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Oxygen isotopes in CO₃ chondrites

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OXYGEN ISOTOPES IN CO3 CHONDRITES R. C Greenwood, I. A. Franchi and C.T. Pillinger Planetary and Space Sciences Research Institute, Open University, Walton Hall, Milton Keynes, MK7 6AA, U.K.. (R.C.Greenwood@open.ac.uk).

Introduction: The results of a number of studies seem to indicate that CO3 chondrites can be subdivided into a metamorphic series analogous to that seen in ordinary chondrites [1,2,3]. It has been suggested that this sequence is the result of hydrothermal alteration on the CO parent body [4]. One particularly intriguing feature of CO3 chondrites is the reported general correlation between whole rock oxygen isotope values and petrographic subtype, such that values appear to become increasingly ^{18}O -rich with increasing metamorphic grade [4,5]. In view of the importance of trying to disentangle nebular from later parent body processes we have undertaken a further investigation of the oxygen isotope systematics of CO3 chondrites.

Experimental techniques: Oxygen isotope analyses were undertaken using the techniques described by [6]. Whole rock samples (0.5-2 mg) were heated in the presence of excess BrF_3 using a focused beam infrared laser. Meteorite samples were either fused in vacuum to form a glass bead prior to fluorination, or were reacted directly as powders without prior fusion. In the latter case the power of the laser was incremented gradually over a ten-minute period to avoid violent ejection of powders from the sample wells, which can be a significant problem when dealing with volatile-rich material such as carbonaceous chondrites. No significant variation was observed in the results from the two approaches. After fluorination the O_2 released is purified by passing it through two cryogenic nitrogen traps and over a bed of heated KBr. O_2 was analysed using a Micromass Prism III dual inlet mass spectrometer. Analytical precision based on replicate analyses of international standards is approximately $\pm 0.04\%$ for $\delta^{17}\text{O}$ and $\pm 0.08\%$ for $\delta^{18}\text{O}$ [6]

Results: The following CO3 chondrites were analysed as part of this study: ALH77307(3.0), Felix (3.2), Ornans (3.3), Lance (3.4), ALH77003 (3.5), Warrenton (3.6), Isna (3.7) (figures in brackets are the metamorphic subtypes of Scott and Jones [3]). The results obtained are plotted on figure 1. With the notable exception of ALH77307 (3.0), data for all the other analysed samples fall within an extremely restricted area on the oxygen three-isotope plot (figure 1), being even more limited in range than that obtained by Clayton and Mayeda [5]. In particular, our analyses do not seem to corroborate the ^{18}O enriched values for Lance (3.4) and Warrenton (3.6) found by Clayton and Mayeda [5],

instead these meteorites are slightly ^{16}O enriched compared to the other samples. Our analysis of ALH77307 is similar to that obtained by Clayton and Mayeda [5] and indicates that this meteorite is significantly depleted in ^{18}O compared to the other CO3 samples analysed.

Discussion: Evidence for a metamorphic sequence within the CO3 chondrites comes from a number of sources. On the basis of increasing textural recrystallization and decreasing compositional heterogeneity McSween [1] was the first to suggest that the group could be subdivided and proposed a three-fold sequence from I-III. Using analyses of olivines and low-calc pyroxenes in porphyritic chondrules Scott and Jones [3] divided the group into a sequence of subtypes ranging from 3.0 to 3.7. Further evidence in support of a metamorphic sequence comes from progressive changes in CAI mineralogy with increasing grade [7, 8]. Thermoluminescence properties [2] and percentage of rimmed amoeboid olivine inclusion [4] also show correlated changes with increasing grade.

In addition to the above features it has been suggested that whole rock oxygen isotope compositions show a general correlation with metamorphic subtype such that samples become increasingly ^{18}O -rich with increasing grade [4, 5]. This present study was initiated to investigate in detail the systematics of this correlation. It is therefore ironic to report that we were unable to find clear evidence to support this relationship. On the contrary CO3 chondrites form a tight cluster on the three-isotope oxygen plot and display even more restricted variation than indicated by previous studies [5]. There is no immediately obvious explanation for the much smaller range in oxygen isotopic compositions found in this study compared to previous reports. The effects of terrestrial weathering may account for some of the variation in the previous study as those meteorites collected from the Sahara have the heaviest $\delta^{18}\text{O}$ and $\Delta^{17}\text{O}$ values – consistent with the influence of terrestrial weathering products formed in a hot desert. Clearly there is the issue of sample heterogeneity, with a mixture of CAIs, ferromagnesium silicates and matrix components all with potentially very large isotopic variations. Heterogeneity is clearly present as can be seen by the relatively large error bars (figure 1), up to 7 times larger than expected from homogeneous samples [6]. Differences in the size of crushed samples

used in the two studies might go some way to explaining these results, however the samples employed here were not particularly large (generally less than 200 mg) and therefore may not be significantly more representative than those used in the previous work [5].

From the results of this study it would appear that while CO3 chondrites have undoubtedly experienced parent body metamorphism as well as moderate to weak aqueous alteration this was not accompanied by significant changes in their oxygen isotope composition. One possible explanation is that although a fluid phase was involved in the metamorphism, as suggested by Rubin [4], fluid rock ratios were extremely low in comparison to that seen in other carbonaceous chondrite groups.

Our analysis of ALH77307 is in good agreement with the results obtained by Clayton and Mayeda [5]. In view of the restricted range displayed by other CO3 chondrites ALH77307 appears to have an anomalous oxygen isotopic composition. Once again, the effects of terrestrial contamination may be important, as a mixing line extrapolated from ALH77307 to the mean of the other CO3s intercepts the terrestrial fractionation line at around -28% – a value reasonably consistent with Antarctic weathering products. However, the deviation of ALH77307 from the other CO3s is quite small and therefore it is difficult to adequately constrain this extrapolation accurately. However, the oxygen anomaly of ALH77307 may be more fundamental. Although this meteorite was originally classified as a CO3 by [9] on the basis of petrography, its higher matrix content (40-50%) compared to other CO3s and a chemical composition more like CMs than COs has meant that this original classification has been disputed [10]. It was concluded [10] that ALH77307 is unique, having affinities intermediate between CM and CO chondrites. The data presented here would seem to confirm this view. It has been suggested [5] that the least altered CO chondrites may have a composition similar to the anhydrous component of CMs prior to the onset of pervasive hydrothermal alteration. The results presented here (figure 1) add further weight to the suggestion [5] that ALH77307 has a composition similar to this precursor material. However, ALH77307 may have been modified by both parent body and terrestrial alteration processes and therefore further work is required to establish in detail the nature of the relationship between COs, CMs and apparently unique meteorites such as ALH77307.

Conclusions: With the exception of ALH77307 CO3 chondrites appear to display significantly more restricted O-isotope variation than previously suggested. There appears to be no evidence for a correlation between whole rock oxygen isotope compositions and progressive metamorphic alteration in CO3 chondrites. ALH77307 has an oxygen isotope composition distinct from other members of the CO3 group and should be reclassified as a unique chondrite. ALH77307 may have a composition similar to the anhydrous precursor material to CM2 chondrites prior to the onset of pervasive hydrothermal alteration.

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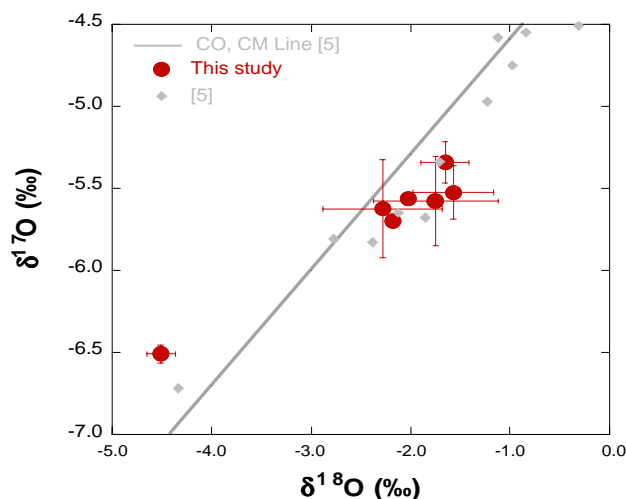


Figure 1 – Oxygen isotopic composition of CO3s. Only ALH77307 has an isotopic composition distinct from the rest of the CO3 meteorites. Error bars are 1σ on mean of replicates. Previous results [5] are shown for reference, as is the slope 0.70 line defined by bulk CO, CM and CM matrix samples [5].