CONTINUING THE SEARCH FOR THE MOST PRIMITIVE CO CHONDRITES: THE OXYGEN ISOTOPE PERSPECTIVE.
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Introduction: Primitive chondritic meteorites, and in particular carbonaceous chondrites, provide critical evidence concerning the conditions that prevailed during the earliest stages of Solar System formation. However, truly pristine chondrites are extremely rare, with most samples having been modified to a variable extent by secondary asteroidal processes, including aqueous alteration and thermal metamorphism. The search for the least altered chondrites remains something of a Holy Grail in meteoritical science.

Based on a range of parameters, including presolar silicate grain contents, bulk H, C and N abundances, carbon and hydrogen isotopic compositions and XRD determined modal mineralogies, it has recently been recognized that a small group of Antarctic CO3s are amongst the most primitive meteorites yet recognized [1, 2,3]. In particular, Dominion Range 08006 has the highest matrix-normalized presolar silicate abundance of any chondrite so far studied [1].

In attempting to assess the relationships, both within, and between various groups of carbonaceous chondrites, bulk oxygen isotope analysis has proved to be a highly effective technique [4, 5, 6]. Consequently, we have undertaken a detailed oxygen isotope investigation of primitive Antarctic COs, with the principal aim of understanding their relationship with other well-characterized members of the group, in particular the six known CO3 falls. Unfortunately, Antarctic meteorites are known to have experienced variable degrees of terrestrial weathering [7] and CO3 samples are no exception to this [5]. One additional, aim of the oxygen isotope work was to assess the extent of terrestrial weathering in the primitive COs.

Finally, COs and CMs are known to be related groups [8], with primitive CO-like material proposed to be the precursor material to the CMs prior to the onset of the extensive aqueous alteration on their parent body [4]. Oxygen isotope analysis of primitive Antarctic COs provides an opportunity to reassess this proposal.

Materials and methods: Bulk oxygen isotope analysis was undertaken on 14 untreated Antarctic COs. The powders used were those prepared for the previous study of [2]. Samples analyzed are the same as those listed in Table 1 of [2], except Dominion Range 03238, which was not analyzed and Allan Hills A77307 which was prepared as an EATG residue (see below) from a different source powder. Table 1 of [2] lists possible pairings and suggests that the primitive COs comprise at least 4 distinct meteorites. For comparison with the Antarctic COs, all six CO3 falls (Felix, Kainsaz, Lance, Ornans, Moss and Warrenton) were reanalyzed as part of this study.

Previous studies indicate that leaching of meteorite finds in a solution of ethanolamine thioglycollate (EATG) is efficient at removing terrestrial weathering products, without significantly disturbing the primary oxygen isotope composition of both achondrites [7] and equilibrated ordinary chondrites [9]. Accordingly, to assess the level of terrestrial weathering experienced by the Antarctic COs a subset of 7 were treated with EATG. For comparison, the weathered, non-Antarctic CO Colony and Antarctic COs ALHA77307 and Allan Hills 82101 were also leached in EATG.

Oxygen isotope analysis was performed by infrared laser-assisted fluorination at the Open University [10]. Individual replicates weighed approximately 2mg. System precision, as determined by replicate analyses of our internal obsidian standard, is: ±0.05‰ for $\delta^{17}O$; ±0.09‰ for $\delta^{18}O$; ±0.02‰ for $\Delta^{17}O$ (2σ).

Results: Oxygen isotope analyses for treated and untreated Antarctic COs and non-Antarctic CO falls and finds are plotted in Fig.1.

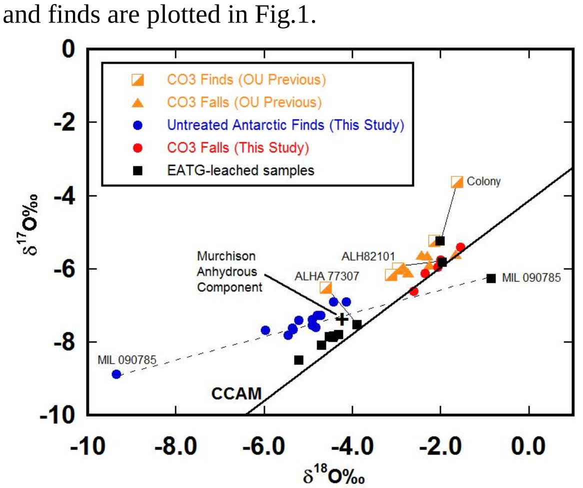

Fig. 1 Oxygen isotope composition of Antarctic primitive COs shown in relation to CO falls and finds (this study and [5].

With the notable exception of Miller Range 090785, untreated primitive COs plot as a relatively tight cluster somewhat to the left of the CCAM in Fig.

1. On the basis of its bulk H and δD composition, MIL 090785 is thought to be significantly more effected by terrestrial weathering than the other Antarctic COs [2]. The oxygen isotope composition of MIL 090785 would appear to support this conclusion. Compared to the untreated Antarctic COs, CO3 falls and some finds (here and [5]) are displaced to heavier isotopic compositions, with a distinct gap separating the two groups (Fig. 1). CO3 falls (this study) plot along the CCAM line, whereas previous Open University CO falls data [5] are somewhat more dispersed (Fig. 1). The reason for this is unclear, but may reflect incomplete fluorination in the case of the earlier analyses, which were undertaken using an earlier generation laser system.

EATG-leached Antarctic primitive COs show a marked shift towards the CCAM line in Fig. 1. This is also shown by the leached residue of ALHA77307, another Antarctic CO known to have an extremely primitive composition [2, 11, 12]. In contrast, the weathered sample MIL 090785 displays a much larger shift, with the EATG residue plotting well to the right of the CCAM line. It is unclear why MIL 090785 displays this extreme behaviour, but this is presumably a reflection of its more extensively altered composition.

ALH 82101 has an estimated metamorphic grade of 3.3 compared to 3.0 for ALHA77307 [5]. In marked contrast to the behaviour of ALHA77307, the EATG residue for ALH 82101 is displaced in the direction of the CO3 falls and not the Antarctic EATG residues (Fig. 1). This suggests that the gap between the primitive COs (treated and untreated) and CO3 falls reflects a genuine compositional difference and is not a weathering artifact. In contrast, the EATG residue for Colony shifts towards the CO3 falls grouping and not the primitive COs. However, while Colony is of a lower grade than ALH 82101, based on structural analysis of its organic matter, it is of a significantly higher grade than ALHA77307 [12].

Discussion: Oxygen isotope analysis appears to show a clear distinction between the primitive COs and the more metamorphosed falls and finds. There is also evidence that the Antarctic finds have undergone some degree of terrestrial weathering. Thus, the primitive CO EATG residues show a distinct shift towards the CCAM line compared to the untreated samples in Fig. 1. However, the fact that the EATG residues remain as a distinct ^{16}O-enriched cluster when compared to the CO3 falls would seem to indicate that this is a primary feature. There are a number of possible explanations for this distribution. It could be argued that the primitive COs sample a distinct parent body compared to the more metamorphosed falls and finds. While differences do exist amongst CO3 samples, such as between the CAI population in Dominion Range 08004 and DOM 08006 compared to that of ALHA77307 [13], in general the group shows coherent petrographic and textural characteristics [14]. While it is impossible to know definitively how many asteroids are sampled by the COs, our working assumption is that they are all from a single parent body. Thermal modeling suggests that this body had a radius of at least 50km [15].

Alternatively, the variation along the CCAM line displayed by the COs (Fig. 1) might reflect variable interaction with a ^{16}O-poor reservoir, generally identified as water [16]. Thus, the primitive COs would have interacted less with this aqueous reservoir than the more thermally altered types. While there is clear mineralogical and texture evidence that COs have experienced aqueous alteration, the nature and extent of this process remain poorly understood [11,12].

Anhydrous mineral separates from the Murchison CM2 chondrite were used by [4] to define the precursor composition for the CM group as whole. As can be seen from Fig. 1, the Murchison mineral separates plot close to both the untreated and EATG-leached primitive Antarctic COs. New oxygen isotope analyses of CMs [8] are also consistent with a close relationship between the COs and CMs and this is further supported by their textural and mineralogical similarities [17].

Conclusions: Oxygen isotope analysis indicates that primitive Antarctic COs are distinct from the higher grade members of the group, being more ^{16}O-enriched. While the Antarctic COs have suffered some terrestrial contamination, EATG treatment suggests that this compositional difference is a primary feature. The compositional similarity between Murchison anhydrous silicates and primitive Antarctic COs strengthens the genetic link between the CMs and COs.

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