Synthesis of Extreme Organics in Meteorites

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1. Introduction

Meteoritic organic compounds trace the history of the solar system; from quiescent to violent. Species or their precursors were formed in the temperature and radiation extremes of the interstellar medium, the collapse of the protosolar nebula into our solar system, and the environment within fragmented planetessimals before they arrive on Earth to be collected and analysed (Figure 1).

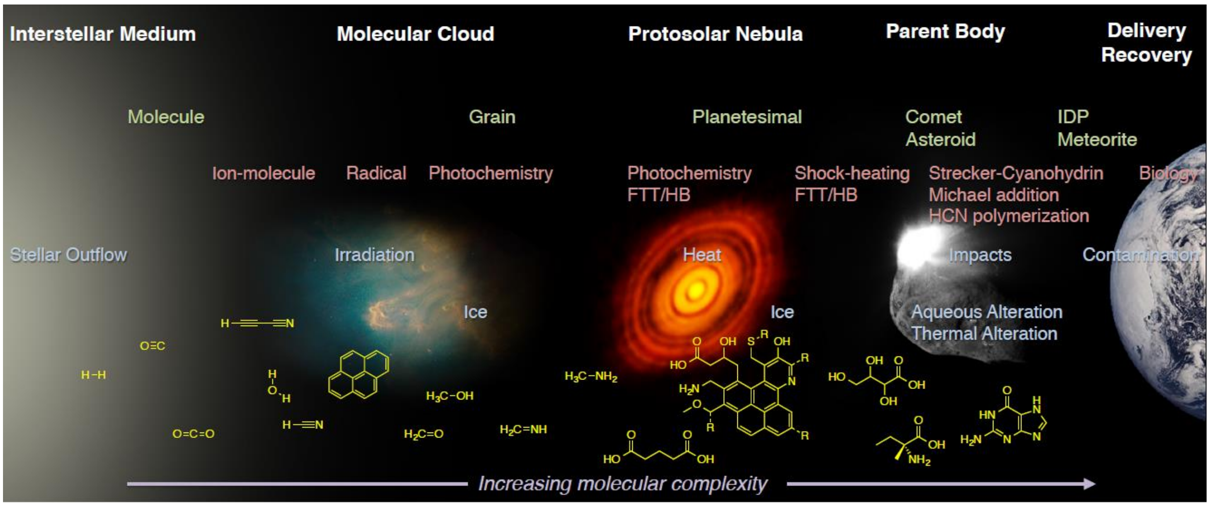

Figure 1: The formation and evolution of simple molecules to more complex organic compounds from the interstellar medium to small bodies and planets in solar systems. Representative reaction mechanism, processes, and example molecules are shown [from 1].

Analyses of primitive carbonaceous chondrites over the last five decades have revealed a major insoluble organic component, as well as a complex and highly diverse suite of soluble organic molecules that includes aliphatic and aromatic hydrocarbons, carboxylic acids, hydroxy acids, N-heterocycles, sugar acids, polyols, amino acids, amines, and many other molecules that have not yet been identified.

Comparing a suite of compounds across meteorite petrology revels correlations with the meteorite parent body, suggesting that thermal and aqueous alteration in primitive asteroids played an important role in the formation and destruction organics, including amplification of L-amino acids that may have contributed to the origin of homochirality in life on Earth. Amino acids are the best studied example (Figure 2) [2].

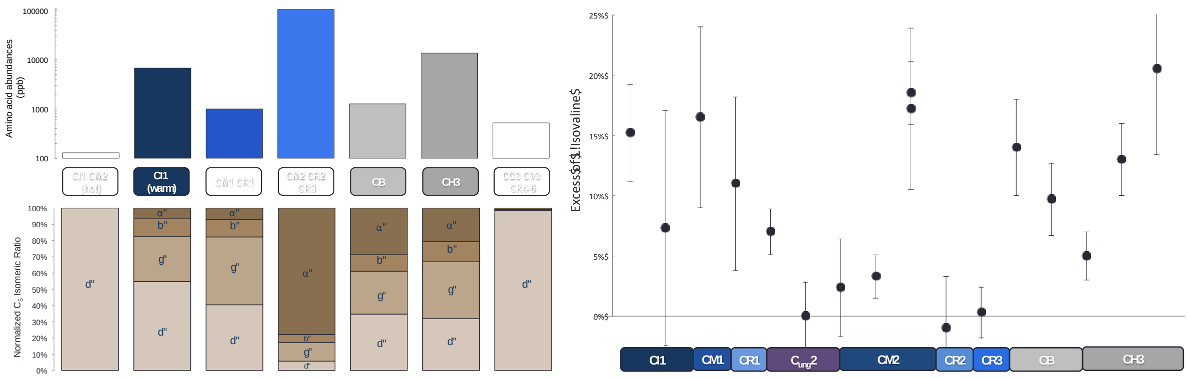

Figure 2: Average total amino acid abundances (top left) and structural distributions of amine position (α, β, ɣ, and δ) in 5-carbon aliphatic amino acids (bottom left) in carbonaceous chondrites vary greatly with class and petrographic type, and extent of aqueous and thermal alteration on the parent body. L-Enantiomeric excesses of the amino acid isovaline (right) [from 2].

Amino acids are useful, not just because of their obvious relevance to the origin of life and habitability, but the can be employed to elucidate the chemical pathways that were active in a particular meteorite's parent body (Figure 3) [3].

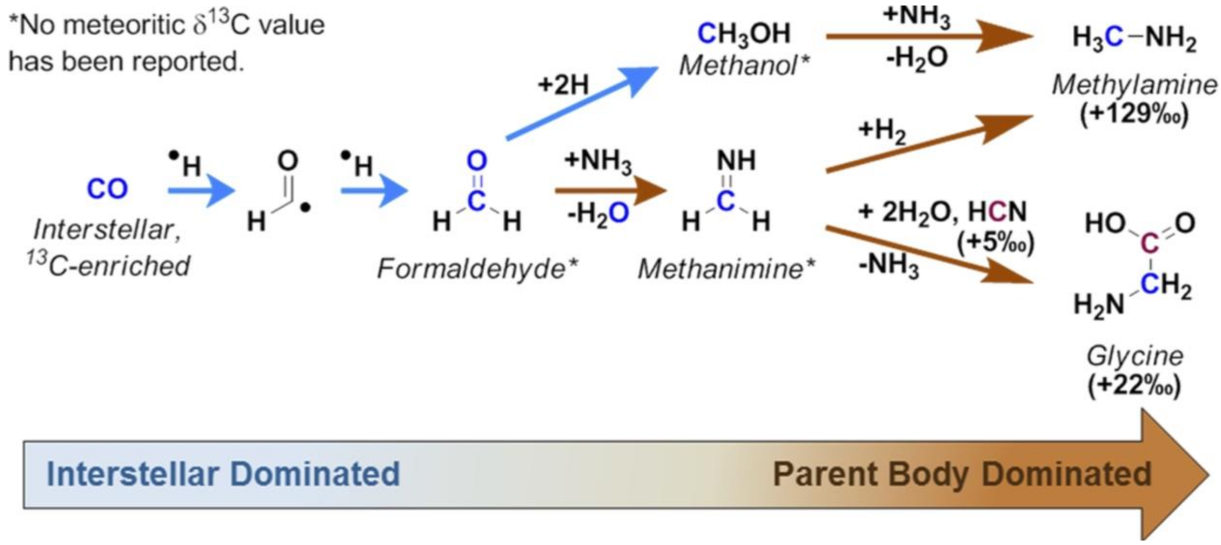

Figure 3: The Strecker-cyanohydrin synthesis and reductive amination of formaldehyde is one of several potential synthetic routes for glycine and methylamine. In the Murchison meteorite ^{13}C-enriched CO from the interstellar medium results in ^{13}C-enriched glycine and methylamine. These reactions may be dominant but not exclusive inside the indicated environments. [from 3]

The presence of chiral excesses in some amino acids [2] also point to an unknown enrichment and amplification process in solar system history. Though amino acids and related compounds are informative and perhaps the best studied, they not the only interesting class of compounds which can be extracted from meteorites [e.g. 1].

The complex mixture organics and the presence of chiral asymmetry in meteorites could have implications for the potential of habitability and complicate the discrimination of meteoritic influx, terrestrial contamination, and extra-terrestrial biomarkers.

2. References

[1] Glavin D.P., O'D. Alexander, C.M., Aponte, J.C., Dworkin, J.P., Elsila, J.E., and Yabuta, H. The origin and evolution of organic matter in carbonaceous chondrites and links to their parent bodies, in Primitive Meteorites and Asteroids, ed. Neyda Abreu, Elsevier, in press.

[2] Elsila, J.E., Aponte, J.C., Blackmond, D.G., Burton, A.S., Dworkin, J.P., and Glavin, D.P. Meteoritic amino acids: Diversity in compositions reflects parent body histories, ACS Central Science, Vol. 2, pp. 370-379, 2016.

[3] Aponte, J.C., Elsila, J.E., Glavin, D.P., Milam, S.N., Charnley, S.B., and Dworkin, J.P. Pathways to meteoritic glycine and methylamine, ACS Earth and Space Chemistry, 1, 3-13, 2017.

Short Summary

The study of organic compounds, especially amino acids, in a range of meteorites trace the history of the solar system and the material available for habitable worlds.