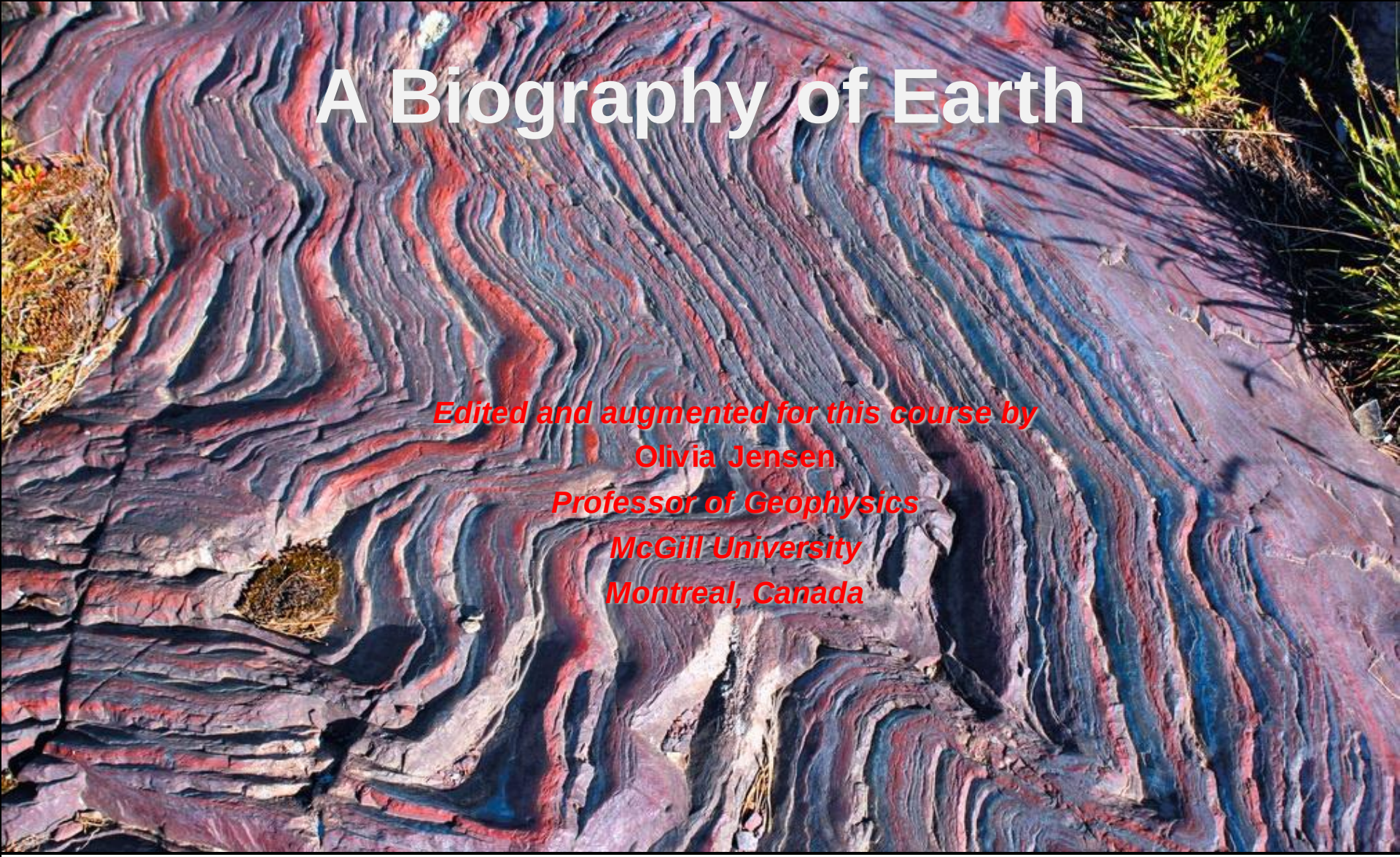
A Biography of Earth



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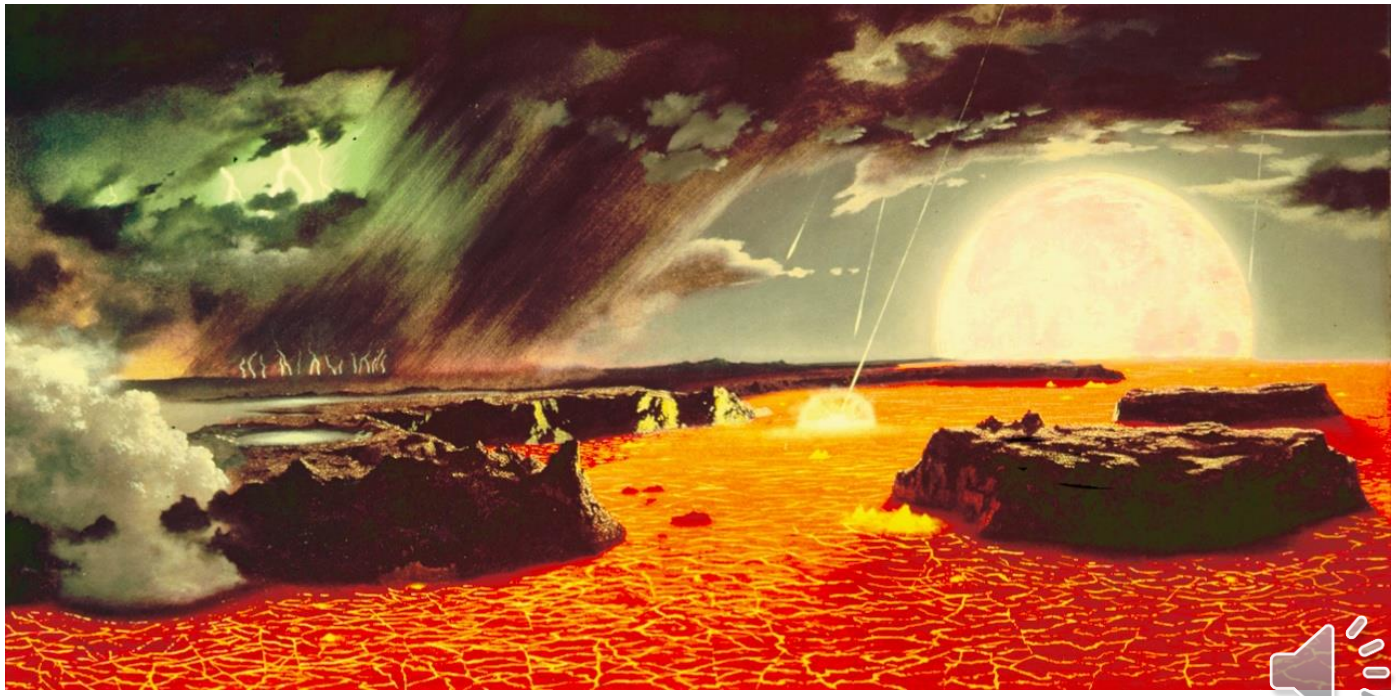
Earth Has a History

- Earth is a complex system undergoing constant change.
- Geologic materials record conditions and changes.
  - Earth consists of physical, chemical, and biological systems that interact and evolve: The Earth System
  - Continents grow, migrate, rift, and erode.
  - Ocean basins form, grow, and close.
  - Species emerge, flourish, and become extinct.

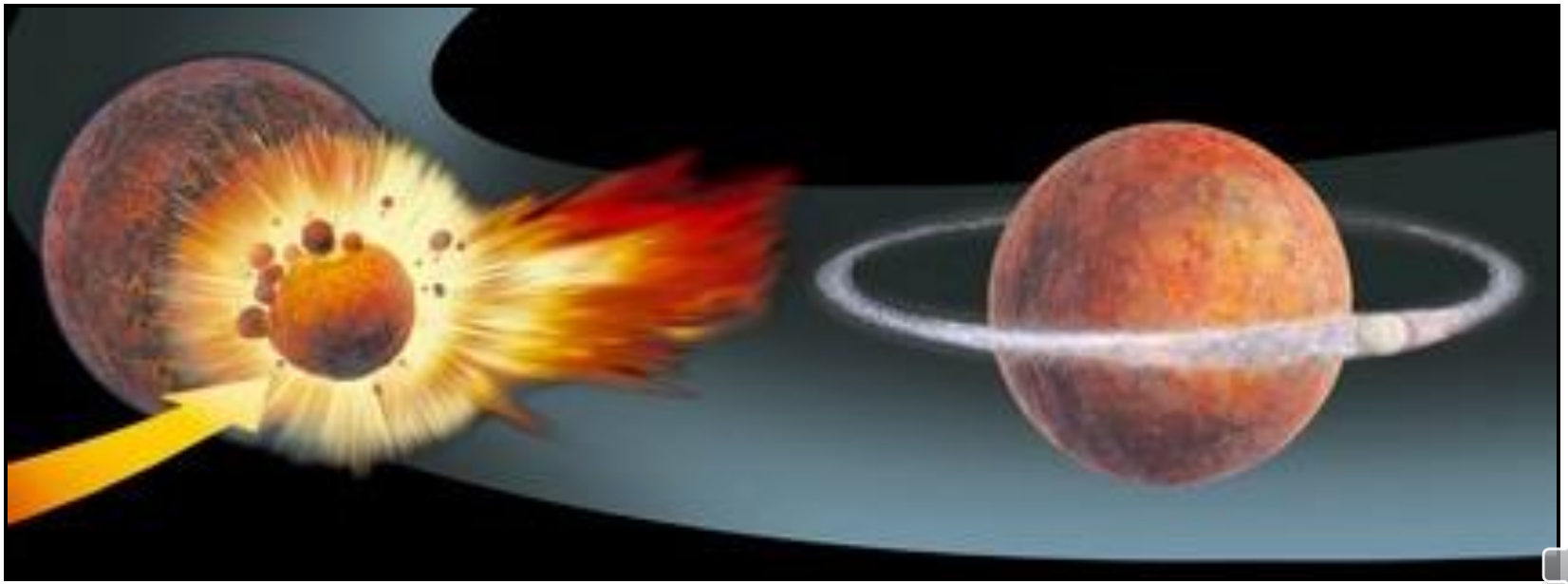
The Hadean Eon

- *Hadean* = hell-like (period before our rock record)
- Earth formed ~4.57 Ga, based on radiometric analysis of planetesimal-fragment meteorites.
- Differentiated into core and mantle by 4.5 Ga.
- Much of surface remained a magma ocean until ~ 4.4 Ga.



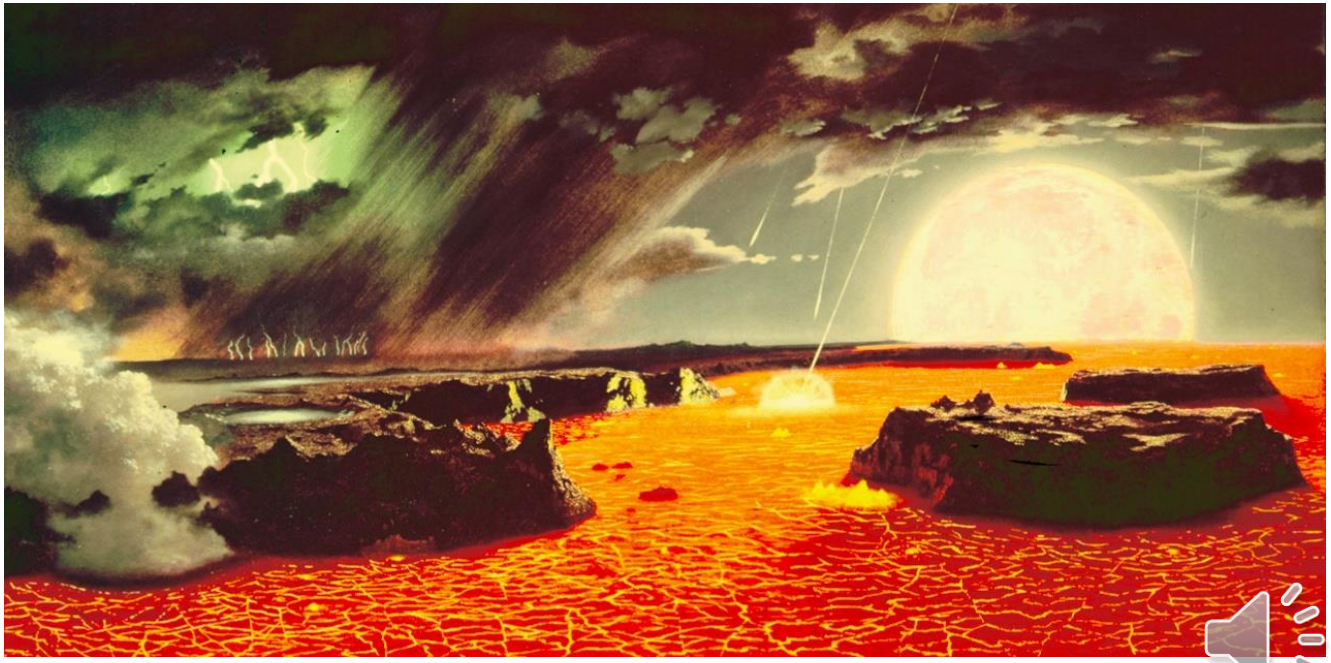
The Hadean Eon

- Collision with a Mars-sized protoplanet ~4.5 Ga
  - Ejected large amount of earth's mantle and crust into nearby space. Created a magma ocean >100km deep.
  - Much of the ejected material caught in orbit and coalesced quickly to form Earth's moon.
  - Moon's orbit initially much closer than today.



The Hadean Eon

- **Earth's Hadean atmosphere was different from ours.**
  - **Probably formed by "outgassing" from mantle and subsequent volcanism: CO_2, N_2, CH_4, SO_2 , H_2O**
  - **Colliding comets may have contributed some H_2O**
  - **Humans and most modern life forms could not possibly have survived in this early atmosphere.**



The Hadean Eon

- **Earth's Hadean atmosphere was different from ours.**
  - **Early atmosphere was denser than ours.**
  - **Contained water vapor (H_2O), nitrogen (N_2), methane (CH_4), ammonia (NH_3), hydrogen (H_2), carbon dioxide (CO_2), and sulfur dioxide (SO_2).**

The Hadean Eon

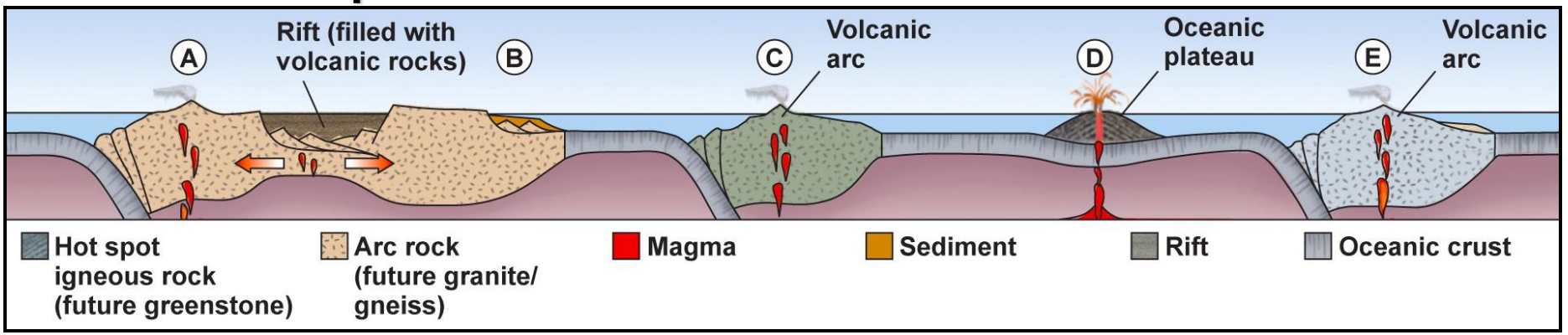
- Ongoing search for older rocks
  - Oldest geologic material found is zircon 4.4 Ga.
  - Oldest crustal rock found is 4.03 Ga or 4.28 Ga(?).
  - Oldest sedimentary rock found is 3.85 Ga.
- Are there no preserved rocks older than 4.28 Ga?
  - Late-heavy bombardment of Earth and its moon by meteorites 4.0 – 3.85 Ga, destroyed nearly all of Earth's earliest surface.

The Archean Eon

- ***Archean*** **= beginning**
- **From the end of the Hadean to 2.5 Ga (Proterozoic)**
- **First abundance of preserved crustal rocks Plate tectonics began during or just before the Archean.**

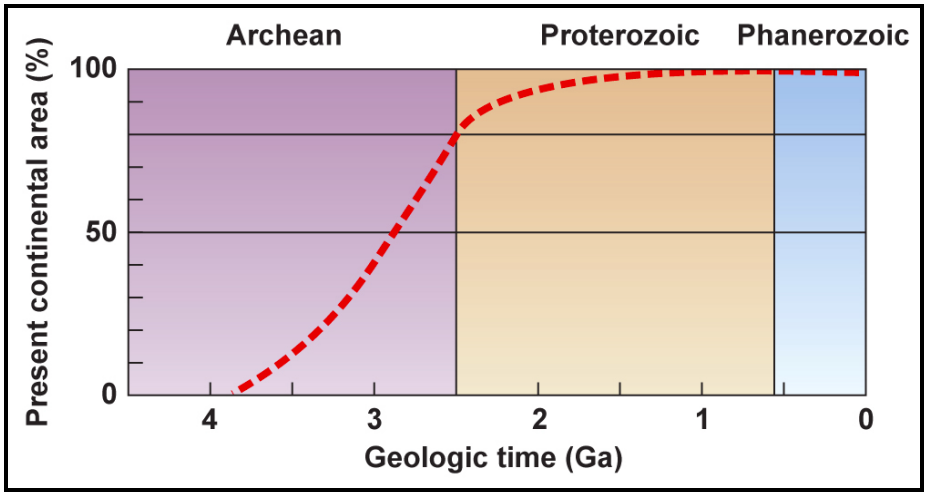
The Archean Eon

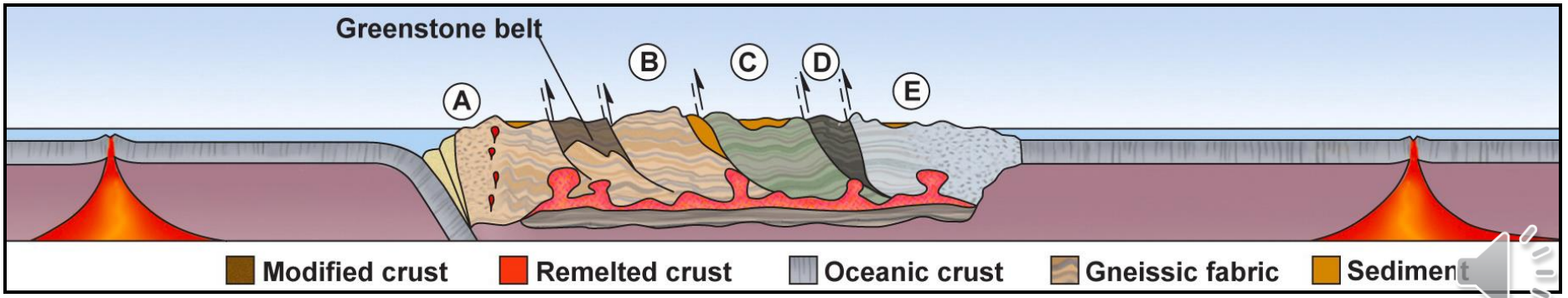
- **Early plate tectonics—unsure of model**
  - **Early crust was probably made up of mafic igneous rocks formed as island-arcs and hot-spot volcanoes.**
  - **Partial melting of basaltic crust with H_2O creates felsic rocks.**
  - **Small blocks of buoyant crust develop.**
  - **Rifting led to flood basalts.**
  - **Erosion produced sediments.**



The Archean Eon

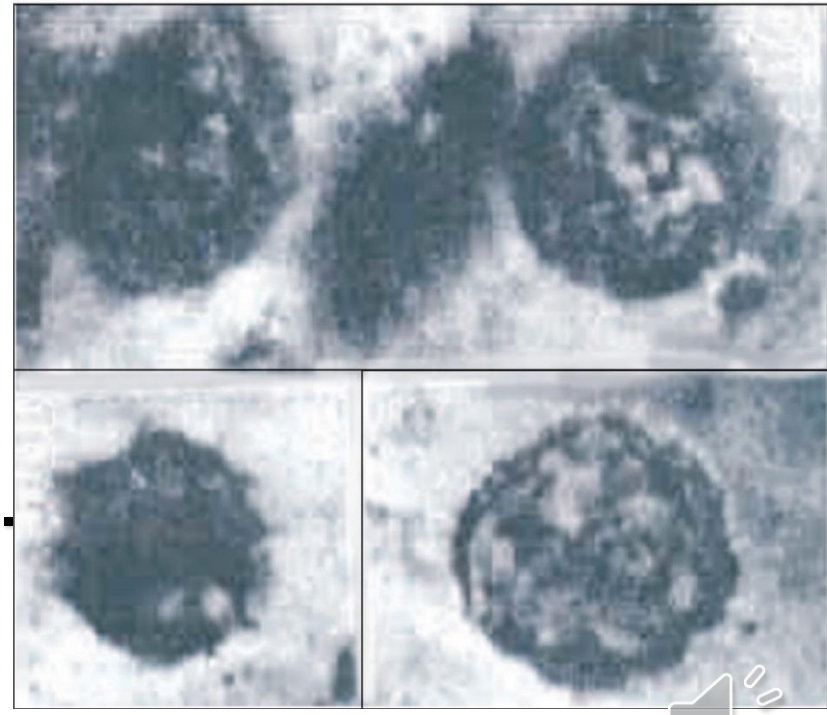
- Protocontinents were formed by collisions of buoyant blocks.
  - Volcanic arcs, hot spots, and sedimentary debris were sutured together as the first continents.
  - End of Archean, continental crust reached ~ 85% of present area.





The Archean Eon

- **First Life**
  - Around 3.2 Ga—oldest undisputed fossils.
  - Shapes in rocks indicate organisms as old as 3.4–3.5 Ga
  - Possibly as old as 3.8 Ga, possibly even older
  - Photosynthesis occurring by late Archean: $CO_2 > O_2$
- **Origins of life?**
  - Probably from deep, dark submarine hot-water vents —"black smokers"
  - Thermophilic (heat-loving) bacteria or prokaryote archaea can exist in extreme conditions.

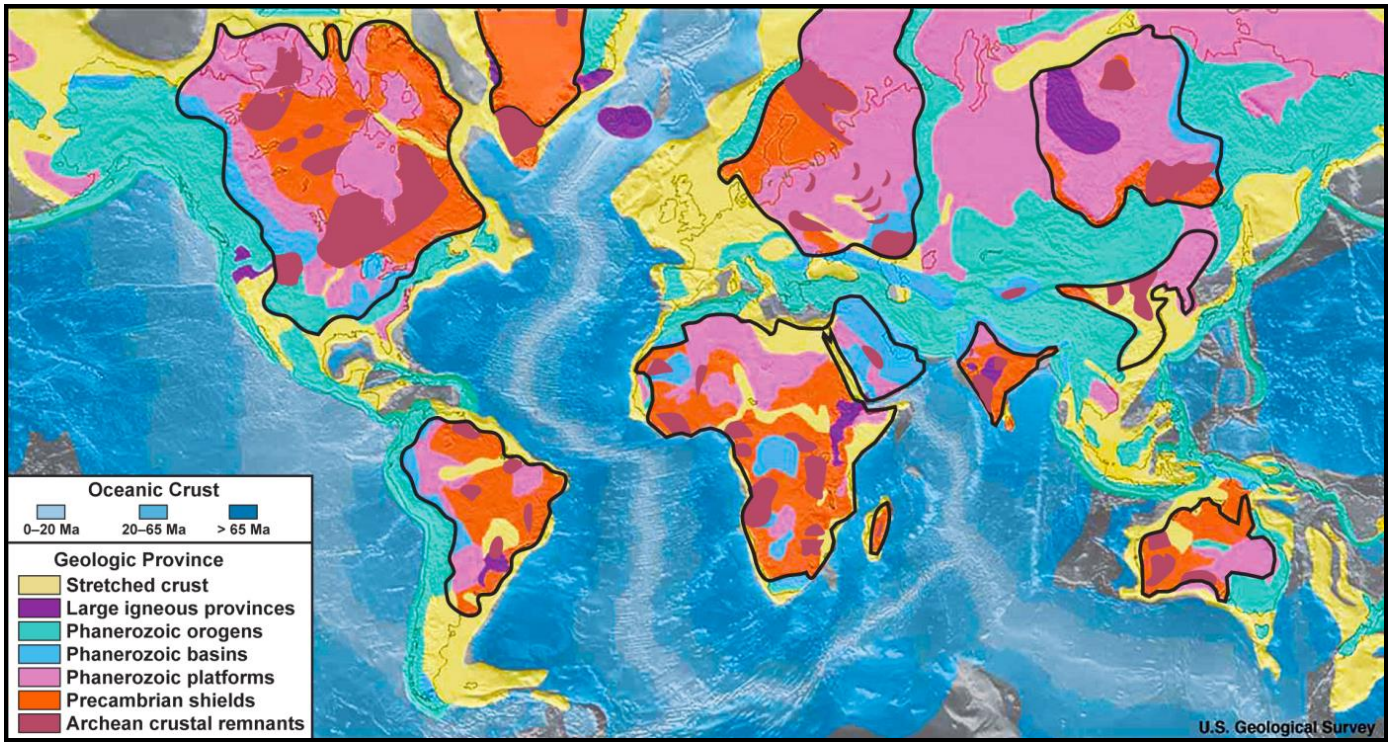


The Archean Eon

- **Archean strata contain stromatolites:**
  - **The first large fossil structures – layered mounds of sediment**
  - **Still exist, growing today near Australia**
  - **Alternating layers of cyanobacteria and sediment settling from water**
  - **First appear ~ 3.5 Ga**
  - **Check out display in Redpath Museum**

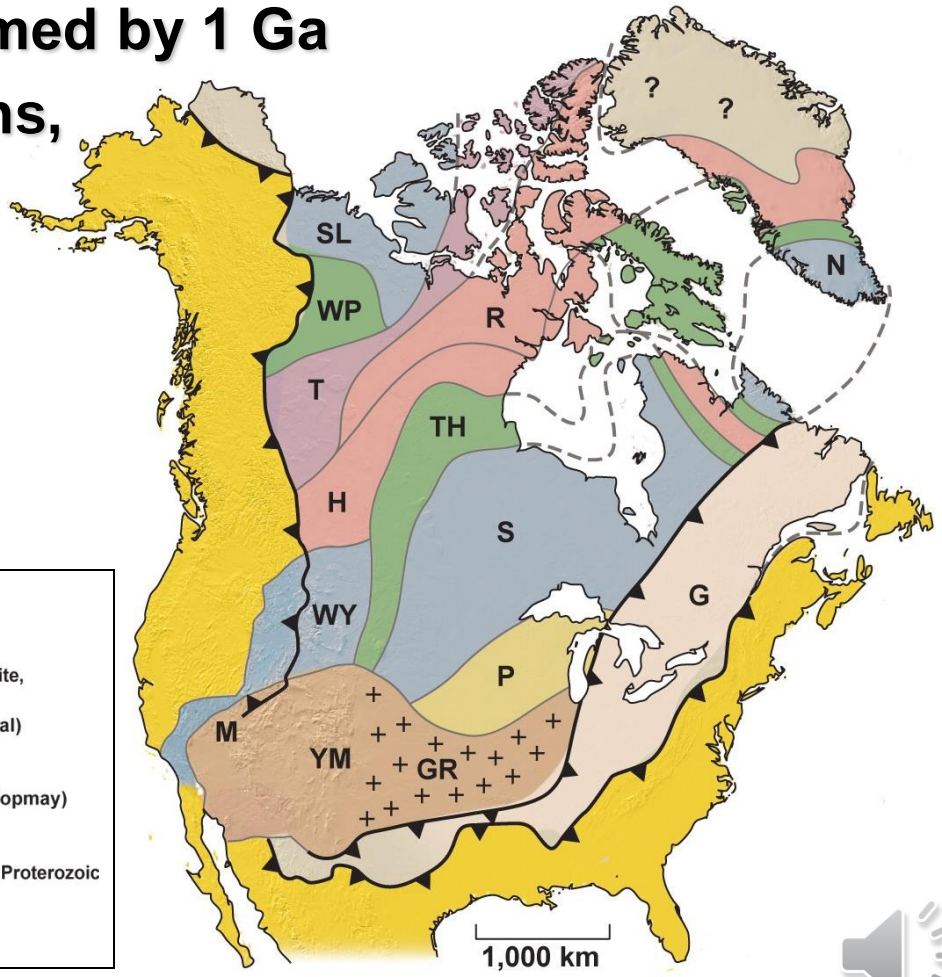
The Proterozoic Eon

- ***Proterozoic*** **= early life**
- **Around 2.5 Ga to 542 Ma**
- **Several rounds of super-continent assembly and rifting**
- **90% of continental crust formed by middle Proterozoic**



The Proterozoic Eon

- **Growth of continental crust—cratons:**
  - **Cold, stable, interior regions of continental crust**
  - **All of today's cratons formed by 1 Ga**
  - **Consist of distinct orogens, blocks, and terrains**
- **Parts of a craton:**
  - **Shield**
  - **Platform**
  - **Basement**



- Phanerozoic orogen
- 1.1- Ga collisional orogen (G = Grenville)
- 1.6- to 1.7- Ga accreted crust covered by granite and rhyolite, where patterned (GR = granite-rhyolite province)
- 1.6- to 1.7- Ga accreted crust (YM = Yavapai and Mazatzal)
- 1.8- Ga accreted crust (P = Penokean)
- 1.8- Ga collisional orogen (TH = Trans-Hudson; WP = Wopmay)
- 1.9- Ga collisional orogen (T = Thelon)
- Archean rocks, later deformed and metamorphosed in the Proterozoic (H = Hearn; R = Rae)
- Relicts of Archean crust (WY = Wyoming; M = Mojave; S = Superior; N = Nain; SL = Slave)

The Proterozoic Eon

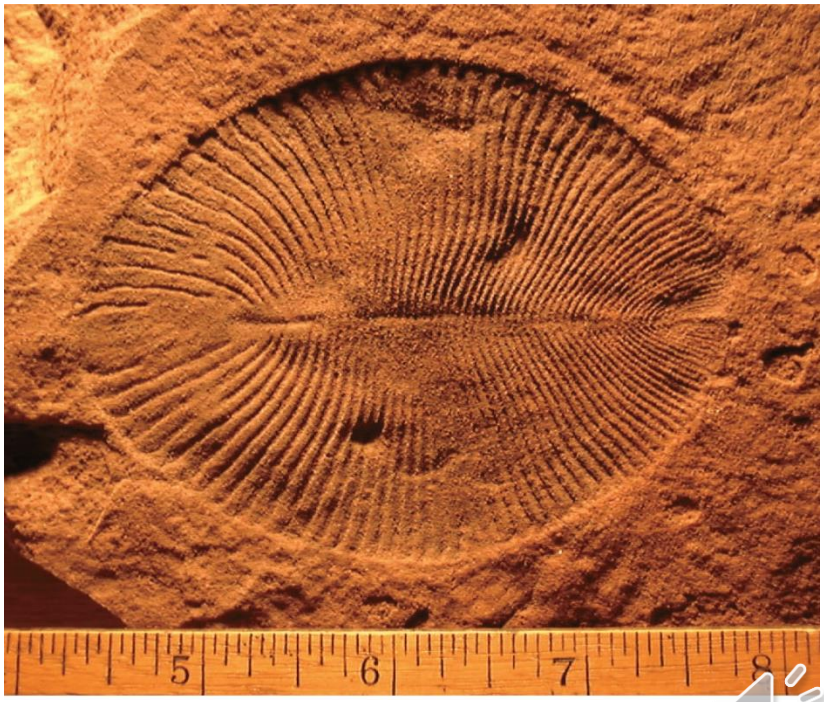
- **Continental collisions form Proterozoic supercontinents.**
  - **Rodinia formed ~ 1 Ga, concurrent with Grenville orogeny**
  - **Rodinia rifted apart ~ 700 Ma.**
  - **Pannotia formed ~ 600 Ma.**
  - **Precursors to present-day continents can be identified.**

The Proterozoic Eon

- Atmospheric oxygen rose dramatically after the appearance of photosynthetic organisms ~ 2.4 Ga.
  - Great Oxygenation Event
  - 2.4–1.8 Ga: Banded Iron Formations (BIF)

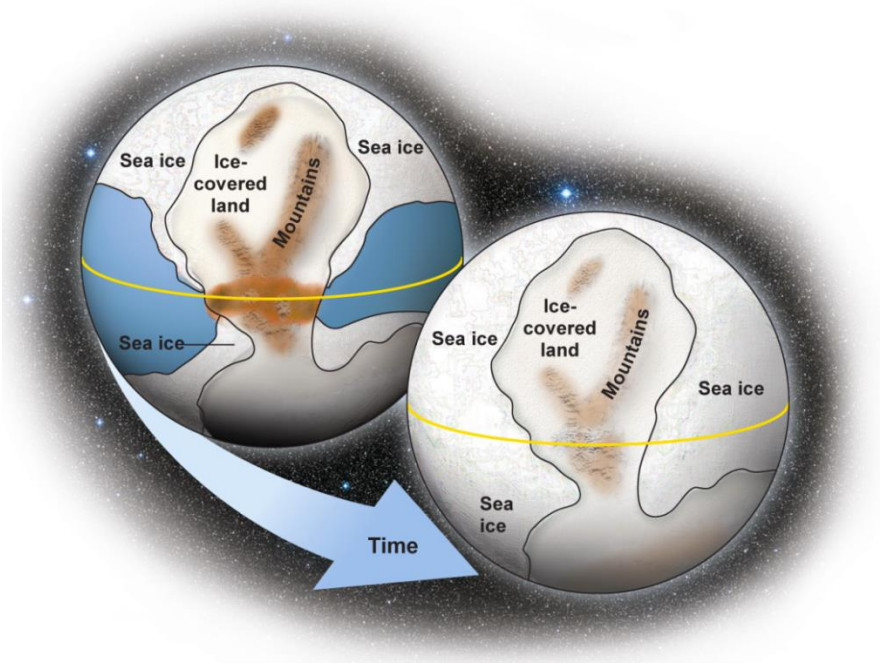
The Proterozoic Eon

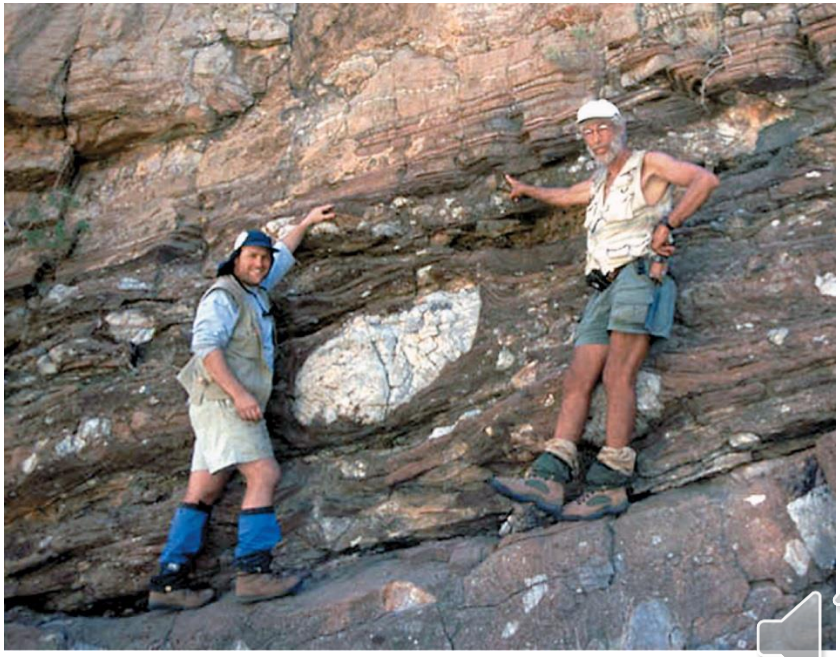
- **Life forms evolved slowly.**
  - **Eukaryotes (bacteria with nuclei) evolved ~2.7–2.1 Ga.**
  - **Multicellular life forms appeared by 750 Ma.**
  - **Large life forms leaving obviously recognizable fossils evolved ~620 Ma.**
  - **Ediacaran fauna appeared in the late Proterozoic.**
    - ✔ **Complex, soft-bodied forms**
    - ✔ **Resembled jellyfish, worms**



The Proterozoic Snowball Earth

- Major climate shifts in late Proterozoic
- Glaciers covered continents, ocean surface frozen.
- Many life forms probably became extinct as ocean chemistry and photochemistry changed due to ice cover.
- CO_2 from volcanism warmed Earth, ended major ice age.



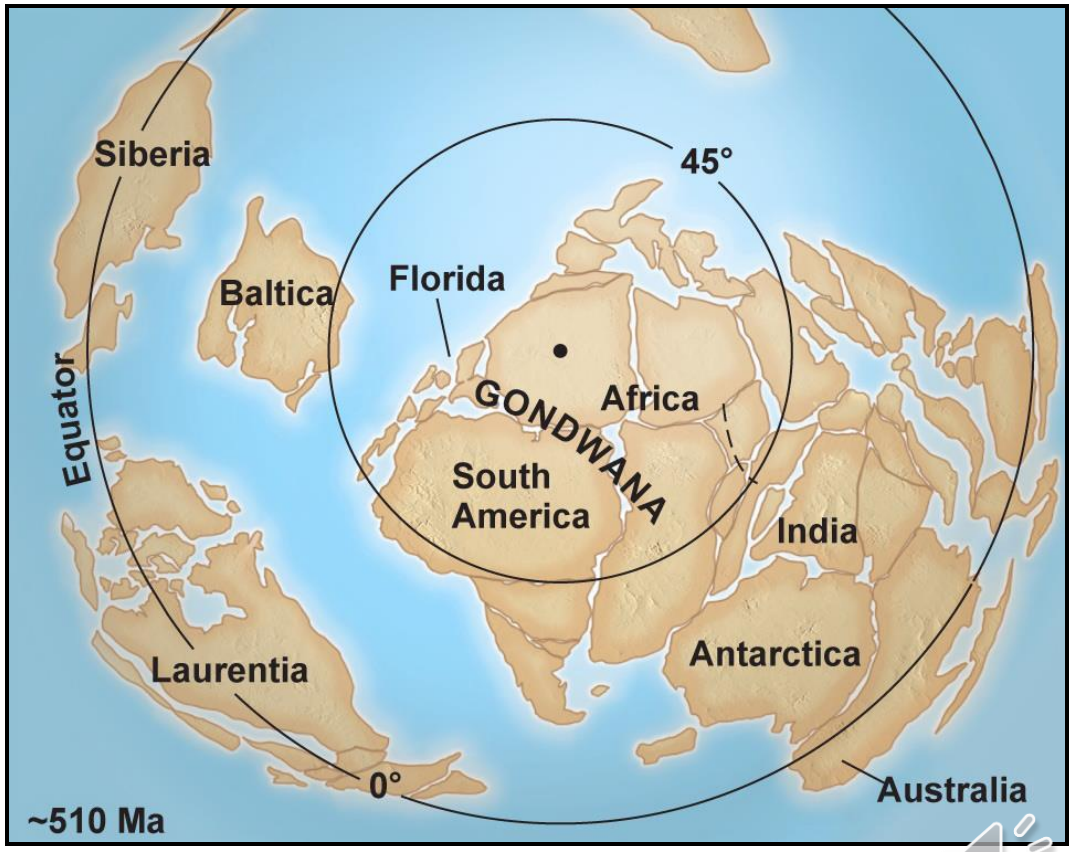


The Phanerozoic Eon

- *Phanerozoic* = visible life
- From 542 Ma to present
- Defined by widespread, diverse life forms
  - Carbonate shells, skeletal material enhance preservation
- Divided into three eras:
  - The Paleozoic Era: 542–252 Ma
  - The Mesozoic Era: 251–65 Ma
  - The Cenozoic Era: 65 Ma to present

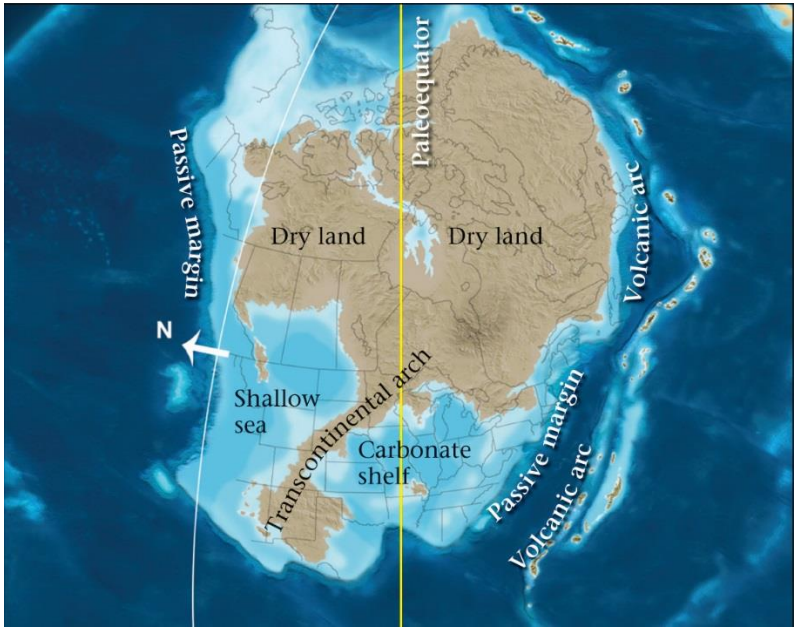
The Early Paleozoic

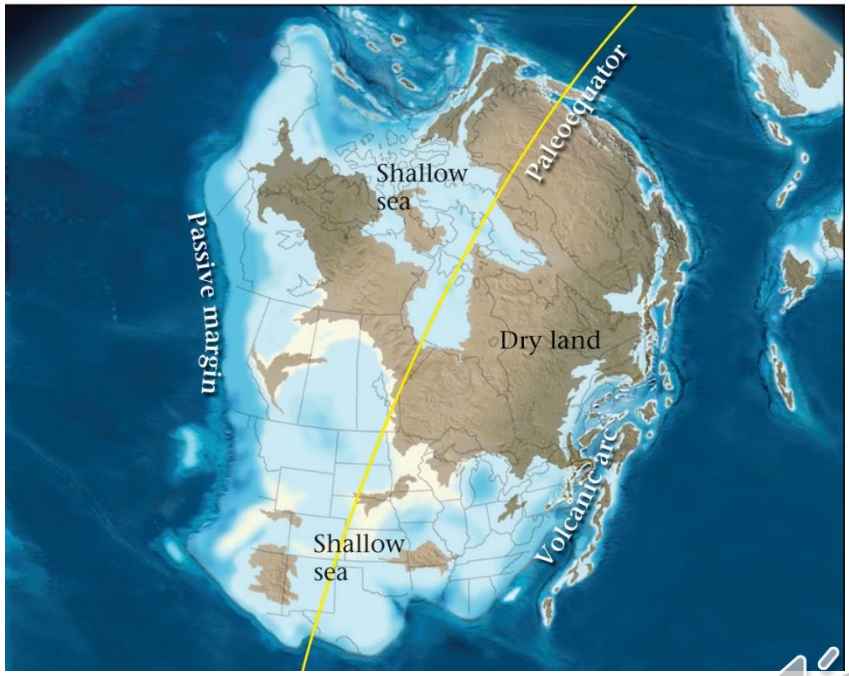
- Vast, shallow epicontinental seas and platform deposits
- Early Paleozoic rifting of Pannotia created:
  - New ocean basins
  - The Siberian craton
  - Baltica (Europe); Laurentia (North America, Greenland)
  - Gondwana (South America, Africa, India, and Australia)
  - Epicontinental seas



The Early Paleozoic

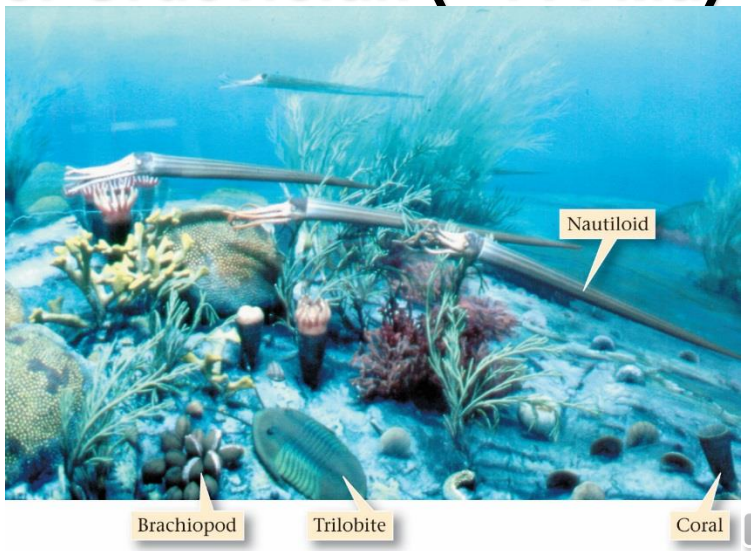
- Worldwide sea levels rose and fell several times during the Paleozoic.
  - Transgression = widespread rise in sea level
  - Regression = widespread fall in sea level
- Taconic orogeny created pre-Appalachians.





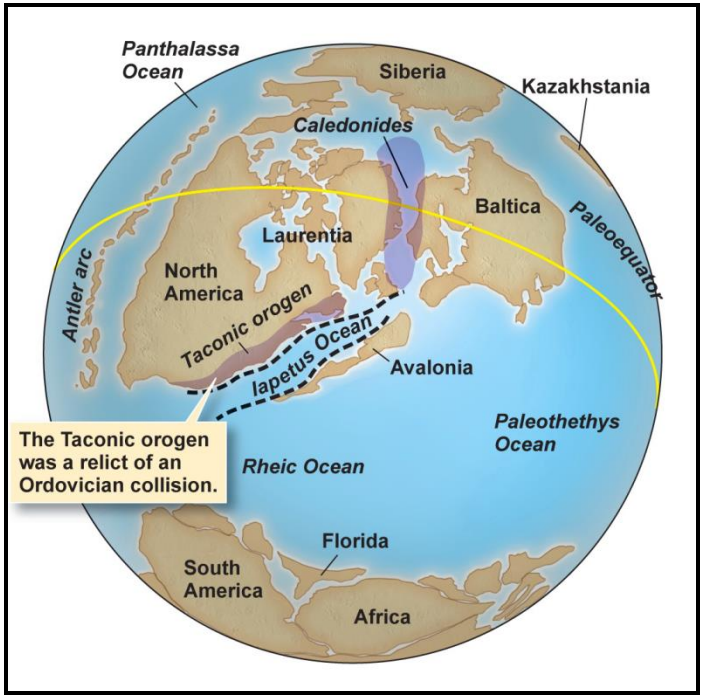
Early Paleozoic

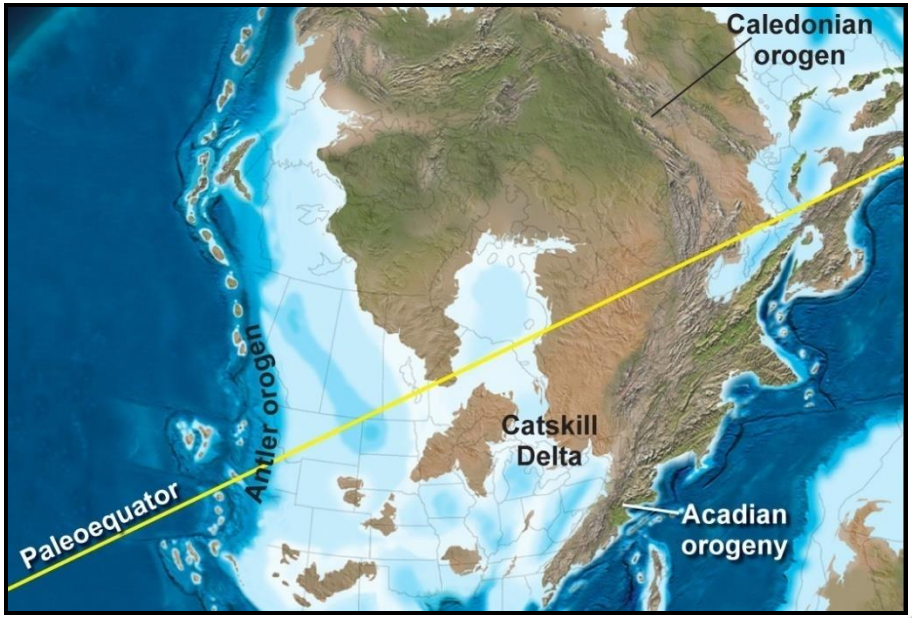
- Biological diversification of life shortly after 542 Ma
  - Cambrian explosion —rapid diversification of life forms
  - Did breakup of Pannotia into separate landmasses open new ecological niches and stimulate evolution?
  - Paleozoic life forms included conodonts, trilobites, brachiopods, nautiloids, gastropods, graptolites, crinoids, echinoderms, jawless fishes.
- Mass-extinction event at end of Ordovician (~444 Ma)
  - Driven by glaciation and sea-level lowering?



The Middle Paleozoic

- **Silurian (444 – 419 Ma) "greenhouse"**
  - Sea levels rose, climate warmed, continents flooded.
  - Vast reef complexes in shallow epicontinental seas.
  - New marine species evolved in the early Silurian.
  - Acadian orogeny uplifts early Appalachian Mountains.



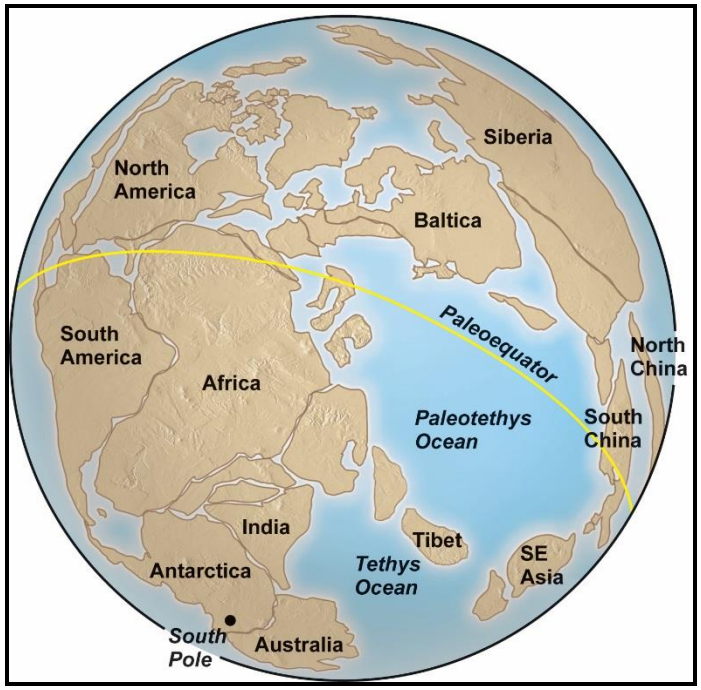


Middle Paleozoic: Life Arrives on Land

- Around 420 Ma: life emerges from the sea, adapts to living and reproducing on land.
- First amphibians in Late Devonian: Tiktaalik fossil.
- Crustaceans, spiders, scorpions, insects evolved.
- Land plants evolved, developed:
  - Protective tissues
  - Vascular systems
  - Seeds
  - Size

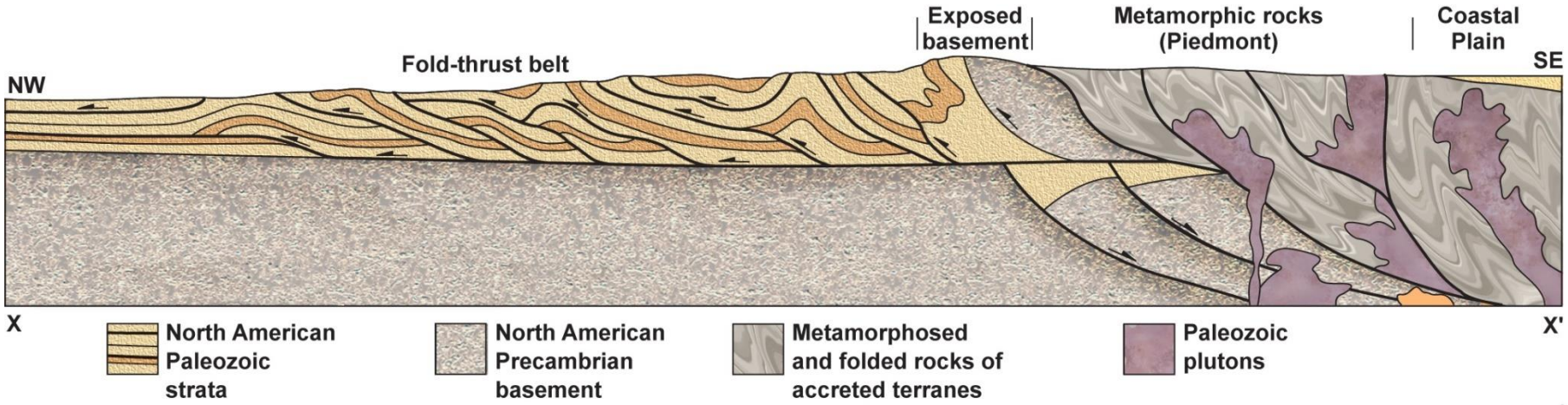
Late Paleozoic Era

- Global cooling and regressing seas initially
- Epicontinental seas replaced with coastal swamps
  - Formation of thick coal beds in (sub)tropics
- Continental collisions led to formation of Pangea.
  - Alleghanian orogeny: final collision of Appalachian uplift



Late Paleozoic Era

- Pangea collisions caused vast continental deformation.
  - Eastern North America collided with northwest Africa.
    - Appalachian and Ouachita Mountains grew.
    - Large-scale folding and thrust faulting occurred.
    - Thrust-faults emplaced Precambrian basement atop Paleozoic sedimentary rocks.
  - Rocks across North American continent were impacted.



Late Paleozoic Era

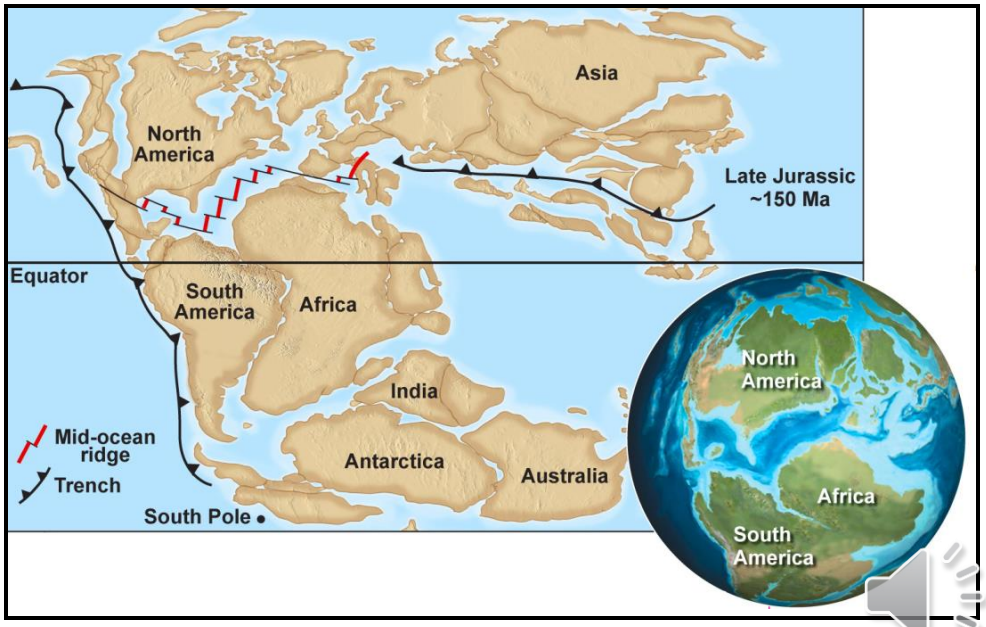
- Plant cover and forests continued to evolve, expand.
  - Gymnosperms, cycads widespread in the Permian Period.
- Reptiles first appeared.
  - Hard-shelled eggs allowed reproduction on land.
- Largest mass-extinction event at end of Permian Period.
  - > 95% of marine species disappeared.
  - Possibly related to intense volcanism.
    - Changed atmosphere and oceans.

Late Paleozoic Era

- **Largest mass-extinction event at end of Permian Period.**

Mesozoic Era: When Dinosaurs Ruled

- Pangaea breaks up; modern features begin to appear.
- Late Triassic rifting of Pangaea formed deep basins.
  - Vast salt deposits formed from evaporation of inland seas.
  - Thick sediments filled the basins.
- Jurassic Period
  - Continued rifting opens proto-Atlantic Ocean.
  - West coast of North America becomes convergent margin.



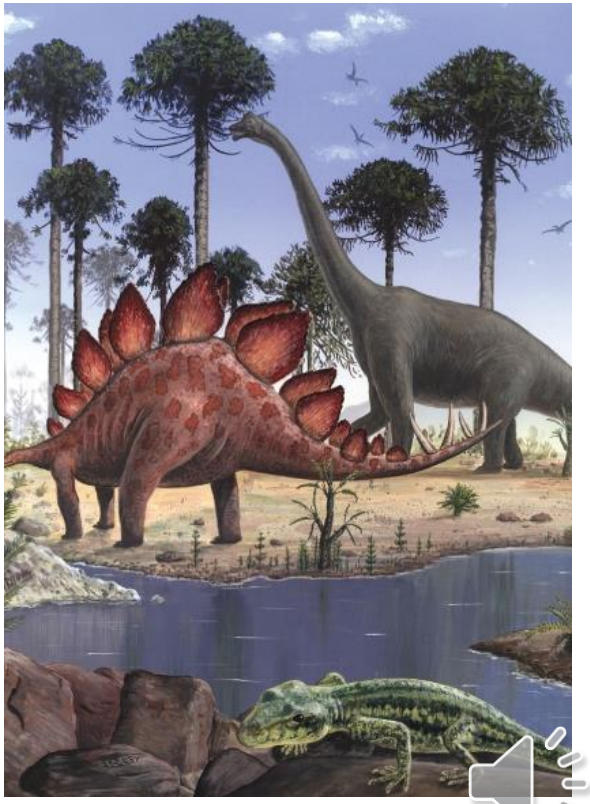
Mesozoic Era: Life Evolution

- Mesozoic Era: the age of dinosaurs and reptiles
- Triassic:
  - Rapid evolution of species after Permian extinction
  - Swimming reptiles evolved.
  - New types of corals evolved.
  - First turtles and flying reptiles appeared.
- Late Triassic:
  - The first dinosaurs
  - Earliest ancestors of mammals

Mesozoic Evolution

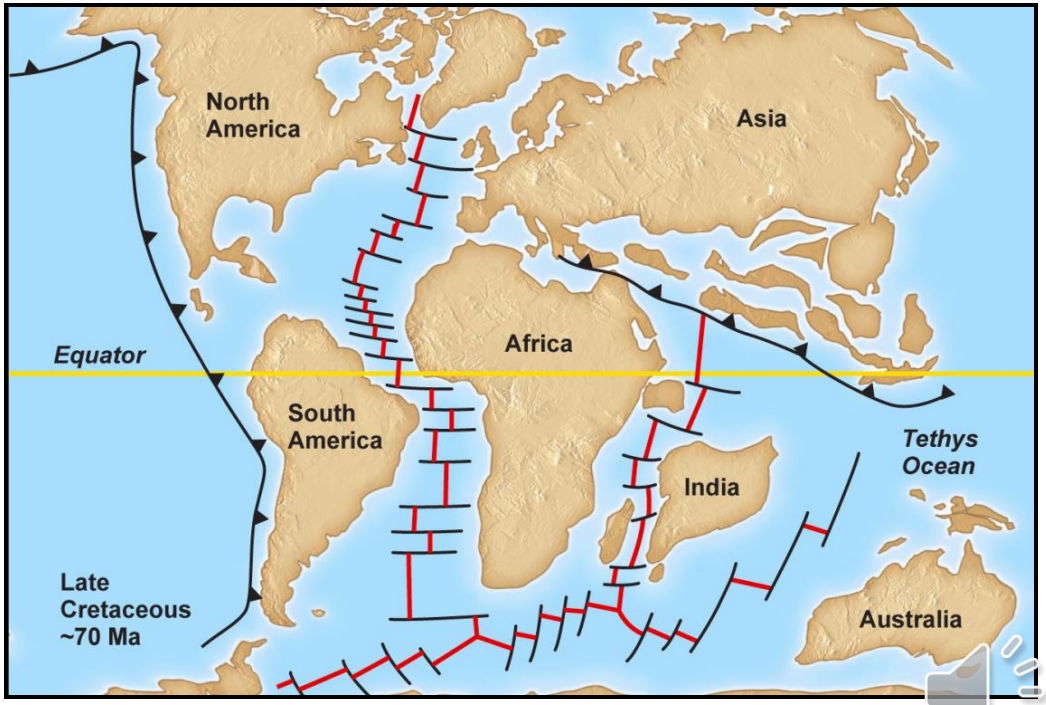
- **Late Triassic and Jurassic evolution**
  - **Sauropod dinosaurs—weighing up to 100 tons!**
  - **Stegosaurus and other large dinosaurs**
  - **Huge swimming reptiles, giant sea turtles**
  - **First feathered birds (*Archaeopteryx*)**

Fig. 11.15



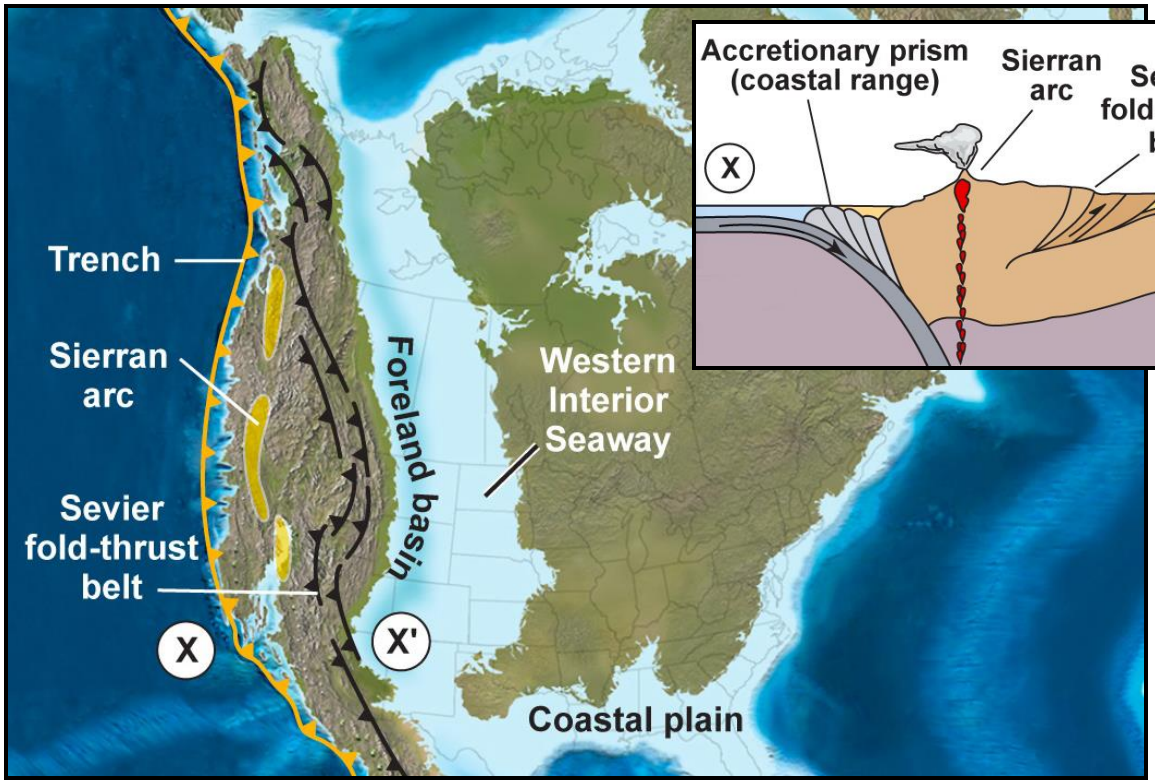
Late Mesozoic Era: Cretaceous Period

- Breakup of Pangea continued.
  - South Atlantic Ocean opened.
  - South America, Africa, Antarctica, Australia separated.
  - India broke from Gondwana, migrated north toward Asia.
- Sea level rose dramatically.
  - Vast seaways flooded continental interiors.



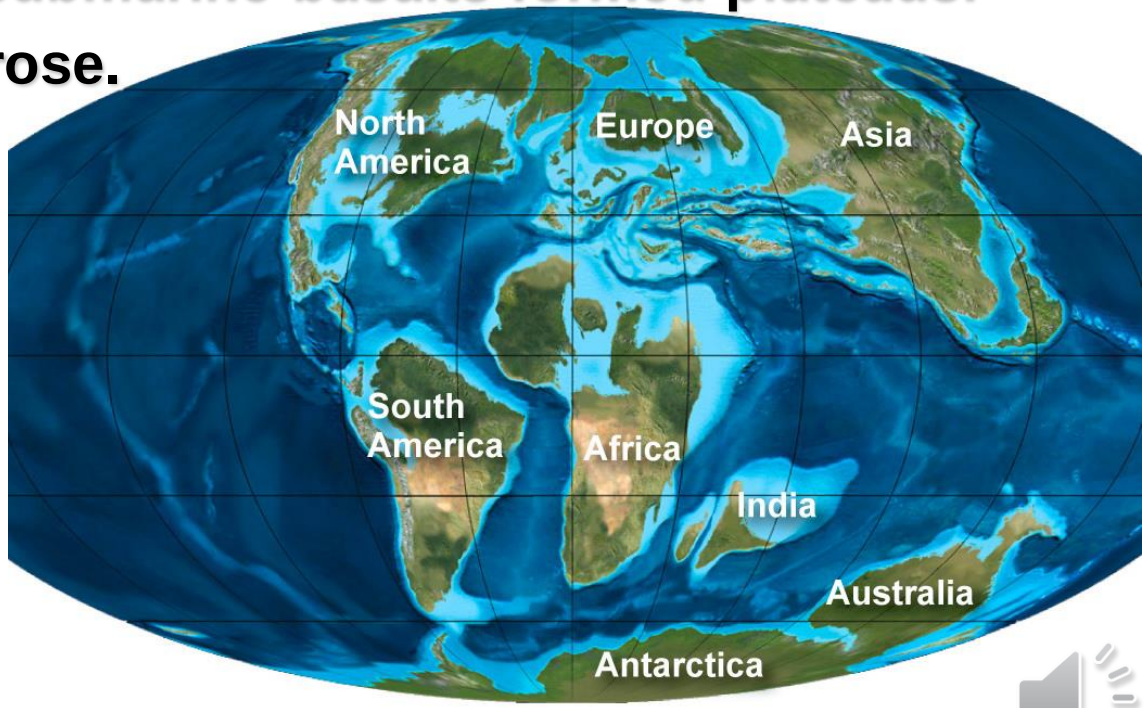
Late Mesozoic Era: Cretaceous Period

- Plutons from Sierran arc in western North America
  - Eroded and uplifted as the Sierra Nevada today.
- Sevier orogeny produced Canadian Rockies.
- Laramide orogeny formed Rocky Mountains in the U.S.



Late Mesozoic Era: Cretaceous Period

- Plate tectonic activity increased in the Cretaceous.
- Sea-floor spreading occurred at rates over 3 times faster than today.
  - Sea level rose as buoyant, new oceanic crust displaced ocean water.
  - Vast eruptions of submarine basalts formed plateaus.
  - Atmospheric CO_2 rose.
- Sea-level rise and increased CO_2 lead to warming climate.

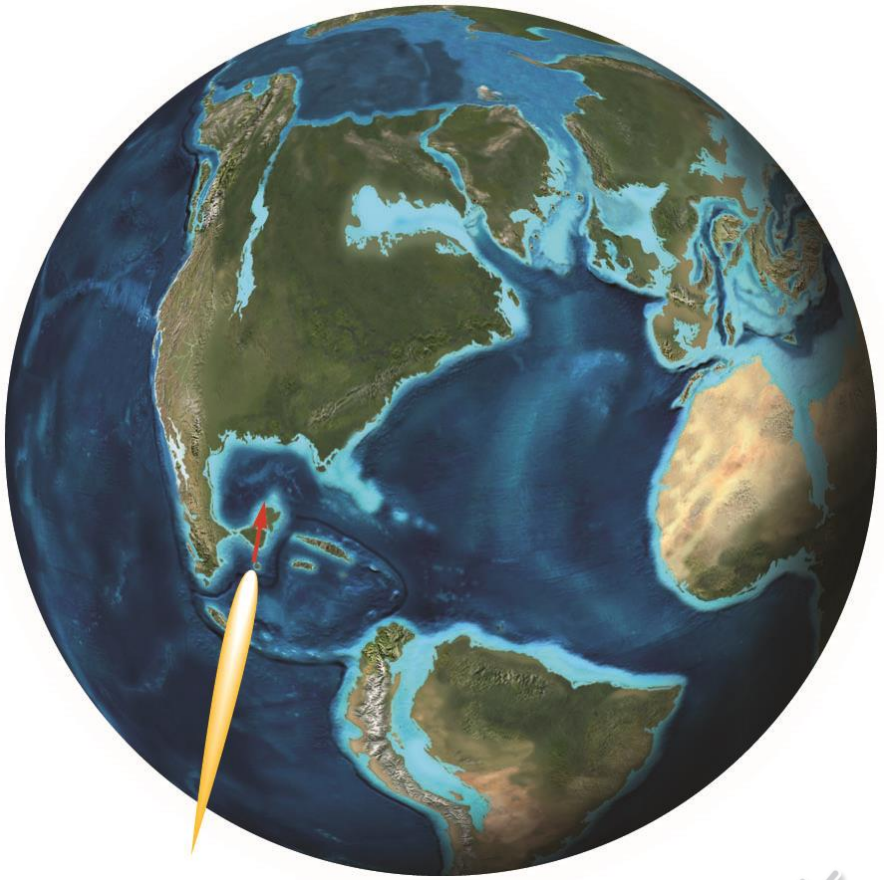


Late Mesozoic Era: Life Evolution

- Modern fish appeared and became dominant.
  - Shorter jaws, rounded scales, symmetrical tails, specialized fins
- Huge swimming reptiles and giant turtles (4m shells!)
- Flowering plants (angiosperms) and hardwood trees
- Mammals expanded and specialized but remained small.

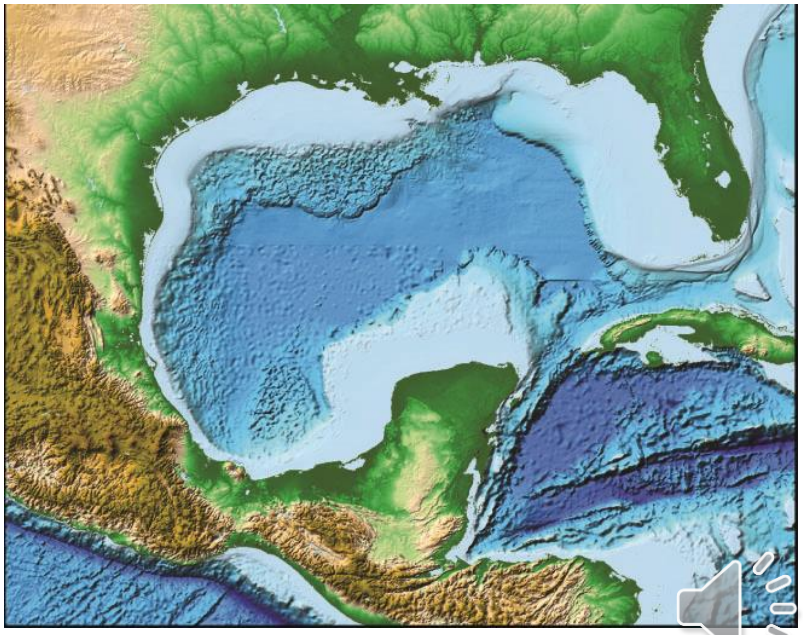
The “K-T (K-Pg) Boundary Event”

- **Widespread extinction occurred at the end of the Cretaceous period. Disappearances include:**
  - **All (except avian) dinosaurs**
  - **75% of plant species**
  - **90% of plankton species**



The "K-T (K-Pg) Boundary Event"

- The Chicxulub crater—66 Ma, 100 km wide x 16 km deep
- Sediments around the world, dated at ~66 Ma, show:
  - A layer of clay between layers of plankton skeletons (i.e., a disruption of the plankton ecosystem and food chain)
  - The clay contains iridium, abundant only(?) in meteorites.
  - "Shock quartz," formed only under tremendous pressure
  - Small glass spherules, formed from instantly melted magma thrown into the air
  - Ash from burned plants and wood.
- Impact would have generated 2-km-high tsunami.



The “K-T (K-Pg) Boundary Event”

Chicxulub or Deccan Traps?

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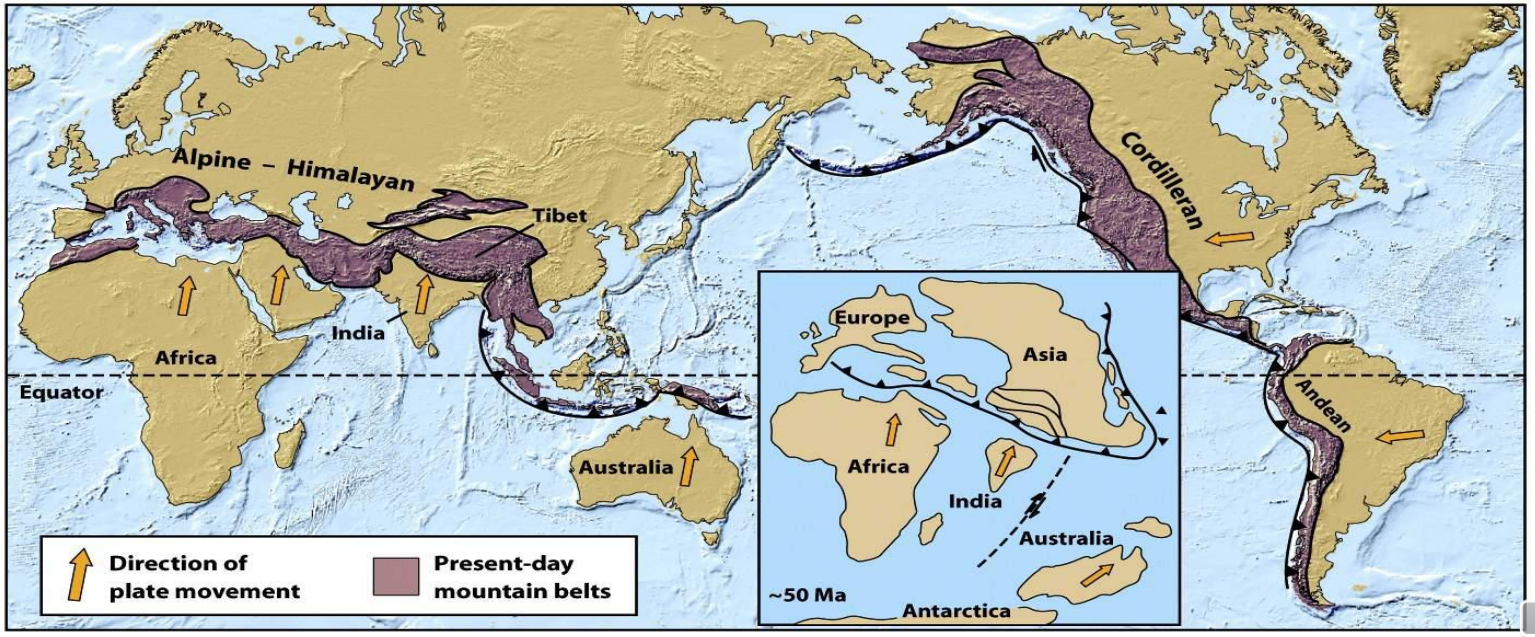
The “K-T (K-Pg) Boundary Event”

Chicxulub or Deccan Traps?

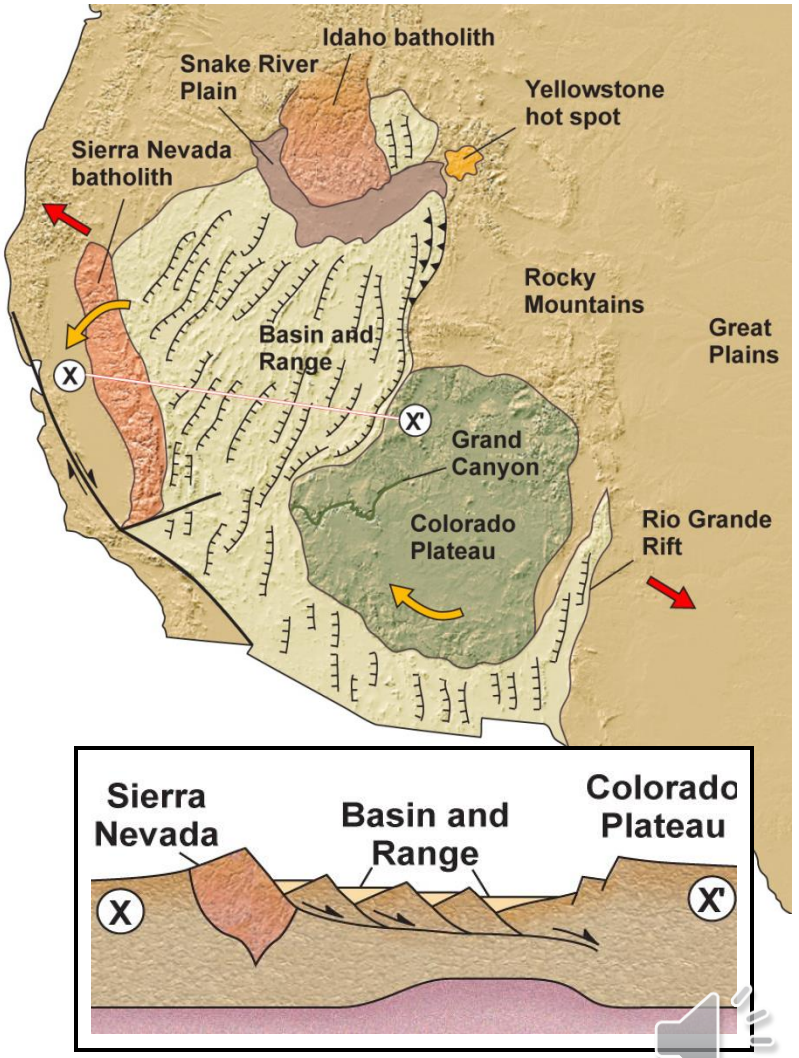
The Cenozoic Era

- **Final breakup of Pangea**
  - Australia rifted from Antarctica.
  - Greenland rifted from North America.
- **Continental collision:**
  - Italy, Turkey, Iran, India, etc., collide with Eurasia.
  - Forms the Alpine-Himalayan orogeny, the longest one on Earth.



The Cenozoic Era

- **Western North America began evolving to what we see today.**
  - **Subduction changed to transform activity between 25 and 40 Ma, eventually forming the San Andreas fault.**
  - **The interior western U.S. was stretched, breaking into small mountain ranges and basins to form the Basin and Range.**
  - **North America drifted west over a mantle hot spot, which erupted lavas of the Snake River Plain and more recently the Yellowstone caldera.**



The Cenozoic Era

- There was a cooling climate throughout the Cenozoic.
- Ice sheets increased during the Cenozoic:
  - Glaciers formed and have remained on Antarctica beginning ~ 34 Ma.
  - Pleistocene Ice Age began ~ 2.5 Ma. Ice advanced and retreated > 20 times.

The Cenozoic Era

- **The Pleistocene ice ages:**
  - **Sea level dropped, exposing sea floor of the Bering Strait, between Alaska and Russia (Bering Strait land bridge).**
  - **Humans may have migrated along the coastline from Asia to North America during one of the ice ages.**
- **The last ice age ended rapidly at 11 ka, yielding the present interglacial period (the Holocene Epoch).**

The Cenozoic Era: Age of Mammals

- Recovery after K-T impact led to new species.
- Dinosaurs extinct, but early bird descendants radiated.
- Grasses newly appeared, rapidly expanded.
- Rapid diversification of mammals:
  - Giant mammals: mammoths, beavers, sloths
  - Giant mammals went extinct ~10 ka.

The Cenozoic Era: Age of Mammals

- Ape-like primates diversified in Miocene, ~ 20 Ma.
- Human genus of primates (*Homo*): 2.4 Ma
  - Earliest known use of tools: *Homo erectus*, 1.6 Ma
  - *Homo sapiens* diverged from *Homo neanderthalensis* (Neanderthals) about 500 ka.
  - Modern *Homo sapiens* appeared about 200 ka.