THREE DIMENSIONAL FTIR SPECTRO-MICROTOMOGRAPHY OF CARBONACEOUS CHONDRITES.

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Introduction: Carbonaceous chondrites are primitive meteorites whose chemical composition is highly heterogeneous. Their composition can be affected by various extraterrestrial processes in different enviroments, such as aqueous and thermal alteration in their parent bodies. Study of organic matter, its distribution, and spatial relationships is key to understanding processes and mechanisms for the formation of organic matter in the early solar system [1]. Our knowledge on formation and processing of organic matter is very poor [2], however study of composition and petrology of carbonaceous chondrites in situ can reveal these complex parent body processes and origin of constituents of meteorites.

We have previously shown that organic matter and mineral species can be mapped in situ in meteorites using two-dimensional infrared images with high resolution [3,4], which reveals relationships between organic matter and minerals micron length scales. In this work we study spatial distributions of organics and minerals in Murchison by utilizing a highly novel technique: synchrotron-based three dimensional infrared microspectroscopy. This technique is potentially the most efficient method for investigation of how and where different molecular functional groups are spatially distributed in situ in extraterrestrial samples.

Experimental: Three-dimensional infrared microtomography has recently been made possible for the first time, which reveals internal chemical composition and spatial distributions. A full mid-infrared range spectrum is obtained for every voxel, providing a fourth spectral dimension [5]. We have conducted our FTIR spectro-microtomography experiments at IRENI beamline at the Synchrotron Radiation Center, University of Wisconsin in Madison. A large number of transmission images were collected as the meteorite sample was rotated in time. These images constitute our tomographic dataset for three-dimensional representation of the meteorite sample [e.g., 6]. Additionally, full mid-infrared spectrum was collected for each orientation as a fourth dimension. Reconstruction of tomographic data is done in software.

Results: Infrared spectrum of the Murchison sample studied here shows signatures of several molecular functional groups. Si-O stretching, C-H bending, C=O stretching, C-H stretching, and O-H stretching vibrational modes are among those we observed. Three-dimensional reconstructions show that silicate-rich and silicate-poor regions are distinctly visible in the reconstruction. Structural water obtained from H-O-H bending vibrational modes is distributed roughly uniformly throughout the grain, and appears as small grains. Distinct from the others is the distribution of carbonyls, which is distributed mostly in the lower half of the grain.

Figure 1. Three dimensional reconstruction of Si-O stretch in silicates (left) and C-H bend in aliphatics (right).

In addition to individual reconstructions, we also generated reconstructions of combinations of chemical functional groups in order to reveal relative spatial relations among organics and minerals, and allow pair-wise comparisons in three dimensions. For instance, sulfates and structural water appear to overlap well, which may have implications regarding the formation of sulfates from aqueous alteration. Finally, we generated reconstructions of all of the components observed in this study, which makes up the whole Murchison grain (Figure 2).

Figure 2. Three dimensional reconstruction of all of the chemical components observed in this study via infrared micro-spectroscopy.

The fourth dimension in our dataset is the infrared spectra. In addition to visual investigation in three-dimensional space, different regions of the grain can be studied spectrally since reconstruction of the whole Murchison grain investigated here consists of more than two million voxels, each with associated full mid-infrared spectrum. Infrared spectra extracted from different regions of the studied Murchison grain presents correlations of organics with minerals. For instance, silicates and sulfates appear to be positively correlated with carbonates, all of which are products of aqueous alteration.

Summary: Three-dimensional infrared spectro-microtomography is a highly novel non-destructive technique which has the advantage of locating specific organics and minerals within samples of interest in three dimensional space and reveiling their interrelationships. Infrared spectra obtained from voxels offer spectral characterization of meteoritic constituents within their local mineralogy. This technique has significant potential for the investigation and characterization of extraterrestrial samples including samples returned from missions such as Osiris-REx and Hayabusa-2.

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