Phylogenetic distribution of pore characteristics (first criterion).

Here is our first tree with the first criterion. Already, it’s kind of indicating that the petaloids in the spatangoids and the petaloids in the cassiduloids, clypeasteroids are not homologous because they are both showing this trait, but they don’t share a common ancestor.



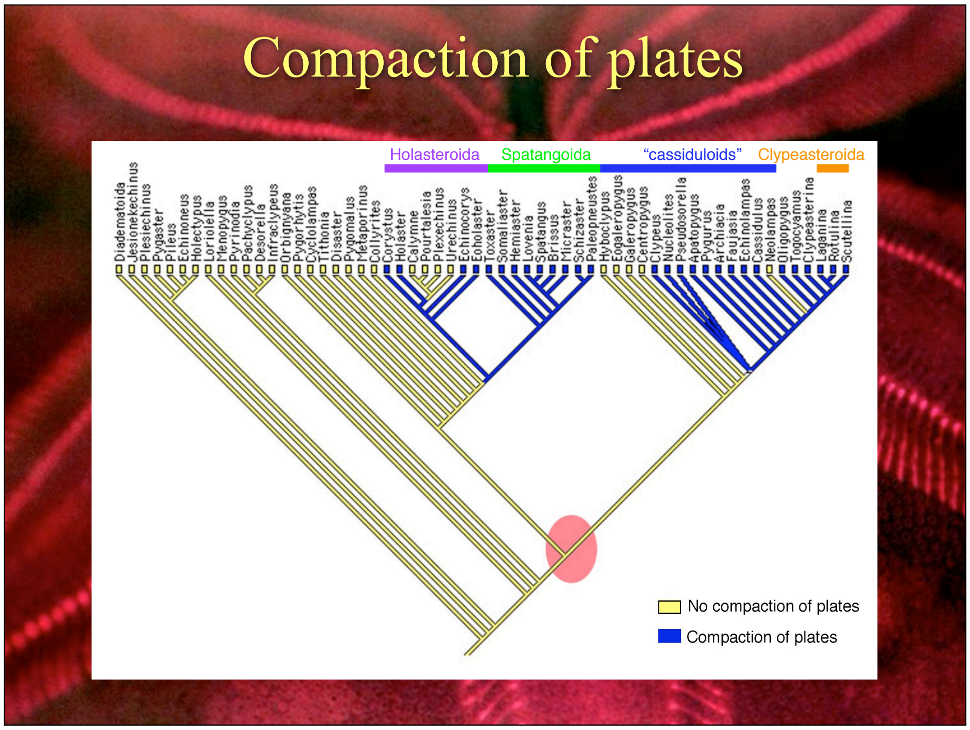
Side 21: Phylogenetic distribution of outer pore shapes (second criterion).

This second criterion did not turn out to be a good choice. Turns out, some spatangoids do have elongated outer pores and some don’t, and that kind of messed up the clade. As you can see, MacClade didn’t really know whether to make the branch rooting the spatangoids yellow or blue.



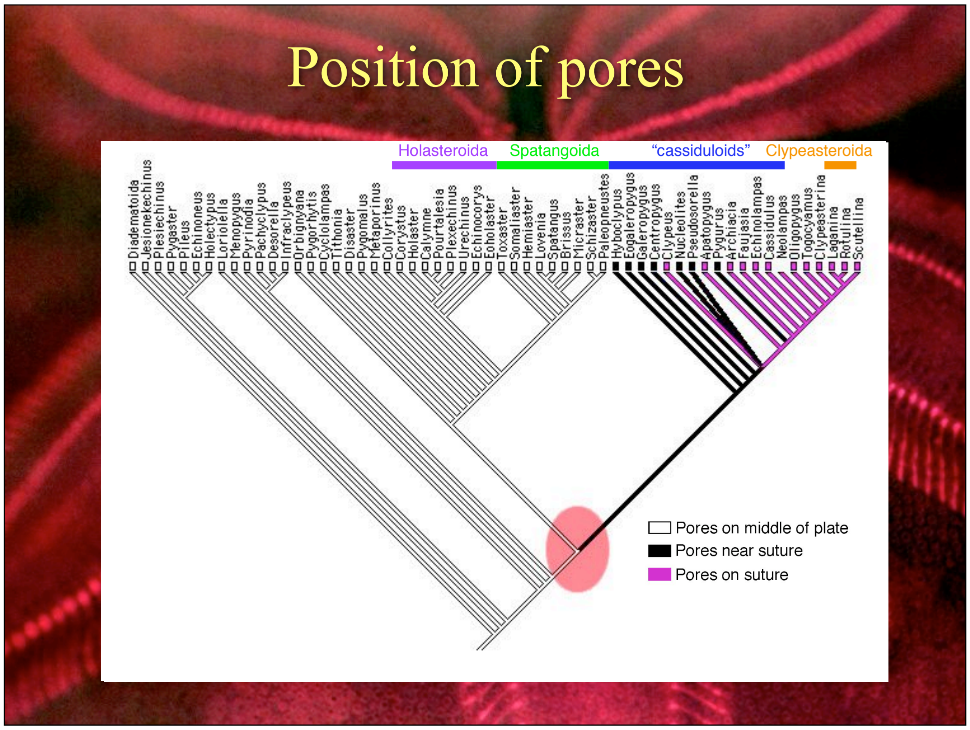
Slide 22: Phylogenetic distribution of ambulacra characteristics (third criterion).

We get a similar result for the widening of the ambulacra as we did in the first criteria. Again, the heart urchins are sharing this trait with the lamp urchins and sand dollars, but they don’t share a common ancestor.



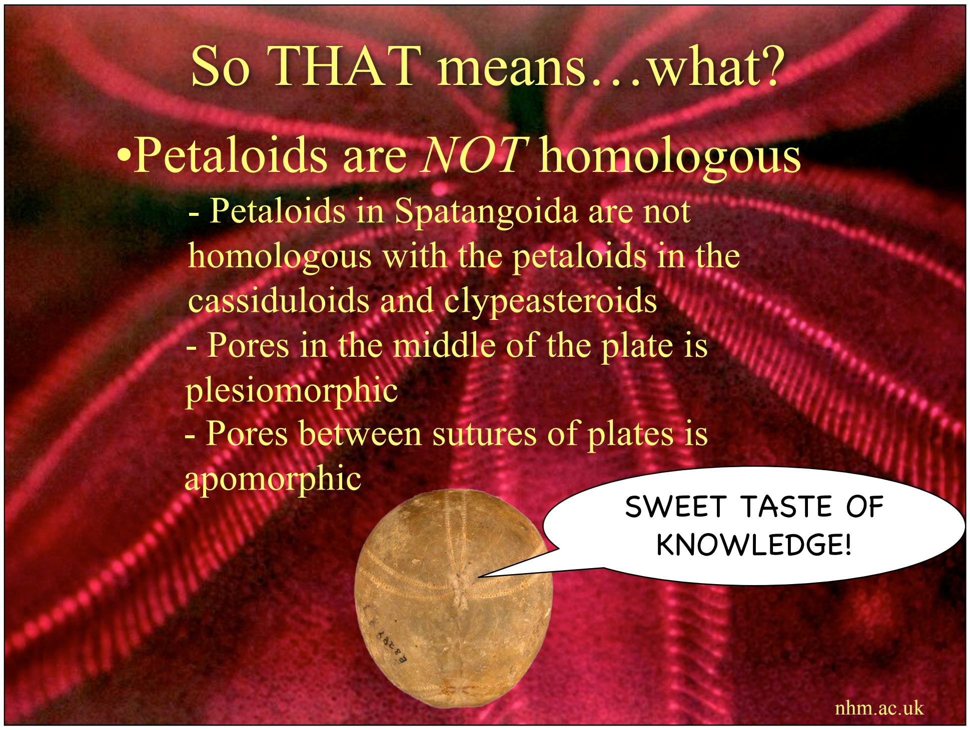
Slide 23: Phylogenetic distribution of plate features (fourth criterion).

Compaction of plates was another not terribly fantastic criterion. It makes some sense in the heart urchins, lamp urchins, etc., but the trait is showing up in the holasteroids, and they're not supposed to have petaloids. This criteria was difficult because for a lot of the basal taxa, we didn't have any specimens so we had to look at pictures. And plate compaction is all relative. Sometimes, the plates were more compacted on the aboral side of the animal than down the sides, but they weren't as compacted as you would find in an specimen that had petaloids.



Slide 24: Phylogenetic distribution of pore position (fifth criterion).

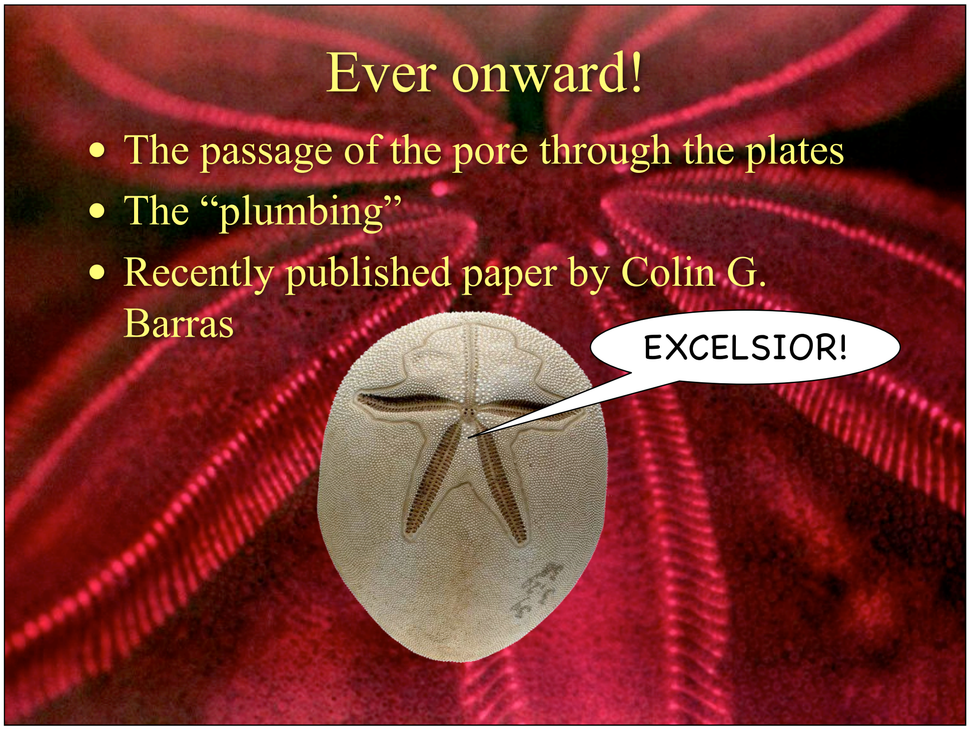
Position of pores was really important because this really brought home the fact that all petaloids are not homologous. The spantagoids have pores in the middle of the plate, while their also petaloid friends have them either near the suture, or more crownward where it’s ON the suture. The clade involving the cassiduloids and clypeasteroids were interesting because you can kind of see the migration of the plates toward the sutures. Here with the basal lamp urchins, they’re near the suture, and then you start to see them on the sutures.



Slide 25: Ecological implications.

Heart urchins and lamp urchins both faced the same ecological challenges and were able to over come the problem by coming up with nearly the same solution, petaloids.

Morphological implications: they all start with the same equipment, but were able to create different kinds of petaloids that look similar superficially.

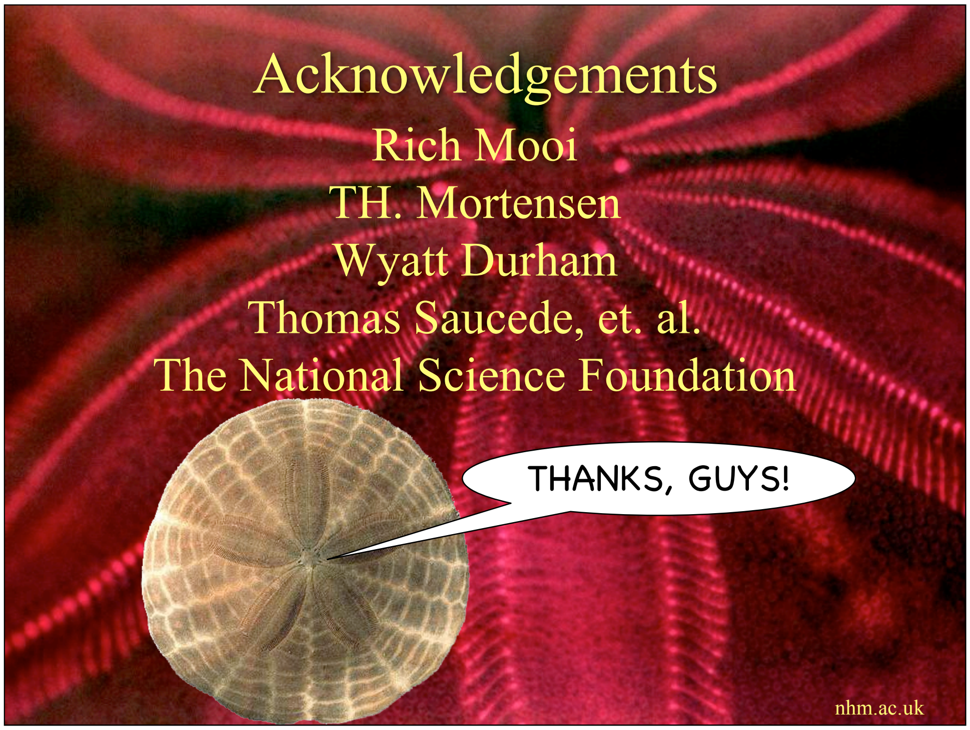


Slide 26: Future directions.

Passage of pores through the plates: sometimes the pores on the outside appear to be on the suture, but as they pass through the test, on the interior they are found in the middle of the plates.

Plumbing: if the water vascular system of animals that have petaloids are different from those who do not have petaloids.

Barras: recently published a paper, and he placed the clades Holasteroida and Spatangoida in a slightly different place in the Irregularia tree than we did. It would be interesting to see if his data would change our results.



Slide 27: Acknowledgments.