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What can we learn from carbon on Mars?

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Abstract

UPPER READING LEVEL

Mars is currently dry and cold and doesn't have much of an atmosphere, but what was it like in the past? Did Mars ever have a climate or environment that could support life? Luckily, we have rovers on Mars that can help us investigate!

We used the Curiosity Rover on Mars to sample the planet's surface where there might have been a lake long ago. We looked at the carbon in our sample to see how much there was and where it came from. This could give us clues about what the environment was like and if there used to be organisms living in the area. Our data suggest that there is more carbon on Mars than we had expected. Most of the carbon came from meteorites and volcanic rock. We can't rule out that it came from living things, but we need a lot more information to help us figure it out.

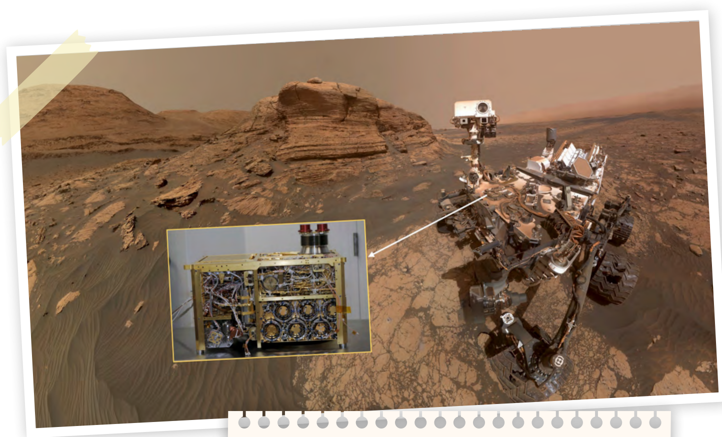
Introduction

Did you know that you are made up of carbon? All life that we know of contains **organic carbon**. Lots of other things contain organic carbon too, like volcanic rocks and **meteorites**. The amount of organic carbon in an environment is a good indication of how many chemical reactions can occur there. So, finding out how much organic carbon is on Mars and where it came from could help us figure out if the planet once supported life.

Luckily, we can look at the **ratio** of carbon **isotopes** in a sample to help us find out. An isotope is an atom that has the same number of protons as other atoms of the element, but it has a different number of neutrons. For example, carbon usually has 6 neutrons (carbon-12), but sometimes it can have 7 neutrons (carbon-13). The ratio of carbon-13 to carbon-12 will be different based on how the sample was formed.

We compare carbon isotope ratios to a specific sample of **inorganic carbon** on Earth. This is the **carbon isotope value** (**$\delta^{13}C$**). Using this value can make it easier to compare samples from lots of different sources. For example, biological sources actively take up more carbon-12 and less carbon-13.

Scientists think that over 200 meteorites from Mars have landed on Earth! We have measured the amount of carbon in some of these meteorites. Our experiments on Mars produced more carbon than our experiments on meteorites.



"Selfie" of the Curiosity rover with inset showing the Sample Analysis at Mars (SAM) instrument before being installed.
Images: NASA/JPL-Caltech/MSSS

This means they will be lighter and have a negative carbon isotope value. Non-biological sources, like inorganic carbon, form using whatever ratio of carbon isotopes happen to be nearby. This means they will have less carbon-12 and more carbon-13 than biological sources. They will be heavier and have carbon isotope values that are positive or near zero.

But how can we do these experiments on Mars? With the help of the Curiosity Rover!

Methods

We sent the Curiosity Rover to take a sample at the Yellowknife Bay Formation (Fig. 1). It looks like it could have been a lake-like environment sometime in the past. It might even have supported life!

Then we used the Sample Analysis at Mars instrument on the Curiosity Rover to do four tests.

1. We **combusted** our sample at 550°C.
2. We left our sample in the instrument overnight. Then we combusted the sample again at 550°C. We know there are carbon-containing contaminants in the instrument from other chemistry experiments. (There are no people on Mars to help clean up!) We wanted to know what impact this carbon had on our results.
3. We immediately combusted the sample again, but this time at 870°C. Some carbon was likely stuck in **macromolecules** or minerals. Only higher temperatures can release this type of carbon.
4. The next day we combusted what was left of our sample at 870°C.

For each test, we combusted our sample for 25 minutes in the presence of oxygen. Each time we combusted the sample it produced lots of gases, like carbon dioxide. After each test, we measured how much carbon from these gases was produced using a **laser spectrometer**. We also determined the carbon isotope ratio of the carbon dioxide.

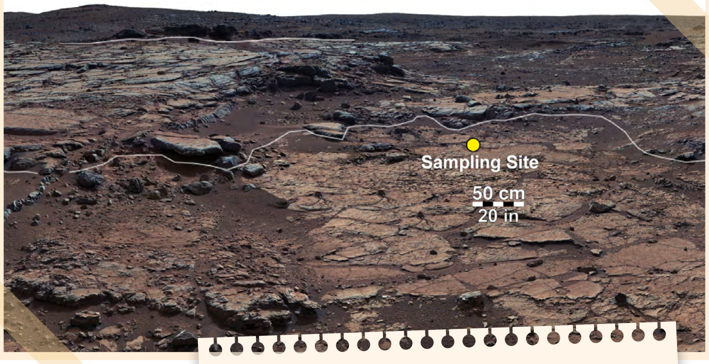


Figure 1:
Our drill site in the Yellowknife Bay Formation, which is 3.5 billion years old.
Image: NASA/JPL-Caltech/MSSS

Which steps in the experiment produced the most carbon?

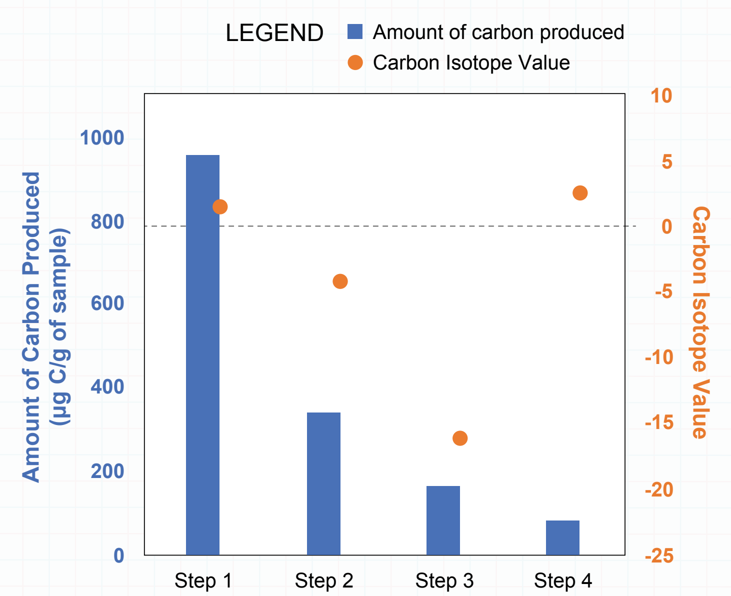


Figure 2:
The amount of carbon and carbon isotope values for each of the four tests. Values above zero have more carbon-13 than the standard. Values below have less carbon-13 than the standard.

Results

Test 1 produced the most carbon and test 4 produced the least. Our experiment produced twice as much carbon as previous experiments without oxygen.

During our lower temperature tests, we found lots of carbon contamination from our instrument. But at least 45% of the carbon came from Mars rocks. The isotope values for steps 1 and 2 were +1.5 and -4.3 (Figure 2).

We found that the bulk (organic and inorganic) carbon isotope value for steps 3 and 4 combined was -3.6. We used a model to help us estimate the isotope value for organic carbon only, and found it ranged from -32.9 to -10.1.

Discussion

At low temperatures we found that a lot of carbon came from instrument contamination. This can help us analyze future results better. The rest of the carbon could have come from meteorites, **carbonate**, or small carbon-containing molecules formed by reactions with sunlight.

We produced 40 times more carbon at high temperatures than previous experiments without oxygen. This suggests that there is enough carbon for lots of chemical reactions to take place. These could include reactions in biological organisms. Our isotope values at high temperatures overlap most closely with carbonate, volcanic rocks, and meteorites found on Mars. However, they also overlap with biological organisms. So, while other sources are more likely, we can't rule out a biological source.

A lot of the carbon we combusted at high temperatures was likely stuck in macromolecules or other minerals. It doesn't decompose or break down very quickly. That means it has been preserved for billions of years. In the future, we'd love to see if there's any extra chemical information preserved in this type of carbon. This could give us hints about how it was formed or altered over its history.

Conclusion

Scientists have always wondered if we are alone in the universe. As we explore more of space, we will likely keep looking for evidence of life. Our study identified a lot of possibilities for the source of carbon on Mars. We can't confirm that it came from biological organisms, but it's still one possibility.

If you're interested in the exploration of Mars and its environmental history, make sure to follow all the news on NASA's Mars Exploration Program website. You can find out about the missions, look at pictures taken by the rovers, and read all the newest findings!

Glossary of Key Terms

Carbonate - CO_3^{2-}, an inorganic carbon-containing molecule. It is the chief component in many types of sedimentary rock, including limestone, calcite, and dolomite.

Carbon isotope value ($\delta^{13}C$) - the ratio of carbon-13 to carbon-12 in a sample relative to a known sample of inorganic carbon called the Pee-Dee Belemnite (a sample of limestone rock). Carbon isotope values for plants are about -26. The ocean has carbon isotope values of about -10.

Combustion - the chemical reaction of a substance in the presence of oxygen. It often produces gases like carbon dioxide and water vapor. When things combust they don't necessarily produce a flame like something being burned does, but a lot of people use the words 'combust' and 'burn' interchangeably.

Inorganic carbon - carbon that is not bonded to any hydrogen atoms. Some examples are carbon dioxide, carbonic acid, and carbonate.

Isotope - each of multiple forms of the same element that contain the same number of protons, but different numbers of neutrons. This means that their atomic mass is different, but they have the same chemical properties.

Laser spectrometer - an instrument that uses lasers to measure the amounts of different gases in a sample. It can also measure their isotope ratios.

Macromolecule - a molecule containing a large number of atoms that are bonded together. Examples include proteins, nucleic acids, and carbohydrates. Macromolecules can also be made from inorganic materials.

Meteorite - a rock that falls to the surface of a planet from space. These rocks are usually older than anything found on the surface of the planet they land on. They might come from other planets or asteroids or comets in our solar system.

Organic carbon - carbon that is bonded to hydrogen atoms. Examples include methane, amino acids, and sugars.

Ratio - a relationship between two things, expressed as an amount.

Check your understanding

1. Why did the researchers choose to take samples in the Yellowknife Bay Formation on Mars?

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2. Why did we combust our sample at two different temperatures?

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3. Where did we determine the carbon in our sample came from? Why can't we say for sure whether it came from biological sources?

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4. Brainstorm with your classmates. What are some challenges that scientists might face when they try to do research on Mars?

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5. Bonus research task: What evidence would researchers need to collect to show that Mars could have supported life?

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