Update on Permian-Triassic Extinction Landscape

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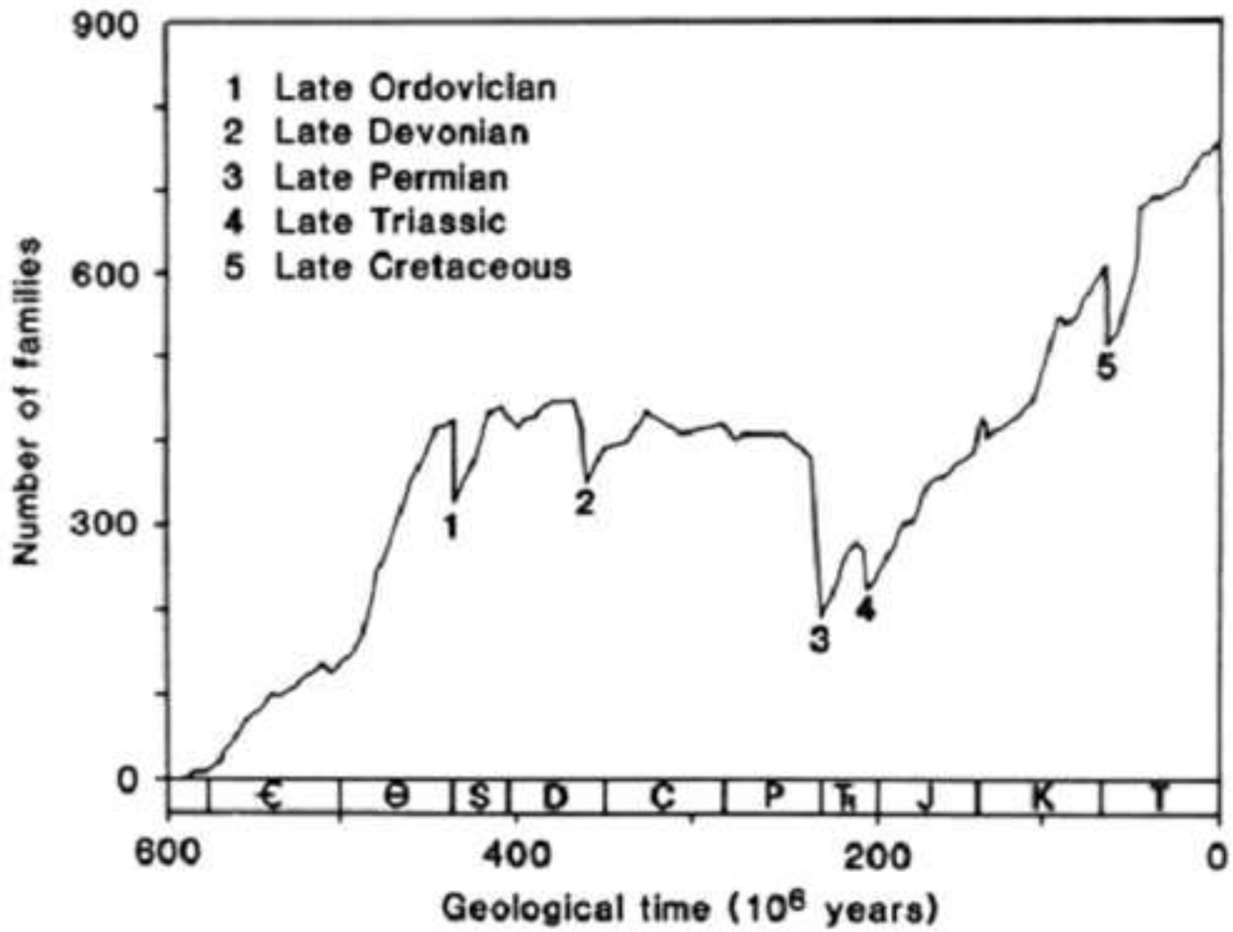
Permian-Triassic Mass Extinction

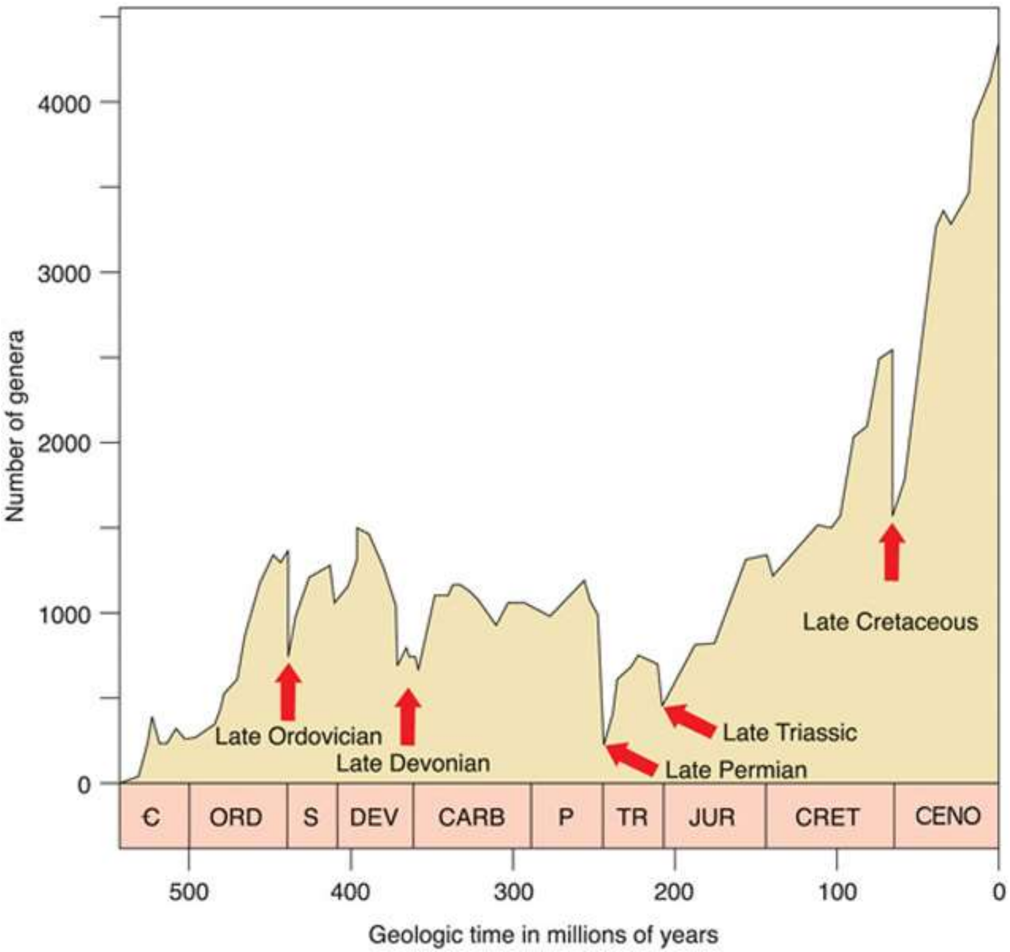
- A profoundly important event in the history of Earth and the Solar System.
- Latest estimates indicate that ~81% of marine species became extinct (Stanley, 2016).
- Modern consensus is that it was due to Earth-bound processes.
- A vast interdisciplinary Geobiological puzzle that is only beginning to be solved.

Biodiversity and Phanerozoic Mass Extinctions



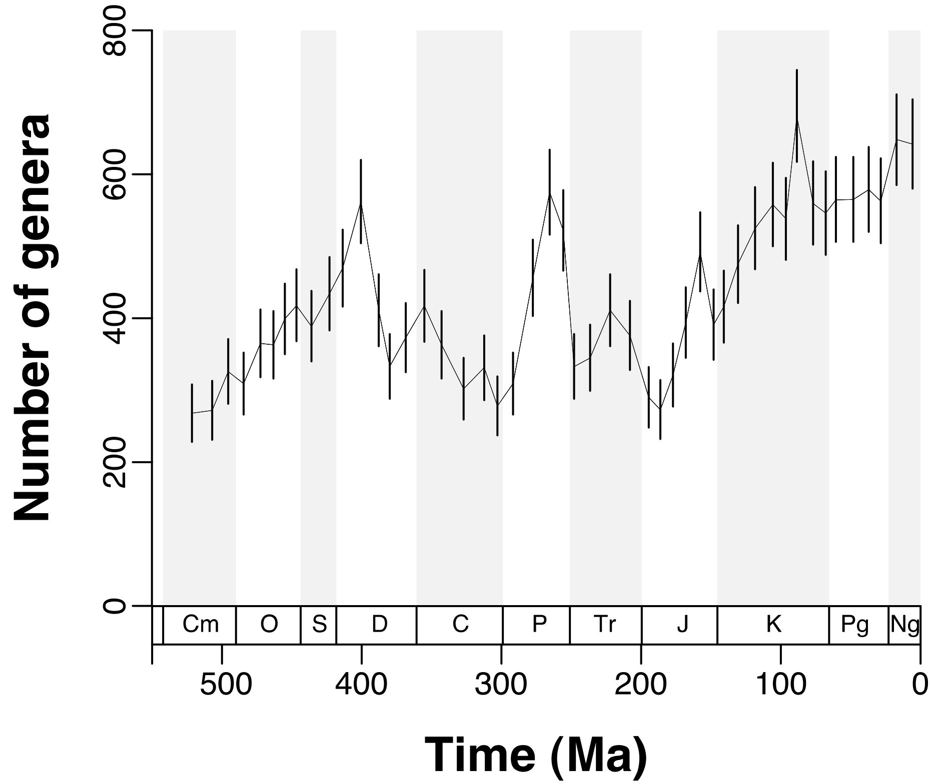
From Raup and Sepkoski (1982)

Biodiversity and Phanerozoic Mass Extinctions



Modified from Sepkoski (1994)

Biodiversity and Phanerozoic Mass Extinctions



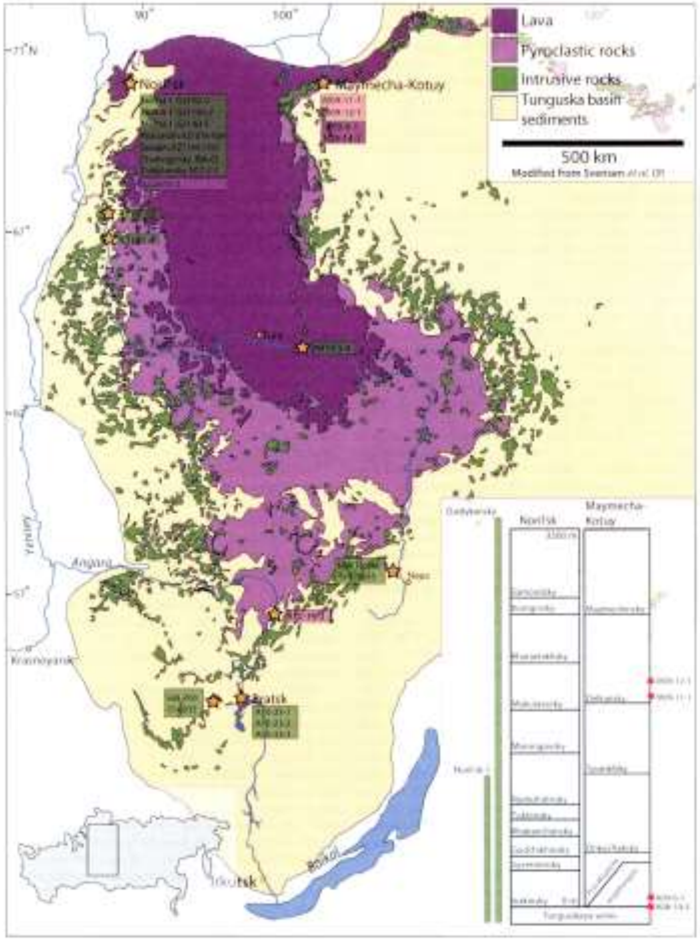
From Alroy et al. (2008)

Selectivity of the End-Permian Mass Extinction

- "Sea urchins nearly became as extinct as their Paleozoic cousins, the blastoids. But two species, *Miocidaris* and a close relative, survived the trials of the Permo-Triassic boundary. From these two pioneering species came the incredible diversity of all modern sea urchins. Why did they survive, and how did they come to be such vital players in modern oceans?"
- Erwin (2006)

Photograph by Paul Nicklen National Geographic

Siberian Traps and End-Permian Mass Extinction

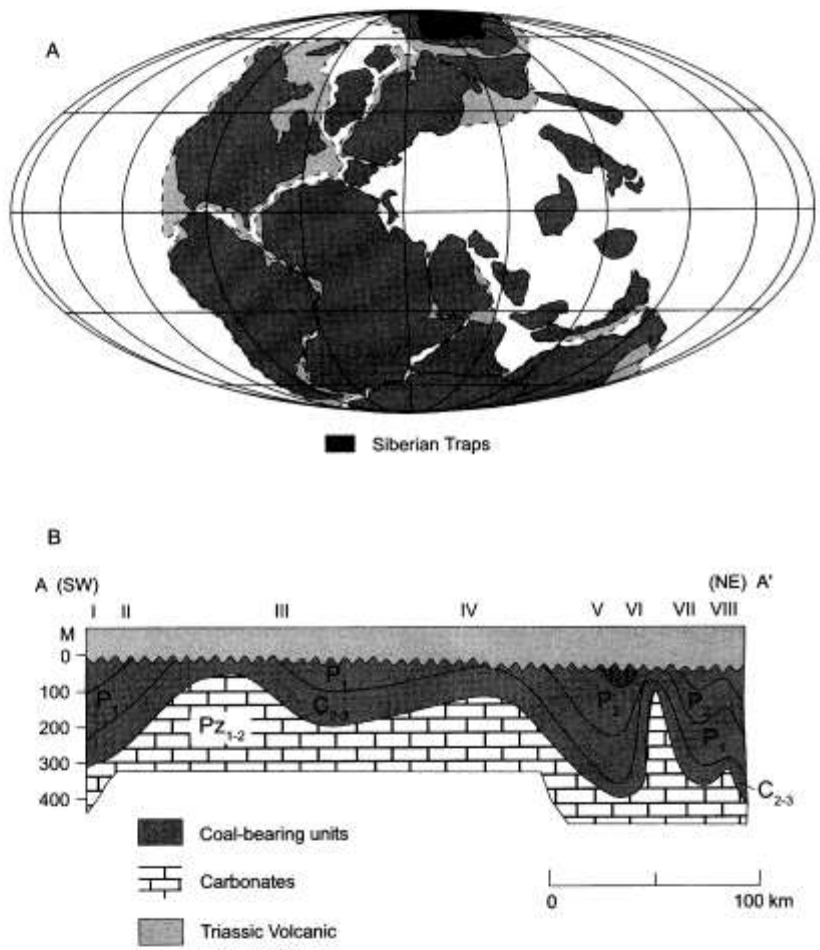


From Burgess and Bowring (2015)

Siberian Traps and End-Permian Mass Extinction

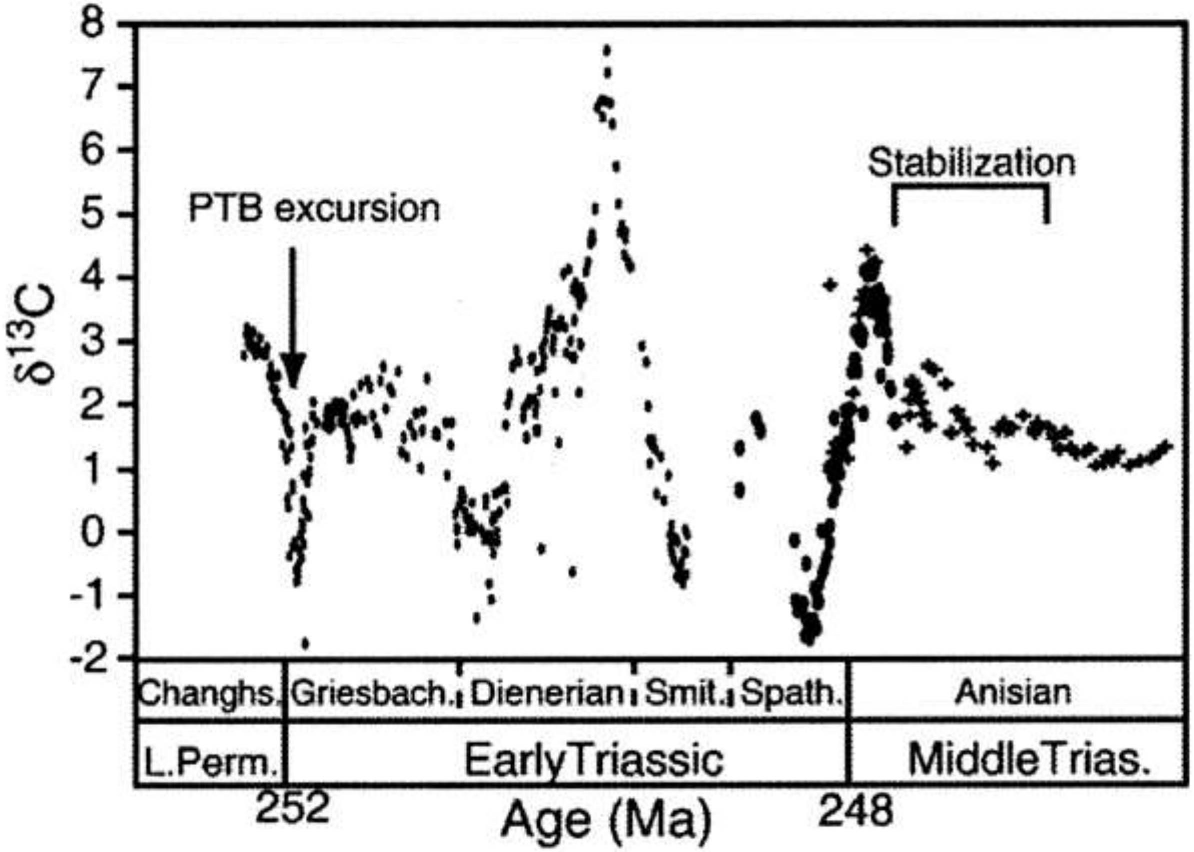
From: media.photobucket.com

Siberian Traps and Coal



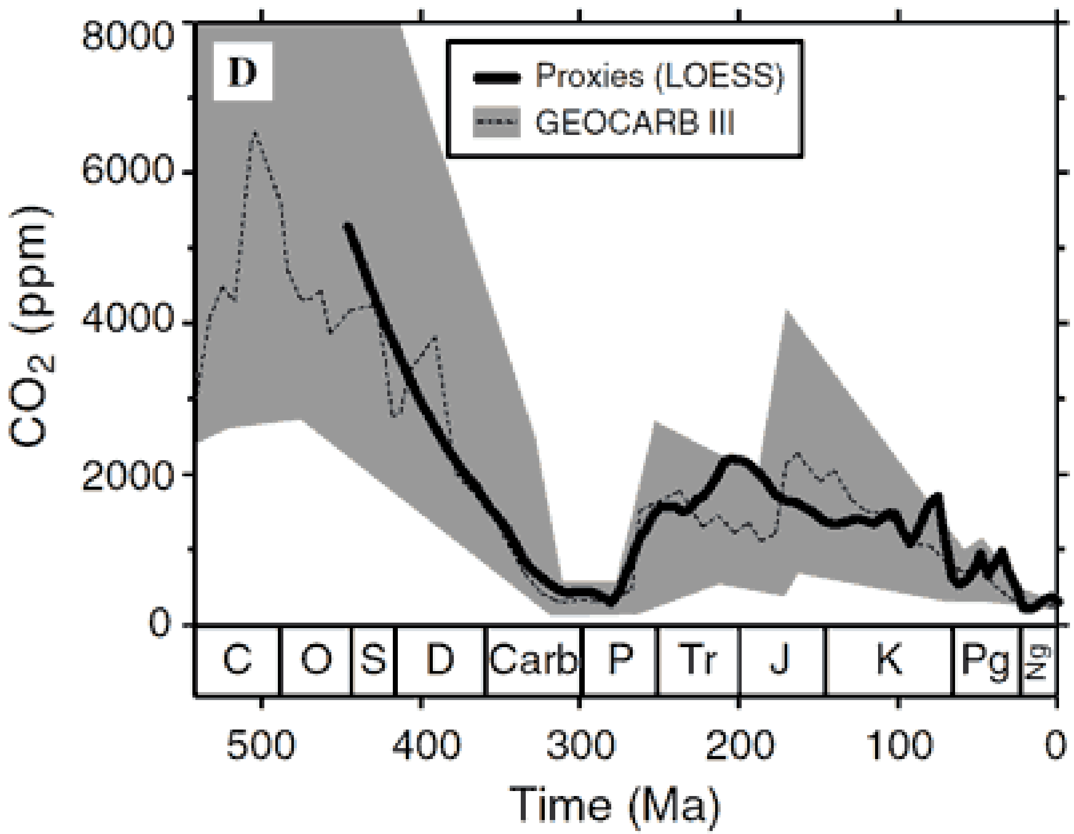
From Erwin (2006)

Carbon Isotope Record and Siberian Trap Volcanism



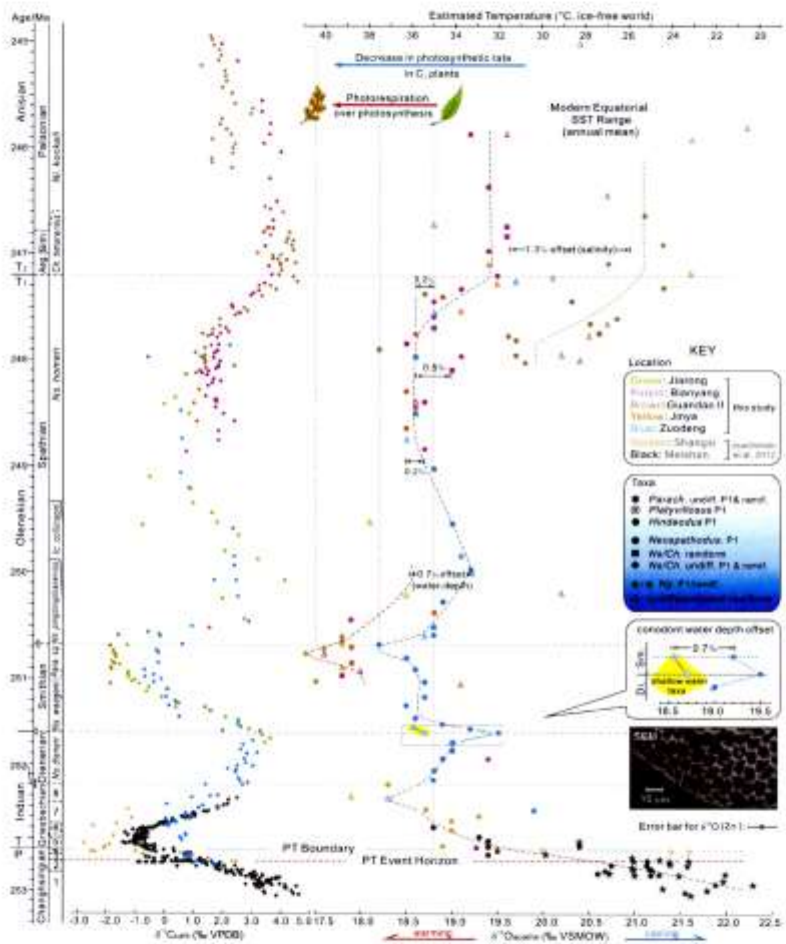
From Payne and Kump (2007)

Phanerozoic CO_2 Trends



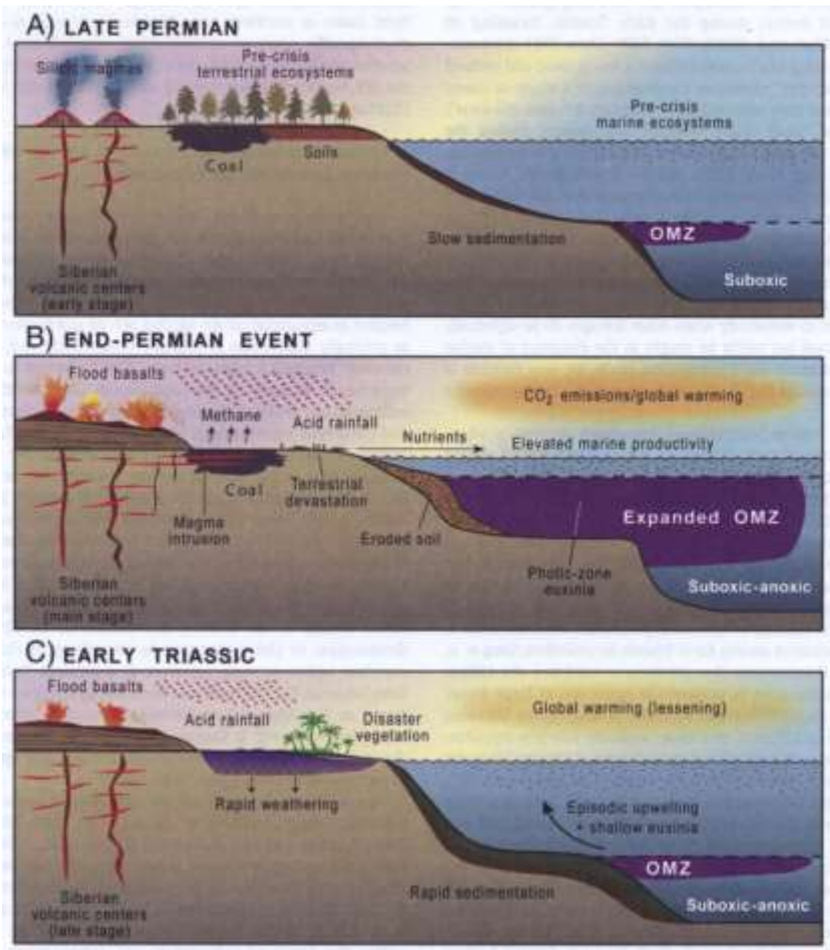
From Royer (2006)

Temperature



From Sun et al. (2012)

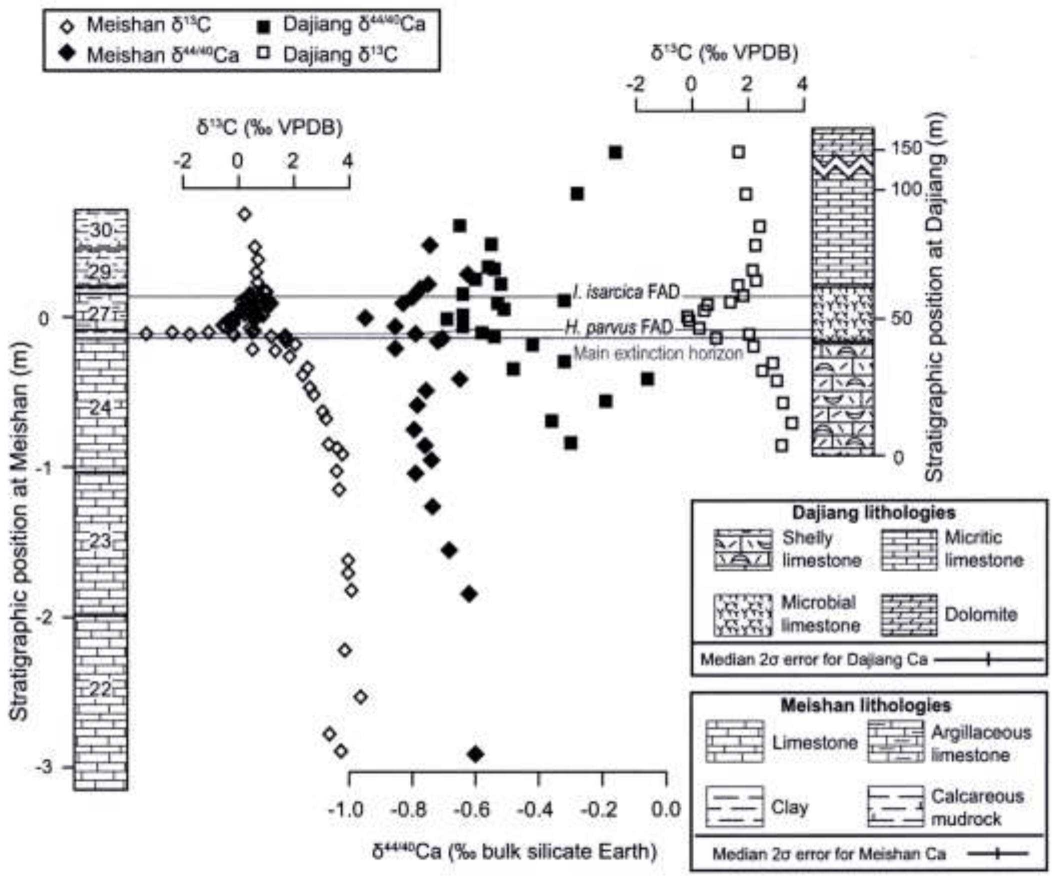
Ocean Anoxia and Euxinia



From Algeo et al. (2011)

From Ward (2006)

Ocean Acidification

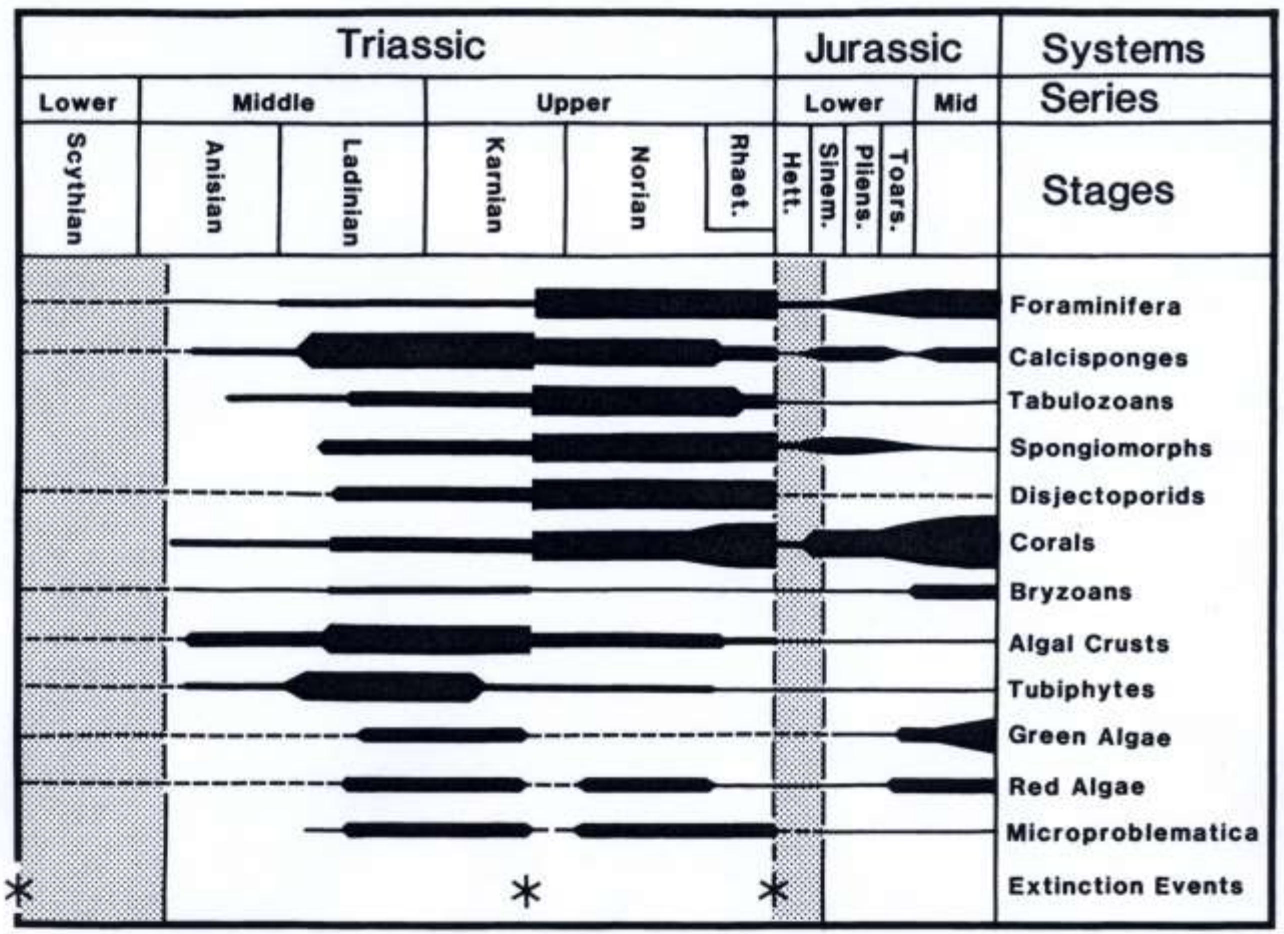


From Hinojosa et al. (2012)

Metazoan Reefs

- Represent large-scale ecosystem engineering in many nearshore marine carbonate environments.
- Mediate physical, chemical and biological oceanographic processes.
- Contain much of the biodiversity of modern oceans.

Reef Systems

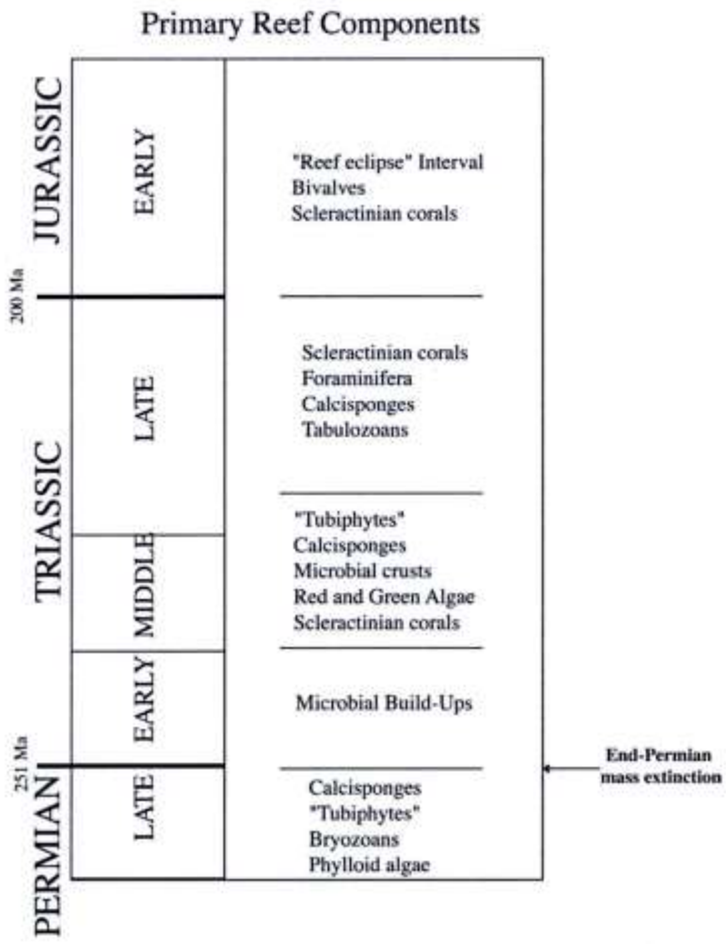


From Stanley (1988)

Early Triassic Microbialites

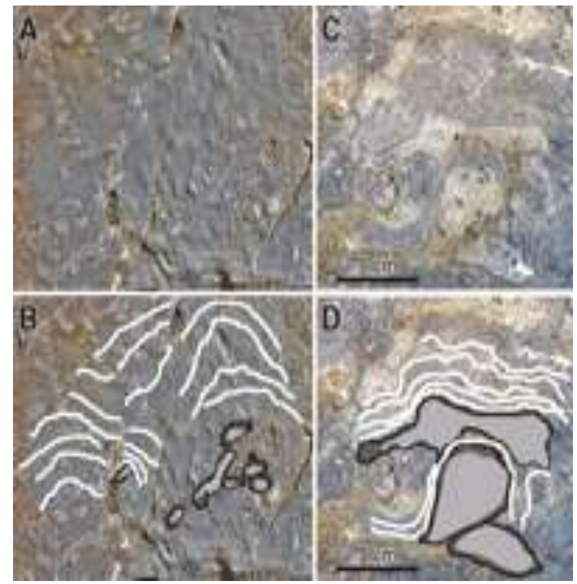
Courtesy of S. Pruss

Reef Systems



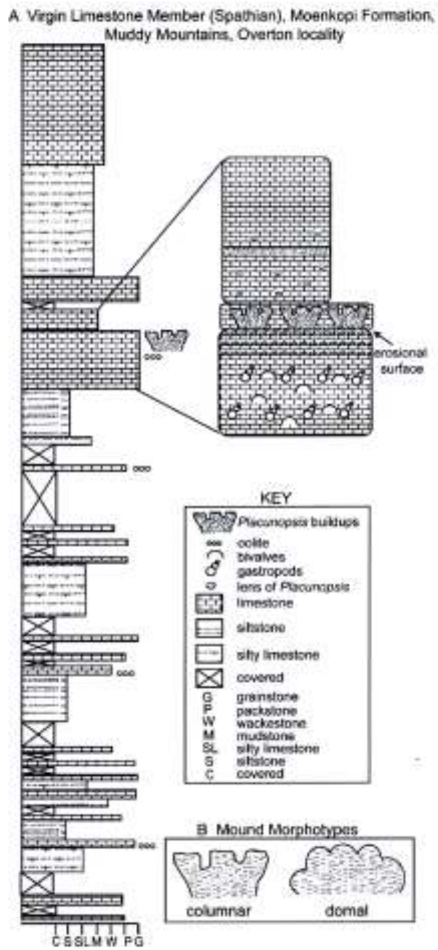
From Pruss and Bottjer (2005)

Microbial-Sponge Reefs

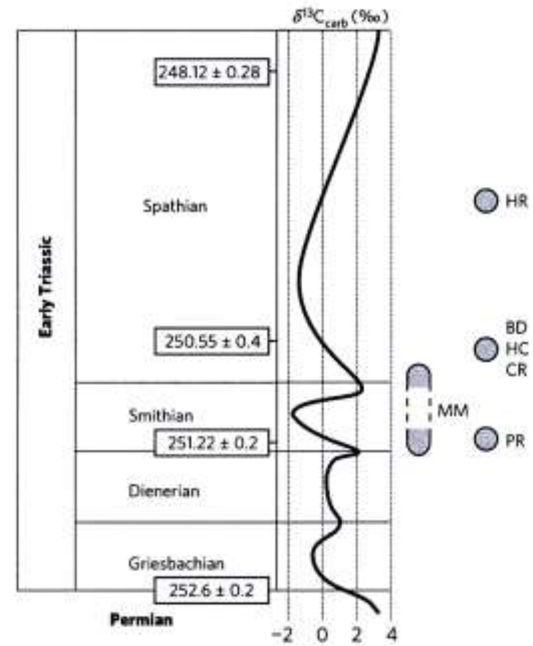


From Marenco et al. (2012)

From Reef Gap to Reef Eclipse



From Pruss et al. (2007)

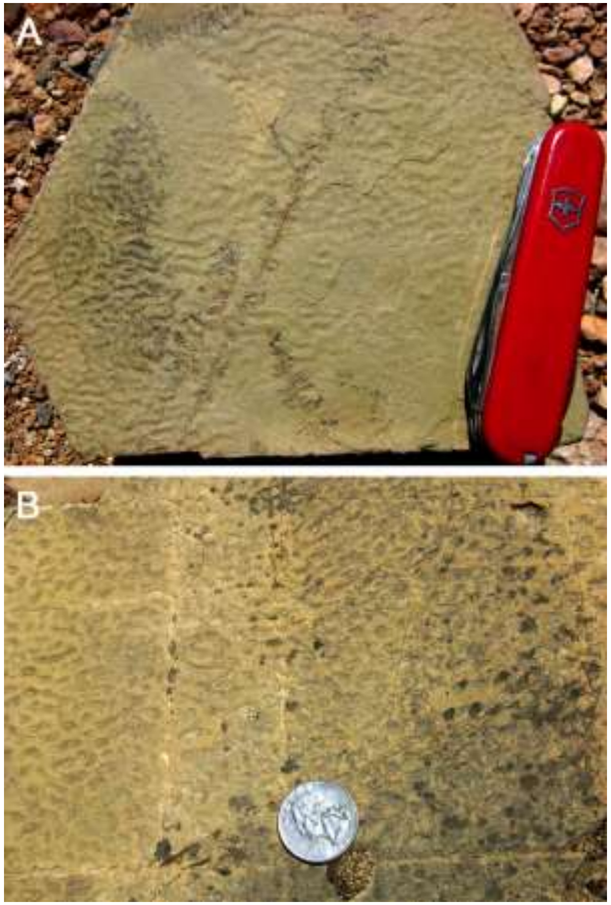


From Brayard et al. (2011)

Bioturbation

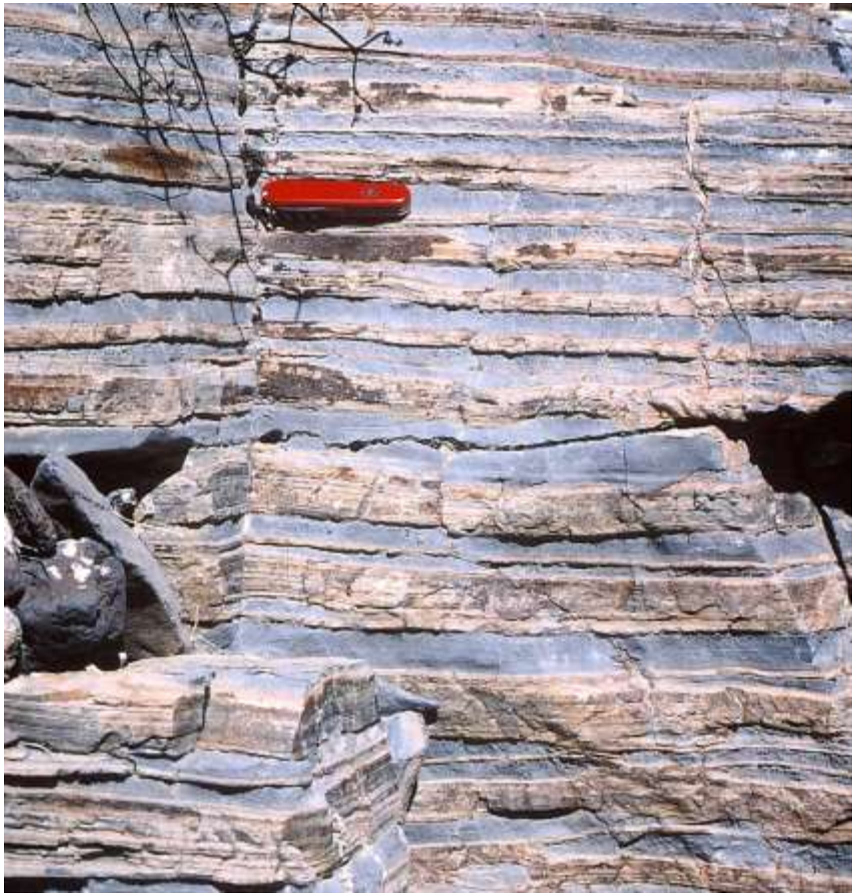
- Represents large-scale ecosystem engineering of level-bottom marine environments.
- Level of bioturbation affects stability of substrate.
- Amount and depth of bioturbation affects irrigation of the seafloor including oxygen level and biogeochemical cycles.
- Affects particle size of seafloor sediments.

Microbial Structures in Siliciclastic Environments



From Mata and Bottjer (2012)

Early Triassic Bioturbation



End-Permian Mass Extinction and Bioturbation

Permian

pre-extinction

- fully developed mixed layer
- complex tiering structures
- efficient geochemical cycling

Griesbachian-Smithian

(early) post-extinction

- depletion of the mixed layer
- firmground conditions at or close to the sediment-water interface
- reappearance of microbialites
- drop in sulfate concentration and increase in $\delta^{34}S$ of sulfate
- dominance of shallow-tier structures

Spathian

progressing recovery

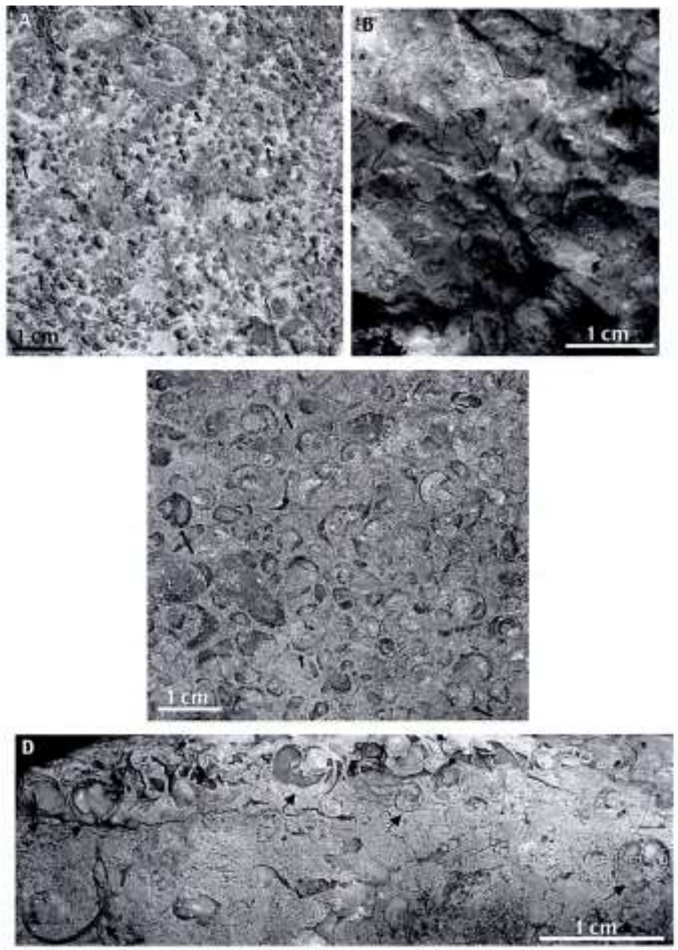
- re-establishment of the mixed layer
- re-establishment of the geochemical cycling
- re-establishment of complex tiering structures

From Hofmann et al. (2015)

Size Reduction

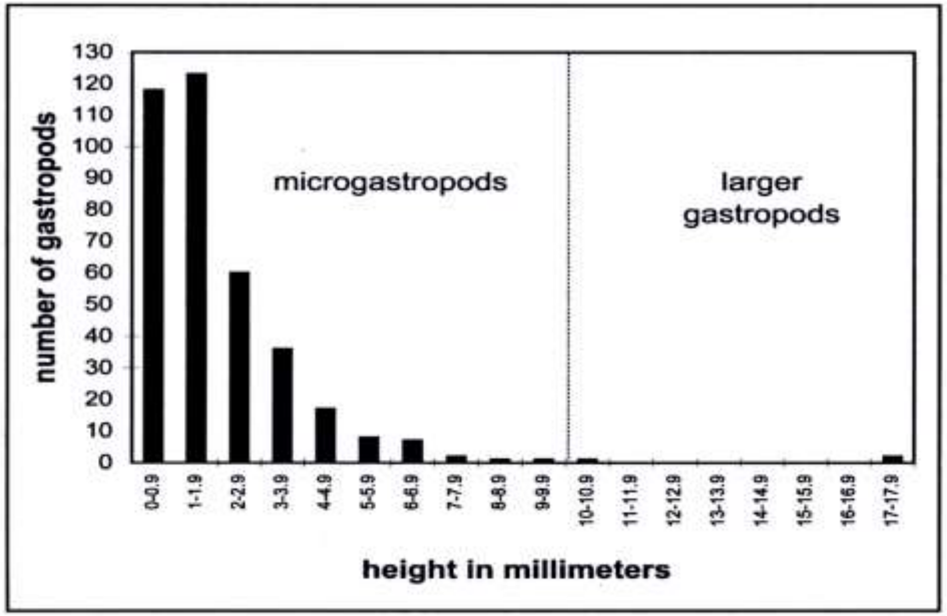
- Affects biomass and energy flow through communities.
- Alters ecosystem engineering by reducing size and products of engineering organisms.

Microgastropods



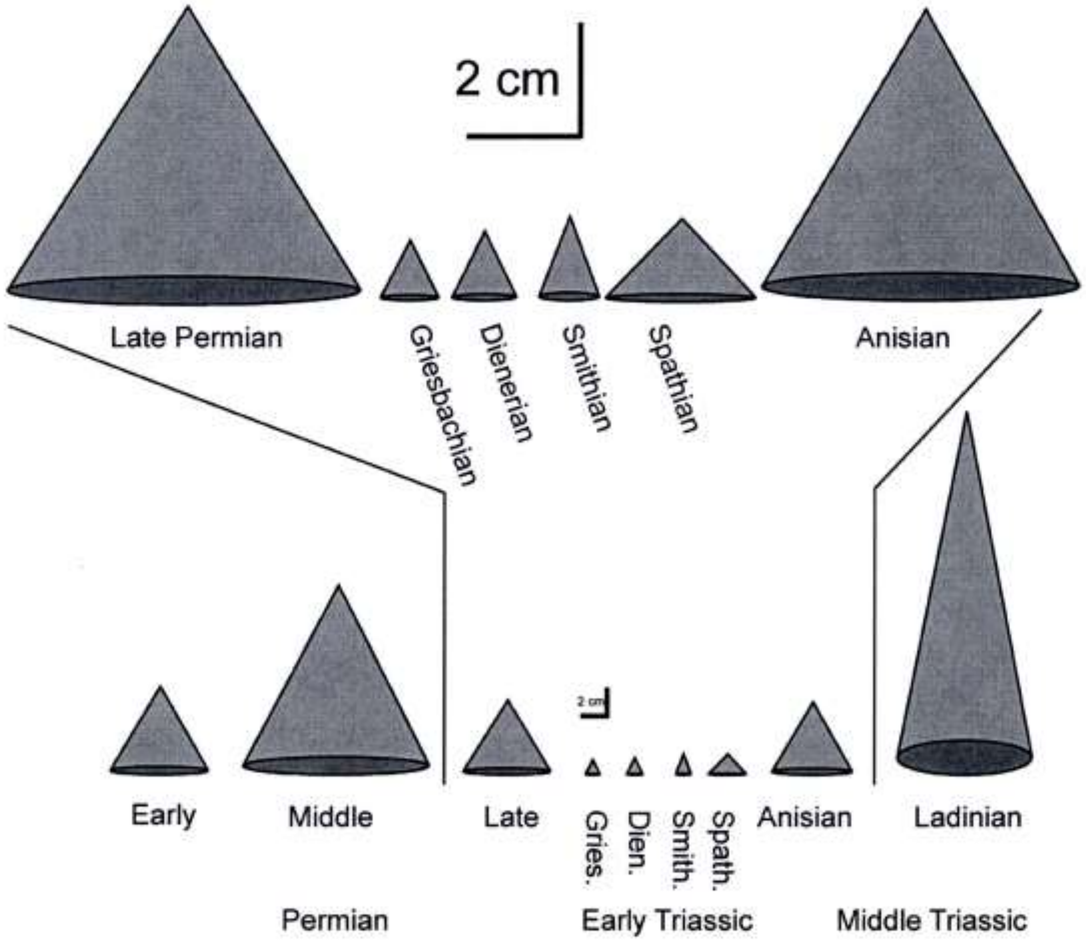
From Fraiser and Bottjer (2004)

Microgastropods



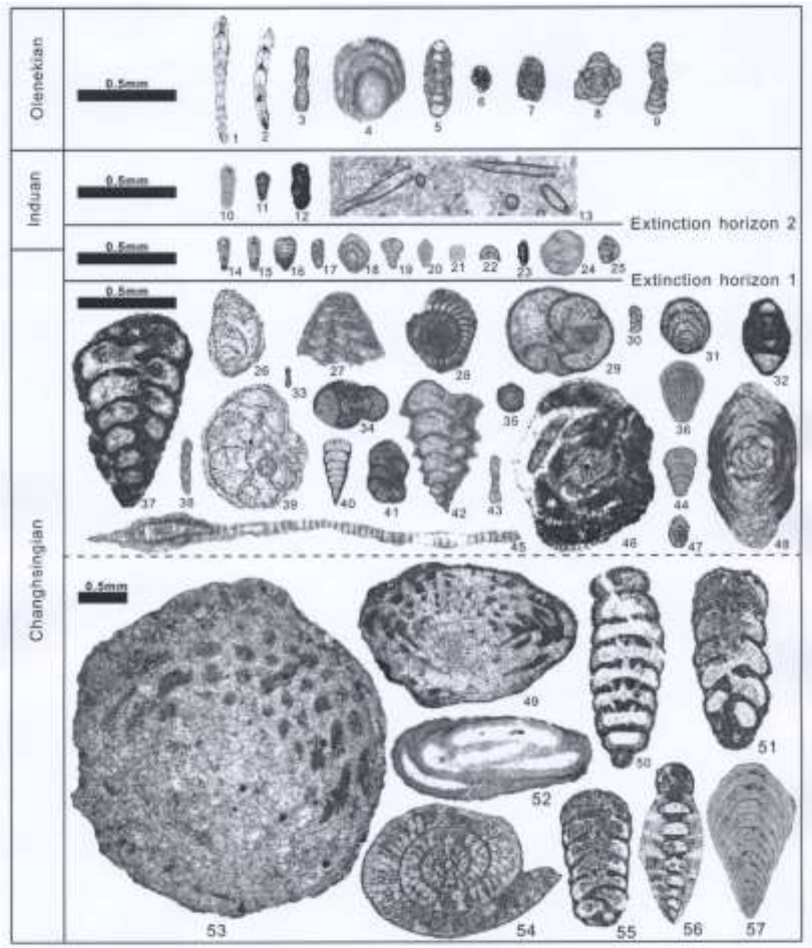
From Fraiser and Bottjer (2004)

Microgastropods



From Payne (2005)

Foraminifera

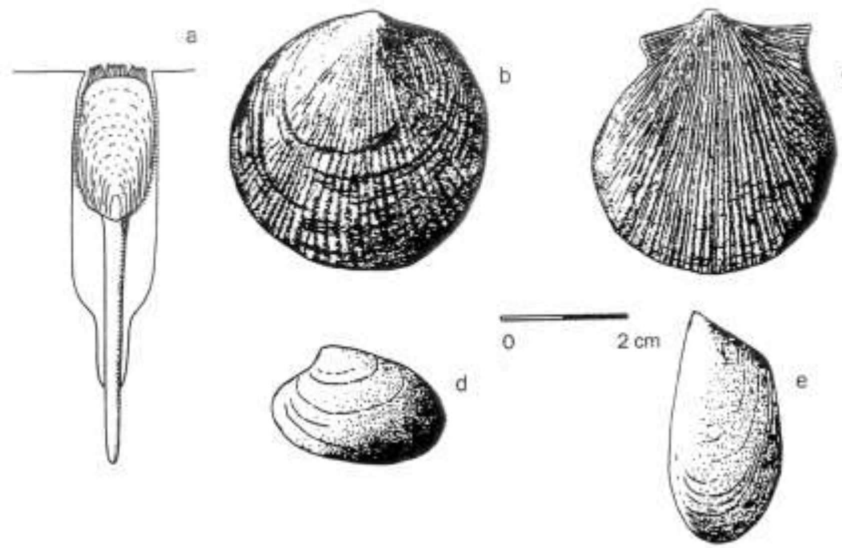


From Song et al. (2011)

Disaster Taxa

- As dominants capture much of the biomass and energy flow through an ecosystem.
- Act as significant ecosystem engineers in the community.
- As dominants can prevent other organisms from colonizing the seafloor – trophic amensalism.

Disaster Taxa



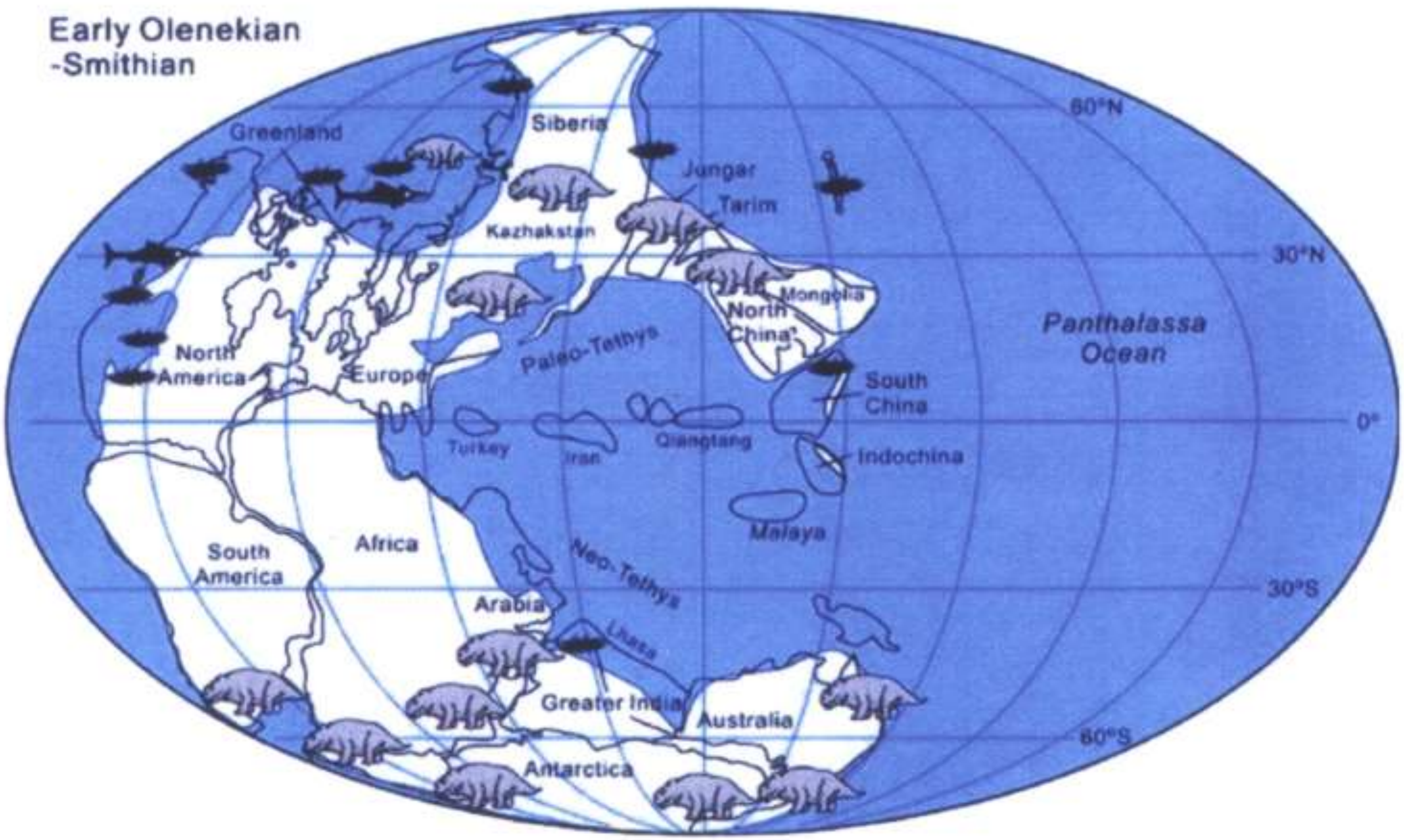
Courtesy of E. Petsios

From Benton (2003)

Latitudinal Shifts

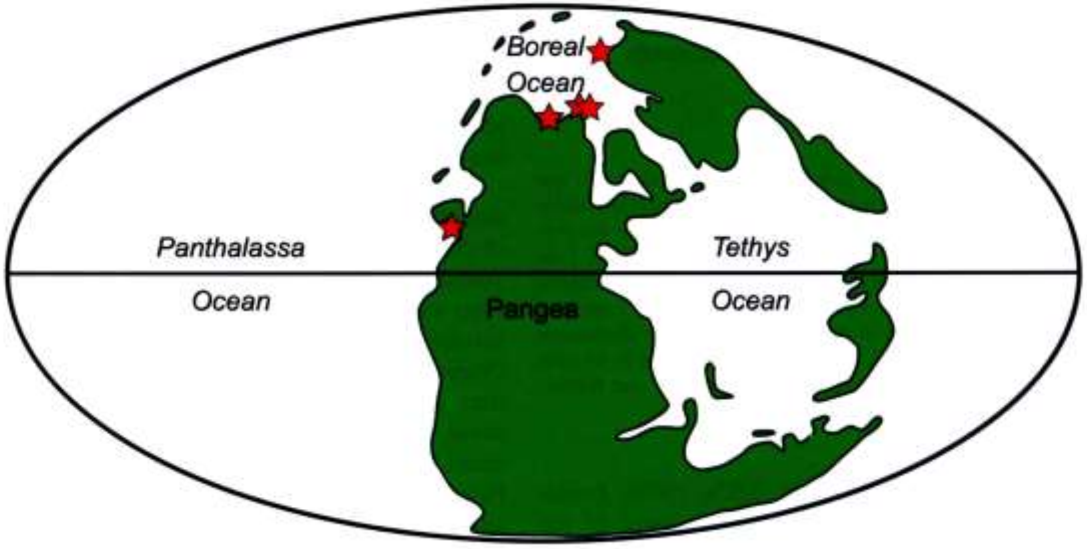
- Indicates how much movement of faunas towards the poles can occur with specific global temperature increases.
- Demonstrates the amount at which communities can break-up and re-assemble as they move towards the poles.
- Affects the latitudinal distribution of ecosystem engineering processes.

Latitudinal Shifts



From Sun et al. (2012)

Latitudinal Shifts

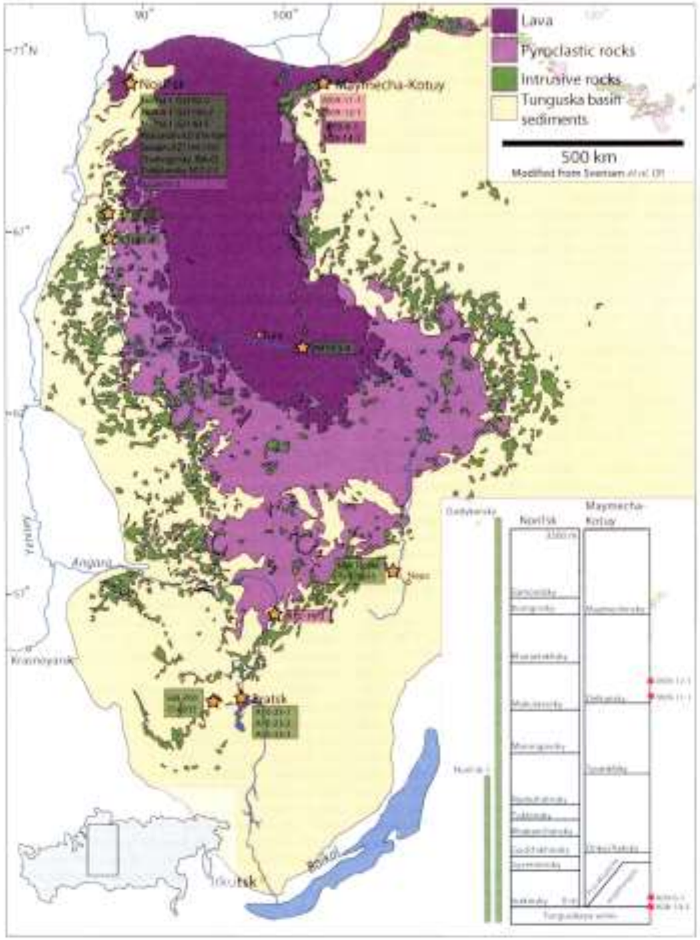


From Bottjer et al. (2008)

Notable Recent Updates

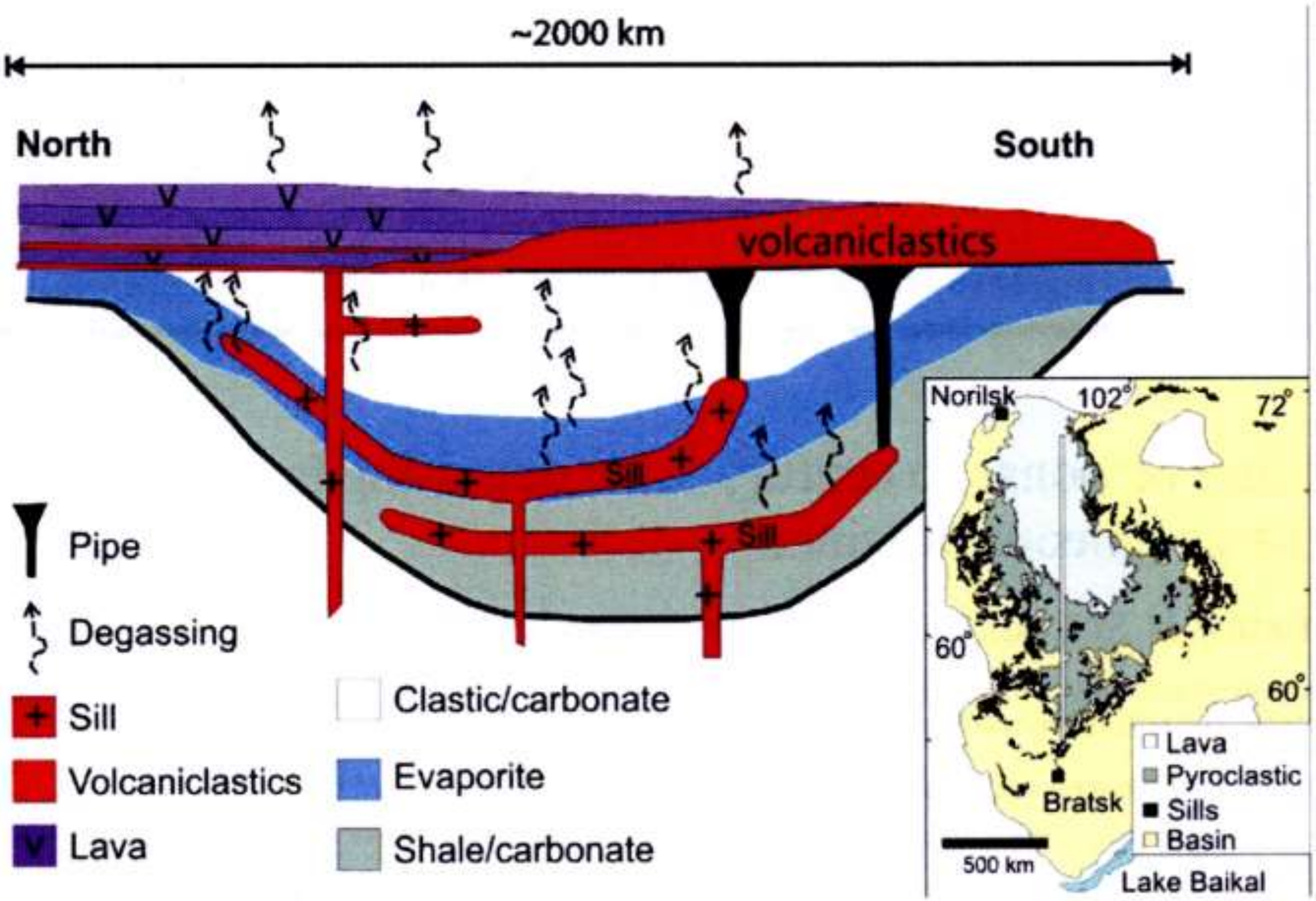
- Understanding the Siberian Traps
- Radiometric dating of events during the mass extinction interval.
- Geobiological mechanism proposed for the cause of the mass extinction.

Siberian Traps



From Burgess and Bowring (2015)

Siberian Traps

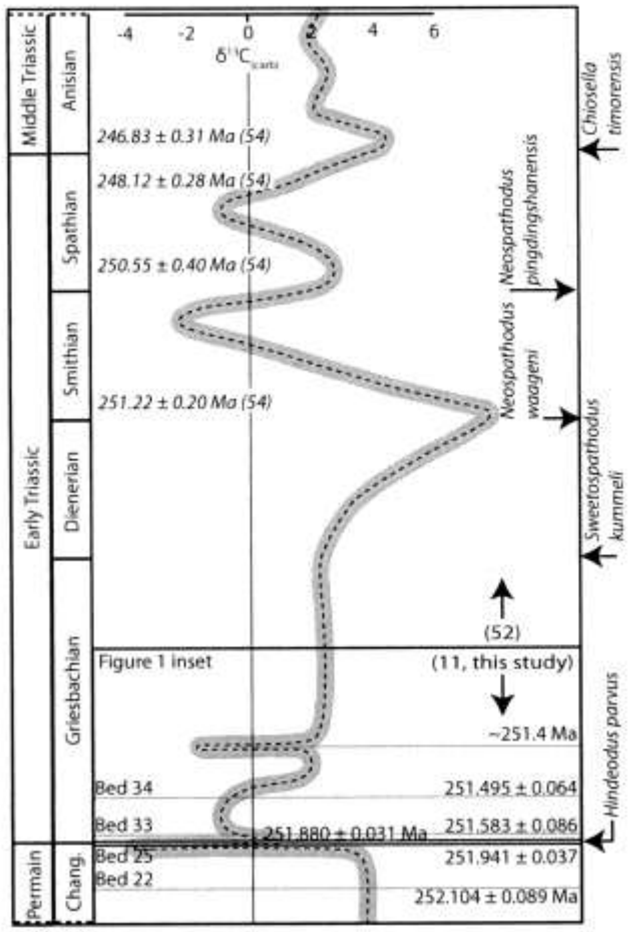


From Stordal et al. (2017)

Meishan, South China

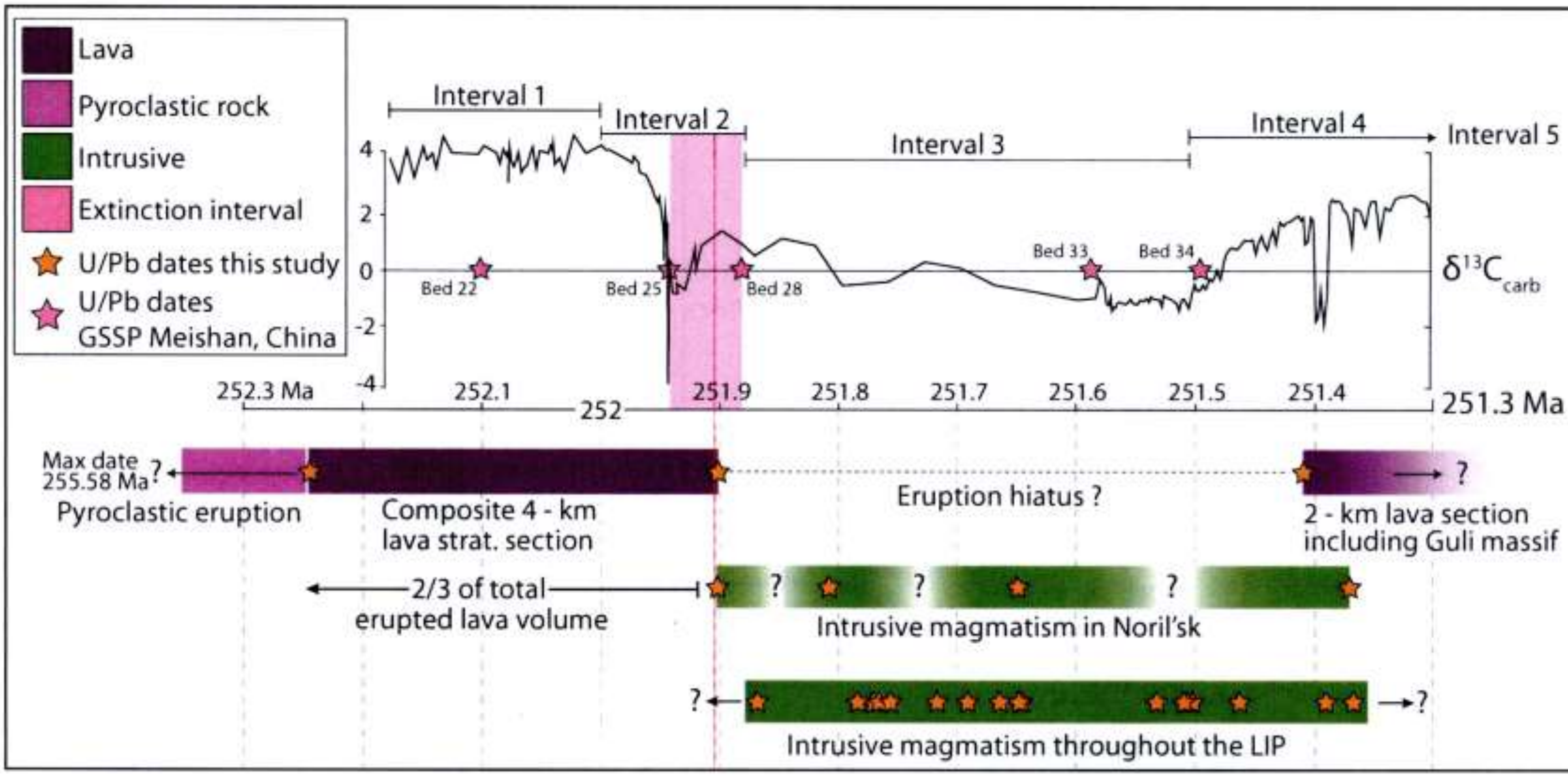
From Chen et al. (2015)

Meishan, South China



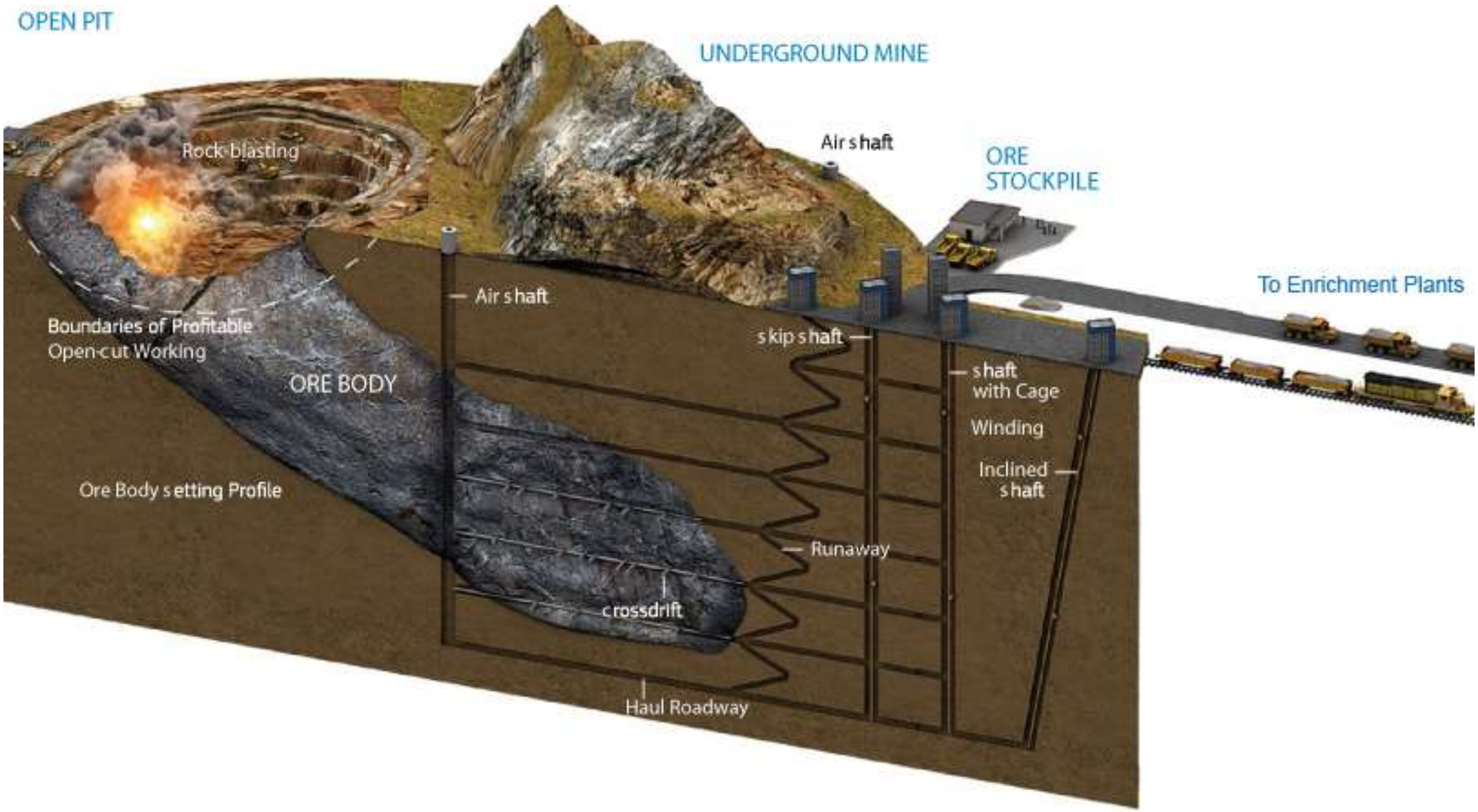
From Burgess et al. (2014)

Siberian Traps and Meishan



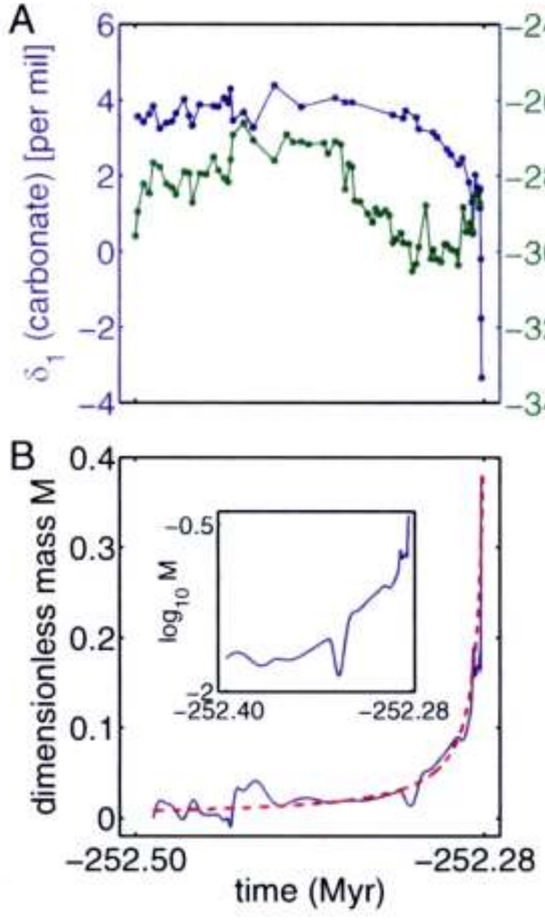
From Burgess and Bowring (2015)

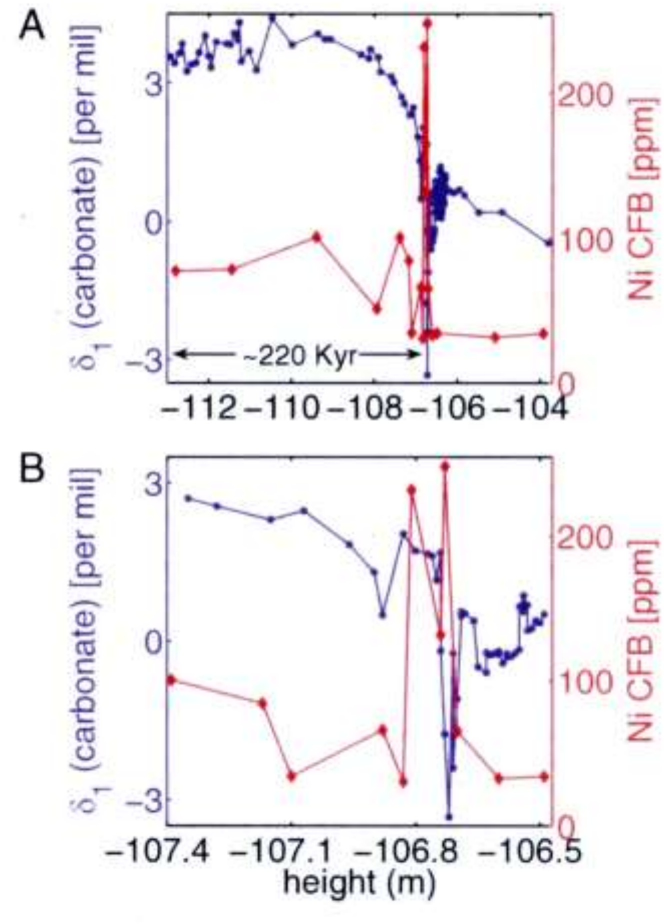
Noril'sk Nickel Ore Deposits



From Norilsk Nickel Annual Report (2014)

Trends in Marine Inorganic Carbon and Nickel Across the Mass Extinction Interval at Meishan





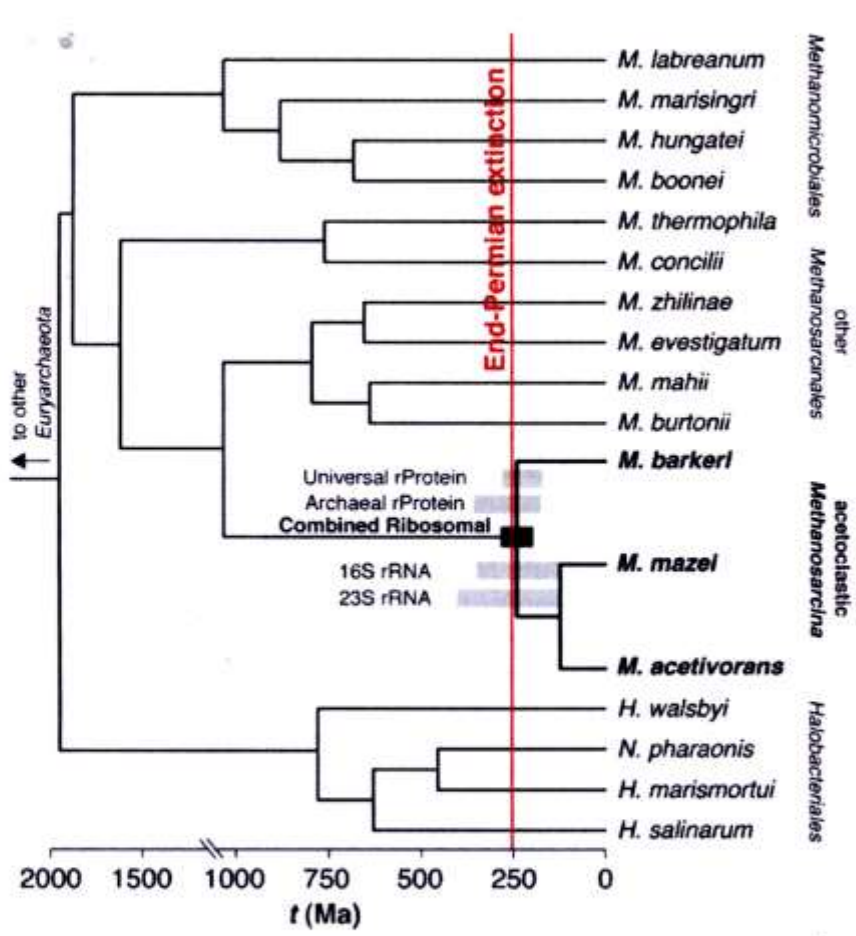
From Rothman et al. (2014)

Methanosarcina

- The genus *Methanosarcina* is a eurarchaeote archaea that produces methane. These single-celled anaerobic methanogens live in colonies and produce methane using all of the three metabolic pathways involved in methanogenesis. One of these pathways consumes acetate in an energy-efficient way, and was known to have evolved by gene transfer some time after the mid-Ordovician. But, exactly when did this happen?

From Whitehead Center of Genome Research

Phylogenetic Analysis of Acetoclastic *Methanosarcina*



From Rothman et al. (2014)

Methanosarcina and the End-Permian Mass Extinction

- Using molecular clock analyses of fifty genomes, this paper concluded that *Methanosarcina* acquired the ability to consume acetate in a more efficient way, using acetate kinase and phosphoacetyl transferase, at about the time of the end-Permian mass extinction. The genes for these enzymes were acquired in a single horizontal gene transfer event from a cellulose-degrading bacterium. The paper hypothesizes that with extensive organic carbon deposits in the ocean and nickel from Siberian Trap eruptions, *Methanosarcina* populations increased dramatically. This would have led to the production of abundant methane, much of which would have broken down to CO2, leading to intense greenhouse conditions.

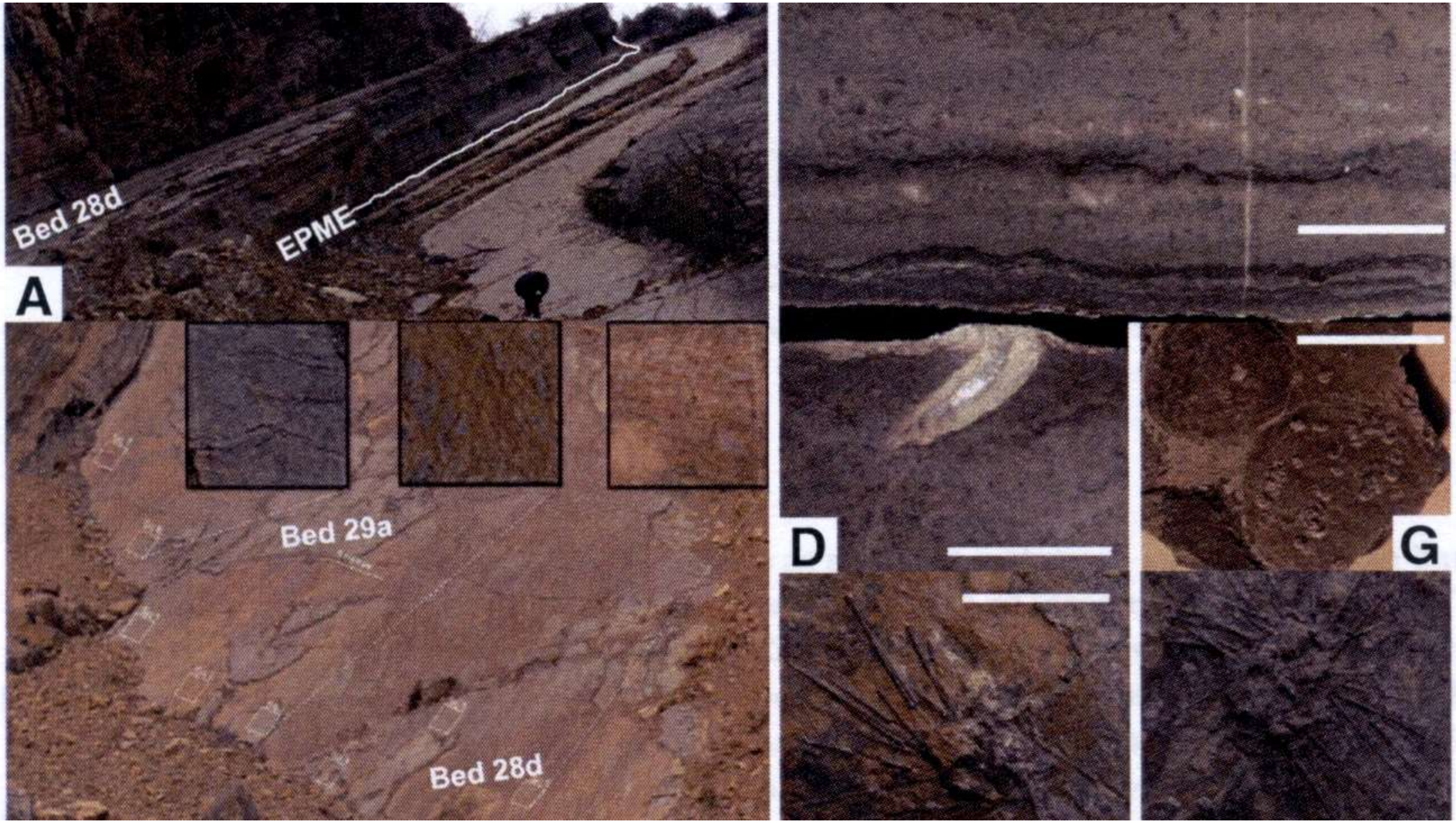
Notable Recent Updates

- Role of refuges in surviving the mass extinction.
- Newly discovered survivors of the mass extinction.
- Planetary-scale ecological effects of the mass extinction and recovery can now be shown through analysis of paleobiological “big data”.

Echinoids

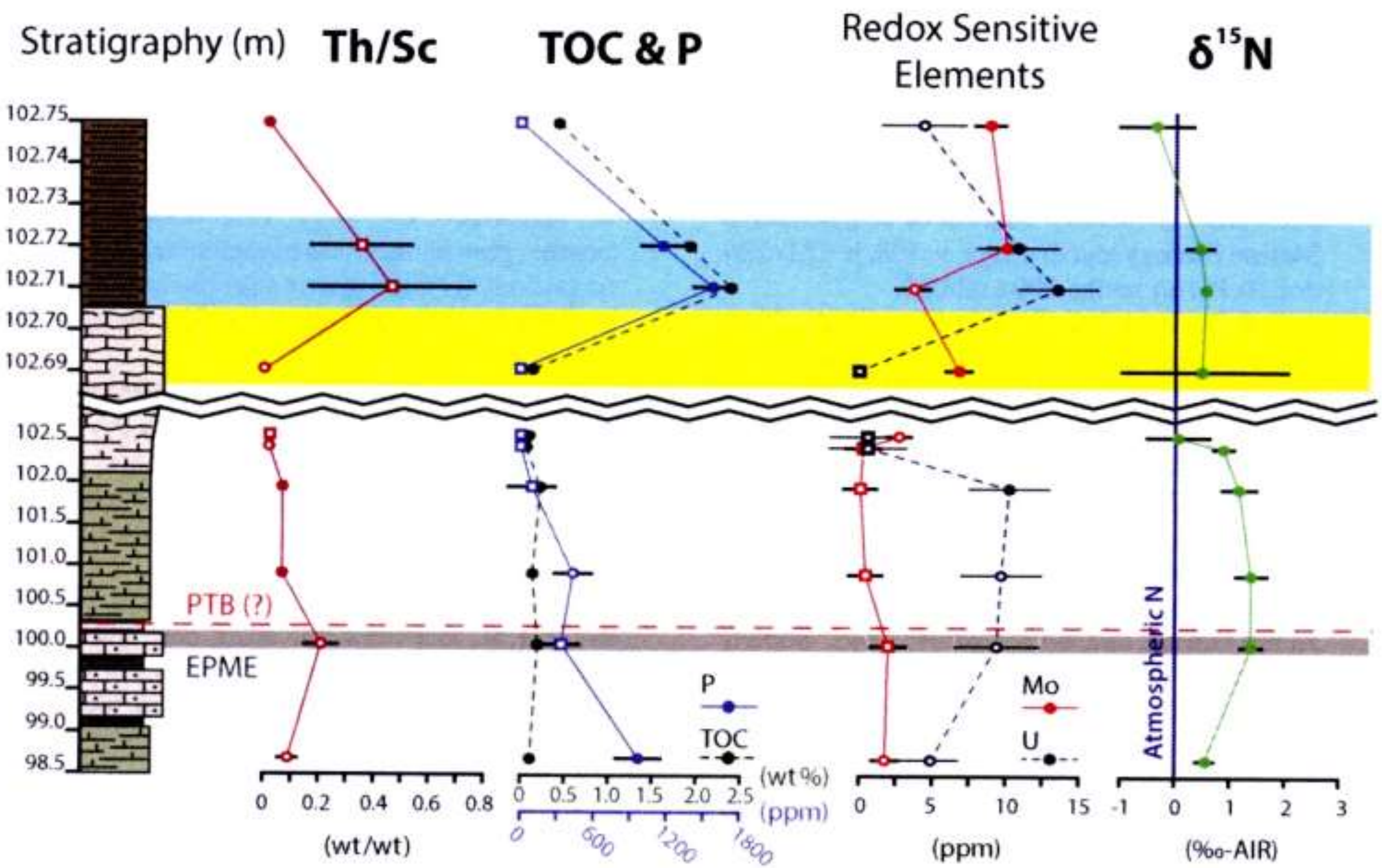
Photograph by Paul Nicklen National Geographic

Early Triassic Echinoid Fossil Record



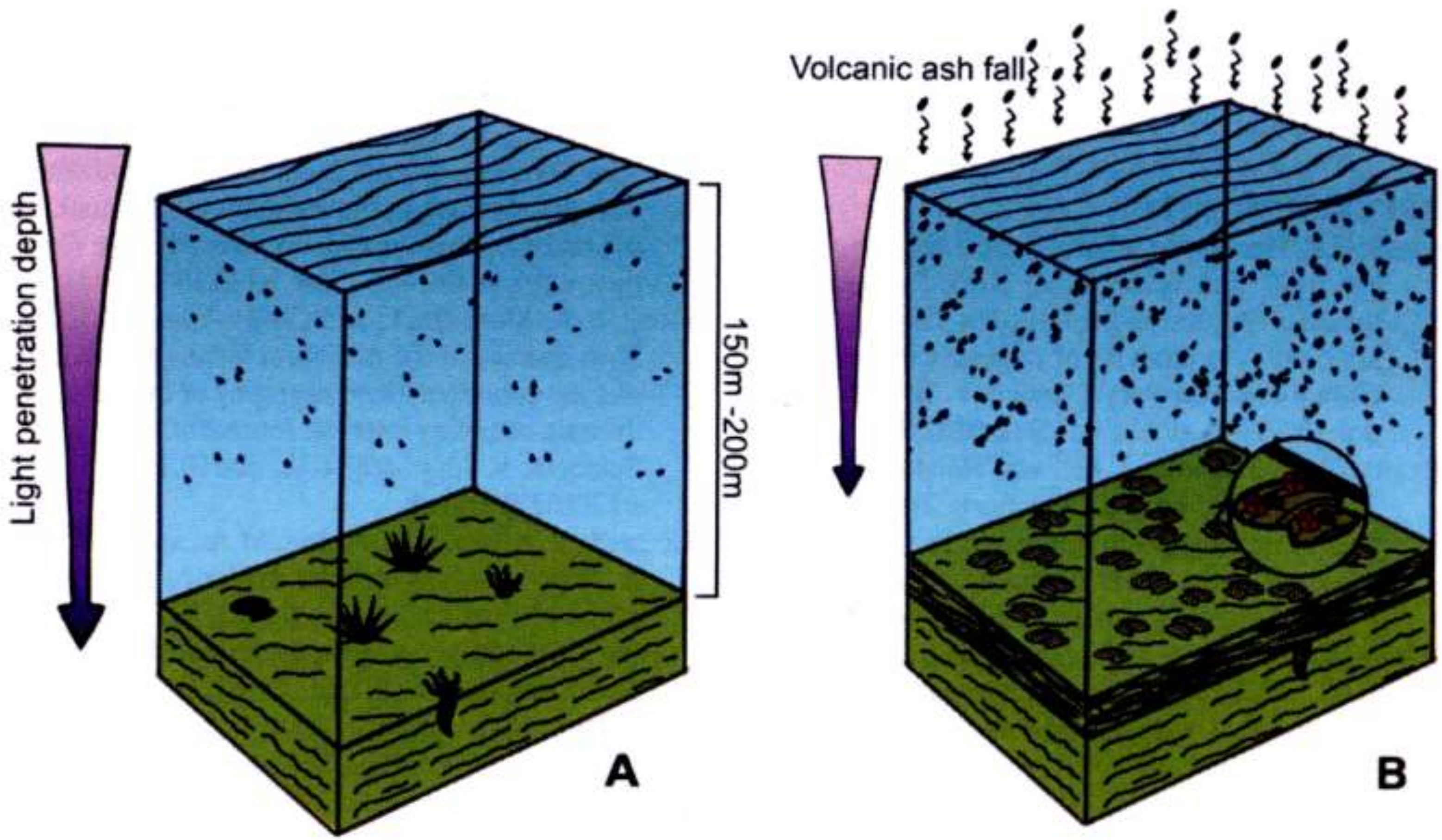
From Godbold et al. (2017)

Early Triassic Echinoid Refuge



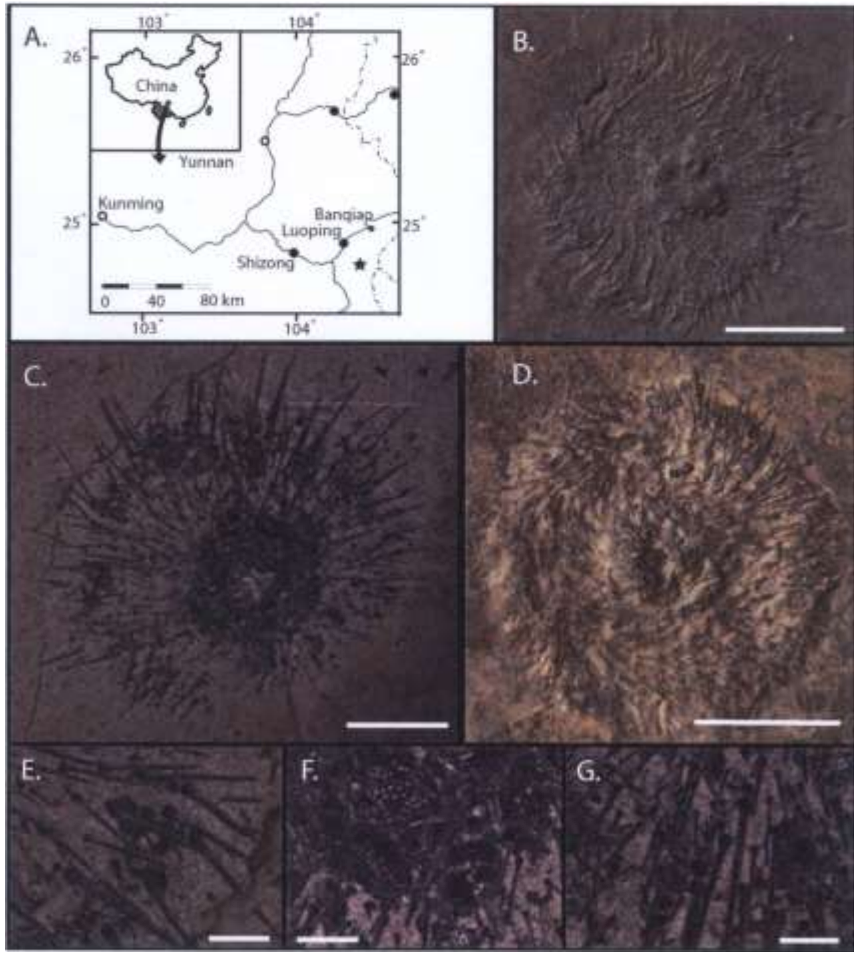
From Godbold et al. (2017)

Early Triassic Echinoid Refuge

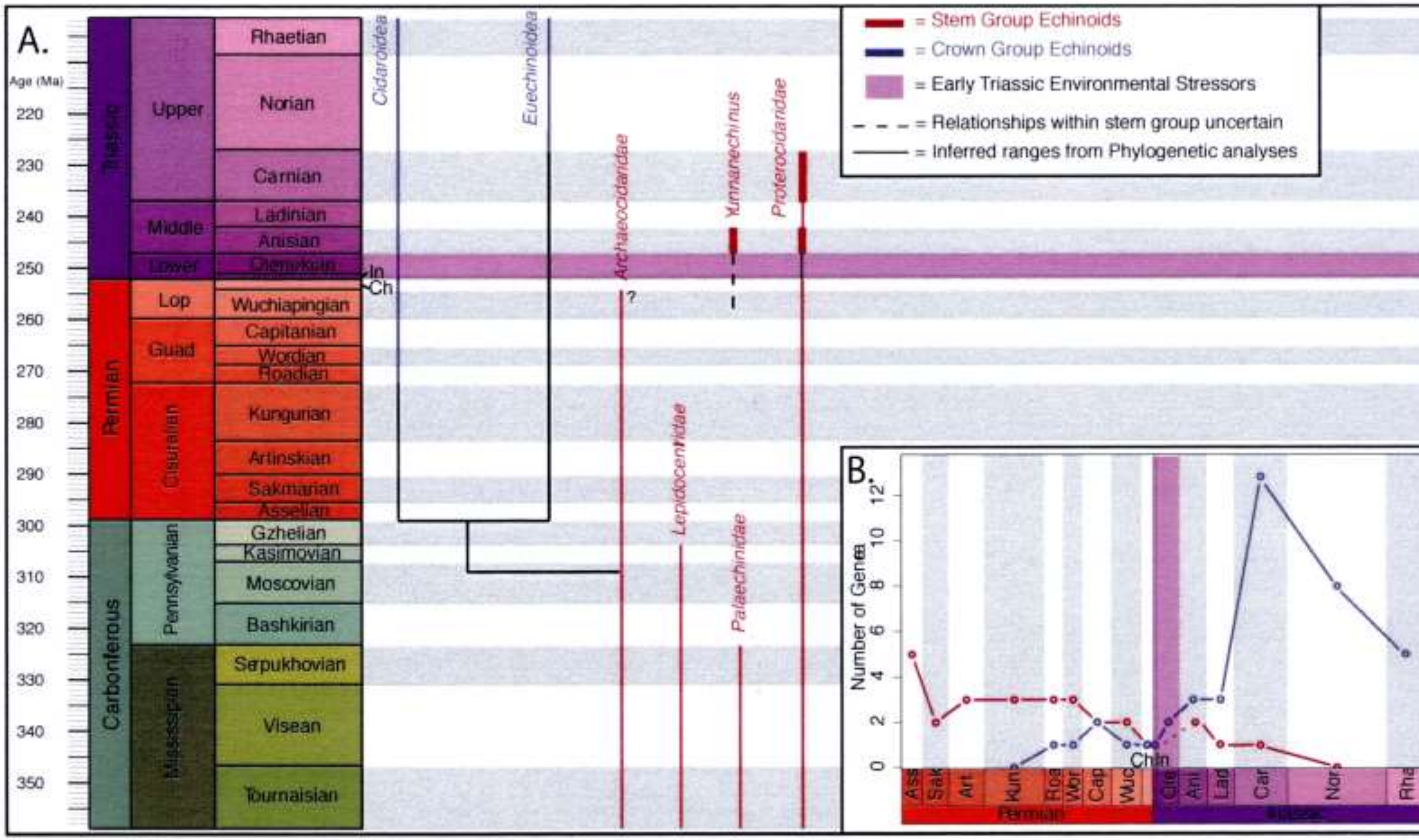


From Godbold et al. (2017)

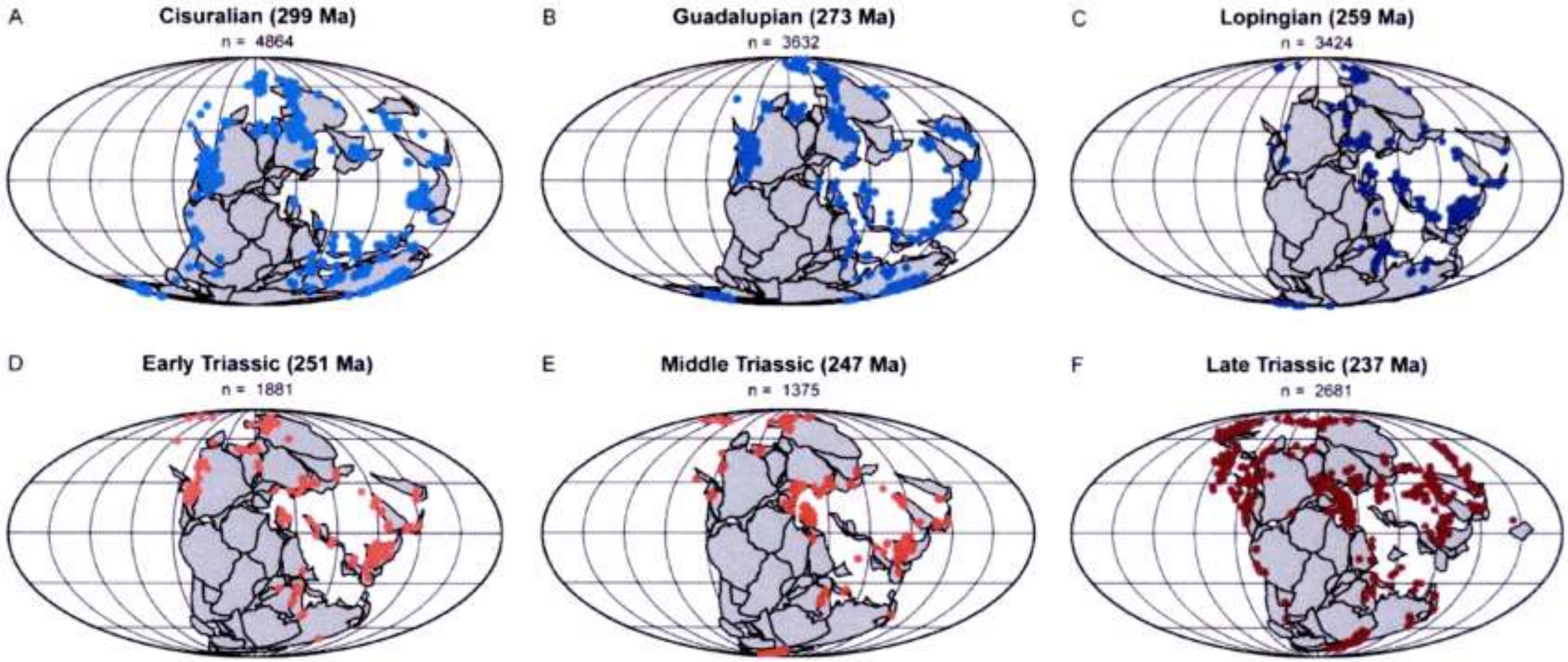
Middle Triassic Echinoid Fossil Record



Revised Permian-Triassic Echinoid Fossil Record



Paleogeographic Distribution of Marine Benthic Assemblage Data From Paleobiology Database

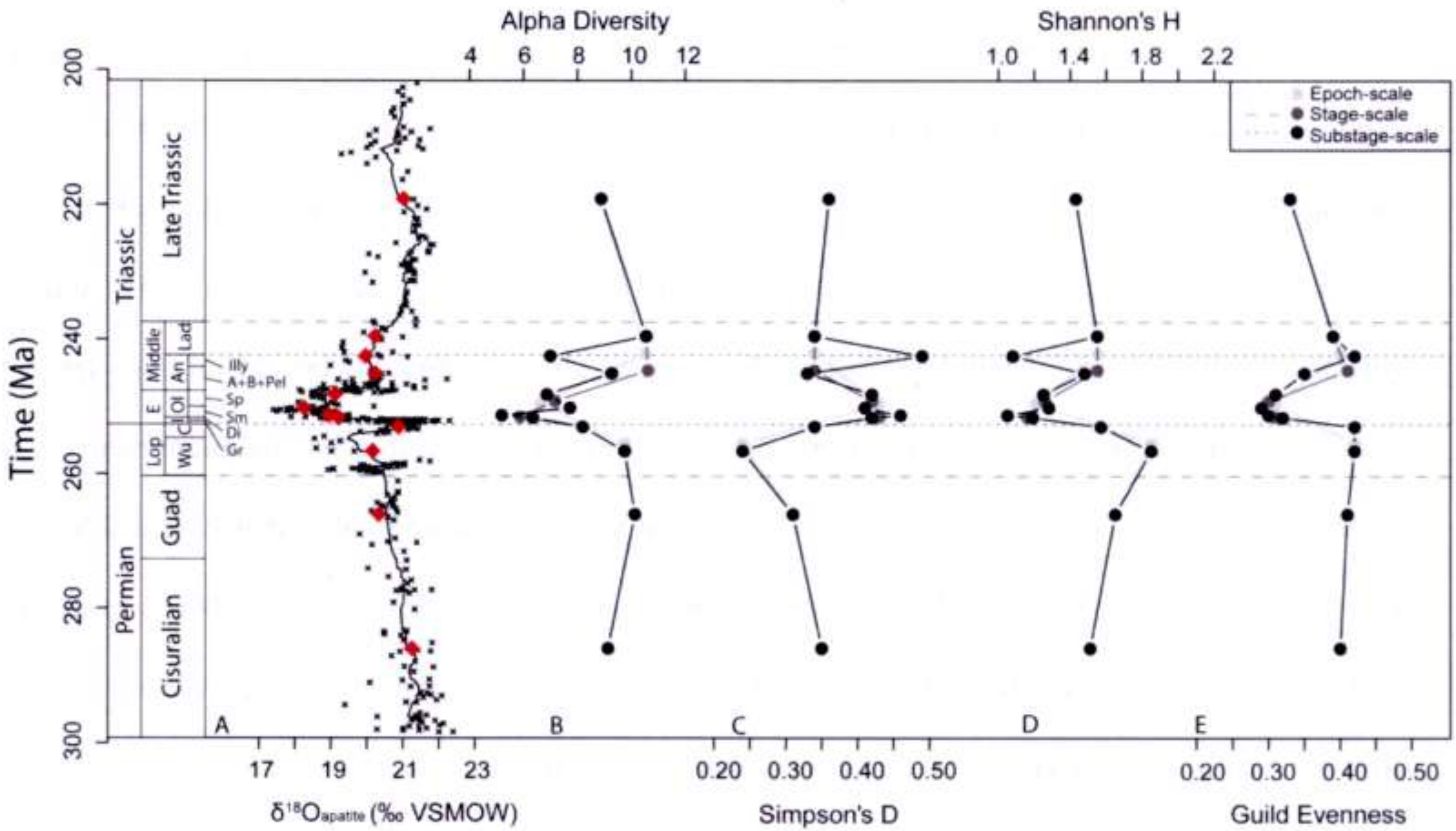


From Petsios et al. (in press)

Ecological Metrics Through the Permian and Triassic Transition

- Alpha diversity is the number of genera (richness) from an assemblage or community.
- Simpson's Dominance Index (D) and Shannon's Diversity Index (H) are diversity metrics that account for both richness and abundance. Simpson's D is more sensitive to highly dominant taxa, and Shannon's H places greater importance on rare taxa in an assemblage. Higher values of Simpson's D and lower values of Shannon's H indicate a greater prevalence of assemblages dominated by a few taxa, and are inversely correlated.
- An ecological guild is a group of species that exploit the same resources, and the number of guilds in an assemblage or community is considered to be a measure of ecospace utilization and health. Guild Evenness utilizes guild richness and abundance data to determine if genera are distributed evenly within guilds or are concentrated within a subset of guilds.

Summary of Ecological Metrics and Oxygen Isotopes Spanning the Permian and Triassic



From Petsios et al. (in press)

Conclusions

- Geobiological interactions of Earth and life processes on a planetary scale led to the largest known biological crisis for life, which continued for 5 or more million years after the mass extinction.
- The largely intact Siberian Traps allows a relatively detailed reconstruction of this large igneous province magmatic system.
- Numerous fossiliferous sedimentary outcrops across the surface of Earth provide an extensive record of this mass extinction and recovery.
- The mass extinction was first recognized by general surveys of fossil content in sedimentary rocks, but detailed studies over the past few decades have resulted in a much greater understanding of what happened to life and how it survived.
- The exact killing mechanism has yet to be resolved, but we are getting closer to an answer.
- Much remains to be done!