

FLUID EVOLUTION ON CARBONACEOUS ASTEROIDS: INTERROGATING THE CARBONATE RECORD

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Introduction: As exploration and sample return missions to water and organic-rich solar system bodies proceed, understanding the nature and timing of reactions between water and rock in the early solar system has become an increasingly important area of study. Many carbonaceous asteroids show signs of having hosted liquid water early in their history, with resulting complex organic and inorganic chemistries. Carbonaceous chondrites record a variety of fluid conditions and histories, with variation in alteration extent, fluid chemistry, isotopic composition, and alteration temperature. However, detangling the contributions of each variable in the evolution of the fluid has proven challenging. We have initiated a systematic study of multiple stable isotope systems in carbonate minerals using new techniques in both in-situ and bulk carbonate analyses to identify the temperatures and isotopic compositions of fluids present in various generations of aqueous alteration in CM chondrites spanning the full range of alteration extent.

In-situ analysis of carbonates: In-situ work by ion microprobe is required to take advantage of petrologic information in the small and complex assemblages in which carbonates are found. Previous ion probe studies of carbonates carried out at high spatial resolution have revealed wide ranges of isotopic and chemical compositions from several generations of carbonate precipitation, even within single thin sections [1, and others]. These studies require closely matrix-matched standards, as use of carbonate standards with incorrectly-matched iron and magnesium contents can result in errors of up to ~15‰ in $\delta^{18}\text{O}$ [2-4] and several per mil in $\delta^{13}\text{C}$ [3,5]. In previous studies of meteoritic carbonate, matrix mismatches are likely to lead to errors in dolomite measurements of up to ~5‰ in $\delta^{18}\text{O}$ and ~2‰ in $\delta^{13}\text{C}$ if a dolomite standard of incorrect Fe content is used, obscuring the conclusions about fluid evolution which can be drawn regarding these samples.

We plan in-situ measurements of $\delta^{18}\text{O}$, $\Delta^{17}\text{O}$, and $\delta^{13}\text{C}$ using the Cameca ims-1290 at UCLA from chemically and texturally well-characterized carbonates from a suite of CM chondrites ranging from fully-hydrated CM 1.0 to more weakly-altered (2.8) samples. We have also characterized several terrestrial calcite, dolomite, and mixed carbonates of a variety of compositions for use as appropriately matrix-matched standards for sample-standard bracketing during the analysis. First results from our CM samples will be presented at the conference.

Bulk carbonate digestion: The clumped-isotope thermometer can be applied to CO_2 gas evolved from carbonate minerals to determine the temperature of formation independently of the fluid's composition, as the temperature is determined by the relative proportion of bonds between ^{13}C and ^{18}O in the crystal, measured as the mass-47 ($^{13}\text{C}^{18}\text{O}^{16}\text{O}$) isotopologue of CO_2 . This technique has been applied to carbonaceous chondrites in the past, but because the digestion averages a potentially diverse population of carbonates, previously obtained temperatures could be artifacts of mixing various populations of different isotopic compositions and temperatures rather than true formation temperatures [6]. The value of $\Delta^{17}\text{O}$ of the sample is also required to apply the clumped isotope thermometer, but previous clumped-isotope work in meteorites relied on literature data to estimate $\Delta^{17}\text{O}$. Due to the heterogeneous and brecciated nature of many carbonaceous chondrites, $\Delta^{17}\text{O}$ can vary between individual splits of the same meteorite and should ideally be measured from the same digestion as the clumped species.

To overcome these limitations, we plan stepped phosphoric acid digestion of a suite of CM chondrite samples spanning the full range of alteration extent, as described in [7]. In addition to measuring $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and Δ^{47} , we will use the Nu Panorama, a large-geometry gas source mass spectrometer with extremely high mass resolution and stability to simultaneously determine $\Delta^{17}\text{O}$ and two clumped species, Δ^{47} and Δ^{48} , for the same digestions [8]. The use of two clumped isotope thermometers for a single sample can identify the presence of mixing if the two clumped-isotope thermometers do not yield the same temperature. The populations of carbonates identified by in-situ study can be used to further constrain mixing and identify the temperatures at which the various populations formed. We will present tests and preliminary results of this method at the conference.

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