

A typical rock formation



Moenkopi Formation (red rocks at the base of the cliff), Shinarump Conglomerate (thin white layer), Chinle Formation (grey, purple and red layers) and Wingate Formation (buff colored cliff at the top); note how the Shinarump Member pinches out towards the center of the image. Capitol Gorge, Capitol Reef National Park, Utah

Relative dating: some principles to follow...

1

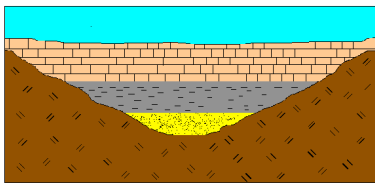
Principle of superposition



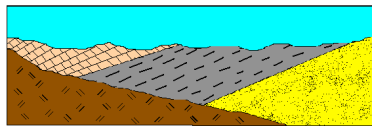
Sandstone bedding, Sandstone Formation, Black Hills of South Dakota

2

Principle of original horizontality



Original Horizontal Strata



Tilted Strata

3

Principle of lateral continuity



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4

Principle of cross-cutting relationships



Normal fault cutting across volcanic tuff layers near Kingman, Arizona



Basalt dikes cutting across bedding in the Moenkopi shales, Capitol Reef National Park, Utah



5

Principle of inclusions



Xenolith inclusion in the granite at Enchanted Rock State Park, Texas



Xenolith inclusion in the granite at Enchanted Rock State Park, Texas

6

Principles of unconformities (missing time)



Disconformity in the Dakota Formation (red arrow); note the stream channel that has cut into older layers, including the Cow Spring Formation. Coal Mine Canyon, Arizona



Angular unconformity between the Furnace Creek Formation and overlying gravels, near Zabriskie Point, Death Valley National Park, CA



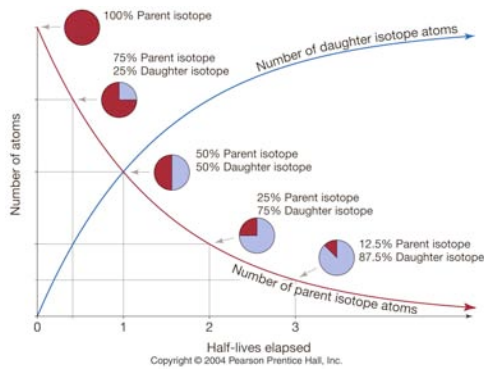
Disconformity in the Dakota Formation (red arrow); note the stream channel that has cut into older layers, including the Cow Spring Formation. Coal Mine Canyon, Arizona

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Radiometric Age Dating

- Uses unstable isotopes of naturally occurring elements. The isotopes decay: they change into different elements or different isotopes of the same element.
- The rate of decay is known (has been measured in the laboratory) for a variety of isotopes.
- When igneous rocks form, there is 100% parent and 0% daughter isotopes in the rock.
- The ratio of the parent and daughter isotopes can be measured using a mass spectrometer.

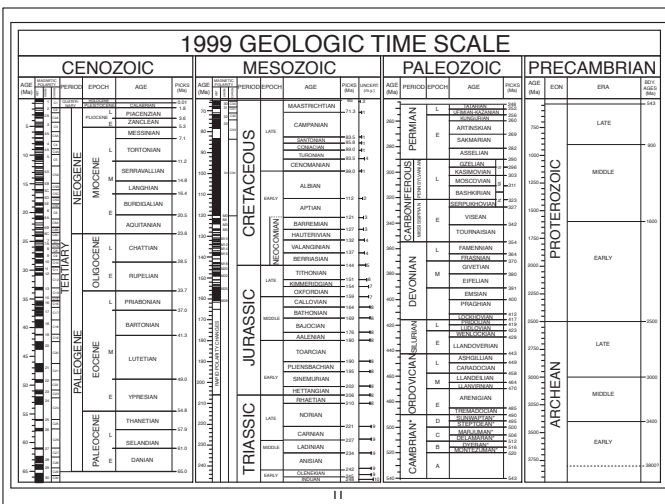
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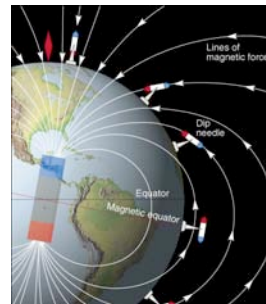
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Method	Parent isotope	Daughter isotope	Half life	Dating range
Rubidium-strontium	Rb-87	Sr-87	47 by	10m-4.6b
Uranium-lead	U-238	Pb-206	4.5 by	10m-4.6b
Uranium-lead	U-235	Pb-207	71.3 my	10m-4.6b
Thorium-lead	Th-232	Pb-208	14.1 by	10m-4.6b
Potassium-argon	K-40	Ar-40	1.3 by	.1m-4.6b
Carbon-14	C-14	N-14	5730 y	100-100,000

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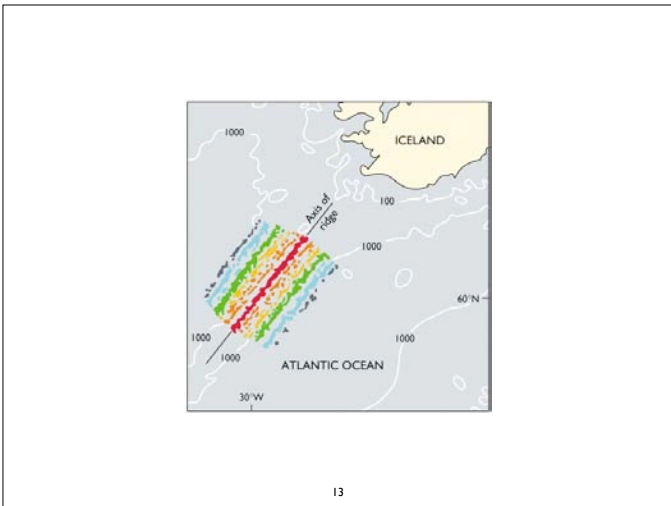
Paleomagnetism



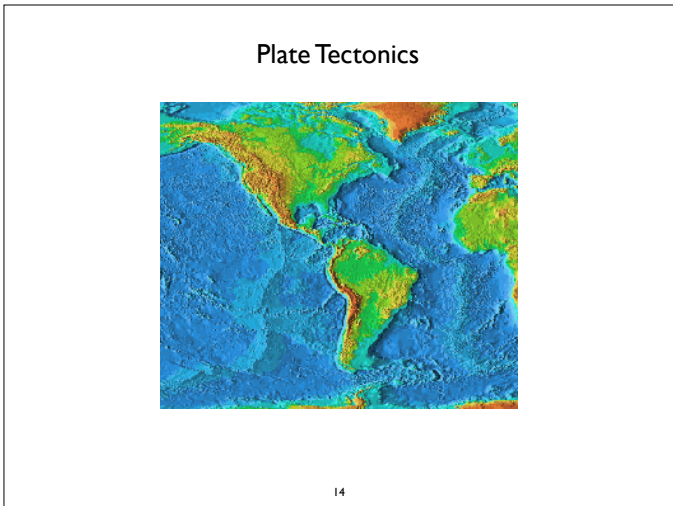
Earth has a dipole magnetic field, with the direction in line with the axis of spin.

When rocks form, they are permanently magnetized in the direction of the current magnetic latitude.

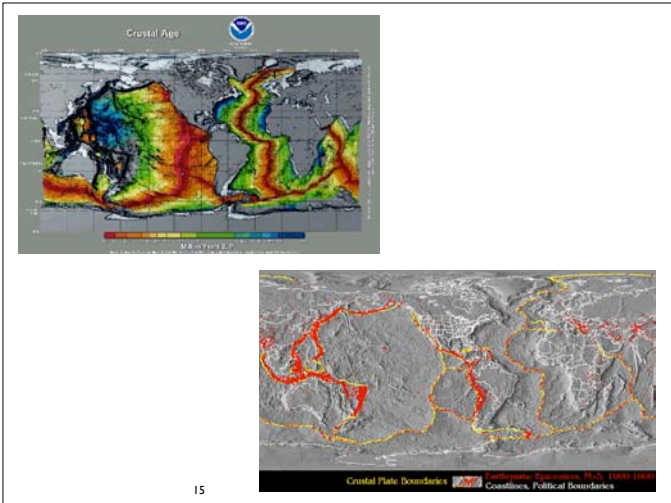
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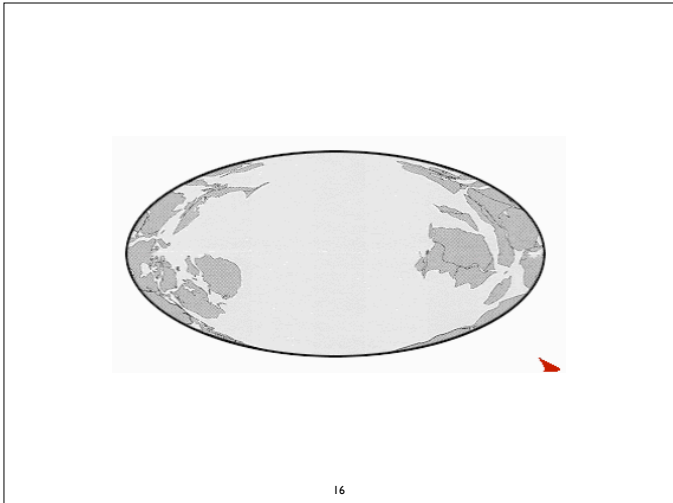
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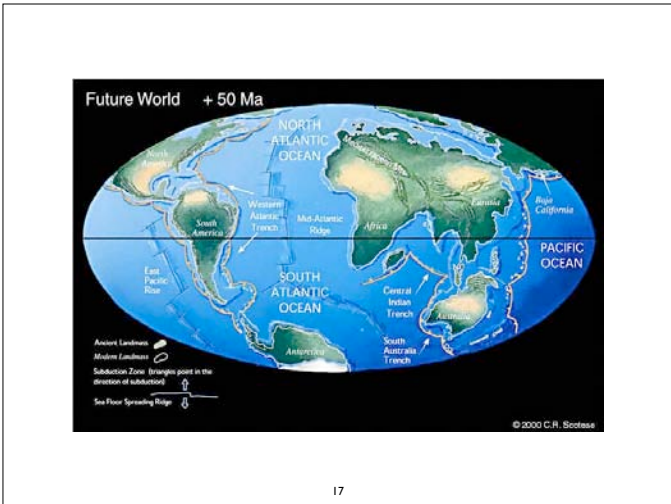
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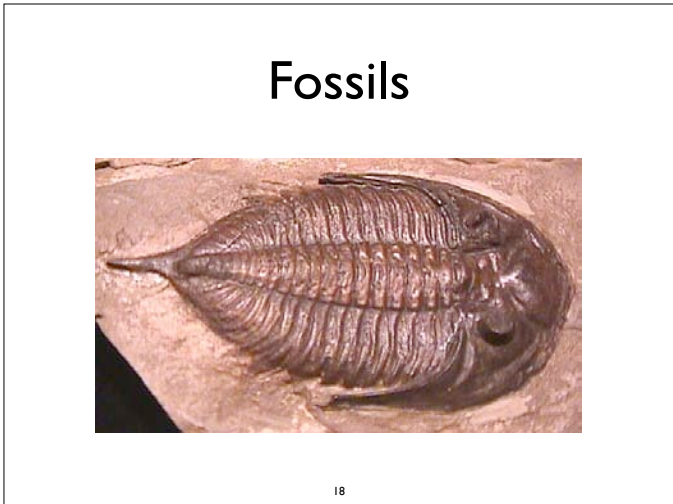
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A fossil is any recognizable evidence of preexisting life.

- Types of fossils:
- (1) Trace fossils
 - (2) Preserved material

Fossils are our only direct evidence of what organisms looked like in the past.

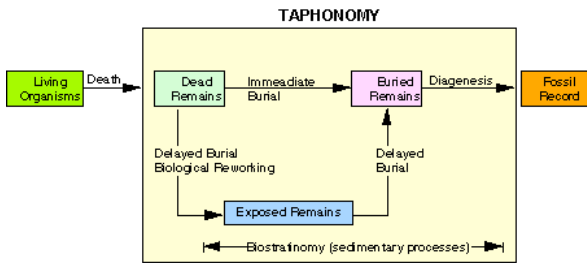
The fossil record is a biased one.

Where is the time?



Sandstone bedding, Sandance Formation, Black Hills of South Dakota

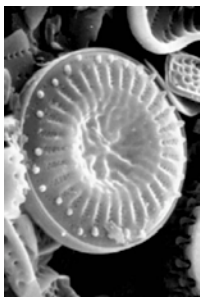
Taphonomy: The study of the process of fossilization, from death of the organism to discovery by the paleontologist.



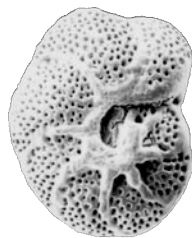
Types of biases in the fossil record

- Fossils with no hard parts are rarely preserved. Fossil record is mostly a record of shells and bones.
- Organisms that lived in areas where they are likely to be preserved.
- Time averaging of fossil beds.
- Post-mortem transport, scavenging,

Microfossils



Diatoms



Foraminifera

"Invertebrates"



Vertebrates



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Stromatolites



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Transitional Forms



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D. Donuton (Basilosauridae) from the middle to late Eocene of Egypt



C. Rodhocetus (Protocetidae) from the early middle Eocene of Pakistan



B. Pakicetus (Pakicetidae) from the earliest middle Eocene of Pakistan



A. Elomeryx (Anthracotheriidae) from the Oligocene of Europe, North America, Asia



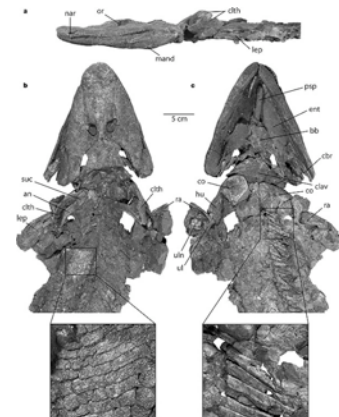
Basilosaurus hind leg

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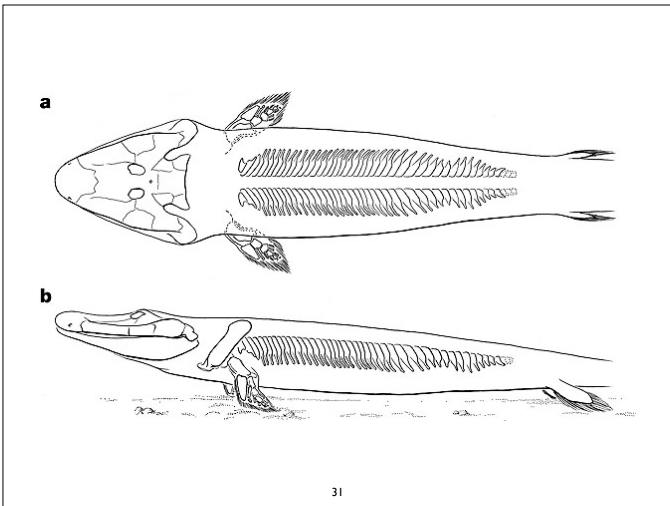
Ankle bones of the archaeocetes Rodhocetus (Eocene) on the left, a pronghorn (middle) and Artiocetus (right). Note the double-pulleyed astragalus. Other features in common are a notched cuboid and a prominent fibular facet.

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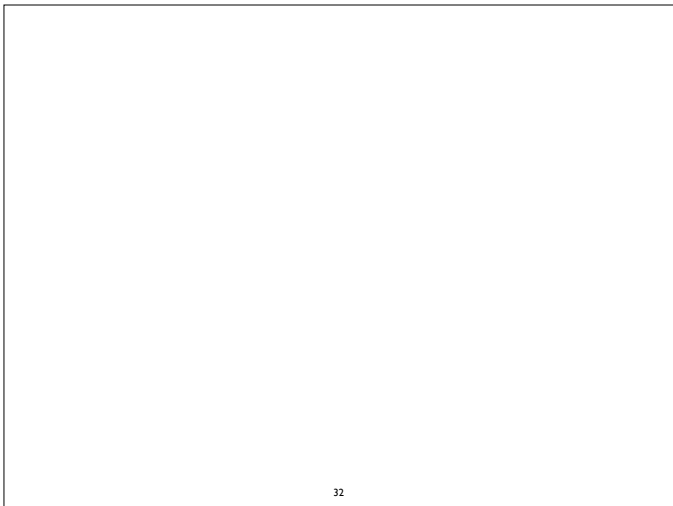


Tiktaalik roseae (late Devonian)

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Microfossils from the Apex Chert, North Pole, Australia

About 3.465 billion years old, resembling filamentous cyanobacteria

Stromatolite, North Pole deposits, Western Australia

about 3.5 billion years old

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Extant stromatolite showing closeup of cyanobacteria

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Proterozoic (2.5 bya to 544 mya). Evolution of organisms with oxygenic photosynthesis caused an increase in oxygen levels. Rising oxygen levels in the world's oceans caused the formation of iron oxide, often preserved in the banded iron formation.

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Eukaryotic milestones

- 2.7 bya: chemical traces of eukaryotic-type lipids in fossil organic matter (controversial).
- 2.1 bya: *Grypania spiralis*, the first fairly well-accepted fossil eukaryote
- 1.6-1.8 bya: origin of single-celled algae of unknown type, known as acritarchs

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Grypania spiralis from Michigan

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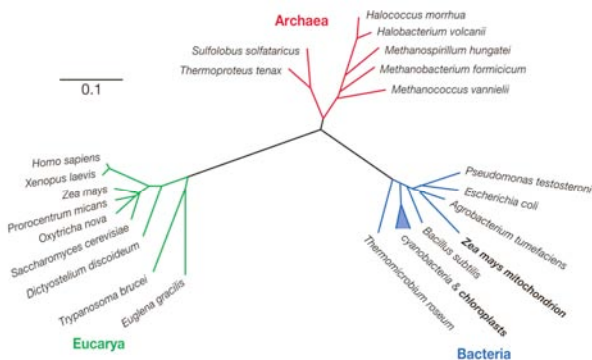
acritarch

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Endosymbiosis hypothesis for the origin of organelles

- Organelles originated in symbiotic union of ancestral prokaryotes

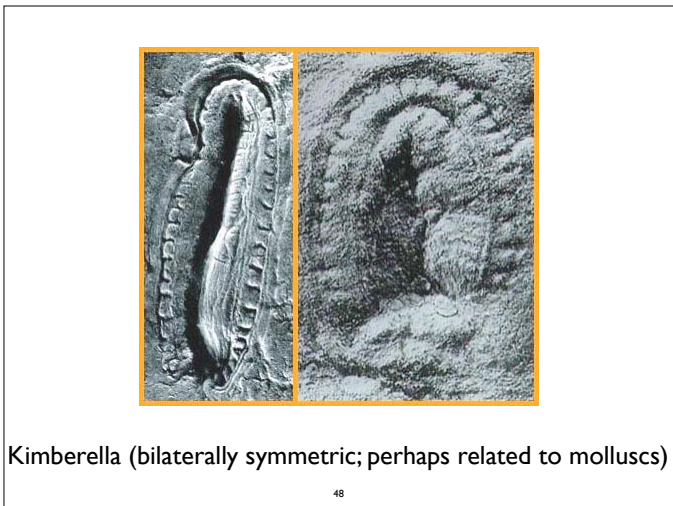
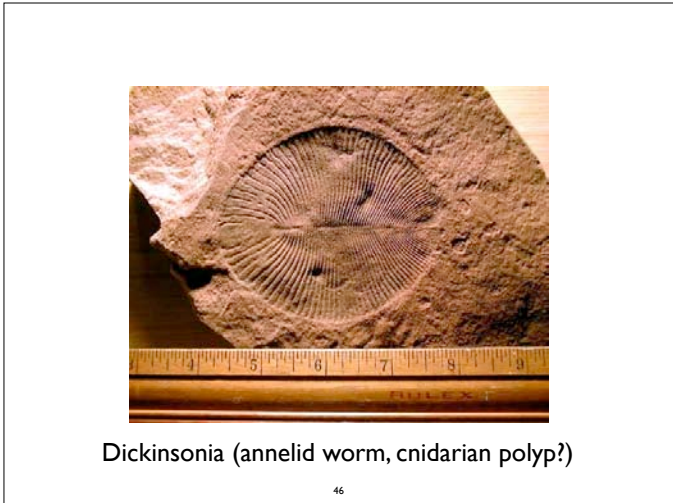
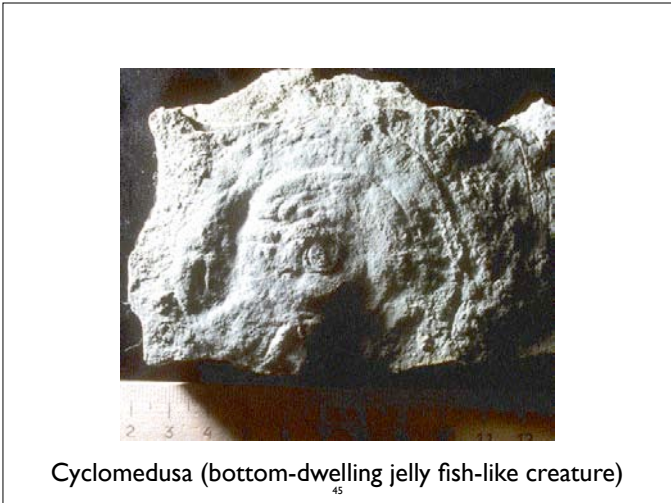
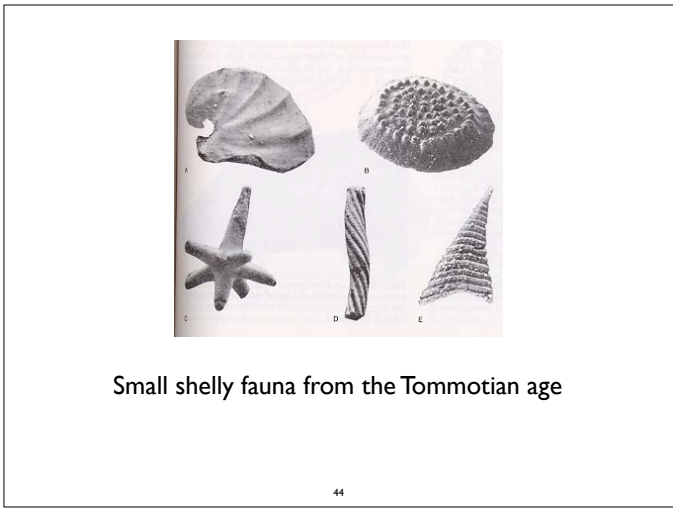
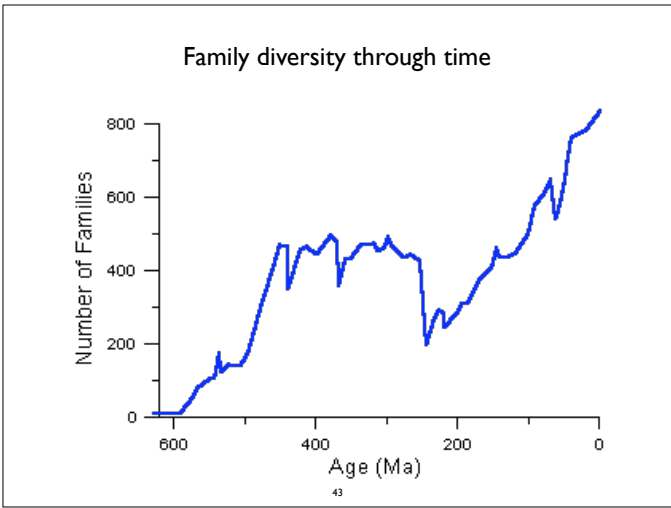
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Cambrian Explosion

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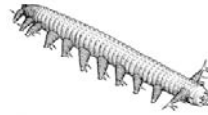


Charles Walcott



Burgess Shale

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Aysheaia
(velvet worm)



50



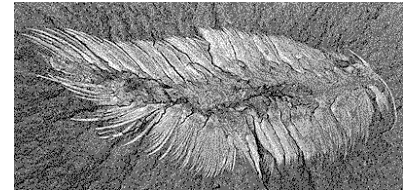
Pikaia
(primitive chordate)



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Canadia
(polychaete worm)



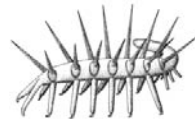
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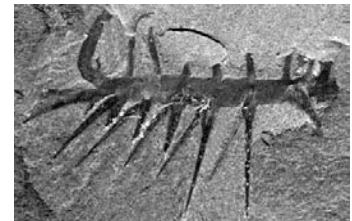
Ottoia
(priapulid worm)



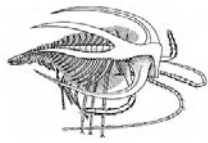
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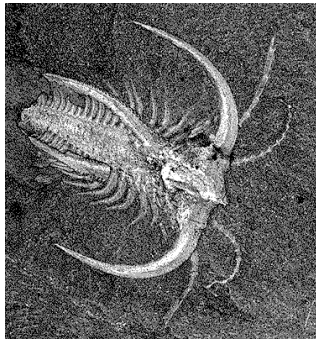
Hallucigenia
(onychophoran: velvet worm)



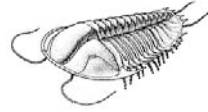
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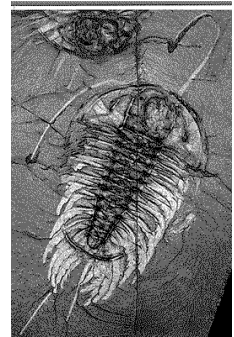
Marrella
(primitive arthropod)



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Olenoides
(trilobite)



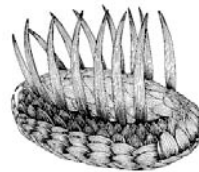
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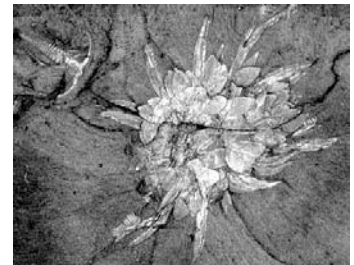
Opabinia
(???)
(five eyes and proboscis!)



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Wiwaxia
(???)



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What caused the Cambrian explosion?

- rising oxygen levels allowed larger body sizes
- evolution of key developmental genes
- evolution of skeletons (allowing larger body size)
- predation (arms race between predators and prey)

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Is the Cambrian explosion an illusion?

- Major phyla originated much earlier, but Cambrian/pre-Cambrian marks the passing of a taphonomic threshold.
- Some molecular phylogenetic analyses support an earlier divergence of phyla.

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Morphological Disparity

- Gould: Diversity in the Cambrian was much greater (witness the Burgess Shale Creatures), and today's diversity in body forms is a result of a perhaps random winnowing of the Cambrian diversity.
- Conway-Morris: Most of the Burgess Shale creatures can be placed with modern phyla.

