Synthesis of Amino Acid Precursors with Organic Solids in Planetesimals with Liquid Water

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Introduction: Amino acids are important ingredients of life that would have been delivered to Earth by extraterrestrial sources, e.g., comets and meteorites. Amino acids are found in aqueously altered carbonaceous chondrites in good part in the form of precursors that release amino acids after acid hydrolysis [e.g. 1]. Meanwhile, most of the organic carbon (>70 weight %) in carbonaceous chondrites exists in the form of solvent insoluble organic matter (IOM) with complex macromolecular structures [e.g. 2]. Complex macromolecular organic matter can be produced by either photolysis of interstellar ices [e.g. 3] or aqueous chemistry in planetesimals [e.g. 4]. We focused on the synthesis of amino acids during aqueous alteration, and demonstrated one-pot synthesis of a complex suite of amino acids simultaneously with IOM via hydrothermal experiments simulating the aqueous processing [5].

Experimental: We conducted hydrothermal experiments isothermally at 90°C up to 250°C for 72 hours with a starting solution containing formaldehyde, glycolaldehyde (the simplest condensate of formaldehyde), ammonia, and water with a molar ratio of $C/N/H_2O$ (7.2:0.72:100) and some $Ca(OH)_2$, following our previous method of organic solid synthesis [6]. This starting composition was selected on the basis of the assumption that organic matter in carbonaceous chondrites and comets was formed from a common precursor material that originated in the outer solar system and/or the interstellar medium. We studied the amino acid products by high performance liquid chromatography (HPLC) and ultra performance liquid chromatography with fluorescence detection/quadrupole time-of-flight hybrid mass spectrometry (UPLC-FD/QToF-MS).

Results and Discussion: Amino acid products from hydrothermal experiments after acid hydrolysis include α-, β-, and γ-amino acids up to five carbons, for which relative abundances are similar to those extracted from carbonaceous chondrites [5]. The amino acid abundances are much lower in the nonhydrolyzed fraction than in the acid-hydrolyzed fraction, which suggests that most of the amino acid experimental products are present as the bound form. The yield of amino acids after acid hydrolysis of our experimental products, ~20 μg of glycine relative to 20 mg of organic solids [6], is consistent with that in the Murchison meteorite, where yields of glycine and IOM are 7 μg/g and 20 mg/g, respectively [7]. Preliminary results from the experiments with minerals show that both montmorillonite (clay) and olivine enhance the yield of amino acids.

Conclusions: The aqueous chemistry in planetesimals, starting from ubiquitous simple molecules such as formaldehyde and ammonia, is a plausible scenario to explain the wide variety of organic matter including amino acids and organic solids found in the aqueously altered chondrites.

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