Tracing the origins of organic matter in Martian sediments

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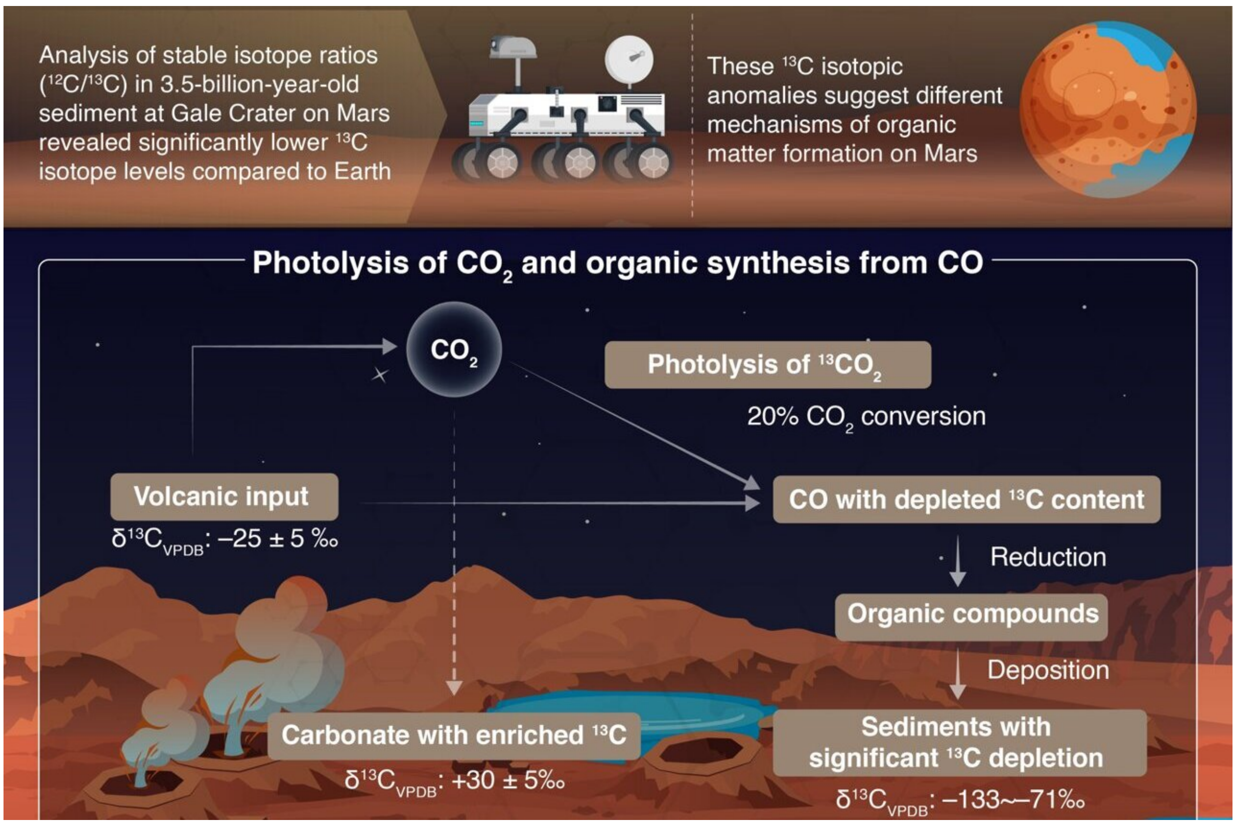

The atmospheric origin of organic matter suggests that Mar surfaces may contain larger amounts of organic compounds than previously anticipated. Credit: Tokyo Tech

Although Mars presents a barren, dusty landscape with no signs of life so far, its geological features such as deltas, lakebeds, and river valleys strongly suggest a past where water once flowed abundantly on its surface. To explore this possibility, scientists examine sediments preserved near these formations. The composition of these sediments holds clues about the early environmental conditions, the processes that shaped the planet over time, and even potential signs of past life.

In one such analysis, sediments collected by the Curiosity rover from Gale Crater, believed to be an ancient lake formed approximately 3.8 billion years ago due to an asteroid impact, revealed organic matter. However, this organic matter had a significantly lower amount of the carbon-13 isotope (^{13}C) relative to carbon-12 isotopes (^{12}C) compared to what is found on Earth, suggesting different processes of organic matter formation on Mars.

Now, a study published in the journal *Nature Geoscience* on May 9, 2024, elucidates this discrepancy. A research team, led by Professor Yuichiro Ueno from Tokyo Institute of Technology and Professor Matthew Johnson from the University of Copenhagen, found that the photodissociation of carbon dioxide (CO_2) in the atmosphere to carbon monoxide (CO) and subsequent reduction result in organic matter with depleted ^{13}C content.

"On measuring the stable isotope ratio between ^{13}C and ^{12}C, the Martian organic matter has a ^{13}C abundance of 0.92% to 0.99% of the carbon that makes it up. This is extremely low compared to Earth's sedimentary organic matter, which is about 1.04%, and atmospheric CO_2, around 1.07%, both of which are biological remnants, and are not similar to the organic matter in meteorites, which is about 1.05%," explains Ueno.

Early Mars had an atmosphere rich in CO_2 containing both ^{13}C and ^{12}C isotopes. The researchers simulated different conditions of the Martian atmosphere's composition and temperature in laboratory experiments. They found that when $^{12}CO_2$ is exposed to solar ultraviolet (UV) light, it preferentially absorbs UV radiation, leading to its dissociation into CO depleted in ^{13}C, leaving behind CO_2 enriched in ^{13}C.

This isotopic fractionation (separation of isotopes) is also observed in the upper atmospheres of Mars and Earth, where UV irradiation from the sun causes CO_2 to dissociate into CO with depleted ^{13}C content. In a reducing Martian atmosphere, CO transforms into simple organic compounds such as formaldehyde and carboxylic acids.

During the early Martian era, with surface temperatures close to the freezing point of water and not exceeding 300 K (27°C), these compounds may have dissolved in water and settled in sediments.

Using model calculations, the researchers found that in an atmosphere with a CO_2 to CO ratio of 90:10, a 20% conversion of CO_2 to CO would lead to sedimentary organic matter with $\delta^{13}C_{VPDB}$ values of -135‰. Also, the remaining CO_2 would be enriched in ^{13}C with $\delta^{13}C_{VPDB}$ values of +20‰. These values closely match those seen in sediments analyzed by the Curiosity rover and estimated from a Martian meteorite. This finding points to an atmospheric process rather than a biological one as the main source of organic matter formation on early Mars.

"If the estimation in this research is correct, there may be an unexpected amount of organic material present in Martian sediments. This suggests that future explorations of Mars might uncover large quantities of organic matter," says Ueno.

More information: Yuichiro Ueno et al, Synthesis of ^{13}C-depleted organic matter from CO in a reducing early Martian atmosphere, *Nature Geoscience* (2024). DOI: 10.1038/s41561-024-01443-z

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