THERMAL CONDITIONS OF FLUID CIRCULATION IN HYDRATED ASTEROIDS

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Introduction: Asteroids are super-kilometer-sized bodies formed by gravitational instability in turbulent regions of the protoplanetary disk. Hydrated C-type asteroids −the most common bodies in the main asteroid belt experienced subsequent heating due to heat released by the decay of ^{26}Al. However, quantitative estimation of their thermal histories has not yet been possible, leading to considerable uncertainty on the physical characteristics of early-formed primitive rocky bodies. Aqueously-formed carbonaceous chondritic minerals such as carbonates represent direct snapshots of the asteroidal fluids and can in theory be used to decipher their thermal evolution. However, determining carbonate precipitation temperatures requires knowing the O-isotopic compositions of their parent fluids, which itself requires to know the carbonate precipitation temperatures, leading to a seemingly endless problem. Here we report *in situ* O-isotopic analyses of Ca-carbonates and propose a new isotopic alteration model that reconciles petrographic observations and formation temperatures of CM carbonates.

Methods: Detailed observations of calcite grains in polished sections of the CM2 Murchison and Mukundpura were made using a scanning electron microscope (SEM) JEOL JSM-6510 equipped with an Energy Dispersive X-ray (EDX) Genesis detector. Their oxygen isotopic compositions were determined using a CAMECA ims 1280 HR2 ion microprobe at CRPG (Nancy, France).

Results: Only calcite grains surrounded by serpentine (hereafter T1 calcite) were found in the two polished sections of Murchison. O-isotopic measurements show that Murchison's T1 calcites have $\delta^{18}O$ values between 25.5 and 41.5‰, $\delta^{17}O$ values between 14.5 and 23.5‰ and $\Delta^{17}O$ values between -1.1 and 1.8‰ (n = 24). In contrary, two types of carbonates were found in the polished section of Mukundpura: (i) T1 calcite grains and (ii) polycrystalline grains of calcite containing Fe-Ni sulfide inclusions (hereafter T2 calcite). O-isotopic analyses on Mukundpura's Ca-carbonates reveal that (i) T1 calcites have $\delta^{18}O$ values between 27.4 and 38.2‰, $\delta^{17}O$ values between 13.3 and 18.5‰ and $\Delta^{17}O$ values between -1.4 and -0.2‰ (n = 8), whereas (ii) T2 calcites have $\delta^{18}O$ values between 12.4 and 18.6‰, $\delta^{17}O$ values between 4.2 and 7.3‰ and $\Delta^{17}O$ values between -4 and -0.9‰ (n = 13).

Discussion: Our data define a mass-independent trend that is similar, within errors, from those commonly reported in different CM chondrites [1-3]. In first approximation, this trend suggest that the O-isotopic compositions of CM carbonates is essentially controlled by variable degrees of isotopic exchanges between ^{16}O-rich anhydrous silicates and a $^{17-18}O$-rich fluid [4]. However, when considering only T1 calcites, their O-isotopic compositions define a distinct trend that is indistinguishable, within errors, from the TFL (i.e., average $\Delta^{17}O = -0.4 \pm 1.0$). Conversely, T2 calcites exhibit clustered $\delta^{17}O$- $\delta^{18}O$ values with average $\Delta^{17}O$ of -2.6 ± 1.0, which artificially generate the aforementioned mass-independent trend. This demonstrates that petrographic observations of carbonates are essential for understanding the O-isotopic evolution of asteroidal fluids and the constraints they bear.

Direct estimations of the O-isotopic composition of asteroidal alteration fluids was possible thanks to CO_2 clumped-isotope thermometry (Δ^{47}, [5]). Based on measurements performed on the T1 calcite-dominated CM chondrites Murchison and Murray, this led to alteration fluids ranging from $\delta^{18}O = 2$ ‰ and $\Delta^{17}O = -0.55$ ‰ to $\delta^{18}O = 6.8$ ‰ and $\Delta^{17}O = -0.49$ ‰. As these fluids experienced oxygen isotopic exchanges with the anhydrous CM chondrite protolith ($\delta^{18}O = -3.8$ ‰, $\delta^{17}O = -6.5$ ‰; [6]), they define two trends that delimit the possible O-isotopic compositions of the alteration fluids. Considering these extreme trends, the precipitation temperatures of each calcite and serpentine can be calculated according their respective isotopic fractionation factor α. Our isotopic approach allows a formation sequence of CM secondary phases to be proposed, characterized by a temperature increase from T1 calcites < serpentines < T2 calcites. This implies that fluid circulation in CM parent body-(ies) occurs during a prograde evolution of the temperature, where T1 calcites formed first at T = 0-30 °C, followed by the precipitation of (Fe,S)-rich serpentine and tochilinite at T = 30-100°C and then T2 calcites at T = 110-140°C.

References:
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