INVESTIGATING THE EFFECTS OF HYDROTHERMAL ALTERATION ON ABUNDANCES AND STABLE ISOTOPIC COMPOSITIONS OF METEORITIC ORGANIC MATTER THROUGH LABORATORY SIMULATIONS. D. N. Simkus1,2,3, D. I. Foustoukos4, H. L. McLain1,2,3, C. M. O’D. Alexander5, J. C. Aponte1, F. Seguin1,3,5, G. D. Cody6, J. E. Elsila1, and J. P. Dworkin1. 1NASA Goddard Space Flight Center (GSFC), Greenbelt, MD, USA, 2Catholic University of America, Washington, DC, USA, 3Center for Research and Exploration in Space Science and Technology, NASA GSFC, Greenbelt, MD, USA, 4Carnegie Institution of Washington (CIW), Washington, DC, USA, 5University of Maryland Baltimore County, MD, USA

Introduction: Chemical reactions within asteroids driven by hydrothermal alteration are thought to have played a key role in synthesizing biologically relevant organic molecules in the early solar system. These chemical processes are recorded in the abundances and stable isotope ratios of meteoritic organic matter [1, 2].

By measuring the molecular distributions and stable carbon isotope (δ13C) ratios of meteoritic soluble and insoluble organic matter (SOM and IOM, respectively) we gain insights into the prebiotic inventory of the early solar system, the structural relationships between meteoritic compound classes, and the abiogenic synthesis of organic molecules within parent body asteroids. However, the relationship between hydrothermal alteration and the synthesis/preservation of organic matter in the asteroid parent body can be difficult to decipher based on meteorite studies alone because individual meteorite samples have not only experienced varying levels of parent body alteration, but they also had distinct compositions of organic building blocks and water and, in many cases, have been exposed to differing levels of terrestrial weathering [3].

Here, we have eliminated these sources of uncertainty by simulating parent body aqueous alteration on meteorite samples of known starting compositions. We investigated the influence of hydrothermal processing on SOM (aldehydes, ketones, monocarboxylic acids (MCAs), and amino acids) and IOM by mimicking relatively low-temperature (150°C) parent body aqueous alteration on samples of the Murchison meteorite.

Materials and Methods: All glassware, ceramics, and tools used for sample preparation and analysis were heated at 500°C overnight before use. A 1.1 g sample of Murchison meteorite (U. Illinois, Chicago) was crushed into a homogenous powder using a mortar and pestle and divided into two ~ 0.5 g bulk samples (Bulk 1 and 2; Scheme 1). Alteration experiments were carried out on (1) bulk meteorite powders and (2) isolated IOM, to test our hypothesis that IOM-derived SOM is a primary influence on meteoritic organic compound abundances and δ13C values.

Unaltered meteorite: Bulk 1 represents the starting baseline composition of a relatively “unaltered meteorite”, and was extracted and analyzed using established methods for SOM analysis (aldehydes, ketones, MCAs, and amino acids) [4 – 10], bulk H, C, and N analysis of meteorite powders [11], and elemental and isotopic analysis of isolated IOM [11].

Alteration of bulk meteorite powder: Bulk 2 was carried through an alteration experiment as follows: Five 100 mg aliquots of the bulk meteorite powder were sealed under vacuum, each with 200 µL of ultrapure water in 10 mm-diameter glass tubes. The samples were hydrothermally processed at 150°C for 7 days. After heating, the supernatants (“bulk alteration fluid”) were collected and prepared for SOM analysis, and the residual meteorite powder was analyzed.

Alteration of IOM: In addition to the alteration experiment conducted on bulk meteorite powder, isolated IOM was hydrothermally altered in the absence of SOM and minerals to monitor specifically for IOM-derived aldehydes, ketones, MCAs, and amino acids. Hydrothermal alteration of the IOM was carried out as follows: 1.3 mg of Murchison IOM was sealed under vacuum with 200 µL of ultrapure water in a 10 mm-diameter glass tube and processed at 150°C for 7 days. After heating, the supernatant (“IOM alteration fluid”) was collected and prepared for SOM analysis, and the residual IOM was analyzed.

Scheme 1. Schematic of sample types and experiments carried out in this study to evaluate the compositions of an (1) unaltered meteorite, (2) hydrothermally altered meteorite, and (3) IOM-derived SOM. Blue ovals: SOM samples. Orange ovals: IOM samples.
For each set of SOM and IOM analyses, all sample types (“unaltered meteorite,” “bulk alteration fluid,” “altered meteorite,” and “IOM alteration fluid”) were analyzed at the same time to eliminate the potential for temporal instrumental effects. Samples were stored in the -20°C freezer until all samples were ready for analysis. Procedural blanks were prepared and analyzed in parallel with the meteorite samples for all experiments.

Results and Discussion: The hydrothermal alteration reactions conducted on bulk meteorite powders and isolated IOM resulted in distinct shifts in molecular distributions and stable isotopic abundances. General trends included the following:

- Except for formaldehyde, the aldehyde abundances in the bulk alteration fluid were notably high, indicating that aldehydes were produced or released from meteoritic organic matter through hydrothermal processing of bulk meteorite powder.
- Ketones did not follow the same shift. Individual ketone abundances remained constant or decreased through hydrothermal processing.
- Formic acid abundances in the bulk alteration fluid and in the altered meteorite samples were relatively low, indicating that formic acid reacted quickly during hydrothermal processing [12].
- Other MCAs (e.g., acetic acid, propanoic acid, etc.) increased in abundances in the alteration fluid, indicating they were produced or released through hydrothermal processing.
- The relative abundances of amino acids varied through hydrothermal processing and generally decreased, suggesting they reacted or decomposed through alteration-driven chemistry [13].
- Compound-specific δ13C values for aldehydes and ketones detected in the residual altered meteorite were shifted towards 13C-depleted values. This shift towards 13C-depleted values was observed for some, but not all, MCAs.
- Trace levels of aldehydes, ketones, MCAs, and amino acids were detected above background levels in the IOM alteration fluids, suggesting that some SOM may be IOM-derived. The measured δ13C values for these compounds were relatively 13C-depleted.
- IOM δ13C values shifted towards relatively 13C-enriched compositions through hydrothermal processing, suggesting a preferential loss/reaction of isotopically light carbon.

Conclusions and Future Work: Our alteration experiments produced clear compositional differences between unaltered and altered meteorite materials, revealing interesting shifts in stable carbon isotope abundances. These molecular and isotopic changes will be discussed in detail in comparison to trends observed from previous meteorite studies [e.g., 8, 10, 14, 15] and simulation work [e.g., 16, 17], and future work will repeat these experiments using other CM and CR carbonaceous chondrite samples.

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