Composition of Irradiation Residue from Jupiter Trojan Laboratory Simulations

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Abstract

Today's Jupiter Trojan asteroids may have originated in the Kuiper Belt (eg. Morbidelli et al. *Nature* 2005, Nesvorny et al. *ApJ* 2013) and migrated to capture at their present locations. If this is the case, it is expected that their surfaces will contain chemical traces of this history. Our work broadly considers laboratory simulations of this history. In this work we report on the refractory residue left behind when irradiated mixed ice samples were brought to Earth-normal conditions and removed from the vacuum system. Ices that will be discussed include a 3:3:3:1 mixture of H_2S:NH_3:CH_3OH:H_2O; and a 3:3:1 mixture of NH_3:CH_3OH:H_2O. After deposition at 50K, the ices were irradiated with a beam of 10 keV electrons to form a processed crust mixed with unreacted ices. The films were then warmed to 142K under irradiation over several days. After stopping irradiation, the mixtures were slowly heated through the desorption temperatures of the unreacted ices (about 150-180K), leaving only more-stable compounds behind, and up to room temperature. Some of the reaction products were seen to desorb during heating to room temperature, while a significant amount remained as a refractory residue. After backfilling the vacuum system with nitrogen gas, residues were analyzed by Fourier Transform Infrared Spectroscopy, Secondary Ion Mass Spectrometry, and Gas Chromatograph Mass Spectrometry. Results indicate a complex chemistry including aliphatic and aromatic hydrocarbons, and nitrogen and sulfur-containing organics. Notably, when sulfur is not present, a number of nitrogen-containing organic candidates are identified, however, in the mixtures containing sulfur, sulfur-containing compounds appear to dominate the chemistry. While these experiments were conducted with Trojan asteroids in mind, the results are also relevant to comets and other cold locations in the solar system that have experienced large swings in temperature.

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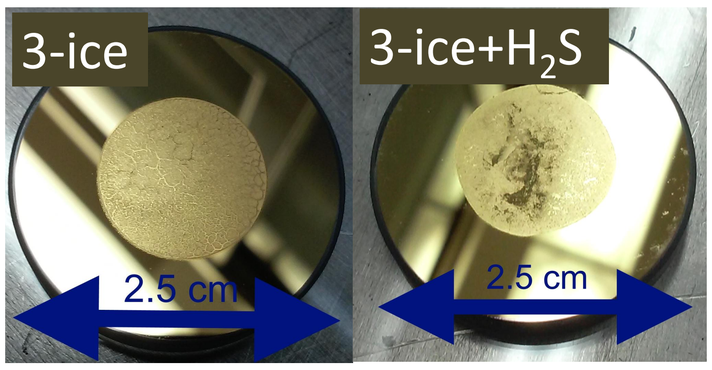
Images

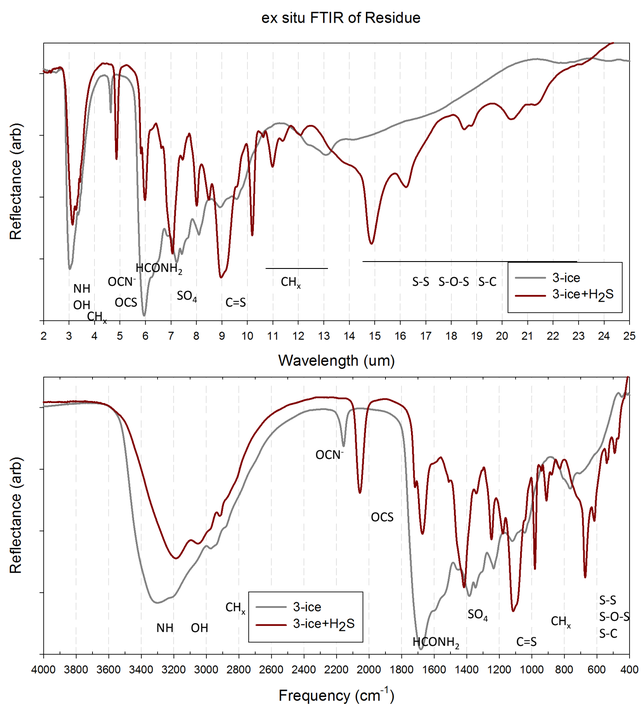
Images of the residues upon removal from the vacuum system. Lighting angle was chosen to draw out the physical morphology of the samples.

The 3-ice residue contained a network of thin cracks defining polygonal clumps of residue up to a few hundred micrometers in size. This residue was easily removed from the surrounding copper mount with methanol.

The 3-ice+H_2S residue appeared more diffuse and lacked an obvious crack network. This residue was difficult to remove with basic alcohols or acetone, but largely dissolved in dichloromethane.



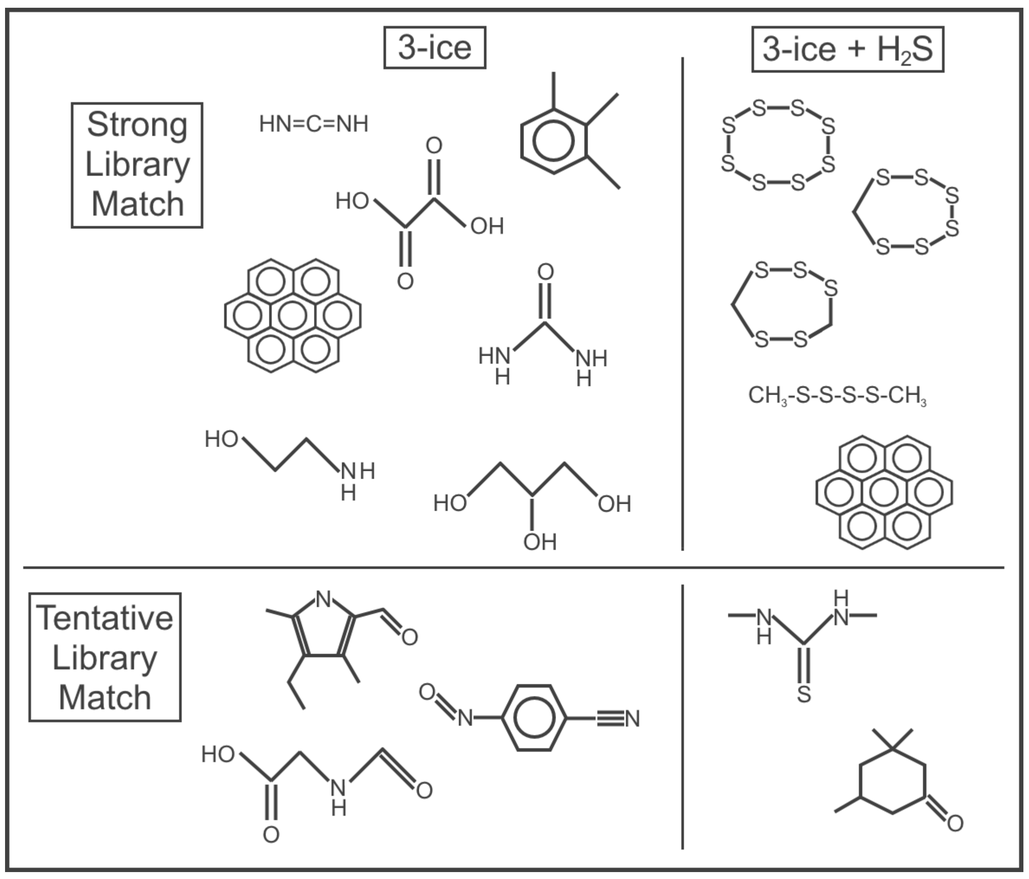
FTIR



Fourier Transform Infrared Spectrometry of residues in reflectance geometry was collected less than 48 hours after removal from the vacuum system. Tentative feature identifications are included on the plots. The inclusion of sulfur in the experiment (red line) dramatically changed the spectra. Numerous absorptions assigned to sulfur-containing species appear. In addition, absorptions assigned to nitrogen-containing species diminish, and some types of CH_x bonds appear to be absent. The S-R features are weak bonds, so their appearance indicates large amounts of these species.

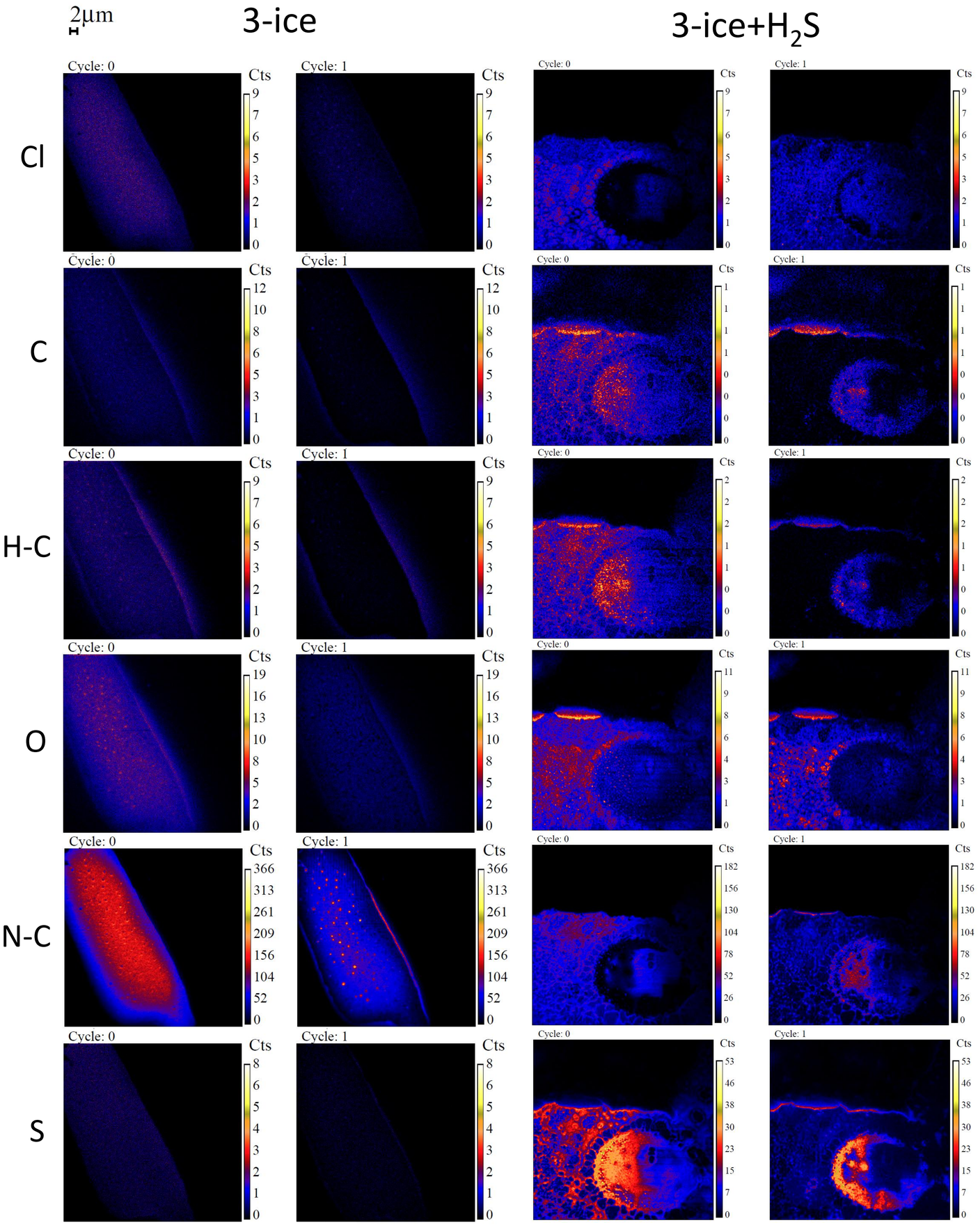
GC-MS

Extraction for Gas Chromatography - Mass Spectrometry was performed by scraping the residue off of the substrate with a clean razor blade followed by dissolving in dichloromethane. (The 3-ice+H_2S residue did not completely dissolve.) Triple-washing and several concentrating steps were used to reduce the solution to less than 20uL. Solvent-blanks were performed in parallel, to identify contaminants. All compounds were identified by library search for a single GC elution peak.



nanoSIMS

Secondary-Ion Mass Spectrometry images were collected with a CAMECA NanoSIMS 50L with Cesium sputtering source, magnetic sector mass sorting, and simultaneous collection with multiple detectors. No suitable standard was identified, so ionization and detection efficiencies are unknown. Therefore, data are reported as raw counts and are only suitable for comparison within a given image. Each image is 50x50 um with 0.05 um resolution and has its own color scale. Chlorine was tracked as a baseline. Oxygen appears to be anti-correlated with both nitrogen and sulfur. Nitrogen is generally found with sulfur, but sulfur occurs without nitrogen. Sub-micrometer texture was clearly different between the two residues.



Conclusions

The inclusion of H_2S in the irradiated ice dramatically changed the chemistry and physical morphology of the resulting room temperature residue. Several oxygen- and nitrogen-containing organics were detected in the 3-ice, but sulfur dominated the chemistry of the 3-ice+H_2S. The 3-ice residue showed a network of cracks, and about 1um pits or particles. The 3-ice+H2S residue was less homogenous and contained larger pits or particles of various sizes.