HUMINANITY

Series of PowerPoint Presentations by J. W. Gardner

- **Misbeliefs – Acquisition & Probable Examples**
- **Big Picture Science – Observable Universe**
- **Big Picture Science – Planet Earth**
- **Big Picture Science – Life on Earth**
- **Basic Science Sampler – Quantum Physics, Relativistic Physics and Thermodynamics**

One of Three Presentations on Big Picture Science

Subject	Key Theory
Observable Universe	Big Bang
Planet Earth	Plate Tectonics
Life on Earth	Evolution

Planet Earth

Ancient Earth

Brief history

Age determination

Geologic time

Chemical Cycles, AGW

Water, Nitrogen, Phosphorous, Sulfur, Carbon

Anthropogenic global warming

Dynamic Earth

Convection cells

Magnetic field reversals

Plate tectonics

Supercontinent succession

Ice ages

Earth Scaping

Plate tectonics + erosion

Shortcuts to topics underlined

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Planet Earth – Brief History

- Sun and planets form 4.5 – 4.6 Gya from gravitational collapse of molecular cloud containing hydrogen, helium and heavier elements, some expelled from multiple supernova
- About same time, a Mars-sized object collides with new Earth, spewing debris into nearby space, which coalesces as Moon
- After Earth has cooled for about 700 My, water in atmosphere condenses and falls as rain to form ocean
- Within the Earth, lighter molten material rises to the surface, solidifying to form tectonic plates. Tugged by convection in the upper mantle, plates move and interact, continuously changing Earth surface

1 Gya = 1 billion years ago. Sun is believed to be a third-generation star

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1 My = 1 million years

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Ancient Earth – Early Scientific Dating

- **Geologists first to become aware of great age of Earth, as evidenced in James Hutton's 1788 Theory of the Earth**

  The result, therefore, of our present enquiry is, that we find no vestige of a beginning – no prospect of an end

- **More than fifty scientific attempts to date the Earth in 1800s. Most popular methods based on (i) sediment accumulation, (ii) cooling of the Earth and (iii) cooling of the Sun. Most estimates ranged from 10s of millions to 100s of millions of years. None had a chance of yielding an accurate age**

- **Key would be 20th century knowledge of radioactive decay**

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Dalrymple (2001) *The Age of the Earth*

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Radiometric Earth Ages

- **Oldest rocks on Earth**
  Western Greenland: 3.7– 3.8 Gyr (4 methods)
- **Oldest minerals on Earth**
  Zircon crystals in W. Australia sedimentary rocks: 4.0 – 4.2 Gyr
- **Oldest Moon rocks (brought back by Apollo astronauts)**
  Lunar Highlands: 4.4 – 4.5 Gyr (2 methods)
- **Meteorites**
  Majority of 70 well-dated meteorites: 4.4 – 4.6 Gyr (5 methods)
- **"Best" age of Earth**
  Canyon Diablo iron meteorite: **4.54 Gyr** (time for lead isotopes to evolve from composition at time of solar system formation)

USGS. https://geomaps.wr.usgs.gov/parks/gtime/ageofearth.html

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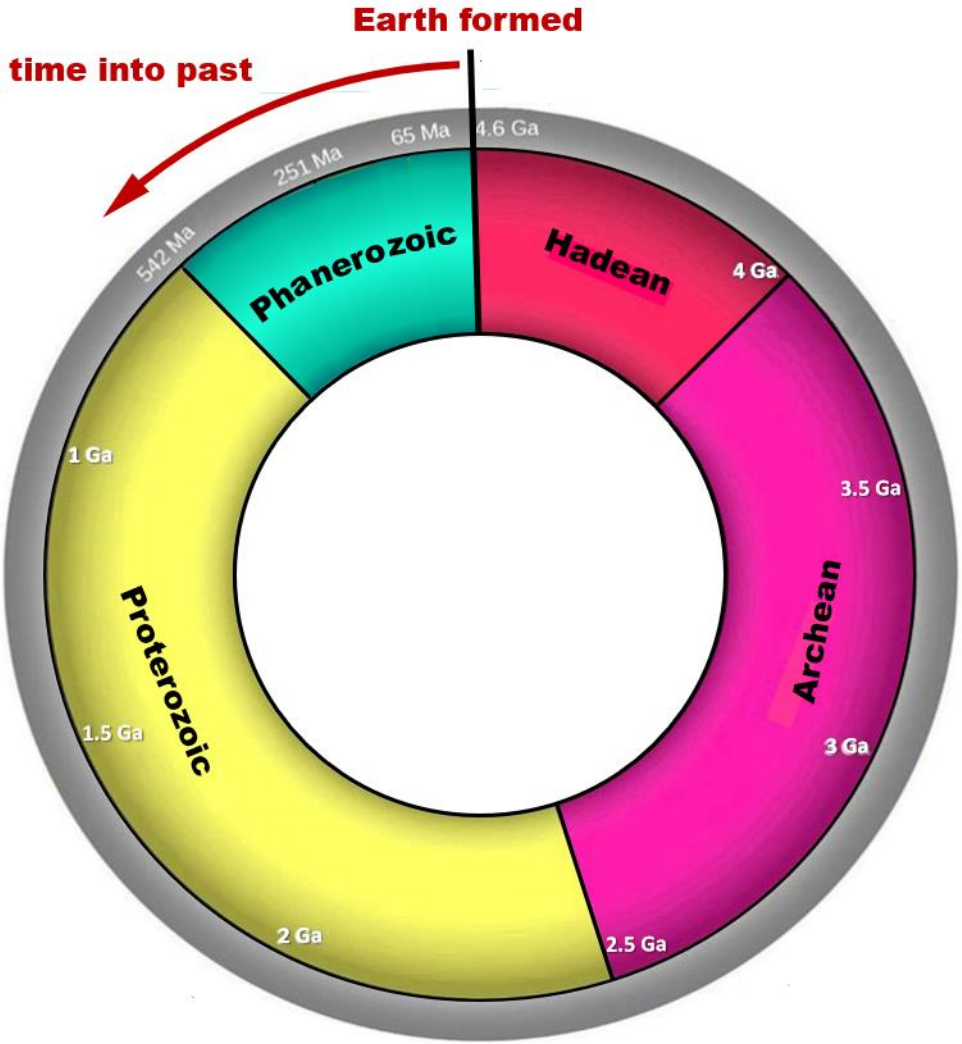
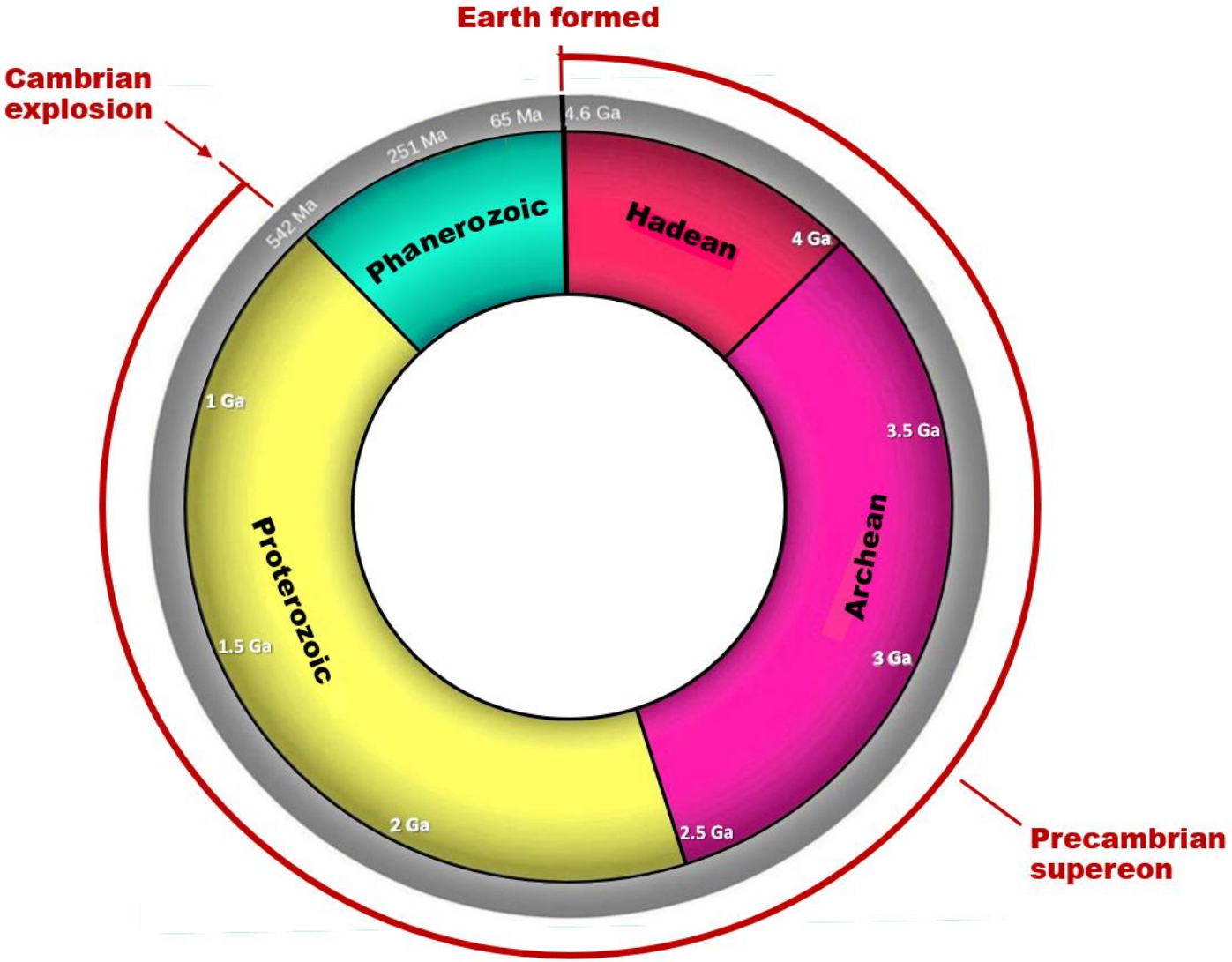
Geologic Time – Eons



Hadean, Archaean, Proterozoic and Phanerozoic are eons

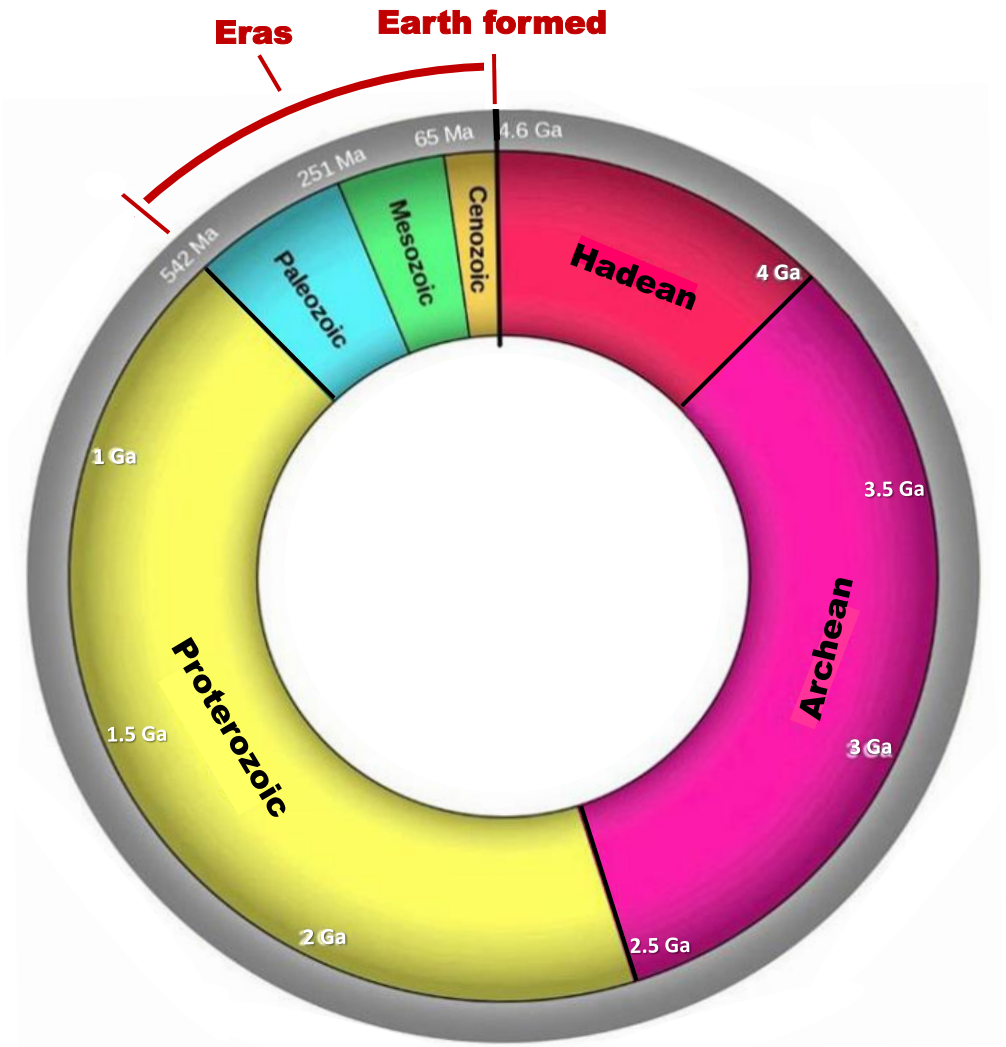
Time wheel from Wikipedia "Geological History of the Earth" article (modified)

Geologic Time – Precambrian Supereon



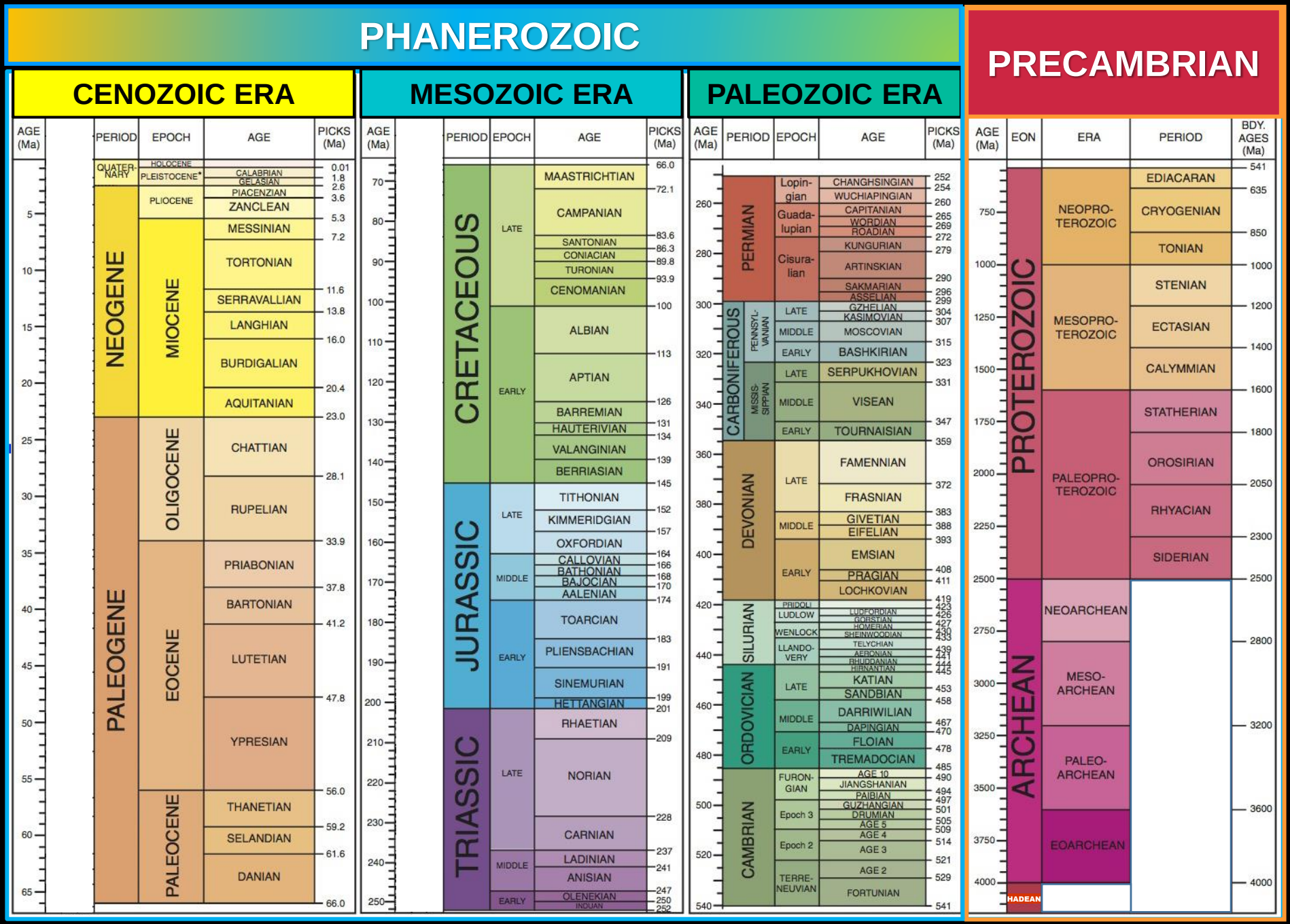
"Explosion" refers to rapid appearance of complex macroscopic life early in Phanerozoic

Geologic Time – Eras



Partitioning of Phanerozoic into eras

Proterozoic and Archean (but not Hadean) also broken into eras (next slide, which also shows smaller intervals of geologic time in use (periods, epochs and ages)



Logarithmic time scale. Hadean and Phanerozoic of similar duration. Source: GSA (modified)

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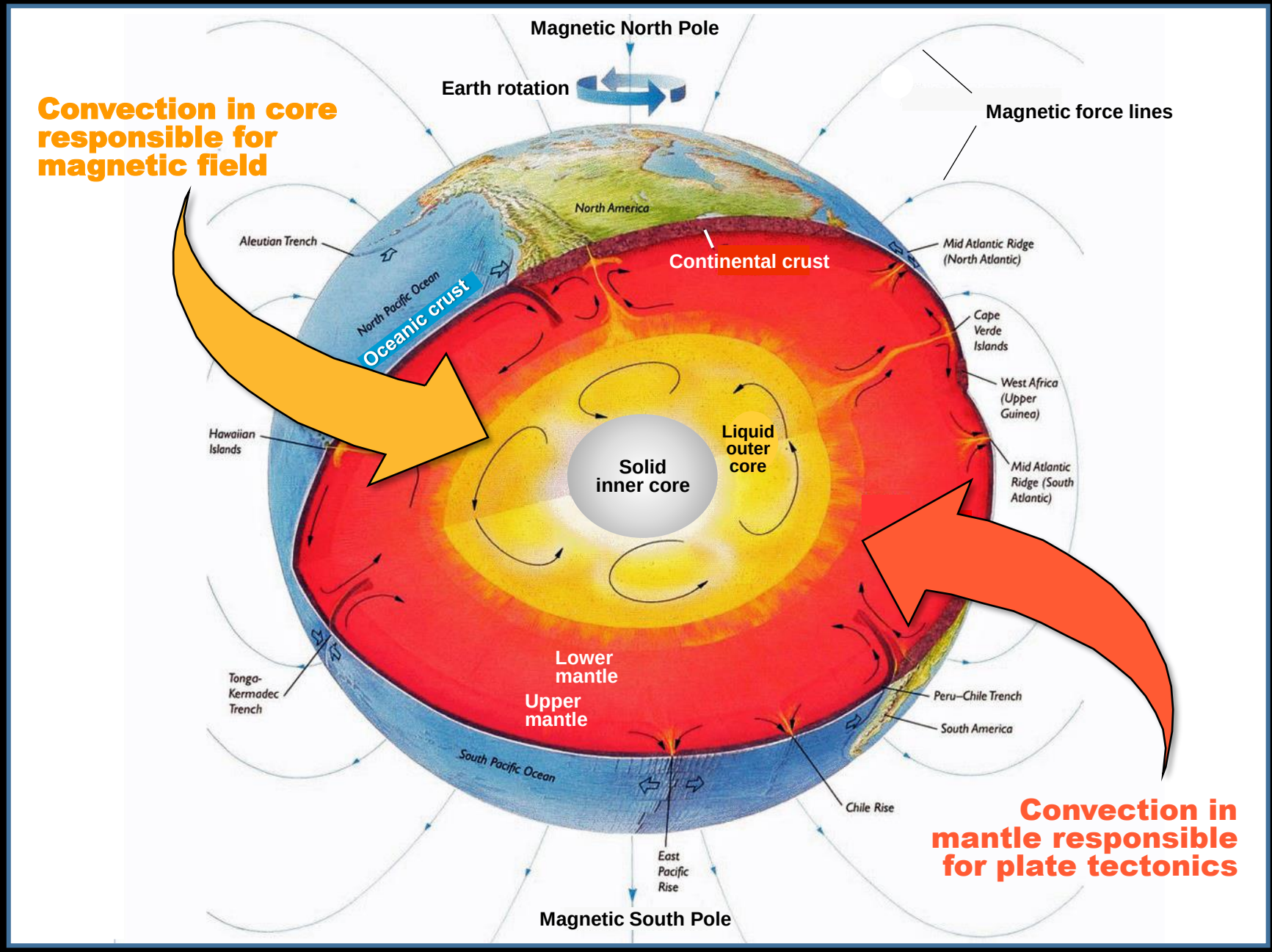
Dynamic Earth – Cutaway



Lamb & Singleton (1998), *Earth Story: The Forces That Have Shaped Our Planet* (modified)

Dynamic Earth – Drivers

- Energy responsible for convection currents that in turn are responsible for magnetic field and plate tectonics comes from two roughly equal internal sources
  - Residual primordial heat
  - Heat from radioactive decay
- Most phenomena above crust are driven by Earth's rotation, by gravity (Earth, Moon, Sun) & by radiant energy from Sun*

*Solar radiation energy reaching the Earth dwarfs thermal energy escaping the Earth's interior. However, essentially all of the solar energy is radiated back into space

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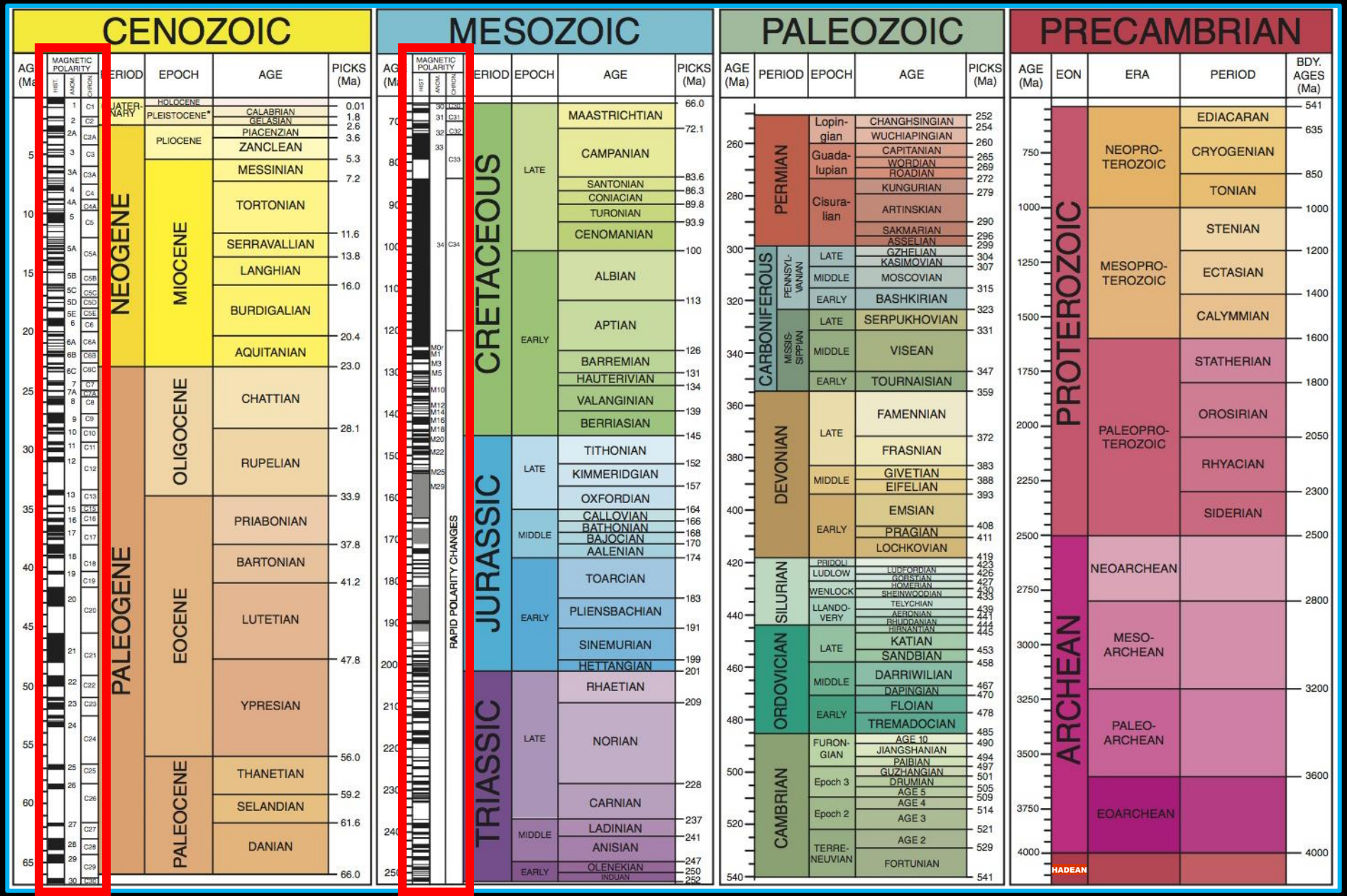
Magnetic Field Reversals Since Paleozoic Era



Such reversals also occurred earlier. Interesting "quiet period" during Cretaceous. Source: GSA (modified)

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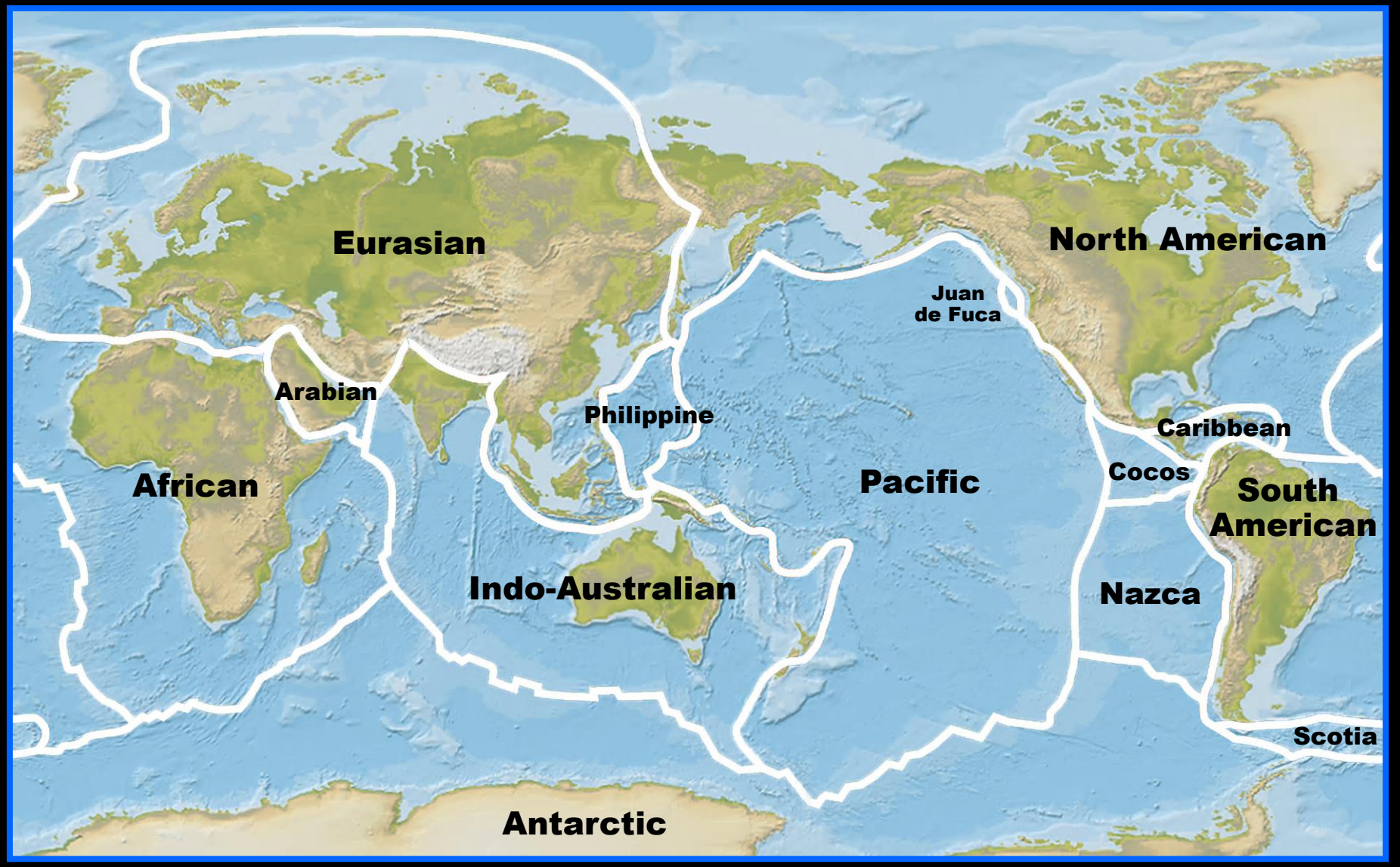
Tectonic Plates

- Rigid plates comprising Earth's outermost solid shell (some plates beneath ocean)
- Exact definitions vary, but differences not important here
- Plate shapes & sizes change by interactions at boundaries

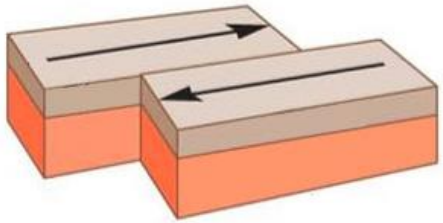
Tectonic Plates



View in which most plates are whole or nearly so. Most of Antarctic plate missing. Source: Dorling Kindersley

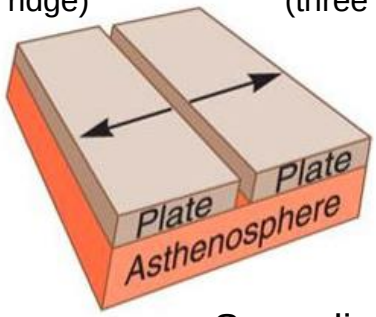
Plate Boundaries

Transform
(e.g. San Andreas fault)



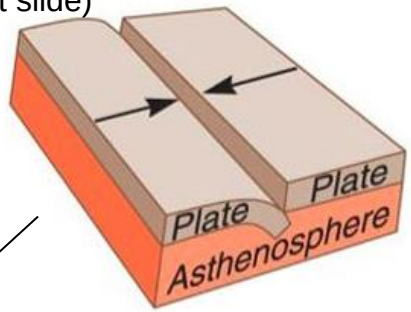
Shearing

Divergent or Ridge
(e.g. mid-Atlantic ridge)

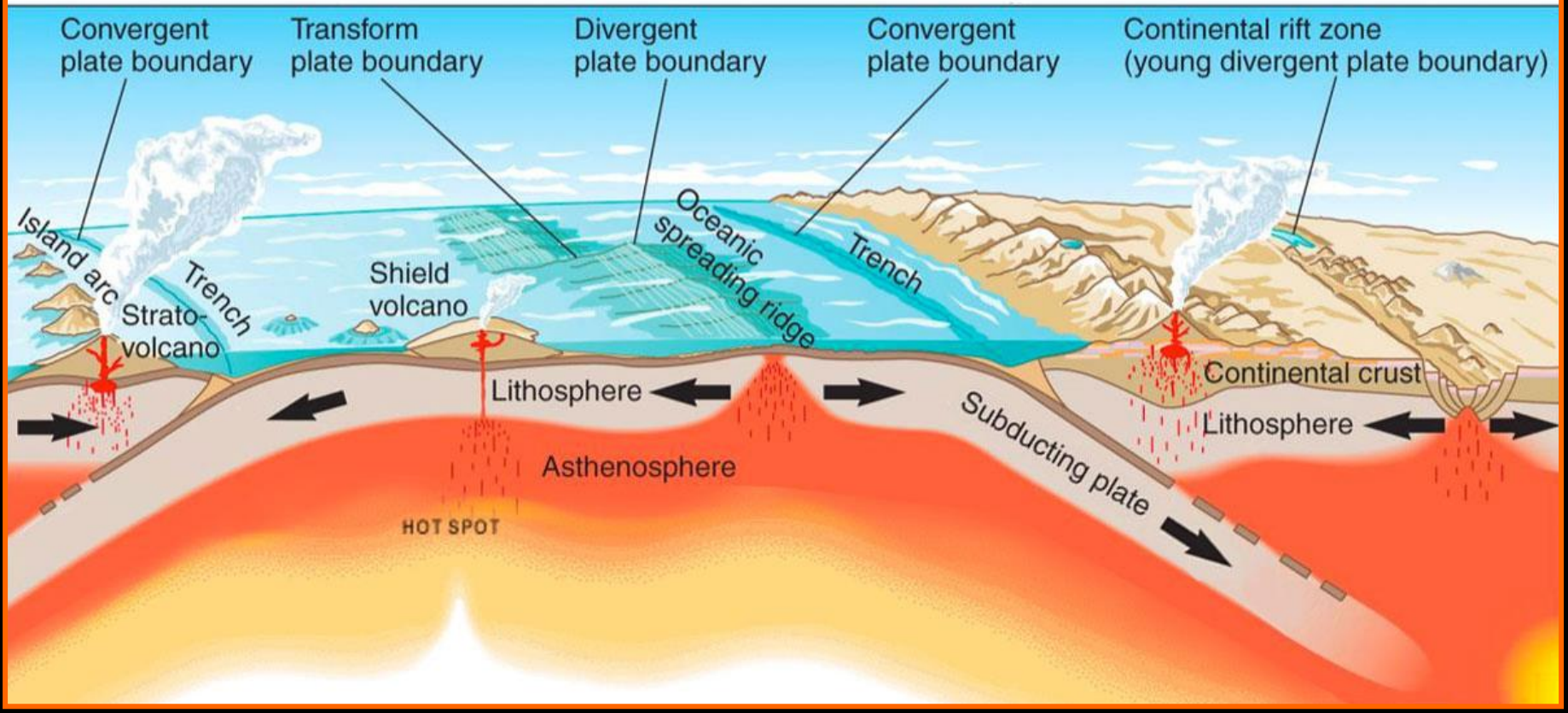


Spreading

Convergent
(three subtypes; see next slide)



Subducting

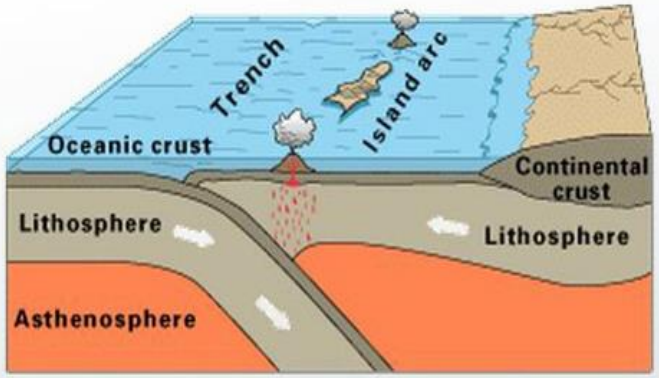


Composite of USGS images

Convergent Boundary Subtypes

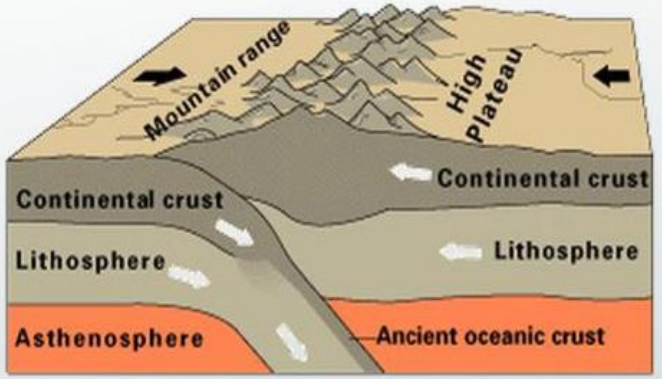
Ocean Crust Under Ocean Crust

(e.g. formation of Aleutians)



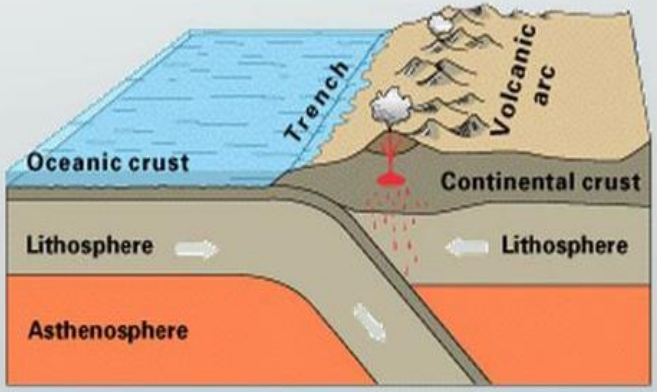
Continental Crust Under Cont. Crust

(e.g. formation of Himalayas)



Ocean Crust Under Continental Crust

(e.g. formation of Cascades)



USGS

Tectonic Plates

Previous image shifted westward to align roughly with following four maps. Also, almost all of Antarctic plate now chopped off

Divergent Boundaries & Plate Creation

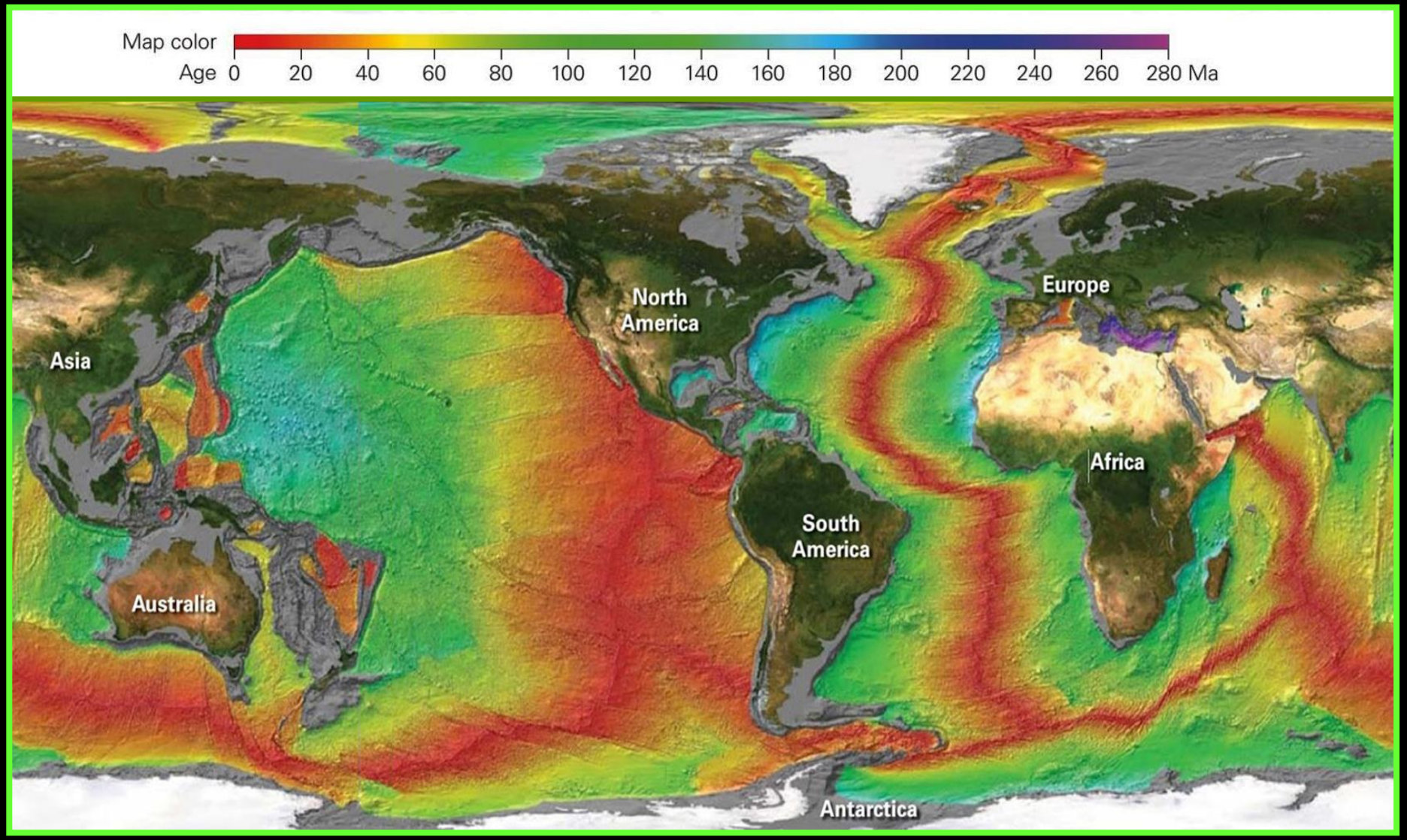


Plate material created at divergent boundaries (darkest red areas, where age = 0). Image: NOAA JPG: 7676x4615 (from work of Müller, et al, 2008. doi:10.1029/2007GC001743). Oldest crust in Mediterranean

Because Earth surface area is fixed, plate creation must be balanced by plate destruction

Convergent Boundaries & Plate Destruction

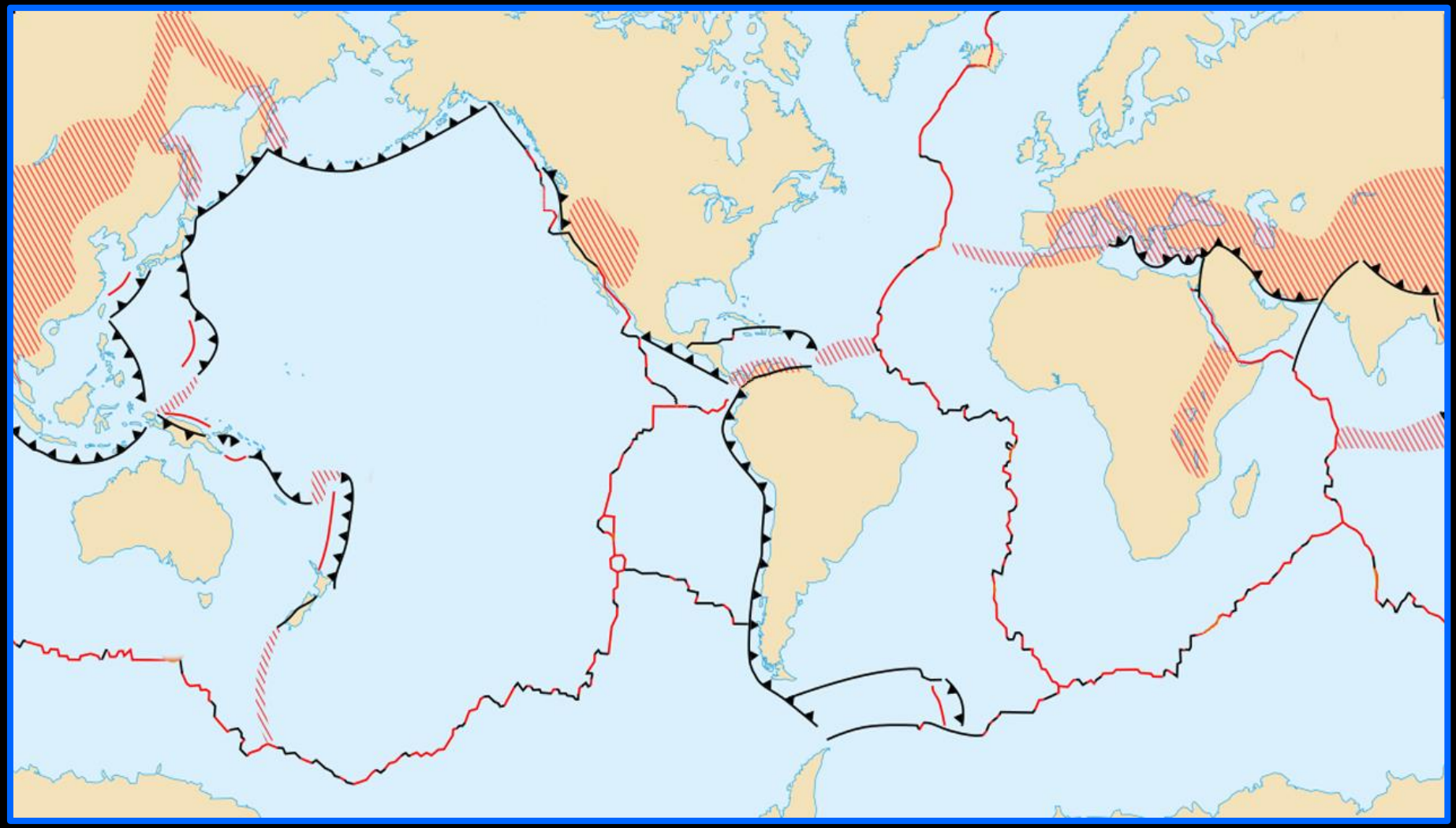
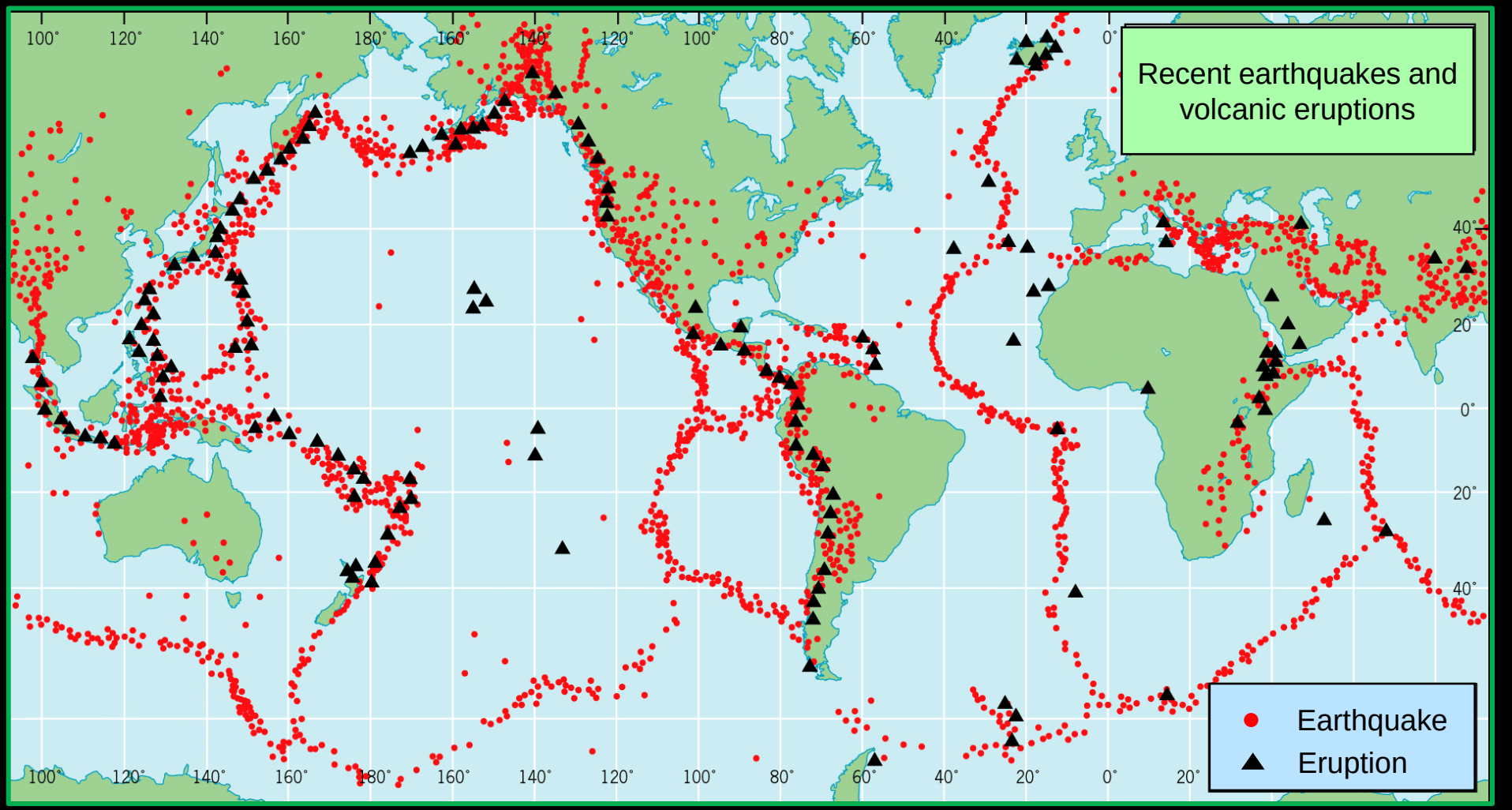


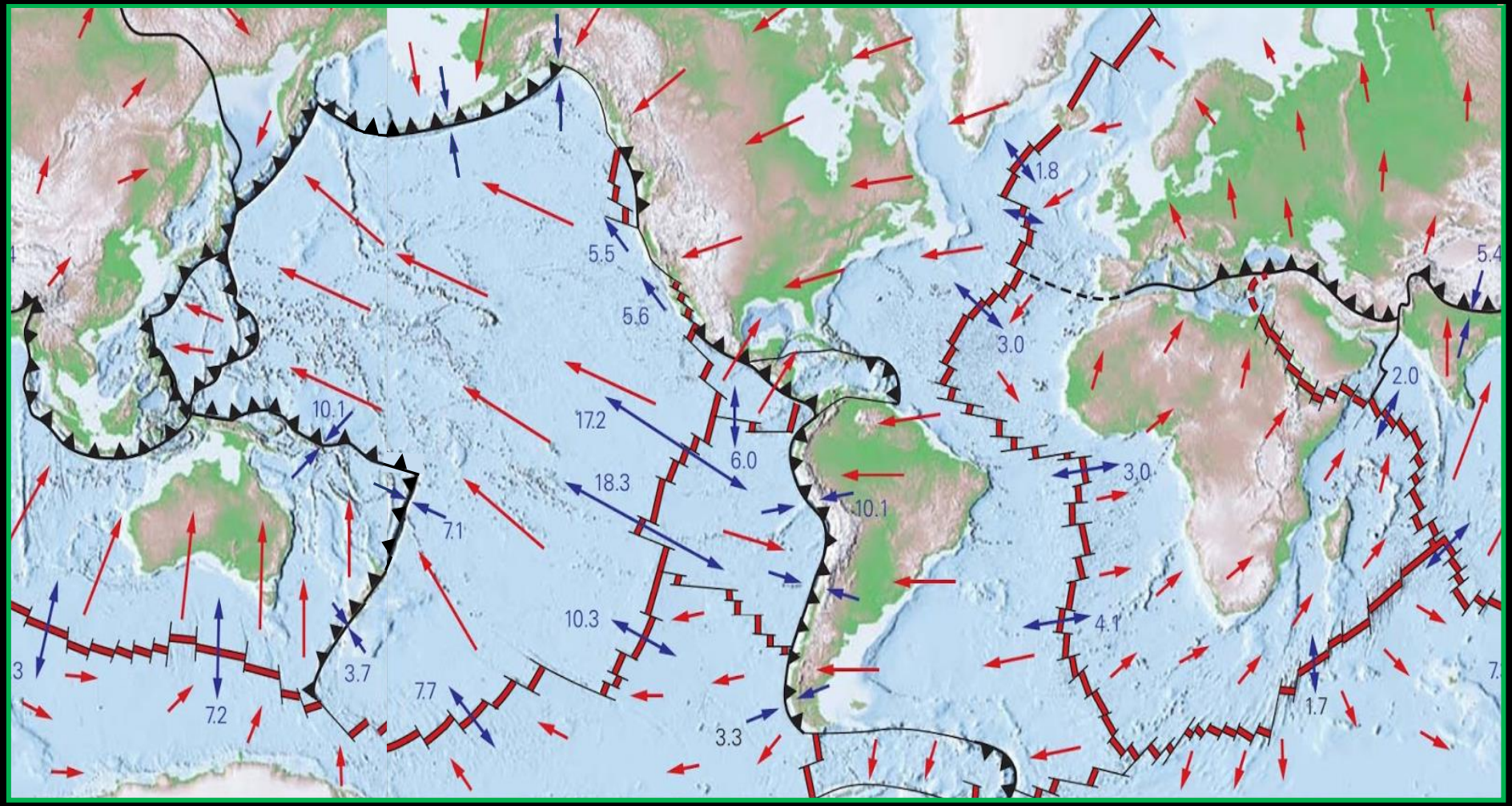
Plate material destroyed at convergent boundaries (subduction zones, denoted by triangles). Most volcanoes occur near subduction zones (next slide). Striped areas indicate diffuse plate boundaries. Wikipedia Commons

Earthquakes & Volcanoes



Earthquake activity (red dots) associated with most plate boundaries. But many quakes also occur away from plate boundaries. Most volcanoes (black triangles) occur near subduction zones. Particularly on western two-thirds of map. Much weaker correlation on eastern one-third. Number of volcanoes in diffuse zone in Great Rift Valley. Image from The Dialogue "How Plate Tectonics Is Connected With Life on the Planet"

Tectonic Plate Velocities



Velocities of tectonic plates in cm/yr. From Khattak (2016) "What Drives Plate Motion, and How Fast Do Plates Move?" U. Peshawar. Map shifted sideways to align with preceding maps. Plates move roughly at rate of human fingernail growth

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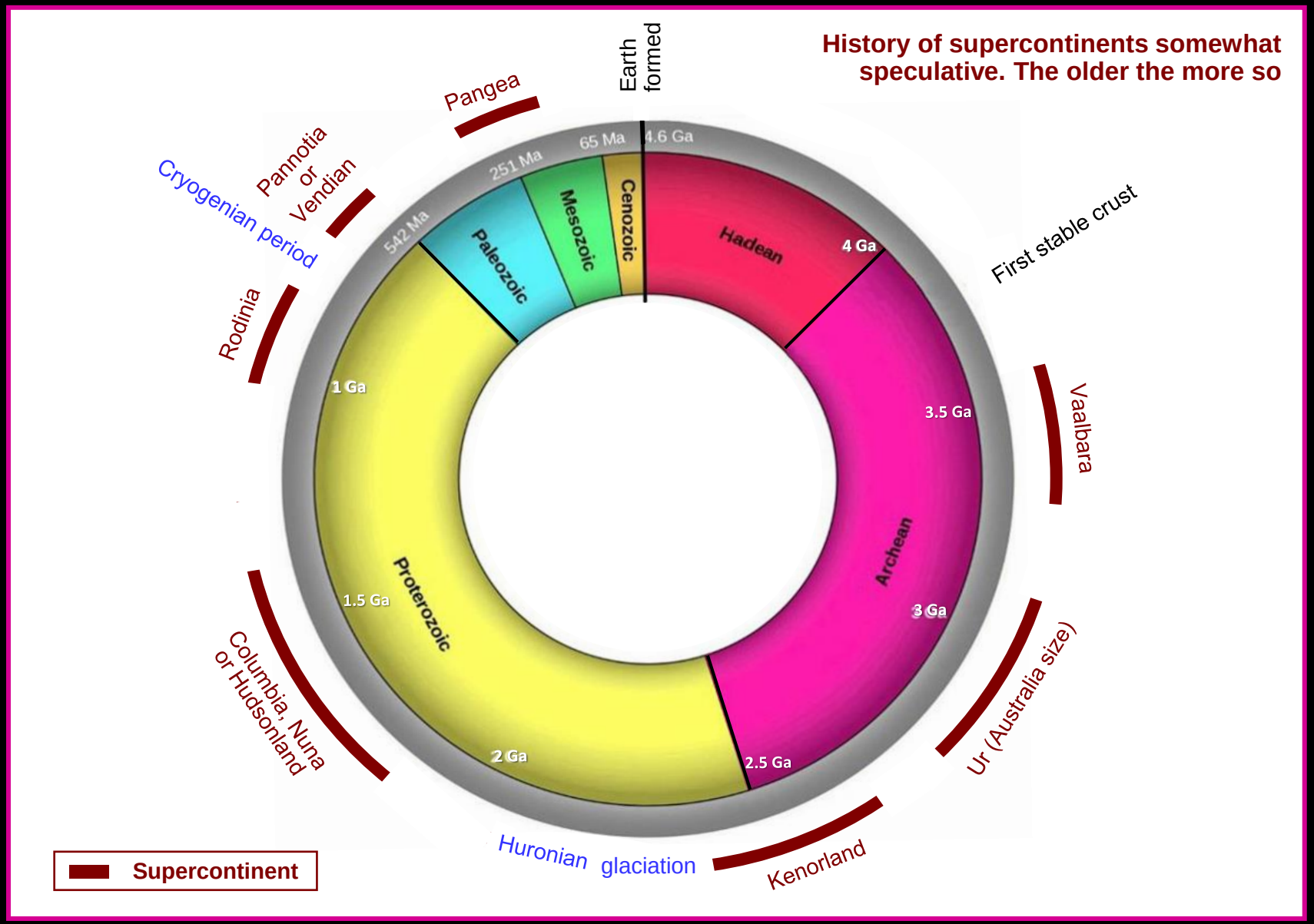
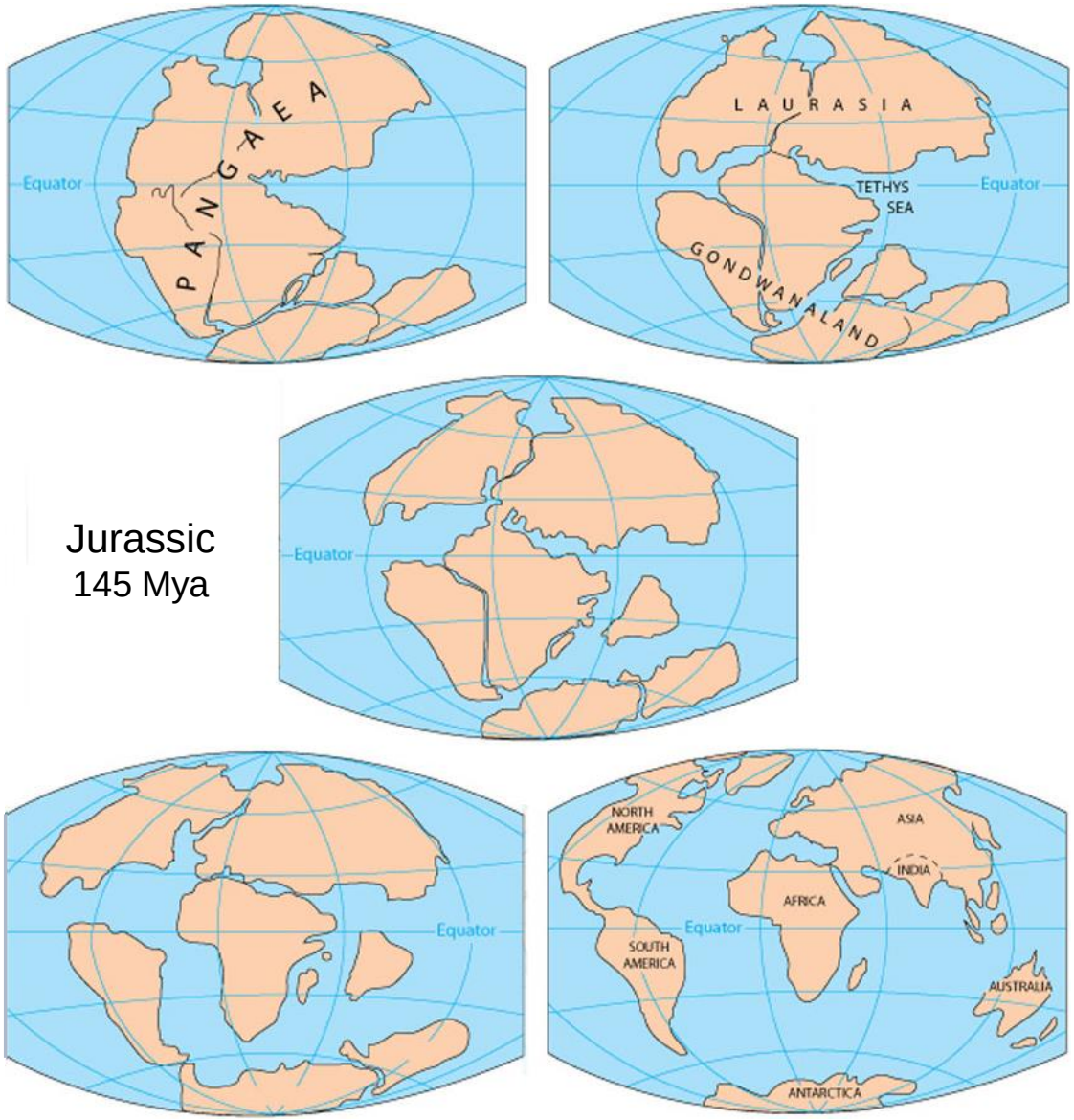
Supercontinent Succession



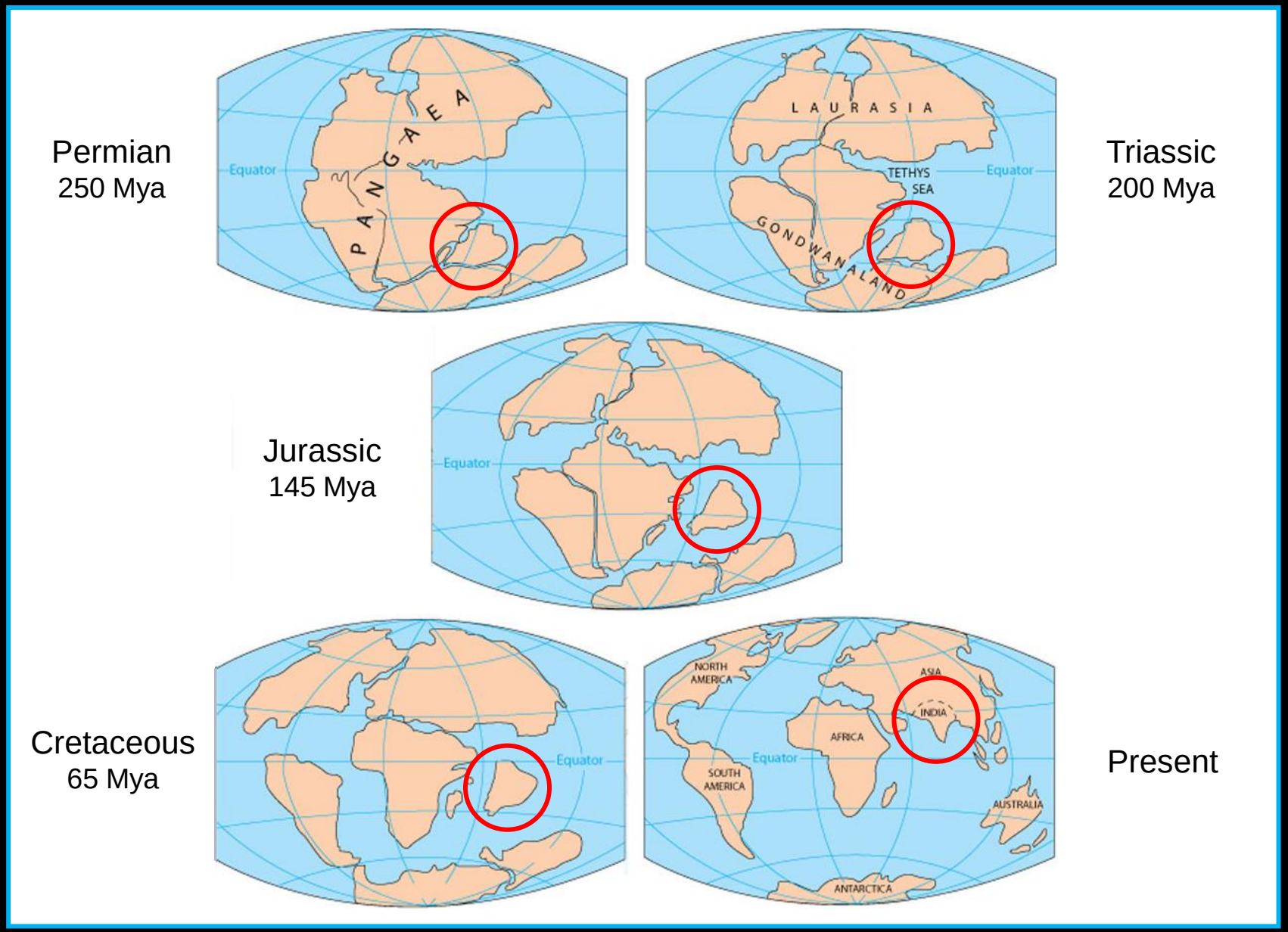
Base circle from Wikipedia "Geological History of the Earth" article. Supercontinent dates from Wikipedia "List of Supercontinents" article. Also shown are two most severe ice ages (Huronian and Cryogenian)

Breakup of Pangea



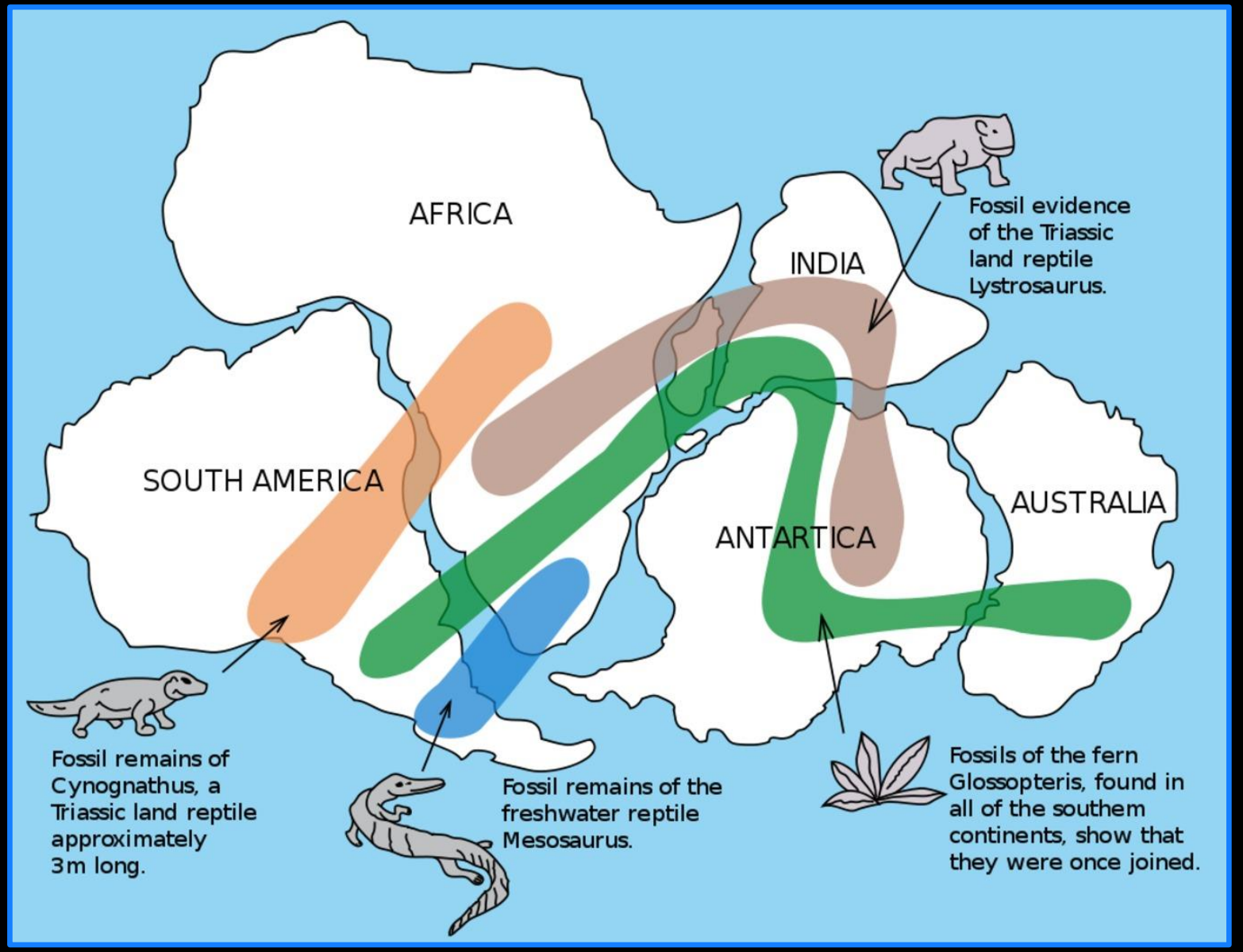
Wiki Commons

Breakup of Pangea – Journey of Indian Plate



Indian plate travels from Antarctic to collide with Asia and create Himalayan Plateau

Fossil Evidence of Gondwanaland



Continuous fossil bands across Gondwanaland. Wiki Commons. Pieces of such evidence noted by Snider-Pellegrini (1858) and Wegener (1912). But general acceptance of moving continents only came with validation of seafloor spreading in 1960s

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An ice age is a geologic period in which thick ice sheets cover vast areas of land

Ice Ages

Name	Mya	Comments
Quaternary (aka Pleistocene)	2.6 – 0.012	Best known ice age. Primarily affected Northern Hemisphere
Karoo	360 – 260	Covered portions of Gondwana around South Pole
Andean-Saharan	450 – 420	Minor ice age
Cryogenian (aka Sturtian-Varangian)	720 – 635	Most severe ice age. Might have covered entire planet ("Snowball Earth")
Huronian (aka Makganyene)	2400 – 2100	Longest ice age. Followed Great Oxygenation
Pongola	2900 – 2780	Somewhat speculative (?)

From Wikipedia "Timeline of Glaciation" and "Ice Age" articles

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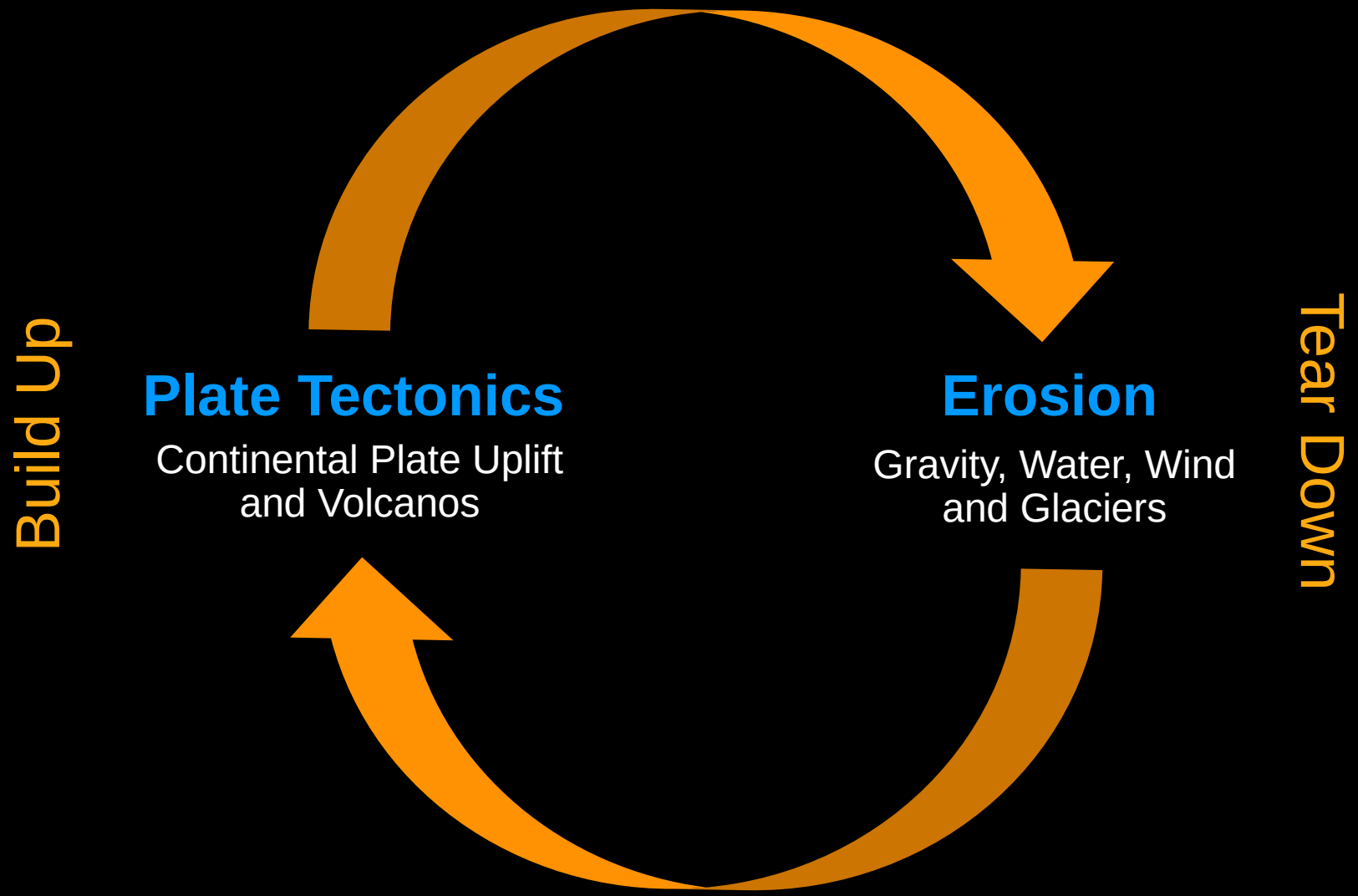
Earth-Scaping

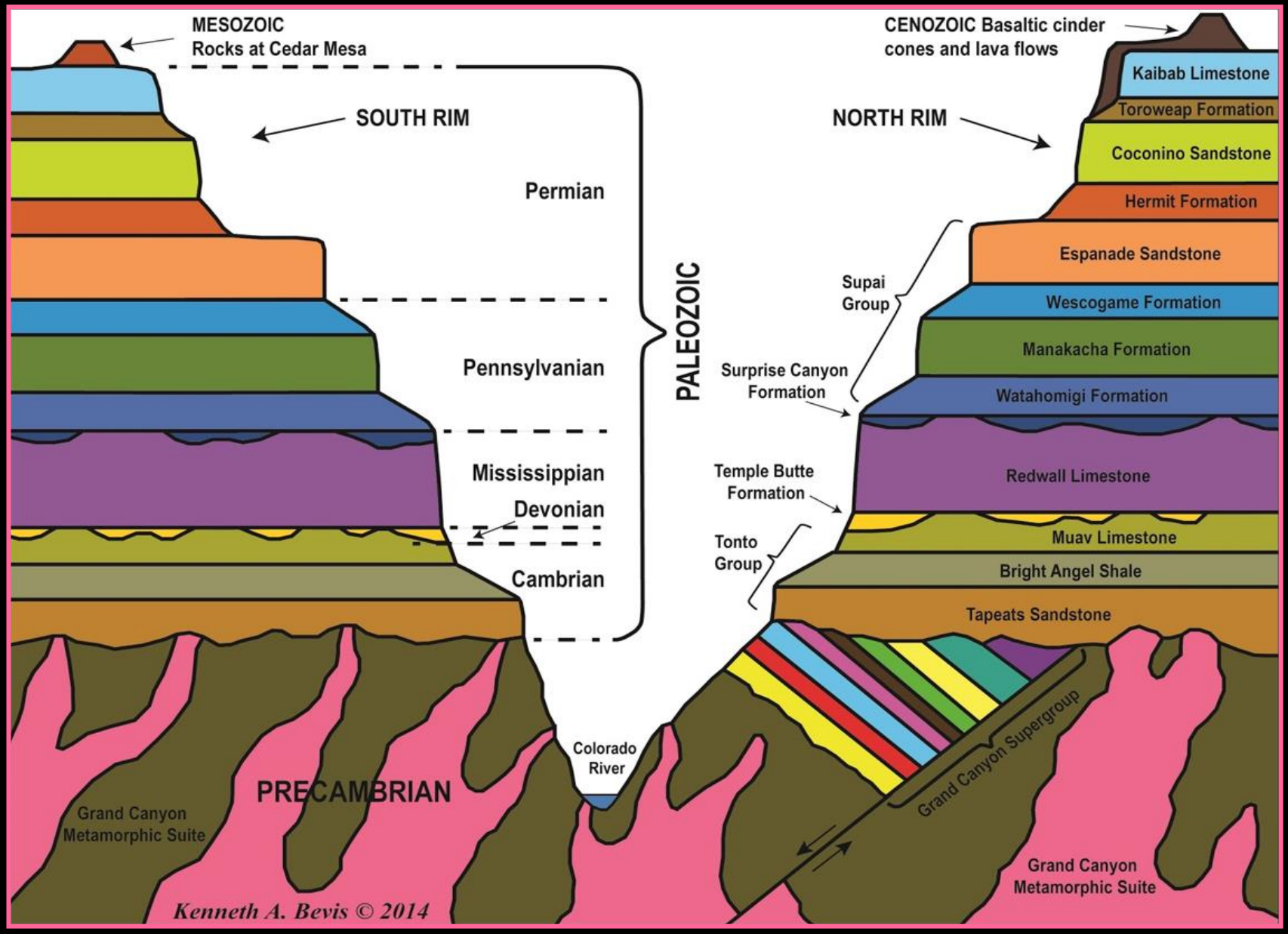


After Wikipedia "Erosion and Tectonics" article. Most volcanos occur at tectonic plate boundaries. A small minority (hot spots) occur elsewhere, such as those that have created the Hawaiian islands

Uplift & Erosion Example – Grand Canyon

Plate tectonics uplifted sedimentary rock roughly 2 miles above sea level to form the Colorado Plateau (Four Corners area of US). The Colorado River then carved out the Grand Canyon on its way to Mexico

Exposed Rock of Grand Canyon



Roughly 40 major sedimentary layers ranging in age from 200 to 2000 Myr are exposed

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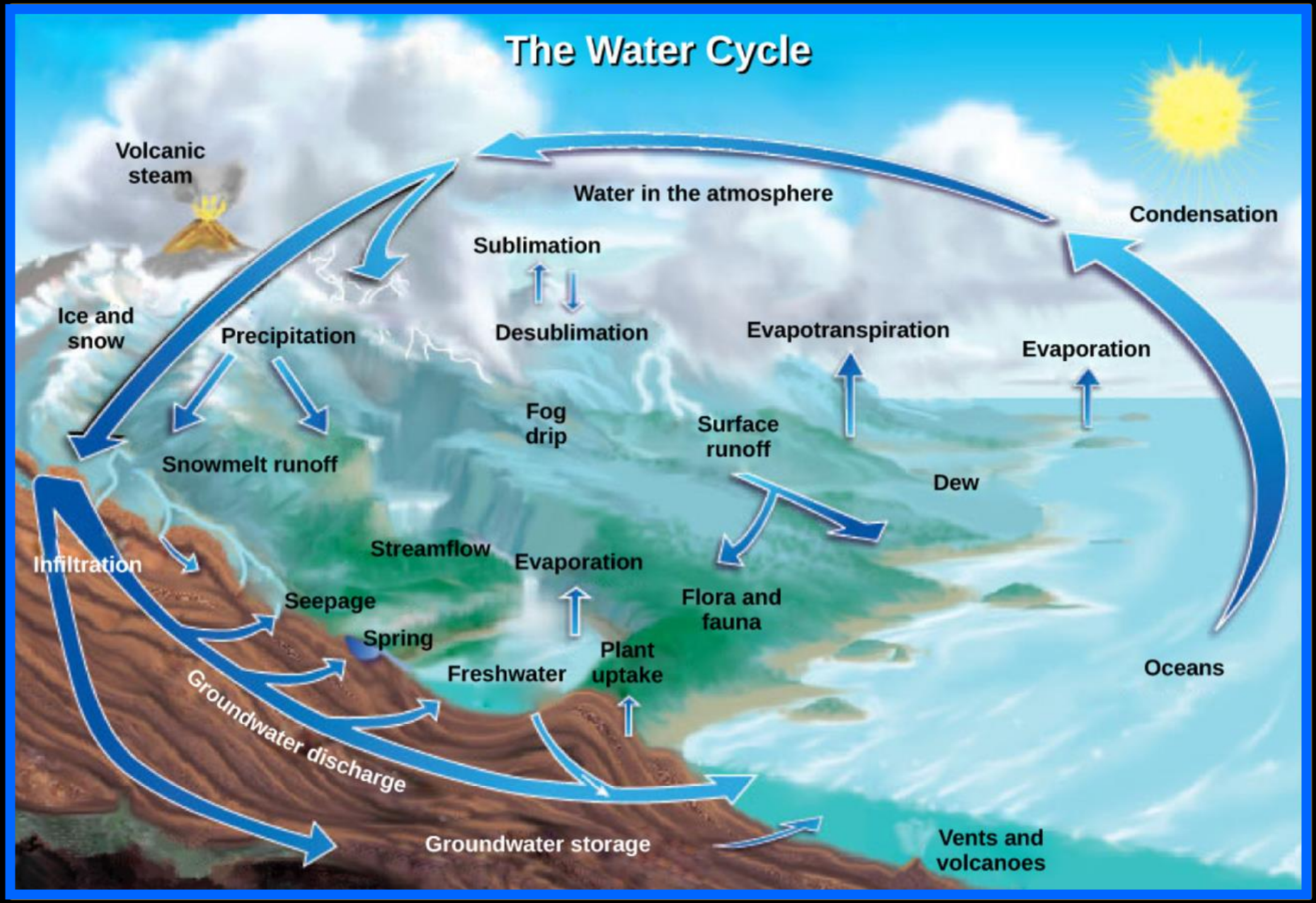
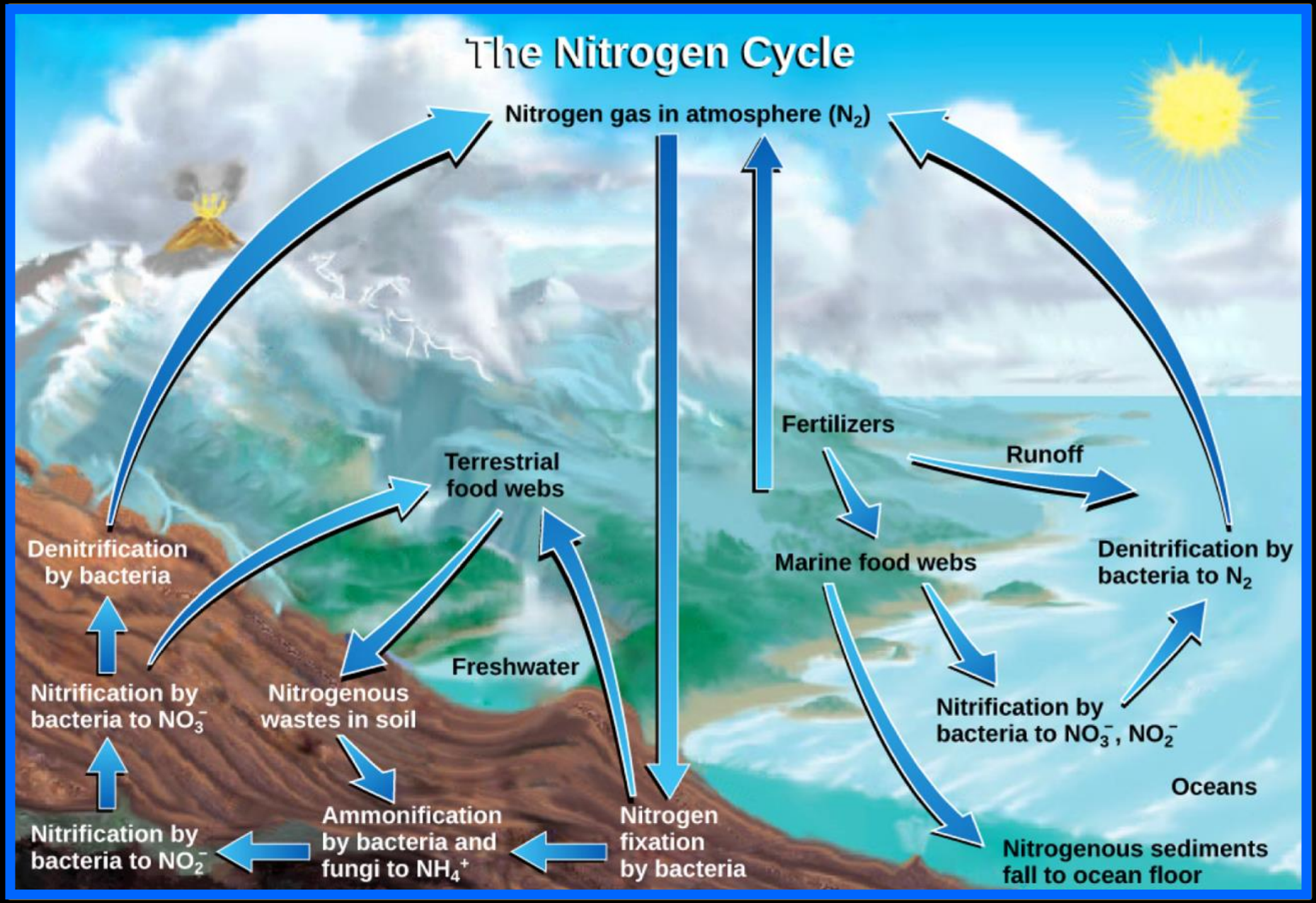
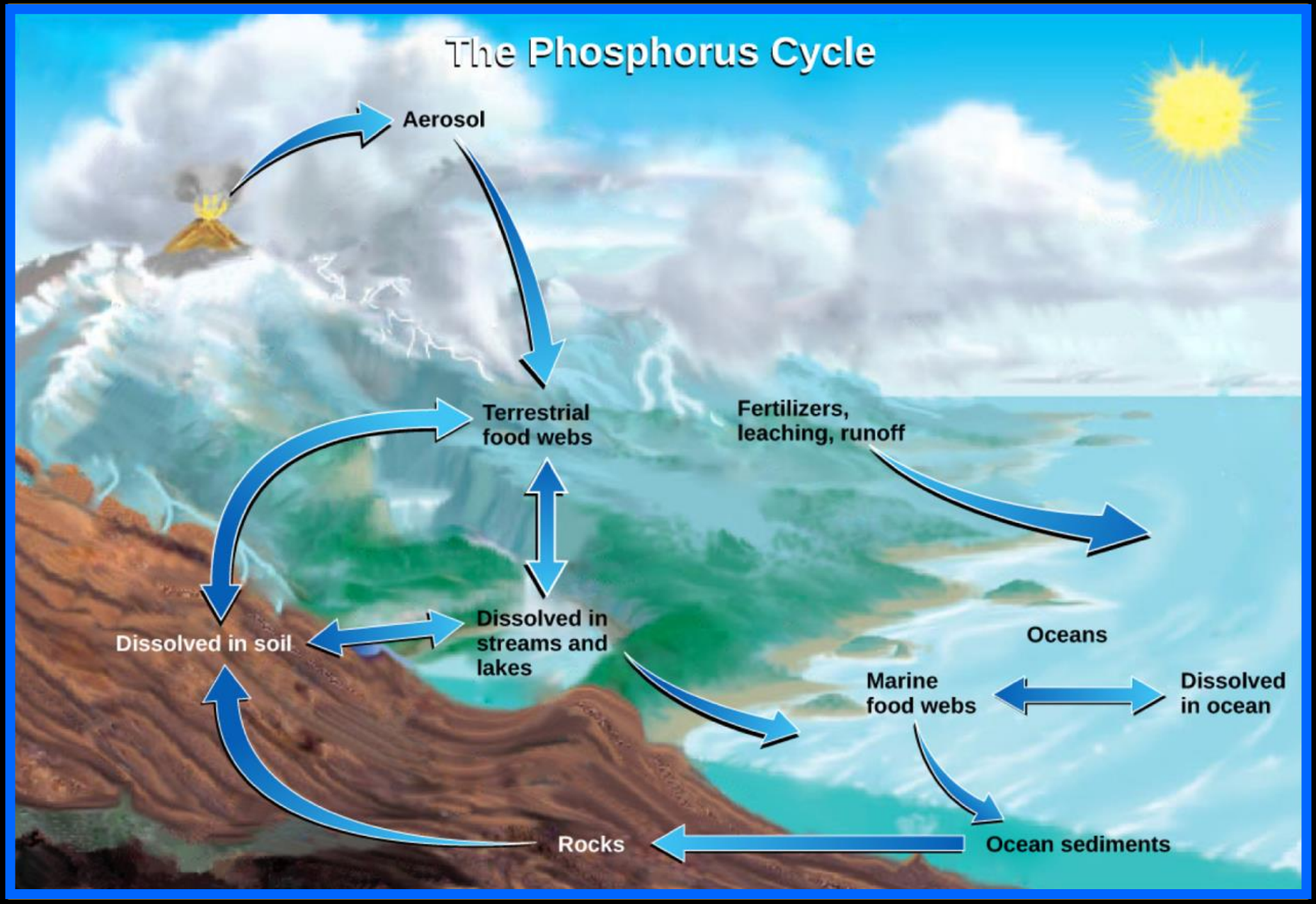
Earth, via lifeforms, continuously recycles chemicals



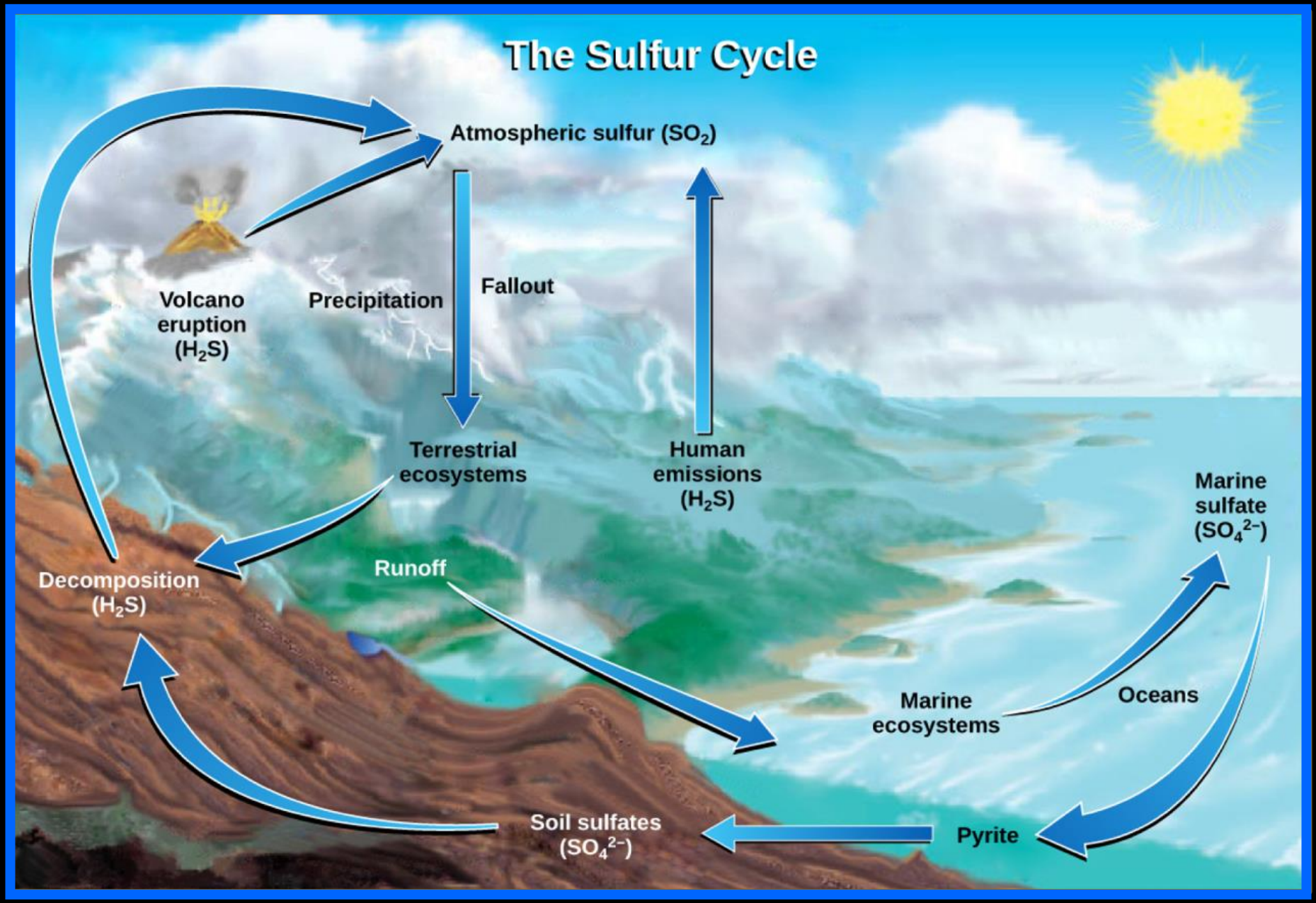
Water from land & oceans enters atmosphere by evaporation or sublimation, where it condenses into clouds & falls as rain or snow. Precipitated water may enter freshwater bodies or infiltrate soil. Cycle complete when surface or groundwater reenters ocean. From *Concepts of Biology*, OpenStax. Modification Evans & Perlman USGS work



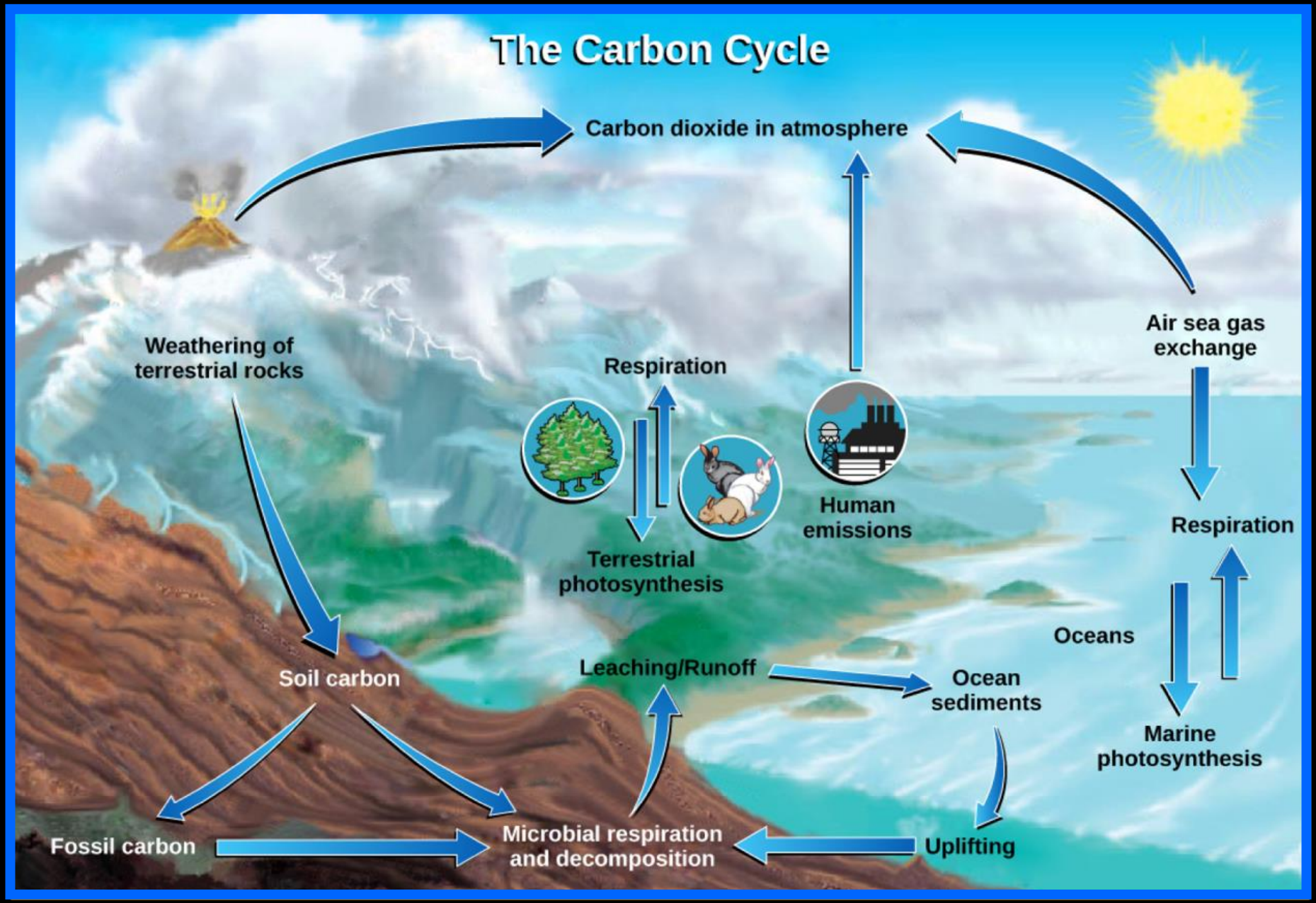
Nitrogen enters living world from atmosphere through nitrogen-fixing bacteria. This nitrogen and nitrogenous waste from animals is then processed back into gaseous nitrogen by soil bacteria, which also supply terrestrial food webs with the organic nitrogen. From *Concepts of Biology*, OpenStax. Modification of USGS work of Evans and Perlman



Phosphorus in nature exists as phosphate ion (PO_4^{3-}). Weathering of rocks & volcanic activity releases phosphate into soil, water, and air, where it enters terrestrial food webs. Phosphate enters oceans in surface runoff, groundwater flow, & river flow. Phosphate dissolved in ocean water cycles into marine food webs. Some phosphate from webs falls to ocean floor as sediment. From *Concepts of Biology*, OpenStax. Modification of USGS work of Evans and Perlman



Sulfur dioxide from atmosphere becomes available to terrestrial & marine ecosystems when dissolved in precipitation as weak sulfuric acid or when it falls directly to Earth as fallout. Weathering of rocks also makes sulfates available to terrestrial ecosystems. Decomposition of organisms returns sulfates to ocean, soil, and atmosphere. From *Concepts of Biology*, OpenStax. Modification of USGS work of Evans and Perlman



CO_2 exists in atmosphere & waters. Photosynthesis converts CO_2 gas to organic carbon. Respiration cycles organic carbon back into CO_2 gas. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground & becomes fossilized. Volcanic activity & more recently human activity bring stored carbon back into carbon cycle. From *Concepts of Biology*, OpenStax. Modification of USGS work of Evans and Perlman

At times certain chemicals build up in the atmosphere.*
Humans are responsible for a current buildup of CO_2

*Two natural examples are (i) the Great Oxygenation Event early in the Proterozoic eon and (ii) an oxygen buildup in the Carboniferous period due to extensive forestation

Planet Earth

Ancient Earth

Brief history

Age determination

Geologic time

Chemical Cycles, AGW

Water, Nitrogen, Phosphorous, Sulfur, Carbon

Anthropogenic global warming

Dynamic Earth

Convection cells

Magnetic field reversals

Plate tectonics

Supercontinent succession

Ice ages

Earth Scaping

Plate tectonics + erosion

Today there is an overwhelming consensus among climate scientists that anthropogenic warming is occurring

Anthropogenic Global Warming

- Global-average temperature fluctuates from year to year. El Niños raise it. La Niñas and volcanoes lower it
- 5-year local regression temperature has risen dramatically since 1960s. Some other factor must be responsible
- Major culprit is increasing CO_2 presence in atmosphere due, in large part, to burning of fossil fuels
- Other changes include rising sea level, melting polar ice, more extreme weather events & damage to the biosphere

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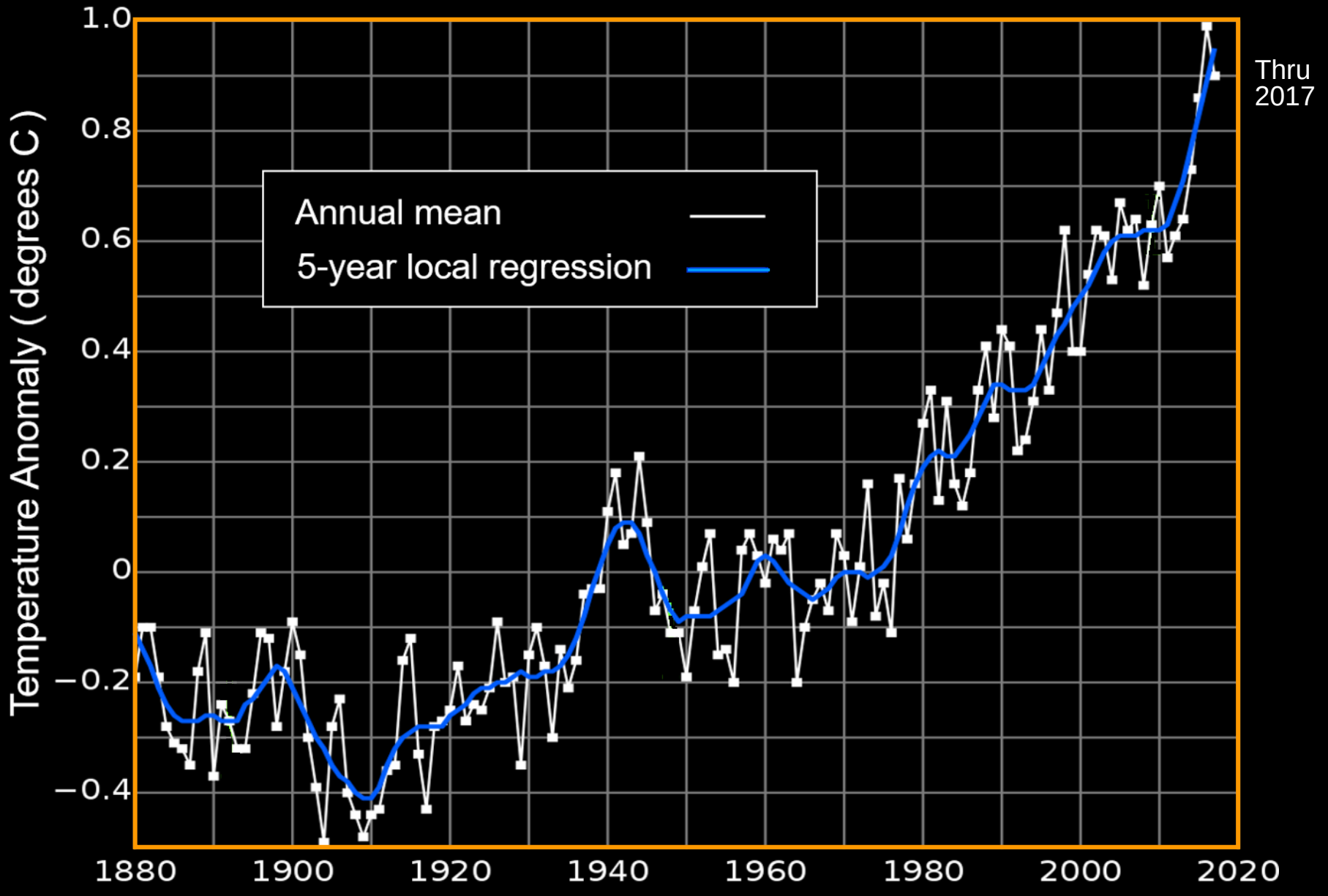
Global Mean Atmospheric Temperature Rise



From Wikipedia "Global Warming" article via Berkeley Earth. Blue curve has barely dipped since 1960s

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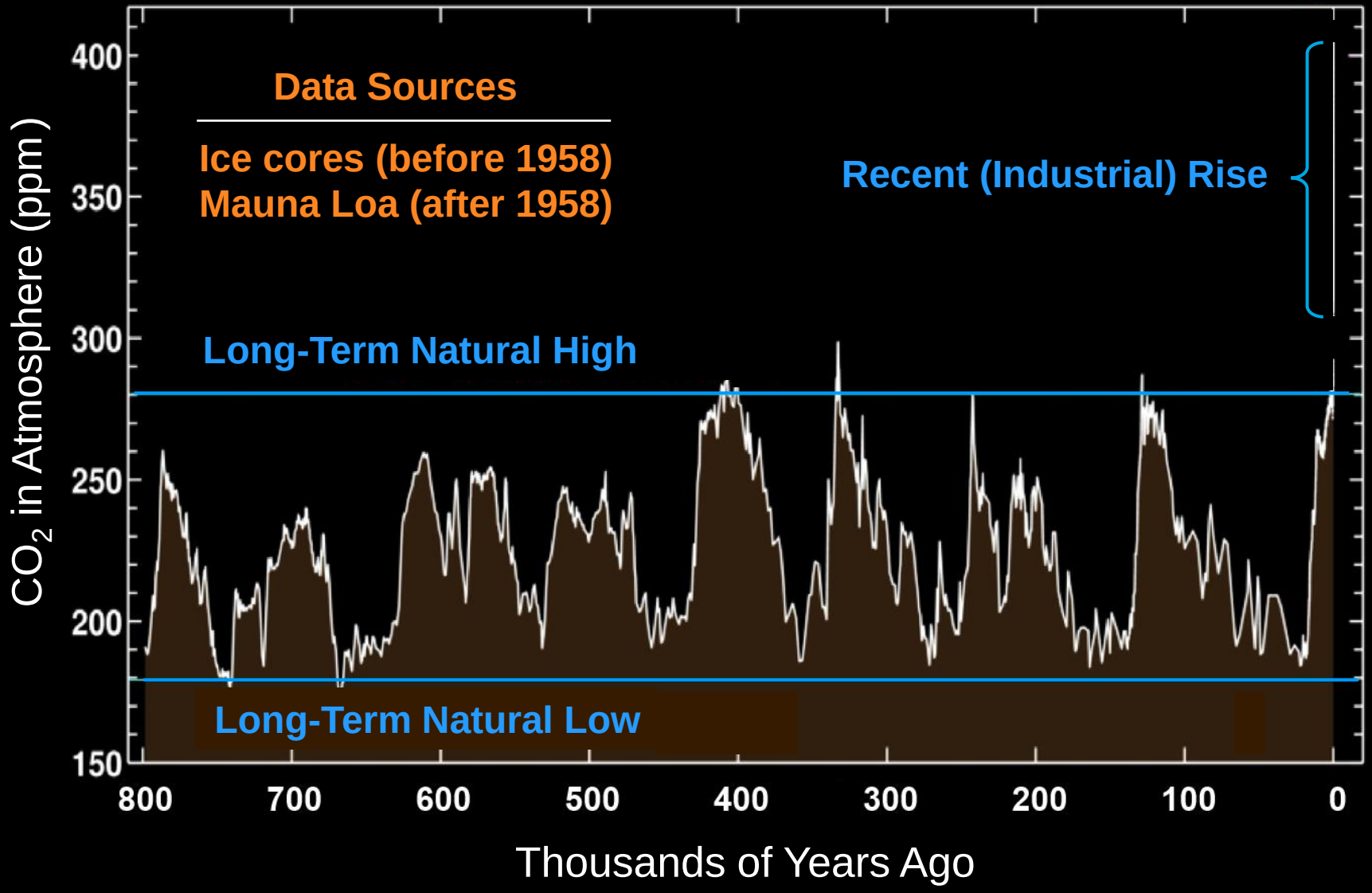
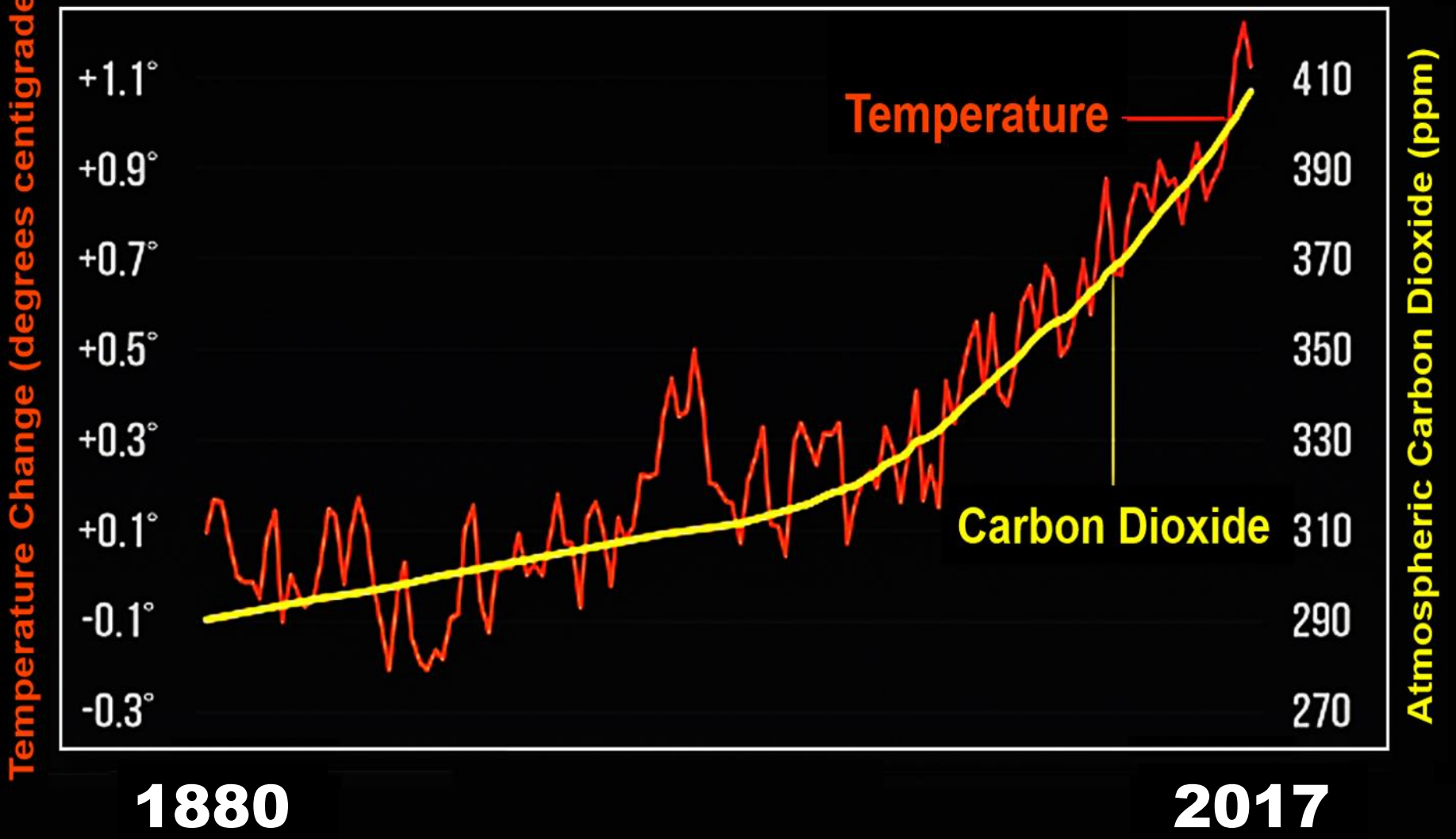
Long-Term Atmospheric CO_2 Concentration



Scripps Institution of Oceanography

Anthropogenic Global Warming and Atmospheric CO_2 Content



Graph from Climate Central. Data from NASA GISS, NOAA NCEL, ESRL

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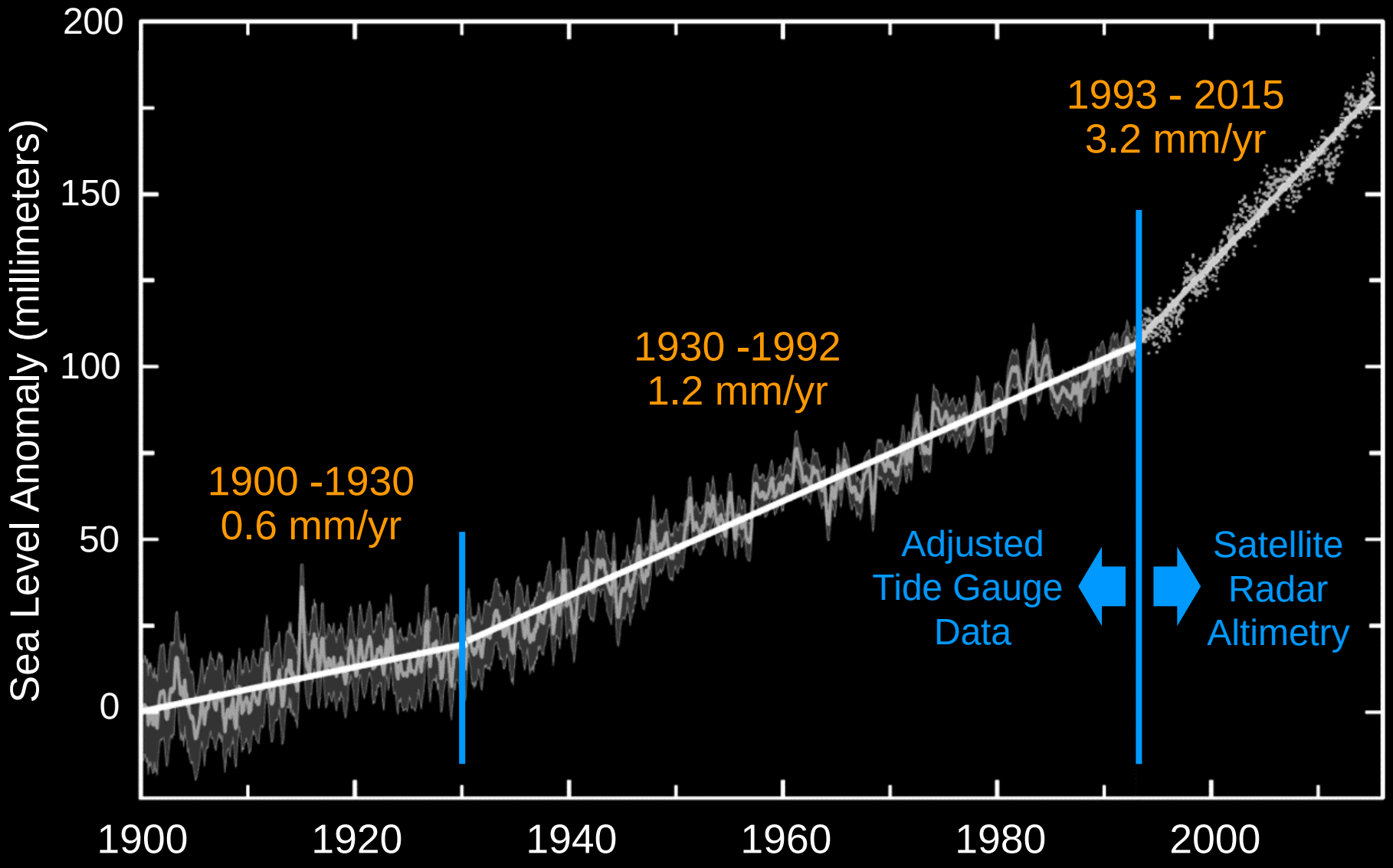
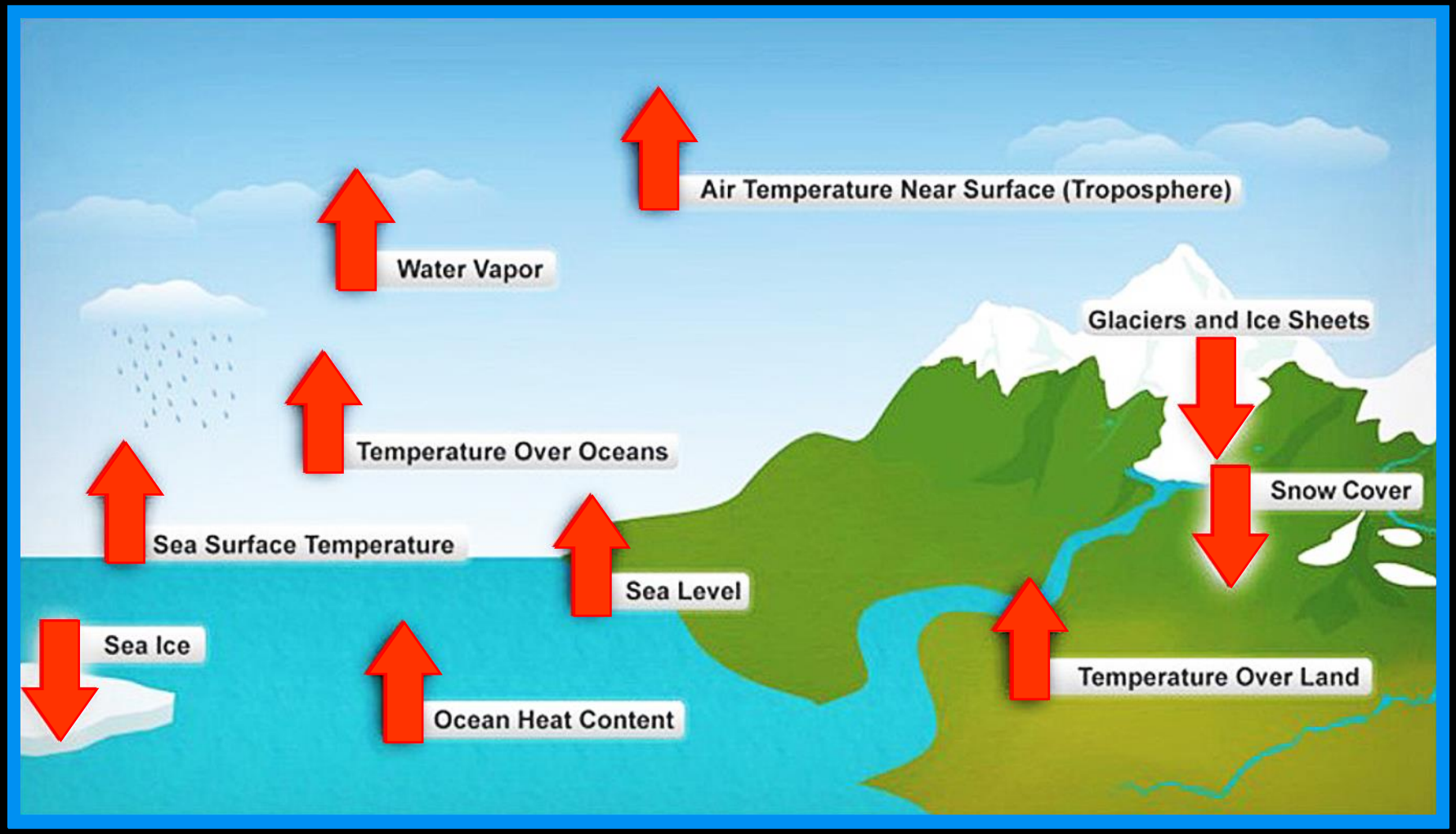
Global Mean Sea Level Rise



From Hawaii.gov. Rising ocean level is caused by (i) increases in ocean mass from melting glaciers / ice sheets and (ii) thermal expansion associated with increasing ocean temperatures

Ten Indicators of a Warming World

All Observed



NOAA NCDC

Anthropogenic Warming Not New Idea

- 1896 Calculations by Svante Arrhenius indicate that cutting CO_2 in atmosphere by half could produce an ice age whereas doubling CO_2 could produce a warming of 5 to 6 °C
- 1958 In Bell Labs Science Series* film *The Unchained Goddess,* Dr. Research mentions that humans might be unwittingly changing the world's climate through releases in factories and automobiles of more than six billion tons of carbon dioxide every year. Severe consequences possible (e.g. submerging NYC, even skyscrapers)
- 1968 Stanford Research Institute (SRI) report prepared by Elmer Robinson and R.C. Robbins for the American Petroleum Institute notes that "Man is now engaged in a vast geophysical experiment with his environment, the Earth" and "significant temperature changes are almost certain to occur by the year 2000"**

*Series included *Our Mr. Sun* (1956) and *Hemo the Magnificent* (1957). **From 3/15/18 Guardian article "It's 50 years since climate change was first seen. Now time is running out" by Richard Wiles

Paris Agreement

Environmental accord adopted in 2015 by nearly every nation to address climate change and impact. The deal aims to reduce global greenhouse gas emissions to limit the global temperature increase in the 20th century to 2 °C above preindustrial levels, while pursuing means to limit the increase to 1.5 °C

The agreement includes commitments from all major emitting countries to cut their climate-altering pollution and to strengthen those commitments over time. The pact provides a pathway for developed nations to assist developing nations in their climate mitigation and adaptation efforts. It also creates a framework for transparent monitoring, reporting, & ratcheting up of countries' individual and collective climate goals

Unfortunately, President Trump has made it known he plans to withdraw the U.S. from the accord. The earliest this can be done is in 2020

IPCC Special Report on Global Warming of 1.5 °C

Summary for Policy Makers

Prepared for UNFCCC (2018)

IPCC = Intergovernmental Panel on Climate Change. UNFCCC = United Nations Framework Convention on Climate Change. 1.5 °C refers to rise above pre-industrial levels

1.5 °C warming over preindustrial levels would be significantly less harmful than 2.0 °C

Impact of 1.5 °C and 2.0 °C Warming

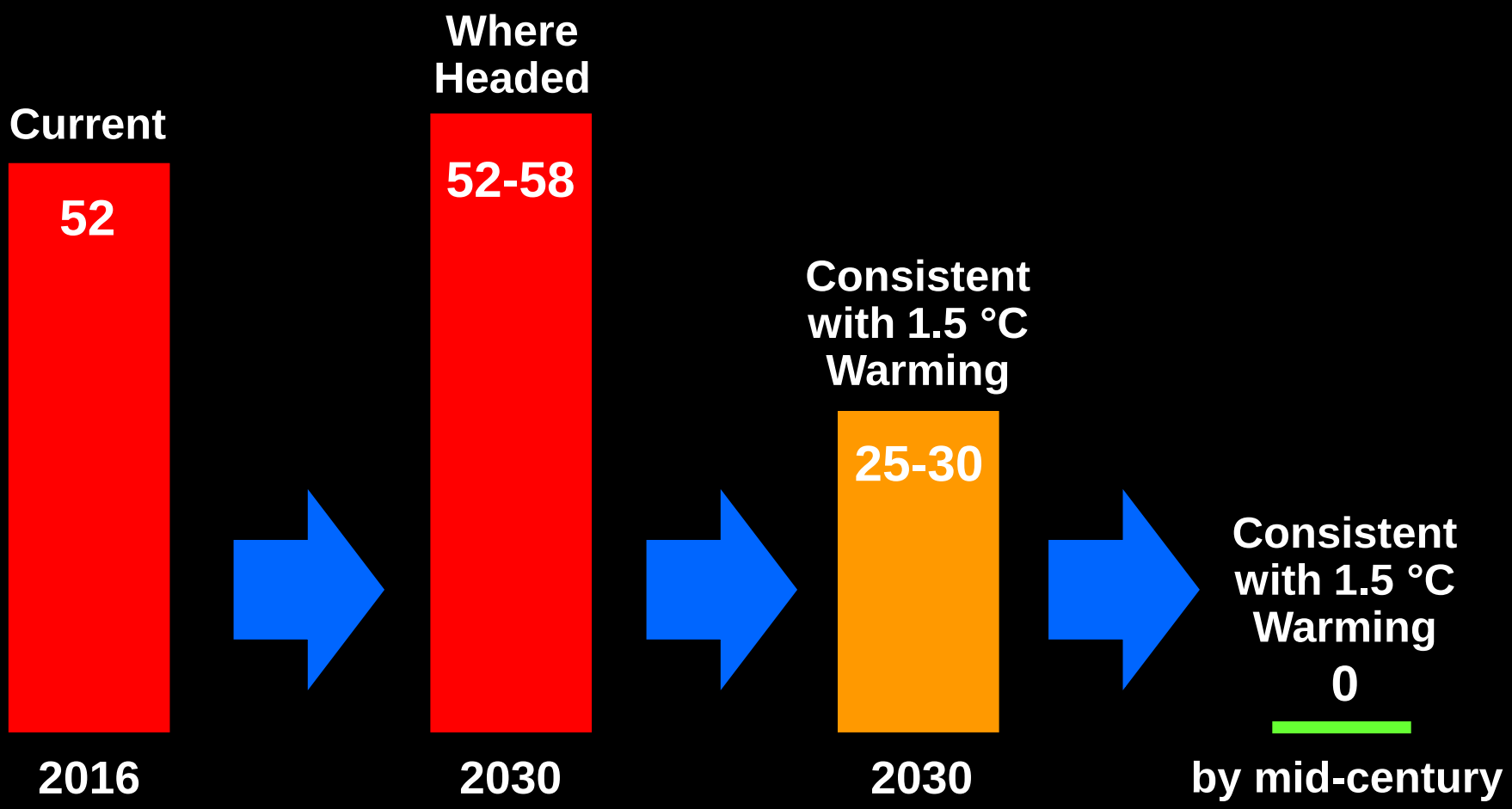
Change	1.5°C over preindustrial	2.0°C over preindustrial
Number of ice-free arctic sea summers	≥ 1 / 100 yr	≥ 1 / 10 yr
Sea level rise by 2100 (meters)	0.40	0.46
Thawing of artic permafrost (million km^2)	4.8	6.6

IPCC Special Report results tabulated by Kelly Levin in "8 Things You Need to Know about the IPCC 1.5 °C Report" WRI (Oct 7, 2018). Impact on biosphere in Life on Earth presentation

Unfortunately the world appears headed for increases greater than 2.0 °C above preindustrial levels, especially without US engagement

Annual Anthropogenic CO_2 Emissions

Billion Tons



From "8 Things You Need to Know about the IPCC 1.5 °C Report", Levin, WRI (Oct 7, 2018)

Not good at all

Anthropogenic changes to the biosphere discussed in Life on Earth presentation

The End