Indian Institute of Technology, Kanpur

Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

Lecture 25. Geological Time Scale

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Aims of this lecture

- Geological Time Scale: relative and absolute (numerical) ages
- Biography of the Earth

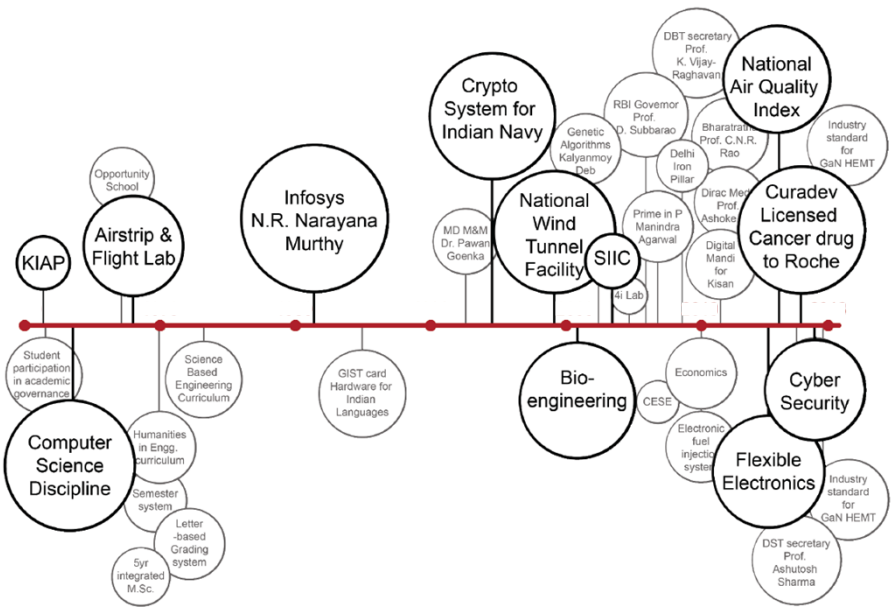
Reading:
Marshak's Book (Part-IV)
Grotinger & Jordan's book (Chapter 8)
[*for the entire week*]

Relative and absolute (numerical) ages

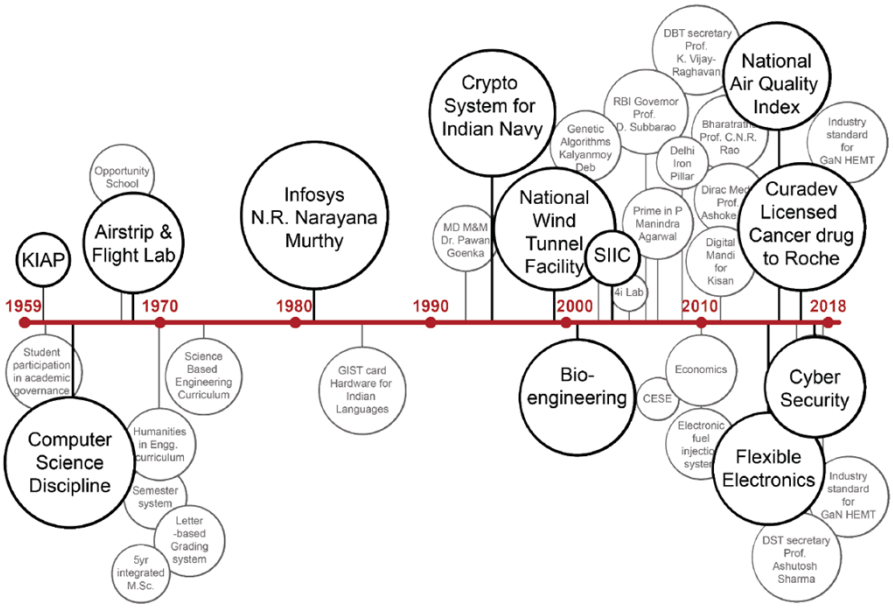
- Geologists studied the principles stratigraphic successions (previous lecture) and the Theory of Uniformitarianism (*physical processes we observe operating today also operated in the past, at roughly comparable rates* OR *present is the key to the past*) to determine the ***relative ages*** of the rocks structures, and other geologic features at a given location (Geologic Events).

- The relative ages cannot suggest time-line in the Earth history. of the rocks structures, and other geologic features at a given location (Geologic Events). This situation changed with the discovery of radioactivity. The overall determination and interpretation of numerical ages as **geochronology**. The technique of isotopic dating has been vastly improved over the years and we can now know more or less precisely the time-lines of the past geological events (***the Numerical Age***).

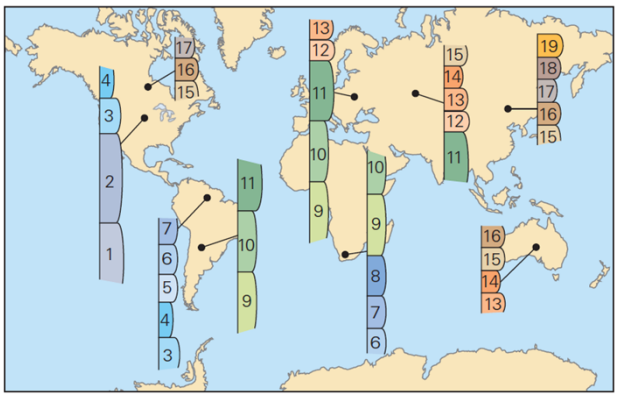
Relative timeline of IIT Kanpur



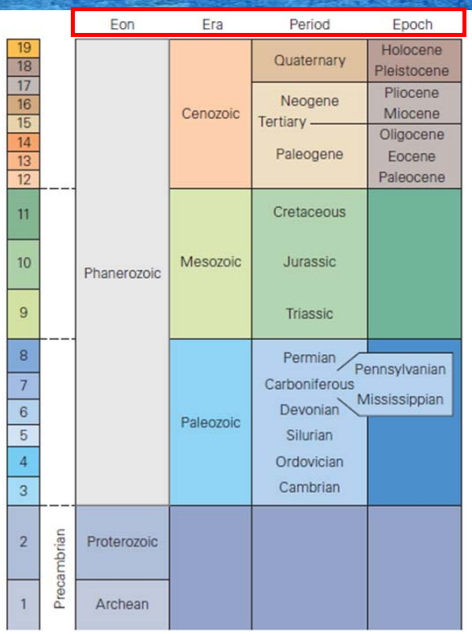
Absolute (numerical) timeline of IIT Kanpur



Relative Geological Time Scale



By correlating strata from locality to locality at millions of places around the world, geologists have pieced together a composite stratigraphic column, called the **geologic column**, that represents the entirety of Earth history.



Relative Geological Time Scale

EONS: The largest subdivisions break Earth's history into the *Hadean, Archean, Proterozoic*, and Phanerozoic—the first three of these, together, constitute the **Precambrian**.

- there is no rock record from Hadean

- *zoic* means LIFE, Proterozoic → first life; Phanerozoic → visible life

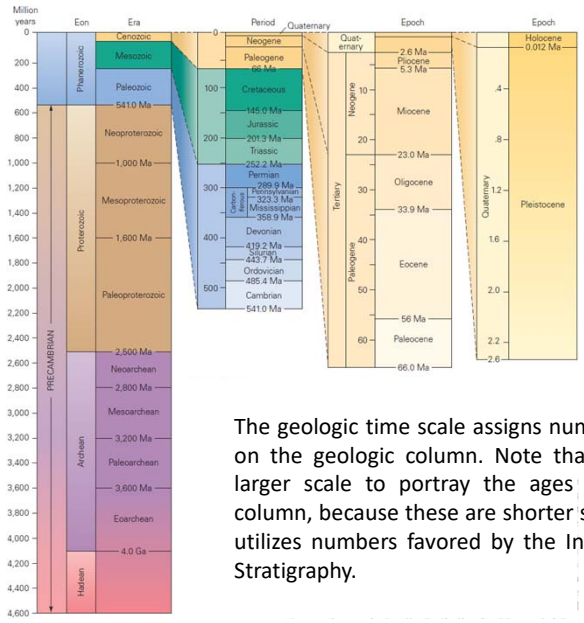
- because decades after the EONS had been named, geologists discovered that the earliest life, cells of bacteria and archaea, actually appeared during the Archean Eon.

ERAS: Eons are subdivided into **eras**. The Phanerozoic Eon, for example includes, in order from oldest to youngest, the Paleozoic (*ancient life*), Mesozoic (*middle life*), and Cenozoic (*recent life*) Eras.

Eras are further subdivided to **PERIODS** and each periods into **EPOCHS**.

- The names of the Periods are mostly from places where the signature rocks are best exposed

Absolute (Numerical) Geological Time Scale

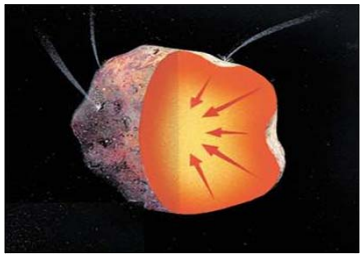


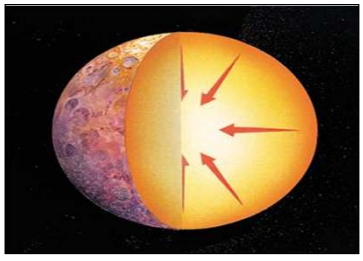
The geologic time scale assigns numerical ages to the intervals on the geologic column. Note that we have to change to a larger scale to portray the ages of intervals higher in the column, because these are shorter subdivisions. This time scale utilizes numbers favored by the International Commission on Stratigraphy.

Biography of the Earth

The Hadean Eon

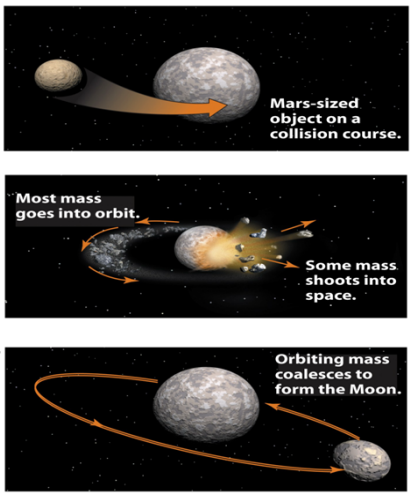
- The time between 4.57 and 3.8 Ga is the Hadean Eon.
  - Named for Hades, the Greek god of the underworld.
  - Began with formation of Earth by planetesimal accretion.
- Earth was heated by impacts and radioactive decay.
- Earth was hot enough to partially melt by ~ 4.5 Ga.
  - The molten Earth underwent chemical differentiation.
    - Gravity pulled molten iron into the center.
    - The ultramafic mantle remained as a thick shell.





The Hadean Eon

- After differentiation, Earth smashed a protoplanet.
- The size of Mars, this planet blasted…
  - A sizeable chunk of Earth's mantle.
  - Much of the protoplanet's mantle.
- Debris from the collision formed a ring around Earth.
- This debris coalesced to form the moon.
- When 1st formed, moon was much closer (20,000 km).
- Today it is 19x farther away (384,000 km).



The Hadean Eon

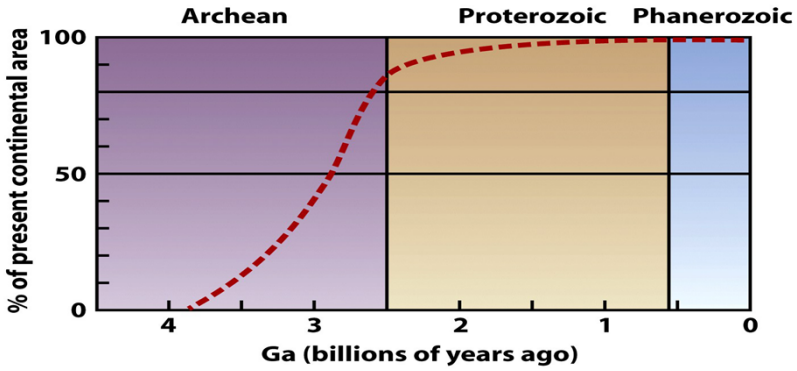
- Earth was inhospitable; a molten surface.
  - Evidence of solidified igneous rock dates from 4.4 Ga.
    - This evidence is from zircon grains, not a whole rock.
- Volcanic outgassing created a deadly atmosphere.
  - N_2, NH_3, CH_4, H_2O, CO, CO_2, and SO_4^{2-} were components.
  - This atmosphere had a greater density that today's.
- Early formed crust was bombarded by meteorites.
  - Meteorite impacts were abundant between 4.0 and 3.9 Ga.
    - This would have destroyed early formed crust.
    - Oldest evidence of crust is 4.03 Ga.
- The first oceans formed as rain from the skies.
  - Liquid water required cooling of the surface.
  - First evidence of oceans from marine sediments ~ 3.85 Ga.

The Archean Eon

- Time of significant change to planet Earth.
- ~3.8 Ga, Earth had cooled to form lithosphere.
  - Intense meteorite bombardment ceased.
  - Portions of the rock record begin to survive.
- Had plate tectonics started yet? Two models:
  - Many small microplates, island arcs, and hot spot volcanoes rapidly formed and subducted crust.
  - Archean lithosphere was too hot to subduct; hot spot plume volcanics dominated formation of crust.

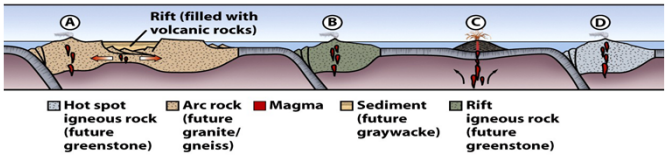
The Archean Eon

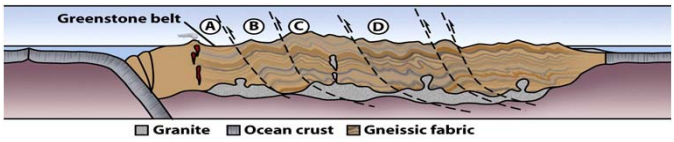
- Volume of continental crust increased dramatically.
  - 85% of modern continental area present by end of Archean.
  - Signals full development of plate tectonic processes.



The Archean Eon

- How did continental crust form?
  - Low-density felsic rocks formed above subduction zones.
    - Felsic crustal blocks grew via continental collision.
    - Felsic sediments accumulated near continental crust.
  - Mantle hot spots built mafic volcanoes.
  - Continental crust is too buoyant to subduct.
    - Jams subduction trenches.
    - Shuts off subduction.
    - Creates thickened, uplifted continental crust.
  - Frequent collisions sutured volcanic arcs, hot spots, and sedimentary debris together as protocontinents.





The Archean Eon

- Archean cratons consist of 5 principal rock types.
  - Gneiss – Hi-grade metamorphics from Archean collisions.
  - Greenstone – Metamorphosed fragments of mafic rocks.
  - Granite – Magmas from partial melting of the crust.
  - Graywacke – Sedimentary debris derived from arcs.
  - Chert – Silica precipitated in the deep sea.
- Archean shallow sediments are poorly known.
  - There were few shallow depositional settings, or…
  - Few examples have survived destruction by erosion.
- Sedimentary processes were clearly operating.
  - Transport rounded sediment grains.

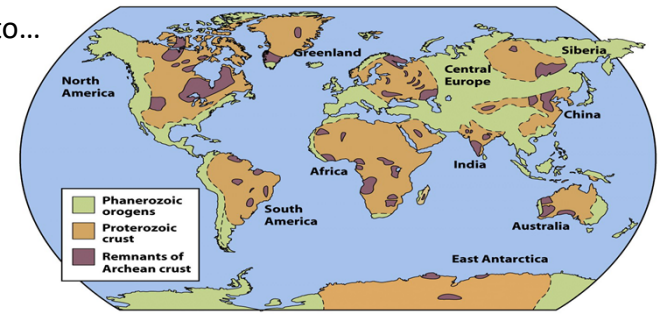
The Archean Eon

- Life first appeared during the Archean. Evidence?
  - Biomarker molecules; Isotopic signatures; Fossil cells.
- Clear evidence of life in rocks dated to 3.5 Ga.
  - Life may have started earlier.
- Oldest undisputed bacteria fossils ~ 3.2 Ga.
- Rocks after 3.2 Ga contain stromatolites.
  - Layered mats of cyanobacteria (blue-green algae).
  - Sediments stuck to mucous coatings on algal filaments.
- Photosynthesis changed Earth's atmosphere.
  - Converted CO_2 and H_2O to organic matter and free oxygen.

Khelen et al., 2017

The Proterozoic Eon

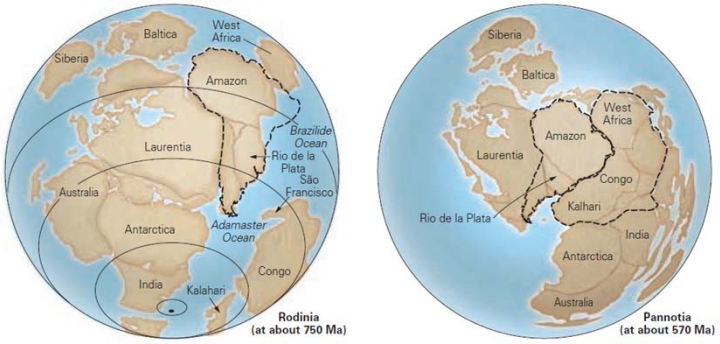
- Protero = first; zoic = life.
  - Named before Archean life was discovered.
- ~ 2 Ga (2.5 to 0.542 Ga); almost ½ of Earth history.
- The unfamiliar Archean world changed to…
  - Fewer, larger lithospheric plates.
  - Larger continental landmasses.
  - An oxygenated atmosphere.



- New continental crust formed, but at slower rates.
  - 90% of Earth's continental crust by the middle Proterozoic.
  - Continents grew by addition of volcanic arcs.
  - Continents cooled and strengthened to become cratons.

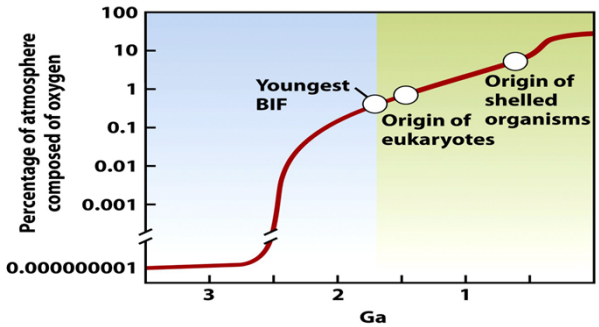
The Proterozoic Eon

- Continental collision created Precambrian supercontinents.
  - Rodinia – Formed ~ 1 Ga.
  - The Grenville orogeny formed an extensive mountain belt.
- Pannotia – A short-lived supercontinent ~ 570 Ma.



The Proterozoic Eon

- Atmospheric oxygen (O_2) skyrocketed 2.4 to 2.2 Ga.
  - Currently, O_2 is 21% of the atmosphere.
  - Before 2.2 Ga, detrital pyrite in sediments indicated no O_2.
  - Redbeds (red from Fe-oxides) don't appear before 2.2 Ga.
  - Banded iron formations (BIFs) – Fe dissolved in the ocean reacted with O_2, forming worldwide iron oxide deposits.

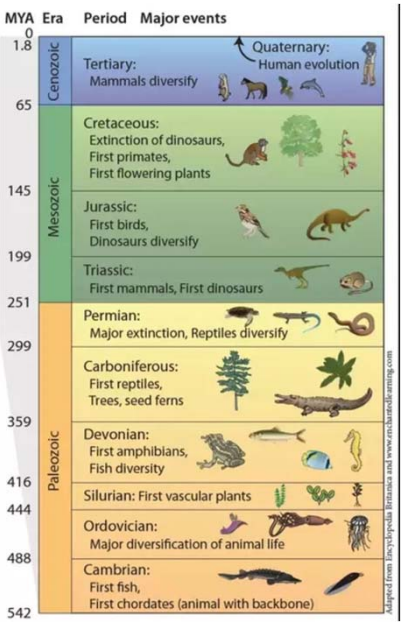


The Proterozoic Eon

- Atmospheric O_2 permitted diversification and multicellular of life (~500 Ma).
- Ediacaran fauna – Unusual soft-bodied fossils.
  - Preserved in end Proterozoic sediments; Multicellular invertebrates resembling worms and jellyfish.
  - Two events: assembly and break-up of Pannotia; Global cooling

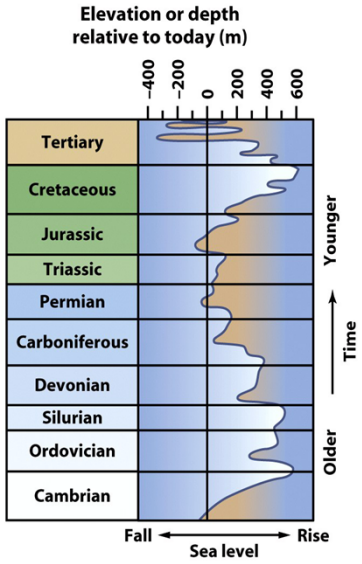
The Phanerozoic Eon

- Phaneros = visible; zoic = life.
- The most recent 542 Ma of Earth history.
  - Began with appearance of diverse hard-shelled organisms.
    - Hardshells vastly increased fossil preservation.
    - Made possible a more complete archive of life on Earth.
- The Phanerozoic is divided into 3 eras.
  - Paleozoic – Ancient life (Trilobites, Nautiloids).
  - Mesozoic – Middle life (Brachiopods, Dinosaurs).
  - Cenozoic – Recent life (early Horses, Mammoths..).
- Eras emphasize changes in Earth's biota.



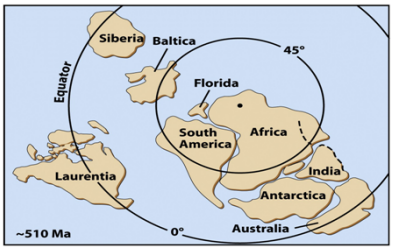
The Proterozoic Eon

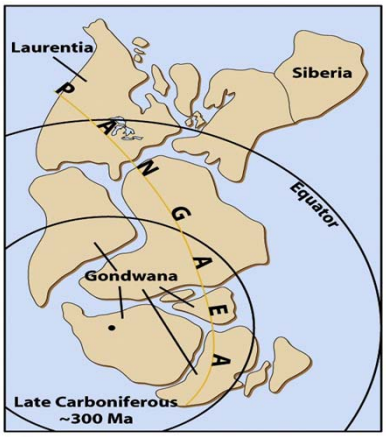
- Tectonic plates and continental blocks rearranged.
- New supercontinents formed and rifted apart.
- Numerous orogenic belts were created and eroded.
- Phanerozoic sea level (SL) has changed often.
- High sea level flooded continental interiors (sediment deposition).
- Low sea level exposed continental margins (erosion or nondeposition.)

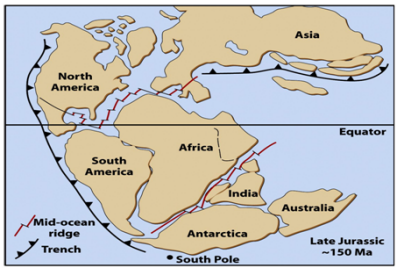


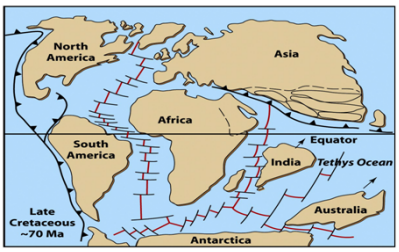
The Proterozoic Eon

- Rearrangements of the continents



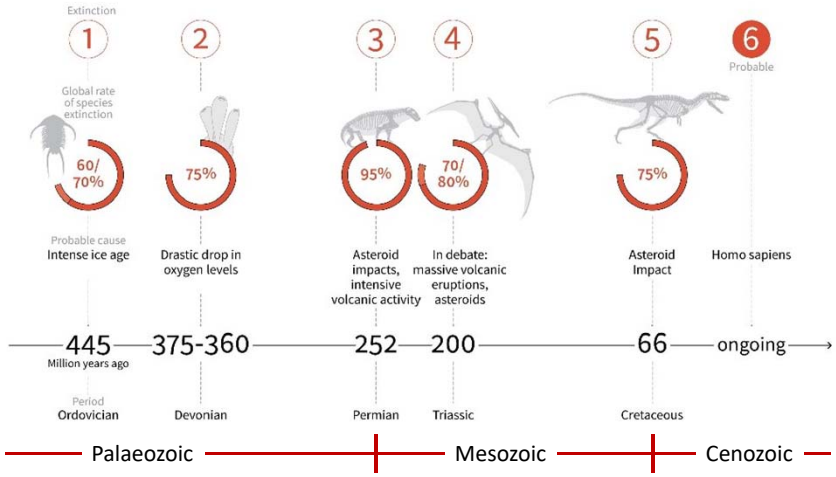






The Proterozoic Eon

Global Mass extinctions
More than 99 % of all organisms that have ever lived on Earth are extinct.



Next Lecture

Methods of Numerical Age Dating