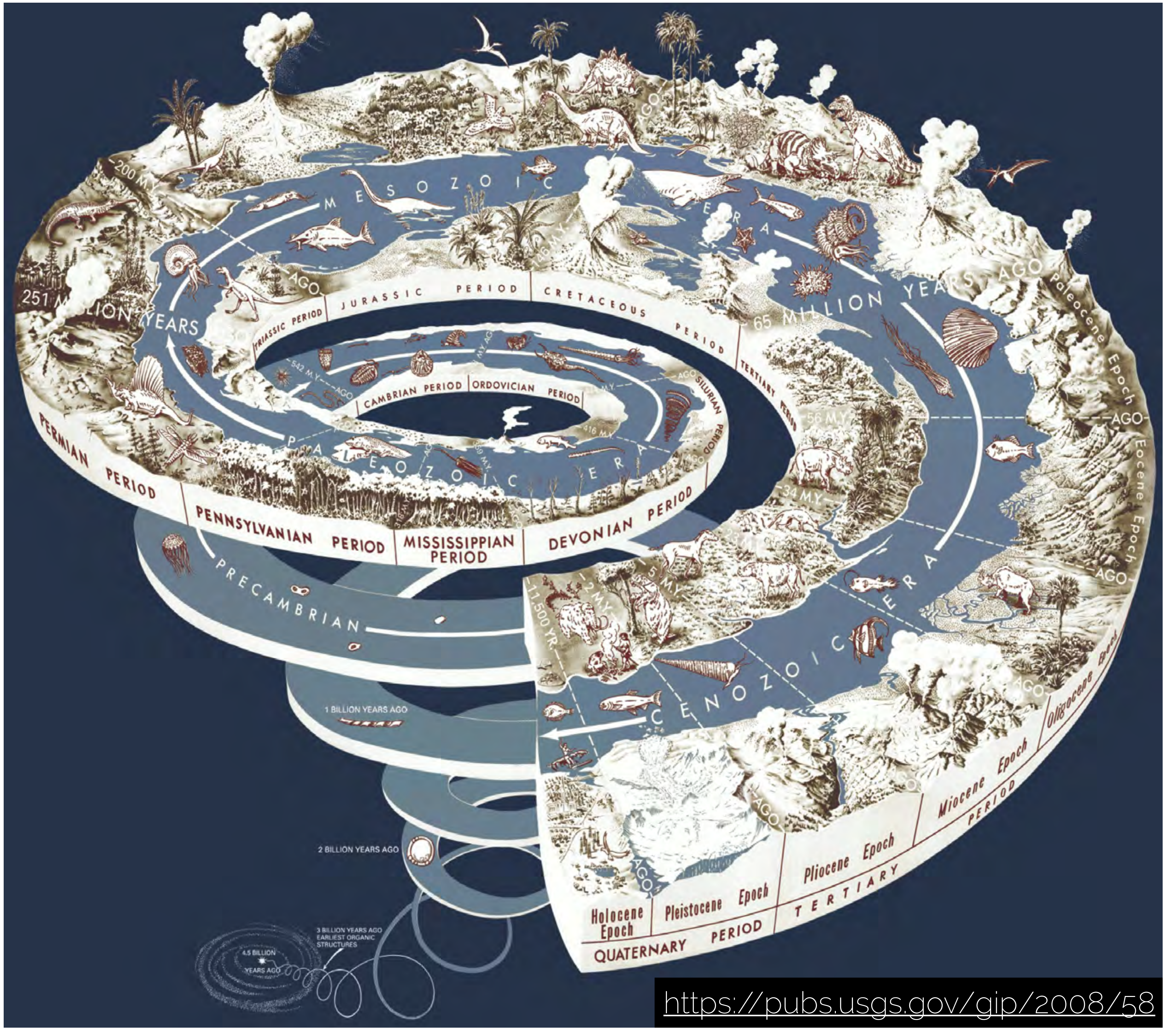
Speciation & Extinction in the Fossil Record

Macroevolution (BIOL 465X & EEOB 565X) Spring 2022 – Iowa State University

Extinction and speciation are apparent in the fossil record

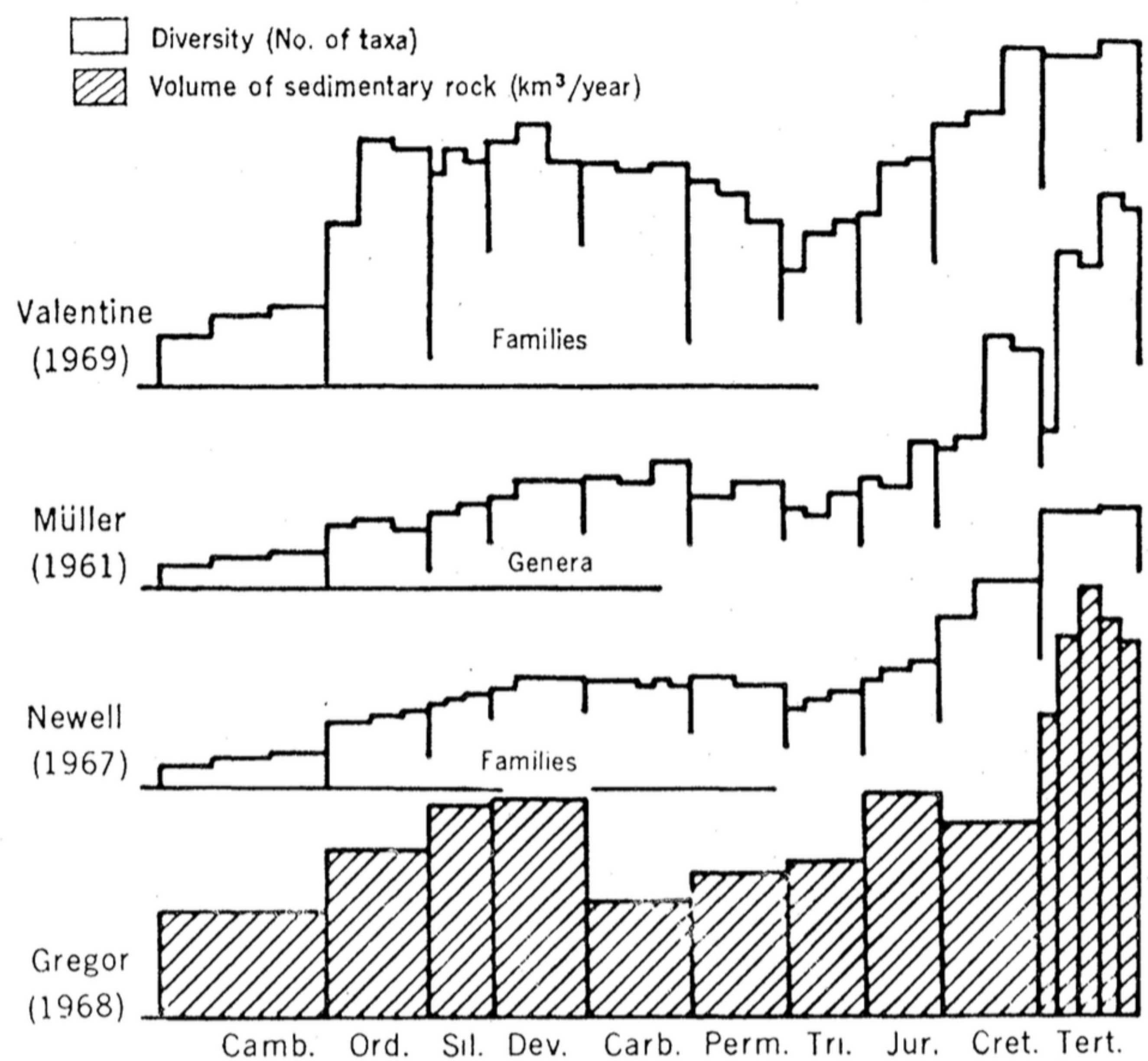


https://pubs.usgs.gov/gip/2008/58

Patterns of diversity in the fossil record

"The overall pattern is one of (i) a rapid rise in the number of taxa during the Cambrian and Early Ordovician, (ii) a maximum at about the Devonian, (iii) a slight but persistent decline to a minimum in the Early Triassic, and (iv) a rapid increase to an all-time high in diversity at the end of the Tertiary."

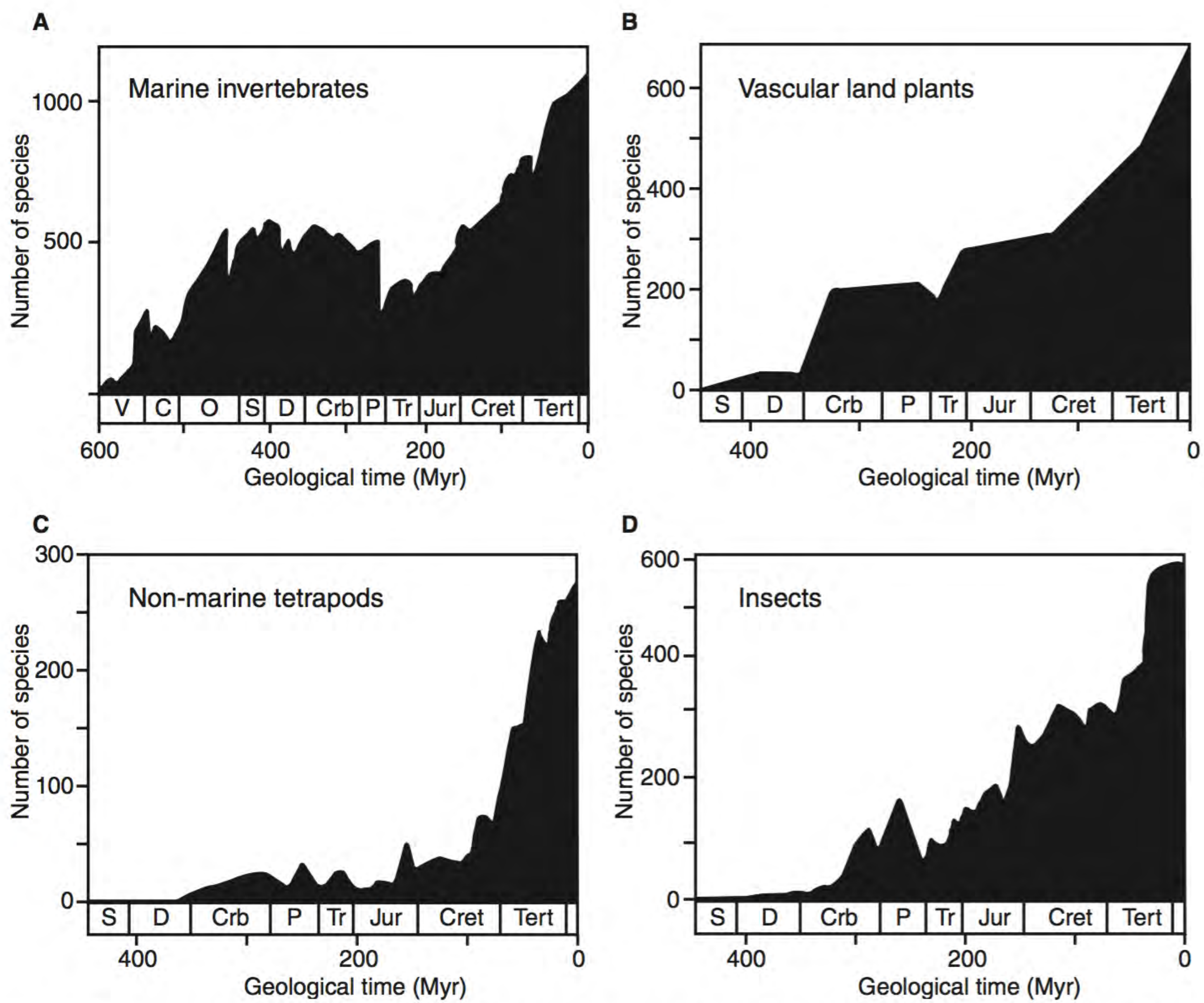
Comparing the number of taxa and rock volume in the Phanerozoic (541-0 million years ago)



(Raup 1972)

Patterns of diversity in the fossil record

How did life become so diverse?

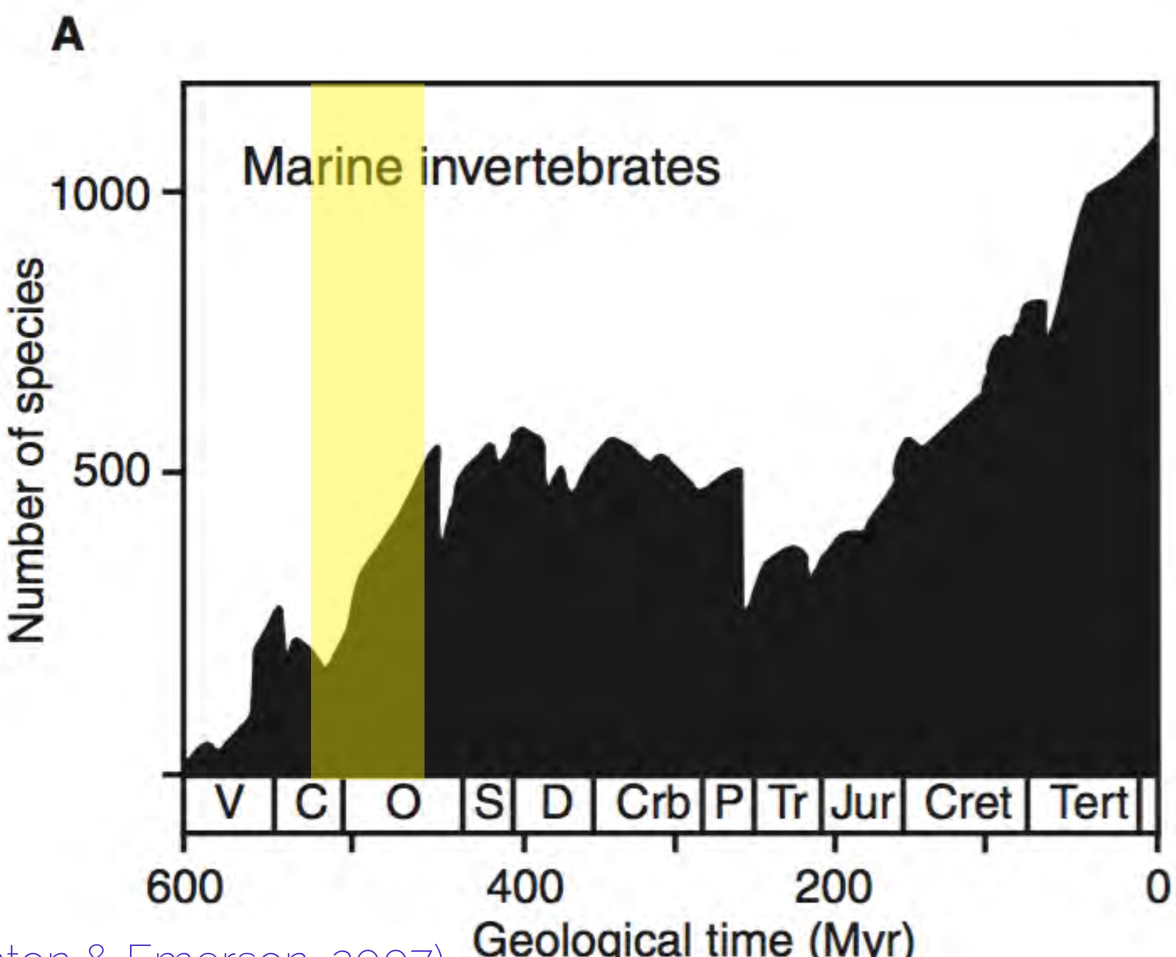


TEXT-FIG. 1. Patterns of diversification of: A, families of marine invertebrates; B, species of vascular land plants; C, families of non-marine tetrapods; and D, families of insects (based on Sepkoski 1984; Benton 1985; Niklas *et al.* 1985; Labandeira and Sepkoski 1993).

(Benton & Emerson, 2007)

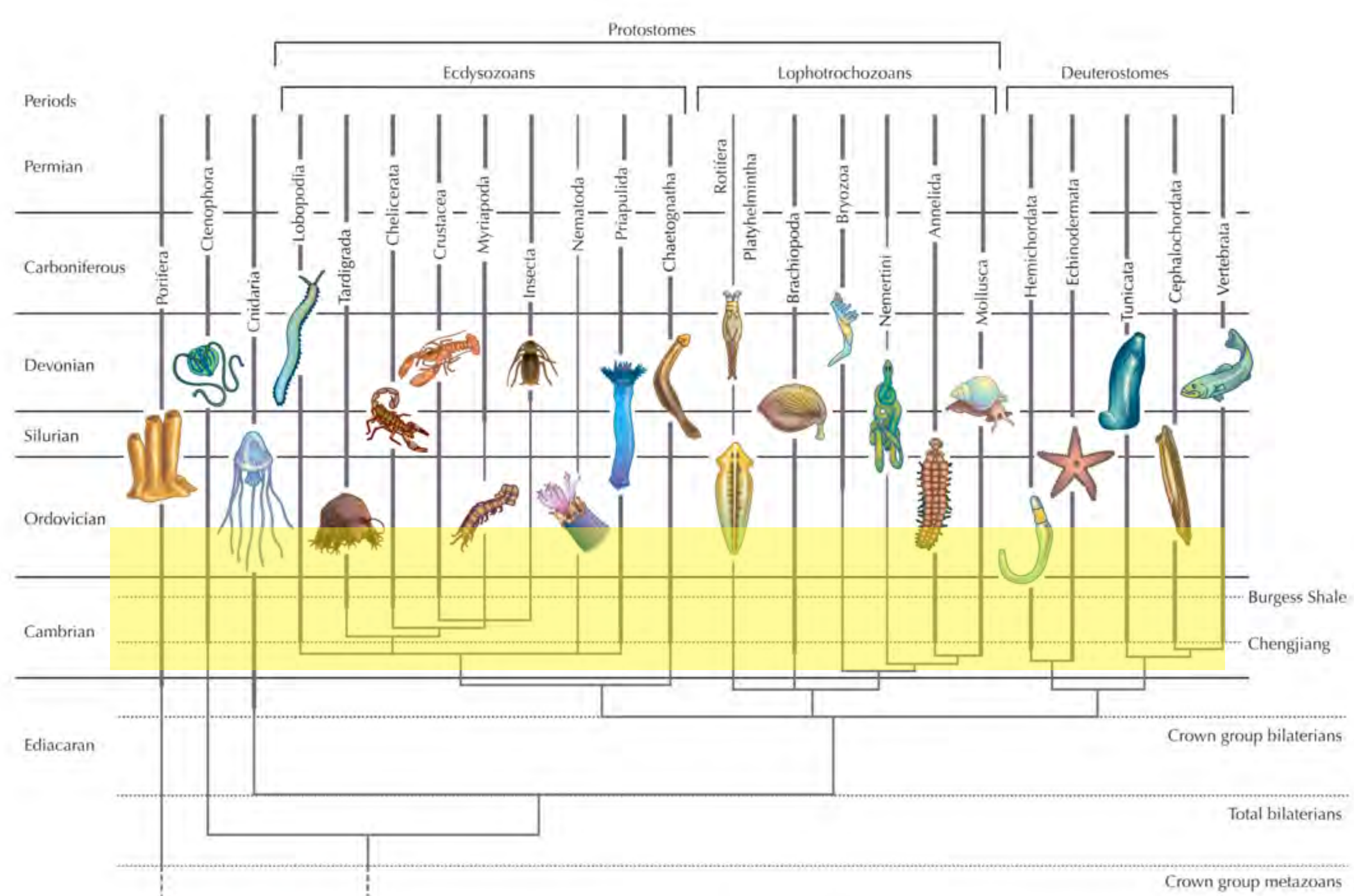
Evolutionary radiations

The Cambrian Explosion



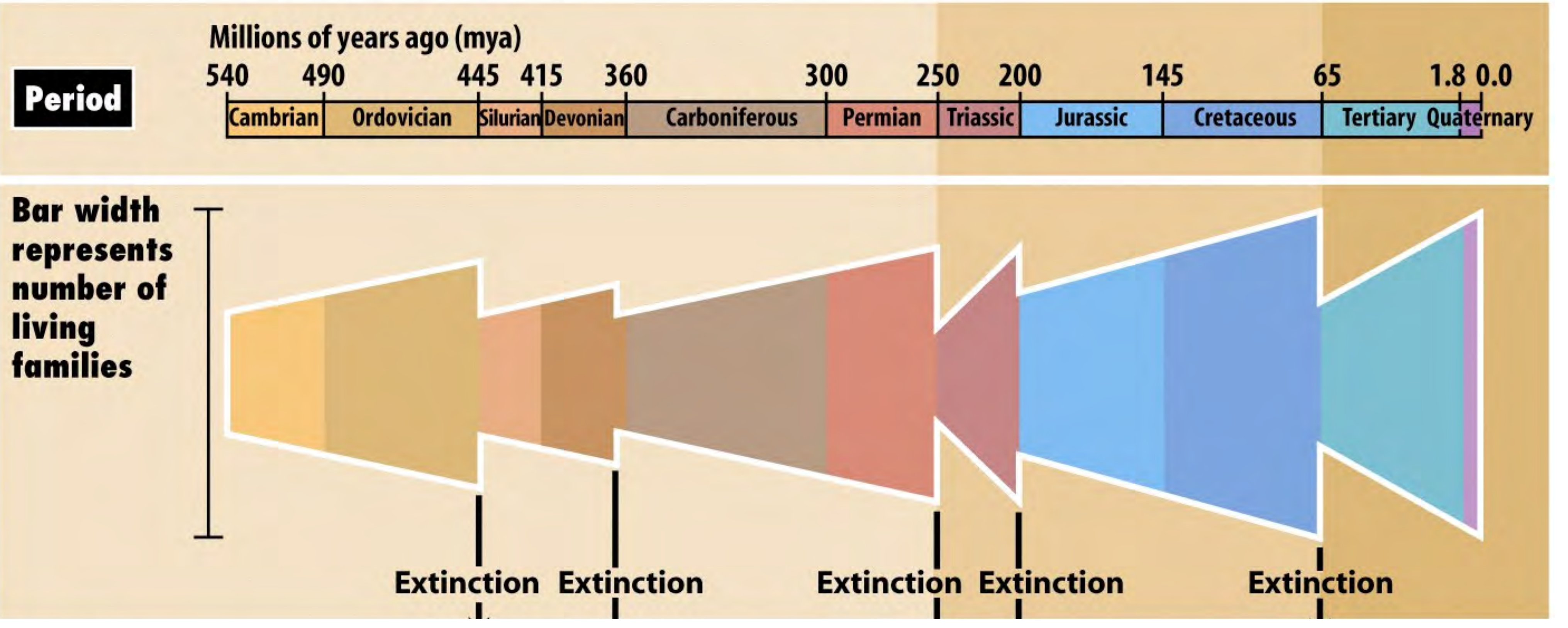
(Benton & Emerson, 2007)

"…a rapid rise in the number of taxa during the Cambrian and Early Ordovician" (Raup 1972)



Most major animal phyla appeared during this time

Mass extinctions

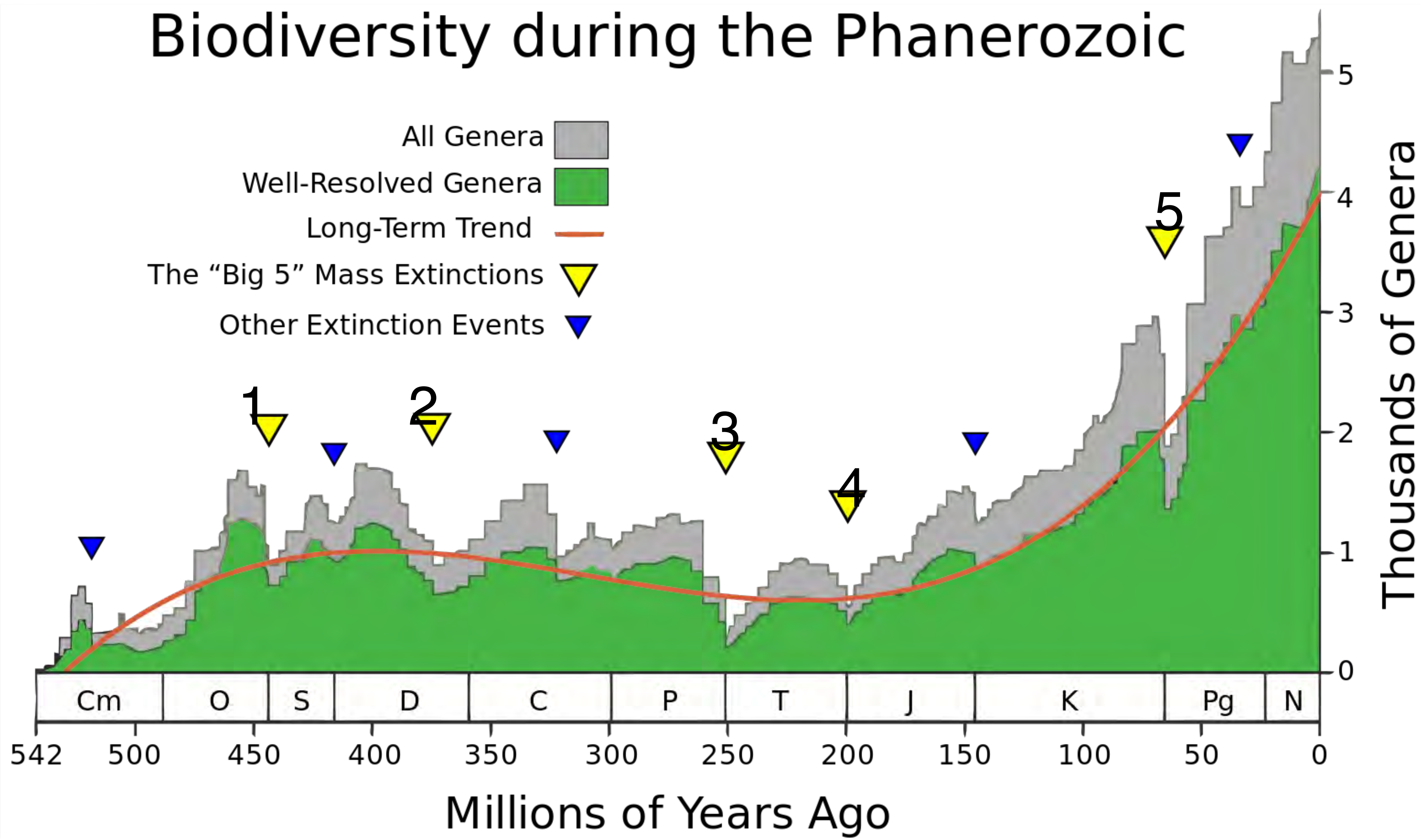


Periods during the Earth's history when a very large proportion of the living species go extinct.

During these time intervals, the rate of extinction is much higher than the normal (or background) rate.

There are 5 major extinctions observed in the fossil record when most of the diversity on Earth went extinct.

Mass extinctions



https://en.wikipedia.org/wiki/Phanerozoic#/media/File:Phanerozoic_Biodiversity.svg

(Rhode & Muller 2005)

Mass extinction events show elevated extinction rates

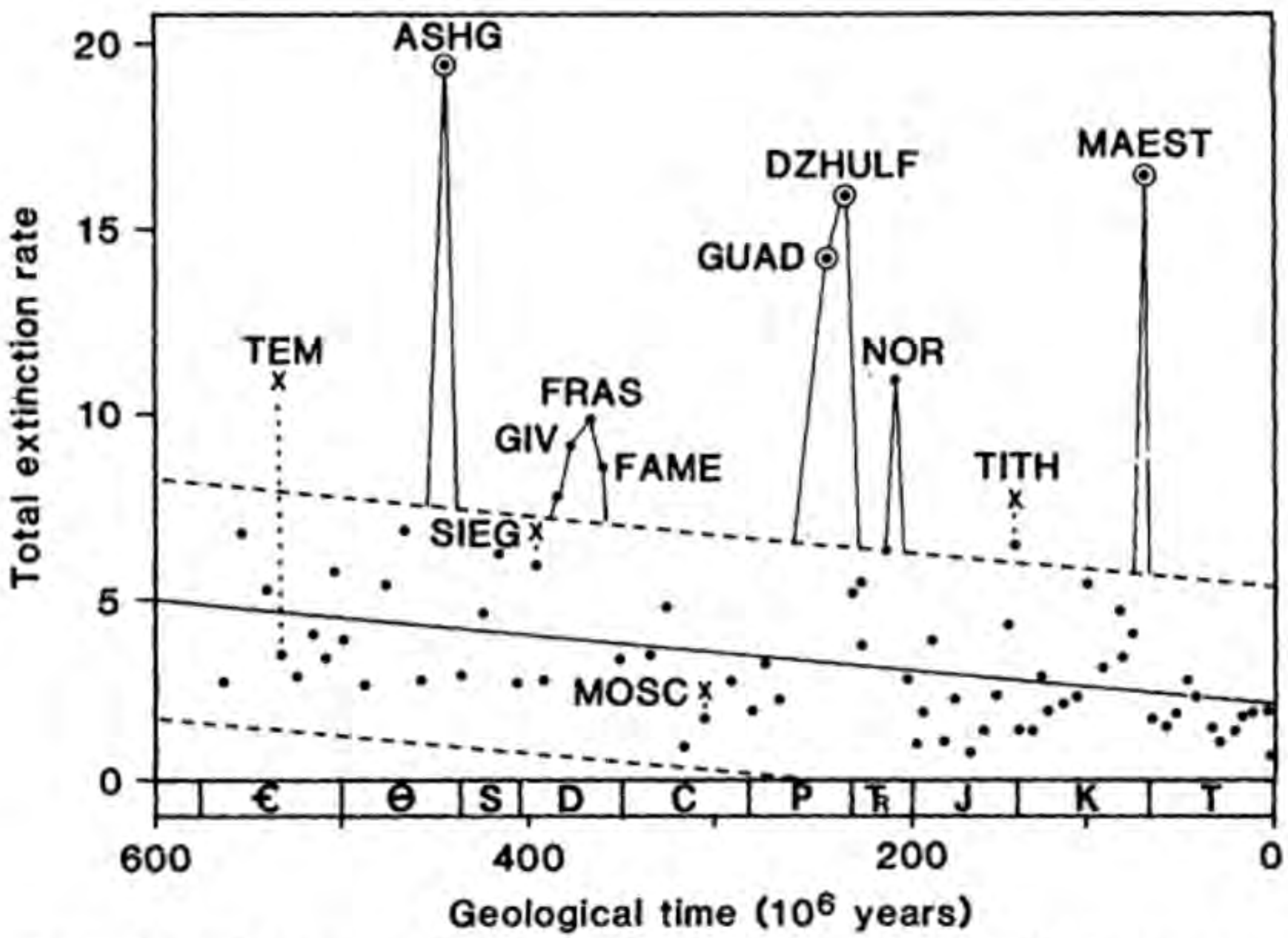
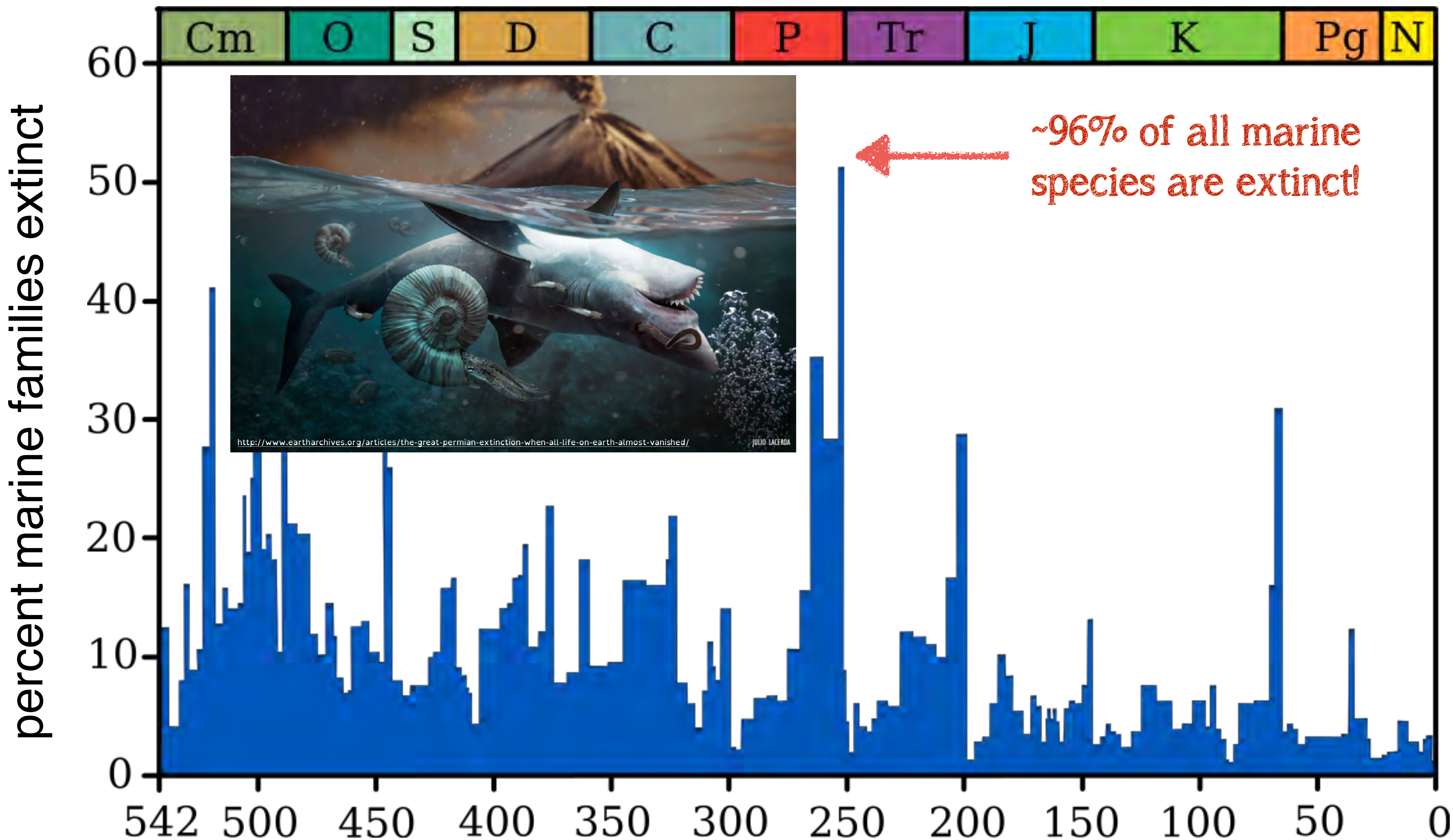


Fig. 1. Total extinction rate (extinctions per million years) through time for families of marine invertebrates and vertebrates. The plot shows statistically significant mass extinctions late in the Ordovician (ASHG), Permian (GUAD-DZHULF), Triassic (NOR), and Cretaceous (MAEST). An extinction event in the late Devonian (GIV-FRAS-FAME) is noticeable but not statistically significant. Circled points are those where the departure from the main cluster is highly significant ($P < .01$); X's indicate those cases where inclusion of rarely preserved animal groups substantially increases the calculated extinction rate (the point directly below the X is the rate calculated without the rarely preserved groups). The figure also shows a general decline in background extinction rate through time. The regression line is fit to the 67 points having extinction rates less than eight families per 10^6 years, and the dashed lines define the 95 percent confidence band for the regression. Abbreviations: TEM, Templetonian; ASHG, Ashgillian; SIEG, Siegenian; GIV, Givetian; FRAS, Frasnian; FAME, Famennian; MOSC, Moscovian; GUAD, Guadalupian; DZHULF, Dzhulfian; NOR, Norian; TITH, Tithonian; MAEST, Maestrichtian.

(Raup & Sepkoski 1982)

Permian-Triassic Mass Extinction



https://en.wikipedia.org/wiki/File:Extinction_intensity.svg

(Rhode & Muller 2005)

Permian-Triassic Mass Extinction

The Great Dying

Loss of 96% of marine species and 70% of terrestrial species

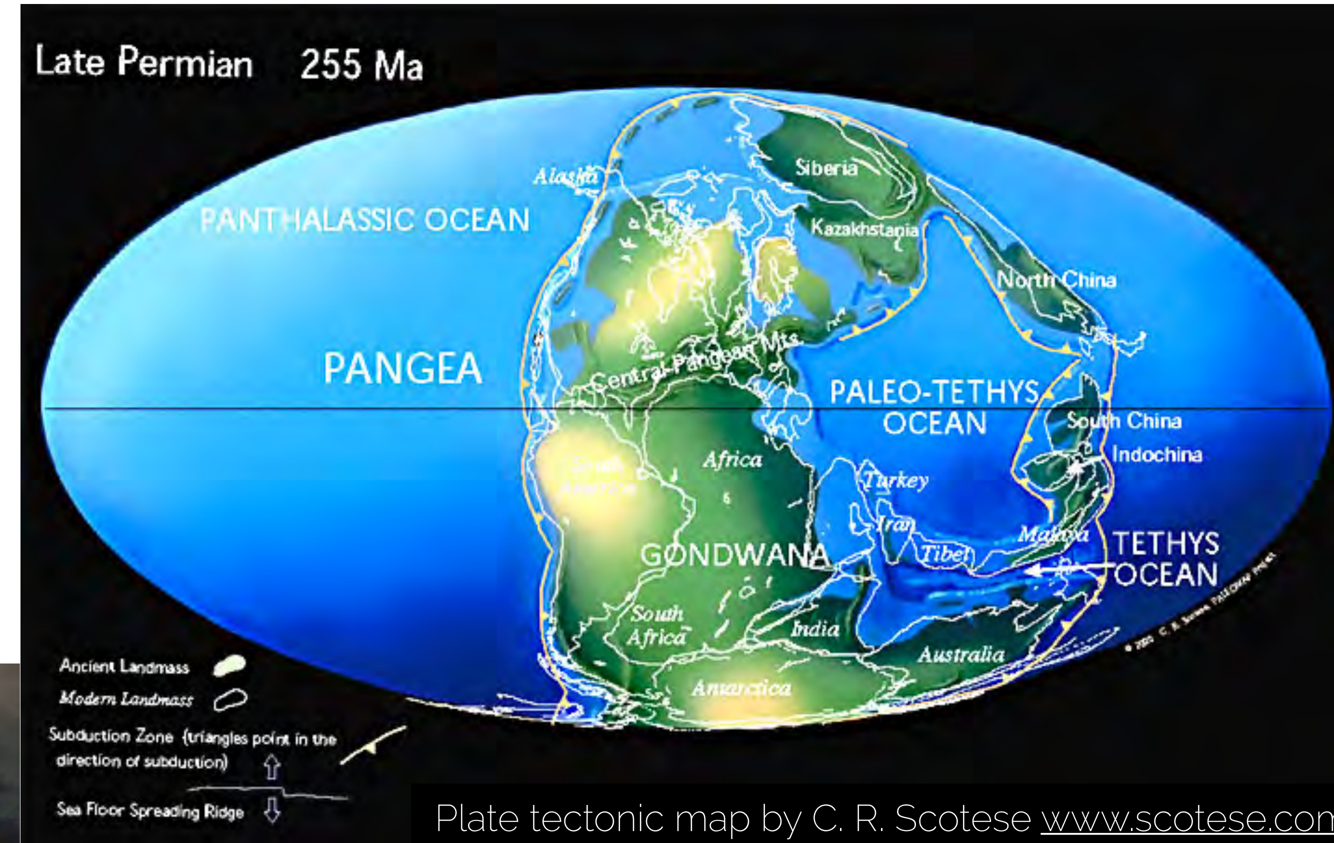


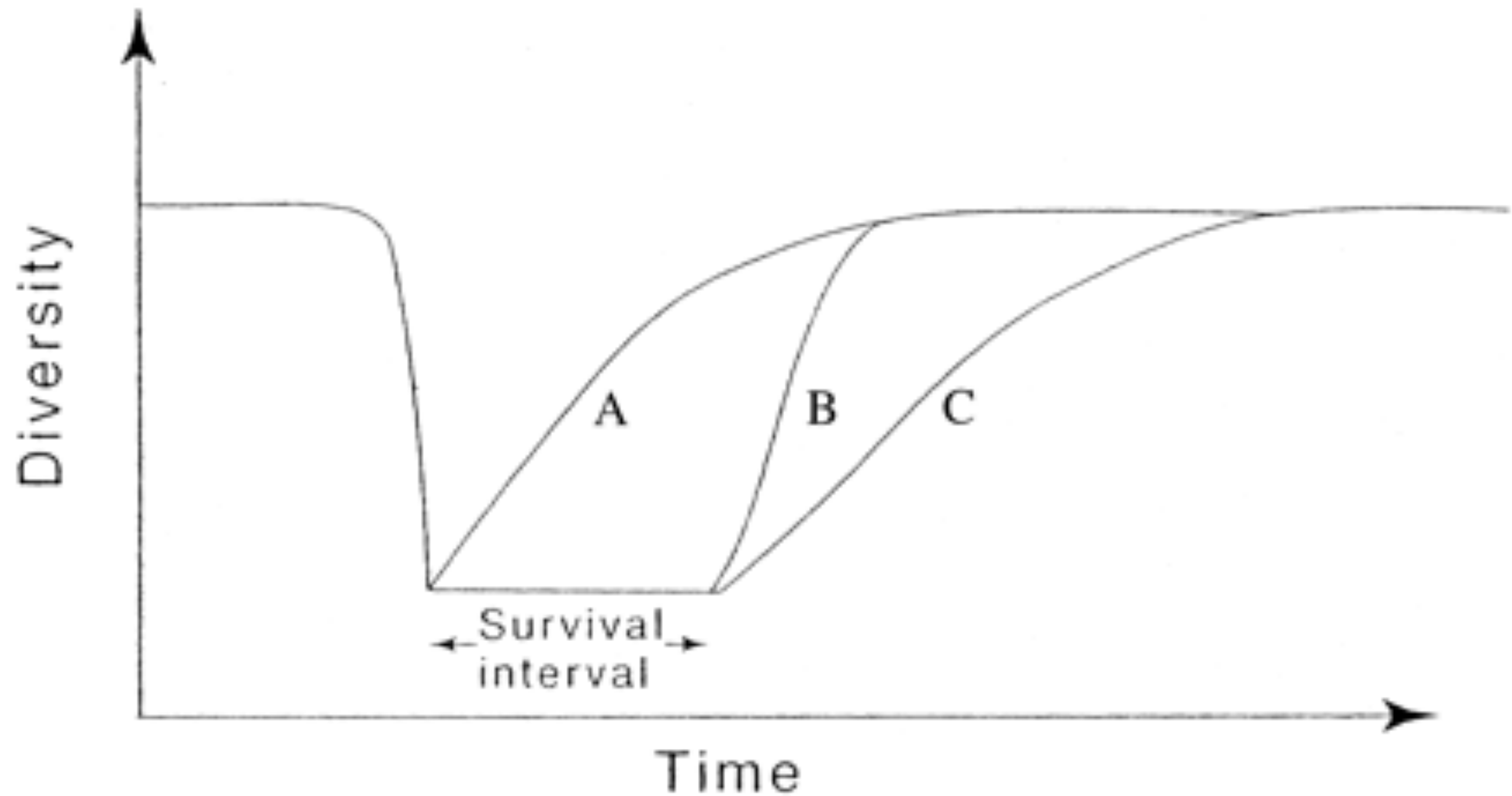
Plate tectonic map by C. R. Scotese www.scotese.com

http://www.eartharchives.org/articles/the-great-permian-extinction-when-all-life-on-earth-almost-vanished/

Causes include:
large-scale volcanism, ocean acidification, acid rain, anoxia, formation of Pangea

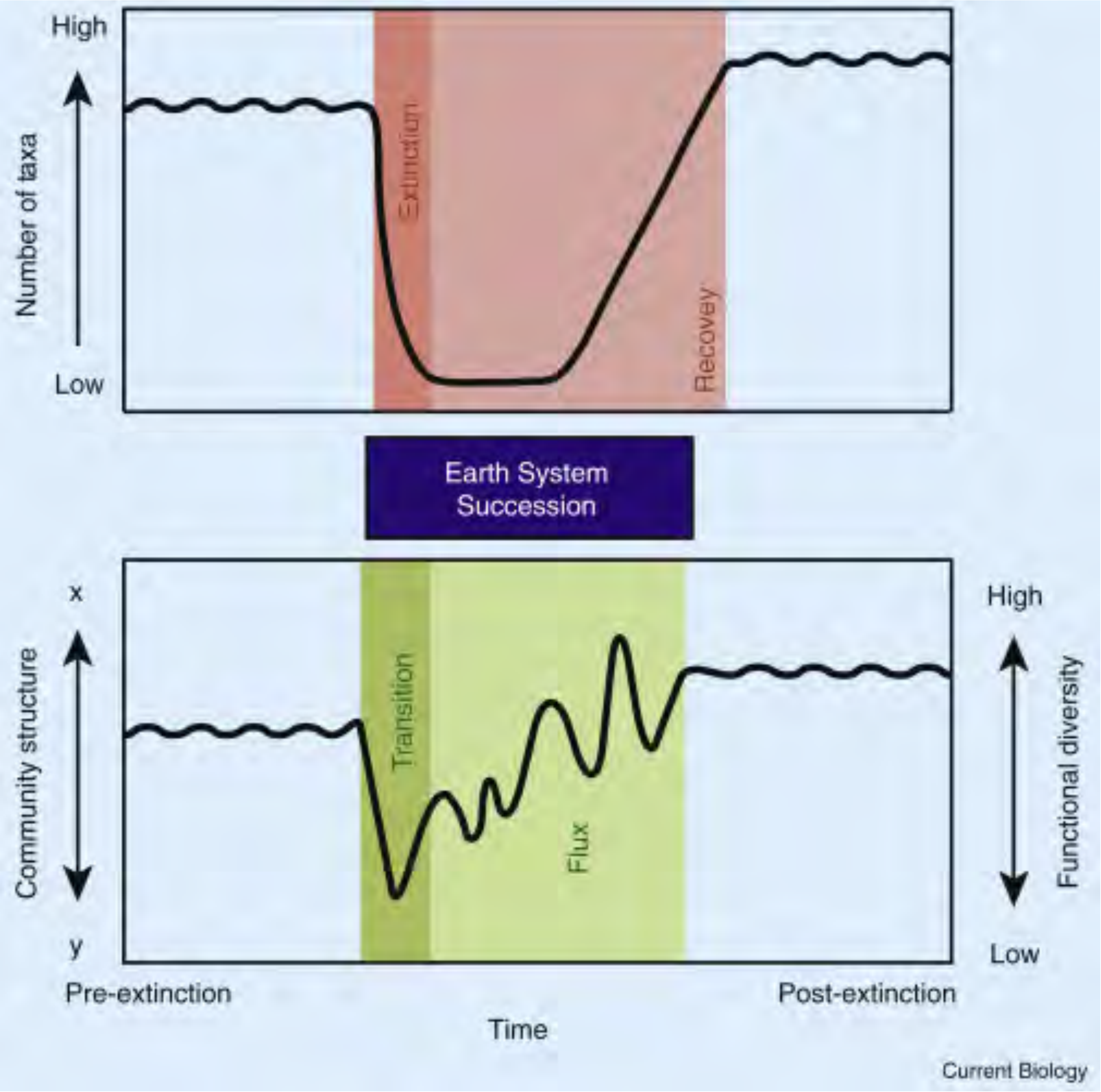
Recovery after mass extinction

Often measured in return to similar levels of diversity, even though the community composition is different



(Irwin 2001)

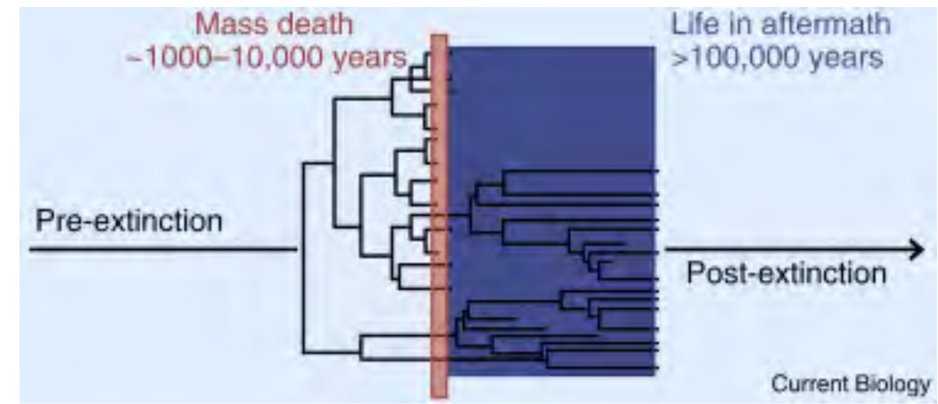
Recovery after mass extinction

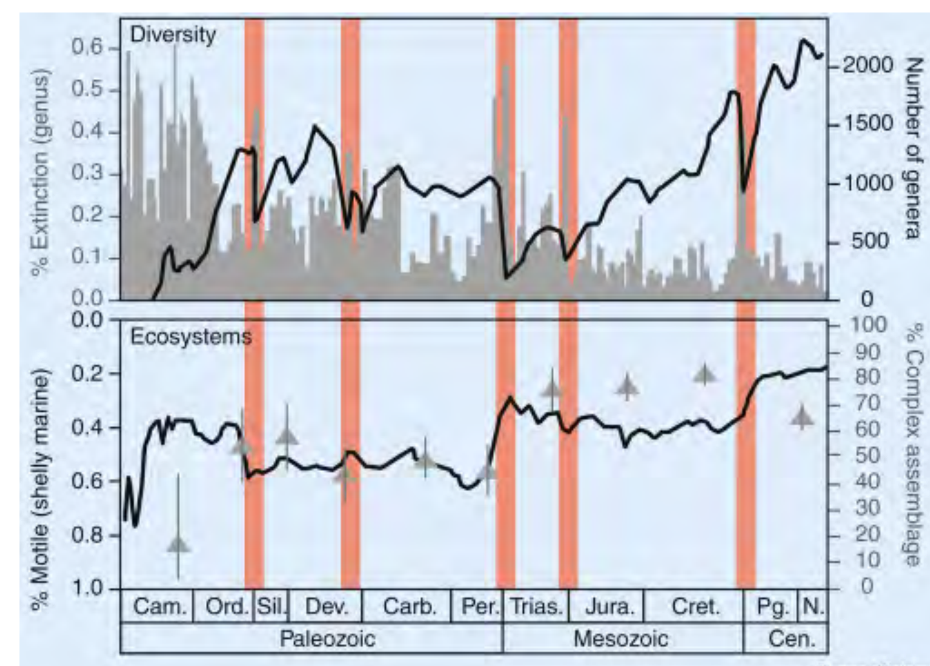


(Hull 2015)

Recovery after mass extinction

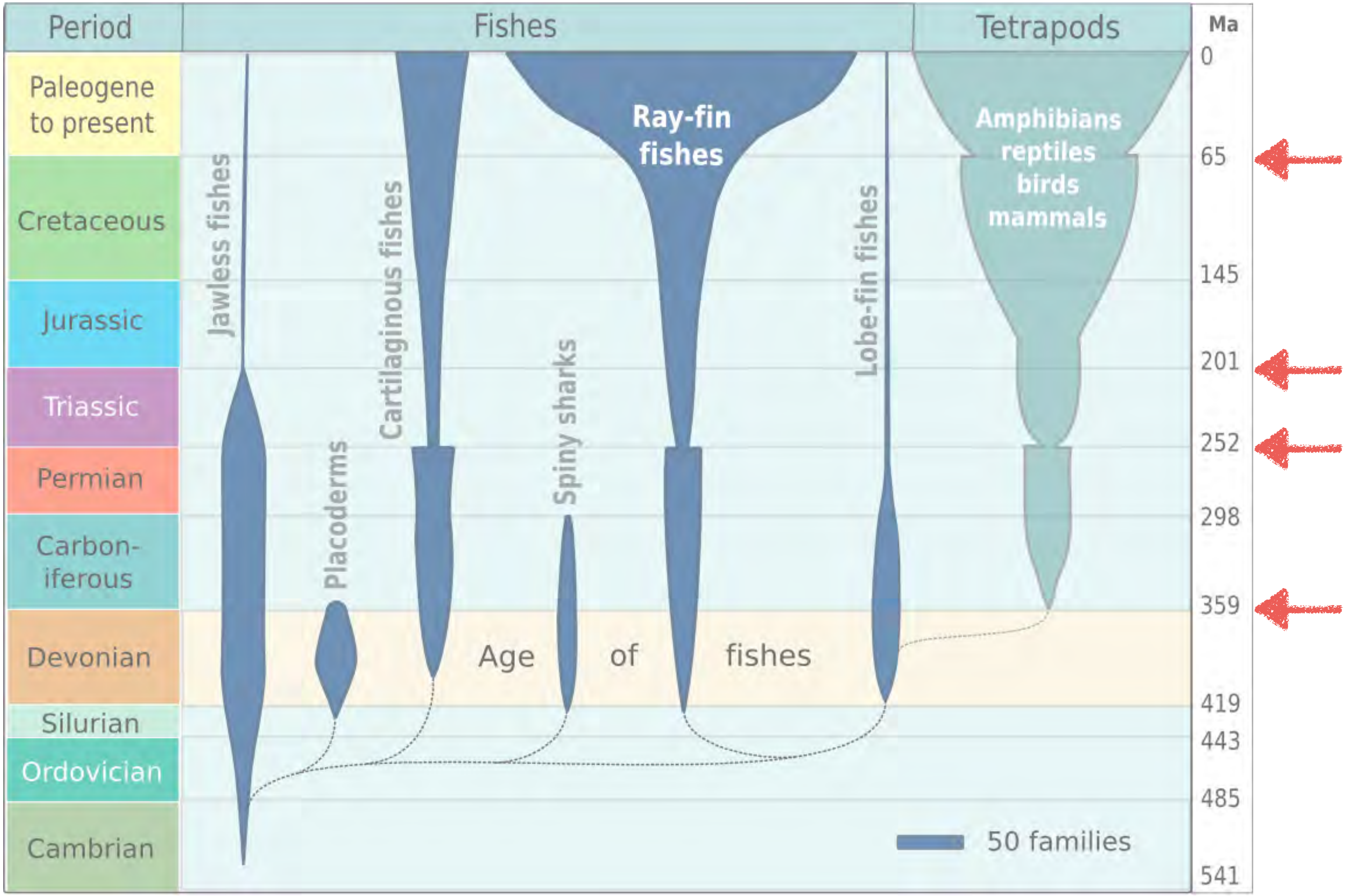
Event	Trigger	Losers	Winners
Ordovician-Silurian (OS)	Glaciation	Strophomenid & rhynchonellid brachiopods, nautiloids, trilobites, crinoids, conodonts, graptolites	Siliceous sponges, tabulate corals
Late Devonian (F/F)	Glaciation	Stromatoporoids, tabulate corals, trilobites, cricoconarids, eurypterids, brachiopods, ammonoids, agnathans, placoderms	Chondrichthyans, actinopterygians (ray-finned fishes)
Permian-Triassic (PT)	Volcanism	Brachiopods, crinoids, ammonoids trilobites, tabulate and rugose corals, basal tetrapods	Bivalves, gastropods, malacostracans, echinoids, scleractinian corals, archosaurs
Triassic-Jurassic (TJ)	Volcanism	Calcareous sponges, scleractinian corals, brachiopods, nautiloids, ammonites	Siliceous sponges, dinosaurs
Cretaceous-Paleogene KPg)	Impact	Non-avian dinosaurs, ammonites, calcareous plankton, mosasaurs, pterosaurs, rudist bivalves	Birds, mammals, spiny-rayed fishes





(Hull 2015)

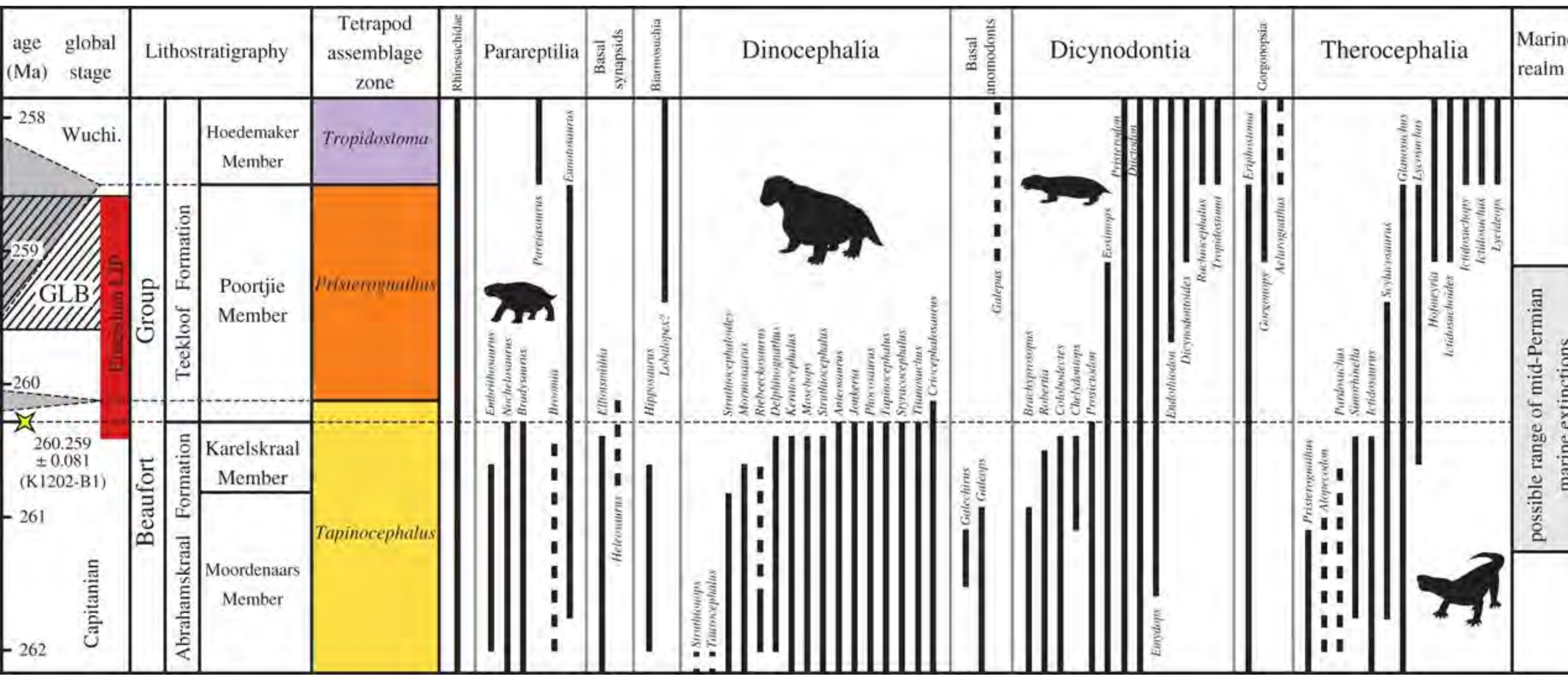
Turnover



(Benton, 2015. Vertebrate Paleontology)

Stratigraphic range data

Paleontological data are curated in databases that contain the first and last appearances of taxa.



(Day et al. 2015)

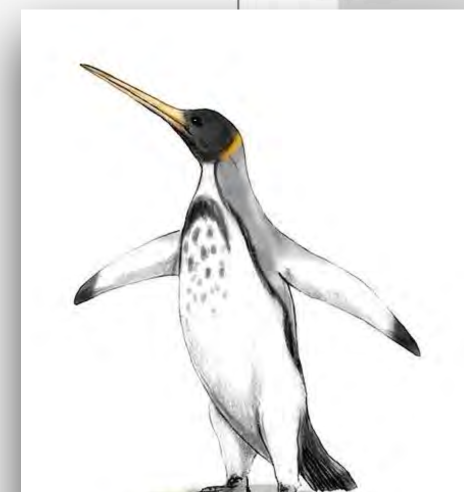
Paleontological databases

https://paleobiodb.org

What data exist for fossil lineages?

Main Menu | About | Download | Search | Search the database | Login

Basic info | Taxonomic history | Classification | Relationships | Morphology | Ecology and taphonomy | External Literature Search | **Age range and collections**



A reconstruction of the fossil penguin *Icadyptes*

Spheniscidae

Reptilia - Avetheropoda - Spheniscidae

Age range

Maximum range based only on fossils: base of the Ypresian to the top of the Holocene *or* 56.00000 to 0.00000 Ma
Minimum age of oldest fossil (stem group age): 55.8 Ma

Collections (114 total)

Time interval	Ma	Country or state	Original ID and collection number
Teurian	66.0 - 55.8	New Zealand (South Island)	Crossvallia waiparensis (203390 203391 203392)
Late/Upper Paleocene	58.7 - 55.8	Antarctica	Crossvallia unienwillia (74613)
Ypresian	56.0 - 47.8	Antarctica (Seymour Island)	Palaeeudyptes gunnari (63549)
Ypresian	56.0 - 47.8	Antarctica	Spheniscidae indet. (32360 52067 100414 120576)
Ypresian - Lutetian	56.0 - 41.3	Antarctica (Seymour Island)	Palaeeudyptes gunnari (63551)
Eocene	56.0 - 33.9	Chile	Spheniscidae indet. (99572)
Middle Eocene - Late/Upper Eocene	48.6 - 33.9	Chile	Spheniscidae indet., Palaeeudyptes sp. (99479)
Lutetian	47.8 - 41.3	Antarctica (Seymour Island)	Spheniscidae indet. (176083)

 https://paleobiodb.org/classic/checkTaxonInfo?taxon_no=39710

What questions can we ask with these data?

What factors influenced diversity in the Cambrian?

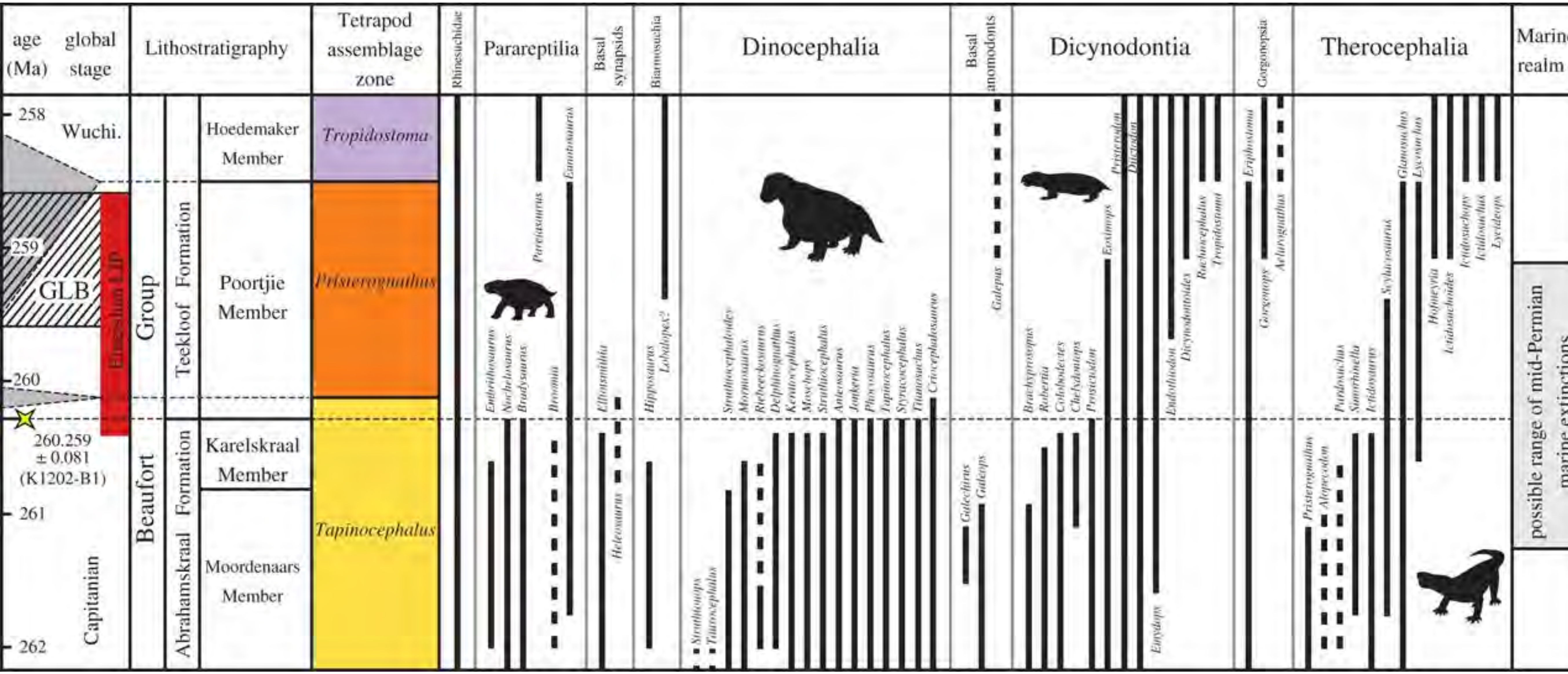
Is there an association between global temperature and biodiversity?

Were dinosaurs declining in diversification prior to the Chicxulub Impact?

Are human-activities correlated with an increase in rates of extinction in the Anthropocene?

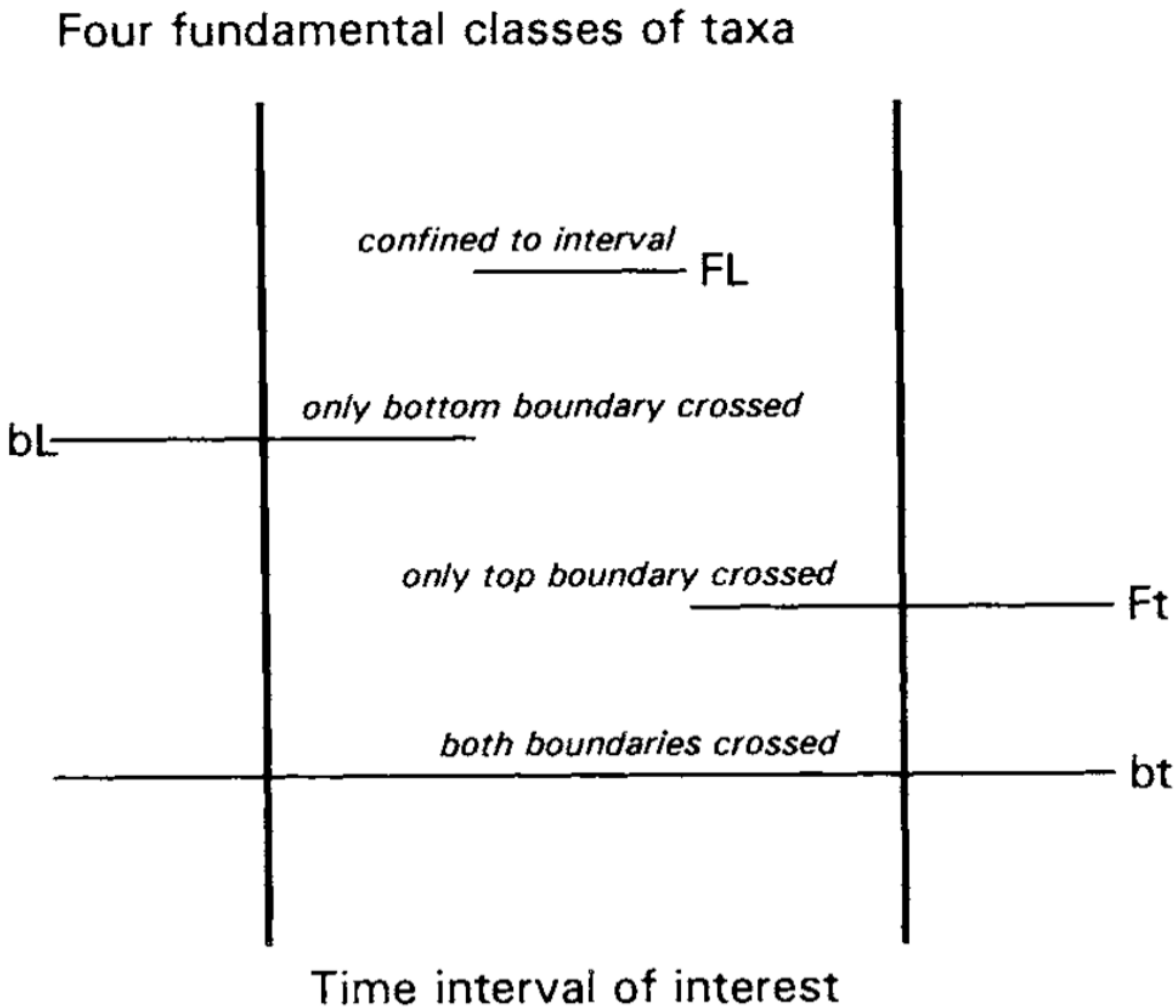
…and much, much more…

Stratigraphic range data



(Day et al. 2015)

Measuring rates of speciation and extinction



(Foote 2000)

Measuring rates of speciation and extinction

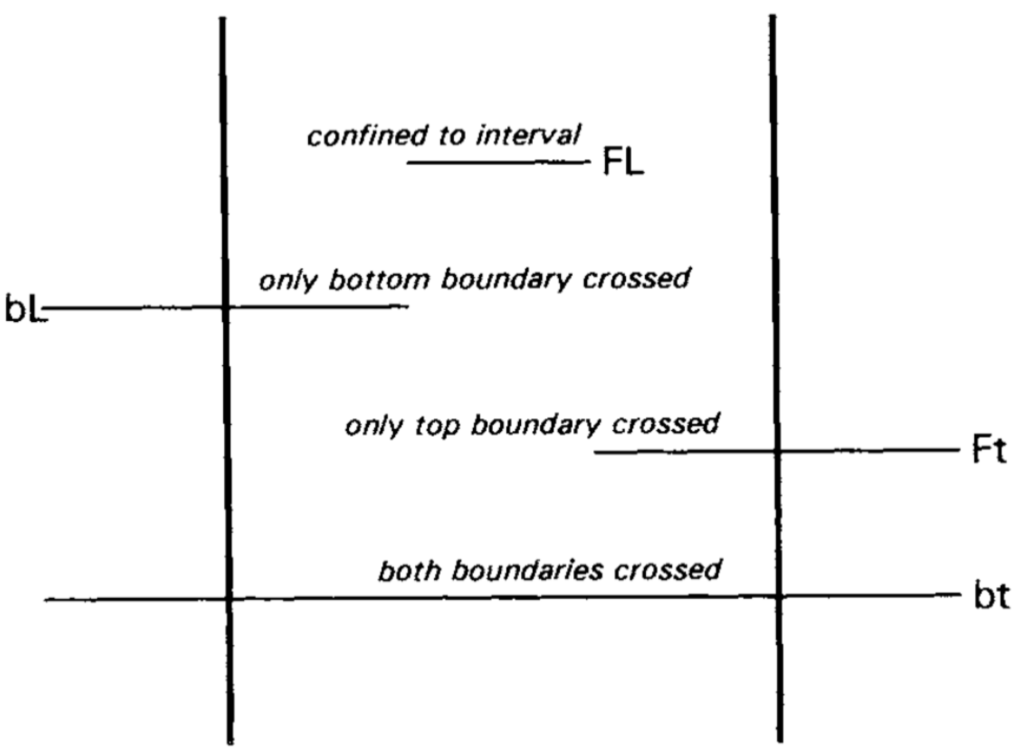
singletons – taxa confined to the interval, i.e., taxa whose first and last appearance are both within the interval t_i (*FL*);

bottom boundary crossers – taxa that cross the bottom boundary and make their last appearance during the interval (*bL*);

top boundary crossers – taxa that make their first appearance during the interval and cross the top boundary (*Ft*);

range through taxa – taxa that range through the entire interval, crossing both the top and bottom boundaries (*bt*).

Four fundamental classes of taxa



Time interval of interest

(Foote 2000)

Measuring per-interval rates of speciation and extinction

Use the proportions of first & last appearances during a given interval

speciation $$\lambda = \left(\frac{N_{FL} + N_{Ft}}{N_{tot}} \right) \times \frac{1}{\Delta t_i}$$

extinction $$\mu = \left(\frac{N_{FL} + N_{bL}}{N_{tot}} \right) \times \frac{1}{\Delta t_i}$$

(Foote 2000)

Measuring per-interval rates of speciation and extinction

Use the proportions of first & last appearances during a given interval

number of originations

speciation $$\lambda = \left(\frac{N_{FL} + N_{Ft}}{N_{tot}}\right) \times \frac{1}{\Delta t_i}$$

total diversity

time interval

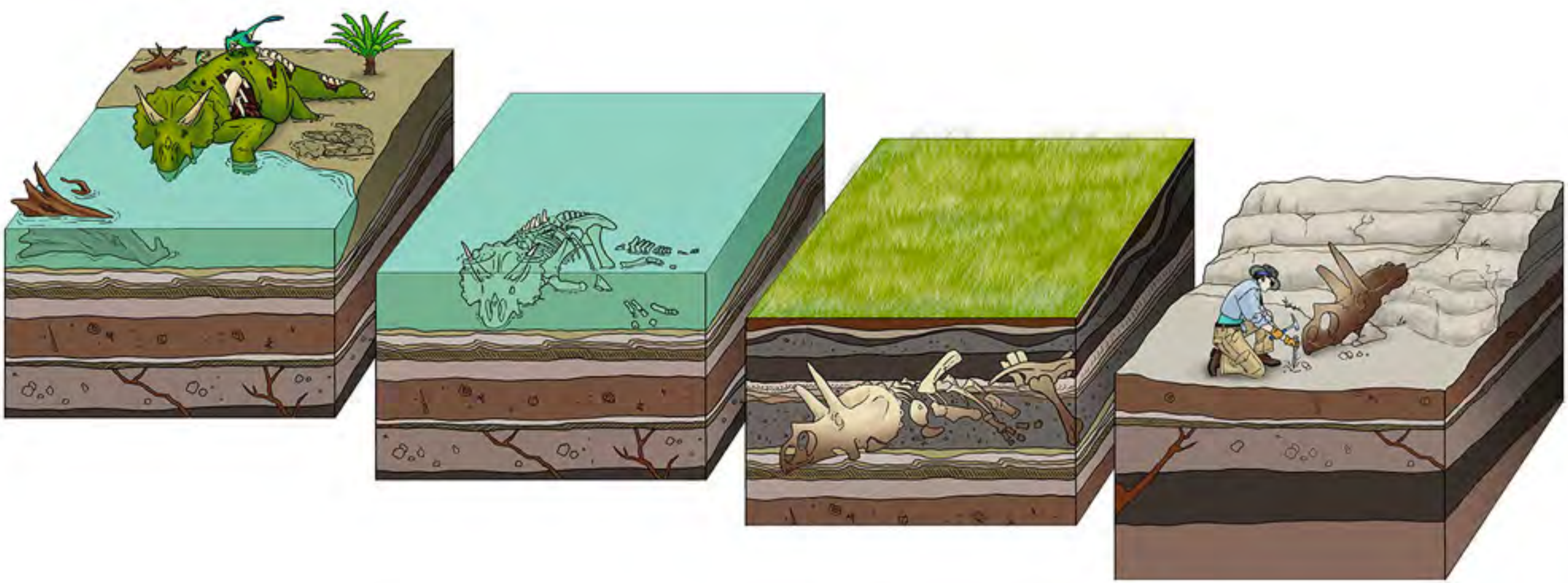
number of extinctions

extinction $$\mu = \left(\frac{N_{FL} + N_{bL}}{N_{tot}}\right) \times \frac{1}{\Delta t_i}$$

(Foote 2000)

Taphonomy

The area of geology that considers the process by which an organism is fossilized, preserved, and recovered



(image by Becky Barnes, ND Geological Survey)

There are many factors that influence the observed fossil record

Lagerstätten effect: because some deposits are extremely species rich, this may be because of high rates of fossil preservation/recovery or high rates of diversification

http://www.rmoutlook.com/Magic-of-Burgess-shale-continues-to-amaze-20140925

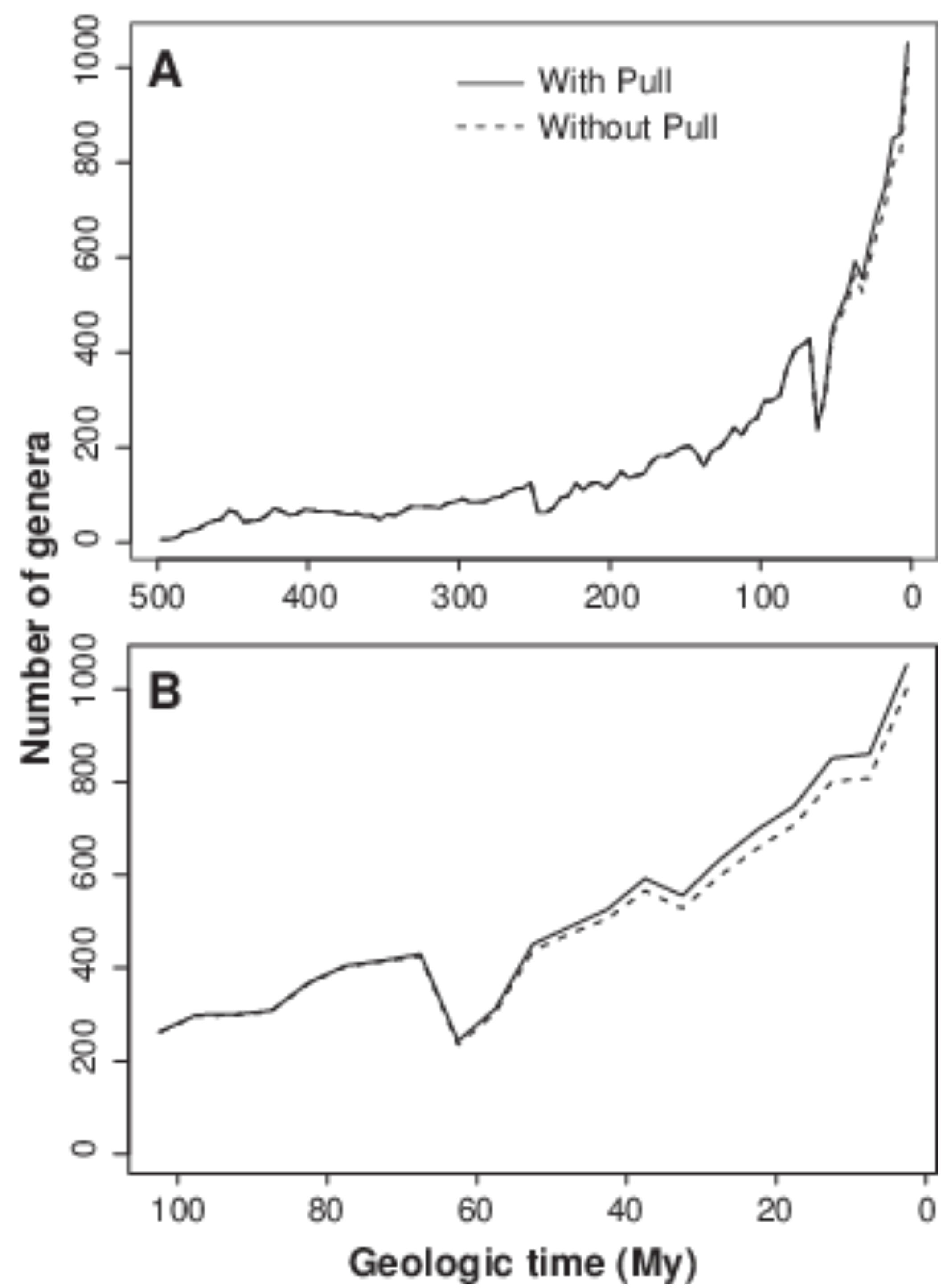
Signor–Lipps effect: because the first and last appearance of a fossil taxon is not the first or last representative of the lineage, we cannot precisely "observe" extinction events.

http://vertebrates.si.edu/fishes/coelacanth/coelacanth_wider.html

There are many factors that influence the observed fossil record

Pull of the recent: Because younger (including living) species are sampled, this extends the stratigraphic ranges of many taxa to the present through intervals where fossils are not observed. This leads to higher apparent diversity in the Cenozoic (the last 66 My)

Genus-level richness of marine bivalves



(Jablonski 2003)

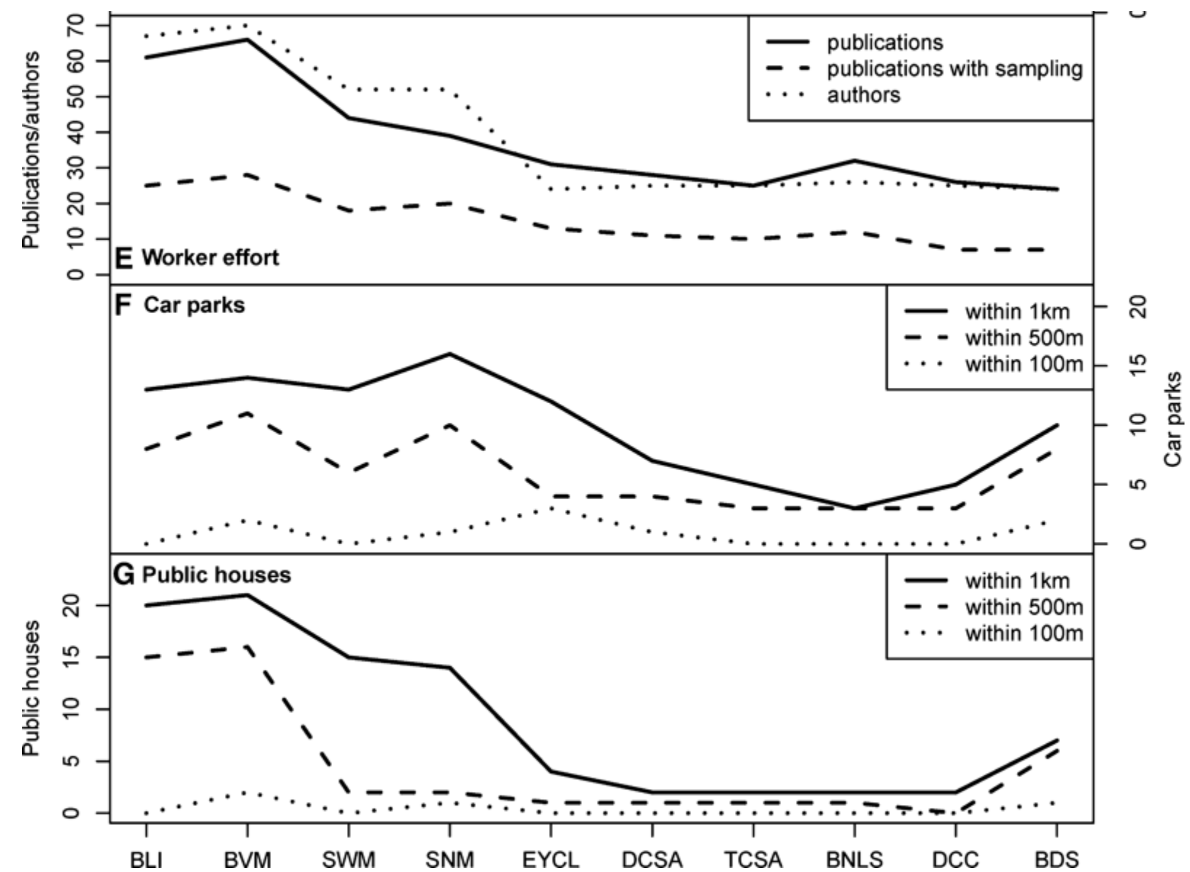
There are many factors that influence the observed fossil record

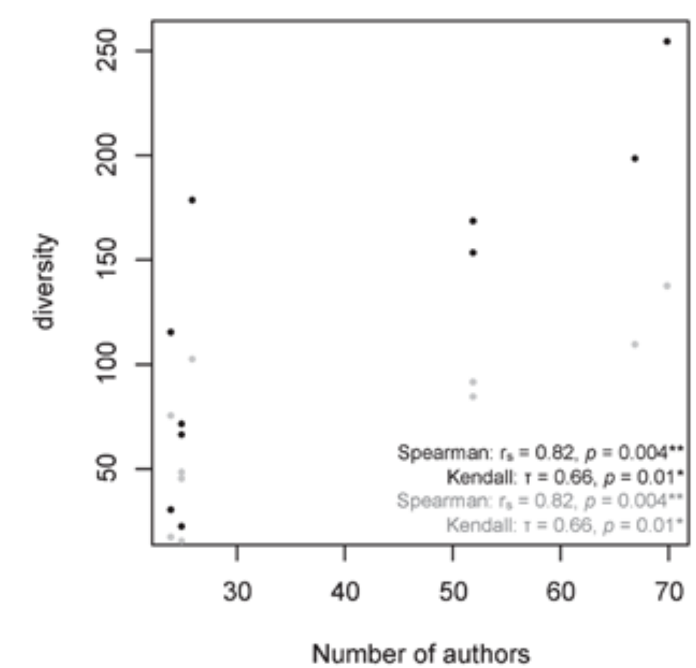
Human-related factors play a major role in rates of fossil recovery.

Fossils are more likely to be sampled if they are accessible.

We are more likely to recognize fossils of certain taxa.

We are more likely to look for fossils of taxa we like (e.g., dinosaurs).





(Dunhill et al 2012)

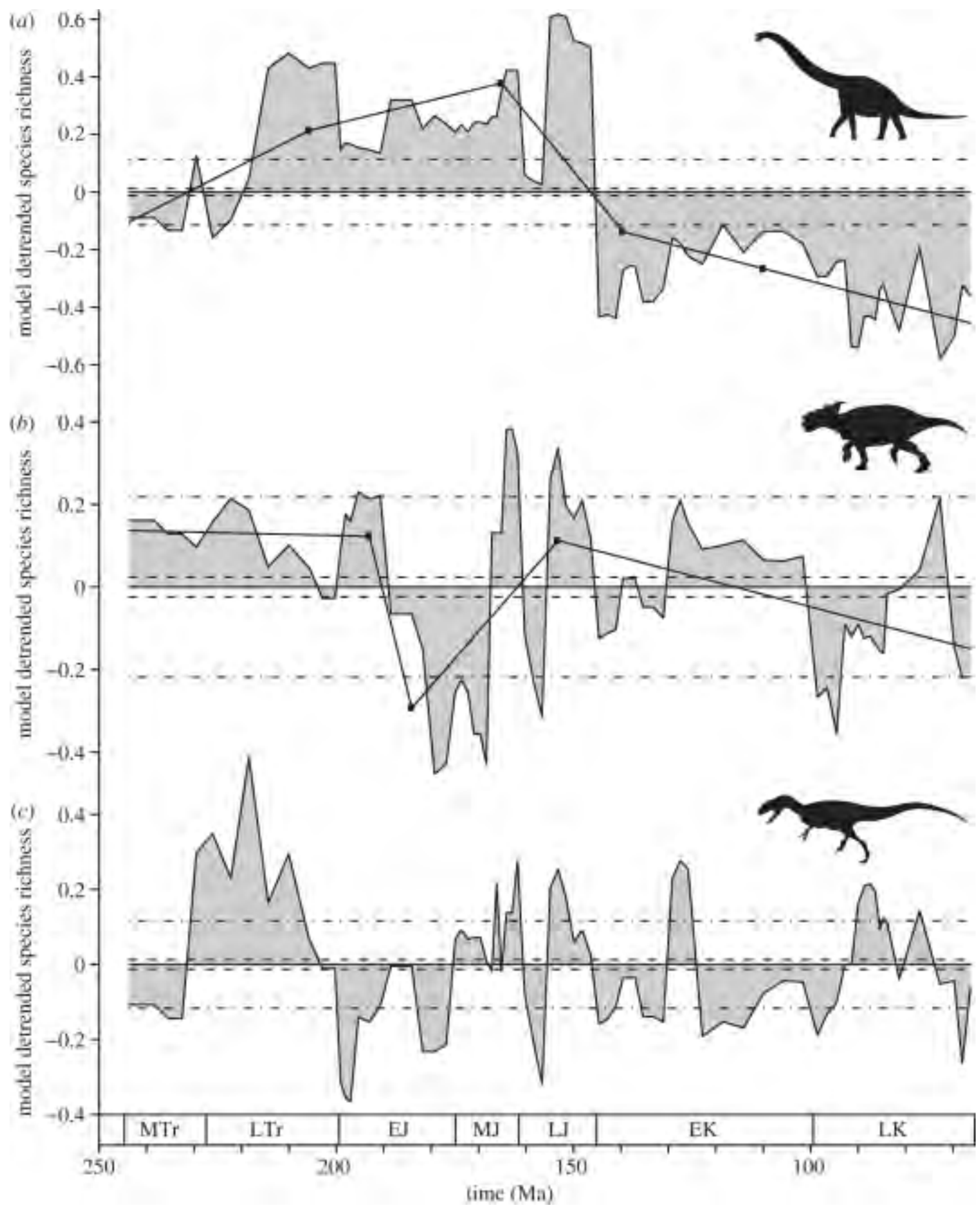
Can estimates of diversification rates account for incomplete sampling?

Foote (2000) and other studies (e.g., Alroy 2008) developed approaches that accommodate incomplete sampling by removing singleton taxa (taxa appearing entirely within a single interval), defining additional categories of stratigraphic ranges, and/or applying sampling corrections.

Other methods apply an explicit model of lineage speciation, extinction, and fossil recovery. (We will learn more about these methods later on in the semester.)

Dinosaur extinction

Was dinosaur species richness in decline before the impact?

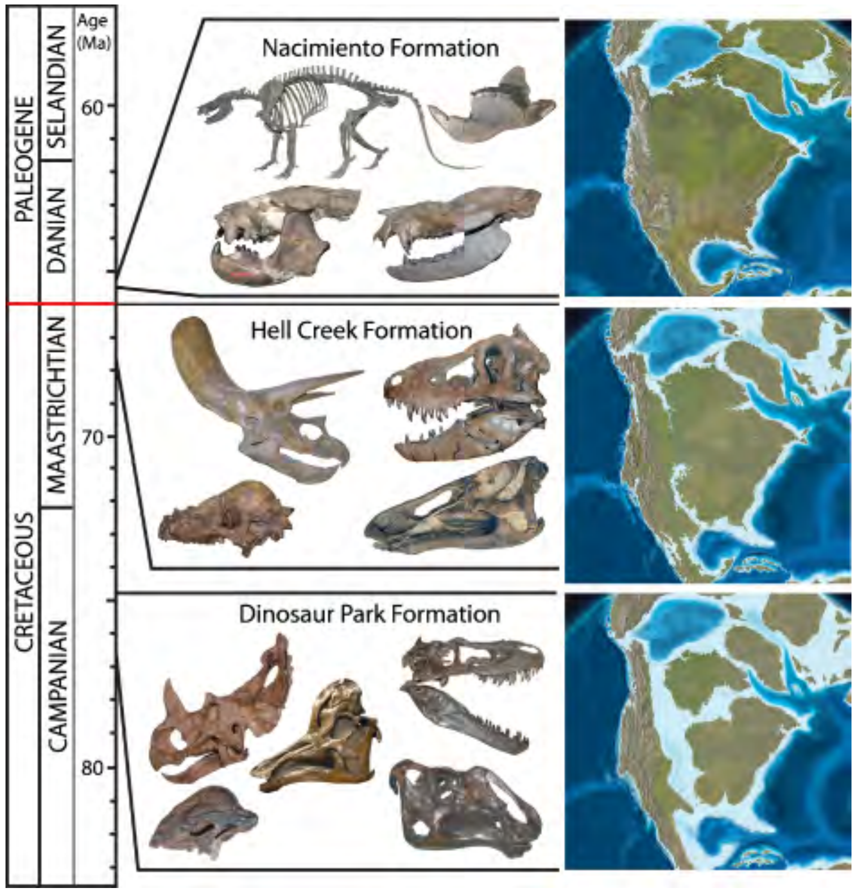


Species richness time series:
(a) sauropodomorphs
(b) ornithischians
(c) theropods

Trends show gradual decline for sauropods and ornithischians, and no significant trend for theropods

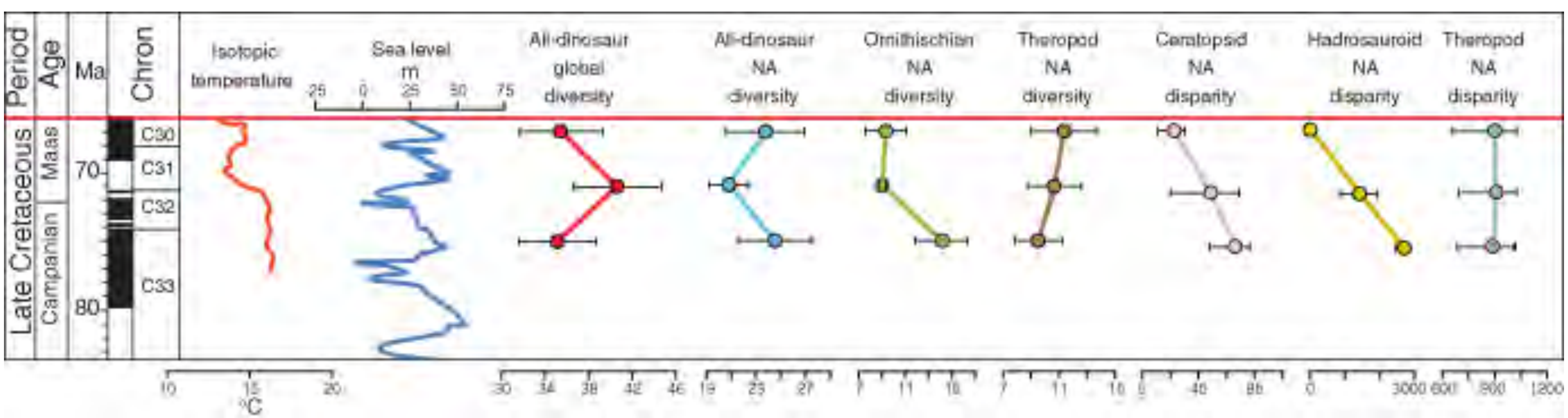
(Lloyd 2012)

Was dinosaur species richness in decline before the impact?



North American terrestrial fauna composition significantly changed after the end of the Cretaceous.

There are no significant declines in global dinosaur diversity in the Late Cretaceous



(Brusatte et al 2014)