Fundamentals of Earth Sciences (ESO 213A)

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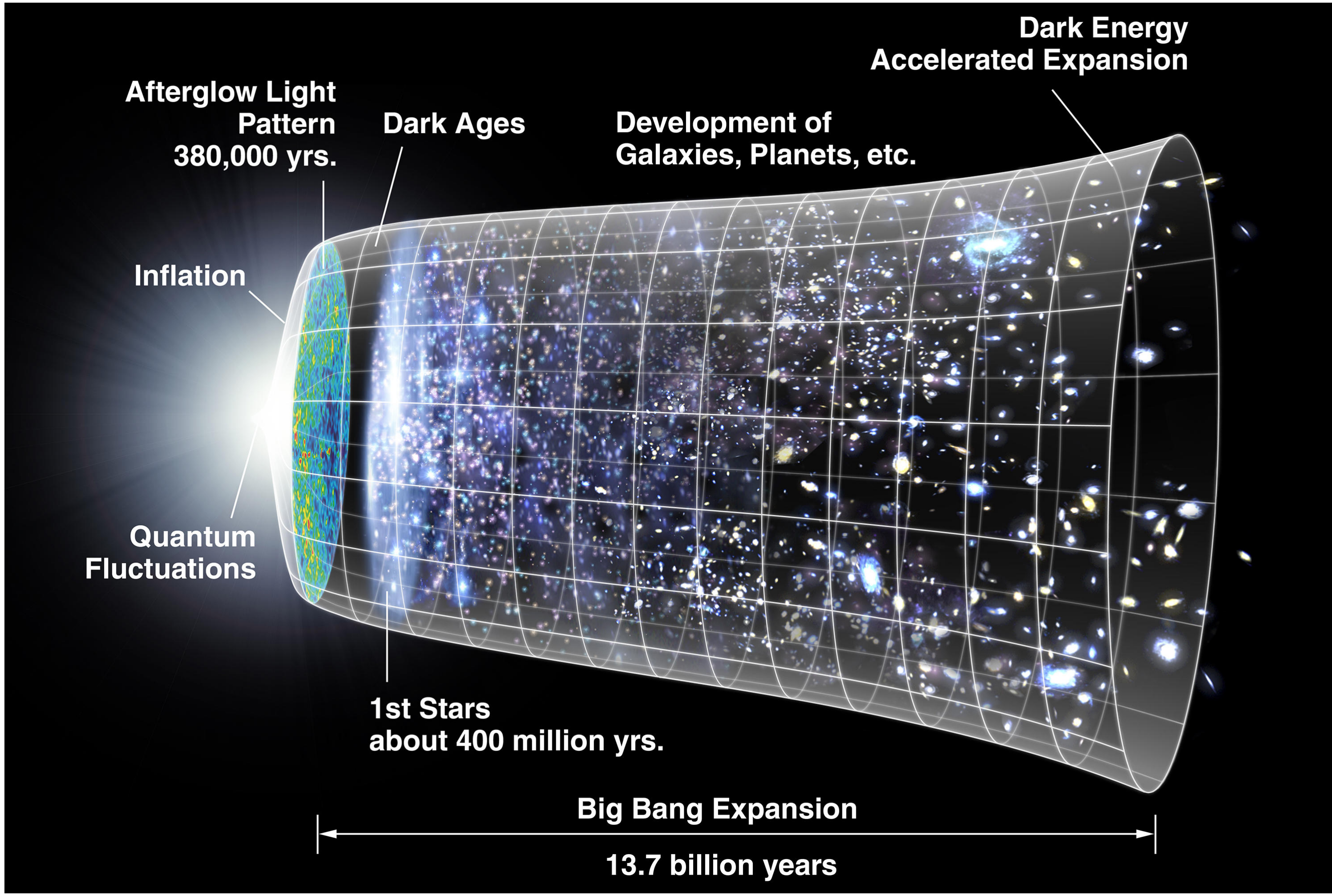
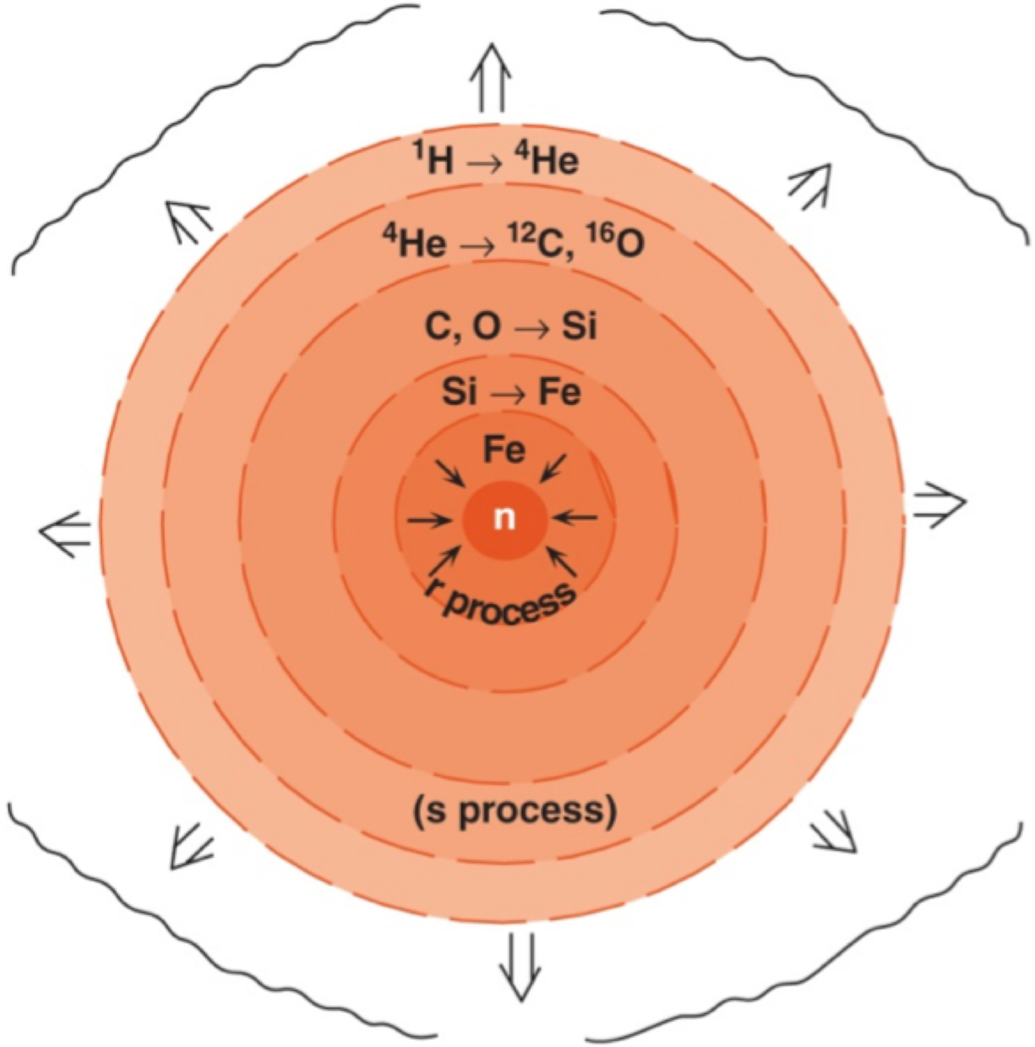
Department of Earth Sciences

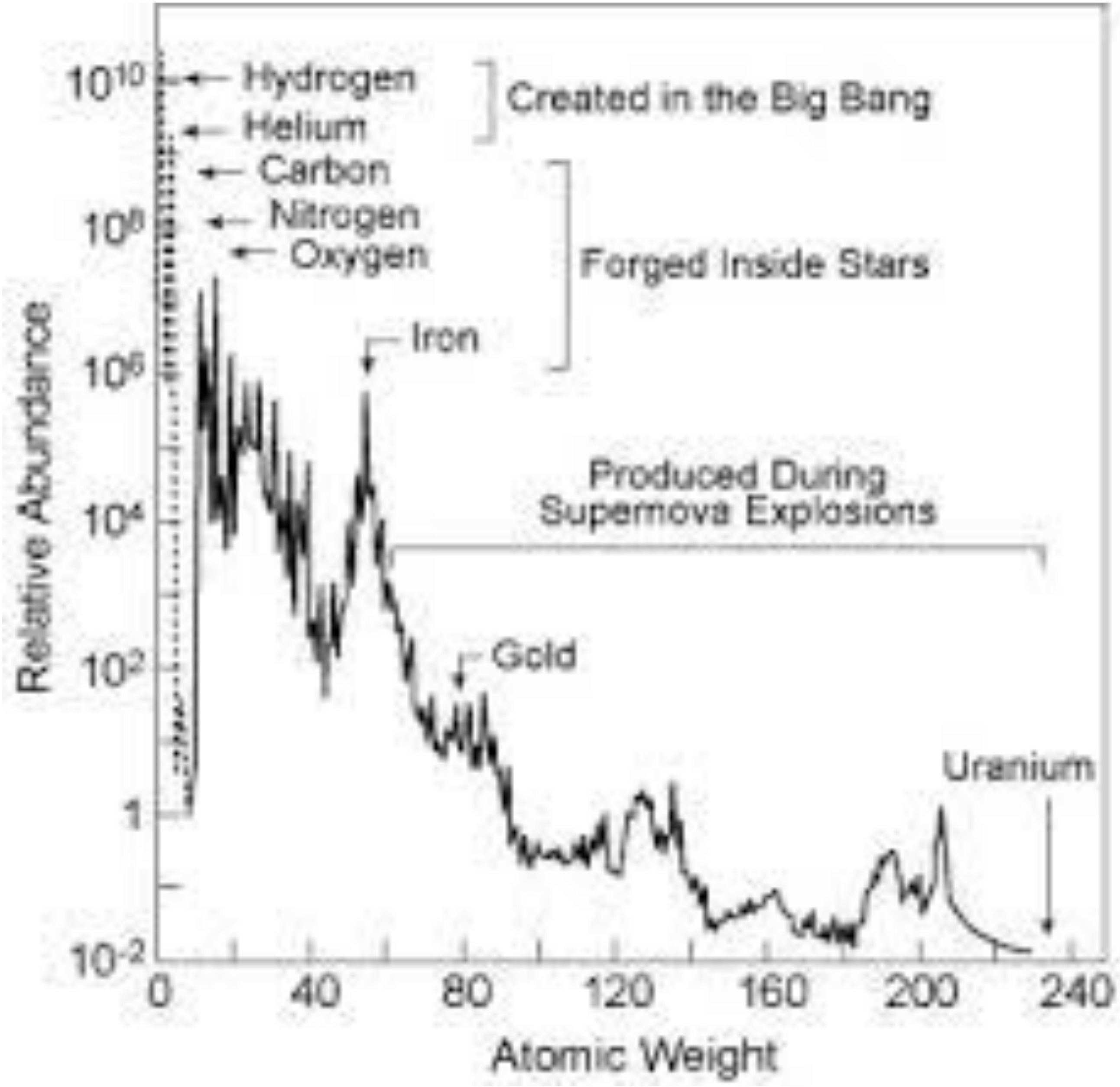
Lecture 3: Origin of Earth, Moon and Atmosphere

Last Class: Review

- Big Bang Theory (13.7 billions of years ago)
- Nucleosynthesis (BigBang or Primordial and Stellar)
- Supernova Explosion
- Origin of our Solar System (4.57 billions of years ago)







Gravity & Fusion

Stellar Nucleosynthesis && Neutron capture (s-r) processes

Formation of Solar System

4.57 billions years ago

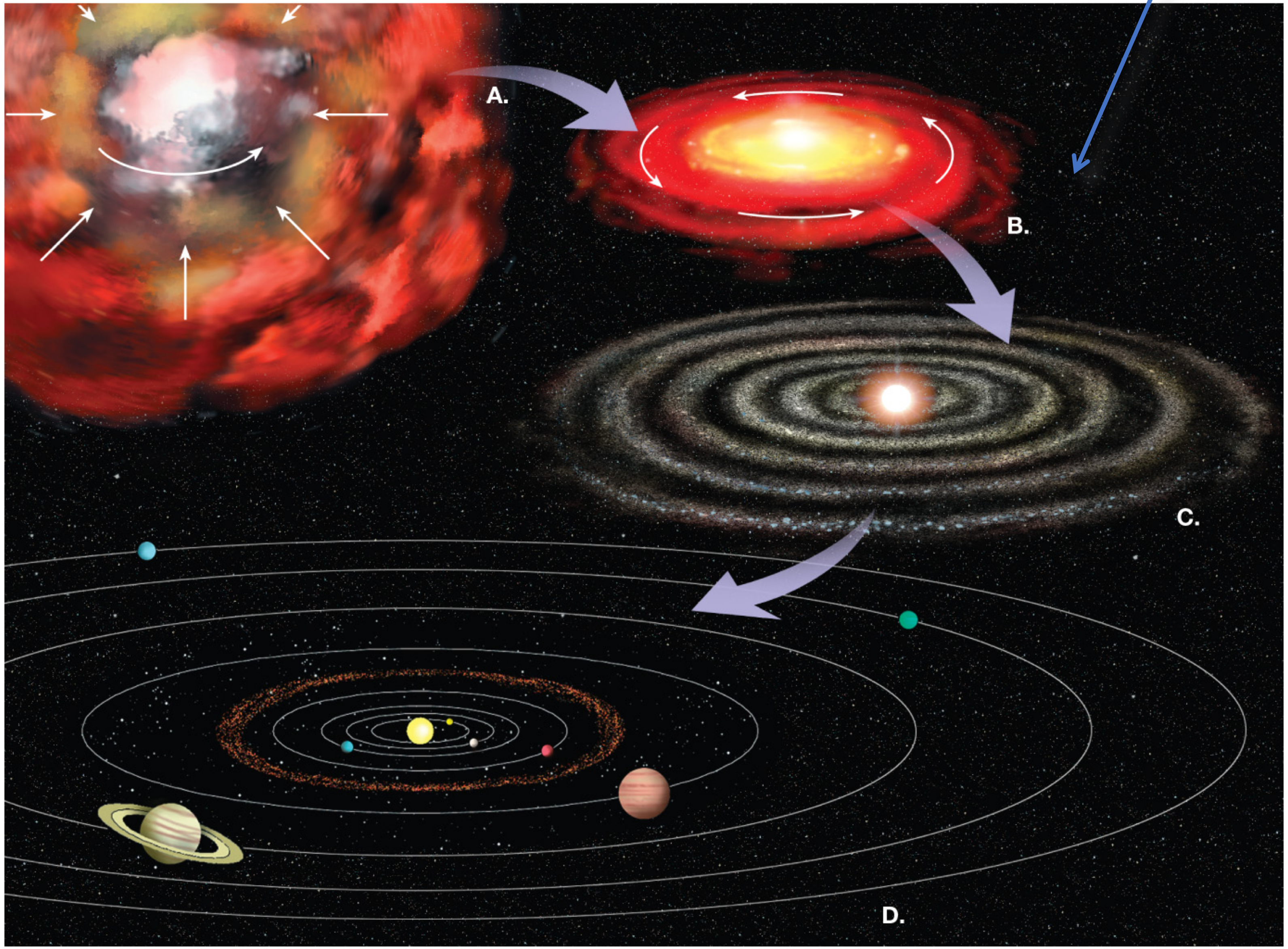
1. Cosmic cloud formed from dust of previous Supernovae

2. Gravity pulls particle closer and increase rotation

3. Nuclear reaction begins ~ 5 billion years ago at the centre of the cloud due to high concentration of material

4. Remaining particle continues to come closer and **accretion** took place

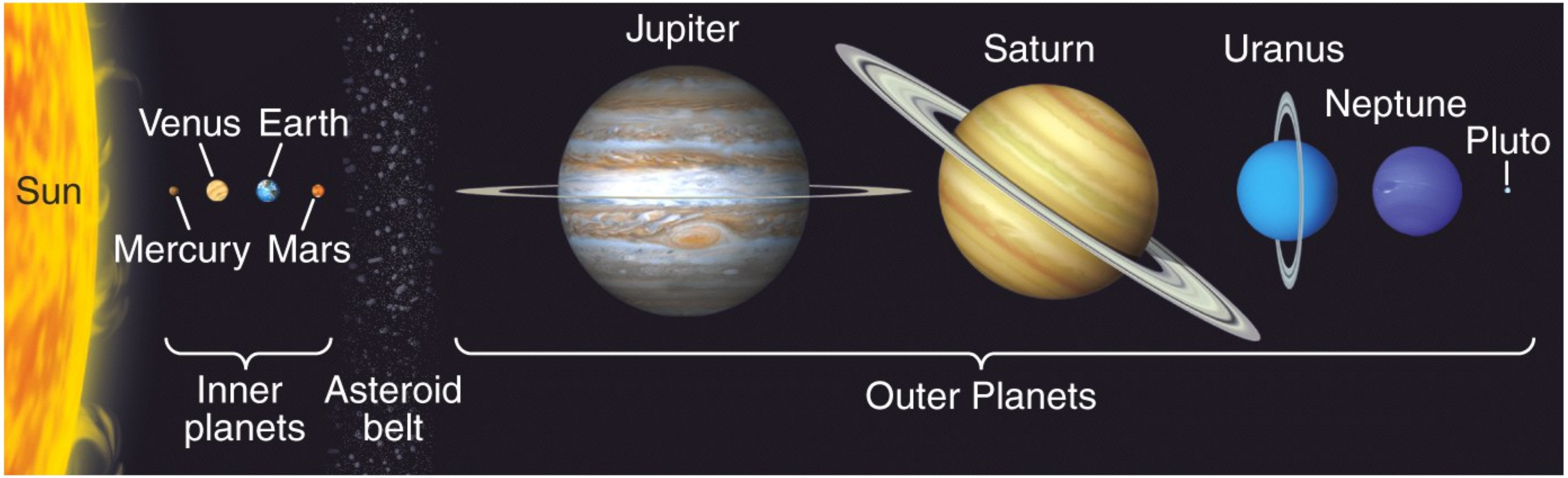
5. Eventually larger particles accreted and formed 'planets'



Dust >rocks >planetesimals >embryos >planets

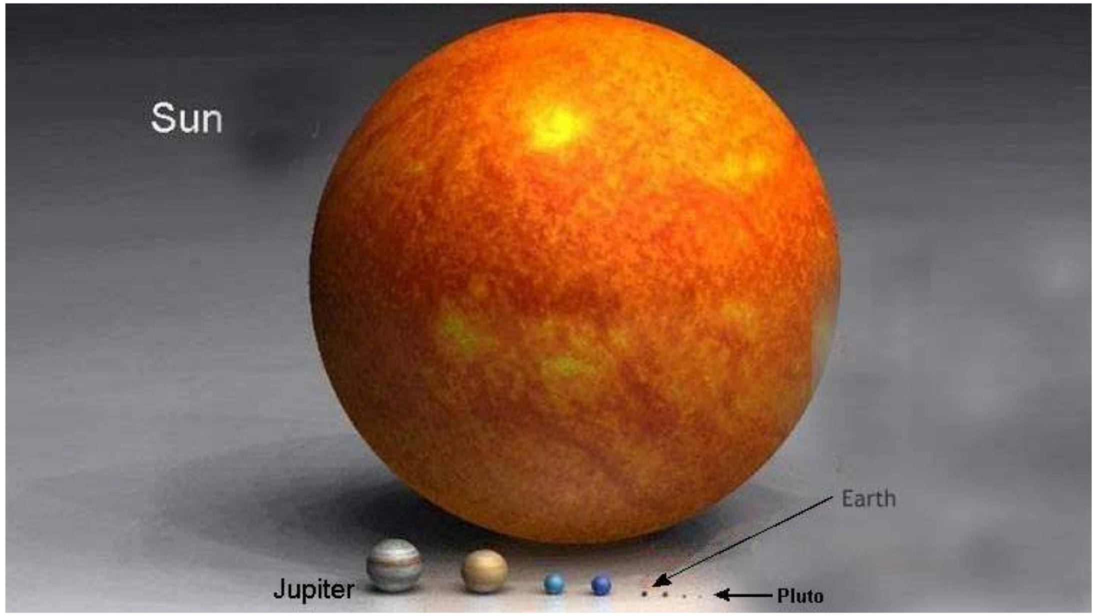
The Nebular Theory

Today's Solar System



'Pluto is a dwarf planet'
- By IAU in 2006

Sizes of the planets relative to Sun



Sun-planet distance
(relative to Earth: AU)

Mercury	0.4 AU
Venus	0.7
Earth	1.0
Mars	1.5
Jupiter	5.2
Saturn	9.5
Uranus	19
Neptune	30

1 AU = 150 million km

Two different types of planets in Solar system:

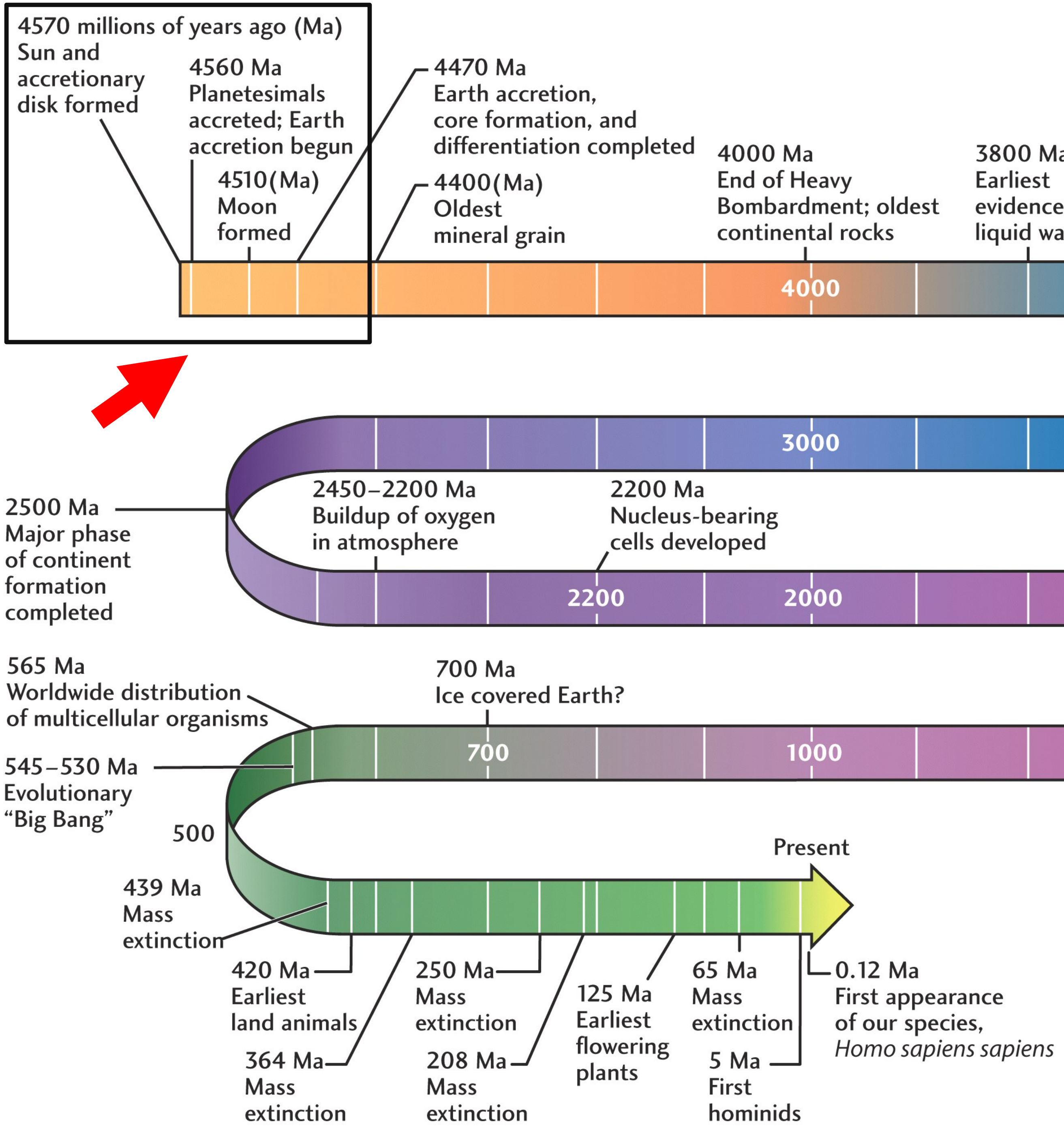
1. Terrestrial planet:

Mercury, Venus, Earth, Mars
(Small rocky, dense, closer to Sun)

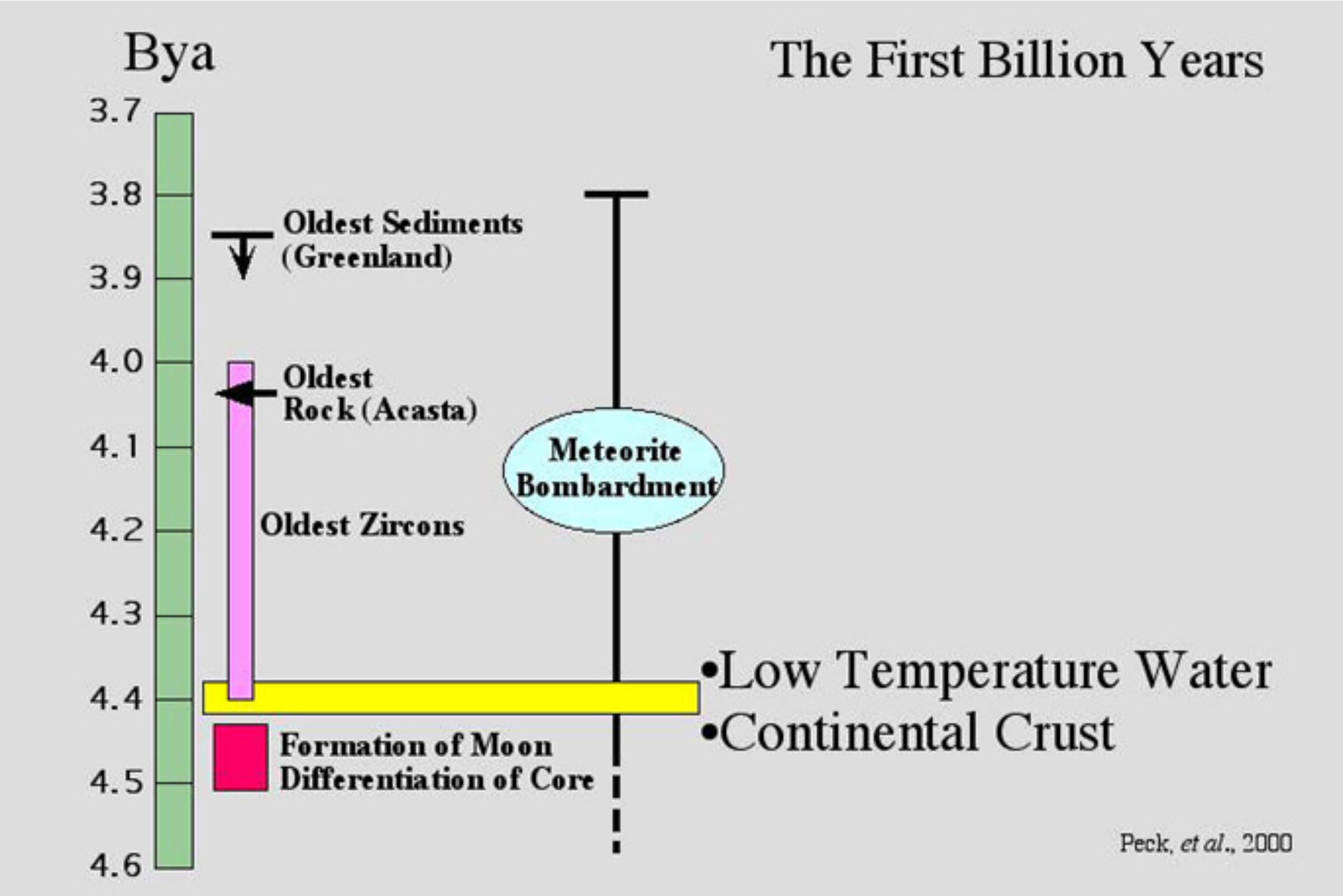
2. Jovian planets

Jupiter, Saturn, Uranus, Neptune
(larger, more gaseous, less dense, away from Sun)

Geologic Time Scale



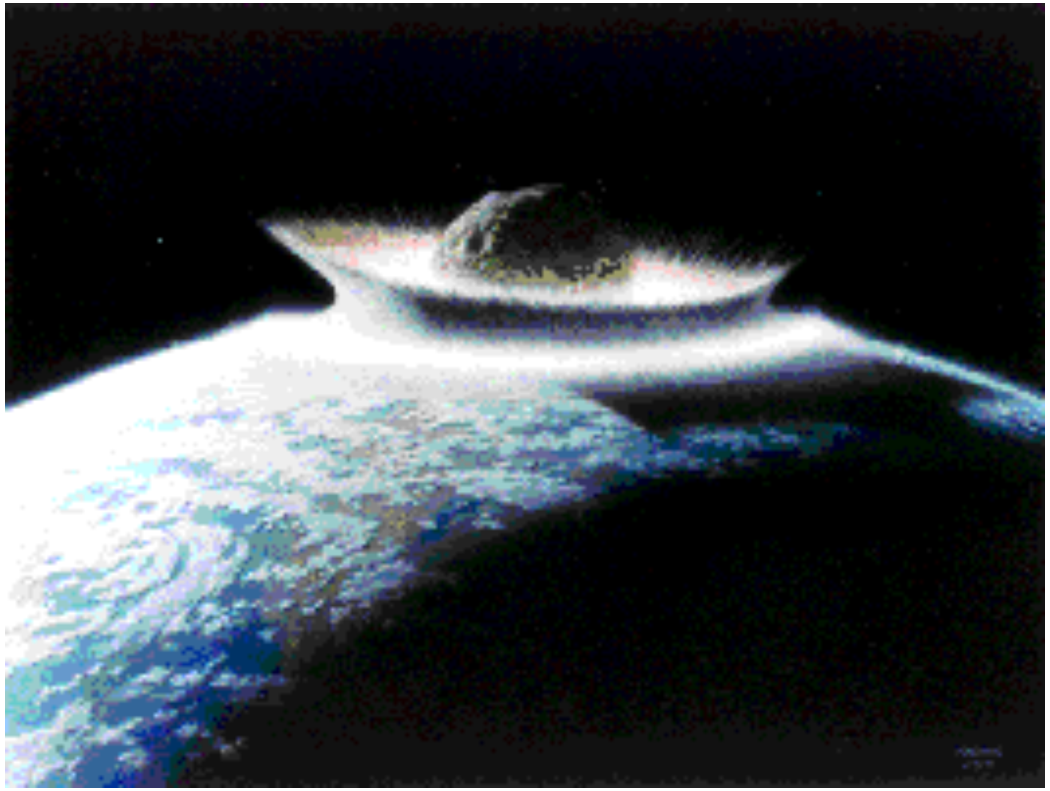
Connecting the dots: From planet formation to early Earth
Computational astrophysics meets field geology!

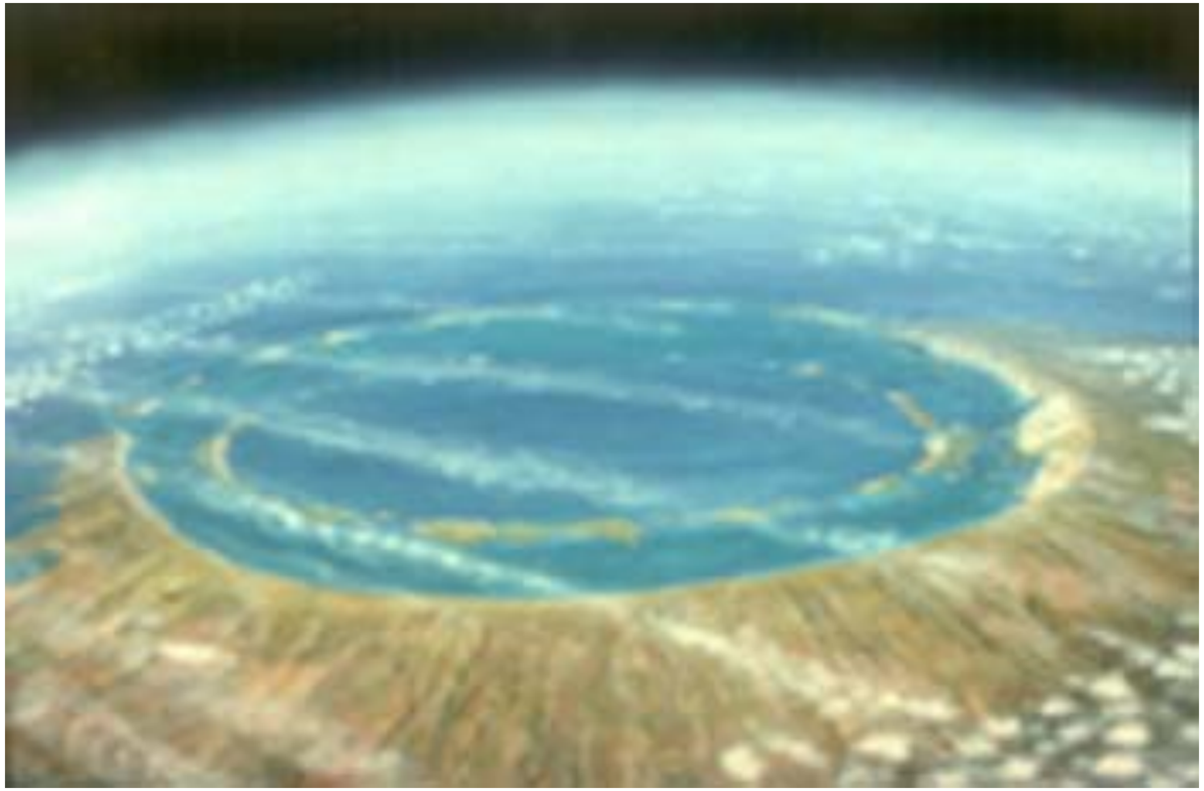


Bombardment From Space

For the first 50 million years of its existence, the surface of the Earth was repeatedly pulverized by asteroids and comets of all sizes

One of these collisions formed the Moon





Chelyabinsk meteor entered Earth's atmosphere over the southern Ural region in Russia on 15 February 2013

Formation of the Moon

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

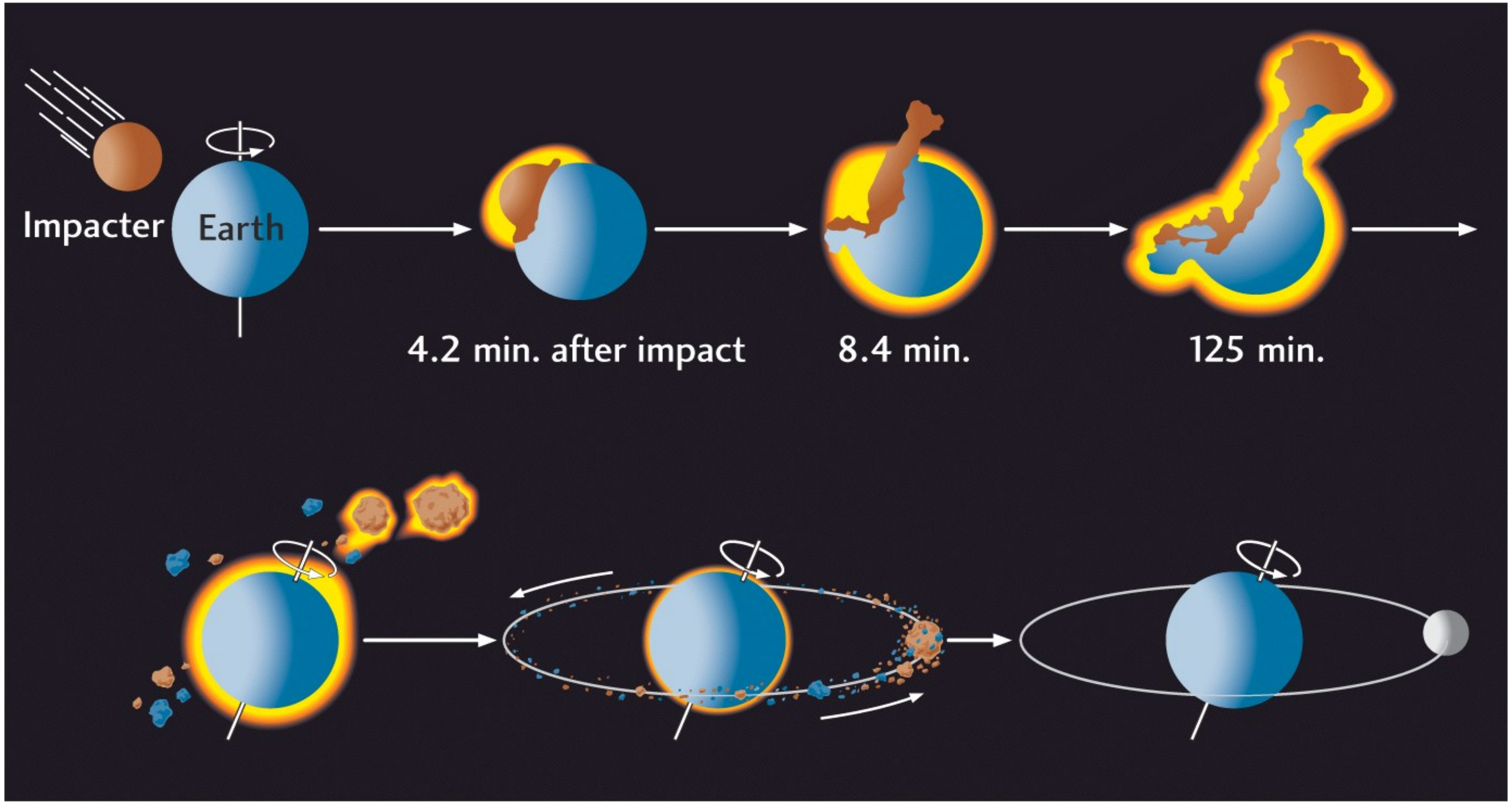
This idea was first proposed about 30 years ago, but it took calculations by modern high-speed computers to prove the feasibility

Why Moon Formation is Important?

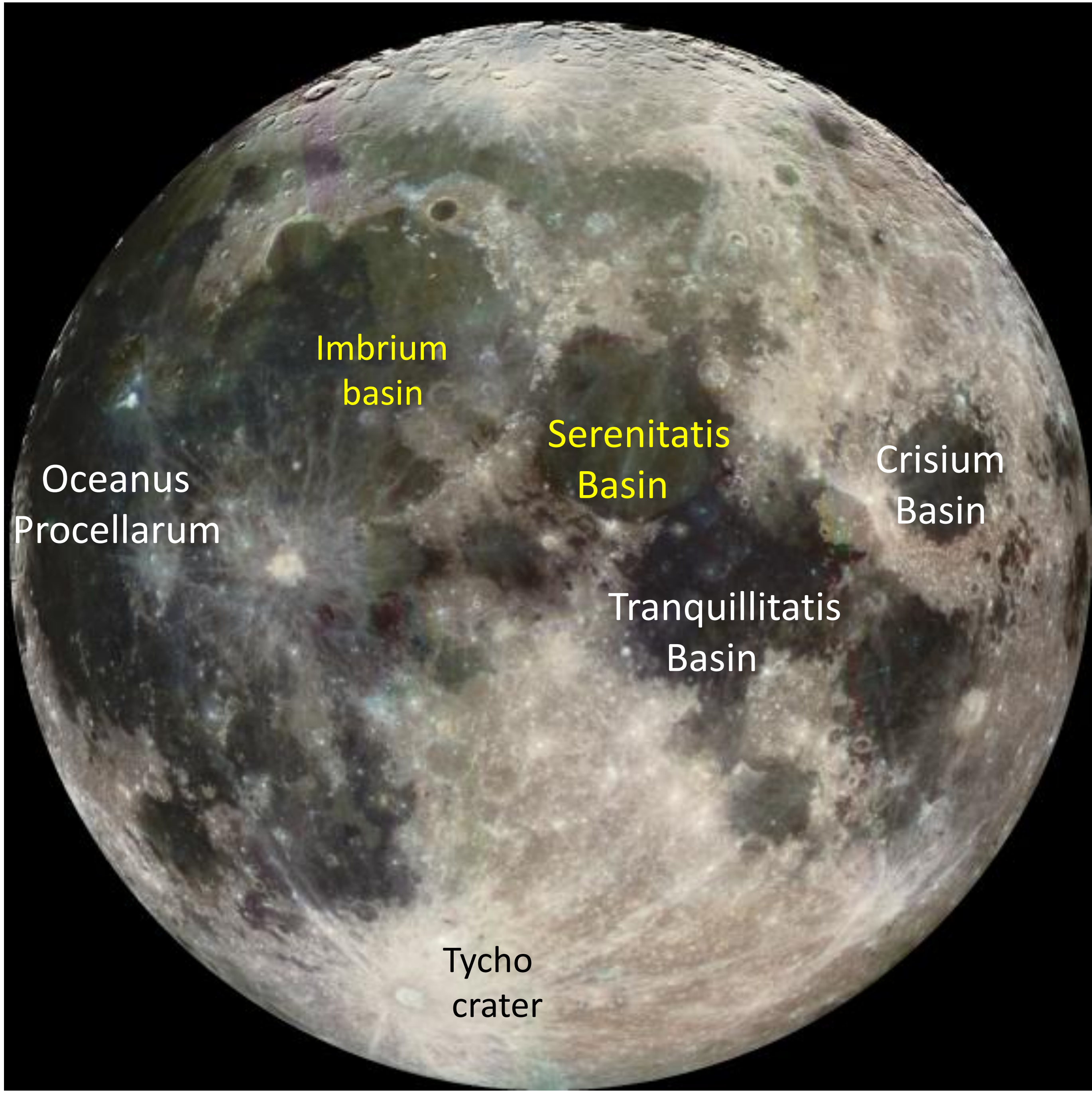
Formation of the Moon

This collision had to be very spectacular!

A considerable amount of material was blown off into space, but most fell back onto the Earth



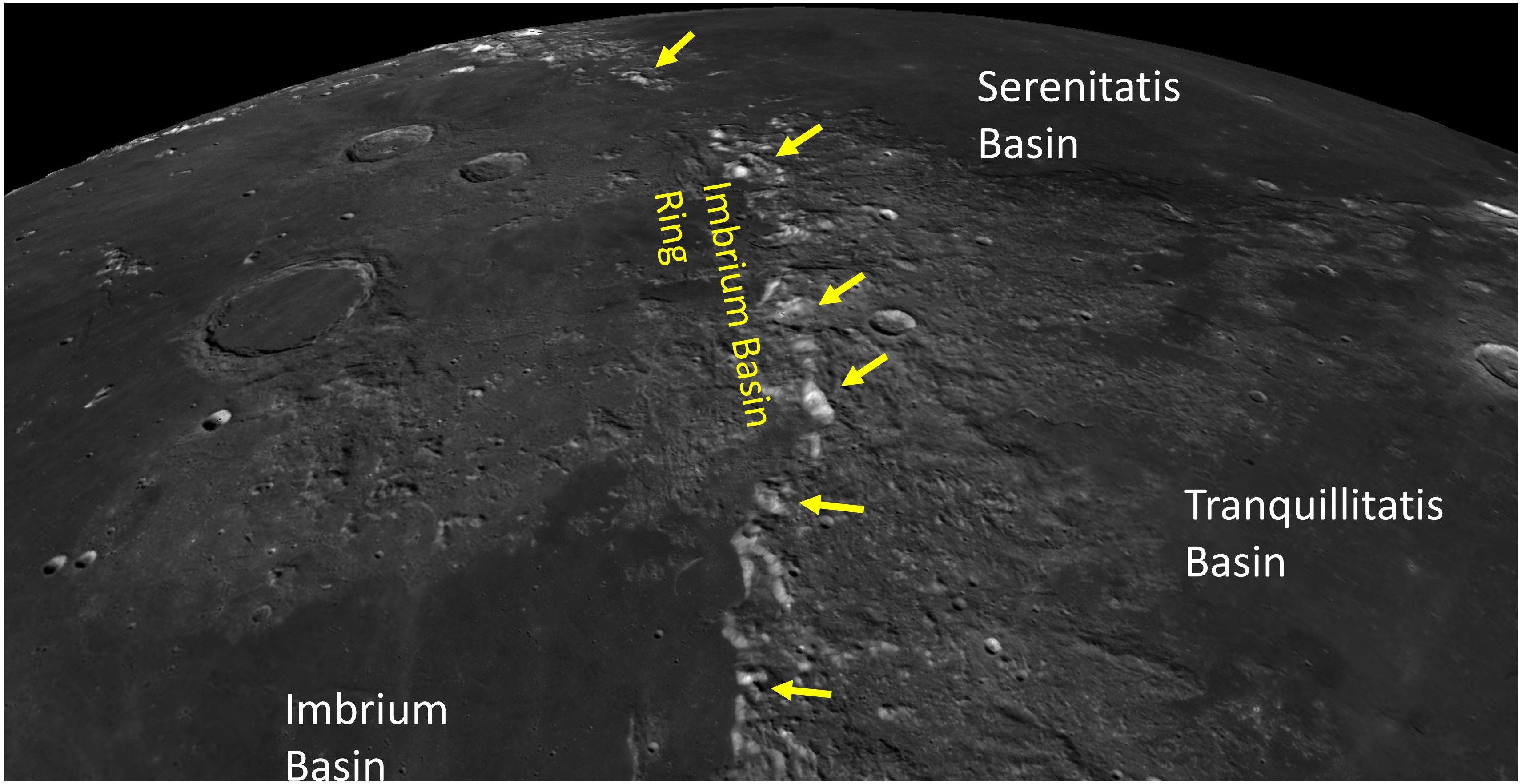
Moon from Galileo spacecraft. The distinct bright ray crater at the bottom of the image is the Tycho impact crater. The dark areas are lava rock filled impact basins: Oceanus Procellarum (more than 2,500 km), Mare Imbrium (diameter of 1145 km), Mare Serenitatis (diameter 674 km) and Mare Tranquillitatis (diameter 873 km), and Mare Crisium (diameter 556 km). This picture contains images through the Violet, 756 nm, 968 nm filters.



Lunar Impact *Basins*

<u>Both Earth and Moon were struck by numerous large asteroids and comets in their early history. These impacts produced deep basins up to 2500 km across surrounded by high rings of mountains on the Moon</u> and are visible to the human eye as prominent circular structures.

A view of the mountains that surround the Imbrium impact basin. Lava flow observed both side of the ridge.

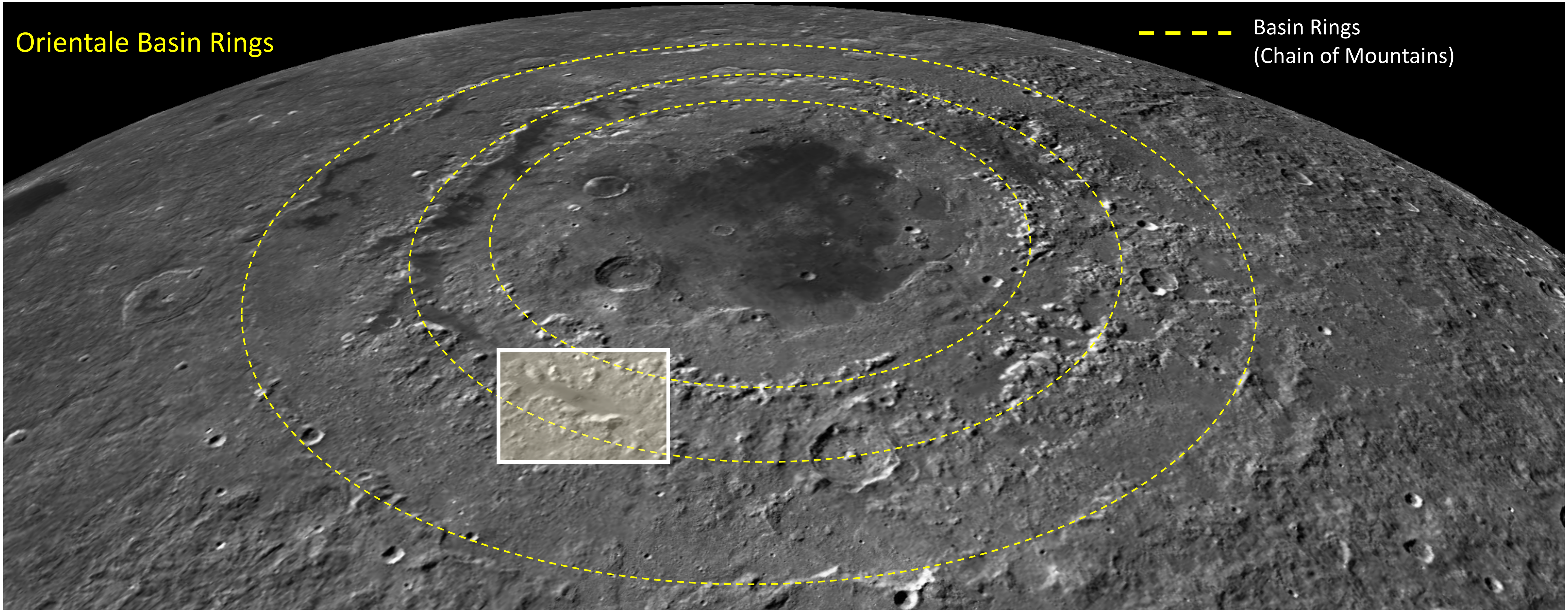


Courtesy of Prof. D. Dhingra

Big, frequent impacts until 3.8 billion years ago

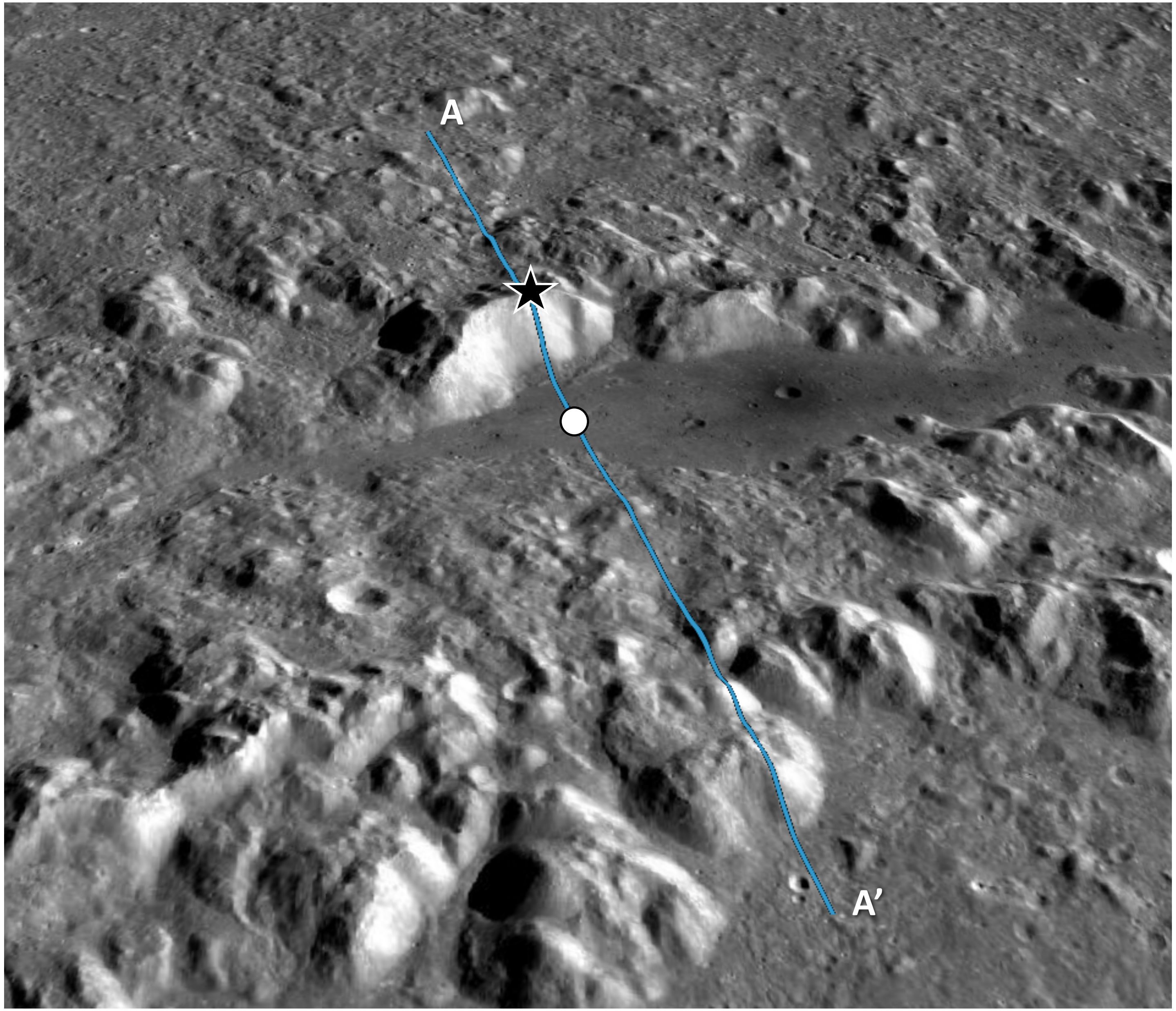
Impact events continue on all moons and planets today

Lunar Impact *Basins*



Courtesy of Prof. D. Dhingra

Three mountain rings surround the Orientale impact basin. Diameter of the outer ring is ~900 km. <u>Both the Imbrium and the Orientale impacts occurred around 3.8 billion years ago.</u>



How high are the basin rings?

Height of mountain: 5.4 km !

Courtesy of Prof. D. Dhingra

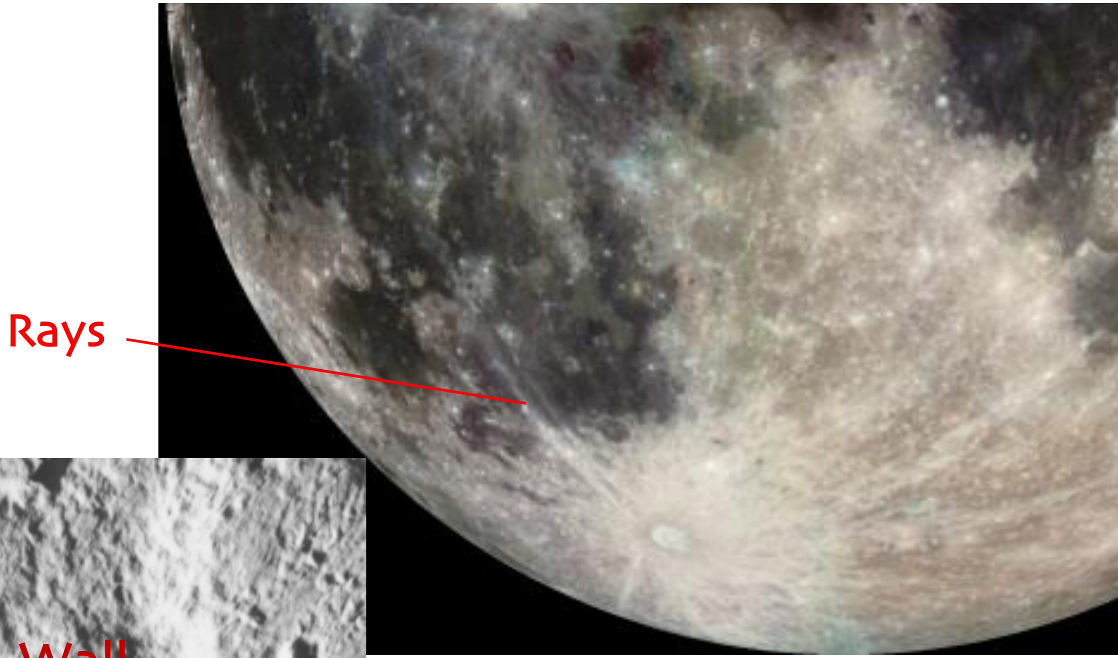
Magma Ocean Rocks

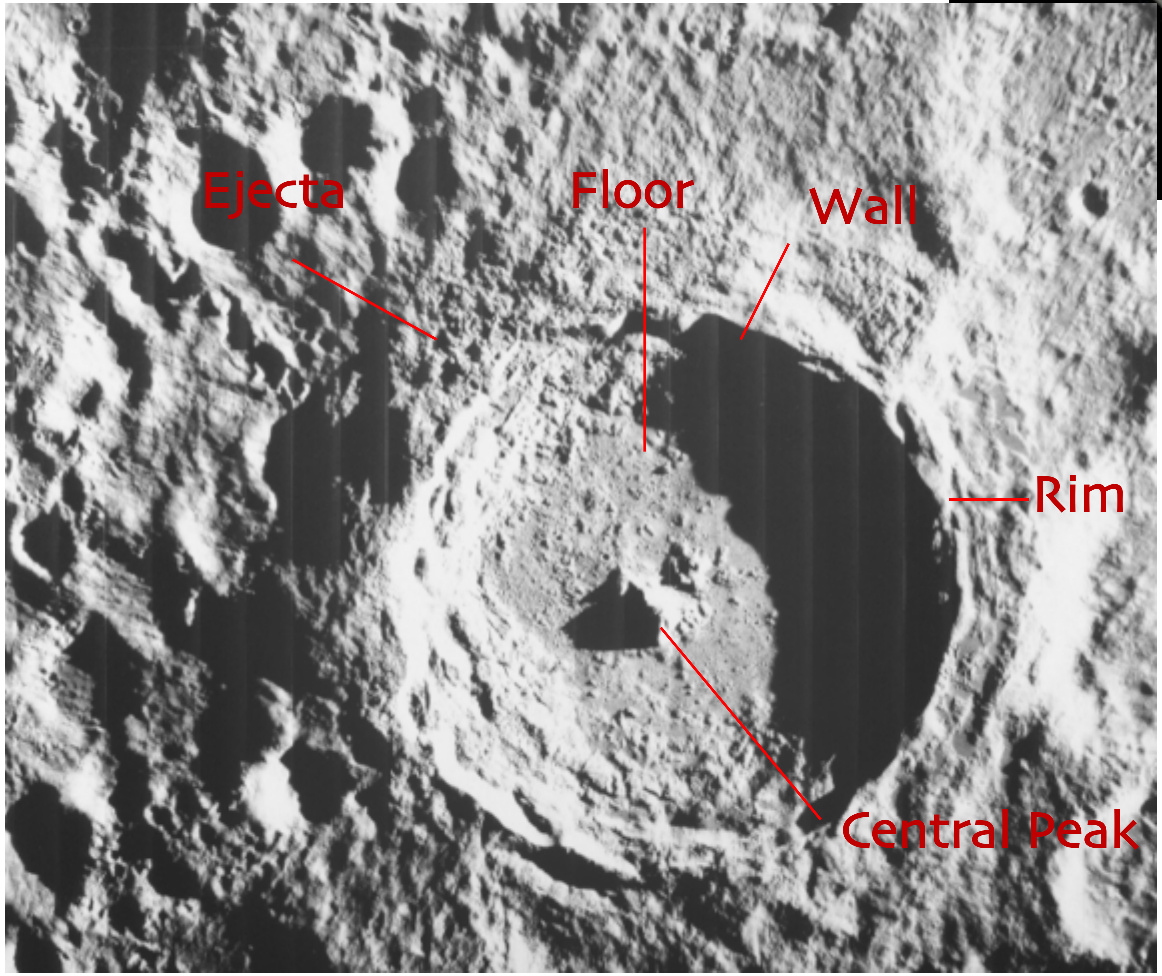
These are two examples of rocks that crystallized from the lunar magma ocean. Both are made primarily of the mineral plagioclase, which gives the lunar highlands its light gray color. The troctolite also contains some greenish olivine grains (troctolite may be later intrusion).

60025
Anorthosite
4.44-4.51 Ga
95% Plag Feld (anorthite)
Magma Ocean!
No Water!

76535
Troctolite
4.2-4.3 Ga

This image clearly shows both the central peak and terracing in the walls of Tycho. Tycho is in the lunar highlands, and the terrain surrounding the crater is quite rugged. [Multispectral images obtained by the Clementine spacecraft]() show that the central peak has a different composition than the surrounding material, presumably because the central peak is composed of material that originated at greater depths in the Moon's crust. *(Lunar Orbiter image V-125M.)*





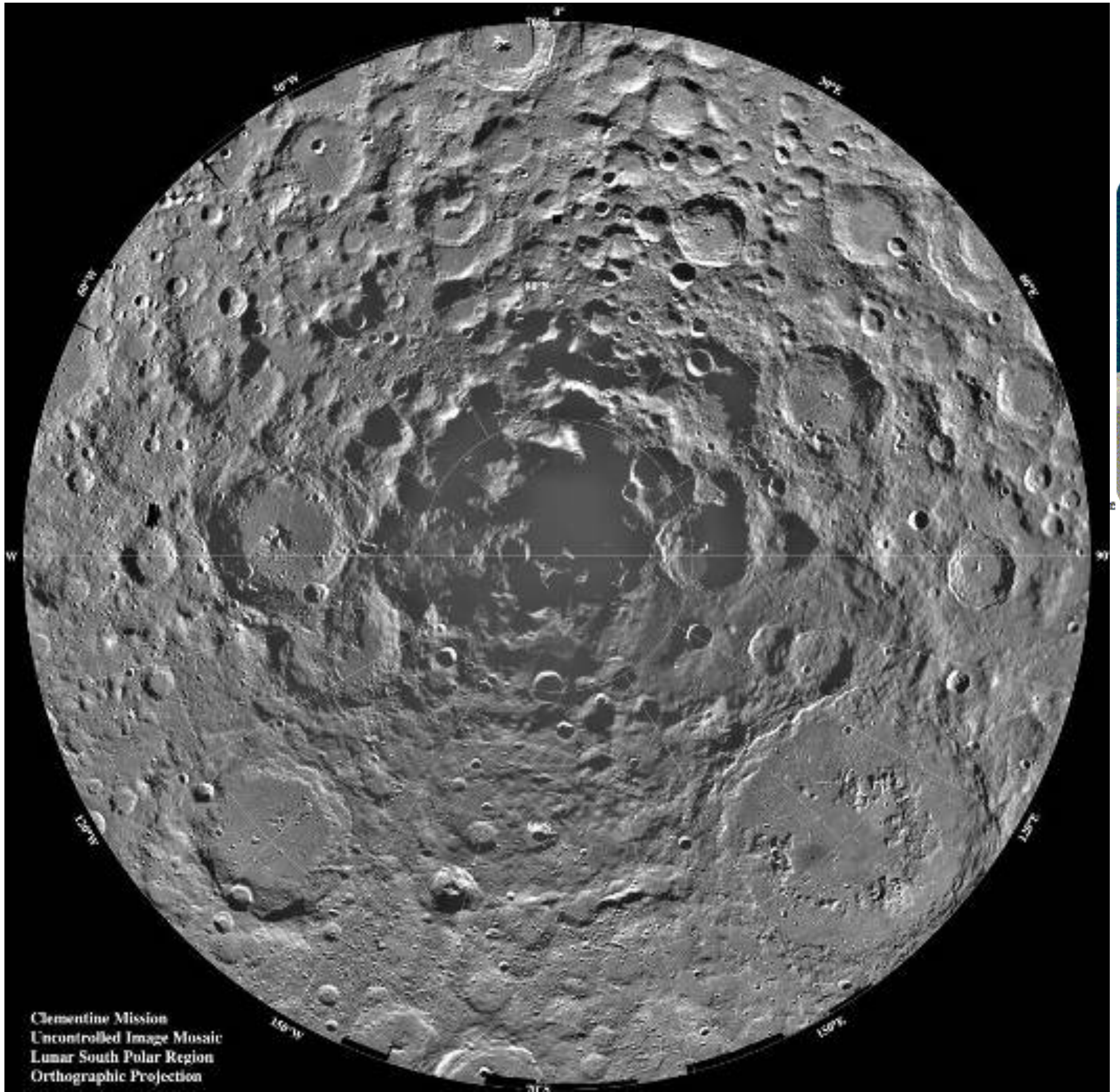
Tycho Crater

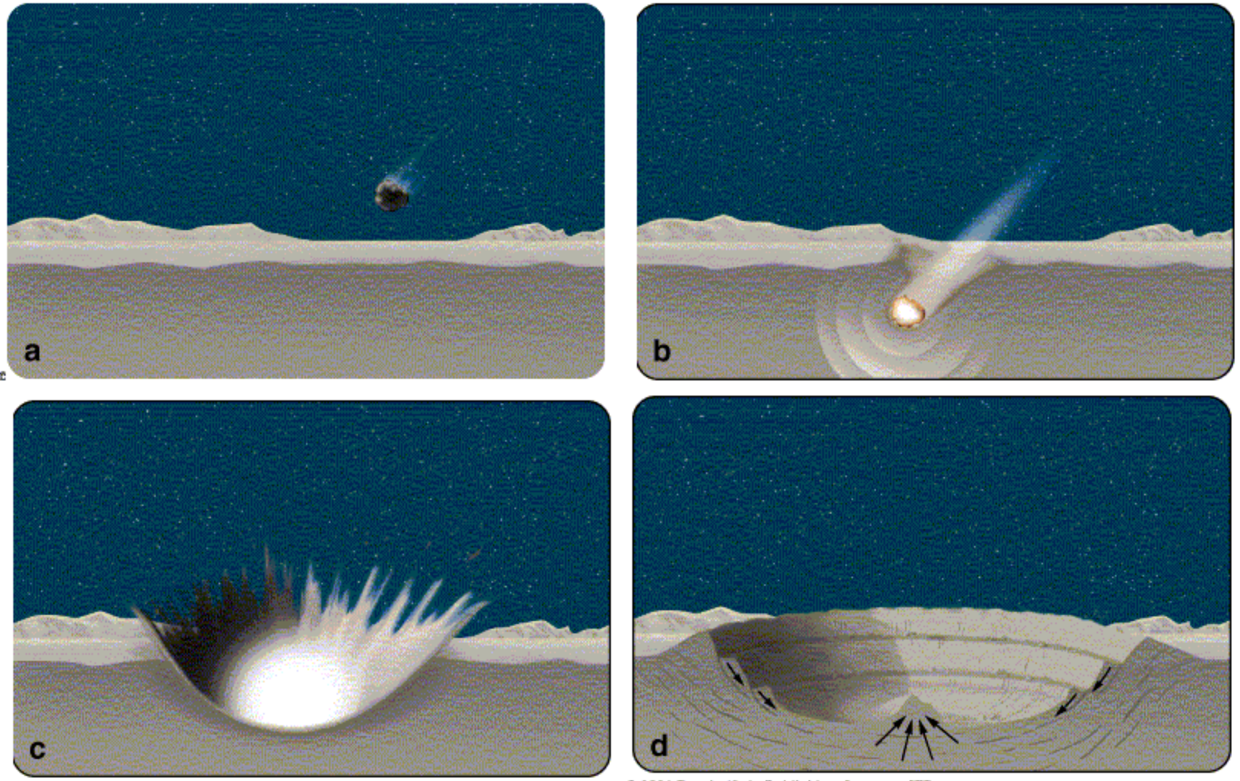
Young – 100 MY

85 kilometers diameter

Fresh (rays) = young

Impacts …"the most fundamental process on the terrestrial planets…" *Eugene and Carolyn Shoemaker*





Lunar Geologic History
Mare Volcanism

Lunar Volcanism

Portions of the Moon's interior remained hot enough to produce magma for more than a billion years after it formed. Molten rock flowed onto the lunar surface through cracks in the crust, spreading out and filling the low regions in the impact basins. The lava cooled quickly, forming the fine-grained, dark rocks — basalt — sampled during the Apollo missions. The dark areas seen on the Moon are basaltic lava plains 4.2 to 1 billion. Volcanism in circular Mare Imbrium (left image). At right, shadows reveal the edges of a long lava flow from the lower left to the upper right of the image. The volcanism in Mare Imbrium occurred about 3.3 billion years ago (7 am on our clock). Because of its small size, the Moon cooled quickly and was mostly dead volcanically by 3 billion years ago, although limited volcanism in isolated regions is thought to have occurred as recently as 1 to 2 billion years ago.

Mare Imbrium

SW Mare Imbrium

Moon Becomes Geologically Inactive

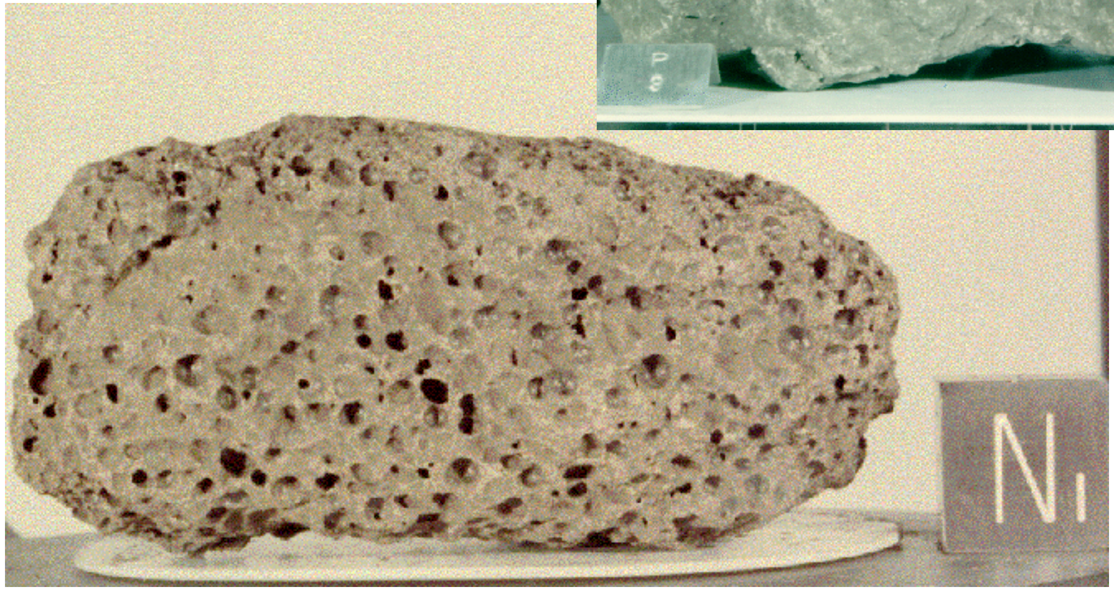
Lunar volcanism decreased significantly by 3 billion years ago and ceased completely by about 1 billion years ago as the interior of this small body cooled.

Volcanism *after* impacts – most before 3 Ga (to 1 Ga)

Lunar Basalts

These rocks are typical of lunar volcanic rocks. Collected on Apollo 15, both are 3.3 billion year old basalts, similar to those produced by volcanos such as Hawaii on Earth. The lower image (sample 15016) contained some type of gas, possibly carbon monoxide, which formed the round holes known as vesicles.

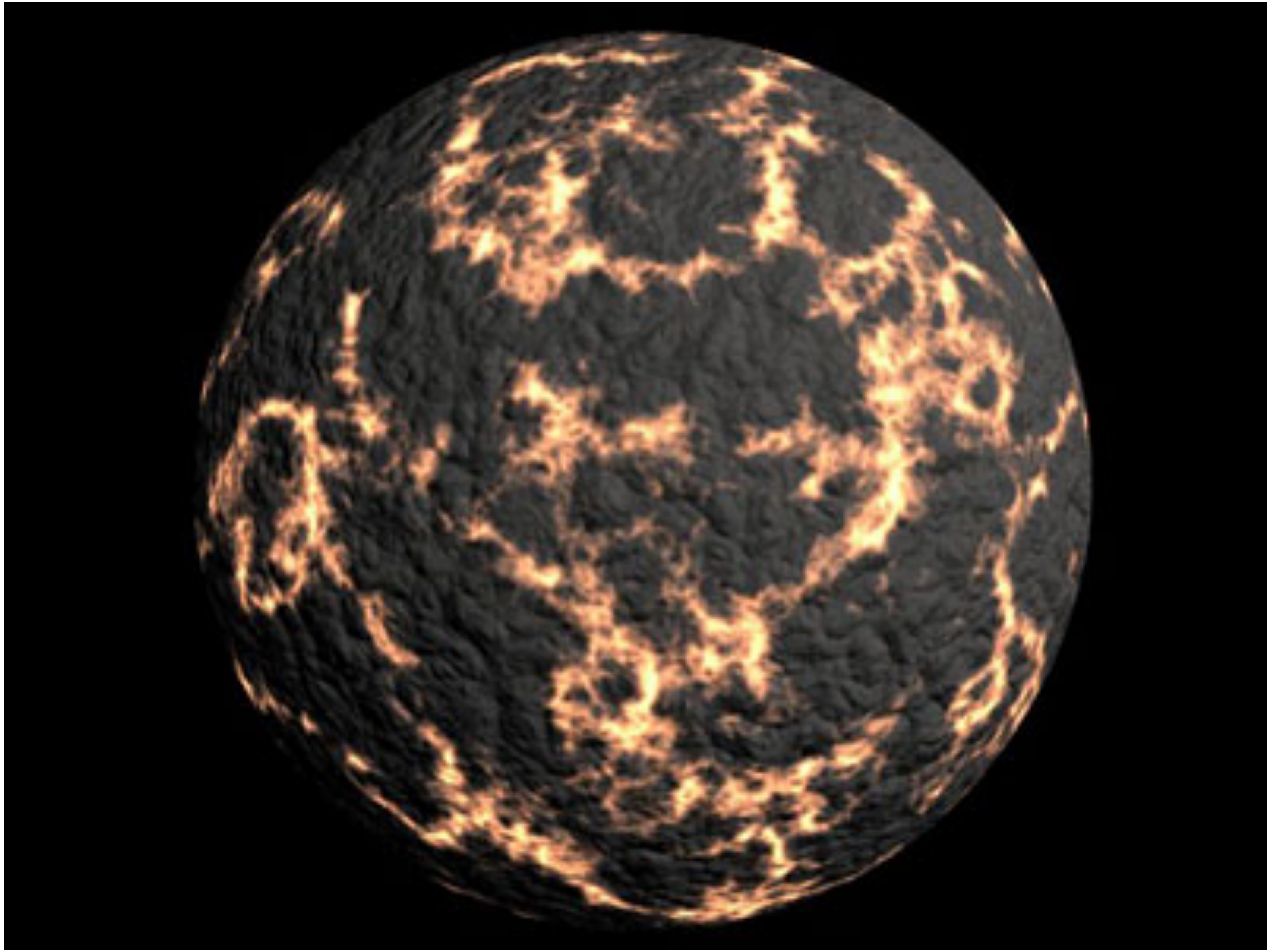
15555



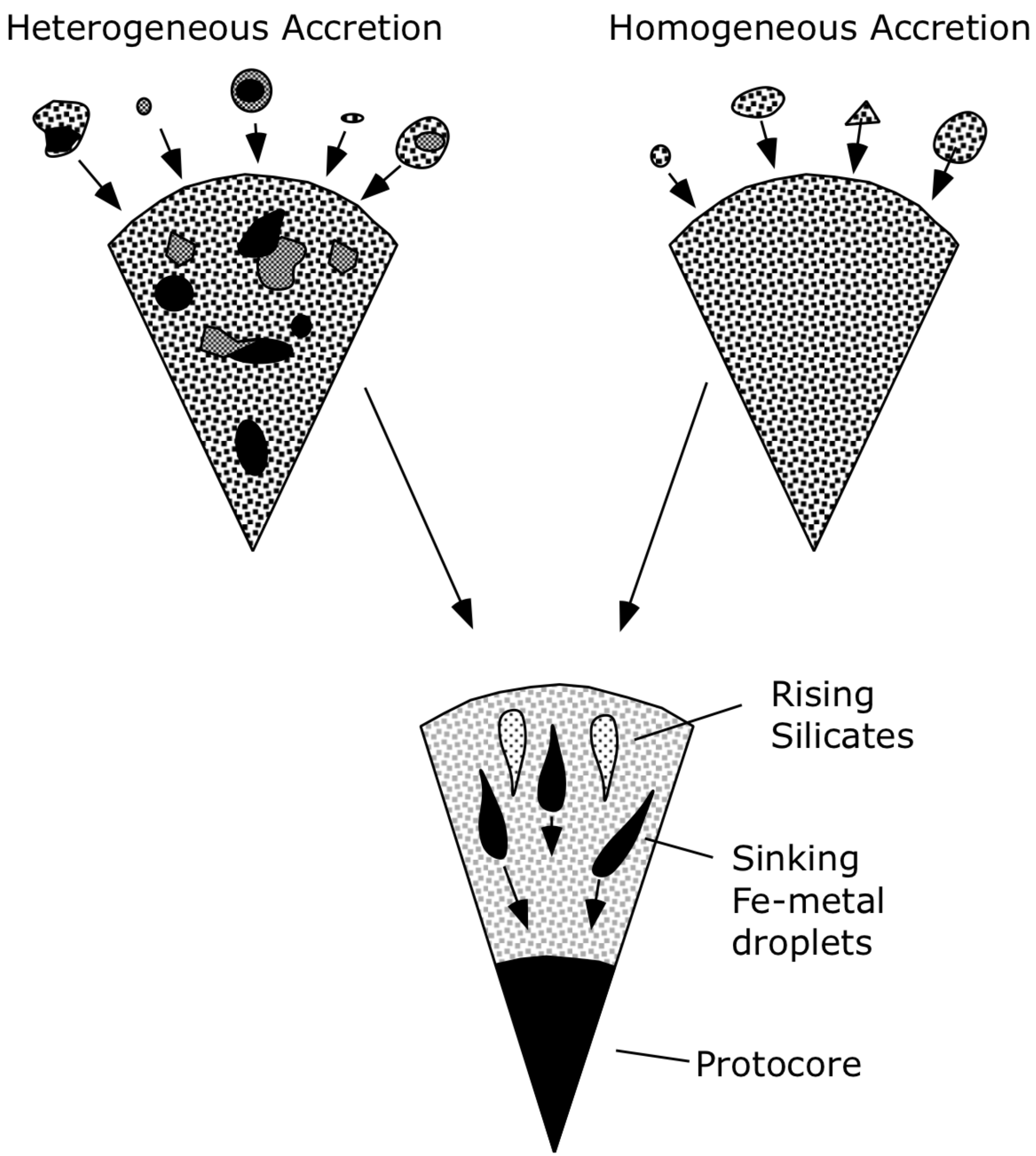
3.3 Ga

15016

The Early Earth Heats Up (Magma Ocean)



Origin of the Earth's Internal Layering



Origin of the earth by accretion of planet-forming materials.

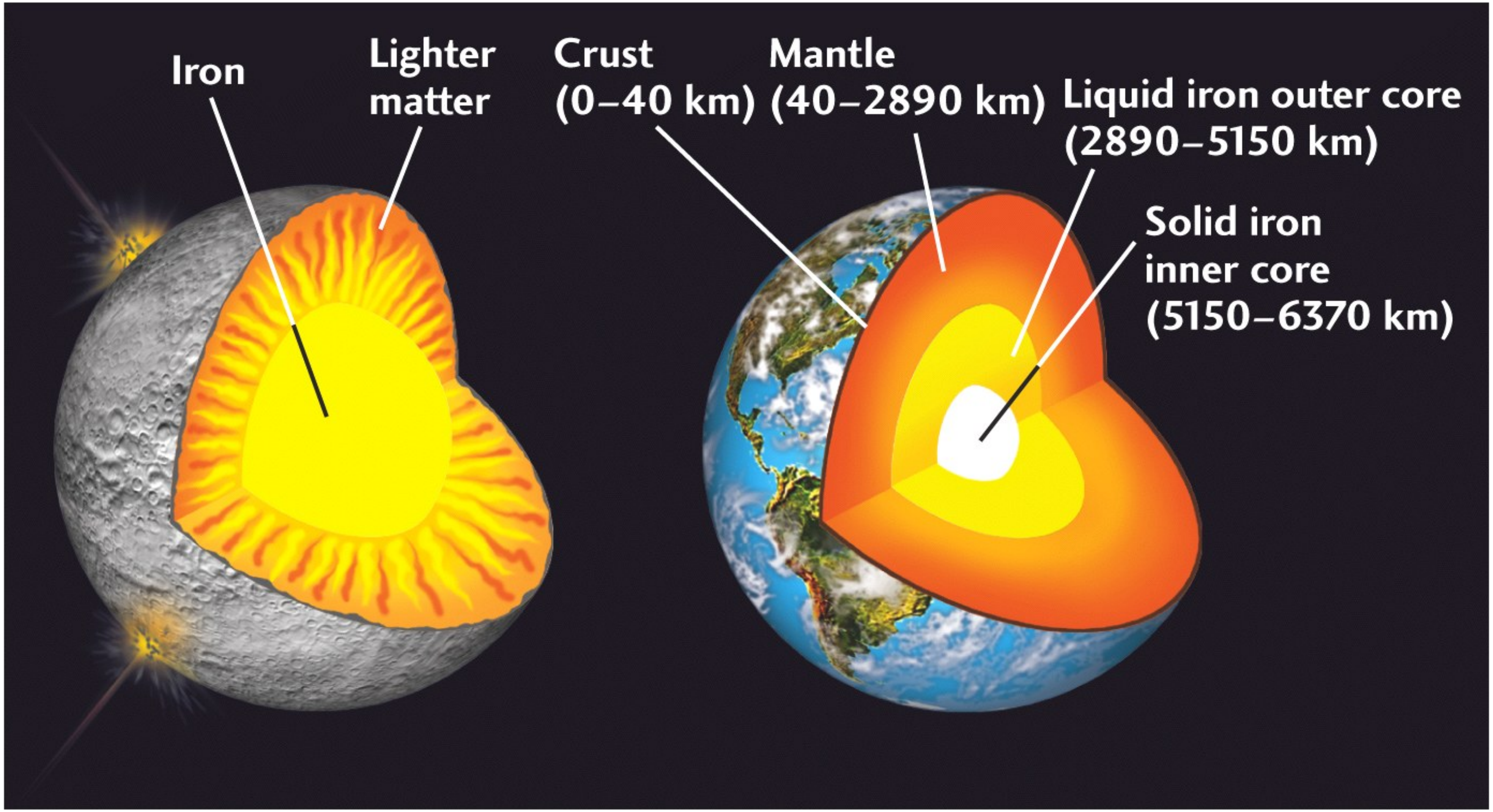
Terrestrial (inner) planets undergo differentiation process that includes melting and separation into layers

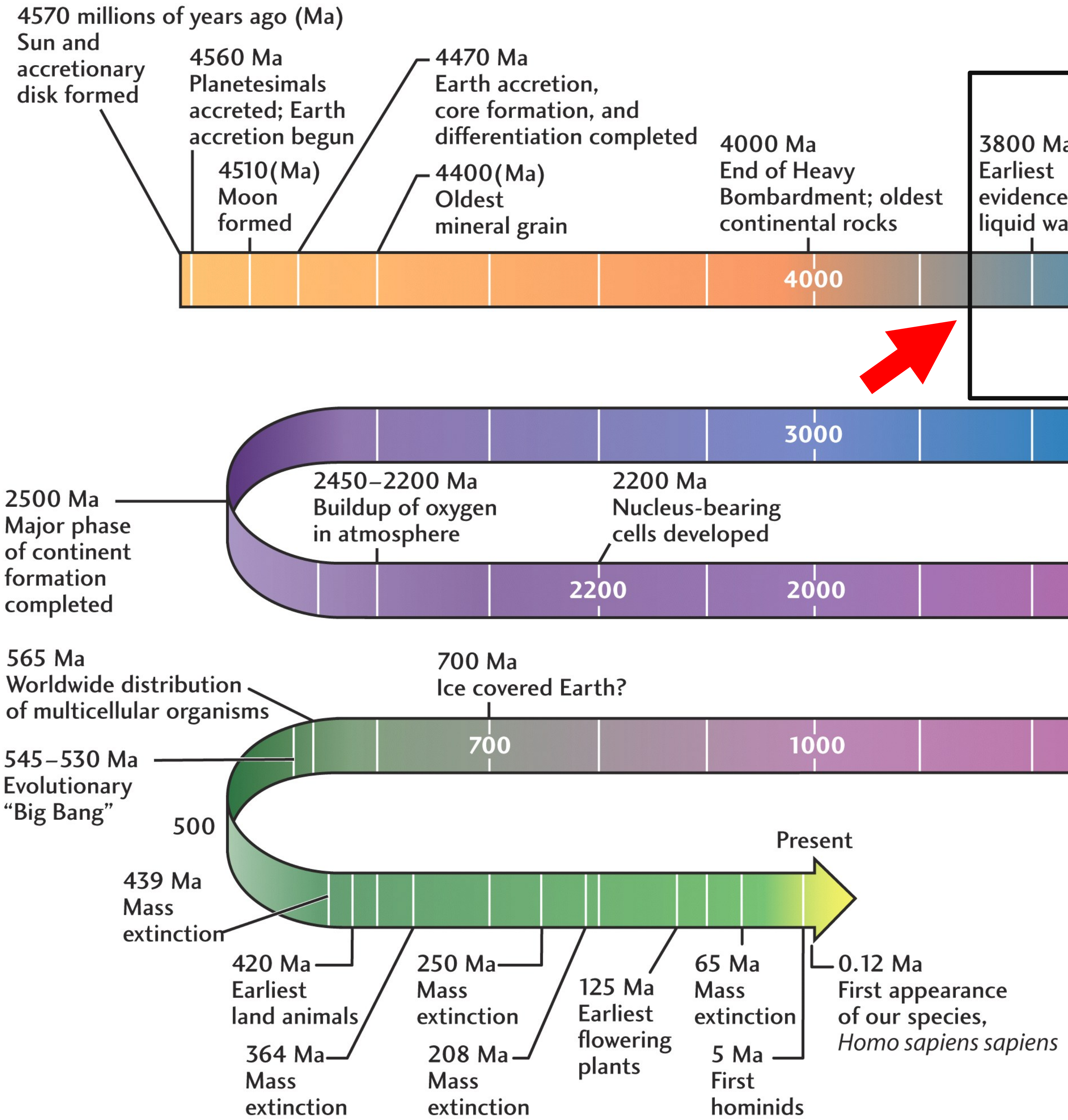
As rocks undergo collision during accretion phase and produce heat causing melting and eventually forms different layers

Denser material sinks to centre of the planet and lighter ones rises to surface

Global Chemical Differentiation

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




4570 millions of years ago (Ma)
Sun and accretionary disk formed
4560 Ma
Planetesimals accreted; Earth accretion begun
4510(Ma)
Moon formed
4470 Ma
Earth accretion, core formation, and differentiation completed
4400(Ma)
Oldest mineral grain
4000 Ma
End of Heavy Bombardment; oldest continental rocks
3800 Ma
Earliest evidence for liquid water
4000
3500 Ma
Earliest evidence for life
3000
2500 Ma
Major phase of continent formation completed
2450–2200 Ma
Buildup of oxygen in atmosphere
2200 Ma
Nucleus-bearing cells developed
2200
2000
1500
565 Ma
Worldwide distribution of multicellular organisms
700 Ma
Ice covered Earth?
700
1000
545–530 Ma
Evolutionary "Big Bang"
500
Present
439 Ma
Mass extinction
420 Ma
Earliest land animals
364 Ma
Mass extinction
250 Ma
Mass extinction
208 Ma
Mass extinction
125 Ma
Earliest flowering plants
65 Ma
Mass extinction
5 Ma
First hominids
0.12 Ma
First appearance of our species, *Homo sapiens sapiens*

The Evolving Atmosphere

Right after its creation, the Earth is thought to have had a <u>thin atmosphere</u> composed primarily of helium (He) and hydrogen (H) gases

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 mostly

composed of CO_2, H_2O and NH_3

The released gases were probably similar to those created by modern volcanic eruptions

Creating the Oceans

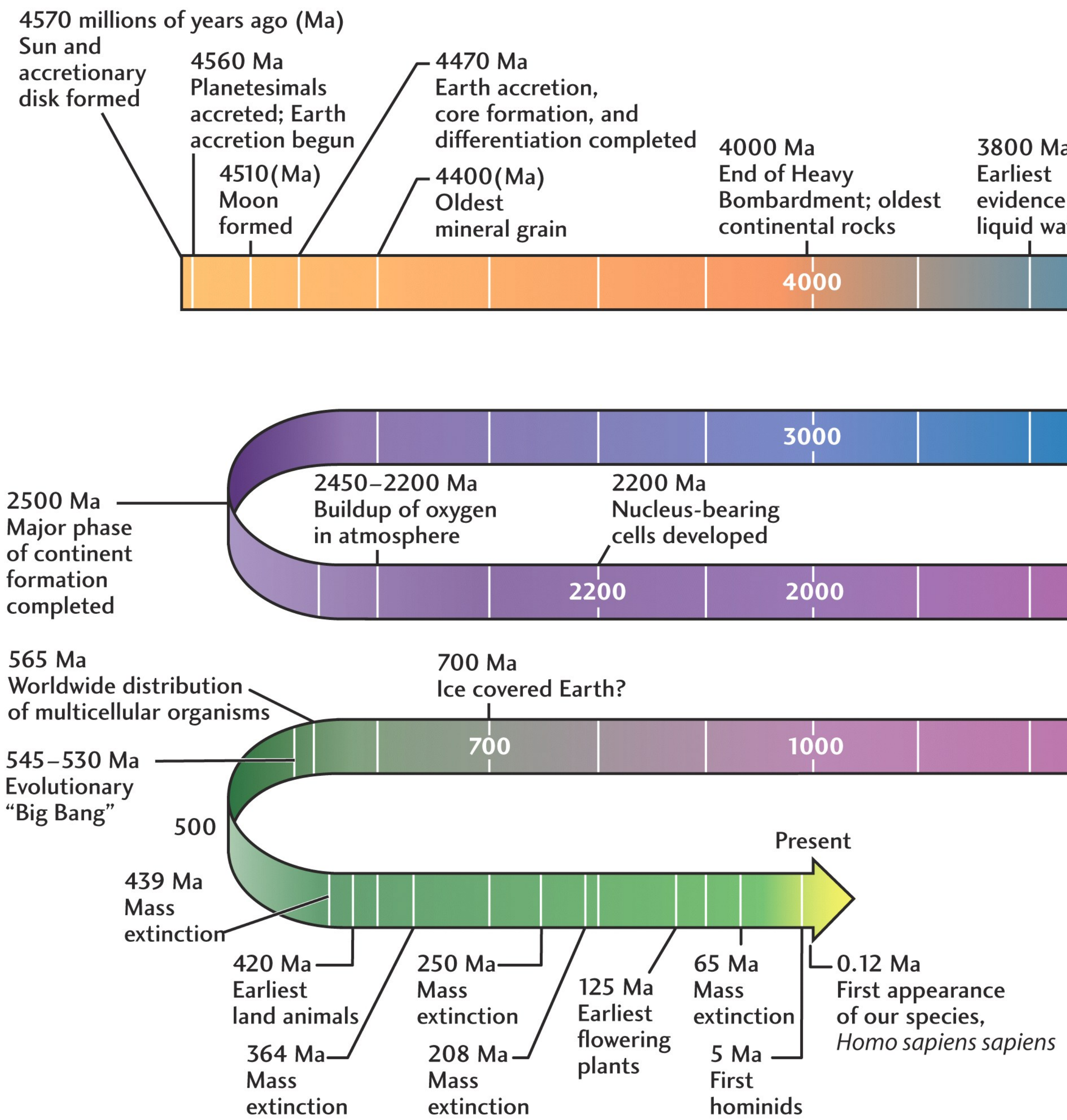
By 3.5 billion years ago, when the Earth was a billion years old, it had a thick atmosphere composed of CO_2, methane, water vapor and other volcanic gases

Earth cooled with time.

It is hypothesized that water vapor escaping from the interior of the Earth via countless volcanic eruptions produced rain for millions of years and eventually created oceans (this took hundreds of millions of years)

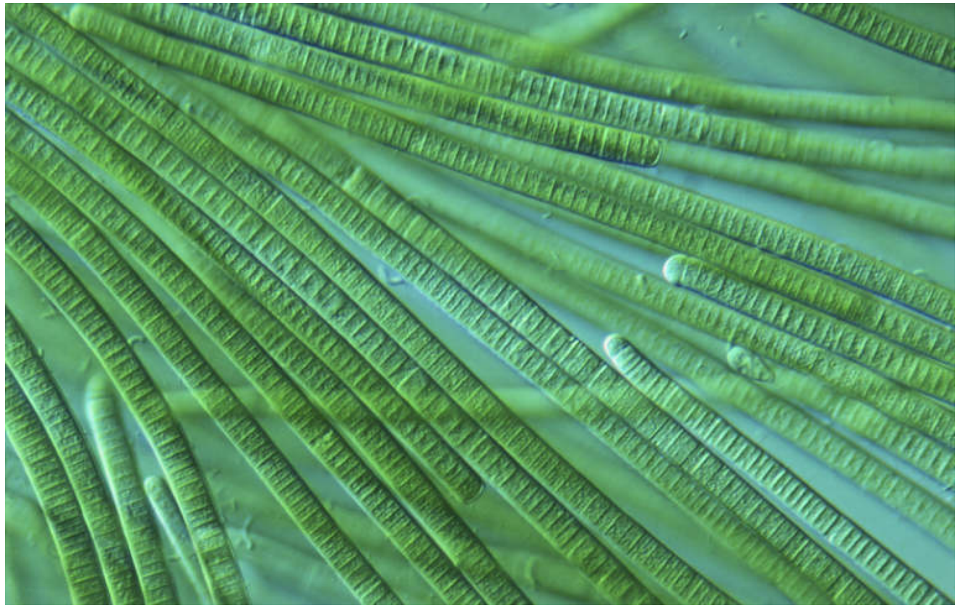
But O_2 is still Missing!

Geologic Time



Cyanobacteria

Cyanobacteria, commonly called blue-green algae, is a phylum of bacteria that obtain their energy through photosynthesis



CO_2 and N_2 dissolved into Oceans and Cyanobacteria developed in oceans which started photosynthesis using sunlight, H_2O and CO_2.

This was the first life on Earth

Evidence of Early Life

The 3.5 billion year old fossilized algae mats, which are called stromatolites, are considered to be the earliest known life on earth. Stromatolites are formed in shallow seas or lagoons when millions of cyanobacteria (a primitive type of bacteria) live together in a colony.

They are found in ‘Shark bay’ lagoon in Western Australia

Stromatolites are mound like bio-accretionary structures. Microbial mats by Cyanobacteria developed on top surfaces of stromatolitic deposits and then was trapped by cycle of sedimentation. Eventually another layer of microbial mat developed on top of the earlier layer and again was trapped by sedimentation. Thus stromatolites grew preserving history.

Banded Iron Formations (BIF)

How do we know that there was no oxygen in the early Earth atmosphere?

It is hypothesized that the banded iron layers were formed in sea water as the result of free oxygen released by photosynthetic cyanobacteria combining with dissolved iron in the oceans to form insoluble iron oxides, which precipitated out, forming a thin layer on the seafloor

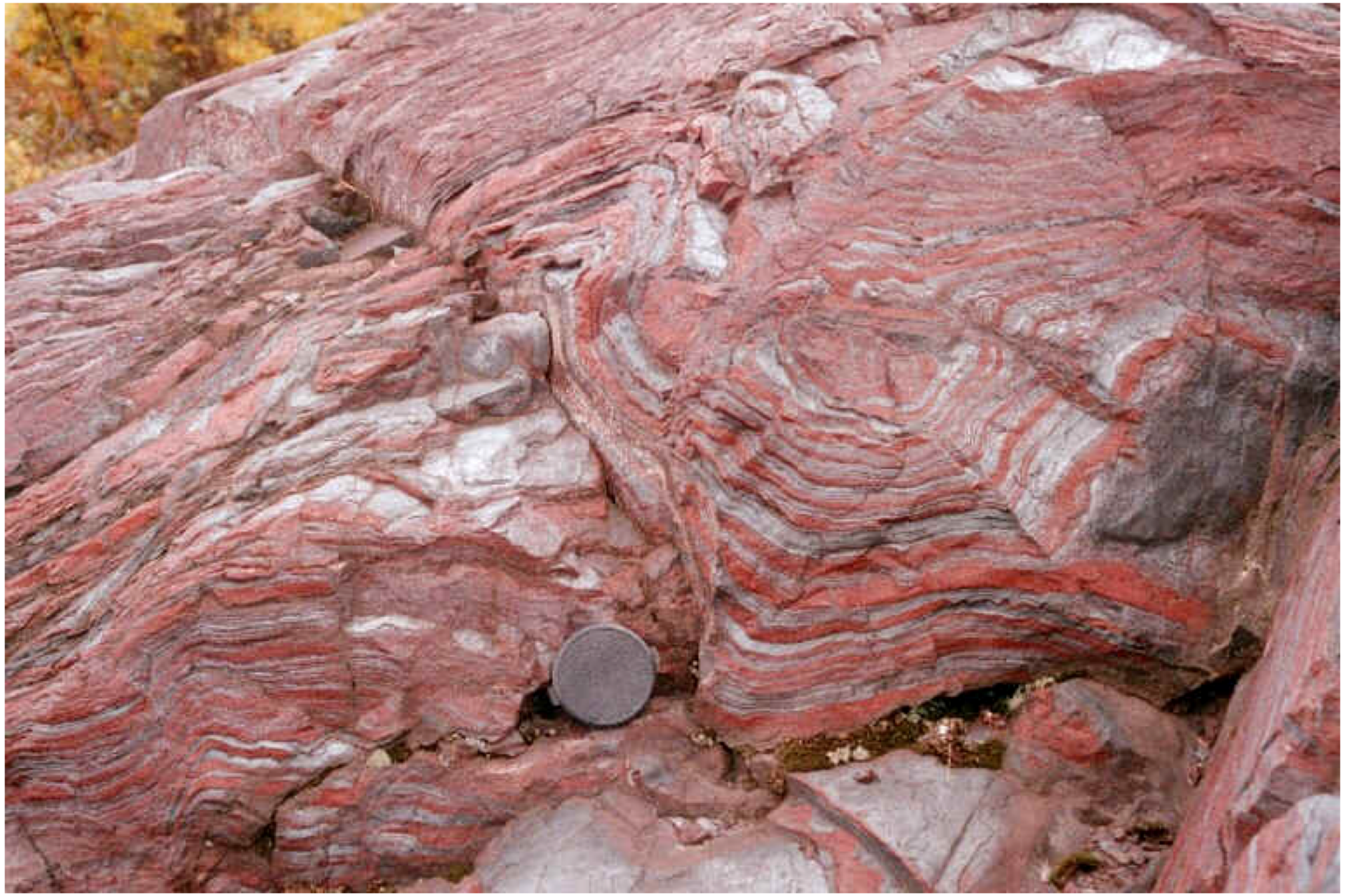
The structures consist of repeated thin layers of iron oxides, either magnetite or hematite, alternating with bands of iron-poor shale and chert

Banded Iron Formations (BIF)

BIFs are primarily found in very old sedimentary rocks, ranging from over 3 to 1.8 billion years in age

Iron rich basalt leached iron into acidic ocean formed due to dissolved CO_2. Photosynthesis of Cyanobacteria produced free oxygen which oxidized iron (Fe^{+2} and Fe^{+3}) to produce red iron (III) oxide (Fe_2O_3) on the ocean floor

Banded Iron Formations



Water must have been replenished with fresh, Iron enriched ocean water cyclically, leading to fresh deposition of BIF

<u>BIF indicates seasonality</u> with iron-rich layers and also <u>indicates possibility of a period of more sunlight availability</u> with increasing photosynthesis, alternating with iron poor layers with low availability of sunlight with less photosynthesis

Oxygen Evolution in the Atmosphere

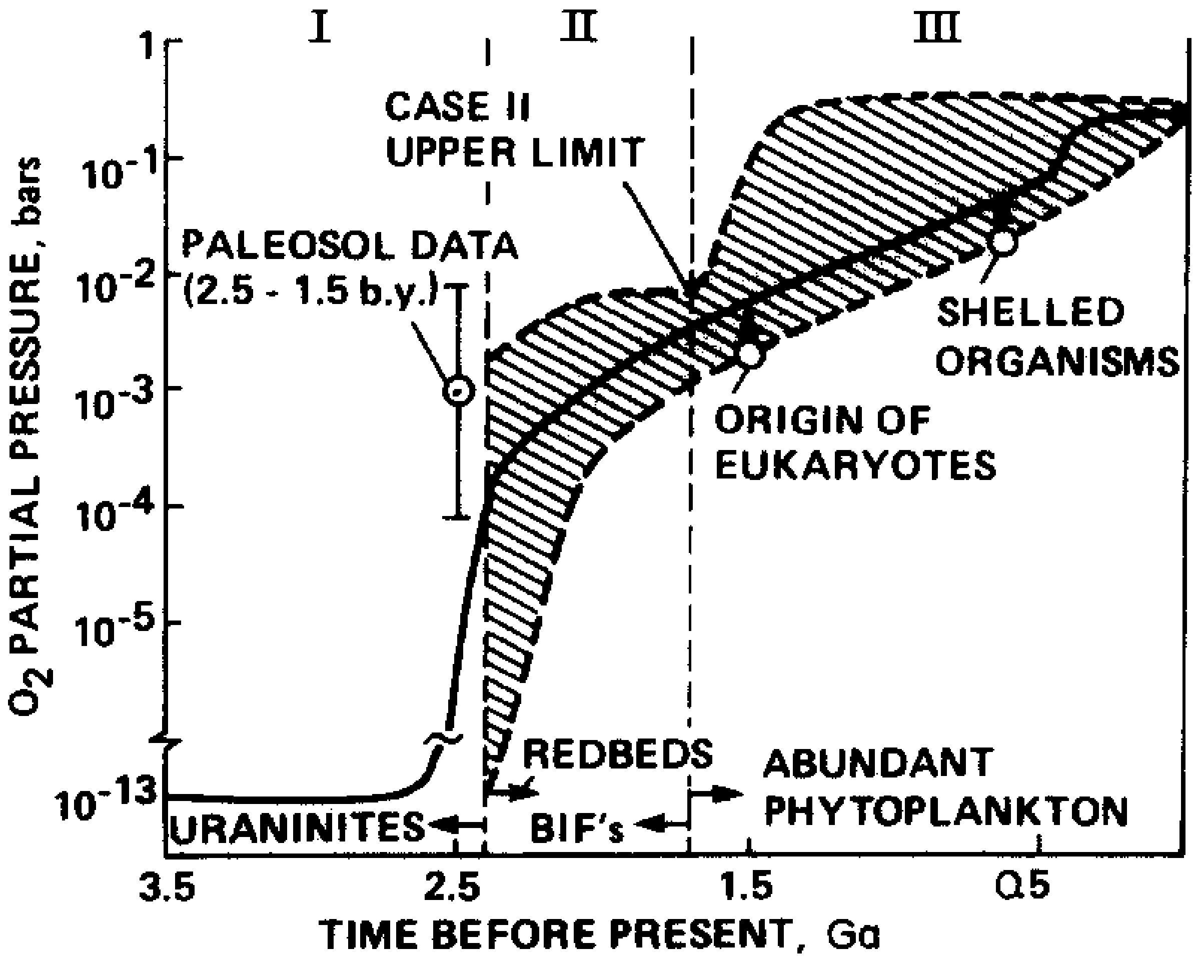


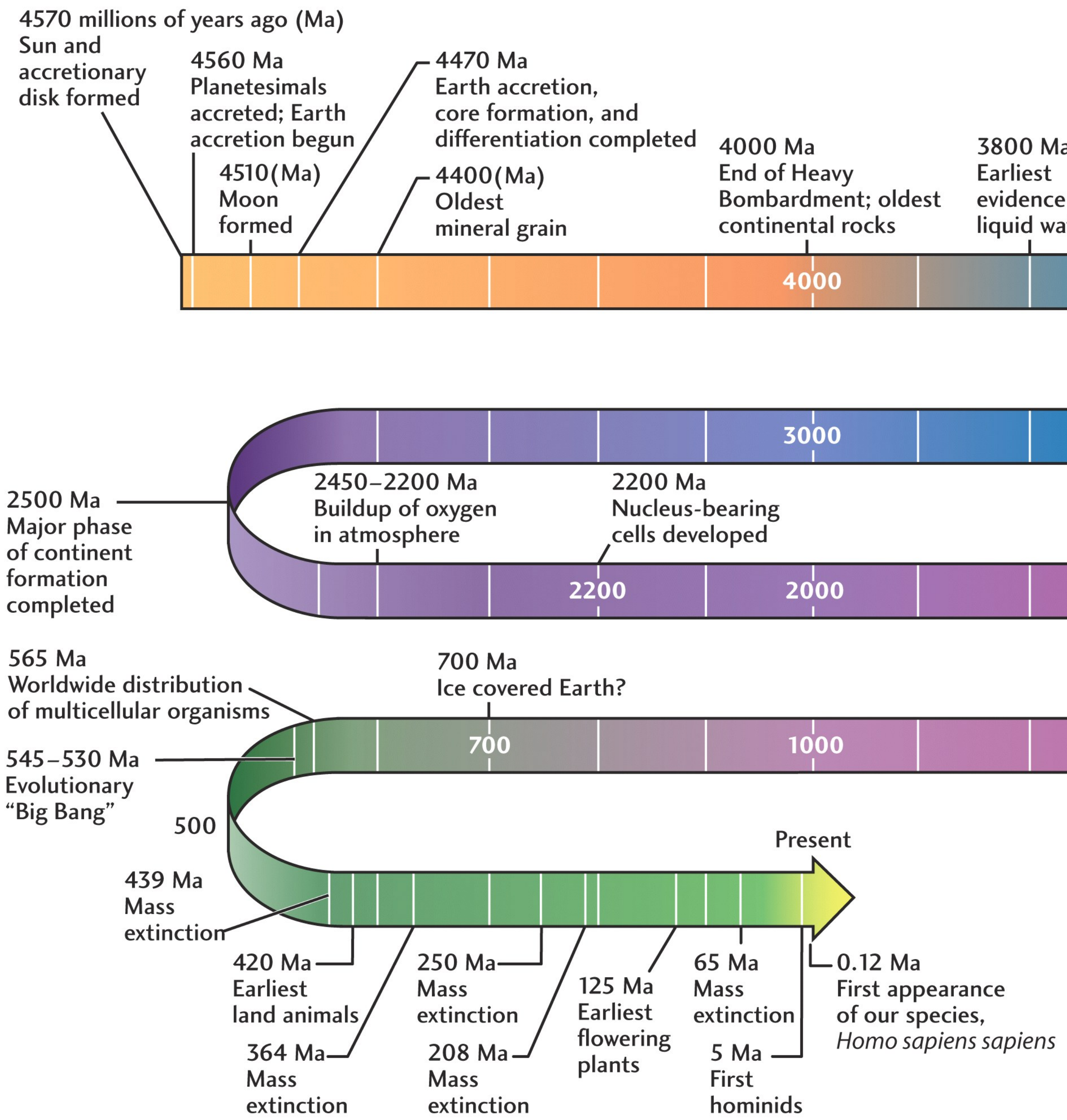
Fig. 7. Estimated change in pO_2 over geologic time. Again, the solid curve is a best guess, and the shaded area represents the range of uncertainty. The point labelled 'paleosol data' is derived from the results of Holland and Zbinden (1986), assuming that $pCO_2 = 0.05$ bar.

Kasting 1987

Cyanobacteria were considered to be the source of oxygen and was responsible for BIF precipitation between 3.5-1.8 Ba.

Free O_2 released into ocean participated in Fe oxidation until all Fe was depleted

Increasing O_2 production eventually released into atmosphere and the environment shifted to irreversible oxidizing state from a reducing state



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3800 Ma
Earliest evidence for liquid water
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3500 Ma
Earliest evidence for life
3000
2500 Ma
Major phase of continent formation completed
2450–2200 Ma
Buildup of oxygen in atmosphere
2200 Ma
Nucleus-bearing cells developed
2200
2000
1500
565 Ma
Worldwide distribution of multicellular organisms
700 Ma
Ice covered Earth?
700
1000
545–530 Ma
Evolutionary "Big Bang"
500
Present
439 Ma
Mass extinction
420 Ma
Earliest land animals
364 Ma
Mass extinction
250 Ma
Mass extinction
208 Ma
Mass extinction
125 Ma
Earliest flowering plants
65 Ma
Mass extinction
5 Ma
First hominids
0.12 Ma
First appearance of our species, *Homo sapiens sapiens*