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THE EARTH AND ITS RESOURCES
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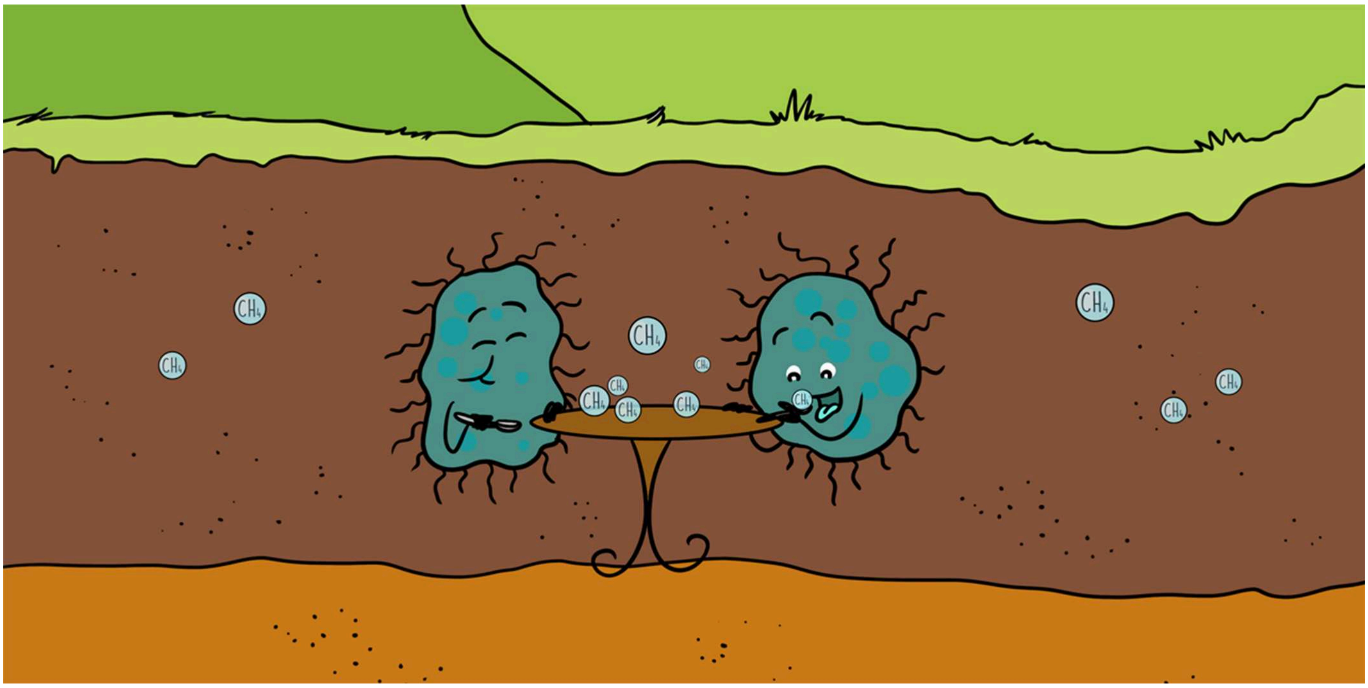

THE ROLE OF MICROORGANISMS IN THE METHANE CYCLE

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YOUNG REVIEWER:

ADAM
AGE: 13

Have you heard about methane gas? Maybe the word methane is not familiar to you, but in fact, this gas is widely found in our daily lives, in our atmosphere, and in the solar system. Methane is a gas that is naturally produced in all kinds of environments, and it comes from the breakdown of organic (formerly living) materials. Methane gas is effective at trapping heat and it also burns very easily. So, methane is one of the most important fuels for humans. Additionally, the methane in the atmosphere helps regulate the climate on Earth. However, the amount of methane in the atmosphere has been steadily increasing for the past 200 years, which concerns the scientific community. Surprisingly, recent studies have indicated that levels of methane are regulated by tiny microbes. In this article, we encourage you to learn about the methane cycle, the microbes

that make and eat methane, and why more research is needed on this gas.

WHAT IS METHANE AND WHY IS IT IMPORTANT TO HUMANS?

Methane is a simple compound, formed by one atom of carbon and four atoms of hydrogen (CH_4). Methane exists as a gas in the environment and is one of the most important fossil fuels for human society. When the methane molecule breaks down, it produces heat. Because of this property, some of our homes are fueled by methane gas, which is used to cook, heat our water, and fuel our furnaces and fireplaces. Methane can also be collected and transformed into electricity, serving as a natural energy source. Methane is also found in animal burps and farts (yes, you read correctly, farts!). Methane is one of the most abundant gases produced in the digestive tract as food is broken down. To summarize, methane is a common atmospheric gas. Remarkably, methane production and breakdown on Earth are processes driven mainly by microorganisms.

MICROBES/ MICROORGANISMS

Very small forms of life including bacteria, fungi, and some diminutive algae.

ORGANIC MATTER

All cells and substances made by living organisms, including living and dead animals and plants.

Microorganisms (microbes) are the smallest life forms known, invisible to unaided eyes. They are found in all habitats and ecosystems on Earth, in our daily surroundings as well as the most hostile and extreme habitats. Although they are extremely small, the diversity and abundance of microorganisms are enormous and remarkable. Recent estimates predict that 90–99% of the microbial species on Earth are still undiscovered [1]. Microbes are the major players in the recycling of **organic matter** and important nutrients on Earth. They also regulate the production and breakdown of some atmospheric gases, including carbon dioxide, the oxygen we breathe, and of course, methane.

Methane has drawn the attention of the scientific community because its concentration in the atmosphere has almost tripled, since the Industrial Revolution began in the eighteenth century. Importantly, some studies indicate that these recent increases in atmospheric methane are happening more quickly as compared to geological time scales. Suggesting the influence of human activities associated to methane emissions. The problem with increased methane in the atmosphere is that, methane gas has the ability to trap the heat energy from the Sun and prevent this heat energy from returning to space, resulting in something known as the green-house effect. This heat-trapping capacity is very important, because it helps the Earth to stay warm enough to sustain life [2]. However, too much methane accumulation impacts the climate and contributes to global warming. Today, the methane cycle is a major research topic, since we need a deeper understanding of where all the methane on earth comes from and how it is transformed.

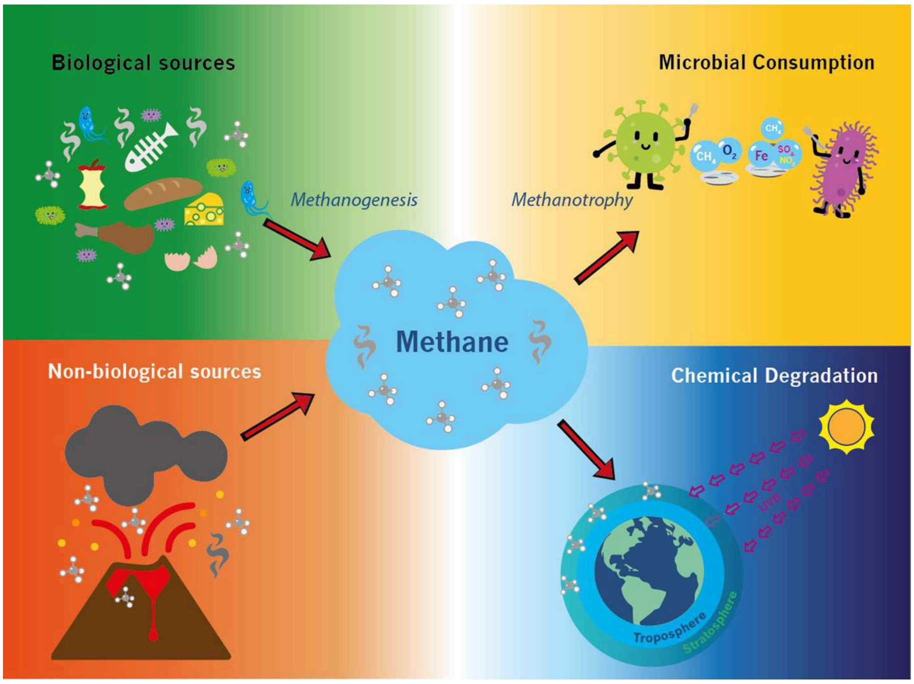

Figure 1

Figure 1

Diagram of the methane cycle showing sources of methane production and methane breakdown on Earth.

METHANE PRODUCTION IN ECOSYSTEMS

There are two known forms of methane production on Earth, called non-biological and biological methane sources. Non-biological methane production occurs without the participation of living organisms. Non-biological methane can be released by volcanoes or formed underground, under high pressures and temperatures. These geological processes normally involve the transformation of rocks that are melted with heat and water (Figure 1). Biological methane production is only done by microorganisms. The current estimates suggest that 90–95% of the methane released into the atmosphere has a biological origin and is produced exclusively as a result of microbial activity!

The process of biological methane production is called *methanogenesis*. The best studied methane-producing microorganisms are named methanogenic archaea or simply *methanogens*. Methanogens have a complex **metabolism** that allows them to create methane as they produce the energy they need to survive. Interestingly, atmospheric oxygen which we need to breath and obtain energy, is toxic to some methanogens, so these microorganisms are generally found in areas where oxygen is limited or absent, such as underground, in the sediments at the bottom of lakes, lagoons, wetlands, and oceans, and even inside the intestines of all types of animals, including worms, termites, cows, and humans.

METABOLISM

All the chemical reactions needed to keep a cell or organism alive. Metabolism refers to how living things make and break down nutrients.

Methanogenesis is the terminal step in the food chain that occurs in the absence of atmospheric oxygen. This gas is produced as a consequence of the total degradation of organic matter, where complex molecules are degraded into their most basic compounds and then are converted to methane by methanogens. This means that in all kinds of environments, the remains of dead organisms, such as plants and animals are slowly decomposed by microbes (Figure 1). This allows the return of the nutrients to the food chain, and the last step involves methane production [3].

ONCE METHANE IS PRODUCED, HOW IS IT REMOVED FROM THE ENVIRONMENT?

Removal of methane from the environment also occurs by both non-biological and biological methods. The main way that atmospheric methane is removed occurs by a non-biological method, which takes place in the zones of the atmosphere known as the troposphere and the stratosphere. These are the lowest layers of Earth's atmosphere, from 0 to 10 km and 10 to 50 km above sea level, respectively. In these zones, methane is broken down by chemical reactions driven by ultraviolet light from the sun. It is calculated that more than 90% of the methane in the atmosphere is broken down through this process (Figure 1).

Biological removal of methane on Earth, as incredible as it seems, is exclusively performed by microbes!

There are some microorganisms that "eat" methane to get energy. This process is named *methano-trophy* and the microbes that carry out this process are called *methanotrophs*. "*Trophos*" means "one who is nourished from." Methanotrophs inhabit ecosystems where methane is produced, mainly under the surface of soil or sediments. Because these methanotrophs live under the soil, atmospheric methane does not come into contact with those organisms. Since the methanotrophs cannot break down the methane in the atmosphere, it accumulates. However, a very interesting phenomenon happens here. Somehow, methane produced in soils gets trapped between the soil particles and is actually there where methanotrophs take the gas for its consumption. This prevents methane from being released from the soil into the atmosphere, significantly impacting the atmospheric methane budget. As an example, it has been estimated that ∼40–60% of the methane produced in wetland habitats is consumed by microbes before it can escape into the atmosphere. This means that methanotrophs are very important in soils, to prevent the release of greenhouse gases into the atmosphere where they can contribute to global warming.

Methanotrophs can eat methane both in the presence and in the absence of atmospheric oxygen. Methanotrophs that can tolerate oxygen, actually use it in the process of breaking down methane. Regularly, these microbes are found in soils where oxygen starts to

Figure 2

If there is methane in other parts of our solar system, could microbes be there, too?

Figure 2

be absent because it cannot penetrate the compressed soil-particles. These oxygen minimum zones contain most of the methanotrophs and are found in all kinds of ecosystems on Earth.

Methanotrophs that do not use oxygen to break down methane, prefer to use other exotic sources of energy, accompanying the methane with some fraction of the organic matter, or with sulfur, nitrogen, and even some metals, such as iron or manganese. Here, methane is the big meal and the other elements are the complements. Interestingly, this process was firstly hypothesized by geo-chemical evidence, but remained elusive until the early 2000s, because it is extremely difficult to grow these microbes in the lab to study them.

METHANE BEYOND EARTH

Here on Earth, microorganisms play a big role in the recycling of methane. So, we could say that methane is related to the presence of life on our planet. Surprisingly, recent evidence obtained by telescopes and remote artifacts has identified methane in other places in our solar system, including on Mars and on Saturn's icy moons Titan and Enceladus [4]. This is very exciting and makes us wonder if there are some kinds of microbes in those places that are producing or consuming that methane!

Methane on Mars was first identified with Earth-based telescopes in the early 2000s, and its presence was proven when the Mars rovers Spirit and Opportunity explored that planet (Figure 2). The scientific community has been wondering if this methane originates from biological processes, but all the scientific evidence collected so far indicates that this methane comes from non-biological sources. Currently, there is no evidence of biological activity on the surface of Mars, but the research continues, because we know that methane also is a source of energy for some microbial life.

Two spacecraft missions, Cassini-Huygens and Voyager, have been studying Saturn. Both spacecrafts have found evidence of organic molecules, including methane on Saturn's moons, Titan and Enceladus (Figure 2). These moons have a lot of water and ice on their surfaces, probably similar to the polar ice caps on Earth. As strange as it seems, data suggest that both Titan and Enceladus have oceans of liquid methane, ethane, and nitrogen that form lakes and rivers, covered with rocks of water-ice.

Figure 2 illustrates methane gas detected on other planetary bodies of our Solar System.

The exploration of extreme environments on Earth, such the Antarctic ice shelves, can help us understand the origin and evolution of extraterrestrial methane. Currently, scientists are studying how microbes can survive in permanently ice-covered ecosystems, because if we can better understand the methane cycle in extreme environments here on Earth, that would help us to also understand how methanogenesis and methanotrophy could potentially exist on the extreme environments of other planets. It is only natural to predict that methanogens and methanotrophs could be amongst the creatures inhabiting other planetary bodies ... and that we are not alone in the universe, but share it with a wide range of microbes!

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

ADAM, AGE: 13
Hi, my name is Adam. I live with my parents, older brother, dog, fish, and two birds. I am a big fan of Science and History. I like to draw, write, and read. My favorite sport is soccer (or football). I enjoy swimming in the ocean and playing video games.

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