CE/SC 10110-20110

Earth’s Biography

Earth

Portrait of a Planet

Fifth Edition

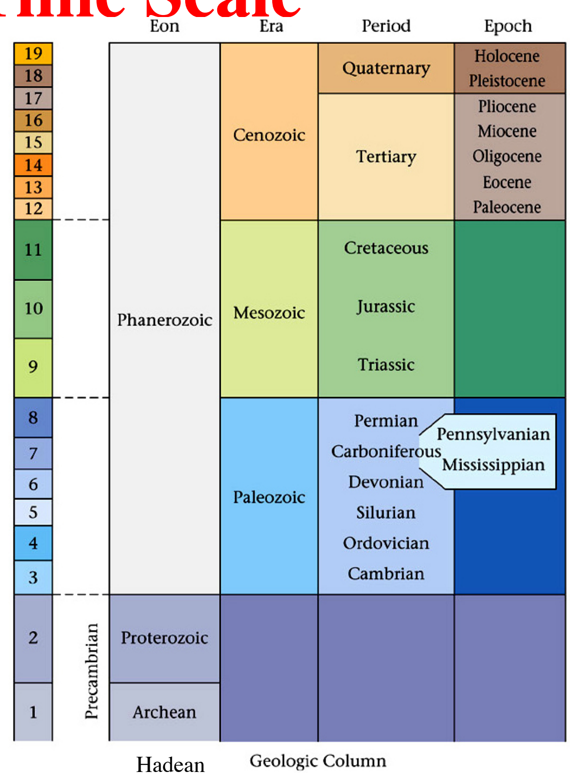
Chapter 13

Geologic Time Scale

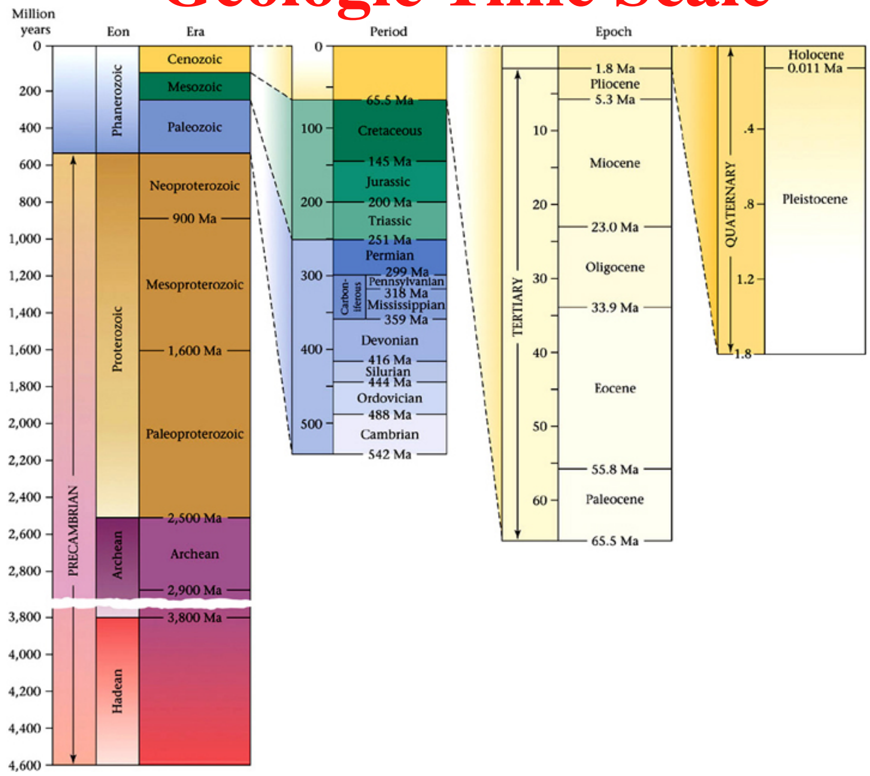
Worldwide relative time scale, based primarily on fossil assemblages.

Consists of **4 EONS**, one of which contains **3 ERAS**, which are subdivided into **periods**, which are in turn divided into **EPOCHS**.

Hadean, Archean, and Proterozoic = Precambrian



Geologic Time Scale

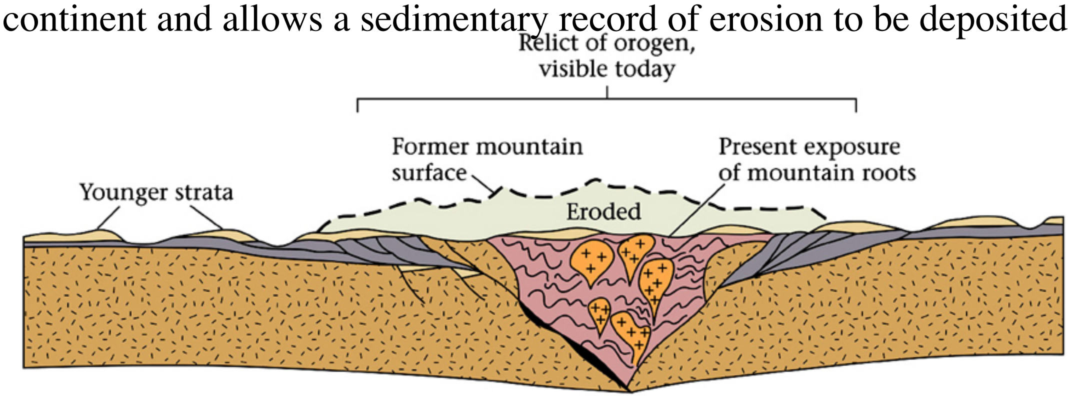


Tools for Unraveling Earth's History

Identifying Ancient Orogens: Ancient mountain ranges mark convergent zones, but can be eroded in as little at 50 m.y.

Look at rock record - igneous and metamorphic rocks form core of mountains. Folds and faults will also be present.

Foreland Sedimentary Basins form on continents adjacent to mountain ranges - weight of the mountains depresses surrounding continent and allows a sedimentary record of erosion to be deposited.



Tools for Unraveling Earth's History

Recognizing Continental Growth:

Continents have grown incrementally.

Radiometric dating used to date the rocks - when they came out of the mantle, when they were metamorphosed.

Identities of the rocks identify the tectonic environment in which they formed.

Recognizing Past Depositional Environments:

Environments at any one location change with time.

Study sedimentary sequences - environment controls the type of sediment deposited and the organisms that lived there.

Recognizing Past Sea Level Changes:

Changes in depositional environment produce characteristic sequences.

Marine limestone overlies an alluvial fan deposit = rising sea level.

Tools for Unraveling Earth's History

Recognizing Past Positions of Continents:

1. Paleomagnetism of continental rocks gives latitude;
2. Study marine magnetic anomalies to reconstruct the change over the width of an ocean;
3. Compare rocks and fossils from different continents - correlations.

Recognizing Past Climates:

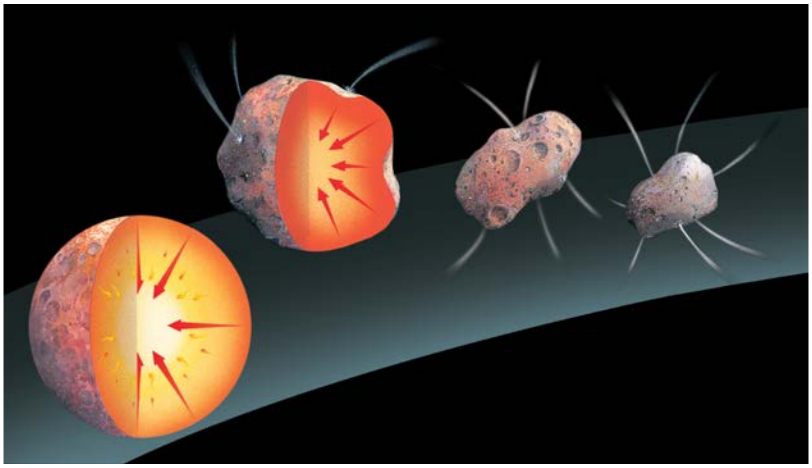
Fossils and rock types give an indication of climate.

Can also use the $^{18}O/^{16}O$ in fossil shells (temperature).

Recognizing Evolution:

Documenting changes in species throughout a stratigraphic sequence.

The Hadean Eon (4.54-3.8 Ga)



- Formation of Earth by planetesimal accretion.
- Earth heated by impacts and radioactive decay - hot enough to partially melt by ~4.5 Ga.
- The molten Earth underwent chemical differentiation as gravity pulled molten iron into the center.
- The ultramafic mantle remained as a thick outer shell.

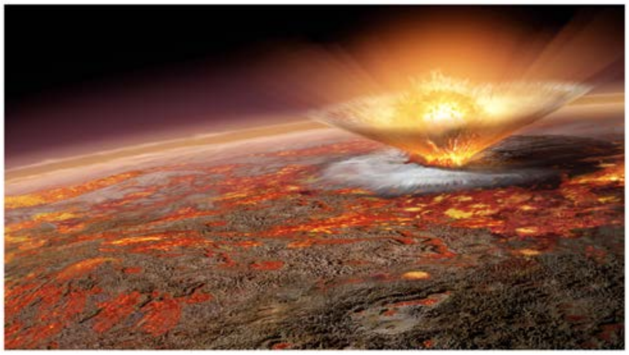
The Hadean Eon (4.54-3.8 Ga)

Chondritic meteorite age = age of solar system formation = 4.57 Ga.

Oldest rock ~4.28 Ga = gneiss - no environmental information.

4.57 - 3.8 = Hadean: bombardments, much more heat from radioactivity (short-lived radionuclides still active).

Likely that the surface was magma, but recently some zircons from Australia gave an age of ~4.4 Ga, suggesting some solid igneous rocks were present.



Internal differentiation occurred.

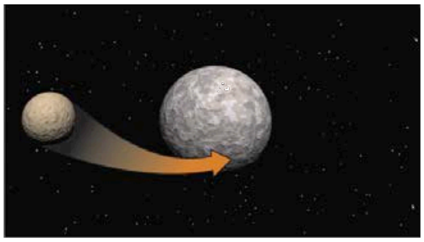
Moon formation occurred - was only 20,000 km from Earth (now it is 384,000 km).

The Moon suggests at 3.9-4.0 Ga there was a late heavy bombardment.

Lots of outgassing - CH_4, NH_3, H_2, N_2, CO_2, SO_2. Also cometary impact. Early atmosphere may have been 250 times thicker.

Marine sediments found ~3.85 Ga = liquid water.

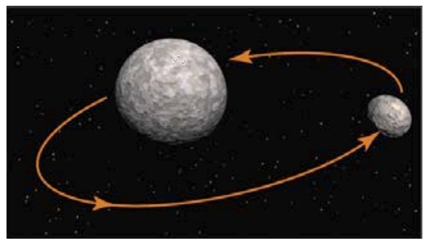
The Hadean Eon (4.54-3.8 Ga)



After differentiation, Earth was smashed by a Mars-sized protoplanet that blasted a part of Earth's mantle into space.

The debris from the collision formed a ring around Earth that coalesced into the Moon.

Thus, the Moon has a composition similar to Earth's mantle.

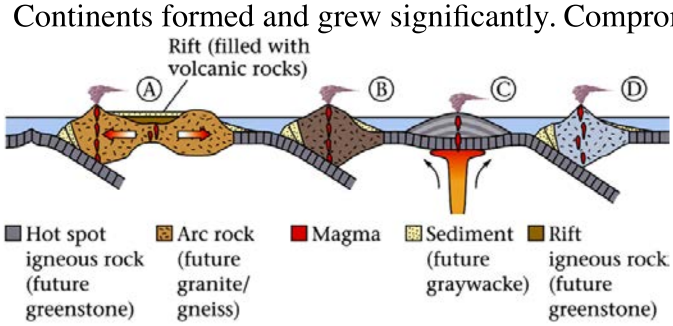


The Archean Eon (3.8-2.5 Ga)

Starts once the heavy bombardment finally stopped at ~3.8 Ga.

Plate tectonics may not have been active (the mantle was still much hotter than present day - plume volcanism may have been the norm).

Continents formed and grew significantly. Compromise model:

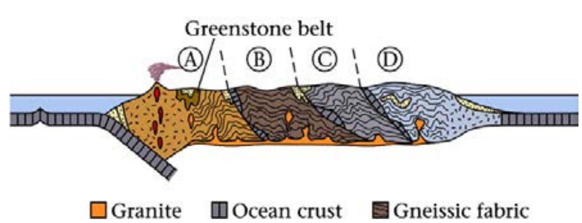


Felsic-intermediate (buoyant) crustal rocks formed at subduction zones and hot-spot volcanoes.

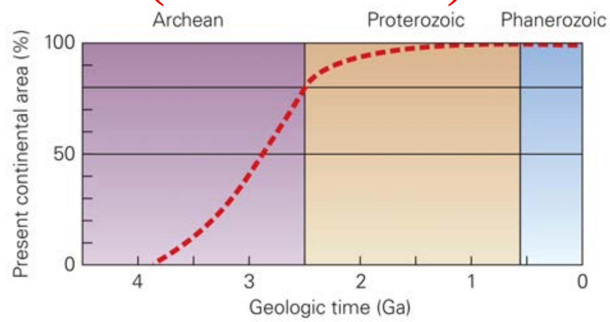
Frequent collisions sutured these into ***protocontinents***.

Some rifted and filled with basalt.

Oldest Rocks = 4.28 Ga: see http://www.msnbc.com/id/26890176



The Archean Eon (3.8-2.5 Ga)

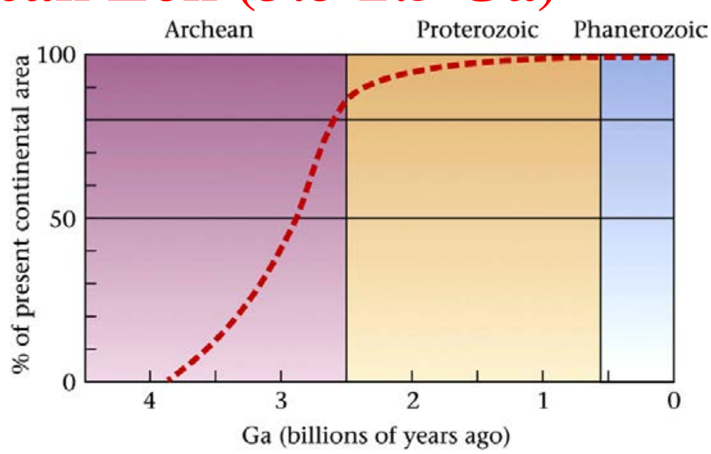


The Archean Eon was a time of significant change to planet Earth.

- Birth of continents and of life on Earth.
- By ~3.85 Ga, Earth had cooled to form lithosphere, intense
- meteorite bombardment ceased, and parts of the rock record begin
- to survive.
- The volume of continental crust increased dramatically (by the
- end of the Archean, ~85% of modern continental area was
- present).
- This indicates that plate tectonics was in action.

The Archean Eon (3.8-2.5 Ga)

By 2.7 Ga the first ***cratons*** had formed and by the end of the Archean, 80% of the continents had formed.



Archean Rocks:

Gneiss - relicts of metamorphism in collisional zones;

Greenstone - metamorphosed relicts of oceanic crust;

Granite - partial melts of the crust in collisional zones or above hot-spots;

Graywacke - erosional products from arcs;

Chert - precipitation of silica in the deep ocean.

Shallow water sediments are rare - either continental shelves were too small and the sediments didn't form, or they have been eroded away.

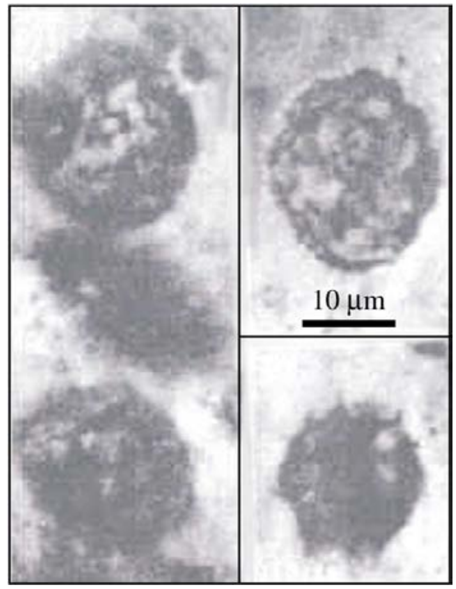
The Archean Eon (3.8-2.5 Ga)

Life began in the Archean - evidence:

Chemical (Molecular) Fossils: These biomarkers are durable chemicals only produced by the metabolism of living organisms.

Isotopic Signatures: Stable carbon isotopes $^{12}C/^{13}C$ - organisms prefer ^{12}C.

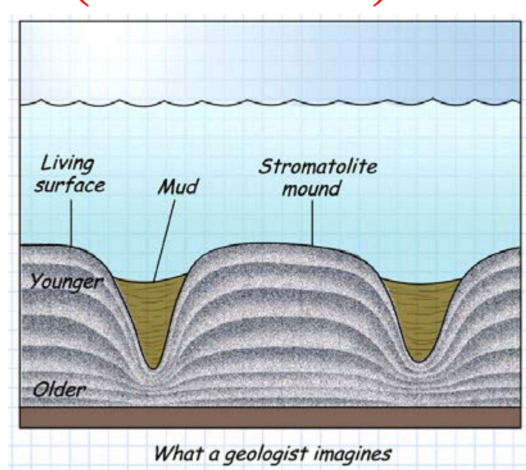
Fossil Forms: shapes representing algae or bacteria have been found, but these shapes can also be formed by inorganic means.



The Archean Eon (3.8-2.5 Ga)

Oldest undisputable fossils ~3.2 Ga = ***Stromatolites***.

These are distinctive mounds of sediment formed by mats of ***cyanobacteria***, which secrete a substance that traps sediment



Cyanobacteria changed Earth's atmosphere forever by converting CO_2 and H_2O into hydrocarbon food and a catastrophically deadly waste product: free oxygen.

The Archean Eon (3.8-2.5 Ga)

Stromatolites are still living - Shark Bay, Western Australia.



http://www.sharkbay.org/terrestial_enviroment/page_15.htm

By the end of the Archean:

Continents had formed;

Life had colonized deep and shallow seas;

Plate tectonics was occurring;

Atmosphere was gradually accumulating oxygen (although it would still have been toxic for us!).

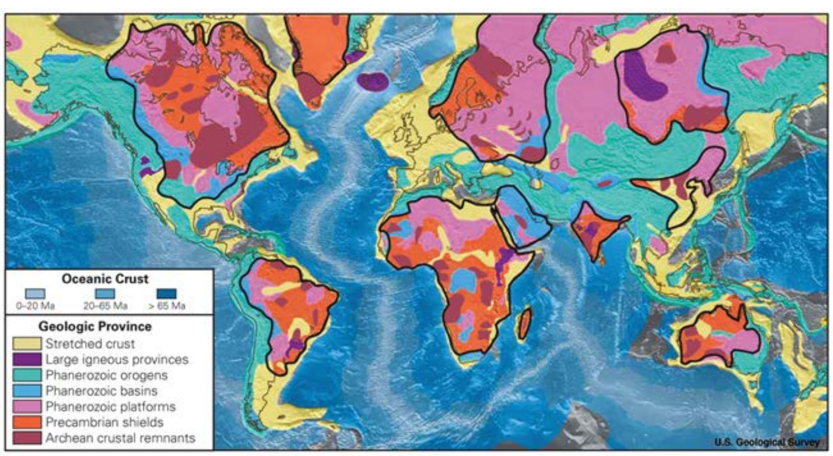
The Proterozoic Eon (2.5-0.541 Ga)

2.5 Ga - 0.542 Ga.

Large plates developed and atmosphere became richer in oxygen (although content was lower than the present day ~21%). Needed to form O_3 - protection from harmful UV rays.

At the end of the eon, >90% of the continents were made by 1.8 Ga - accretion of volcanic arcs was the primary means during the Proterozoic.

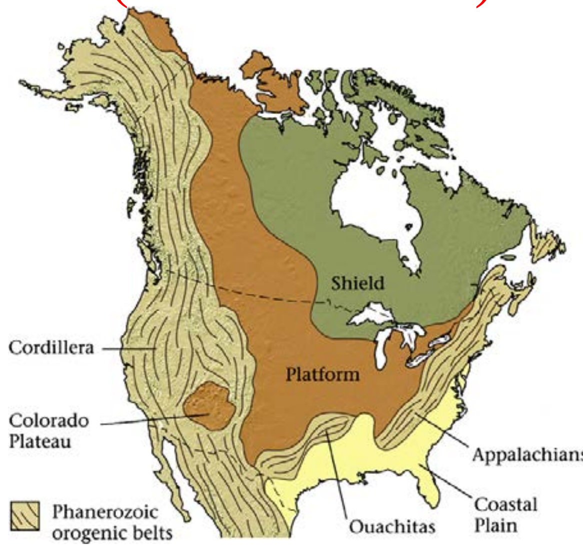
Some strengthened into cratons.

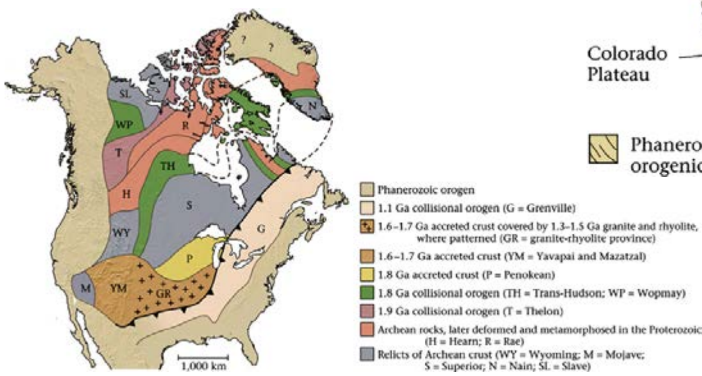


The Proterozoic Eon (2.5-0.541 Ga)

Outcrops of Precambrian rocks in a broad, low-lying region = ***shield*** (e.g., Canadian Shield - several Archean blocks sutured together).

Precambrian rocks in US are buried under Phanerozoic strata = ***continental*** or ***cratonic platform***.





Most of the US craton = sutured volcanic arcs = accretionary orogens.

The Proterozoic Eon (2.5-0.541 Ga)

~1Ga = supercontinent of **Rodinia**.

Last major collision to form this = ***Grenville Orogeny*** (outcrops in eastern Canada and along the crest of the Appalachians.

800-600 Ma, Rodinia turned "inside out" forming the short-lived supercontinent of **Pannotia**.

The Proterozoic Eon (2.5-0.541 Ga)

Increased oxygen in the atmosphere promoted diversification of life in the oceans.
Evidence: before 2.2 Ga, sulfide occurs as clasts in sediments.

"**Banded Iron Formations**" were deposited - the red = hematite (Fe_2O_3) in the late Archean/early Proterozoic. Did not form after 1.88 Ga - lack of Fe in the oceans.
Increased oxygen = increase in photosynthetic organisms.

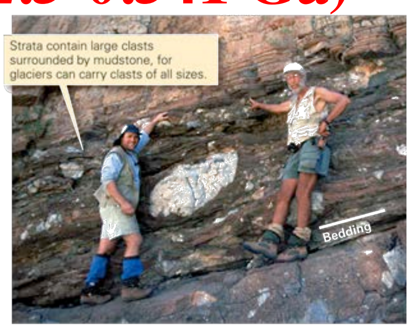
1,000-542 Ma: development of multicelled organisms - lack of hard parts. Worms & Jellyfish are the closest present day equivalents.

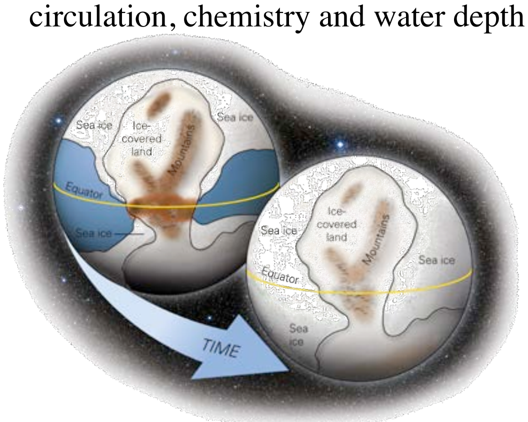
Simple organisms gave way to complex ones. The ***Ediacaran*** fauna, soft-bodied, multicellular invertebrates
resembling worms and jellyfish, appear in the fossil record at the end of the Proterozoic

The Proterozoic Eon (2.5-0.541 Ga)

The Ediacaran fauna arose in conjunction with two events: the assembly and breakup of Pannotia and a global cooling possibly resulting in a "***snowball Earth***".

Formation & breakup of Pannotia: this created new ecological niches through changes in ocean circulation, chemistry and water depth.

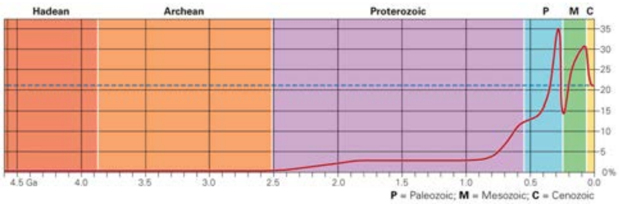




Life diversified rapidly after snowball conditions waned.

Radical climate shifts: evidence indicates glacial deposits at the equator – "***Snowball Earth***".
Ice cover on the oceans cut off oxygen causing extinctions.
CO_2 continued to be put into the atmosphere from volcanism, so over time, the temperature rose and the ice melted.
New niches available through this also.

The Proterozoic Eon (2.5-0.541 Ga)



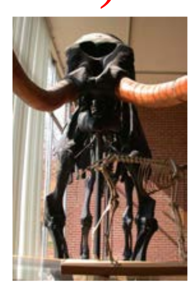
- Atmospheric O_2 accelerated the diversification of life by permitting aerobic respiration. Eukaryotic (nucleated) cells evolved by at least 1.0 Ga—a big step on the way to multicellular life.
- O_2 buildup resulted in the formation of the ozone layer, which blocked deadly ultraviolet (UV) radiation.
- Prior to the ozone layer, exposed land was bathed in UV.

The Phanerozoic Eon (≤0.541 Ga)

phaneros = visible; zoic = life

Three Phanerozoic Eras

- Paleozoic—ancient life
- Mesozoic—middle life
- Cenozoic—recent life



Tectonic plates and continental blocks continued to be rearranged during the Phanerozoic. The map of Earth looked different throughout the Eon. A new supercontinent formed and rifted apart and numerous orogenic belts were created and eroded.

The Phanerozoic began with the first hard-shelled organisms, which greatly increased fossil preservation. Hard parts made a more complete archive of past life possible.

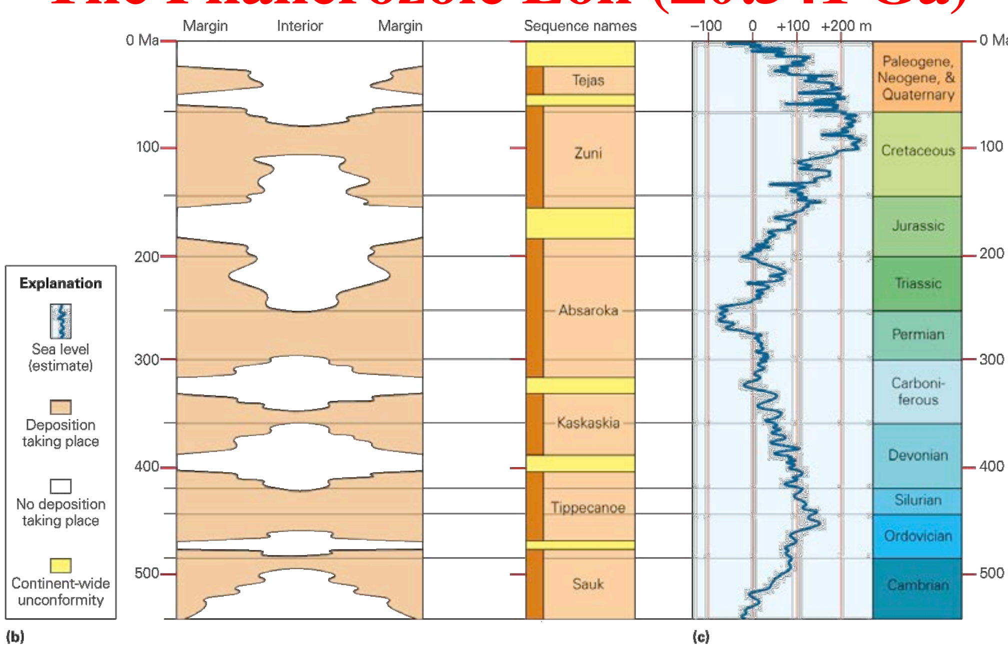
The Phanerozoic Eon (≤0.541 Ga)

The Early Paleozoic Era: Cambrian & Ordovician

Rifting of Pannotia left four large continental fragments: Gondwana (South America, Africa, Antarctica, India, Australia); Laurentia (North America and Greenland); Baltica (Europe); and Siberia.

Part of Gondwana was over the South Pole in the late Ordovician as indicated by glacial deposits.

The Phanerozoic Eon (≤0.541 Ga)

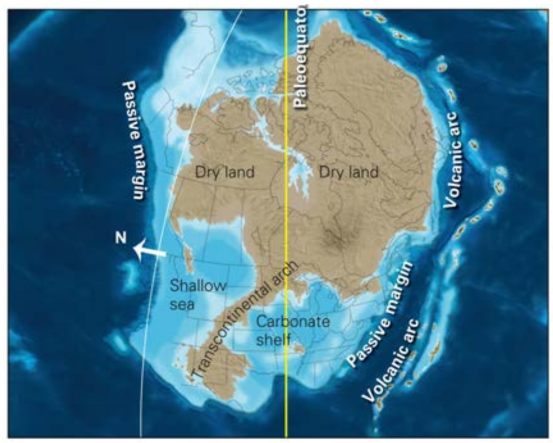


Sea level (SL) has changed many times. High SL flooded continental interiors & initiated sedimentation. Low SL exposed continental margins & initiated erosion/ nondeposition.

The Phanerozoic Eon (≤0.541 Ga)

The Early Paleozoic Era: Cambrian & Ordovician (541-444 Ma)

- North America developed passive margins off the present U.S. coasts.
- By the Middle Ordovician, however, an east-dipping subduction zone off the (now) east coast was closing the narrow Iapetus Ocean.
- During the Cambro-Ordovician, marine invasions flooded the low-lying interior of North America.

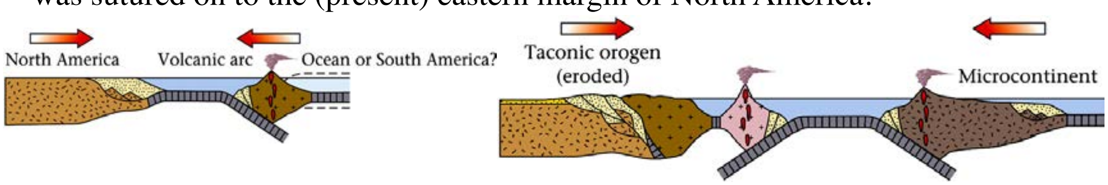


Much of Laurentia covered by shallow seas: epicontinental seas. Lots of light, warm = life abounded.

The Phanerozoic Eon (≤0.541 Ga)

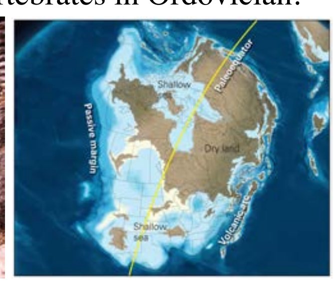
The Early Paleozoic Era: Cambrian & Ordovician (541-444 Ma)

Middle Ordovician: eastern margin of Laurentia = **Taconic Orogeny**. Began the formation of the Appalachians. Started with collision with a volcanic arc, which was sutured on to the (present) eastern margin of North America.



<u>Cambrian life explosion</u>: organisms with hard parts (simple tube/cone shaped shells). More complexity = Trilobites, Molluscs, Brachiopods, first vertebrates in Ordovician.



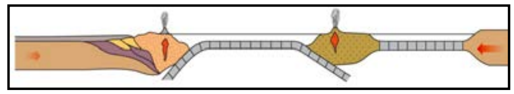


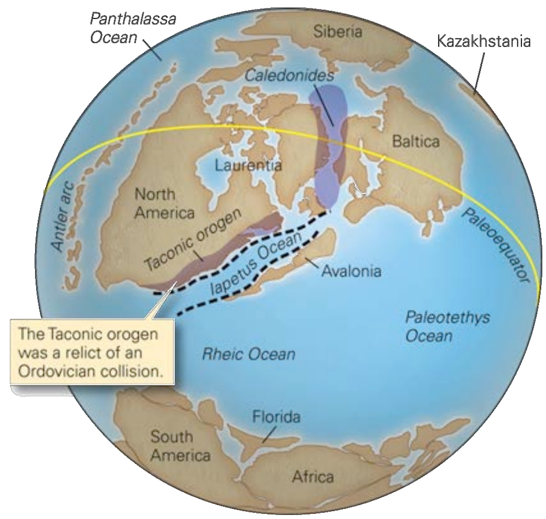
Life only in oceans. Mass extinction at the end of the Ordovician. Glaciation plus lower sea level?

The Phanerozoic Eon (≤0.541 Ga)

The Middle Paleozoic Era: Silurian & Devonian (444-359 Ma)

Beginning of the Silurian = greenhouse climate: sea level rise producing broad continental shelves.



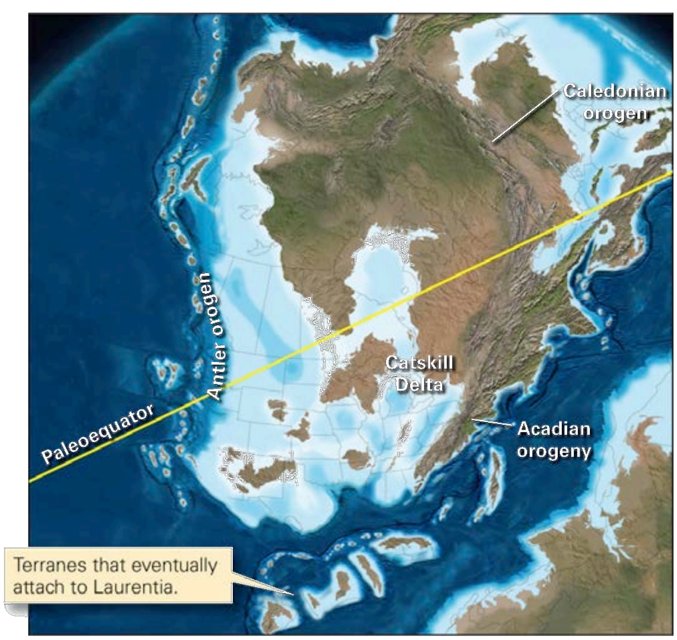


Eastern US underwent **Acadian Orogeny** (**Caledonian Orogeny** in Europe).
Western US = passive margin (opposite of today).
Late Devonian, western US underwent the **Antler Orogeny**.

Land colonized by ***vascular plants***.
Late Devonian = vegetated swamps plus associated insects, arachnids, and crustaceans.
First amphibians with lungs.

The Phanerozoic Eon (≤0.541 Ga)

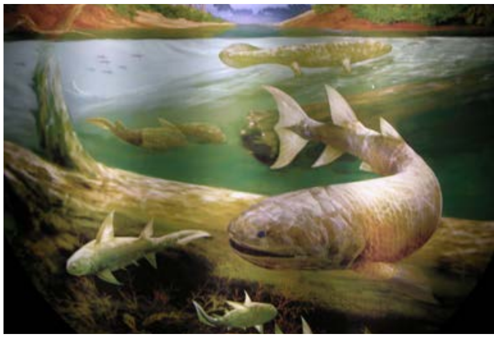
The Middle Paleozoic Era: Silurian & Devonian (444-359 Ma)



In the late Devonian, the **Acadian orogeny** created a second pulse of Appalachian mountains that shed sediments onto the craton, forming the Catskill Delta. The **Antler orogenic belt** was uplifted on the west coast.

The Phanerozoic Eon (≤0.541 Ga)

The Middle Paleozoic Era: Silurian & Devonian (444-359 Ma)



New species of trilobites (left inset), eurypterids (upper right inset), gastropods, crinoids, and bivalves replaced those lost to extinction. Fish thrived and rapidly diversified. The Devonian is known as the Age of Fishes.

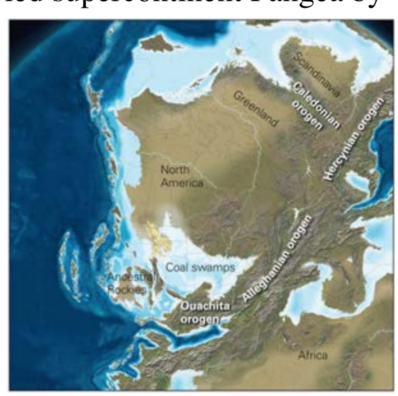
Land colonized by vascular plants – first forests. Late Devonian = vegetated swamps plus associated insects, arachnids, and crustaceans. The first land animals (scorpions, spiders, insects, and crustaceans) - first amphibians with lungs.

A fossil that was transitional between fish and amphibians was discovered in 1996. Tiktaalik was a lobe-finned fish that could do push-ups and look around on a swivel-jointed neck.

The Phanerozoic Eon (≤0.541 Ga)

The Late Paleozoic Era: Carboniferous & Permian (359-251 Ma)

- Climatic cooling followed the mid-Paleozoic greenhouse.
- Seas regressed from the continents and clastics choked out the carbonates.
- Thick coals formed near the tropics.
- Gondwana moved over the South Pole and was covered by ice sheets.
- Collisions assembled supercontinent Pangea by mid-Permian.

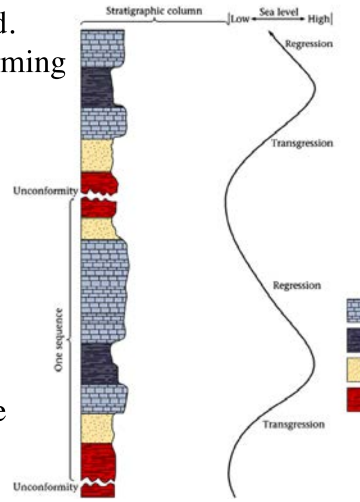


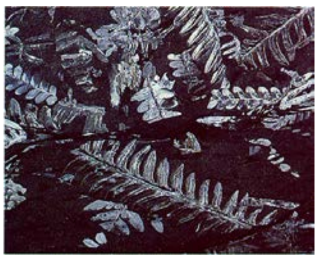
The largest collision occurred when Gondwana smashed into Laurentia and Baltica to drive the **Alleghanian** orogeny (the third and final pulse of the Appalachians – **Hercynian** Orogeny in Europe).

The Phanerozoic Eon (≤0.541 Ga)

The Late Paleozoic Era: Carboniferous & Permian (359-251 Ma)

Climate cooled and seas gradually retreated. During Carboniferous, areas previously forming Limestone, now hosted coastal swamps.

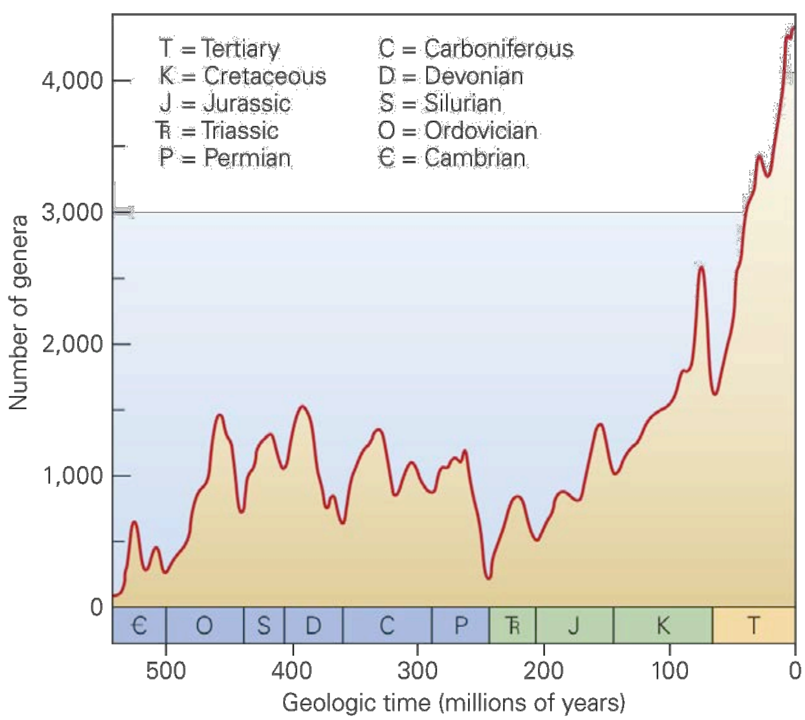




Laurentia lay close the equator - perfect for the development of the coal measures. Dense vegetation and large insects (dragon flies with 36 inch wing-spans). Reptiles appeared by the end of the Permian = eggs with hard shells so no longer dependent on water for reproducing.

Mass extinction at the end of Permian (>90% of all species wiped out). Cause unknown.

Mass Extinctions



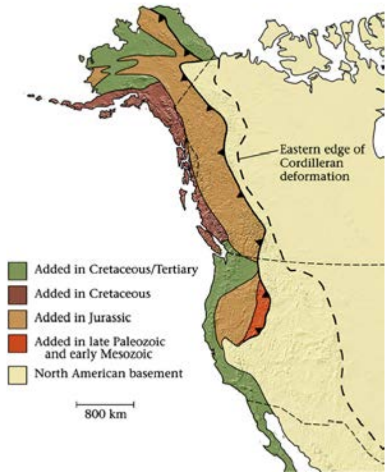
The Phanerozoic Eon (≤0.541 Ga)

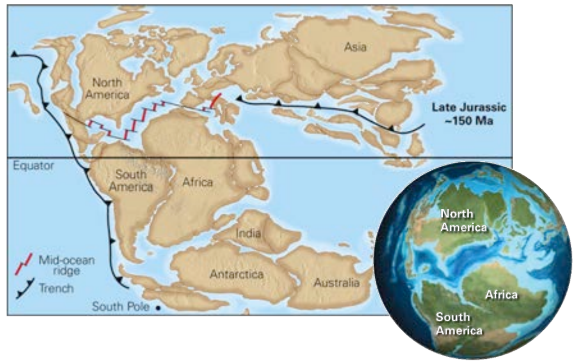
The Early & Middle Mesozoic Era: Triassic & Jurassic (251-145 Ma)

Pangaea lasted for ~100 m.y.

Break up started in late Triassic and by the end of the Jurassic, the North Atlantic ocean had formed.

Early Jurassic = greenhouse conditions; Middle Jurassic saw sea level rise.





Western US: **Sonoma Orogeny** (late Permian/early Triassic). **Nevada Orogeny** (late Jurassic). North America grew by accretion of crustal fragments and island arcs.

The Phanerozoic Eon (≤0.541 Ga)

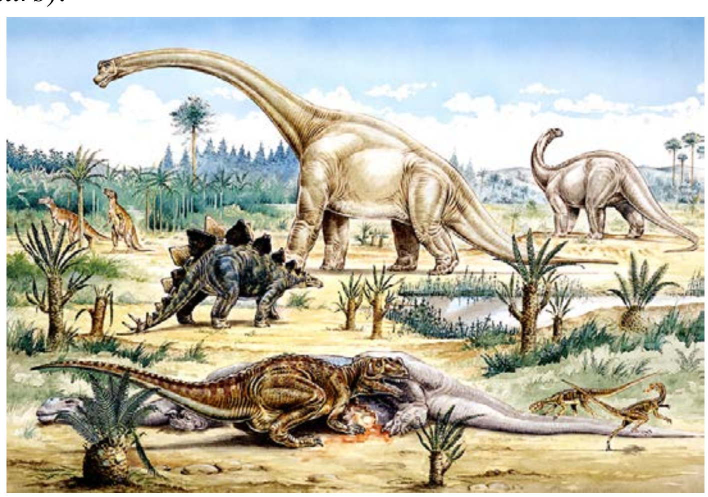
The Early & Middle Mesozoic Era: 251-145 Ma

Life evolved rapidly after the Permian mass extinction - many vacant ecological niches: swimming reptiles (e.g., *Plesiosaurs*); corals became the dominant reef builder; flying reptiles (*Pterosaurs*).

End of Triassic = appearance of the first true dinosaurs (legs were under their bodies rather than off to the sides. New evidence suggests dinosaurs were warm-blooded.

End of Jurassic, sauropod dinosaurs up to 100 tons (e.g., *Seismosaurus*) developed. Also bird with feathers.

First mammals = Triassic.



Tyrannosaurus rex was NOT a Jurassic dinosaur!

The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period (145-65 Ma)

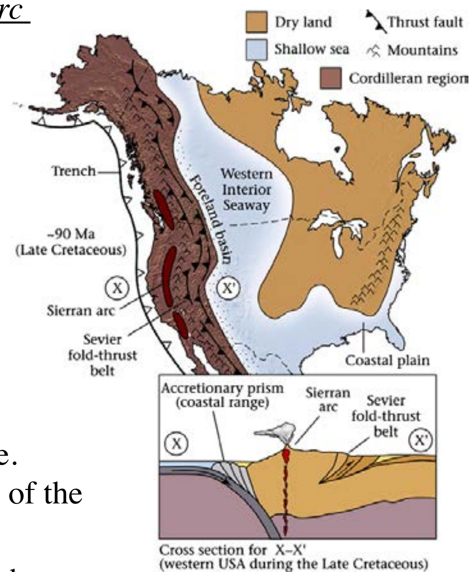
Late Jurassic through the Cretaceous = _*Sierran Arc*_ on the western margin of North America.

Greenhouse conditions. Sea levels the highest they have been for 200 m.y.

Chalk deposits in Europe, limestone + sandstone in North America.

Shallow seas flooded many continents.

Break up of Pangaea continued - South Atlantic opened, India, Antarctica, and Australia all broke apart.



Cross section for X–X' (western USA during the Late Cretaceous)

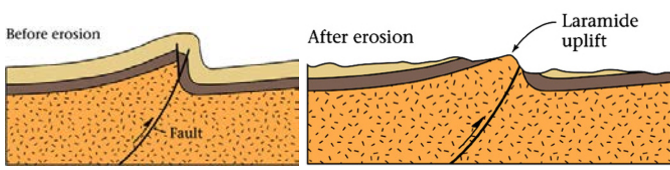
In the western US, the *Sierran Arc* was still active. Remnants seen today in eroded granite batholiths of the Sierra Nevada.

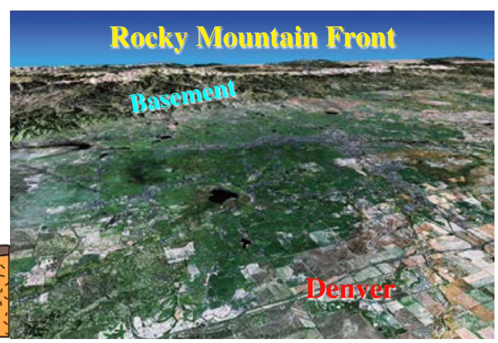
Compressional forces in the west produced large thrust faults = **Sevier Orogeny**.

The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period 145-65 Ma

End of Cretaceous produce ***basement uplifts*** in CO, WY and UT due to the shallow angle of subduction (not seen in the Canadian Rockies) = **Laramide Orogeny**.

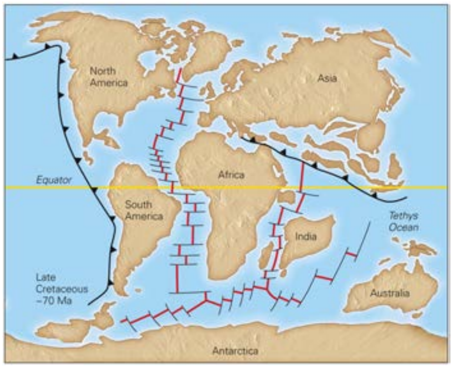




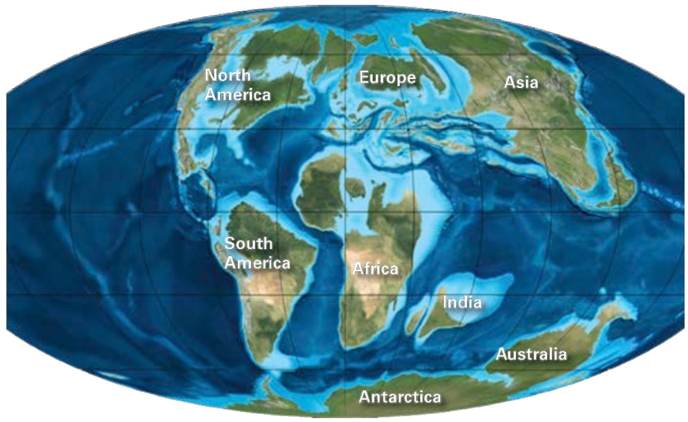
During the **Laramide Orogeny**, deformation shifted eastward, from the Sevier fold-thrust belt to the belt of the Laramide uplifts.

The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period 145-65 Ma



By the late Cretaceous, the Atlantic Ocean had formed and India had broken away from Gondwana and was racing on a collision course toward Asia.



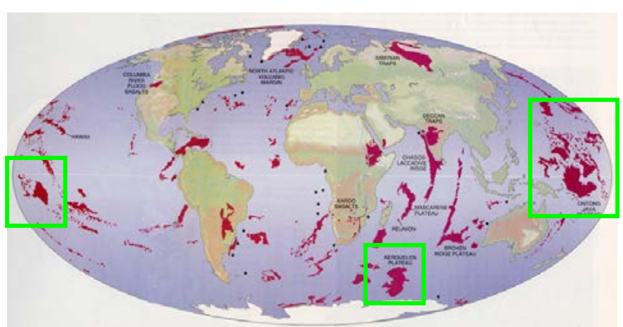
The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period 145-65 Ma

Relationship between tectonic events, global climate and sea level changes during the Cretaceous:

Pangaea break up produced lots of mid-ocean ridges. Young ocean crust is buoyant. Also, spreading was ~3 times faster than today so more of the ocean basins were covered with young, buoyant oceanic crust.

Superplumes, especially in the Pacific, erupted during the Cretaceous - added a lot of CO_2 to the atmosphere and promoted global warming.



Combined, these events promoted sea level rise.

The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period 145-65 Ma

Modern fish appeared along with flowering plants (angiosperms).

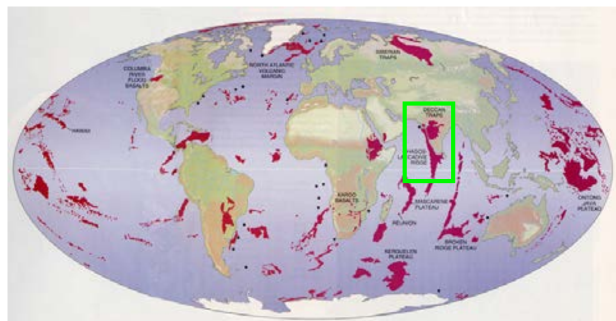
Large swimming reptiles and huge turtles (shells = 4 m across).

Dinosaurs reached their peak - grazing herds on plains were preyed upon by meat-eaters (NOTE: T-Rex = Cretaceous, NOT Jurassic),

Pterosaurs with 11 m wing spans.

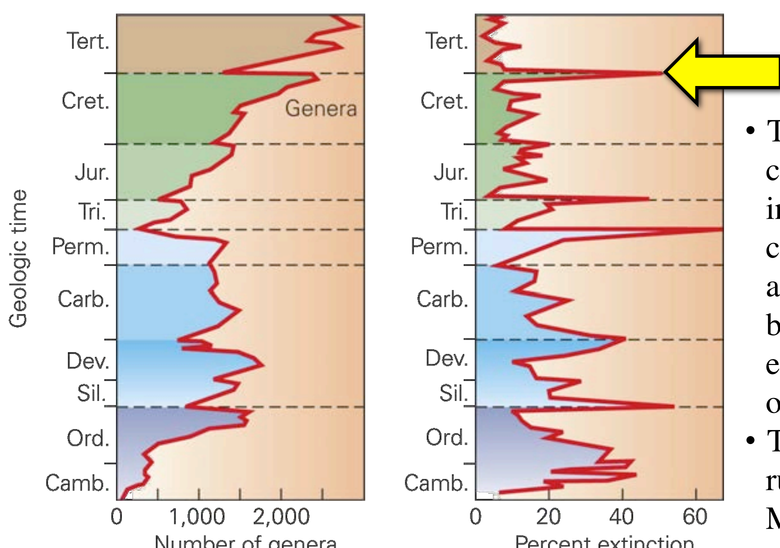
Mammals diversified, but remained small.

Mass extinction at the end of the Cretaceous - asteroid impact coupled with ***Deccan Traps*** large igneous province.



The Phanerozoic Eon (≤0.541 Ga)

The Late Mesozoic Era: Cretaceous Period 145-65 Ma

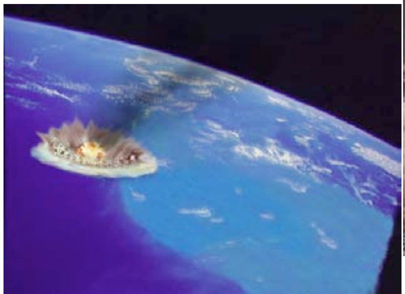


The K-T (Cretaceous-Tertiary) Boundary Event

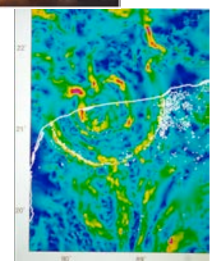
- The K-T boundary is characterized by an almost instantaneous global change in fossil assemblages brought about by the sudden mass extinction of most species on Earth.
- The dinosaurs, which had ruled the planet for 150 Ma, vanished; 90% of plankton and 75% of plant species disappeared forever.

K-T Boundary Mass Extinction

Chicxulub.



Initial air blast > 300 mph. 2 km high tsunamis.



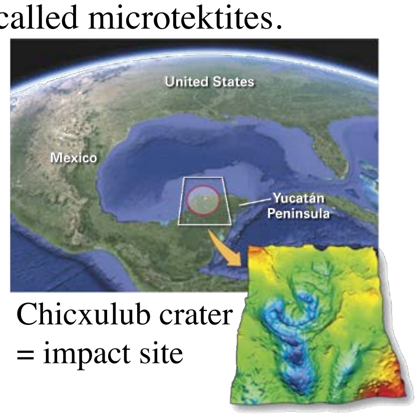
Vaporization and melting of the asteroid and target rocks. A lot of hot material would have been ejected into the upper atmosphere if not beyond.

As material came back down, friction heated the material. This would have been a world wide event so the atmosphere became like a pizza oven for several hours. Lots of fires! Material in the upper atmosphere blocked out the sun and cooled the Earth. The impact blasted debris into the atmosphere (including sulfate aerosols from vaporized gypsum) that blotted out the Sun; shut down photosynthesis.

K-T Boundary Mass Extinction

Boundary clay layer is highly enriched in Iridium (Ir), an element rare on Earth and abundant in meteorites. Ir enrichment in K-T boundary clay worldwide. Evidence for an impact includes a thin layer of plankton-free clay that separates plankton-rich chalk at the K-T boundary - plankton were shut off for a short time.
The clay also contains pressure-shocked quartz and tiny impact glass spheres called microtektites.

2 km high tsunami



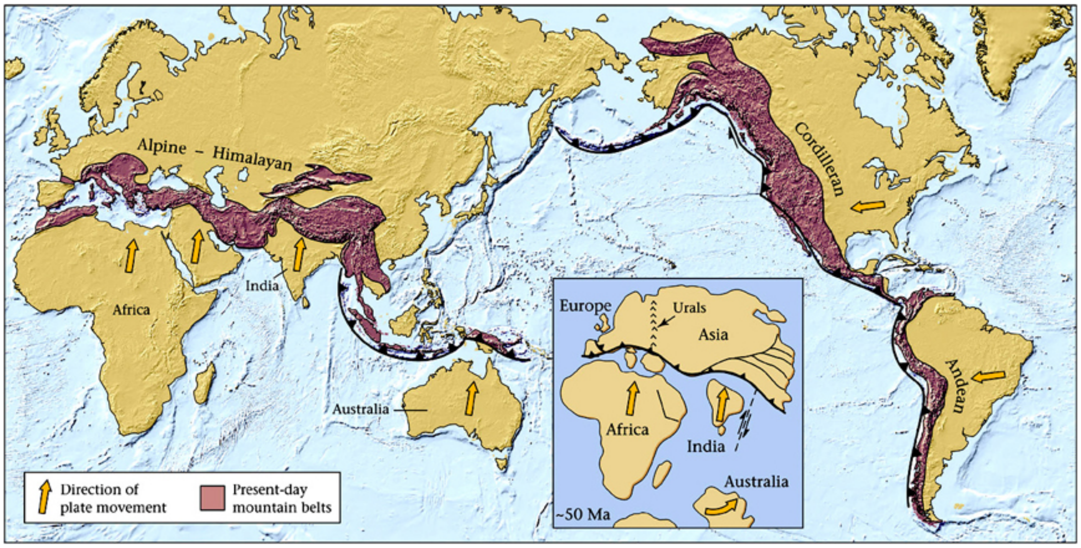
Chicxulub crater = impact site

The Phanerozoic Eon (≤0.541 Ga)

The Cenozoic Era: 65 Ma-Present

Africa and India collided with Eurasia = Alpine-Himalayan Chain of mountains.

Atlantic and Indian oceans continued to grow, and Pacific ocean continued to shrink.

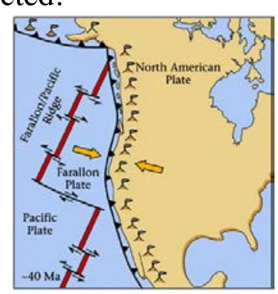


The Phanerozoic Eon (≤0.541 Ga)

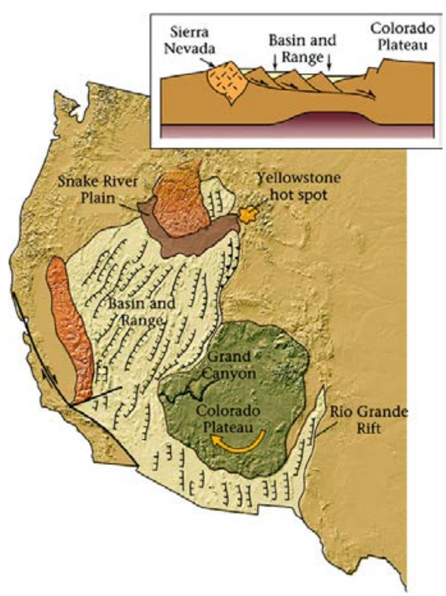
The Cenozoic Era: 65 Ma-Present

Subduction of the Farallon Plate was almost completed at ~40 Ma when the Farallon mid-ocean ridge was subducted.

Upon subduction of the ridge, the active margin changed from a convergent boundary to a transform boundary.

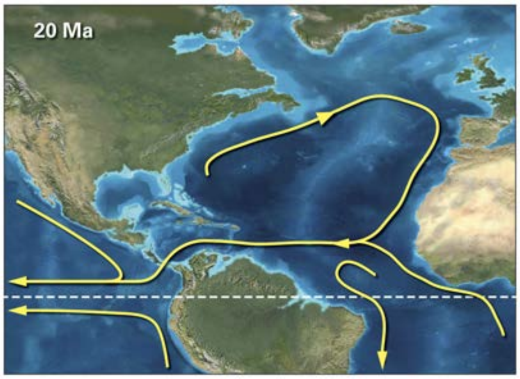


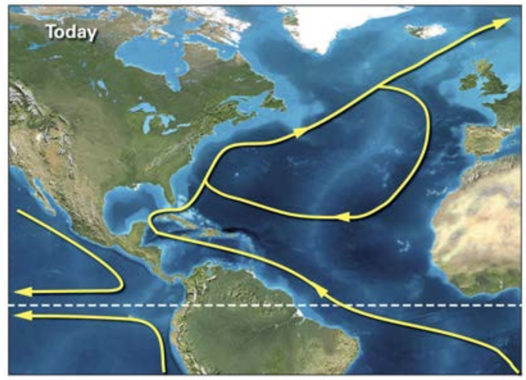
South of the Cascades, stretching commenced and produced the Basin and Range Province.



The Phanerozoic Eon (≤0.541 Ga)

The Cenozoic Era: 65 Ma-Present





- Global climate has gradually cooled since the Cretaceous. The Antarctic ice cap reappeared in the early Oligocene.
- The Isthmus of Panama emerged 2.5 Ma, cutting off circulation between the Atlantic and the Pacific.
- This reduced temperature equalization and permitted the Arctic Ocean to freeze.

The Phanerozoic Eon (≤0.541 Ga)

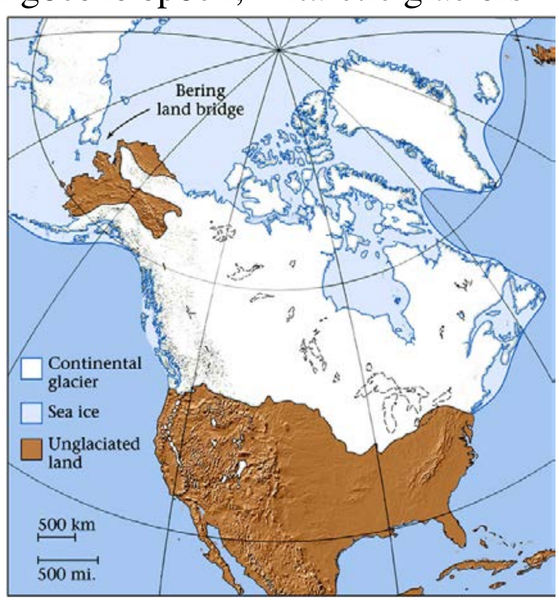
The Cenozoic Era: 65 Ma-Present

Global cooling occurred - by the Oligocene epoch, Antarctic glaciers appeared (first time since the Triassic).

Continued cooling through the Miocene and Pliocene set the scene for the Pleistocene Ice Age that started ~ 2 Ma.

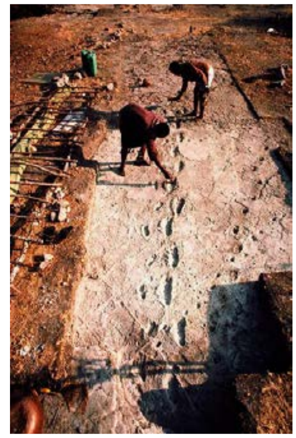
The Bering land bridge allowed species from Asia into the Americas.

Ice age ended ~11,000 years ago.



The Phanerozoic Eon

The Cenozoic Era: 65 Ma-Present



Plants, insects, and small animals survived the K-T extinction.
Mammals took over as the Dinosaurs did not survive much past 65 Ma. Birds are their descendants.
During the Miocene the first human-like primate appeared.
The *Homo* genus appeared ~2.4 Ma.
Fossil evidence indicates that *Homo erectus* (capable of making tools) appeared at ~1.6 Ma.
The line leading to *Homo sapiens* diverged from *Homo neanderthalensis* ~500,000 years ago.

Much of human evolution occurred the radically shifting climatic conditions of the Pleistocene epoch.

Summary

Tools for Unravelling Earth History:

Recognizing - Orogens; Continental Growth; Past Depositional Environments; Past Sea Level Changes; Paleolatitudes; Past Climates; Evolution.

Hadean Eon.
Archean Eon.
Proterozoic Eon.
Phanerozoic Eon: Paleozoic; Mesozoic; Cenozoic.