Habitable planet Earth: We owe everything to microbes!

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1. Introduction

"Life would not long remain possible in the absence of microbes" a quote of the famous scientist Louis Pasteur [16]. I even want to go further and claim that "A habitable planet can only exists, or become habitable, with the help of microbes". To strengthen this claim, let us just take a look at planet Earth.

2. The formation of planet Earth and a possible start of life

Four and half billion years ago a lifeless planet, Earth, was formed by a series of hostile astrophysical forces and events [10, 12, 20]. A sizeable quantity of water was most probably already present in the primary materials that formed Earth [7]. As a consequence chemical forces helped shaping our planet right from the start [4]. Rocks weathered and eroded, minerals repeatedly dissolved and precipitated. Below the surface of the water of the first oceans, hundreds of thousands of different types of hydrothermal vents generated a multitude of extreme physico-chemical conditions. Immense pressure fluctuations and temperature gradients, cycled water from a super critical liquid in the proximity of molten magma, to a very cold solution, only a few meters away from the chimney of the hydrothermal vent. These extreme conditions lasted for millions of years and may have turned substantial amounts of simple inorganic molecules, like H_2, H_2O, CO_2, N_2, NH_3, CN, H_2S, PO_4^{2-} and CO, ubiquitous present in the Universe and on the early Earth, into life essential–, biochemical– and organo–minerals. Less than a billion years after the formation of the Earth, the variety and concentration of the chemical building blocks of life were divers and high enough, to possibly allow the abiotic formation of the very first living cellular structures, protocells. The thermal cycling conditions in the vicinity of hydrothermal vents, resembling conditions generated in modern PCR-machines, probably stimulated the biochemical polymerase reactions of biochemical molecules like peptides and RNA. Clays may very well have been the key to the formation of the first protocells, as vesicle formation and RNA polymerization can be catalysed by montmorillonite [5]. The membranes of protocells were most likely very simple structures, possibly entirely composed out of fatty acids that are, in contrast with the complex phospholipids and phospholipid acids of current cell membranes, highly permeable and could very easily split up or fuse with one and another [2] [21]. This property is probably one of the reasons why first life was dominated by processes like, endosymbiosis and lateral gene transfer, horizontal evolution, thereby adding and mixing the information carried by internal present polynucleotides. The protocells evolved first into prokaryotic Bacteria and almost simultaneously into Archaea. Later on, endosymbiosis probably generated the first Eukaryotic cells.

3. Historical geological impact of microbes

The first major impact of life on Earth was a microbial induced climate change. A massive production and release of methane most probably forced hydrogen away from Earth's surface into open space. This process might have preceded the first great oxygenation event that happened about 2.33 billion years ago, caused by oxygen producing photosynthetic cyanobacteria [11]. An event that irreversible changed Earth's geochemistry [13]. A second global microbial impact that happened about 600 millions years ago, was the oxygenation of Earth's atmosphere. The ice cap that was formed during the biggest ice age ever encountered by our planet, "Snowball Earth", melted and caused nutrient rich water to flood into the oceans, that triggered a second more massive outburst of oxygen producing photosynthetic cyanobacteria. The result was an exponential increase of the oxygen concentration of Earth's atmosphere. The impact of microbes could also be devastating. Earth's greatest mass extinction event, the End-Permian Extinction event, colloquially known as the Great Dying event, is linked to an outburst of methanogens [17]. This End-Permian Extinction event occurred about 252 million years ago, and the bio-methane release lead to the extinction of 96% of all marine species [1] and 70% of the terrestrial vertebrate species [18]. Today, on the current Earth, microbes are very often integrally involved in numerous geo(chemical) cycling of elements. Not only natural processes but also world wide anthropogenic activities, like mining, often require and obtain the help of microbes to avoid life threatening element accumulation.

4. Endosymbiosis: How Eukaryotes were formed

Since the work of Lynn Margulis, we know that we owe our very existence to microbes [14]. Endosymbiosis is the process that created the first eukaryotic cells, which ultimately evolved to all known multicellular species, including us humans. Two of the most important endosymbiotic evidences we know of today, are the mitochondria and chloroplasts. The proto-mitochondrion was probably very closely related to bacteria belonging to the class of the alpha-proteobacteria, the genus *Rickettsia* [8]. Genetics of the chloroplasts revealed that they belong to the phylum of the cyanobacteria [15].

5. Relationship of microbes and Eukaryotes

Almost all eukaryotic species, plants and animals, need microbes for survival. For instance, the origin of 90% of the nitrogen present in plants, could only have been assimilated with the help of microbes. Also, higher animals and even humans harbour a huge amount of microbes. A revised and recent estimate suggests that the human body contains approximately the same number of bacterial – and human cells [19]. This symbiosis with microbes is necessary for the host as microbes digest food components into essential and bioavailable nutrients and educate our immune system for a better protection against pathogens. More and more evidence is becoming available proving that the impact of these symbiotic bacteria extends much further then digestion or teaching the immune system alone. There is strong indication that brain development and diseases, like autism and obesity, are linked to the function and diversity of the human microbiome [3], [6]. A recent new discipline of biology, the gnotobiology, aims to study eukaryotic life without microbes. Although, gnotobiology succeeded in generating germ-free animals, the consequences of eukaryotic live without microbes are not yet fully understood [9].

6. Conclusion

This paper illustrates the tremendous impact microbes have on the formation of habitable planet. It also shows the historical and unbreakable relationship between Eukaryotes and symbiotic microbes.

7. References

[1] Benton, M.J., When Life Nearly Died: The Greatest Mass Extinction of All Time. Thames & Hudson, 2005.

[2] Black, R.A., Blosser, M.C., A Self-Assembled Aggregate Composed of a Fatty Acid Membrane and the Building Blocks of Biological Polymers Provides a First Step in the Emergence of Protocells. Life (Basel) 6, 2016

[3] Chen, Z., Guo, L., Zhang, et al., Incorporation of therapeutically modified bacteria into gut microbiota inhibits obesity. J Clin Invest 124, 3391-3406, 2014

[4] Cilek, V., Earth System: History and Natural Variability. Eolss Publishers, 2009.

[5] Cole, L.A., Biology of Life: Biochemistry, Physiology and Philosophy. Elsevier Science, 2016.

[6] Diaz Heijtz, R., Wang, S., Anuar, et al., Normal gut microbiota modulates brain development and behavior. Proc Natl Acad Sci U S A 108, 3047-3052, 2011.

[7] Drake, M.J., Origin of water in the terrestrial planets. Meteorit Planet Sci 40, 519-527, 2005.

[8] Emelyanov, V.V., Mitochondrial connection to the origin of the eukaryotic cell. Eur J Biochem 270, 1599-1618, 2003.

[9] Gilbert, J.A., Neufeld, J.D., Life in a World without Microbes. PLoS Biol 12, 3, 2014.

[10] Gomes, R., Levison, H.F., Tsiganis, K., Morbidelli, A., Origin of the cataclysmic Late Heavy Bombardment period of the terrestrial planets. Nature 435, 466-469, 2005.

[11] Izon, G., Zerkle, A.L., Williford, K.H., et al., Biological regulation of atmospheric chemistry en route to planetary oxygenation. Proc Natl Acad Sci U S A 114, E2571-E2579, 2017.

[12] Jacobson, S.A., Walsh, K.J., Earth and Terrestrial Planet Formation, The Early Earth. John Wiley & Sons, Inc, pp. 49-70, 2015.

[13] Luo, G., Ono, S., Beukes, N.J., Wang, D.T., Xie, S., Summons, R.E., Rapid oxygenation of Earth's atmosphere 2.33 billion years ago. Sci Adv 2, e1600134, 2016.

[14] Margulis, L., Fester, R., Symbiosis as a Source of Evolutionary Innovation: Speciation and Morphogenesis. MIT Press, 1991.

[15] Mereschkowsky, C., Über Natur und Ursprung der Chromatophoren im Pflanzenreiche. Biol Centralbl 25, 12, 1905.

[16] Pasteur, L., Observation relative à la note précédente de M. Duclaux. Compte Rendus Ge Acad Sci 100, 1885.

[17] Rothman, D.H., Fournier, G.P., French, K.L., et al., Methanogenic burst in the end-Permian carbon cycle. Proc Natl Acad Sci U S A 111, 5462-5467, 2014.

[18] Sahney, S., Benton, M.J., Recovery from the most profound mass extinction of all time. Proc Biol Sci 275, 759-765, 2008.

[19] Sender, R., Fuchs, S., Milo, R., Revised Estimates for the Number of Human and Bacteria Cells in the Body. PLoS Biol 14, e1002533, 2016.

[20] Young, E.D., Kohl, I.E., Warren, P.H., Rubie, D.C., Jacobson, S.A., Morbidelli, A., Oxygen isotopic evidence for vigorous mixing during the Moon-forming giant impact. Science 351, 493-496, 2016.

Short Summary

We owe everything to microbes: our oxygenated world, a sequence of beneficial climate changes for oxygen breathing mammalians, a habitable Earth, our own eukaryotic existence by well organized endosymbiosis processes, our daily live and our health. Maintaining this chronology and relationship with microbes might be essential when envisaging exoplanet colonisation.