

A Brief History of Skeletons in the Oceans



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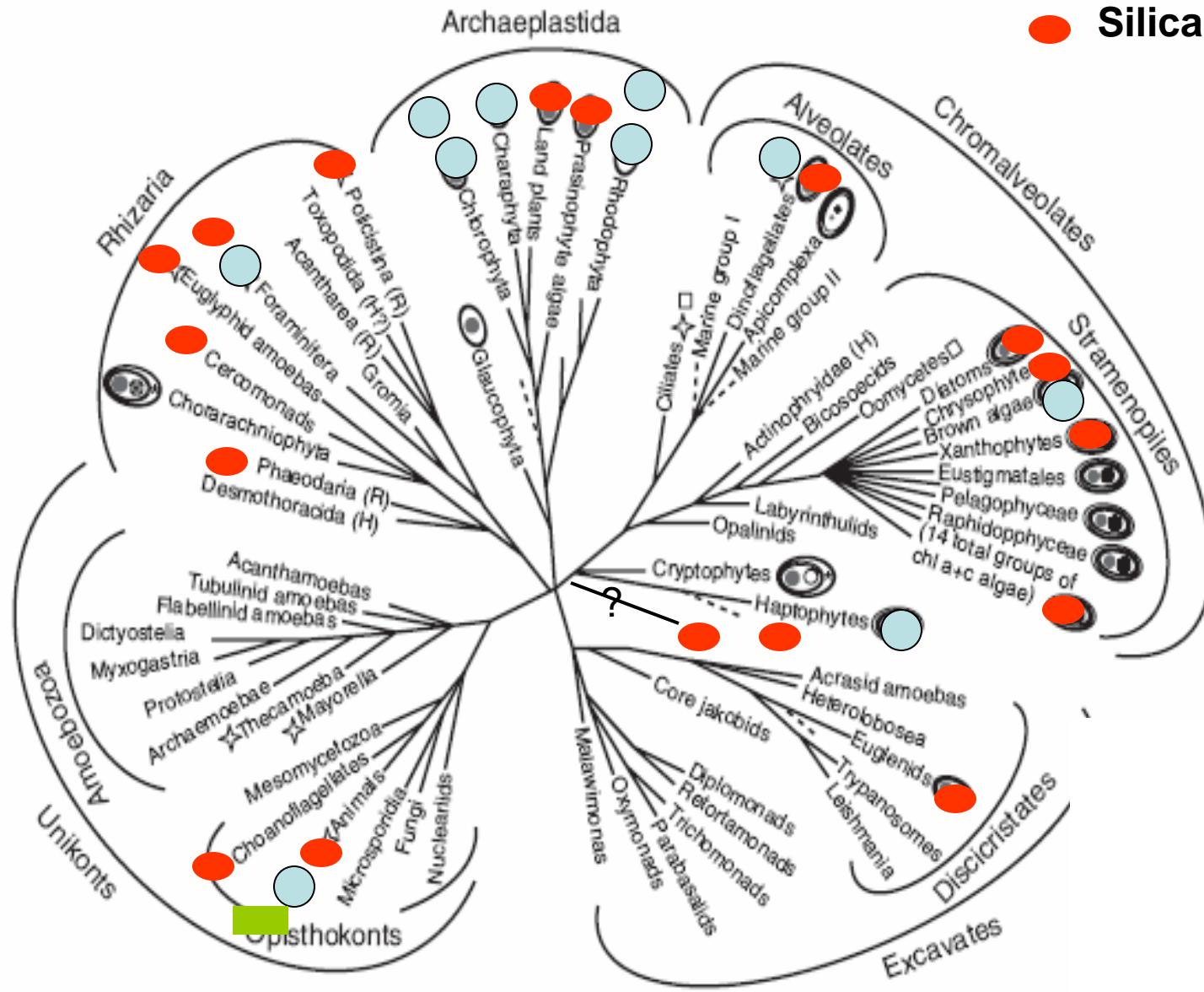
Motivating questions

- Evolutionary history may find at least partial explanation in skeletal physiology
- Evolutionary history may inform thinking about our evolutionary present and future



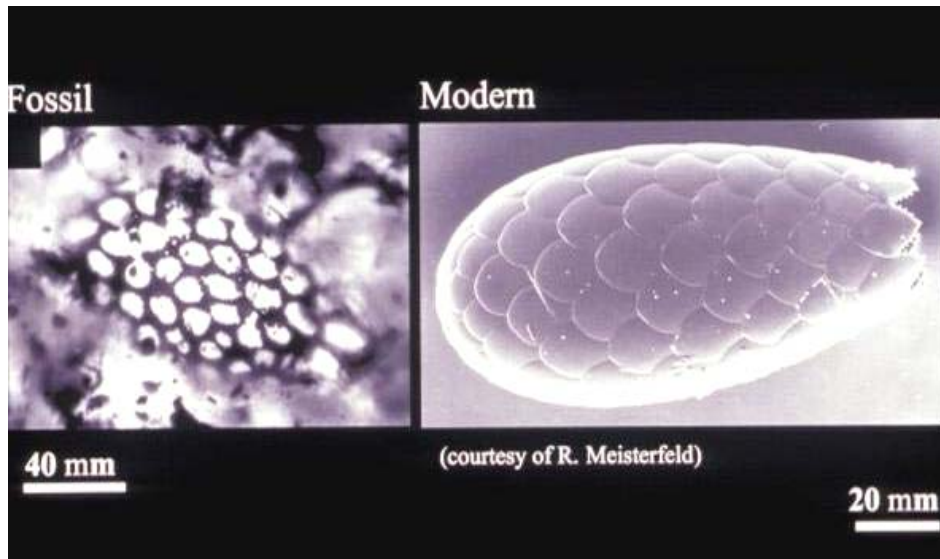
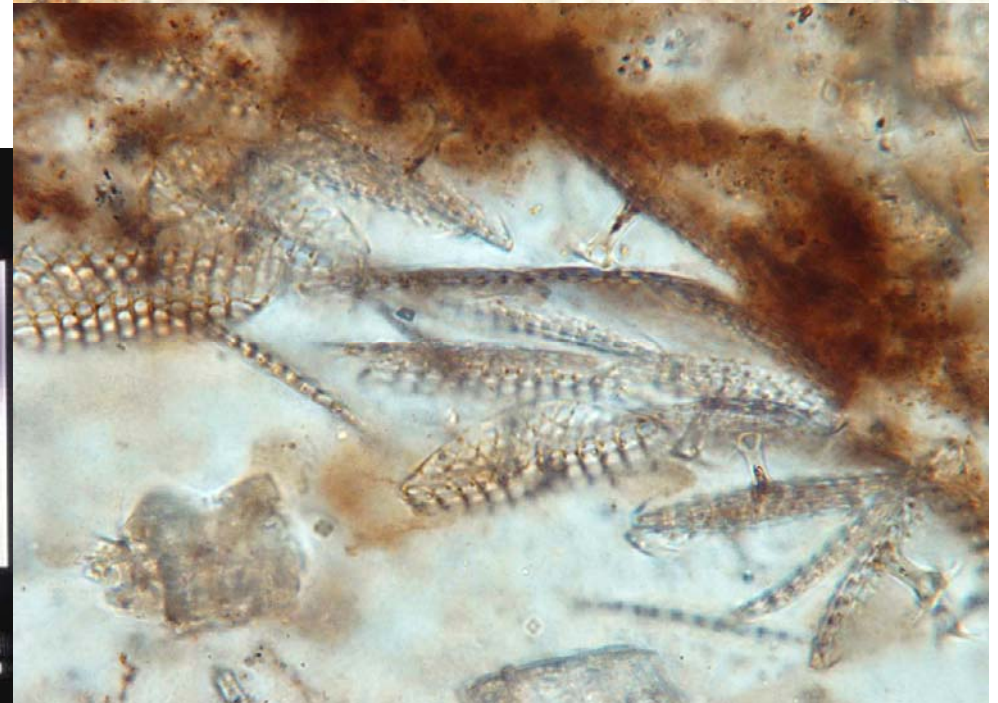
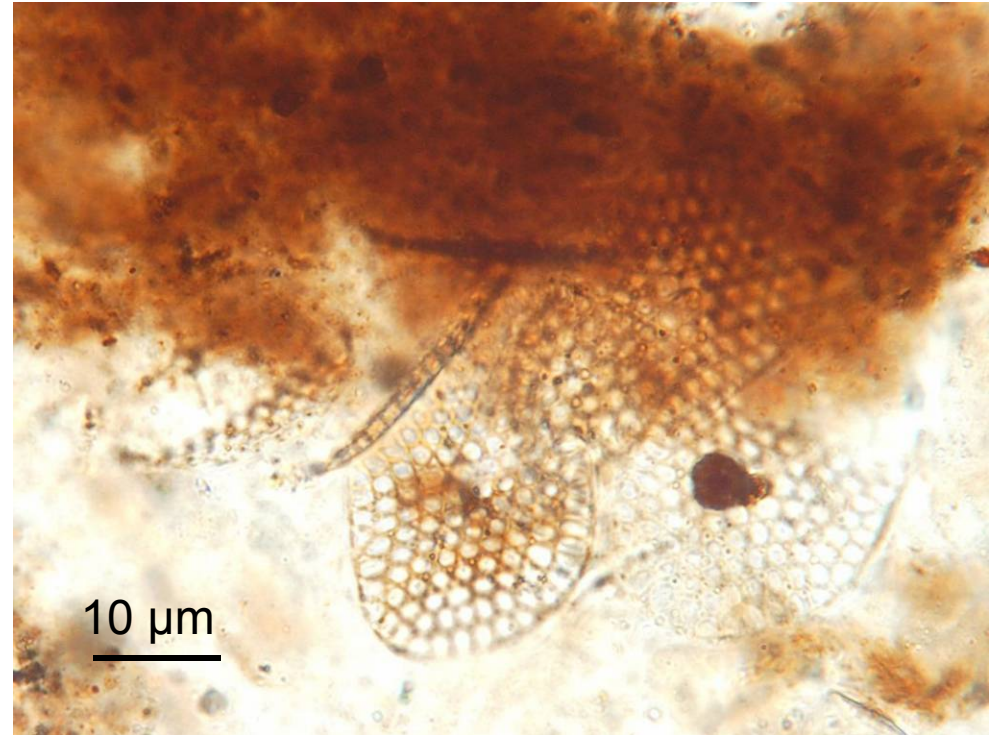
Phylogeny source: Fehling et al., 2007

- Ca Carbonate
- Ca-Phosphate
- Silica

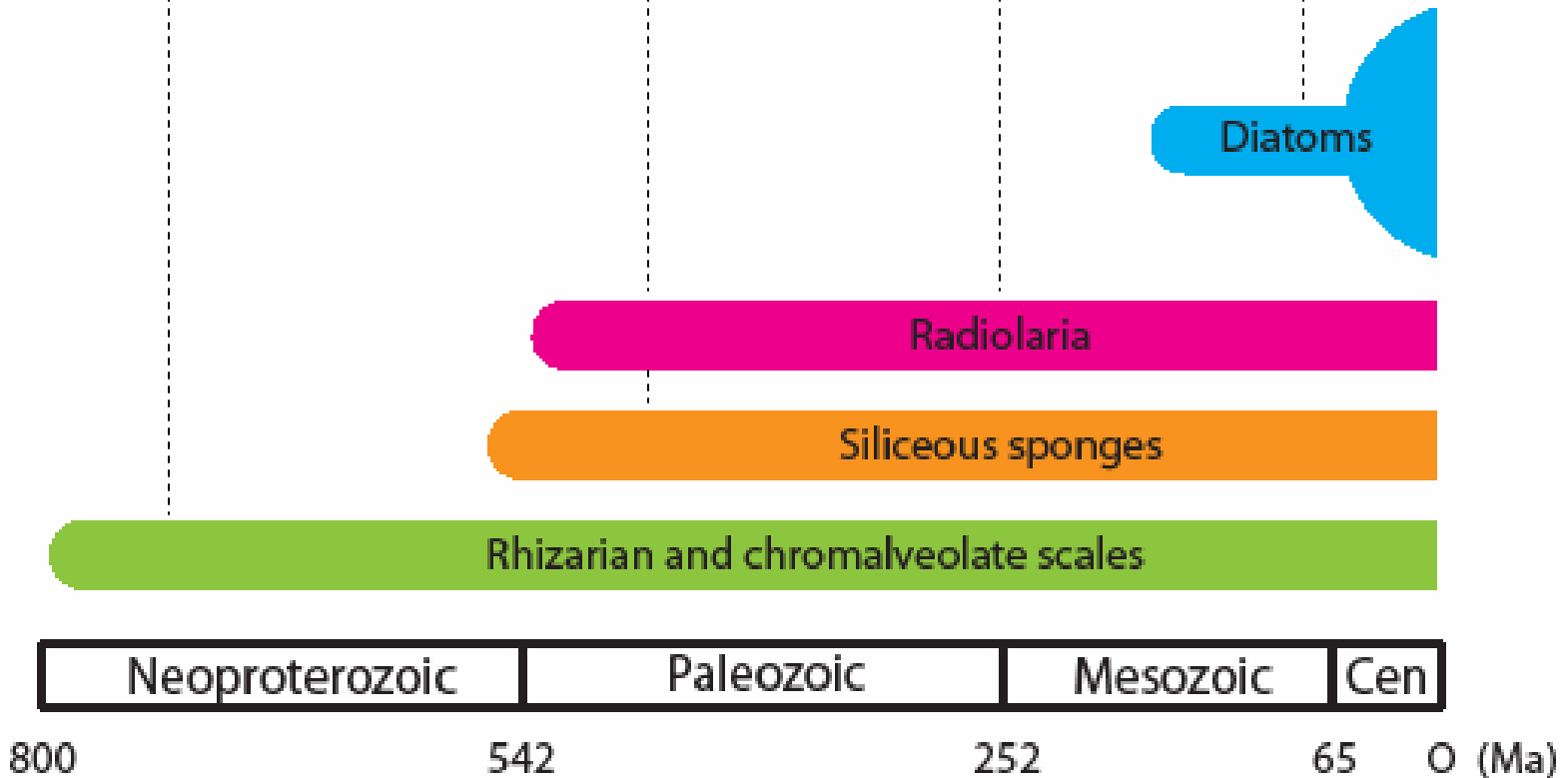
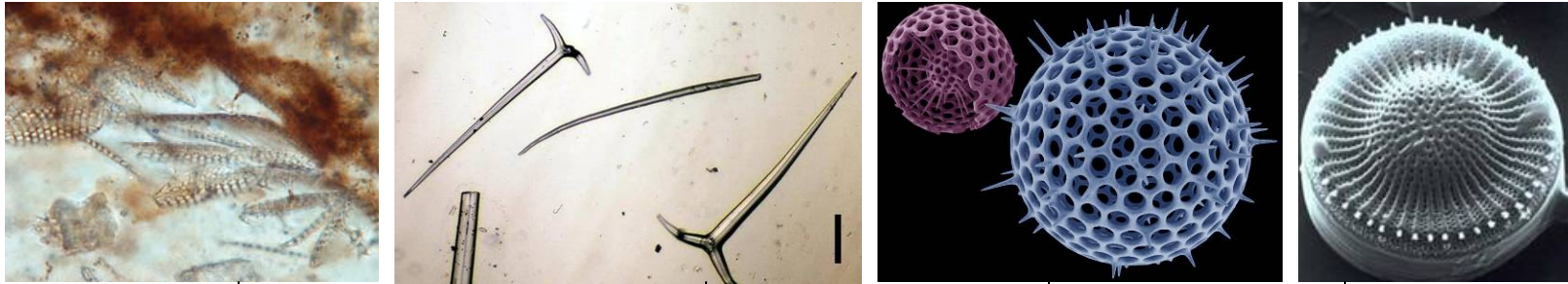


Earliest evidence for eukaryotic biomineralization

- Basal chromalveolate (?) scales in 800-750 Ma chert
- 750 Ma rhizarian test and modern euglyphids, with silica scales

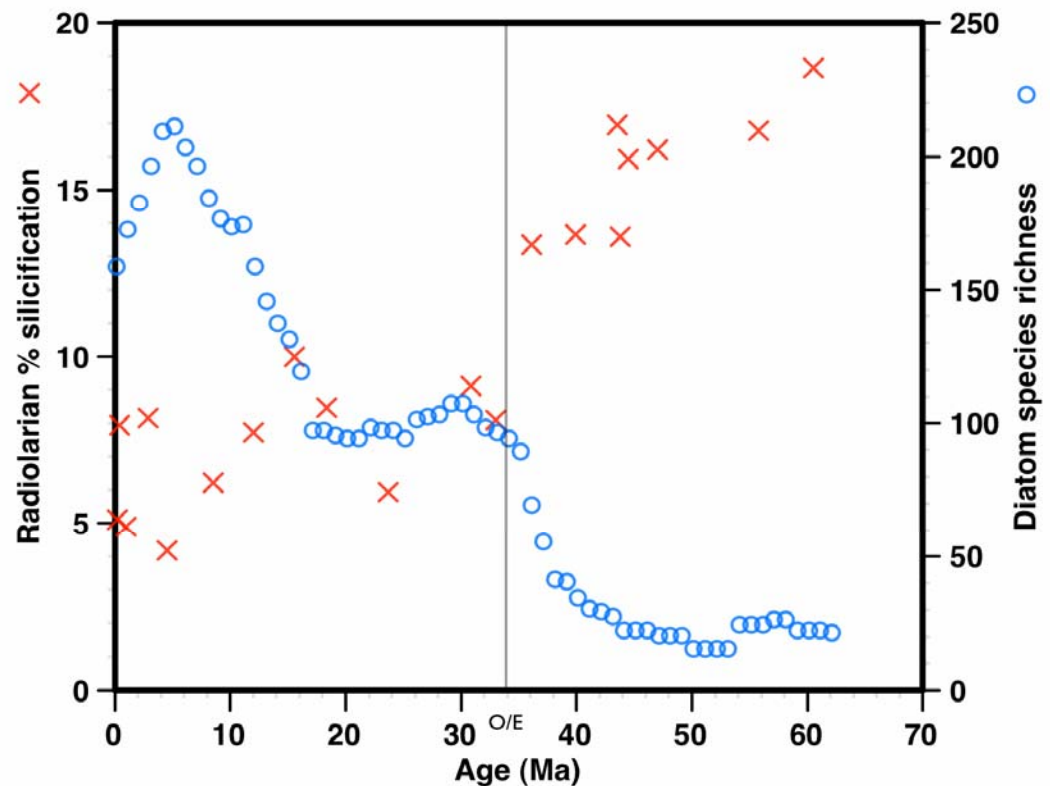


Geologic History of SiO₂ skeletons



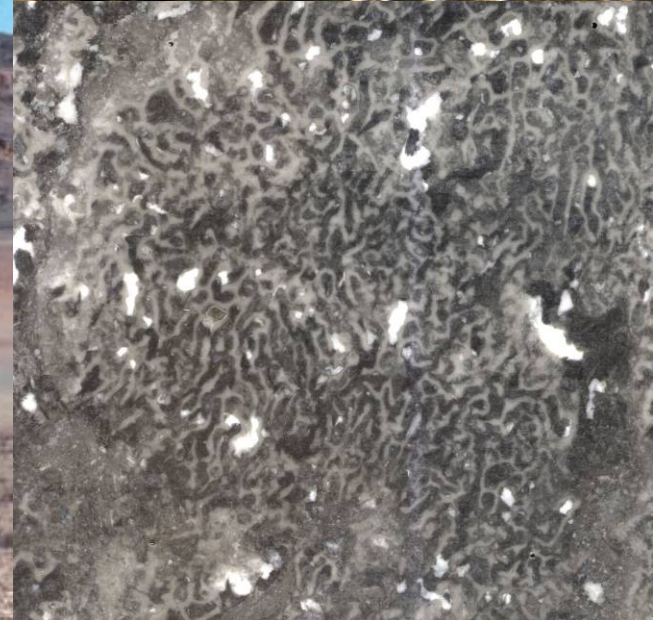
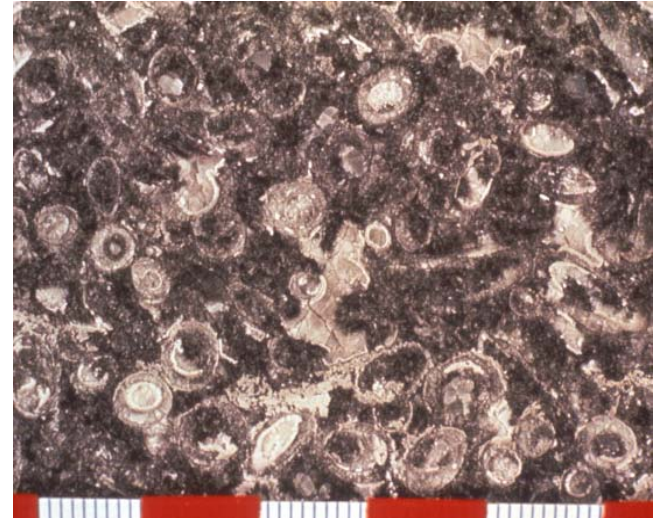
Responses to Diatom Radiation

- Radiolaria: decreasing silica use per test (Harper and Knoll, 1975; Kotrc, 2006)
- Sponges: Retreat to deeper waters spicule morphology (Maldonado et al., 1999)
- Diatoms: Decrease test size (Finkel et al., 2004)

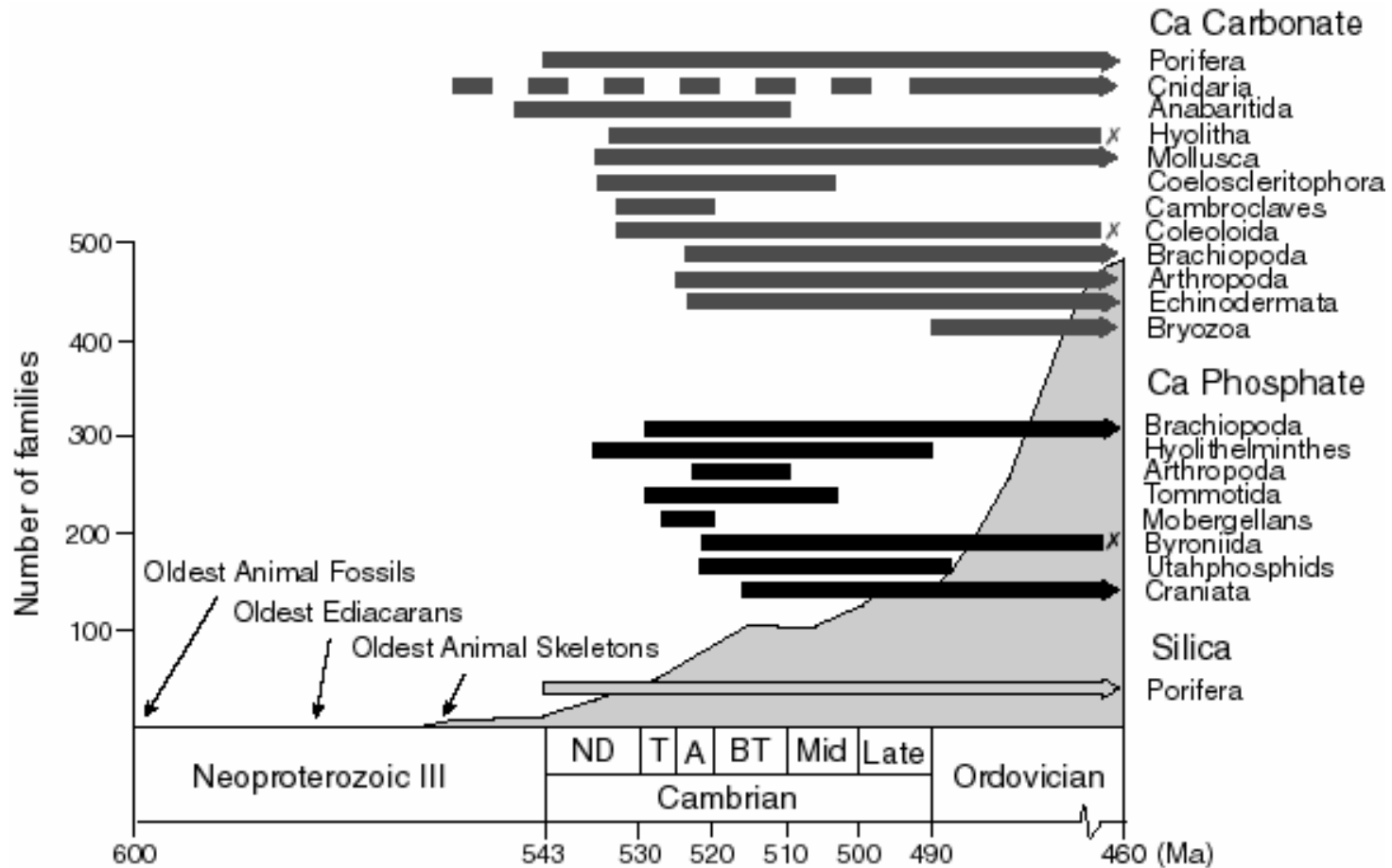


Kotrc, 2006

CaCO₃ biomineralization in reef-dwelling, sponge- to cnidarian-grade animals (< 549 Ma)



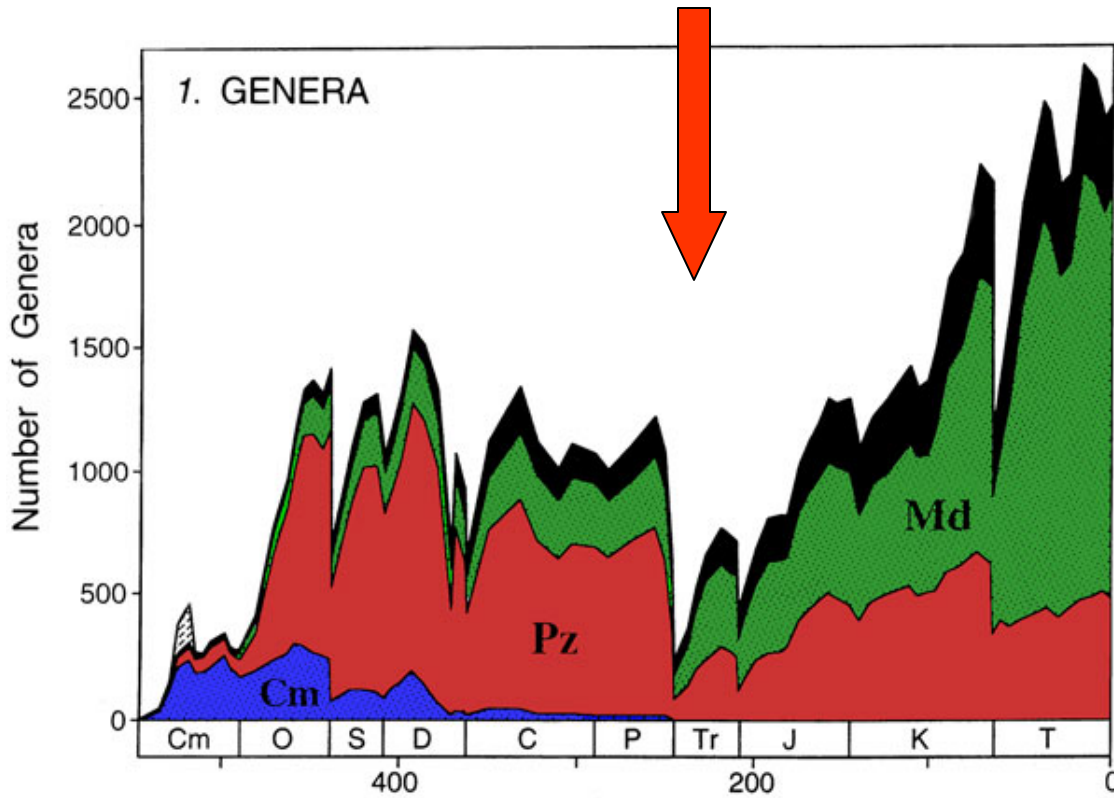
Summary of Cambrian Skeletal Evolution



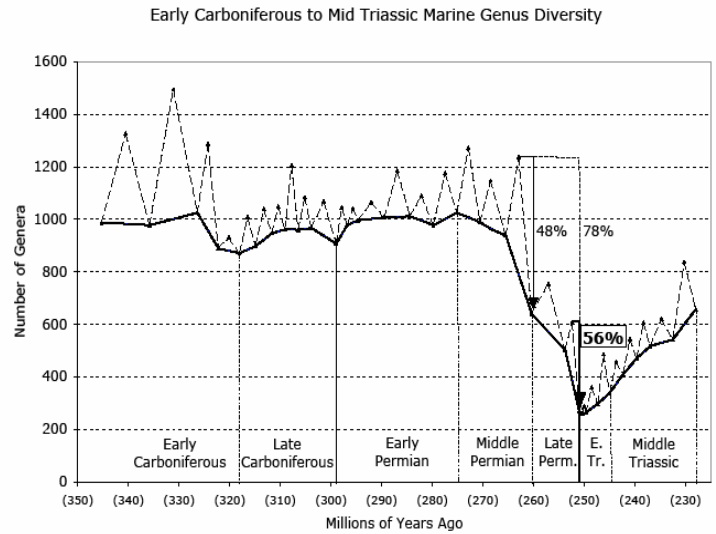
After Bengtson and Conway Morris, 1992)

Skeletons: dynamic diversity history

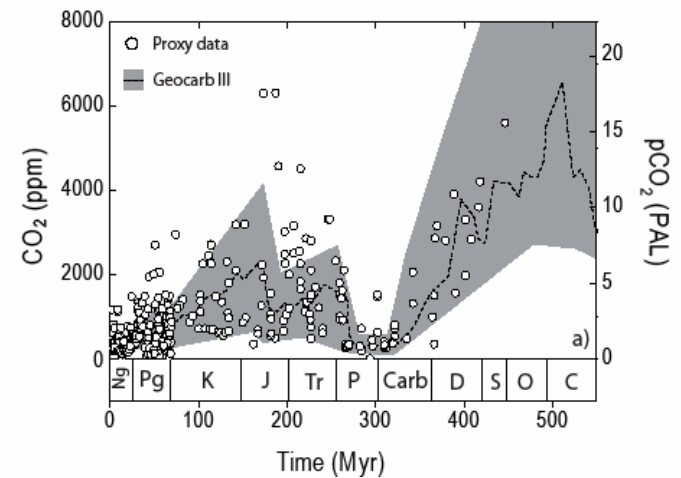
End-Permian mass extinction



<http://strata.ummp.lsa.umich.edu/jack/>



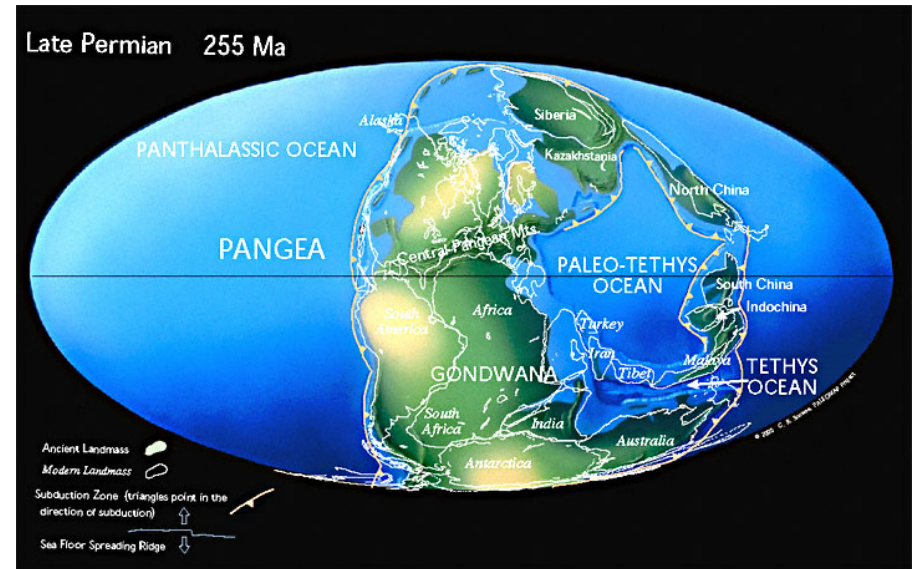
Knoll et al., EPSL 2007



Berner and Kothavala, 2001

End-Permian Mass Extinction

- Major flood basalts
 - Volume est. 10^6 km^3
 - CO_2 emission 10^{17-19} mol
 - ($10^{1-3} \times$ Late Permian atm)
- Enhanced by carbonates coal (thermogenic methane release)
- Widespread dysoxia in Late Permian Panthallasic ocean



Proposed Killers:

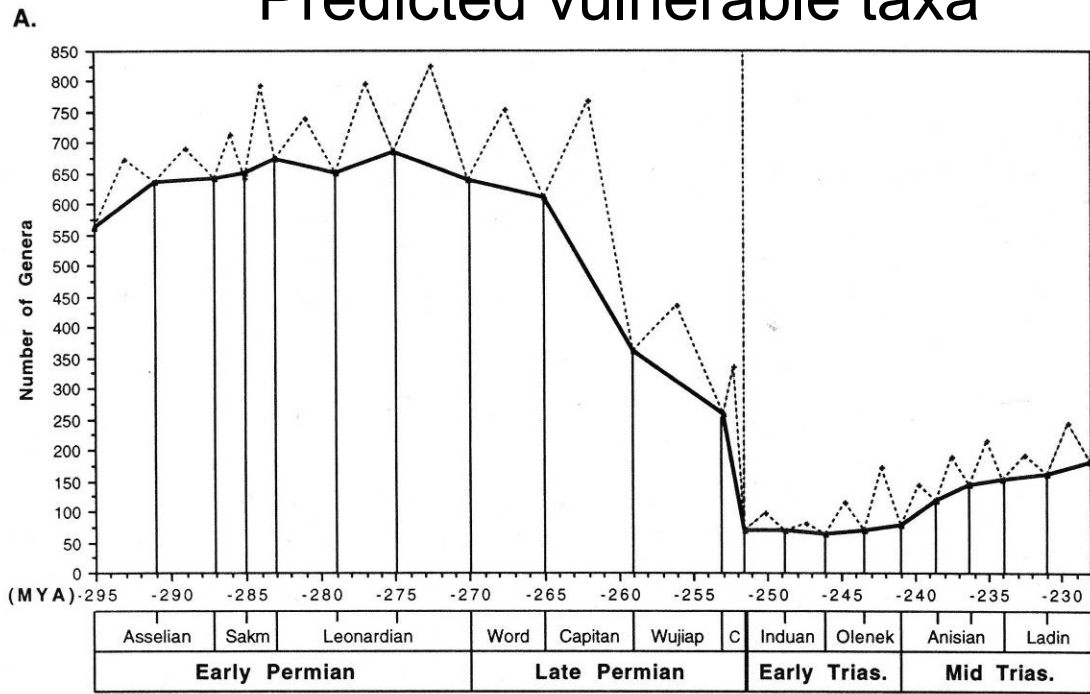
Carbon dioxide: ocean acidification, hypercapnia, global warming

Temperature: global warming (CH_4 and CO_2) -- physiology x geography

Oxygen: expansion of anoxia (asphyxiation, and more CO_2)

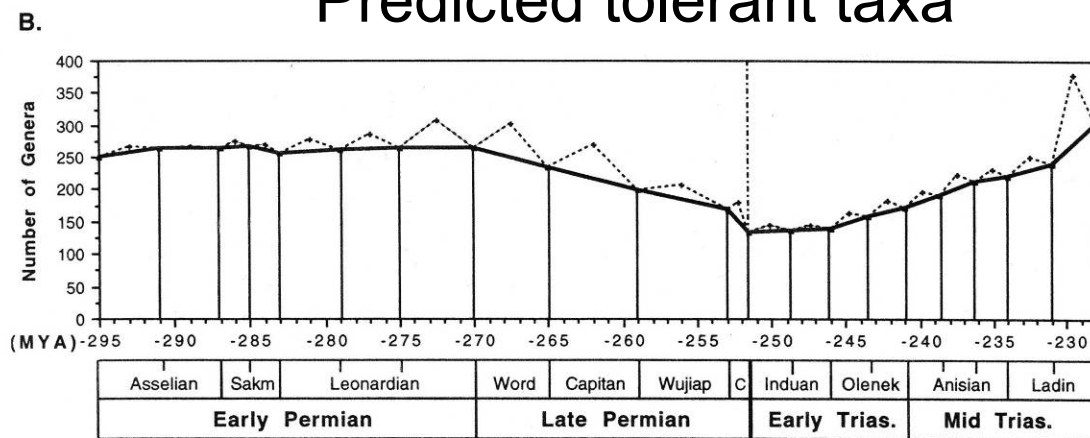
H_2S : sulfide toxicity

Predicted vulnerable taxa



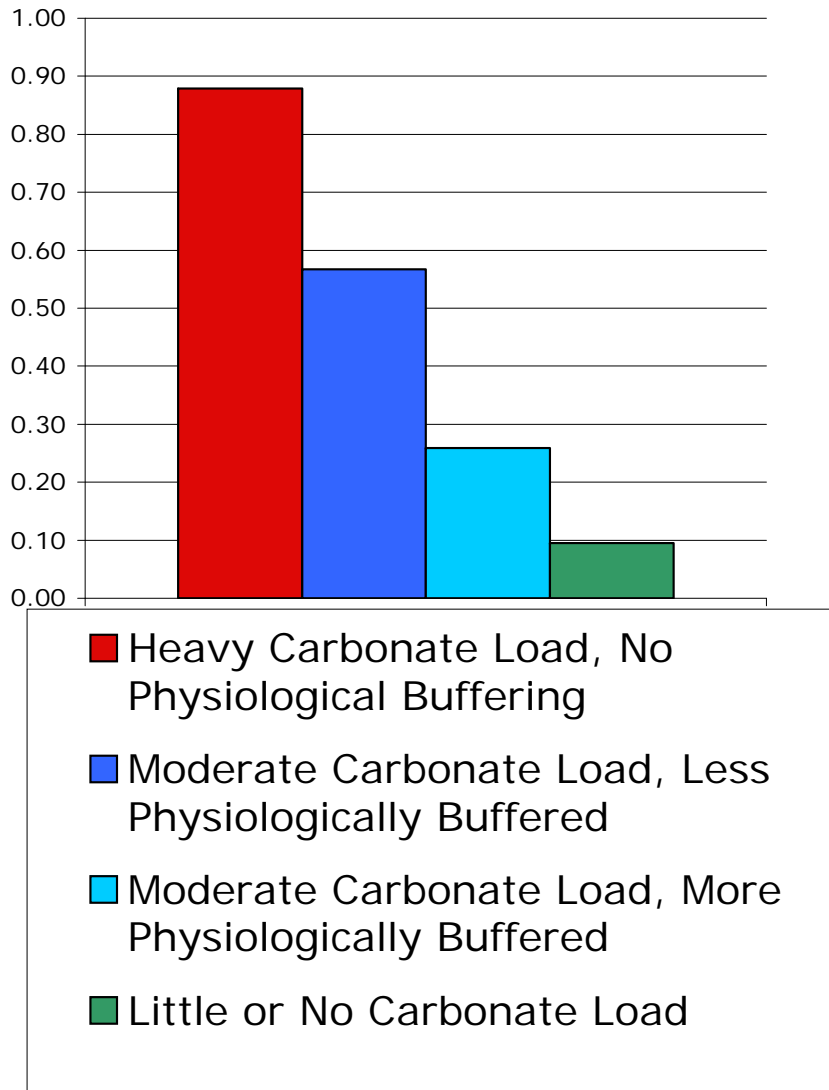
Selectivity
with respect
to CO₂

Predicted tolerant taxa



Knoll et al, 1996

End-Permian selectivity: Skeletal Physiology



Knoll et al, 2007, EPSL

■ Corals; calcareous sponges, bryozoa and brachiopods; stalked echinoderms

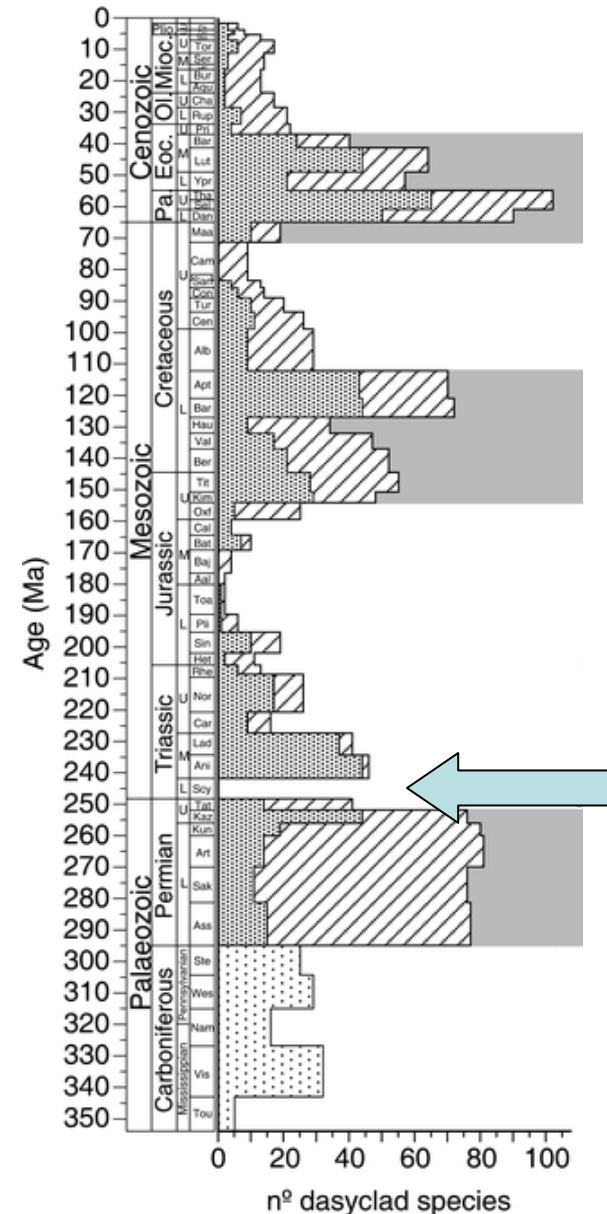
■ Epifaunal sedentary bivalves and snails, ammonoid cephalopods, ostracods, echinoid echinoderms

■ Infaunal burrowing bivalves, nautiloid cephalopods, malacostracan arthropods

■ Vertebrates (including conodonts), silica sponges; ctenostomate bryozoans, holothurians

More skeleton selectivity

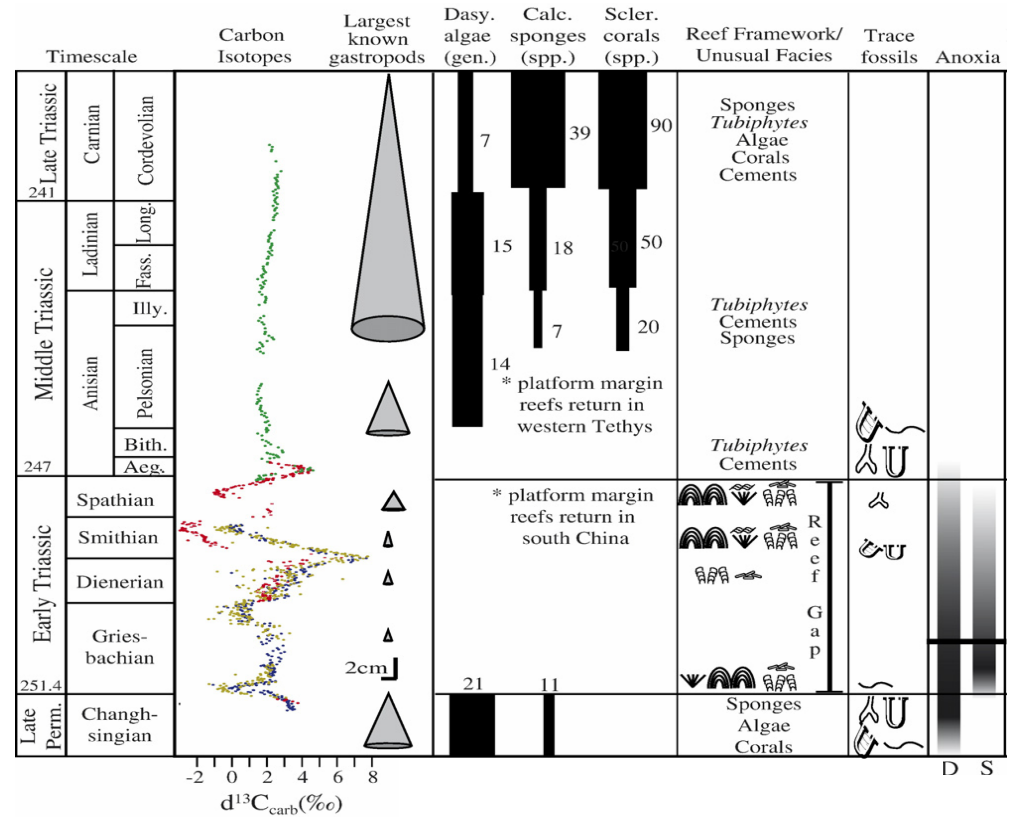
- Paleozoic corals disappear, but sea anemones persist (give rise to scleractinian corals)
- Skeletonized green algae disappear (Fig), but multiple unskeletonized sister groups persist
- Calcified red algae disappear, but multiple uncalcified lines persist
- Calcified foraminiferans lose most diversity; agglutinated forams lose little diversity



Aguirre and Riding (2005)

Problem: Recovery only in Mid- Triassic

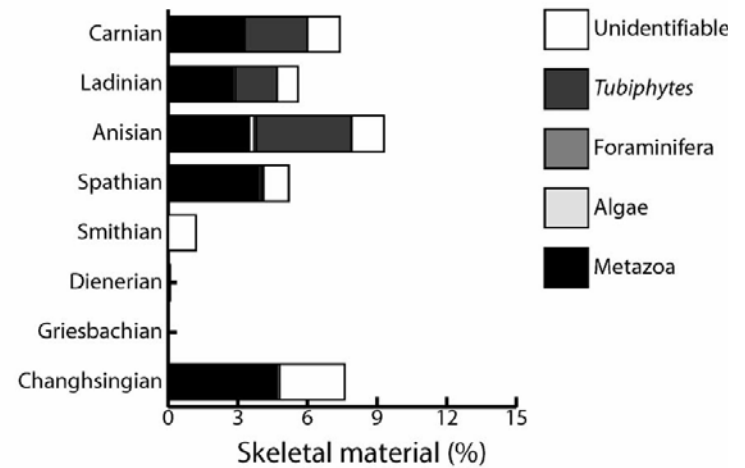
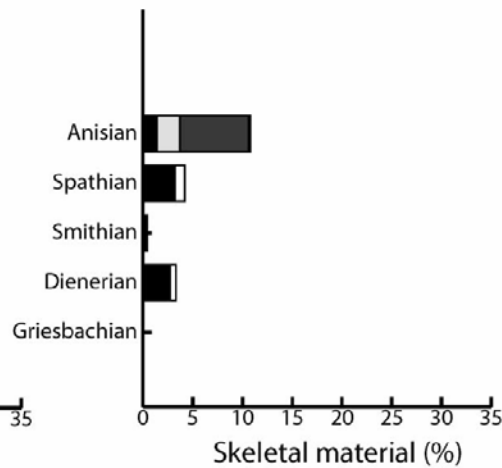
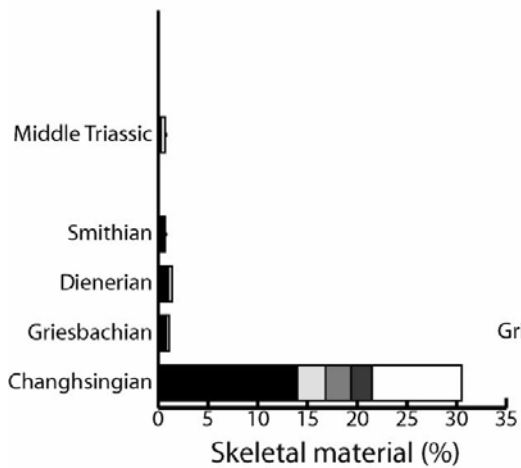
Knoll et al., 2007 (right)
Payne et al., 2006 (below)



Platform interior

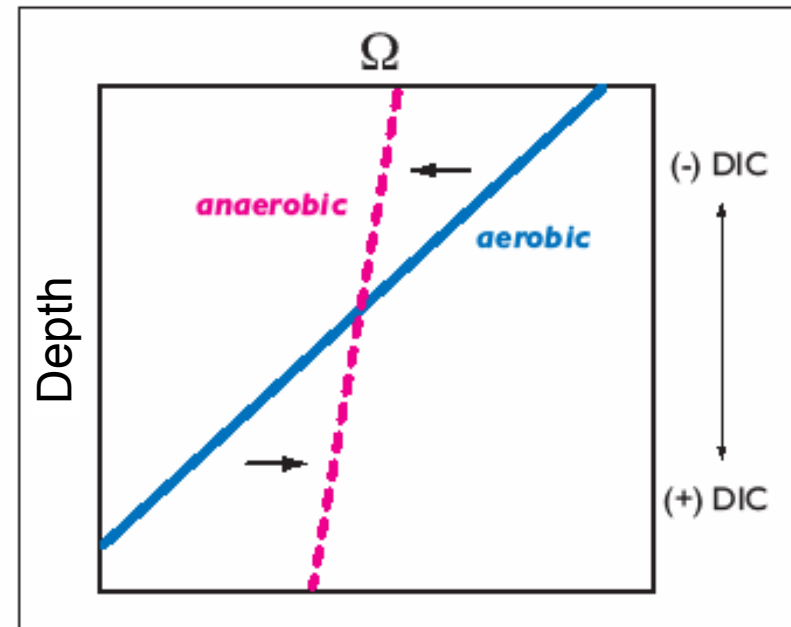
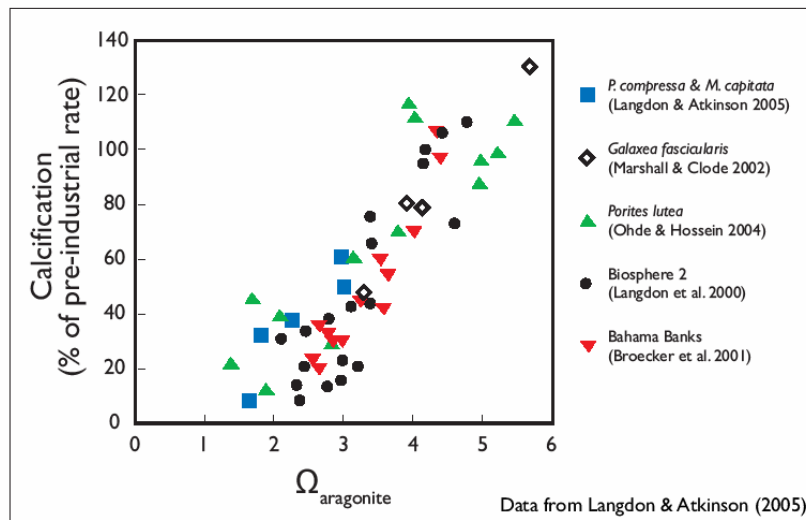
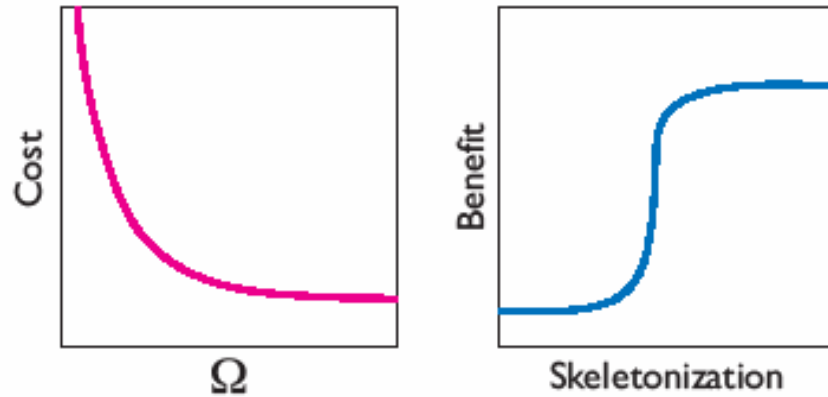
Platform margin

Basin margin



Redox influence on surface ocean Ω

(Higgins, Fischer and Schrag)



Conclusions

- Key events in the history of marine life reflect the changing costs and benefits of skeletal biomineralization.
- Evolutionary trajectories of silica precipitating organisms reflect evolution of new participants in silica cycle
- Evolutionary trajectories of calcifying organisms more likely to reflect physical history of oceans, including redox depth gradient
- The way forward is a merger of once distinct research programs:
 - **Paleontology**: identify patterns of skeletal evolution
 - **Geochemistry**: Identify patterns of ocean evolution
 - **Physiology**: Conceptual and experimental bridge between paleobiology and geochemistry
- Lessons for the present/future?
 - Calibration points; the present is rare
 - Timescale of adaptation; patterns of vulnerability
 - A sense of finality, based on recovery times in geological history