4600 MYA

Earth Origins

There is nothing under your feet. The Earth does not exist yet.

In the Orion Arm of the Milky Way galaxy, a huge star explodes into a supernova, spewing heavy elements. The resulting pressure wave forces a cloud of hydrogen gas to compress into a smaller star, our Sun. The newly formed Sun is less luminous than it is at present, emitting only 70% of the energy it does today.

Gas and dust grains from this event join together into larger and larger lumps of matter, which eventually build the eight planets of our solar system. By 4550 MYA, Earth has accreted together at a distance from the Sun at which the temperature is not so hot that the water evaporates, but not so cold that it freezes. It is within this zone that the liquid water necessary for life can be found.

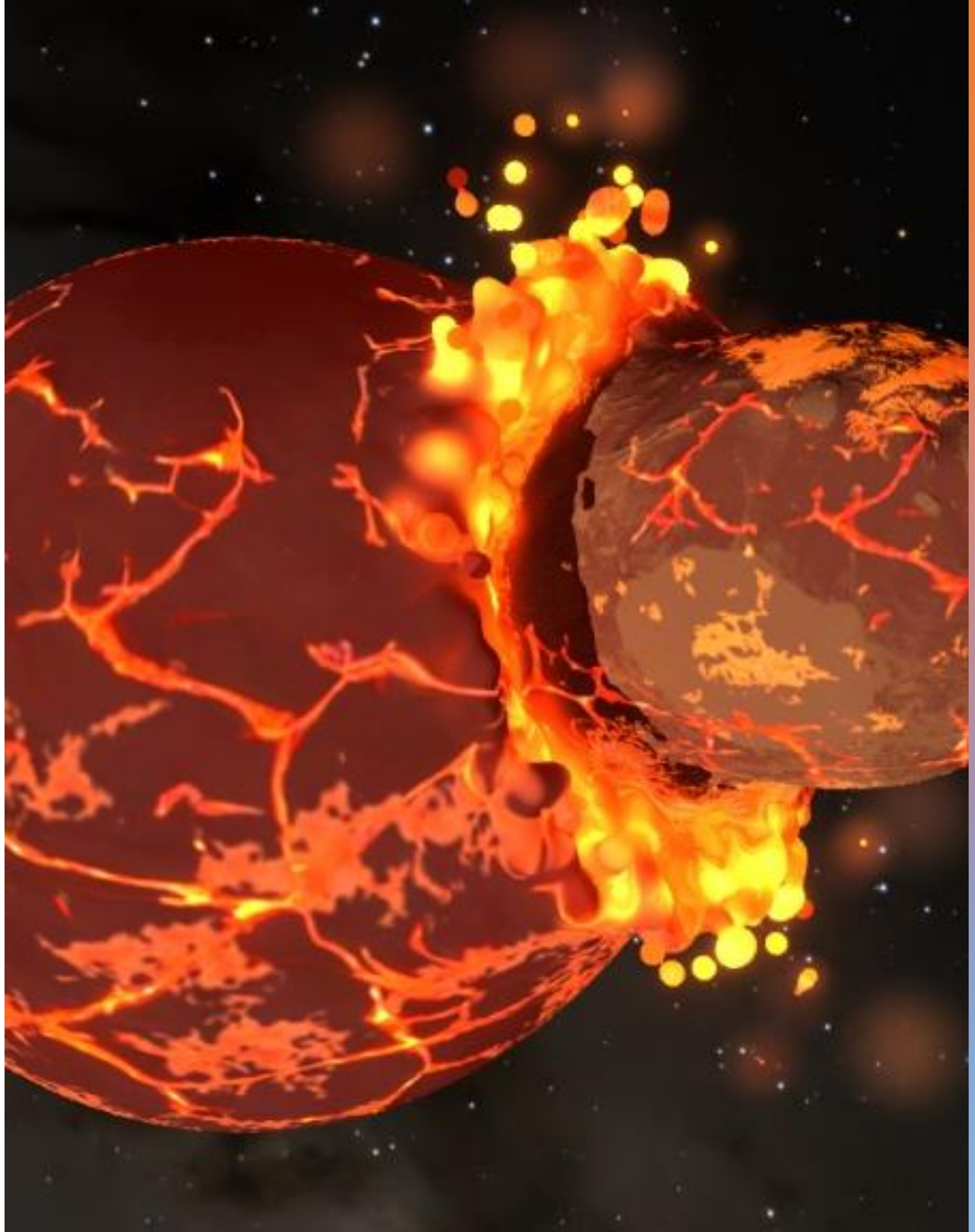
4470 MYA

Moon Formation

The Moon likely forms when Theia, a planet the size of Mars, hits Earth, sending vast amounts of molten rock into nearby space. The speed and angle of this impact is such that the debris emitted is quickly captured by Earth's gravity, forming the Moon. The gravitational interaction between the Moon and our planet stabilises the tilt and rotation of Earth, giving predictable seasons.

At this time, the Moon is much closer to Earth and thus appears about 10 times bigger. The Moon is moving away from Earth at a speed of about 4 cm every year – roughly the speed your fingernails grow.

Theia's collision also adds iron to Earth's core, which increases the intensity of Earth's magnetic field. This shields Earth from harmful cosmic rays and solar wind and protects the Earth's atmosphere from dissipating.



4400 MYA

First Earth Crusts

It’s hot beneath your feet. Heavy metals, iron, and nickel have sunk and formed into a core; lighter materials are rising. The Earth is spinning more than three times faster than today, shedding heat and starting to form the first tentative crusts – slivers of solid rock floating on red hot magma. Earth’s gravitational field is strong enough to grip her atmosphere, partly due to iron in the core.

The oldest surviving minerals on Earth, tiny zircon crystals, date back to this period. Scientists were able to calculate the age of these crystals using radiometric dating, which means measuring the decay of radioactive isotopes within the crystals.

Examining the chemical and physical composition of these crystals also allowed scientists to learn something about Earth’s climate. It was very hot! Surface temperatures may have been more than 200^{o}C.

4100 MYA
Late Heavy Bombardment

Earth is continuously cracked and smashed up by planetessimals (small protoplanets) hurtling in from the solar system, causing tremendous heating. This provides Earth with additional amounts of water and other key elements, such as carbon, which are later incorporated into the bodies of living beings.

Earth is still a hothouse. The Earth's core may be cooling, but surface temperatures remain high as a result of powerful asteroid impacts and intense volcanic activity. The first oceans are beginning to form in depressions in the Earth's crust – but much of this water evaporates due to the high temperatures on Earth's surface.

"BENNU'S JOURNEY – Early Earth" by NASA Goddard Space Centre used under CC BY 2.0/Cropped from original

3800 MYA
Last Universal Common Ancestor

With the Late Heavy Bombardment ending, the Earth now has suitable conditions for the development of life: 1) energy from the Sun and the inner heat of the Earth; 2) the existence of liquid water; 3) the essential elements for life – carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur; 4) the right temperature and pressure on Earth's surface.

Perhaps now, in deep-sea hydrothermal vents, an early single-celled ancestor of all present life appears. Known as LUCA (Last Universal Common Ancestor), we do not know how this organism originated, nor exactly what chemicals it is composed of. No direct evidence of it remains.

Scientists inferred that life first emerged 3800 MYA by studying the ratio of Carbon-12 in ancient rocks. This conclusion is based on the fact that living organisms take up Carbon-12 in preference to Carbon-13. A higher ratio of Carbon-12 in ancient rocks indicates that living organisms were present.

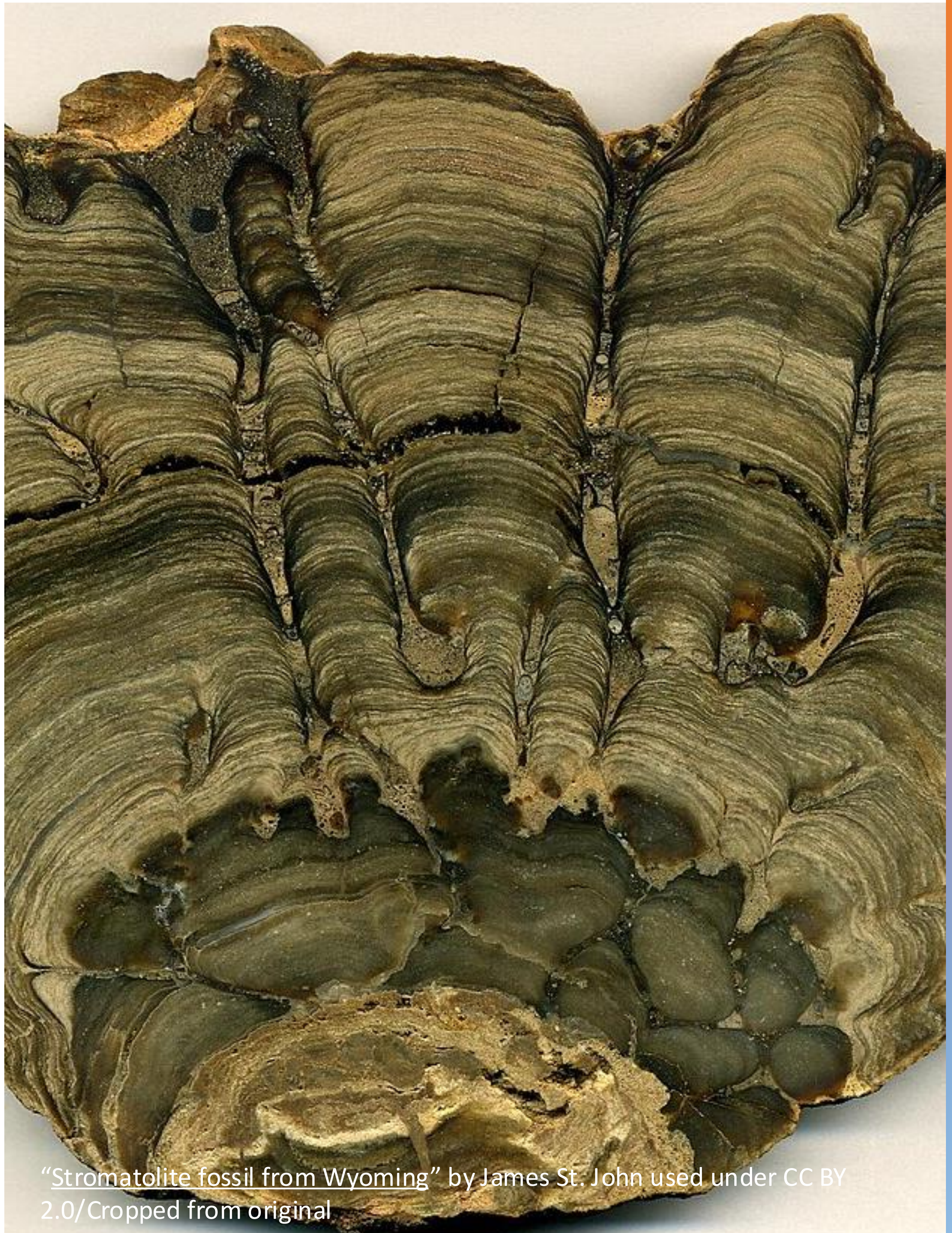
3500 MYA

Oldest Fossils

The oldest microscopic fossils date back to this period, tiny specimens of stromatolites (pictured). Stromatolites are stony structures built by colonies of bacteria that stick themselves together with mucus. This process traps minerals and creates a reef ecosystem that circulates nutrients and recycles waste.

All life at this time is prokaryotic (cells with no nucleus) and confined to the oceans. Living organisms must adapt to abiotic conditions (e.g. light, temperature, water). Life is still too rare to have any major effect on the global climate or on the distribution of key elements (such as carbon, nitrogen, phosphorus, and sulfur) on the Earth surface.

Over deep time, as we will see, a new dynamic will emerge, enabling the coevolution of living and nonliving aspects of the planet. When this happens, life starts to change the composition of the environment.

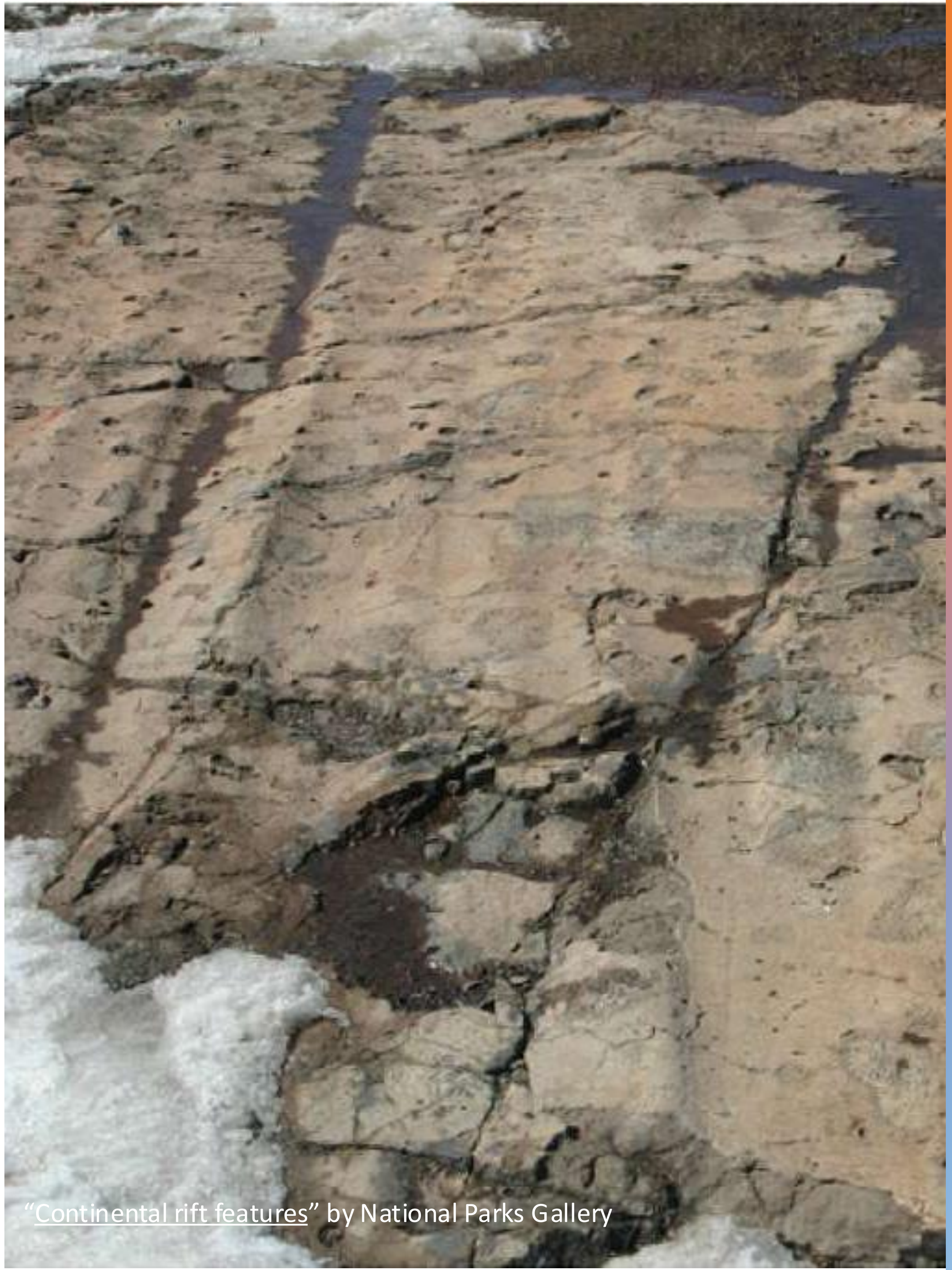


3100 MYA

Vaalbara – First Supercontinent

The continuous movement of Earth's crust on top of the hot, slowly flowing magma jams together proto-continents to form Vaalbara, the first supercontinent. This first land mass doesn't have the conditions suitable for prokaryotic organisms to survive, although microbial mats might exist around the water's edge. The remains of this supercontinent can be found in present-day South Africa and Western Australia.

For supercontinents to form, plate tectonics is essential, and some scientists believe Earth had to be just the right size for this to occur. Too small and the Earth would generate insufficient convective stress to keep the plates moving; too big and the intense gravitational field would lock the plates together. There is increasing recognition of a supercontinent cycle – the period amalgamation and break-up of single large landmasses – having profound consequences on our Earth's system.



"Continental rift features" by National Parks Gallery

2900 MYA

Oxygenic Photosynthesis

Around now, a green-pigmented bacterium discovers a way of making food. Using the power of sunlight, this bacterium combine water with carbon dioxide from the atmosphere, producing sugar and releasing oxygen gas as a waste product. This amazing feat – oxygenic photosynthesis – increases the energy available to life by 10 times.

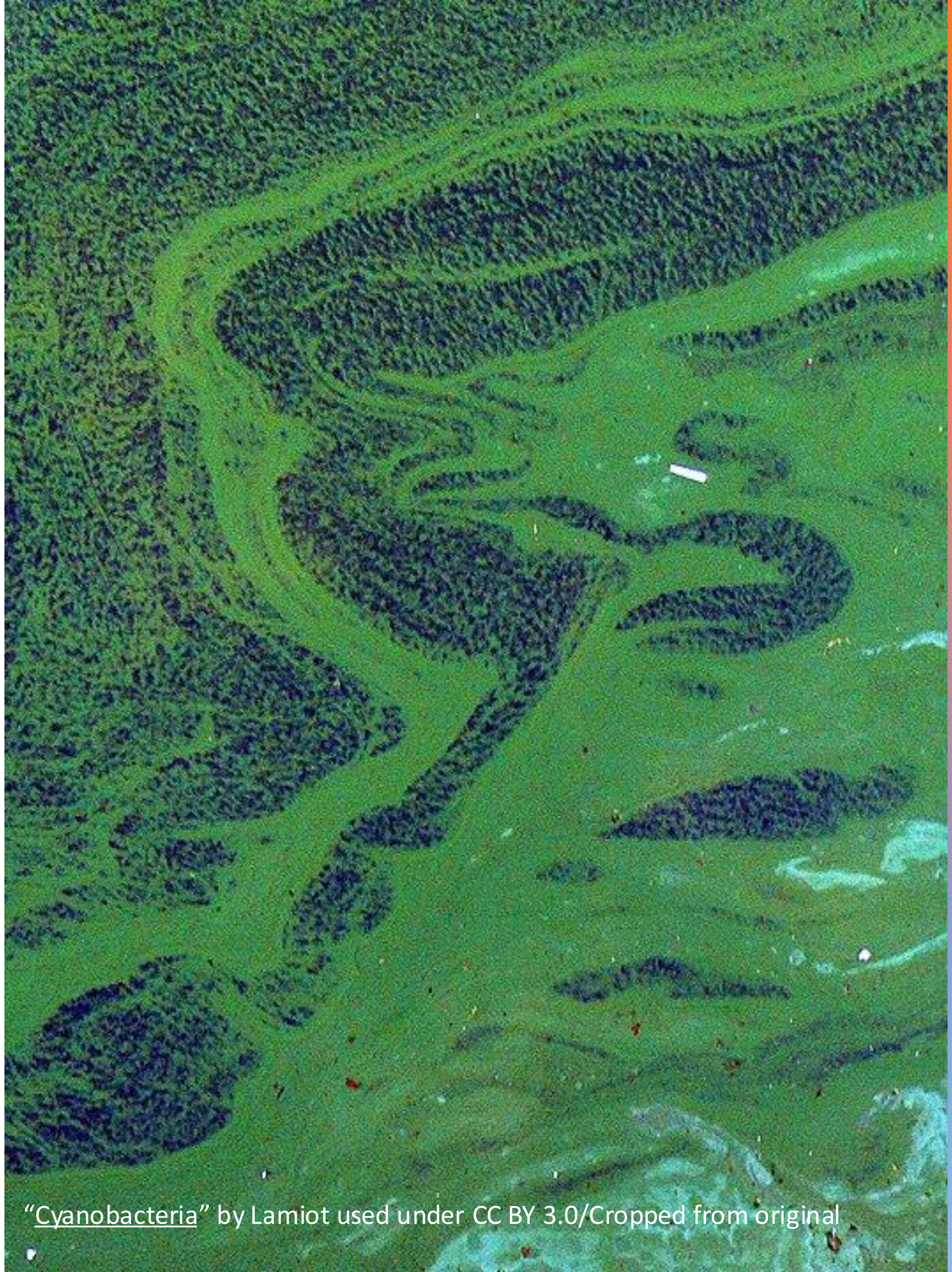
The organisms responsible are cyanobacteria – photosynthesizers that cover vast areas of the Earth's ocean. The 'whiffs' of oxygen produced by the cyanobacteria, however, do not accumulate to any great extent since the oxygen reacts with dissolved iron in seawater, creating rust particles that sink to the ocean depths. However, some oxygen is spared, with tiny amounts bubbling up into the atmosphere.

"Bacteria seen by microscopes" by Turek

2800 MYA
Living Earth

Cyanobacteria remove so much carbon dioxide from the atmosphere that the Earth is in danger of becoming a snowball. However, other bacteria in ocean sediments release carbon dioxide and methane by decomposing the dead bodies of photosynthesizers which sink down from the surface waters. This process recycles carbon dioxide back into the atmosphere, maintaining Earth's hothouse climate.

The relationship between these two bacterial ecosystems may mark the beginning of Gaia – the phenomenon in which, without conscious foresight or planning, feedbacks between the living and nonliving parts of the environment keep the Earth in a habitable state for life.



2400 MYA
The Great Oxidation

Finally, iron and other oxygen-absorbing compounds are fully saturated with the oxygen produced by photosynthesizing cyanobacteria. Oxygen gas in the atmosphere now shoots up from nothing to 1%. This is the Great Oxidation, which opens new opportunities for prokaryotes, since more oxygen gas is now available for powering complex cellular structures and metabolic processes. This is one of the most significant changes in all Earth history.

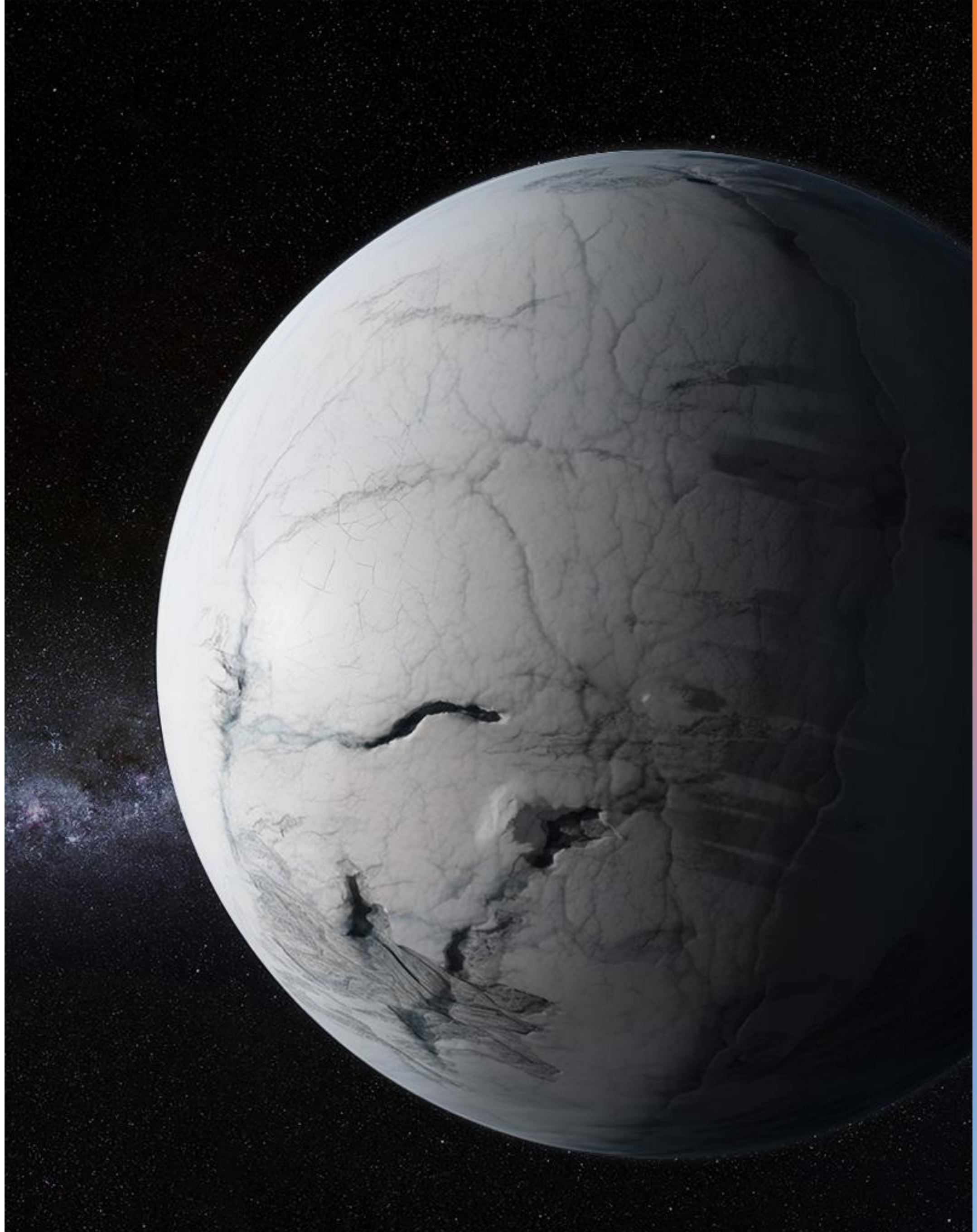
The presence of iron oxide in rock formations from this time (pictured) provides a record of the presence of comparatively high levels of oxygen becoming widespread around 2400 – 1800 MYA.

2300 MYA
Snowball Earth

We are now half-way back to the present day and it's freezing! The Earth is a frozen ball, with ice sheets extending to the equator, producing what scientists call Snowball Earth.

Scientists hypothesise that the cooling of Earth's climate was caused by oxygen gas, produced by photosynthesizing bacteria, reacting with the greenhouse gas methane, stripping it out of the atmosphere and causing dramatic cooling.

How life survives is uncertain. Prokaryotes may survive in a suspended state, or they may have stayed close to hydrothermal vents.



1700 MYA

Multicellular Life

The ice sheets blanketing the Earth have melted, possibly due to the massive outgassing of CO_2 by volcanoes.

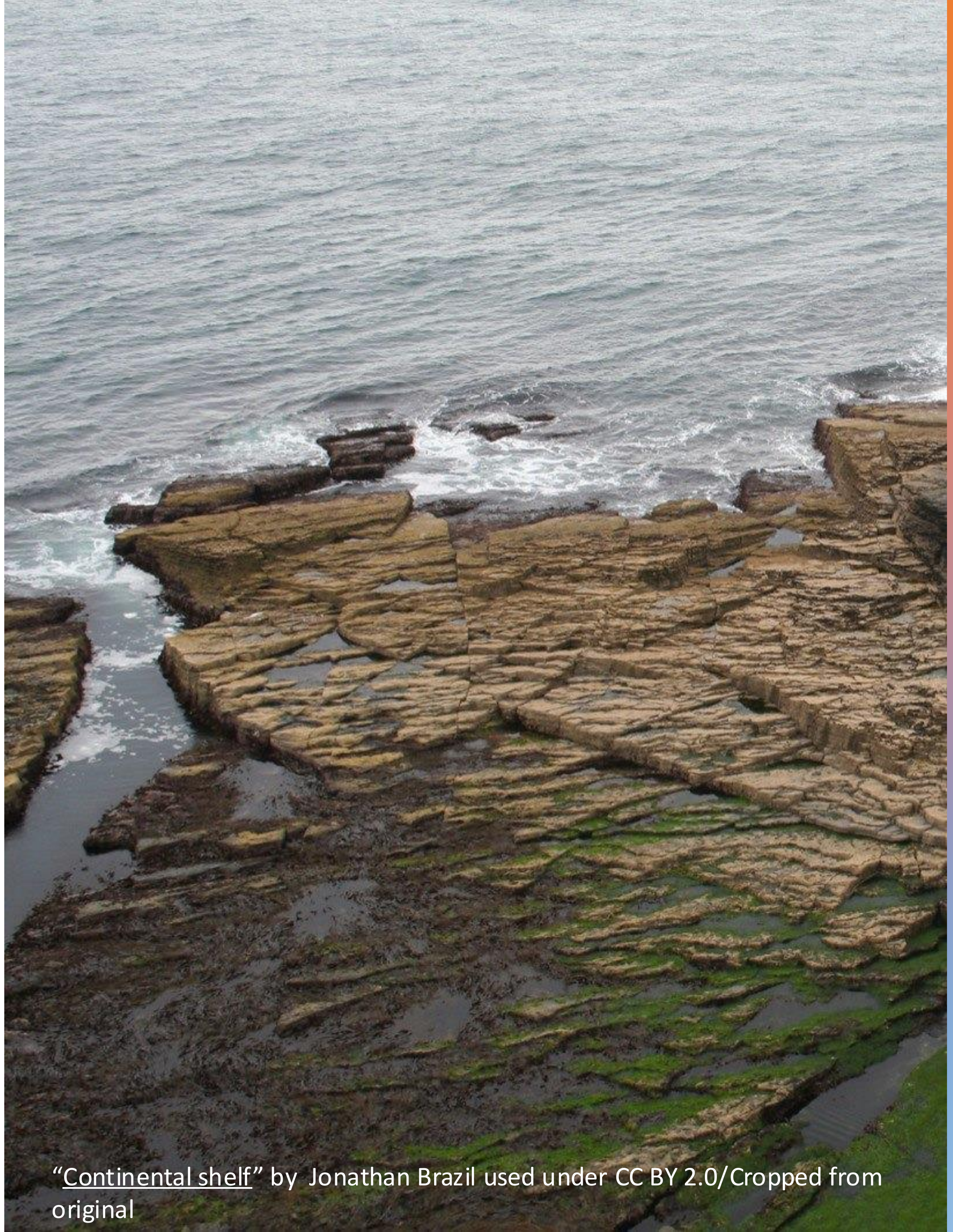
Multicellular life now makes its first appearance. All multicellular organisms, such as animals, plants, and most fungi, are composed of a multitude of eukaryotic cells that have learned to live together in a highly integrated, cooperative relationship in which each individual cell contributes to the wellbeing of the organism of which it forms a part.

The emergence of multicellularity enables the increase of both the complexity and size of living beings. We humans are a good example, being made up of ~ 37 trillion cells, of 200+ different cell types.

1100 MYA
Rodinia Supercontinent

We are almost two-thirds of the way through our journey. Earth has gone through many supercontinent cycles. Four supercontinents - Vaalbara, Ur, Kenorland, Columbia – have formed and then broken up. Now, the supercontinent Rodinia is assembling. Large continental areas which will later become Australia and Antarctica are linked to future North and South America, Siberia, Scandinavia/Western Europe, and West Africa.

Mats of terrestrial cyanobacteria colonise the edges of the supercontinent where there is sufficient moisture, but just like all previous supercontinents, Rodinia is mostly a barren expanse of bare rock intersected by huge river systems. A single vast mountain range 20,000 km long straddles the entire continent, the remains of which can still be found today in the Appalachians in North America and northwest Scotland.



700 MYA

More Snowball Earths

With temperatures plummeting to -50^{o}C at the equator, the Earth is once more a snowball with just a few ice-free refuges remaining – likely near small volcanic springs or hydrothermal vents – protecting some forms of multicellular life.

Scientists hypothesise that this global cooling was triggered by lichens, which began colonising continental land surfaces around 800 MYA. Lichens release acids that break down the minerals in rocks. Rivers wash these minerals into the ocean, where they stimulate photosynthesizers, triggering even more cooling via the removal of atmospheric carbon dioxide. Eventually volcanoes pump carbon dioxide into the atmosphere warming the Earth and melting the ice.

There were no thermometers around 700 MYA, so paleoclimatologists rely on proxies like rocks and fossils to infer Earth's past climates. For example, the magnesium-to-calcium ratio in fossilised shellfish is linked to sea surface temperatures, with warmer water leading marine organisms to incorporate less magnesium into their shells.

470 MYA

First Land Plants

Most life is still in the oceans. However, by 470 MYA, the continents are invaded by the first moss-like land plants. Some of these plants later evolve into vascular plants (pictured) with roots and internal tubes transporting water and nutrients.

Around 445 MYA, 85% of all sea life is wiped out in an event known as the Ordovician-Silurian Mass Extinction. The likely cause is the supercontinent Gondwana moving southward, causing an ice age which lowers sea levels and changes the chemical composition of the oceans.

385 MYA

The Carboniferous

Ferns, horsetails, and plants with seeds emerge – some growing 30m+ in vast forests. Soon after, the first four-limbed, five-digit vertebrates (tetrapods) emerge from the water onto land – the early amphibians.

We enter the Carboniferous (coal-bearing) Period, when extensive forests cover much of the continents, which are drifting together to form Pangaea. Lignin is one of the unique innovations of this period, providing the structural rigidity to make plants woody. Initially no organisms were able to decompose this wood, and some of it fossilises into coal

The forests extracted vast amounts of CO_2 from the atmosphere, triggering an ice age around the South Pole. The planet was heading toward another Snowball, but this was avoided when fungi returned CO_2 to the atmosphere by inventing ways of decomposing wood.

330 MYA insects with compound eyes take flight. 315 MYA reptiles appear.

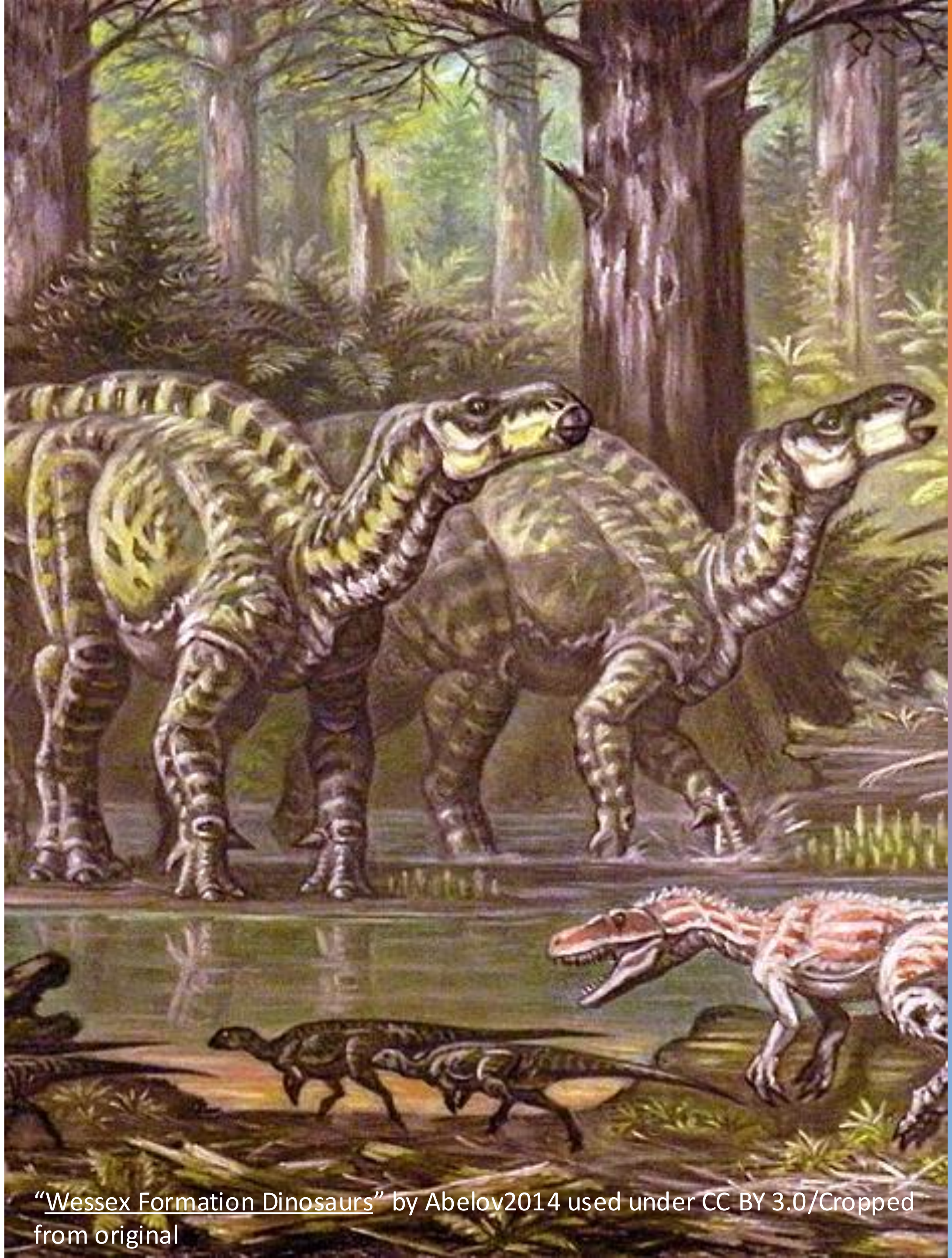
200 MYA

Dinosaurs Dominate

The coming together of the Pangaea supercontinent causes massive volcanic activity, greatly warming the planet by up to 8^{o}C, creating an arid supercontinent. These changes cause 96% of all marine species and 70% of terrestrial vertebrates to vanish.

The recovery takes millions of years. During the recovery period, dinosaurs appear and quickly become dominant. Most have feathers. Pterosaurs fly overheard.

There is wide diversification of life on Earth. The first flowering plants blossom. The first birds appear. Moths and butterflies take flight. Marine molluscs known as ammonites are now common in the oceans. Ocean-based plesiosaurs become numerous, using their newly developed flippers to propel themselves through the seas. Large crocodiles also roam. During this time, placental and marsupial mammals also inhabit the land.



65 MYA

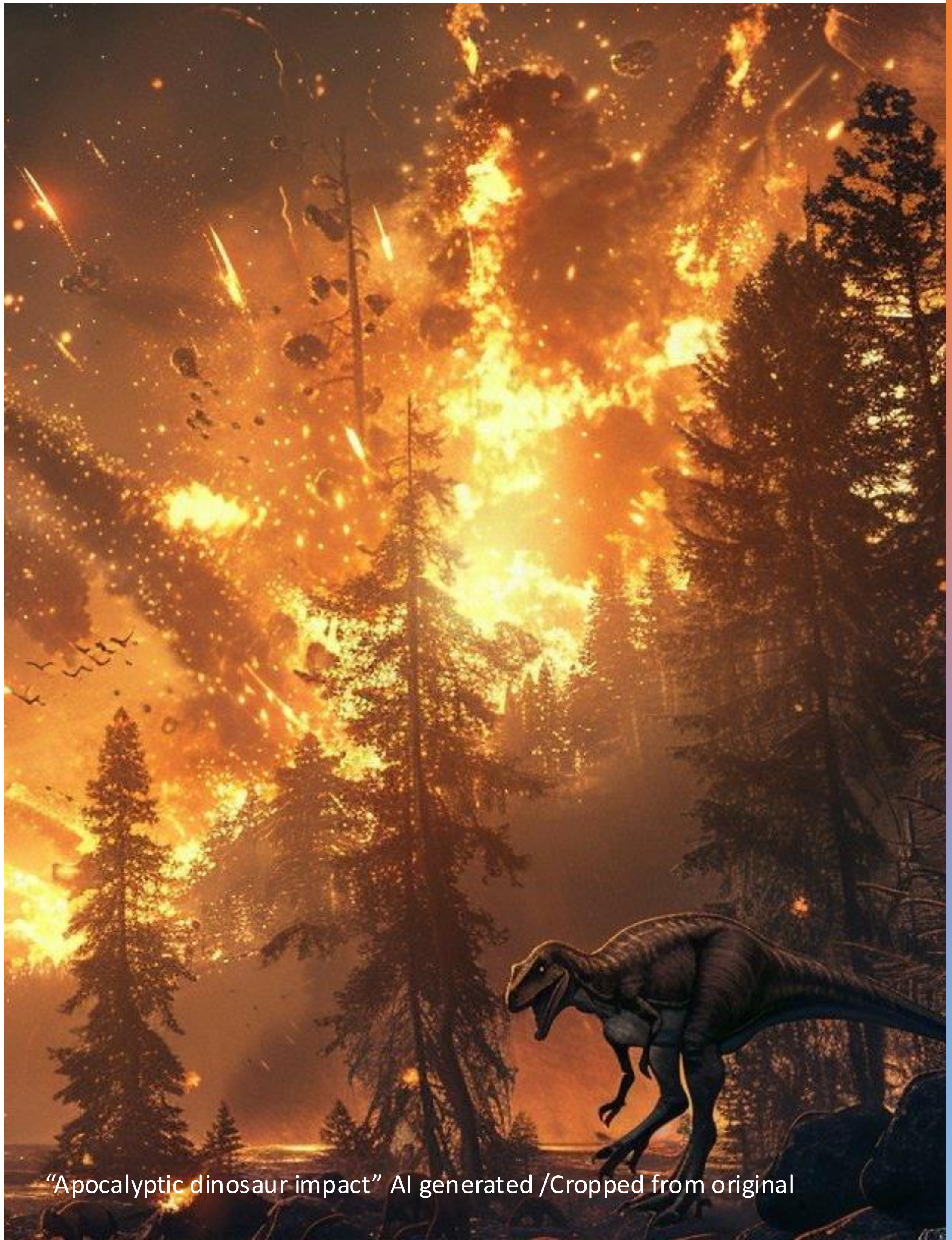
Fifth Mass Extinction

Insects such as bees are pollinating the widespread flowering plants. Bony fish are in the seas – food for rays and sharks.

Then, an asteroid 10-15 km wide travelling at 100,000 km/h hits the Yucatan Peninsula in present-day Mexico, contributing to Earth's fifth mass extinction event.

The huge dust cloud that forms from the asteroid impact causes Earth to go dark for at least a year and leads to the extinction of 75% of all plant and animal species. Non-avian dinosaurs, pterosaurs, and ammonites all vanish.

Following this mass extinction, thousands of bird species evolve from a single dinosaur group. The planet starts to warm, and animals such as small horses, bats, rabbits, and armadillos appear.



"Apocalyptic dinosaur impact" AI generated /Cropped from original

1 MYA
The Dawn of Humans

Stop walking. Look around. Look at yourself. We are now going to measure time through the measurements of your body. You have travelled 4,599 million years, and you are just one step away from now.

- 200,000 years ago (a handspan from thumb to baby finger): *Homo sapiens* appears. We have hairstyles! Tantrums! Lies! Daydreams! Music! Tellers of stories like this one!
- 8,000 years ago (the width of a fingernail): We have farming!
- 6,000 years ago: We have writing!
- 150 years ago (the width of a hair): Humans begin burning the fossilised remains of 400-million-year-old trees. The Industrial Revolution begins!

Now, we're back in the present. What's next? What *could* we be? What *should* we be?