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Insights into the Formation and Evolution of Organics within Carbonaceous Chondrite Meteorites from Hyperspectral Raman and Infrared Mapping

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Abstract

Here we present results of high-resolution (~µm-scaled) hyperspectral maps of several carbonaceous chondrite meteorites surfaces, imaged in both Raman and potentially high resolution FT-IR (Nano-IR). These maps allow for analysis of multiple variables simultaneously, and can be utilized to discern conditions favorable or disfavor able to specific organics formation/destruction, and may provide insight into the primordial evolution of these meteorites and their parent bodies during the early formation of the Solar System.

1. Introduction

Carbonaceous chondrites parent bodies possessed several conditions that promote the formation of complex organic species (notably including peptide bond formation at lower temperatures, and polycyclic aromatic hydrocarbons at higher temperatures). Many carbonaceous chondrites experienced peak metamorphic temperatures (PMTs) conducive to the formation of peptide bonds, including**:** **i)** temperature ranges of 85 - 150 °C, **ii)** mineral and/or metal catalytic surfaces, **iii)** high levels of precursor chemical species available, such as amino acids and/or hydroxy acids, **iv)** as well as the presence of an aqueous environment. The PMT for carbonaceous chondrites can be derived via Raman spectroscopy of the D/G carbon bands, as well as the presence of particular mineral catalysts, and some information on the levels of organics present (*e.g.,* PAHS). These spatial studies can be correlated with additional techniques to gain additional insights into the evolution of organic matter within these bodies by combining these efforts with results on: **i)** Complimentary information from nanoIR, down to 10-20 nm in spatial scale, **ii)** The elemental composition down to atomic scales, from SEM/TEM-EDS, **iii)** further information about the volatile content from down to 100-nm in scale from time-of-flight secondary ion mass spectrometry (ToF-SIMS) and high-resolution two-laser desorption mass spectrometry (HR-L2MS).

2. Meteorite Sample Information

We have performed Raman, SEM/TEM, ToF-SIMS, HR-L2MS, and occasionally nanoIR analyses on several samples, including Murchison (CM2), Allende (CV3), Tagish Lake (C2), Jbilet Winselwan (CM2), Aguas Zarcas (CM2), and Jaipur (CM2) meteorites.

3. Hyperspectral Fitting Routine

An automated fitting procedure has been developed utilizing to analyse high-resolution hyperspectral maps, including: **i)** Lorentzian curve fitting to derive PMTs using equation 1 [1], **ii)** Pseudo-Voigt curve fitting has also been implemented to derive PMTs by equation 2 [2], **iii)** determination of the proportions of olivine and Mg/Fe ratios in the samples, based on equations 3-5 [3], and **iv)** levels of different PAHs present based on fluorescence levels.

4. Equations Used

Temperature fitting:

$$\mathrm{PMT}(^\circ\mathrm{C}) = 931 - 5.1 \times \Gamma_D + 0.0091 \times \Gamma_D^2. \quad (1)$$

$$\mathrm{PMT}(^\circ\mathrm{C}) = -6.9 \times \Gamma_D + 1054.4 \quad (2)$$

Olivine Type Fitting:

$$\mathrm{Mg\#} = -0.17744 - 0.050049\omega + 0.0026479\omega^2 \quad (3)$$

$$\mathrm{Mg\#} = [\mathrm{Mg}/(\mathrm{Mg} + \mathrm{Fe})] \quad (4)$$

$$\omega = \text{Center peak 2} - \text{Center peak 1} \quad (5)$$

5. Example Property Maps

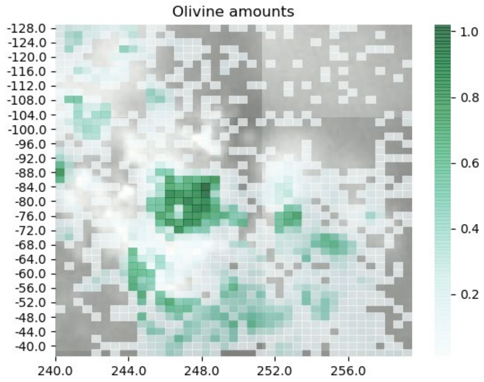

Figure 1: Amount of olivine in Murchison

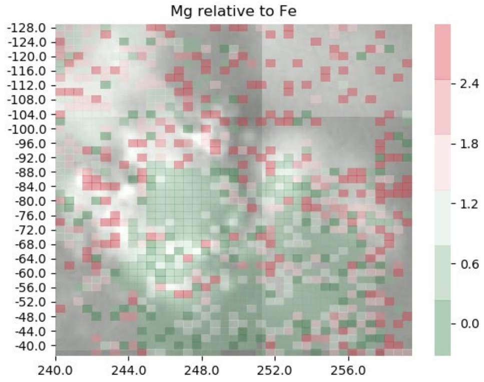

Figure 2: Ratio of Mg/Fe in Olivine (in Murchison)

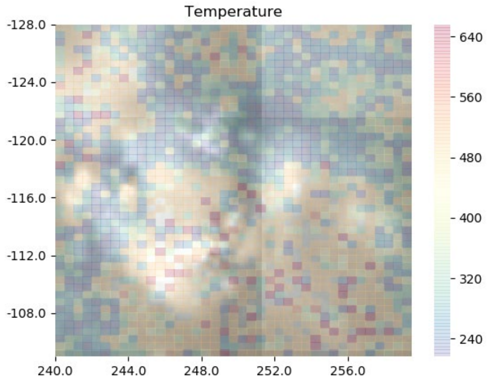

Figure 3: Peak Metamorphic Temperature (PMT), derived from Raman spectroscopy in Murchison

6. Summary and Conclusions

Correlations between environmental conditions and molecular inventories as a function of meteorite will be presented - these multiple variable maps will later be cross-referenced with other types of fitting to determine favorable formation conditions for specific classes of organic molecules. Preliminary ToF-SIMS, HR-L2MS, nanoIR, and SEM/TEM-EDS data may be presented, as well as correlations between the Nano-IR, ToF-SIMS, HR-L2MS, TEM/SEM-EDS data and the multi-variable Raman maps, with a focus on the observed variations and similarities of the organic inventories common to these meteorites. The potential implications of these findings will be discussed in terms of the origins of these bodies, and their role in the dispersal of organic species throughout the early Solar System.

Acknowledgements

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