Chemistry of formaldehyde and ammonia in the Solar System small bodies

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Formaldehyde and ammonia is ubiquitous in the universe. Comets contain up to 4% H_2CO and up to 1.5% NH_3 relative to H_2O, and interstellar medium (ISM) contains up to 8% H_2CO and up to 80% NH_3 relative to H_2O [1]. Cody et al. [2] proposed the formation scenario of insoluble organic matter (IOM) in chondritic meteorites, in the presence of liquid water starting with formaldehyde and glycolaldehyde that is the simplest sugar produced by two H_2CO molecules. We have conducted further experimental studies and showed that the presence of ammonia enhanced the IOM like organic solid formation via formose reaction followed by carbonization [3]. These studies were focusing on the solid materials, and now we study the liquid phase of the products with various analytical methods including electrospray ionization mass spectrometry (ESI-MS), X-ray absorption near edge structure (XANES), infrared spectroscopy and amino acid analyses using high performance liquid chromatography (HPLC).

Each starting solution contained 1mL water with 2 mmol formaldehyde, 1 mmol glycolaldehyde, 0.4 mmol ammonia (equivalent to H_2O : C : N = 100 : 7.2 : 0.72) with catalytic amount of $Ca(OH)_2$, and was sealed in a glass tube, then isothermally heated at 90 degrees C up to 250 degrees C. XANES and FTIR analyses showed that aromatic or olefinic C=C bond abundance increased with temperature in the soluble fractions. This indicates that the insoluble residues precipitate as a result of increase in the hydrophobic moieties in the products as the reaction proceeds. This is consistent with the previous results that the amount of insoluble fractions (organic solids) increases with temperature [3]. Acid hydrolysis of the solutions produced various amino acids up to four carbons. Alanine abundance was larger than glycine, and may indicate high abundance of methyl ($-CH_3$) or methylene ($-CH_2-$) substitutions in the amino acid precursor molecules. ESI-MS results suggested that various carbohydrates (CHO molecules) and these with nitrogen containing substitutions. This is somewhat consistent with ultrahigh-resolution ESI-MS analysis of the Murchison meteorite extract that shows various CHO and CHNO molecules [4], although only formaldehyde and ammonia chemistry cannot explain all of the diverse molecules found in this meteorite.

References:

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