

## Oxygen isotopic ratio of the primordial water in CM chondrites

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CM chondrites are aqueously altered to various degrees in their parent body. Water ice accreted on the CM parent body reacted with primary anhydrous rock and organic matter producing secondary minerals. The O and H isotopic ratios of the primordial water are key constraints on its origin, however, they are still not well-constrained due to complex isotope exchange between water, rock, and organic matter during the aqueous alteration. Here I investigate the O isotopic ratio of the primordial water in CM chondrites based on bulk O isotopic ratios of CM chondrites and H abundances of their phyllosilicate. Most of the O and H data are from Clayton and Mayeda (1999) and Alexadner et al. (2013).

CM Falls show an apparent correlation between bulk  $\delta^{18}\text{O}$  values and H abundances of their phyllosilicate. The regression line of the CM Falls passes through the representative compositions of anhydrous silicate and phyllosilicate matrix in CM chondrites, indicating a mixing line between these two components as endmembers. This well-defined mixing line strongly indicates that the O isotopic ratios of bulk CM chondrites reflect variable amounts of anhydrous silicate and phyllosilicate, i.e., degrees of alteration. A consequence from the mixing line is that phyllosilicate in CM chondrites must have a common O isotopic ratio irrespective of their alteration degrees.

Oxygen isotopic ratios of phyllosilicate are dependent not only on alteration degrees but also on water/rock ratios. Here alteration degrees ( $f$ ) are evaluated as fraction of anhydrous silicate reacted, and water/rock ratios ( $x$ ) are expressed as ratios of O moles in water to those in anhydrous rock. In a closed system alteration model by Clayton and Mayeda (1999), O isotopic ratios of phyllosilicate are expressed as a function of  $f/x$  based on a mass balance calculation of water, anhydrous silicate, and phyllosilicate. If there is enough water to completely alter anhydrous rock (i.e., large  $x$ ), then  $f$  can range from 0 to 1. In contrast, if anhydrous rock remains after complete consumption of water (i.e., small  $x$ ),  $f$  cannot reach to 1 but only take values smaller than 1 depending on  $x$ . Thus,  $f/x$  values have a maximum, when water is completely consumed by the aqueous alteration and O isotopic ratios of phyllosilicate should be the same. Given apparent occurrence of anhydrous silicate that remains unaltered, water/rock ratios are likely a limiting factor for the alteration degrees of CM chondrites. Complete water consumption is thus the most straightforward explanation for the similar O isotopic ratios inferred for CM phyllosilicate. Neither alteration temperatures nor hydration reaction considered in the calculation does this conclusion rely on. If no water remained in the system after the aqueous alteration, water/rock ratios of individual CM chondrites can be deduced from H abundances of their phyllosilicate. The deduced  $x$  values range from 0.11 to 0.29 (0.19–0.49 by volume ratios). The variable water/rock ratios would suggest heterogeneous water ice accretion on the CM chondrite parent body.

An important implication from this scenario is the O isotopic ratio of the primordial water. In an O three-isotope plot, the O isotopic ratio of CM phyllosilicate should be on the line connecting the O isotopic ratios of the anhydrous silicate and the primordial water. Based on the mass-balance calculation by Clayton and Mayeda (1999), the inferred  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O}$  values of the primordial water are  $\sim 65$  and  $\sim 43$  ‰, respectively. These estimates depend on hydration reaction considered in the calculation.

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