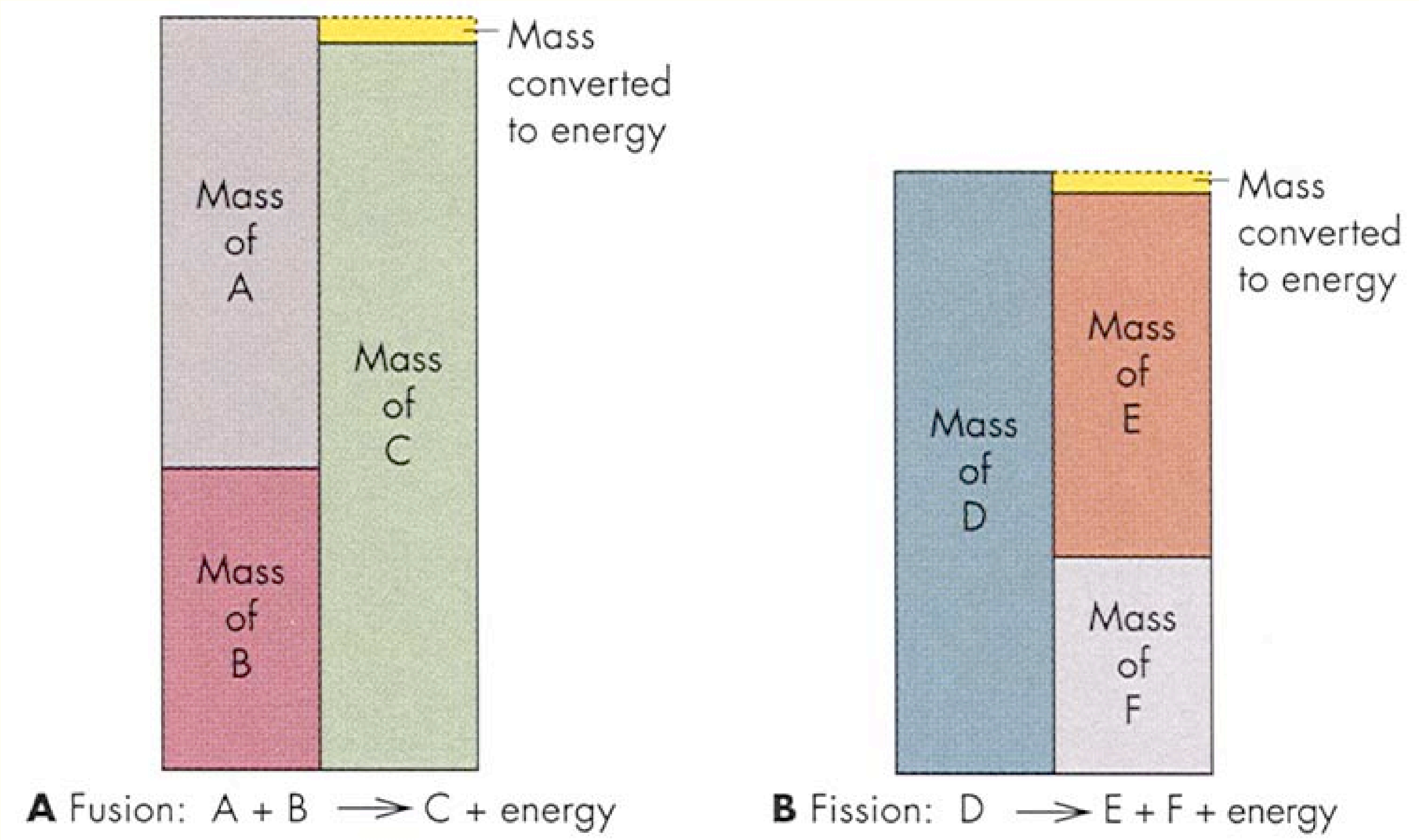
AST 309L Part IV.
Evolution, Convergence, Intelligence

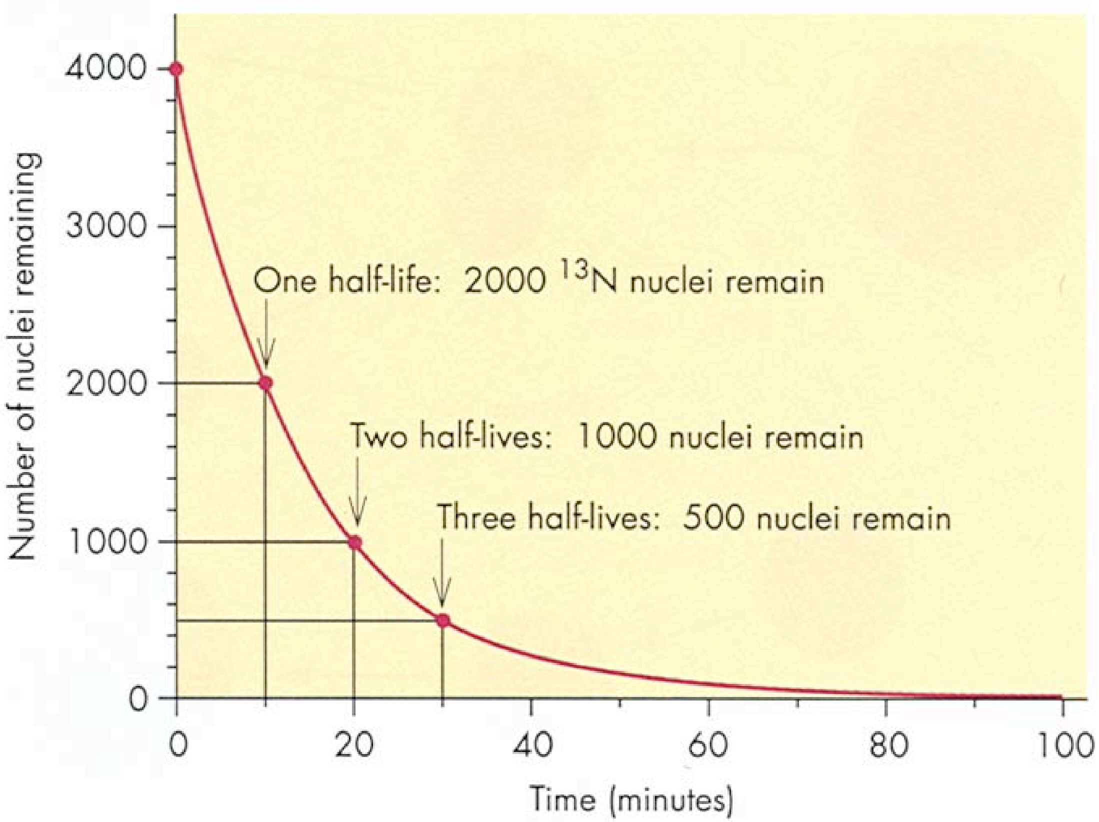
Fusion vs. Fission



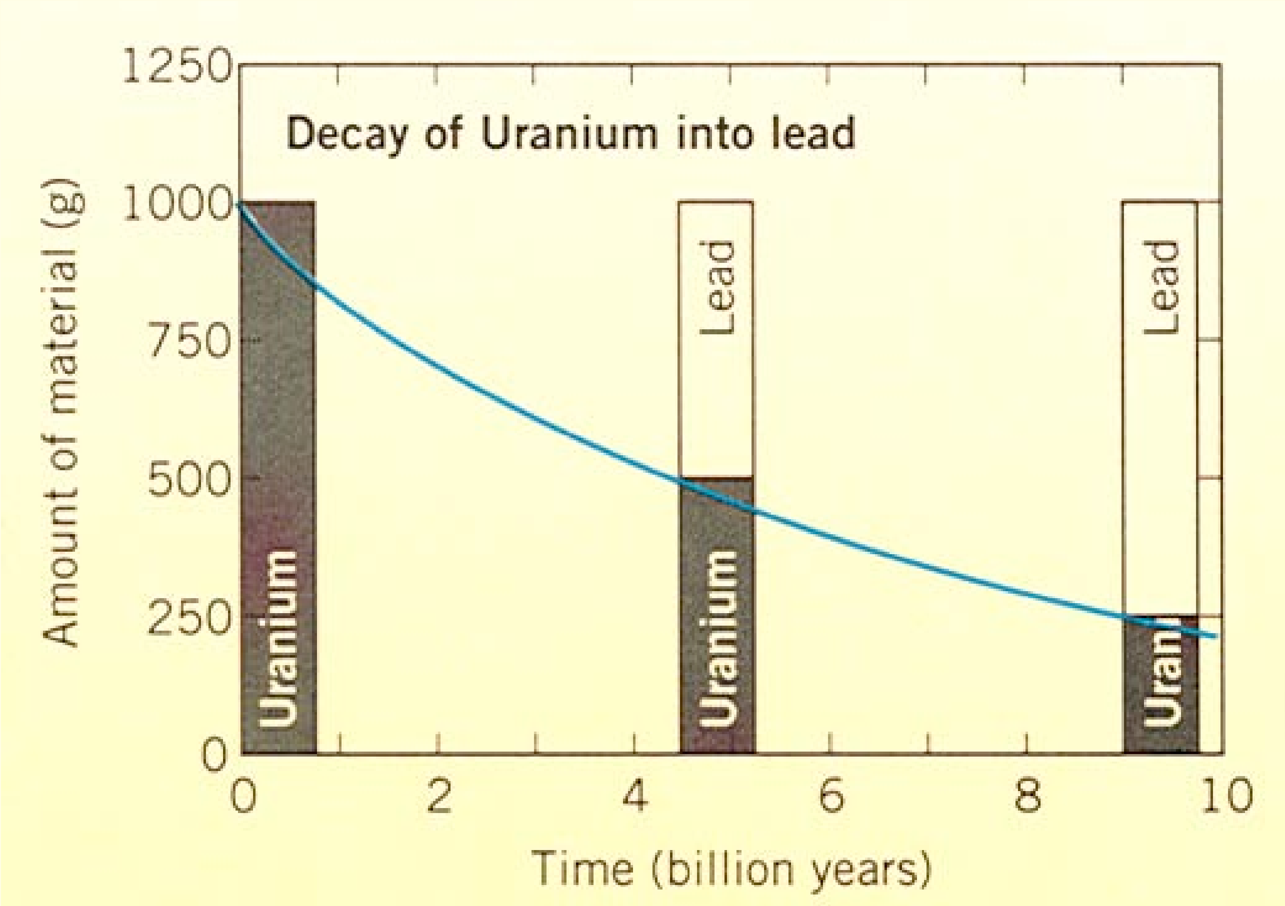
13N radioactive decay: idea of half-life

The Number of Remaining ^{13}N Nuclei Declines with Time

^{13}N is an unstable isotope with a half-life of 10 minutes. After one half-life, only half of the original 4000 nuclei remain. During each succeeding half-life, the number of remaining nuclei drops by half.



Uranium radioactive decay

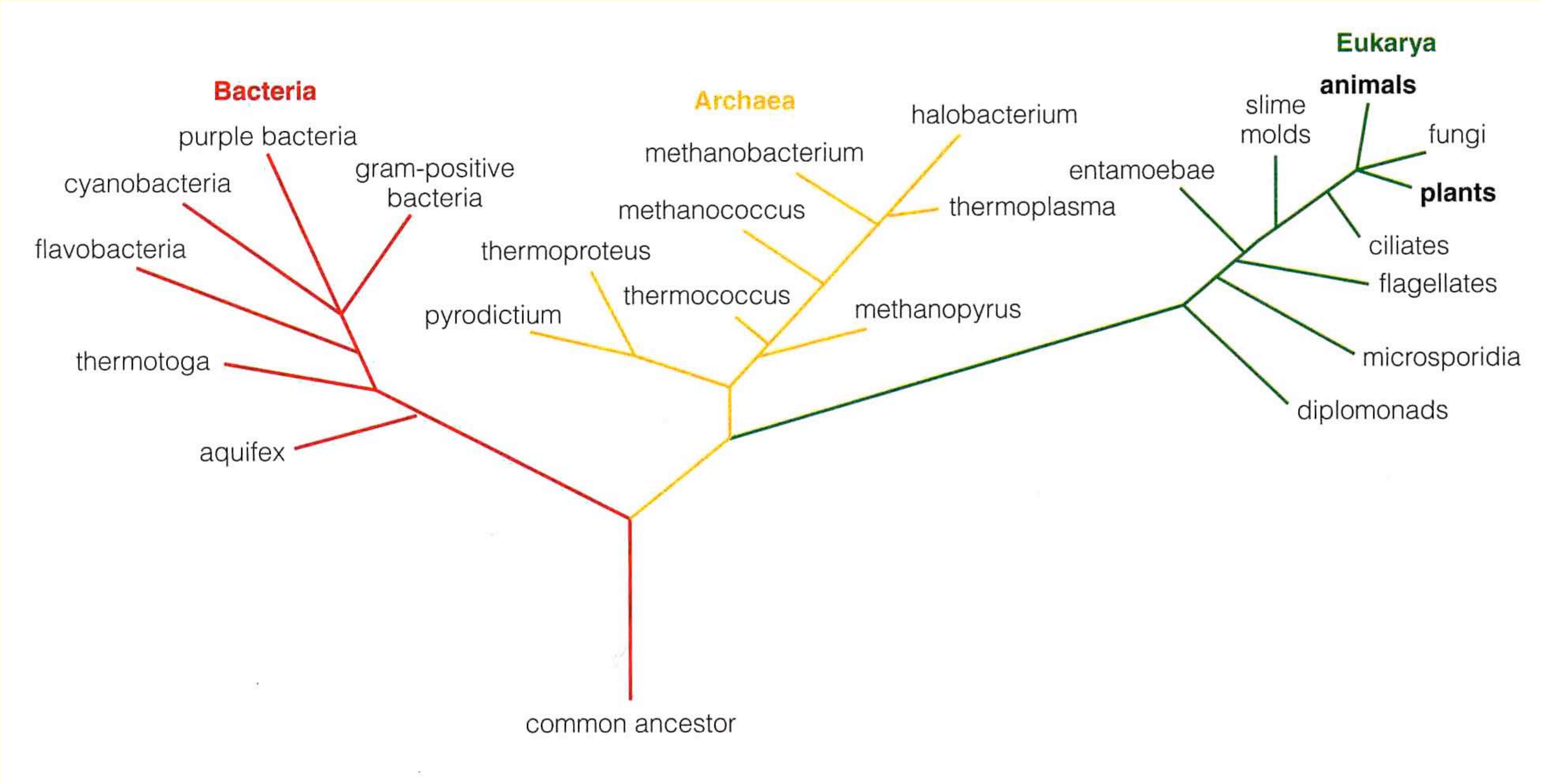


Useful radioactive isotopes for age determinations

Several Isotopes Useful in Radioactive Dating			
Isotope	**Half-Life (years)**	**Useful Range**	**Dating Applications**
Carbon-14	5730	500 to 50,000 years	Charcoal, organic material
Tritium (^3_1H)	12.3	1 to 100 years	Aged wines
Potassium-40	1.3×10^9	10,000 years to the oldest Earth samples	Rocks, the Earth's crust, the moon's crust
Rhenium-187	4.3×10^{10}	4×10^7 years to oldest samples in the universe	Meteorites
Uranium-238	4.5×10^9	10^7 years to the oldest Earth samples	Rocks, the Earth's crust

Establishing biological nature of fossils: stomatolites (below), 12C/13C ratio, …

Tree of life from comparisons of small subunit ribosomal RNA (shared by all living things) sequences (same as in text). See notes for method.



Tree of life--a few branch ages indicated

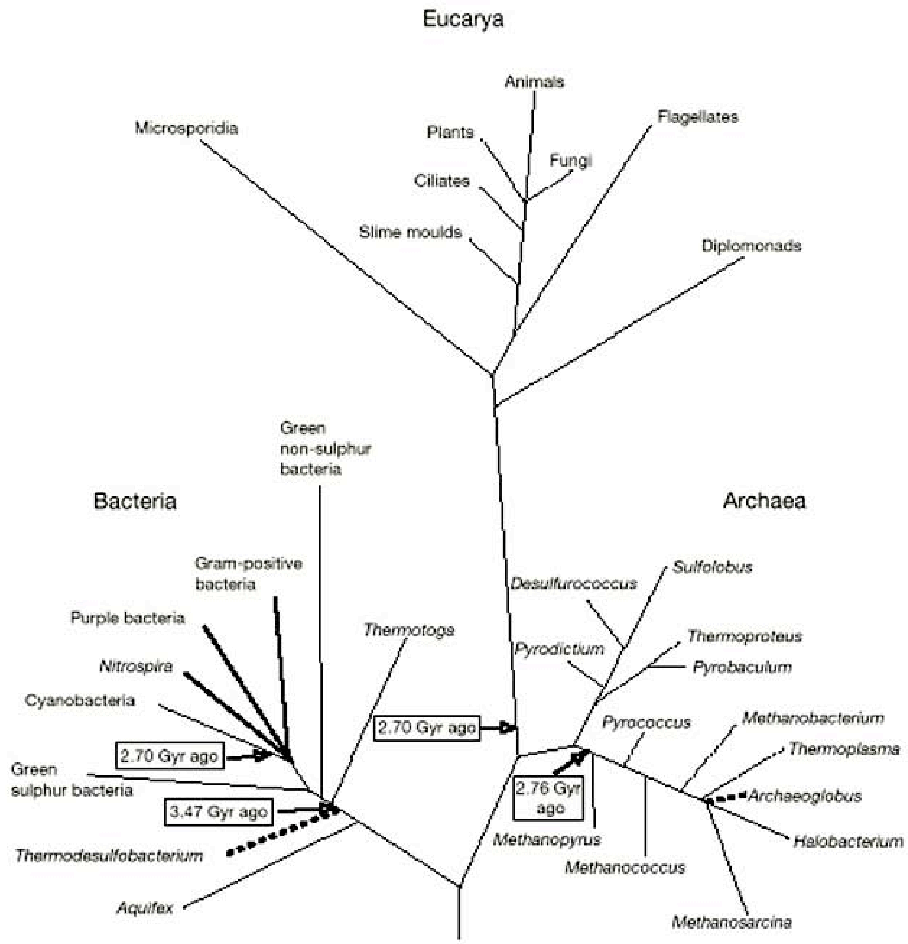


Figure 4 The tree of life based on SSU rRNA sequence analysis, with some temporal constraints on branching. The tree is modified from ref. 2, and abstracted from phylogenetic trees presented in refs 26 and 27. The time calibration points are from ref. 30, with our additional constraint of 3.47 Gyr placed in the Bacterial domain. Lineages housing sulphate-reducers metabolizing at temperatures > 70 °C are shown by broken black lines, while lineages supporting sulphate-reducers metabolizing at < 70 °C are shown by heavy black lines.

Tree of life with thermophiles and hyperthermophiles in bold

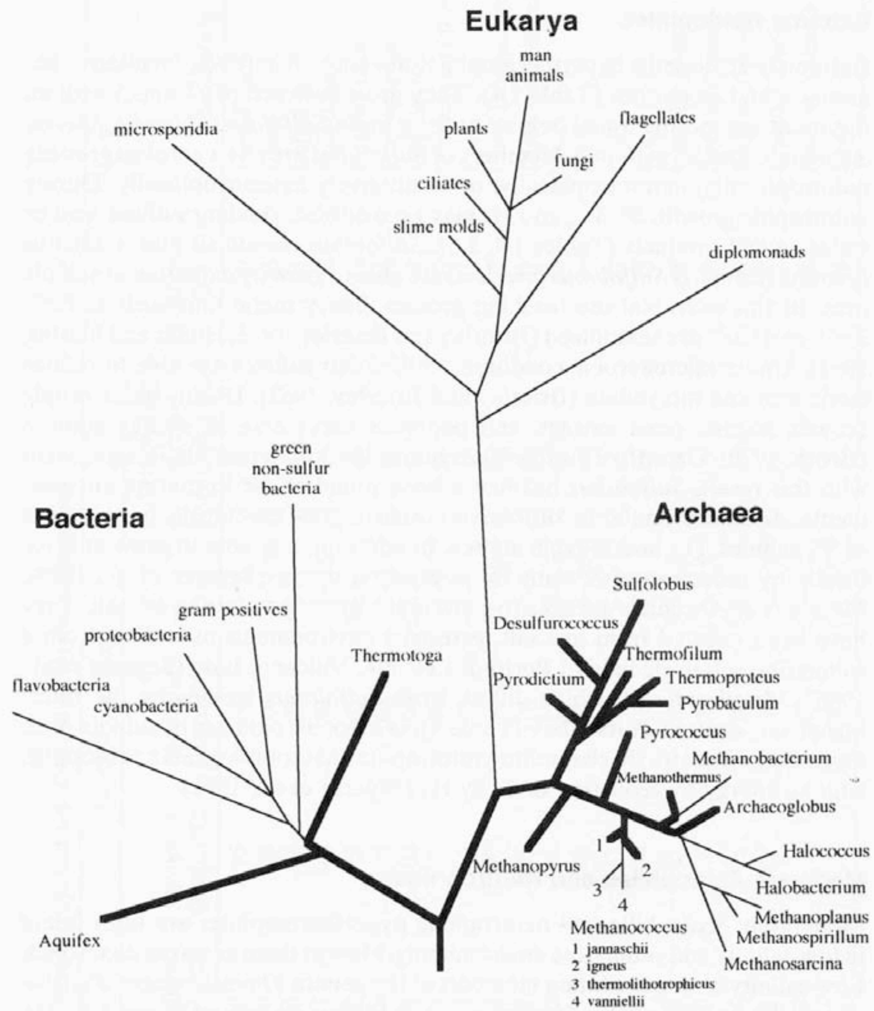


Figure 1.1. Hyperthermophiles within the 16S rRNA-based phylogenetic tree; schematically redrawn and modified from Woese et al. 1990.

Tree of life showing photosynthesizing bacteria, hyperthermophiles, and methanogenic archeans

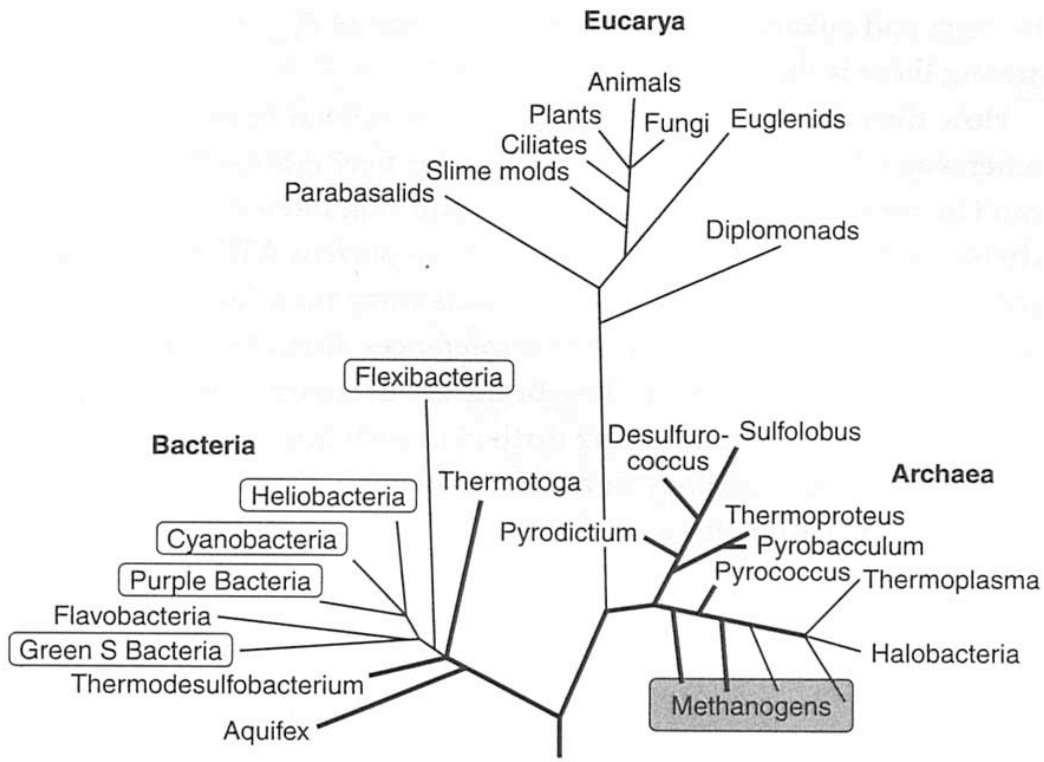
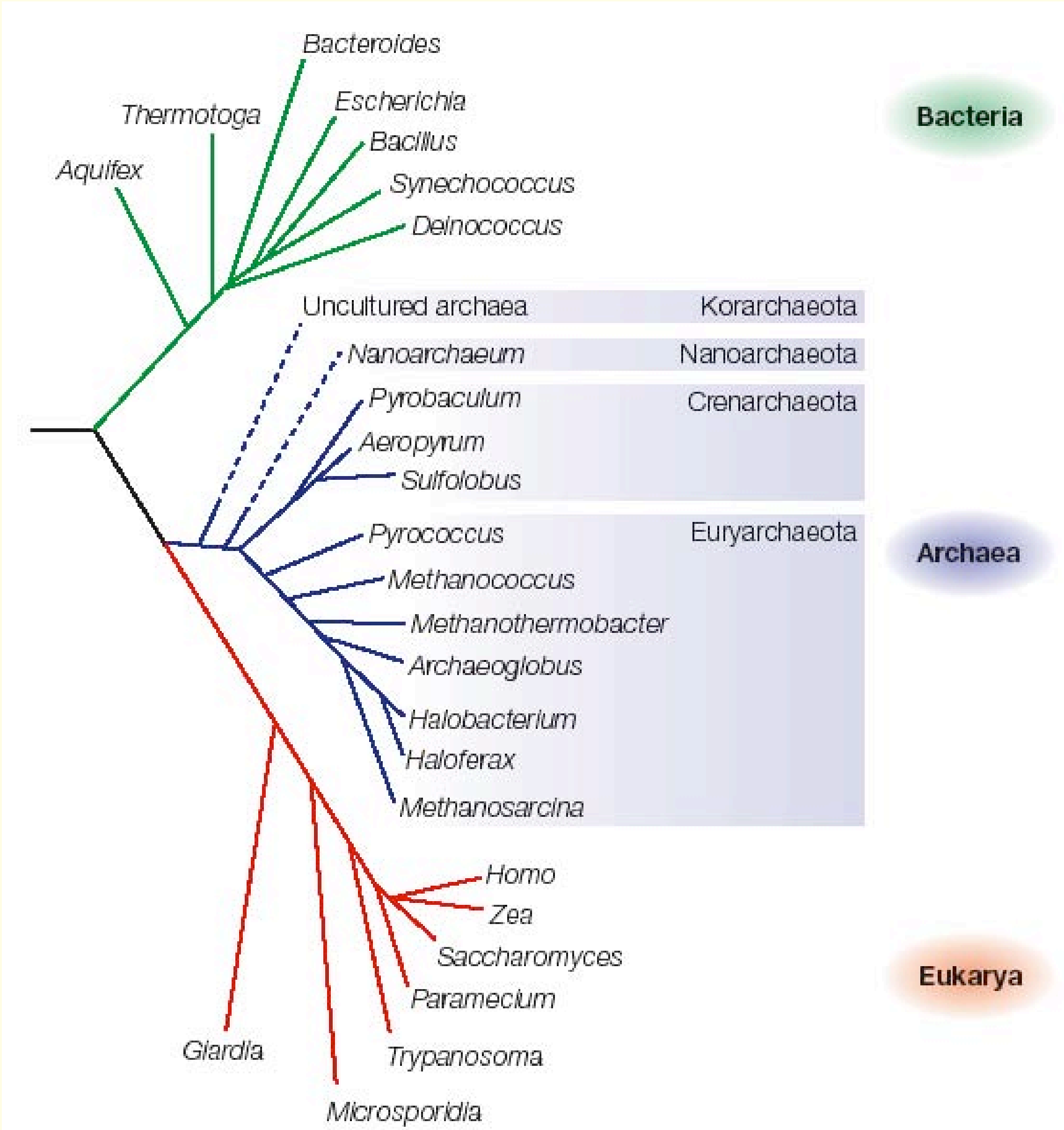
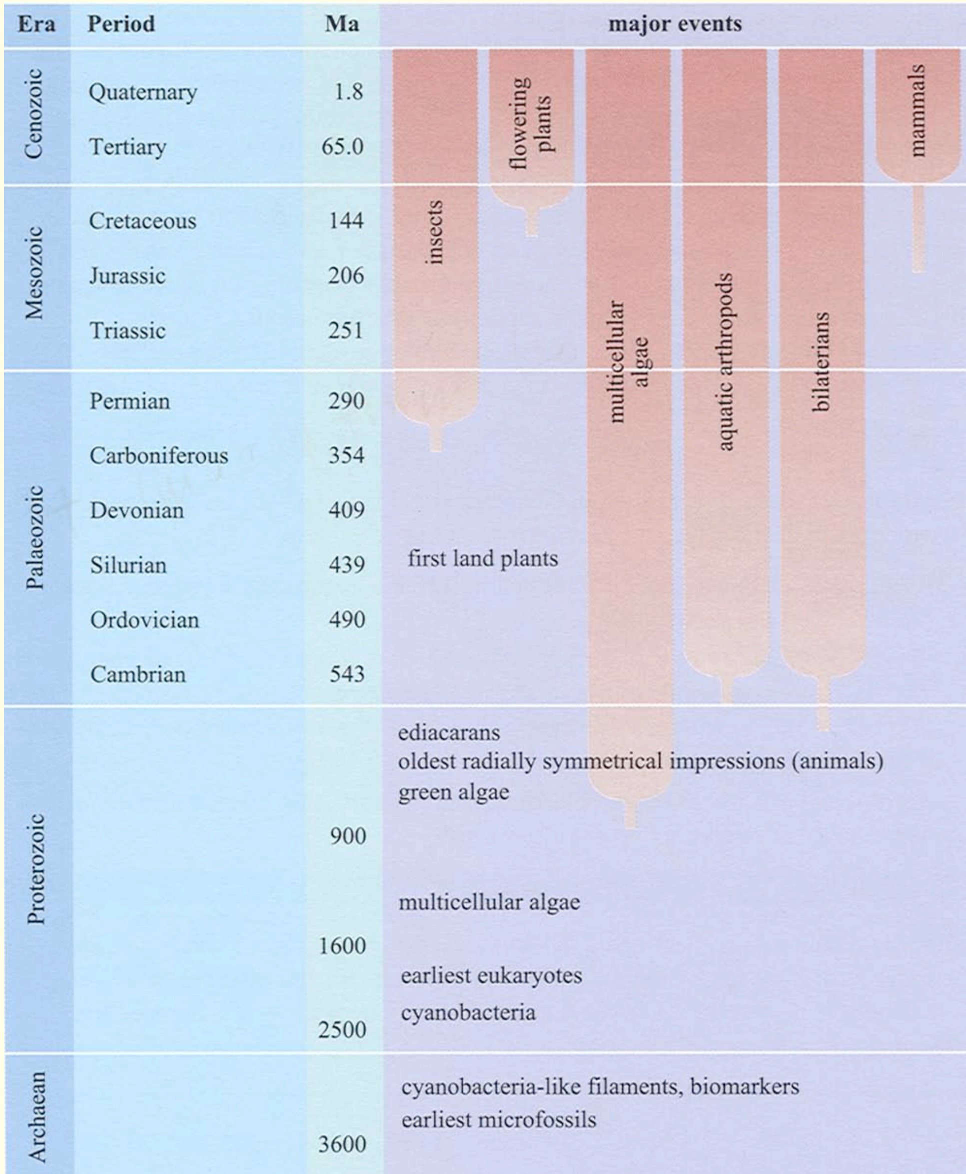


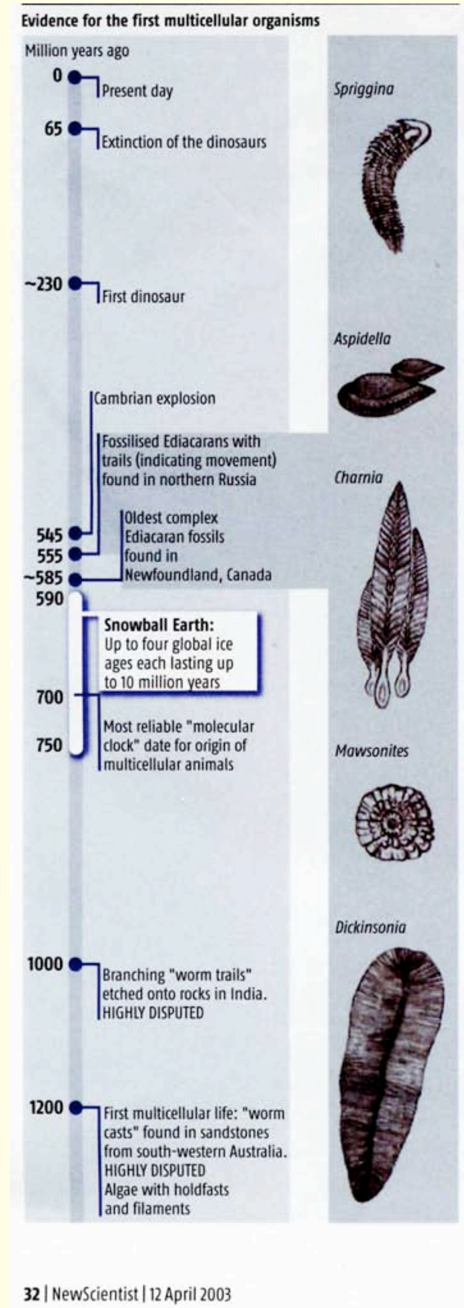
Figure 2.1. The Tree of Life, a depiction of the genealogical relationships of living organisms, based on sequence comparisons of genes that code for RNA in the small subunit of the ribosomes found in all cells. Note the three principal branches, made up of Bacteria, Archaea, and Eucarya. Branch lengths indicate degree of difference among gene sequences; because genes can evolve at different rates, however, this does not necessarily translate into time. Bacterial groups with photosynthetic members are highlighted by clear boxes; methanogenic archeans fall within the shaded box. Heavy lines denote hyperthermophiles—groups of organisms that live at high temperatures. (Adapted from a depiction of the tree by Karl Stetter)

Tree of life showing Giardia--one of earliest eukaryotes?

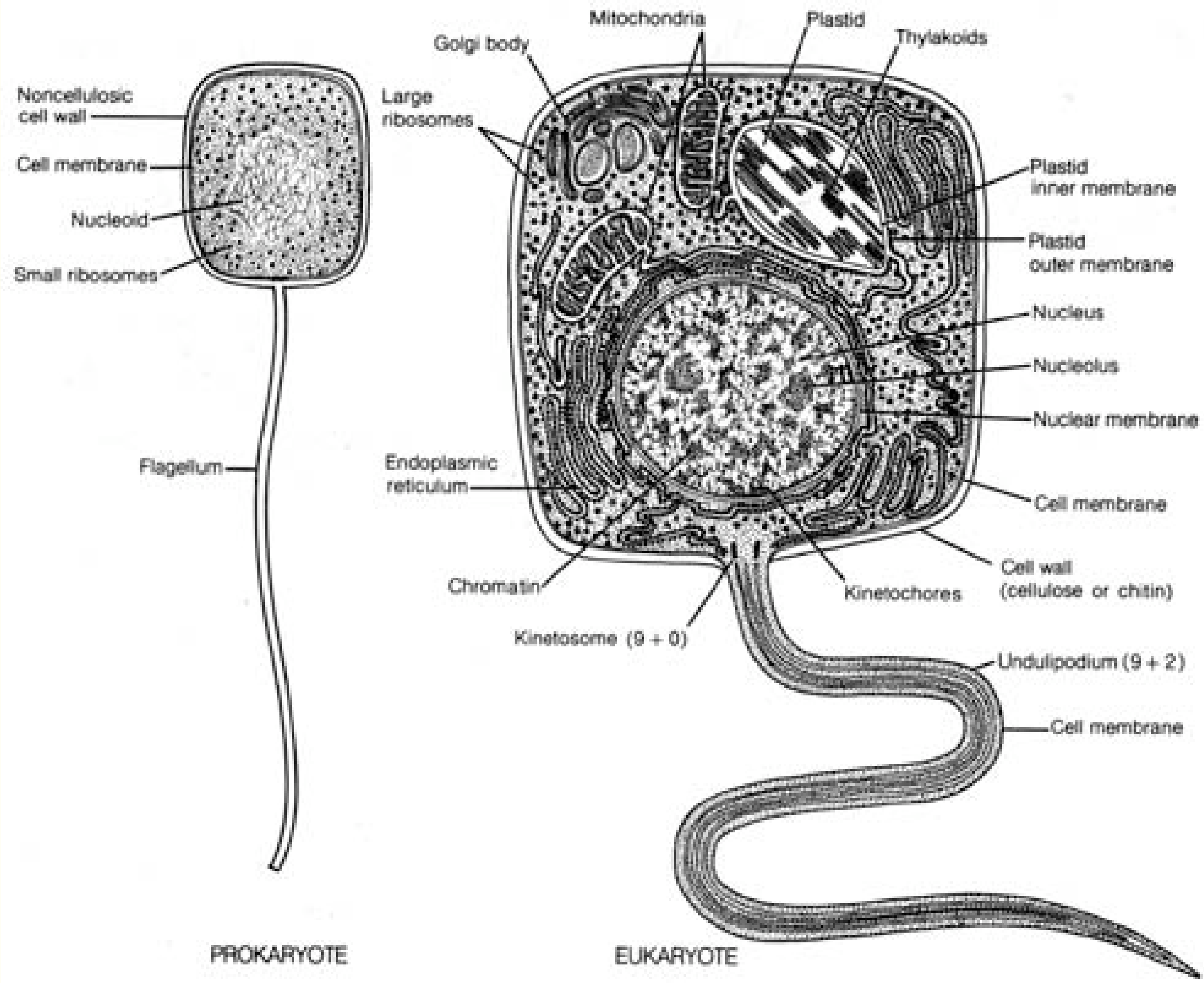


History of life on Earth

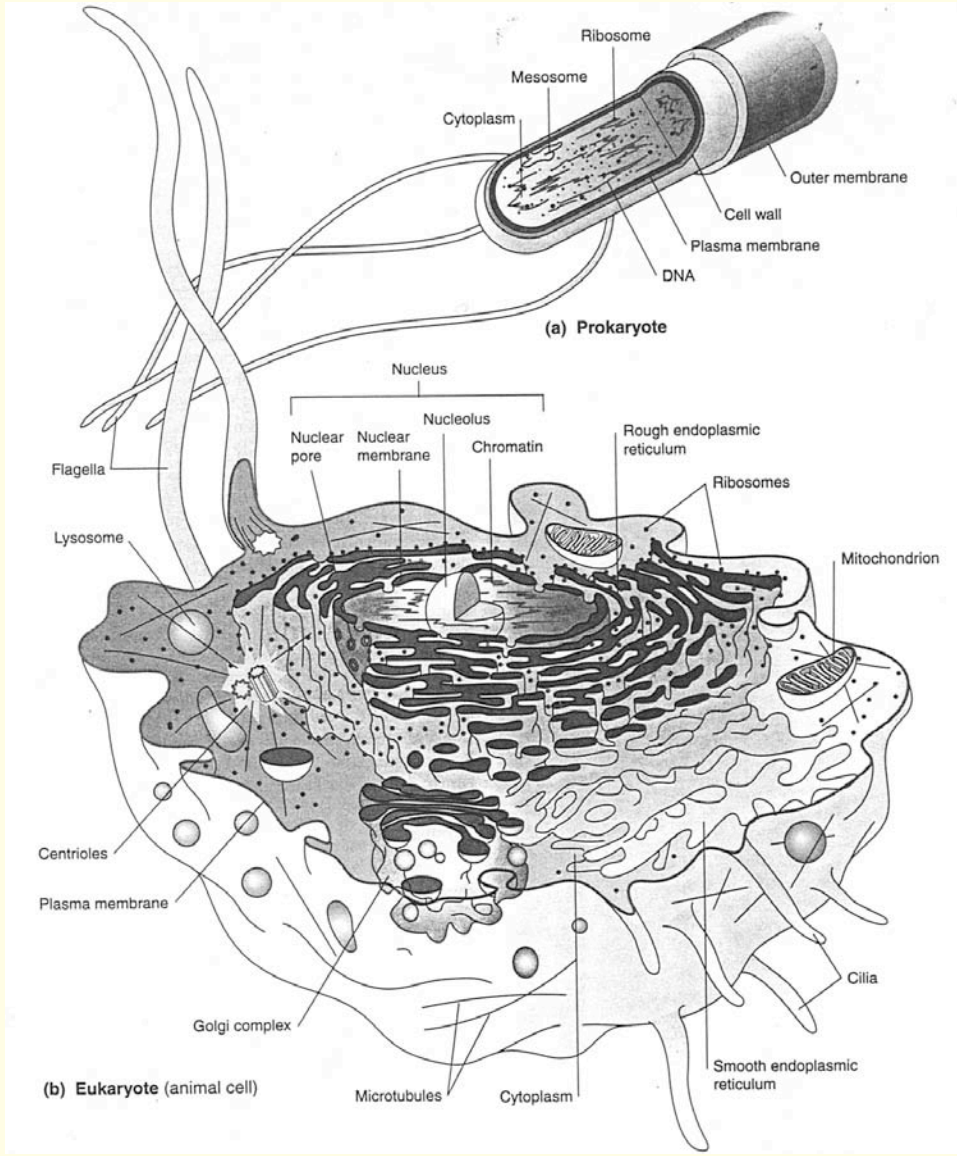




Prokaryote-Eukaryote cells



Prokaryote-Eukaryote difference in complexity again



One model for endosymbiotic origin of eukaryotes--viral invasion

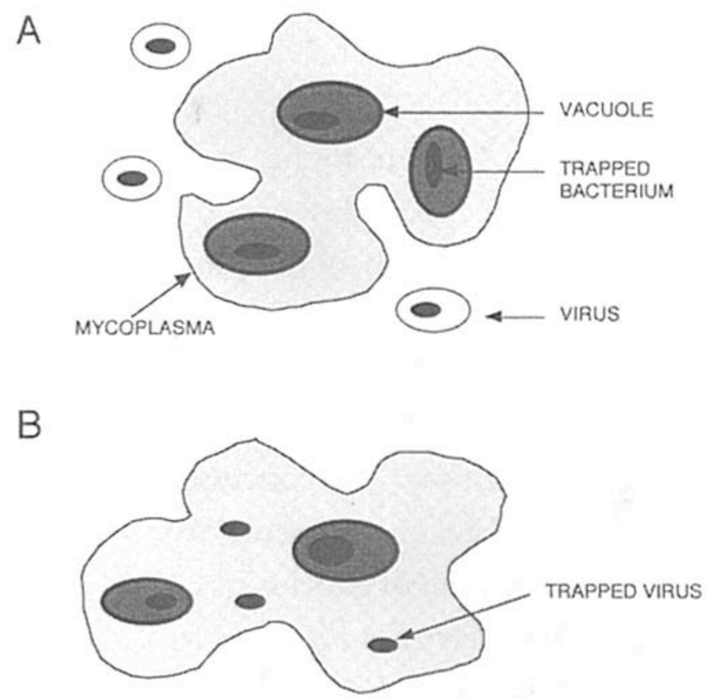
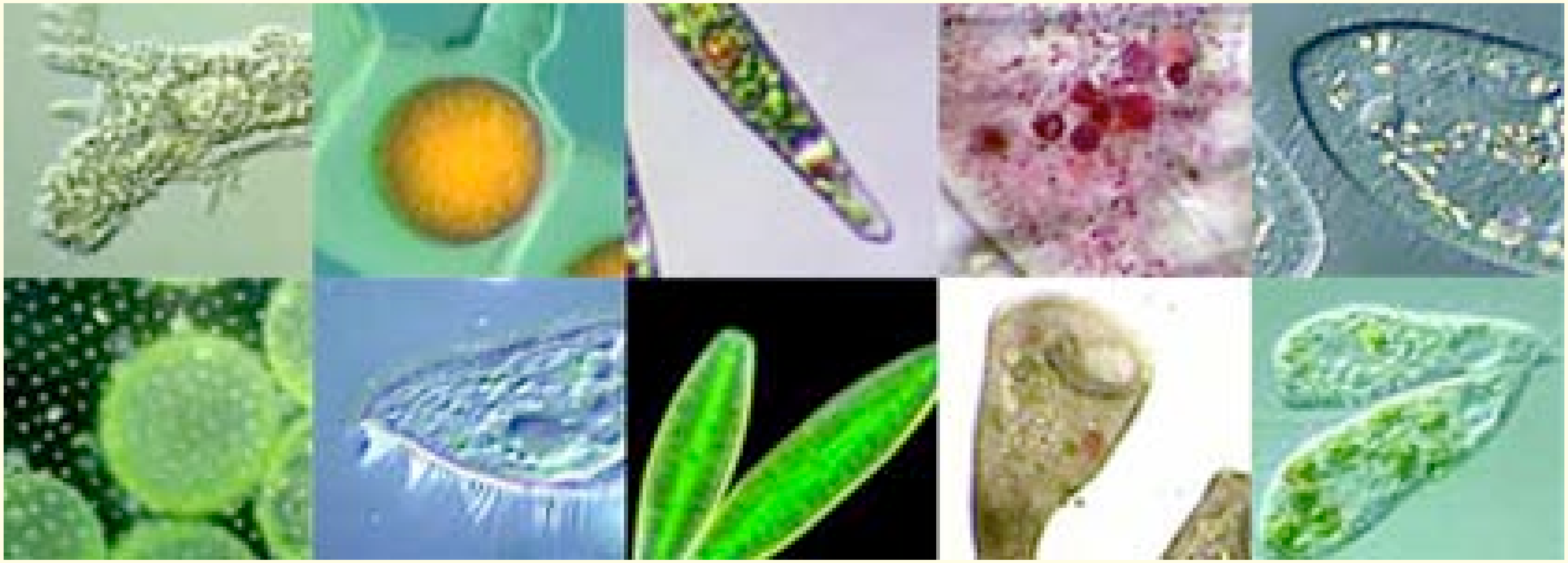


FIGURE 5.15 The virus hypothesis. **A:** An archaeal mycoplasma with bacterial endosymbionts trapped in vacuoles. Virus particles surround this cell. **B:** A mycoplasma, with endosymbionts, stably infected by a complex DNA-containing virus destined to become the eukaryotic chromosome. After fusion with the mycoplasma membrane, the virus particles have lost their lipid membrane. (Adapted from Bell, P. J. L. 2001. Viral eukaryogenesis: Was the ancestor of the nucleus a complex DNA virus? *Journal of Molecular Evolution* 53:251-256.)

We see mostly Eukaryotic life forms (below) but by far the most numerous and varied (by number, species, diversity, metabolic activities, habitat, …) are the bacteria. In many views eukaryotes are nothing but vehicles for bacterial symbiosis.



Filling up the atmosphere with oxygen due to photosynthesis: evidence from banded iron formations

Puzzling evidence: the formation of pyrite (above) and banded iron formations (left) indicate that atmospheric oxygen levels did not rise until at least 1 billion years after photosynthesizing cyanobacteria had evolved.

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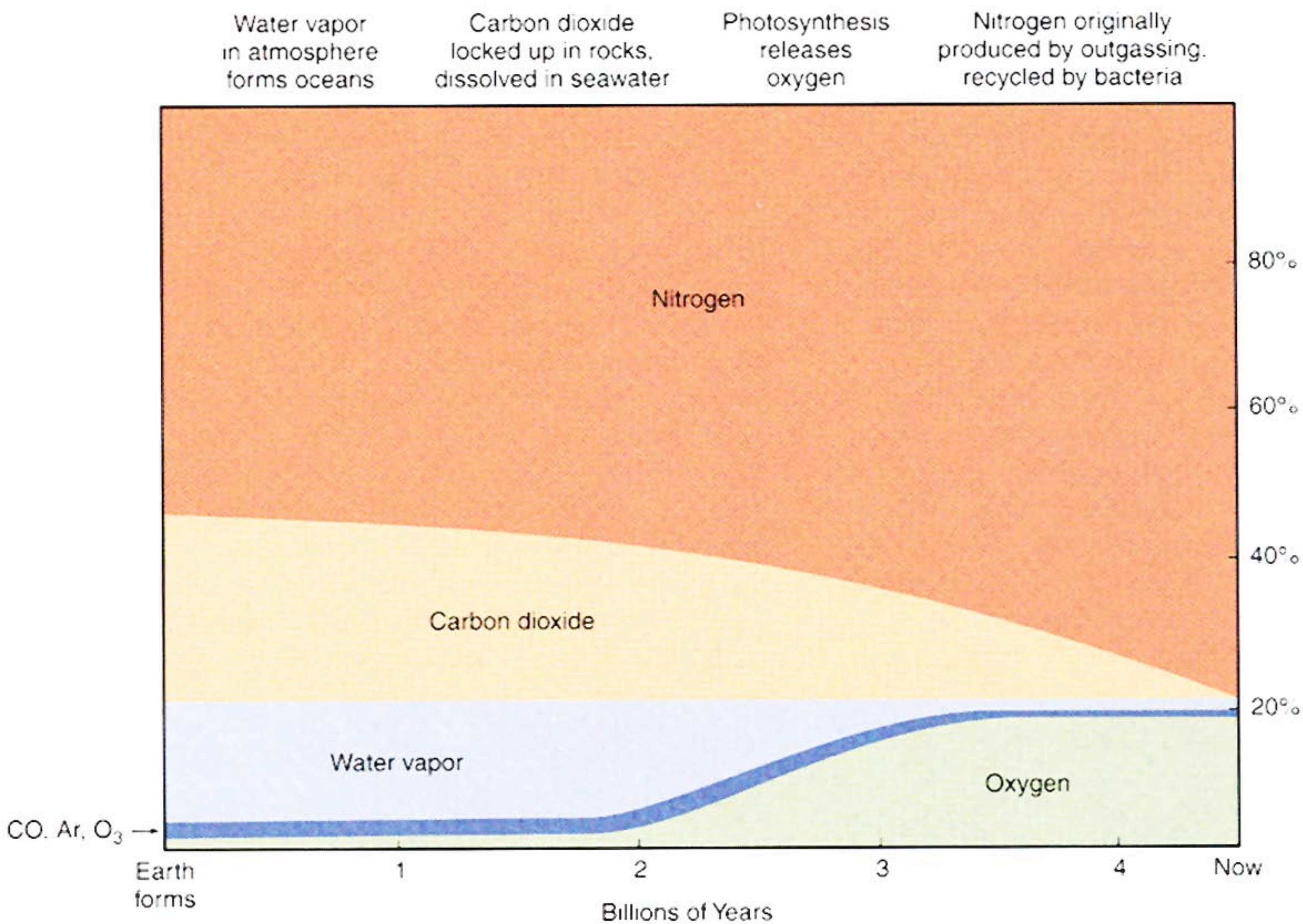
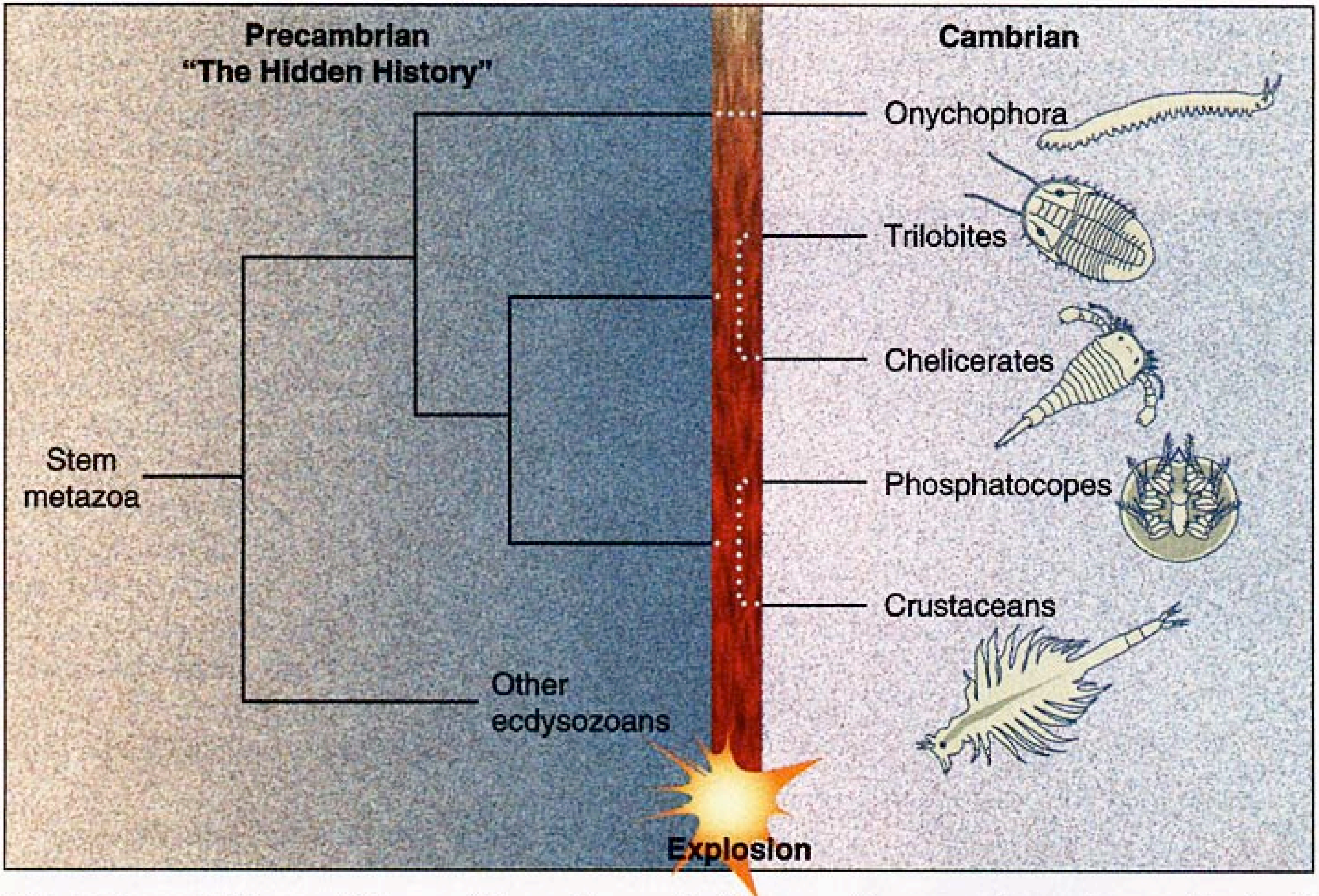
Approximate evolution of the composition of Earth's atmosphere

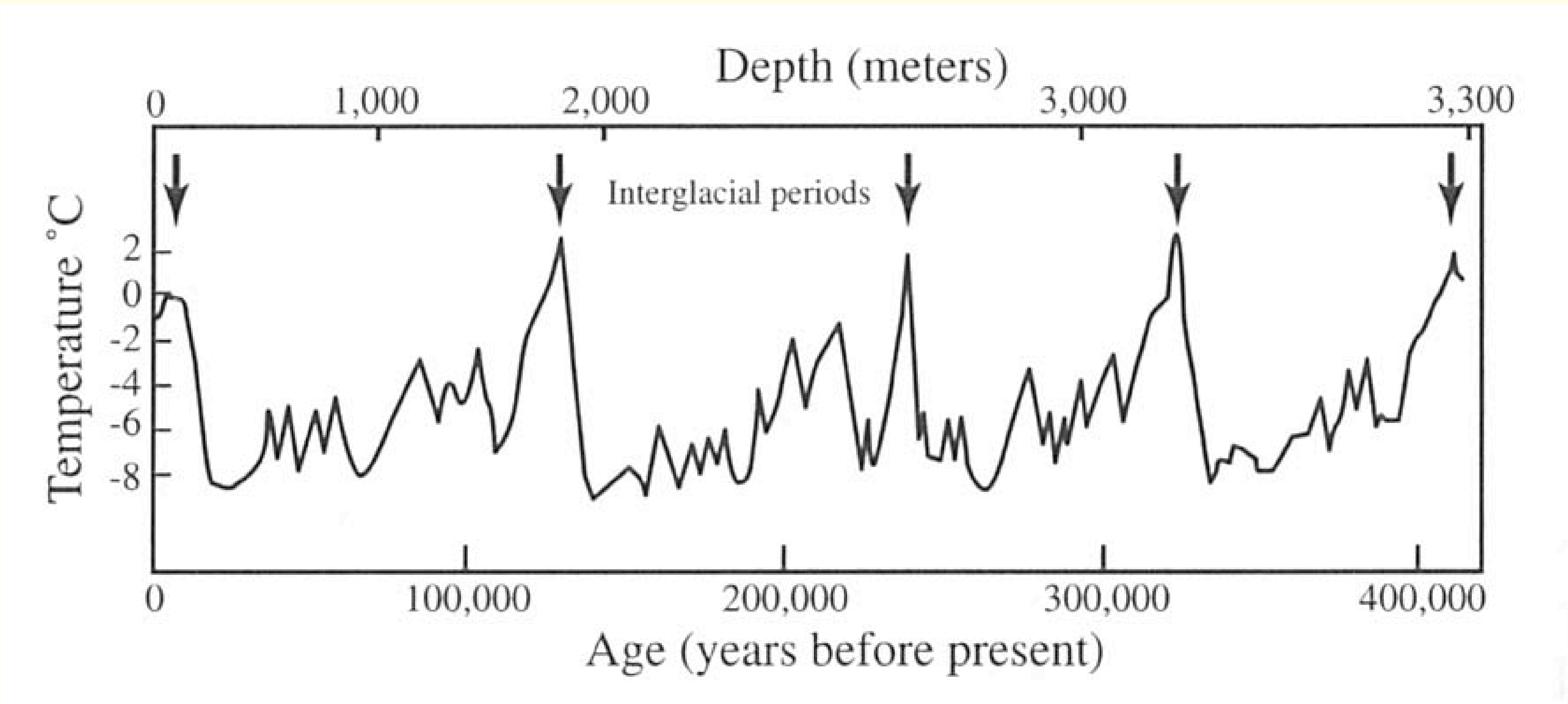


A crucial evolutionary "event": the Precambrian/Cambrian transition and the appearance of larger, more complex organisms in a short period of time

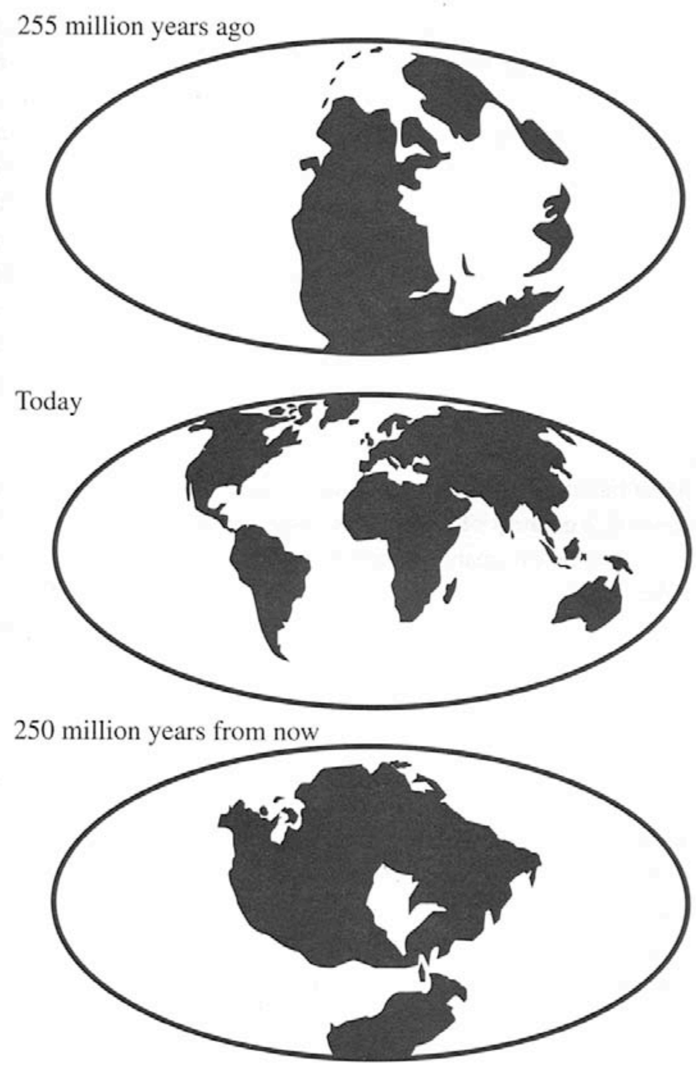


The early evolutionary history of the arthropods. The new discovery of a crustacean-like fossil (Phophatocope) in the early Cambrian pushes the branching events leading up to it and its relatives further back in time—into the Precambrian. Drawings are not to scale.

The environment mattered too: This shows how Earth's history alternated between glacial and interglacial periods back to 400,000 yr ("Snowball Earth" episode probably occurred a little earlier)



Throughout Earth's history the distribution of land mass has been changing radically: this leads to large changes in climate regulation that has affected life (see textbook)



Most of the world's landmass was assembled in a single great continent 255 million years ago. After spreading to the world we know today the continents are predicted to merge once again 250 million years from now. Figure derived from Chris Scotese's Paleomap Project.

Examples of very old microfossils and modern counterparts

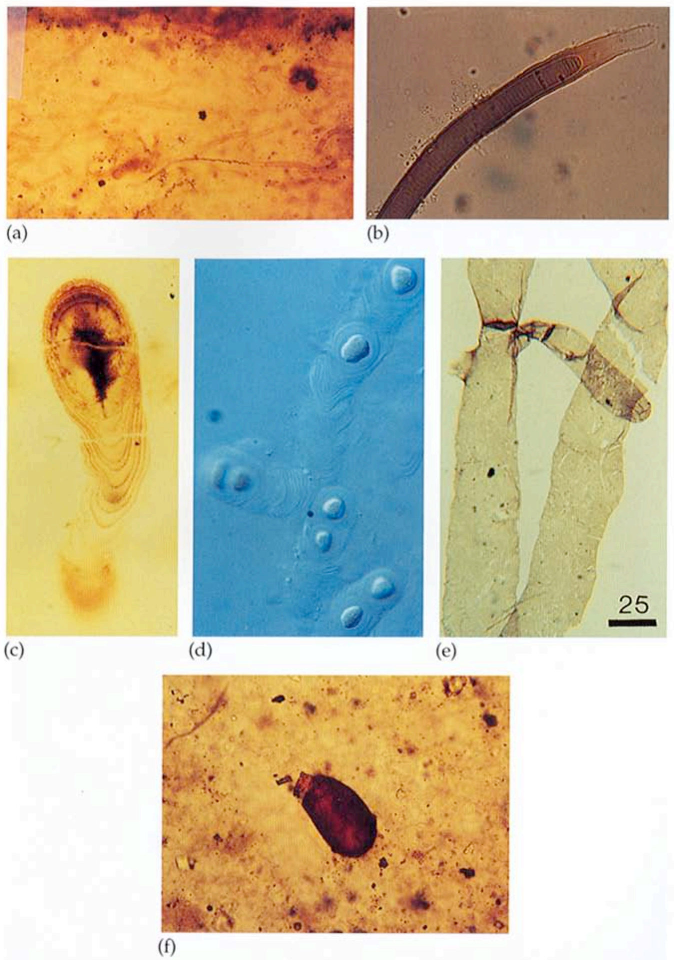


Plate 2. Fossils in Akademikerbeen cherts and shales, and some living counterparts. (a) Filamentous fossils of mat-forming microorganisms in Spitsbergen chert; each tube is about 10 microns wide. (b) The cyanobacterial genus, *Lyngbya*, which provides a modern counterpart for the fossils in a. (The specimen is 15 microns wide.) Note the extracellular sheath that surrounds the ribbon of cells. Because it is not easily destroyed by bacteria, this sheath, rather than the cells it contains, is likely to enter the fossil record. (c) *Polybessurus bipartitus*, a distinctive stalk-forming microorganism in Spitsbergen cherts; specimen

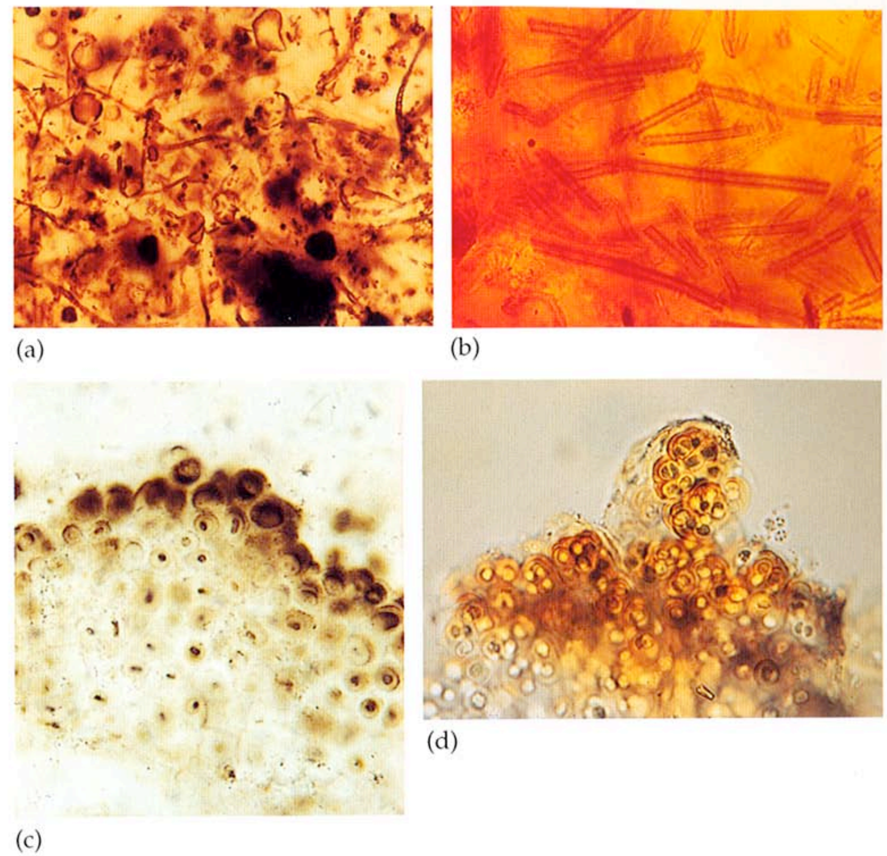


Plate 3. Early Proterozoic microfossils and their modern counterparts. (a) A microscopic view of Gunflint chert, chockablock with tiny fossils. (b) *Leptothrix*, a modern iron-loving bacterium thought to be similar to the filaments in Gunflint fossil assemblages. In both figures, the filamentous organisms are 1–2 microns across. (c) *Eoentophysalis* cyanobacteria in early Proterozoic chert from the Belcher Islands, Canada. (d) A modern *Entophysalis* species for comparison (ellipsoidal envelopes around cells are 6–10 microns wide in both illustrations). (Photo (c) courtesy of Hans Hofmann; photo (d) courtesy of John Bauld)

Cyanobacterial microfossils: Age ~ 1.5 billion years

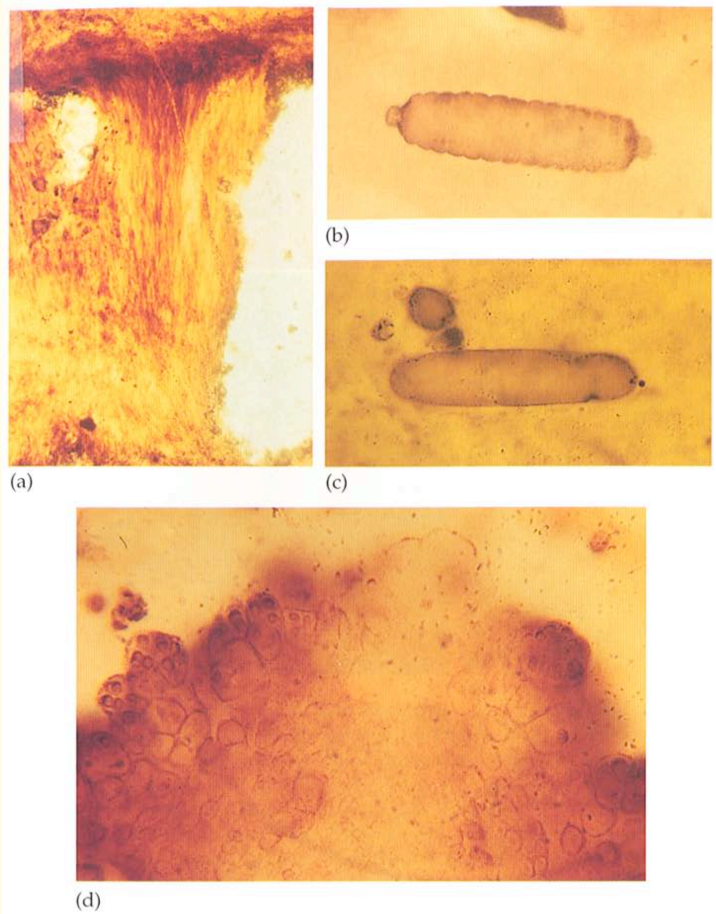


Plate 4. Cyanobacterial microfossils in cherts of the 1.5-billion-year-old Bil'yakh Group. (a) A vertical tuft of tubular filaments, preserved in this orientation by very early formation of calcium carbonate cement (each filament is about 8 microns across). (b) A filamentous cyanobacterium, showing how cells were arranged along its length; the specimen is actually preserved as a lightly pigmented cast, originally made in rapidly cemented carbonate sediment (fossil is 85 microns long).(c) *Archaeoellipsoides*, the large (80 microns long, in this case) cigar-shaped fossil interpreted as the specialized reproductive cell of an *Anabaena*-like cyanobacterium. (d) 1.5-billion-year-old mat-building colony of *Eoentophysalis*; see plate 3d for its modern counterpart.

Eukaryotic microfossils: Ages 1.5 to 0.57 billion years

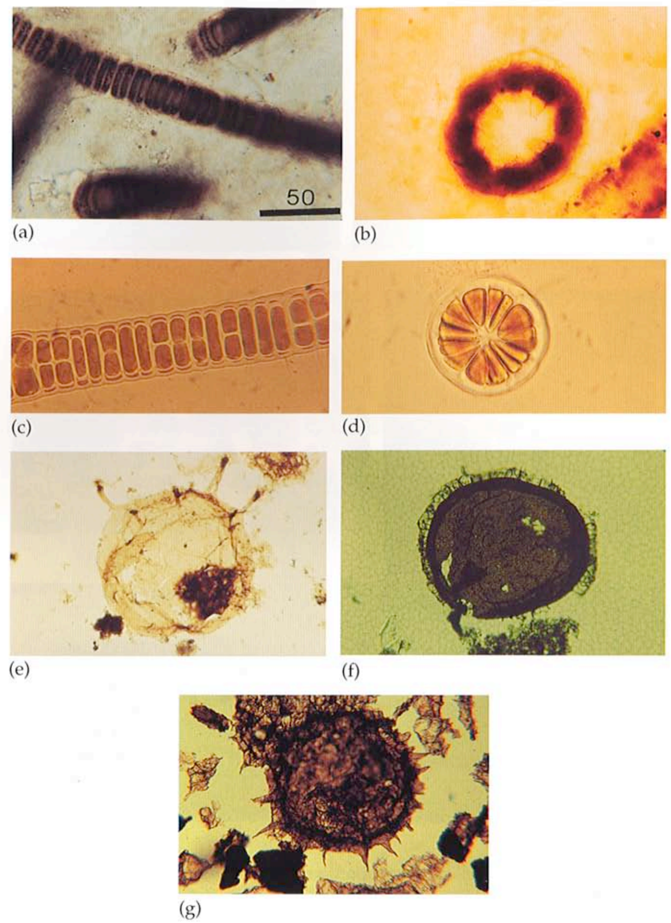


Plate 6. Fossils of Proterozoic eukaryotes. (a) and (b) illustrate the fossil *Bangiomorpha* in ca. 1.2-billion-year-old cherts from arctic Canada. (c) and (d) show the living red alga *Bangia*. All specimens are about 60 microns in cross-sectional diameter. (e) *Tappania*, a 1.5-billion-year-old microfossil from northern Australia; fossil is 120 microns wide. (f) A lavishly ornamented microfossil (200 microns in diameter) interpreted as the reproductive spores of algae from ca. 1.3-billion-year-old rocks in China. (g) A large (more than 200 microns) spiny microfossil from ca. 570–590-million-year-old rocks in Australia. (Photos (a)–(d) courtesy of Nicholas Butterfield)

Ediacaran (Precambrian/Cambrian transition) fossils

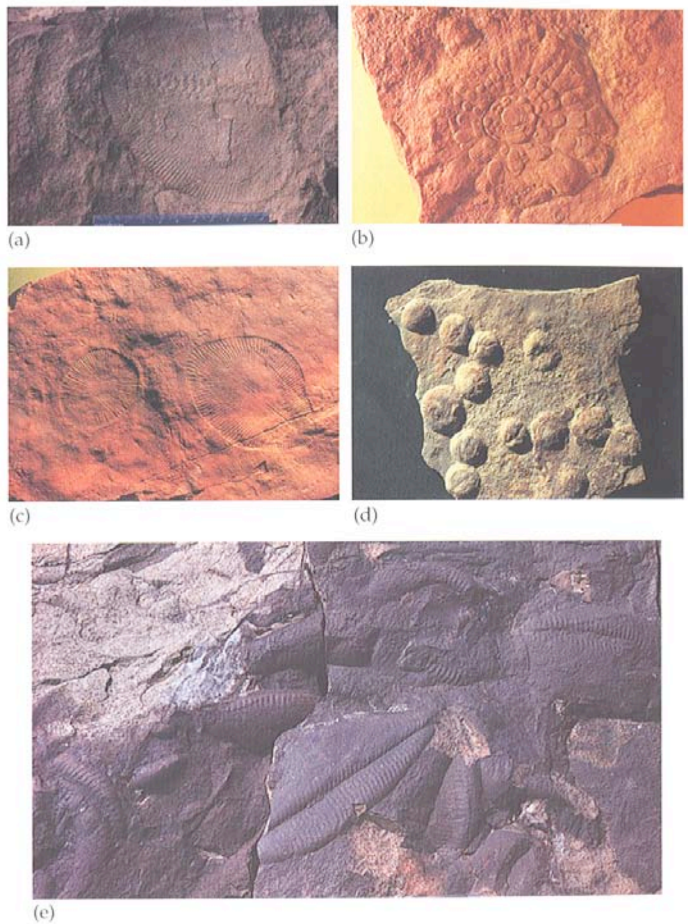
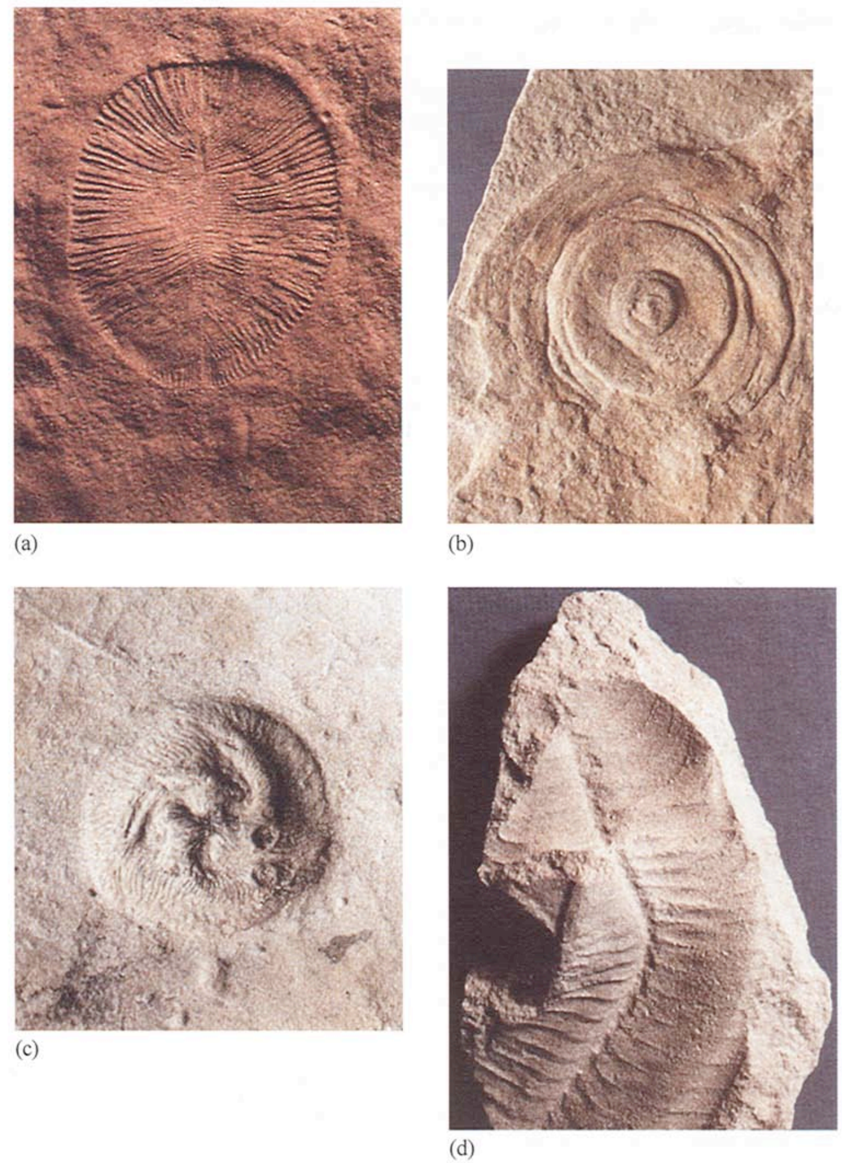


Plate 7. Ediacaran fossils from Namibia and elsewhere. (a) *Swartpuntia*, a three-winged fossil found in the uppermost Proterozoic beds of the Nama Group; only two "wings" are evident in these fossils. (b) *Mawsonites*, a 4-inch disk from South Australia, interpreted an a sea anemone–like animal or the holdfast of a sea pen–like colony. (c) *Dickinsonia*, the most celebrated (and controversial) of vendobiont fossils. This specimen is from the Ediacara Hills of South Australia. (d) *Beltanelliformis*, a spherical green alga, here seen in latest Proterozoic sandstones from the Ukraine; specimens 1/2 to 3/4 inch across. (e) *Pteridinium*, another three-winged fossil found in sandstones of the Nama Group. (Photos (b) and (c) courtesy of Richard Jenkins)



Sudden increase in complexity after Precambrian/Cambrian transition ~ 550 Myr ago

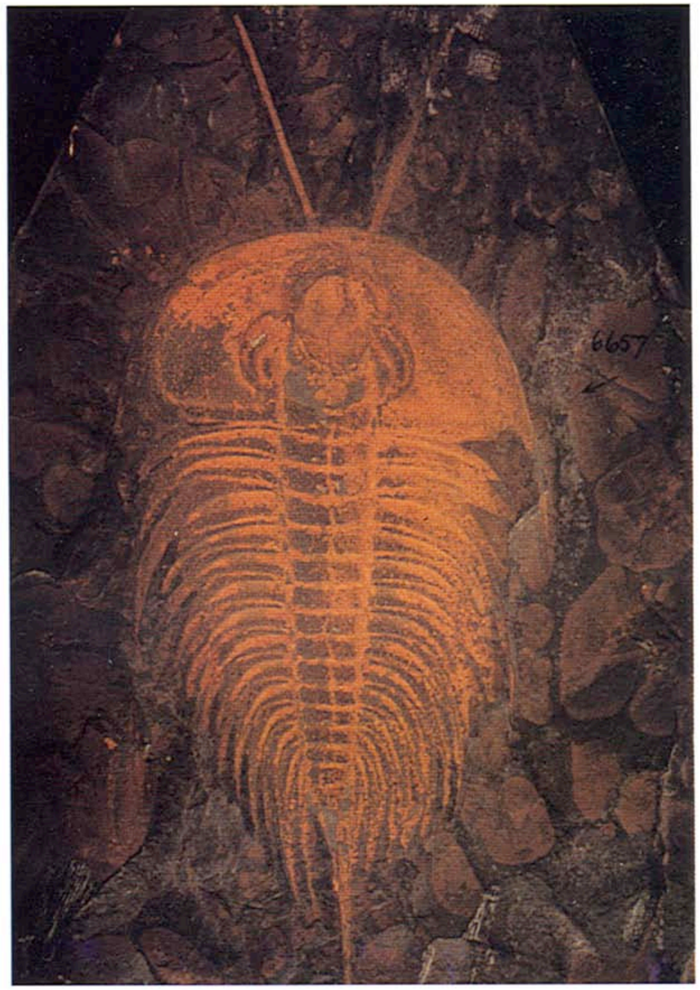
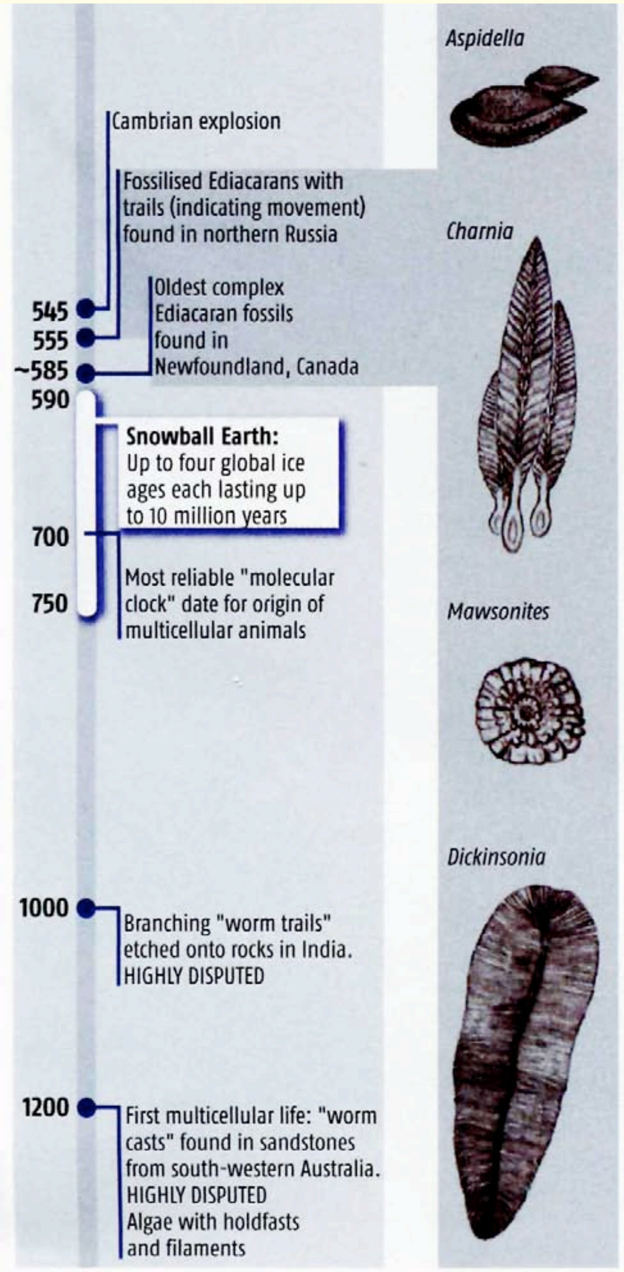
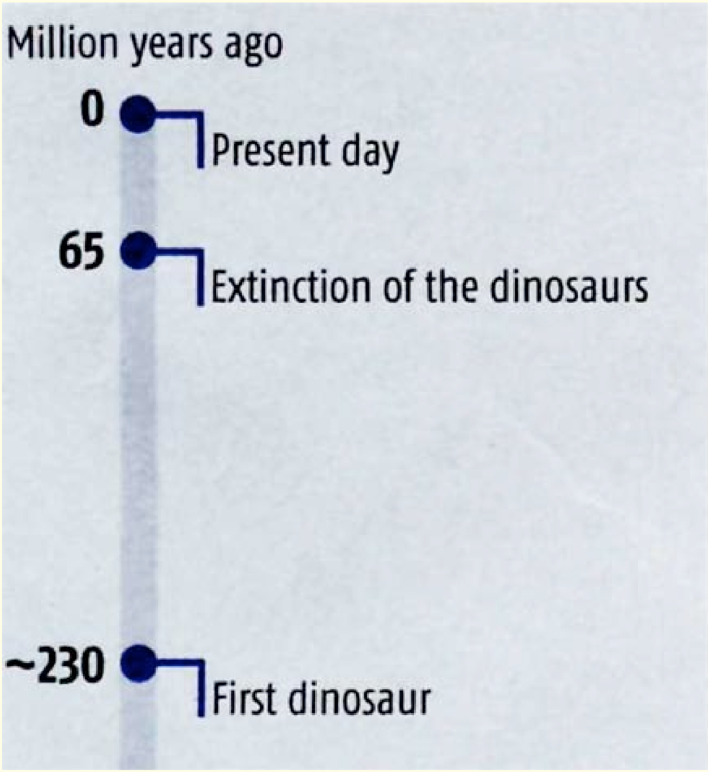


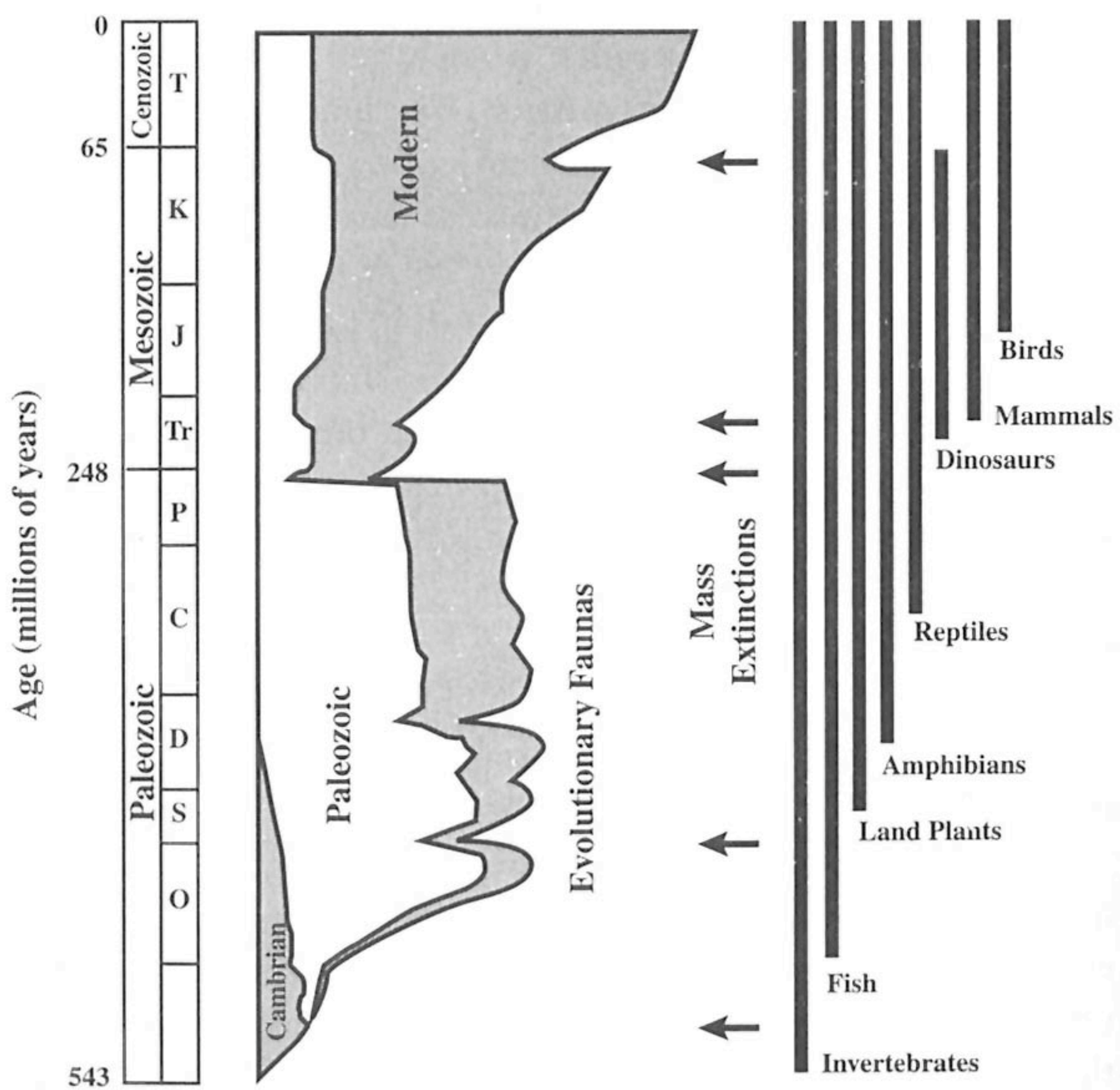
Plate 8. The trilobite *Olenellus*, illustrating the tremendous complexity achieved by Early Cambrian animals. (Photo courtesy of Bruce Lieberman)

Summary of some major events since 1200 Myr ago





Diversity continued to "explode" after the Precambrian/Cambrian transition



The diversity of multicellular organisms over the past 543 million years.

Review of major evolutionary events

- Earliest biomarkers ~ 3500 to 3800 Myr.
- Lateral (horizontal) transfer of genetic information between bacteria rampant
- Photosynthesis ~ 3000 Myr ago? (recent evidence pushes back to *very* early times, ~ 3600 Myr)
- "Oxygen holocaust"--atmosphere fills up with O_2 after crust saturated (~ 2000 Myr). But this also probably made energy production more effective for eukaryotes (text, p. 127).
- Origin of eukaryotes by endosymbiosis (mitochondria, chloroplasts,…)--establishes "modularity" as major structural feature of complex design. (Fig. 5.11 in text) Notice similarity in timing for atmospheric oxygen and eukaryotes
- Meiotic (sexual) reproduction--increases diversity, prevents mutational meltdown (~ 1000 Myr?), allows development of larger genomes?

Major evolutionary events (continued)

- Snowball Earth episode (?)--complete glaciation (~ 600-800 Myr?). [See outside readings for details. Also text, p. 106 in ch. 4]

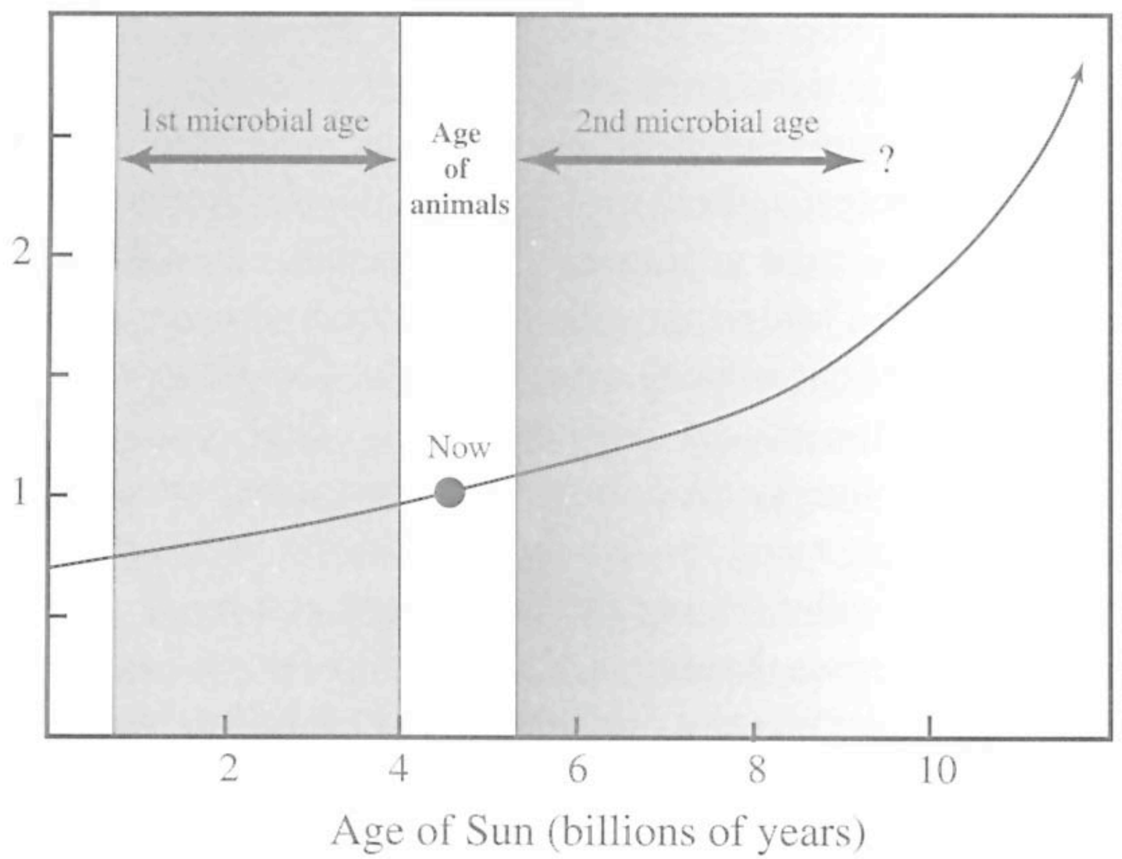
- Cambrian explosion--sudden appearance of large and complex life forms (545 Myr). Without this event, no SETI. [Outside readings and pp. 128-129 in text]

- Colonization of land by plants and fungi, leading to land animals (~ 500 Myr)--no predators yet! [pp. 129-130 in text. Note importance for SETI].

- Mass extinctions: several major, many minor, between ~ 500 Myr and 65 Myr (and some would say today). 65 Myr extinction ⇒ "dinosaur extinction" due to large asteroid impact (also called K-T event). No mammal dominance without this? See pp. 130-137 in text for good discussion + class notes.

- Hominids to earliest homo sapiens: 6 to 0.2 Myr (will discuss separately). Sec. 5.6 in text + class notes + outside readings on intelligence)

The Sun’s brightening could lead to a second (and final) microbial era in the future: If duration of “animal era” is so brief, chances of communication (SETI) would be very small.



For its first 10 billion years, the Sun slowly increases in brightness. The effect is gradual but it is the major reason why Earth’s biological capabilities change dramatically with time. The brief age when evolution and environmental conditions allow plants and animals to exist is bracketed by two long-duration ages when the Earth is solely inhabited by microbes invisible to the naked eye.

So 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, pouchesw, sonar, eyes, jet propulsion, even social structures.

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

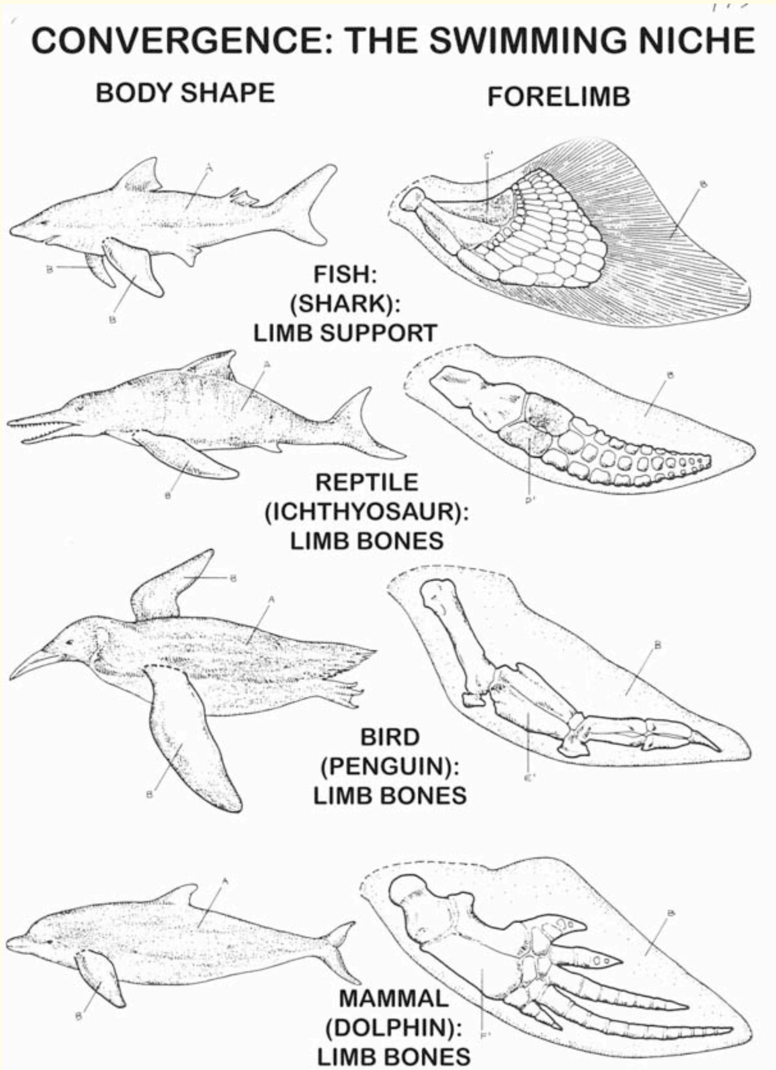
- Also, interpreting traits is tricky because of things like *exaptation* (see class notes)

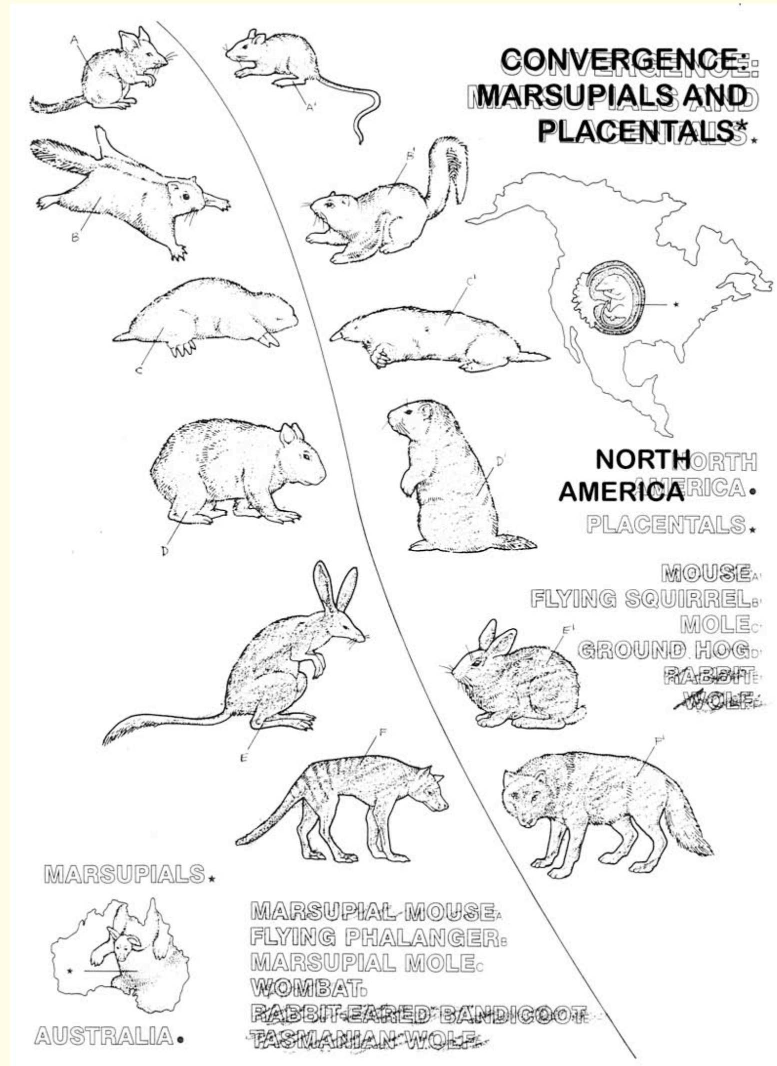
- And *some* traits would be very useful (adaptive) but have never arisen (e.g. cellulose-digesting enzyme in animals), or have arisen only once (the case of woodpeckers is discussed in class notes).

- And there are undoubtedly processes, especially environmental processes like impacts, that are completely unpredictable. We'll discuss mass extinctions next.

- 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, beginning of Part II of notes).

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





Convergence: burrowing mammals

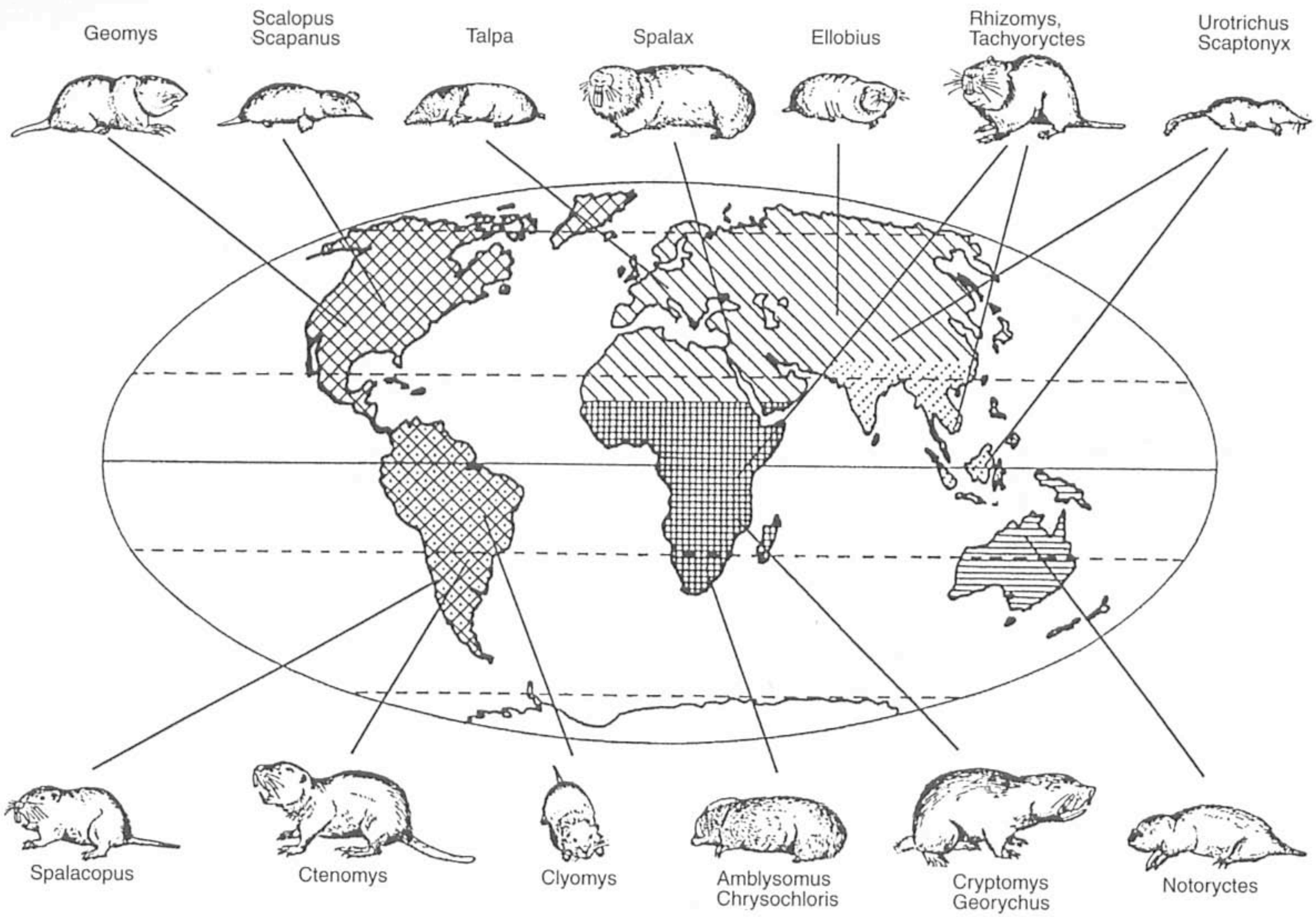
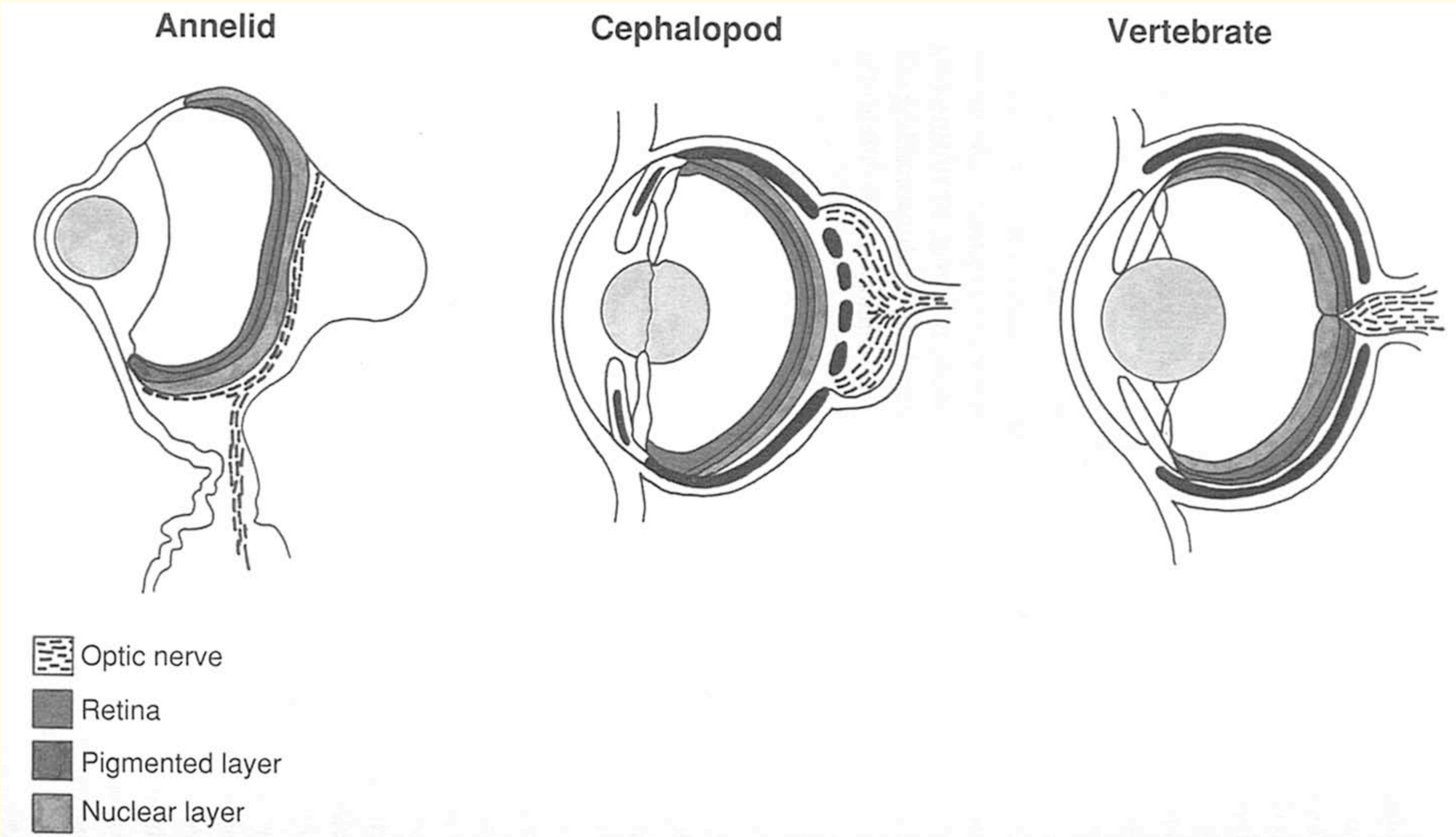
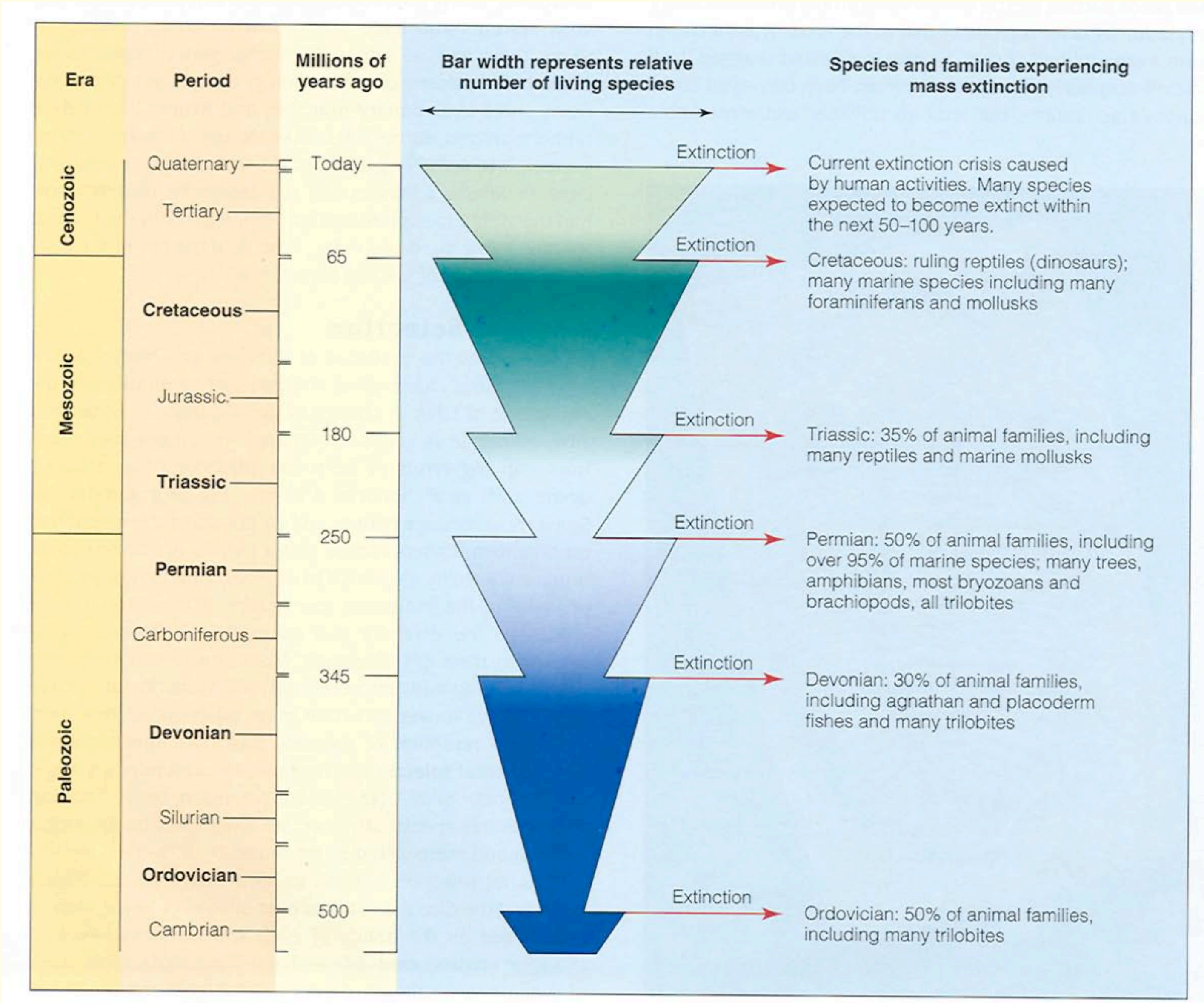


FIGURE 6.8 Convergent evolution in the burrowing (fossorial) mammals, including the familiar mole (*Talpa*), mole-rat (*Spalax*), and marsupial mole (*Notoryctes*). (Reproduced from fig. 1 of E. Nevo (1995) Mammalian evolution underground. The ecological–genetic–phenetic interfaces, *Acta Theriologica*,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

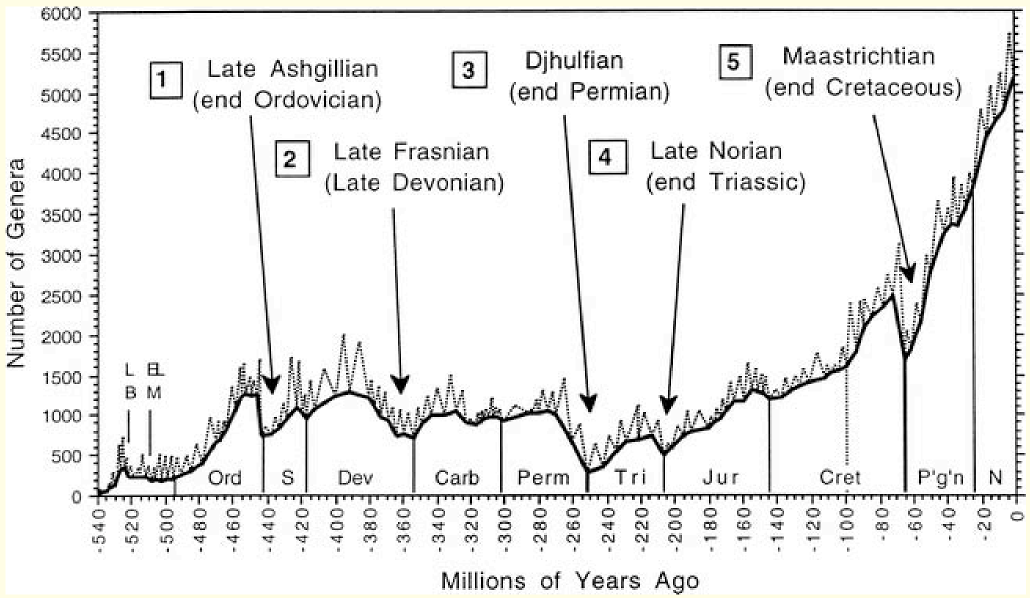
Convergence: complex eye design

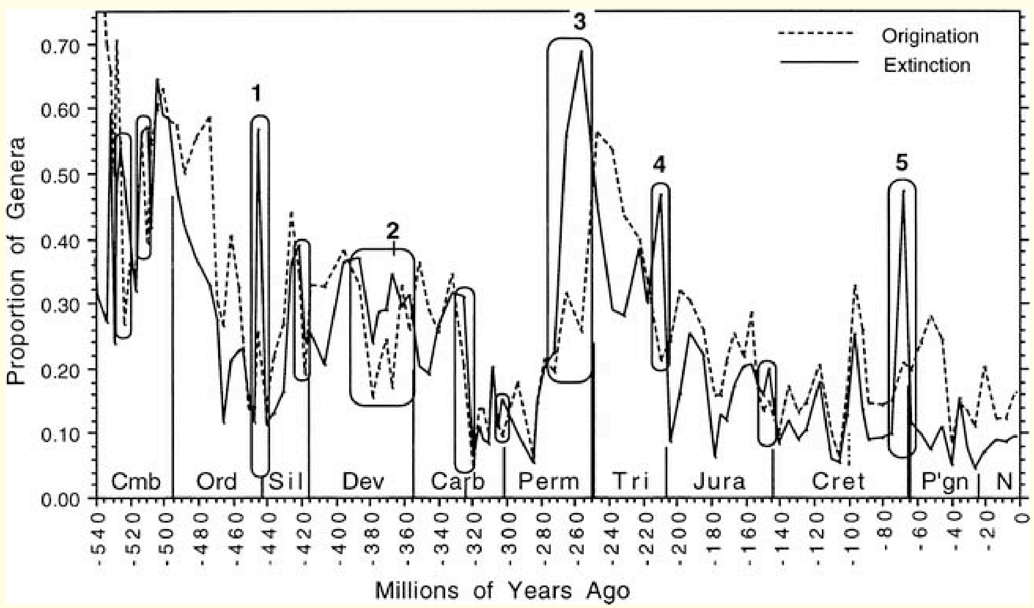


Major Mass Extinctions



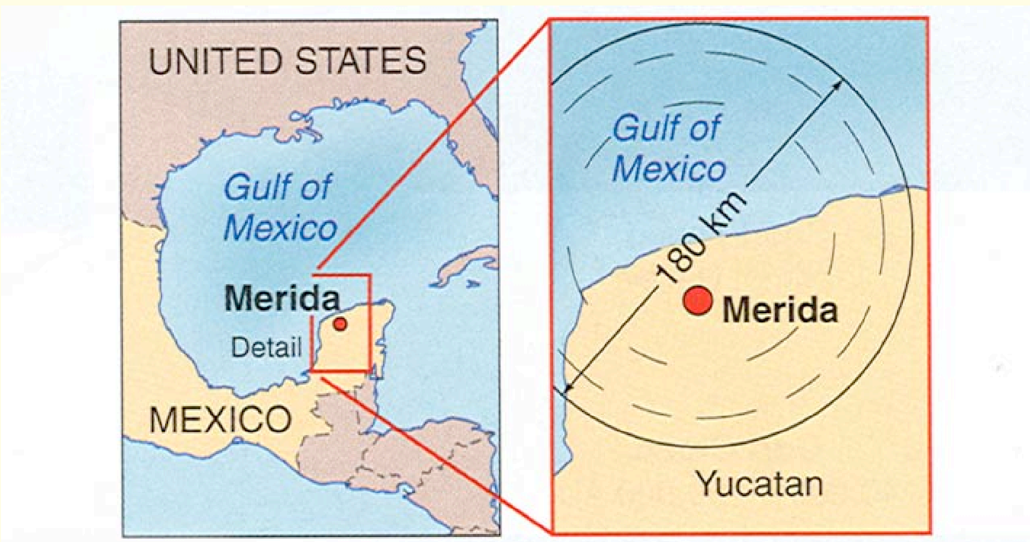
Mass extinction by genera: extinction and origination





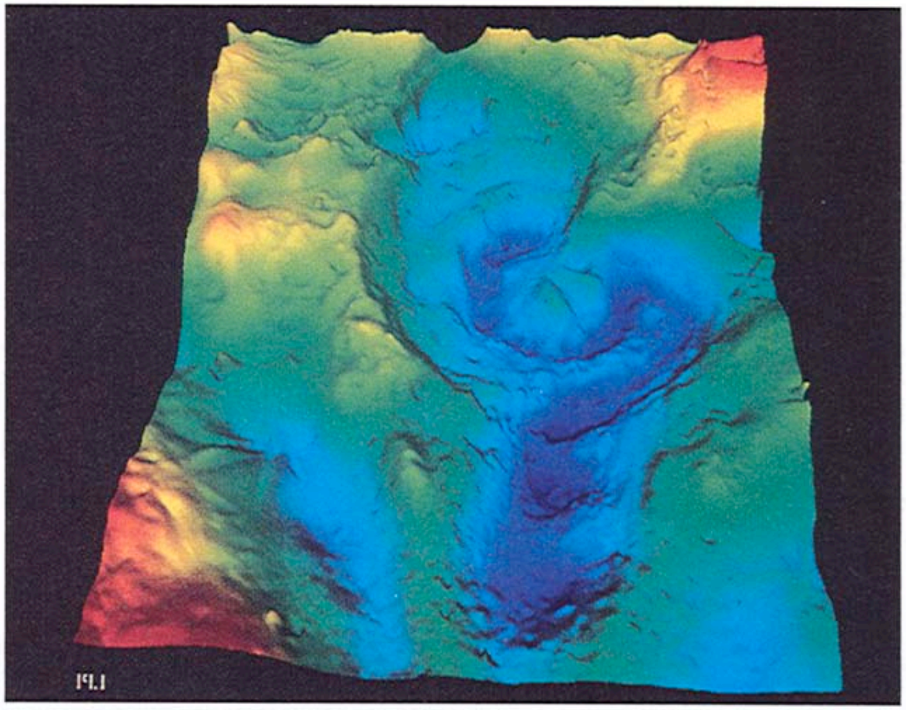
Mass extinction at 65 Myr: Almost certainly ~10 km bolide impact

- 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!



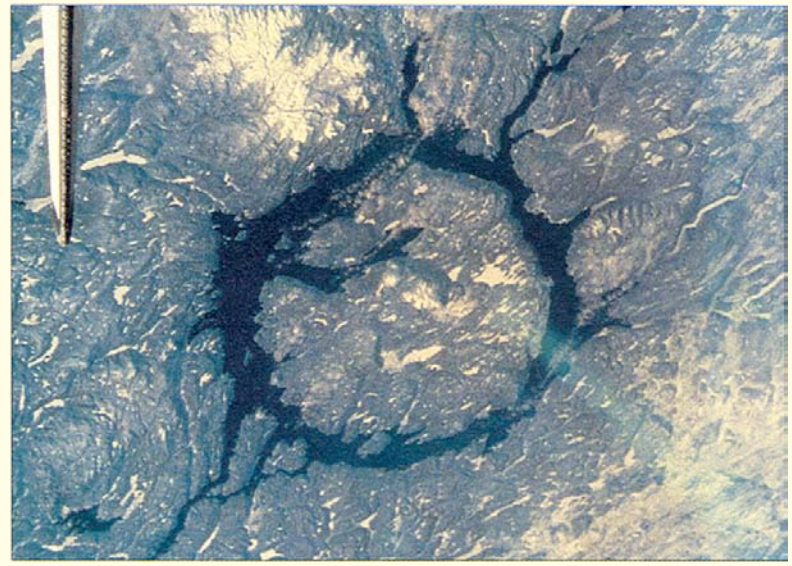
The Chicxulub crater off the Yucatan coast of Mexico measures 180–300 km across, making it one of the largest craters formed in the inner solar system during the last 4 billion years. It is not completely visible from above, but was detected by measuring slight variations in Earth's gravitational pull—measurements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

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.

Some large impact craters *not* associated with enhanced extinction



- Large crater near Quebec, Canada

Consequences and rates of impact of bolides with different sizes