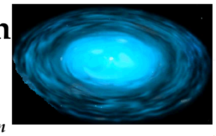
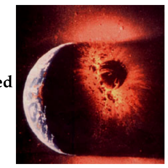
A Brief History of Life

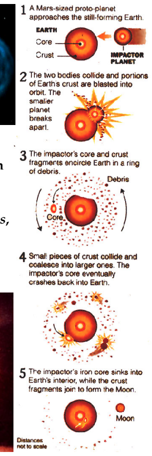
History of the Earth (Sears Tower: 1450 ft, antennas 350 ft)

The Hadean Eon



- Earth and Solar System formed by coagulation and gravitational contraction from a large cloud of gas and dust around the Sun (*accretion disc*) 'about' 4.6 Bya:
  - The sun formed the nucleus, shrinking by gravitational compaction until it reached a stage where thermonuclear fusion reactions were ignited.
  - Surrounding particles within the cloud coalesced into *planetesimals*, which aggregated to form *microplanets.*
- The energy of the collisions between the larger microplanets, as well as interior radioactive and gravitational heating, generated a huge amount of heat.
- Earth and other planets would have been initially molten.
- The Earth and the Moon were formed by a collision between two proto-planets: a Mars-sized body and a somewhat larger one.





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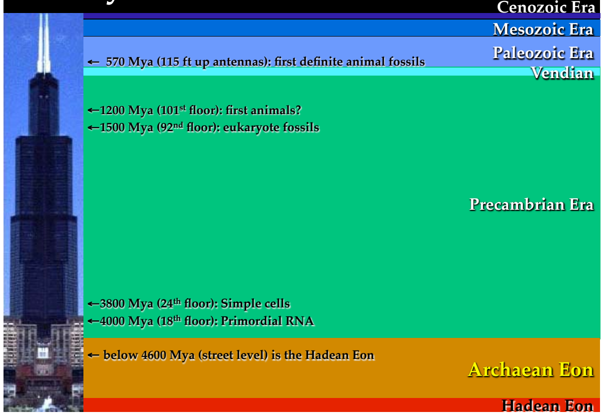

The Archaean Eon

- Once most of the planetesimals were gone, the planetary bombardment stopped, and a stable rocky crust was able to form after about 4.5 to 4.6 Bya.
  - This is the beginning of the rock record that is currently present on the Earth (i.e., the age of the oldest rocks on earth and also of Moon rocks).
- Earth probably had a primeval atmosphere of CO_2, N_2 , and H_2O vapor (with small amounts of CO, NH_3, and CH_4):
  - Initial steam atmosphere was made of water from hydrated minerals and (probably) comets
  - As the Earth began to cool, water condensed out of the atmosphere and filled the ocean basins about 4.3-4.4 Bya (initial ocean temperatures about 100 °C).
  - Proto-life formed in the "soup" of primordial organic molecules, either in the early oceans or in clay or rocks within the crust itself.
- Living organisms began to alter the Earth's atmosphere: greatly *decreasing* CO_2 and CH_4 levels (removing these greenhouse gases decreased temperature), while greatly *increasing* atmospheric O_2 (causing metals to precipitate out of the oceans) and N_2.

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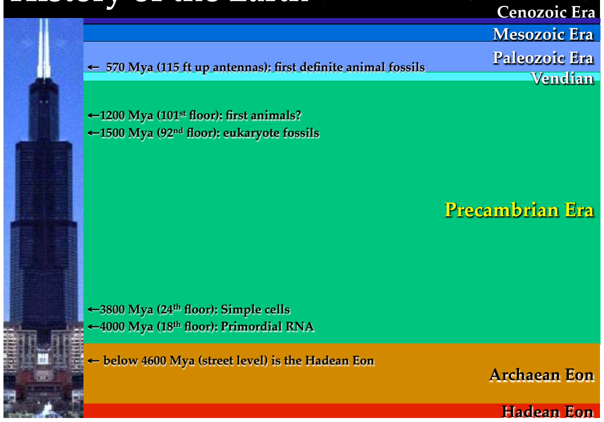


Evolution of Life on Earth

First (prokaryote) life marks beginning of *Precambrian Era*

- First organisms probably similar to modern *Archaea.*
- Possibly fed upon carbohydrates, proteins, nucleic acids, produced from "primordial soup" of chemicals by chemical reactions, heat, and electrical discharges (lightning).
- Early microbial life likely *heterotrophic*, but as the energy-supplying 'soup' became exhausted, energy-producing (*autotrophic*) organisms become competitive.

First fossil evidence of life dates from ca. 3.5-3.8 Bya

- Chains of cells similar to modern cyanobacteria ('blue-green algae').
- *Stromatolyte* 'rocks' are formed from minerals secreted by these algal mats (actually, the mats are communities of aerobic and anaerobic heterotrophic bacteria).

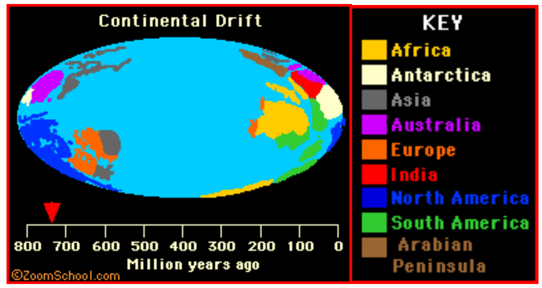
A Brief History of Life

Evolution of Life on Earth

- **Early autotrophs:**
  - Produce their own food.
  - Use light energy to split water and extract electrons for energy.
  - Produce *oxygen* as waste product. *Begin modifying planetary atmosphere!* Forced extinction of most anaerobic species.
  - Provided food source for other (*heterotrophic*) organisms.
  - No non-microbial life for next 2 Ga at least.
- **About 2 Ga, first eukaryotes probably appeared:**
  - First eukaryote *fossils* date from about 1.5 Bya.
  - Incorporation of prokaryote functions into organelles.
  - 'Division of labor' - increased cellular specialization.
  - 'Animal' life evolves independently from several eukaryote types.

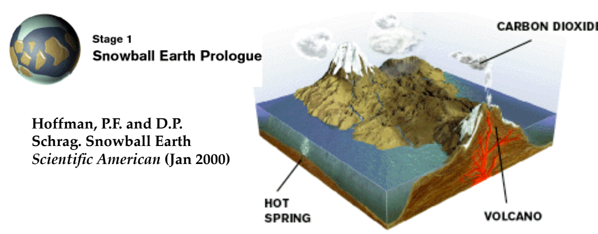
Distribution of Continents and Oceans

- Distribution patterns of continents and oceans have altered the climate of the planet and produced a diversity of habitats.
- This may not have been required for animal life to have evolved or for it to exist, but climatic diversity *has* promoted greater diversity of habitats, and therefore of species.



'Snowball Earth'

- Over the past several decades, evidence has steadily mounted that the Earth underwent as many as four extreme climate oscillations between 750 and 580 Mya:
  - The temperature decreased to -50 °C, and entire surface of the Earth's oceans froze to a depth of nearly 1 km.
  - All but a tiny fraction of the planet's primitive organisms died out.
- Evidence for the 'formation of 'Snowball Earth' includes:
  - The presence of glacial debris near sea level in the tropics (glaciers near the equator today survive only at ≥5,000 m above sea level, and during the worst of the last ice age they reached no lower than 4,000 m).
  - Mixed with the glacial debris are unusual deposits of iron-rich rock, that should not have been able to form in an atmosphere containing oxygen, yet by that time the present oxygen-rich atmosphere had already evolved.
  - Carbon isotope ratios in the rocks indicate at a prolonged decrease in biological activity.
- Climate models indicate these cold spells ended when:
  - A few volcanoes slowly released CO_2 into the air. Because the ice prevented the CO_2 from dissolving in the ocean, the gas gradually accumulated to high levels.
  - The increased CO_2 trapped more and more heat in the atmosphere, rapidly warmed the planet, and began to melt the ice. In just a few hundred years, a severe greenhouse effect was in full swing. Organisms that survived the deep freeze had to rapidly adapt to a hot environment.



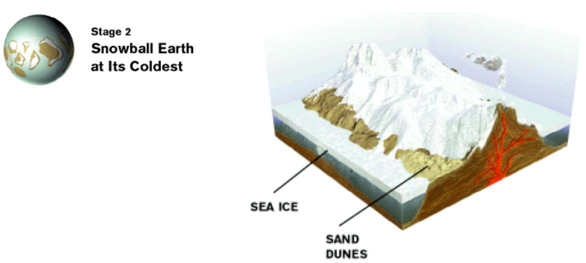
Hoffman, P.F. and D.P. Schrag. Snowball Earth *Scientific American* (Jan 2000)

Breakup of a single landmass 770 Mya leaves small continents scattered near the equator. Formerly landlocked areas are now closer to oceanic sources of moisture.

Increased rainfall removes more CO_2 from the air and erodes continental rocks more quickly. Global temperatures fall, and large ice packs form in the polar oceans.

The white ice has a higher albedo than the darker seawater, reflecting more solar energy from the Earth into space driving temperatures even lower.

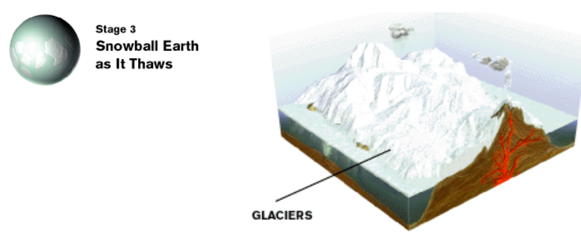
This feedback cycle triggers an unstoppable cooling effect that will engulf the planet in ice within a few thousand years.



Average global temperatures plummet to -50 °C shortly after the runaway freeze begins. The oceans ice over to an average depth of more than 1 km, limited only by heat emanating slowly from the earth's interior.

Most microscopic marine organisms die, but a few cling to life around volcanic hot springs and hydrothermic rift vents.

The cold, dry air stops the growth of land glaciers, creating vast deserts of windblown sand. With no rainfall, CO_2 emitted from volcanoes is not removed from the atmosphere. As CO_2 accumulates, the Earth warms and sea ice slowly thins.



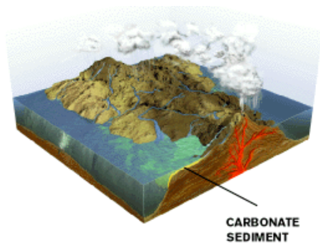
Concentration of atmospheric CO_2 in the atmosphere increases 1,000× as a result of some 10 My of normal volcanic activity. The ongoing greenhouse warming effect pushes temperatures to the melting point at the equator.

As the planet heats up, moisture from sea ice sublimating near the equator refreezes at higher elevations and feeds the growth of land glaciers. The open water that eventually forms in the tropics absorbs more solar energy and initiates a faster rise in global temperatures.

In a matter of centuries, a brutally hot, wet world will replace the deep freeze.

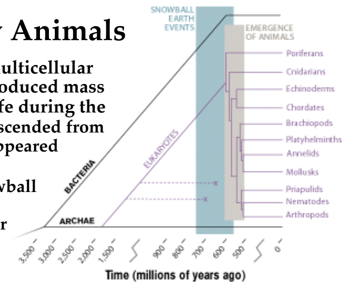
A Brief History of Life

Stage 4
Hothouse Aftermath



As tropical oceans thaw, seawater evaporates and works, together with CO_2, to produce even more intense greenhouse conditions. Surface temperatures soar to more than 50 °C, driving an intense cycle of evaporation and rainfall.
Torrents of carbonic acid rain erode the rock debris left in the wake of the retreating glaciers. Swollen rivers wash bicarbonate and other ions into the oceans, where they form carbonate sediments.
The global climate returns to 'normal'.

Evolution of Early Animals



- Increase in O_2 and rise of multicellular eukaryotes undoubtedly produced mass extinction(s) of microbial life during the Precambrian All animals descended from the first eukaryotes, which appeared about 2 Bya.
- By the time of the first 'Snowball Earth' episode more than 1 billion years later, unicellular protozoa and filamentous algae are still the only eukaryotes.
- Despite the extreme climate, which may have "pruned" the eukaryote "family tree" (dashed lines), all of the animal phyla that have ever inhabited the Earth emerged within a narrow time interval after the last snowball event.
- The prolonged genetic isolation and intense selective pressure intrinsic to a 'Snowball Earth' and the warming that followed could be responsible for this explosion of new life-forms.

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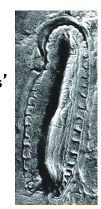
Cenozoic Era
Mesozoic Era
← 570 Mya (115 ft up antennas): first definite animal fossils
Paleozoic Era
Vendian
←1200 Mya (101st floor): first animals?
←1500 Mya (92nd floor): eukaryote fossils
Precambrian Era
←3800 Mya (24th floor): Simple cells
←4000 Mya (18th floor): Primordial RNA
← below 4600 Mya (street level) is the Hadean Eon
Archaean Eon
Hadean Eon

Early Evolution of Animals

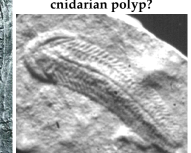
In rocks from the latest *Precambrian*, during a period now called the *Vendian* or *'Ediacaran'* (ca. 650 to 580 Mya), fossils of macroscopic soft-bodied organisms can be found in a few localities on all continents except Antarctica (e.g., Ediacara Hills of southern Australia, White Sea of Russia).

- At various times, these have been considered to be algae, lichens, giant protozoans, or even a separate Kingdom unrelated to anything today.
- Some of these fossils are simple 'blobs' that are hard to interpret and could represent almost anything. Some are most like cnidarians, worms, or soft-bodied relatives of the arthropods. Others are less easy to interpret and may belong to extinct phyla.
- Vendian rocks also contain trace fossils (probably made by wormlike animals slithering over mud).

Dickinsonia: an annelid (segmented worm)? A cnidarian polyp?



Kimberella: a box jellyfish? A mollusc?



Spriggina: described as an annelid, but was likely an arthropod

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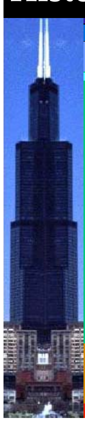

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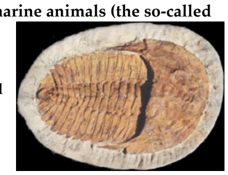
Archaean Eon
Hadean Eon

Paleozoic ('early animals') *Era* (580-245 Mya)

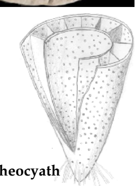
Six periods, each with major advances:

Cambrian Period (580-505 Mya)

- About 570–540 Mya, there was a radiation of marine animals (the so-called *'Cambrian Explosion'*):
  - Unique Vendian animals disappeared.
  - First unambiguous evidence of animals: fossils show the presence of virtually all modern animal phyla (plus a few phyla that are now extinct).
  - First chordates *and* vertebrates!
  - Believed to be a consequence of increased O_2 levels: aerobic metabolism allows larger and more active life.
- Fauna dominated by *deposit feeders* (eat sediment and digest any organic matter within it)
  - Trilobites comprised 90% of skeletonized fauna
  - Other arthropods, simple brachiopods, mollusks and archeocyaths ('colander sponges') also abundant
- Little *tiering* (subdividing the space above and below the sediment-water interface)



trilobite



archeocyath

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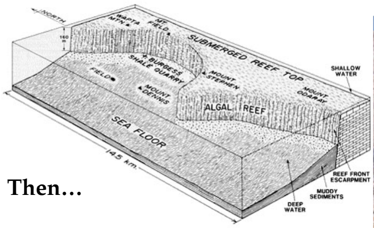
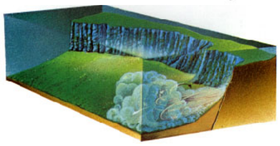
The Burgess Shale Site



Then…

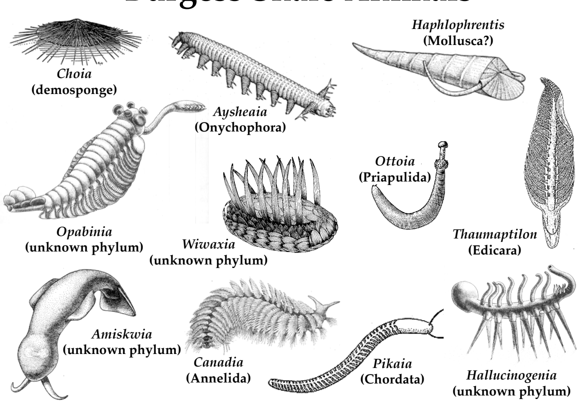


…and now

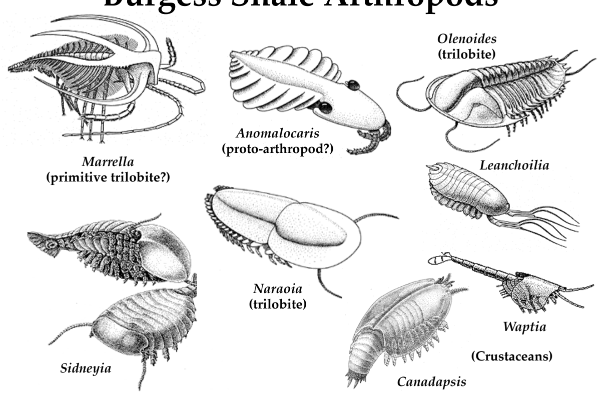
The Burgess Shale Reef Ecosystem

- The Burgess Shale site is located in an area that today consists of mountains about 3.2 km high (Wapta, Dennis, and Stephen), 480 km ENE of Vancouver, British Columbia
- About 530 Mya, this area was shallow ocean near the equator.
- An "avalanche" of fine mud sliding down from the submerged reef top apparently buried animals living at its foot.
- The hard parts of the animals were preserved as fossils. Unlike most other Cambrian sites, however, the fine mud also penetrated and filled all available spaces within the animals, thus preserving the shapes and locations of all the soft parts.
- This is a rare event has made these fossils extremely valuable to paleontologists. The fossils here were first discovered in 1909, but were forgotten for over 70 years

Burgess Shale Animals

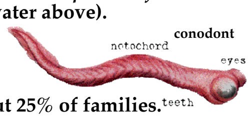


Burgess Shale Arthropods



Paleozoic Era, *Ordovician Period* (505-440 Mya)

- Increase in marine invertebrates: brachiopods, bryozoans, and corals predominate.
- Echinoderms (especially crinoids), graptolites, and mollusks were abundant (nautiloid cephalopods were dominant predators).
- Increase in tiering, as animals that extend up into the water column (crinoids, branching and tabular corals) become predominant.
- Beginning of domination by *epifaunal suspension feeders* (live on bottom, filter food from water above).
- First definitely fish-like *agnathan* (jawless) vertebrates (*conodonts*) appear.



- Ends with mass extinction of about 25% of families.

Subsequent Mass Extinctions

Since animals evolved, there have been five mass extinctions that mark the boundaries of geological Eras and Periods:

- Ordovician-Silurian (~438 Mya): 85% of species.
- Late Devonian- early Carboniferous (367 Mya): 82% of species.
- Permian-Triassic (~250 Mya): 96% of species.
- Triassic-Jurassic (~202 Mya): 76% of species.
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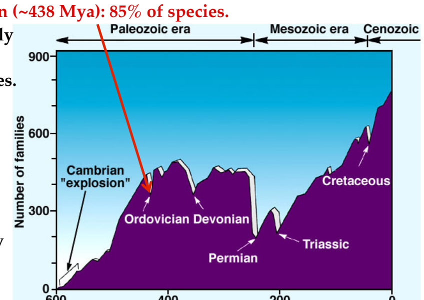

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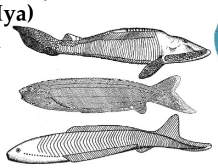
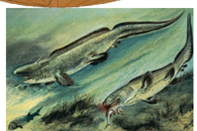
Paleozoic Era, *Silurian Period* (440-407 Mya)



- Increase in *agnathans*: three new orders of benthic, heavily-armored jawless 'fishes' (*ostracoderms*).
- First jawed fishes with paired fins (shark-like *cladoselachians*).

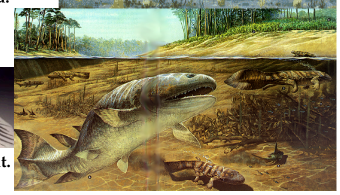


- First land (vascular, but seedless) plants: cycads, tree ferns, and giant club mosses.
- Arthropods (including *eurypterids*: giant 'sea scorpions') abundant in shallow, fresh- or brackish-water marshes. These, and relatives of modern scorpions and millipedes become the first land animals.

Paleozoic Era, *Devonian Period* (407-360 Mya)

- Increased fish diversity: ostracoderms early on, acanthodians ('spiny sharks'), first ray- and lobe-finned (*crossopterygian*) bony fishes later.
- Armored, predatory *placoderms* were dominant marine predators.
- Bivalves, graptolites, crinoid and blastoid echinoderms all present. *Ammonite* cephalopods appeared. Shallow seas dominated by brachiopods and reef-building corals.
- Trilobites very bizarre, mostly gone by end of Devonian.

- Insects, arachnids were abundant.
- Plant diversity increased (first seed plants).



First land *tetrapod* vertebrates (*labyrinthodont* amphibians) evolved

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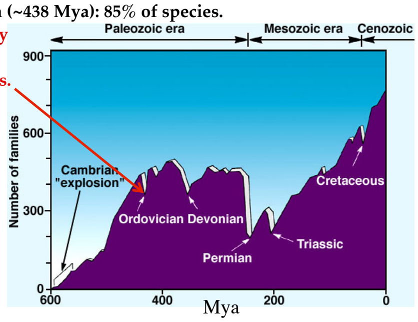


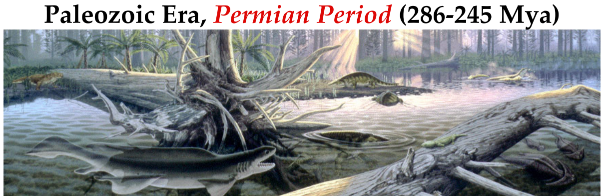
Paleozoic Era, *Carboniferous Period* (360-286 Mya)

Mississippian (360-330 Mya), *Pennsylvanian* (330-286 Mya)

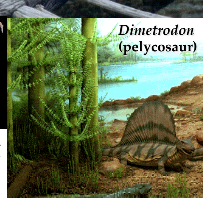
- Huge forests of giant mosses and ferns → fossil fuel deposits ('coal forests').
- Increased amphibian diversity.
- First gymnosperms, winged insects (higher O_2 from all this photosynthesis allowed many insects to become *huge*).
- Mississippian known as the "*Age of crinoids*", these flower-like echinoderms were very abundant in warm waters around Laurasia (notably, areas that today are Illinois and Indiana).

- First reptiles (cotylosaurs, 'stem reptiles') the group that all other reptiles evolved from: turtles most direct descendant).

Paleozoic Era, *Permian Period* (286-245 Mya)



- Increased insect and reptile diversity: *pelycosaurs* (some of which later evolved into mammal-like reptiles (*therapsids*) appeared.
- Ended with worst mass extinction in Earth's history (96% of all spp):
  - All remaining trilobites, any corals, most ammonites, blastoids, graptolites, brachiopods and crinoids (only one group of each of last two survives, never again dominate the marine environment).
  - Many land animals also extinct, especially amphibians (75% of all families) and early reptiles (80% of all families).



Dimetrodon (pelycosaur)

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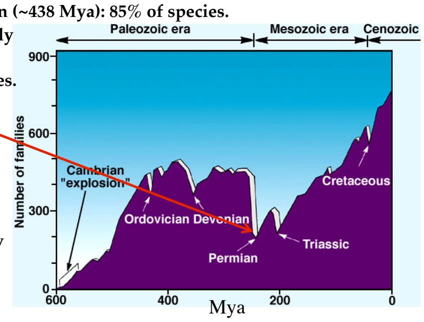
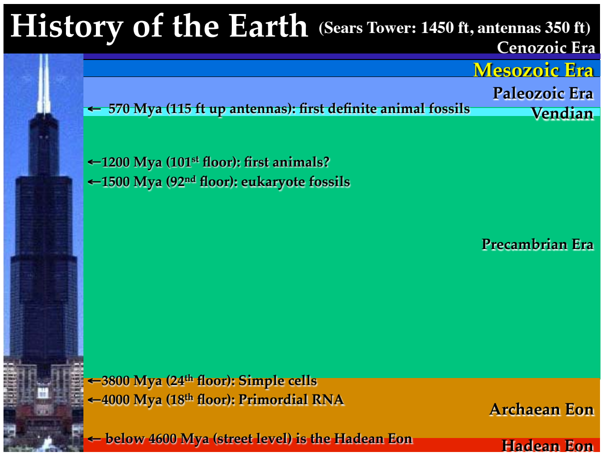


A Brief History of Life

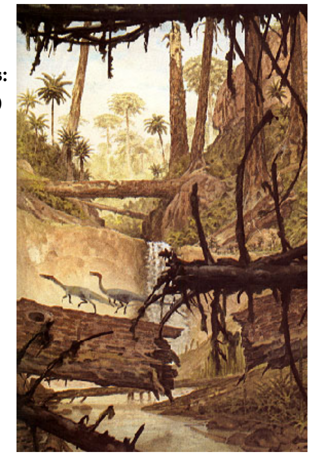


Mesozoic ('middle animals') *Era* (245-65 Mya)

'Age of Reptiles', three periods:

Triassic Period (245-210 Mya)

- Reptiles and plants that survived the Permian mass extinction underwent rapid evolution.
- Gymnosperms dominate land plants.
- Arthropods dominate seas.
- First dinosaurs.
- First insectivorous mammals.
- Supercontinent *Pangaea* ('all land') begins to split into northern (*Laurasia*) and southern (*Gondwana*) super-continents.



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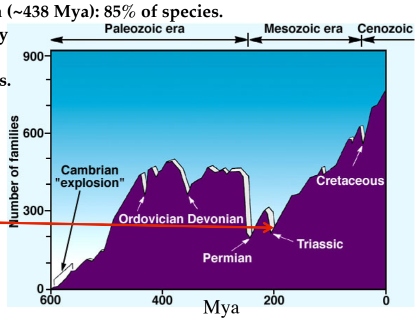
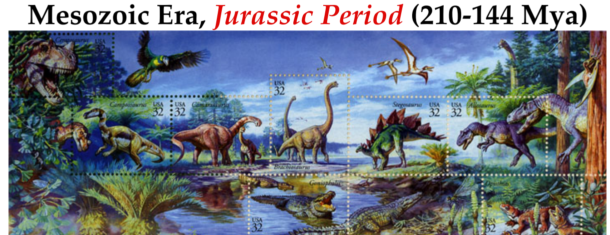
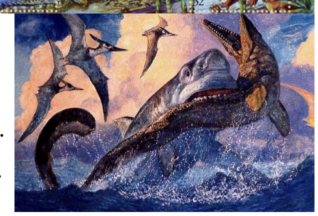


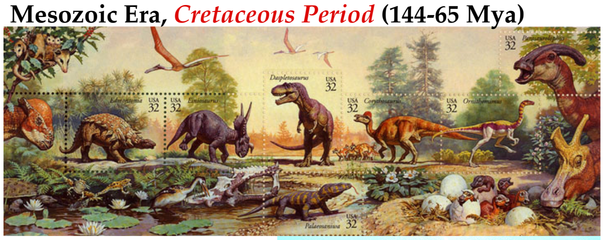
Mesozoic Era, *Jurassic Period* (210-144 Mya)



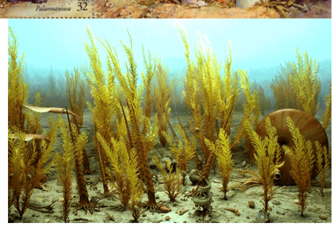
- *'Age of dinosaurs'*: explosive increase in diversity of dinosaurs and other reptiles: pterosaurs (flying reptiles) and mosasaurs, ichthyosaurs, and plesiosaurs (swimming reptiles).
- Forests of gymnosperms and ferns cover most of land surface.
- First birds appeared.



Mesozoic Era, *Cretaceous Period* (144-65 Mya)



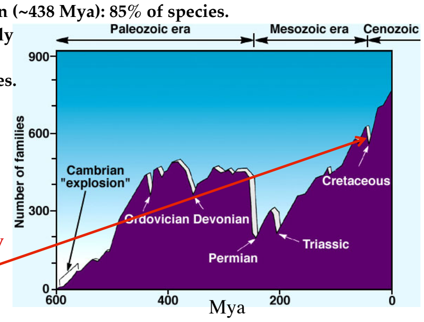
- First flowering plants.
- First modern birds.
- Theropod dinosaurs were abundant and diverse.
- Many flying and marine reptiles, the largest that ever lived.



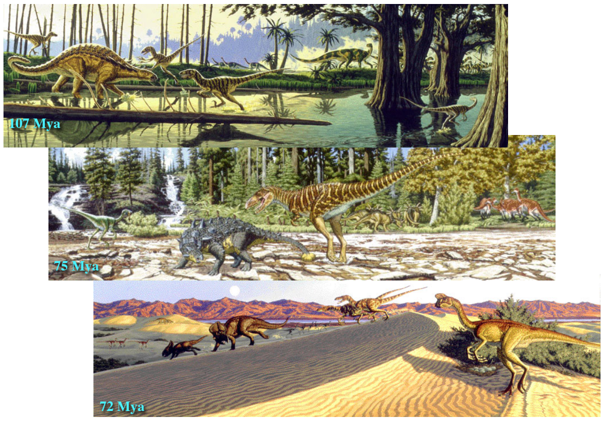
Subsequent Mass Extinctions

Since animals evolved, there have been five mass extinctions that mark the boundaries of geological Eras and Periods:

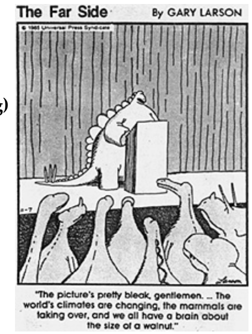
- Ordovician-Silurian (~438 Mya): 85% of species.
- Late Devonian- early Carboniferous (367 Mya): 82% of species.
- Permian-Triassic (~250 Mya): 96% of species.
- Triassic-Jurassic (~202 Mya): 76% of species.
- Cretaceous-Tertiary (65 Mya): 70% of species.



Climate Change During the Cretaceous



The End-Cretaceous Mass Extinction



- About 65 Mya (marking the end of the Cretaceous), almost all of large (>150 kg) vertebrates on Earth (all dinosaurs, plesiosaurs, mosasaurs, and pterosaurs) suddenly became extinct.
- At the same time, most plankton (especially foraminiferans) and many invertebrates (especially reef-dwellers, such as ammonites) became extinct, as did many land plants.
- Why did dinosaurs all go suddenly extinct all over the world, after having been so successful for 165 Ma?
  - Dinosaurs seemed to have had no trouble surviving the climate changes that resulted from continental breakup (and were living at latitudes as high as present-day Alaska and Antarctica).
  - They had survived the volcanic eruptions at the end of the Triassic, and were evolving into more sophisticated forms right up to the time of their disappearance.

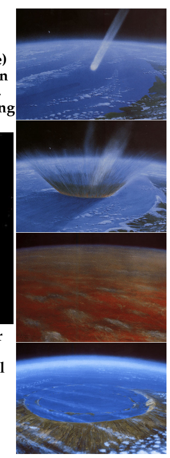
The Impact Hypothesis

Evidence for the impact was first discovered by Walter and Luis Alvarez and their colleagues from UC Berkeley*:

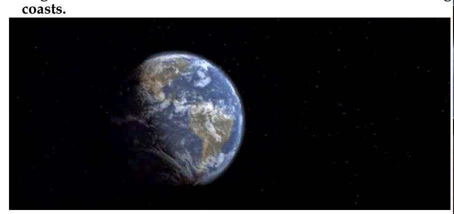
- They studied the elemental composition of the thin layer of clay at the Cretaceous-Tertiary ("K-T") boundary in Gubbio, Italy
- They found that these and other rocks laid down precisely at the K-T boundary contain high amounts of the element iridium (Ir)
  - Ir is much rarer than gold on Earth, yet in the K-T boundary clay, Ir is usually 2× as abundant as gold, sometimes more
  - Ir is found in high concentrations in meteorites, however, suggesting that Ir was scattered worldwide from a cloud of debris that formed as an asteroid struck somewhere on Earth.
- The Alvarez group estimated that an asteroid big enough to scatter the estimated amount of Ir in the worldwide spike at the K-T boundary may have been about 10 km (6 miles) across. This would result from a blast as large as 10,000 10-megaton H-bombs.

*Alvarez, L.W., W. Alvarez, F. Asaro, and H.V. Michel. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science* 208: 1095-1108.

Effects of Bolide Impact



- Computer models suggest that if an asteroid or comet (bolide) hit the Earth, it would pass through the atmosphere and ocean almost as if they were not there. If the impact occurred at sea, huge tidal waves would have devastated all of the surrounding coasts.



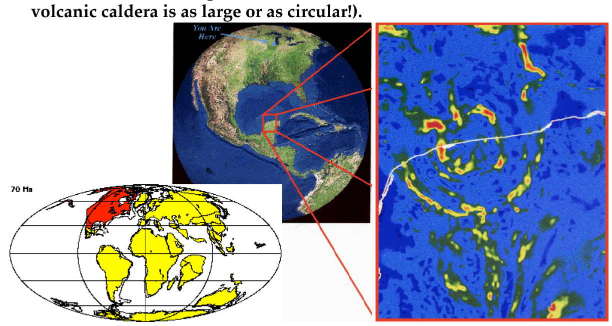
- The bolide would blast a crater in the Earth's crust 100 km or more across. The smallest pieces of debris would be spread worldwide by the blast, as the bolide vaporized into a fireball projecting above the stratosphere.
- The dust would combine with soot from continent-wide wildfires, screening out the Sun for years. Nitrogen oxides from heating the atmosphere would produce acid rain.

Evidence for the Impact Hypothesis

- Well-known meteorite impact structures often have fragments of shocked quartz and microscopic glass spherules associated with them:
  - The glass is formed as the target rock is melted in the impact, blasted into the air as a spray of droplets, and almost immediately solidifies (in time, such deposits can erode into clays such as those seen at the K-T boundary).
  - Shocked quartz is formed when quartz crystals undergo a sudden pulse of great pressure (not even volcanic explosions generate enough force).
- Throughout the Caribbean basin are *tektites* (larger melt rock blobs from meteorite impacts) and evidence of tsunami damage:
  - All over North America, the K-T boundary clay contains glass spherules
  - Just above the clay is a thinner layer that contains Ir. together with fragments of shocked quartz.
  - This layer is only a few mm thick, but in total it contains more than a one km^3 of shocked quartz in North America alone.
  - The shocked quartz zone extends west onto the Pacific Ocean floor, but is rare in K-T boundary rocks elsewhere: some very tiny fragments occur in European sites.
  - Granules of soot are also common in KT boundary layers.
- All this evidence implies that the K-T impact occurred on or near North America, with the Ir coming from the vaporized asteroid and the tektites, spherules, and shocked quartz coming from continental rocks at the impact site. *But where is the crater?*

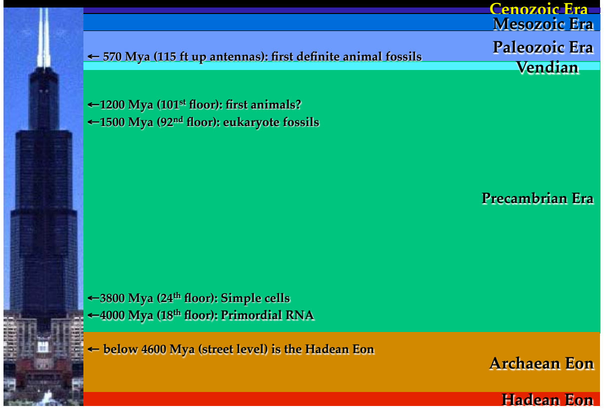
The Chicxulub End-Cretaceous Impact Crater

- At least 170 km in diameter (may be as large as 300 km diameter).
- Buried under 1 km of younger sedimentary rocks (revealed by gravitational anomaly mapping).
- Consistent with an impact of a 10 to 15 km diameter asteroid (no volcanic caldera is as large or as circular!).



A Brief History of Life

History of the Earth (Sears Tower: 1450 ft, antennas 350 ft)



Cenozoic ('new animals') *Era* (65 Mya-present)

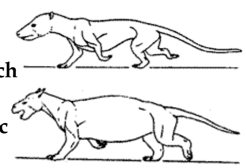
'*Age of Mammals*', two periods: the first, the *Tertiary Period* (65-1.7 Mya), five *Epochs*:

Paleocene Epoch (65-57 Mya)

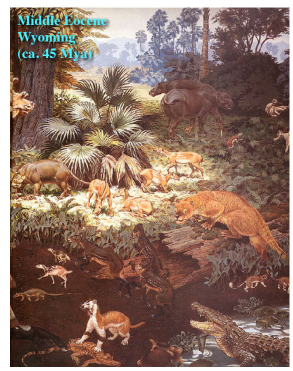
- 10 °C decrease at end of Cretaceous (subtropical to a warm temperate climate): warming trend throughout.
- Marine gastropods and bivalves were very similar to modern forms.
- Soft-bodied squids replaced hard-shelled ammonites as the dominant cephalopod mollusks.
- Sharks were *very* plentiful.
- New forms of sea urchins and foraminiferans replaced Mesozoic types.

Cenozoic Era, *Paleocene Epoch* (65-57 Mya)

- *Explosive* radiation of mammals, as they filled most of the ecological niches vacated by the dinosaurs.
- Within only 12 My, mammals as diverse as bats (small, flying), whales (huge, swimming) and primates appeared, all descended from shrew-like and rat-like ancestors.
- Initially, all were small (none any larger than a small bear, most much smaller).
- Smaller brains than later Cenozoic mammals.
- Long-bodied, short-legged, and plantigrade (walking on the soles of their feet).
- All had five toes on each foot.

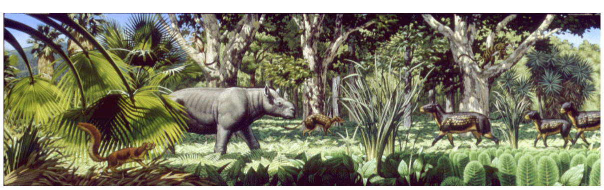


Cenozoic Era, Tertiary Period, *Eocene Epoch* (57-36 Mya)



- About 55.5 Mya, huge amounts of CH_4 released into atmosphere, triggering a global warming period lasting 10,000-20,000 yr, and killing off many deep sea species.
- Great increase in variety and sizes of mammals:
  - Number of mammalian families doubled.
  - Early elephants appeared.
  - Evolution of the horse from size of a small dog at end of Paleocene.
- Most modern genera of bony fishes appeared.
- Huge flightless birds filled the roles of terrestrial predators left vacant by the disappearance of the dinosaurs.
- Near end of Eocene, dramatic worldwide cooling (-12 °C) and drying:
  - Extinction of many marine mollusks, ostracods, foraminiferans.
  - First grasses appeared: more fire-tolerant than many other plants.

Early Eocene: Wyoming (ca. 50 Mya)



Middle Eocene: Messel, Germany (49 Mya)

Covered by a large lake, surrounded by dense rain forest

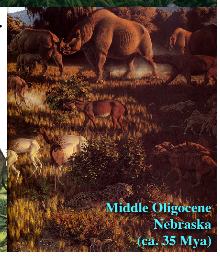
Many fossil fishes (including first percids), reptiles (turtles, crocodilians), and mammals

(1) *Europolemur*
(2) *Paleochiropteryx*
(3) *Kopidodon* (fruit eater)
(4) *Messelornis*
(5) *Messelobunodon*
(6) anteater
(7) pangolin
(8) woodpecker
(9) *Paroodectes* (predator)
(10) jewel beetle
(11) ants
(12) *Propaleotherium* (horse)
(13) *Leptictidium* (insectivore)
(14) *Pholidocercus* (insectivore)

Cenozoic Era, Tertiary Period, *Oligocene Epoch* (36-23 Mya)

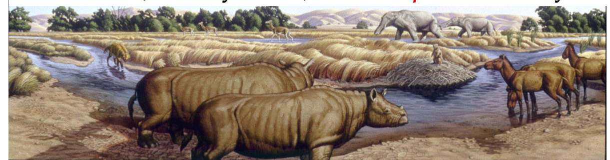
- Most modern genera of mammals were present.
- Monkeys appeared (35 Mya).
- Mammals continued to increase in size:
  - 'Elephants' (mammoths and mastodons) were very diverse.
  - Rhinoceros-like *titanotheres* were largest land mammals of all time.
- Continued climatic cooling and drying.

Indricotherium transouralicum (4 m tall at shoulder height)



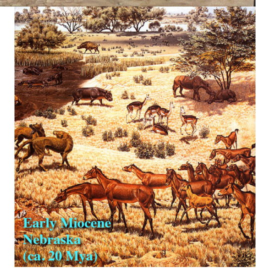
Middle Oligocene Nebraska (ca. 35 Mya)

Cenozoic Era, Tertiary Period, *Miocene Epoch* (23-5.2 Mya)



Neogene (Miocene and Pliocene) "*Age of frogs, rats, mice, snakes, and songbirds*": extensive adaptive radiations in these groups

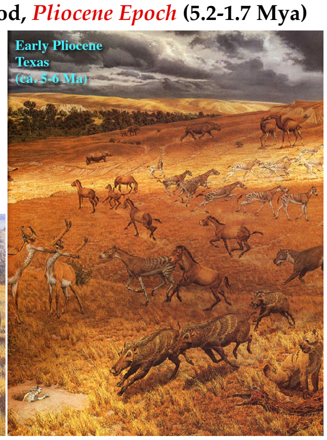
- First apes appeared (20 Mya).
- Odd-toed ungulates (horses, tapirs, rhinos) declined.
- Even-toed ('cloven-hoofed') ungulates (deer, cows, sheep, goats, pigs, bison, camels) diversified.
- Diversification of herbivores led to rise of new carnivores ('*lions and tigers and bears, oh my!*').
- Continued cooling and drying.



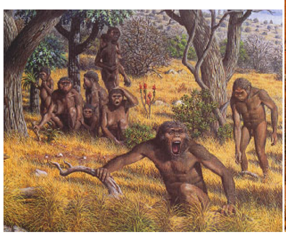
Early Miocene Nebraska (ca. 20 Mya)

Cenozoic Era, Tertiary Period, *Pliocene Epoch* (5.2-1.7 Mya)

- More cooling and drying: forest greatly decreased, grasslands increased.
- Trees primarily near edges of rivers and lakes.
- Several additional members of family Hominidae and first *Homo* species.



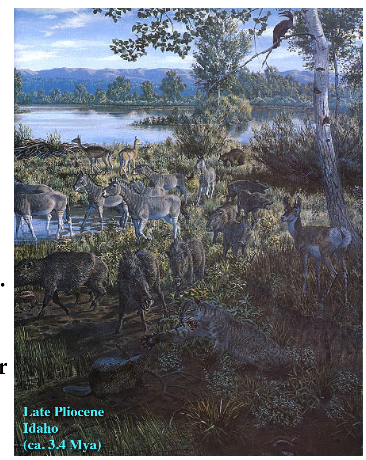
Early Pliocene Texas (ca. 5-6 Ma)



Cenozoic Era, Tertiary Period, Pliocene Epoch (5.2-1.7 Mya)

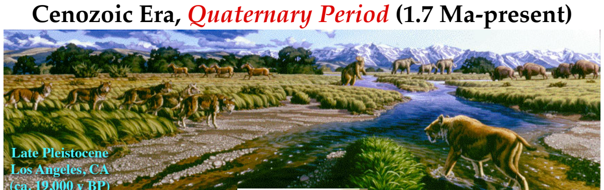
'*Ice Age*' begins in late Pliocene

- Climates cooler, drier, and more seasonal.
- Strong and rapid climatic fluctuations.
- Many glacial expansions, separated by warmer interglacial intervals.



Late Pliocene Idaho (ca. 3.4 Mya)

Cenozoic Era, *Quaternary Period* (1.7 Ma-present)



Late Pleistocene Los Angeles, CA (ca. 19,000 y BP)

Two Epochs:

Pleistocene Epoch (1.7 Mya - 10,000 y BP)

- Repeated glaciation events trigger several mass extinctions.
- Expansion and radiation of species during intervals when glaciers retreat.
- Lots of elephants, rhinos, camels, cats, and horses.
- Evolution of *Homo sapiens*.

*Not!

Late Pleistocene Alaska (ca. 12,000 yr BP)

Cenozoic Era, Quaternary Period, *Holocene (Recent) Epoch*

Begins with end of glaciations about 10,000 yr BP, next glaciers due (?):

- Increase in herbaceous plant species.
- All other species of *Homo* extinct.

Homo sapiens begins causing extinctions of many species of *megafauna* (large mammals, tortoises, lizards, and giant flightless birds) throughout the late Pleistocene and into the Holocene.

Greatly accelerated by development of technology. The beginning of the "Anthropocene"?

Human-caused mass extinction continue today, far rivaling the rate of previous mass extinctions over the Earth's history (estimated at 1 to 1000 species *per day*!).