EXPERIMENTAL SIMULATION OF FORMATION PROCESSES OF METAMORPHOSED CARBONATEOUS CHONDRITES.

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Introduction: Among known groups of carbonaceous chondrites there is a group of metamorphosed carbonaceous CM chondrites (MCCs), all members of which experienced thermal metamorphism after parent body aqueous alteration [1-4]. Texturally, these meteorites resemble CM2 chondrites, but differ in mineralogy, bulk chemistry and oxygen isotopic compositions. For instance, recently investigated MCCs Dhofar 225 and Dhofar 735 have affinities to the Belgica-like group of MCCs (Belgica 7904 and Yamato 86720) [5] (Fig. 1). Experimental results [5] showed that the oxygen isotopic compositions of Dhofar 225, Dhofar 725 and Belgica-like MCCs could not be derived from those of typical CM2 chondrites via a one-stage dehydration process caused by thermal metamorphism. Some investigations showed that carbonaceous chondrites may have experienced several repeated hydration-dehydration events [6]. Here we report results of experimental investigations of oxygen isotope fractionation of terrestrial olivine undergoing hydration-dehydration to test the hypothesis of multiple processing of the MCC parent asteroid and to confirm a possible genetic relationship between CM2s and MCCs.

Results: We used terrestrial olivine ($Fo_{90.9}$) with composition similar to MCCs. The olivine was powdered to a grain size of 1-10 μm and placed inside a nickel ampoule embedded in a steel autoclave. Hydration of olivine was conducted under T =300°C, P_{H2O} = 300 bar, for 100 days. We propose that hydration of olivine with water mass-independently enriched in ^{18}O (Table 1) allows better observation of all differences in oxygen compositions of the experimental product, and prepared water with high $\delta^{18}O$. This composition was similar in $\delta^{18}O$ to that calculated by [7] for the hydration process of anhydrous silicates from carbonaceous chondrites. The olivine was almost completely converted to serpentine during the hydration experiment that was confirmed by X-ray diffraction based on typical peaks (Fig. 1) compared to primary olivine. A chip (100 mg) of the serpentine obtained in the hydration experiment was powdered and homogenized. The sample was placed into a molybdenum crucible and heated under vacuum (~6 x 10^{-6} atm). It was heated to 900° C for an hour at this temperature corresponding to that at which olivine forms by complete dehydration of serpentine [8]. Oxygen isotopic compositions of olivine, experimental serpentine and dehydrated serpentine were determined by laser fluorination using the method described in [9] (Table 1, Fig. 2). Oxygen isotopic composition of experimental water (only $\delta^{18}O$) was determined by TC/EA (high-temperature carbon reduction and continuous flow elemental analyzer) coupled to a Delta Plus XP isotope ratio mass spectrometer via a ConFlo 3 interface. A glassy carbon tube at 1450°C was used in the furnace. The sample (0.2 μL) was injected into an on-line pyrolysis after five sample washes of 0.2 μL to prevent cross-contamination. Triplicate $\delta^{18}O$ analyses of water samples yielded 1σ of 0.3 ‰. Measurements of $\delta^{17}O$ in water samples were not possible, although the results of our experiments indicate that the water, as expected, was depleted in ^{17}O.

Discussion: The experiment on hydration-dehydration hypothesized that carbonaceous chondrites may have experienced several hydration-dehydration cycles and in this case the oxygen isotopic composition in the final material of a meteorite will record effects from both processes – aqueous alteration and thermal metamorphism on the parent body. The total result of the process of hydration-dehydration of terrestrial olivine in our experiments was enrichment in ^{18}O of the final material, dehydrated serpentine (olivine 2), by ~ 17 ‰ in $\delta^{18}O$ (Fig. 2, 3).

During hydration the oxygen isotopic exchange was equilibrated as confirmed by calculations of the mass balance, leading to the enrichment of experimental serpentine in ^{18}O. In the dehydration process, enrichment in ^{18}O resulted from mass-fractionation effects.

The total effect in $\delta^{18}O$ in the final dehydrated serpentine (which turned to olivine 2), overlaps the range of oxygen isotopic values of CMs and MCCs (Fig. 3). We note that the water and starting materials employed in this study had ^{17}O enrichments/depletions reversed from that of the CM precursor components, but similar $\delta^{18}O$. As such, the results are still very useful although the starting conditions are not entirely analogous. Indeed, the oxygen isotopic compositions of nebular silicates - precursors of phyllosilicates from CM2s, have $\delta^{18}O$ values somewhat lower (-4.2 ‰) [7] than those used here. Therefore, it should require several hydration-dehadration events to reach the oxygen isotopic composition of MCCs. Our results don't exclude the existence of a separate group of MCCs based on differences in their bulk chemistry and several mineralogical characteristics; however, several mineralogical differences, such as a low concentration of H_2O and a lack of tochilinite, could be explained by thermal metamorphism of CM material. Ultraviolet, visible and near infrared reflectance spectra of MCCs resemble those of C-, G-, B- and F-asteroids [10], which suggests that the surfaces of these asteroids may contain metamorphosed carbonaceous chondrite-like material. It has been proposed that the main source of heating during metamorphism is the energy of impact events, but the material of MCCs doesn't demonstrate shock features, although we can't exclude shock-induced quenching. Alternatively, the material of MCCs could be formed at the surface of asteroids with perihelion near the Sun, such as Phaethon [11] or Icarus [12]. Multiple approaches of these asteroids to the Sun could result in their heating and formation of the MCCs material during hydration-dehydration processes.

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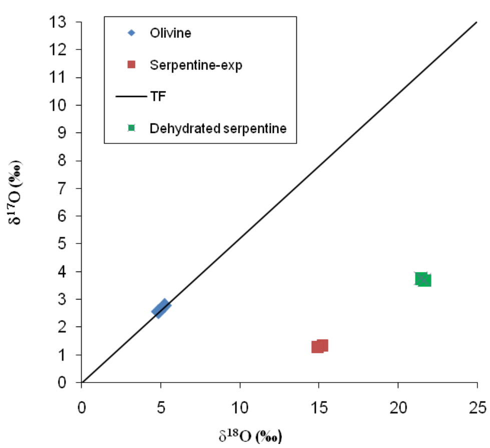

Fig. 1. Oxygen isotopic compositions of CMs, MCCs (Belgica-7904-like), Dhofar 225 and 735, terrestrial olivine, experimental serpentine, and dehydrated serpentine.

Table 1. Oxygen isotopic composition of olivine, experimental serpentine, dehydrated serpentine and experimental water (1 –before hydration, 2 - after hydration) (‰):

	$\delta^{17}O$	$\delta^{18}O$	Δ17O
Olivine	2.55	4.85	0.03
	2.78	5.23	0.04
Serpentine	1.32	15.21	-6.59
	1.25	14.93	-6.51
Dehydrated serpentine	3.74	21.46	-7.42
	3.68	21.68	-7.59
Water 1		21.5	
Water 2		37.1	

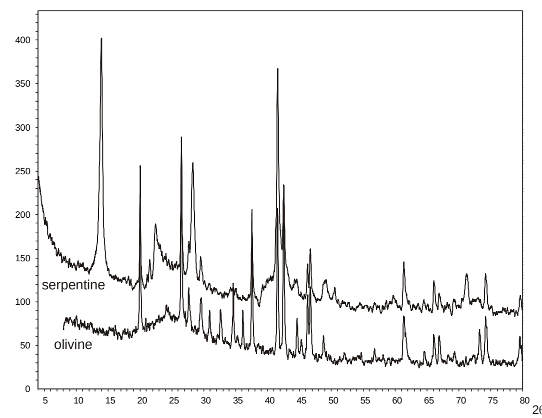

Fig. 2. Powder diffractometer traces for olivine and serpentine produced in the hydration experiment.

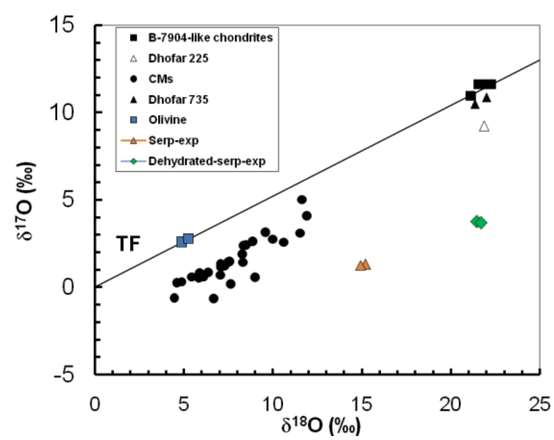

Fig. 3. Oxygen isotopic compositions of terrestrial olivine, experimental serpentine and dehydrated serpentine.