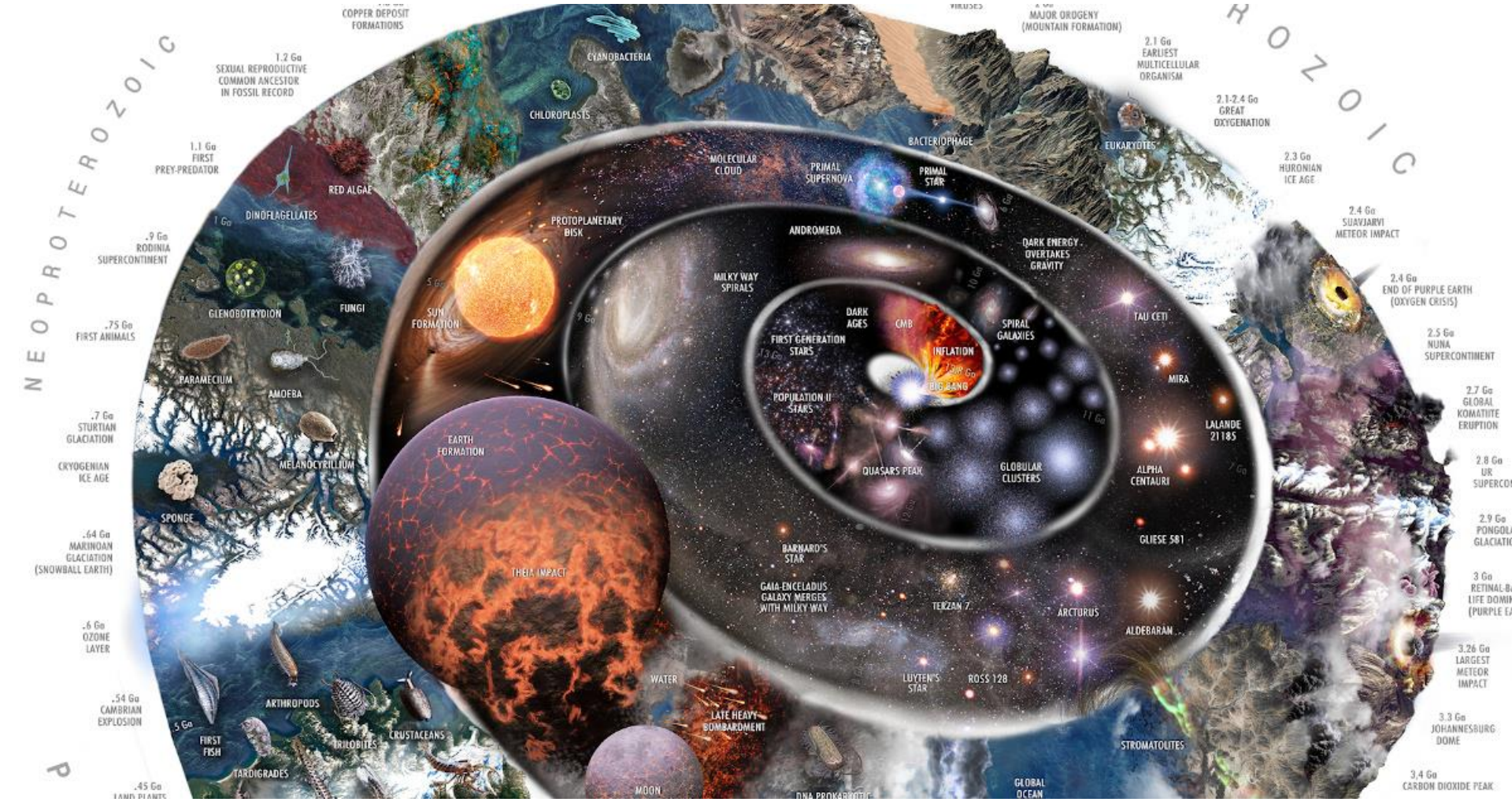
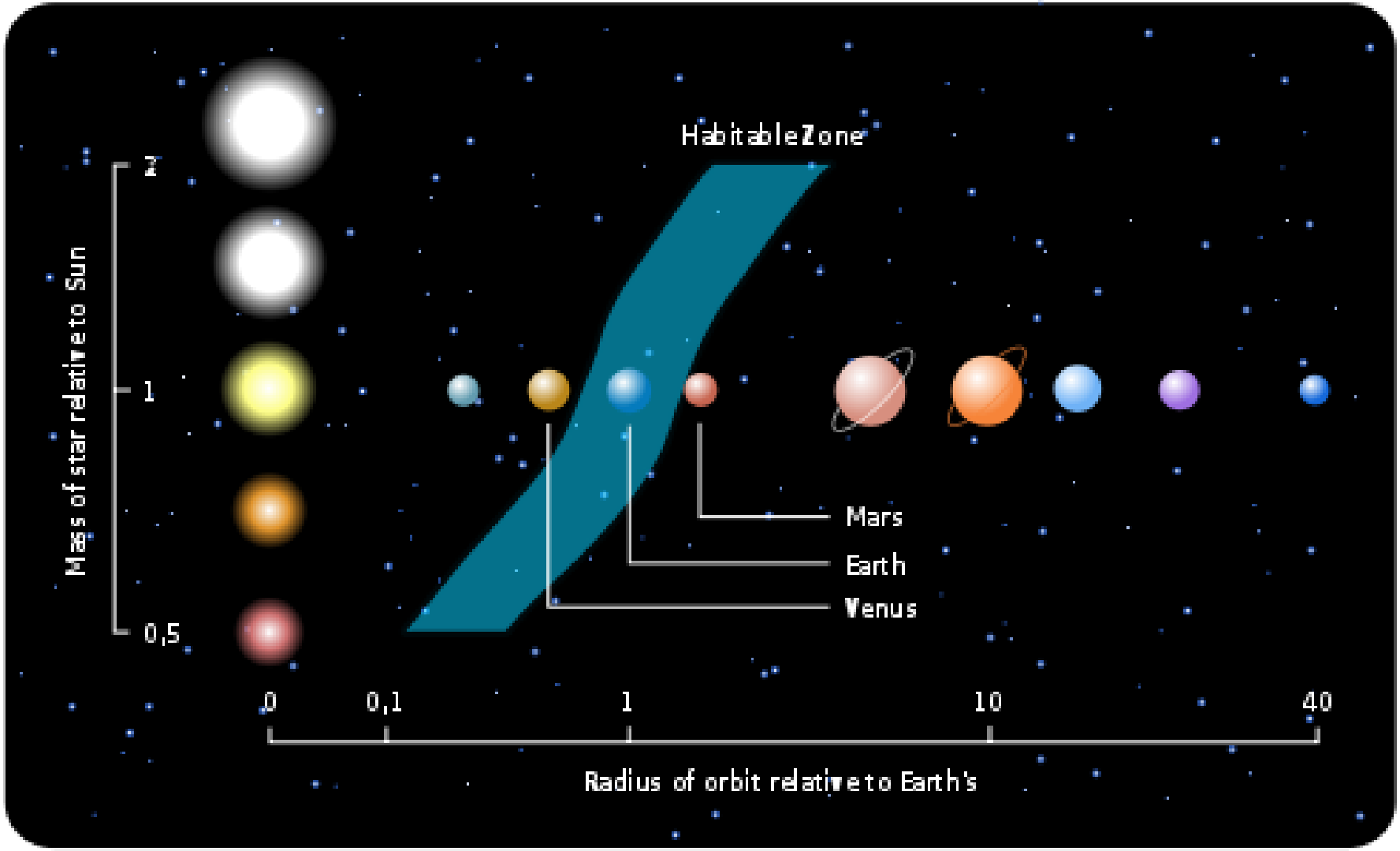
Earth's Evolution Through Geologic Time



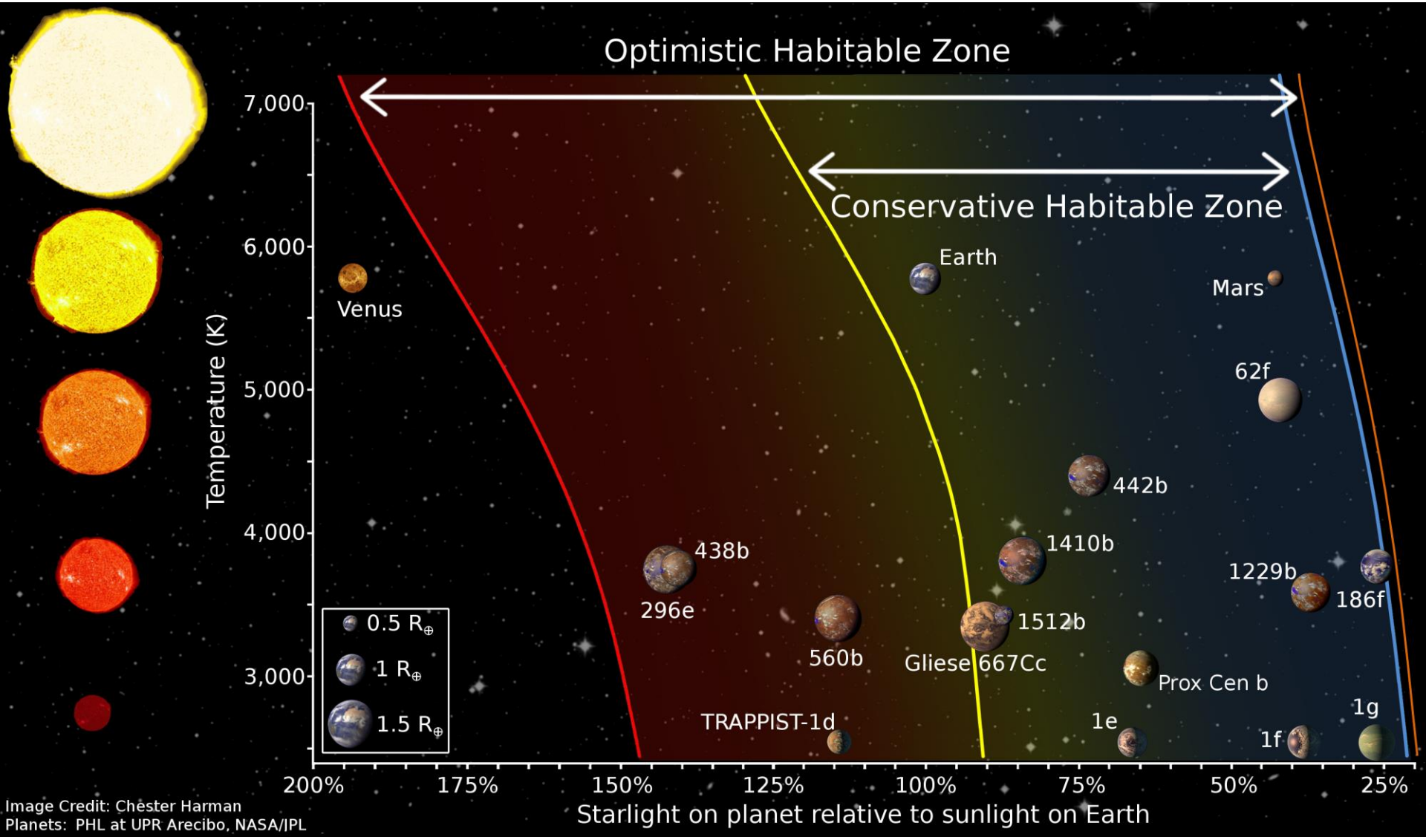
What Makes Earth Habitable?

The Habitable Zone: Sufficient atmospheric pressure so liquid water can be maintained on the surface

- The right planet
  - Correct size to support life as we know it
  - Molten metallic core
  - Plate tectonics
- The right location—distance from the Sun
- The right time
  - Atmosphere has evolved over time
  - Geologic events have shaped Earth


Habitable Zone
Mass of star relative to Sun
2
1
0,5
Mars
Earth
Venus
0
0,1
1
10
40
Radius of orbit relative to Earth's

Exoplanets


Optimistic Habitable Zone
Conservative Habitable Zone
Temperature (K)
7,000
6,000
5,000
4,000
3,000
Venus
Earth
Mars
62f
442b
1410b
438b
296e
1229b
186f
1512b
560b
Gliese 667Cc
Prox Cen b
TRAPPIST-1d
1e
1f
1g
0.5 R⊕
1 R⊕
1.5 R⊕
200%
175%
150%
125%
100%
75%
50%
25%
Starlight on planet relative to sunlight on Earth
Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/IPL

How did our solar system come to be?

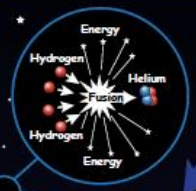
National Aeronautics and Space Administration

It all began about 4.6 billion years ago in a wispy cloud of gas and dust.

At some point, part of the cloud collapsed in on itself—possibly because the shockwave of a nearby supernova explosion caused it to compress.

The result: a flat spinning disk of dust and gas.

4.6 Billion Years Ago



When enough material collected at this disk's center, nuclear fusion began. Our sun was born. It gobbled up 99.8% of all the material.

These clumps became planets, dwarf planets, asteroids, comets, and moons.

This cloud was a small part of a much bigger cloud.

Nuclear fusion occurs when hydrogen atoms fuse into helium.

The material left behind by the sun clumped together into bigger and bigger pieces.

Present

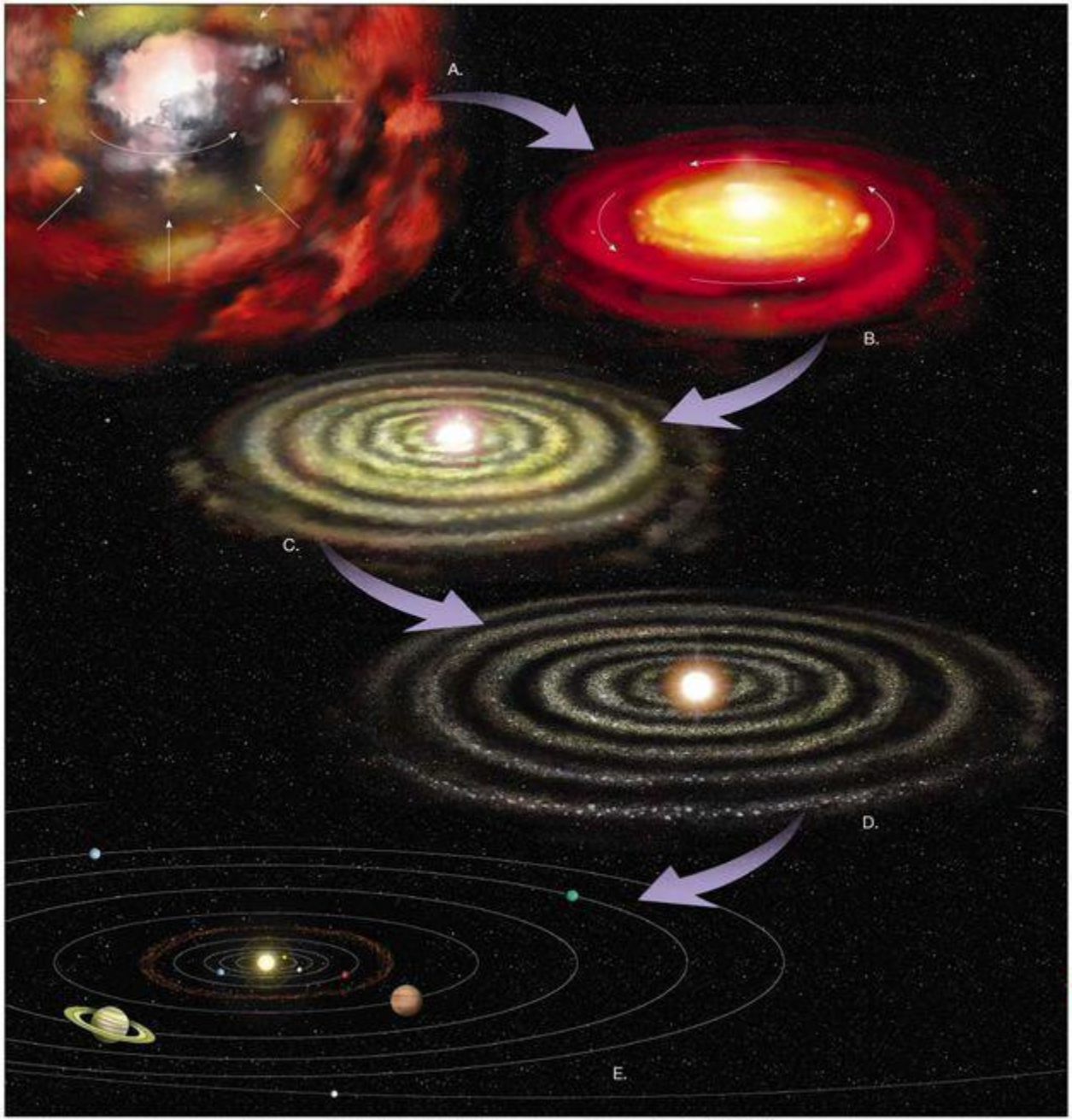
Only rocky things could survive close to the sun, so gaseous and icy material collected further away. That's how our solar system came to be the place it is today!

Comets and asteroids are the left over remains of the solar system's formation.

Space Place in a Snap!

Accretion

The nebular hypothesis

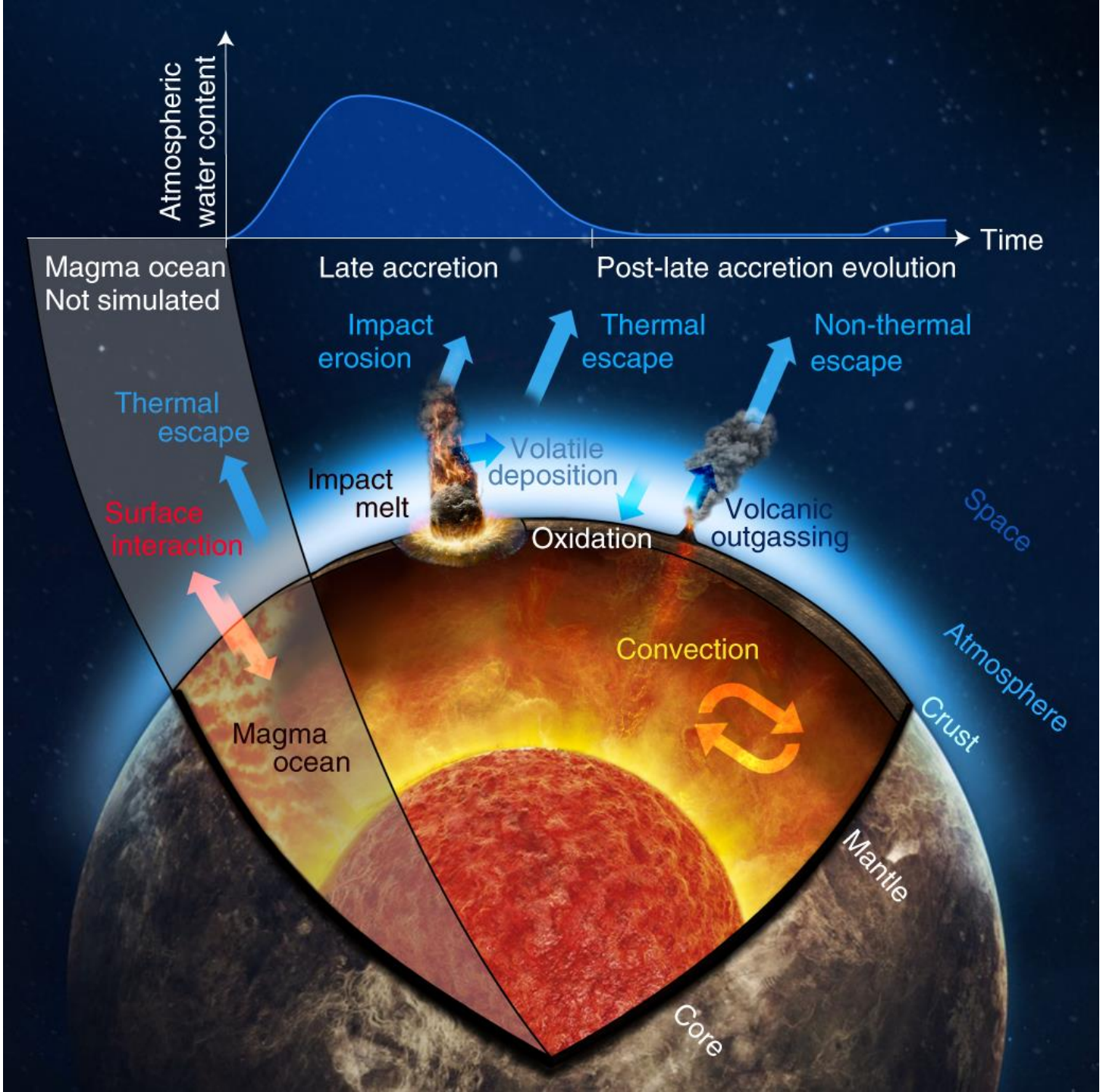


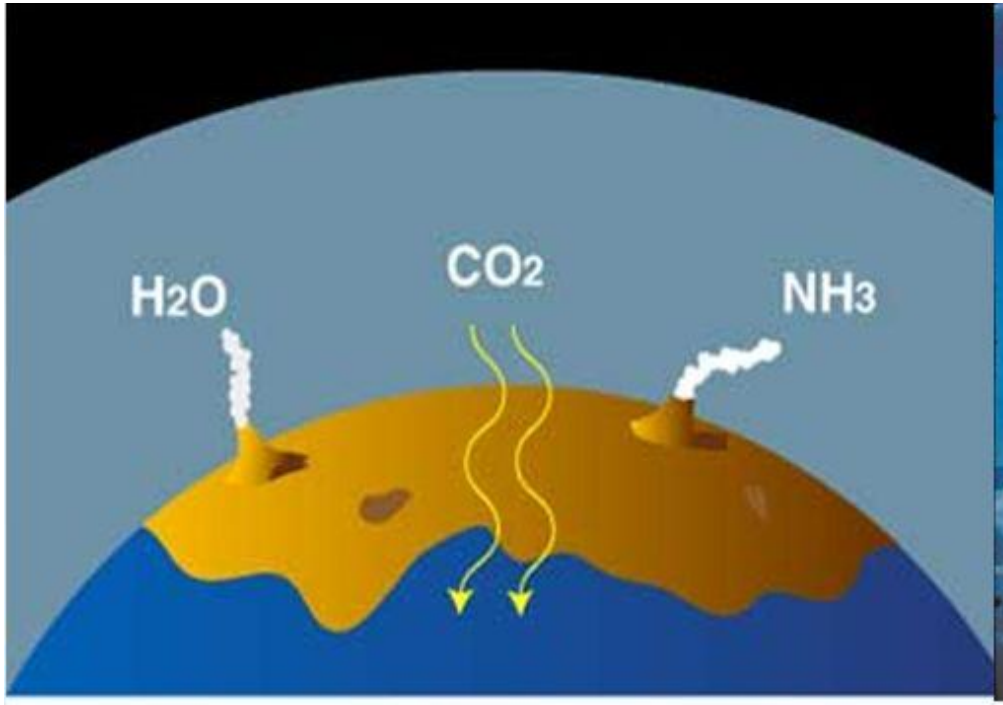
The solar nebula (gas) contracted, cooled and *condensed* into dust sized particles that accreted (stuck together as the result of collisions) into protoplanets (asteroid sized bodies) and then larger planets

http://meteorites.asu.edu/

The Hadean Eon

The Hadean Eon

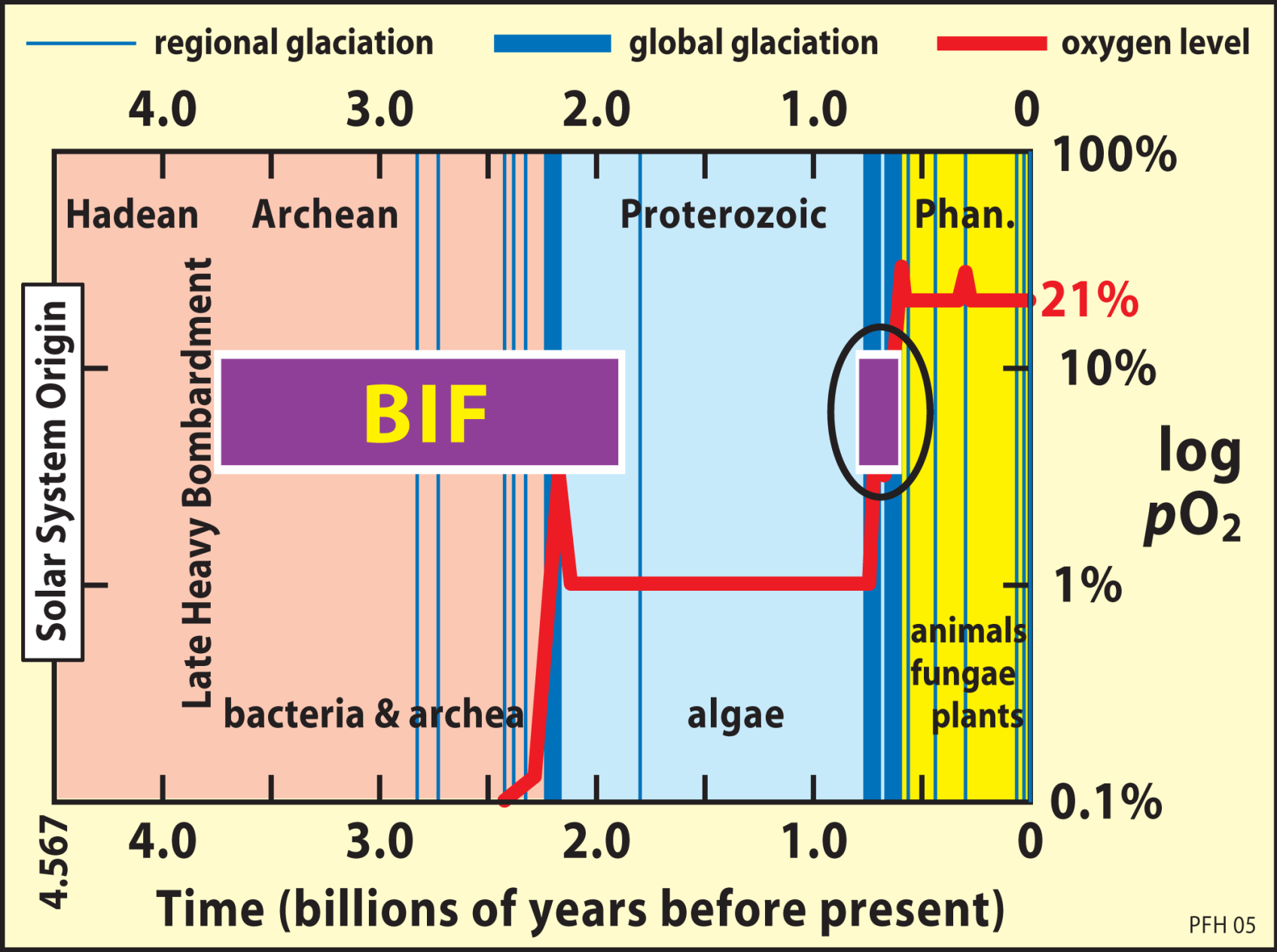

Atmospheric water content
Time
Magma ocean
Not simulated
Late accretion
Post-late accretion evolution
Impact erosion
Thermal escape
Non-thermal escape
Thermal escape
Surface interaction
Impact melt
Volatile deposition
Oxidation
Volcanic outgassing
Space
Atmosphere
Crust
Mantle
Core
Convection
Magma ocean

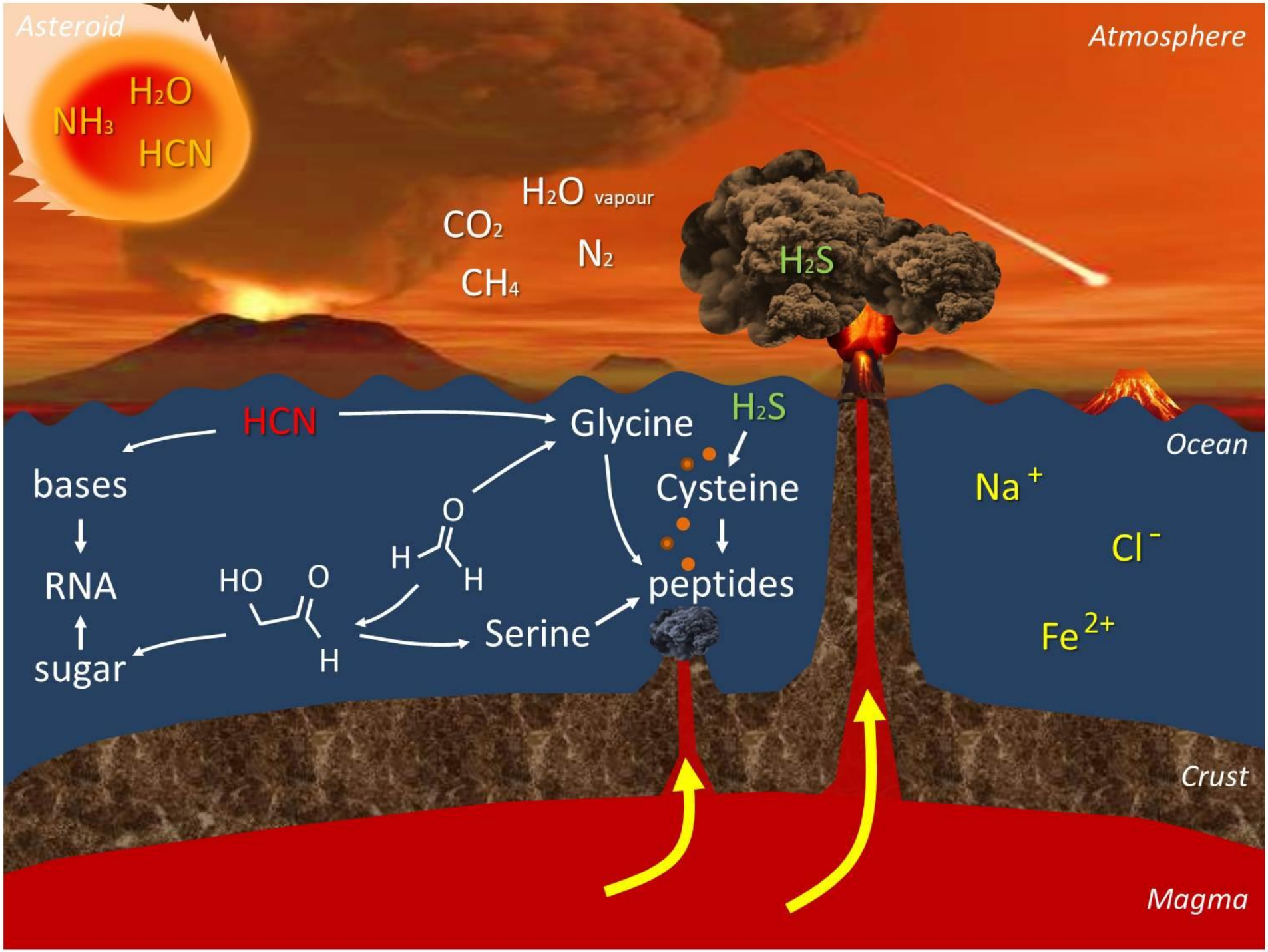


Atmosphere #2

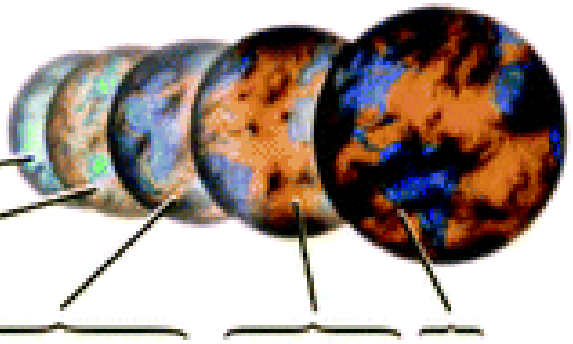
EARTH'S SECOND ATMOSPHERE

- The second atmosphere was the result of outgassing from wide spread volcanic activity.
- The early atmosphere was probably rich in carbon dioxide (CO_2), nitrogen (N_2), methane(CH_4), ammonia (NH_3), and water vapor (H_2O)
- This atmosphere was void of free oxygen (O_2)


regional glaciation
global glaciation
oxygen level
4.0
3.0
2.0
1.0
0
100%
Hadean
Archean
Proterozoic
Phan.
21%
10%
Solar System Origin
Late Heavy Bombardment
BIF
log
pO2
1%
animals
fungae
plants
bacteria & archea
algae
0.1%
4.567
4.0
3.0
2.0
1.0
0
Time (billions of years before present)
PFH 05


Asteroid
H_2O
NH_3
HCN
Atmosphere
H_2O vapour
CO_2
N_2
CH_4
H_2S
HCN
Glycine
H_2S
bases
Cysteine
Ocean
Na^+
RNA
peptides
Cl^-
Fe^{2+}
sugar
Serine
Crust
Magma

Earth's Atmosphere Through Time



Escape to space

Water, H_2, CO

Steam Atm.

?

Temperature

Ice Ages

CO_2

O_2

Impacts ?

CH_4

+ other reduced gases

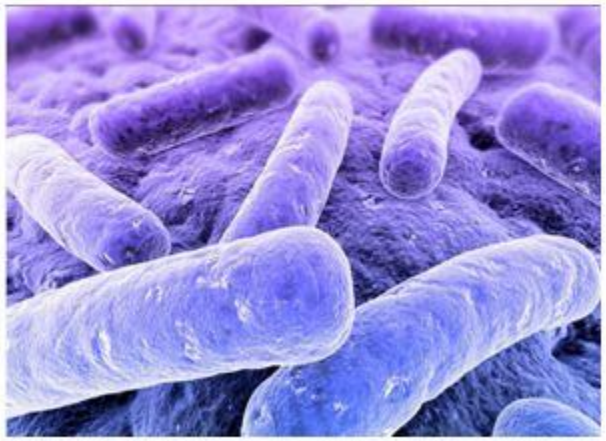
Abundance

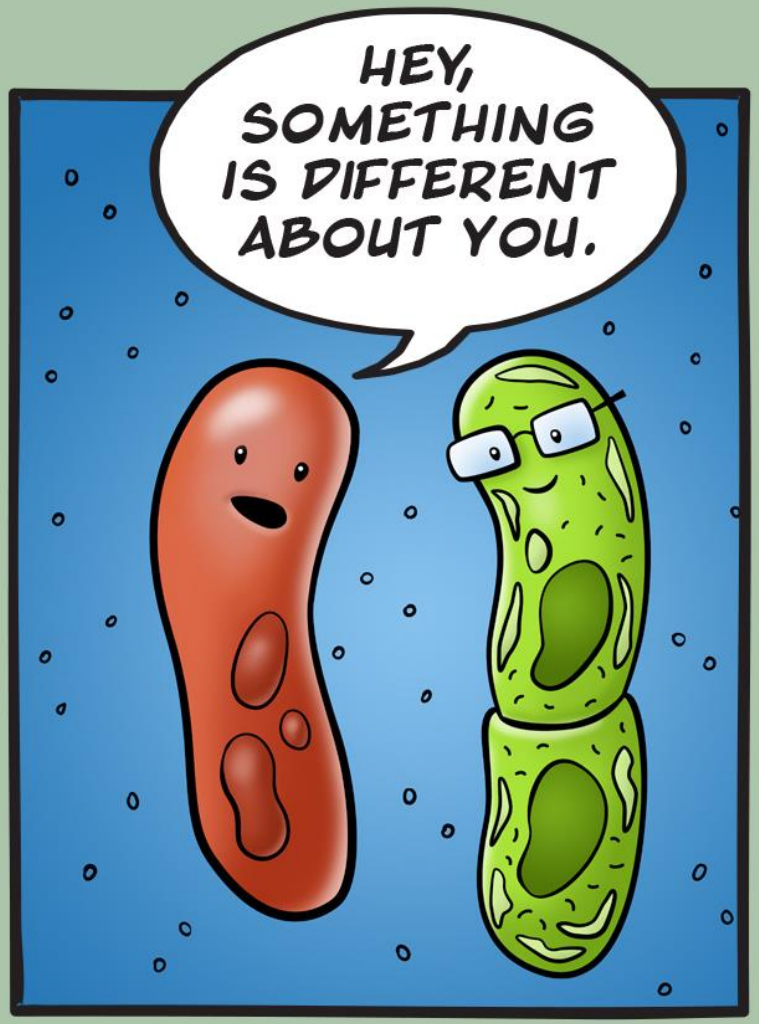
4.56 4.46 4.44 4.2 3.8 3.5 2.2 0.6 Today

Time before present, billions of years

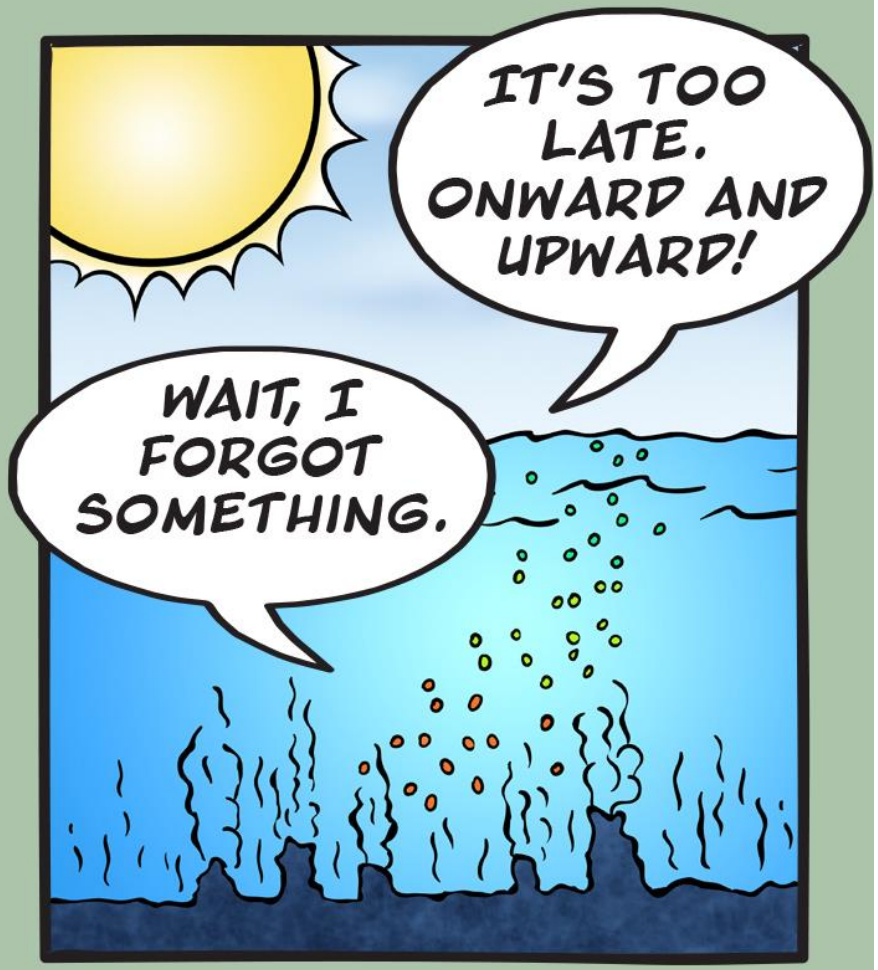
EVOLUTION OF PHOTOSYNTHESIS

- First photosynthetic organisms (prokaryotes) appeared ca. 3.5 bya
- Likely used hydrogen sulfide (H_2S) as electron source
- Earliest forms of photosynthesis were <u>anoxygenic</u> - light energy captured & converted to ATP *without* production of O_2, so H_2O not used as electron donor
  - Extant examples: green sulfur bacteria, purple bacteria, heliobacteria

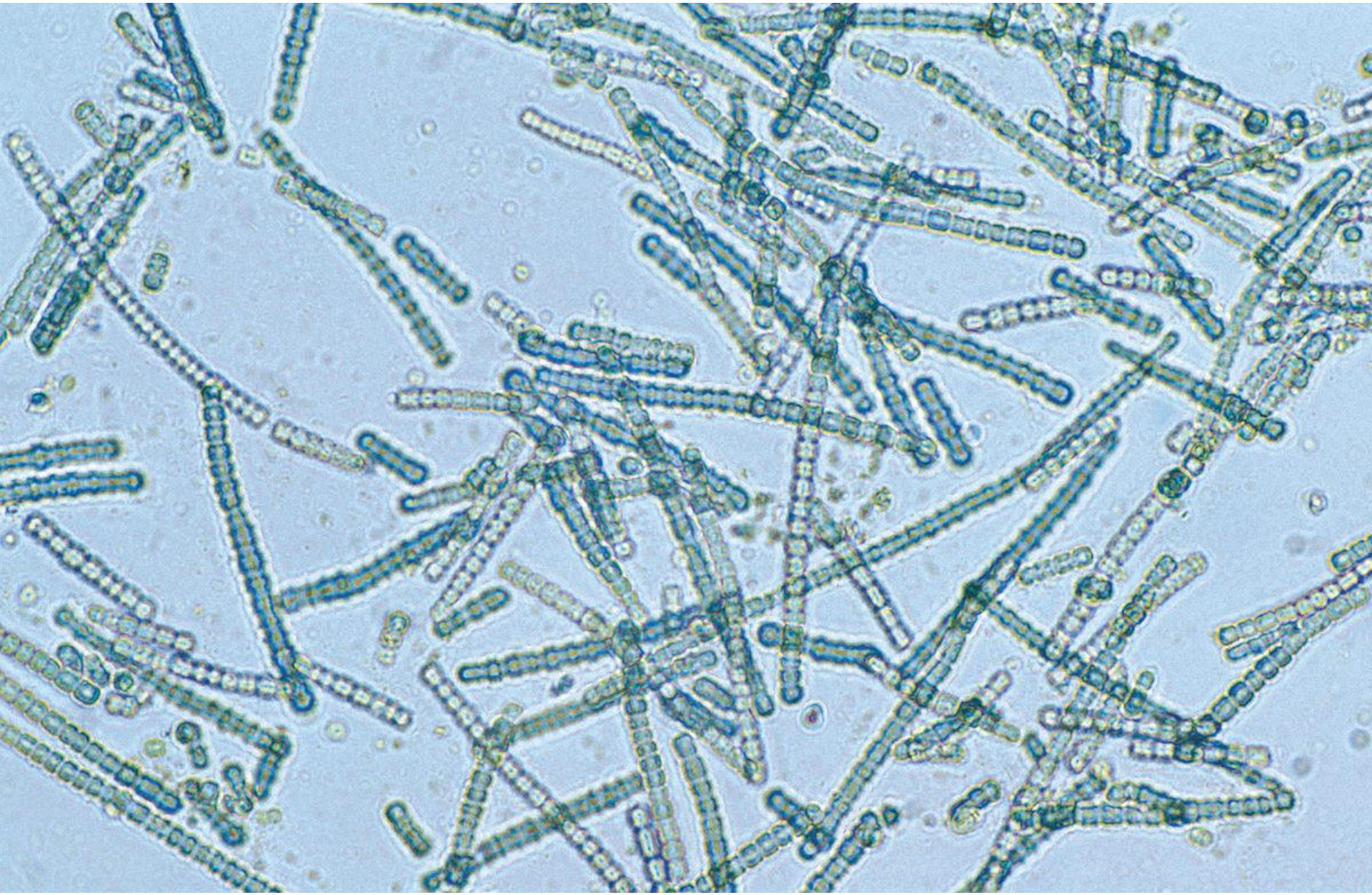




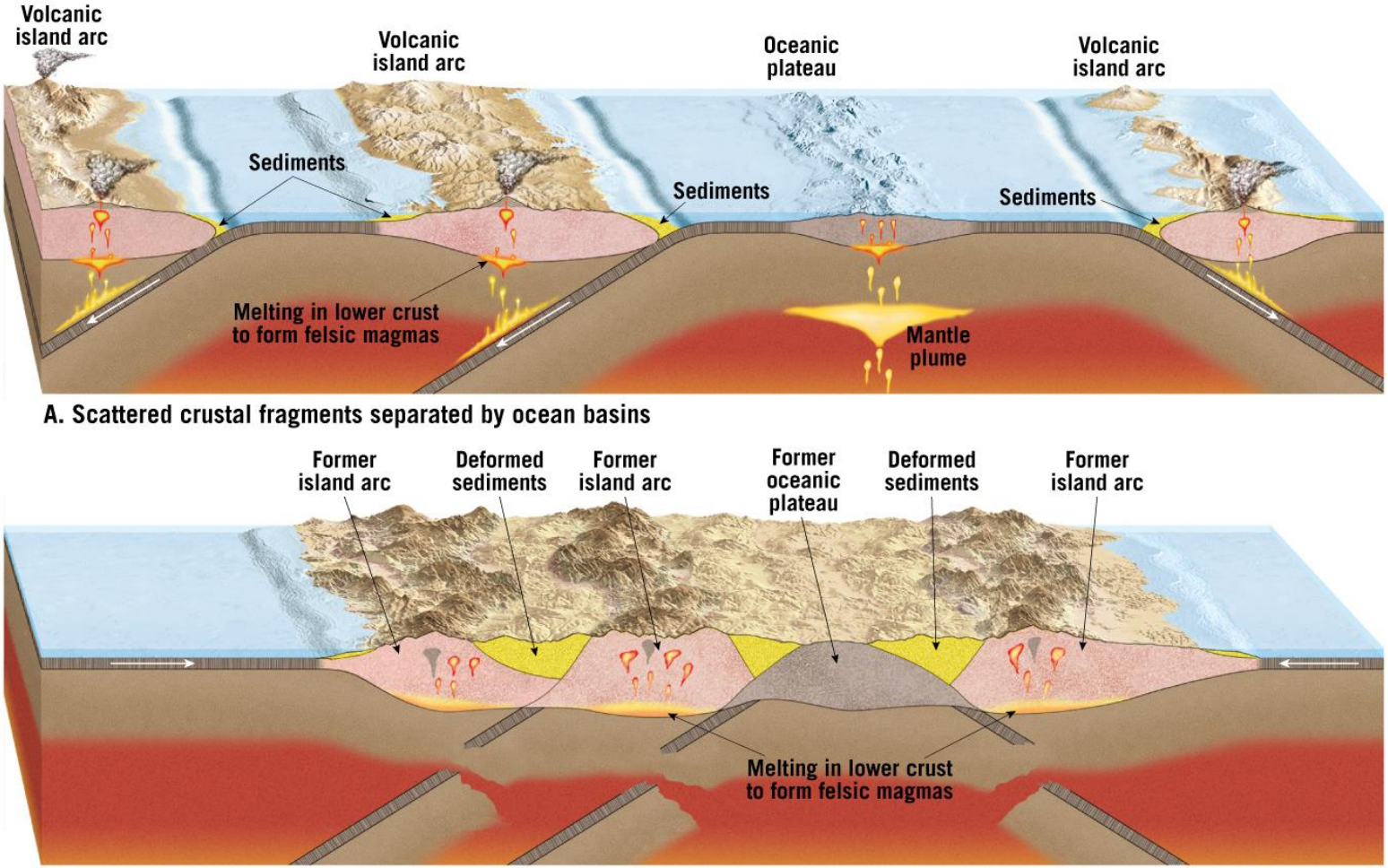
Some bacteria developed "oxygen-evolving complexes" and "chlorophyll reaction centers," allowing them to extract electrons from water using light from the sun.



The evolutionary innovations led to an exodus, and the first photosynthetic pioneers left for more well-lit pastures.



Formation of Continents



Distribution of Crustal Material Remaining from the Archean and Proterozoic Eons

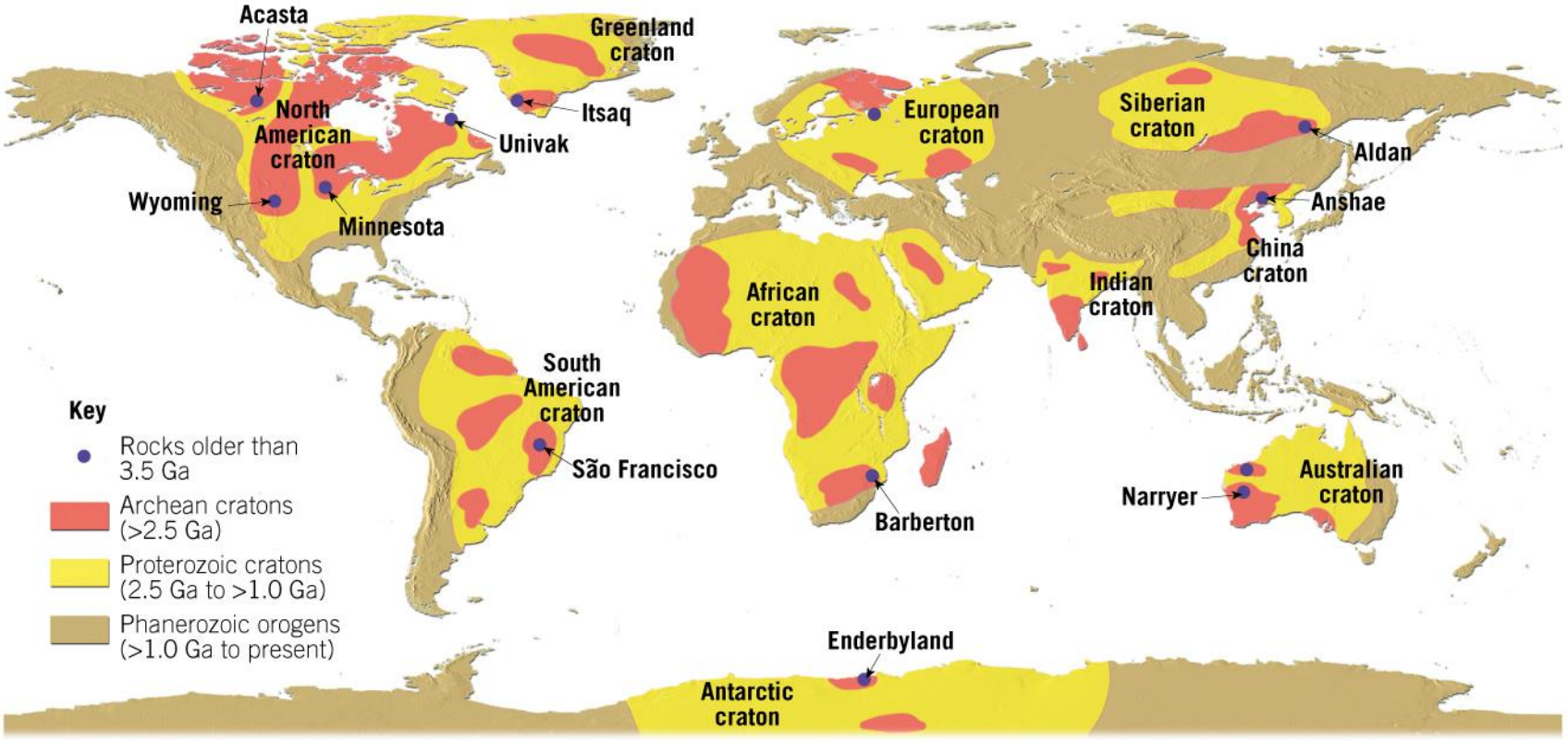


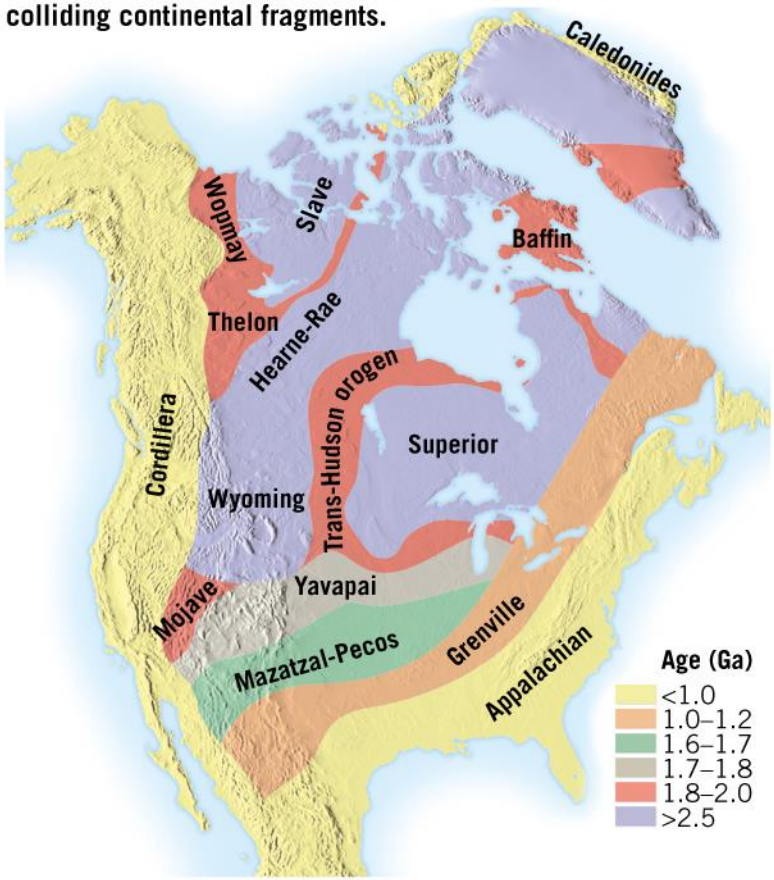
Figure 1. Simplified tectonic map of North America. BR - Basin and Range; BRO - Brooks Range; MK - Mackenzie Mountains; MA - Marathon uplift; OU - Ouachita Mountains; M.A.R. - Mid-Atlantic Ridge; E.P.R. - East Pacific Rise.

The Making of North America

- Very little crust older than 3.5 billion remains
- Major continental growth 2.5–3.5 billion years ago
- Largely built by 1 billion years ago

The Major Geologic Provinces of North America

North America was assembled from crustal blocks that were joined by processes very similar to modern plate tectonics. Ancient collisions produced mountain belts that include remnant volcanic island arcs, trapped by colliding continental fragments.



Supercontinents of the Precambrian

- Supercontinents
  - Large landmasses that consist of all, or nearly all, existing continents
  - Supercontinent Cycle: rifting and dispersal of one supercontinent followed by long periods of gradual reassembly
    - Pangaea—most recent
    - Rodinia—larger, earlier than Pangaea

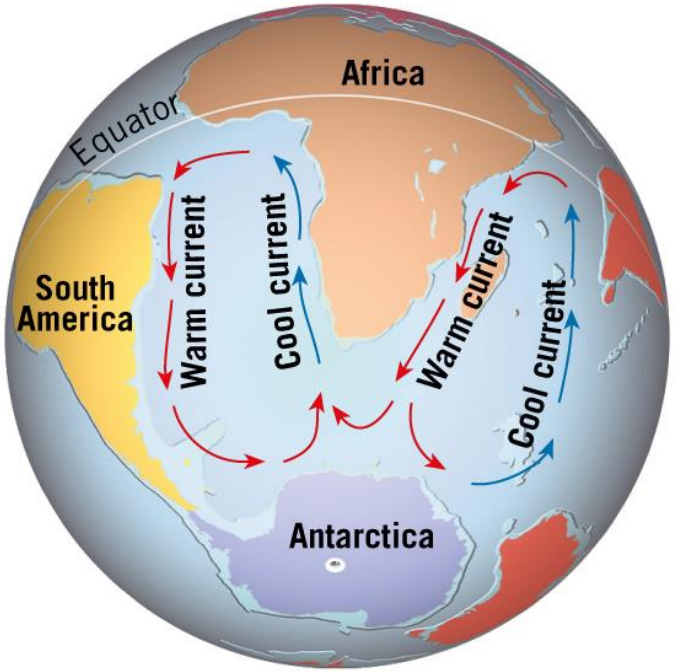
Possible Configuration of the Supercontinent Rodinia

Supercontinents of the Precambrian

- Climate
  - Movement of continents changes ocean current patterns
  - Affects precipitation and temperature
- Sea-Level Changes
  - Significant and numerous changes in geologic history related to assembly and dispersal of supercontinents
  - Directly related to seafloor spreading

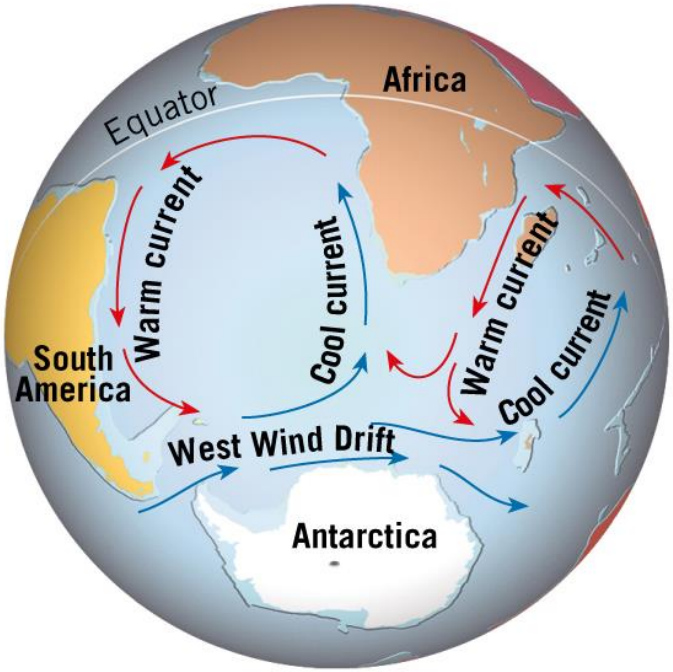
Connection between Ocean Circulation and the Climate in Antarctica

50 million years ago warm ocean currents kept Antarctica nearly ice free.



A. Antarctica not extensively glaciated

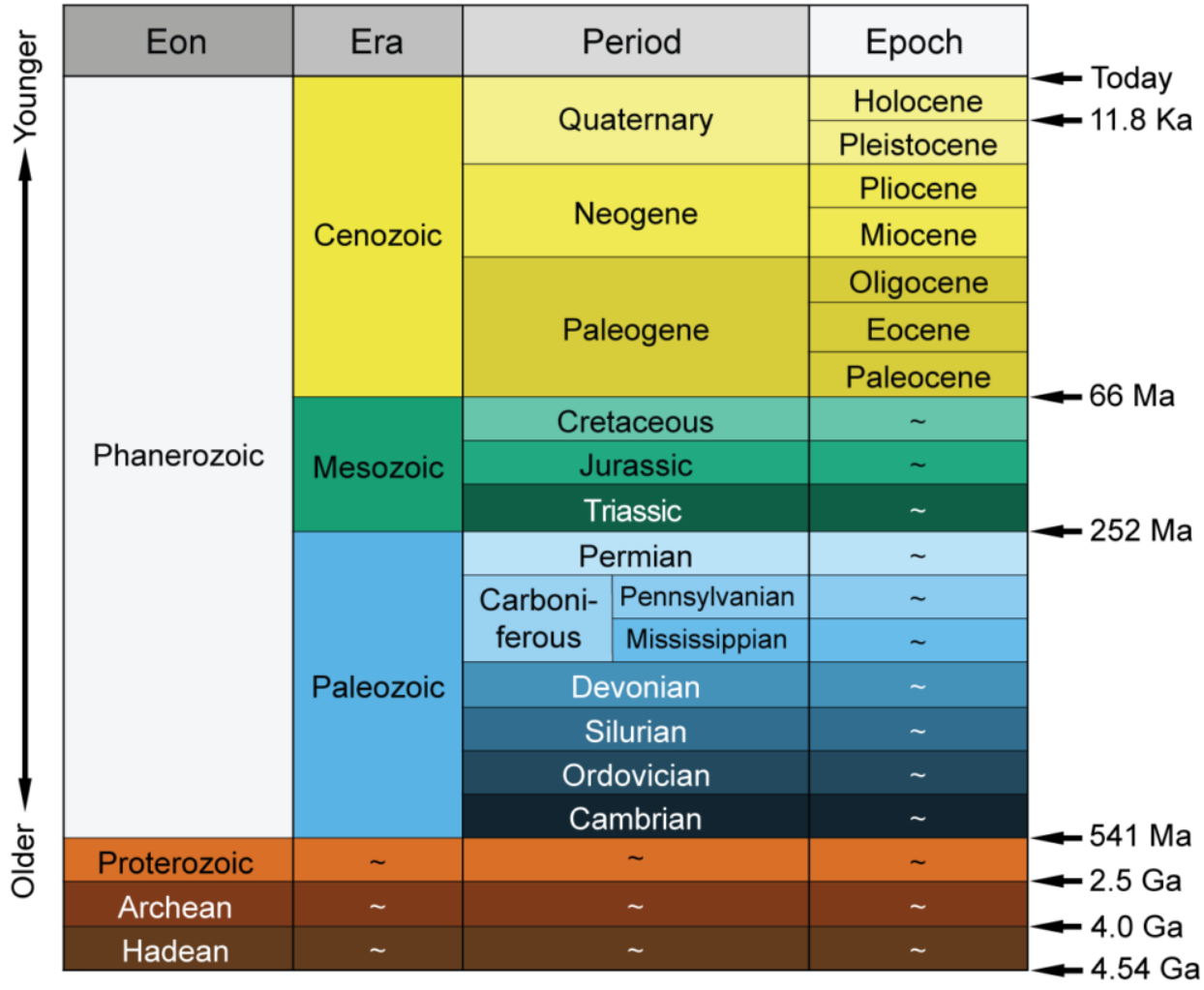
As South America separated from Antarctica, the West Wind Drift developed. This newly formed ocean current effectively cut Antarctica off from warm currents and contributed to the formation of its vast ice sheets.

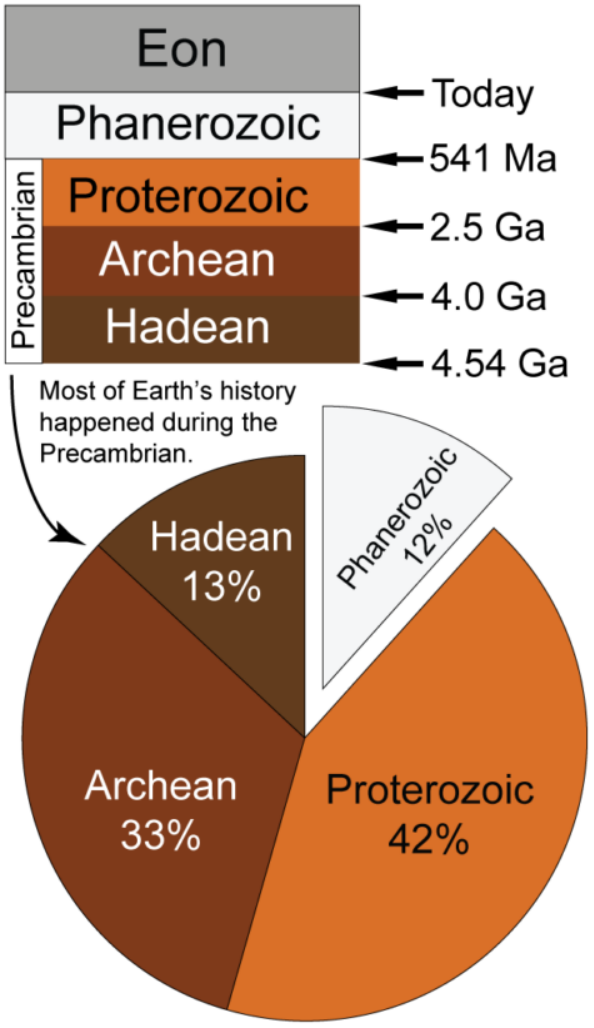


B. Antarctica covered by continental-size ice sheets

Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents

- Structure of the geologic time scale
  - An eon represents the greatest expanse of time
    - The Phanerozoic eon ("visible life") is the most recent eon, which began about 542 million years ago, divided into eras
      - Paleozoic era ("ancient life")
      - Mesozoic era ("middle life")
      - Cenozoic era ("recent life")

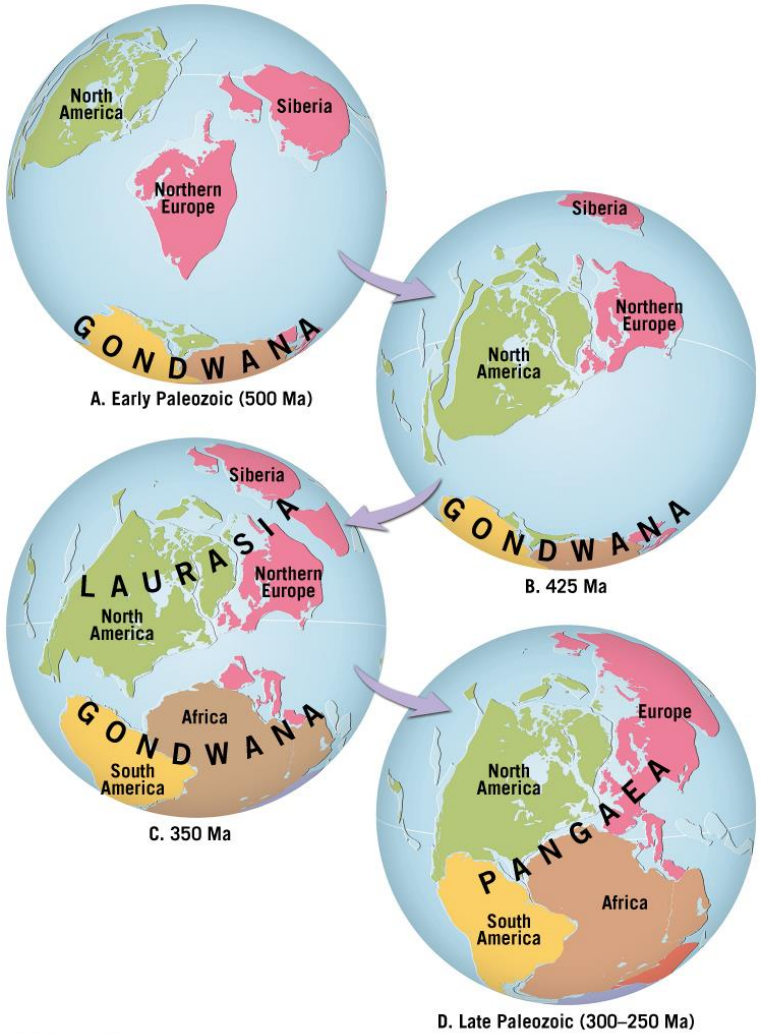

Younger
Older
Eon
Era
Period
Epoch
Phanerozoic
Cenozoic
Quaternary
Holocene
Pleistocene
Neogene
Pliocene
Miocene
Paleogene
Oligocene
Eocene
Paleocene
Mesozoic
Cretaceous
Jurassic
Triassic
Paleozoic
Permian
Carboni-ferous
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Proterozoic
Archean
Hadean
~
Today
11.8 Ka
66 Ma
252 Ma
541 Ma
2.5 Ga
4.0 Ga
4.54 Ga


Eon
Phanerozoic
Precambrian
Proterozoic
Archean
Hadean
Today
541 Ma
2.5 Ga
4.0 Ga
4.54 Ga
Most of Earth's history happened during the Precambrian.
Hadean 13%
Phanerozoic 12%
Archean 33%
Proterozoic 42%

Paleozoic History

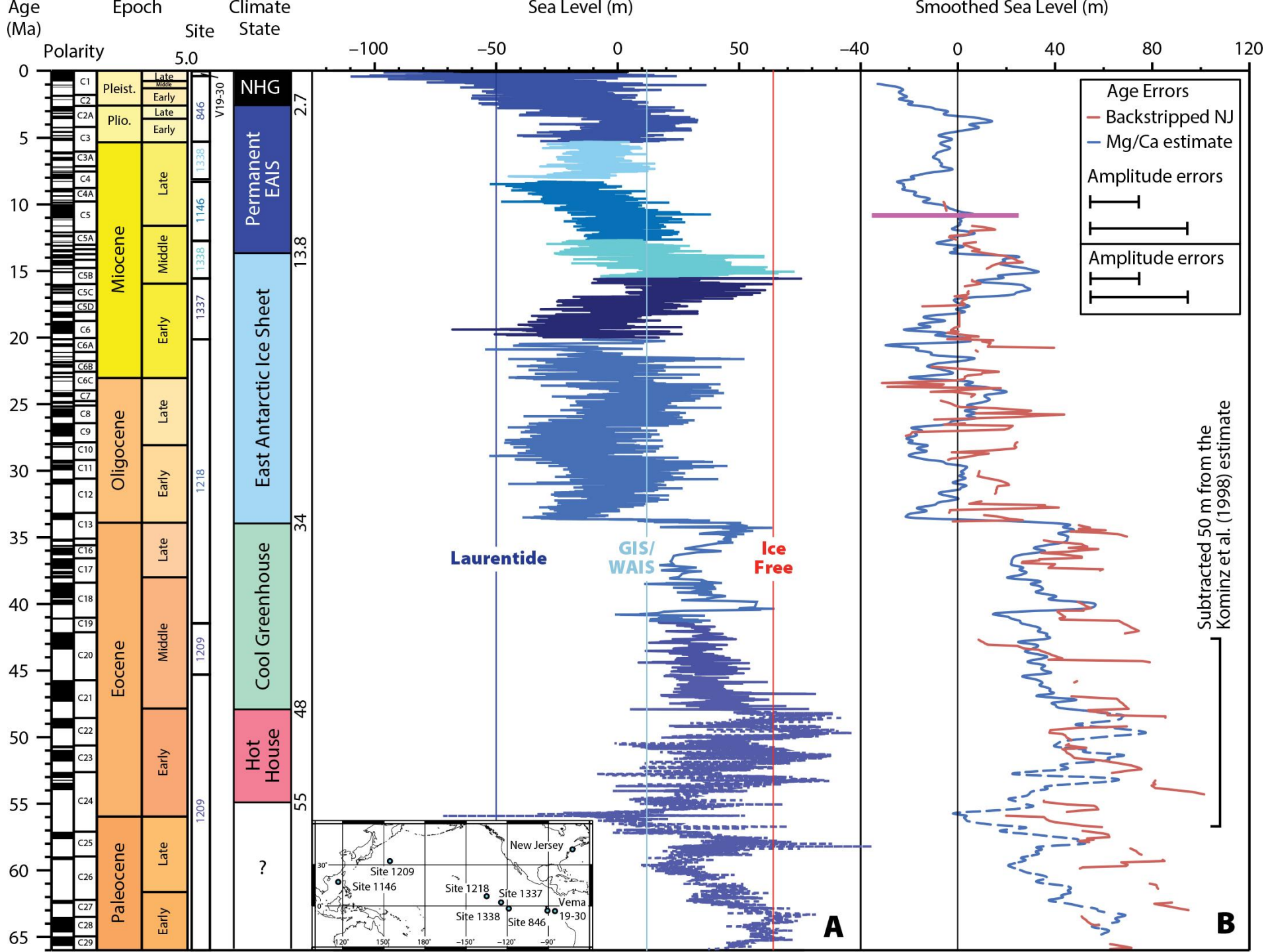
- Paleozoic era
  - Dominated by continental collisions as Pangaea began to assemble
    - Formed the Caledonian, Appalachian, and Ural Mountains

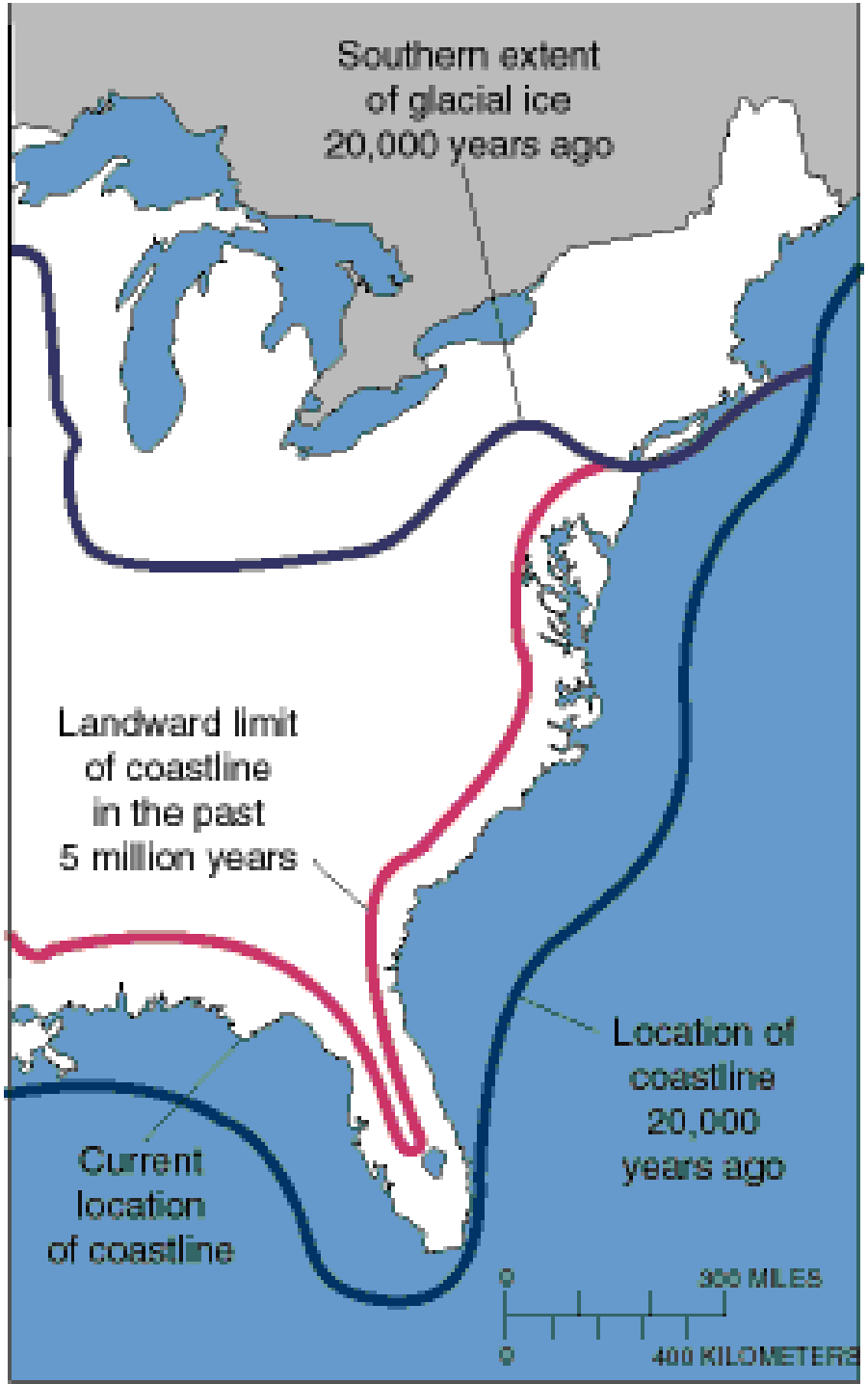
Formation of Pangaea



Mesozoic History

- Sea-Level Changes
  - Early Mesozoic: much of the land was above sea level
  - Middle Mesozoic seas invaded western North America
- Coal formation in Western North America
- Pangaea began to break apart
  - Resulted in crustal deformation along the entire western margin of North America, subduction
  - Formed the North American Cordillera (Sierra Nevada and Rocky Mountains)


Age (Ma)
Epoch
Site
Climate State
Sea Level (m)
Smoothed Sea Level (m)
Polarity
5.0
−100
−50
0
50
−40
0
40
80
120
Pleist.
Plio.
Miocene
Oligocene
Eocene
Paleocene
Late
Middle
Early
846
1338
1146
1337
1218
1209
V19-30
NHG
Permanent EAIS
East Antarctic Ice Sheet
Cool Greenhouse
Hot House
?
2.7
13.8
34
48
55
Laurentide
GIS/ WAIS
Ice Free
Age Errors
Backstripped NJ
Mg/Ca estimate
Amplitude errors
Amplitude errors
Subtracted 50 m from the Kominz et al. (1998) estimate
New Jersey
Site 1209
Site 1146
Site 1218
Site 1337
Vema 19-30
Site 1338
Site 846
A
B


Southern extent
of glacial ice
20,000 years ago
Landward limit
of coastline
in the past
5 million years
Location of
coastline
20,000
years ago
Current
location
of coastline
300 MILES
400 KILOMETERS

Cenozoic History

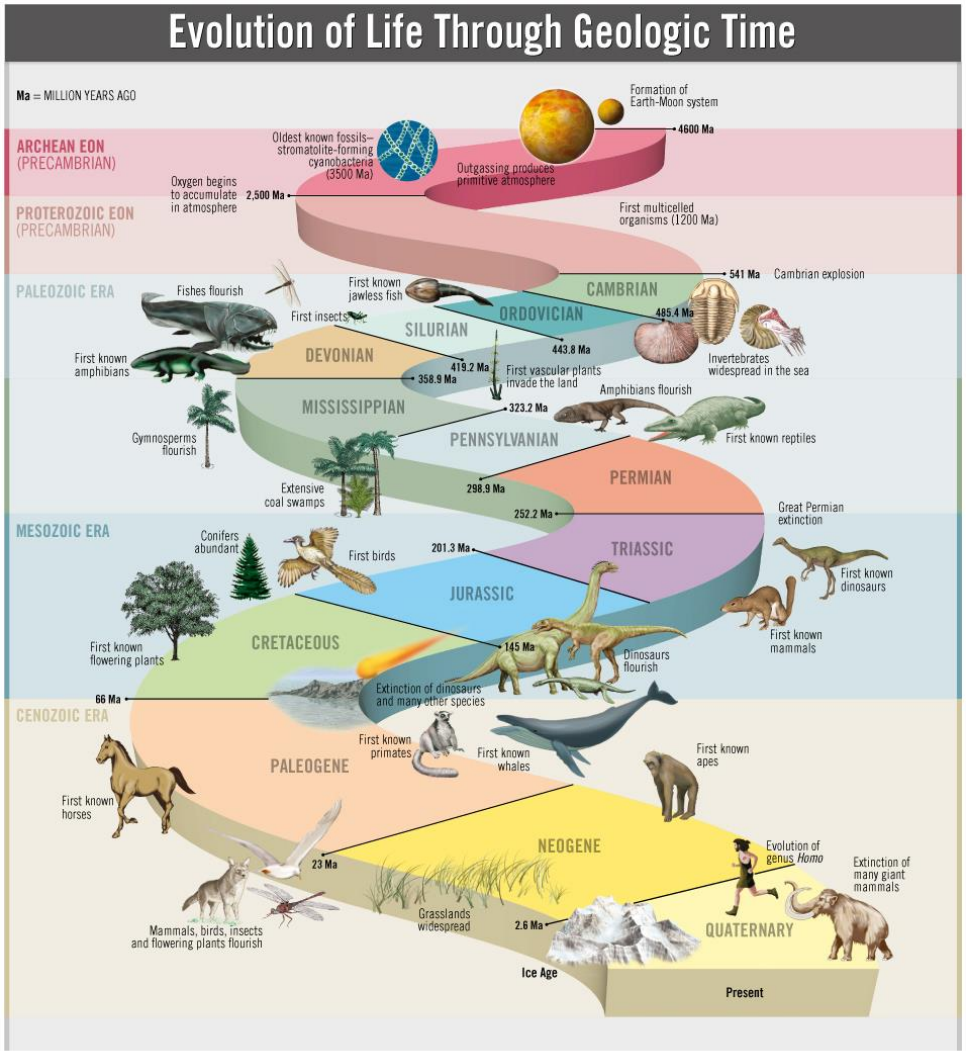
- Much of North America was above sea level throughout the Cenozoic
  - Eastern North America
    - Removed from active plate boundaries, was tectonically stable
  - Western North America
    - Laramide Orogeny (Rocky Mountains building) was ending
    - Basin and Range Province was forming
    - Volcanic activity was extensive

Earth's First Life

Describe some of the hypotheses on the origin of life and the characteristics of early prokaryotes, eukaryotes, and multicellular organisms.

- Oldest fossils are at least 3.5 billion years old
- Origin of Life
  - Considerable Debate, but need:
  - Hospitable environment
  - Chemical raw materials
    - Proteins: primary structural material, composed of amino acids
    - Nucleic acids: allow for replication (DNA, RNA)

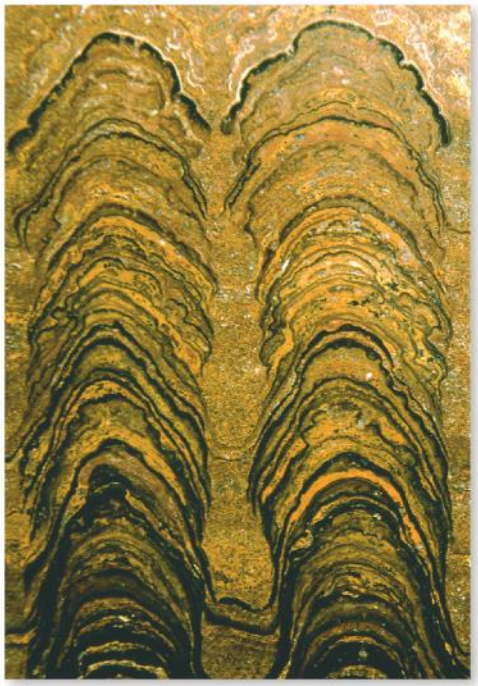
Figure 12.19
Evolution of life Through Geologic Time



Earth's First Life

- Prokaryotes
  - First known organisms
  - Single-celled bacteria
  - DNA is segregated from the rest of the cell nucleus
  - Cyanobacteria is an example
    - Used solar energy to synthesize organic compounds, thus producing their own food
    - Fossil evidence of these bacteria include layered mounds called stromatolites

Figure 12.20
Stromatolites Are Among the Most Common Precambrian Fossils



A.

B.

Earth's First Life

- Eukaryotes
  - Genetic material is segregated into a nucleus
  - More complex than prokaryotes
  - Single celled and complex multicellular

12.7 Paleozoic Era: Life Explodes

List the major developments in the history of life during the Paleozoic era.

- Cambrian explosion: expansion in biodiversity at 541 million years ago
  - All major invertebrates became widespread
    - Jellyfish
    - Sponges
    - Worms
    - Mollusks
    - Arthropods
  - Life restricted to oceans

Paleozoic Era: Life Explodes

- Early Paleozoic Life
  - Hard shells and skeletons
  - Predators and defense mechanisms evolve
  - Known for the evolution of trilobites: early relatives of modern crabs and lobsters

CAMBRIAN PERIOD

About 542 million years ago, the Earth witnessed a great expansion of animal life equivalent to the big bang. This period is also known as the trilobite era, named after the characteristic organisms of that time and one of the first arthropods. Trilobites coexisted with sponges, seaweeds, a range of invertebrates and the first vertebrates without jaws.

THE EARTH AND ITS CHANGES

The land masses were located in the southern hemisphere. The biggest was Gondwana, covering present Southern continents. Laurentia was the second biggest and included most of the present North-America.

1.97 ft.
LENGTH

ANOMALOCARIS

The largest arthropod predator of that era. It had a round mouth with sharp teeth and thorny appendages, allowing it to seize its prey.

PIKAIA

One of the first known chordates. Its tail was like a fin.

MARELLA

This 4 inch arthropod swam along the sea bottom.

PORIFERA

All the types originated in this period. They grew on the sea bed with seaweeds.

HALLUCIGENIA

It had spines it used as protection and to move.

PRIAPULIDA

Sea worms that lived buried in the sand or mud.

Paleozoic Era: Life Explodes

- Mid-Paleozoic Life
  - Land plants evolve from green algae, evolving a vascular system
  - Oceans evolve vertebrates, the ancestors of modern fish


fine art
america

Paleozoic Era: Life Explodes

- Late Paleozoic Life
  - Vertebrates move on to land, evolving from lobe-finned fish
  - Ancestors of amphibians took over land environments
  - Reptiles evolve, developing an egg that can be laid on land, and dominate the land environment

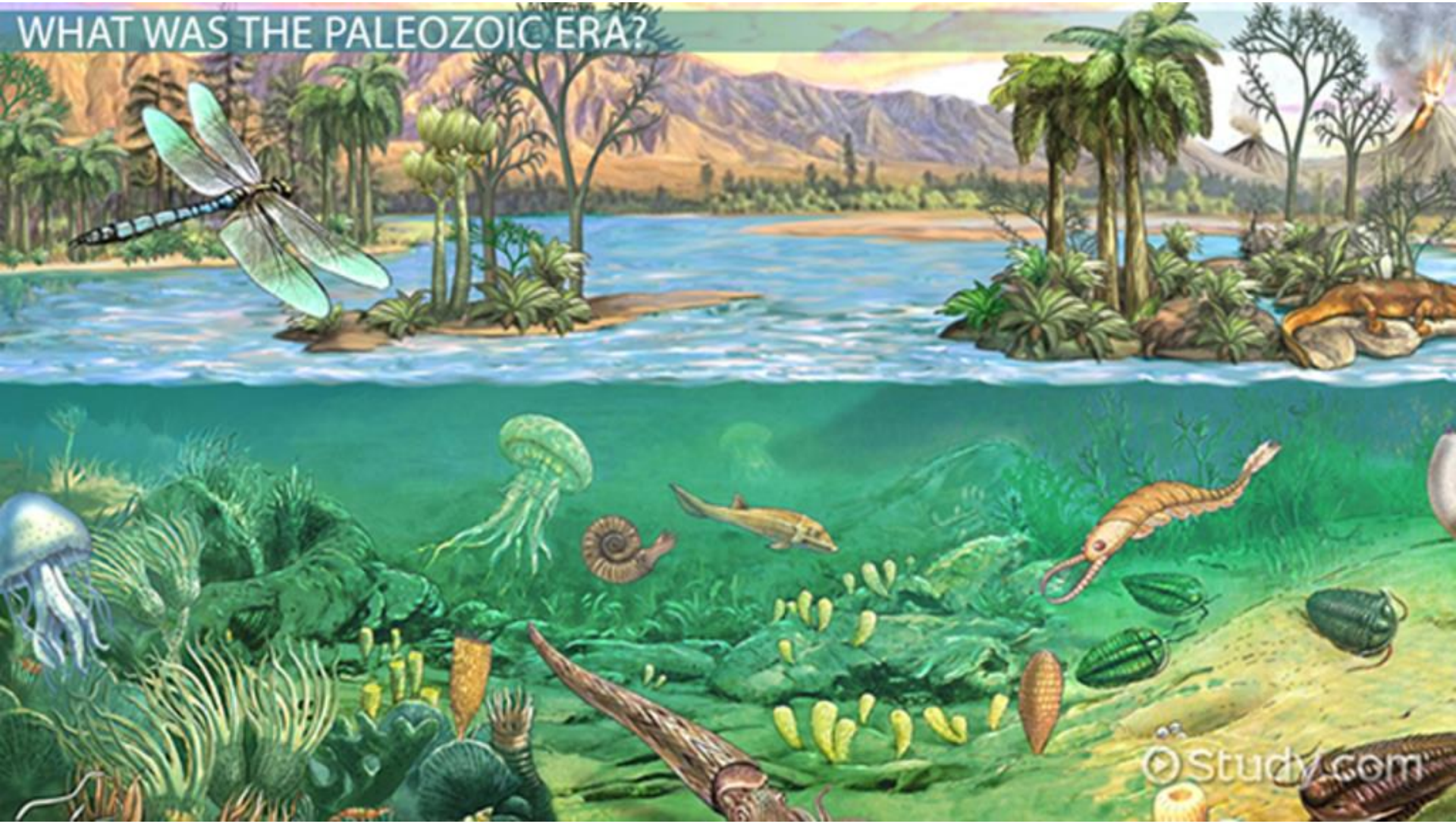
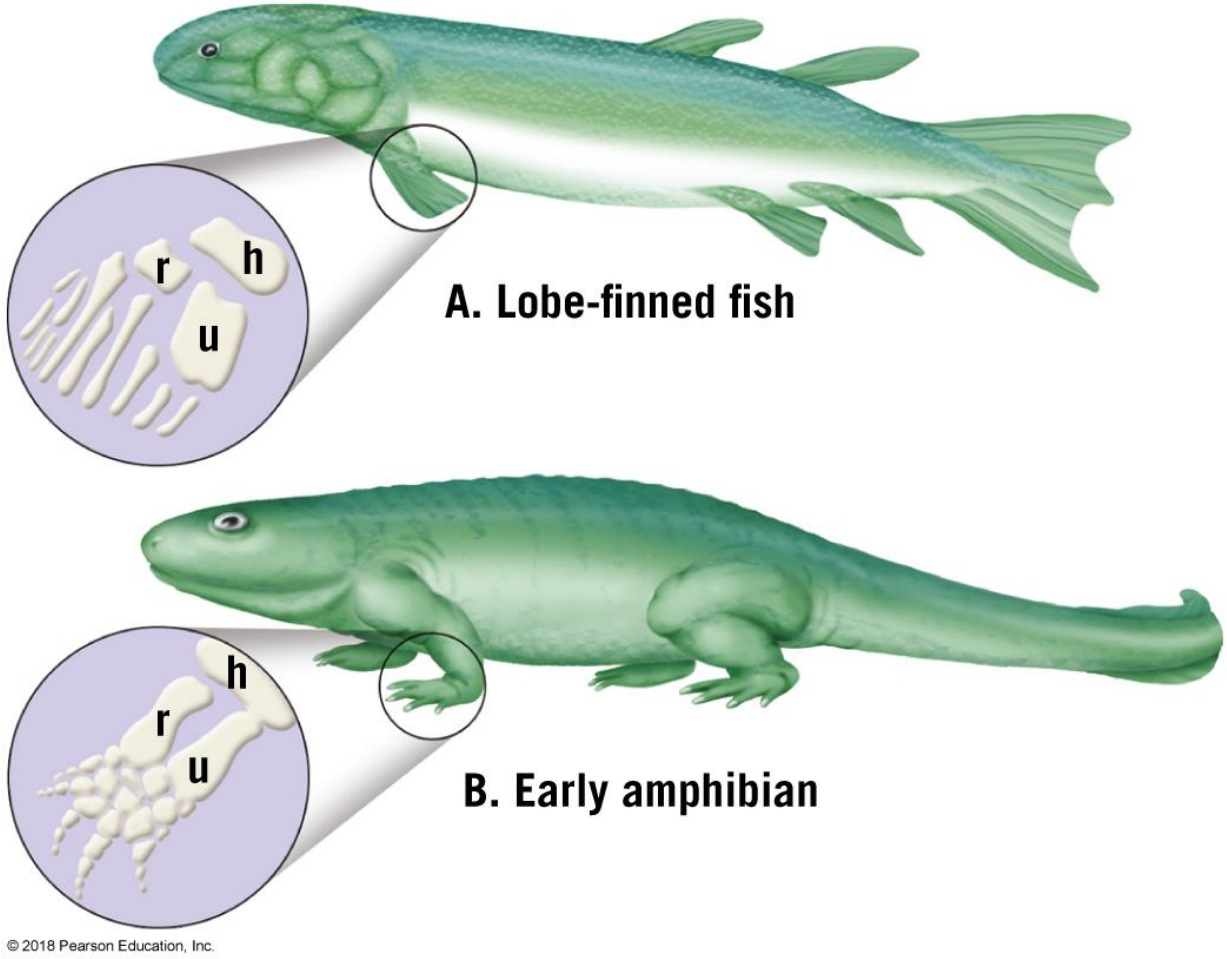

WHAT WAS THE PALEOZOIC ERA?
Study.com

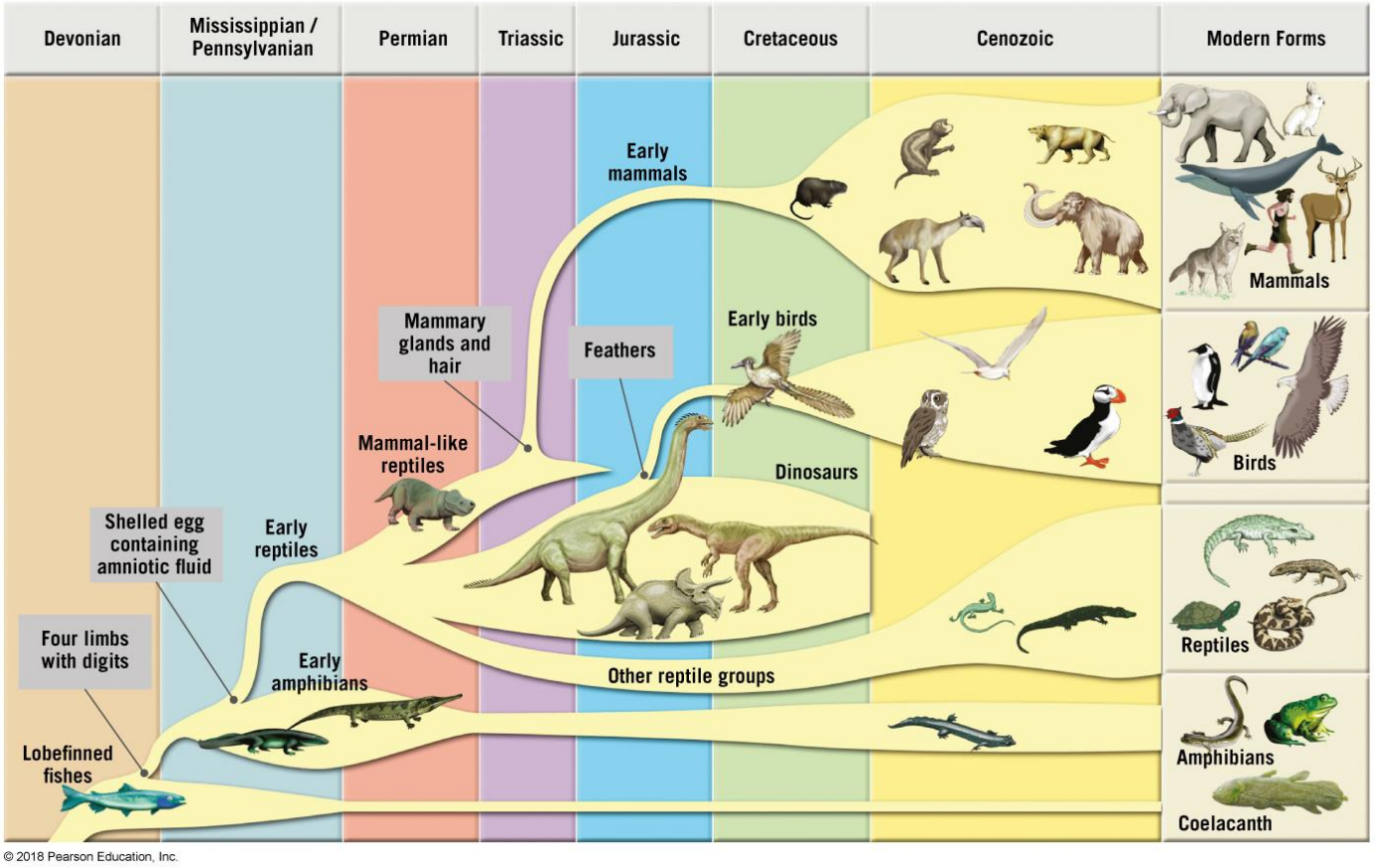
Figure 12.25
Comparison of the Anatomical Features of a Lobe-Finned Fish and an Early Amphibian



The Great Permian Extinction

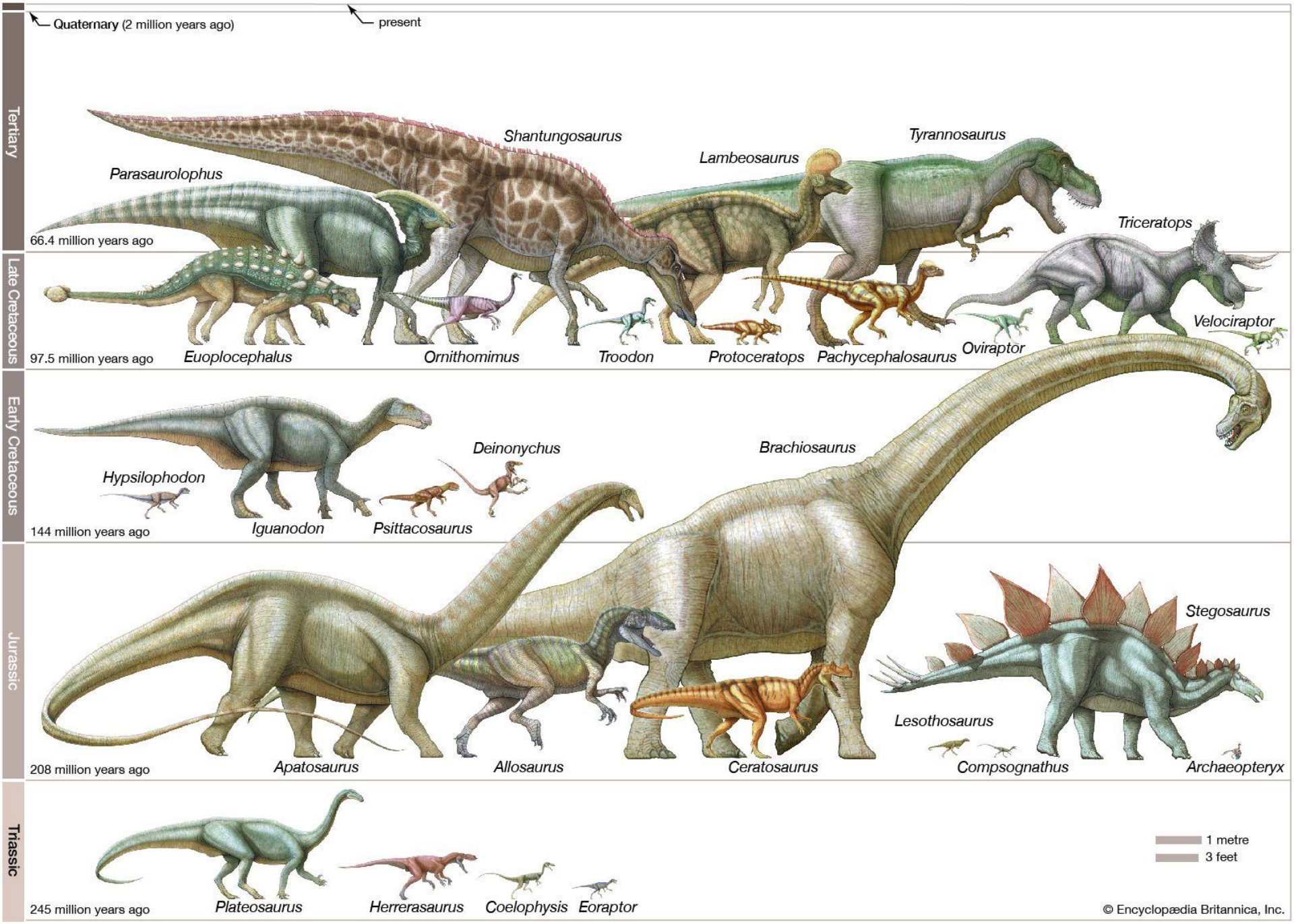
- Mass extinction occurred, killing 70 percent of land vertebrates and 90 percent of all marine organisms
- Most severe extinction in last 500 million years
- Organisms that survived took over Earth

Relationships of Major Land-Dwelling Vertebrate Groups and Other Divergence from Lobefin Fish



Mesozoic Era: Dinosaurs Dominate the Land

- Gymnosperms become dominant trees
- Reptiles take over land, sea, and sky
  - Land: dinosaurs
  - Sea: marine reptiles evolved from land reptiles re-entering the ocean
  - Sky: evolved wings and ultimately feathers


Quaternary (2 million years ago)
present
Tertiary
Late Cretaceous
Early Cretaceous
Jurassic
Triassic
Parasaurolophus
Shantungosaurus
Lambeosaurus
Tyrannosaurus
Triceratops
66.4 million years ago
97.5 million years ago
Euoplocephalus
Ornithomimus
Troodon
Protoceratops
Pachycephalosaurus
Oviraptor
Velociraptor
Hypsilophodon
Deinonychus
Brachiosaurus
144 million years ago
Iguanodon
Psittacosaurus
Stegosaurus
Lesothosaurus
208 million years ago
Apatosaurus
Allosaurus
Ceratosaurus
Compsognathus
Archaeopteryx
245 million years ago
Plateosaurus
Herrerasaurus
Coelophysis
Eoraptor
1 metre
3 feet
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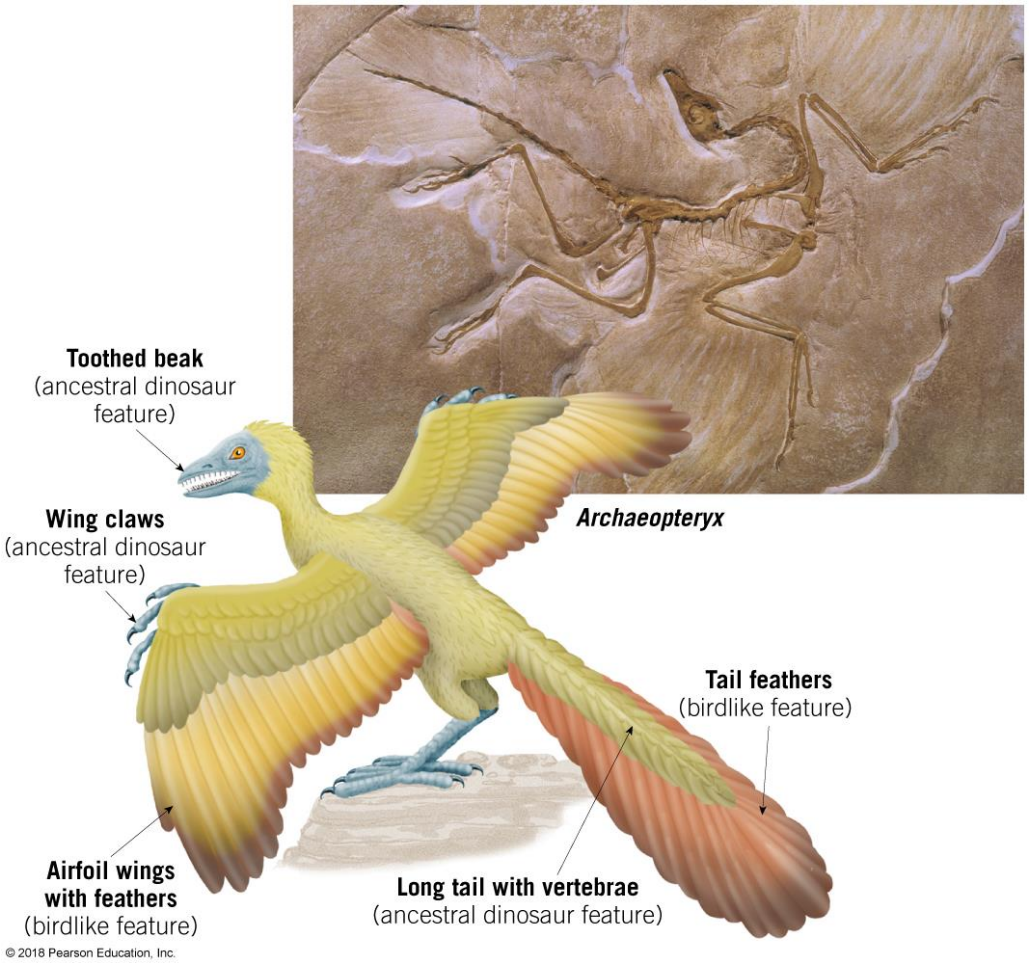
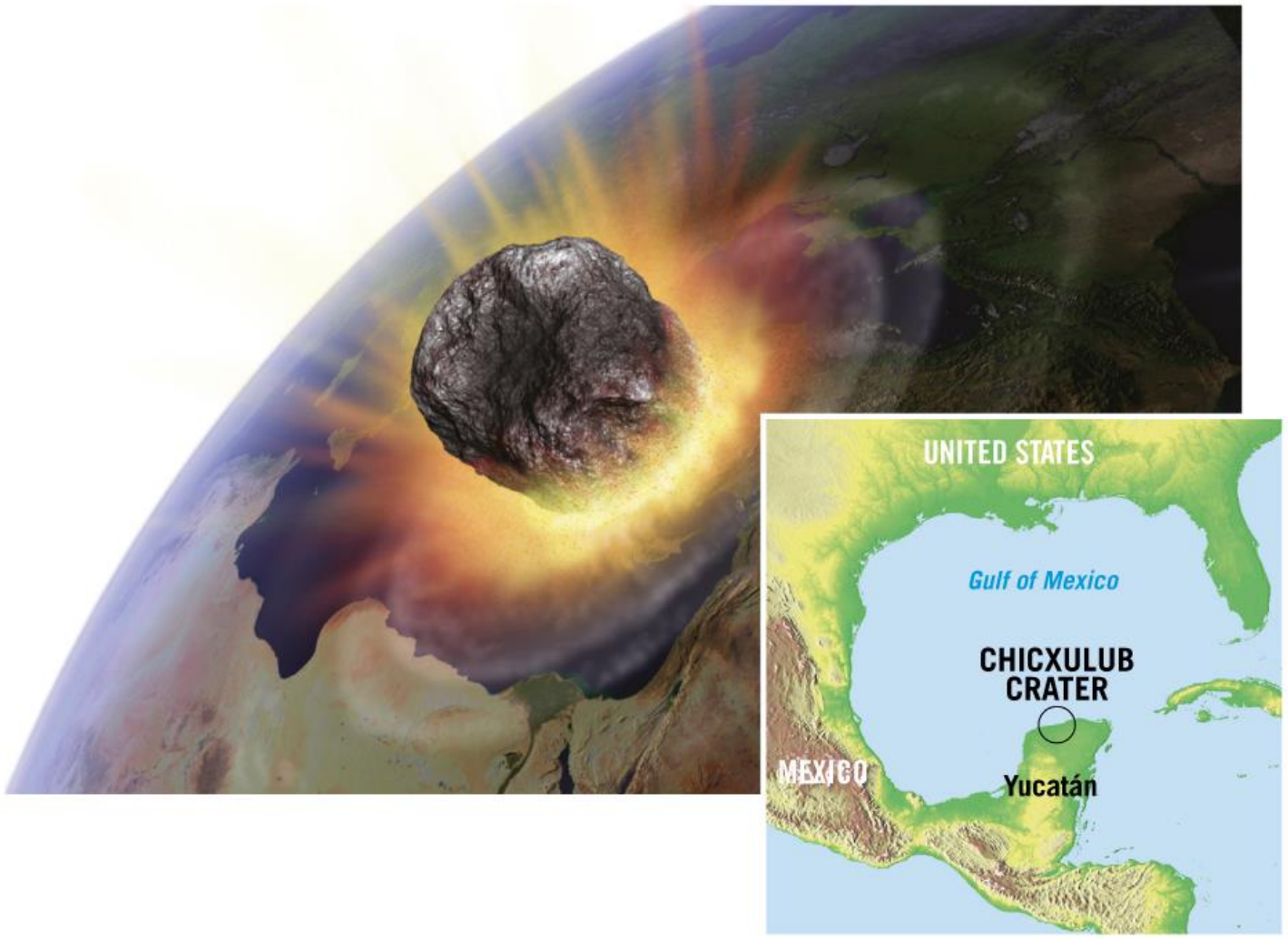
Archaeopteryx, a Transitional Form Related to Modern Birds



Mesozoic Era: Dinosaurs Dominate the Land

- Demise of the Dinosaurs
  - Mass extinction of 75 percent of all plant and animal species
  - Two causes
    - Volcanic eruptions
      - Gas erupted caused global warming, causing some organisms to die and others to decline
    - Meteor impact followed
      - Suspended dust blocked sunlight, causing global cooling

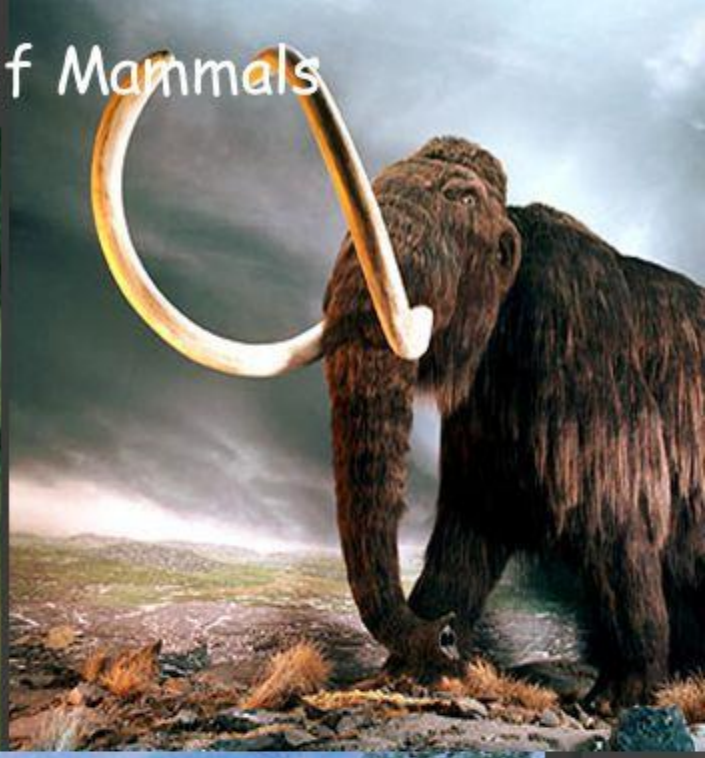
Chicxulub Crater



12.9 Cenozoic Era: Mammals Diversify

- Angiosperms (flowering plants) became dominant
- Mammals survived the extinction and rapidly diversified
  - Have mammary glands, hair, and are endothermic
  - Evolved into three groups:
    - Monotreme (egg layers)
    - Marsupial (pouched)
    - Placental (having a placenta)

Earth Science 13.4 Cenozoic Era : Age of Mammals



Cenozoic Era : The Age of Mammals

Cenozoic Era: Mammals Diversify

- Humans evolve from placental mammals
  - Branched off from lineage of modern chimps 6.5 million years ago
  - Over 20 extinct species of primates closely related to humans have been unearthed.
  - Modern humans developed large brains and bipedal locomotion
- Large mammals became extinct, perhaps due to hunting by humans