Key Events in the History of Earth and Life

Our planet Earth is with us for many years. It always has known, how to deal with extreme climatic changes, has found a harmony and continue to flourish. Paradoxically, six major mass extinctions acted as a driving machine for new evolution of life. But nowadays, many species are going to extinct, and I do not think that this will bring us benefits. In this essay, I will write about key history events of our miraculous planet, how life have developed across time – from microscopic prokaryotic cells in the oceans, to most intelligent species, and finish with the contemporary climate crisis.

The oldest minerals and rocks on Earth

First, it is good to introduce several key terms in refers to enhance understanding of further concepts. An element is any substance that cannot be decomposed into simpler substances by ordinary chemical processes and therefore, elements are the fundamental materials of which all matter is composed. As all ages of geological events are calibrated by isotopic dating techniques, it is necessary to define following terms. Isotopes are variants of a particular chemical element, in other words, they have the same atomic number but different number of neutrons (Ball, 2019). A parent isotope is one that undergoes natural radioactive decay to form a daughter isotope. The isotopic dating technique is based on comparison between the observed abundance of a naturally occurring radioactive isotope and its decay products. To use this process, we need to know decay rates, and consequently we are observing the half-lives and ratio. The most common naturally occurring radioactive isotopes are for example Rubidium, Strontium, Uranium, Lead… We know many different types of radiometric dating schemes, and one of them - the uranium-lead dating is the most sophisticated (see Fig.1). It allows us to date rocks that formed and crystallised from 1 million years to over 4.5 billion years ago (Karabinos, 2019).

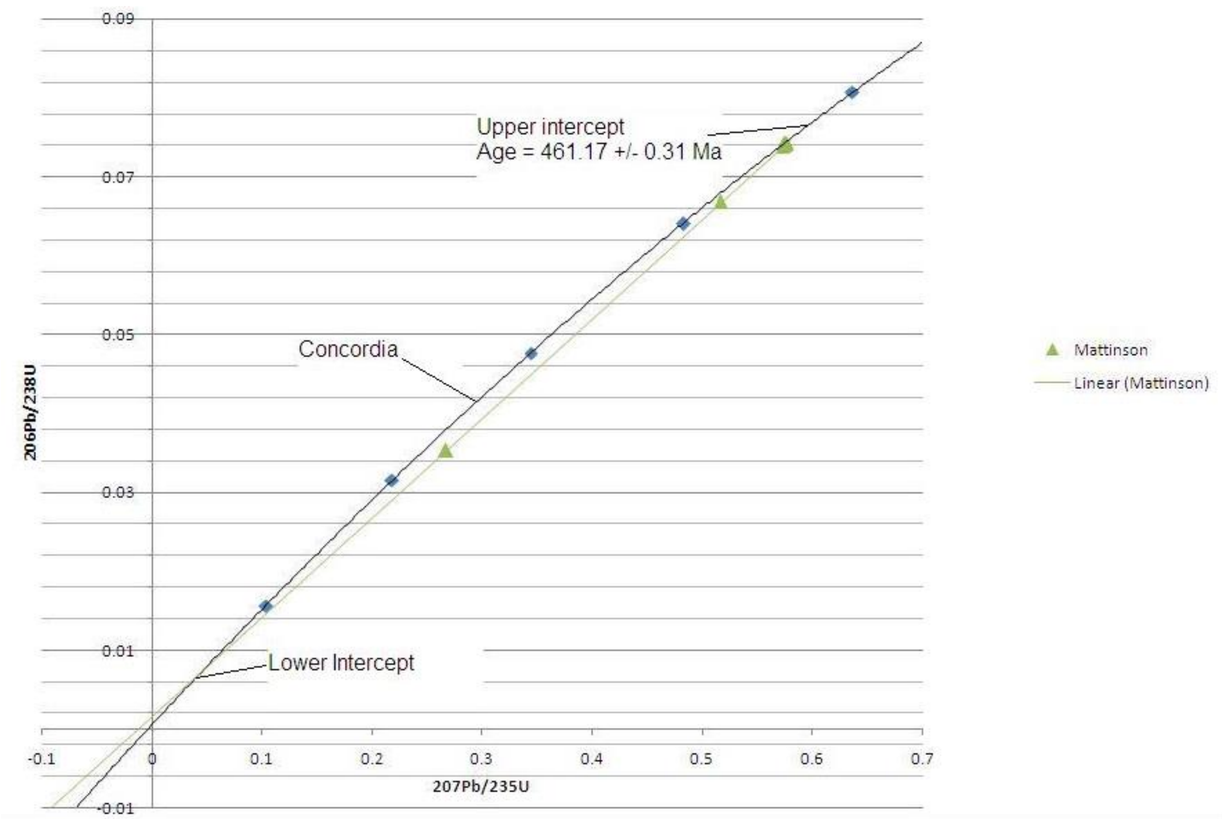

Figure 1. Concordia diagram is used during uranium-lead dating. This allows us to check our values against others. Source: https://en.wikipedia.org/wiki/Uranium%E2%80%93lead_dating

The best mineral for dating the age of the Earth is zircon, because of its unique features such as strength, resilience, and ability to host a wealth of isotopic information. Moreover, the oldest dated mineral grains are detrital zircon grains, which are four billion years old and probably formed from an evolving magmatic source. These grains are from The Jack Hills in mid-west Australia and represent the earliest evidence for continental crust and oceans on the Earth. Tonalitic Acasta Gneiss Complex in Canada is the only precisely dated Hadean rock unit on the Earth – a 4,019 ± 1.8 Ma (AMNH).

Snowball Earth

As time passed, The Great Oxidation Event took place 2.4-2.0 billion years ago, caused by rising oxygen level from photosynthesizes stromatolites. Oxygen in atmosphere formed ozone layer, protecting later life forms from UV radiation (Song-Can Chen et al., 2020). The Precambrian is not famous just because of this event, but also thanks to fascinating phenomena known as the Snowball Earth. The Snowball Earth theory come up with the idea when entirely Earth's surface became frozen during the Cryogenian period.

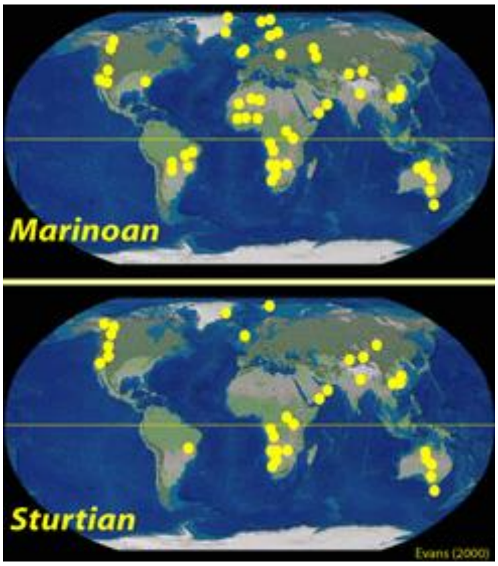

Figure 2. Distribution of glacial deposits during the first (Marinoan) and second (Sturtian) glaciations. The yellow dots show the locations of glaciers. Adapted from Hoffman, 1998.

Scientists contend that at least two Snowball Earth glaciations occurred, an older one between 717 and 660 million years ago, and a younger one that terminated 635 million years ago (see fig.2). Geologists look for dropstones and carbonate rocks in sedimentary layers, to identify these glaciations. For the first Marinoan glaciation, field investigations show evidence in China, Svalbard archipelago and South Australia. The Snowball Earth is caused by rapid weathering of Earth's continents where CO_2 is pulled out of the atmosphere, which causes colling. Decrease in temperature formed ice and created albedo effect, which causes more cooling. But this status once ended, and earth returned to normal conditions. During the glaciation, volcanoes still operate and produce CO_2, which causes a greenhouse effect. Temperature increases and consequently melts ice which then add a lot of nutrients to a seawater. As added ions enhance the increase of alkalinity, carbonates precipitate and form "cap carbonates", what is one of the typical features for a Snowball Earth (Poppick, 2019). The Cryogenian is also known as the period where have been found the first metazoan ever- Otavia (sponge like thing), made of prokaryotic cells. There is an evidence that animals evolve after the second snowball, and therefore Snowball Earth conditions relate to the evolution of animal life. The plankton bloomed and produced enormous amount of oxygen. After ice melted, richness of nutrients probably drove the incredible step in evolution, resulted in the Cambrian explosion of life (Ravilious, 2015).

Cambrian Explosion

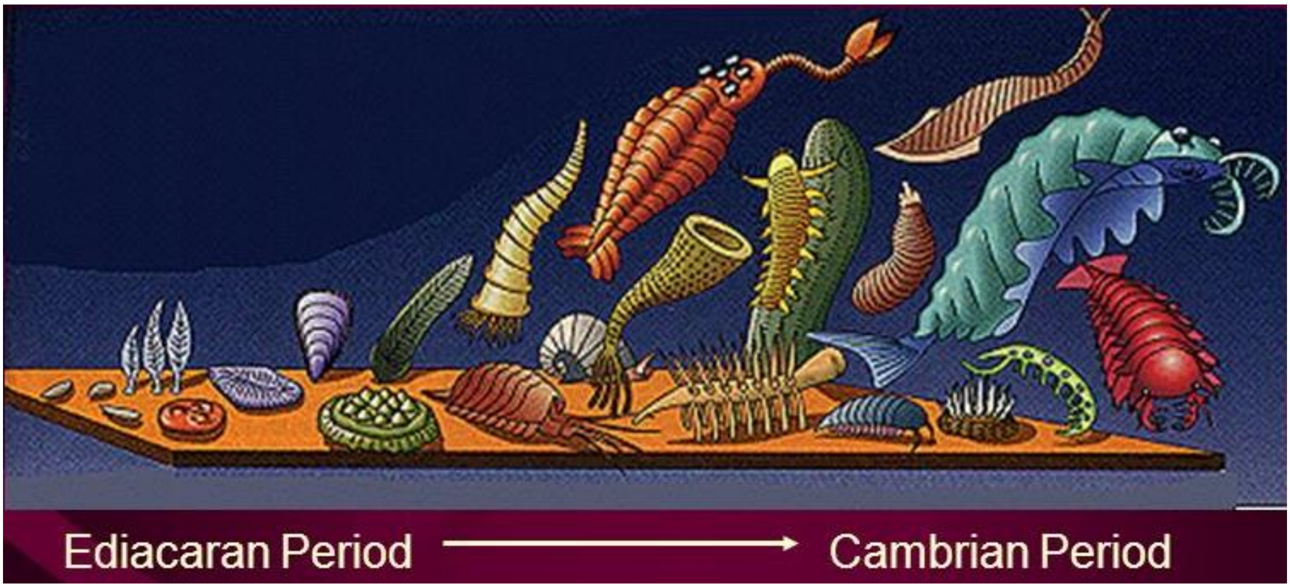

Figure 3. Illustration of how animals evolved through Ediacaran and Cambrian periods, including different weapons or defence systems in their own way, suited to various ways of life. Adapted from M.Miller, 2015.

The end of Precambrian time ended, and the Phanerozoic eon (541 million years ago to the present) has begun. The boundary between these two eons is defined by the first abundant occurrence of macrofossils. This eon including Palaeozoic, Mesozoic, and Cenozoic eras. The first period of this eon is Cambrian-officially distinguished by the first appearance of a certain burrowing trace fossil - *Treptichnus pedum* (Laflamme et al., 2008). Neoproterozoic animals got their energy via pumping water through their skin. They fed on bacteria and their skeleton looked like as a jellyfish. The Ediacaran biota differs from the Cambrian in the way of lifestyle- whereas Ediacaran animals just sit on the seafloor, the Cambrian animals were able to move (see fig.3). During this period, the chordates evolved, and their size depended on oxygen levels. As animals started to eat each other, teeth have evolved also. Amongst typical early Cambrian animals belong trilobites, brachiopods, sea sponges and arthropods, which were burrowing on the seafloor or were able to swim (Darroch, 2018). The fossil evidence of the Cambrian metazoan life could be found in Greenland, China, and Canada. *Funisia* is one of the representative fossils, describing a heterogenous group of animals that have in common cylindrical shape and a soft body without limbs. Competition in Cambrian seas helped cause an explosion in diversity, known as “Cambrian arms rase”. There are several hypotheses about this concept. The one suggests that animals could grow large with plentiful oxygen which had accumulated in the oceans after extreme ice ages occurred between 800 and 550 million years ago. Predators began to eat other animals and their prey reacted by development of thick shells, spikes, and sophisticated methods of hiding. Predators followed suit with specialized ways to track specific prey (see fig.3) (Borel, 2014).

The Rhynie Chert and early environments

During the end of Ordovician, mass extinction took a place and enhance development of new, sophisticated life forms. The first true land plant *Cooksonia* comes from mid-Silurian. This plant was forced to solve several problems with transition on land in order to survive. Water absorption was performed using roots, stomata, and spores. Stems and wood fulfilled support function, whereas leaves were able to absorb sun rays (Kenrick et al., 1997). Fortunately, all these important steps in evolution are preserved in The Rhynie Chert, which is located near the village Rhynie in north east Scotland and is 407 million years old (Ar-Ar dating). (see fig.4).

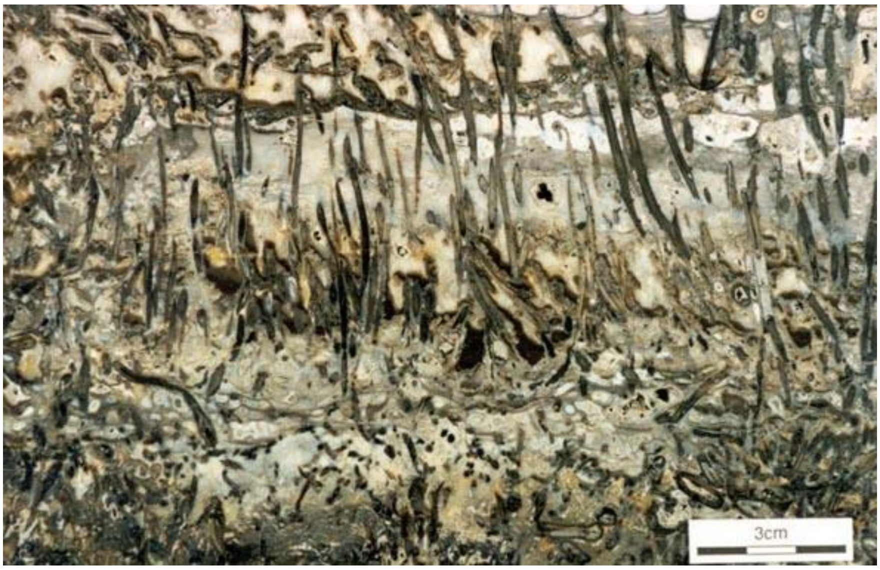

Figure 4. The Rhynie Chert express the oldest hot spring system and preserved plants and animals' community in remarkable details. From Threwin et al., date unknown.

It contains 7 genera of plants, all less than 40 cm tall, and five of these are vascular plants with the proper water management system, containing phloem and xylem. The Chert also preserved earliest known symbiotic mycorrhizal fungi – *Aglaophyton.* The Rhynie Chert was originally deposited as sinter from ancient hot springs. The waters contained dissolved silica, and when the erupted water was cooled, silica was deposited in the form of sinter. Some of the silica trapped plants and animals together with the organic structures (Trewin et al. date unknown). The late Devonian period is known as the "age of fish", when lobe-finned fish and amphibious tetrapods started to inhabit our planet. These first tetrapods were able to rotate their hips and its movement looked like today's lizard movement First land vertebrates include *Tiktaalik* (375 Ma) and *Ichthyostega* (365 Ma), a little bit more adapted to land. *Dunkleosteus* is an extinct genus of arthrodire placoderm fish that existed during the Late Devonian period, about 358–382 million years ago (Molten Sulfur Blog, date unknown). Late Devonian seed ferns (=pteridosperms) produced first seeds and plant roots got bigger and deeper. As roots broke up the rocks, the nutrients were able to dissolve in the soil, and development of true soils flourished. This period ended with mass extinction and gave a place to giants of the coal swamps to spread over our world (Kenrick, 1997).

Carboniferous and Permian Environments

The Carboniferous environments differ from those in Permian, the small trees grew bigger and created dense forests with many swamps, which provided habitats for unbelievable creatures such as *Meganeura* (a giant dragonfly) (see fig.5). Together with the extinct invertebrate *Arthropleura,* they are ranked among the largest insects ever described. These species could have grown to more than 2 metres in length. Coal, a new rock type from wood were predominantly composed from *Calamites* (horsetail) and *Lepidodendron* (a giant club moss).

Figure 5. Illustration of Carboniferous environment as a dense forest with swamps, including the *Meganeura* and reptile. From Kindersley, D., date unknown.

The scientists suggest that organisms grew so huge because of high values of oxygen. During the Carboniferous there was nearly 35% of atmospheric oxygen produced by vast forests full of ferns, mosses, and some of the earliest vascular plants. Wood-eating bacteria have not existed yet, so CO2 was not being released back into atmosphere (Manger, 2020). At the end of carboniferous, much of the forests were replaced by a giant desert at the heart of the continent, with extensive glaciers in the southern hemisphere. Two major groups- the reptiles and the synapsids spent the last period of the Permian, spreading across Pangea. Animals were forced to adapt to even harsher conditions. *Dimetrodon* used its "sail" to stabilize spine, but more importantly, it used it to heat and cool its body as a form of thermoregulation. The Palaeozoic Era ended in cataclysm. The largest mass extinction event in the Phanerozoic wiped out 70% of land vertebrates and 96% of marine species (Hoffman, date unknown). Trilobites, rugose and tabulate corals, blastoids and crinoids show the greatest losses during the Permian extinction. It is debatable, what caused this extinction, but probably combination of volcanic activity, climate change, methane release or meteorite. However, this event brought a favourable condition for microbe populations, and findings suggest that this has important consequences for the evolution of the environment as a whole (Ross, 2020).

The K-Pg (or K-T) boundary mass extinction

The Mesozoic era (251-66 Ma) is composed of 3 periods: Triassic (251-200 Ma), Jurassic (200-145 Ma) and Cretaceous (145-66 Ma). During these periods, many modern groups of animals evolved in the shadow of the reptiles, like mammals, frogs, bees, and flowering plants. Dinosaurs such as Ichthyosaurus, *Eoraptor* (the earliest therapod dinosaur) or *Microraptor* (a cretaceous feathered dinosaur) inhabited the Earth. The Triassic-Jurassic extinction was not as significant as the bigger one on the Cretaceous-Tertiary boundary, which wiped out all dinosaurs (except for birds) and ammonites (Jaggard, 2019). The K-T mass extinction was due to asteroid which smashed into the Yucatan Peninsula and created the Chicxulub crater.

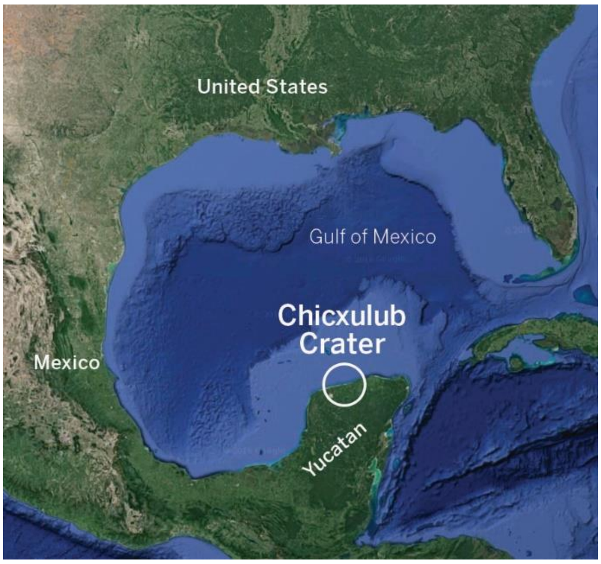

Figure 6. The exact location of Chicxulub Crater at the Yucatan Peninsula. From Texas Geosciences, 2016.

This formed a nuclear dust cloud, which cut out sunlight. Plants were no longer able to photosynthesize, they slowly died and with them also animals which fed on them. However, there is another theory which suggest that the mass extinction was due to climate change, as the consequence of the eruption of the Deccan Traps LIP (India). The evidence of the meteorite hitting is based on measured values of the element iridium (Ir). The iridium deposits significantly increased during K-T boundary and we can find huge amounts of this element in the clay layer. This evidence is highly reliable, because we know that the iridium is not a part of the Earth's crust, but sits deep in the core, and there is no way even with the deepest volcanism, to get to the core of the Earth. The interesting fact is, that the K/T boundary ejecta layer is a "dual layer". The lower layer is filled with tektites, whereas the upper layer is iridium-rich with shocked quartz. This double layering occurs as the consequence of different densities, where the tektites are heavy, so descend quicker from the atmosphere than the iridium, which is much less dense, so takes longer to fall (European Geosciences union, 2012). The mass extinction completed the Mesozoic era, and our current Cenozoic era (66-Present) have been introduced.

The Palaeocene – Eocene Thermal Maximum (PETM)

Soon after the K-Pg extinction, the climates warmed, jungles stretched across the planet and rise of the mammals began. The important concept to consider is PETM, which significantly influenced Cenozoic climate. The hyperthermal is a short-term phase, with an onset of 1 000-100 000 years of rapid global warming, caused by natural events (Dunne, 2017) (see fig.7). They represent natural examples of abrupt climate change and can give us valuable insights into the negative and positive carbon cycle feedbacks. All hyperthermal do not have the same initiating cause, and it is still questionable, what is the most likely driver for their onset (Foster et al.).

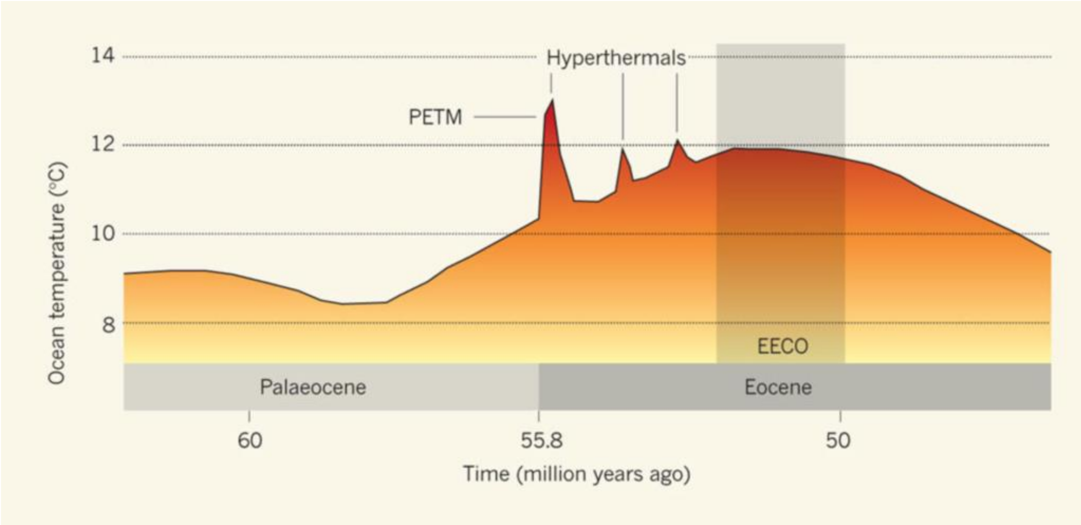

Figure 7. The impact on ocean temperature across Palaeocene-Eocene Thermal Maximum (PETM) and two smaller hyperthermal events. The Early Eocene Climatic Optimum (EECO) represents 12°C. From Svensen, 2012.

The hyperthermals atmospheric recovery usually follow the same pattern, and The Foster et al. (2018) suggest three negative feedback loops, which lead to depletion of atmospheric C: "*1. Carbon dissolved in ocean is neutralised by $CaCo_3$, 2. enhanced temperatures increase silicate weathering, which draws down CO2 on 10 000 years to 1 Myr time scales and 3. Feedback that operates in response to rapid warming related to enhanced organic carbon burial."* The PETM shares the same scenario with the Anthropocene climate change, so as our climate continues to warm, the seasonal climate and hydrological cycle will become more extreme. The extremes amplify and the wet regions will get wetter and dry even drier. During the PETM, the rates of carbon addition were on average 10 000 times slower than modern rates. It is comparable to the average anthropogenic rate over last 150 years. It is useful to study hyperthermal events, as they can tell us unique information about how Earth's climate system behaves with addition of carbon, but they are not direct analogies of the Anthropocene climate change (Foster et al., 2018).

Human origins

The first apes evolved between 8 and 6 million years ago. The "cradle of humankind" is South Africa, where explorations have uncovered over 1 500 fossils representing at least 18 individuals. Moreover, the Great Rift Valley system of East Africa is supposed to be closely connected with the human evolution. As vegetation shifted from dense forest to savannas in east Africa, it gave our ancestors impulse to descend from the trees, and explore new opportunities over open ground, and develop social skills needed for survival (Hogenboom, 2014).

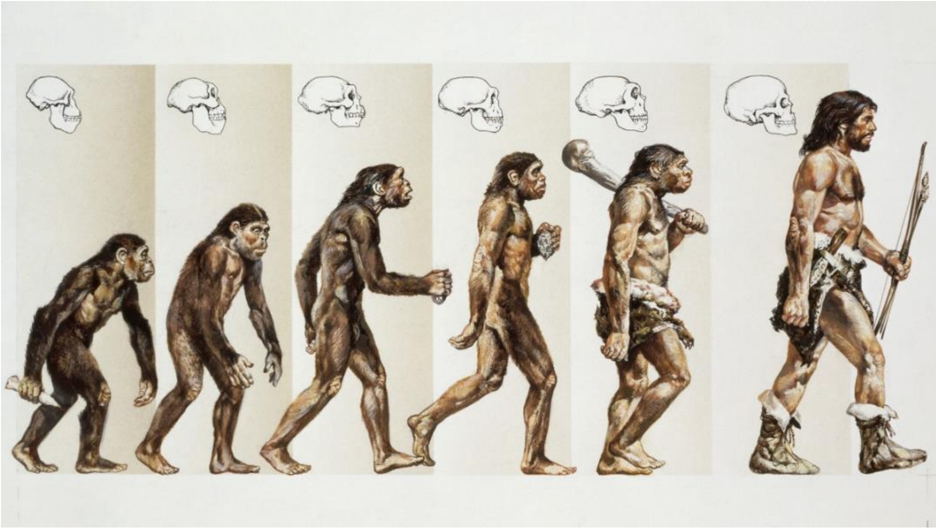

Figure 8. Image illustrates the human lineage through time, from chimpanzee to *Homo Sapiens*, and their development of skull. From Little, B., 2020.

The most well-known hominid skeleton in the world is "Lucy". It is a partial skeleton of a 3.2-million-year-old *Australopithecus Afarensis* from the East Africa. However, the first *Australopithecus* ever discovered is "the Taung Child". It is a fossilised skull of a young child, who lived about 2.8 million years ago in Taung, South Africa. Through time, our body proportions have changed, our jaws and teeth have become smaller, as we no longer need large canines for eating and tearing food. When we moved from trees down, and started to walk, our pelvis developed, and our brain become bigger and smarter to outthink our enemies, as it was not possible to outcompete animals such as mammoths or sabre-toothed cats by strength (see fig.8) (Galway-Witham, 2019). The earliest tool-using human ancestor was *Homo Habilis*, meaning skilful. These toolkits include hammerstones, stone cores, and sharp stone flakes (Smithsonian Institution, date unknown). There are many theories about which hominids were the first to walk upright, but probably a species called *Australopithecus Afarensis*, or our more recent ancestor *Homo Erectus*. The prehistoric caves such as Rouffignac, Font du Gaume, and Lascaux represent valuable artistic expressions of prehistoric fauna, and what our ancestors were hunting and eating. So far, 224 animal representations and 4 human figures have been registered (McKie, 2013).

The Anthropocene

The Anthropocene epoch is unofficial, as it does not appear on the latest version of the International Chronostratigraphic Chart. It is a controversial thing, as researchers need to find a representative marker in the rock record. The potential signal in the rocks to define the onset should be significantly higher values of radioactivity, because of nuclear experiments (Brown, date unknown).

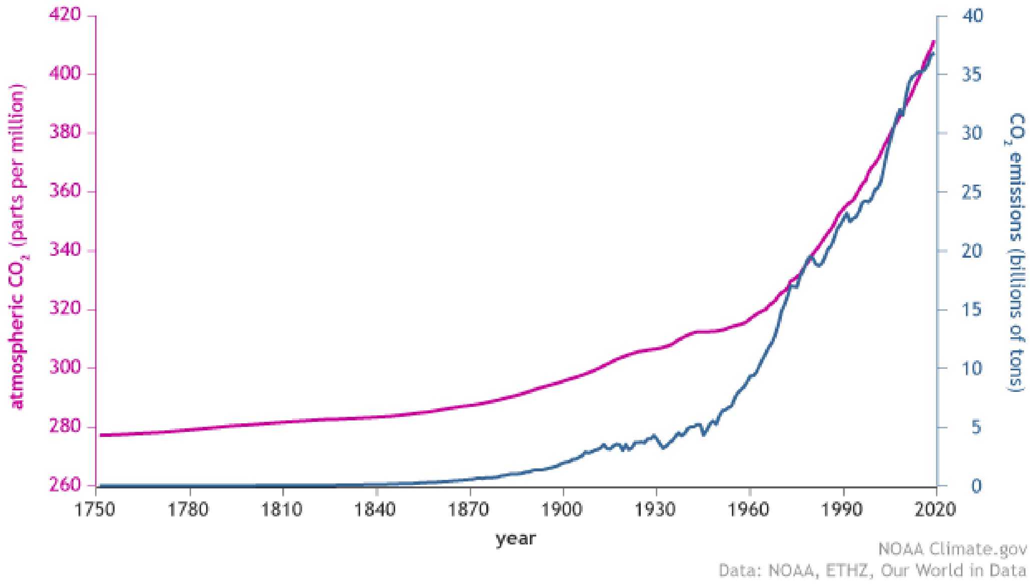

Figure 9. The pink curve represents the atmospheric CO_2 (parts per million), whereas the blue line represents CO_2 emission in billions of tons. Adapted from Diamond, H., date unknown.

The values of atmospheric CO_2 and CO_2 emissions are rising since the start of the Industrial Revolution in 1750 (see fig.9). At the beginning, the emissions rose slowly with the rate about 5 billion tons a year in the mid- 20th century, but by the end of century the rate sharply increased to more than 35 billion tons per year. In the year 2018, the carbon was emitted from different sources in these values: 14.48 billion tonnes from coal-fired stations, 12.27 billion ton from oil consumption, and 7.49 billion ton from gas consumption (Ritchie et al., date unknown). Unfortunately, this is just a fraction of total CO_2 production per one year. The Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to below 2°C, and simultaneously pursuing effort to limit it to 1.5°C via different eco-ways. The agreement stresses the importance of offering help developing nations by developed countries in their climate mitigation (Denchak, 2020). It is debatable, if really each country which signed the agreement, is trying to cut its carbon footprint.

Our planet survived a lot, it was often on the verge of its strength, but it always managed to find a solution and give birth to a new and even more sophisticated life. We must realize that this planet is for us everything, but from the view of the universe, it is always the same tiny planet with no special importance. Many times, it was our Earth that saved humanity by providing suitable resources. Unfortunately, humans are now in a situation when we must save our planet. The only way how to achieve this, is seek for sustainable resources, invented new technological processes, but more importantly, do not go with the flow of contemporary fast and over-consuming trend.

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