*Prompt: “Microbial life can easily live without us; we, however, cannot survive without the global catalysis and environmental it provides.” Do you agree or disagree with this statement? Answer the question using specific reference to your reading discussions and content from evidence worksheets and problem sets.*

As microbial life has existed for at least 3.5 billion years, based on undisputed evidence, they have inhabited the Earth for a significant portion of its 4.6-billion year life, shaping many biogeochemical processes over relatively long time scales (1). Microbes cannot be seen with the naked eye, but their sheer abundance, spanning four orders of magnitude from 1026 to 1030 cells in a given marine or terrestrial habitat, means that they contribute significantly to the large scale biogeochemical cycles on Earth, some of which still exists today in some form (2). With the large abundance in microbial cells in these habitats also comes great genetic diversity, which has evolved as genes are conserved and disappear over the billions of years that microbes have existed, as changes in the Earth’s systems happen over time. Humans have inhabited the Earth at a point in time that is relatively very recent on the geologic time scale compared to the emergence of microbes, with the large-scale changes in the Earth’s systems coming at an even more recent time of around 200 years ago, in a period that has been labelled as the “Anthropocene” (3). As microbes have continuously shaped the biogeochemical landscape of the Earth in the past 3.5 billion years, and still play an integral role in the biogeochemical pathways that still exist and effect the Earth’s atmosphere, land and oceans, it could be said that us humans rely on microbes significantly more than microbes rely on us for survival.

Prior the existence of microbial life appearing about 3.5 billion years ago, the Earth was constantly bombarded by meteorites, which ejects rocks into the atmosphere, and vaporizes the water (1). The resulting water vapour created a greenhouse effect on Earth, keeping the temperatures high at a time when the sun was about 25-30% dimmer, with a water temperature of around 100 degrees C (1). Although this temperature is too high for most forms of life to live, there could possibly be thermophilic prokaryotes that could survive under these conditions. Furthermore, there could be tectonic activity as well, ejecting magma that could acidify the already hot water, further making it more uninhabitable by most organisms (1). These organisms that survive were integral in shaping the biogeochemical landscape of the early Earth through their redox reactions and have laid the ground work for future shifts changes in the Earth’s atmosphere and landscape.

Based on evidence from the Isua Belt in Greenland, the atmosphere could have also consisted of carbon dioxide (CO2) based on the inorganic carbon (carbonate) being formed on water-lain sedimentary rocks (1). Given that the Sun was dimmer, meaning less light reaching the Earth and therefore, cooler temperatures, the potent greenhouse gas produced by methanogenic prokaryotes (methanogens) could have trapped enough heat to support life (4). The anoxic CO2 atmosphere provided the inorganic carbon to be reduced by hydrogen gas (H2), yielding methane, as catalyzed by enzymes produced by methanogens (4). However, the rise in temperature from the greenhouse effect of methane cannot happen indefinitely as there is a negative feedback mechanism, where by an organic haze, produced when methane far exceeds CO2 in the atmosphere (4). This reduces the sunlight that gets through to the Earth’s surface, and can cool down the Earth. This CO2 could also be used by 1,5-bisphosphate carboxylase-oxygenase (Rubisco), an enzyme used to fix inorganic carbon, specifically CO2 in a process known as anoxygenic photosynthesis (1, 5). These processes that take up inorganic carbon leave behind carbonate, which is precipitated out of solution.

The gradual loss of H2 lead to a less reducing environment, allowing for the proliferation of a more oxidizing atmosphere as less methane is produced and reverse reaction of methanogenesis is favoured, resulting in an increase in CO2 (4). The evolution of cyanobacteria coincided with this around 2.7 billion years ago, where the oxygen content of the atmosphere increased (1). As more oxygen appeared, so did more complex eukaryotes, which have incorporated their prokaryotic symbionts as mitochondria and chloroplasts (4-Kasting). About 500 million years after, the Great Oxygenation Event happened, drastically increasing the oxygen content in the atmosphere to one that is similar to today’s atmosphere (4). As more CO2 is now in the atmosphere, Rubisco became more prevalent in the fixation of inorganic carbon and due to it’s preference to take up CO2, there is now more oxygen relative to CO2. This photosynthetic pathway has survived for a couple billion years and the microbial fraction of photosynthesis accounts for a sizeable proportion of the oxygen produced, especially from marine sources (4).

The supply of fixed nitrogen has also changed significantly since the Earth was formed, where nitrogen gas (N2) was initially fixed by relatively slow processes such as lightning fixation (1). As microbes started existing, they started deriving energy from redox reactions, providing selective pressure in favour of those organisms that could fix the very abundant N2 using reducing substrates under anaerobic conditions at the time (5). However, the Earth became more oxygenated over time and the enzyme involved, nitrogenase, is inhibited (5). This then led to greater selective pressure on nitrogen-fixing cyanobacteria, causing them to evolve ways to protect nitrogenase from oxygen (1). This fixed nitrogen in the form of nitrate (NO3-) or ammonium (NH4+) can be used by organisms to be incorporated into nucleic acids and proteins, which are essential for growth and life.

However, as this is a cycle, there are also processes that result in the loss of fixed nitrogen. as nitrogen gas (N2) or nitrous oxide (N2O), whether it be through denitrification, or annamox catalyzed by microbes (5). As these processes are anaerobic, they usually happen in the absence of oxygen, they happen in zones in the ocean called Oxygen Minimum Zones (OMZs) (6). This causes the fixed nitrogen to be lost to the atmosphere as N2. Meanwhile, the N2O released into the atmosphere acts as a greenhouse gas, further intensifying climate change. This leads to further increases in the atmospheric CO2 and temperature, reducing the solubility of oxygen and therefore dissolved oxygen concentration in the ocean, causing the expansion of these OMZs. As more fixed nitrogen is lost, the phytoplankton responsible for a significant portion of the primary production in the ocean and world will become even more nutrient limited. As there is less oxygen from primary productivity, this further exacerbates climate change in the process (7). It is unsure if these processes have evolved over time, but since these processes must start from a more oxidized form of nitrogen, such as NO3- or nitrite (NO2-), they would have evolved after the Earth was significantly more oxygenated 2.3 billion years ago (5).

Microbial cells are microscopic in size and only contain a relatively very small amount of carbon in each cell, but they are very abundant throughout many different habitats on Earth. As microbial abundance is high, there are more individuals that participate in these biogeochemical processes, significantly increasing the scale and output of these processes for them to viable over larger spaces and time scales. With larger spaces, also comes a wide variety of environments such as soil and the oceans that can vary in microbial abundance with different conditions that creates different roles and pathways. Marine environments typically have around 1.5 x 1029 prokaryotic cells and typically contribute a little over 50% of the world’s primary productivity at 51 Pg of carbon per year, largely due to subsurface photosynthetic and heterotrophic prokaryotes (2). Soil has almost double the number of prokaryotic cells at 2.6 x 1029, and they contribute to the break down of organic matter through decomposition, recycling nutrients for other living organisms to grow off (2).

Although the subsurface microbial abundance (both marine and terrestrial subsurface) is hard to measure given the difficulty with collecting samples, it has been estimated that the subsurface microbial abundance is of a magnitude greater than both marine and soil prokaryotes combined and these are mostly anaerobic bacteria that live in the sediments under the sea or terrestrial surface that reduce inorganic carbon to methane (CH4) or sulfate to hydrogen sulfide (H2S) (2). These pathways have evolved from several billion years ago when methanogenesis was common in the anaerobic atmosphere, and appears to have been conserved (1).

Given that microbes have been on Earth for the past 3.5 billion years or longer, today’s metabolic pathways that microbes partake in have survived the several billions of years of evolutionary pressures that arise along the way in a changing biogeochemical landscape. These evolutionary pressures have come in the way of larger scale changes, like the Great Oxygenation Event, as well as smaller scale perturbations that both contribute to refining these microbial pathways through selection by horizontal and vertical gene transfer, making microbes “guardians of metabolism” (8).

On the other hand, the modern human having only been around for around 200,000 years (3, 9), a relatively very small amount of time on the geologic time scale. We have largely depended on microbes to shape the Earth the way it has for the past several billion years, including the biogeochemical cycles and landscape that we take for granted through the microbial control of electron flow between reducing (8). Although microbes do play a role in climate change, it largely depends on anthropogenic activities that release increasingly large amounts of CO2 into the atmosphere that the biogeochemical cycling of microbes could partially mitigate through photosynthesis and increased nutrient availability. However, it is the increase in CO2 also diminishes the ability of microbes to cycle the nutrients that photosynthetic organisms need to produce oxygen and biomass.

In the past 200 years, humans have accelerated the biogeochemical changes on Earth, starting with the Industrial Revolution. This time period is referred to as the “Anthropocene” and it corresponds to a time where atmospheric CO2 and other greenhouse gases have risen significantly due to anthropogenic activities through the burning of fossil fuels and deforestation (9). During this time, the human population also increased significantly, and therefore resource usage (3). With this drastic increase in CO2 levels over a relatively short time scale, the carbon cycle has been disrupted and the microbes probably have not had enough time to fully refine their pathways to mitigate the effects of this.

Although humans have developed a process to fix nitrogen industrially, called the Haber-Bosch Process, this only provides fertilizer to agriculture in the form of ammonium, which can be nitrified by bacteria into NO3­- (5). Although this process does not require the catalysis of microbes, the downstream effects in the oceans do involve them, causing eutrophication from the nitrate that reaches the oceans and creating larger OMZs in the oceans due to higher decomposition of more phytoplankton (5). This reduces the amount of fixed nitrogen available due to the imbalance between nitrification and denitrification in these OMZs and would end up reducing primary production due to nitrogen limitation. Furthermore, N2O is also produced in the process and is released into the atmosphere, acting as a greenhouse gas that can worsen the effects of climate change (5).

Overall, microbes have a sizeable impact on the biogeochemical landscape of the Earth due to the relatively long time they have inhabited and shaped the Earth, as well as their high abundances in different environments coming together to increase the scale of their pathways. They directly influence the nutrient availability for other organisms such as humans, through nitrogen fixation and photosynthesis in pathways that have been refined over their several billion years of existence. As humans started appearing relatively recently on the geological time scale at 200,000 years ago (9), combined with the fact that we have only been changing the biogeochemical landscape for the past 200 years (3), microbes could live without us given their age, continuing with their biogeochemical processes as normal. However, given the rate at which technological advances are occurring in the Anthropocene, could there some way we could greatly reduce our reliance on microbes in the future and shape the biogeochemical landscape of the Earth over a shorter, more viable time scale given that a lot of processes catalyzed by microbes are of a larger scale?

**References:**

1. Nisbet EG, Sleep NH. 2001. The habitat and nature of early life. Nature. 409(6823):1083-1091. [10.1038/35059210](http://dx.doi.org/10.1038/35059210)
2. Whitman WB, Coleman DC, Wiebe WJ. 1998. Prokaryotes: The unseen majority. Proc Natl Acad Sci USA. 95(12):6578-6583.
3. Waters CN, Zalasiewicz J, Summerhayes C, Barnosky AD, Poirier C, Gałuszka A, Cearreta A, Edgeworth M, Ellis EC, Ellis M, Jeandel C, Leinfelder R, McNeill JR, Richter DD, Steffen W, Syvitski J, Vidas D, Wagreich M, Williams M, An Z, Grinevald J, Odada E, Oreskes N, Wolfe AP. 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene.
4. Kasting JF, Siefert JL. 2003. Life and the Evolution of the Earth’s Atmosphere. Science. 296(5570):1066-1068.
5. Canfield DE, Glazer AN, Falkowski PG. 2010. The Evolution and Future of Earth’s Nitrogen Cycle. Science. 330(6001):192-196. [10.1126/science.1186120](http://dx.doi.org/10.1126/science.1186120)
6. Lam P, Kuypers MMM. 2011. Microbial Nitrogen Cycling Processes in Oxygen Minimum Zones. Ann Rev Mar Sci. 3(1):317-345. [10.1146/annurev-marine-120709-142814](http://dx.doi.org/10.1146/annurev-marine-120709-142814)
7. Stramma L, Visbeck M, Brandt P, Tanhua T, Wallace D. 2009. Deoxygenation in the oxygen minimum zone of the eastern tropical North Atlantic. Geophys Res Lett. 36(20):L20607. [10.1029/2009GL039593](http://dx.doi.org/10.1029/2009GL039593)
8. Falkowski PG, Fenchel T, Delong EF. 2008. The Microbial Engines That Drive Earth's Biogeochemical Cycles. Science. 320(5879):1034-1039. [10.1126/science.1153213](https://doi.org/10.1126/science.1153213)
9. Shrag DP.2012. Geobiology of the Anthropocene, p 425-436. *In* Knoll AH, Canfield DE, Konhauser (ed), Fundamentals of Geobiology, Blackwell Publishing Ltd., Hoboken, New Jersey, USA.