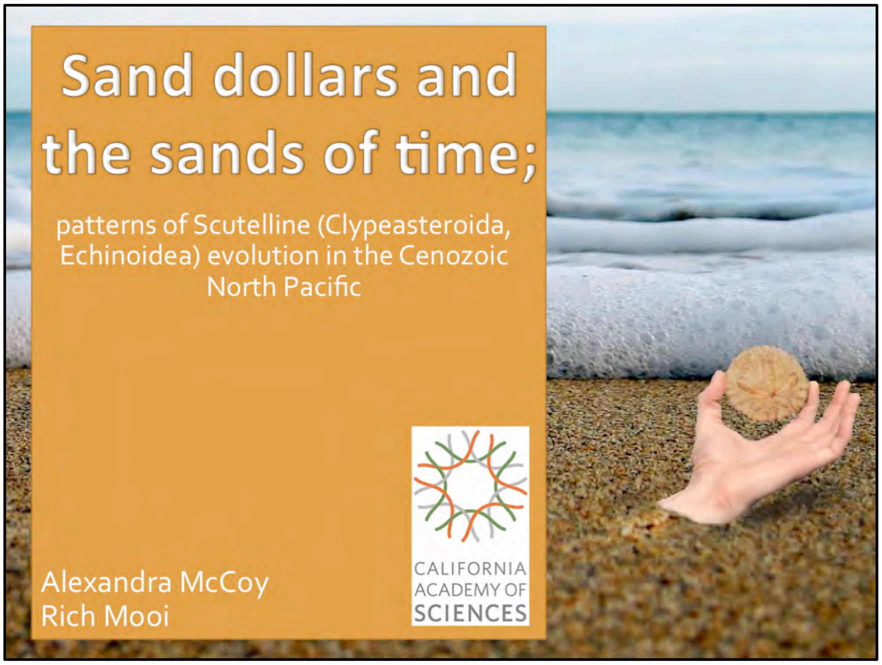


A McCoy, marine biology and legal studies student at UCSC, for the past 8 weeks I have been an SSI intern under the direction of rich mooi here at cal academy

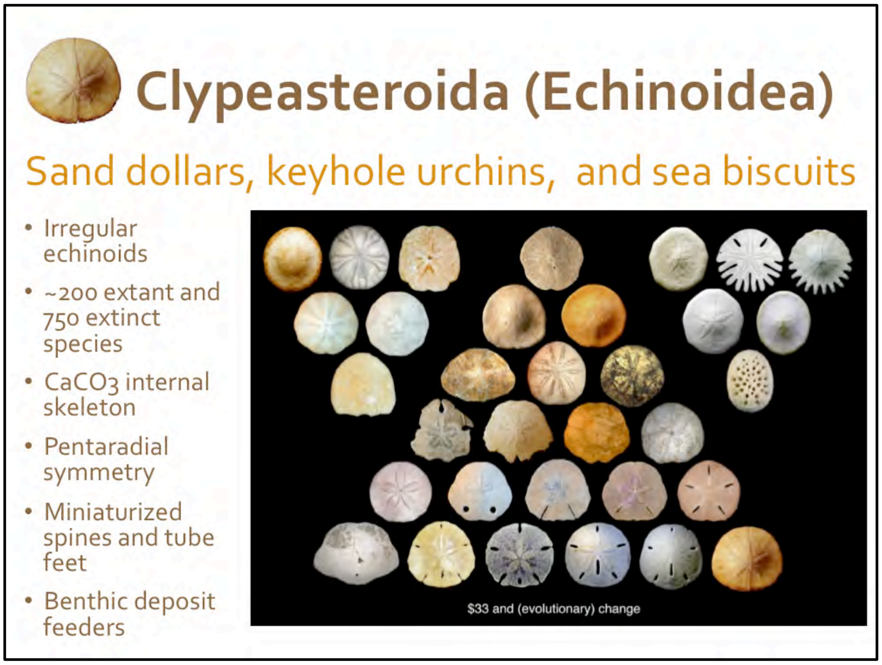
Researching climate change and its effect on ecosystems is a passion of mine so unlike many other lectures which you will hear today, my purpose is not to produce a phylogeny, describe a character, or define new species.

But instead studying evolutionary patterns and processes aids in the development of a greater understanding of patterns past and present which is currently a data limited field.

I analyzed the influences of Cenozoic climate conditions in a geologic context on sand dollar biodiversity. Sand dollars morphology and lifestyle results in strong fossilization potential which makes them strong candidates of study through the Cenozoic.

The "**Anthropocene**", the period during which **geologically significant conditions have been profoundly altered by human activities, is upon us.**

The **fossil record provides data about the past that, when analyzed, illustrate biotic**



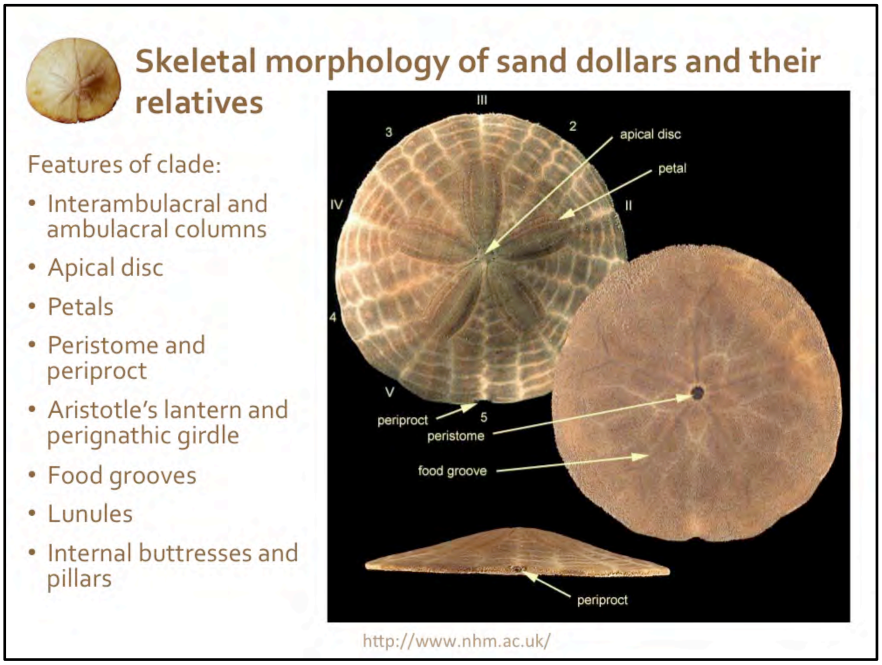
order **Clypeasteroida** irregular echinoids or special urchins refers to species of **extremely flattened burrowing sea urchins (sand dollars), which sometimes have lunules (keyhole urchins), and the not so flat ones (sea biscuits**). This order contains 200 extant and 750 extinct taxa.

Most of you may be familiar with the white disc that can be found while walking along the sea shore. Yet that is actually only their skeletons.

All **Clypeasteroids** contain a **rigid calcium carbonate internal skeleton known as a test and have 5 part symmetry.**

When sand dollars are alive and well inhabiting the sandy seafloors, they are covered with a **fuzz which are miniaturized tube feets and spines**; Tube feet for feeding which pass **food down the food grooves** toward the mouth while the spines for **locomotion due to their high surface area**.

sand dollars are deposit feeders position themselves flat burrowing into soft sediments to feed on organisms like **diatoms and foraminifera** which **live on and in the spaces between sand grains.**



*orient audience – oral aboral marginal anterior posterior

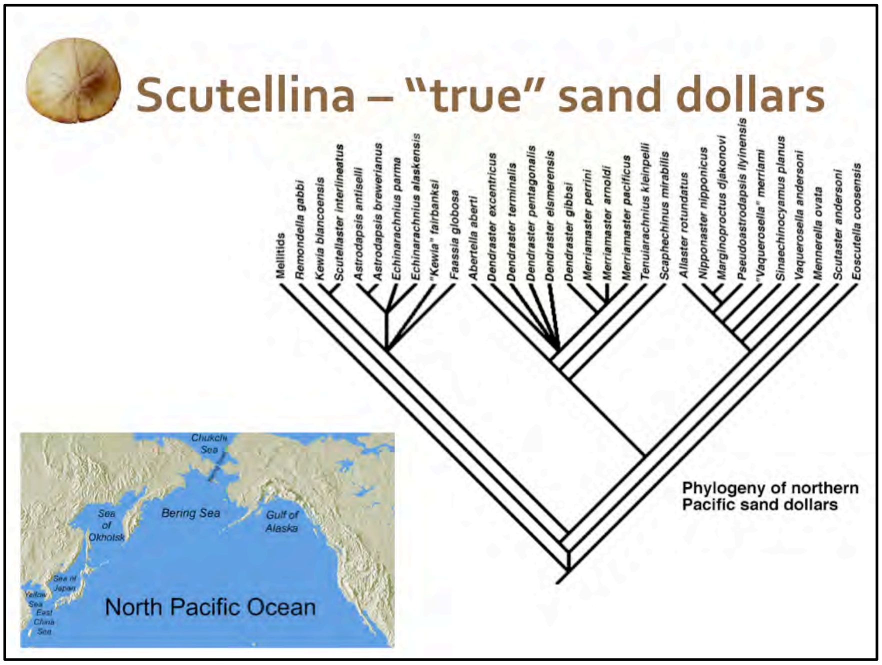
sand dollar internal skeleton (test)   TEN double columns of plates, five **interambulacral columns** (1-5) and five **ambulacral columns** (I-V). Ambulacral plates contain pores for tube feet.

At the apex of the test, lies the **apical disc**. composed of a small number of plates that are the first to form at metamorphosis. It is here that the openings to the gonads emerge.

variously developed **petals**   specialized zones   pore-pairs that support respiratory tube-feet.

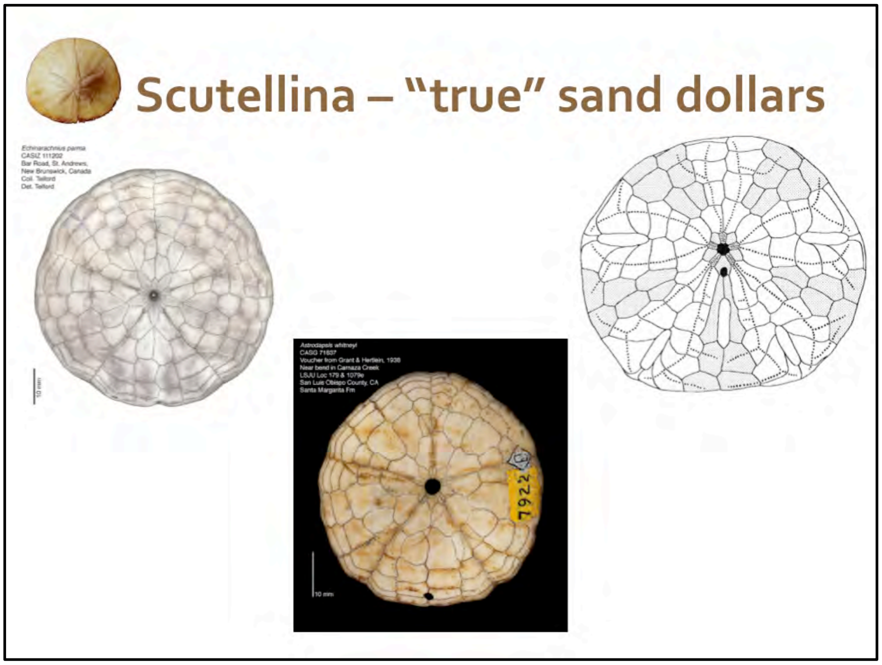
two major openings in test, the peristome and periproct. The **peristome** houses the mouth. The **periproct** houses the anal opening and is situatedorally, marginally, or aborally.

peristome   Aristotle's **lantern** which is a highly fllatened eating apparatus with 5 jaws while the perignathic girdle has muscles that operate the lantern.



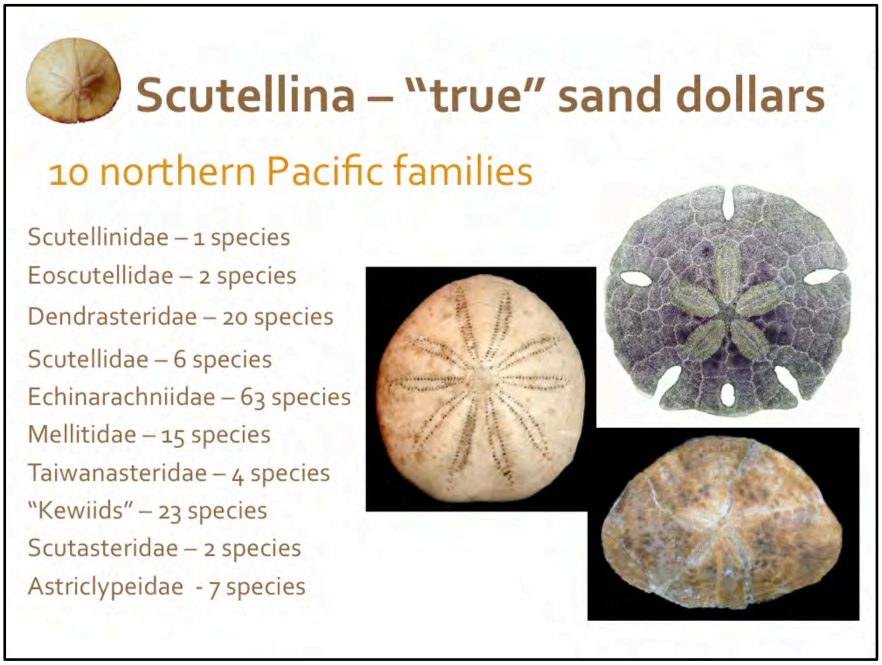
Cladistics studies of these groups are based on **extensive taxon/character matrices** which result in **well-vetted phylogenetic trees.**

My focus has been on the north pacific monophyletic sub order **Scutellina** which defines the true sand dollars in the more northern ecological regions.



Clyperasteriods, and scutellines alike, are immensely diverse and can be **differentiated with various morphological characters.**

Plate maps, or plate architecture, describe significant taxonomic characters, like **plating arrangement of the** **[apical disc](#)** and **shape of the first interambulacral plates surrounding the peristome**, and other morphological features are used to describe a particular taxa.



The first known scutellines to appear on the fossil record in the north pacific are eoscuttellidae and scutellinidae which made their first occurrence in the fossil record in the lower Eocene around 56 Ma.
Quickly the group began diversifying into the 10 main clades known today.

family "kewiids" was formed under the scope of this project. strong signal genera monophyletic group work not published

Images
Purple mellita
Petals echinodiscus
Oblong eoscutella

Fossils

Offer

- Record of organisms
- Historical reference
- Taxonomic insight

Challenges

- Erosion causes distortion
- Fragile, encased in rock
- Location accessibility
- Stratigraphic bias

Fossils are **remains of a plant or animal that lived**.

Fossils are key tools for the dating of rocks and **provide scientists with the framework for relating all events in Earth's history to each other**.

Fossils help scientists discover **past forms of life** and how they lived by providing a record of organisms and historical reference.

In this way scientist can study how **life on earth has changed** over time which proves taxonomic insight.

But challenges do exist when studying fossils.

Fossils are trapped in rock which has undergone many geologic processes possibly eroding the specimen which could lead to sked results when not taken into account.

Because fossils are encased in rock, the rock needs to be broken up to reveal the fossil but this process must be done carefully because fossils are fragile.

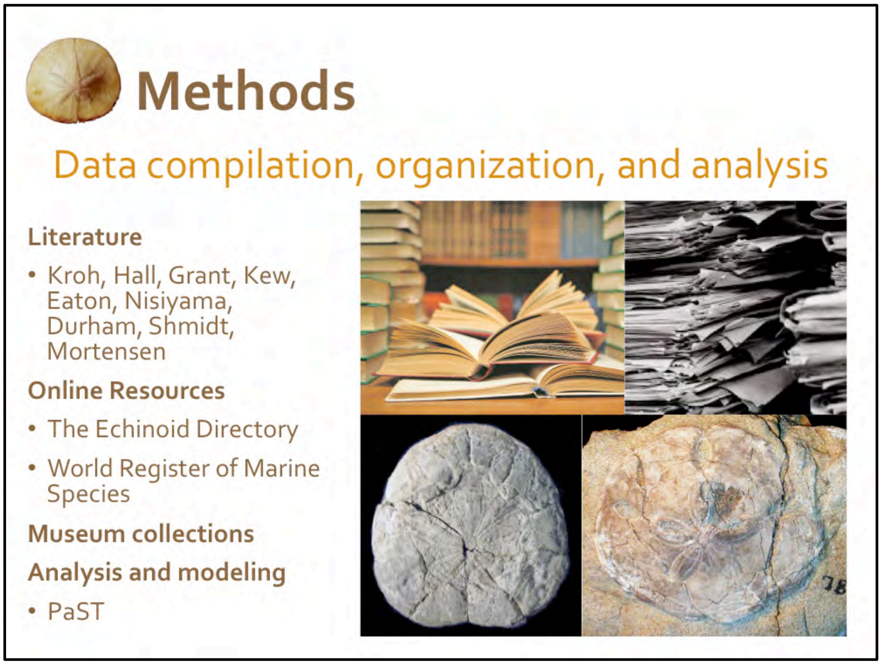
Paleontology is essential for an adequate understanding of the **history of the Earth** and its present conditions.

future of **planet's climate, biodiversity of life, oceanic conditions, and geochemical cycles** already written "deep time" geologic history book with chapters detailing the vast range of conditions the Earth has already seen.

Just like a library that contains large quantities of information within the pages of every book, **museum fossil collections around the world preserve a piece of the story of our planet within every fossil.**

understand past patterns in the context of present and future changes, these collections will become even more important as earth biodiversity is impacted

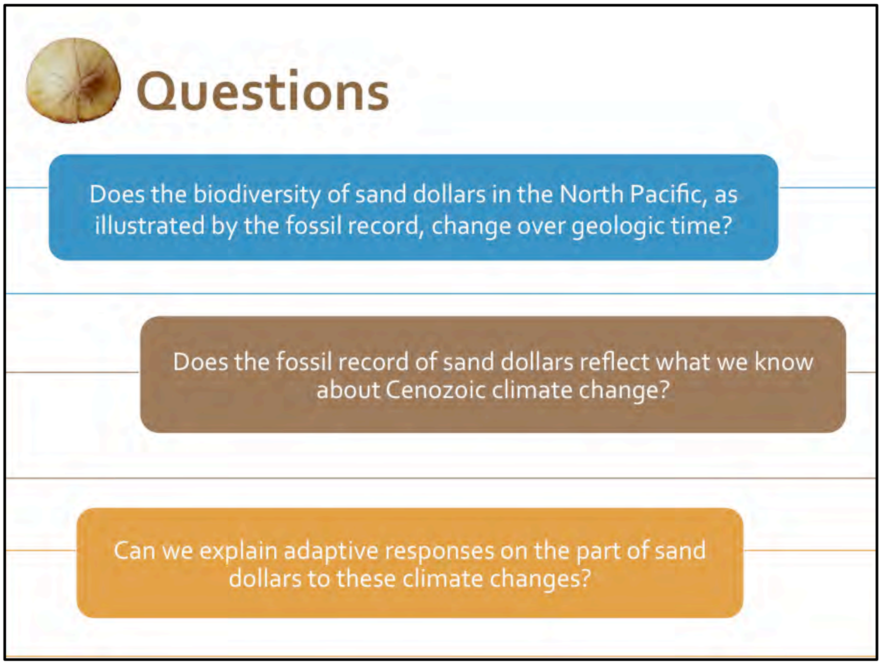
Herbert S zim



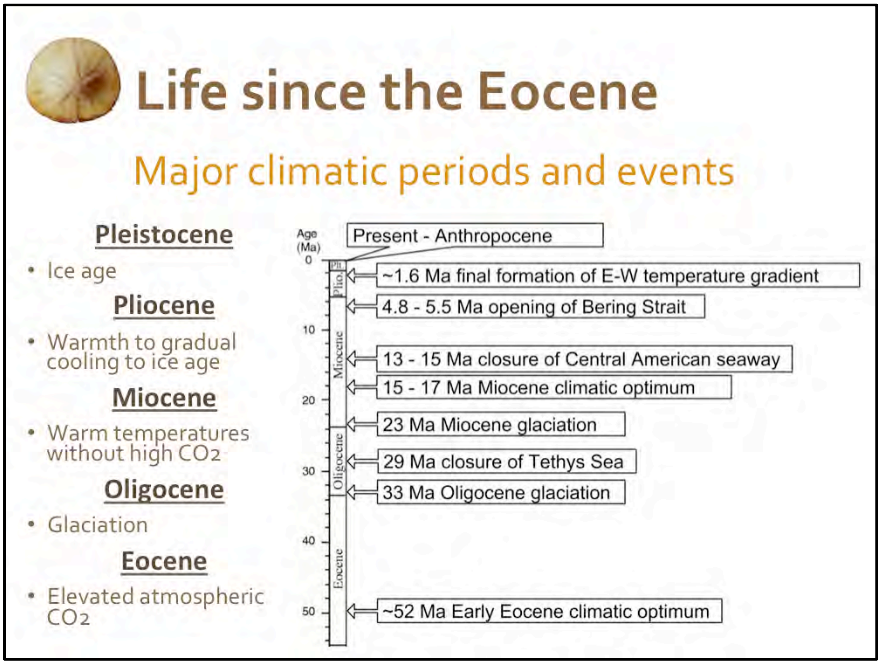
I preformed a **taxonomic paleontological survey of these taxa** and **identified various geologic and environmental factors** was only possible using previous research and literature from various established scientists.

My research was primarily literature based connecting various factors in perspective to the sand dollars which has never been done before

I analyzed various sources of literature along with online resources for **stratigraphic information, general biogeographic data, and morphological characters** which I complied into a database into excel. I then used created diagrams using Photoshop, past or paleontological statistics, and drawing tools.



- Does the fossil record of sand dollars reflect what we know about Cenozoic climate change?
- Can we explain adaptive responses on the part of sand dollars to these climate changes?



This story begins 56 Ma.

climate significant and complex evolution from extreme periods of warmth with ice free poles to cold extremes with massive continental ice sheets

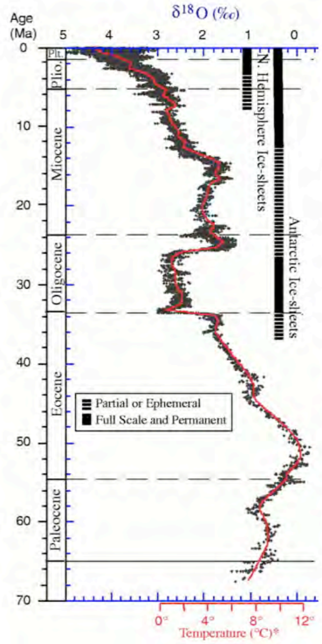
56 mya - Eoc – 23 my - A brief warming eoc start, methane from ocean-floor sediments elevated atmospheric CO2 raised sea levels

34 mya - Olig – 10 my - earth transitions from green house to ice house glaciation occurs Antarctic ice sheets to form. Tethys sea vicarant speciation

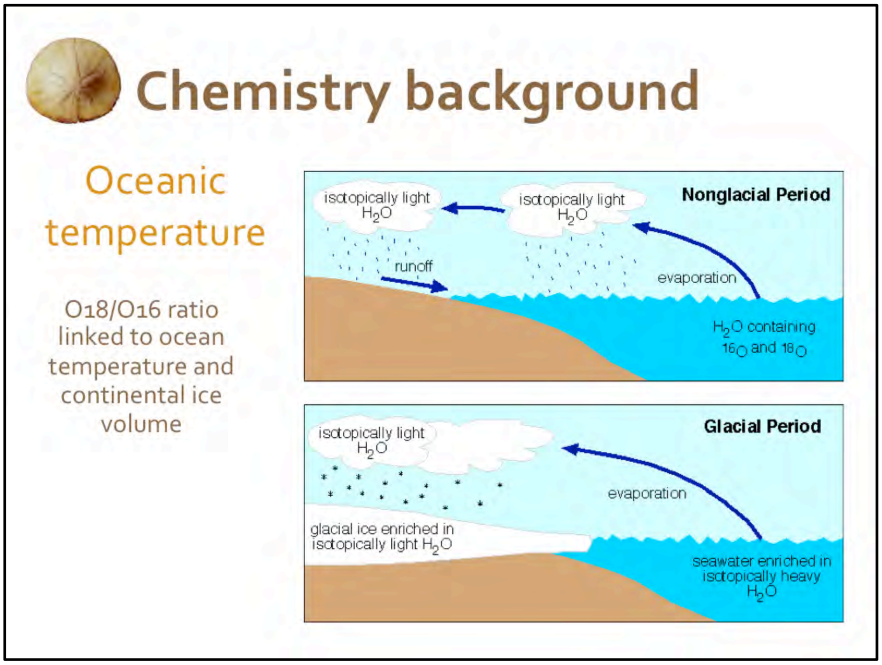
23 mya - Mio – 18 my - Earth's climate from a relatively warm phase (**Miocene climatic optimum**) to a colder mode with reestablishment of permanent ice sheets on Antarctica, thus marking a fundamental step in Cenozoic cooling. Closure of the central American seaway.

5 mya - Plio – 2 my – warmth to gradual cooling to ice age, opening of the bering strait

2.5 - Pleist – 2my – ice age, formation of the E-W zonal temperature gradient



Geological or geochemical proxy evidence for	Future & "Anthropocene"	Deglacial Transition	Oligocene – Pliocene	PETM
pCO$_2$ change	↑	↑	↑	↑
pH change	↓	↓	↓	↓
Saturation Change	↓	↓	–	↓
Temperature Change	↑	↑	↑	↑
Carbon Release		X	X	
Ocean Acidification Score	/3	2	1	3



I am not a chemist and do not expect that anyone here to is but it is important to understand some basic background information to understand how it is that we can resconsrtuct previous climaticic conditions.

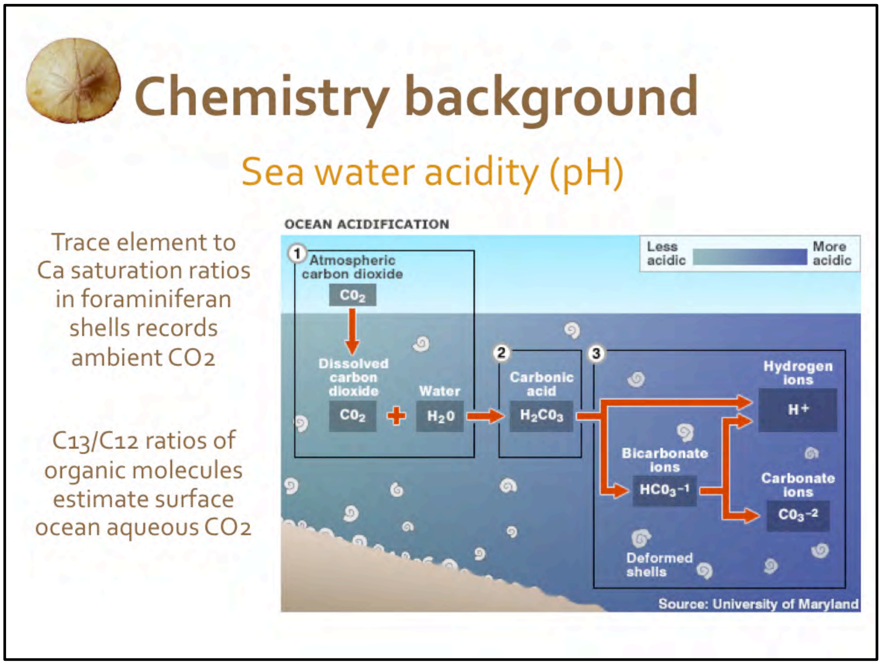
Global and regional climate can be reconstructed by studying the isotopic composition of sedmentary marine starta as Indicators of Changing Climate

Oxygen Isotopes are commonly used to estimate ancient oceanic temperatures

Oxygen atoms have a mass of 16 but a naturally occurring oxygen atom isotope exists which has a mass of 18. Both of these isotopes are stable and do not undergo radioactive decay.

Water molecules (H2O) in the ocean may contain either isotope but the water molecules with O 18 are heavier.

Just as it is harder to throw a heavy object into the air than a light one, it is easier for water molecules containing the lighter oxygen 16 atoms to evaporate into clouds than the heavier oxygen 18 containing water molecules in the ocean.



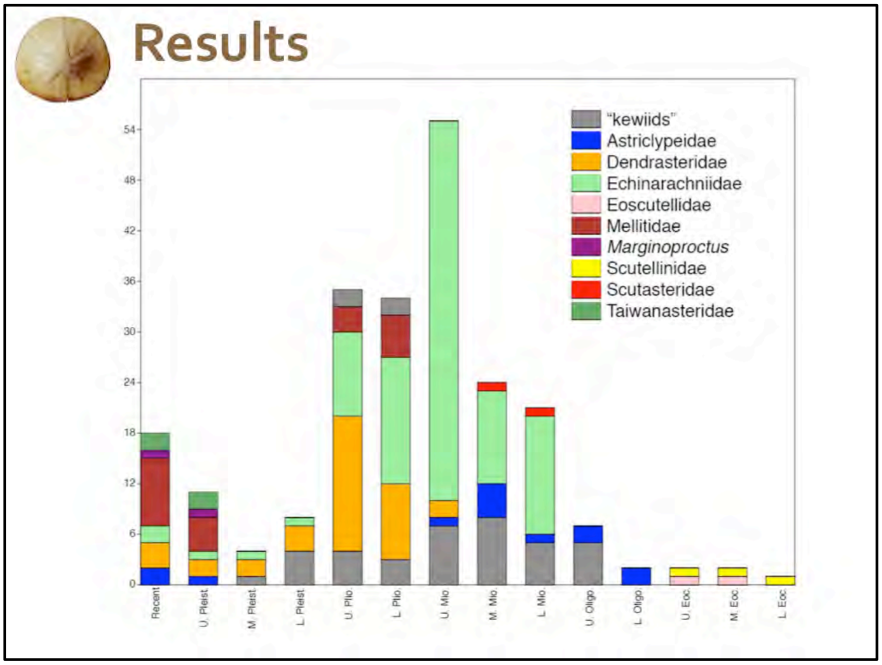
Sea water pH

Atmospheric CO2 interacts with water molecules to form carbonic acid by stripping away H ion. carbonic acid dissolves rapidly to bicarbonate (a base) by again detaching from the hydrogen (an acid).

Carbonate ions bind to H acting as a buffer by reducing pH change yet as it gets depleted, seawater becomes undersaturated with respect to two **calcium carbonate minerals vital for shell-building, aragonite and calcite altering the overall calcification rates of calcareous marine organisms.**

Carbonate levels replenished over hundreds of years, **chemical weathering of limestone rock and dead animals w calcium carbonate shells**

pH describes the concentration of hydrogen ions vs hydroxide ions. Because **direct ocean geochemical proxy observations** for pH are relatively scare, past ocean acidification **inferred from decrease in the accumulation and preservation of CaCO3 in marine sediments.**

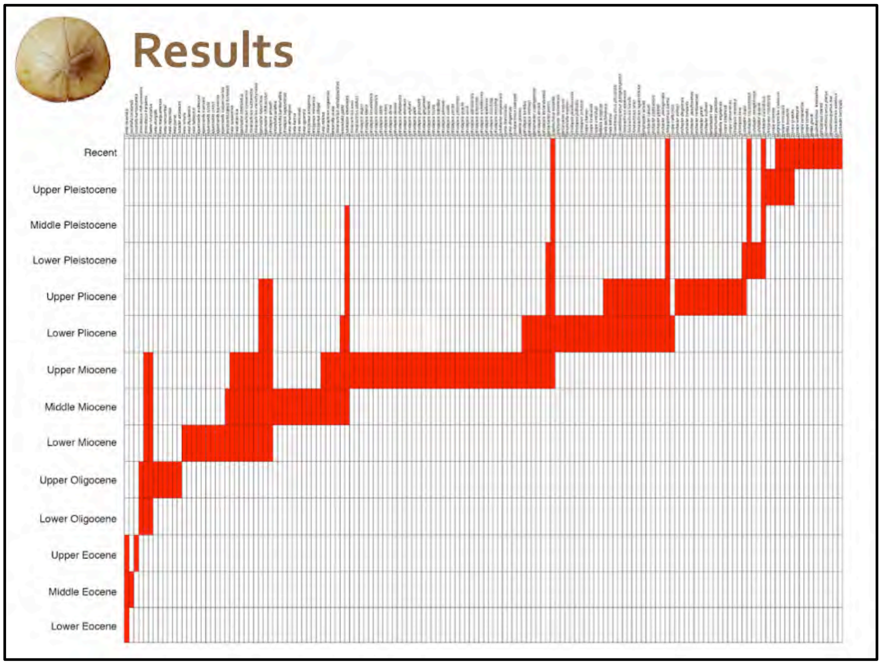


The results from my data led to some interesting correlations.

First documented in the fossil record during the lower Eocene, sand dollars diversified steadily, achieving a peak in taxonomic diversity (54 species) during the upper Miocene.

Some species persisted into the Pliocene and continued to speciate until the largest known extinction of this group when entering the Pleistocene.

There was an evolutionary bottle neck in the middle Pleistocene but then certain species persisted to the present.



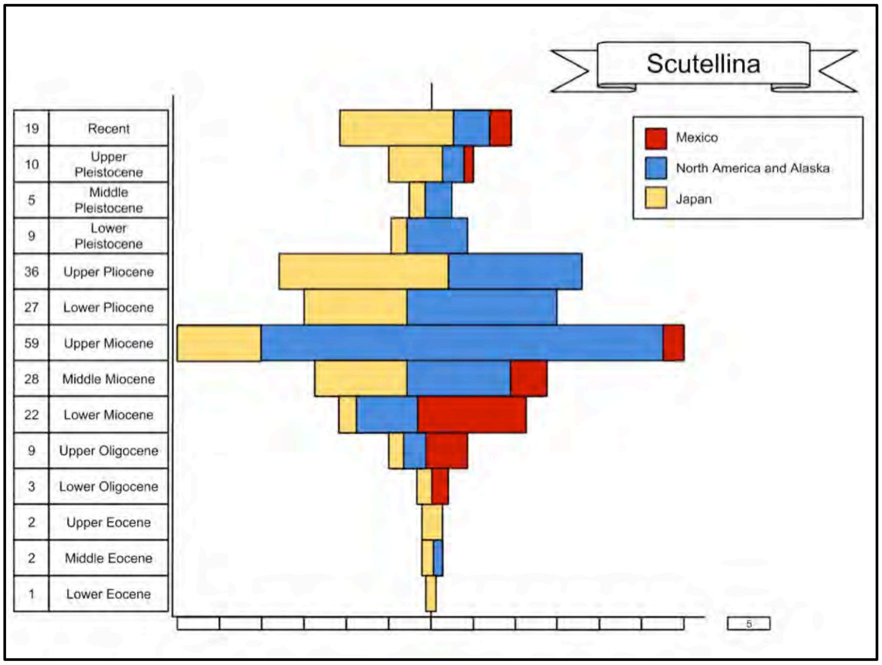
Species highlights:

The first known scutelliod Lenita isrealski genus scutellinidae greenhouse Eocene in Japan extinct as the Tethys sea closed.

Echinodiscus tansiensis (Astriclypeidae) and Allaster rotundatus (scutellidae) both orginiated in the lower Oligocene in Japan with different morphologies and persisted until the end of the Miocene.

2 of the 3 Japanese nipponaster of the 3 species and the type species for Astrodapsis anstiselli (CA/Alaska) were all medium to large species that originated in the lower Miocene and persisted until the end of the Pliocene.

Scutellaster interlineata (kewiidae e pacific) is a eccentric medium sized species with marginal periproct. It began in the middle Miocene and persisted until the end of the middle Pleistocene.



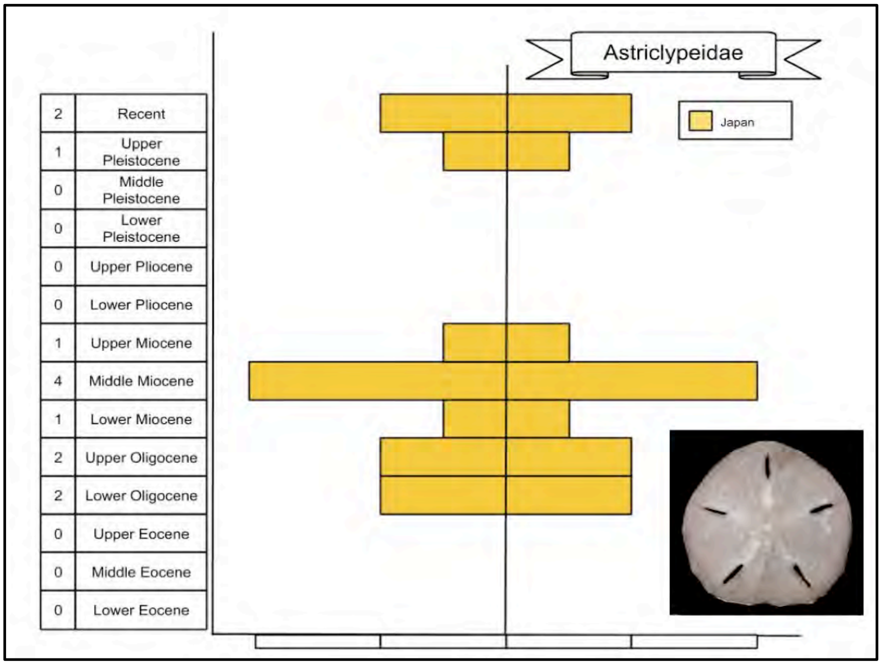
Geographic highlights-

"True" sand dollars originated in Japan where they have remained and the majority of the remaining species can still be found.

The made their first appearance in the southern eastern pacific in the Oligocene where they radiated rapidly until the middle Miocene when they died out just as fast as they originated until the upper Miocene. They were not seen in Mexican waters until the upper Pleistocene.

In the upper Oligocene, they found their way to North America/alaska between the extremes where they consistently speciated until a giant boom in the upper Miocene. By the late Miocene, there were half the numbers as the middle and those began dwindling in the Pleistocene until leaving the remaining species.

Mass extinction affect clades differently. I will now show you a review of stratigraphic spindle of individual families and make correlations to environmental conditions which may have influenced clade wide diversity.

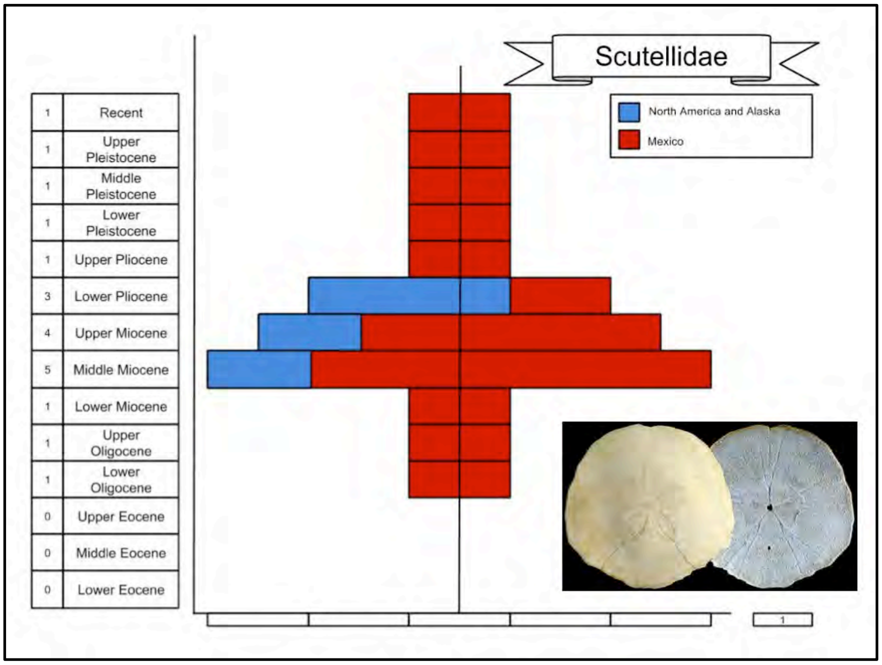


family Astriclypeidae was described in 1912. 8 taxa in 3 genera: Sculpsitechinus, Echinodiscus, and Astriclypeus.
Size: medium to large sand dollars (<25mm) Japan oral periproct and lunules or marginal slits and pressure drainage channels which **permit the free passage of water for locomotion and buoyancy control.**

This clade originated in the lower Oligocene which is the epoch when the Tethys sea between Africa and Europe/Asia disappeared as the continents joined. The tethys sea was rich in marine biodiversity so this tectonic event caused **vaicarant speciation as well as extinctions** of many ancestral forms which we don't have in the fossil record anymore.

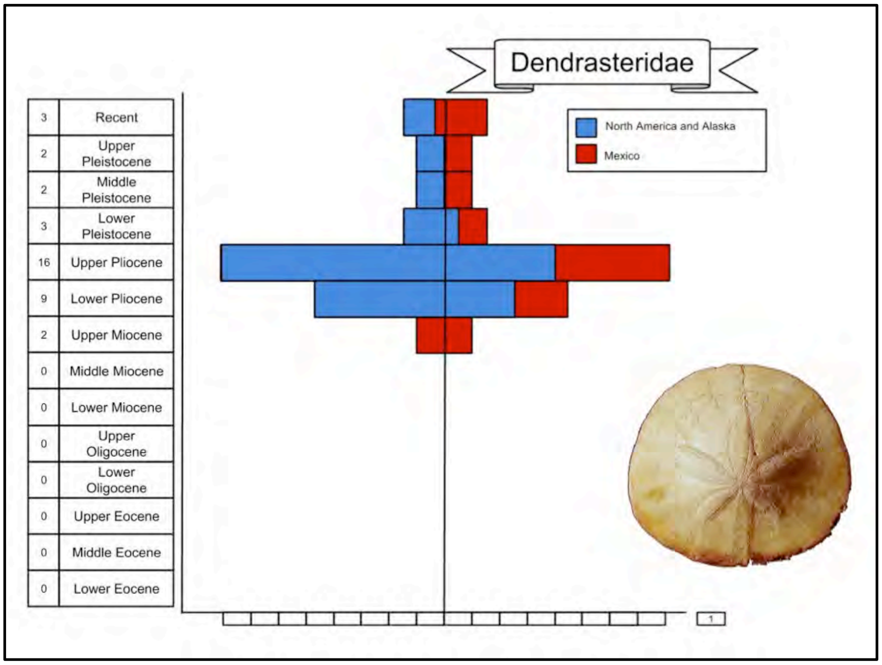
These species began to migrate east of the Thethys sea towards the japan sea as the Miocene began.

In the beginning of the Miocene, the sea of Japan did not exist but instead several large lakes until some active crustal movements **incepted the sea bringing in new warm upwelling currents up from the pacific ocean**. The astriclypedis flourished in diversity in the mid Miocene because of these new warm water habitats which they



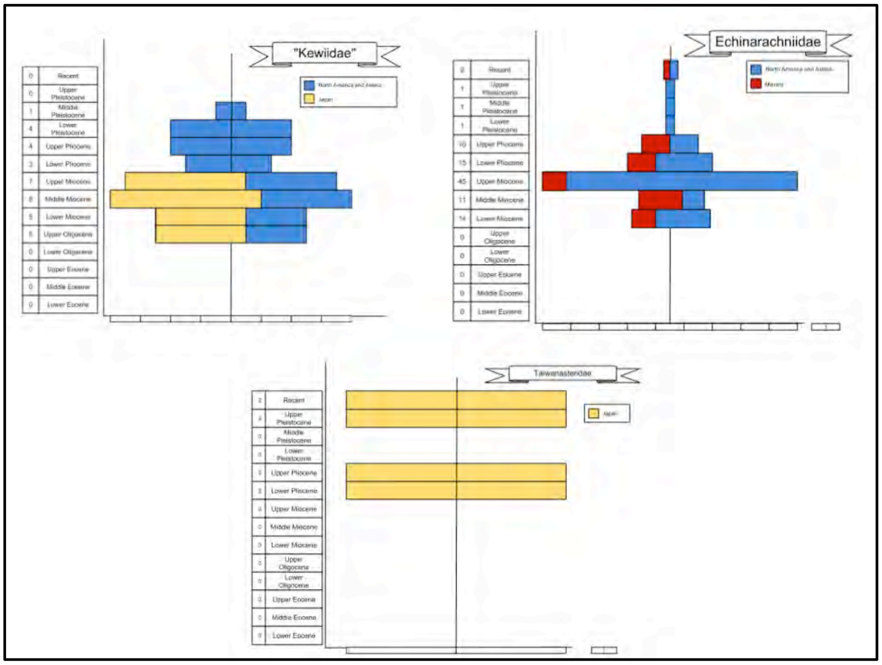
family Scutellidae 1925. 7 taxa in 4 genera: Remondella, Scaphechinus, Mennerella, and Allaster. fairly small sand dollar (>25mm) either oral or marginal periprocts.

Allaster roundatus is the first taxon in this clade in the fossil record appearing in warm Mexican waters in the early Oligocene. This species persists until the middle Miocene when it speciated creating greater taxonomic diversity possibly driven from the recently upwelling events. Remondella migrated north enduring the colder waters. Diversity is consistent until the onset of cooling in the Pliocene which cases a clade wide extinction besides one species Scaphechinus mirabilis which managed to hide from the cold in tropical waters and endure there until today.

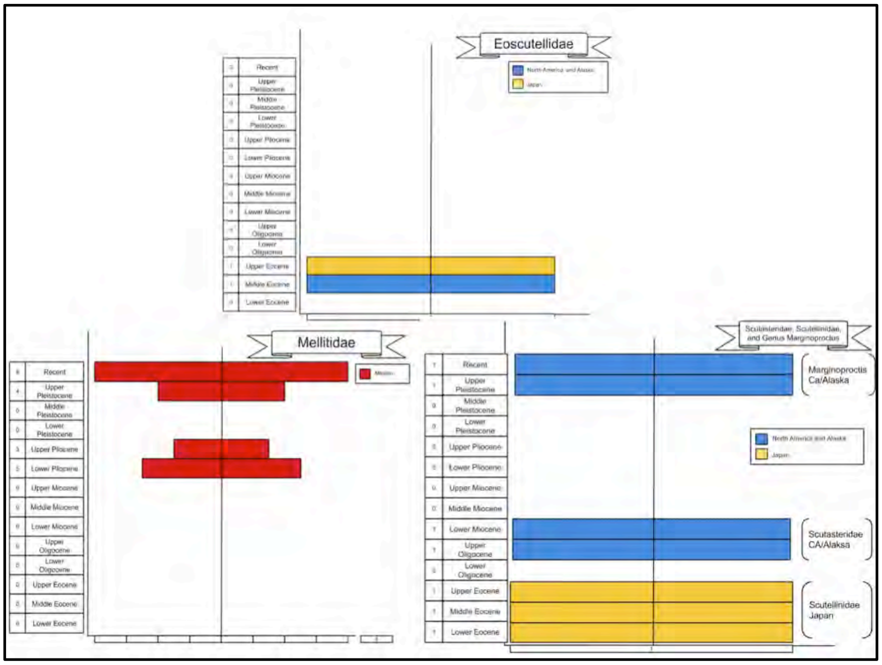


family Dendrasteridae described in 1889. 20 taxa in 2 genera: Merriamaster and Dendraster.
Size: small to large.   eccentric clade   oral periproct and complex food grooves to aboral

Merriamaster taxa originated in warm Mexican waters during the upper Miocene and quickly speciated into dendraster which expanded North into colder temperate waters. Merriamaster and dendraster have a common ancestor and is like dendrasters chunky miniaturized sibling. Merriamaster did not survive the Pleistocene glaciation period but dendrater excentricus managed to persist to be the only living sand dollar along the north American coast while Dendraster vizcainoensis found a niche in Baja.



"Kewiidae"
Echinarachniidae
Taiwanasteridae



It is likely that Mellitidae and Astriclypeiidae originated from a common ancestor in the Tethys sea and then independtly evolved lunules.

New eoscutella species. Rich has at least 2 species which have not been published meaning that the taxa represented by my data does describe the biodiversity of this clade.

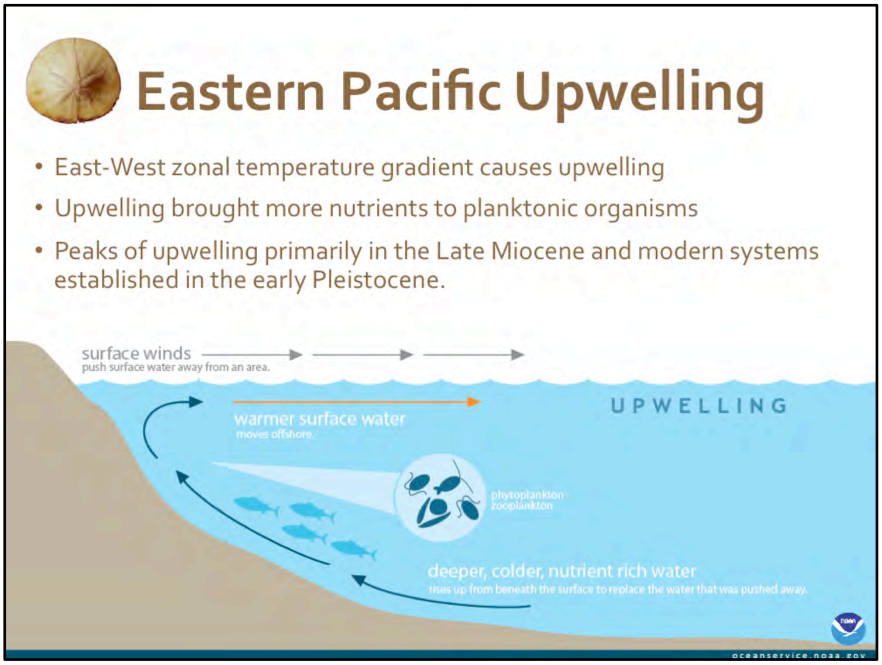
in **response to food limitations** an individual will shift to an alternate feeding habitat, activity or food item **if the gains involved exceed the costs.**

Suspension feeding was possible when the petals with **respiratory tube feet and food grooves migrated posteriorly** from the center of the test enabling the sand dollar **to bury their anterior in the sand and assume a vertical (inclined) position.**

Sand dollars **act opportunistically** in changing environments. **Switching between feeding modes, also known as plasticity in feeding behavior**, is the ability to alternate between suspension feeding in the water columns and deposit feeding on bottom sediments.

Dendraster, Scutaster, and one species of *Echinarachnius* are 3 separate genera which **independently developed facultative suspension feeding behavior** which is relatively rare within the order Clypeasteroida.

Eccentricity is a perculiar triat which has not been studied greatly. But I suspect eccentricity developed with the formation of the E-W zonal temperature gradient



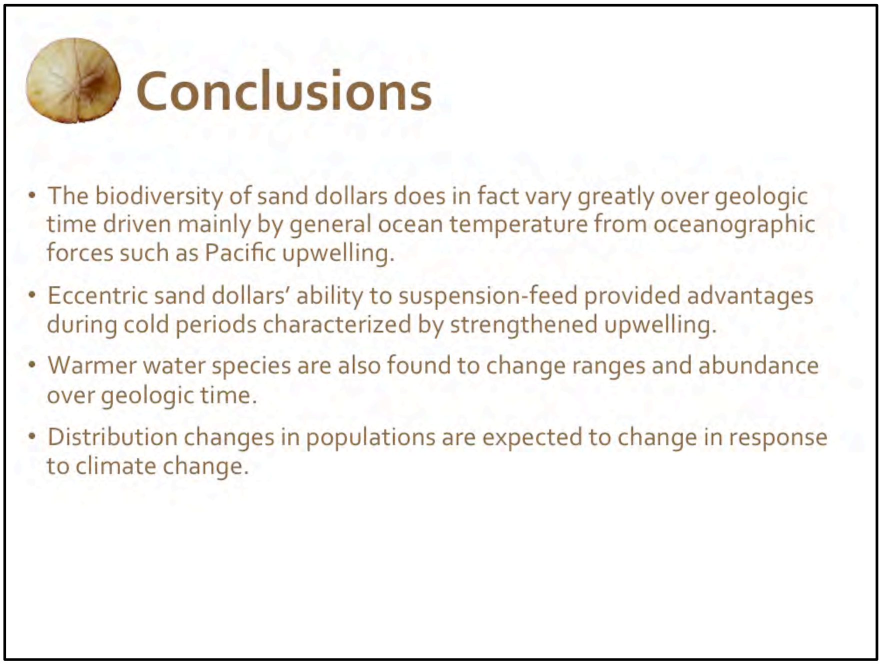
It is widely accepted that **low-latitude tropical oceans play a key role**, particularly in the pacific ocean due to the **western pacific warm pool in the west and the "cold tongue" in the east.**

In the **modern equatorial pacific, there is a long-term and relatively stable east-west asymmetric pattern of the zonal temperature gradient** (sea surface **temperature is higher in the west and lower in the east**) and the asymmetric upper water structure (**thermocline depth is deeper in the west and shallower in the east**). This e-w zonal temperature gradient created the oceanographic phenomenon known as upwelling

Upwelling involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water. The **nutrient-rich upwelled water stimulates the growth and reproduction of primary producers such as phytoplankton**.

There were two main upwelling events recorded by analyzing surface and sub surface planktonic foraminifera in the mid Miocene and the early Pleistocene.

15 – 17 Ma : Earth transitioned from warm phase after the Miocene climatic optimum



Can we explain adaptive responses on the part of sand dollars to these climate changes?
Eccentric sand dollars ability to suspension-feed provided advantages during cold periods characterized by strengthened upwelling.

Dendraster started warm and expanded to cold.

Arbacia (stellate) typically found in Baja and south to panama but just found migrated up to the Monterey bay

Further research

- Look at biogeographic and stratigraphic data for the Scutellina clade worldwide
- Include morphological characters such as petal area and number of respiratory tube feet
- Study suspension feeding efficiency during and outside of upwelling periods

Acknowledgements

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