The History of the Earth

The big Bang

Origin of the Universe

The universe began about 13.9 billion years ago

According to Big Bang theory almost all matter was in the form of energy

$$E = MC^2$$

E = energy, M = mass and C = the speed of light.

And then it exploded

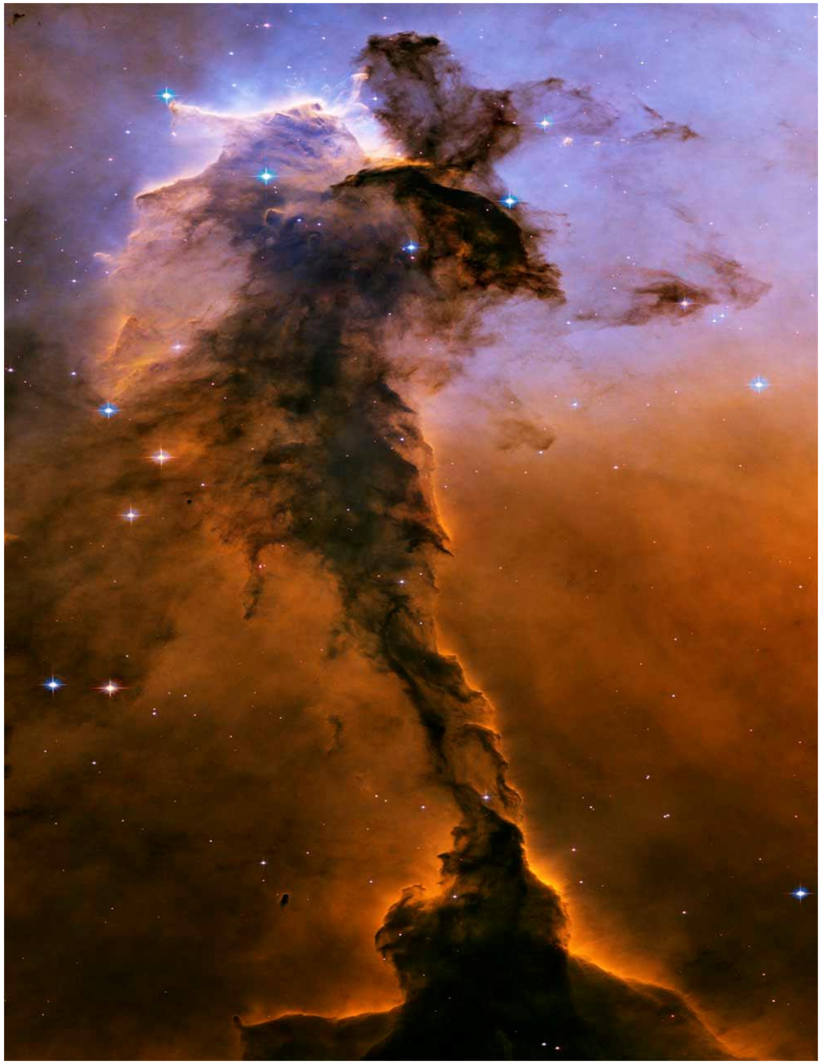
Our Solar system

A large gas cloud (nebula) begins to condense nearly 10 billion years later, ~ 4.6 billion years ago. Most of the mass is in the centre. There is turbulence in the outer parts.

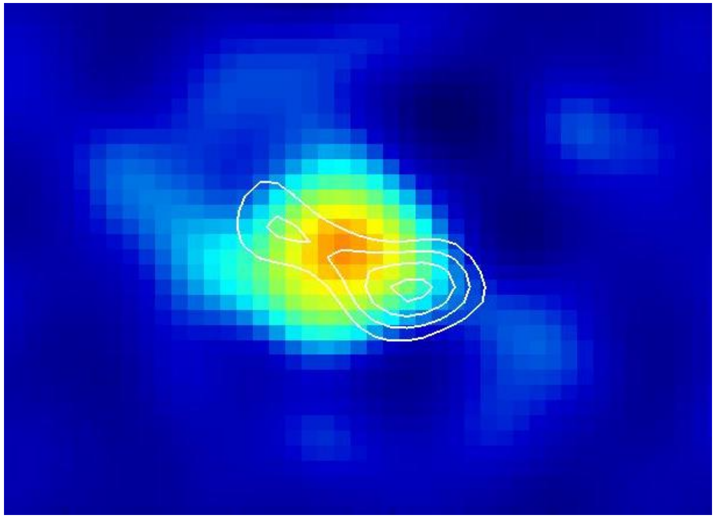
The Nebular Hypothesis

The turbulent eddies collect matter measuring meters across

Small blocks grow and collide, eventually become large aggregates of gas and solid material.



False Color Image of Protostar

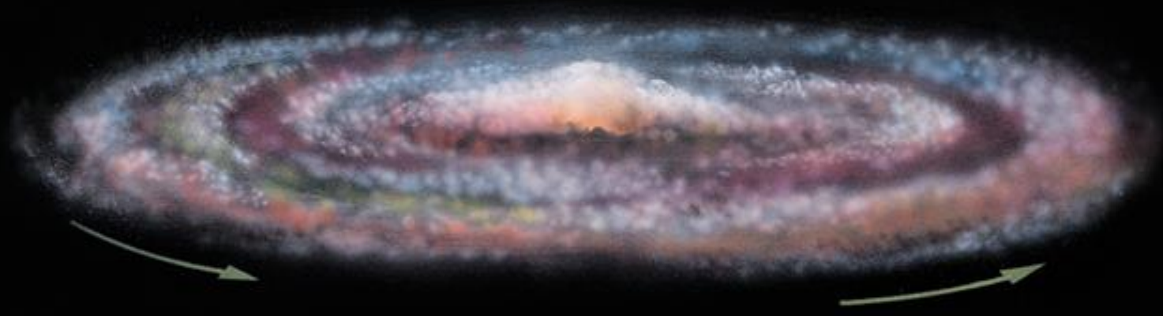


The multi-colored area shows a dust disk surrounding a newborn star

The red-orange area at the center represents the brightest region, which contains the young star

It is surrounded by the cooler, dusty disk (yellow, green and blue)

Evolution of the solar system



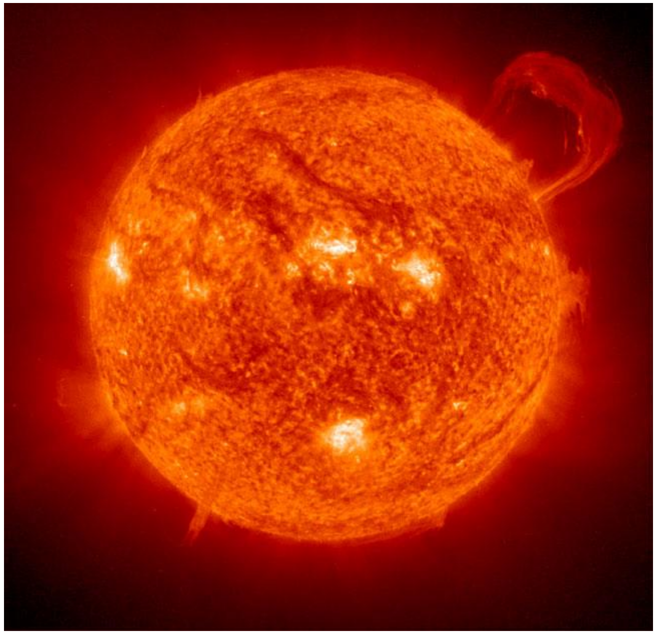
The nebula condenses into a swirling disc, with a central ball surrounded by rings.

A second- or third-generation nebula forms from hydrogen and helium left over from the big bang, as well as from heavier elements that were produced by fusion reactions in stars or during explosion of stars.

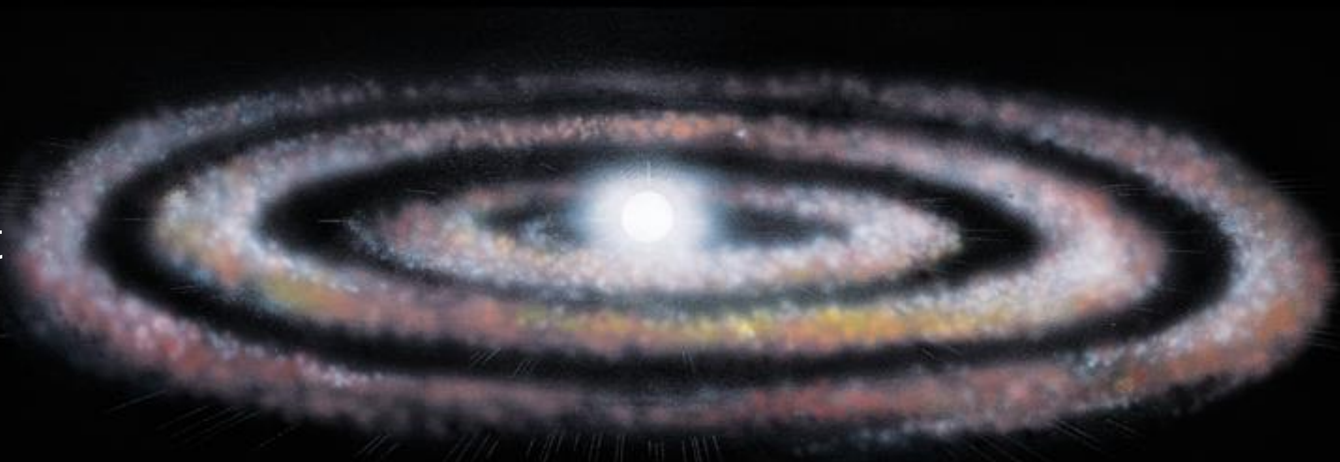
The Sun

After sufficient mass and density was achieved, the temperature of the Sun rose to one million °C, resulting in thermonuclear fusion.

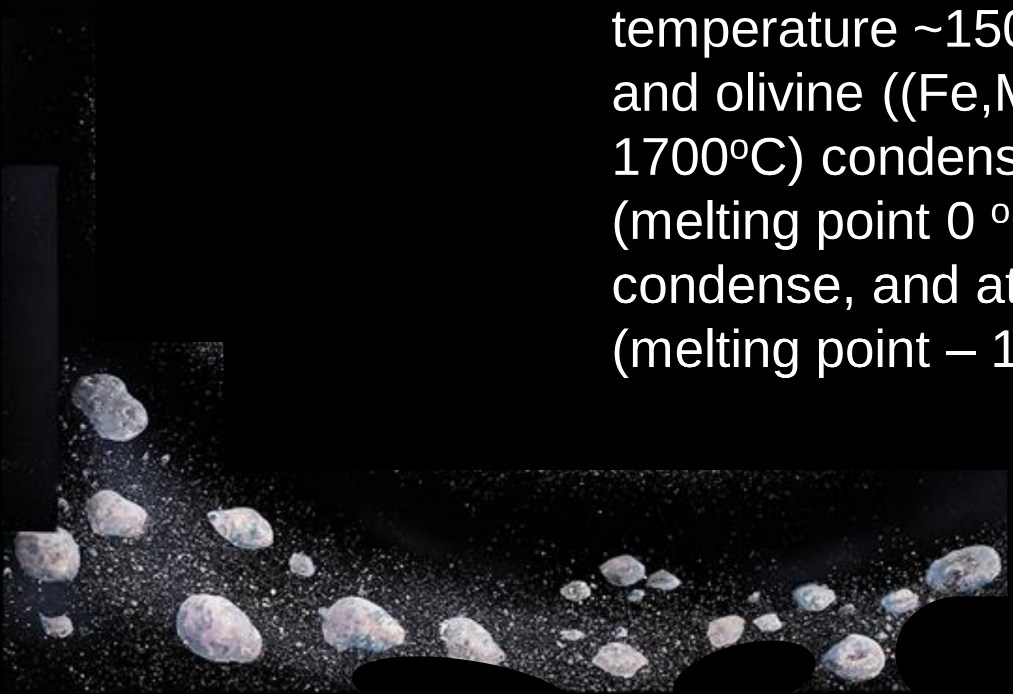
H atom + H atom = He atom + energy

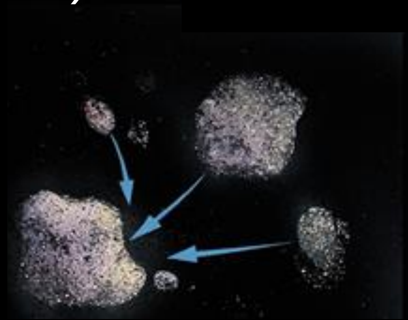


The ball at the center grows dense and hot enough for fusion to begin (> 5x106 ºC). It becomes the Sun. Dust (solid particles) condenses in the rings.



The nature of the matter condensed depends on temperature. At distance of Earth from Sun, temperature ~1500 ºC. Iron (melting point 1538 ºC), and olivine ($(Fe,Mg)_2SiO_4$; melting point 1500 – 1700ºC) condense. At distance of Jupiter, water ice (melting point 0 ºC) and ammonia (melting point -78 ºC) condense, and at distance of Neptune, methane (melting point – 182 ºC) condenses.





Dust particles collide and stick together, forming planetesimals.

Protoplanets

Gravitational forces allow the inner planets to accrue and compact solid matter (including light and heavy atoms)

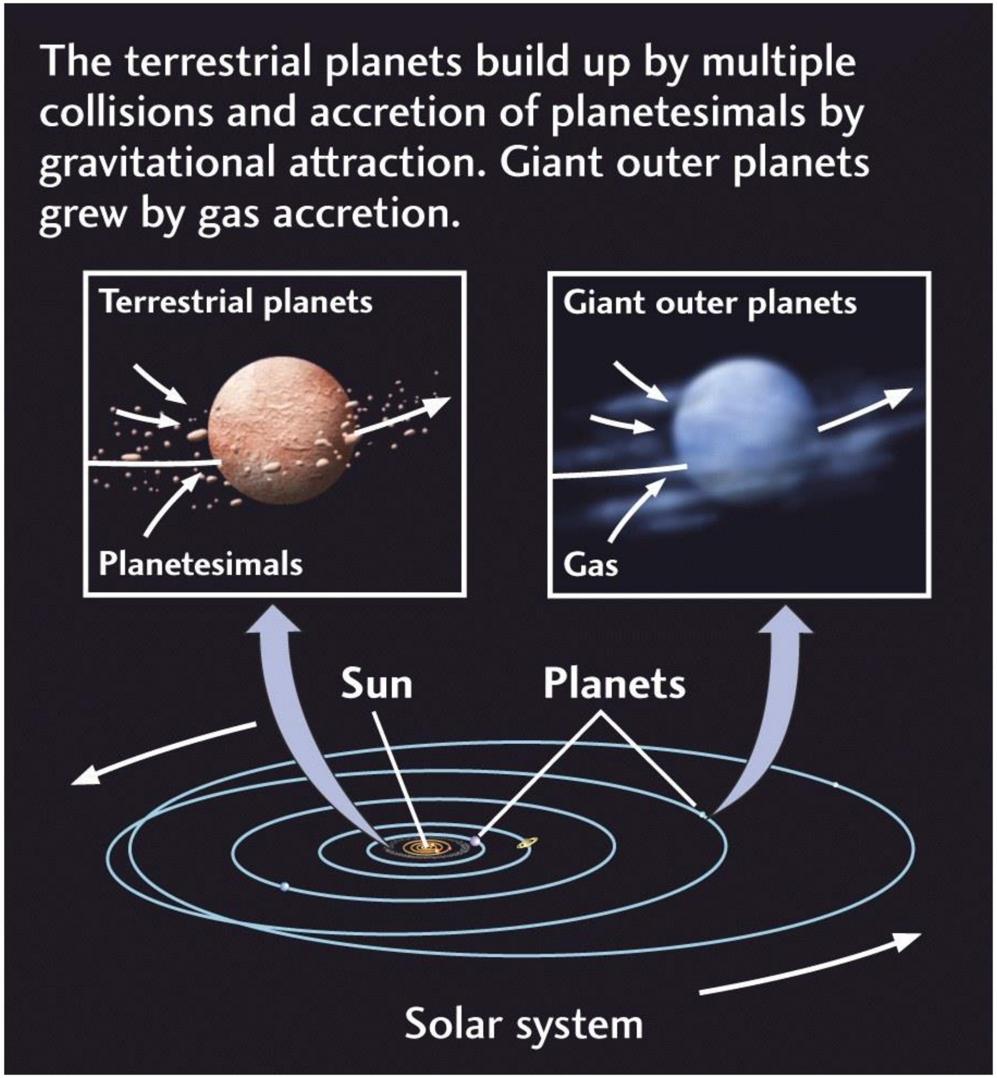
Solar radiation blew gases (primarily hydrogen, helium) away from inner planets

These gases were collected and condensed into the gas giants (Jupiter, Saturn, Uranus, Neptune)

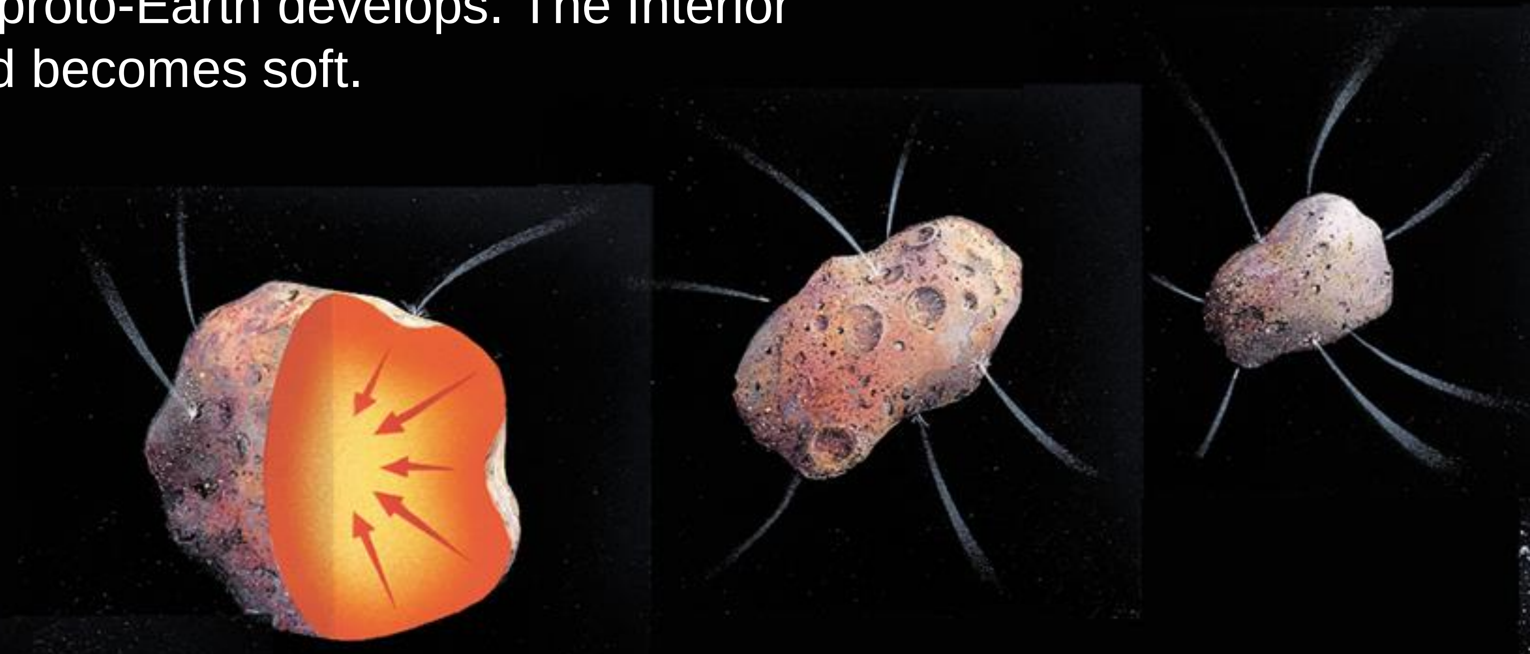
Beyond Neptune, ice and frozen gases form Pluto, Sedna and the Kuiper Belt Objects

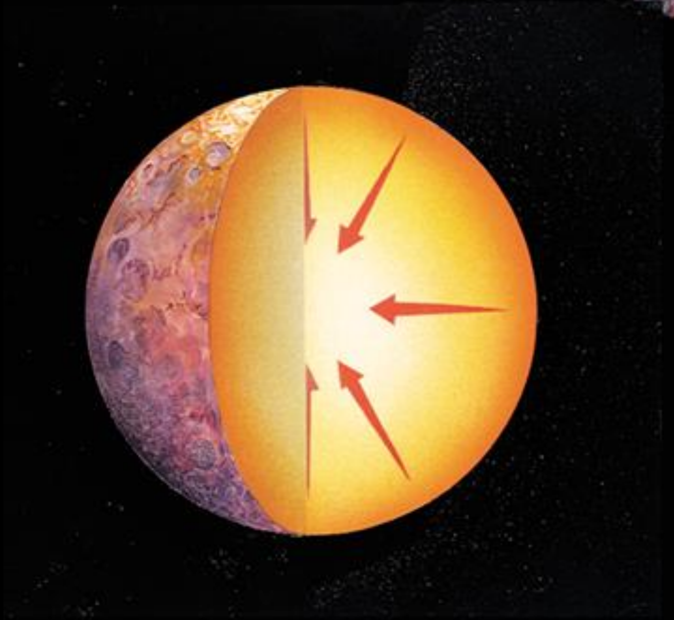
Left-over debris form comets and asteroids

Birth of the Solar System



Planetesimals grow by continuous collisions. Gradually a proto-Earth develops. The Interior heats up and becomes soft.

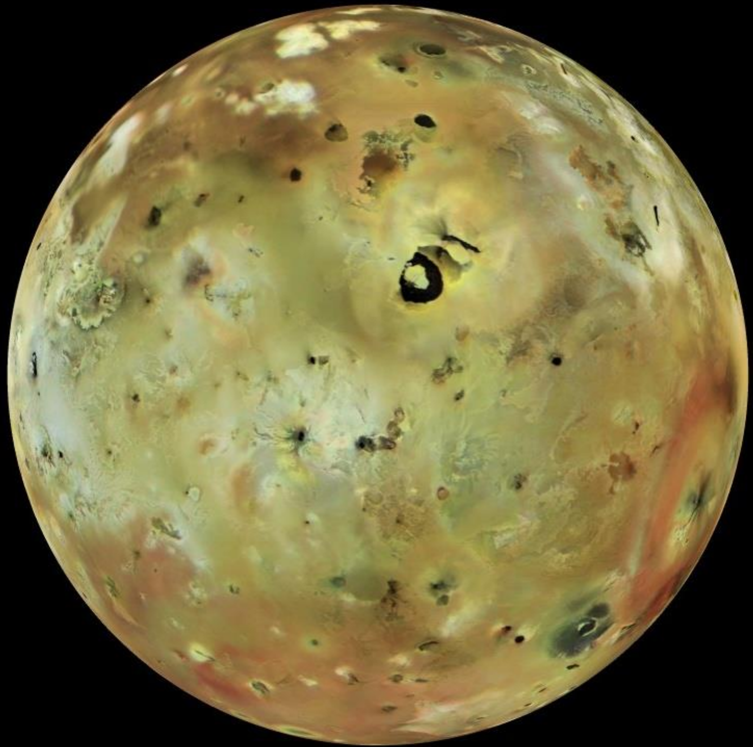


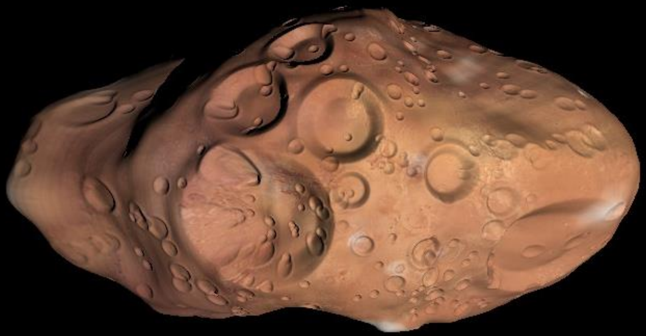


Gravity reshapes the proto-Earth into a sphere.

Gravity and the Moons of Jupiter

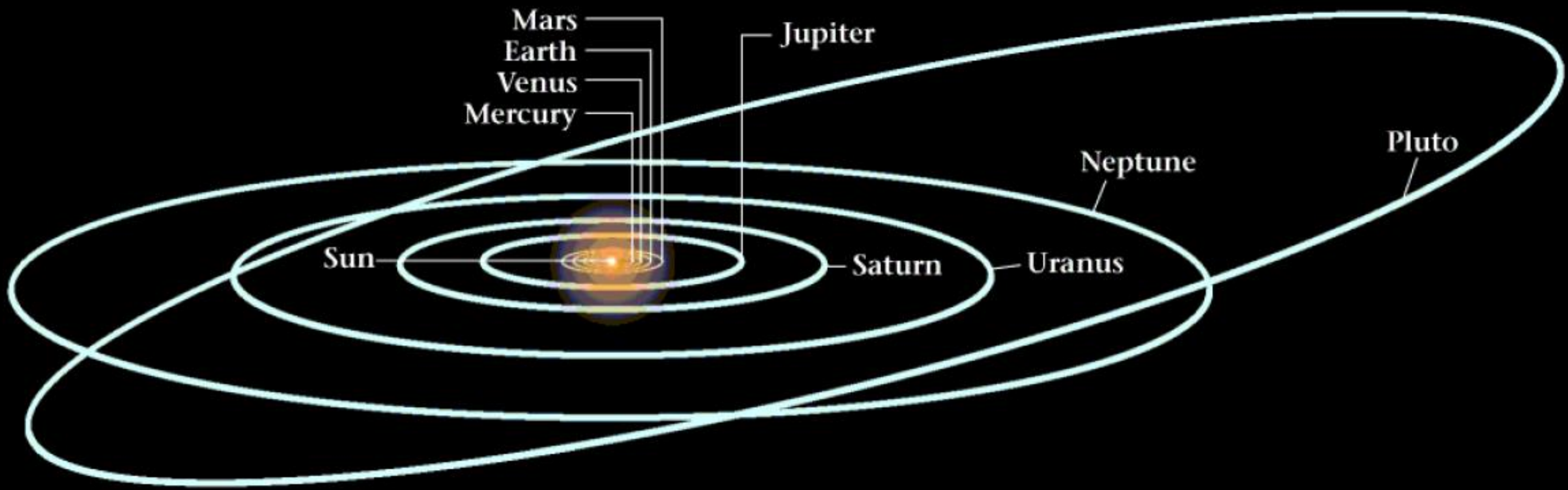
Io – diameter 3600 km

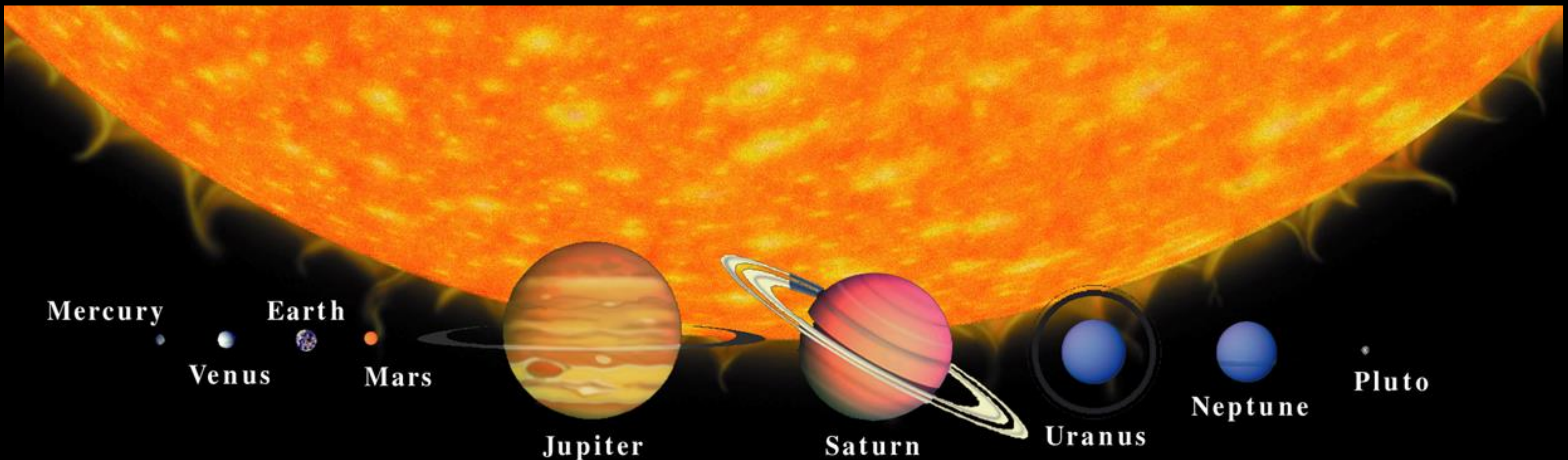




Almathea 270 x 166 x 150 km

The Solar System





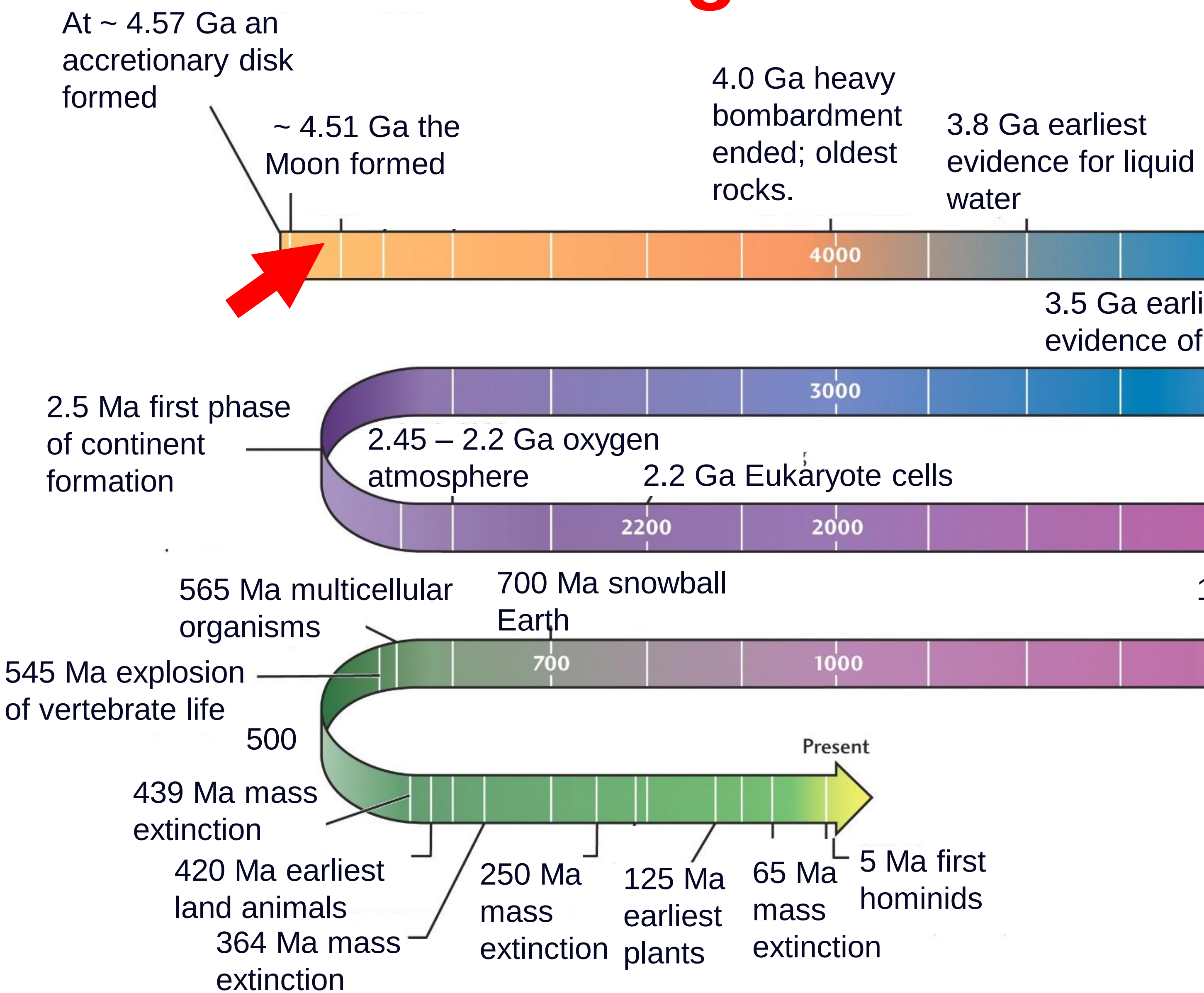
The Age of the Earth

The Earth is ~ 4.57 million years old

Meteorites give us access to debris left over from the formation of the solar system

We can date meteorites using radioactive isotopes and their decay products

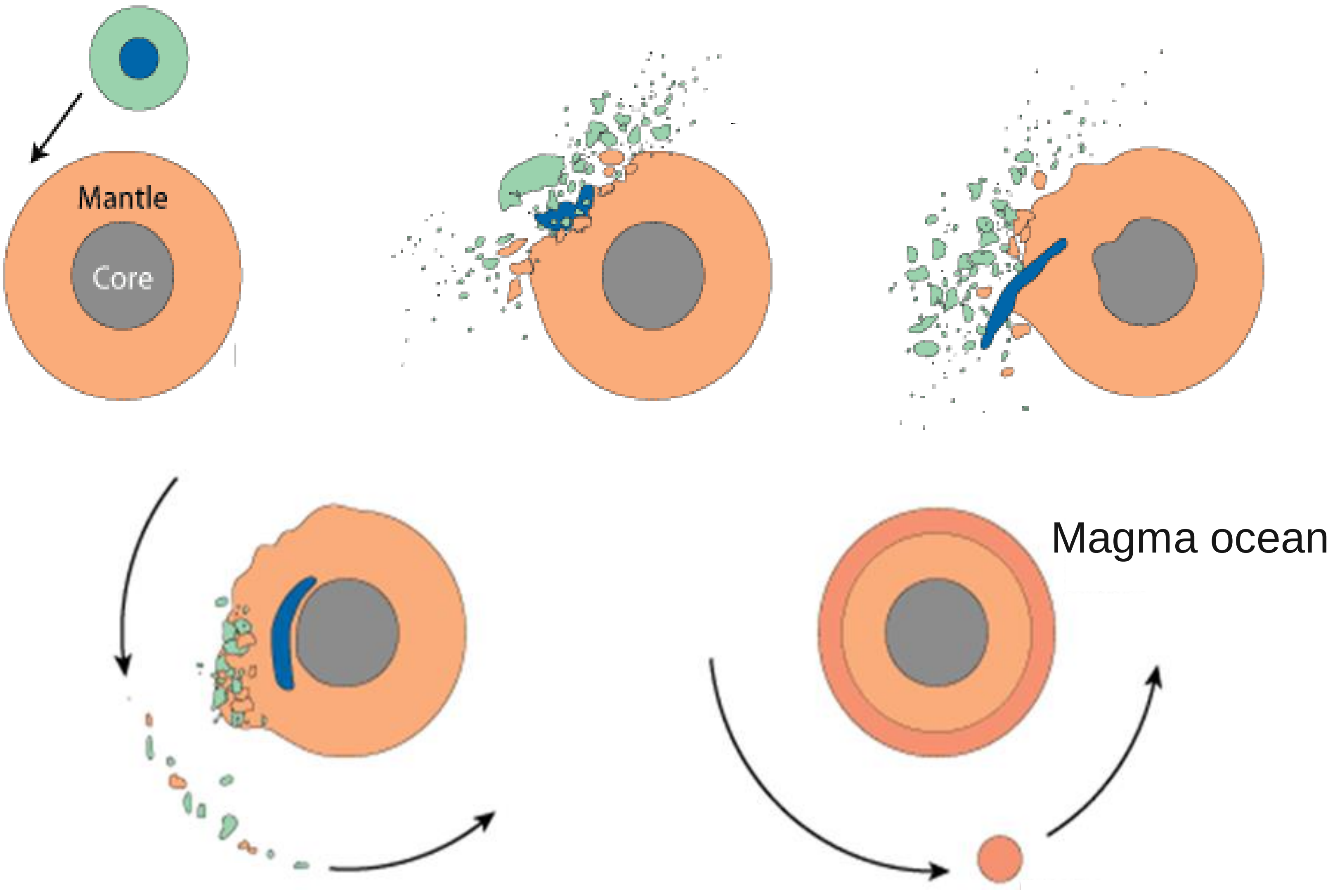
Geologic Time



Formation of the Moon

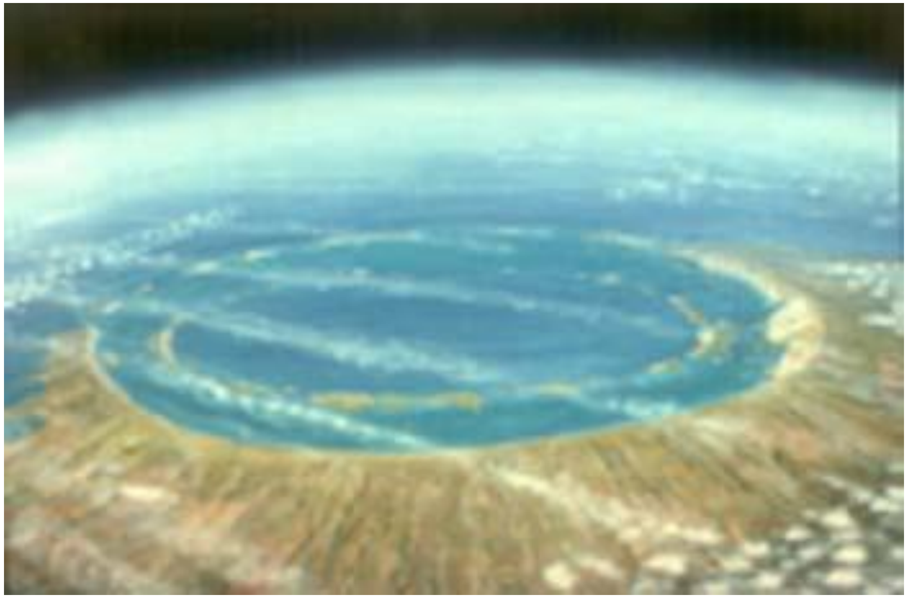
The Giant Impact Hypothesis predicts that around 50 million years after the initial creation of Earth, a planet about the size of Mars collided with Earth

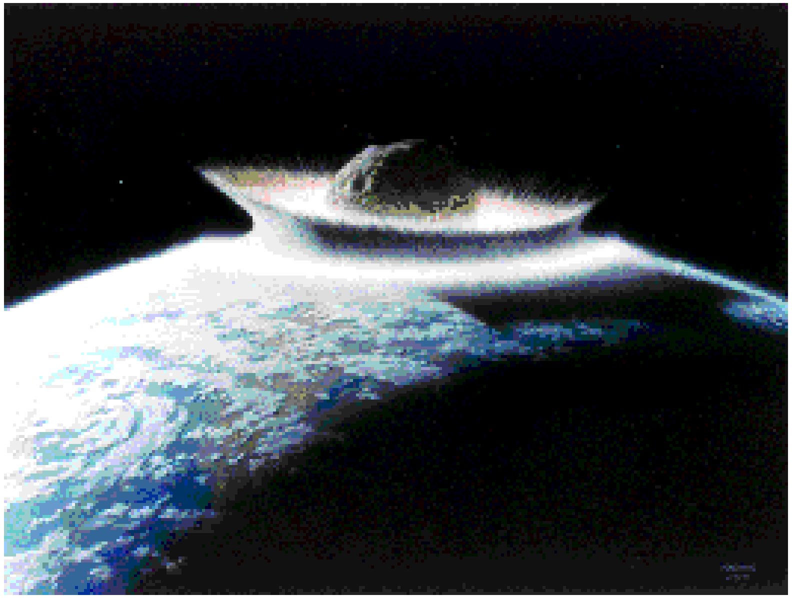
Simulated Formation of the Moon



Bombardment From Space

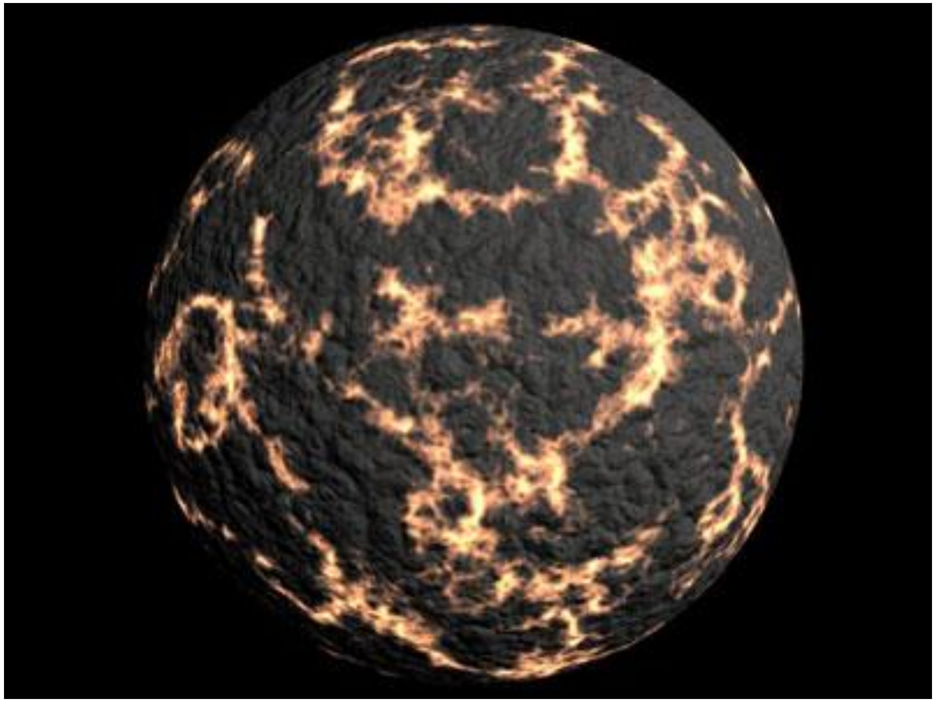
For the first half billion years of its existence, the surface of the Earth was repeatedly pulverized by asteroids and comets of all sizes. However, no evidence has been preserved because of resurfacing





The Early Earth Heats Up

Three major factors that caused heating and melting in the early Earth's interior:



1. Collisions (Transfer of kinetic energy into heat)
2. Compression
3. Radioactivity of elements (e.g. uranium, potassium, or thorium)

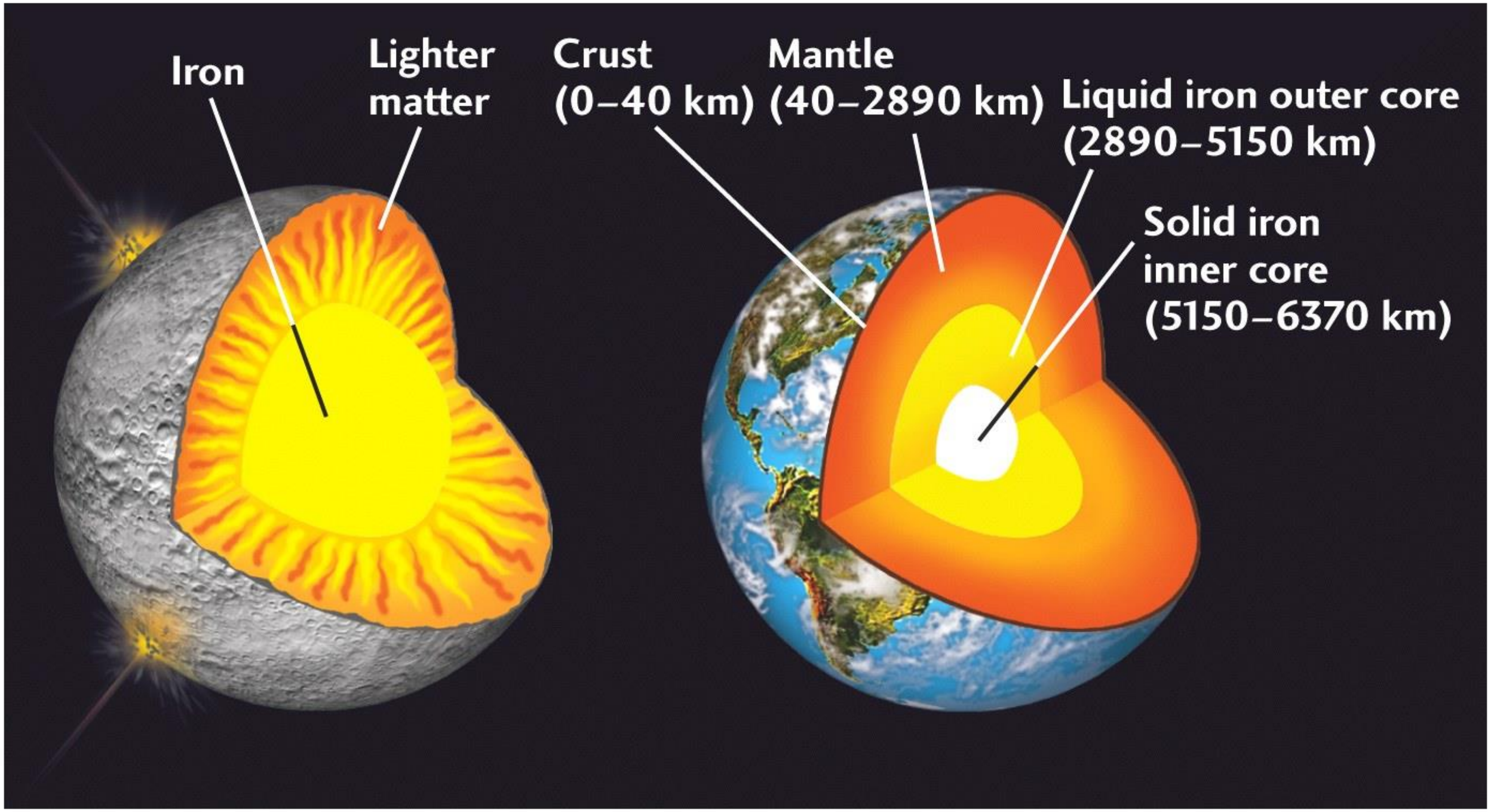
The Core

About 100 million years after initial accretion, temperatures at depths of 400 to 800 km below the Earth's surface reached the melting point of iron (>2,000 ^{o}C)

As a result of global differentiation, the heavier elements, including iron, began to sink down into the core of the Earth, whereas the lighter elements such as oxygen and silica rose up towards the surface.

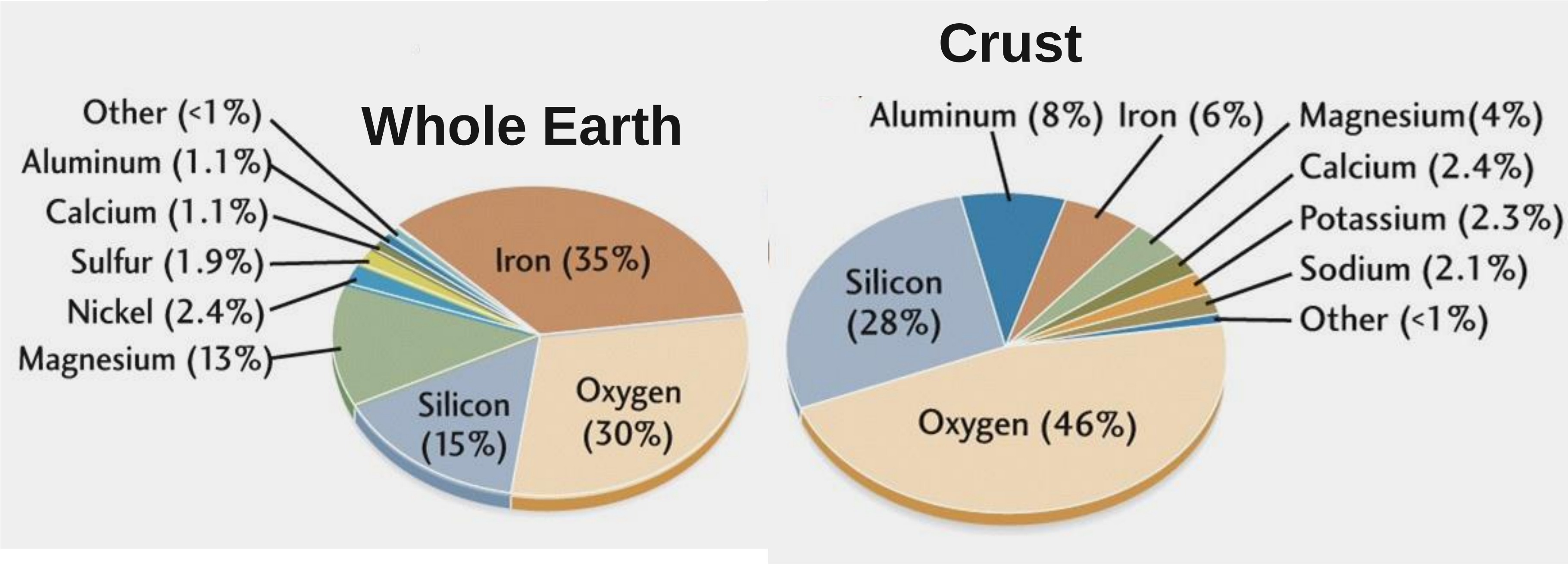
Global Chemical Differentiation

This global chemical differential was completed by about 4.3 billion years ago, and the Earth had developed a inner and outer core, a mantle and crust



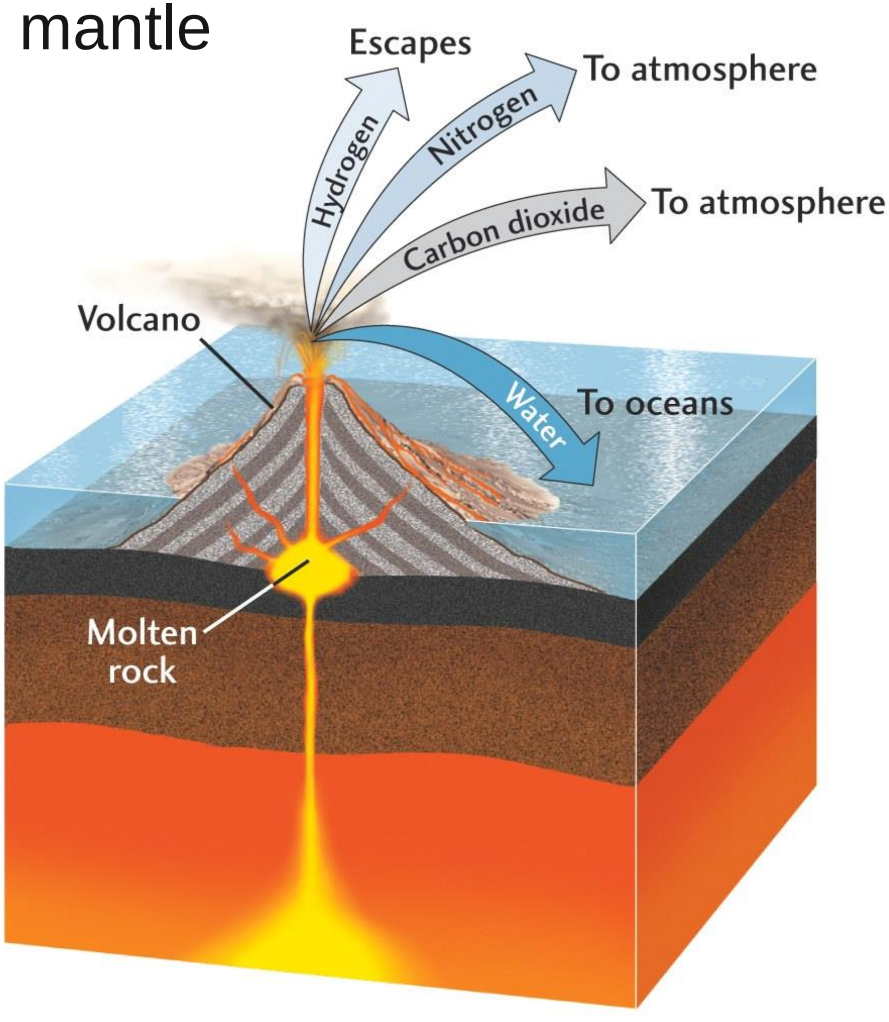
Chemical Composition of Earth

The crust is composed preferentially of the lightest elements and the core of the heaviest elements. Their absolute abundances reflect those of the solar system, with heavier elements being much less common than light elements



Composition of the Upper Earth

Continental and oceanic crust: Composed of crystallised magma and its products generated in the upper parts of the mantle



Oceans and Atmosphere: Fluid and gaseous outer layers produced by release of gases and fluids from volcanic eruptions (in a process called volatile transfer)

The Early Atmosphere

Initially, the Earth is thought to have had a thin atmosphere composed primarily of helium (He) and hydrogen (H)

The Earths gravity could not hold these light gases and they easily escaped into outer space

Today, H and He are very rare in our atmosphere

The Evolving Atmosphere

For the next several hundred million years, volcanic out-gassing began to create a thicker atmosphere composed of a wide variety of gases

The Evolving Atmosphere

The gases included:

Water vapor (H_2O)

Sulfur dioxide (SO_2)

Hydrogen sulfide (H_2S)

Carbon dioxide (CO_2)

Carbon Monoxide (CO)

Ammonia (NH_3)

Methane (CH_4)

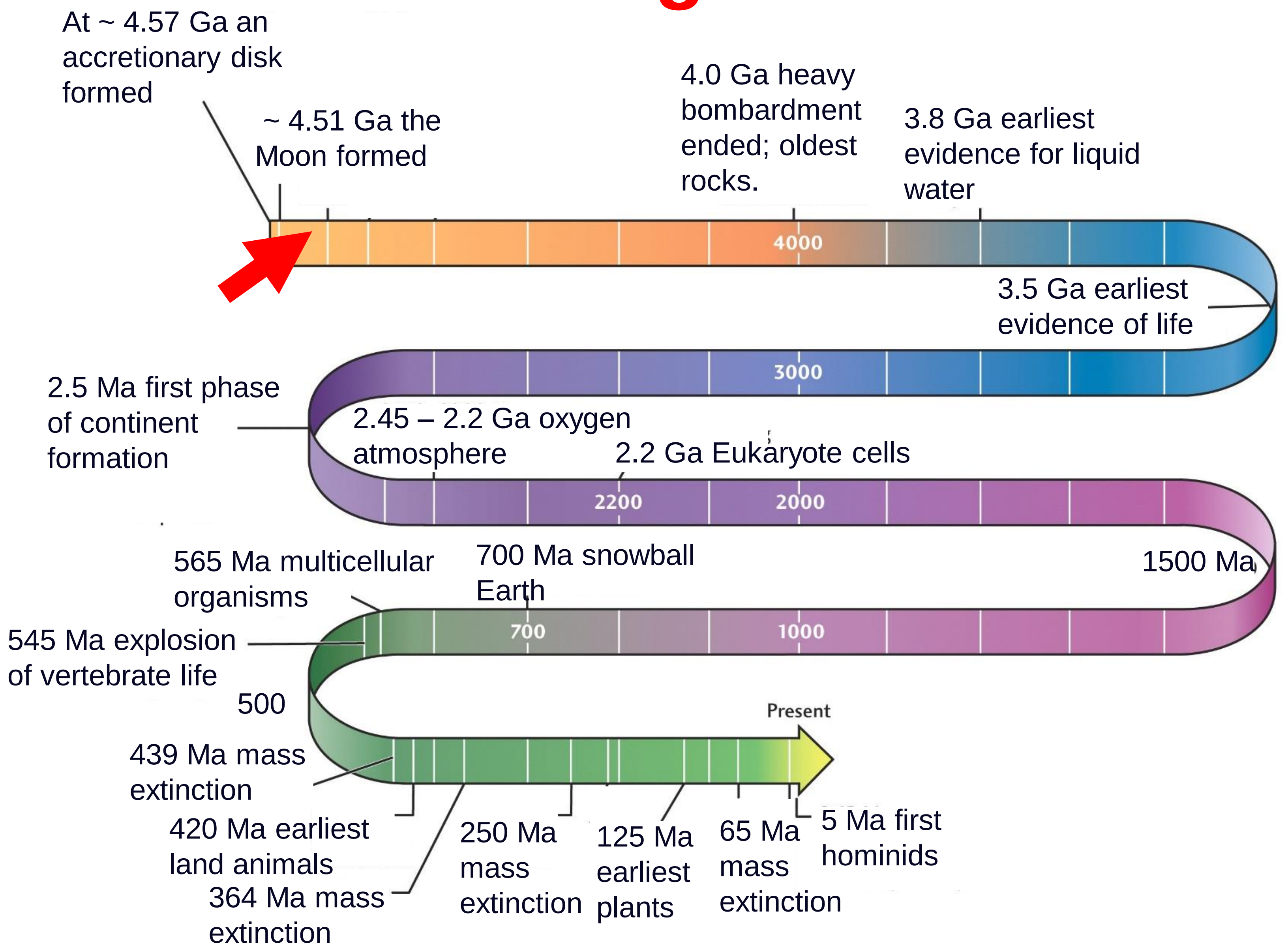
Oxygen came later through bacterial respiration

Creating the Oceans

The oceans formed over hundreds of millions of years from water vapor escaping from the Earth via volcanic eruptions

Comets (dirty ice balls) may also have been a major source of water.

Geologic Time



The Billion Year Old Earth

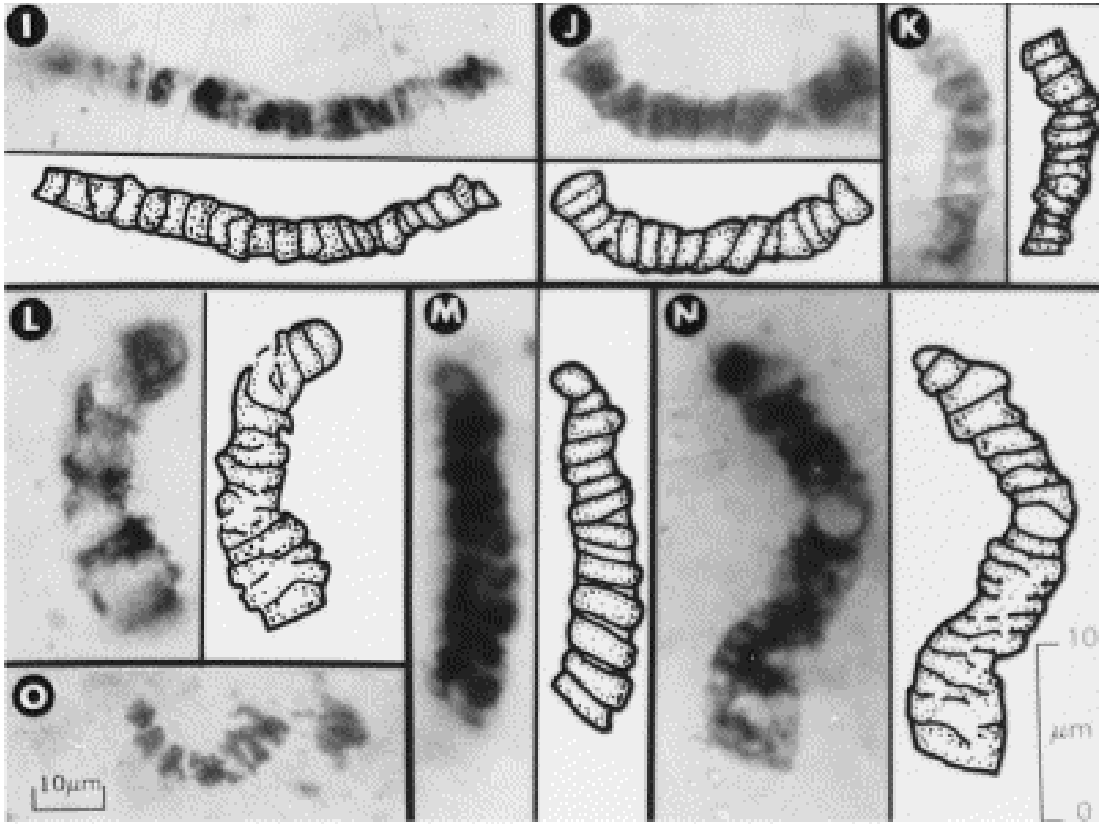
By 3.5 billion years ago, when the Earth had a thick atmosphere composed of CO_2, methane, water vapor and other volcanic gases. It also had extensive oceans with dissolved salts (from volcanic degassing and erosion).

By human standards the early atmosphere was very poisonous

It contained almost no oxygen – today it contains 21 wt.% oxygen.

The Earliest Life

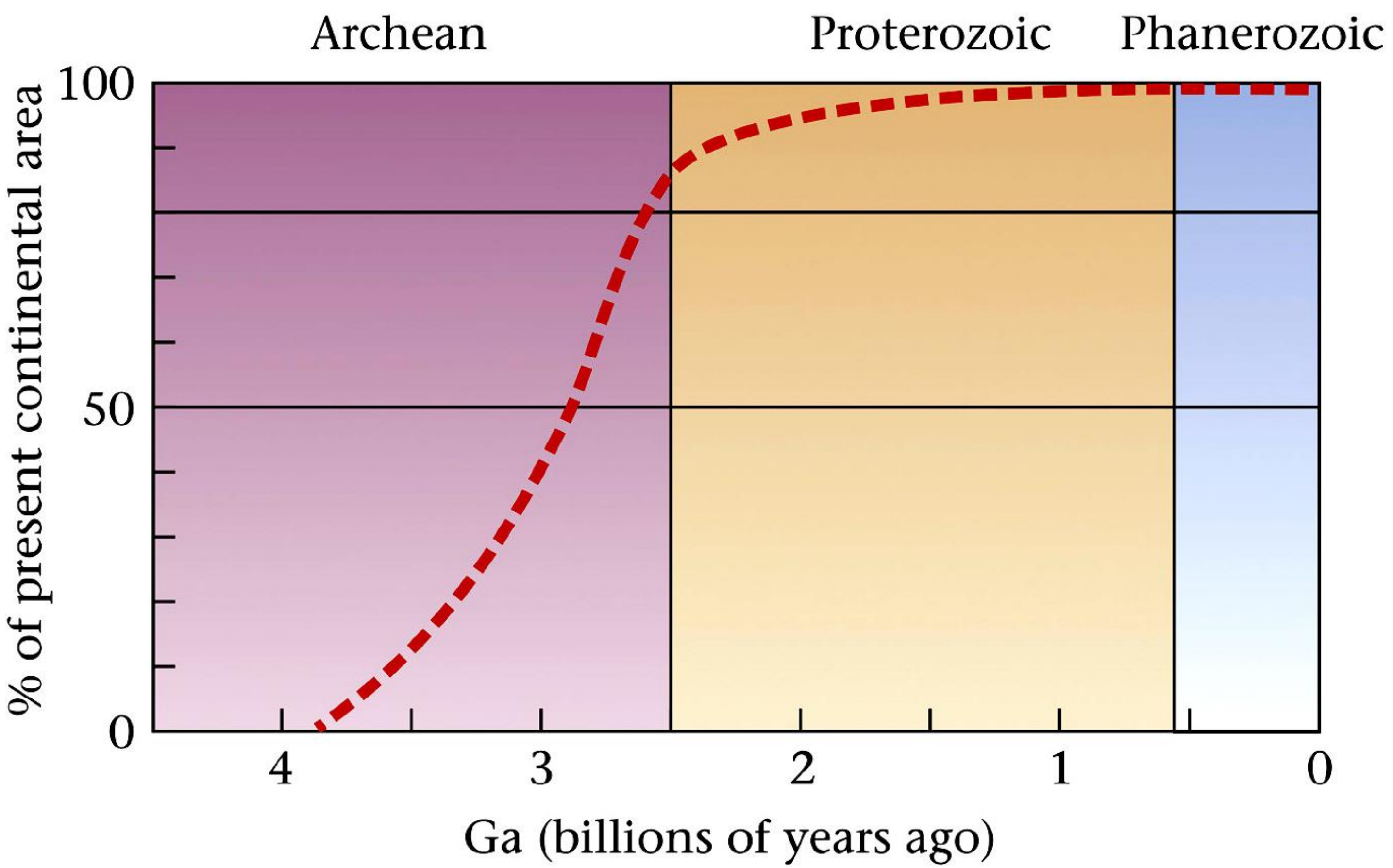
The earliest evidence of life on Earth is preserved in the form of 3.5 billion year old fossil bacteria, in chert (SiO_2 precipitated in the oceans)



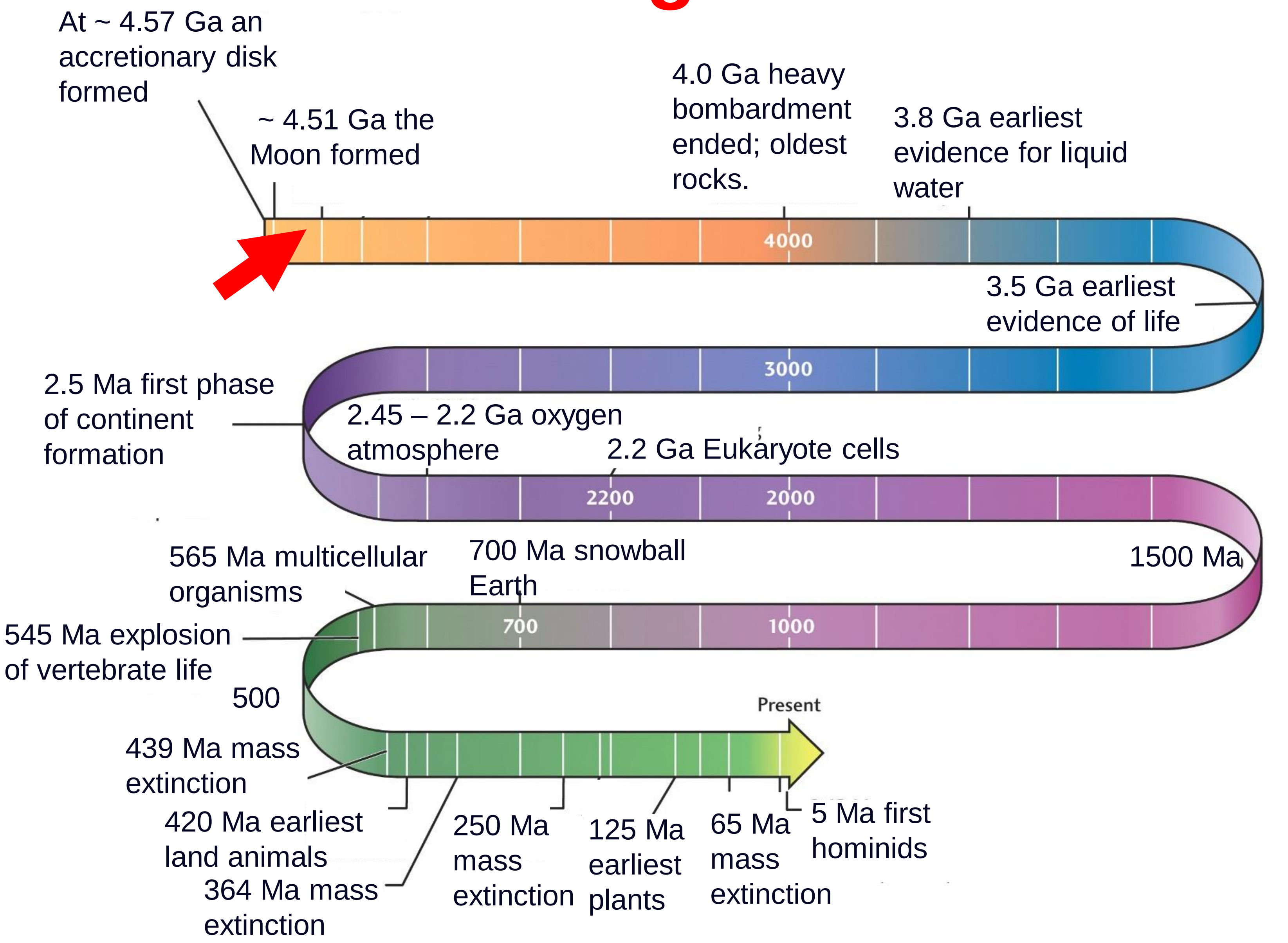
Modern bacteria

The Formation of the Continents

By 2.5 billion years ago, the continents had formed. They rise above the ocean floor because the density of the continental crust (2.8 gr/cm^3) is less than the oceanic crust (3.2 gr/cm^3)



Geologic Time



Cyanobacteria and Photosynthesis

At ~ 2.45 Ga the first cyanobacteria evolved and with it the production of oxygen

Photosynthesis

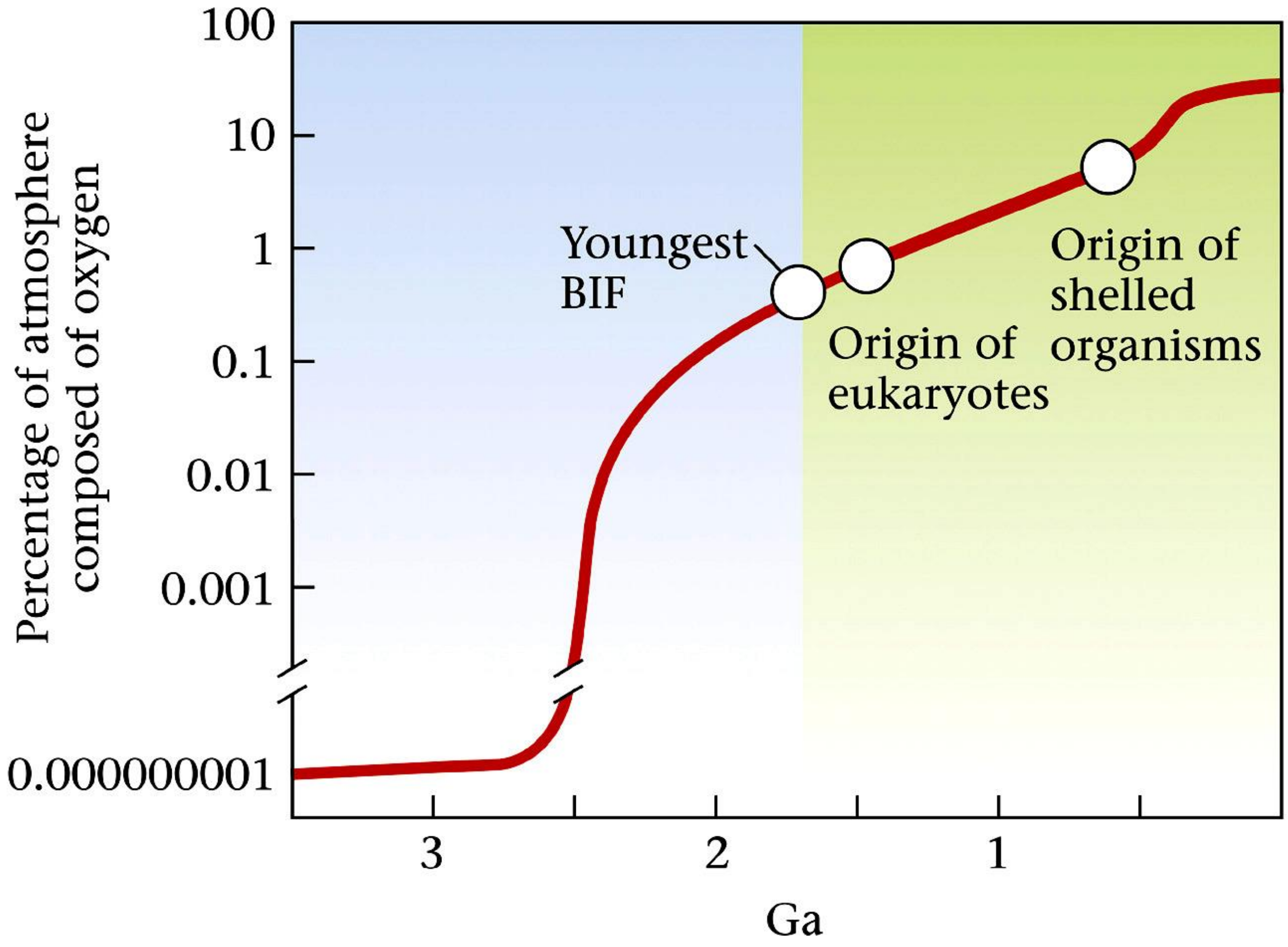
$H_2O + CO_2 = CH_2O + O_2$

Respiration

$CH_2O + O_2 = H_2O + CO_2$

Oxygenation of the atmosphere

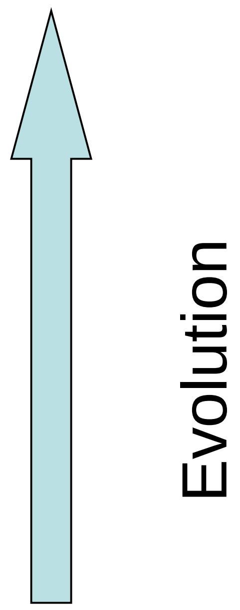
Due to the proliferation of cyanobacteria between 2.45 and 2.2 Ga there was massive oxygenation of the atmosphere.



From Fission to Sex

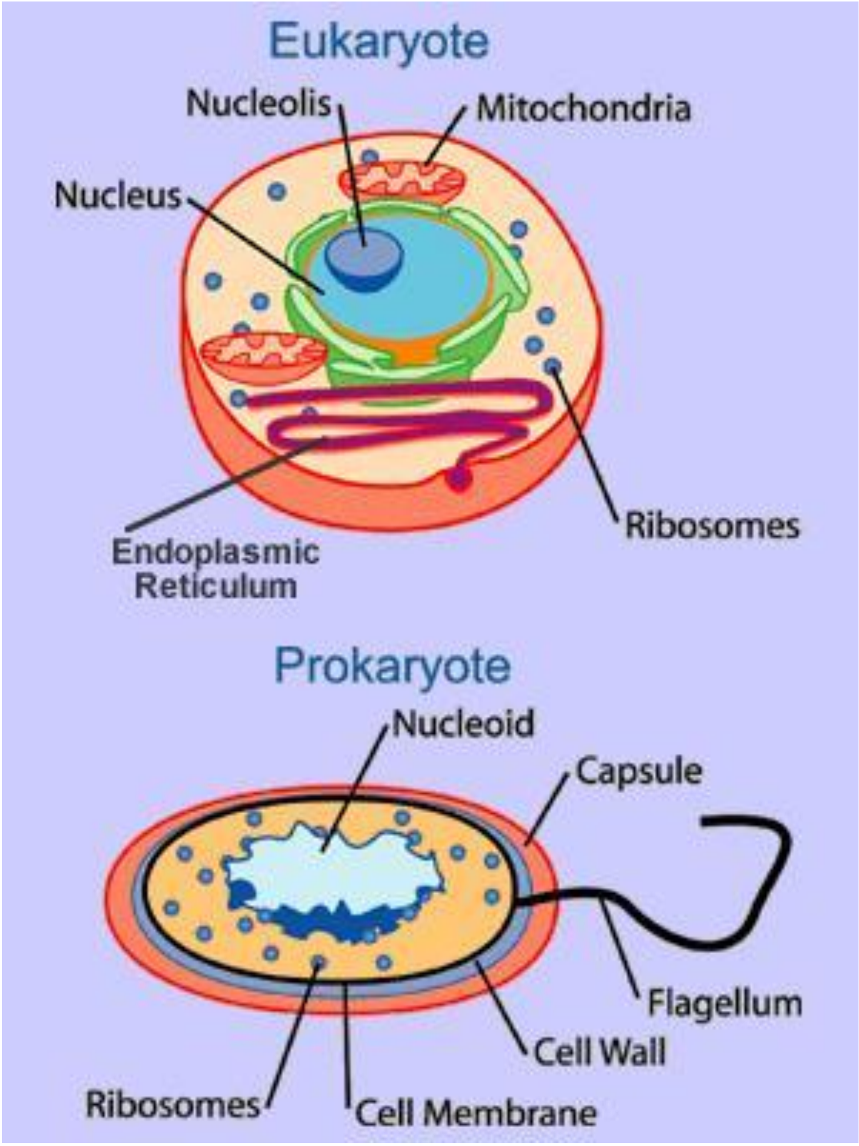
Eukaryotes

The rest of life



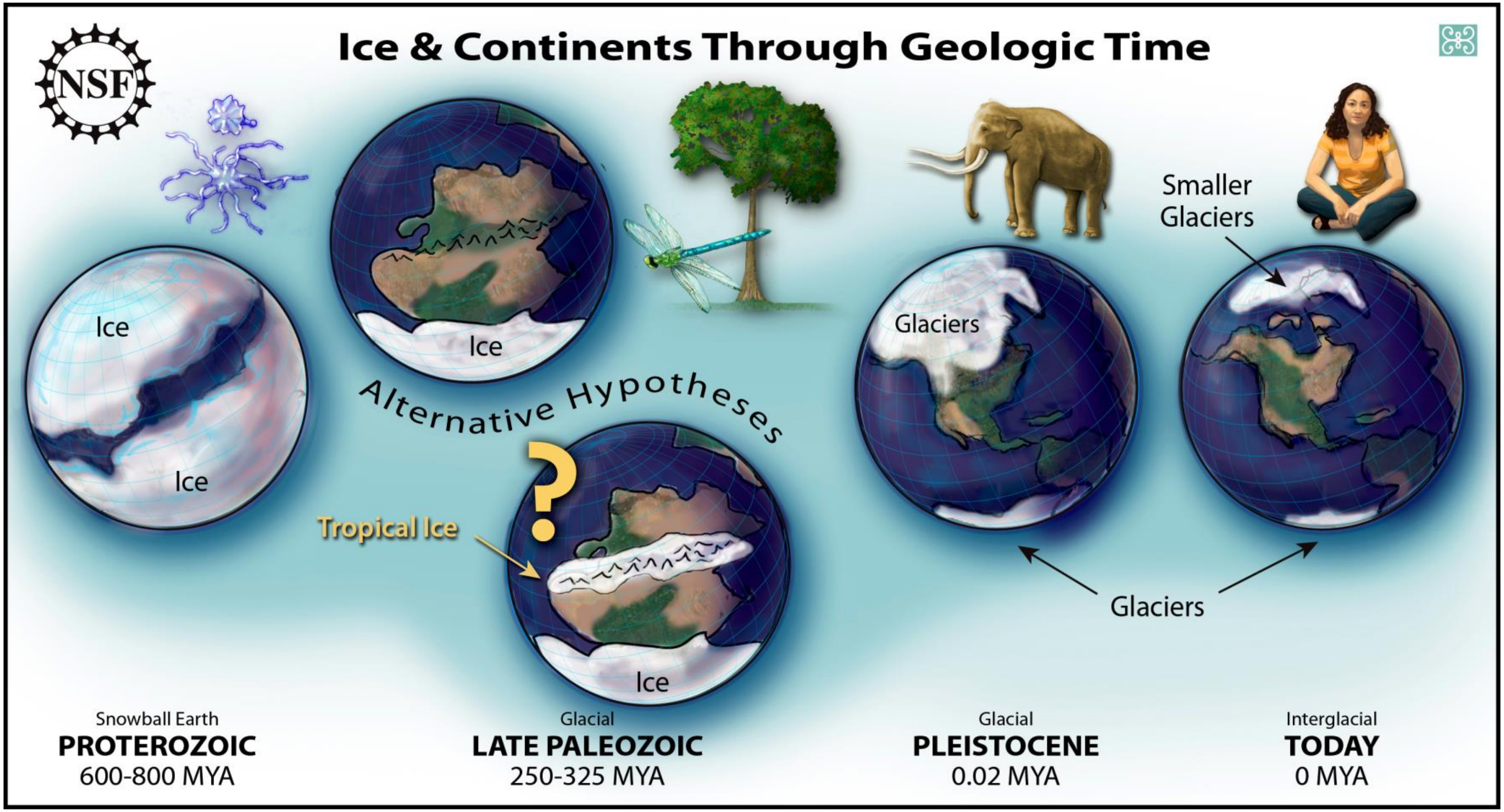
Prokaryotes

Primitive life (Archaea and Bacteria)

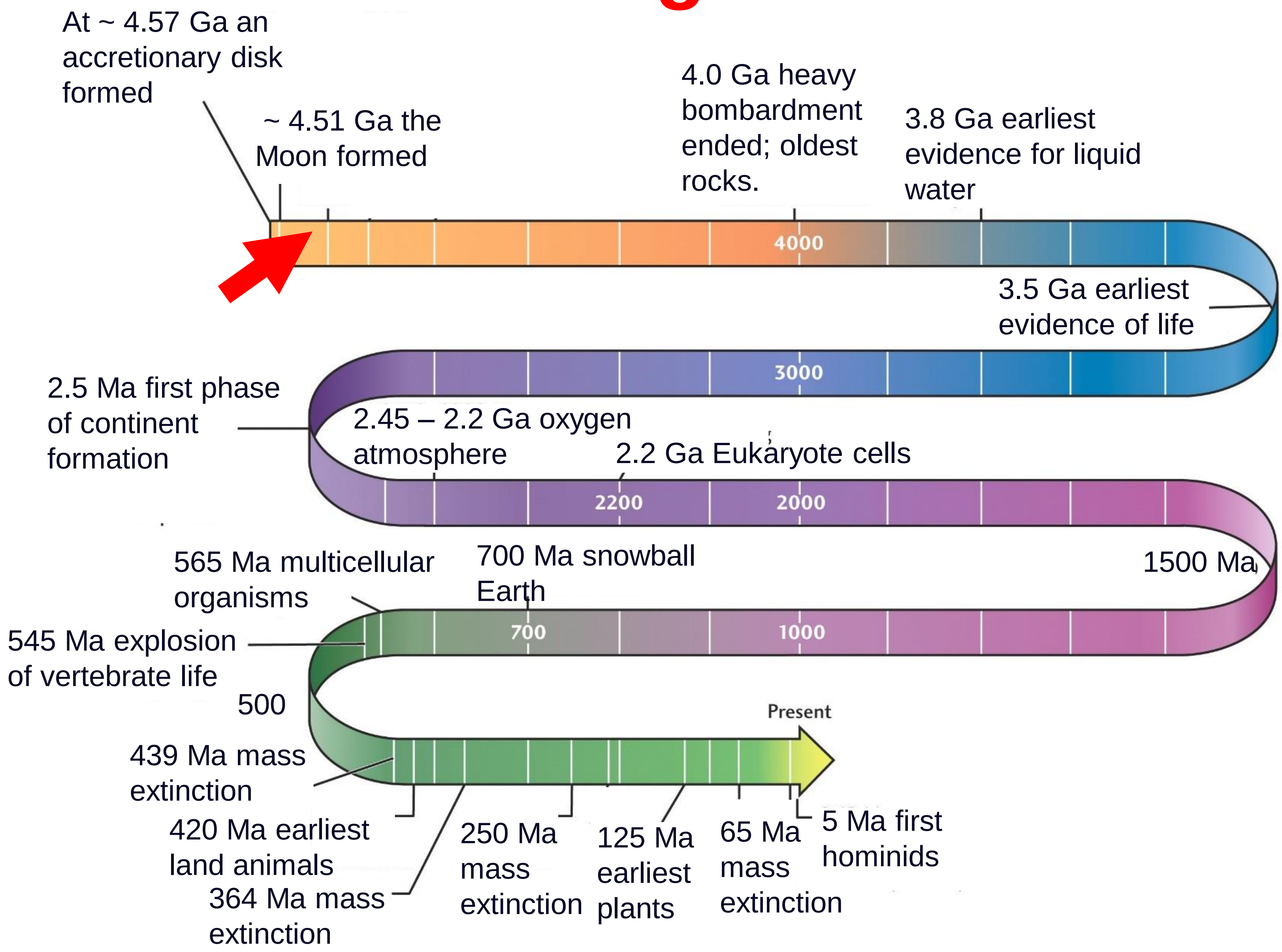


Snowball Earth

Between 600 and 700 Ma the Earth was completely glaciated due to a cold spell induced by volcanic aerosols and the subsequent high albedo. Volcanic build-up of CO_2 ends it



Geologic Time

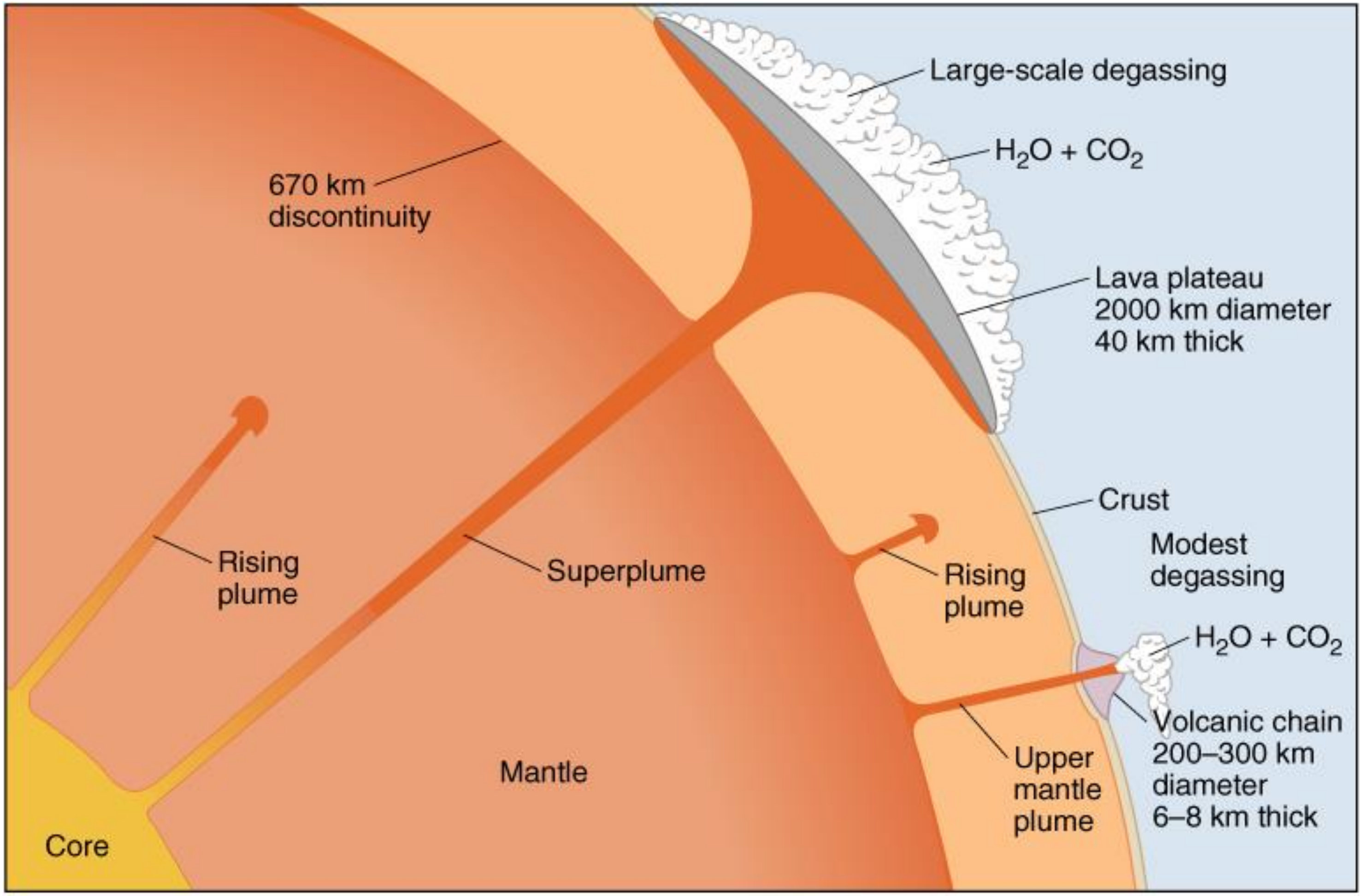


The Cambrian Explosion in Life

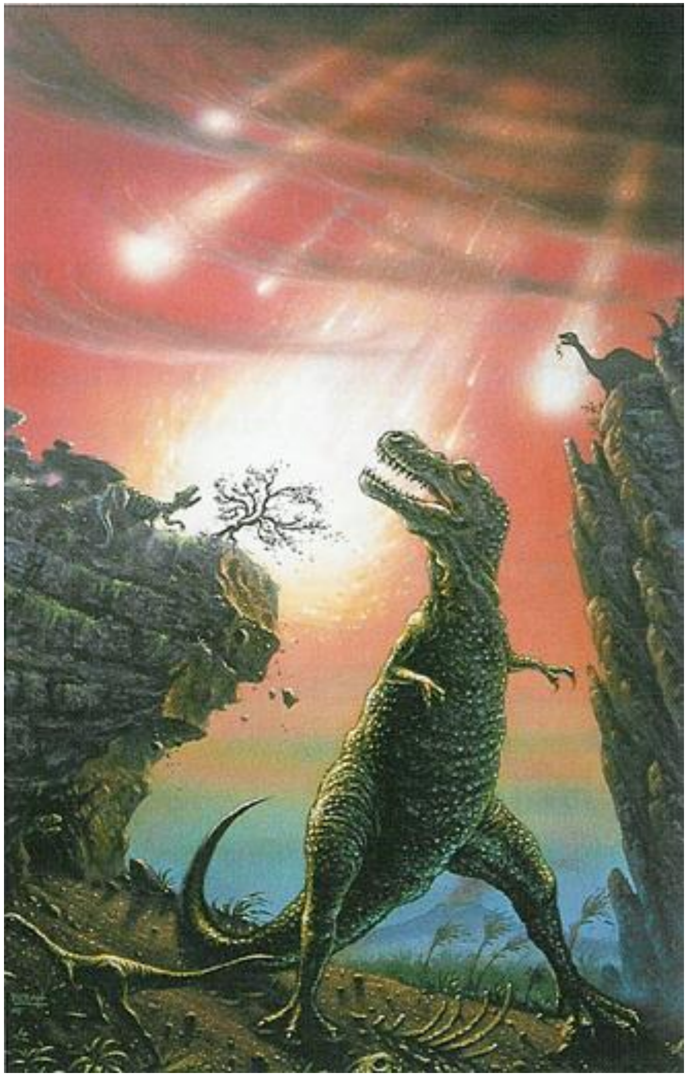
At 545 Ma there was a massive explosion in life forms, during which all phyla present today formed. Reasons for the explosion may have been the development of the ozone layer, higher O_2 levels, elevated Ca, or ecological factors (e.g., eyesight).

The 250 Ma Mass Extinction

A massive outpouring of lava in Siberia, the largest recorded, led to a huge build-up of sulphate aerosols in the atmosphere and a corresponding drop in temperature, killing off a high proportion of plant and animal life

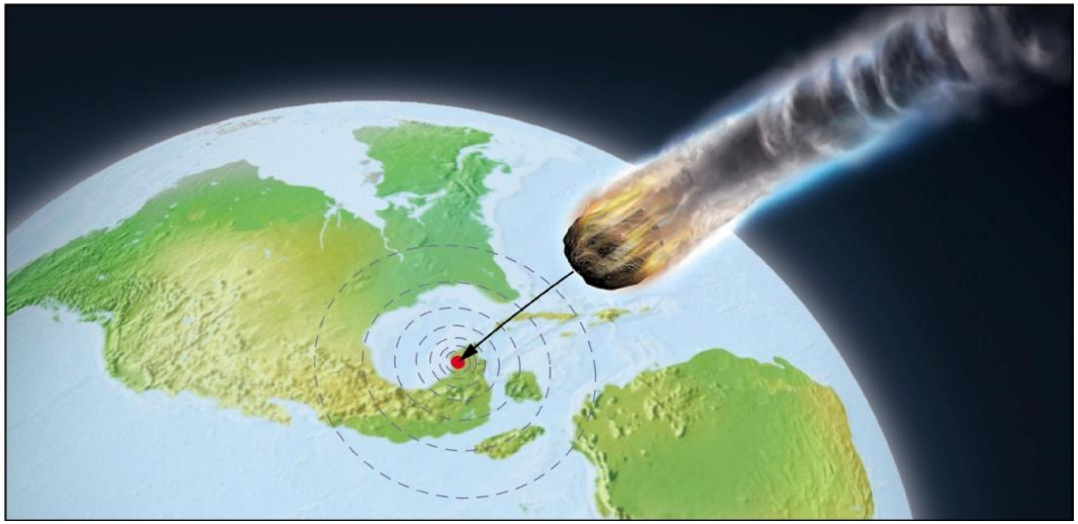


The 65 Ma Mass Extinction

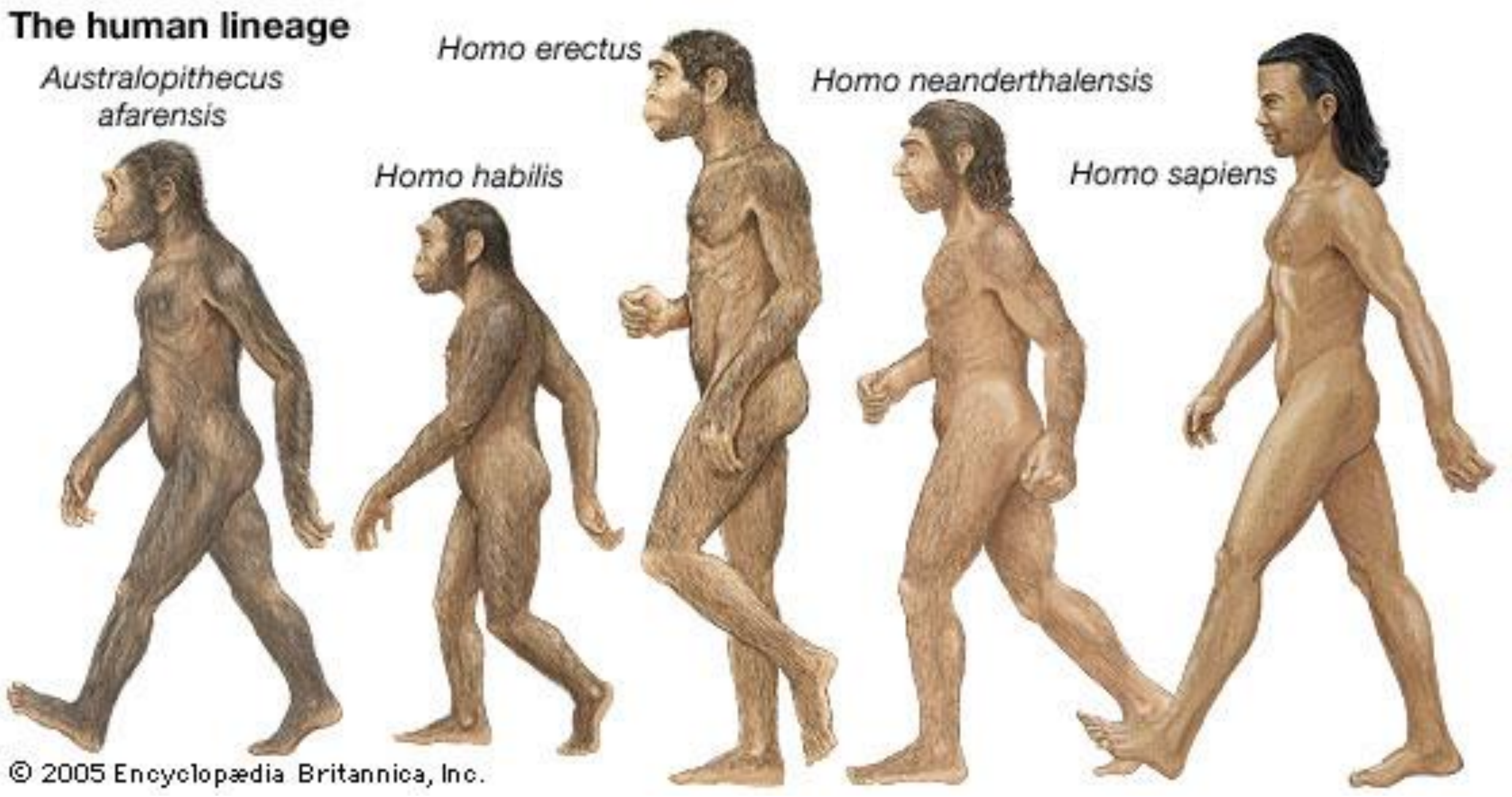


The 10 Km diameter Chicxulub meterorite struck the Yucatan at 65.5 Ma

The material ejected into the atmosphere induced a sharp drop in temperature, killing off many life forms



The Arrival of the Hominids at 5 Ma



The Sixth Mass Extinction

Ecologists estimate that in the next 100 years 50% of present species will be extinct. Will we survive?