



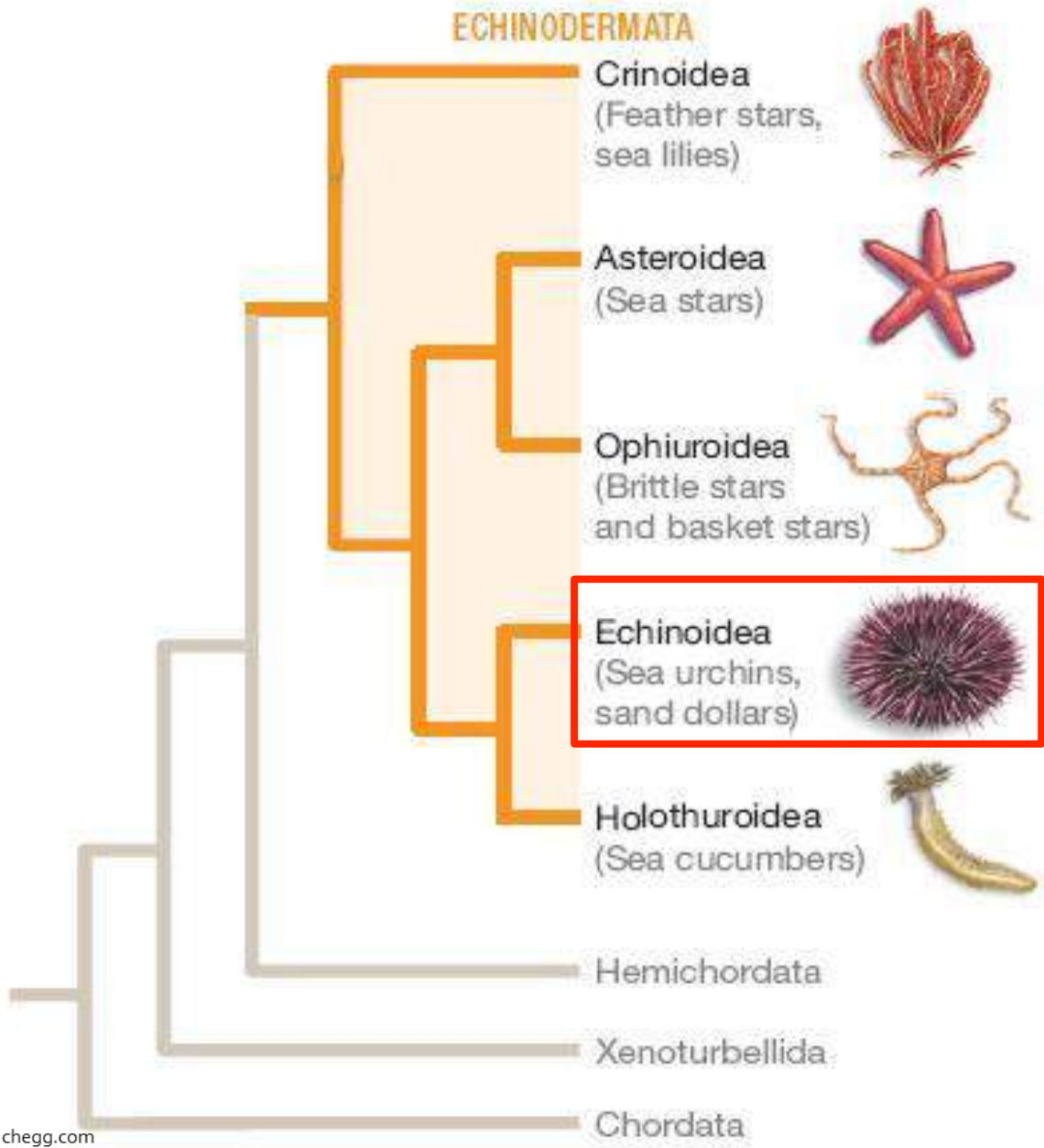
The Hole Truth:

Evolutionary biology of
novel features in keyhole
sand dollars from the
Pliocene of North America

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Dr. Rich Mooi



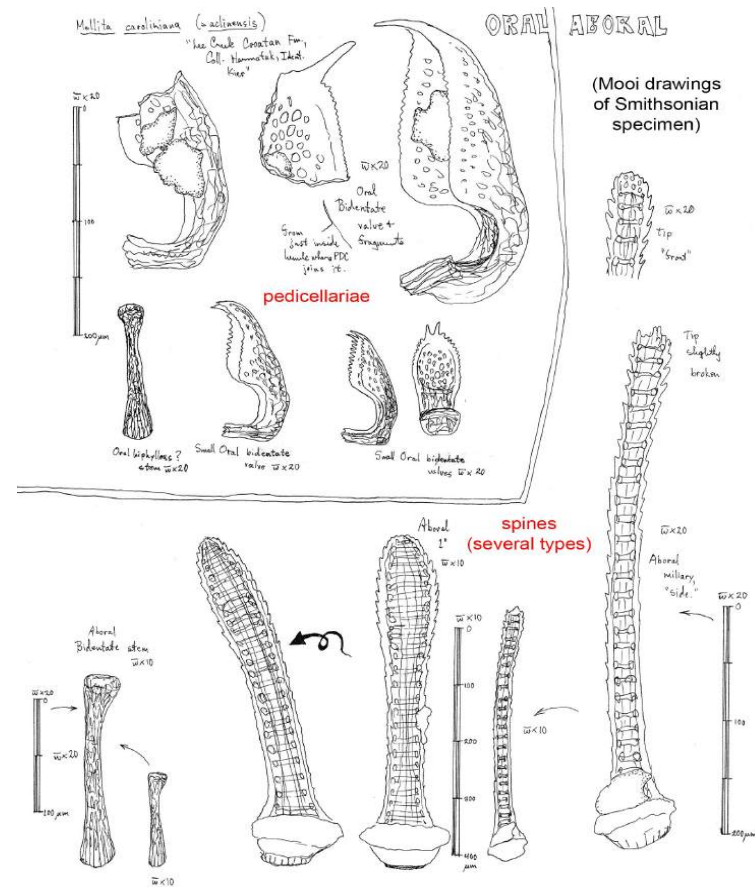


Echinodermata

- Belong to the clade Deuterostomia
- Characterized by:
 - Skeletons composed largely of calcium carbonate
 - Water vascular system for locomotion, respiration, feeding, and sensation
 - Pentaradial body organization in adults

Sand dollars are sea urchins

- Sand dollars are irregular urchins
- They have adaptations to live in sandy bottoms:
 - Miniaturized spines
 - Flattened skeleton (test)
 - Bilateral symmetry
 - Flattened Aristotle's lantern specialized for grinding sand



Aristotle's Lantern:



Sea urchin



Irregular urchin



Heart urchin



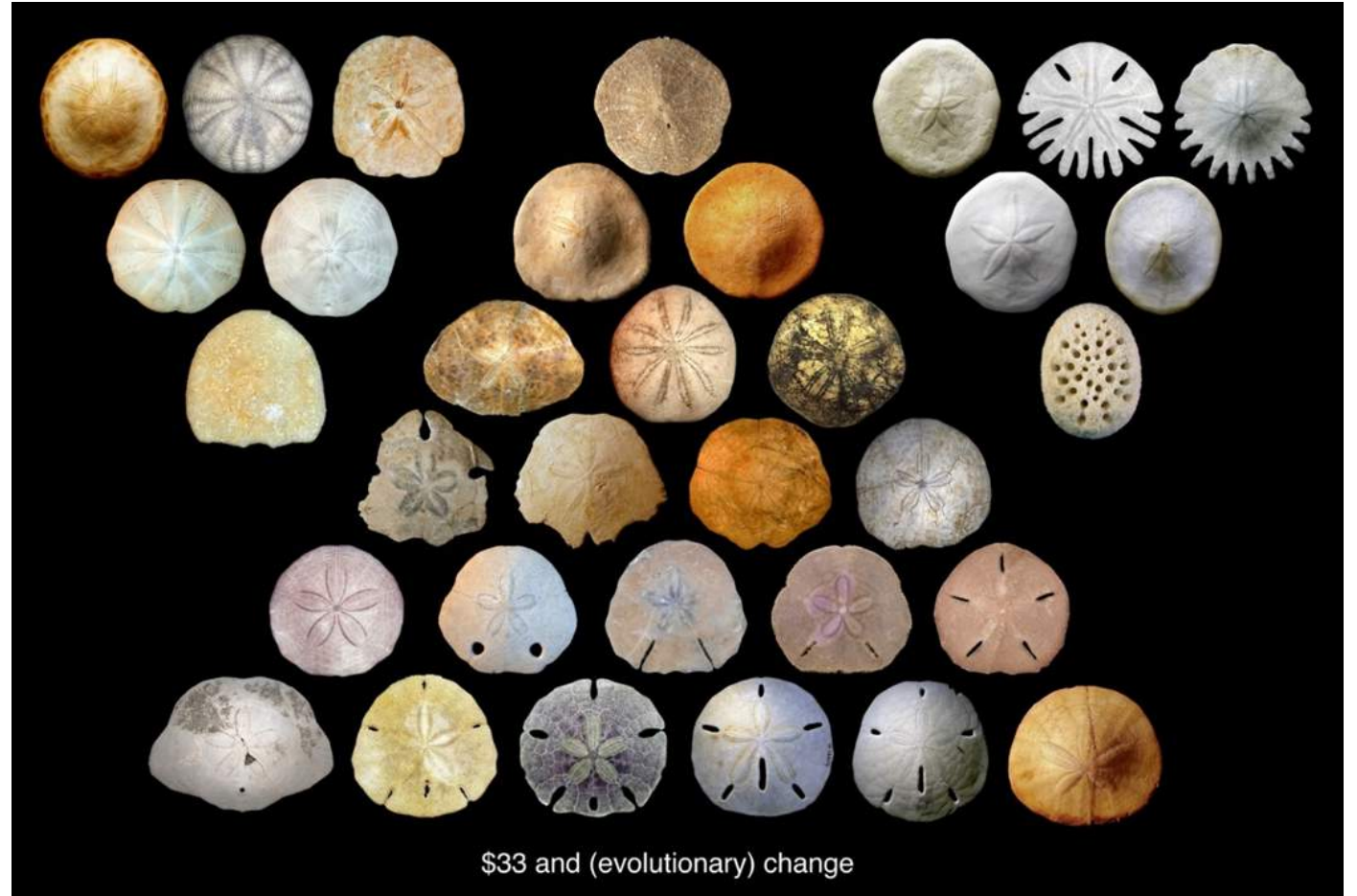
Sea urchin



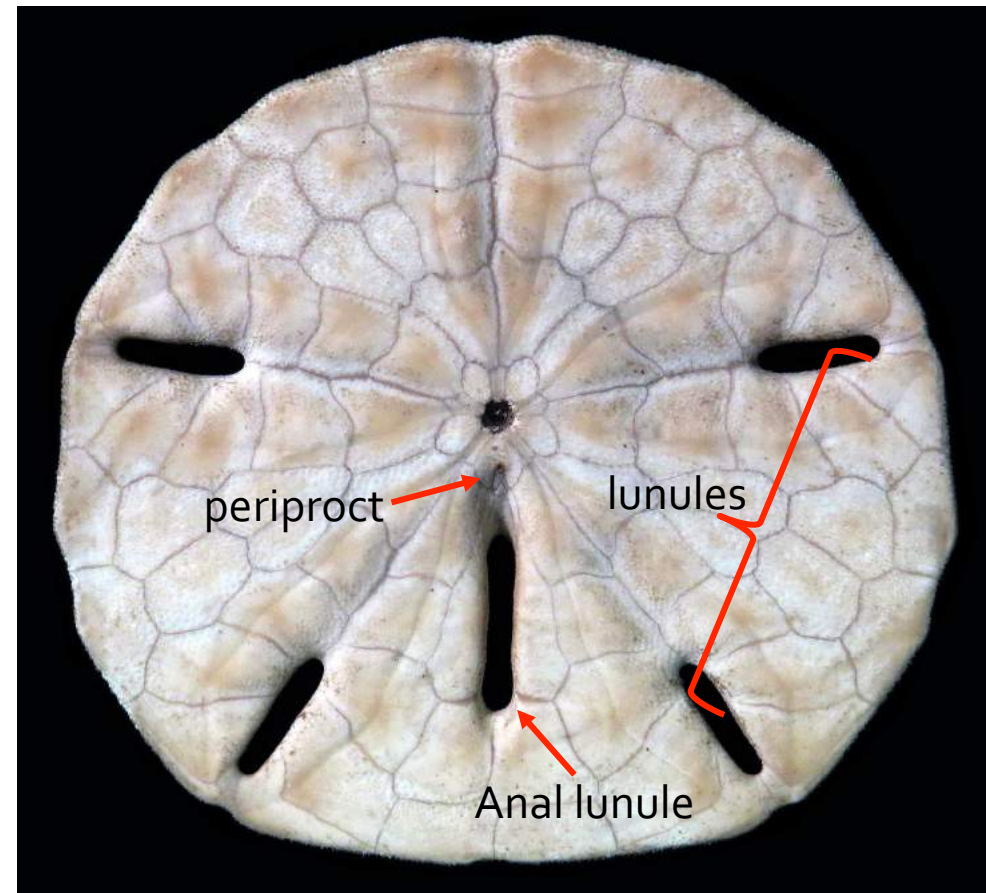
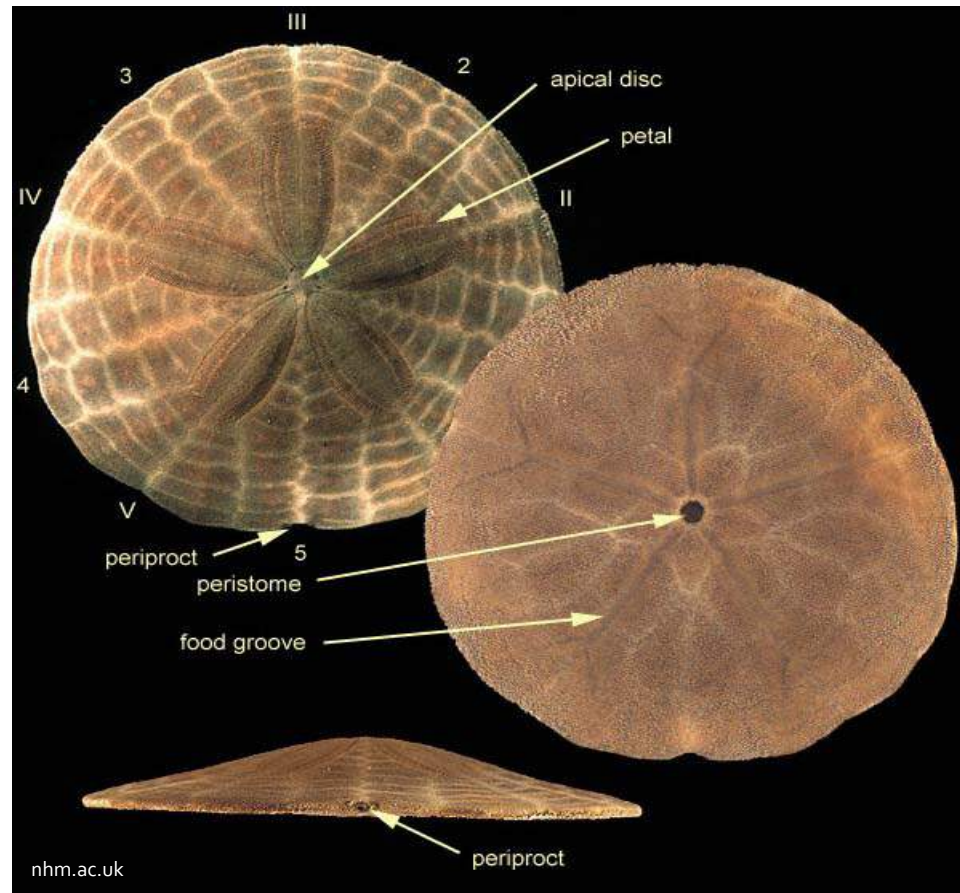
Sand dollar

Echinoidea: Clypeasteroidea

- Includes sand dollars, keyhole urchins, and sea biscuits
- Approx. 250 living species and more than 700 fossil forms
- Bilateral symmetry
- Benthic deposit feeders



Skeletal morphology of sand dollars and their relatives



Lunule function

- Holes that develop in body skeleton (test) & pass completely through test from top to bottom
- Arose as adaptations to hydrodynamic forces in wave-swept environments
- Anal lunules and ambulacral lunules develop differently
- Ambulacral lunules are associated with pressure drainage channels
- This system counteracts lift generated by currents flowing over the curved upper surface-like an airplane wing!
- Sand dollars don't like lift, they like to stay in place

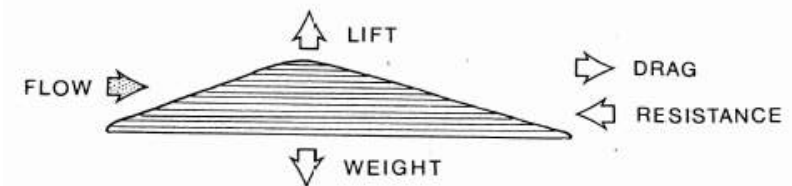
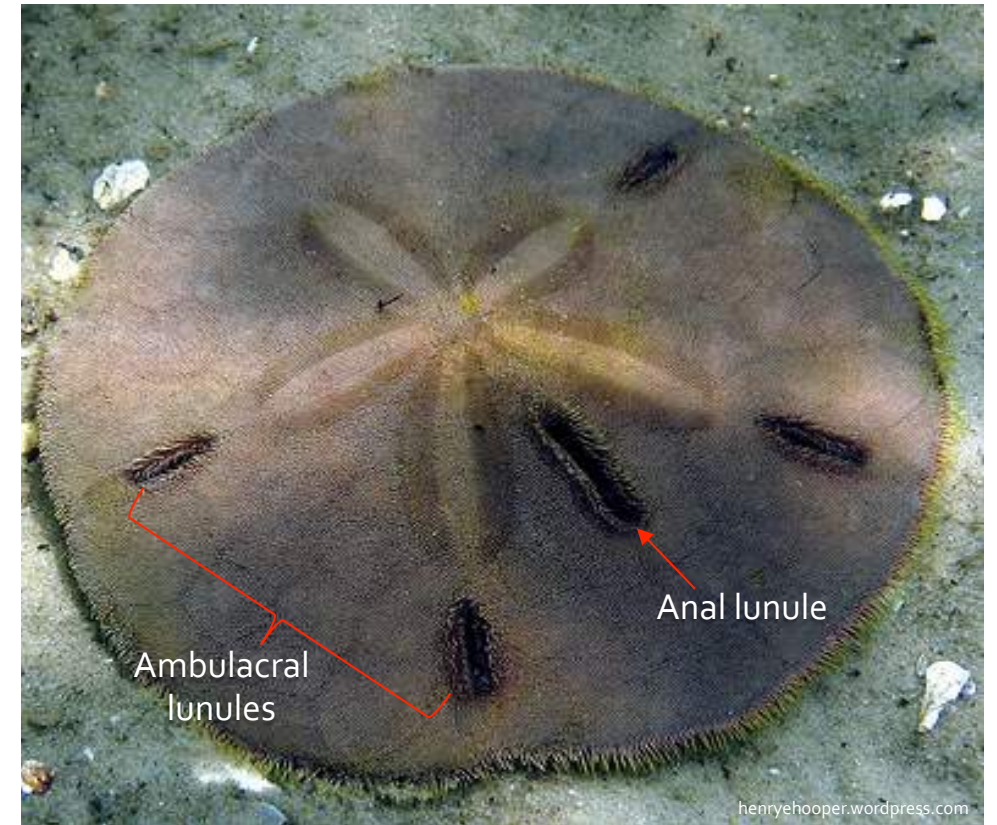
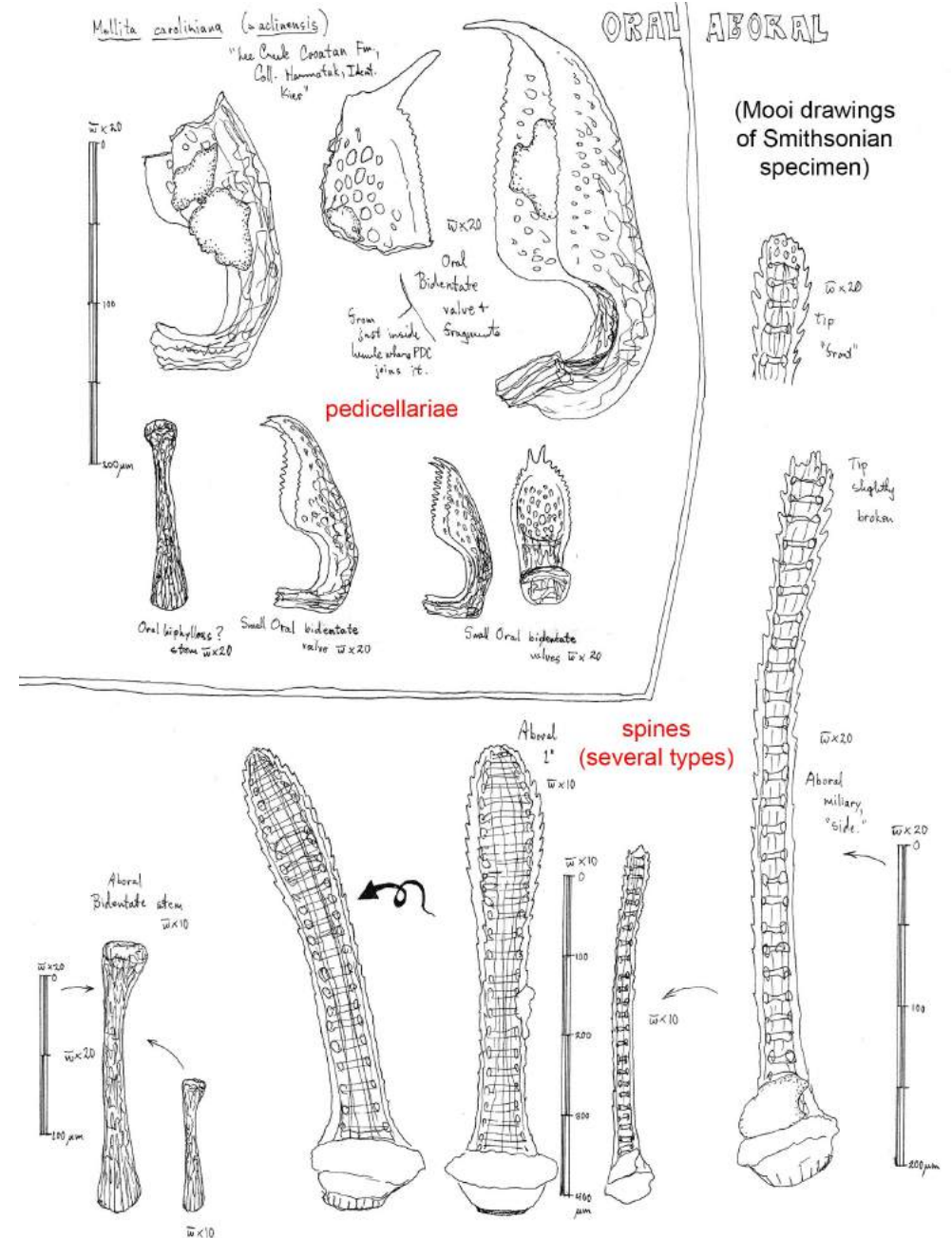


Fig. 2. *Mellita quinquesperforata*. Diagram of forces acting on a sand dollar in moving water. As flow increases so does lift, thus reducing the effective weight of the sand dollar. It remains stable until drag is equal to the frictional resistance, which is given by the product of effective weight and coefficient of static friction

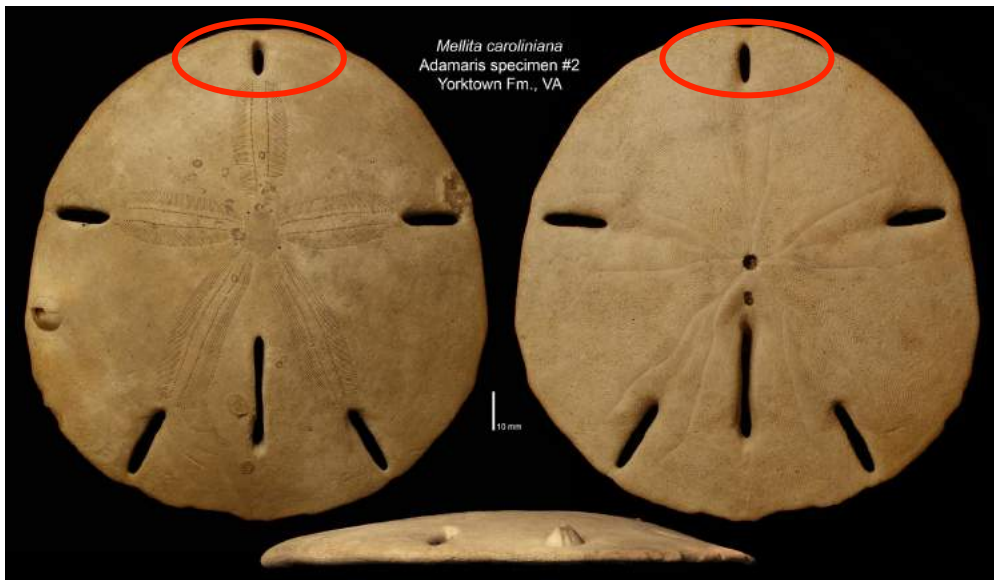
Fossil record

- Allows the exploration of evolutionary change
- Provides information about the environment in which they lived
- Rigid tests allows them to fossilize more readily than other echinoderms
- Fossils can be so detailed that features like spines and pedicellariae (small pincers) can be found
- Finding fossils has become more difficult due to development covering sites

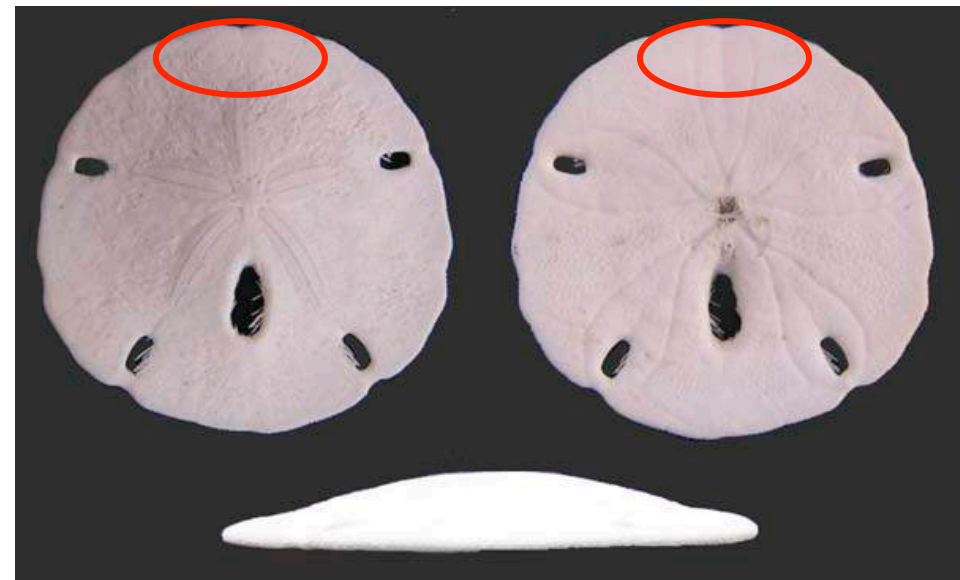


Loss of anteriormost ambulacral lunule in the genus *Mellita*

Fossil



Living



Research Questions



What is the distribution and diversity of fossil *Mellita*?



When and where was the anterior lunule lost?

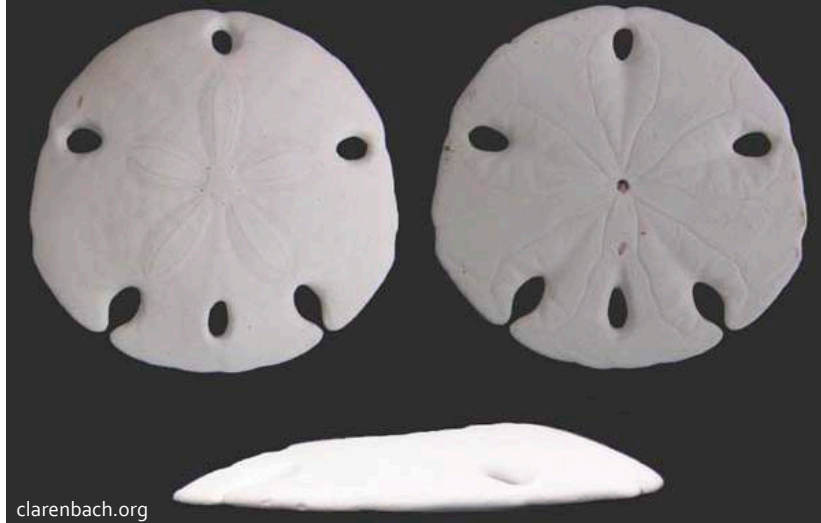


How many species of fossil *Mellita* are there?



What do these species tell us about the evolutionary biology of *Mellita*?

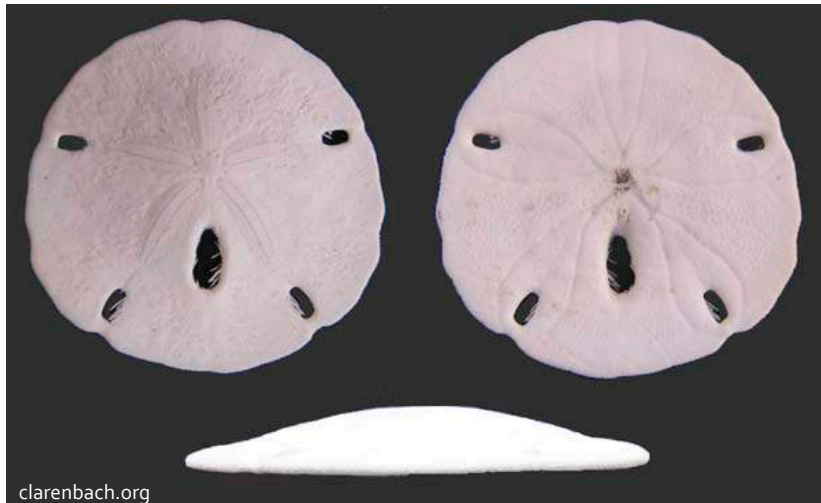
Extant species of keyhole sand dollars



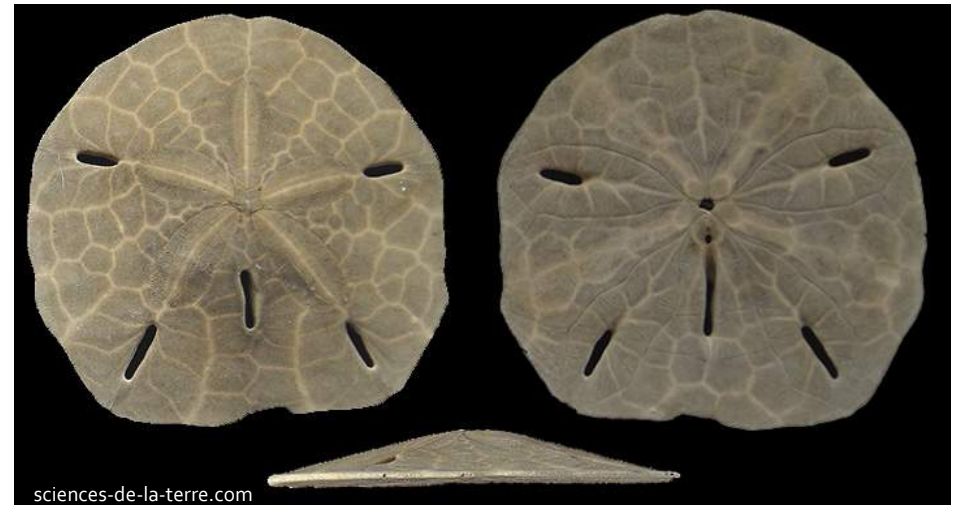
Encope borealis



Leodia sexiesperforata



Mellita isometra



Mellita tenuis

Distribution of living *Mellita*

S.E. Coppard et al. / *Molecular Phylogenetics and Evolution* 69 (2013) 1033–1042

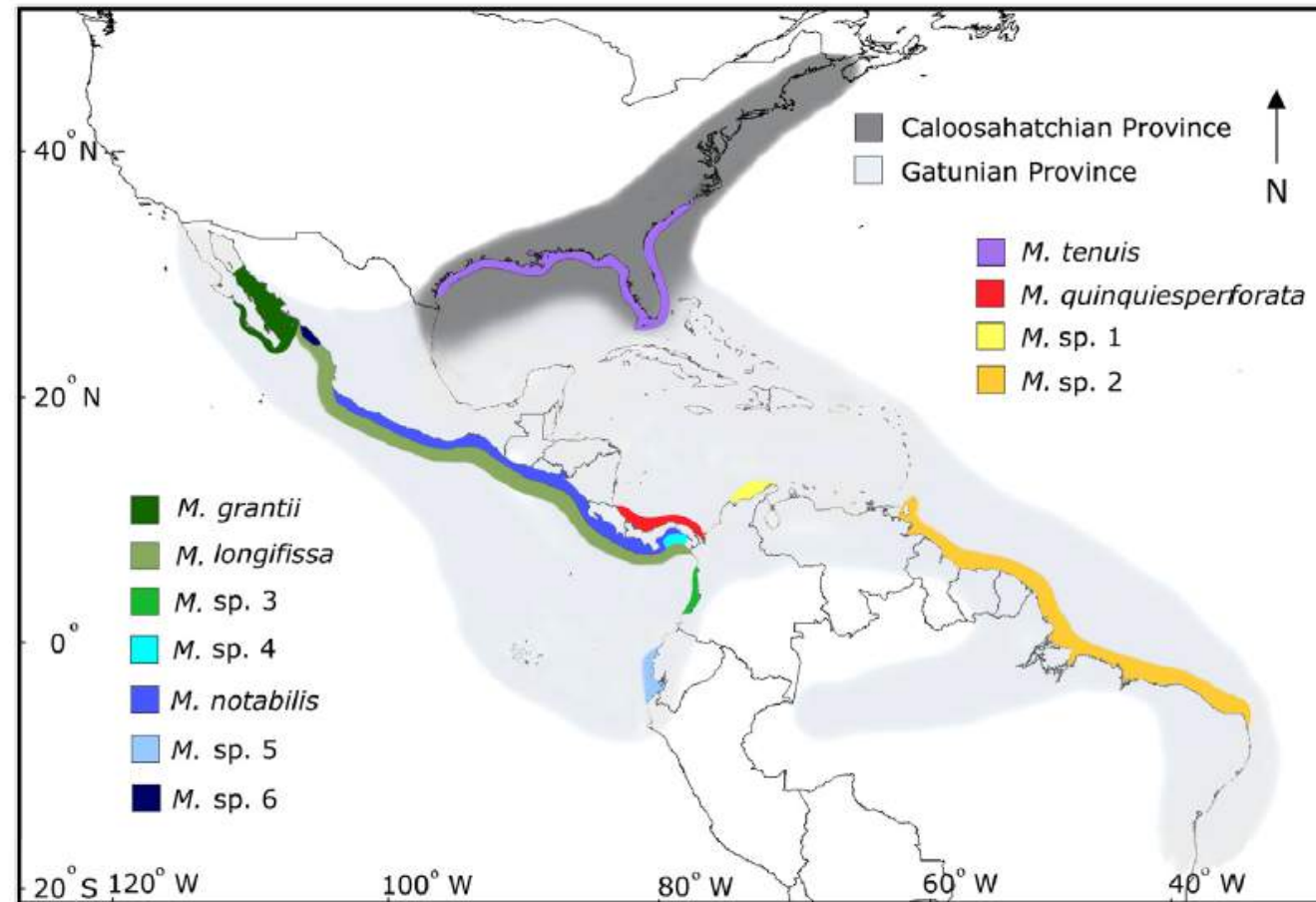
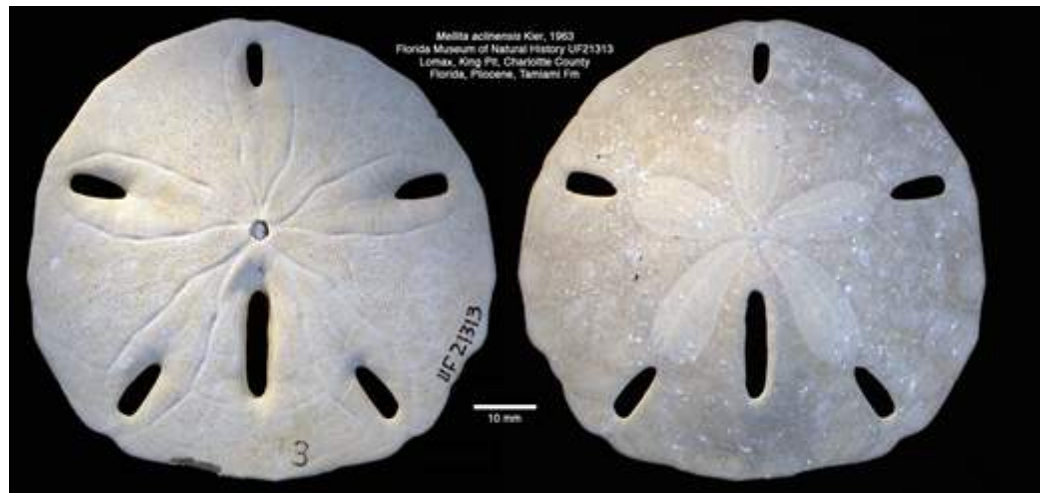
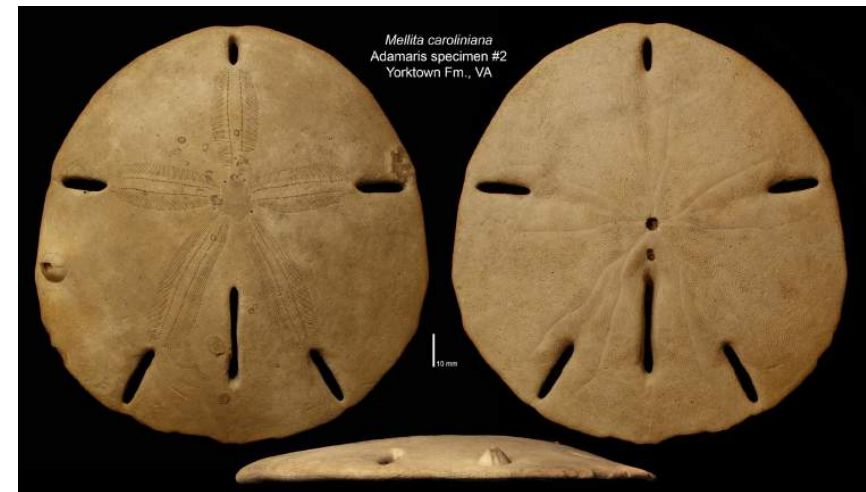


Fig. 4. Geographic distributions of extant species of *Mellita*. The figure also shows the Neogene biogeographic provinces sensu Vermeij (2005).

Extinct species of keyhole sand dollars



Mellita acclinensis

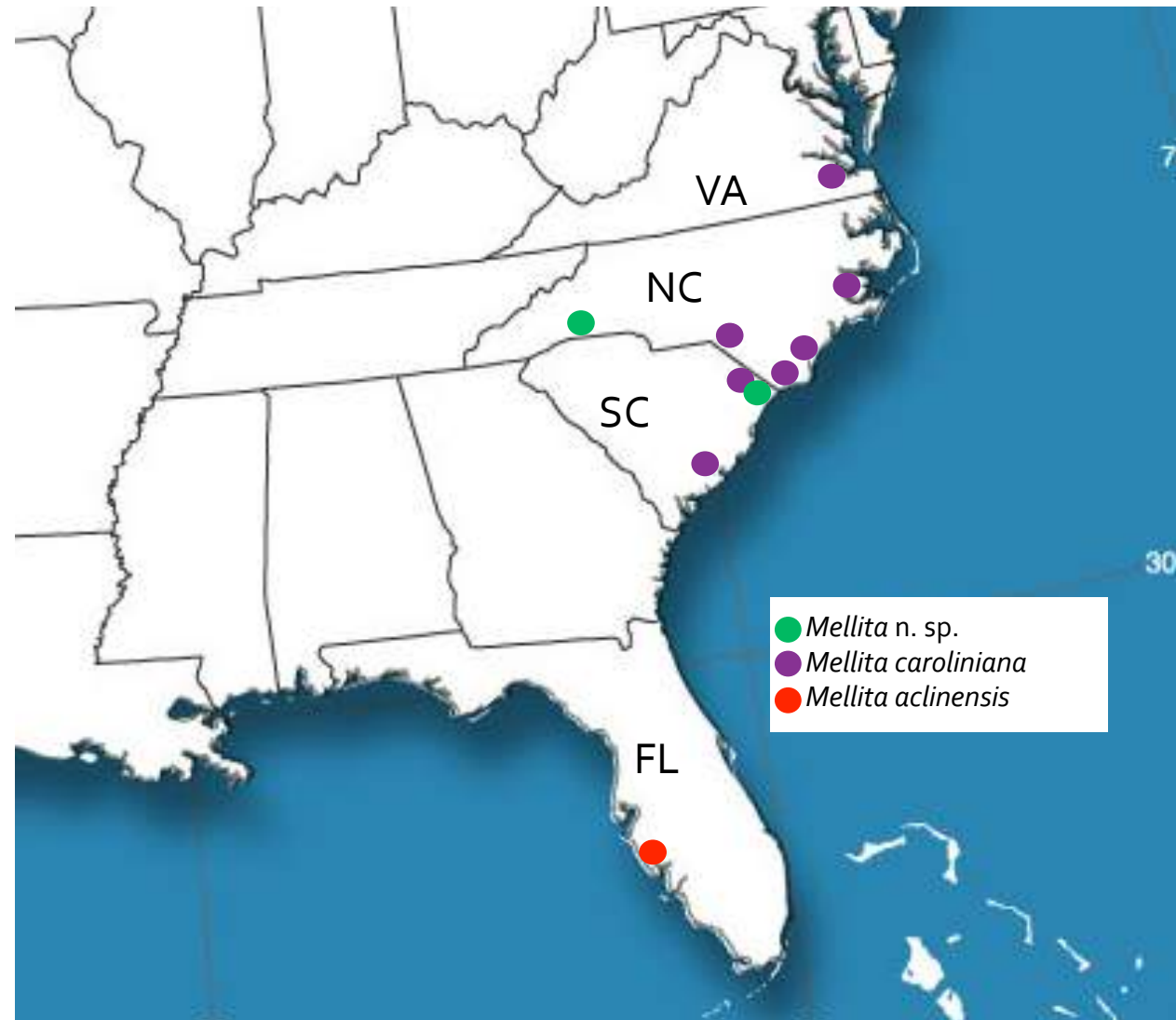


Mellita caroliniana



Mellita n. sp.

Distribution of fossil *Mellita*

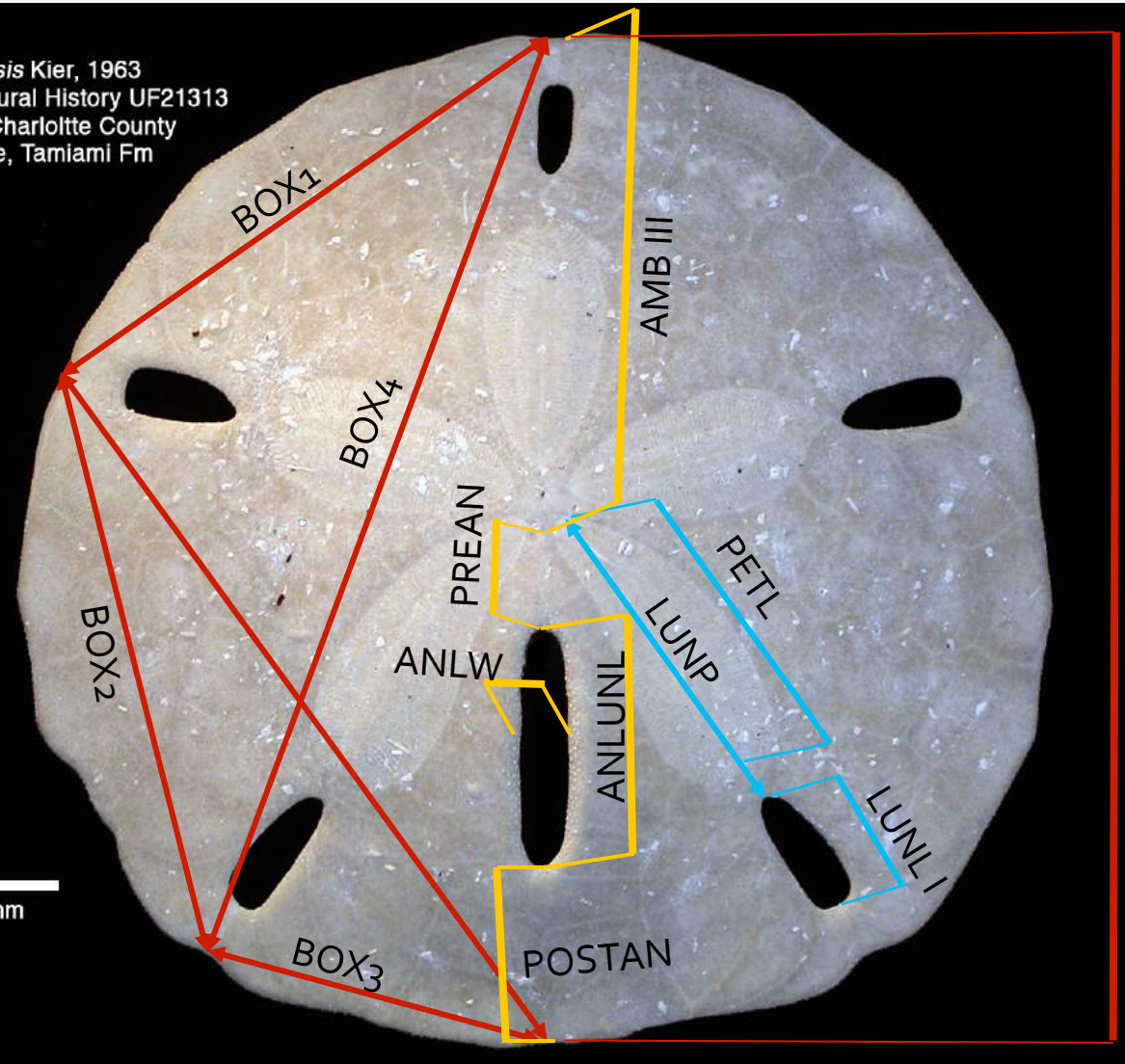
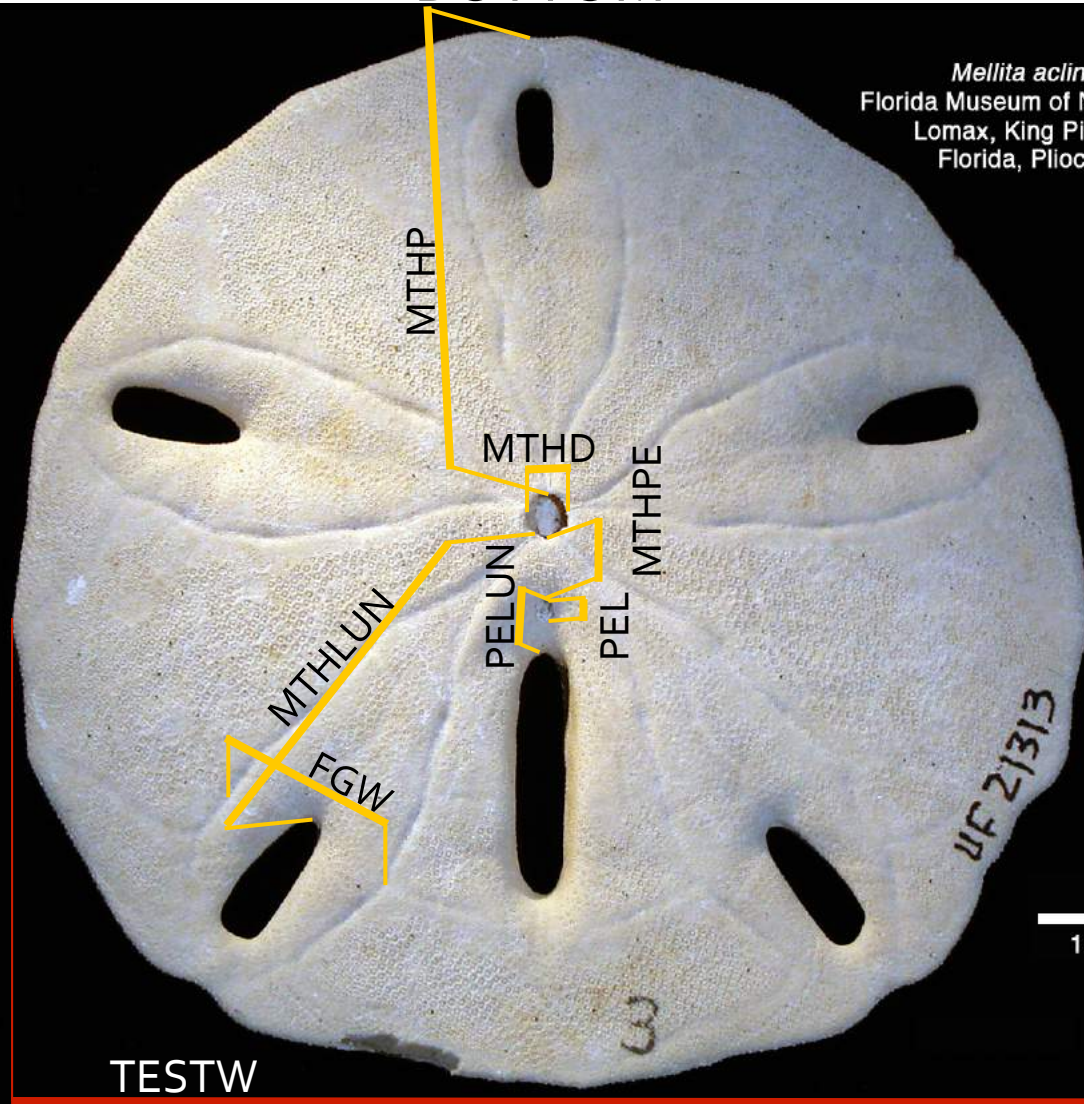


Methods: Measurements

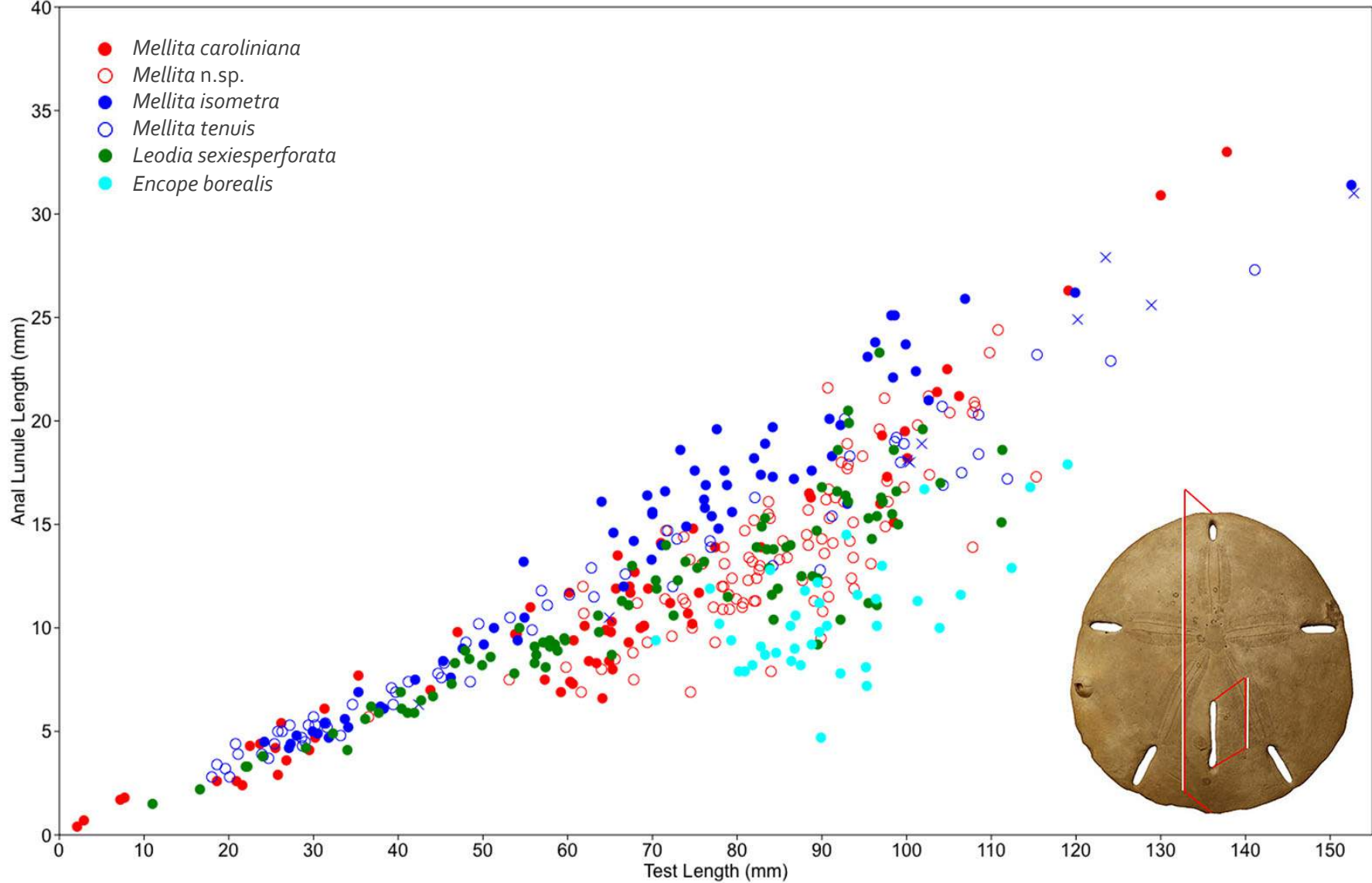
BOTTOM

TOP

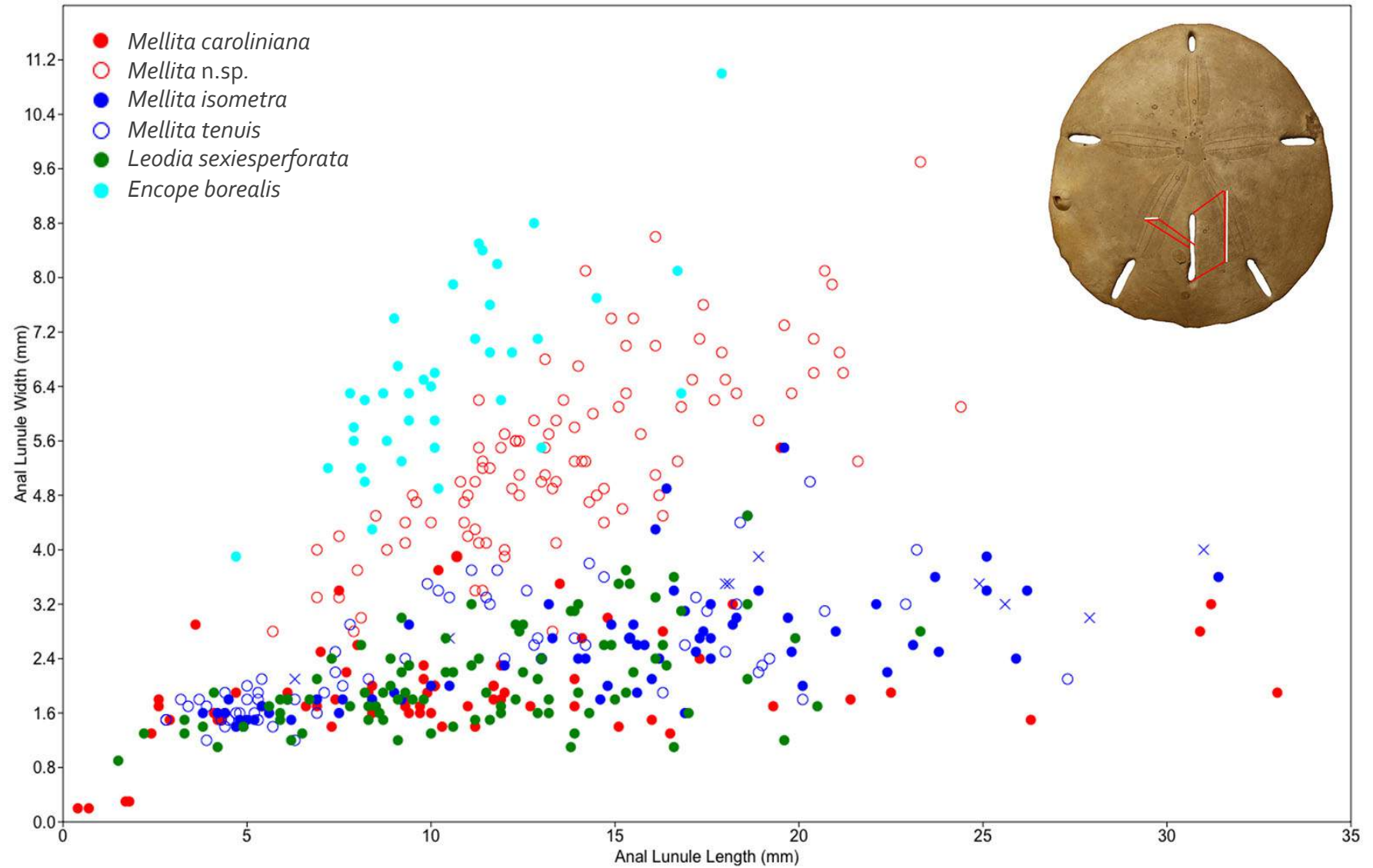
Mellita acclinensis Kier, 1963
Florida Museum of Natural History UF21313
Lomax, King Pit, Charlotte County
Florida, Pliocene, Tamiami Fm



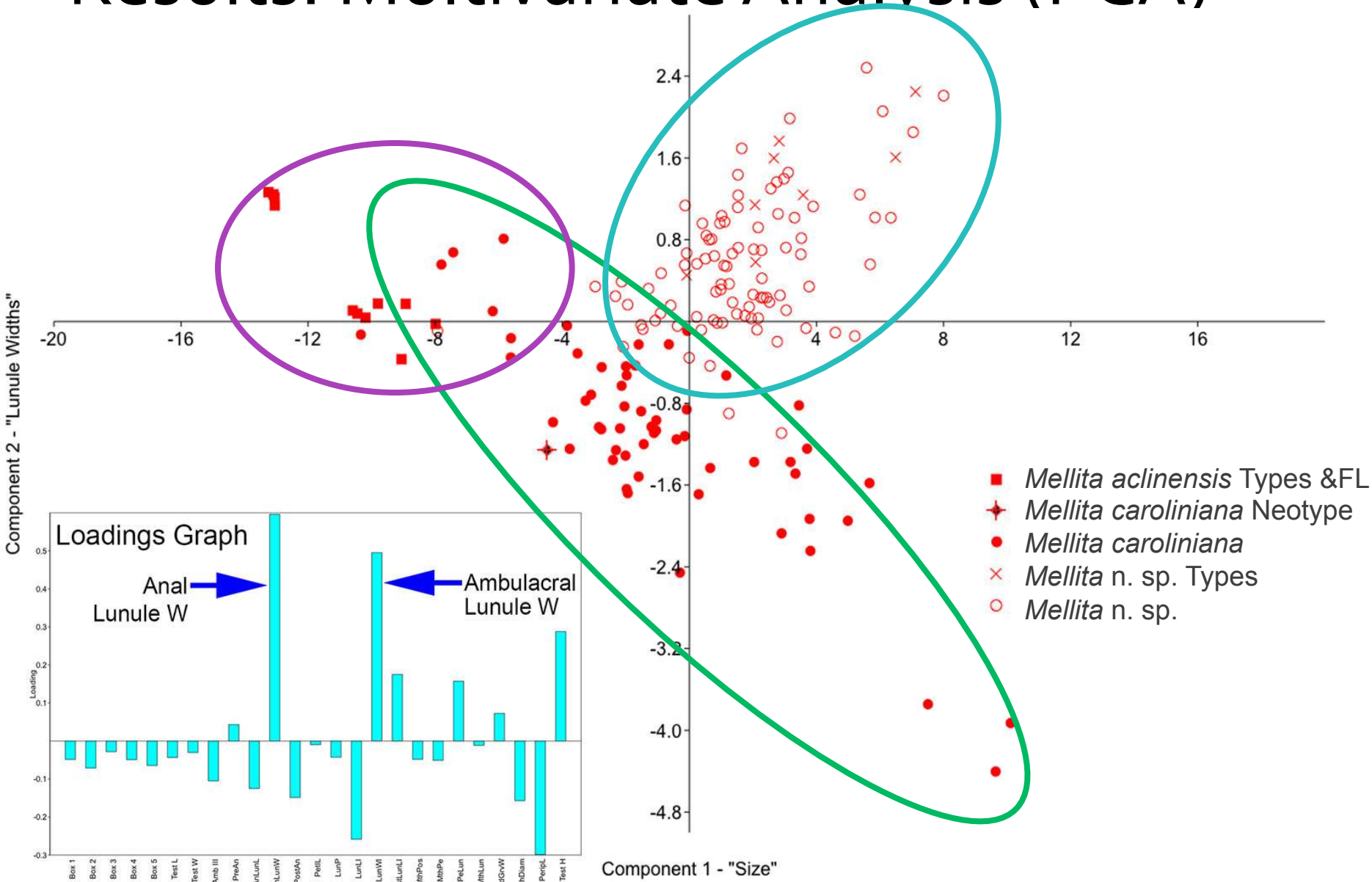
Results: Anal Lunule L vs. Test L



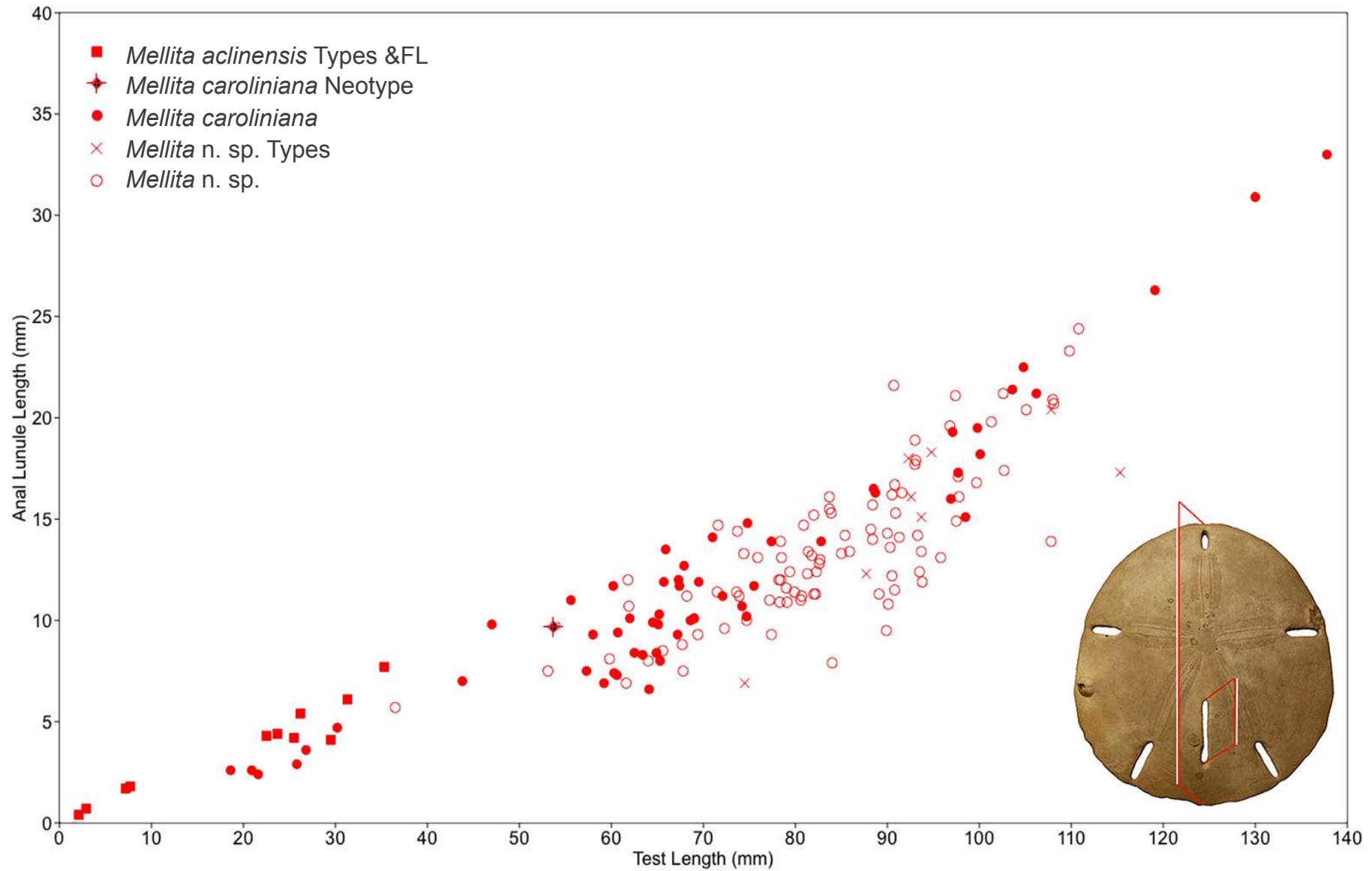
Results: Anal Lunule W vs. Anal Lunule L



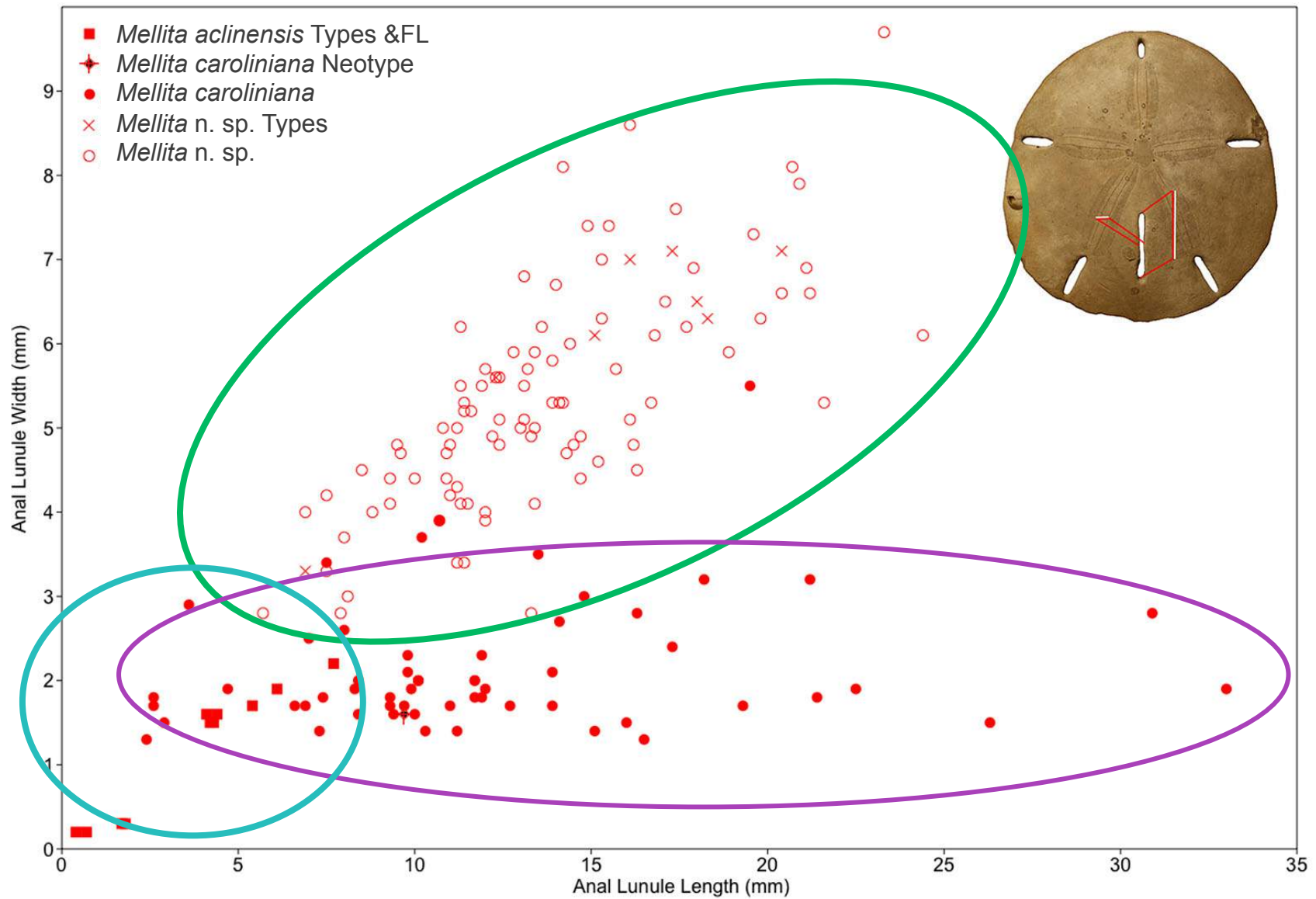
Results: Multivariate Analysis (PCA)



Results: Anal Lunule L vs. Test L



Results: Anal Lunule W vs. Anal Lunule L



Summary



Mellita acclinensis



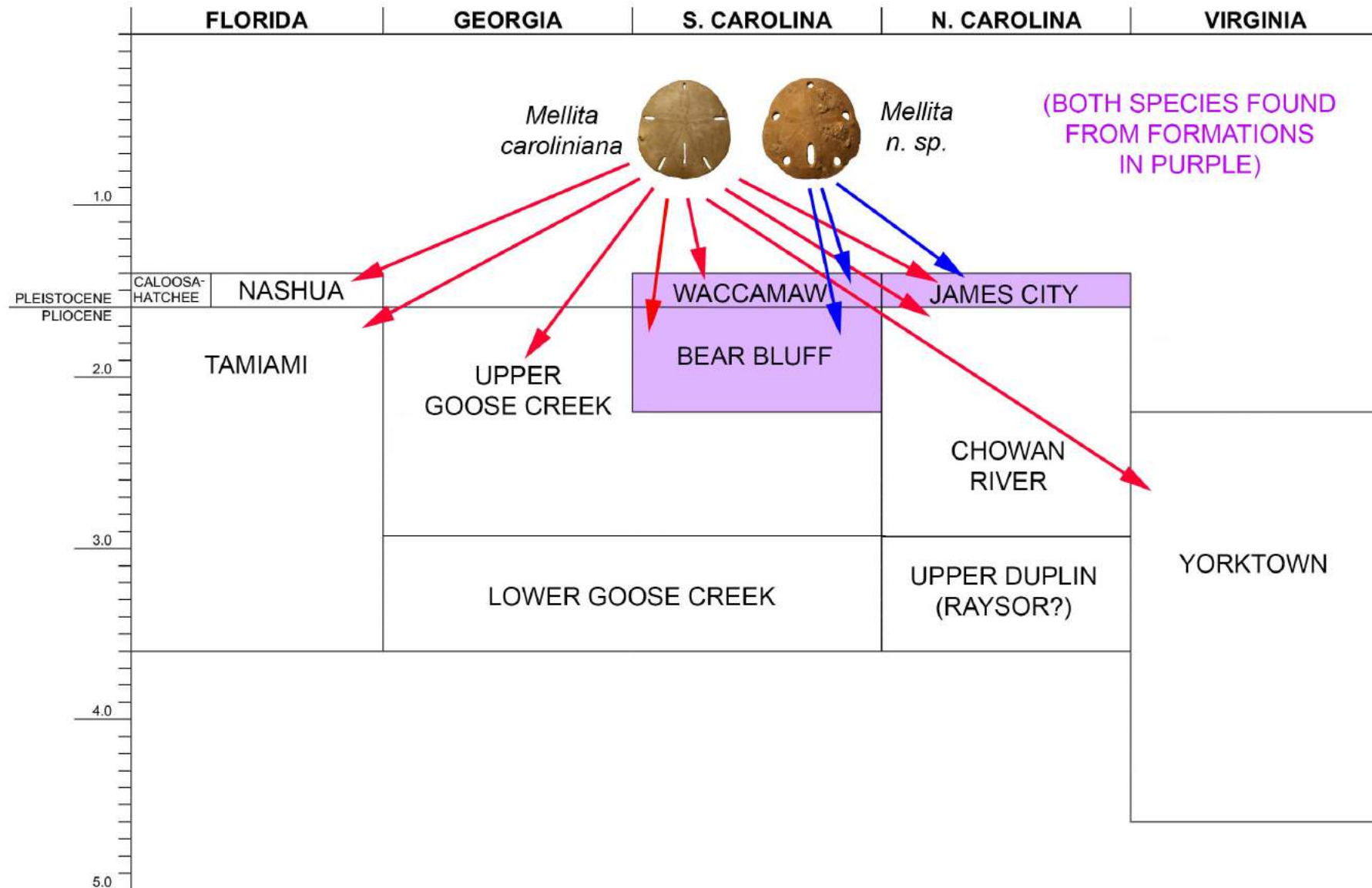
Mellita caroliniana

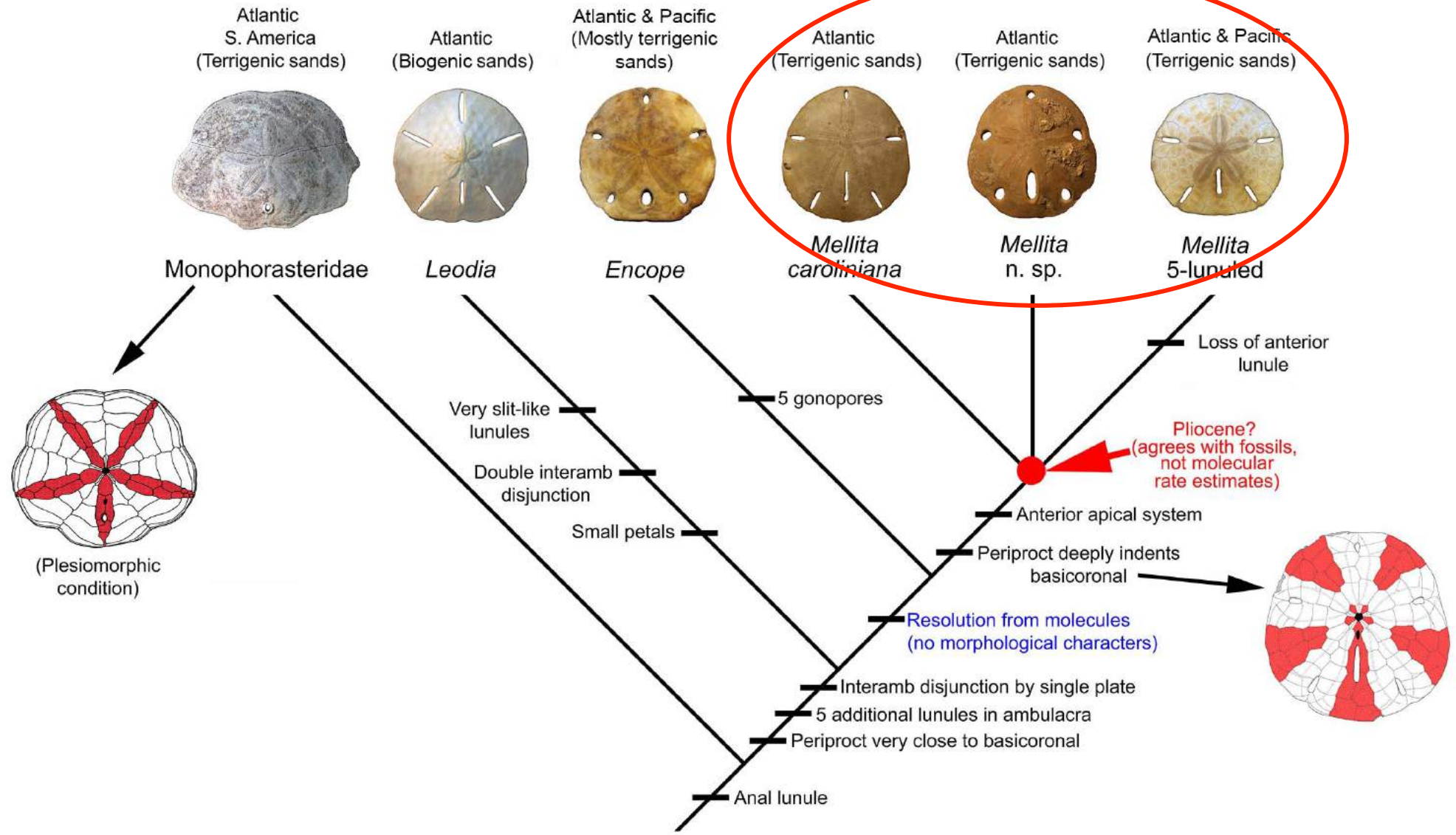


Mellita n. sp.



Stratigraphic distribution of fossil *Mellita*





Conclusions

Diversity and distribution:

- Morphometric data suggest that *Mellita caroliniana* and *M. acclinensis* comprise one species
- *Mellita caroliniana* and *Mellita* n. sp. are different species based largely on differences in the anal lunule width

Loss of the anteriormost lunule:

- The fossil record suggests that the anterior lunule was lost in the Pliocene of southeastern North America
- Preliminary molecular data do not support this conclusion, suggests deeper divergence (approx. 19 million years ago)

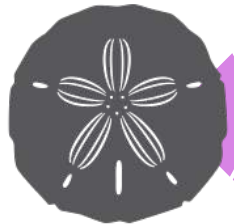
Further Research



Obtain more data on the ecology of the organisms and map it on the phylogeny



Study the movement of the apical system towards the anterior end and possible effect on the loss of the anterior lunule



Find more fossils! [and get better molecular data]

Acknowledgements

Special thanks to:

Rich Mooi

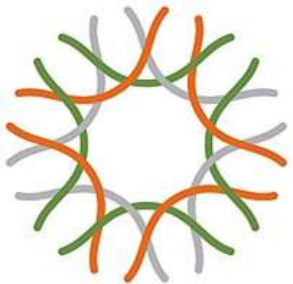
Katherine Piatek & Kelly Larkin

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Collectors that provided sand dollars!



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