Amino Acids in Returned Samples and other Solar System Materials

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Introduction:
The organic contents of asteroids and comets reflect early solar system chemistry, as well as the physical and chemical processes that have occurred in the past 4.5 billion years. Both returned samples and meteorites present an opportunity to understand these organic contents. Meteorites provide samples from a diverse selection of solar system bodies, while returned samples have the advantage of context, known parent bodies, and minimal contamination.

Among the most well-studied of the organic compounds present in these extraterrestrial materials are amino acids. Amino acids are of particular interest to astrobiology and astrochemistry research for several reasons: (1) they are essential to life on Earth; (2) they are a structurally diverse group of compounds; and (3) some of them possess large enantiomeric excesses of extraterrestrial origin. Amino acids have been detected in a variety of meteorites, as well as in materials collected from NASA's Stardust mission to Comet Wild-2 and in lunar samples returned by NASA's Apollo missions. Observations by the ROSINA mass spectrometer also identified glycine in the coma of 67P/Churyumov-Gerasimenko. The abundances, relative distributions, enantiomeric ratios, and stable isotopic composition of amino acids in extraterrestrial materials can be used to understand formation histories and contamination of these materials.

Amino acids in meteorites:
We have examined the abundances, structural distributions, stable isotopic ratios, and enantiomeric compositions of amino acids in meteorites from all eight carbonaceous chondrite groups (CI, CM, CR, CO, CV, CK, CH, and CB), as well as representatives of other meteorite classes[1]. Analytical techniques include liquid chromatography coupled with fluorescence detection and time-of-flight mass spectrometry (LC-FD/ToF-MS) to sensitively measure abundances, and gas chromatography coupled with mass spectrometry and isotope-ratio mass spectrometry (GC-MS/IRMS) to measure compound-specific isotopic ratios. These studies show a wide diversity in the amino acids present across these samples. This diversity highlights the potential roles of parent body processes and composition on the organic content of these bodies, as well as the potential for a variety of formation mechanisms and organic reservoirs in the solar system. In addition, the observed large L-enantiomeric excesses of some proteinogenic amino acids in certain meteorites (up to ~60%) may be relevant to understanding the origin of homochirality in life on Earth, although the potential mechanisms leading to these enantiomeric excesses are currently poorly understood.

Amino acids in returned samples:
Analysis of bulk comet-exposed materials from the Stardust collector by LC-FD/ToF-MS revealed several amines and amino acids, including glycine, methylamine and ethylamine [2]. The origin of these compounds could not be firmly established by LC-FD/ToF-MS data alone, although the distinctive 1:1 ratio of methylamine to ethylamine suggested a cometary origin for those compounds. Subsequent GC-MS/IRMS analyses measured the stable carbon isotopic ratios of glycine and determined its likely extraterrestrial origin for glycine, representing the first detection of a cometary amino acid [3]. The in-situ measurements of glycine in the coma of 67P/Churyumov-Gerasimenko supported the presence of cometary amino acids [4].

Lunar regolith samples returned by NASA's Apollo missions were investigated almost immediately after their return, but these studies yielded inconclusive identifications about the origins of detected amino acids (e.g. [5,6]), in part due to analytical limitations. It was not possible to determine if the detected amino acids were indigenous to the lunar samples or the result of terrestrial contamination. More recently, we applied modern analytical techniques to determine the abundances, distributions, and carbon isotopic ratios of amino acids in lunar regolith from the Apollo 16 and 17 missions. We observed amino acids in low concentrations in all samples. Isotopic and abundance data suggested that terrestrial biological contamination was a primary source of the observed amino acids, but that some contribution from meteoritic infall was also present [7].

The material returned by JAXA's Hayabusa mission from asteroid Itokawa was examined for organic materials, including amino acids. Five individual particles were extracted with organic solvents, but analyses of these extracts showed amino acids present only at levels below those seen in a procedural blank [8]. Future studies with hot-water extraction may be possible, but the small sample sizes available from this returned material may preclude any compound-specific amino acid identification.

Future plans for amino acid studies of returned samples:
Both the samples to be returned by NASA's OSIRIS-REx mission to asteroid Bennu and JAXA's Hayabusa2 mission to asteroid Ryugu are expected to be analyzed for amino acids and other organic materials. Asteroid Bennu is a B-type carbonaceous asteroid whose spectra most closely match those of CI and CM chondrites. A comparison of the amino acid content of the Bennu regolith with previous carbonaceous chondrite studies will help in understanding the potential relationship of these meteorites to asteroid parent bodies. Asteroid Ryugu is a Cg-type asteroid that may preserve some of the most pristine material in the solar system and studies of its organic content and amino acid inventory will add to our knowledge of extraterrestrial organic formation, distribution, and preservation.

References

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