Covered in this file:

These topics are actually all about convergence and contingency, as has all material in this section of the course.

1. Genome-level evolutionary processes:

More random than "natural selection."

(This material is available as a separate document at the course web site. Only a one-page list is given here.)

2. Possible examples of convergence.

And at least one (eye) that is clearly more complicated than any naïve interpretation.

3. Mass extinctions. This was already covered in class, but is included in this set of class notes. Textbook has excellent discussion. This is definitely a random component to any picture of evolution. If you "need" mass extinctions to stimulate development of more complexity (e.g. mammals after extinction of dinosaurs), then the probability might be small…

Evolutionary processes:
more complicated than Darwin could have imagined.

Basic ideas of inheritance, variation, and natural selection still intact, just wildly elaborated. Primary difference is that the genome is much more dynamic than simple point mutations leading to gradual change. Instead, genome evolution is dominated by *mobile elements*, like transposons, plasmids, and more. Those features of the genome are referred to as the "mobilome" (just as an organism's repertoire of proteins is called the "proteome").

Variation--today we know that the variation is genetic, caused partly by mutations due to DNA damage which is not repaired exactly. *Most* of these mutations are deleterious (not adaptive or beneficial). Other, more dynamic, sources of variation are the processes of genome change discussed below.

Punctuated equilibrium --in many cases rate of evolution has not been gradual as originally imagined, but in bursts and lulls ("stasis," long periods during which little evolution of a species occurs). *This is not a theory, just an observation of the fossil record--sometimes developments are rapid.* Today this is easily accepted, given dynamic picture of genome.

Sudden, often catastrophic, environmental changes --Giant impactors, Snowball Earth episodes, alternating glaciations and interglacials, variations in the ozone shield due to giant solar flares,, … Maybe related to punctuated equilibrium, but can't be the whole story (punctuated equilibrium is seen in laboratory bacterial evolution). But certainly **adds a random, chance element to evolution.**

Neutral evolution --neutral mutations can occur, neither deleterious or beneficial, and which get "fixed" in a species is just a matter of chance ("genetic drift"). Kimura proposed that evolution was dominated by neutral mutations ⇒ ***would be big blow to idea of natural selection***. But now understood that genetic drift is just part of the story and natural selection is undoubtedly important in many or most cases. Still, **nearly-neutral evolution is now accepted as a part of the process of evolution, and it is (1) distinctly random; (2) completely at odds with the idea that natural selection drove *all* of evolution.**

Evolutionary processes (cont'd)

Recombination

Exaptation

Lateral (or horizontal) transfer (transposons)

Gene and genome duplication

Epistasis

Mutator genes

Transposable genetic elements

Gene loss

(These are defined and briefly discussed in a "handout" that you can download online.)

The major question for us: How "random" of "chancy" or "unlikely" are these processes and the forms of life they led to?

A few examples of what are usually believed to be examples of convergent evolution.

Things so far probably look pretty "contingent," and will look even more so from the point of view of genome evolution. So we pause to summarize a few cases for "convergence."

Major question for SETI is:
Do we expect some or most of these developments to occur elsewhere?
Was evolution "convergent" ?
We especially want to know if this is the case for complex traits like "intelligence."

Could point to MANY examples (see class notes and pictures to follow): flight, pouches, sonar, eyes, jet propulsion, even social structures.

But these *could* be due to lateral transfer, in particular "*viral transduction*."

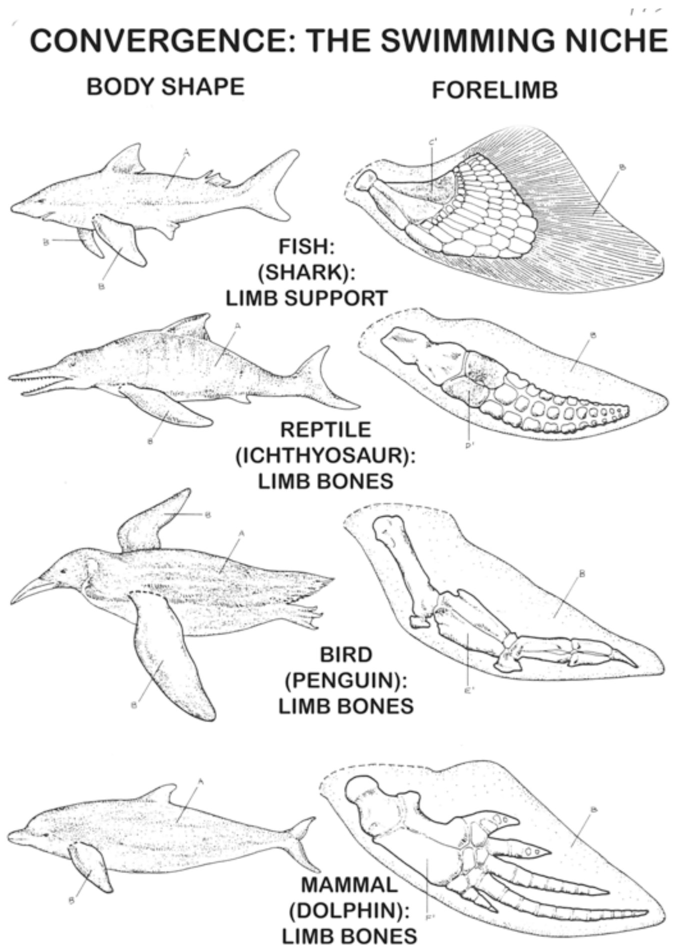
Also, interpreting traits is tricky because of things like *exaptation* (discussed earlier)

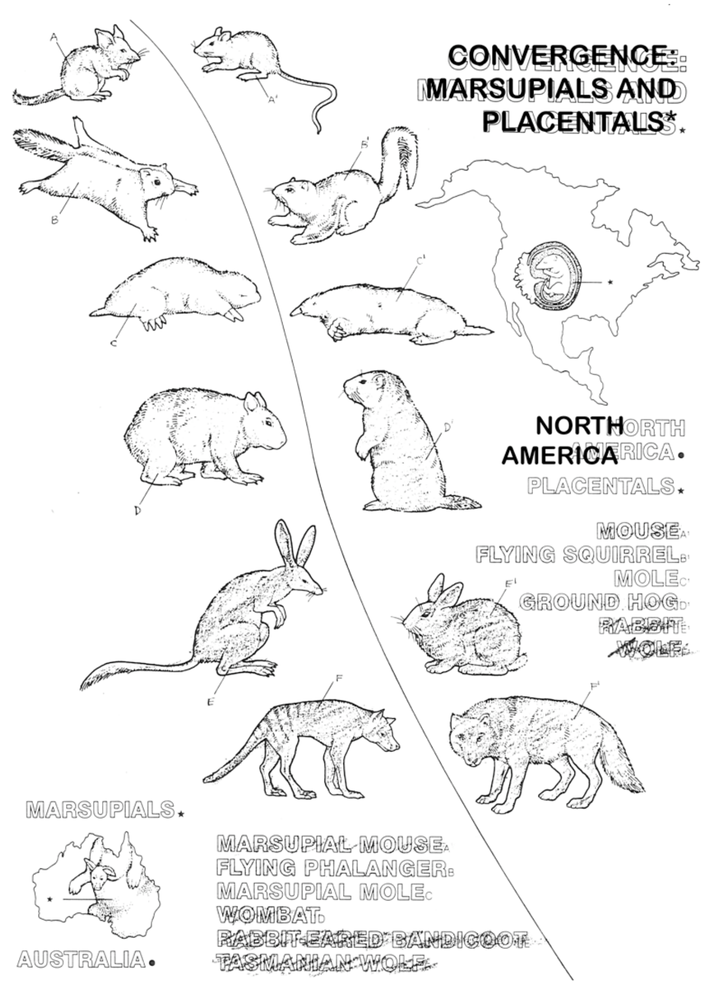
And *some* traits would be very useful (adaptive) but have never arisen (e.g. cellulose-digesting enzyme in animals), or have arisen only once (the case of woodpeckers will probably be discussed in class).

And there are undoubtedly processes, especially environmental processes like impacts, that are completely unpredictable. Mass extinctions are discussed elsewhere in notes

We need to look at the *genome-level processes of evolution* to get any idea about whether we expect convergence to occur or not (next topic in notes).

Examples of convergence of adaptive traits: Swimming and marsupials/placentals





Convergence: burrowing mammals

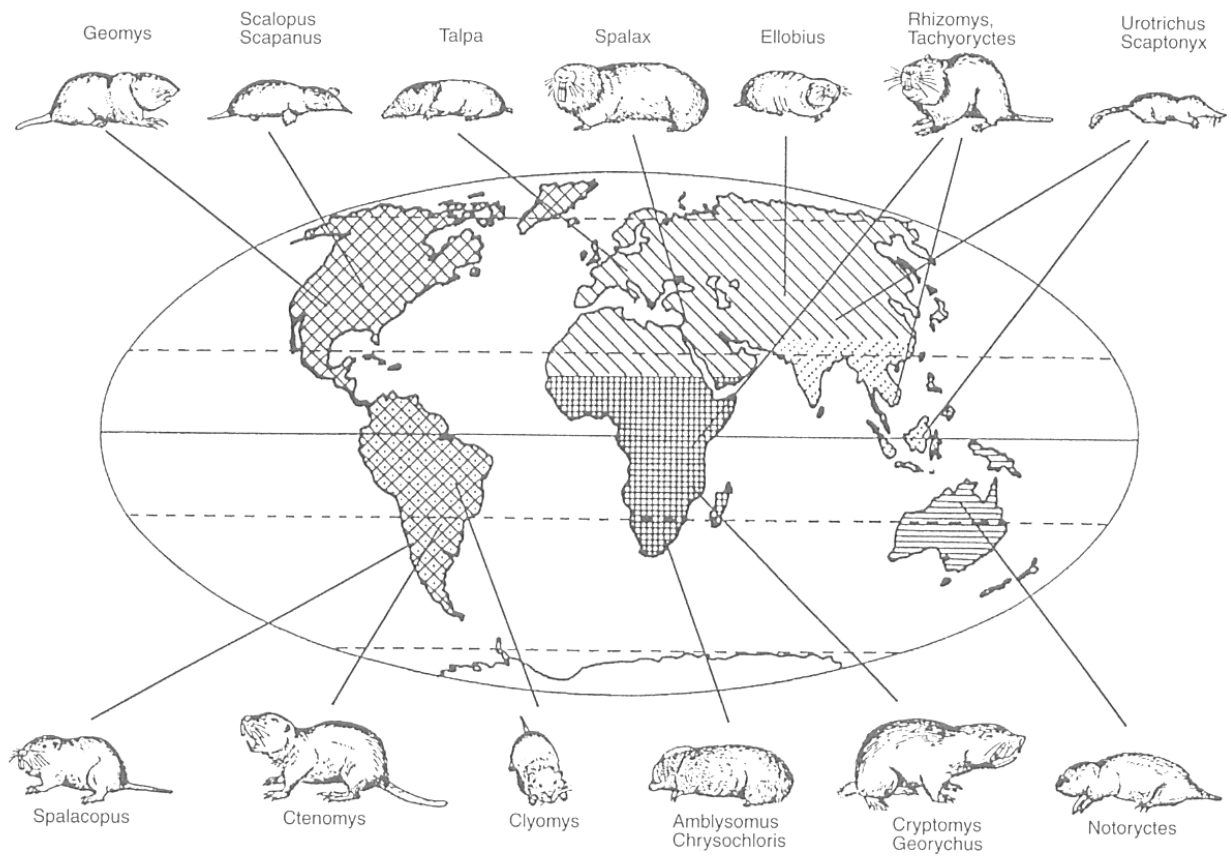


FIGURE 6.8 Convergent evolution in the burrowing (fossorial) mammals, including the familiar mole (*Talpa*), mole-rat (*Spalax*), and marsupial mole (*Notoryctes*). (Reproduced from fig. 1 of E. Nevo (1995) Mammalian evolution underground. The ecological–genetic–phenetic interfaces, *Acta Theriologica*, Supplement 3 (Ecological genetics in mammals II, eds. G. B. Hartl and J. Markowski), pp. 9–31, with permission of author and *Acta Theriologica*.)

Many examples of apparently convergent evolution have been found at the molecular level. Paper below examined a protein that is a cardiovascular risk factor. See references and online (use UTNetCat "find a journal"), citations through ISI Web of Knowledge, to see more examples.

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Genomics 83 (2004) 19–23

GENOMICS

www.elsevier.com/locate/ygeno

Convergent evolution in primates and an insectivore

Dario Boffelli, Jan-Fang Cheng, and Edward M. Rubin*

Genome Sciences Department, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS 84-171, Berkeley, California 94720, USA

Received 19 February 2003; accepted 1 May 2003

Abstract

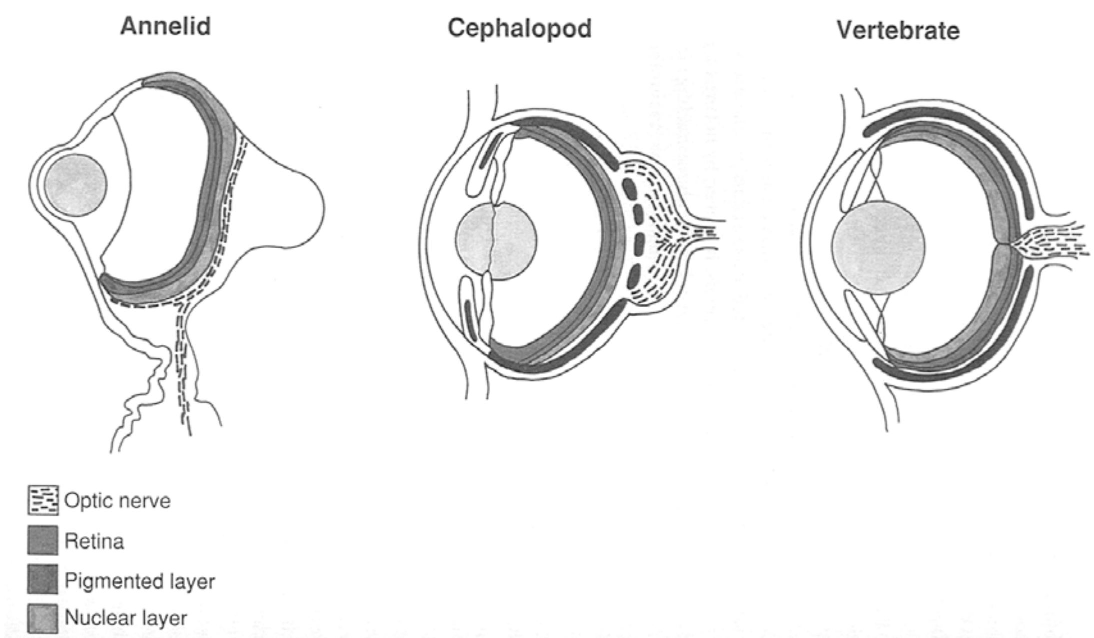
The cardiovascular risk factor LPA has a puzzling distribution among mammals, its presence being limited to a subset of primates and a member of the insectivore lineage, the hedgehog. To explore the evolutionary history of LPA, we performed extensive genomic sequence comparisons of multiple species with and without an LPA gene product, such as human, baboon, hedgehog, lemur, and mouse. This analysis indicated that LPA arose independently in a subset of primates, including baboon and human, and an insectivore, the hedgehog, and was not simply lost by species lacking it. The similar structural domains shared by the hedgehog and primate LPA indicate that they were formed by a unique molecular mechanism involving the convergent evolution of paralogous genes in these distant species.

Complex eye design: Convergence?

- Eye design is usually touted as a clear example of convergence, since similar eye types arose in very distantly related types of animals.

- It is also often cited as a case where it is difficult to understand how such complexity and intricate design could have developed from random mutations--what came before it would not have been an eye, so no adaptive value until this eye design was reached.

- Both views are probably wrong, and the current evidence is more fascinating than either (as shown on next slide). It suggests that *any convergence is at the molecular level.*



The story as told by current research shows a more complex and interesting picture:

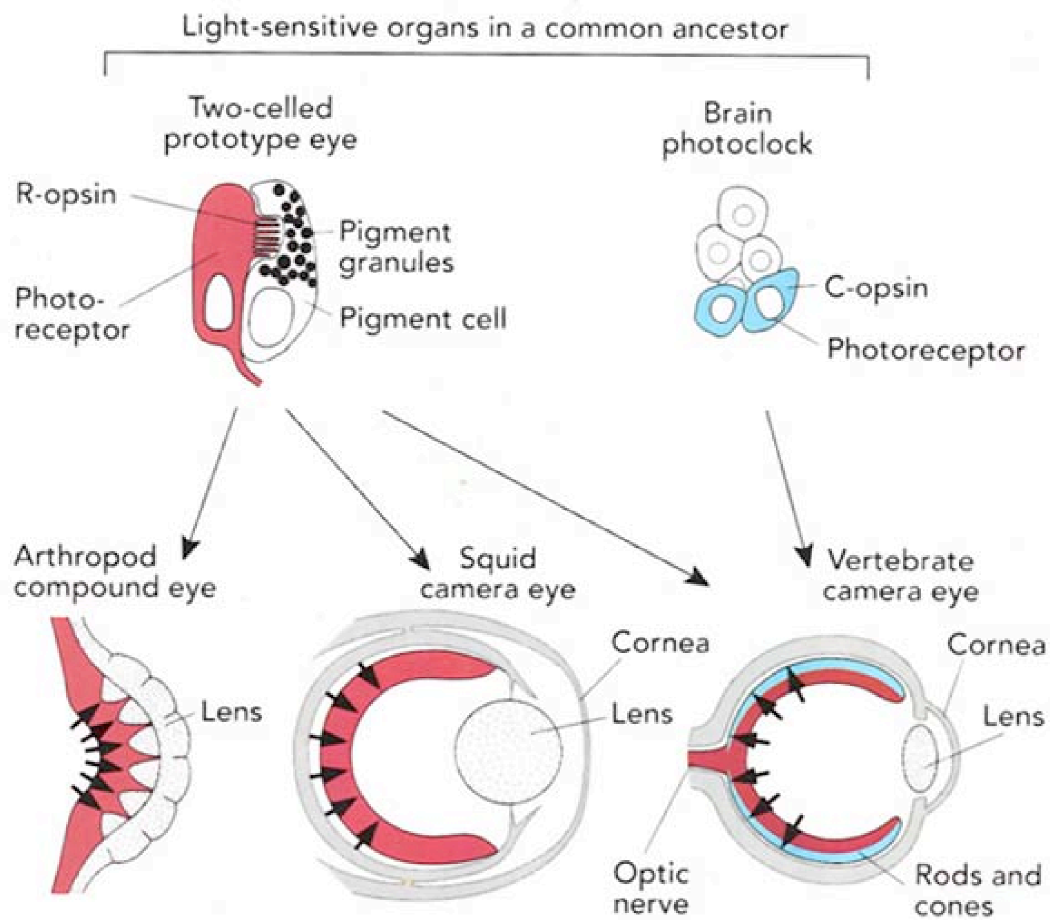
Vast range of eye types evolved is controlled by a single gene: Pax-6.

Using this gene to trace origin of eye structures, result is:

- Each animal eye evolved from a simple photoreceptive structure in a distant common ancestor of arthropds, cephelopods, and vertebrates.
- Ancestor possessed two kinds of light-sensitive organs (upper half), a two-celled prototype eye (red) and a "brain photoclock" (blue) each one with a photoreceptor + light-sensitive protein.

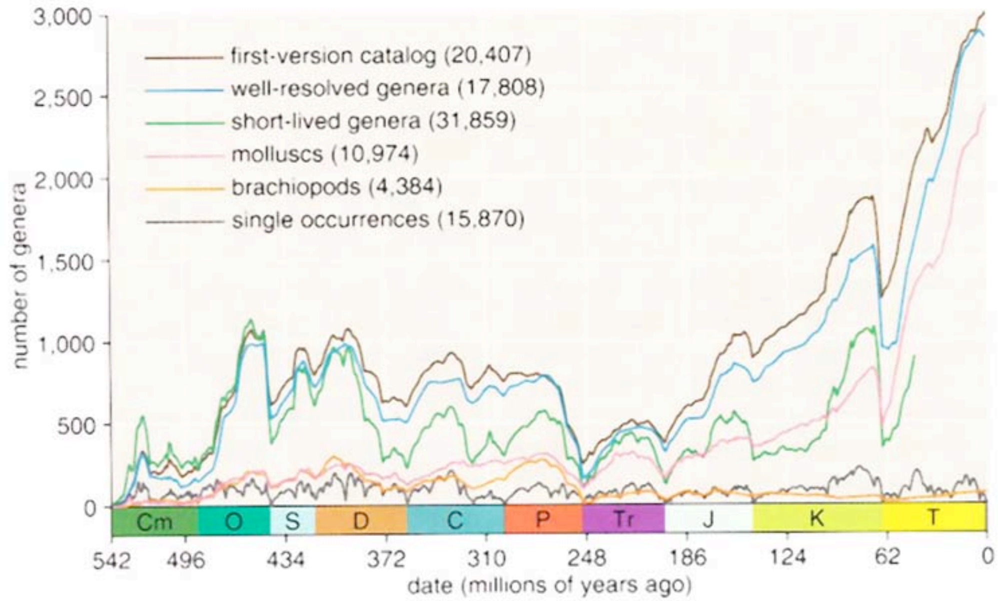
- Arthropod and squid retina (red) incorporated the two-celled prototype eye.
- Vertebrates incorporated *both* kinds of photoreceptor (red and blue).

Now can see eye types as examples of contingency, since it depends completely on the ancestor developing the two kinds of photo-organs. This may have happened only once! Would it happen again "if we could play back the tape"? Or were these kinds of photoreceptors so adaptive that this is convergence?

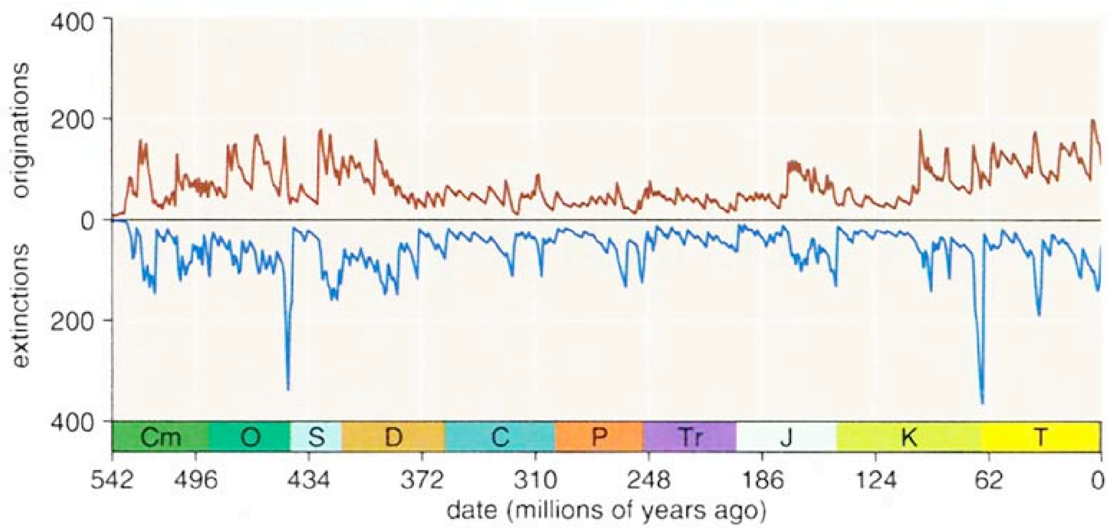


Mass Extinctions

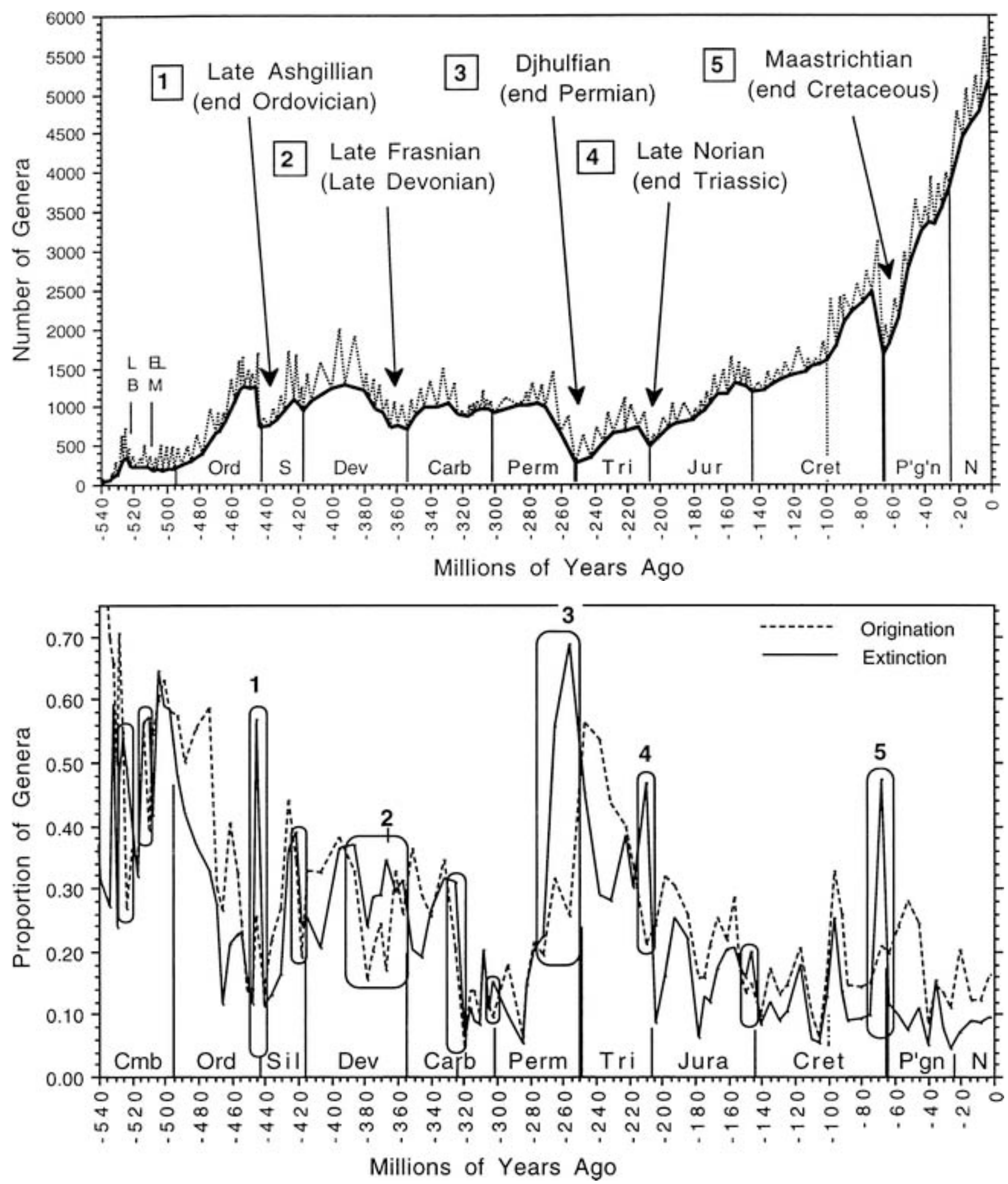
First version of Sepkowski database (marine organisms): "Mass extinction" = steep rate of change of number of genera



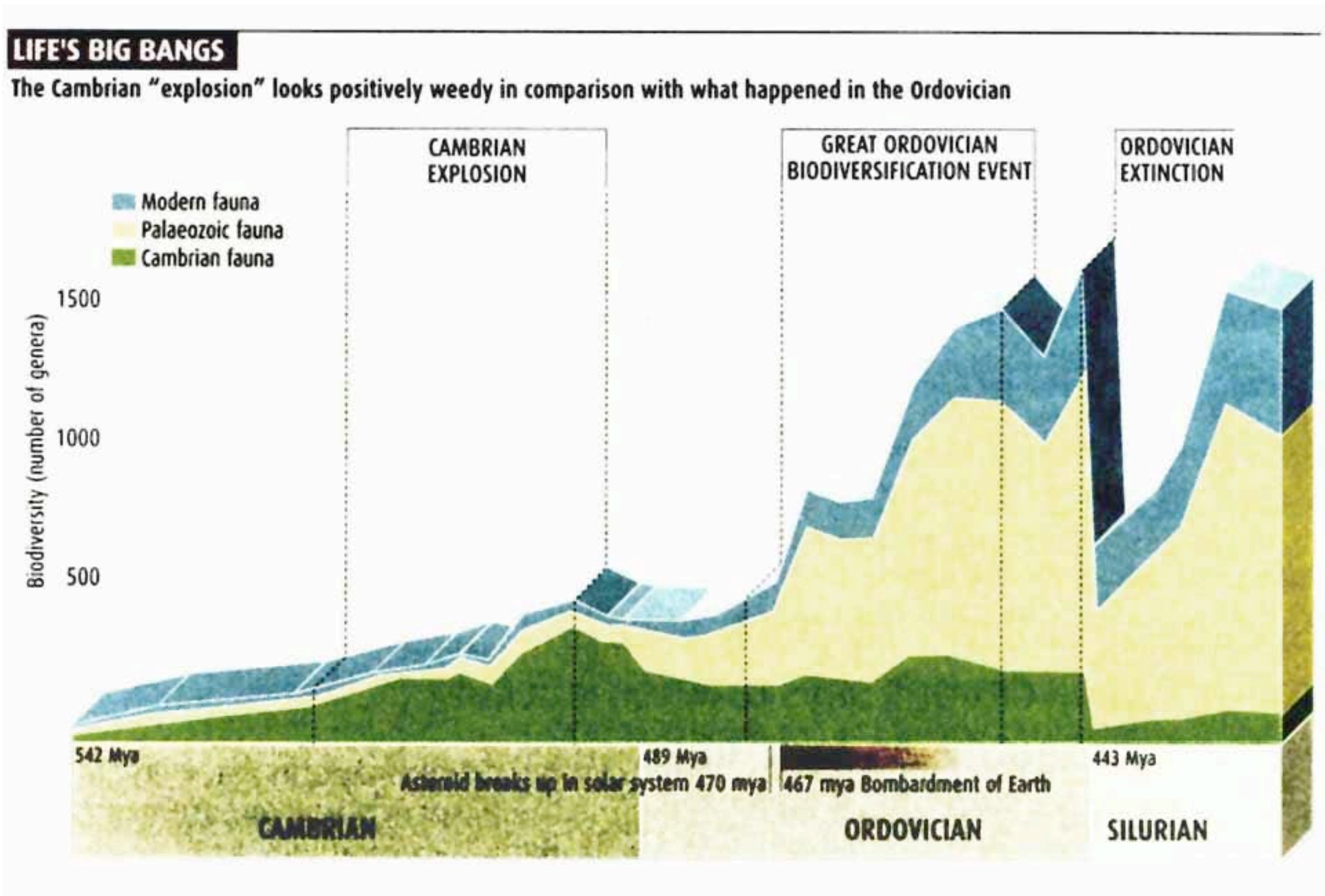
Origination and extinction events: Muller and Rohde 2004



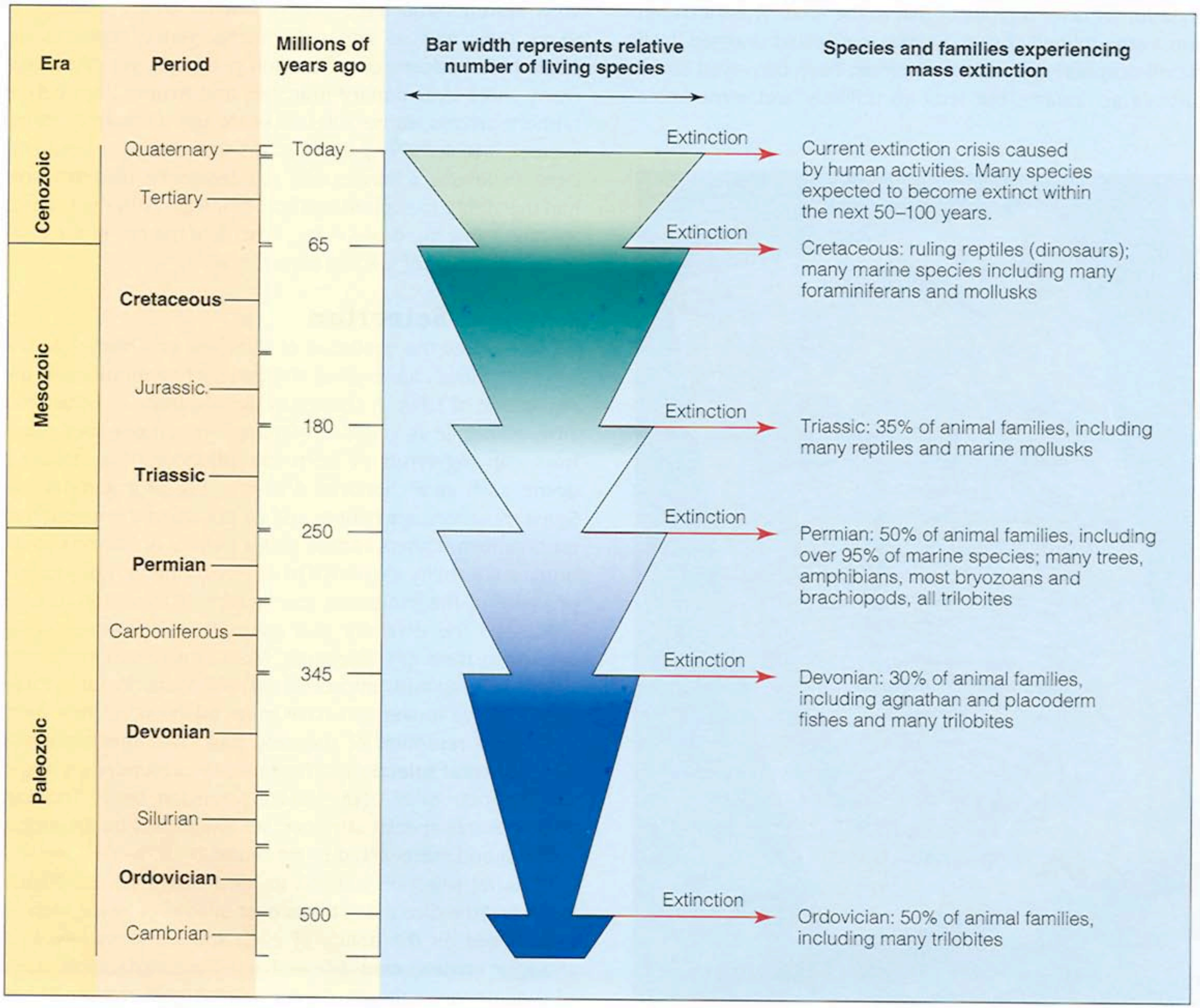
Mass extinction by genera: extinction and origination



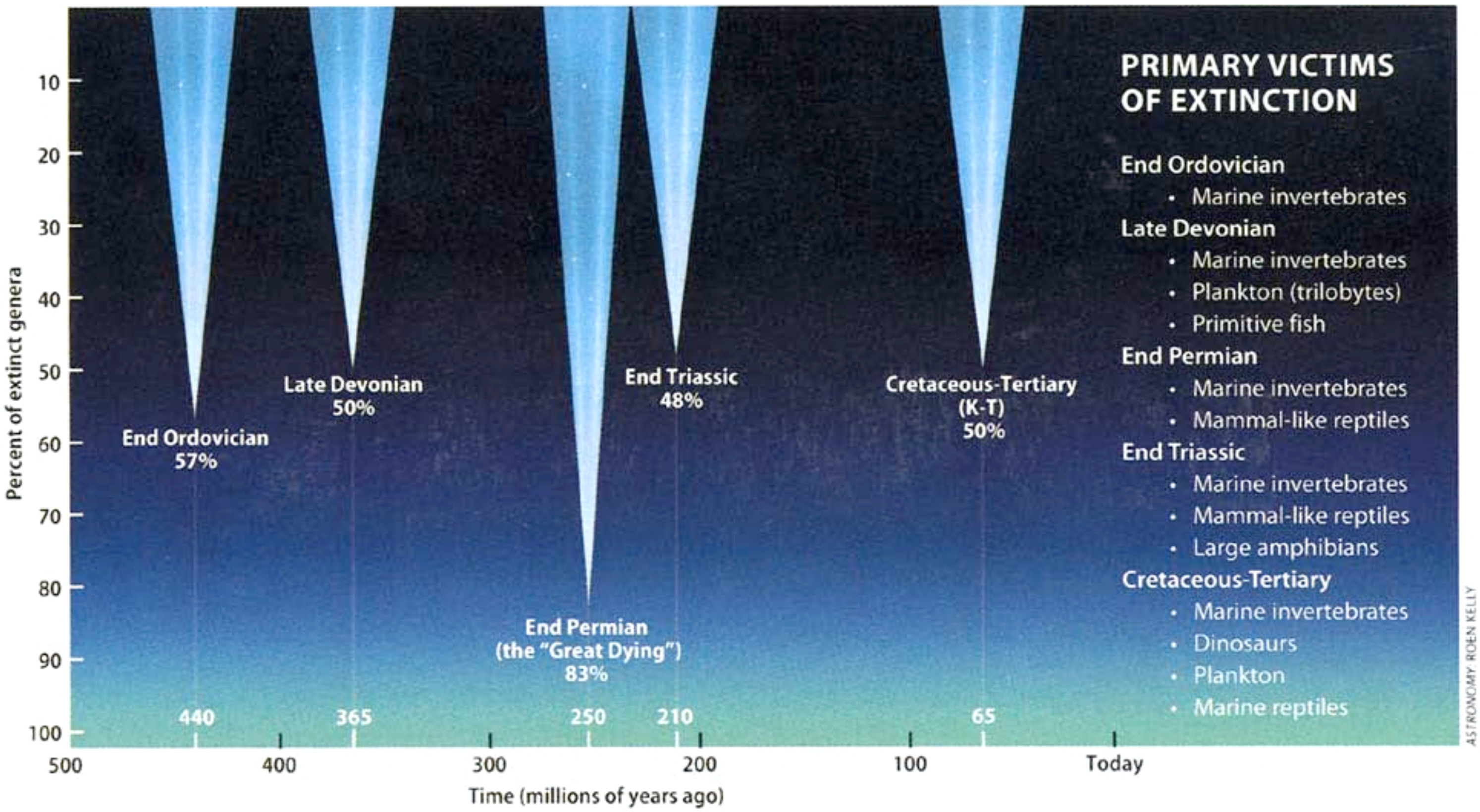
Biodiversity's rapid rise just before the Ordovician mass extinction



Major Mass Extinctions



The “Big Five” mass extinctions and their victims



LIFE ON EARTH experienced several mass extinctions. The “Big Five” are shown here with the percent of genera that died off. Paleontologists use genera (the rank above species and below family) to gauge extinctions because the numbers are better surveyed. The End Permian event was the worst of the Big Five, with 83 percent of genera going extinct, including 95 percent of marine species. Because the dinosaurs died out during the Cretaceous-Tertiary (K-T) extinction, this is the best known, and most studied. The cause of each mass extinction is still not understood, although scientists are all but certain the K-T extinction was associated with a meteor impact. Astronomers speculate a nearby GRB might have caused the End Ordovician extinction by triggering an ice age.

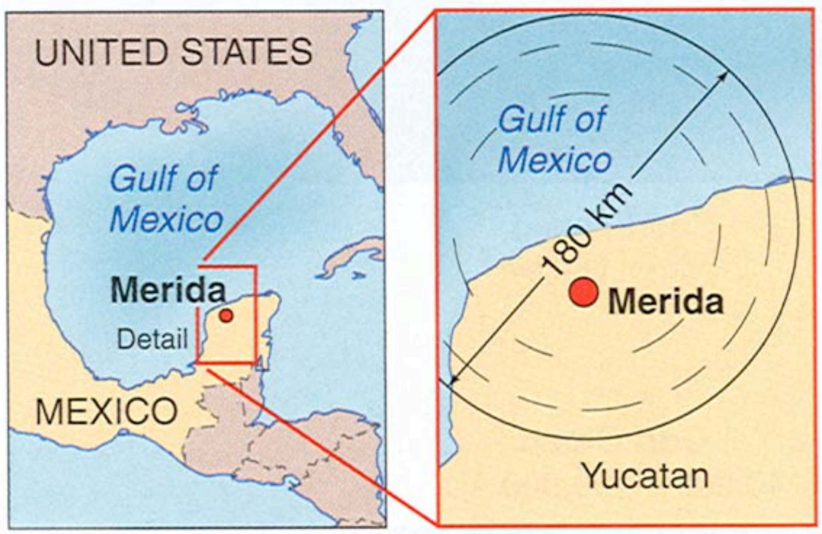
Mass extinction at 65 Myr: Almost certainly ~10 km bolide impact

Iridium-rich layer in 65 Myr sedimentary layers found worldwide (iridium is enhanced in meteorites)

Mass of iridium consistent with impact bolide size ~10 km

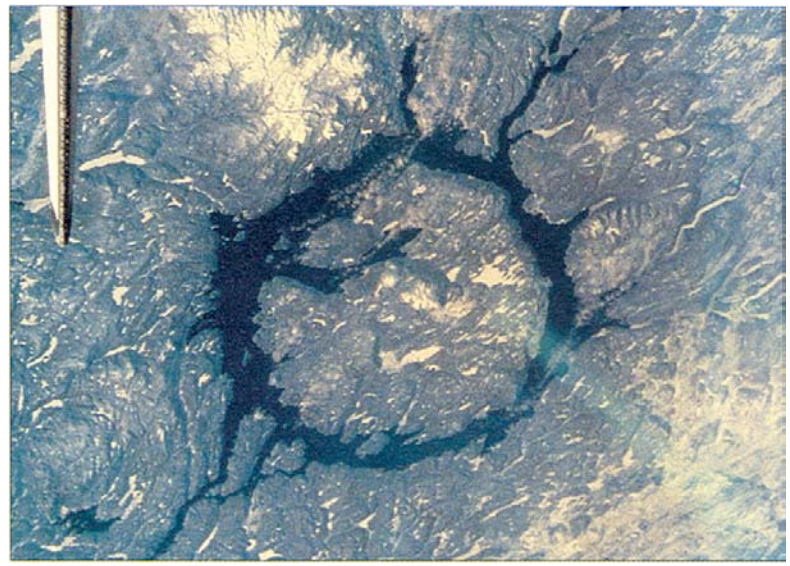
Where is the crater? "Smoking gun" found in

Chixhulub (Yucatan coast, Mexico). Age = 65 Myr!



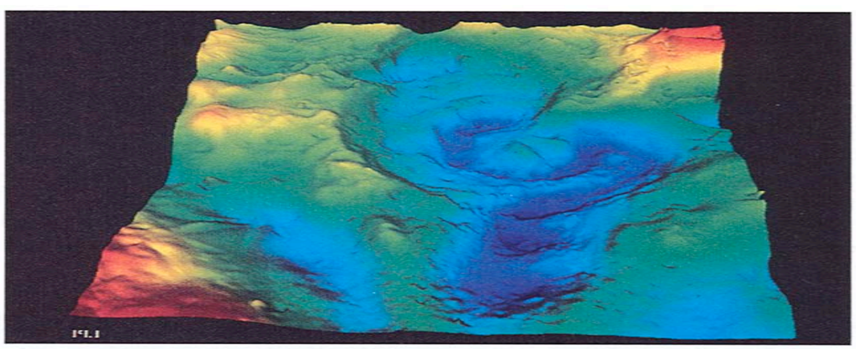
The Chicxulub crater off the Yucatan coast of Mexico measures 180–300 km across, making it one of the largest craters formed in the inner solar system during the last 4 billion years. It is not completely visible from above, but was detected by measuring slight variations in Earth's gravitational pull—measurements made originally for oil exploration.

Some large impact craters *not* associated with enhanced extinction

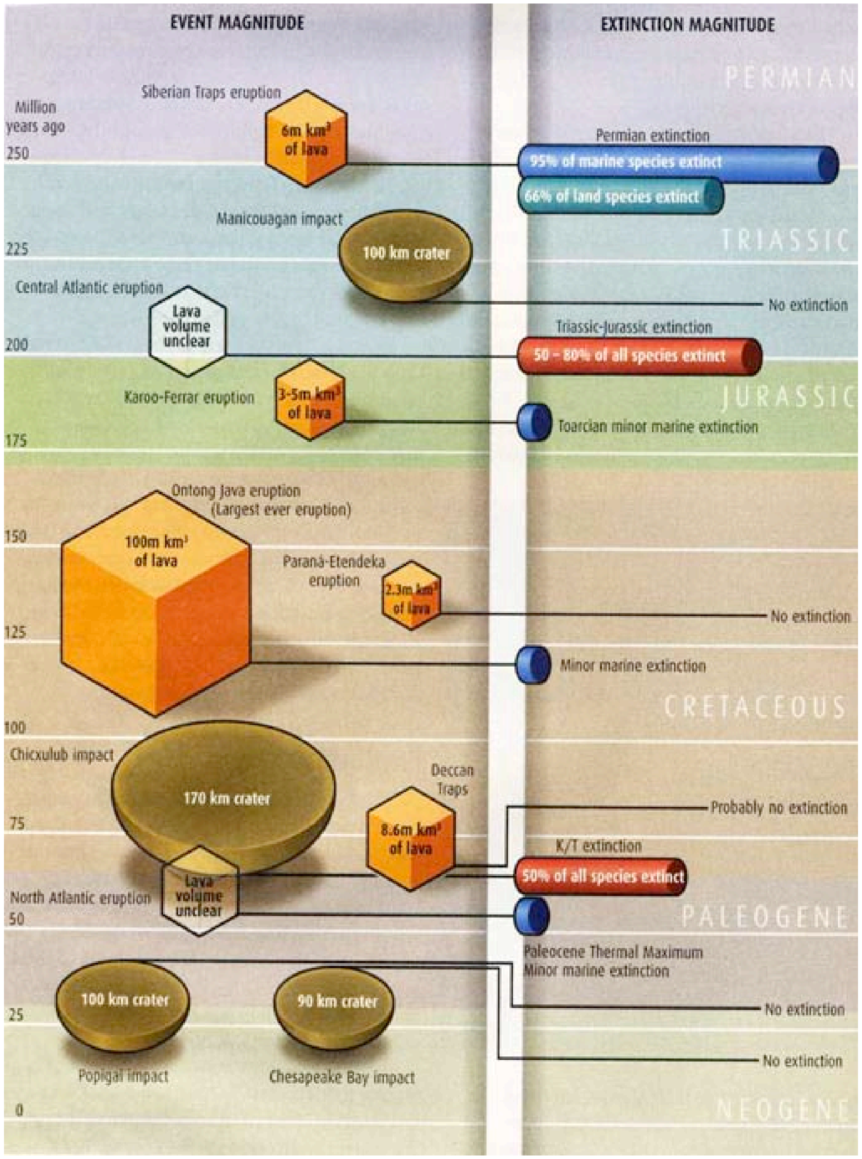


Large crater near Quebec, Canada

Details of Chicxulub structure



The impact structure known as Chicxulub, at the north end of the Yucatán. The blue areas are low-density rocks broken up by the impact. The green mound at the center is denser and probably represents a rebound at the point of impact. It is one of the largest craters known on Earth.



This is a speculative attempt to assign either volcanic episodes (from lava volumes) or bolide impacts (from craters) to each mass extinction

Consequences and rates of impact of bolides with different sizes