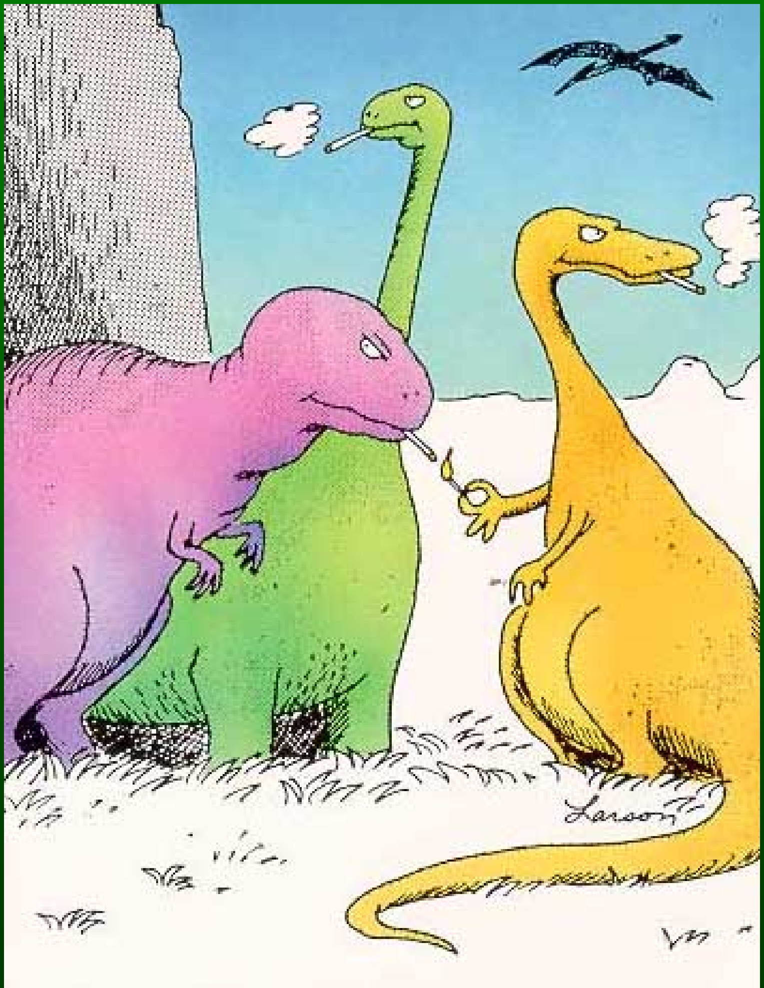
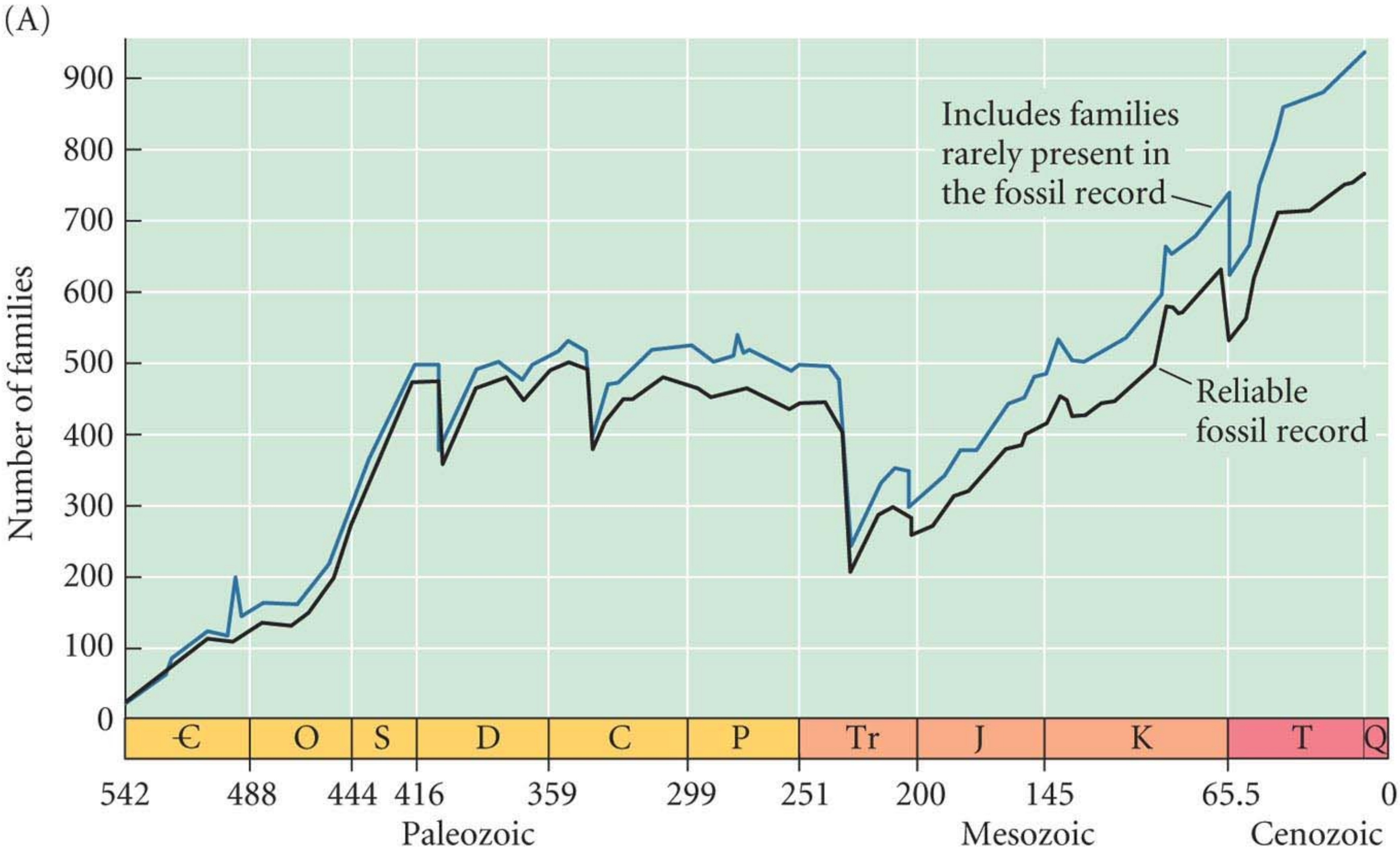
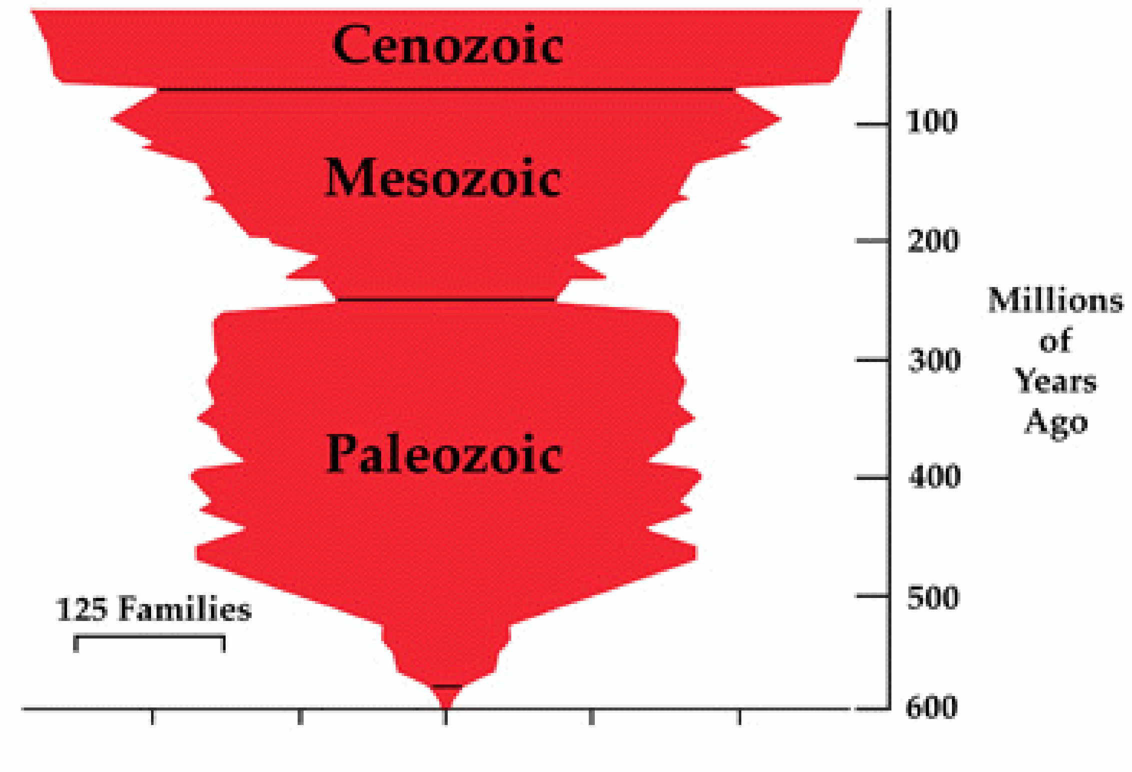
Mass Extinctions &Their Consequences



Taxonomic diversity of skeletonized marine animal families during the Phanerozoic



Spindle diagram of family diversification/extinction



The role of extinction in evolution

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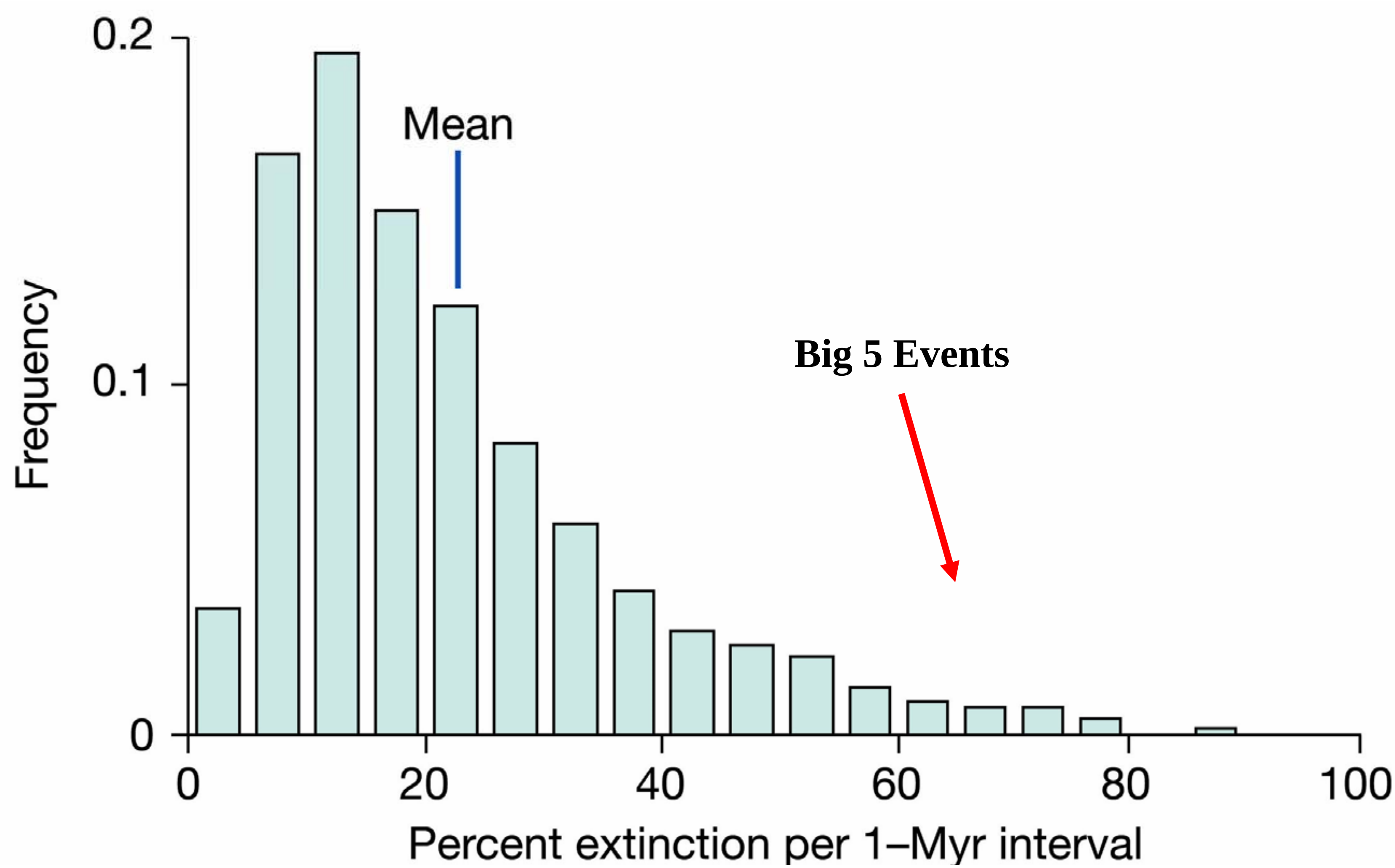
ABSTRACT The extinction of species is not normally considered an important element of neodarwinian theory, in contrast to the opposite phenomenon, speciation. This is surprising in view of the special importance Darwin attached to extinction, and because the number of species extinctions in the history of life is almost the same as the number of originations; present-day biodiversity is the result of a trivial surplus of originations, cumulated over millions of years. For an evolutionary biologist to ignore extinction is probably as foolhardy as for a demographer to ignore mortality. The past decade has seen a resurgence of interest in extinction, yet research on the topic is still at a reconnaissance level, and our present understanding of its role in evolution is weak. Despite uncertainties, extinction probably contains three important elements. (*i*) For geographically widespread species, extinction is likely only if the killing stress is one so rare as to be beyond the experience of the species, and thus outside the reach of natural selection. (*ii*) The largest mass extinctions produce major restructuring of the biosphere wherein some successful groups are eliminated, allowing previously minor groups to expand and diversify. (*iii*) Except for a few cases, there is little evidence that extinction is selective in the positive sense argued by Darwin. It has generally been impossible to predict, before the fact, which species will be victims of an extinction event.

PNAS 1994. 91:6758-6763.

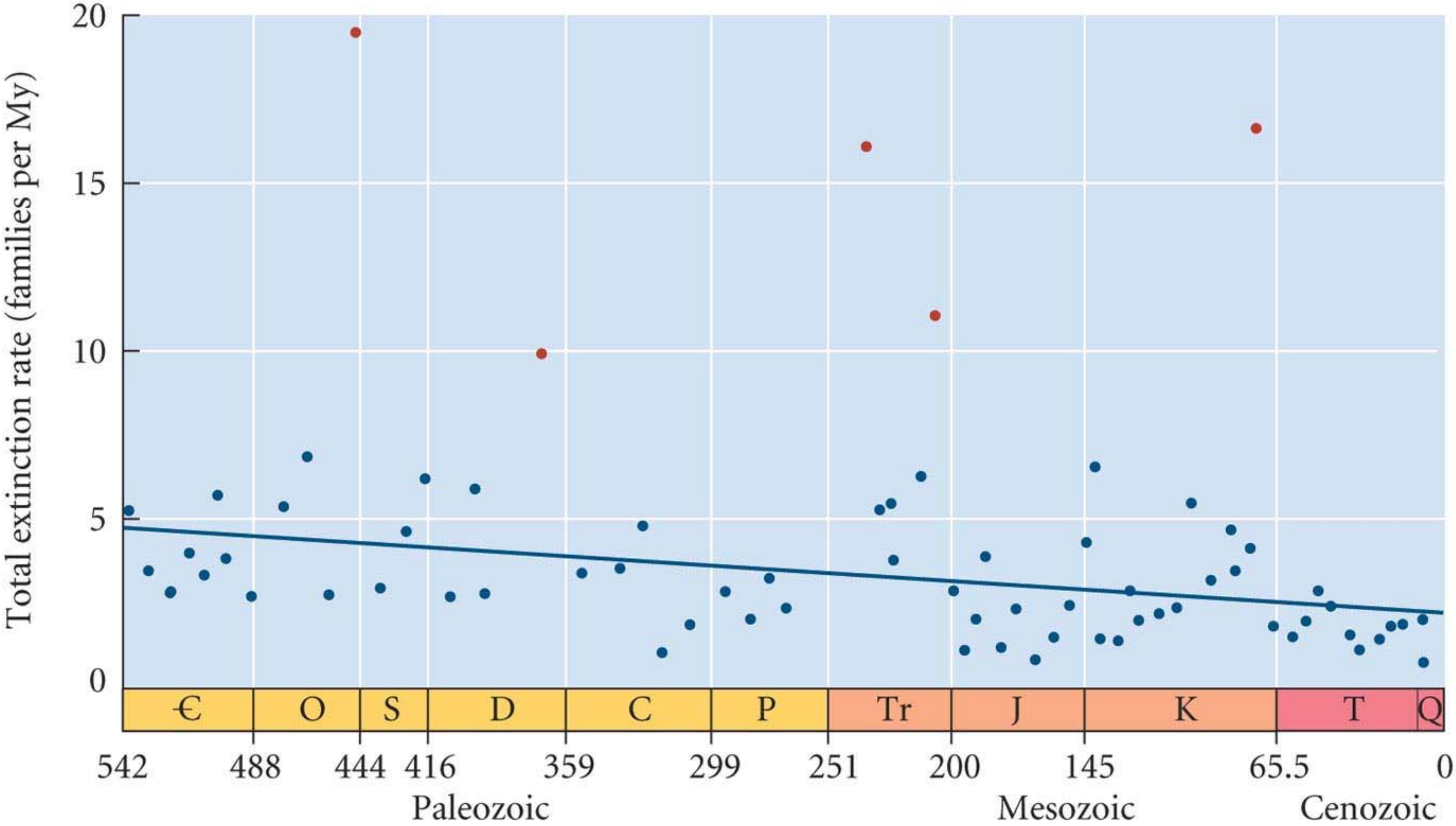
Background vs. Global Mass Extinction Events

- Background Rates = 96% of all extinctions.
- Phanerozoic average @ ~ 25% per 1 Myr.
- Geographic range & larval life styles regarding survivorship.
- Selective opportunities for diversification.
- The Red Queen Hypothesis.

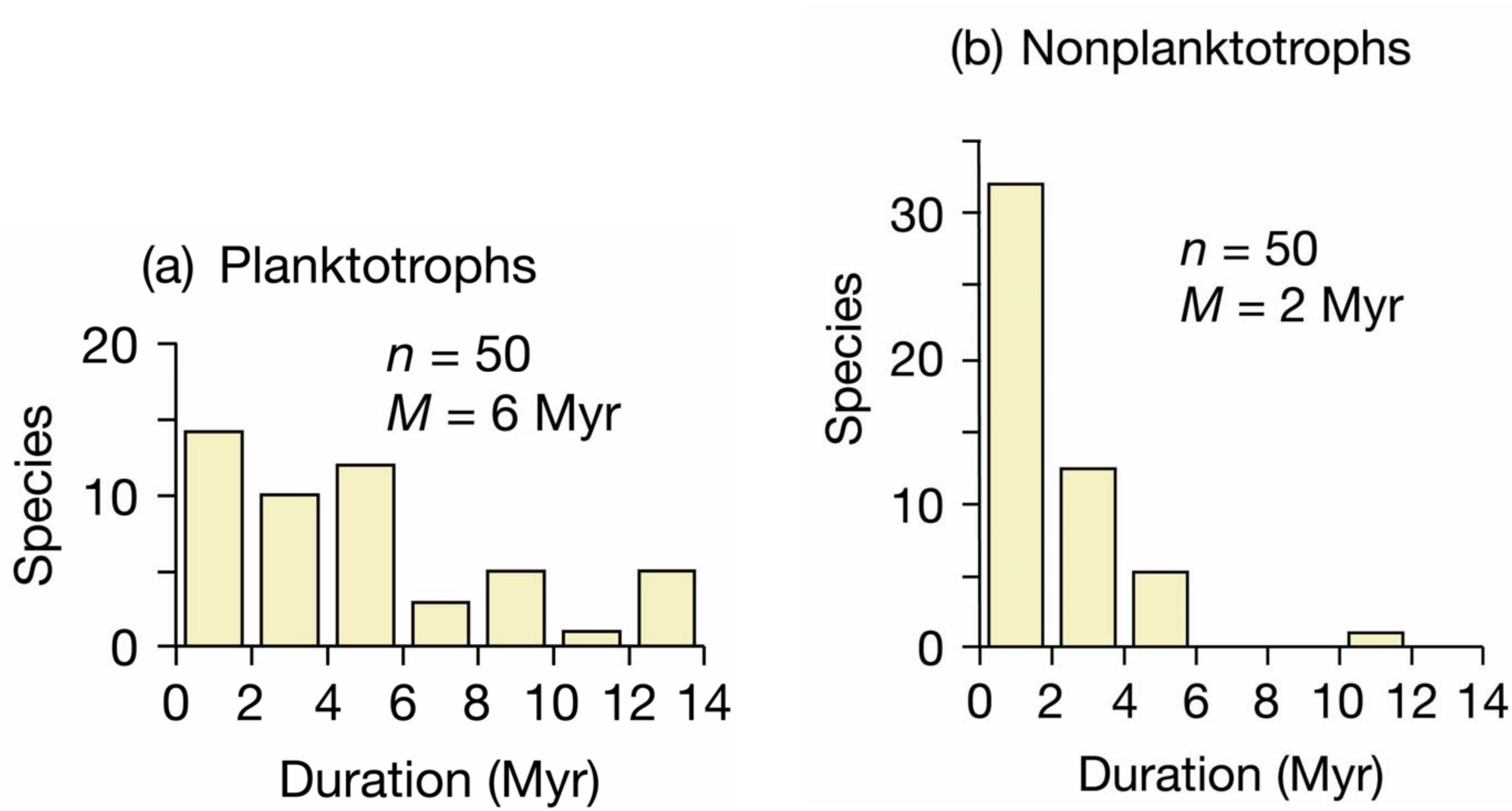
Distribution of extinction intensities across Phanerozoic yields a mean of 25% per 1 Myr, which is the reciprocal of the **mean species duration of ~4 Myr**.



Extinction rates of marine animal families during the Phanerozoic

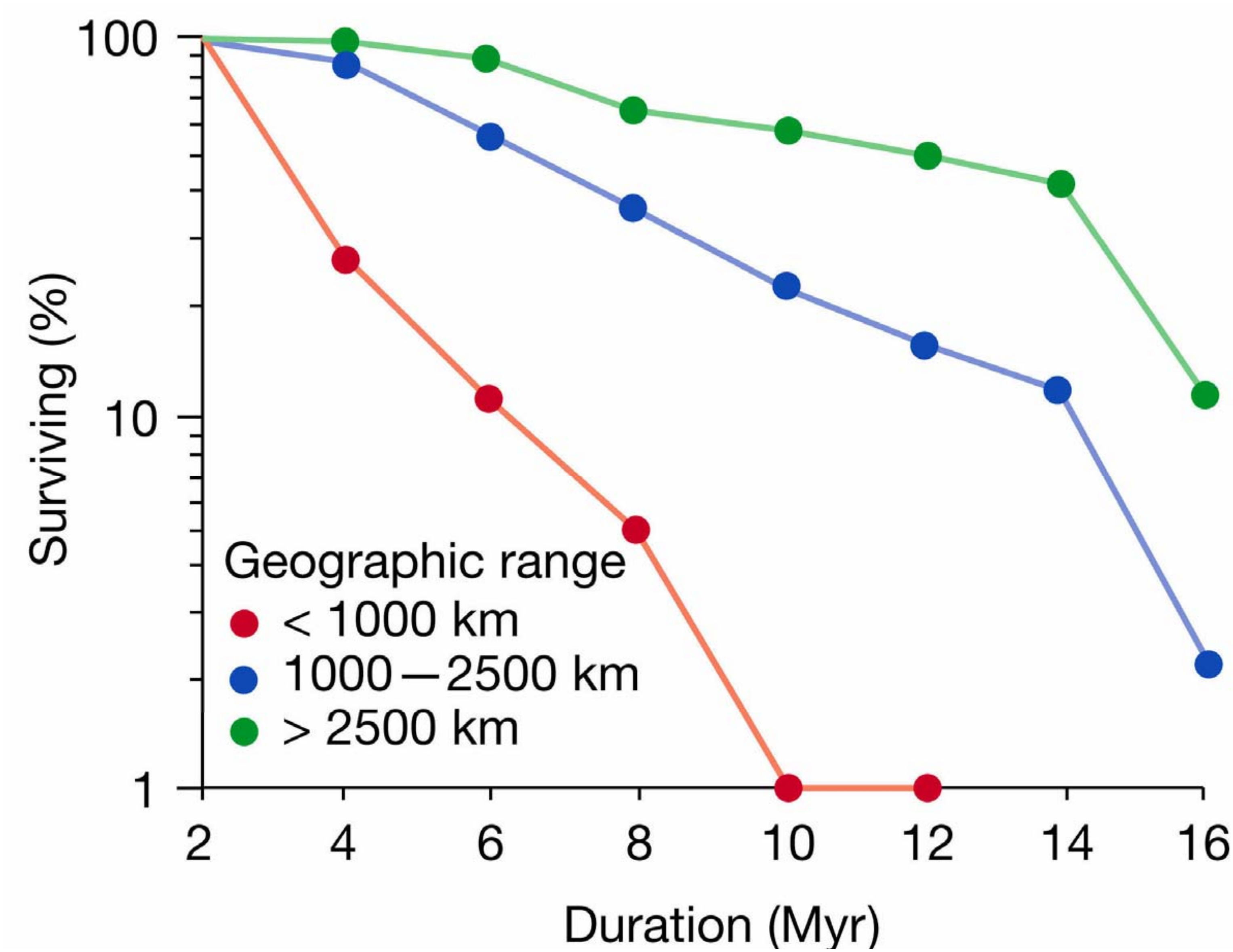


How long does a species of marine bivalve exist?

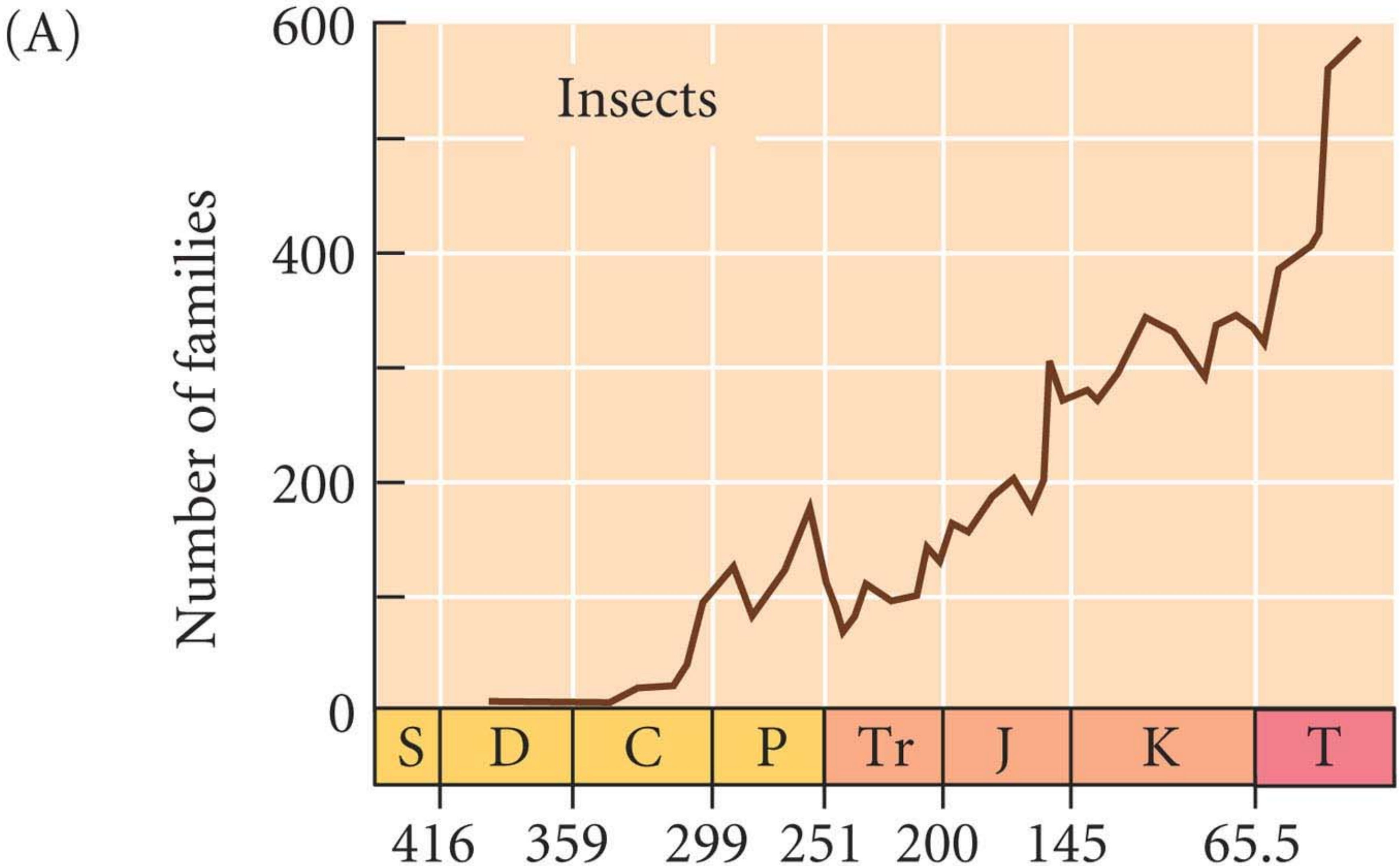


Better adapted for the long haul!

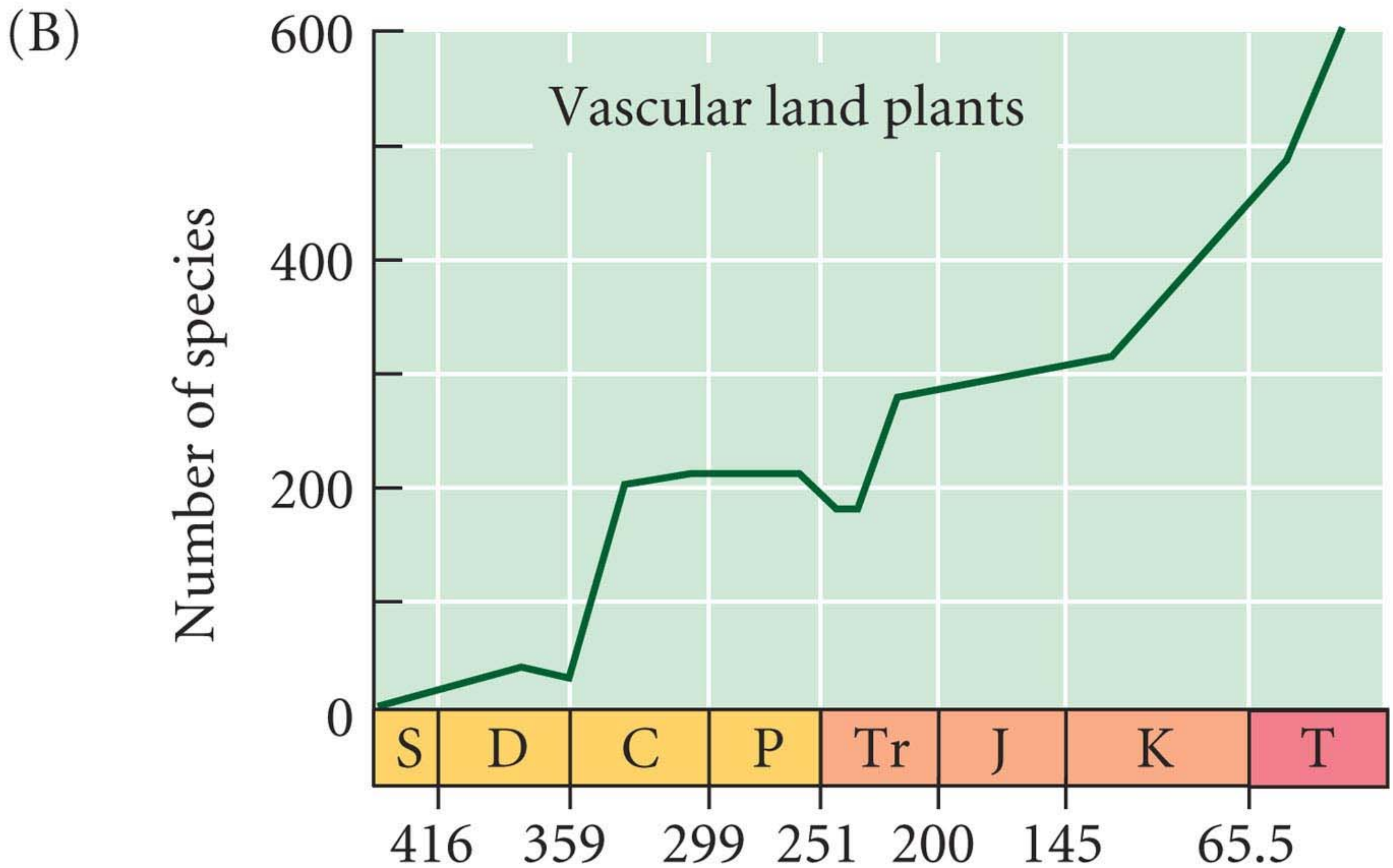
Geographic range affects the survivorship of species!



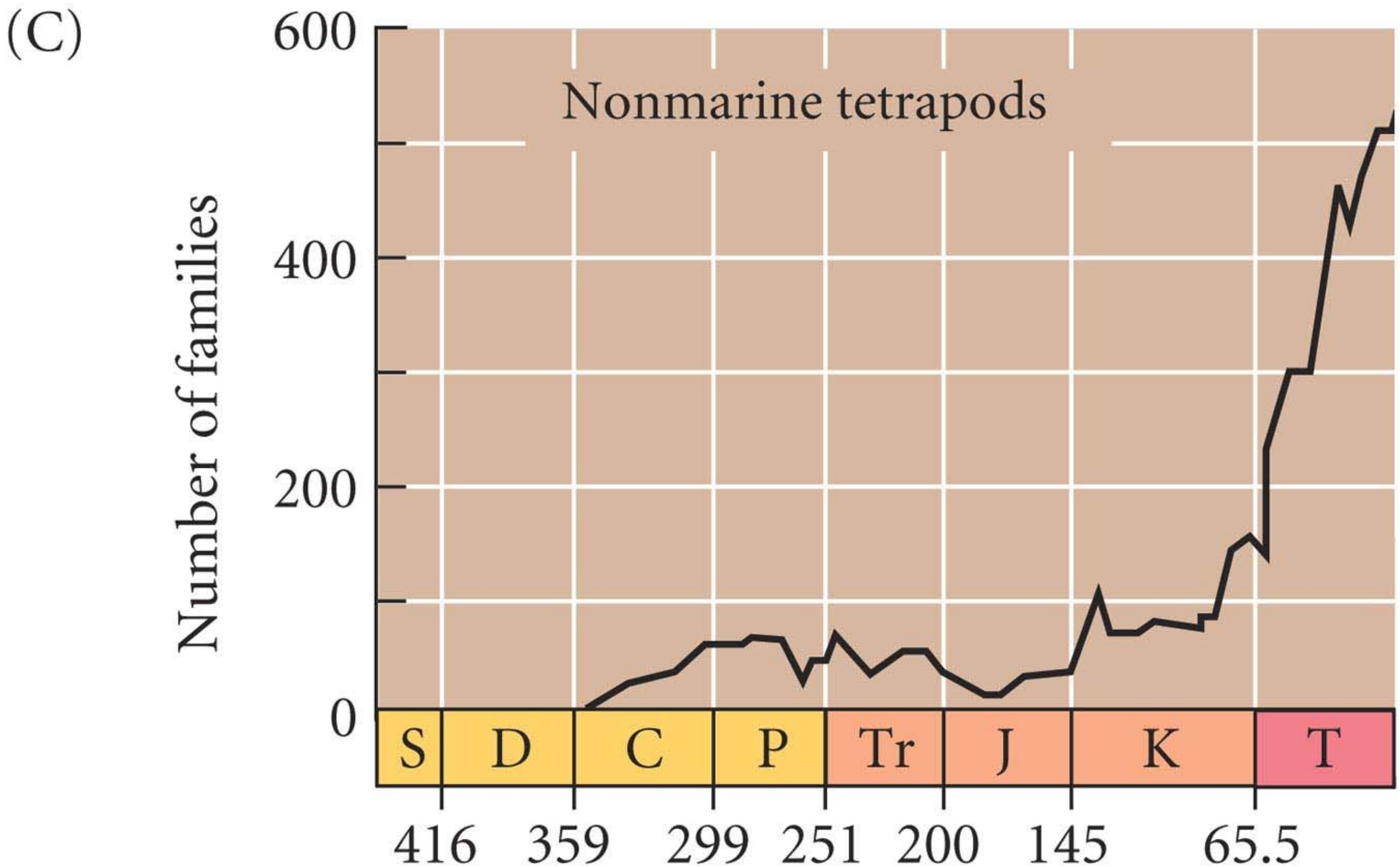
Changes in the number of known families of insects



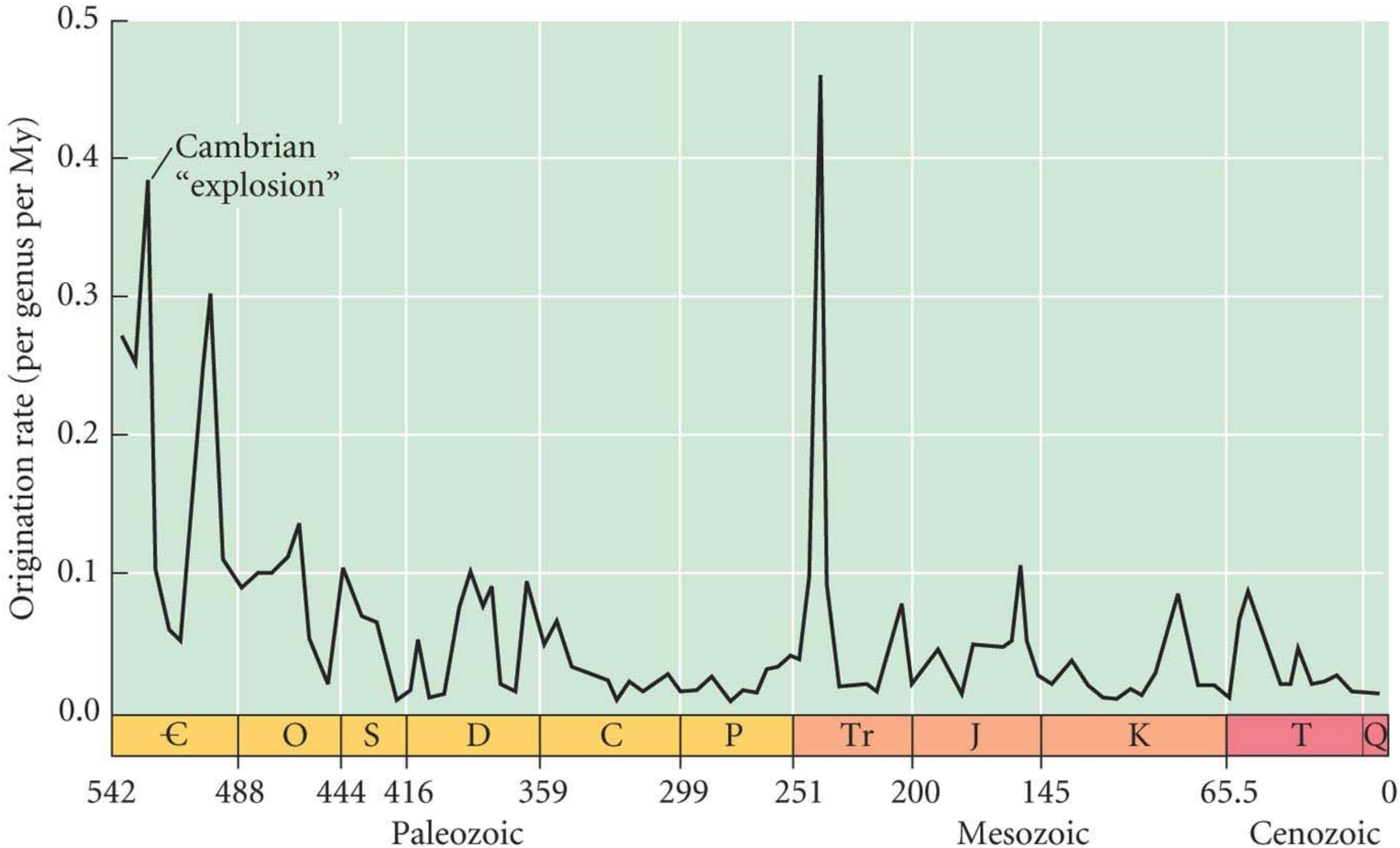
Changes in the number of known species of vascular land plants



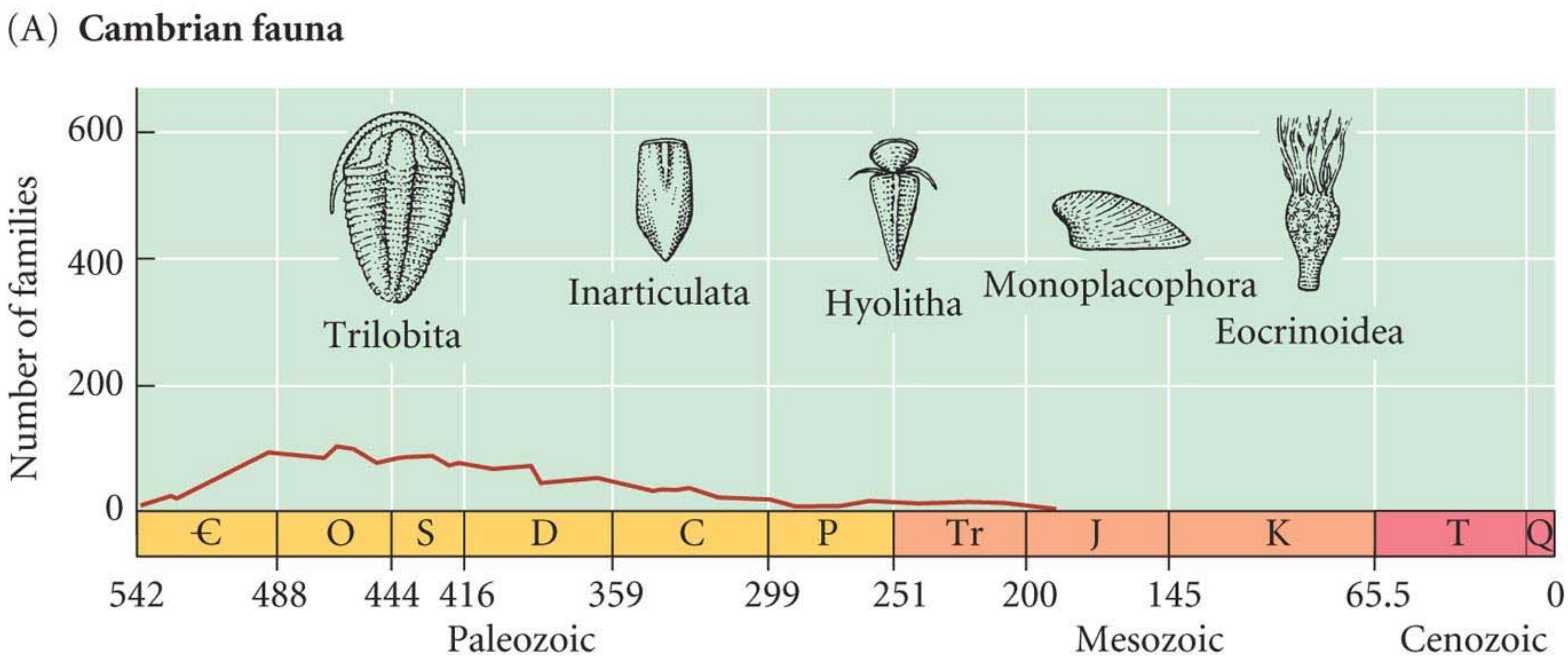
Changes in the number of known families of nonmarine tetrapod vertebrates



Rates of origination of marine animal genera in 107 stages of the Phanerozoic



The history of diversity of the three "evolutionary faunas" in the marine fossil record



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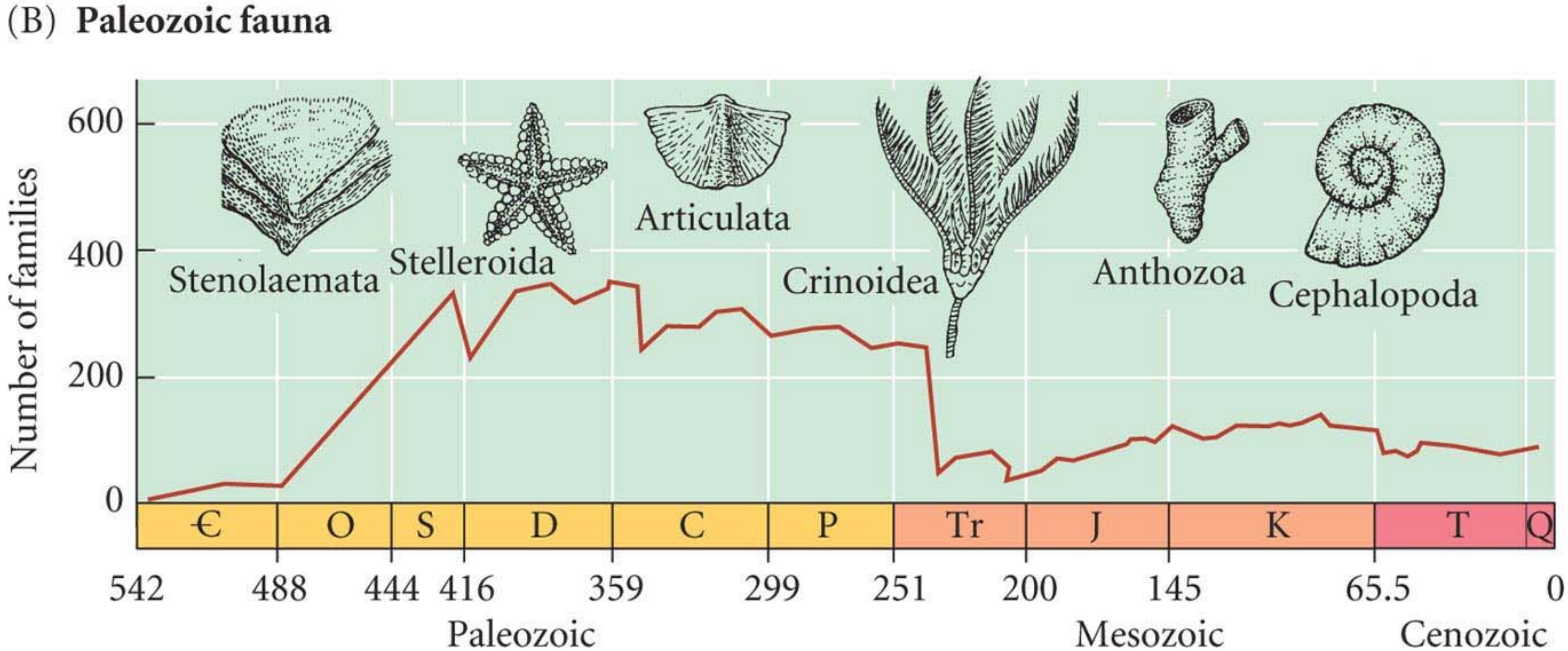

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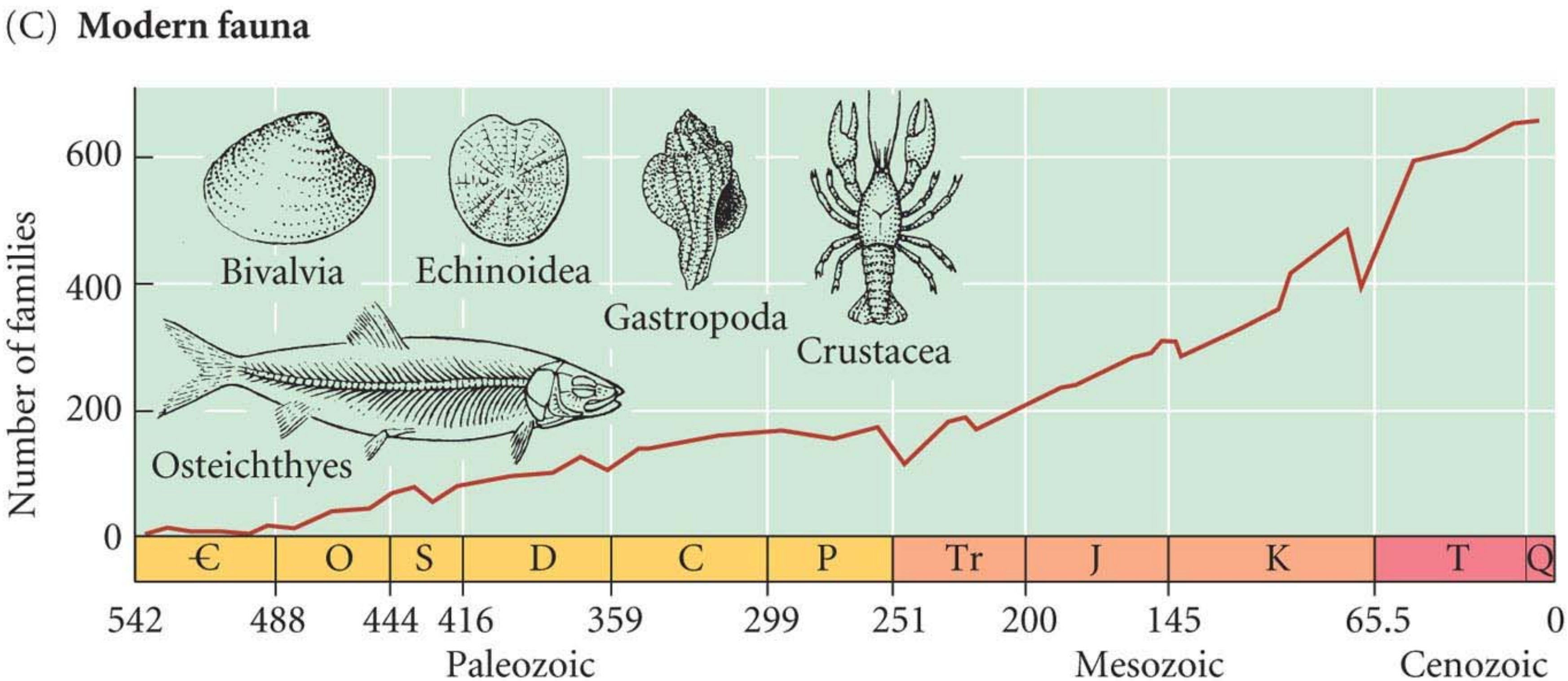
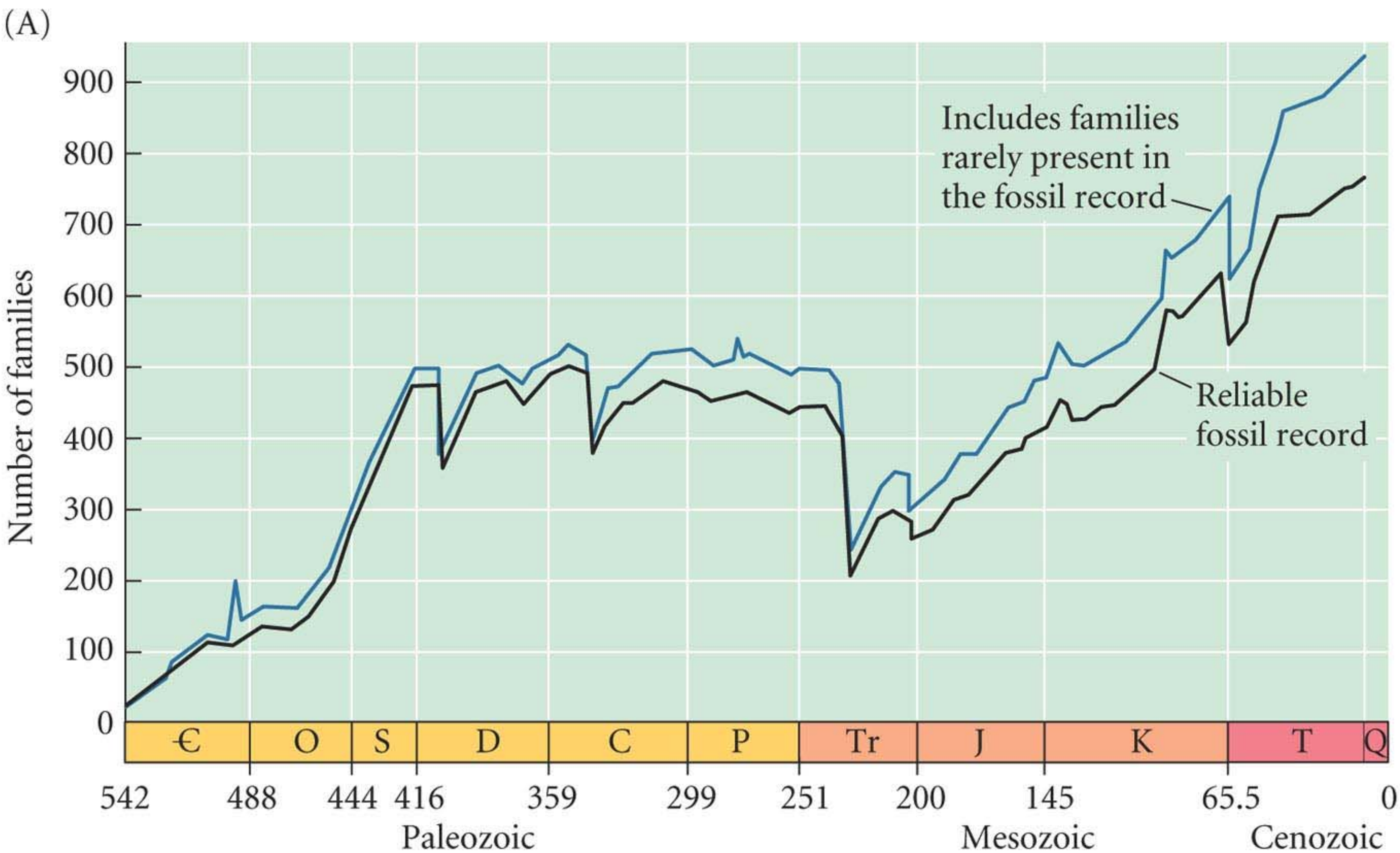


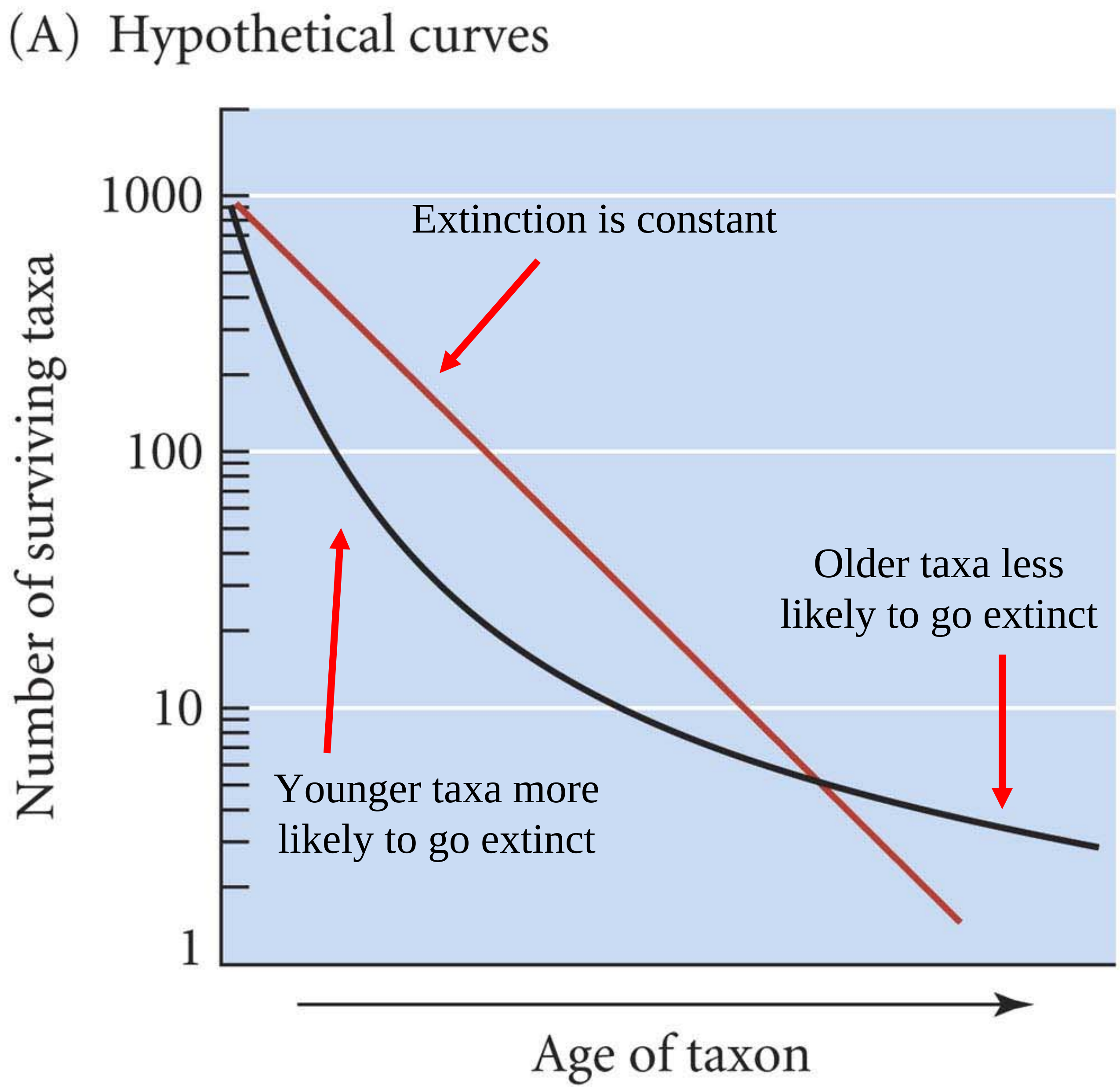
Diversity-Dependent Competition

Is there a target equilibrium?

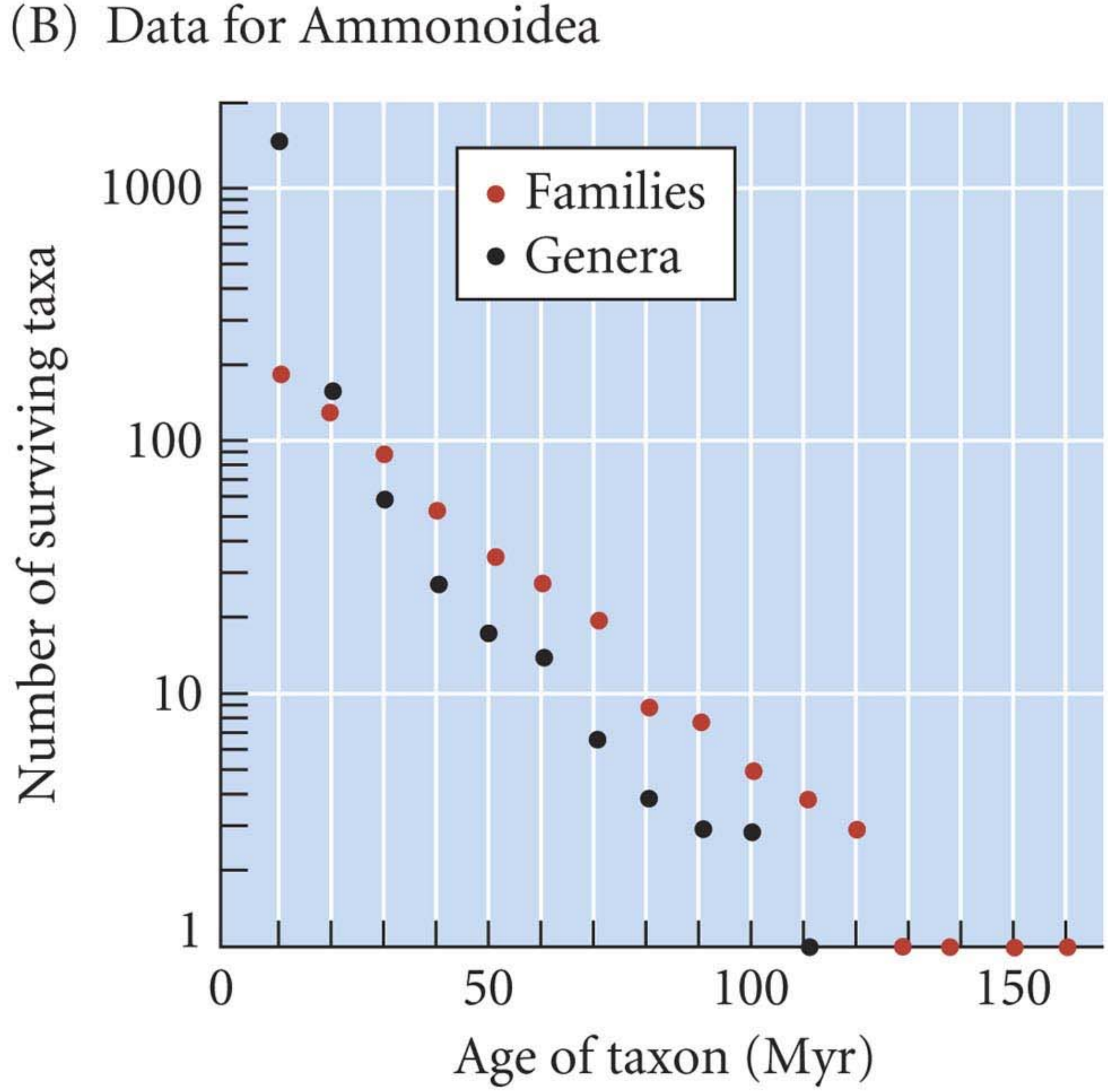
Summation of diversity of the three “evolutionary faunas” in the marine fossil record



Taxonomic survivorship curves



Taxonomic survivorship curves

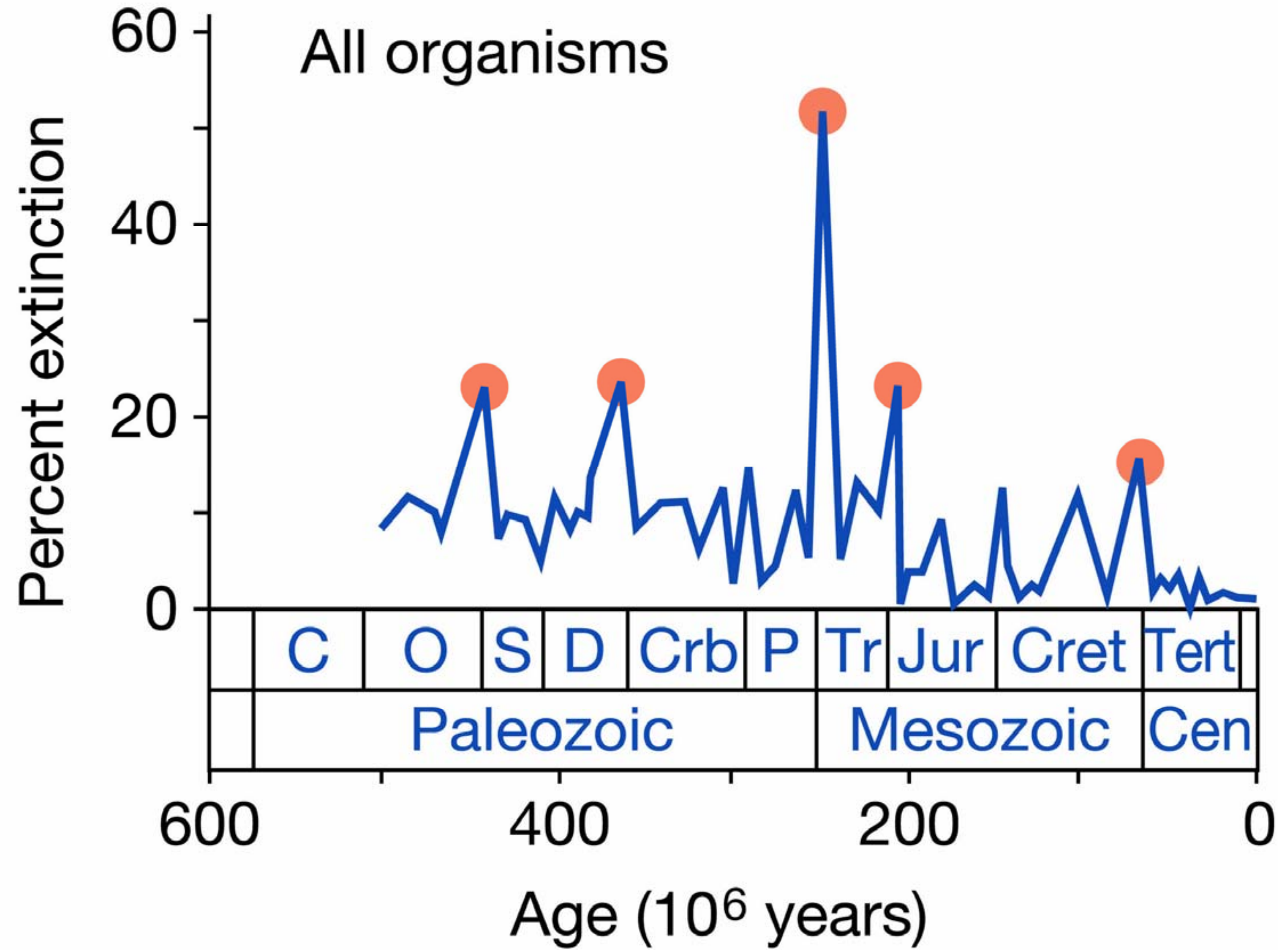


~Constant Probability of Extinction

- Red Queen Hypothesis: Must keep running to stay in same place.
- Constant evolution by competitors, predators, and parasites.

The BIG FIVE of the Phanerozoic

Extinction Episode	Age, Ma	% Extinction
• **Cretaceous (K/T Boundary)**	**65 Ma**	**76**
• Triassic	215 Ma	76
• **Permian (P/T Boundary)**	**250 Ma**	**96**
• Devonian	365 Ma	82
• Ordovician	440 Ma	85



All organisms
Percent extinction
60
40
20
0
C
O
S
D
Crb
P
Tr
Jur
Cret
Tert
Paleozoic
Mesozoic
Cen
600
400
200
0
Age (10⁶ years)

The Permo-Triassic Boundary: The Mother of all Mass Extinctions

- Came close to losing all multicellular life.
- Considered one of the four major advancements.
- Box score of exterminations: 96% of all spp. & 50% of all families.
- Selectivity of the P/T Boundary.
- Multiple Causation Hypothesis.

The Four Major Advancements in Evolutionary Biology

- Origin of life
- Origin of multicellular life (Eukarya)
- Cambrian Explosion
- P/T Boundary Mass Extinction Event

P/T box score of exterminations

Rem: 96% of all spp. & 50% of all <u>families</u>

- 8 of 27 insects
- 21 of 27 reptiles
- 6 of 9 amphibians
- 70% of marine invertebrate genera including most corals.
- 1 major order of forams (the only time this has happened!).

Selectivity of the P/T Boundary

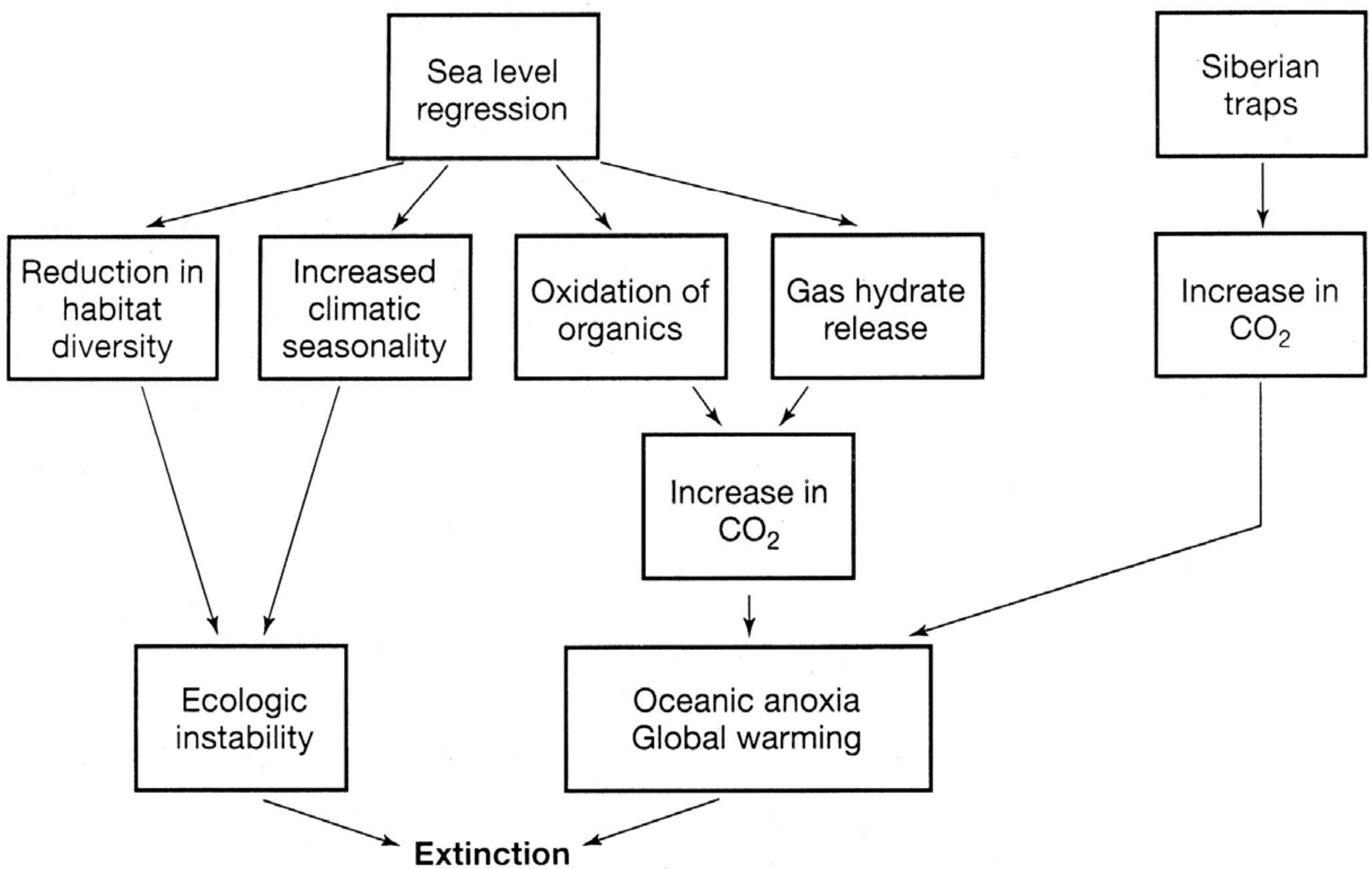
- 35% cosmopolitan genera vs. 93% endemic genera went extinct (same pattern as background extinction).

- END of the **Trilobites** as opposed to other marine arthropods.

Multiple Causation Hypothesis aka "World-went-to-hell" hypothesis

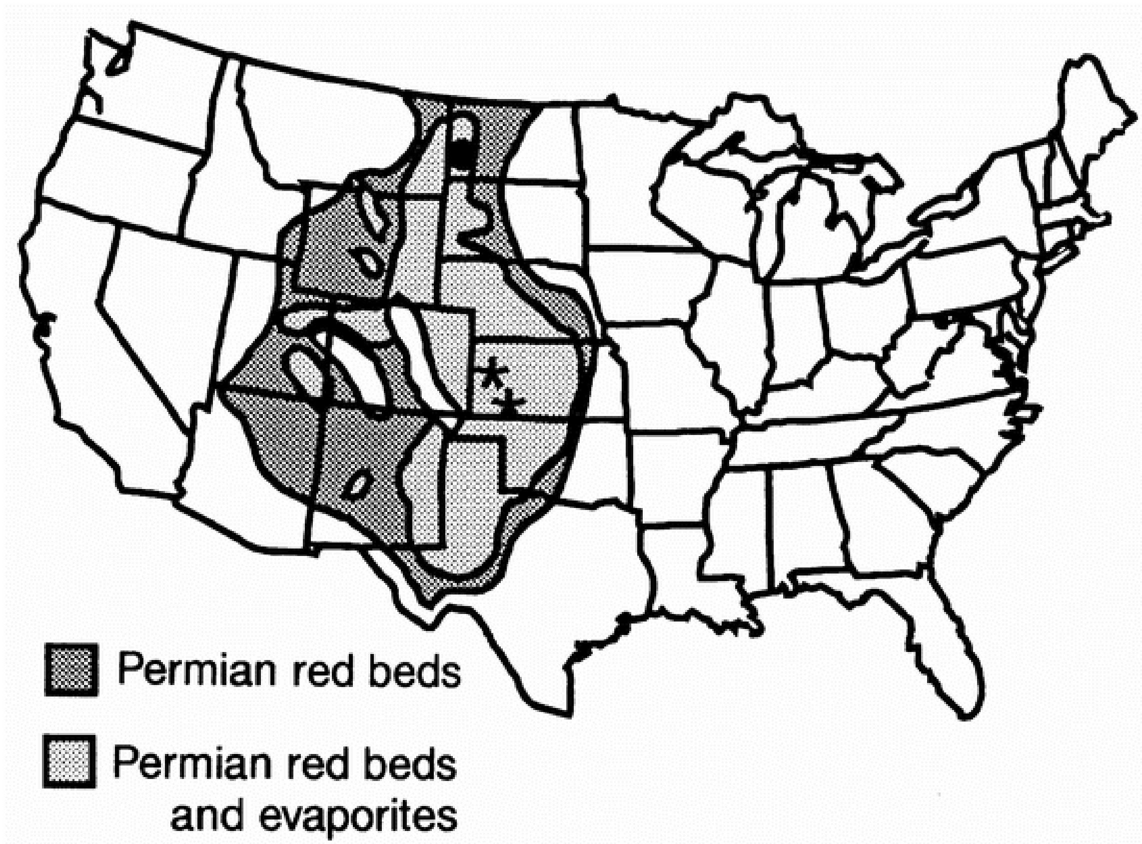
- Researchers tend to search for a single unified cause.....climate change, sea level change, oceanic anoxia, flood basalts, acid rain, etc.
- As much as 5 Ma separation period!
- Bolide impact hypothesis?

Multiple Causation Hypothesis



The Siberian flood basalts aka Siberian traps associated with super volcanism

Extremely acid Permian lakes and ground waters in North America



Benison *et al.*, 1998. Nature 392:911-914.

Impact Event at the Permian-Triassic Boundary: Evidence from Extraterrestrial Noble Gases in Fullerenes

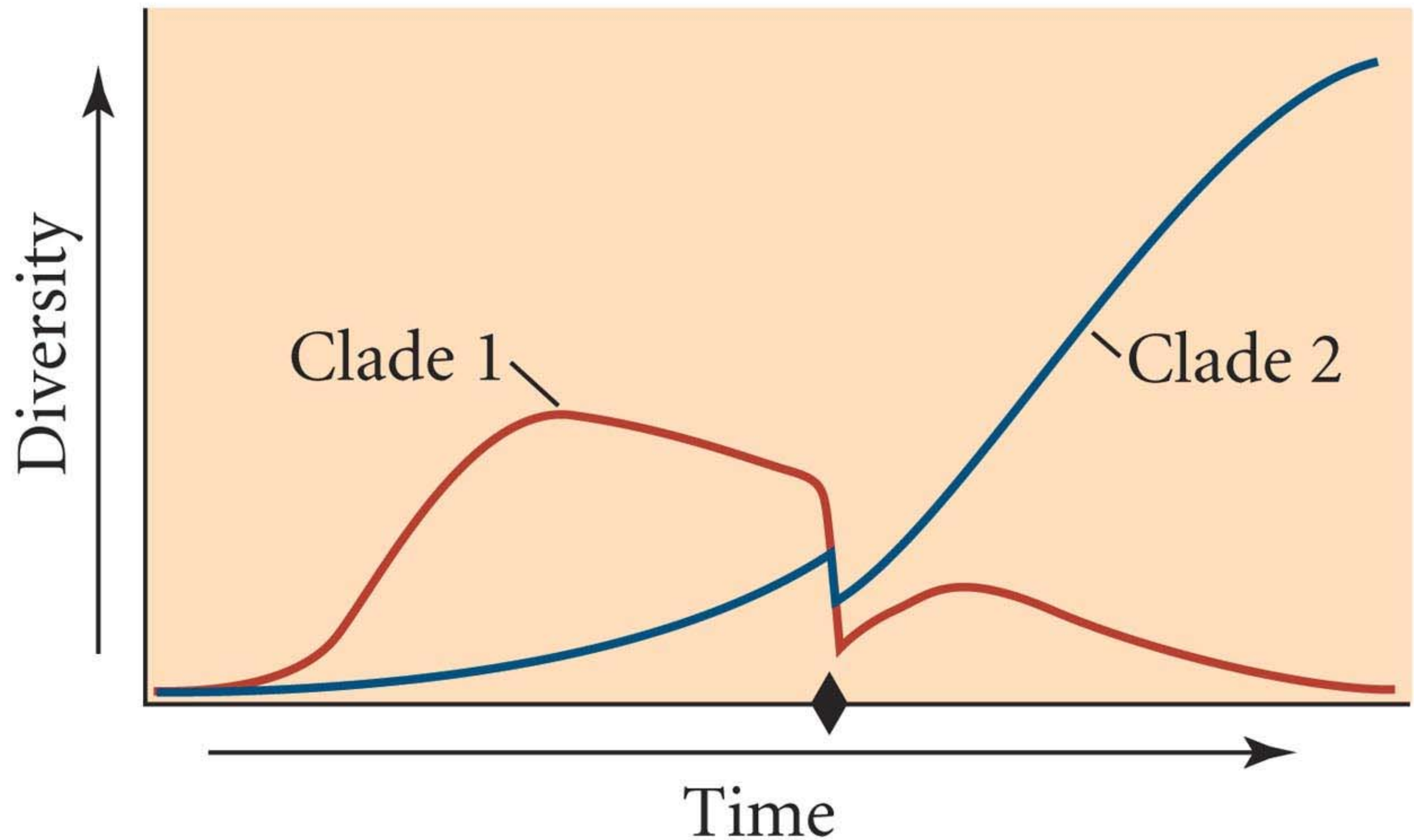
Luann Becker,[1*] Robert J. Poreda,[2] Andrew G. Hunt,[2] Theodore E. Bunch,[3] Michael Rampino[4]

The Permian-Triassic boundary (PTB) event, which occurred about 251.4 million years ago, is marked by the most severe mass extinction in the geologic record. Recent studies of some PTB sites indicate that the extinctions occurred very abruptly, consistent with a catastrophic, possibly extraterrestrial, cause. Fullerenes (C_{60} to C_{200}) from sediments at the PTB contain trapped helium and argon with isotope ratios similar to the planetary component of carbonaceous chondrites. These data imply that an impact event (asteroidal or cometary) accompanied the extinction, as was the case for the Cretaceous-Tertiary extinction event about 65 million years ago.

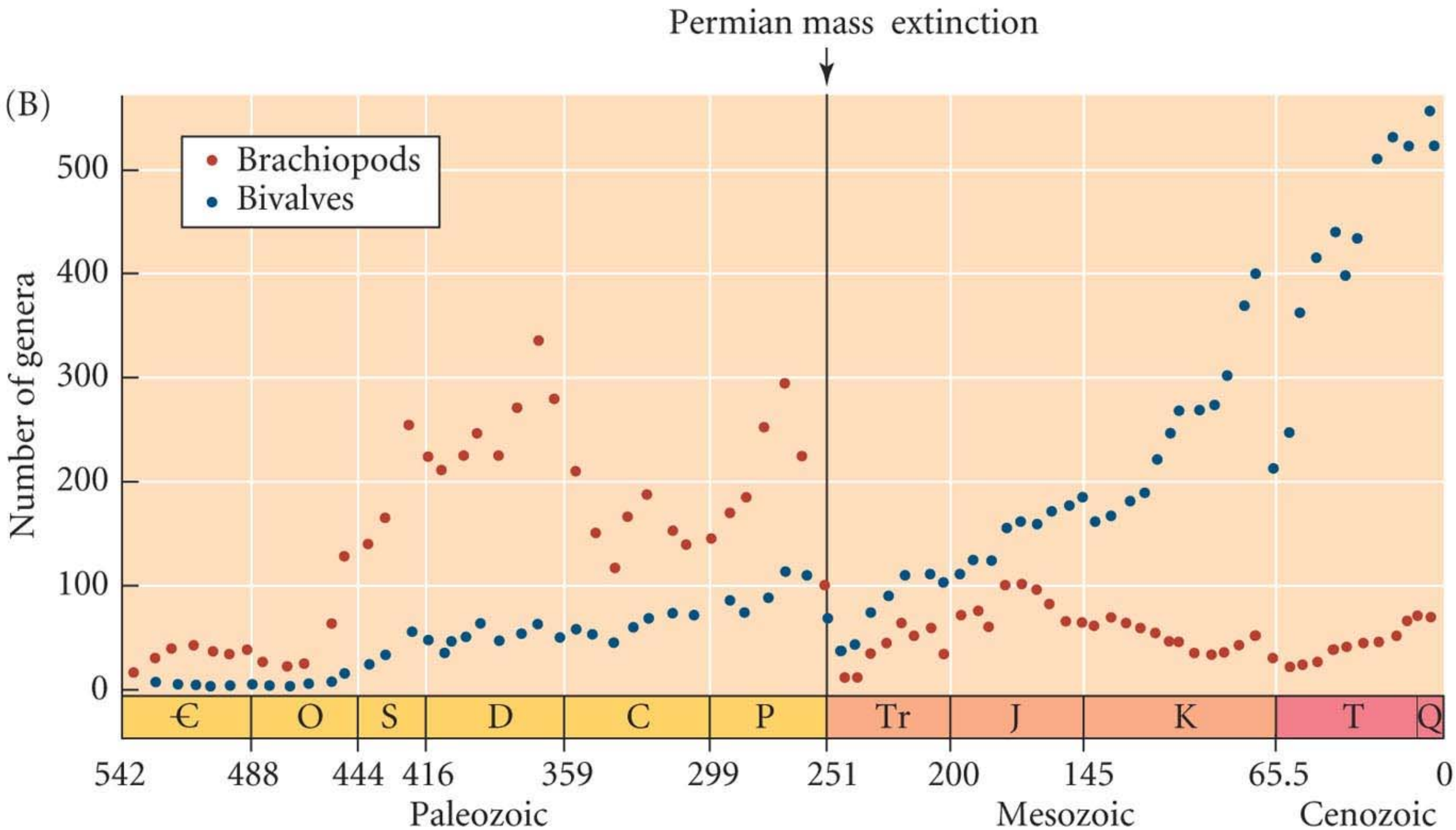
Nature 2001. 291:1530-1533.

Probable **competitive displacement** of brachiopods by bivalves

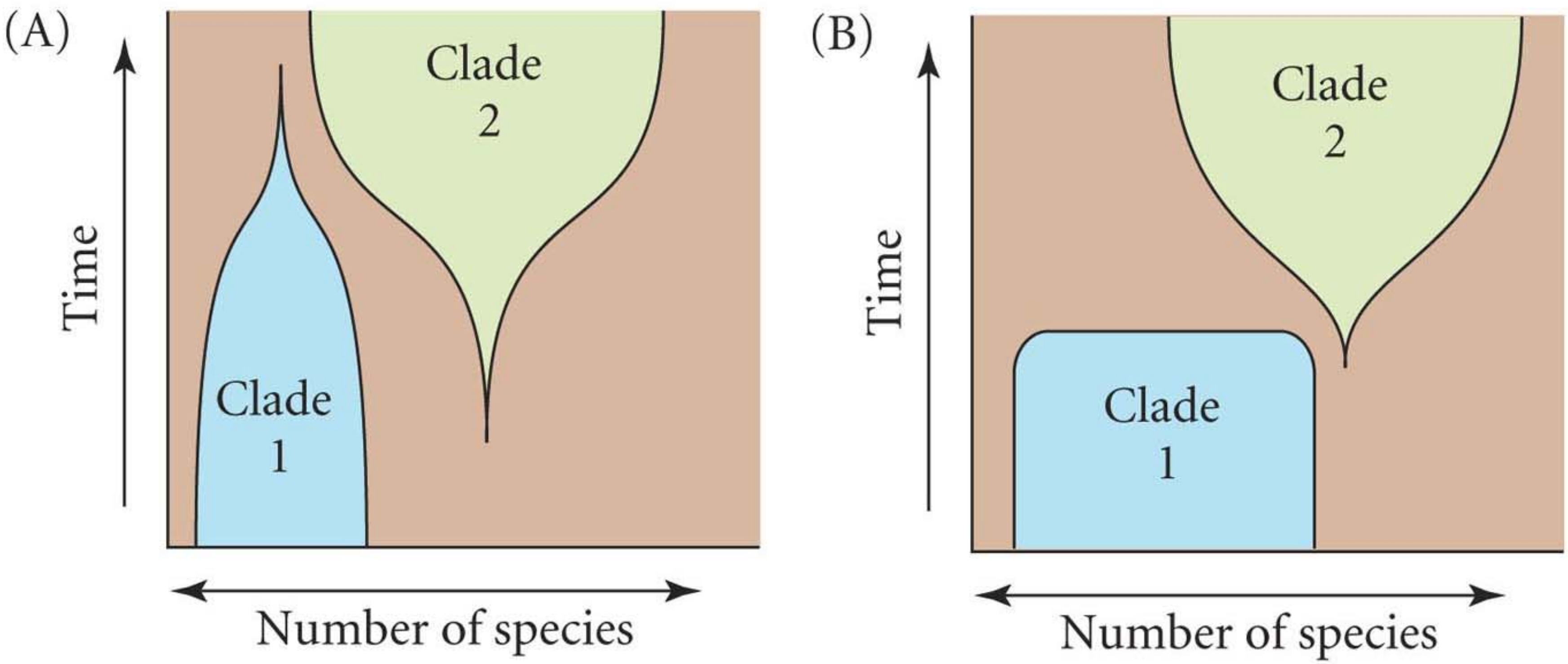
(A)



Probable **competitive displacement** of brachiopods by bivalves



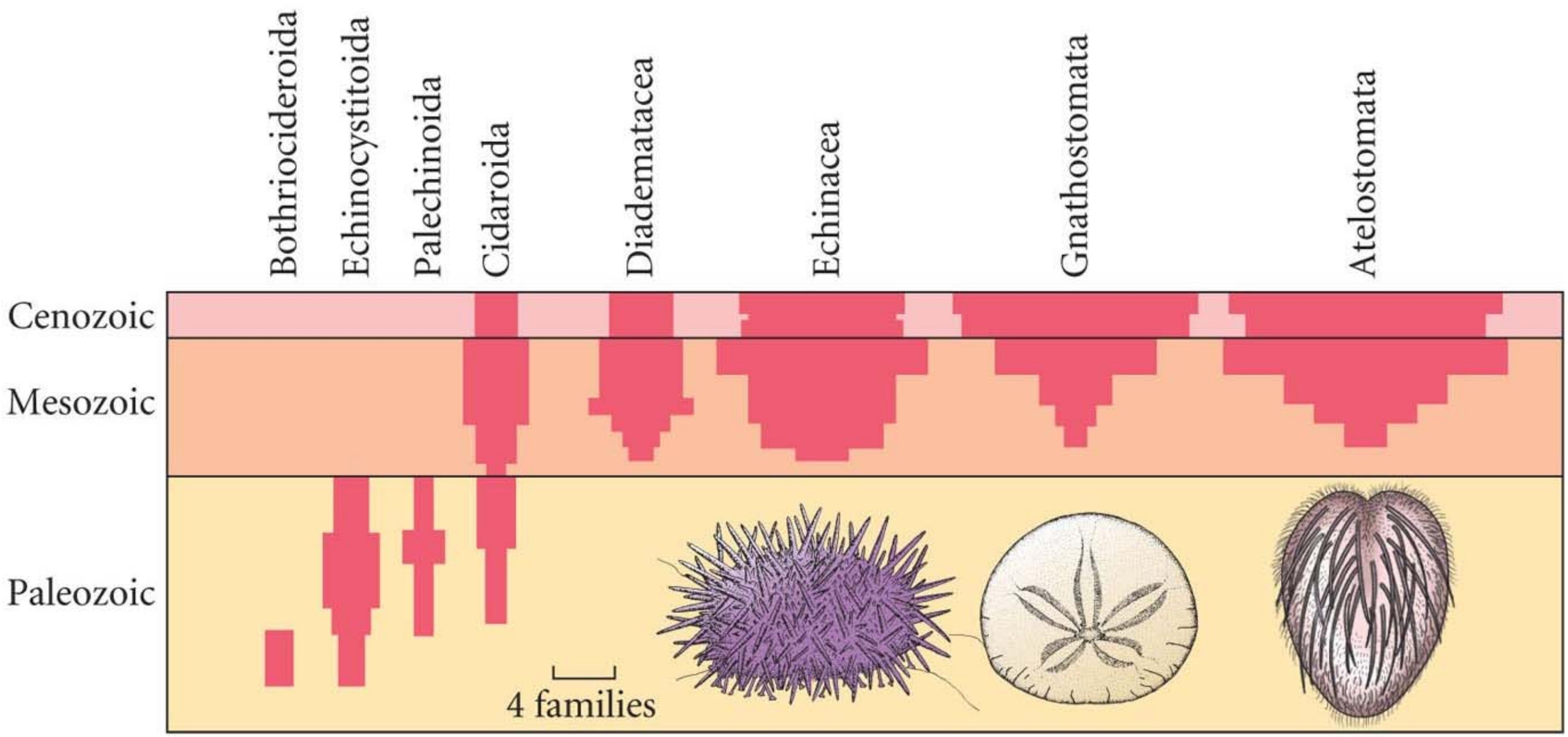
Models of (A) **competitive displacement** and (B) **incumbent replacement**



e.g., Spore-bearing vs. flowering plants

e.g., Dinosaurs and mammals at K/T

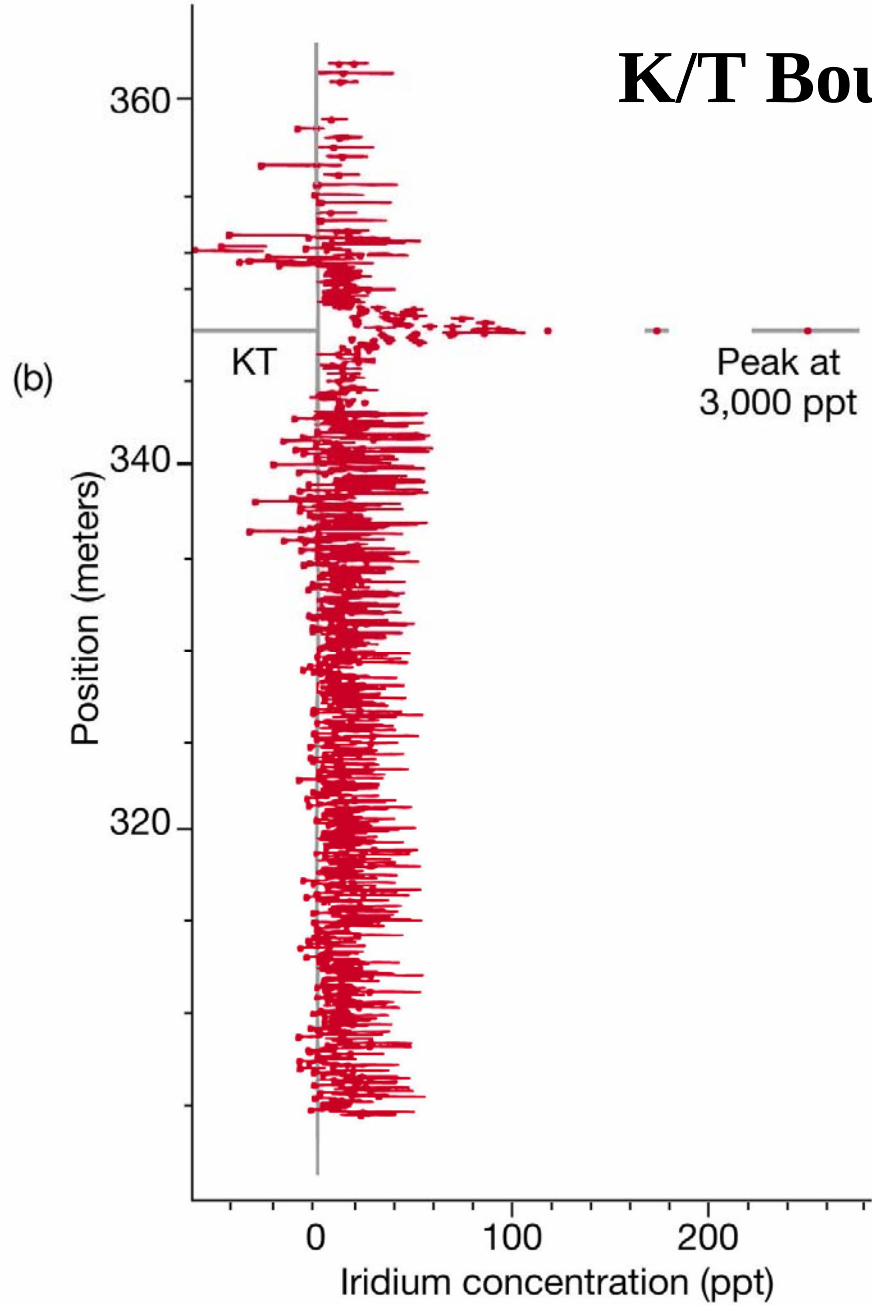
Echinoid diversity increased during the Mesozoic and Cenozoic

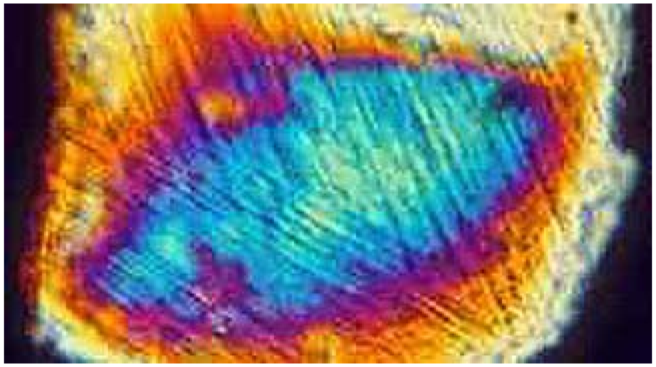


K/T Boundary – Impact extinction

- 60 to 80% kill of all spp.
- END of the **Ammonites** as opposed to other marine molluscs.
- Bivalves were less selectively hit, broad range survival.
- Sea Urchins were selectively hit as well.

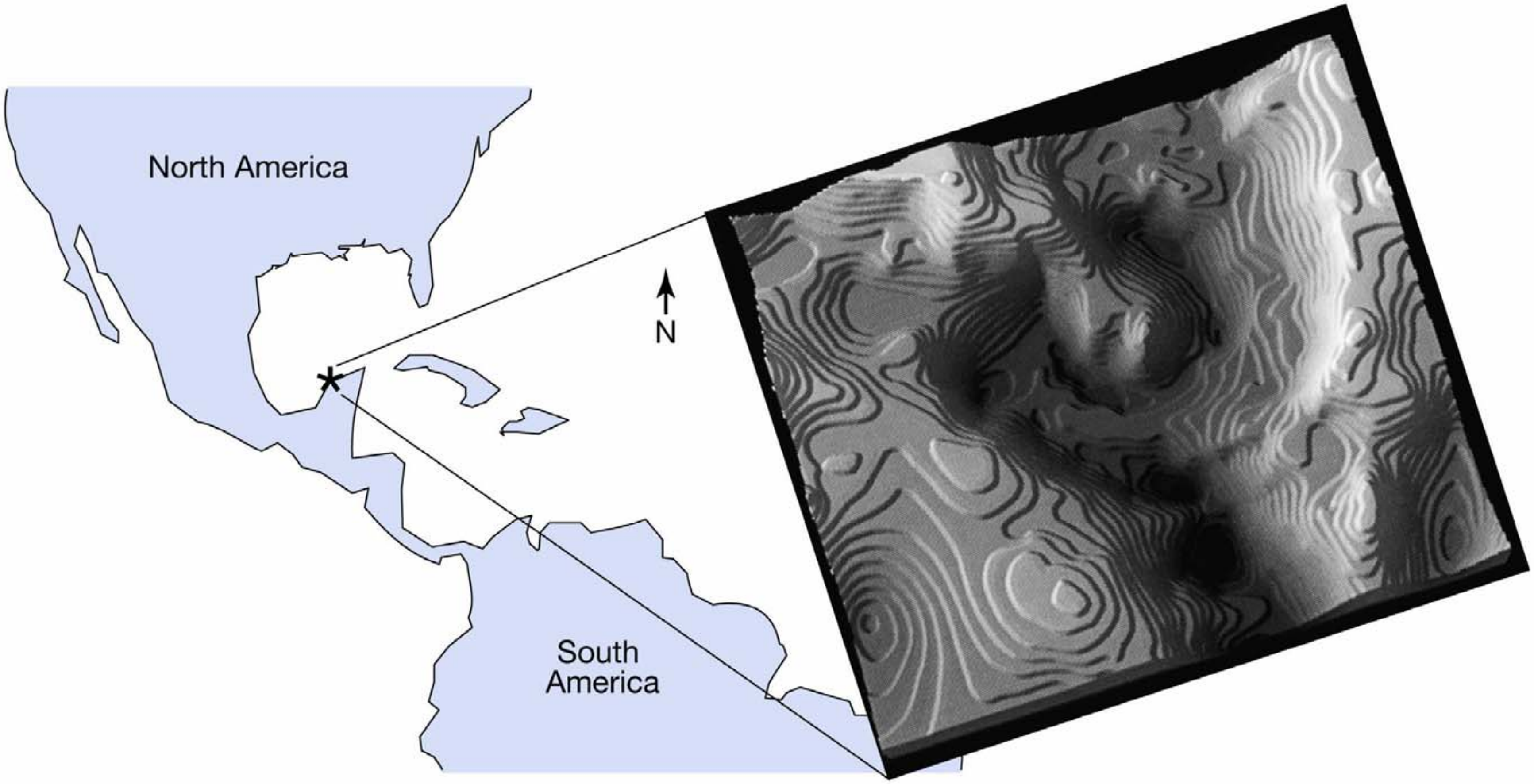
K/T Boundary Iridium Anomaly



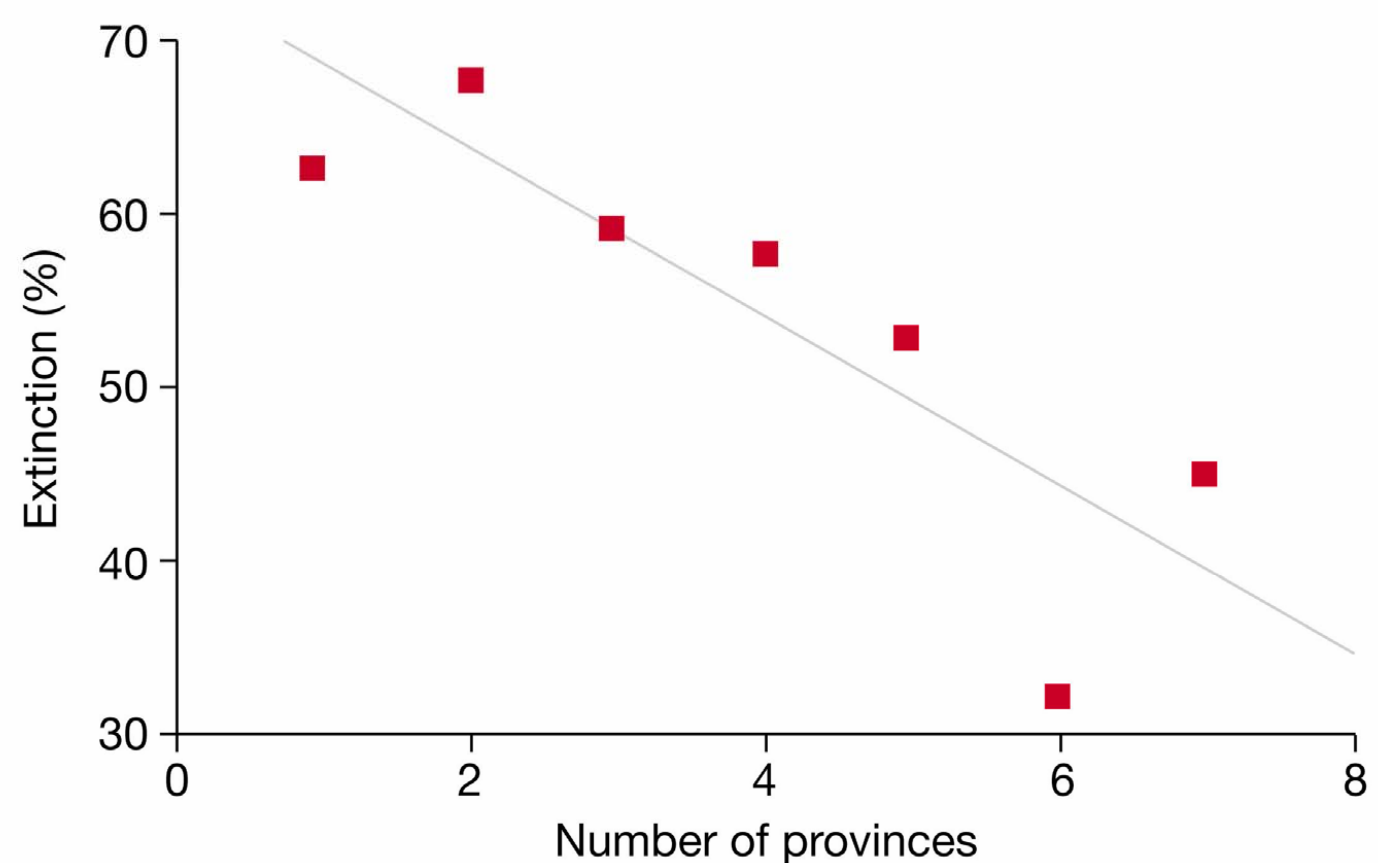


Shocked Quartz

Location and shape of the Chicxulub crater

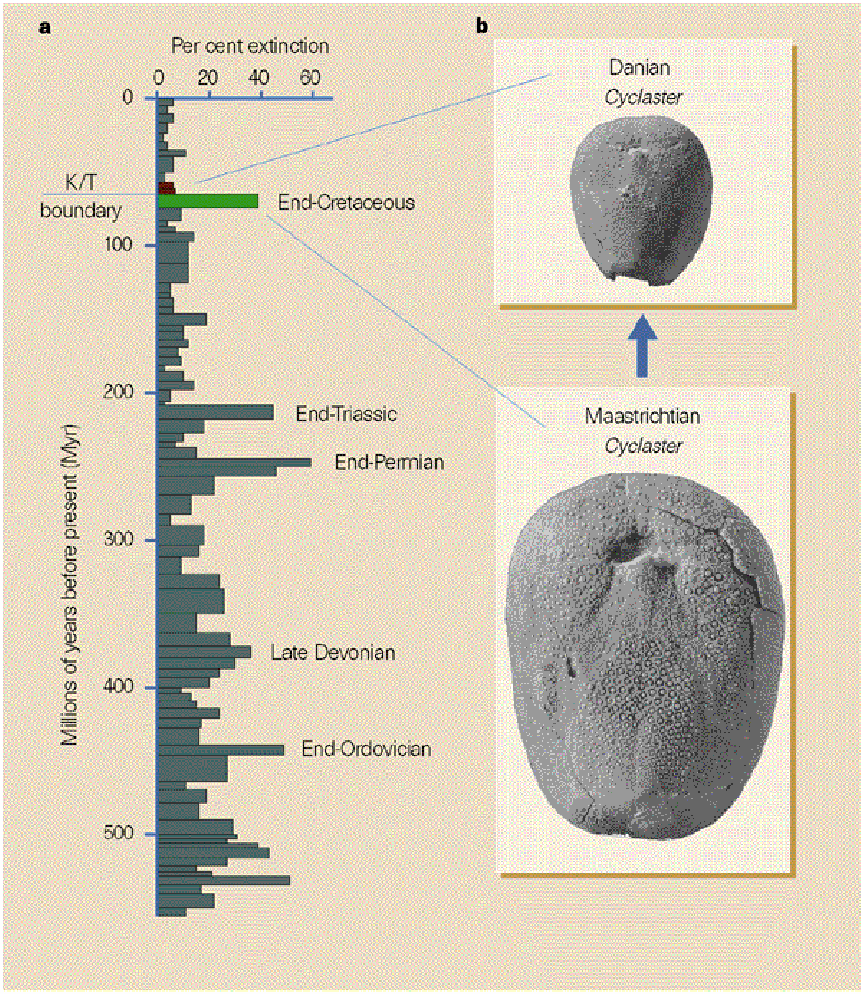


Marine bivalve genera with wide geographic ranges were less likely to become extinct at the K/T boundary

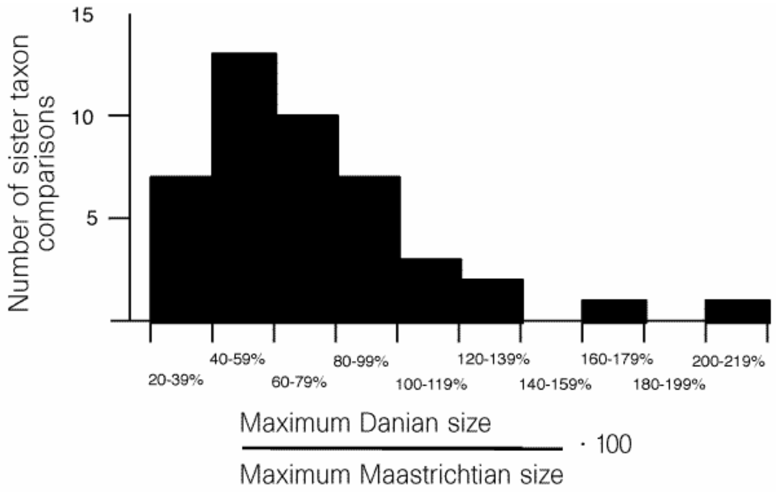


NB: Biogeographic provinces are regions that share similar floras and faunas.

Selectivity of extinction among sea urchins at the K/T due to nutrient supply with selection on benthic adults more than planktotrophic larval stages.



Difference in maximum organism sizes between Maastrichtian and Danian sister taxa.

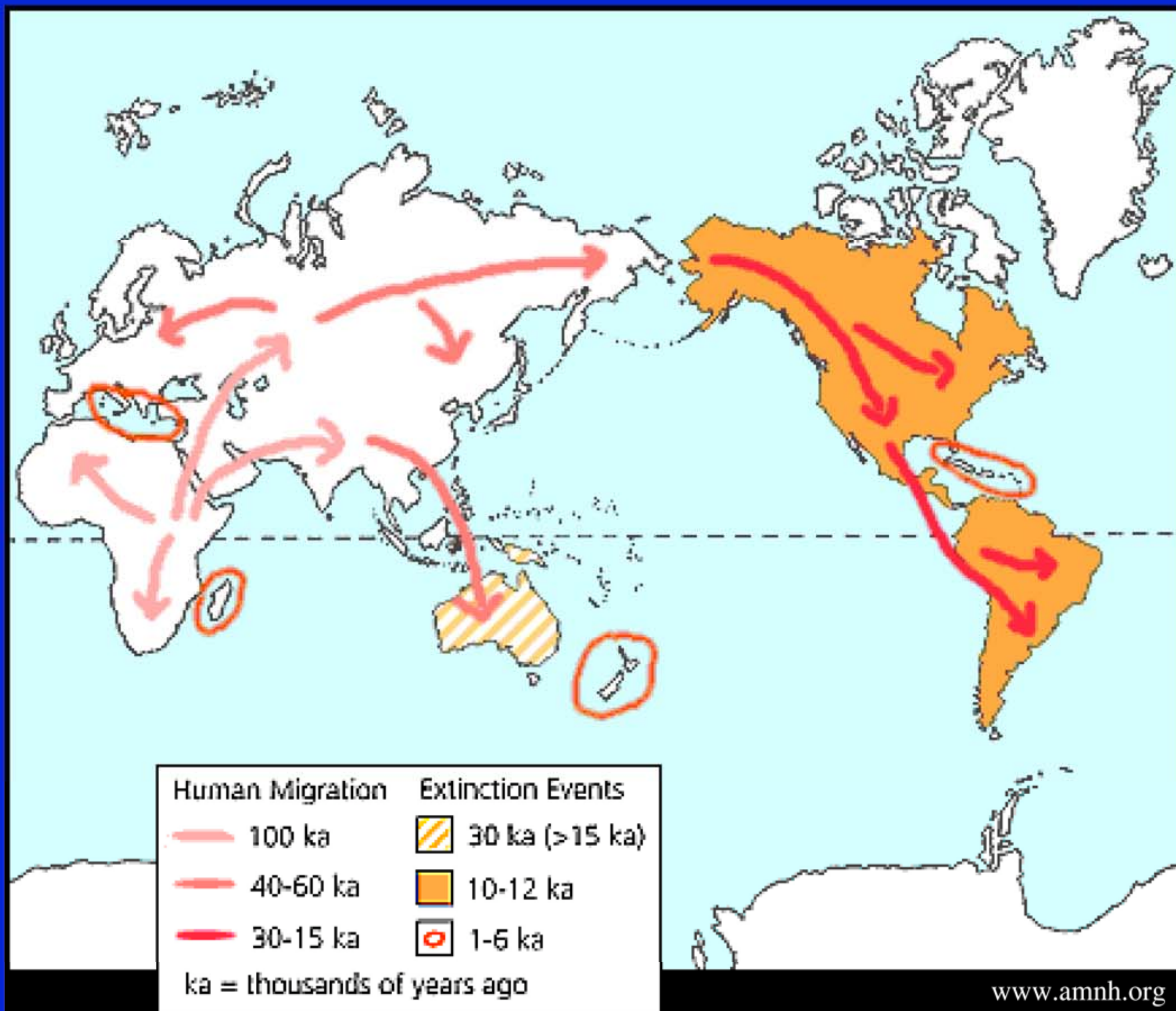


(**a**) The extinction intensity of all marine animal genera measured across the Phanerozoic. (**b**) Sea-urchin lineages that survived the K/T mass extinction, showed a dramatic drop in body size. The sea urchin *Cyclaster* is shown, the Danian specimen being 2.1 cm and the Maastrichtian 3.8 cm in length.

The Human "Meteor"

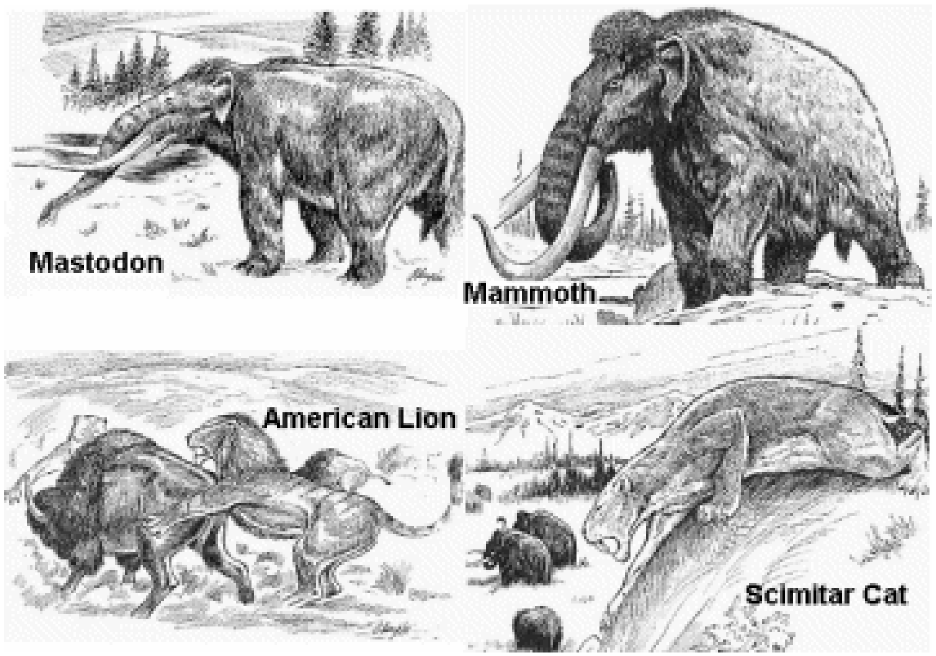
- Pleistocene Megafauna of N. America vs. African Megafauna (Ecological naïveté).
- Polynesian Birds are dropping like flies.
- Habitat destruction and global warming, our biggest experiment.
- Fortuitous Contingency of Cosmic Explosions?

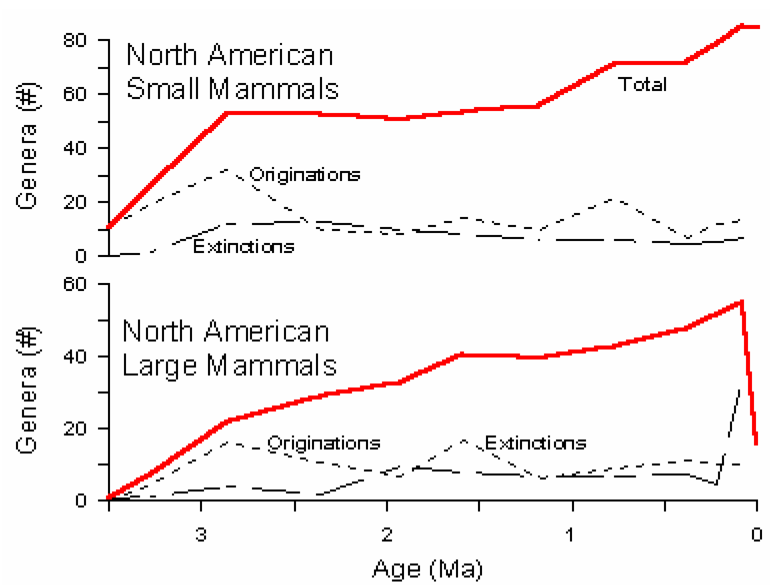
History suggests that humans cause extinction

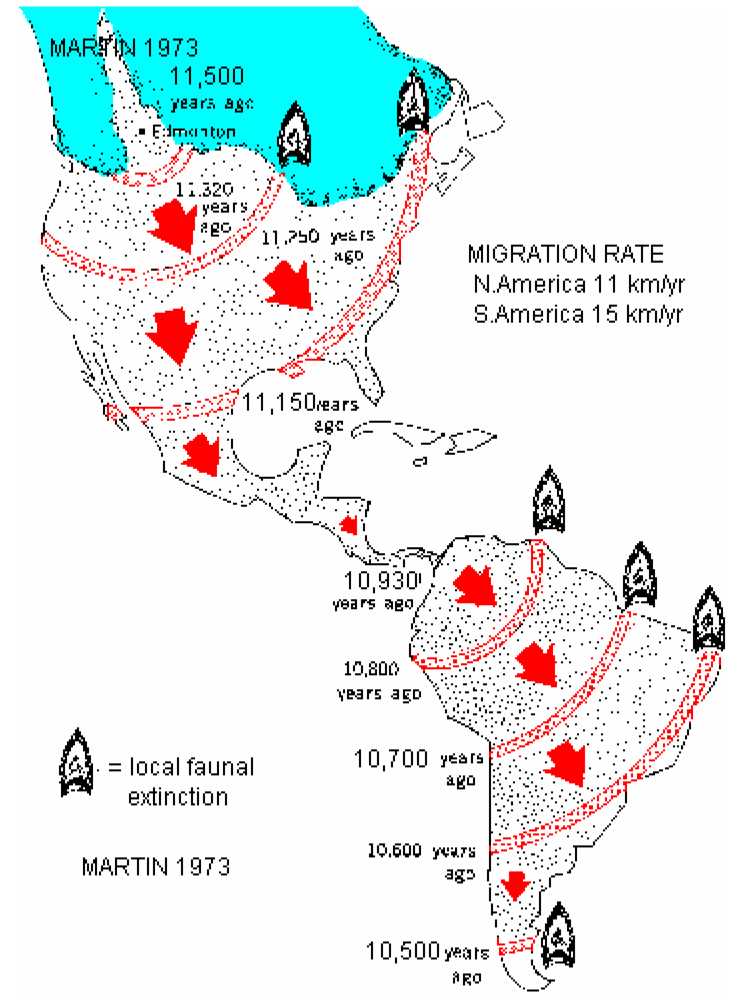


>80% of megafauna extinct in N. Am., S. Am., Australia

Extinction of Pleistocene Megafauna







Bird extinctions on oceanic islands

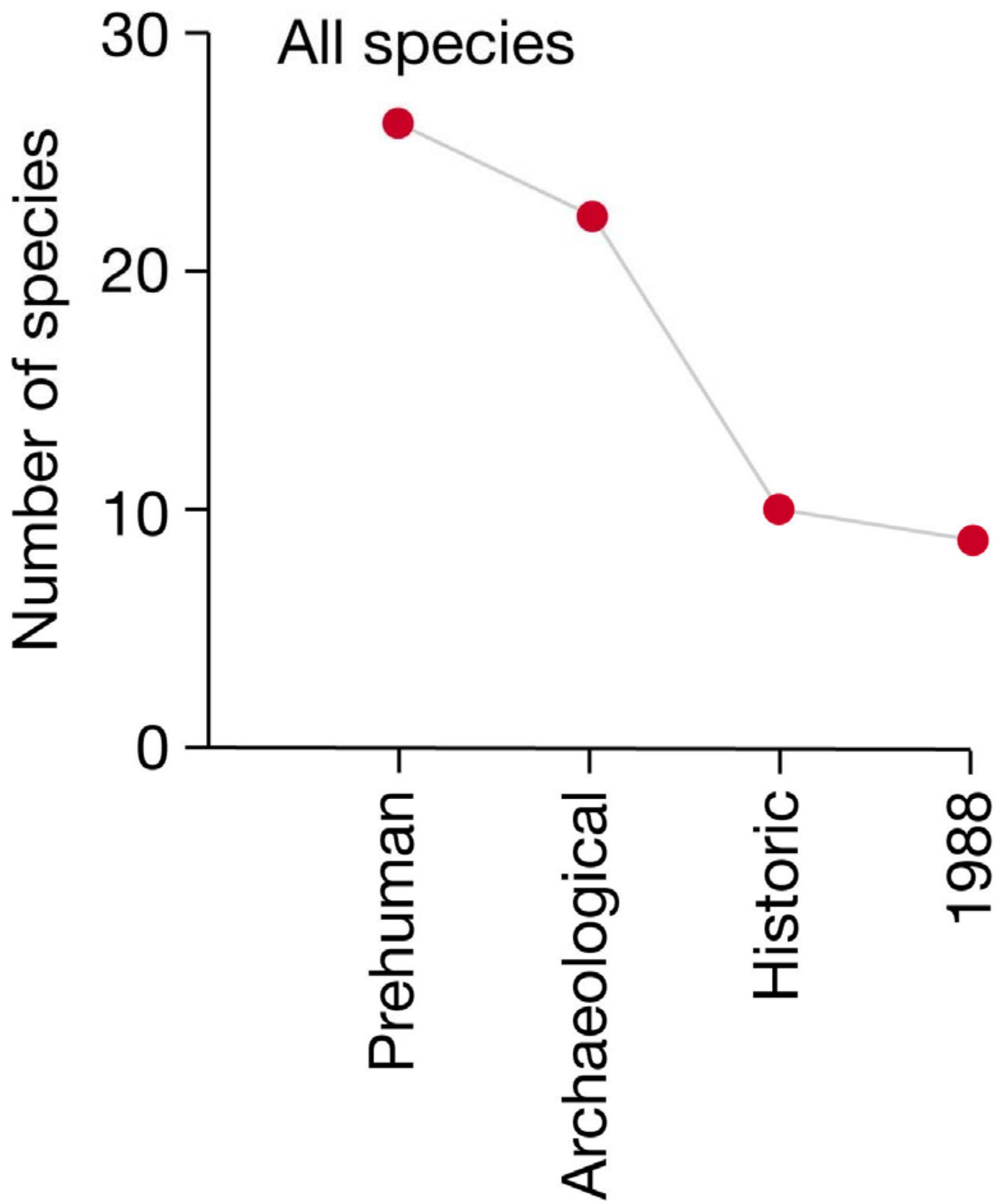
60 species extinct in last 1500 yrs in Hawaii, following human colonization.

An estimated 2000 species of flightless rail used to live on islands in the Pacific…

…only 4 species remain today.

Approximately 1/5 of all bird species in the world have gone extinct in association with human colonization of the Pacific islands.

Forest bird extinctions on ‘Eua (Tonga)



Current estimated extinction rates vs. the Big Five

• Based on rates of deforestation and patterns of tropical diversity and endemism …in the next 30 years, 5-10% of Earth's species will go extinct.

• Such a rate is 100 to 1000 times the background extinction rate.

• How about when global warming kicks into high gear?

• Given the current rate of human population growth, this rate is likely to continue long enough to result in a mass extinction.

• **This will be the first mass extinction caused by an organism.**

The effect of magnetic fields on γ-ray bursts inferred from multi-wavelength observations of the burst of 23 January 1999

T. J. Galama[1], M. S. Briggs[2], R. A. M. J. Wijers[3], P. M. Vreeswijk[1], E. Rol[1], D. Band[4], J. van Paradijs[1,2], C. Kouveliotou[5,6], R. D. Preece[2], M. Bremer[7], I. A. Smith[8], R. P. J. Tilanus[9], A. G. de Bruyn[10,11], R. G. Strom[1,10], G. Pooley[12], A. J. Castro-Tirado[13,14], N. Tanvir[15,16], C. Robinson[17], K. Hurley[18], J. Heise[19], J. Telting[20], R. G. M. Rutten[20], C. Packham[20], R. Swaters[11], J. K. Davies[9], A. Fassia[21], S. F. Green[22], M. J. Foster[22], R. Sagar[23], A. K. Pandey[23], Nilakshi[23], R. K. S. Yadav[23], E. O. Ofek[24], E. Leibowitz[24], P. Ibbetson[24], J. Rhoads[25], E. Falco[26], C. Petry[27], C. Impey[27], T. R. Geballe[28] & D. Bhattacharya[29]

Gamma-ray bursts (GRBs) are thought to arise when an extremely relativistic outflow of particles from a massive explosion (the nature of which is still unclear) interacts with material surrounding the site of the explosion. Observations of the evolving changes in emission at many wavelengths allow us to investigate the origin of the photons, and so potentially determine the nature of the explosion. Here we report the results of γ-ray, optical, infrared, submillimetre, millimetre and radio observations of the burst GRB990123 and its afterglow. Our interpretation of the data indicates that the initial and afterglow emissions are associated with three distinct regions in the fireball. The peak flux of the afterglow, one day after the burst, has a lower frequency than observed for other bursts; this explains the short-lived radio emission. We suggest that the differences between bursts reflect variations in the magnetic-field strength in the afterglow-emitting regions.

Nature 1999. 398:394-399.

Cosmic Explosion - Gamma-ray bursts are the most powerful explosions known in the Universe