Mars: Could life itself have made the planet uninhabitable?

November 3 2022, by Boris Sauterey

Artist's view of what Mars would have looked like a billion years ago. Credit: Stuart Rankin/Flickr,

Four billion years ago, the solar system was still young. Almost fully formed, its planets were starting to experience asteroid strikes a little less frequently. Our own planet could have become habitable as long as 3.9 billion years ago, but its primitive biosphere was much different than it is today. Life had not yet invented photosynthesis, which some 500 million years later would become its main source of energy. The primordial microbes—the common ancestors to all current life forms on Earth—in our planet's oceans therefore had to survive on another source of energy. They consumed chemicals released from inside the planet through its hydrothermal systems and volcanoes, which built up as gas in the atmosphere.

Some of the oldest life forms in our biosphere were microorganisms known as "hydrogenotrophic methanogens" that particularly benefited from the atmospheric composition of the time. Feeding on the CO_2 (carbon dioxide) and H_2 (dihydrogen) that abounded in the atmosphere (with H_2 representing between 0.01 and 0.1% of the atmospheric composition, compared to the current approximate of 0.00005%), they harnessed enough energy to colonize the surface of our planet's oceans.

In return, they released into the atmosphere large amounts of CH_4 (a.k.a., methane, from which they get their name), a potent greenhouse gas that accumulated and heated up the climate. Since our sun at the time was not as bright as it is today, it may not have been able to maintain temperate conditions on the planet's surface without the intervention of other aspects. As such, thanks to these methanogens, the very emergence of life on Earth may itself have helped ensure our planet's habitability, setting the right conditions for the evolution and complexification of the terrestrial biosphere for the billions of years that followed.

While this is the likeliest explanation for the early development of habitability on Earth, what was it like for the other planets of the solar system, such as our neighbor, the red planet? As we continue to explore Mars, it is becoming ever clearer that similar environmental conditions were developing on its surface at the same time as those that enabled methanogens to flourish in the oceans back on Earth.

Microbial life may have resided within the first four kilometers of Mars's porous crust. There it would have had shelter from the harsh surface conditions (in particular, harmful UV rays), more favorable temperatures compatible with liquid water, and a potentially abundant energy source in the form of atmospheric gases released within the crust.

In light of these aspects, our research group was naturally led to one key question: could the same life-generating events that occurred on Earth have also happened on Mars?

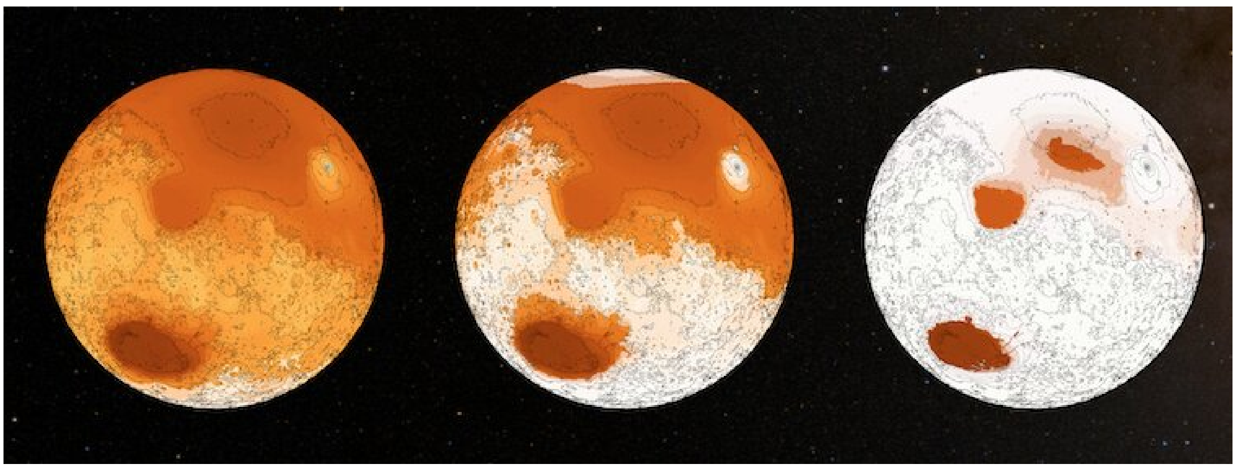
A portrait of Mars from four billion years ago

We set out to answer this question using three models, which culminated in the results recently published in the *Nature Astronomy* science journal. The first model allowed us to estimate how volcanism on Mars's surface, the internal chemistry of its atmosphere, and the emission of certain chemicals into space may have determined the pressure and composition of the planet's atmosphere. The same characteristics would then have determined the nature of the climate.

The second model sought to identify the physical and chemical characteristics of Mars's porous crust—namely, temperature, chemical composition, and the presence of liquid water. These were partly determined by surface conditions (i.e., surface temperature and atmospheric composition) and partly by the planet's internal characteristics (i.e., internal thermal gradient and crust porosity).

These first two models enabled us to simulate the surface and subterranean environments of the young planet Mars. However, many uncertainties remained regarding the main characteristics of this environment (e.g., level of volcanism at the time and crust thermal gradient). To remedy this problem, we used our model to explore a vast number of potential characteristics, which gave rise to a set of scenarios regarding how Mars might have looked some four billion years back.

The third and final model relates to the biology of hypothetical Martian methanogenic microorganisms, based on the theory that they would have been similar to methanogens on Earth, at least in terms of energy needs. Using this model, we could assess the habitability of conditions on Earth for our microbes compared to the underground environmental conditions on Mars, according to each environmental scenario generated by the previous two models.



Topographic maps of Mars approximately 4 billion years ago (with relief indicated in contour lines and orange colour gradient) at various stages (from left to right: initial, intermediate, and final, with the full period spanning between several ten thousand and several hundred thousand years) of evolution of the ice cover on Mars's surface (in white) that occurred as its climate cooled down under the influence of hydrogenotrophic methanogenic microorganisms. Credit: Boris Sauterey, Fourni par l'auteur

Where the given conditions were deemed habitable, the third model evaluated how these microorganisms would have survived under Mars's surface and—alongside the crust and surface models—how this subterranean microbial biosphere would have influenced crust chemical composition, as well as atmosphere and climate. By combining the microscopic scale of the methanogenic microbes' biology with the global scale of Mars's climate, these three models together helped simulate the behavior of the Martian planetary ecosystem.

Subterranean habitability very likely to have existed within Mars's crust

A number of geological clues indicate a flow of liquid water on Mars's surface four billion years ago, which would have formed rivers, lakes and, possibly, even oceans. The Martian climate was therefore more temperate than it is today. In explaining how such a climate could have come about, our surface model assumes that Mars had a dense atmosphere (at around the same density as that of our own planet today) that was particularly rich in CO_2 and H_2, even more so than planet Earth at the time.

This CO_2-rich atmospheric context may essentially have provided the atmospheric H_2 with the characteristics of a remarkably potent greenhouse gas. This H_2 would have been even more powerful than CH_4 under the same conditions. In other words, if 1% of the Martian atmosphere had been H_2, the climate would have been heated more than if 1% had been CH_4.

According to several of our model-generated scenarios, this greenhouse effect alone would not have been enough to produce the climatic conditions needed for maintaining liquid water on the surface of Mars, meaning that the Red Planet was covered in ice. Moreover, if there were suitable temperatures deep within the Martian crust, they would not have made it any more habitable either. Blocked by surface ice, no atmospheric CO_2 and H_2—the essential energy source for methanogenic life—would have been able to penetrate the crust.

Nevertheless, most of our scenarios indicate that the presence of liquid water on the planet's surface would have been possible at least in its warmer regions, where atmospheric CO_2 and H_2 could indeed have penetrated the crust. Our biological model attests that in all of these scenarios, methanogenic microorganisms would have found suitable temperatures and had access to an energy source large enough for their survival within the first few hundred meters of crust. In short, although we do not yet have any factual proof of life on Mars, whether past or present, the Martian crust four billion years ago may very likely have hosted an underground biosphere composed of methanogenic microorganisms.

An ice age triggered by a primitive biosphere

Might these hypothetical Martian methanogenic life forms have warmed up their planet's climate in the same way as their Earthling counterparts? Alas, the answer appears to be: no. A subterranean methanogen-based biosphere would have consumed the large majority of the planet's H_2 and released considerable quantities of CH_4, resulting in profound changes to the Martian atmosphere.

Yet, as we have seen, H_2 was a more powerful greenhouse gas than CH_4 in the context of the early Martian atmosphere, their respective greenhouse effects being opposite to those observed in the Earth's current atmosphere, or what would have been observed in Earth's early atmosphere. Whereas the emergence of methanogenesis on Earth helped set up a favorable climate and consolidated terrestrial habitability, methanogenic life on Mars—by consuming most of the planet's atmospheric H_2—would have drastically cooled its climate by several dozen degrees and contributed to greater ice cover. Even in regions without surface ice, our hypothetical microorganisms would likely have had to seek out more viable temperatures, moving deeper into the crust and farther away from their atmospheric energy source. In this way, the actions of these life forms would have caused Mars to become less hospitable to life than it was initially.

Self-destruction: A standard for life in the universe

In the 1970s, James Lovelock and Lynn Margulis developed the Gaia hypothesis, which proposes that the Earth's habitability is maintained by a synergistic, self-regulating system involving both the terrestrial biosphere and the planet itself. We, the human species, are an unfortunate anomaly in this theory. The Gaia hypothesis has since prompted the emergence of the "Gaian bottleneck" idea. This posits that the universe does not lack the necessary conditions for life, but that when life does appear, it is seldom able to sustain the long-term habitability of its planetary environment.

The findings of our study are even more pessimistic. As shown in the example of Martian methanogenesis, even the simplest life forms can actively jeopardize the habitability of their planetary environment.

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