Tracking the evolution of parent body fluids by oxygen isotope analysis of calcite and dolomite in CM carbonaceous chondrites

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Introduction: The closed system model for the evolution of aqueous solutions in the parent body(ies) of CM carbonaceous chondrites predicts that δ17O, δ18O and Δ17O would have decreased as isotopically heavy liquid water reacted with isotopically light anhydrous silicates [1]. We have sought to test this model by oxygen isotopic analysis of different generations of carbonate minerals that should record solution compositions at various points during progressive fluid-rock interaction. Calcite occurs in all CMs regardless of their degree of alteration, thus suggesting that it formed early and was subsequently preserved, or that it precipitated repeatedly [2]. Dolomite occurs only in the more heavily aqueously altered meteorites and so is likely to have formed relatively late and after the parent body environment had evolved to reach a threshold condition [2]. The closed system model predicts that dolomite should have a lower δ17O, δ18O and Δ17O than some or all of the calcite.

Materials and methods: This study has used five CMs that together span a wide range of degrees of alteration: Murchison (CM2.5), Mighei (CM2.3), Cold Bokkeveld (CM2.2), LaPaz Icefield (LAP) 031166 (CM2.1) and Queen Alexandra Range (QUE) 93005 (CM2.1). Calcite occurs in all five meteorites whereas dolomite is present in Cold Bokkeveld and QUE 93005. Carbonate grains were located and characterised by backscattered electron SEM imaging, then analysed using a NanoSIMS 50L at the Open University. Analyses were performed in spot mode and with a ~50 pA Cs+ ion beam, and the electron gun was used to provide charge compensation. 18O was measured on a Faraday cup and 17O and 18O using electron multipliers. Oxygen isotope data were obtained from calcite in all five CMs and from dolomite in QUE 93005.

Results: Each of the five meteorites contains two populations of calcite grains that differ in their petrographic characteristics and oxygen isotope compositions; they are referred to as ‘type 1’ and ‘type 2’ after [3]. Type 1 calcite occurs as equant grains in the matrix. Its δ18O values range from ~30 to 40 ‰, and Δ17O of most analyses are approximately zero. Type 2 calcite is typically rich in micropores and sulphide inclusions, and its commonplace occurrence within chondrules suggests that it has formed by replacement of olivine. The δ18O values of type 2 calcite are lower than type 1 (~10 to 25‰) and its Δ17O values are within error of type 1 calcite or lower. Petrographic evidence suggests that type 1 calcite formed before type 2. The δ18O values of QUE 93005 dolomite (δ18O 24 to 28‰) fall between types 1 and 2 calcite, and Δ17O (0 to -2‰) overlaps with both.

Discussion: Interpreting these results in the context of an isothermal closed system model would suggest that CM carbonates formed episodically and in the sequence of type 1 calcite-dolomite-type 2 calcite. This interpretation is consistent with petrographic evidence that type 2 calcite formed after type 1. A problem with such a sequence of mineralization is that Murchison, Mighei and LAP 031166 contain both generations of calcite but lack dolomite. This inconsistency could be accounted for if all parent body regions experienced the same fluid evolution (i.e., a secular decrease in δ17O, δ18O and Δ17O), but some regions, in particular those that ended up being mildly altered, never attained the conditions required for dolomite precipitation. For example they remained below a threshold temperature on account of their parent body location. An alternative reason for the lack of dolomite in some CMs is that their aqueous activity ceased at a relatively early stage; in this scenario their type 2 calcite could have precipitated in response to transient heating of remaining aqueous solutions. Another explanation for the type 2 calcite is that it formed in all CMs accompanying the influx of isotopically light and/or hot solutions from other parent body regions. Precipitation of a proportion of the calcite under such open system conditions is consistent with conclusions from recent isotopic investigations of CM carbonates [4], and with the finding of a vein of type 2 calcite in LON 94101, another mildly altered CM [5].

Conclusions: The record of fluid evolution that is contained within CM carbonates does not straightforwardly map onto the closed system model if the dolomite-containing meteorites are interpreted to be the highly evolved end-members of a common alteration sequence. The presence of the petrographically and isotopically distinctive type 2 calcite in all CMs so far studied is intriguing, and may point to its formation during a parent body wide perturbation such as an impact linked to degassing, depressurisation or heating.


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