OXYGEN ISOTOPE EVIDENCE FOR MULTIPLE CM PARENT BODIES: WHAT WILL WE LEARN FROM THE HAYABUSA2 AND OSIRIS-REx SAMPLE RETURN MISSIONS?

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Introduction: CMs are the largest group of carbonaceous chondrites (CC), comprising 37% of observed CC falls [1]. CM-related material is also widespread as inclusions within a diversity of inner Solar System materials, including HEDs, the lunar regolith and ordinary chondrite breccias [2, 3]. Here we present the results of an extensive oxygen isotope study of a wide range of CMs and related meteorites. Our results suggest that CM-like material may originate from a diverse range of asteroids or, alternately, the CM-parent body was more isotopically heterogeneous than previously considered.

Materials and Methods: O-isotope data for CM1 and CM1/2 chondrites [4], CM2s [5,6,7,8] and CO3s [9] were obtained at the Open University by laser-assisted fluorination [10]. CMs pose particular problems for laser fluorination analysis due to reaction with BrF_5 at room temperature [8] and so most analyses were obtained by the "single-shot" method, with just one sample and one standard loaded per tray [8].

CMs: The oxygen isotopic composition of CM1, CM1/2 and CM2 chondrites are plotted in Fig. 1.

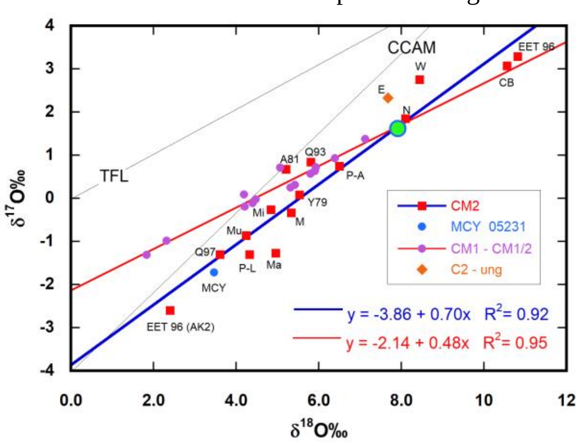

Fig.1 *Oxygen isotope composition of CM chondrites. Symbols CMs: A81:ALHA81002, CB: Cold Bokkeveld, EET 96 (AK2): EET 96029 (AK2) [11], EET 96029 [11]: E: Essebi, Ma: Maribo, Mi: Mighei, M: Murchison, Mu: Murray, N:Nogoya, P-A: Paris-altered, P-L: Paris-less altered, Q93: QUE 93005, Q97: QUE 97990, Y79: Y791198,* W: WIS 91600. *C2-ung E:Essebi. CM1/2 MCY: MCY 05231. Filled green circle is the intercept of the CM2 and CM1-CM1/2 regression lines.*

CM2 analyses in Fig. 1 define a linear trend with a slope of 0.70 [8]. In contrast, CM1 and CM1/2 analyses define a distinct trend with a slope of 0.48 [4]. MCY 05231 CM1/2, which has a relatively low phyllosilicate content [12], plots away from this trend. All the CM1 and CM1/2 chondrites in Fig.1, with the exception of Moapa Valley are Antarctic finds. The best fit line through the CM1 and CM1/2 data, excluding MCY 05231, intersects the terrestrial fractionation line (TFL) close to the value of Standard Light Antarctic Precipitation (SLAP) (Fig. 2). As is also the case for Antarctic CO3s [9], the bulk oxygen isotope composition of CM1s and CM1/2s appears to have been shifted by interaction with Antarctic precipitation. The CM1s and CM1/2 may be more susceptible to low temperature terrestrial alteration as a result of their higher content of fine-grained phyllosilicates and lower crystallinity compared to CM2s [4]. CM1s often have foliated textures and a few (e.g. LAP031166 and Moapa Valley) have been described as having large fractures that may also facilitate ingress of terrestrial fluids The pristine isotopic composition of the CM1s and CM1/2 cannot be determined with certainty, but may correspond to the intersection of the two regression lines in Fig. 1 (green circle) [4].

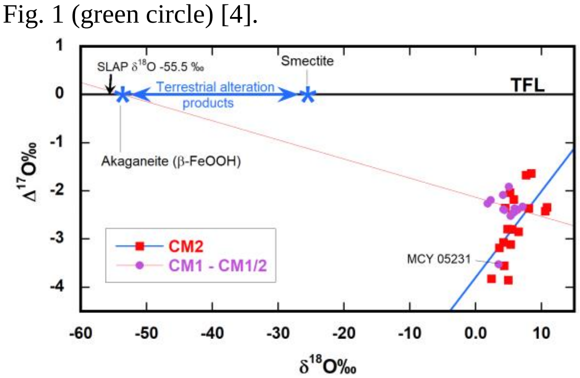

Fig. 2 *Oxygen isotope composition of CM chondrites shown in relation to Antarctic precipitation (SLAP) and weathering products in isotopic equilibrium with it at 0°C [9].*

Primitive CMs: CMs and COs show a range of textural and geochemical similarities and a close genetic relationship between the two groups is generally accepted [14]. However, while the chondrule population within the two groups are essentially indistinguishable [15], differences in terms of mean chondrule size have been reported [16]. A further difference relates to the amount of water that would have been accreted to the parent bodies of the two groups [15], with COs being essentially dry and CMs having experienced significant aqueous alteration [17]. A further important difference is the compositional gap between the two groups on oxygen three isotope plots [8] (Fig. 3).

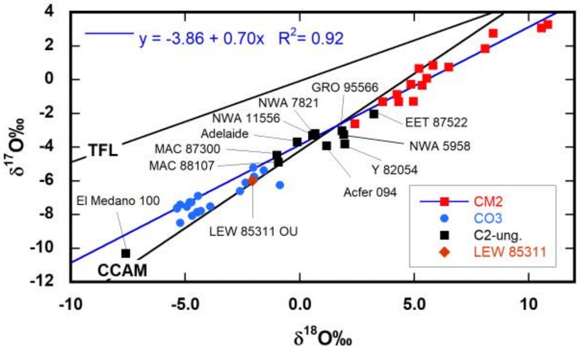

Fig. 3 *Oxygen isotope composition of COs and CM2s. The gap between the two groups is occupied by a number of ungrouped C2 chondrites that may constitute a "primitive" CM group. CO data [9], LEW 85311 [18], other C2-ungrouped data from literature, see text for references.*

Interestingly, the CO-CM oxygen isotope "gap" is effectively filled by a significant number of meteorites, generally classified as C2-ungrouped, which show transitional features between the two groups. LEW 85311, EET 87522 and Y-82054 are currently classified as CM2s, but were identified as ungrouped by [17] on the basis of their ^{16}O-rich oxygen isotope compositions. LEW 85311 appears to be a CM-like meteorite with an anomalously low level of aqueous alteration [18, 19]. NWA 5958 is another ungrouped chondrite with CM-like characteristics [20] and may be related to LEW 85311. The ungrouped C2s Acfer 094 and GRO 95566 were also identified by [19] as having CM affinities, although both are normally considered as unique specimens. MAC 87300 and MAC 88107 are not considered to be paired, but both show affinities to the CO3 chondrites, while displaying evidence of variable degrees of aqueous alteration [21]. Based on the Met. Bull. Descriptions, NWA 7821 and NWA 11556, which have closely similar oxygen compositions (Fig. 3), appear to have some CM-like characteristics. Adelaide is a C2-ungrouped meteorite with affinities to the CO3s and in particular ALH 77307 [22]. Despite its extremely ^{16}O-rich oxygen isotope composition (Fig. 3) El Medano 100, based on its Met. Bull. Description, appears to have a CM-like mineralogy.

How many CM-related parent bodies? Hydrated CC meteorites are dominated by the well-populated CM group. While displaying some CM-like characteristics, it has been suggested that NWA 5958 may be from a distinct parent body to the CM2s [20]. We would tentatively suggest that other ^{16}O-rich, CM-like chondrites that plot in the CO-CM "gap" might be related to NWA 5958. Possible candidates for such a "primitive" CM group, include: EET 87522, GRO 95566, LEW 85311, MAC 87300, MAC 88107, NWA 7821, NWA 11556 and Y-82054. Alternatively, as a number of these samples plot close to the CM2 mixing line in Fig. 3 the CM parent body may be even more isotopically heterogeneous than has previously been considered.

While El Medano 100 appears to show CM-like characteristics its oxygen isotope composition suggests that it is derived from a distinct source to the other C2-ungrouped meteorites. CM1 and CM1/2 chondrites may be derived from the same parent body as the CM2s, but this remains an open question [4].

Conclusions: The gap in oxygen isotope compositions between COs and CMs is occupied by C2-ungrouped meteorites which show affinities to both groups. One possibility is that the CM parent body is more isotopically heterogeneous than previously thought. Alternatively, CM-related material is present on multiple bodies and formed from similar starting materials and then experienced variable degrees of hydrothermal processing. As in the case of the relationship between CM1, CM1/2 and CM2 chondrites, terrestrially recovered samples may be compromised and difficult to interpret. The pristine samples returned from the asteroids Bennu and Ryugu by the OSIRIS-REx and Hayabusa2 missions will provide a unique opportunity to study the diversity of materials present on primitive aqueously altered bodies.

References: [1] Meteoritical Bulletin Database [2] Zolensky M. E. et al. (1996) *MAPS.*, *31*, 518-537. [3] Briani G. et al. (2012) *MAPS.*, *47*, 880-902. [4] King A. J. et al. (2018) LPSC 49, Abstract #2201. [5] Howard K. T. et al. (2010) LPSC 41, Abstract #1595. [6] Howard K. T. et al. (2011) LPSC 42, Abstract #2429. [7] Howard K. T. et al. (2013) LPSC 44, Abstract #2520. [8] Greenwood R. C. et al. (2014) LPSC 45, Abstract #2610. [9] Alexander C. M. O'D et al. (2018) *GCA* 221, 406-420. [10] Greenwood et al. (2017) *Chemie der Erde – Geochem.* 77, 1-43. [11] Lee M. R. et al. (2016) *GCA* 187, 237-259. [12] King A. J. *MAPS.*, *52*, 1197-1215. [13] Howard K. T. et al. (2015) *GCA* 149, 206-222. [14] Weisberg M. K. et al., MESS II, Univ. Arizona Press, [15] Chaumard N. et al. (2018) *GCA* 228, 220-242. [16] Schrader D. L. and Davidson J. (2017) *GCA* 214, 157-171. [17] Clayton R. N. and Mayeda T. K. (1999) GCA 63, 2089-2104. [18] Lee M. R. et al. (2019) this conference. [19] Choe W. H. (2010) *MAPS.*, *45*, 531-554. [20] Jacquet E. et al. (2016) *MAPS.*, *51*, 851-869. [21] Russell S.S. et al. (2000) *MAPS.*, *35*, 1051-1066. [22] Brearley A. J. (1991) *LPSC* 22, 133.