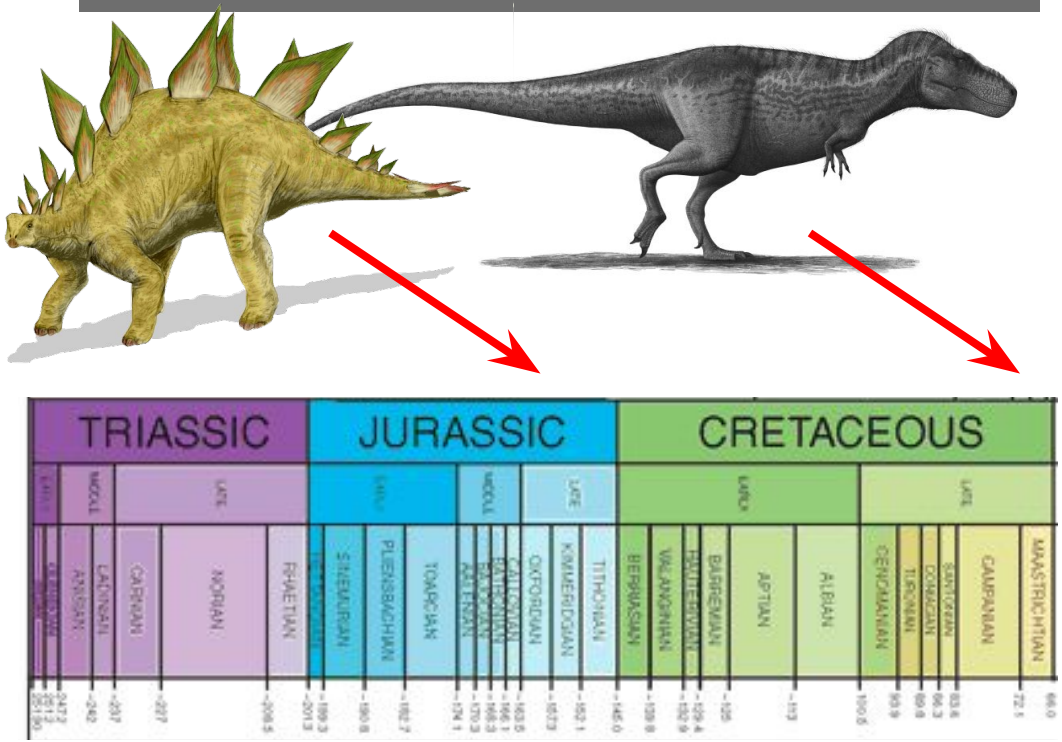
Lecture 9: Paleoclimate and Paleogeography (What did the world of dinosaurs look like?)

Fossil fern from Alexander Island, Antarctic Peninsula, Lower Cretaceous (source)

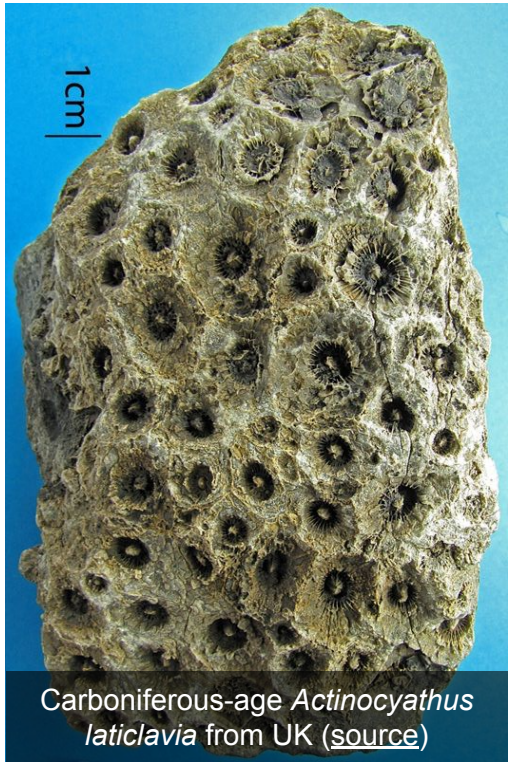
The Mesozoic as “the age of dinosaurs”

- That is a long time ago and a long expanse of time (~186 My)
- The Earth and its climate changed dramatically over this time

Stegosaurus (source) and *Tyrannosaurus* (source)



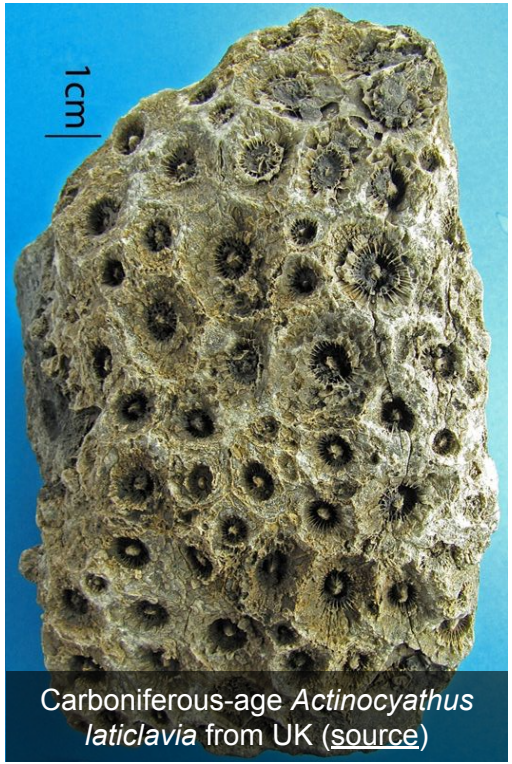
The geologic record reveals major changes in climate over time



Carboniferous-age *Actinocyathus laticlavia* from UK (source)

- The industrial revolution in Great Britain is linked to its large coal deposits
- These deposits are the fossilized remains of vast swamps
- Fossils preserved in these carbon-rich (Carboniferous) rocks contain plants and animals that could never survive in Britain today

The geologic record reveals major changes in climate over time



Carboniferous-age *Actinocyathus laticlavia* from UK (source)

- This lead to the hypothesis that Earth's climate changed significantly over time
- Early support for the ancient history of the Earth

Lyell, Charles. Principles of Geology: Or, The Modern Changes of the Earth and Its Inhabitants Considered as Illustrative of Geology. United Kingdom, J. Murray, 1847.

The discovery of deep time climate change

- Ibn Sina (980 – 1037 CE) developed a theory of mountains >800 years before European geologists

- Recognized the long time required for mountain building through the accumulation of rock sequences

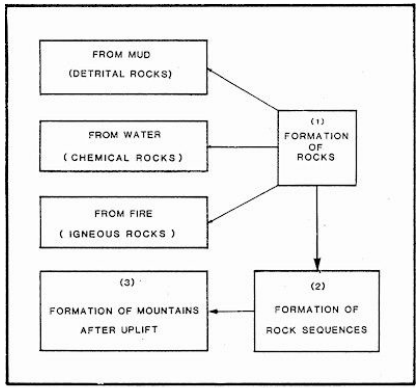


Illustration of Avicenna's Sequence of Events to the Formation of Mountains, after Al-Rawi, 1983c.

Portrait of Ibn Sina c. 1271 (source)

Al-Rawi, Munim M., and S. Al-Hassani. "The Contribution of Ibn Sina (Avicenna) to the development of Earth sciences." United Kingdom: FSTC Limited (2002).

The discovery of deep time climate change

Statue of Shen Kuo (source)

- Chinese polymath Shen Kuo (1031–1095) hypothesized that marine fossils in mountains was evidence of a prehistoric seashore
- Hypothesized that petrified bamboo forests in dry areas of northern China was evidence of long-term climate change

What could cause these changes?

Alfred Wegener (source)

- Wegener's **continental drift hypothesis** suggested continents move over time
- Explained shape of continents, similarities in rock and fossil type across Atlantic

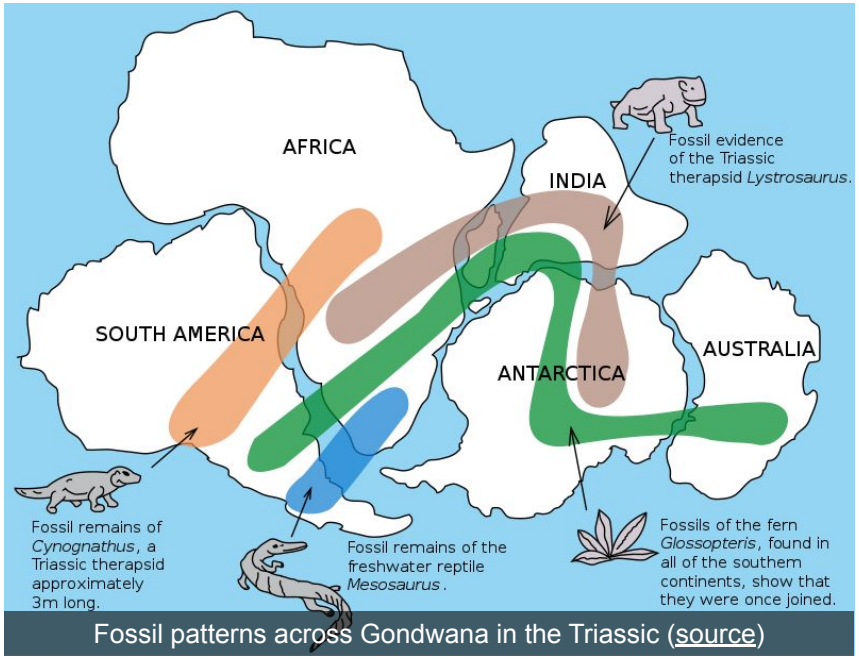
Wegener, Alfred (6 January 1912), "Die Herausbildung der Grossformen der Erdrinde (Kontinente und Ozeane), auf geophysikalischer Grundlage", Petermanns Geographische Mitteilungen, 63: 185–195

What could cause massive changes in climate over deep time?

- **Paleobiogeography** is the distribution of fossils over space

- It provides one line of evidence for continental drift

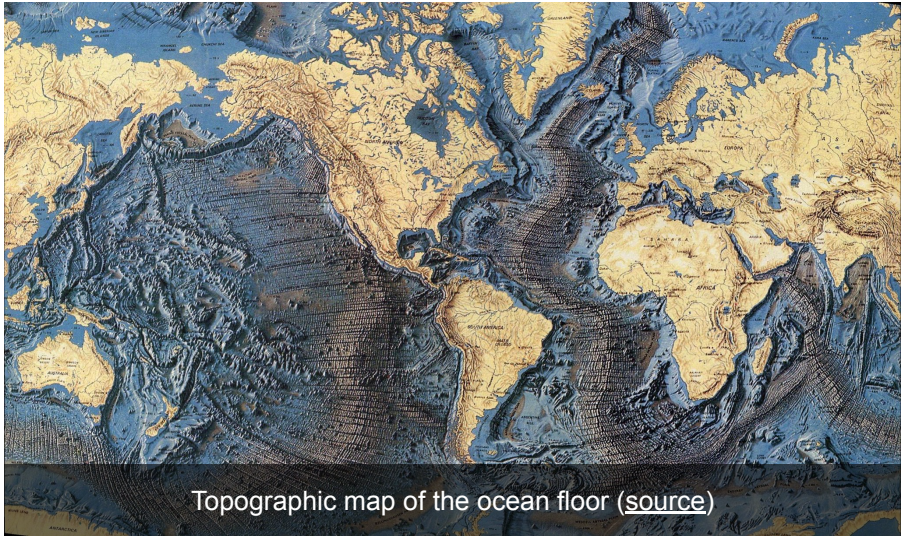
- Largely rejected at first because it lacked a mechanism



Fossil patterns across Gondwana in the Triassic (source)

Wegener, Alfred (6 January 1912), "Die Herausbildung der Grossformen der Erdrinde (Kontinente und Ozeane), auf geophysikalischer Grundlage", Petermanns Geographische Mitteilungen, 63: 185–195

The discovery of plate boundaries



Topographic map of the ocean floor (source)

- The development of sonar submarines during World War 2 resulted in mapping of the ocean floor
- Discovery of great rifts in the ocean

The development of paleomagnetism

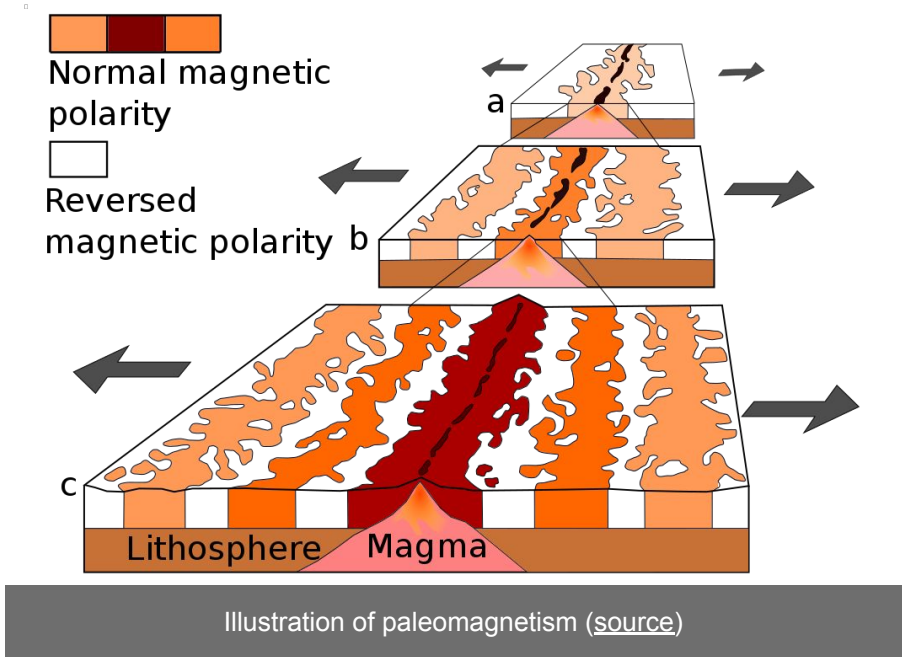
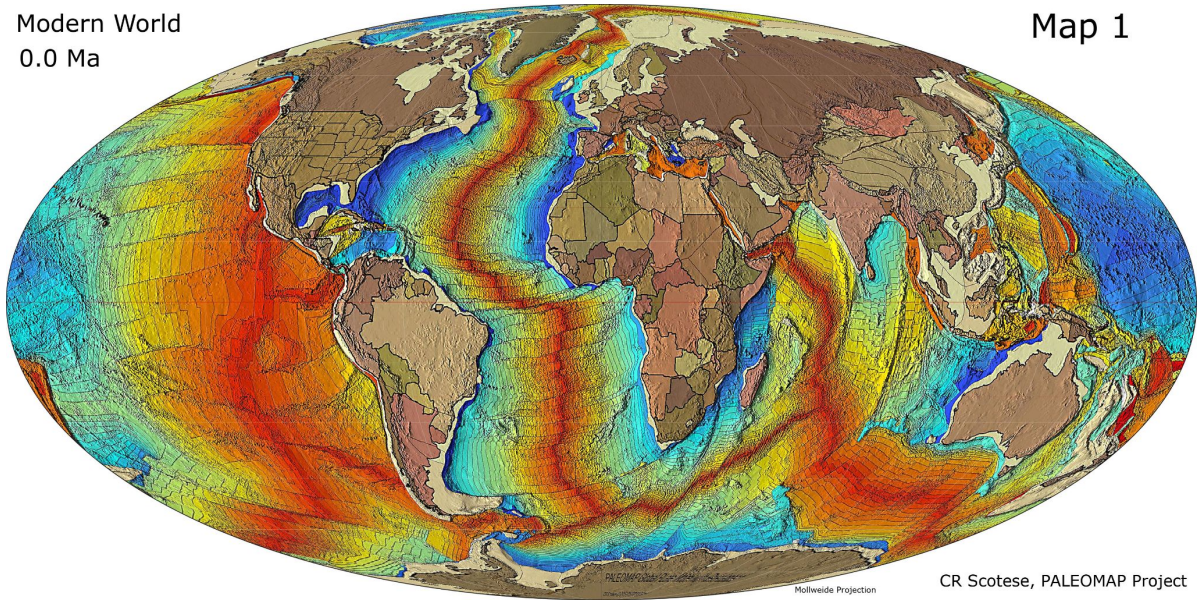


Illustration of paleomagnetism (source)

- In ocean rifts, magnetic minerals in newly-forming rocks record of the direction and intensity of Earth's magnetic field
- They demonstrate that the magnetic pole of Earth varies over time, allowing geologists to study the timing and direction of rift movement

The development of paleomagnetism

- Mapping the ocean floor demonstrates that the Earth's crust is divided into "**plates**" that are slowly moving



Geologic map of the world (source)

The Earth as a dynamic system

- **Plate tectonics theory** provides a framework for understanding these features

- The “solid” earth is a thin crust that sits atop a semi-liquid asthenosphere

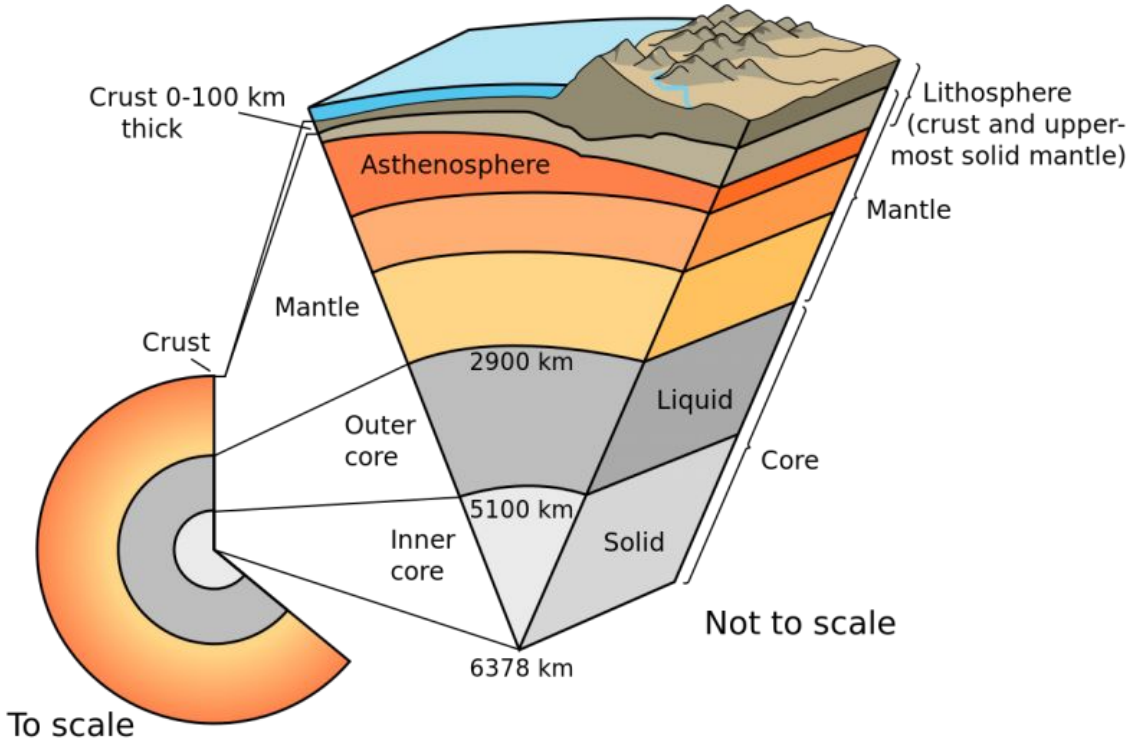
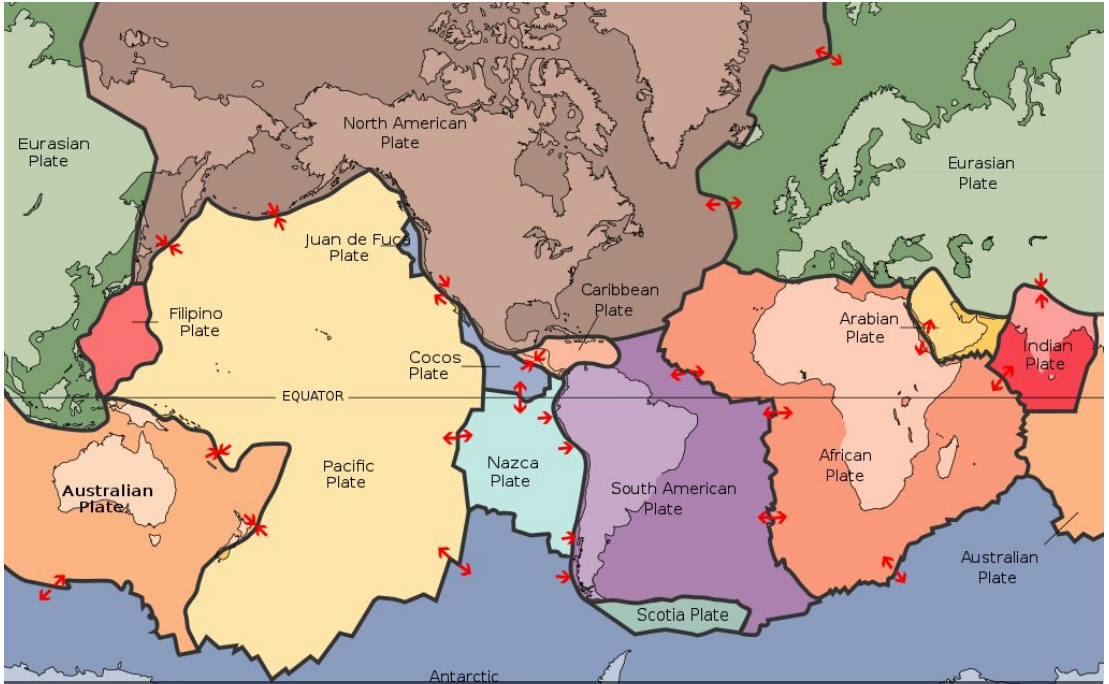


Plate tectonic theory

- Scientists recognize that the crust of the Earth can be broken into different plates
- The movement of the plates is small but measurable



Simplified map of Earth's principal tectonic plates (source)

The Earth as a dynamic system

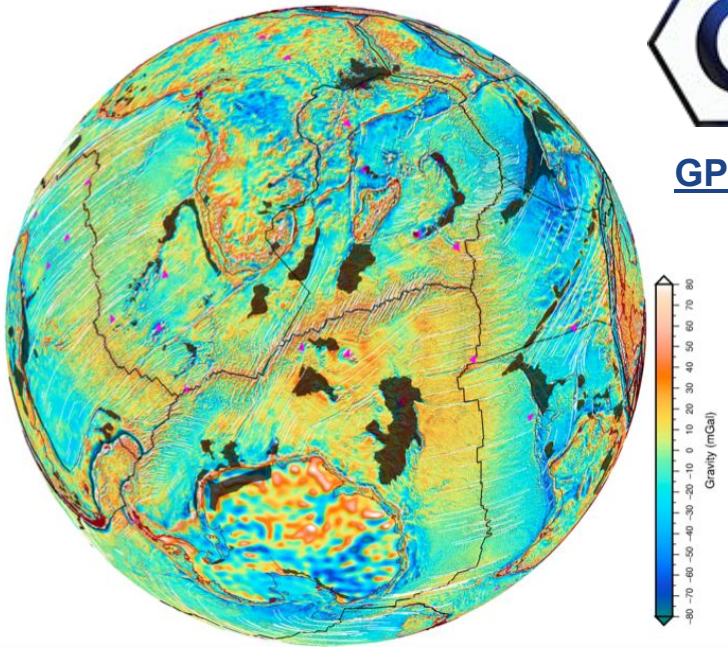
- The Earth is **dynamic:** energy is continually moving through the planet.

- Convection and other movement under the Earth's crust drives movement of the plates

Artistic representation of the Earth's interior (source)

The reconstruction of the plates

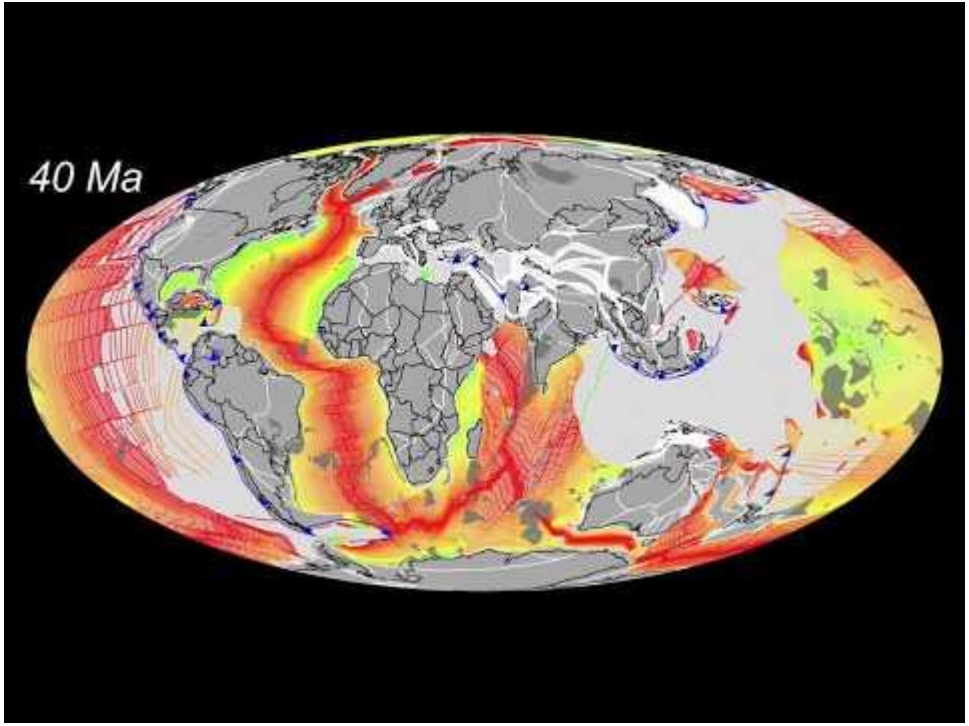
- Stratigraphy (litho and bio) reveals connections between continents
- Geophysics reveals the “fabric” of the crust, demonstrating the direction plates are moving
- This data has been integrated together to reconstruct the movement of continental crust over time



GPlates

Müller, R. Dietmar, et al. "GPlates: building a virtual Earth through deep time." *Geochemistry, Geophysics, Geosystems*19.7 (2018): 2243-2261.

Reconstructing continental drift

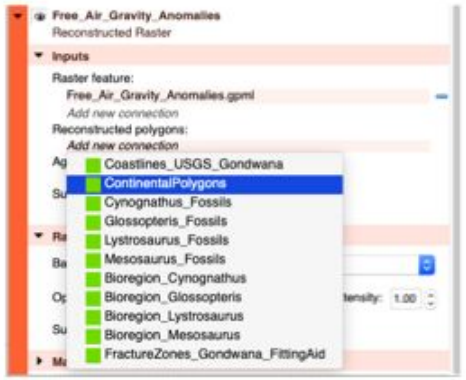


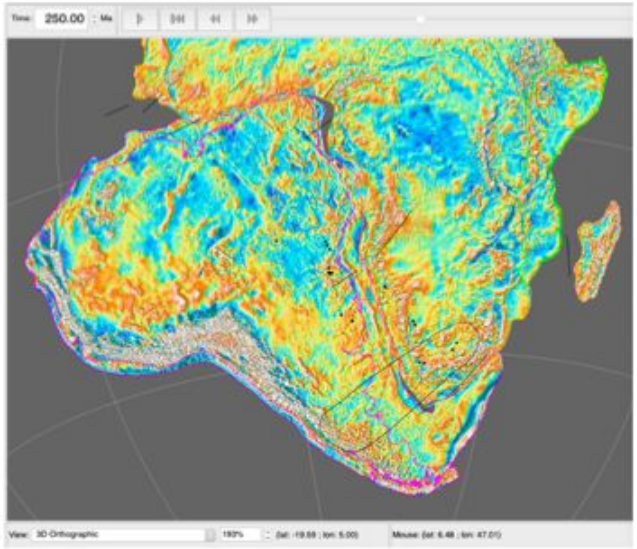
- This data has been integrated together to reconstruct the movement of continental crust over time

Scotese, C. R., and R. Elling. "Plate tectonic evolution during the last 1.5 billion years: The movie, William Smith meeting,“plate tectonics at 50”, Geological Society of London." (2017).

Want to learn more?

- GPlates is open-source and multi-platform
- Tutorial available providing a walkthrough of the reconstruction of Gondwanna

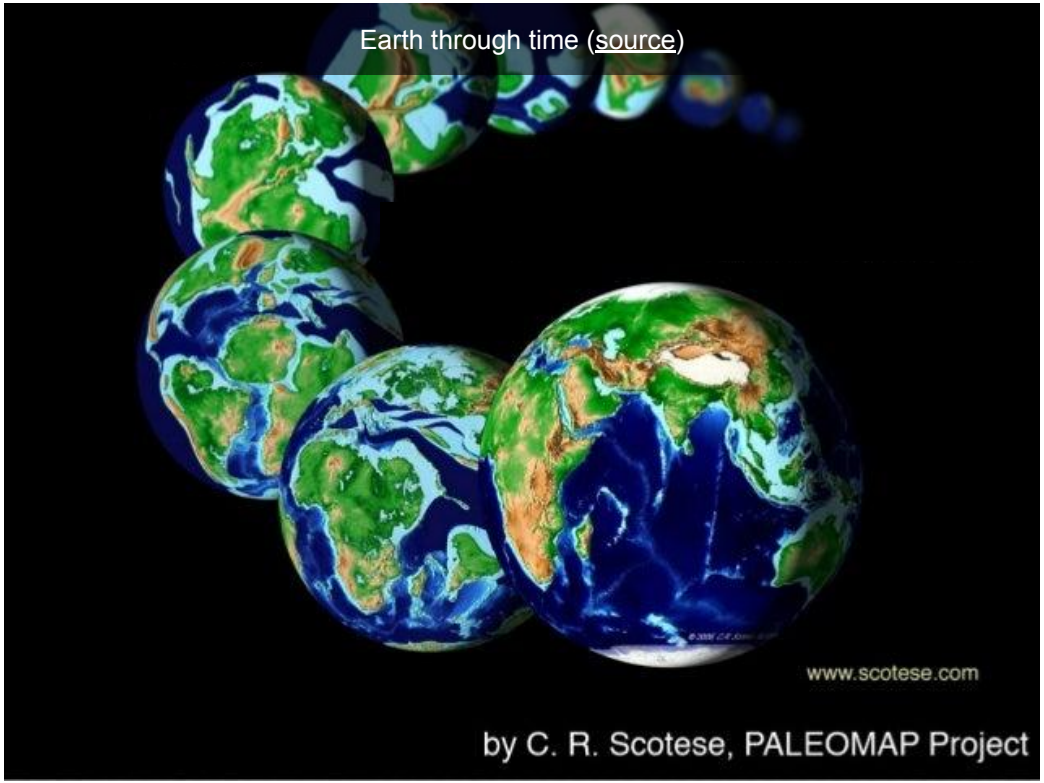




Connecting geography and climate

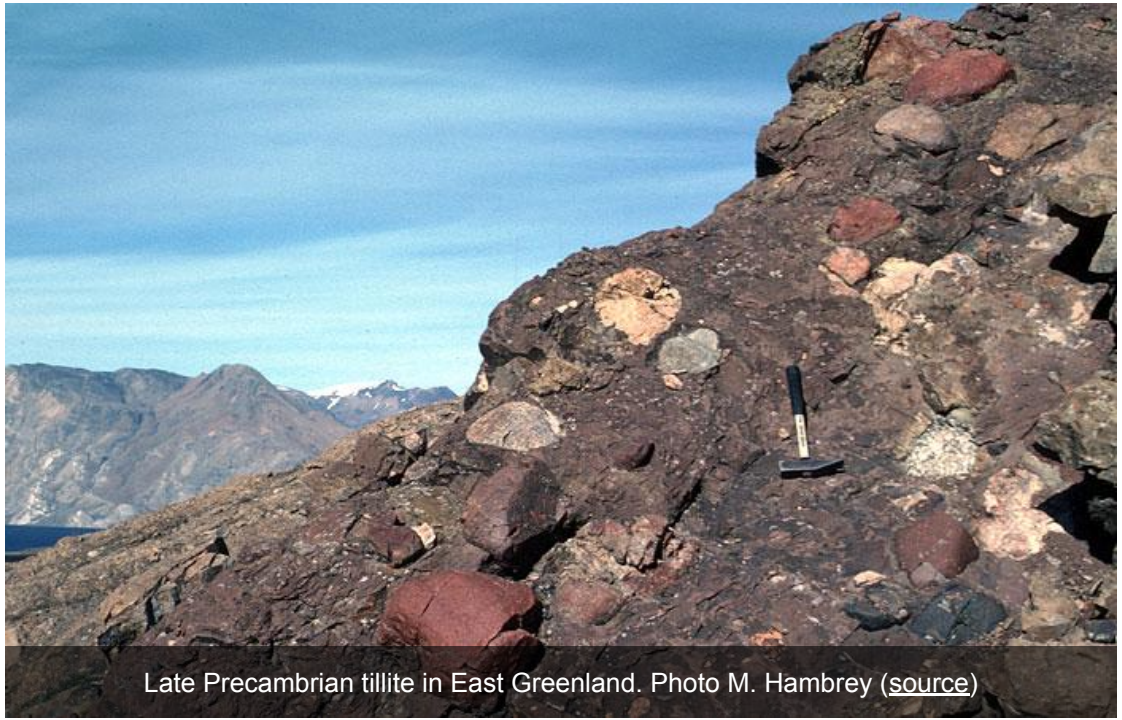
- **Paleoclimatology** is the reconstruction of climate through deep (geologic) time

- This is a critical area of science in the climate change research



Earth through time (source)

Common proxies for paleoclimate



Late Precambrian tillite in East Greenland. Photo M. Hambrey (source)

- **Tillite**: sedimentary rock containing unsorted and unstratified rock material

- Created by glacial deposition

Common proxies for paleoclimate

- **Evaporite**: sedimentary rock formed from a deposit of precipitated minerals

- Caused by the evaporation of salt water (desertification)

Jashak salt dome of Iran (source)

Common proxies for paleoclimate

Kaolinite deposit in Georgia, United States (source)

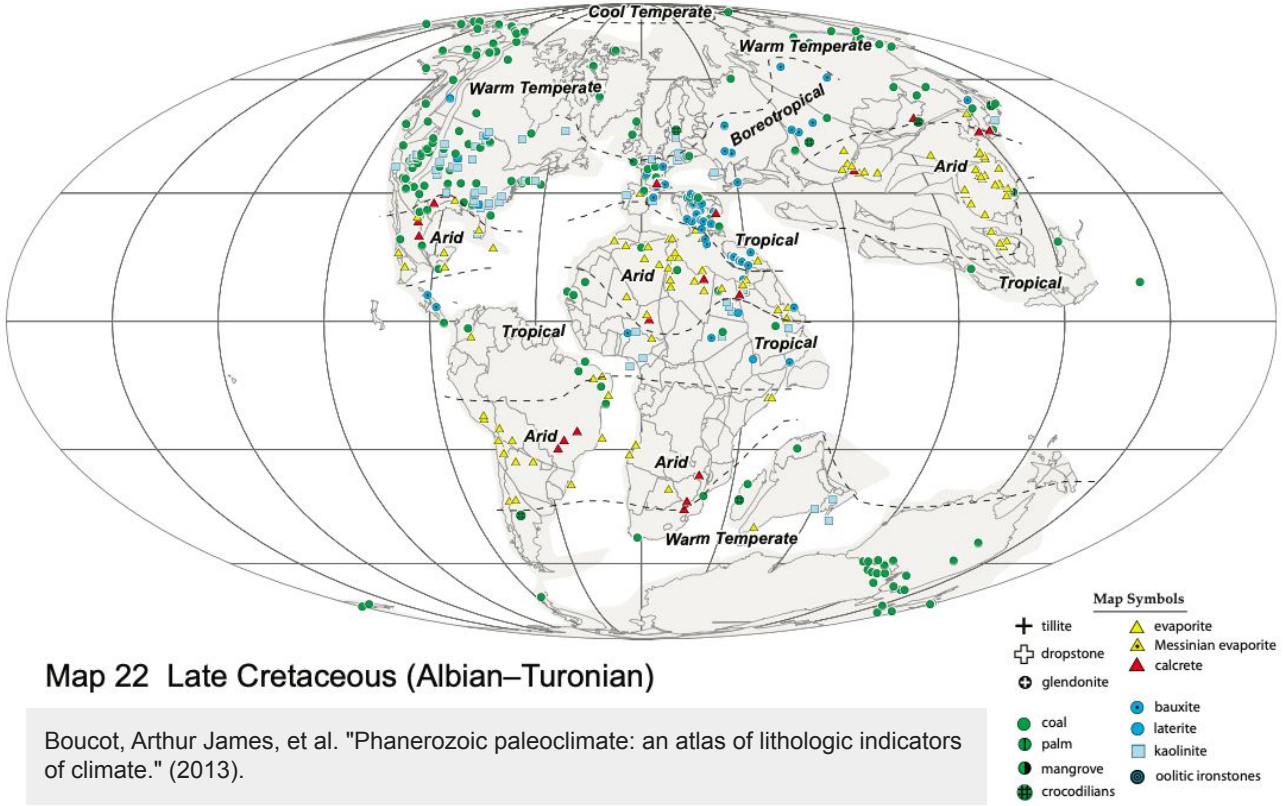
- **Latorite** and **Kaolinite**: sedimentary rock formed from extreme weathering of parent rock
- Requires hot temperatures and large amounts of water

Common proxies for paleoclimate

- Coal is evidence of large forests
- Palm and mangrove fossils demonstrate a warm climate
- Crocodilian fossils also constrain temperatures

Steneosaurus from the Lower Jurassic (Toarcian), Germany (source)

Reconstructing the past: paleoclimate



Map 22 Late Cretaceous (Albian–Turonian)

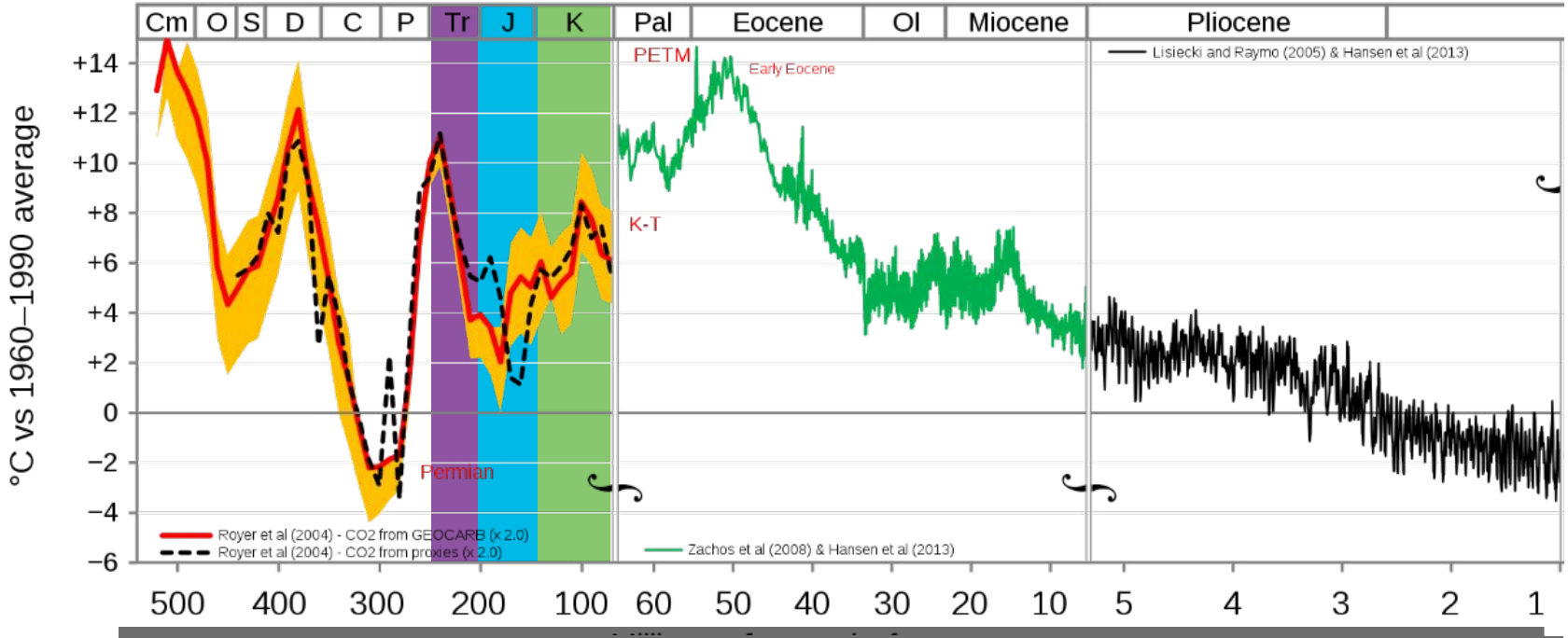
Boucot, Arthur James, et al. "Phanerozoic paleoclimate: an atlas of lithologic indicators of climate." (2013).

Reconstructing mean global temperatures

Foraminifera (*Nummulites*) fossils Bangladesh. Photo by Isma Azam (source)

- Pieced together using temperature proxies (**paleothermometers**)
- Isotope variation in seawater correlates with temperature
- So do certain lipids produced by microbes (molecular fossils)
- Pollen grains, tree rings, the size of stoma in leaves also provide proxies

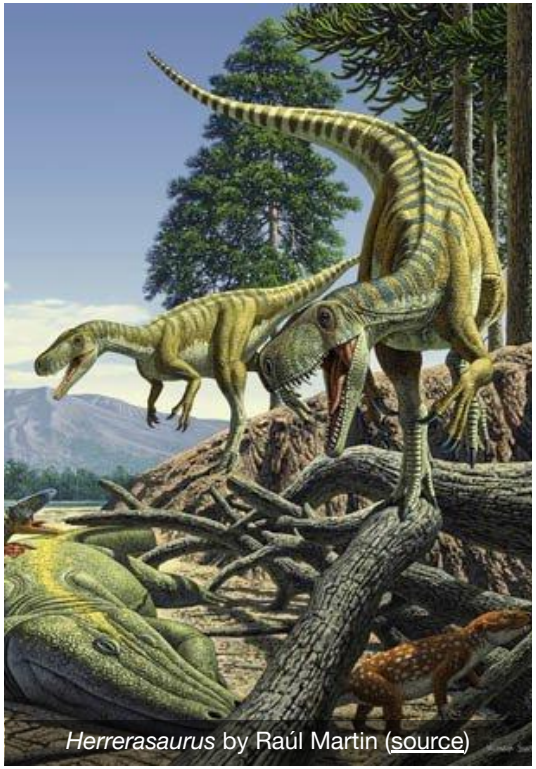
Paleotemperature proxies of the Mesozoic



Paleotemperatures of the last 500 My (source)

Next Part of Class: Putting it all together

- Combine **paleogeography** and **paleoclimate** to see how the world changed through the Mesozoic
- Follow a **cladogram** of dinosaurs to see how the group diversified
- Use **comparative anatomy** to understand how different groups modified the ancestral body plan
- Examine important **bone beds** and **lagerstätte** to see what data can be recovered from fossils



Herrerasaurus by Raúl Martin (source)