Biology 1B—Evolution Lecture 11, Insights from the Fossil Record – timing of events and extinction

Fossil Record

Microevolution —*(speciation)*→ Macroevolution

The **fossil record** is our primary source of information on the past, including the timing of various extinction and evolutionary events and the phenotypes of ancestral forms. Sedimentary rocks created by erosion (often in a marine environment) form strata, with different layers corresponding to different time periods. Consider the Grand Canyon, formed by the Colorado River over 20 million years: the exposed strata, from the top of nearby Bryce Canyon to the bottom of the Grand Canyon itself, cover the last billion years. These layers can be dated by analyzing proportions of different isotopes present in each of the strata.

Fossils provided both key evidence and frustration to Darwin when writing *the Origin of the Species*. Fossils showed there were many creatures which no longer existed; but these animals existed at some point, and must have been adapted to the environment in which they lived. This further reinforced the idea that the present and past are ruled by the same physical processes. However, it was frustrating in that many complex creatures seemed to suddenly appear in the fossil record, without preceding transitional forms. Darwin predicted that these gaps would be filled, and many of the gaps he predicted have now been filled.

Some major transitions in earth history	**Billions of Years Ago**
Earth and Solar System formation	4.5
Earliest prokaryote fossils	3.5
Increase in oxygen – implies photosynthesis	2.7
Single-celled fossil eukaryotes	2.1-1.2
Complex metazoan (multi-celled animals)	0.5
Hominids (apes and humans)	0.005

The Cambrian Explosion is a time period from 550 million years ago (appearance of complex metazoans) when many species and new body forms appear in the fossil record. The fossils preceding that 550 million years ago mark are very scarce, then suddenly there is a large diversity of fossils and body forms.

What caused this diversity? There are several possibilities. Firstly, perhaps before the Cambrian period, all organisms were soft-bodied, and thus did mineralize and leave behind fossils. Supporting this hypothesis is that scientists have discovered fossil impressions of organisms older than the Cambrian period. Another possibility is that the rapid appearance of new species was due to an evolutionary innovation allowing the rapid diversification of body forms that did not exist before. Consider hox genes, and how they allow for entirely different body plans. The evolution of this innovation could allow for rapid diversification of body plans.

The **Burgess Shale** is a site in Canada excavated by Charles Walcott that has given us many excellent Cambrian fossils.

Now, consider fossils in tandem with extinction. Extinction is normal enough: 97% of all species ever extant on Earth are now extinct. We can determine extinction rates by following species that fossilize well through the various rock strata. Eventually, having gone extinct, they stop appearing in the fossil record. The background rate of extinction for marine invertebrates is less than 0.1 extinction per million species per year; or in the following graph, about 3-4 families per MY. However, there are some large peaks in the extinction rates which we call **mass extinctions,** defined as having >75% species extinct within a million years. Two major extinctions we will explore further are the **Permian-Triassic** extinction (250mya) and the **Createous/Paleogene (k/t)** extinction (65mya), which pushed the terrestrial dinosaurs into extinction and lead to adaptive radiation of mammals and birds (= surviving lineage of theropod dinosaurs).

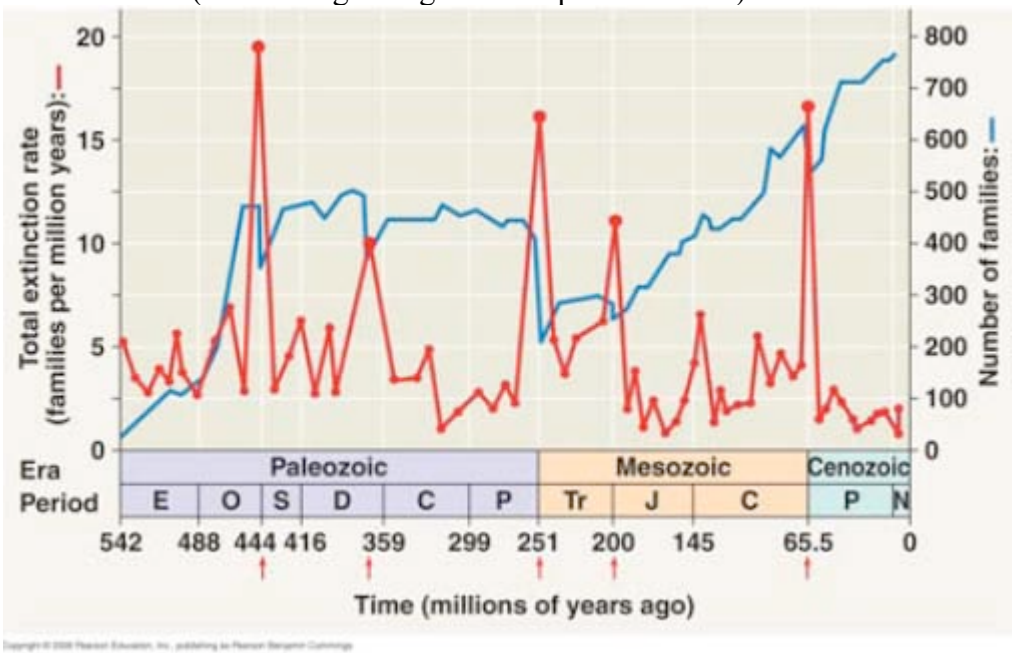


Figure 4: Graph of extinction rates over time, showing mass extinction events.

Extinction

Important points on extinction rates:

- Background rate of extinctions per million species per year:
  About 0.1 extinction per million species of marine invertebrate per year, so if there are roughly 10 million species on the planet, that would imply that about 1 species extinct per year
- Environmental pressures, such as changing temperatures or volcanism, commonly cause extinction of species, but extinction also occurs in a “constant” environment
- Broadly, a typical species lasts 2-10 million years

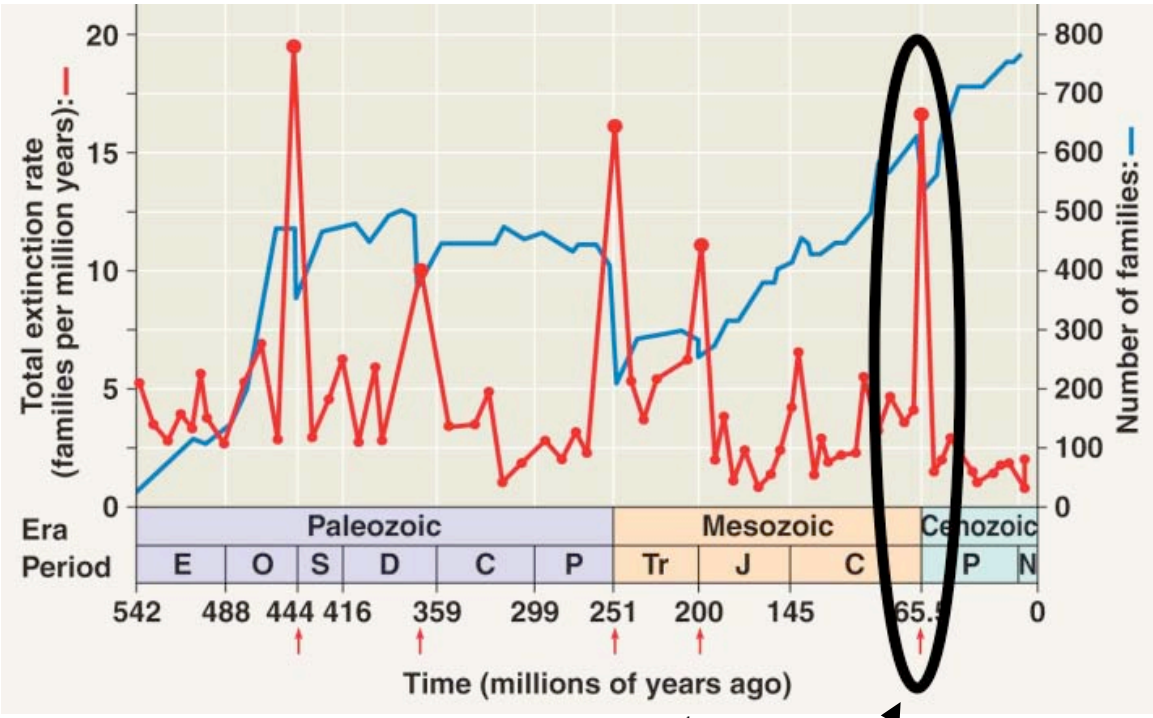
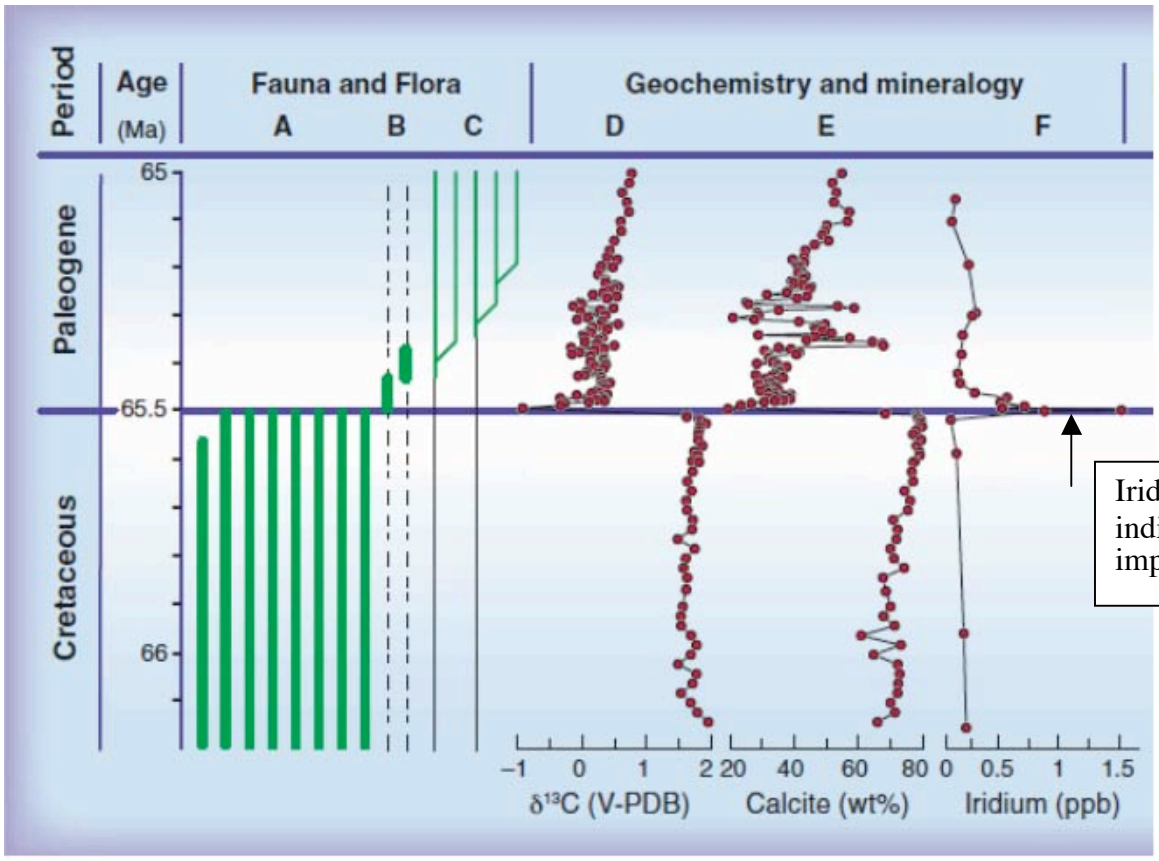


Figure 25.14 (page 521, 8th edition)
Huge extinction the result of a comet impact (more below)

Cretaceous-Paleogene (Tertiary) Extinction—K/T Boundary

- Most importantly, this marked the demise of the terrestrial dinosaurs (save for modern dinosaurs, which are birds)
- With the end of the dinosaurs came the adaptive radiation of the mammals
- Luis and Walter Alvarez (of UC Berkeley!) worked to find what caused the K/T boundary/extinction of the dinosaurs
  --Walter, a paleonotologist, noticed a layer of dark silt between fossils of organisms between the Cretaceous (large-bodied animals) and Paleogene (smaller-bodied animals)
  --He asked his father, a physicist, what might be studied in the isotopes in the dark silt layer
  --They found a huge spike in the amount of iridium, which suggested a comet impact



--Despite the scrutiny and disbelief of the scientific community, the crater the comet would have left in the Yucatan was eventually found

- The massive impact of the comet ejected sediments into the air, halting photosynthesis and changing the carbon cycle of the planet
- It took about 10, 000 years to restore the Earth's normal ecological processes and millions to restore diversity

Are we causing a sixth mass extinction?

- Very difficult to know for sure, as we don't even know how many species there are on the planet (we've only described 1.6 million of perhaps 10-15 million total species). Estimates of the rate of extinction are vary according to time interval over which extinction is measured – estimates spanning >1M years of the fossil record tend to be lower (about 1 extinction per million species per year for terrestrial mammals) and more precise than rated measured over a small time span (e.g the last 100 years).
- Amphibians are closely tied to environmental conditions, and 30% of known species are now endangered
- Better evidence of a mass extinction might come from the loss of megafauna (smilodons, mastodons) that might be the result of humans hunting, climate change, or both

  --North American and Australian megafauna went extinct roughly after humans arrived in North America

--Africa still has many megafauna, suggesting that they evolved with the humans and human ancestors there

- We also see extinctions of large birds, such as rails and moas soon after the recent colonization of Pacific Islands by humans
- A recent reassessment by Tony Barnosky and grad students in IB suggests that we are not yet in a human-caused mass extinction, but extinction rates are elevated and this could lead to a mass extinction if currently threatened species go extinct and this rate of loss is maintained for several hundred years.