Goldschmidt 2024 Abstract
https://doi.org/10.46247/gold2024.23000

Isotopic evidence for the origin and evolution of complex organics in the early solar system

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Carbonaceous meteorites and samples returned from undifferentiated asteroids preserve evidence of diverse, structurally complex organic compounds and macromolecular materials in the early solar system. These organics supplied volatiles to planetary bodies, connect early solar system materials and processes to astronomical observations of organics, and illuminate mechanisms, prebiotic chemistry.

The stable isotopes of H, C, N O and S have long been used to study the origins and evolution of early solar system organics, and the emergence of technologies for measuring site-specific and multiply-substituted isotopologues of organic compounds has enabled more quantitative and specific constraints on the early solar system's organic chemistry.

Anomalous enrichments in multiply D and ^{13}C substituted PAH's from CM and CI chondrites and the Ryugu asteroid suggest a large fraction of these compounds were synthesized by ion-molecule or ice grain chemistry at temperatures of 10's of K, presumably in the interstellar medium or molecular clouds. However, an extensively aqueously altered CM chondrite preserves no such evidence, and D/H ratios of a subset of PAH's from other meteorites suggest partial exchange with parent body water; together, these suggest an organic chemistry in asteroid interiors that reacts and/or generates PAH's.

The site-specific carbon isotope compositions of a, b and di-carboxylic amino acids from the Murchison meteorite preserve records of abiotic organic synthesis pathways (Strecker synthesis, Michael addition, and reductive amination, respectively)—operating on a suite of simple precursors, including aldehydes, ketones and nitriles. The combination of these data with previously published compound specific C and H isotope data suggest a network of organic synthesis that created dozens of small, soluble organics from common precursors, followed by variable exchange of carboxyl groups and hydrogen atoms with D-poor waters. This implies a two-stage history of prebiotic synthesis in the early solar system, drawing on precursors from the ISM or nebula and creating other compounds in asteroidal 'kitchens'.

Finally, new evidence for the timing and location of this organic chemistry in the solar nebula and disk is found in the C and O isotope signatures of solids from primitive meteorites, which exhibit systematic relationships to each other and to the NC/CC dichotomy.