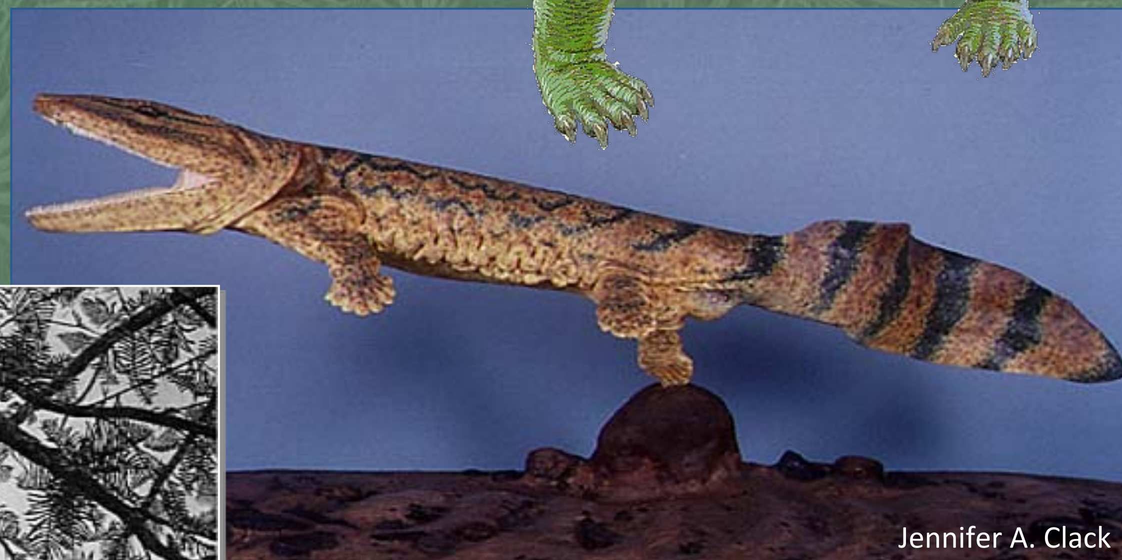
Terrestrial vertebrates
Amniotes
Synapsids
Extinctions

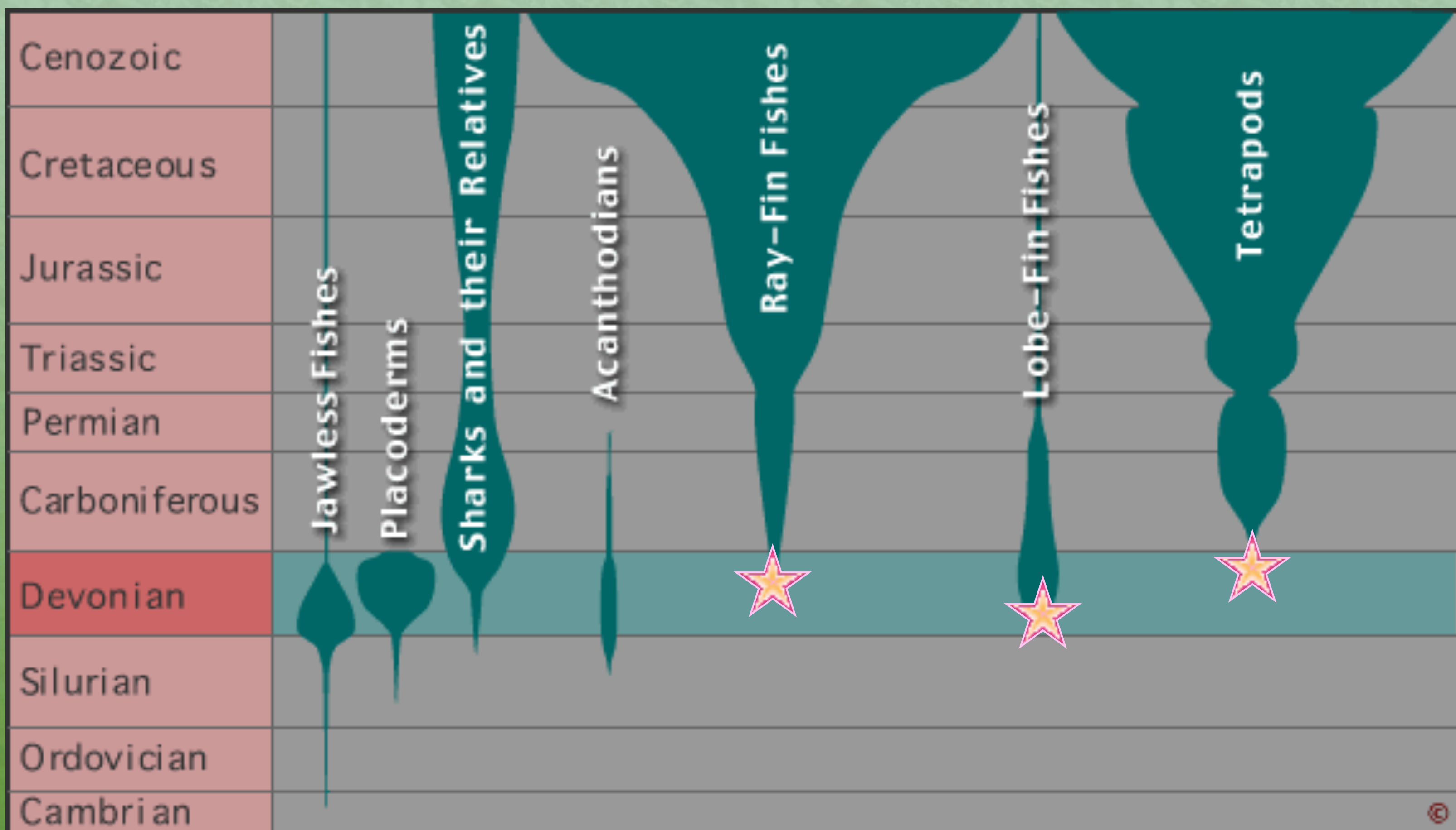
http://www.museums.org.za/



Paleozoic Earth History

Vertebrates

Actinopterygians (ray-fin fishes) and lobe-fin fishes (and their sister group, the tetrapods) appear in the Devonian.

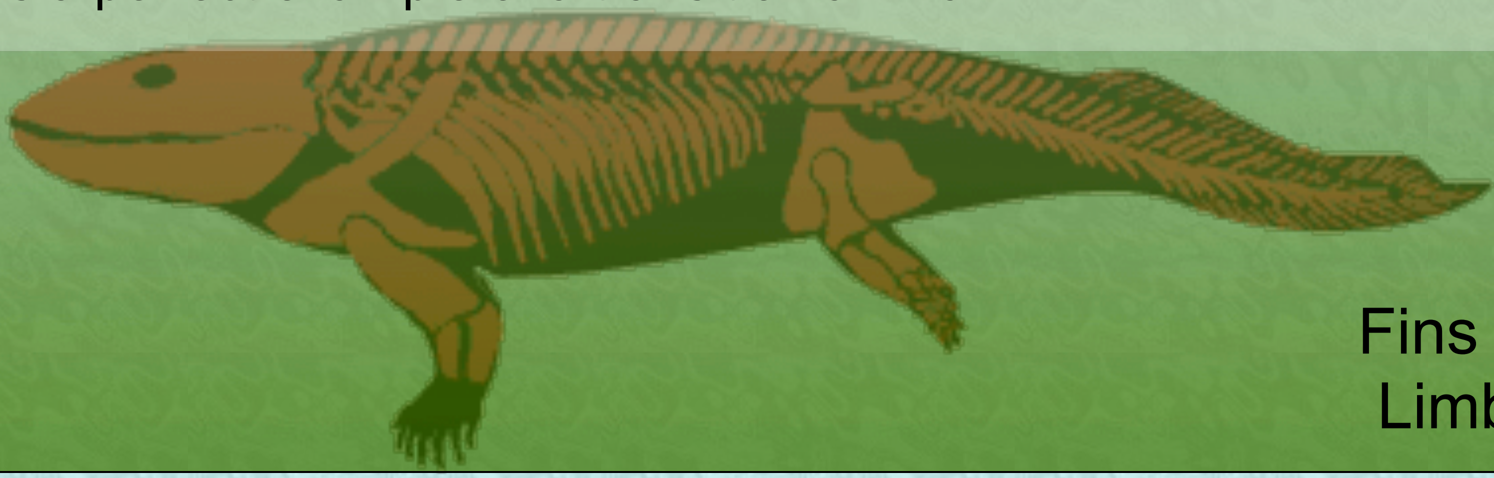


http://www.mdgekko.com/devonian/opportunity/opportunity.html

Ichtyostega

This genus is considered the first tetrapod, even though it probably did not walk (like the reconstruction above).

Some experts consider *Icthyostega* to be the first amphibians. Others believe it should still be classified with the lobe-fin fish. In other words, this is a perfect example of a transition animal.

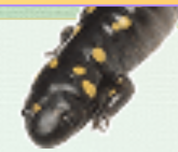


Fins to Limbs

http://www.geocities.com/torosaurio/crdebunk/Icthyostega.html

Tetrapods



Amniotes

There are four major groups of tetrapods:

- Amphibians (partial land-dwellers) - large, paraphyletic and probably polyphyletic group including modern and ancient forms.
- Diapsids - reptiles and birds
- Synapsids - mammals and mammal-like reptiles
- Anapsids - turtles and relatives

The aminiotes can be distinguished from each other by the structure of their skulls - particularly the number and placement of cranial openings behind the eyes.




http://tolweb.org/

Vertebrate Life on Land

Reproduction

Amphibians usually lay their eggs in water, and can have external fertilization of eggs. This dependence on water prevents most amphibians from ever being fully terrestrial.

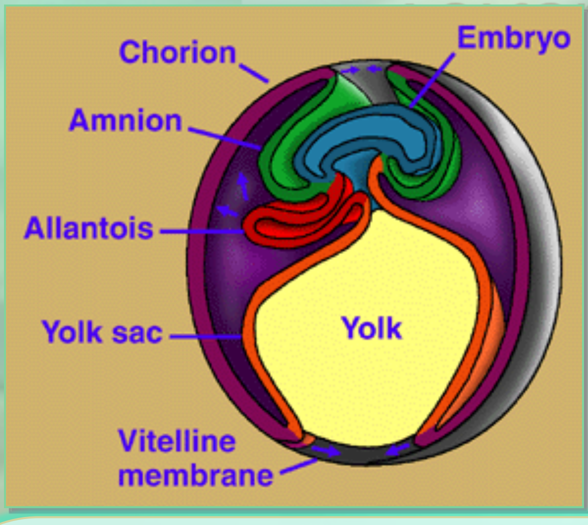
All other terrestrial vertebrates are called “amniotes” because they reproduce with internal fertilization producing a very special egg - the amniotic egg.

Amphibian eggs

Turtle eggs

http://sepwww.stanford.edu/sep/jon/family/aac/2002/amphib/ *http://tolweb.org/* *http://www.turtletimes.com/*

Vertebrate Life on Land



The amniotic egg is a self-contained little life pod that supplies the developing embryo with nutrients and gasses while separating wastes and maintaining a fluid environment.

The egg contains regions and membranes specializing in various tasks, including the:

- Amnion - contains buffering amniotic fluid
- Allantois - controls gas exchange and removes waste from embryo
- Yolk sac - provides food for embryo
- Chorion - enclosing membrane controlling gas and fluid exchange with external environment

Egg-laying amniotes also enclose the egg in a leathery or hard shell.

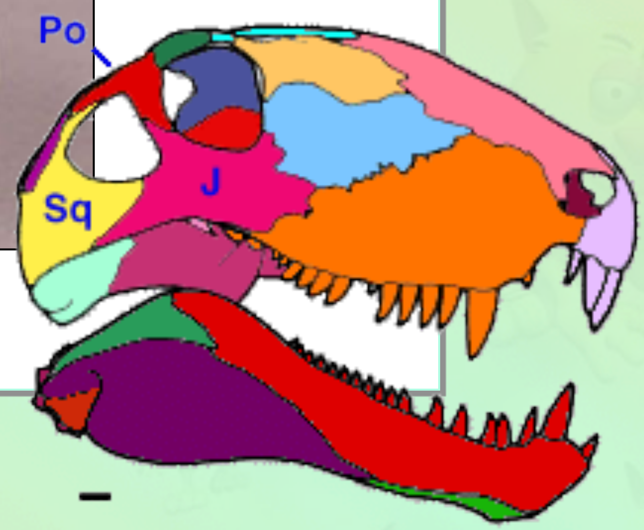
http://tolweb.org/

Diapsids

Hylonomus, a primitive reptile, leaps up for an insect in a coal forest in Nova Scotia during the Carboniferous, some 350 million years ago.

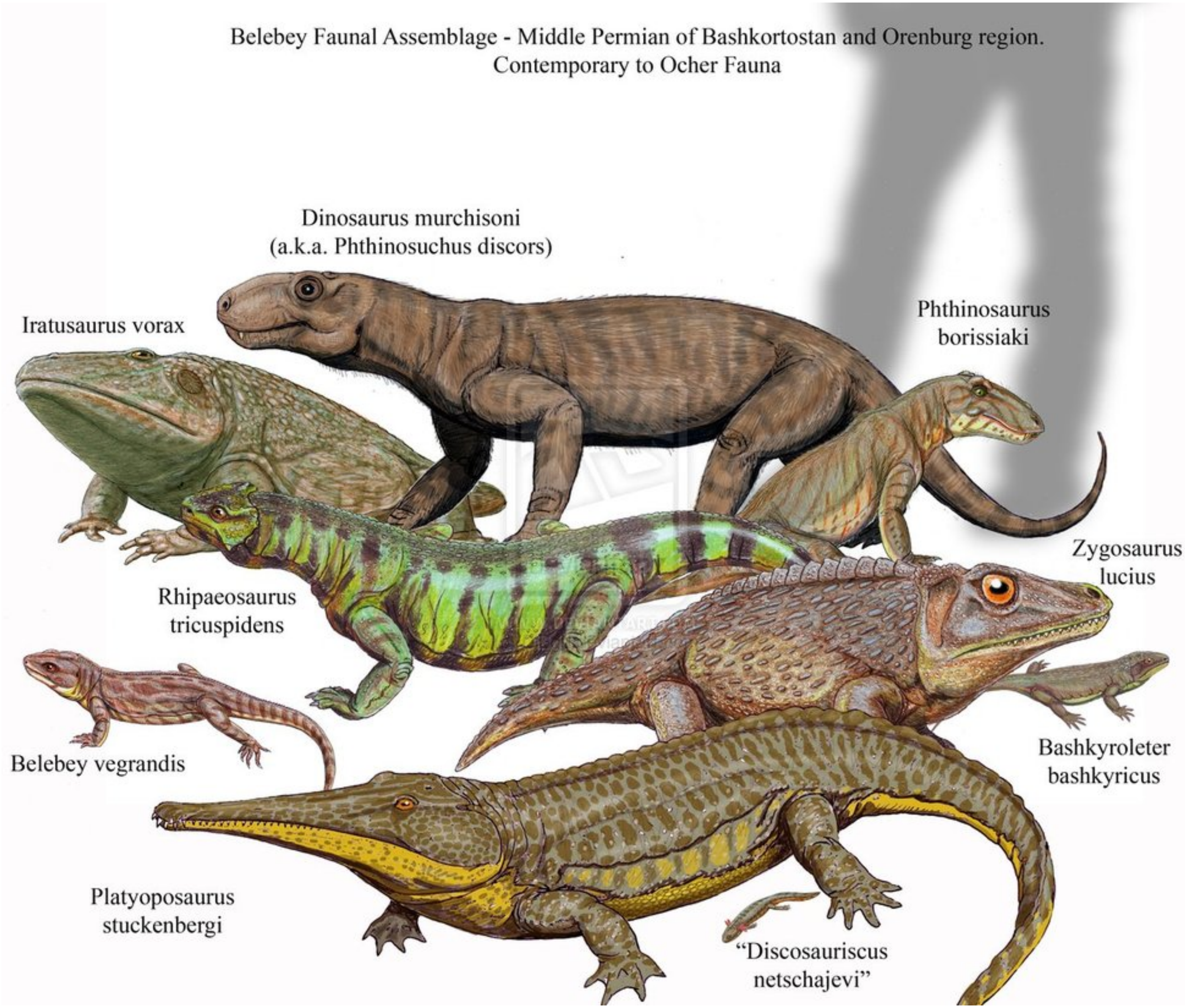
http://gallery.in-tch.com/~earthhistory/

Synapsids

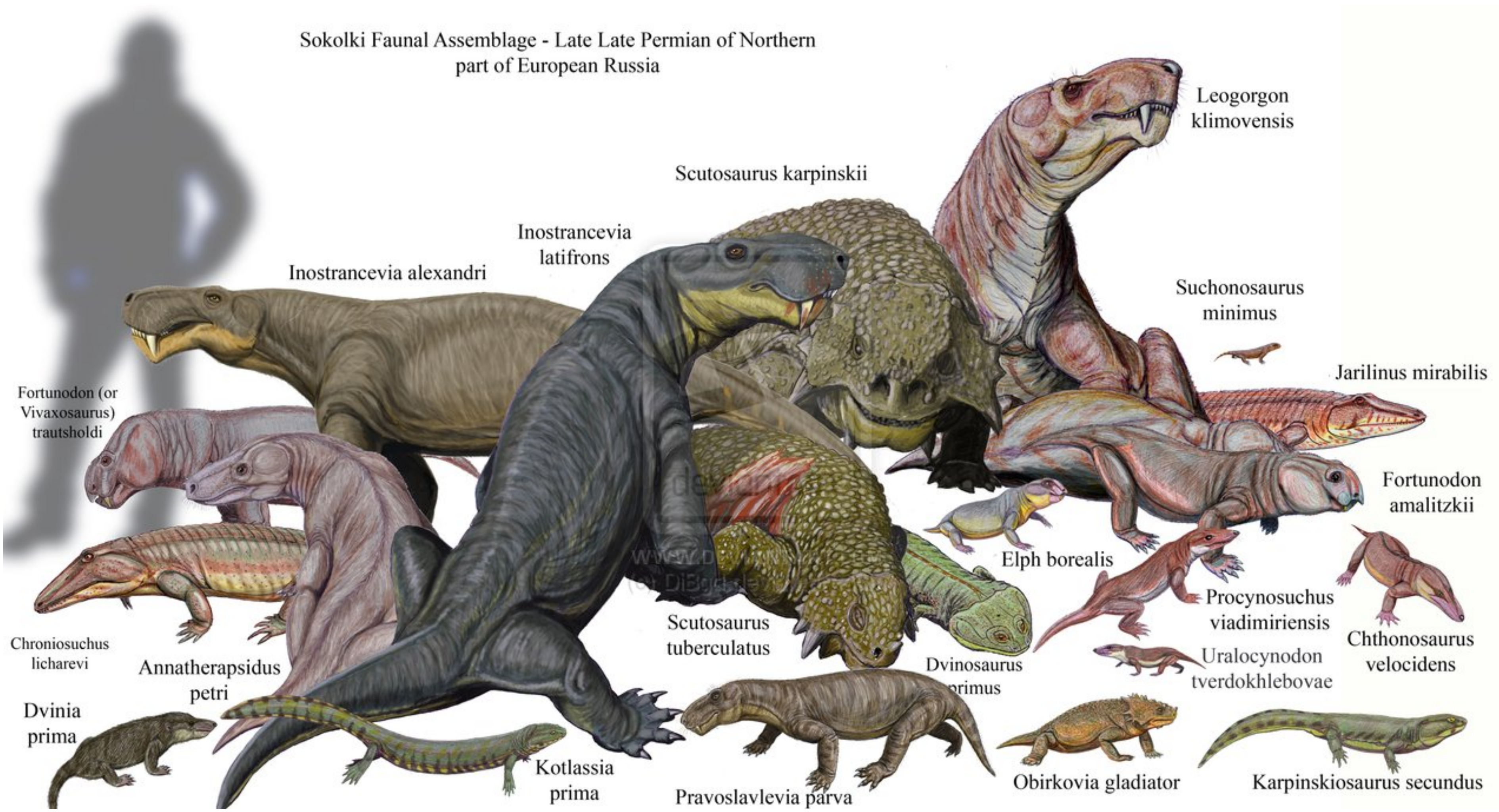


Synapsids - Mammals and their relatives, includes the first very large land animals to evolve on Earth.

http://www.boneclones.com/ *http://tolweb.org*



http://dibgd.deviantart.com/art/Belebey-faunal-Subassemblage-341983097



http://dibgd.deviantart.com/art/Sokolki-Faunal-Assemblage-356905273

Passenger Pigeon

"Normal" Extinction

- Species go extinct when the living generation fails to produce the next generation. After the last member of the last generation dies, the species is extinct.
- 95% (conservative estimate) of all species that ever lived are extinct. Over the long haul, extinction is the natural fate of all species.

http://www.delawaretribeofindians.nsn.us/extinct_birds.html

"Normal" Extinction

- The average "life-span" of species with fossil records is about 5 million years. It is longer for some groups (e.g., clams) and shorter for others (e.g., mammals).

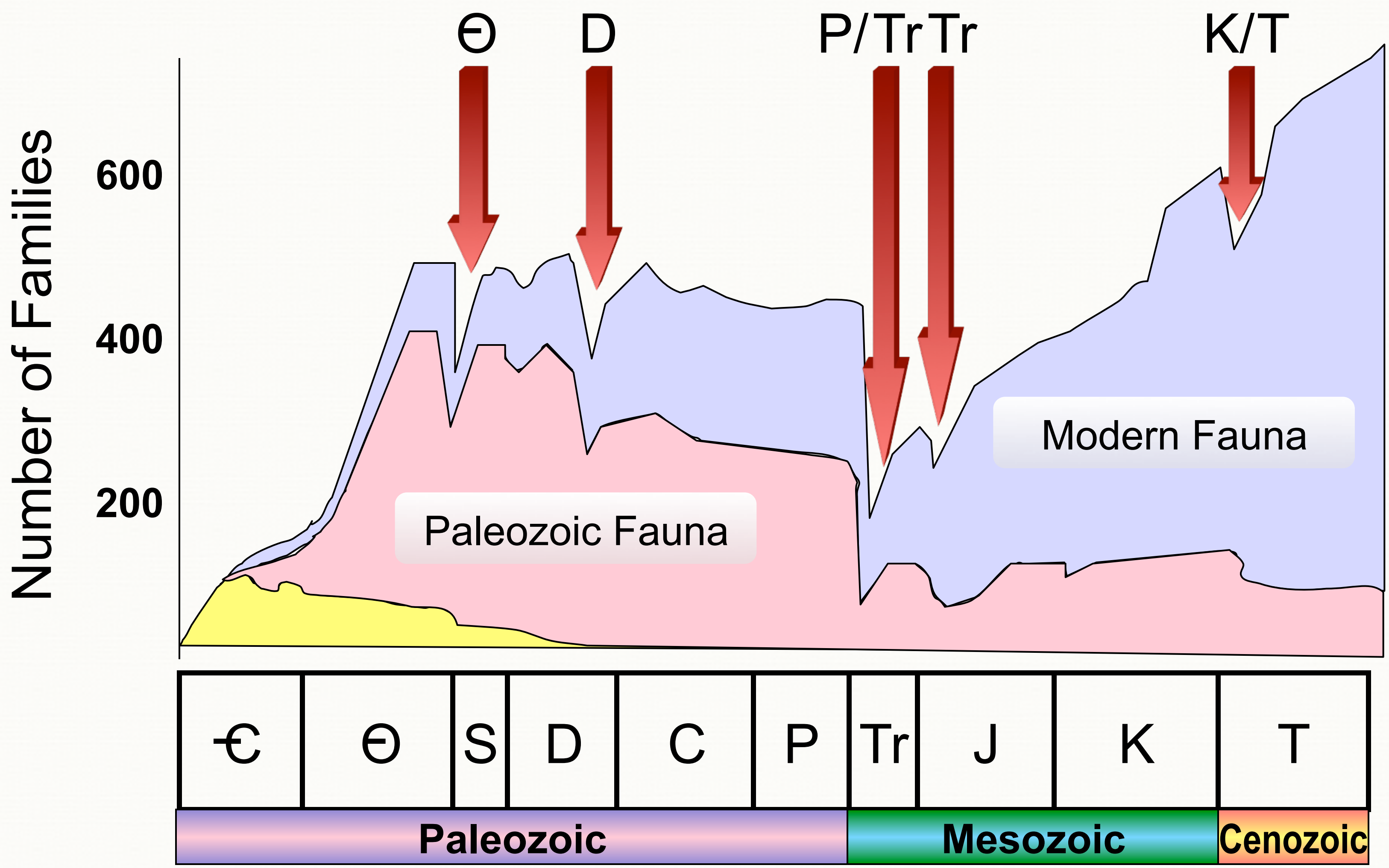
- It is frequently impossible to determine "why" a particular fossil species went extinct. Considering the vast array of possibilities, it is also unreasonable to settle on one cause.

http://www.delawaretribeofindians.nsn.us/extinct_birds.html

“Mass” Extinction

- Mass extinctions involve the extinction of a large number of species, resulting in the extinctions of genera, family, orders, and sometimes classes and phyla.
- Mass extinctions are “events” - meaning that the extinctions are concentrated in a relatively short period of (geologic) time.
- Mass extinctions hit many different taxonomic groups, although not all at the same intensity.

Jack Sepkoski's Three Evolutionary Faunas



Five mass extinction events are generally recognized

The P/Tr Disaster

Before	***After***
High diversity endemic flora/fauna	Low diversity cosmopolitan flora/fauna
Extensive reef communities	No reef communities
Coal production	No coal production
Siliceous oozes (radiolarians)	No siliceous oozes (few radiolarians)
526 families of fossil animals	267 families of fossil animals

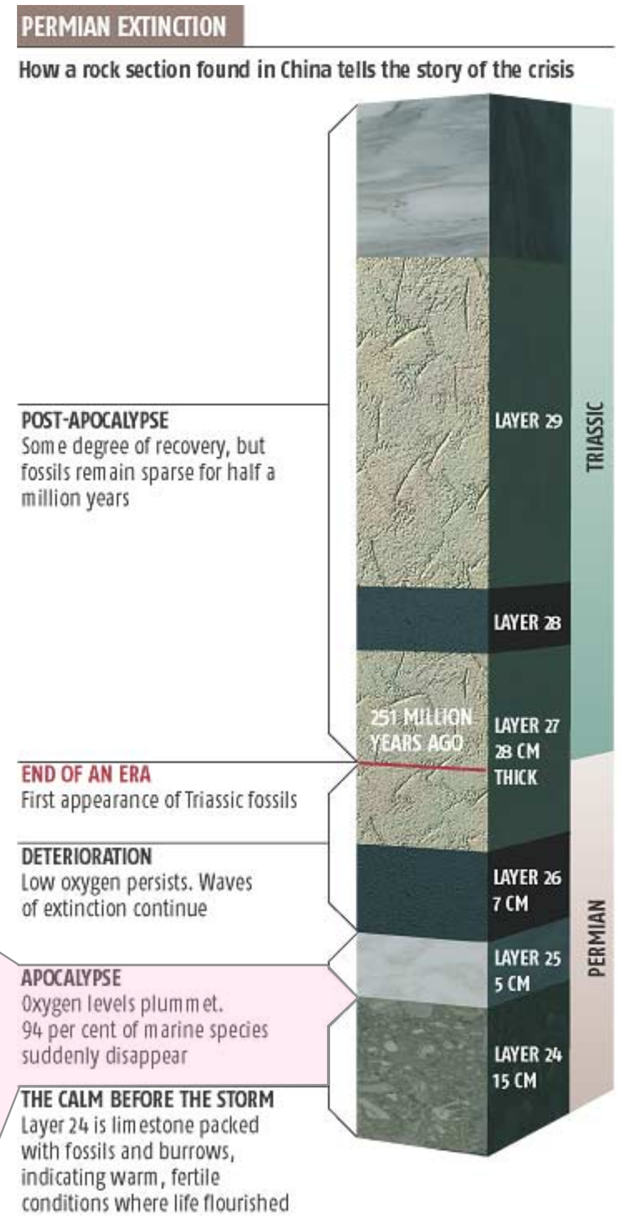
By any measure, this was a highly traumatic - and dramatic - time for life on Earth!

The P/Tr Disaster

An idealized stratigraphic section of the event (i.e., what a geologist would see in the field) based on an outcrop in China.

Extinction event horizon

94% of all marine species found in underlying layer are not found in this layer, or ever again.

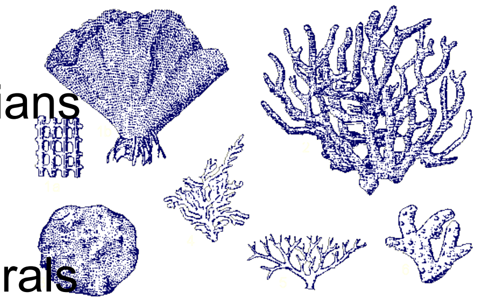


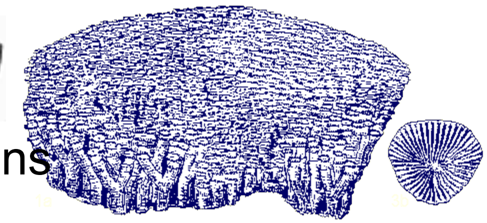
http://palaeo.gly.bris.ac.uk/Essays/wipeout/23925001.jpg

Goners and Near Goners

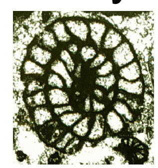
Extinct:

- † pelycosaurs, acanthodians
- † trilobites
- † fusulinid foraminifera
- † rugose and tabulate corals
- † blastoids, all non-camatulate crinoids
- † orthid and productid brachiopods
- † fenestrate, trepostome, and cryptostome bryozoans

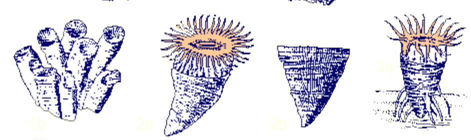


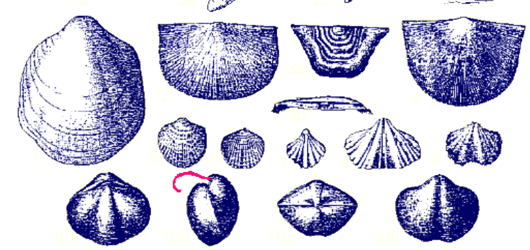


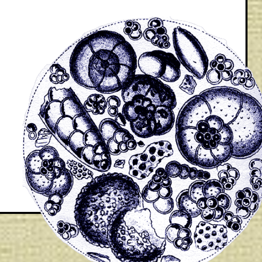
Hard hit (% extinct):



- radiolarians (all but 3 species)
- foraminifera (94% species)
- brachiopods (96% genera)
- ammonoids (97% species)
- gastropods (90% species, 81% of families)
- bryozoans (79% species)
- bivalves (59% species)
- ostracods (8 families survive)





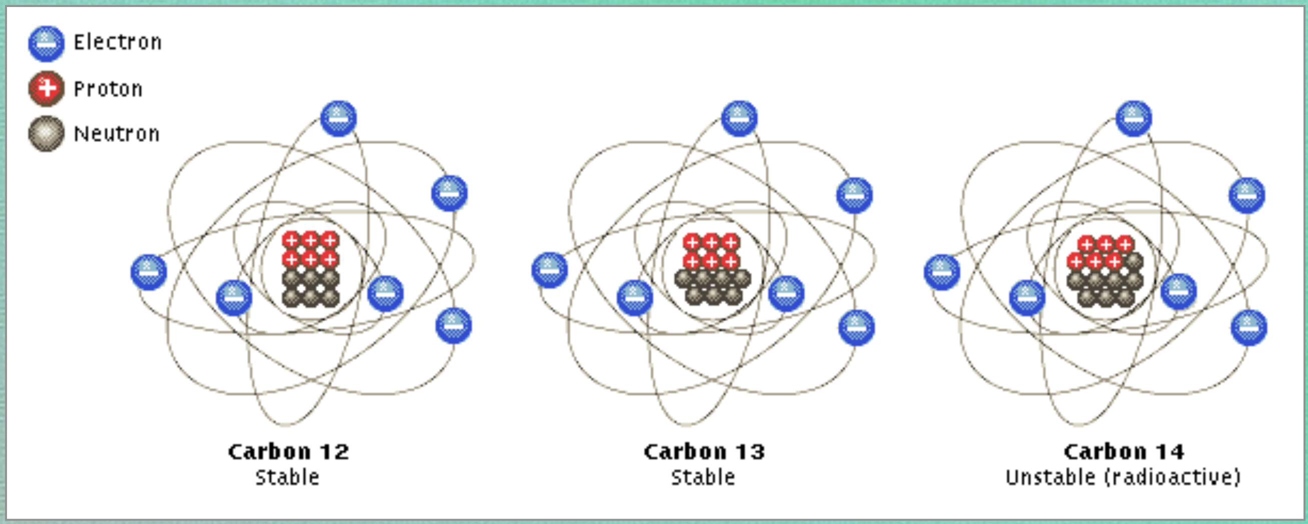


The P/Tr Disaster

Carbon Isotope Anomalies

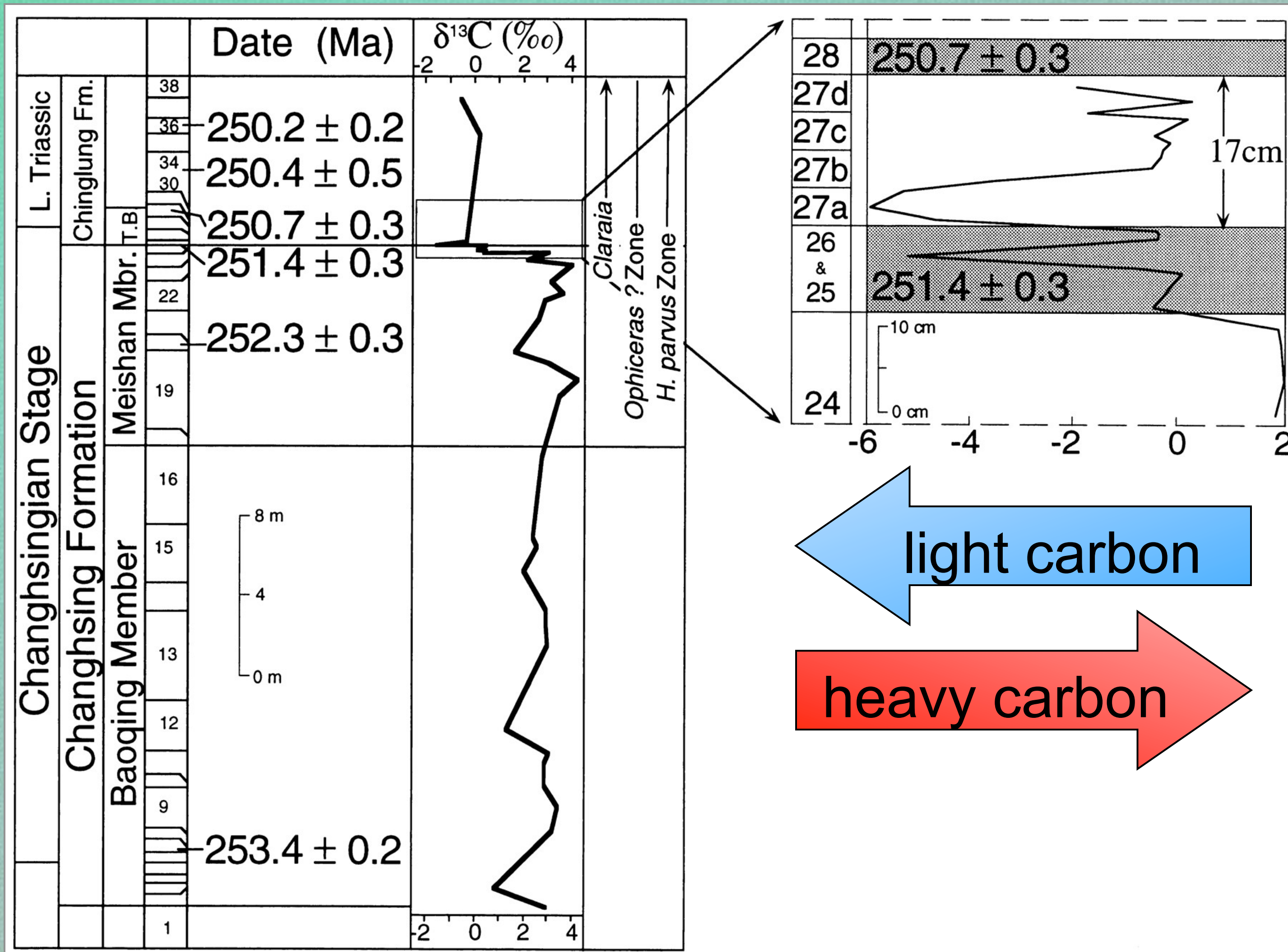
The very important organic element carbon has two stable isotopes - ^{12}C and ^{13}C. Photosynthesis preferentially uses ^{12}C (it's a thermodynamic coincidence), so organic matter (including fossil fuels) tends to be "lighter" than atmospheric and oceanic carbon. Volcanic CO_2 also tends to be have more of the lighter isotope.

The ratio of light to heavy carbon ($\partial^{13}C$) varies through time locally and globally due to many factors. The end Permian extinction was marked by massive global $\partial^{13}C$ shifts.



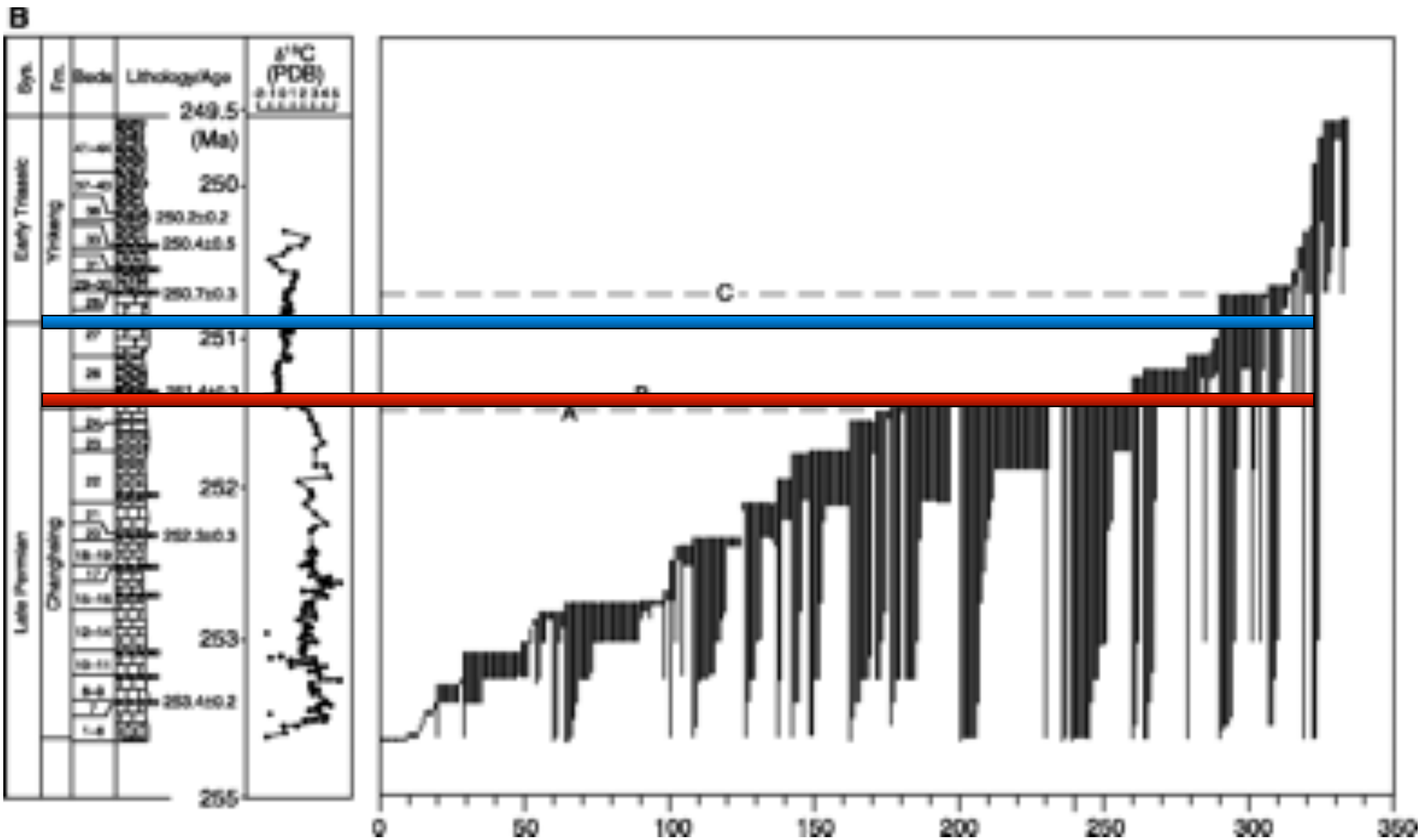
http://www.academic.rccd.cc.ca.us/~freitas/

The P/Tr Disaster



Carbon isotope excursions at end of Permian

http://www.peripatus.gen.nz/paleontology/extinction.html



Ranges of 333 fossil species from the Meishan section in China. The main extinction event (94% species extinction) and carbon isotope excursion both occur before the Permian-Triassic boundary at this locality.

Jin, Y.G., Y. Wang, W. Wang, Q.H. Shang, C.Q. Cao, D.H. Erwin 2000. Pattern of marine mass extinction near the Permian-Triassic boundary of South China. Science 289: 432-436.

The P/Tr Disaster

The carbon isotope anomaly is found everywhere geologists have looked for it, and was clearly a global phenomenon. Plausible causes include:

- Collapse of primary productivity
- Release of carbon dioxide from extensive volcanic events

Neither cause is sufficient to explain the entire anomaly, either alone or combined.

Something else went horribly wrong with the carbon cycle to cause the anomalies. Other causes proposed:

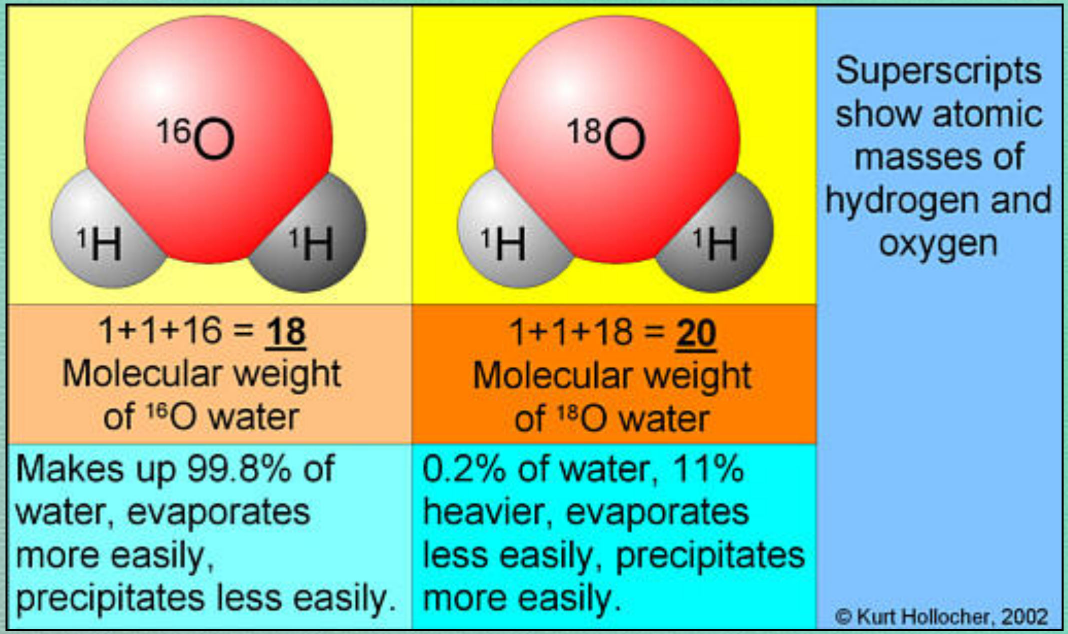
- Release of methane from the ocean floor
- Over-turning of a stratified Panthalassia, releasing massive CO_2 into atmosphere.

All causes involve an increase in atmospheric greenhouse gasses (methane is also a greenhouse gas), causing global warming

The P/Tr Disaster

Oxygen's two stable isotopes (^{16}O and ^{18}O) also vary in abundance through time, primarily due to changing temperature (locally and globally) and global ice volume.

There is a large negative shift in the ratio of the isotopes at the P/Tr boundary, which is most likely due to a large increase in global temperature (6°C or so at the equator). This is consistent with global warming due to increased greenhouse gasses, as well as corresponding to changes in global flora associated with the extinction event.



http://www.union.edu/PUBLIC/GEODEPT/hollocher/kth/illustrations_page.htm

The P/Tr Disaster

Other isotopes also do weird things at the same time as the extinction. Large swings in the relative abundance of sulfur isotopes also occurred at the boundary, coincident with the extinction. The same probable and possible causes suggested for the carbon isotope anomalies apply to the sulfur isotopes.

The stable isotopes of strontium also vary, indicating an increase in the rate of weathering (chemical and mechanical breakdown) of continental rocks. A rise in global CO_2 and temperature would both lead to increased weathering. Arguably, removal of plant cover could cause a similar increasing in weathering.

Dolenec, M. and B. Vokal. 2003. Carbon and sulfur isotope anomalies across the Permian-Triassic boundary (PTB) of Slovenia. Goldschmidt Conference Abstracts 2003: A81.

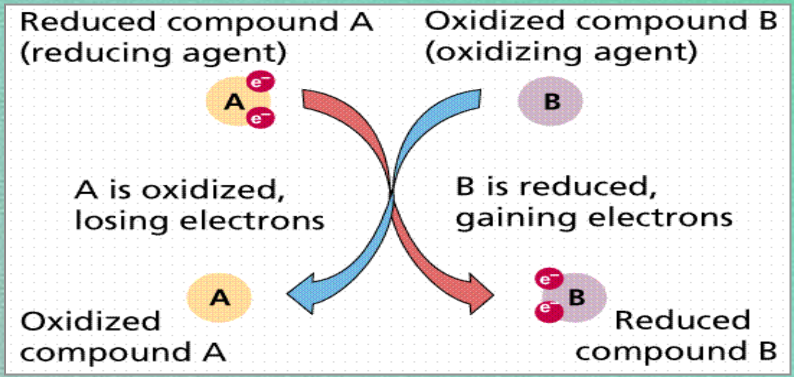
http://www.geocities.com/earthhistory/permo.html

The P/Tr Disaster

Several lines of geochemical evidence indicate that oxygen levels in the ocean were very low for perhaps several million years before the main extinction event, and that dysoxia (low oxygen) or anoxia (no oxygen) occurred from time to time around the globe.

Examples of geochemical evidence for dysoxia and anoxia:

- Presence of iron sulfides instead of iron oxides in marine sediments
- Changes in the relative abundances of rare earth elements in marine sediments
- Increased deposition of uranium due to reducing conditions



http://www.geocities.com/earthhistory/permo.html
http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEnzym.html

The P/Tr Disaster

There are also several lines of evidence in the fossil record supporting some kind of anoxia. These include:

- “Outages” of trace fossils (lack of sediment reworking by burrowers). Burrowing returned to normal after the main extinction event
- A strange period of time when bivalves and gastropods appeared to have been “micronized” - with tiny shells found in the fossil record world-wide for a time. Normal-sized shells returned after the main extinction.

Obviously, lack of oxygen would be rather unfortunate for most animals. Anoxia probably played a part (perhaps a major one) in the extinction. However, it had to be caused by something.

http://www.geocities.com/earthhistory/permo.html

The P/Tr Disaster

Both the terrestrial and marine fossil record indicate massive ecologic collapse in many formerly productive ecosystems. The recovery from the mass extinction was very slow - taking 5 million years or more. Some of the more notable features of this time are:

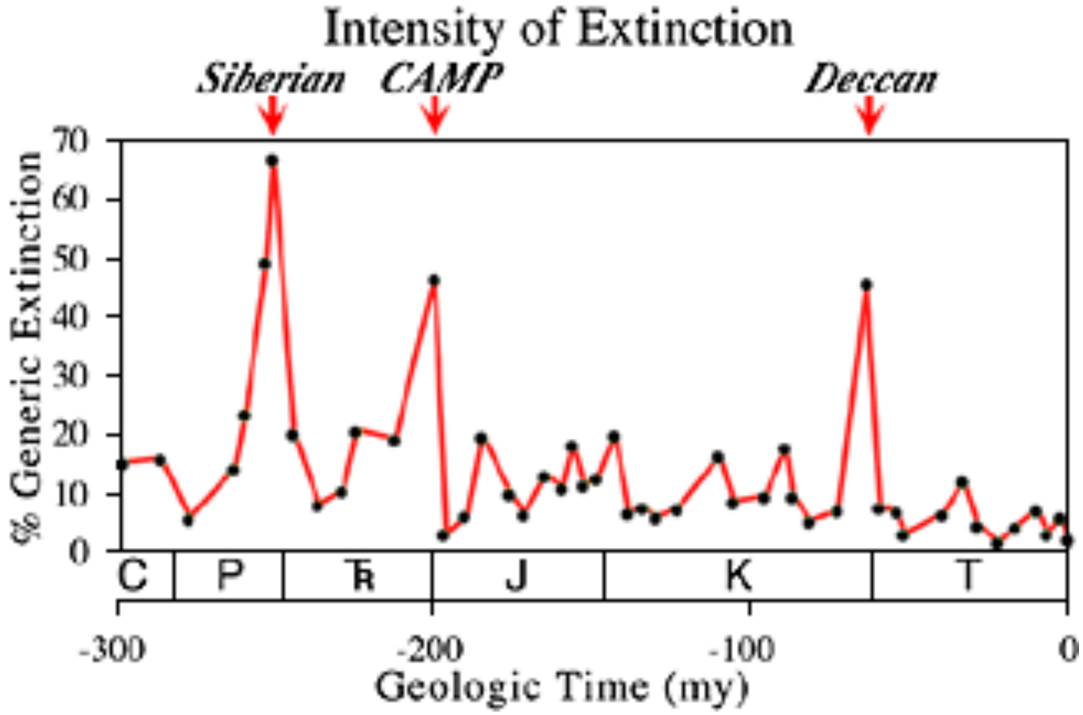
- A “coal gap” lasting for the entire early Triassic - ~10 million years.
- Replacement of the dominant flora elements by “weedy” plants and low diversity assemblages during the early Triassic. Forest ecosystems did not recover for ~5 million years
- High diversity marine reefs disappear completely, returning with different players in the mid-Triassic.
- Stromatolites were found in abundance in “normal” marine environments for the first time since the early Paleozoic, indicating a lack of grazers.

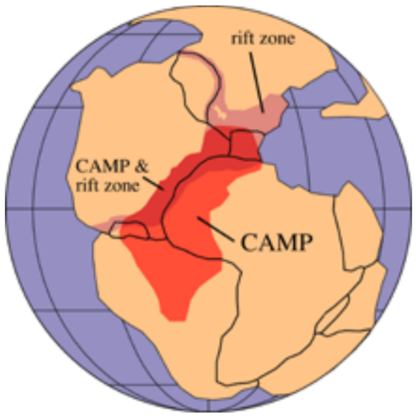
http://www.geocities.com/earthhistory/permo.html

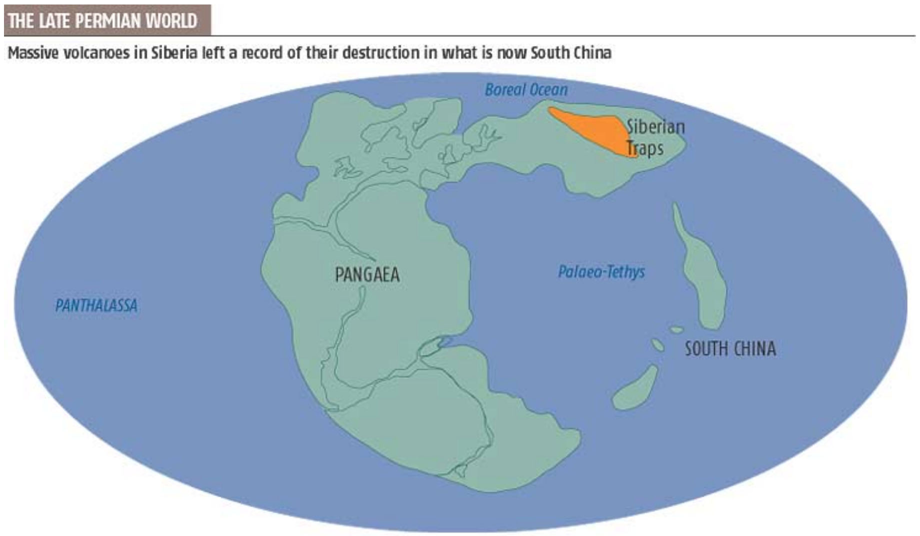
Major Suggested Causes

- **Terrestrial**
  - Climate change/ocean chemistry shifts
  - Atmospheric variation
  - Igneous activity
- **Extraterrestrial**
  - Asteroids/comets hitting Earth
  - Solar irregularity
  - Nearby cosmic events (e.g., supernovae)

The classes of causes are not mutually exclusive - e.g., extraterrestrial events can cause terrestrial change.



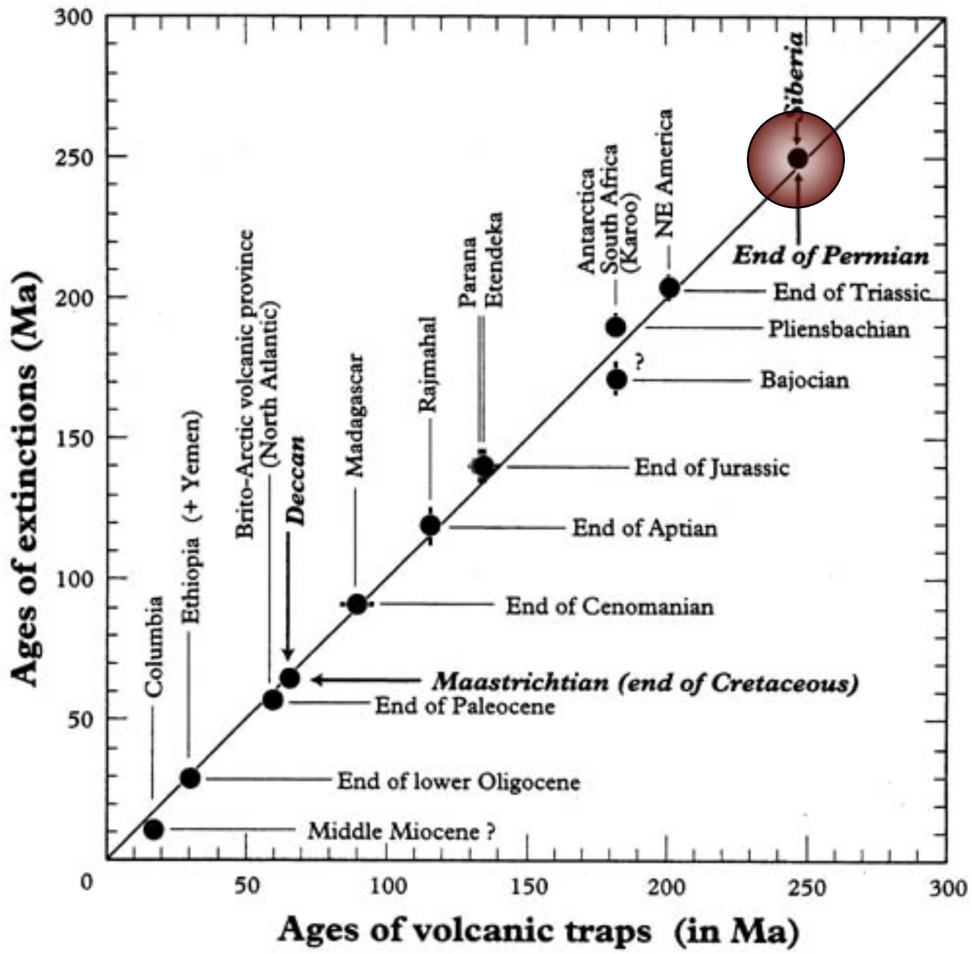




Flood Basalts and Extinction

http://palaeo.gly.bris.ac.uk/Essays/wipeout/23925001.jpg

http://www.ldeo.columbia.edu/~polsen/nbcp/rationale.html



Flood Basalts and Major Extinctions

The correlation between the ages of flood basalt events and major mass extinctions is rather remarkable.

http://faculty.plattsburgh.edu/thomas.wolosz/volcanism.htm