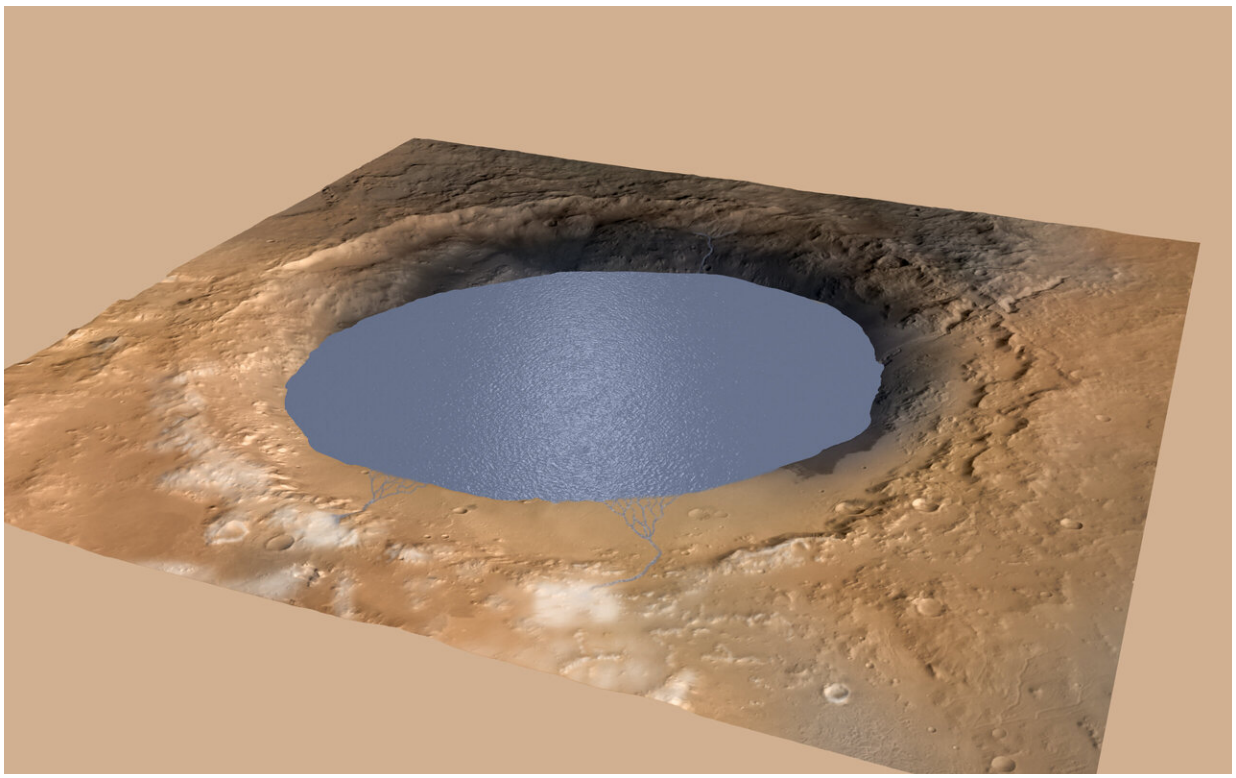
Curiosity rover finds clues to chilly ancient Mars buried in rocks

May 19 2020, by Lonnie Shekhtman



This illustration depicts a lake of water partially filling Mars' Gale Crater. It would have been filled by runoff from snow melting on the crater's northern rim. Evidence of ancient streams, deltas, and lakes that NASA's Curiosity rover has found in the patterns of sedimentary deposits in Gale suggests the crater held a lake like this one more than three billion years ago, filling and drying in multiple cycles over tens of millions of years. Credit: NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS

By studying the chemical elements on Mars today—including carbon and oxygen—scientists can work backwards to piece together the history of a planet that once had the conditions necessary to support life.

Weaving this story, element by element, from roughly 140 million miles (225 million kilometers) away is a painstaking process. But scientists aren't the type to be easily deterred. Orbiters and rovers at Mars have confirmed that the planet once had liquid water, thanks to clues that include dry riverbeds, ancient shorelines, and salty surface chemistry. Using NASA's Curiosity Rover, scientists have found evidence for long-lived lakes. They've also dug up organic compounds, or life's chemical building blocks. The combination of liquid water and organic compounds compels scientists to keep searching Mars for signs of past—or present—life.

Despite the tantalizing evidence found so far, scientists' understanding of Martian history is still unfolding, with several major questions open for debate. For one, was the ancient Martian atmosphere thick enough to keep the planet warm, and thus wet, for the amount of time necessary to sprout and nurture life? And the organic compounds: are they signs of life—or of chemistry that happens when Martian rocks interact with water and sunlight?

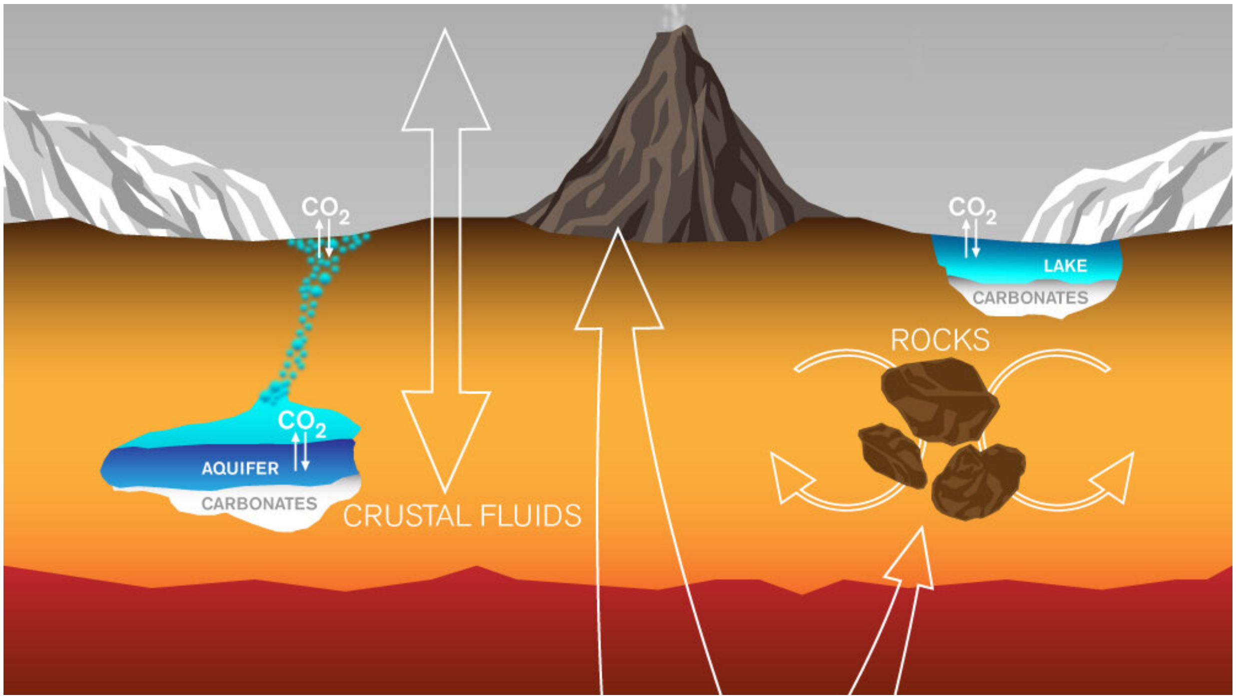
In a recent *Nature Astronomy* report on a multi-year experiment conducted in the chemistry lab inside Curiosity's belly, called Sample Analysis at Mars (SAM), a team of scientists offers some insights to help answer these questions. The team found that certain minerals in rocks at Gale Crater may have formed in an ice-covered lake. These minerals may have formed during a cold stage sandwiched between warmer periods, or after Mars lost most of its atmosphere and began to turn permanently cold.

Gale is a crater the size of Connecticut and Rhode Island combined. It was selected as Curiosity's 2012 landing site because it had signs of past water, including clay minerals that might help trap and preserve ancient organic molecules. Indeed, while exploring the base of a mountain in the center of the crater, called Mount Sharp, Curiosity found a layer of sediments 1,000 feet (304 meters) thick that was deposited as mud in ancient lakes. To form that much sediment an incredible amount of water would have flowed down into those lakes for millions to tens of millions of warm and humid years, some scientists say. But some geological features in the crater also hint at a past that included cold, icy conditions.

"At some point, Mars' surface environment must have experienced a transition from being warm and humid to being cold and dry, as it is now, but exactly when and how that occurred is still a mystery," says Heather Franz, a NASA geochemist based at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Franz, who led the SAM study, notes that factors such as changes in Mars' obliquity and the amount of volcanic activity could have caused the Martian climate to alternate between warm and cold over time. This idea is supported by chemical and mineralogical changes in Martian rocks showing that some layers formed in colder environments and others formed in warmer ones.

In any case, says Franz, the array of data collected by Curiosity so far suggests that the team is seeing evidence for Martian climate change recorded in rocks.



This graphic depicts paths by which carbon has been exchanged among Martian interior, surface rocks, polar caps, waters and atmosphere, and it also depicts a mechanism by which it is lost from the atmosphere. Credit: Lance Hayashida/Caltech

Carbon and oxygen star in the Martian climate story

Franz's team found evidence for a cold ancient environment after the SAM lab extracted the gases carbon dioxide, or CO_2, and oxygen from 13 dust and rock samples. Curiosity collected these samples over the course of five Earth years (Earth years vs. Mars years).

CO_2 is a molecule of one carbon atom bonded with two oxygen atoms, with carbon serving as a key witness in the case of the mysterious Martian climate. In fact, this simple yet versatile element is as critical as water in the search for life elsewhere. On Earth, carbon flows continuously through the air, water, and surface in a well-understood cycle that hinges on life. For example, plants absorb carbon from the atmosphere in the form of CO_2. In return, they produce oxygen, which humans and most other life forms use for respiration in a process that ends with the release of carbon back into the air, again via CO_2, or into the Earth's crust as life forms die and are buried.

Scientists are finding there's also a carbon cycle on Mars and they're working to understand it. With little water or abundant surface life on the Red Planet for at least the past 3 billion years, the carbon cycle is much different than Earth's.

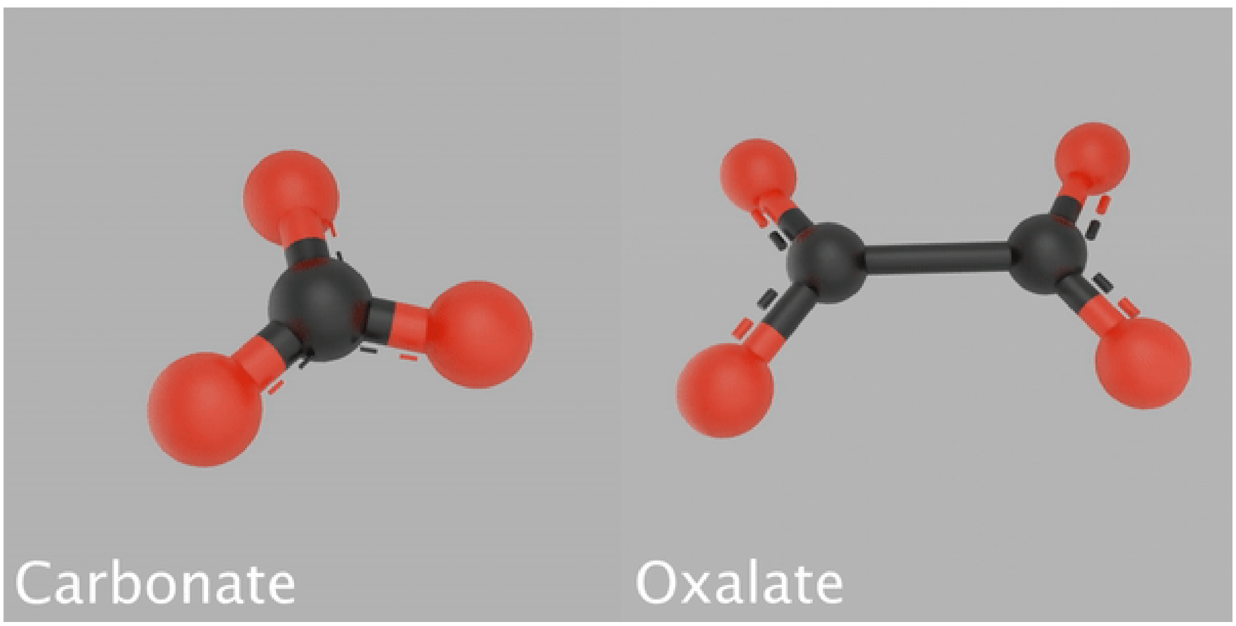
"Nevertheless, the carbon cycling is still happening and is still important because it's not only helping reveal information about Mars' ancient climate," says Paul Mahaffy, principal investigator on SAM and director of the Solar System Exploration Division at NASA Goddard. "It's also showing us that Mars is a dynamic planet that's circulating elements that are the buildings blocks of life as we know it."

The gases build a case for a chilly period

After Curiosity fed rock and dust samples into SAM, the lab heated each one to nearly 1,650 degrees Fahrenheit (900 degrees Celsius) to liberate the gases inside. By looking at the oven temperatures that released the CO_2 and oxygen, scientists could tell what kind of minerals the gases were coming from. This type of information helps them understand how carbon is cycling on Mars.

Various studies have suggested that Mars' ancient atmosphere, containing mostly CO_2, may have been thicker than Earth's is today. Most of it has been lost to space, but some may be stored in rocks at the planet's surface, particularly in the form of carbonates, which are minerals made of carbon and oxygen. On Earth, carbonates are produced when CO_2 from the air is absorbed in the oceans and other bodies of water and then mineralized into rocks. Scientists think the same process happened on Mars and that it could help explain what happened to some of the Martian atmosphere.

Yet, missions to Mars haven't found enough carbonates in the surface to support a thick atmosphere.



This animated image shows a 3D model of a carbonate molecule next to a 3D model of an oxalate molecule. The carbonate is made of a carbon atom that's bonded with three oxygen atoms. The oxalate is made of two carbon atoms bonded with four oxygen atoms. Credit: James Tralie/NASA/Goddard Space Flight Center

Nonetheless, the few carbonates that SAM did detect revealed something interesting about the Martian climate through the isotopes of carbon and oxygen stored in them. Isotopes are versions of each element that have different masses. Because different chemical processes, from rock formation to biological activity, use these isotopes in different proportions, the ratios of heavy to light isotopes in a rock provide scientists with clues to how the rock formed.

In some of the carbonates SAM found, scientists noticed that the oxygen isotopes were lighter than those in the Martian atmosphere. This suggests that the carbonates did not form long ago simply from atmospheric CO_2 absorbed into a lake. If they had, the oxygen isotopes in the rocks would have been slightly heavier than the ones in the air.

While it's possible that the carbonates formed very early in Mars' history, when the atmospheric composition was a bit different than it is today, Franz and her colleagues suggest that the carbonates more likely formed in a freezing lake. In this scenario, the ice could have sucked up heavy oxygen isotopes and left the lightest ones to form carbonates later. Other Curiosity scientists have also presented evidence suggesting that ice-covered lakes could have existed in Gale Crater.

So where is all the carbon?

The low abundance of carbonates on Mars is puzzling, scientists say. If there aren't many of these minerals at Gale Crater, perhaps the early atmosphere was thinner than predicted. Or maybe something else is storing the missing atmospheric carbon.

Based on their analysis, Franz and her colleagues suggest that some carbon could be sequestered in other minerals, such as oxalates, which store carbon and oxygen in a different structure than carbonates. Their hypothesis is based on the temperatures at which CO_2 was released from some samples inside SAM—too low for carbonates, but just right for oxalates—and on the different carbon and oxygen isotope ratios than the scientists saw in the carbonates.

A model of a carbonate molecule next to an oxalate molecule

Oxalates are the most common type of organic mineral produced by plants on Earth. But oxalates also can be produced without biology. One way is through the interaction of atmospheric CO_2 with surface minerals, water, and sunlight, in a process known as abiotic photosynthesis. This type of chemistry is hard to find on Earth because there's abundant life here, but Franz's team hopes to create abiotic photosynthesis in the lab to figure out if it actually could be responsible for the carbon chemistry they're seeing in Gale Crater.

On Earth, abiotic photosynthesis may have paved the way for photosynthesis among some of the first microscopic life forms, which is why finding it on other planets interests astrobiologists.

Even if it turns out that abiotic photosynthesis locked some carbon from the atmosphere into rocks at Gale Crater, Franz and her colleagues would like to study soil and dust from different parts of Mars to understand if their results from Gale Crater reflect a global picture. They may one day get a chance to do so. NASA's Perseverance Mars rover, due to launch to Mars between July and August 2020, plans to pack up samples in Jezero Crater for possible return to labs on Earth.

More information: H. B. Franz et al, Indigenous and exogenous organics and surface–atmosphere cycling inferred from carbon and oxygen isotopes at Gale crater, *Nature Astronomy* (2020). DOI: 10.1038/s41550-019-0990-x

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