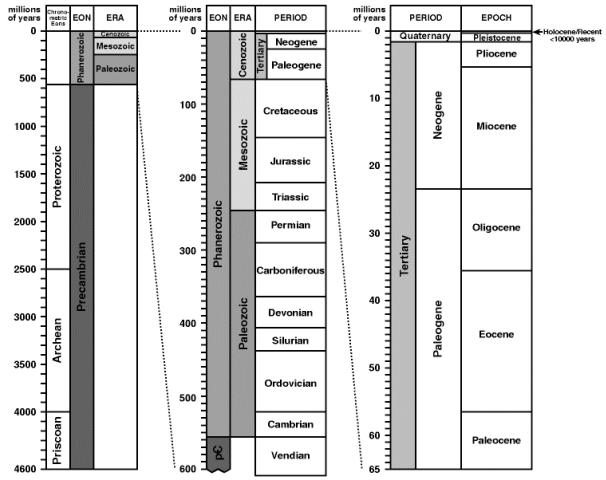
The Complete Fossil Record of the Earth's Entire History

(short version)

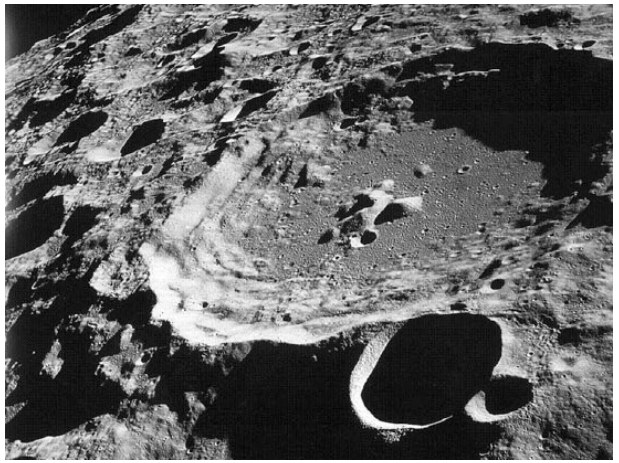
Each of these is subdivided into shorter periods, but I won't hold you responsible for memorizing them. . .



The Six Periods I Will Hold You Responsible For Learning

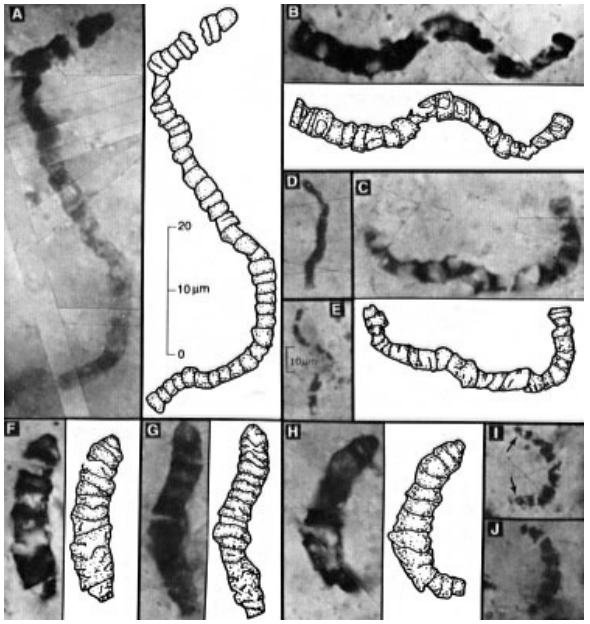
- Hadean—4.6-3.9 bya
- Archaean—3.9-2.5 bya
- Proterozoic—2.5 bya—543 mya
- Phanerozoic—which includes the following:
  - Paleozoic—543-245 mya
  - Mesozoic—245-65 mya
  - Cenozoic—65 mya-present

The *Hadean* (4.6-3.9 billion years ago) was the Earth's *accretion period*. The "proto-Earth" was constantly bombarded by meteorites, and almost no rocks survive from this time period.

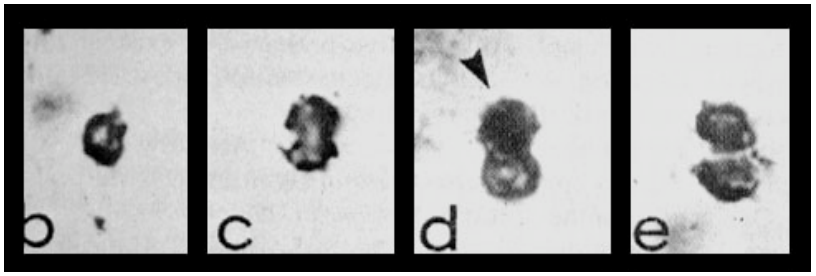


Earliest Fossils

- Several types of microfossils
  - Preserved in *chert* — quartz (SiO_2) with ultramicroscopic crystals, similar to flint. Observable in microscopic thin sections of rock
  - Surprisingly close to living cyanobacteria ("blue-green algae")—cyanobacteria haven't changed much in billions of years!
  - Recent controversy over the oldest claimed fossils (3.5 billion years)—poorly preserved, may not be fossils at all
  - Definite bacterial microfossils by 2.0 billion years

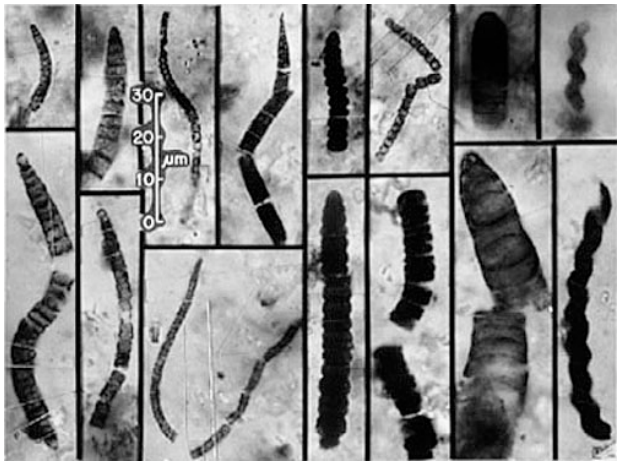


And here they are, the now-controversial oldest fossils claimed, from the 3.5 billion-year-old Apex Chert—found in a rather remote part of Australia.

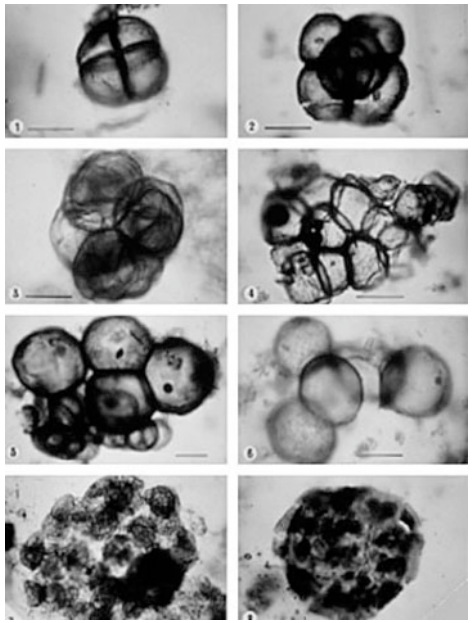


Possible fossils from 3.5 billion-year-old rocks from Swaziland, southern Africa. . .

But somewhat younger rocks have much better preserved microfossils. . .

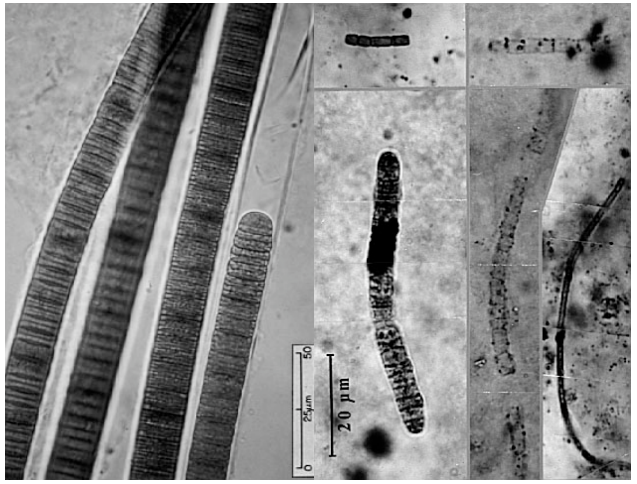


Bitter Springs Formation, Australia, 850 Ma



Here are some more of these very early, microscopic microbial fossils. . .

Roper Group, northern Australia: 1400 Ma



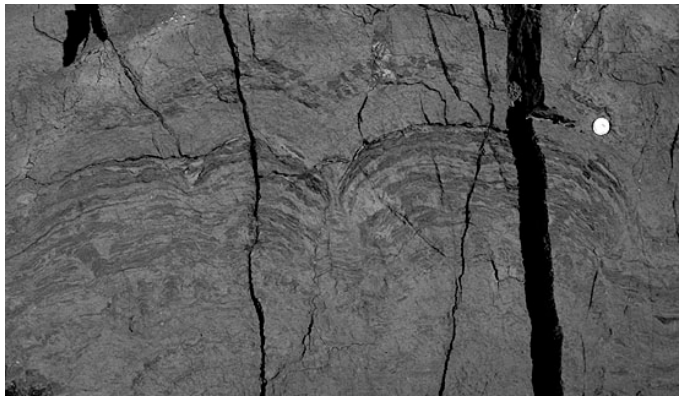
. . . and yet more! Note the similarity between the living cyanobacteria on the left, and the 1.5 billion-year-old fossils on the right. . .

(Still not satisfied? Just gotta have more? Check out the Cyanobacteria Fossil Record page or the Precambrian Life page. . . .)

Pile It On!

- Very early in their history, these microbes began living in mats on the sediment surface
- One mat would get covered with sediment and/or precipitated minerals. . . and a new mat would overgrow the old one.
- Over time, this produces dome-like, layered mounds called *stromatolites*.

Stromatolites are prominent and diverse fossils in the Archaean and especially in the Proterozoic.



Closeup of two stromatolites. Note the distinctive layered pattern in cross-section. In life these would have looked like columns or domes.

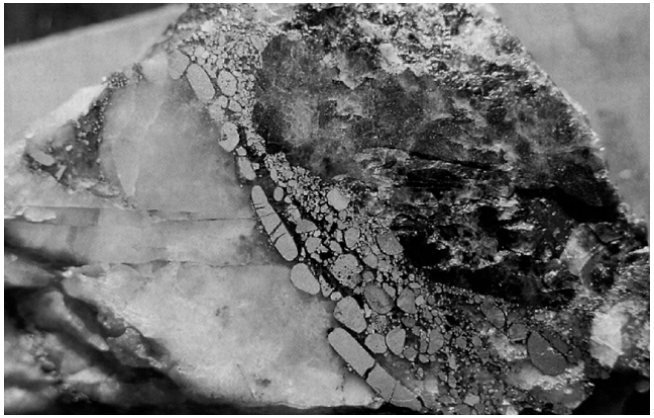
Stromatolites can be seen growing today in a few places, such as Shark Bay, Western Australia.

At Shark Bay, the warm, saline water discourages the growth of animals that would graze away the stromatolites.

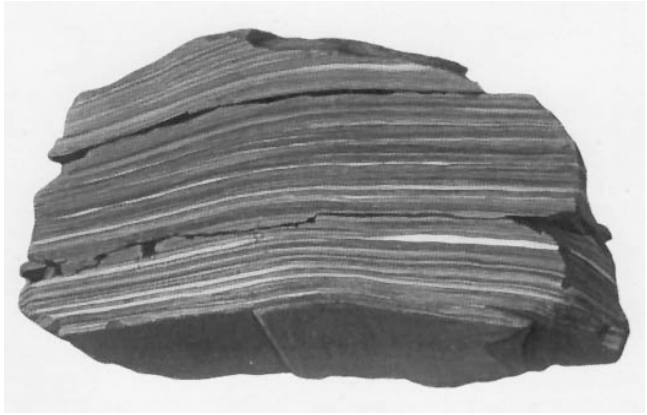
The First Pollution Crisis

- The earliest Earth had no free oxygen in the atmosphere (there's several lines of geochemical evidence for that).
- Photosynthetic microbes "polluted" the atmosphere with oxygen. . .
- . . . but until about 2 billion years ago, in the early *Proterozoic*, that oxygen combined with dissolved iron in the oceans and precipitated out as oxides.

This slab of rock from the Witwatersrand basin of South Africa (2.76-2.89 billion years) contains rounded pebbles of iron pyrite. Pyrite oxidizes quickly—these pebbles could only have formed in the absence of oxygen!

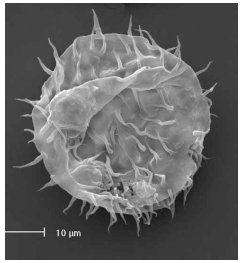


Oxidation of dissolved iron in the oceans led to the formation of *banded iron formations*, or *BIFs*— sedimentary deposits of iron oxides, typically with a banded appearance (frequently mined today as a source of low-grade ore).



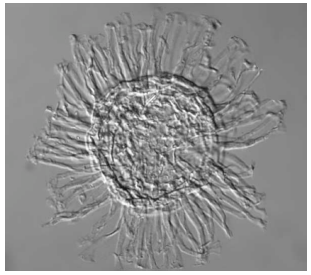
Crisis and Opportunity

- By 2.0-2.3 bya, there was no longer enough dissolved iron in the global oceans to stop the buildup of O_2.
- O_2 in the atmosphere reached 1% of present levels—the minimum to sustain aerobic life.
  - 1% of present levels is called the *Pasteur point*.
- This may have been a key selective pressure in the evolution of *eukaryotes* (cells with nuclei).
  - Oldest definite eukaryote fossils date from about this time.



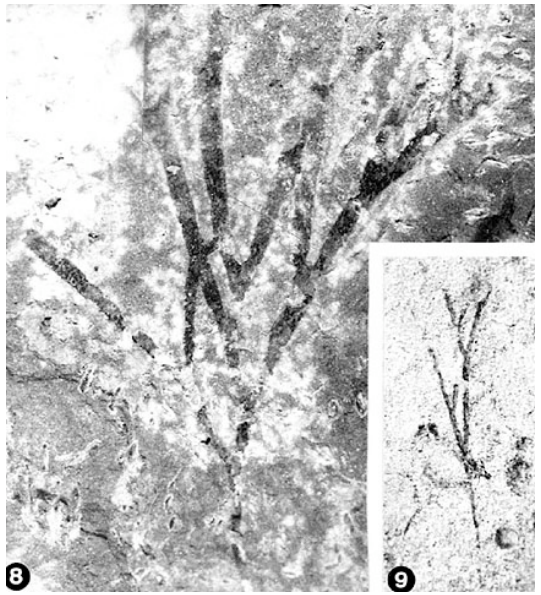
Globosphaeridium

Pertataka



Skiagia

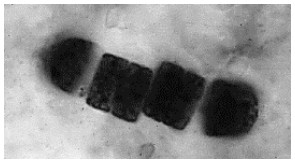
Various fossils of very early eukaryotes, known as *acritarchs* (average size is about 50 microns). These are hollow organic-walled spheres, superficially resembling pollen grains, but more like structures made by many modern groups of single-celled eukaryotic algae.



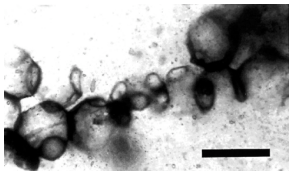
"Carbon film" fossils include many forms that are probably algae. This one, *Konglingophyton*, is very seaweed-like, although exactly what kind of seaweed is not clear.

Source: Steiner, M. 1994. Die neoproterozoischen Megaalgen Südchinas. *Berliner Geowissen-schaftliche Abhandlingen* 15.

Other microfossils in this time frame can be referred to living taxa because of distinctive cell arrangements.



Cyanobacterial filament (cf. *Lyngbya*) 800 m.y.a.



Green algal unicells (cf. *Coelastrum*) ~750 m.y.a.

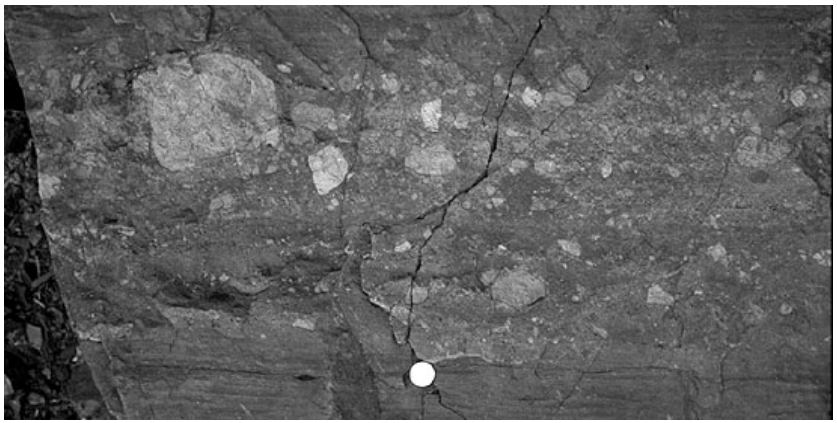
Green algal filament (Ulvophyceae) ~750 m.y.a.

Red algal filament (Bangiophyceae) ~1200 m.y.a.

"Snowball Earth"

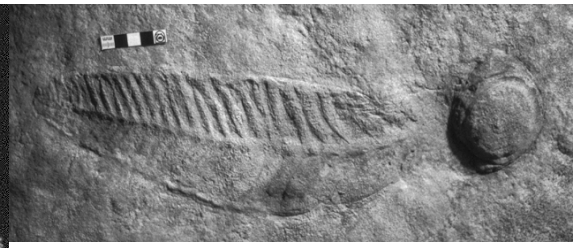
- Evidence for four very severe glacial periods between 750 and 600 million years ago
  - Cause still not certain; topic of much debate
- "Hard snowball" model: Ice covered the entire Earth—oceans completely frozen over; circulation and gas transfer shut down (e.g. Hoffman and Schrag, 2000)

600 million years ago, this *tillite* (upper Kingston Peak Fm), now in the Mojave Desert near the ghost town of Sperry, California, was laid down by a worldwide glacial episode. . . .



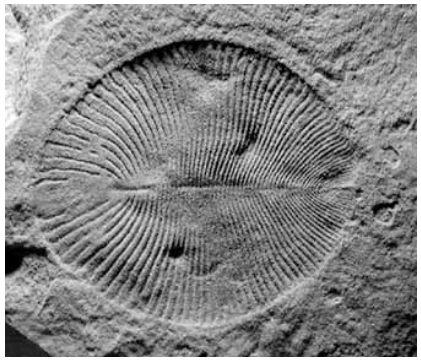
. . . . as is this tillite from southern Australia—which at the time was lying nearly on the Equator.

Right after the glaciation, we find a set of fossils of odd soft-bodued organisms known as the *Ediacara biota* (from the Ediacara Hills, Australia, where they were first documented thoroughly).



Some of the Ediacarans looked like blobs, others like fronds. . .

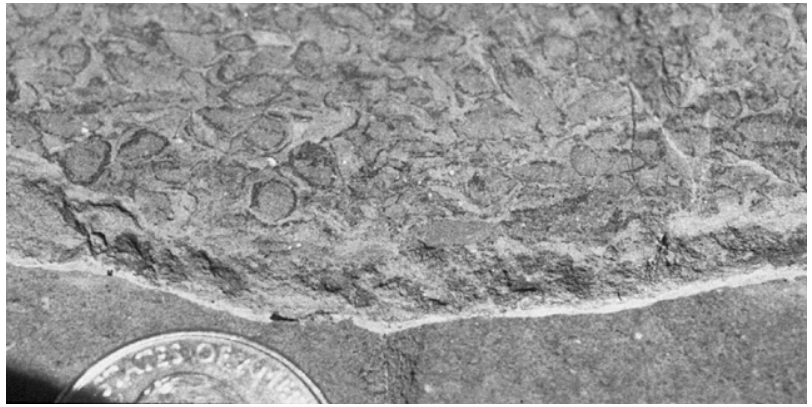
Others (such as *Dickinsonia*, on the left) resemble worms, and some (such as *Tribrachidium*, on the right) are just plain weird. . .



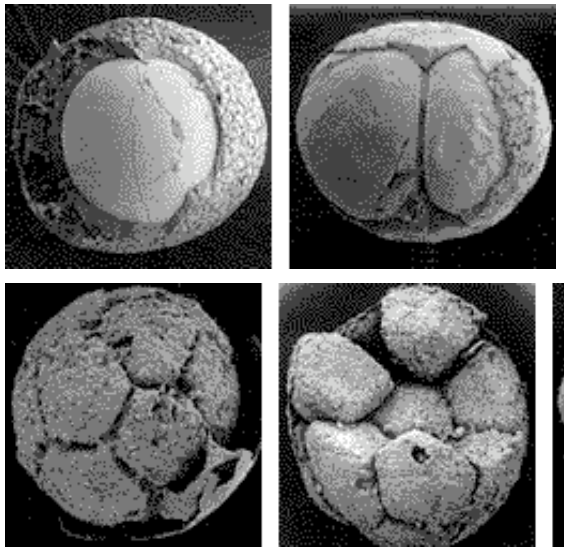
But my favorite is *this* oddball of uncertain affinities. . .

Yorgia waggoneri from north Russia

By about 545 million years ago, we find the oldest mineralized (shelly) fossils. . .



Close-up of a shell bed (cf. *Cloudina*) from Mt. Dunfee, NV

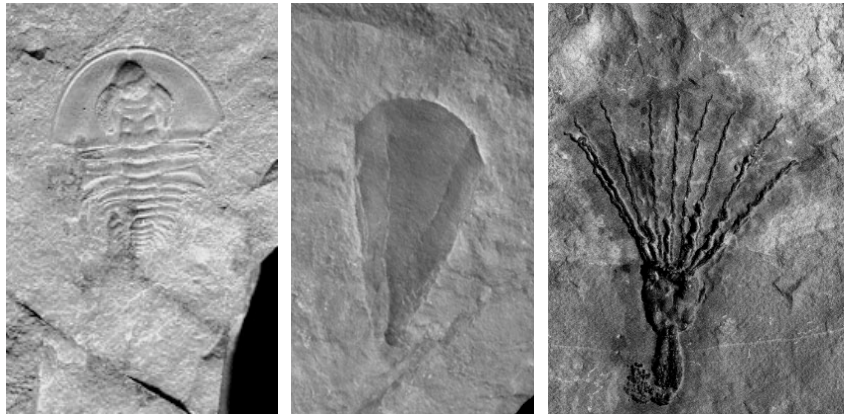


Fossil embryos, 570 million years old, from Doushantuo, China, preserved as phosphate mineral replacements

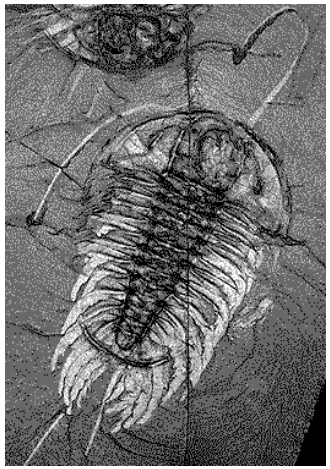
The Cambrian "Explosion"

- The *Cambrian Period*: 543-505 m.y.a.
  - First subdivision of the Paleozoic
- Appearance and early diversification of most animal phyla (though at least some were already)
- Several key sites with unusually good fossil preservation (*Lagerstätten*) literally "flesh out" the fossil record: we know now that soft-bodied animals radiated and diversified too

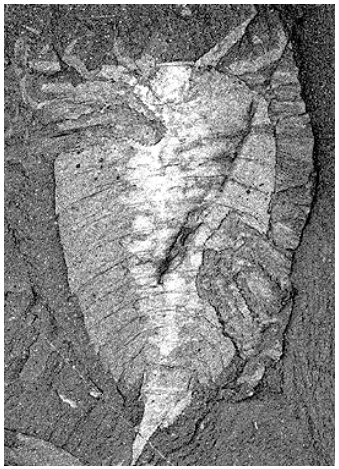
A few early Cambrian fossils of animals with skeletons: the trilobite *Olenellus*, the cone-shaped shell *Hyolithus*, and an early echinoderm, *Gogia*.



Just how big the "Cambrian explosion" was can be gauged from the fossils at the world famous Burgess Shale locality in the Canadian Rocky Mts.

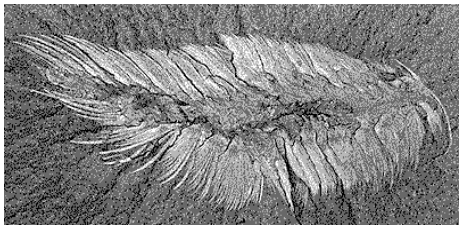


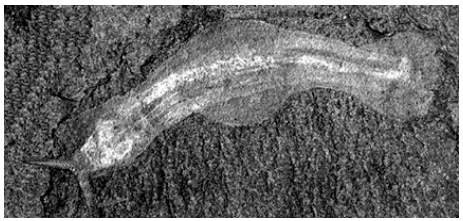
Olenus, a trilobite

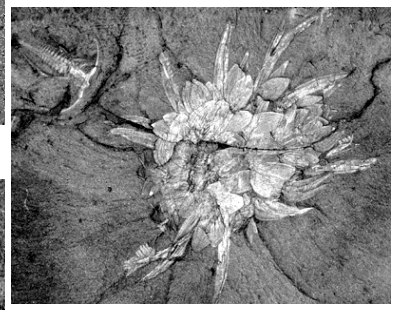


Sidneyia, another arthropod

These include not just arthropods, but segmented worms (like *Canadia*, upper left) and strange beasts (like *Wiwaxia*, right, and *Amiskwia*, lower left)



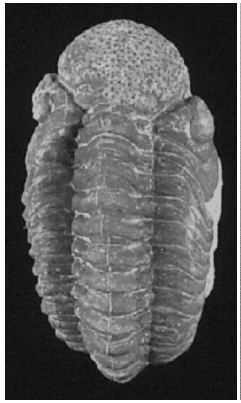




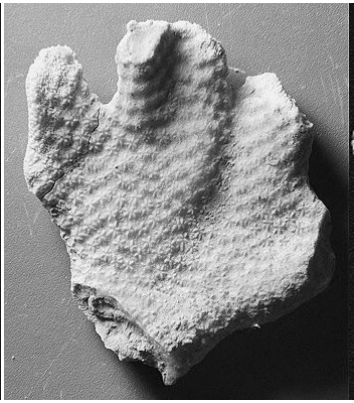
Paleozoic Era

- 543-245 million years ago
- Dominant marine animals: trilobites, brachiopods (superficially clam-like animals but not actually clams). . .
- Plants, insects and vertebrates all evolve land-dwelling forms
- Defined as ending with the greatest mass extinction in history, the *Permo-Triassic extinction*, which killed an estimated 95% of all animal species on the planet

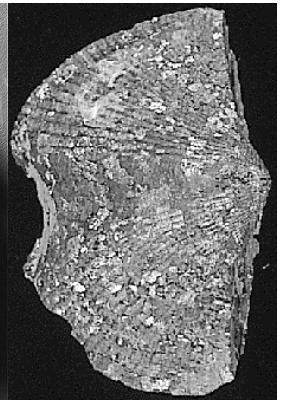
A few typical invertebrates from roughly the middle of the Paleozoic. . .



Phacops, a trilobite

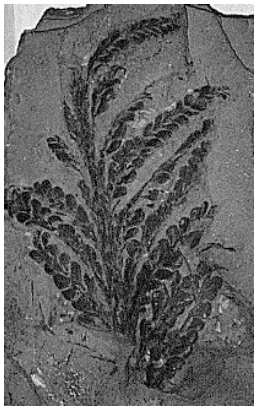


Constellaria, a bryozoan



Paraspirifer, a brachiopod

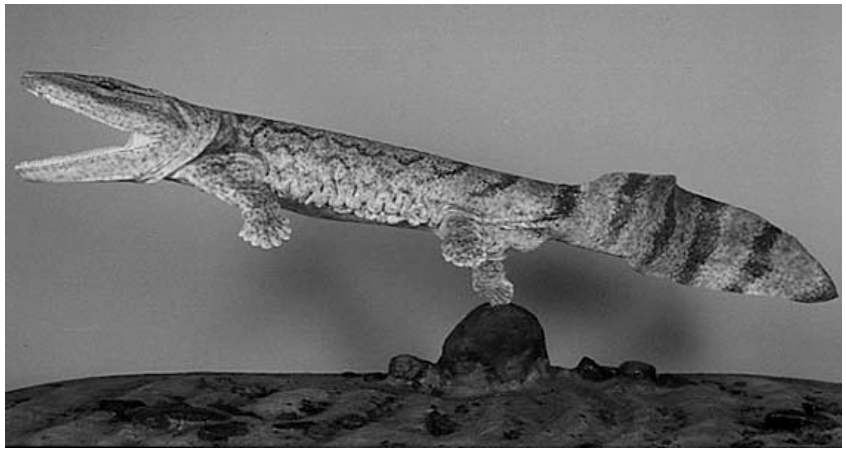
Plant life and insect life was established on land by about 400 million years ago. . .



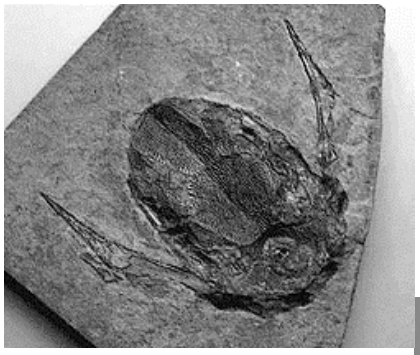
Archaeopteris, foliage of an early seed plant

Heteroneura, insect (wing)

Eurypterus, "sea scorpion" (marine, but related to land scorpions)



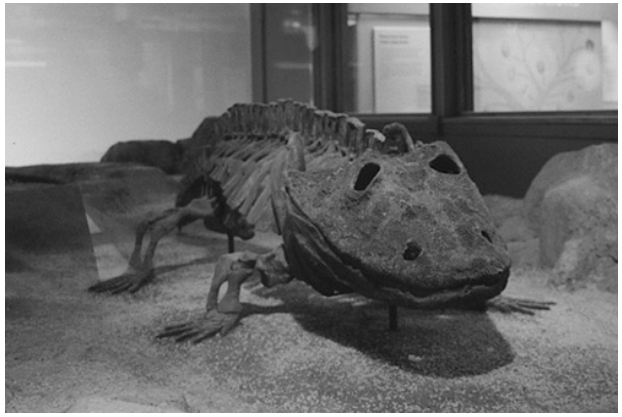
We've already discussed the vertebrate transition to land. . .



Two odd Paleozoic fish. . .

Bothriolepis, a *placoderm* (type of armored Paleozoic fish) with a boxy body, small mouth, and armored pectoral fins

Dunkleosteus, a large predatory placoderm, with sharp jaws but no teeth. (*Dunkleosteus* is the one in the back; that's a former student of mine in front.)

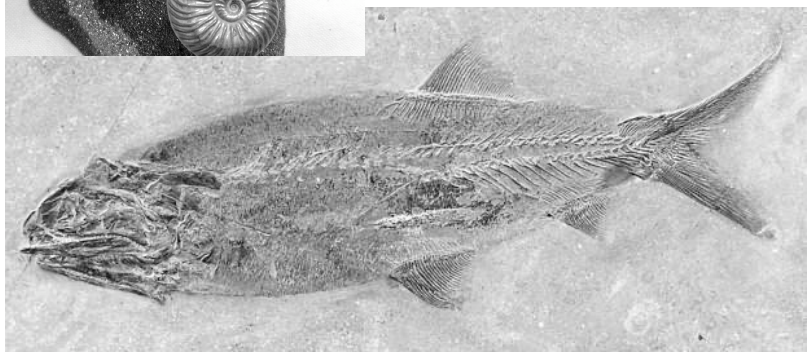


By the end of the Paleozoic, land vertebrates (such as *Eryops*, a temnospondyl amphibian) had diversified greatly.

Mesozoic Era

- 245-65 million years ago
- Dominant marine invertebrates: modern corals; molluscs, including cephalopods (squid relatives) with coiled shells, known as *ammonites*
- Modern groups of bony fish appear and radiate in the Mesozoic as well
- Radiation of reptilian lineages, including *dinosaurs* but also some others
- Mammals, birds, flowering plants, etc. appear during this time but don't massively radiate just yet

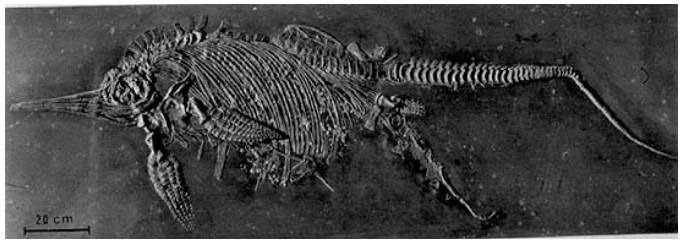
A couple of typical Mesozoic *ammonites* (left) and a Mesozoic fish related to the modern bowfin (right). . .

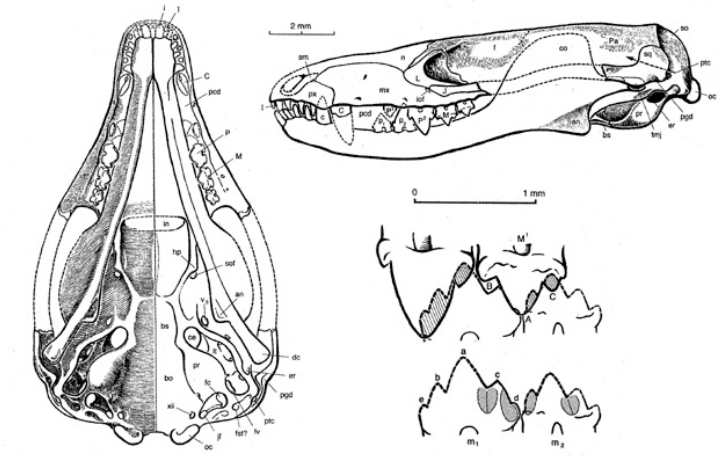


But you guys would rather see some dinosaurs, so here goes:

OK, OK, here's another dino skeleton. . .

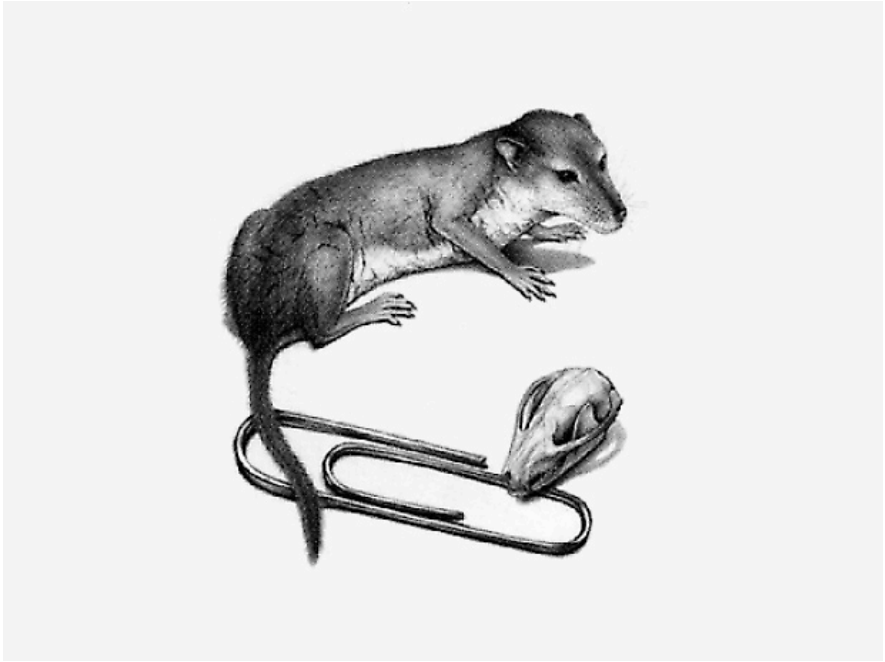
Mesozoic marine reptiles known as *ichthyosaurs*, so well preserved that traces of the soft tissues are visible in silhouette. The specimen below was apparently preserved in the act of giving birth.

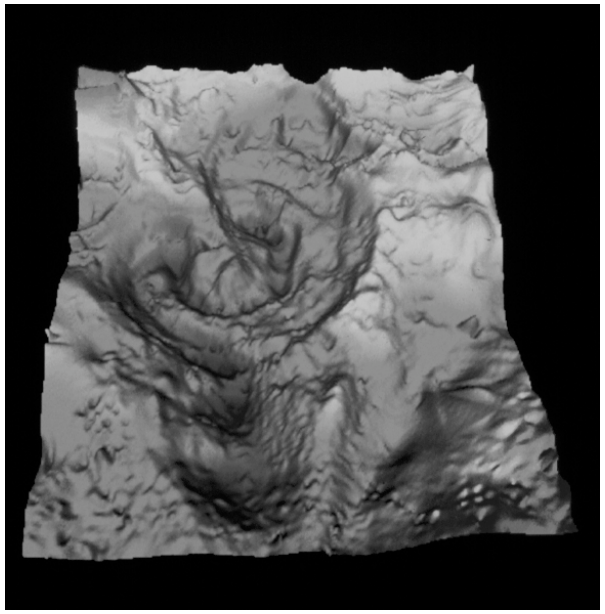




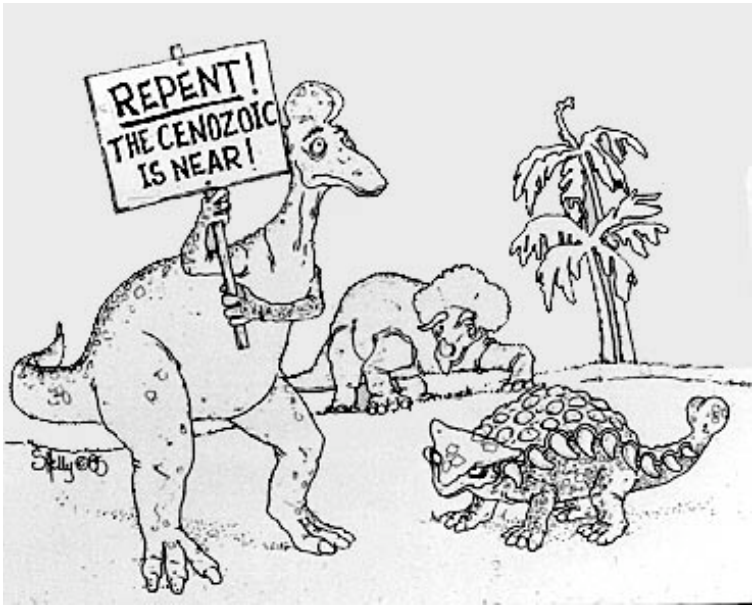
Hadrocodium, described in May 2001 from the Early Jurassic of Yunnan, China, is the closest animal so far known to the common ancestry of all living mammals. The next slide shows what it looked like in life.. . .

Archaeopteryx, from the mid-Mesozoic of Germany, is the oldest known bird, with many traits that show that it evolved from dinosaurian ancestors.





The Meozoic is defined as ending with another mass extinction. This is a *gravity map* of a 300-km buried meteor crater at Chicxulub, Mexico, which has been dated to the end of the Mesozoic and may be the cause of the extinction.

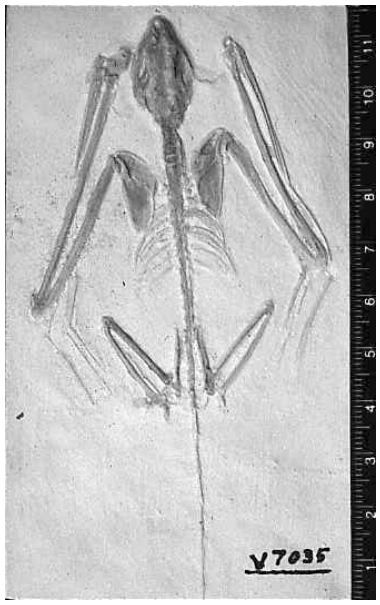


Cenozoic Era

- 65 million years ago to today
- Radiation of mammals, birds, modern flowering plants

A Cenozoic fossil flowering plant: *Platanus wyomingensis*, a sycamore

A Cenozoic fossil mammal: *Icaronycteris*, the oldest known complete fossil bat



A late Cenozoic mammal, *Australopithecus africanus* from South Africa. . .