New NASA study reveals origin of organic matter in Apollo lunar samples

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Astronaut Alan L. Bean, Lunar Module pilot for the Apollo 12 lunar landing mission, holds a container filled with lunar soil collected while exploring the lunar surface. Astronaut Charles "Pete" Conrad Jr., commander, who took this picture, is reflected in the helmet visor. Credit: NASA

A team of NASA-funded scientists has solved an enduring mystery from the Apollo missions to the moon - the origin of organic matter found in lunar samples returned to Earth. Samples of the lunar soil brought back by the Apollo astronauts contain low levels of organic matter in the form of amino acids. Certain amino acids are the building blocks of proteins, essential molecules used by life to build structures like hair and skin and to regulate chemical reactions.

Since the lunar surface is completely inhospitable for known forms of life, scientists don't think the organic matter came from life on the moon. Instead, they think the amino acids could have come from four possible sources. First, since traces of life are everywhere on Earth, the amino acids could be simply contamination from terrestrial sources, either from material brought to the moon by the missions, or from contamination introduced while the samples were being handled back on Earth.

Second, rocket exhaust from the lunar modules contains precursor molecules used to build amino acids (such as hydrogen cyanide or HCN). This contamination could produce amino acids during lunar sample analysis in the lab.

Third, the solar wind - a thin stream of electrically conducting gas continuously blown off the surface of the Sun—contains the elements used to make amino acids, such as hydrogen, carbon, and nitrogen. Just like contamination from lunar module exhaust, material from the solar wind could produce amino acids during sample workup.

Fourth, chemical reactions inside asteroids make amino acids. Fragments from asteroid collisions occasionally fall to Earth as meteorites, bringing their extraterrestrial amino acids with them. The lunar surface is frequently bombarded by meteorites and could have amino acids from asteroids as well.

"People knew amino acids were in the lunar samples, but they didn't know where they came from," said Jamie Elsila of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "The scientists in the 1970s knew the right questions to ask and they tried pretty hard to answer them, but they were limited by the analytical capabilities of the time. We have the technology now, and we've determined that most of the amino acids came from terrestrial contamination, with perhaps a small contribution from meteorite impacts." Elsila is lead author of a paper on this research appearing online in *Geochimica et Cosmochimica Acta* Oct. 28.

The team analyzed seven samples taken during the Apollo missions and stored in a NASA curation facility since return to Earth, and found amino acids in all of them at very low concentrations (105 to 1,910 parts-per-billion). One of the key new capabilities of the Goddard Astrobiology Analytical Laboratory was instrumentation with high enough sensitivity to determine the isotopic composition of an amino acid molecule, according to Elsila. This capability enabled the team to say terrestrial contamination was the primary source of the lunar amino acids.

Isotopes are versions of an element; for example, Carbon-13 has an extra neutron and is a more massive version of the common Carbon-12. Life prefers to use the lighter Carbon-12, which reacts a bit more readily, so amino acid molecules from terrestrial life will have less Carbon-13 compared to amino acids produced by non-biological reactions in asteroids. This is what the team found in one of the lunar samples that was abundant enough for isotopic analysis. The isotopic composition of the amino acids (glycine, β-alanine, and L-alanine) had less Carbon-13 and more closely resembled that from terrestrial sources than that from meteorites.

Isotopic composition also helped rule out the solar wind as the source, since the solar wind has far less Carbon-13 than what was found in the sample.

Also, if the solar wind were responsible for the amino acids, then samples taken from near the lunar surface, which had the highest exposure to the solar wind, should have a greater abundance of amino acids than samples taken from deeper beneath the surface. This is the opposite of what was found - the deepest samples, which were the most sheltered from the solar wind, produced the most amino acids.

A similar result on amino acid abundances helped rule out the lunar module exhaust as a source. If contamination from the exhaust produced the amino acids, then a sample taken from right under the Apollo 17 lunar module should have more amino acids than a sample taken far away. However, the team found that a sample taken from 6.5 kilometers (four miles) away had similar amino acid abundances to the one taken beneath the module.

The ability to determine the orientation of an amino acid molecule was another significant new capability of the Goddard lab that enabled them to discover the origin of the lunar amino acids, according to Elsila. Amino acid molecules can be built in two versions - left and right—that are mirror images of each other, like your hands. Terrestrial life uses the left-handed versions, while non-biological chemistry produces the left-handed and right-handed varieties in equal amounts. In the samples, the team found that the left-handed versions were far more common than right-handed ones for several types of amino acids used to make proteins. Since life uses the left-handed versions, this suggests terrestrial life as the source of these amino acids.

Although most of the amino acids likely came from Earth, the team can't rule out a contribution from meteorites because they found some amino acids that are extremely rare in terrestrial biology but common in meteorites (for example, Alpha-aminoisobutyric acid or AIB). This discovery suggests meteorites may make a small contribution to the amino acids found on the lunar surface, according to Elsila.

The research has important implications for future missions that are looking for extraterrestrial organic matter that may be present, but in very small (trace) amounts. "This work highlights the fact that even with thoughtful and careful contamination control efforts, trace organics in extraterrestrial samples can be overwhelmed by terrestrial sources," said Elsila. "Future missions emphasizing organic analysis must consider not only contamination control but also include 'witness samples' that record the environment and potential contamination as the mission is built and launched to understand the unavoidable contamination background."

This is a lesson taken to heart by NASA's OSIRIS-REx mission, which launches in 2016 to return pristine samples of asteroid Bennu in 2023.

The Apollo samples were taken in the late 1960's and early 1970's, and highlight the lasting value of sample return missions. "These samples were collected before I was born, and the techniques used in our study were not yet invented when the samples were collected; curation of the samples for future work allowed us to identify the origins of the amino acids detected in the samples, a question that the original investigators were unable to resolve," said Elsila.

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