ASSESSING THE OXYGEN ISOTOPE HETEROGENEITY IN AGUAS ZARCAS, MUKUNDPURA AND KOLANG

R. Findlay[1], R. C. Greenwood[1], I. A. Franchi[1], M. Anand[1,2], A. J .King[2] and J.Malley[1] [1]*Planetary and Space Sciences, School of Physical Sciences, Open University, Milton Keynes, Bucks, MK7 6AA, UK. (ross.findlay@open.ac.uk).* [2]*Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK*

Introduction: CM chondrites contain different lithologies as clasts [1] that have experienced variable degrees of aqueous alteration (Fig. 1). Evidence points towards a unique environment of alteration for each lithology, reflected in differences among secondary mineralogy and by extension, chemistry [2,3]. This characteristic is so prominent that it is now encouraged to classify individual CMs as a 'petrologic range' dependent on their clasts, from fully aqueously altered CM1 material to partially altered CM2s [2,3].

In oxygen 3-isotope space, bulk CMs define large arrays with considerable scatter [4-6] (Fig. 2). While this observation is largely driven by interaction of precursor accreted silicates and water-ice with different initial isotopic compositions, the scatter is potentially the result of several different processes, including different starting compositions, changes in alteration conditions, complex closed or open system behaviour [4,7], or terrestrial contamination. The latter point is a valid concern considering the CM trends are dominated by hot and cold desert finds. Three recent falls, Aguas Zarcas CM2 (AZ), Mukundpura CM2 (MP) and Kolang CM1-2 (KO) offer a novel opportunity to correlate oxygen isotopic measurements of unweathered samples with spatially resolved lithologies to better understand the origin of the indigenous signatures.

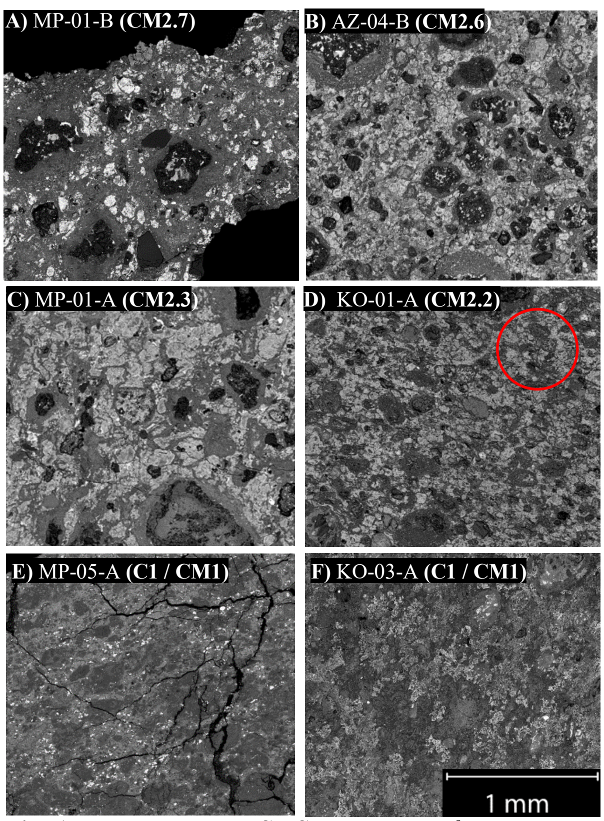

Fig. 1 *Representative BSE SEM images of progressively aqueously altered 'primary lithologies' in AZ, MP and KO. Red circle = micromill spatial resolution.*

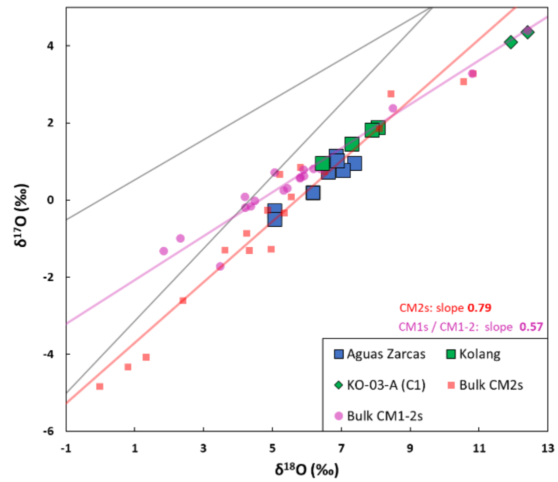

Fig. 2 *Oxygen-3 isotope plot of AZ and KO. CM2 data: [5, 10], CM1-2 data: [6, 11-13]. 2σ uncertainty within symbols. MP is exempt to limit overcrowding.*

Methods: Five polished blocks of AZ, four of MP and three of KO were investigated for lithological variation. The composition of Tochilinite-Cronstedtite Intergrowths (TCIs) in each clast were quantitatively obtained with EDS using a Zeiss Supra 55 VP FEG-SEM [3]. The 'FeO'/SiO_2 ratios of TCIs ('FeO'= Fe^{2+} in phyllosilicates and sulphides, plus Fe^{3+} in cronstedtite) [3] were used to assign a petrologic subtype between 2.0 and 3.0 [2,3] (Fig. 1). Sub classification of CM1/C1 clasts was not attempted as this may be better achieved with phyllosilicate abundances as obtained by X-Ray diffraction) [8].

Each clast was micro-sampled using a New Wave MicroMill equipped with a 500 µm wide ball point tungsten carbide dental bur (Fig. 1, D). The softness of the sample facilitated 'dry excavation' at 20 % drill speed and a short (5s) dwell time. Samples were chosen in areas that represented the sub-µm aqueous alteration products, so large features over 100 µm or more than 20 % of the visual field (e.g. CAI) were excluded to prevent biased sampling. Oxygen isotope measurements were made using a modified 'single shot' laser fluorination method [5]. Approx. 350 µg of powder (2-3 holes) was extracted from each lithology for optimum analysis using the cryogenic microvolume on the mass spectrometer. The small sample-sizes warrant a blank correction, that was measured before and after each analysis. In addition, each sample underwent cryogenic removal of the fragment ion NF^+ (isobaric on $^{16}O^{17}O$) using two cold fingers filled with 13x molecular sieve. Overall 2σ system precision, as obtained through repeat ~120 µg, replicates of our internal obsidian standard (n=8) are: ±0.06 ‰ (2 SD) for $\delta^{17}O$, ±0.08 ‰ for $\delta^{18}O$ and ±0.04 ‰ for $\Delta^{17}O$. These results show very little sacrifice in precision compared to 2 mg samples [9]. Here, $\Delta^{17}O = \delta^{17}O-(0.52* \delta^{18}O)$.

Results and discussion: The oxygen isotopic composition of each lithology is plotted against petrologic subtype in Fig. 3. Where two or more replicates of micro-sampled material were measured, (e.g. Fig. 3, MP-05-A) the reproducibility is excellent, demonstrating effective measurement of the O-isotope composition of the altered material in CM2s, without the ambiguity associated with isotopically diverse un-altered components (e.g. chondrules, CAI). All three meteorites contain lithologies that show remarkably consistent progression of increasing $\delta^{18}O$ and $\Delta^{17}O$ with decreasing petrologic subtype within the CM2 range (2.7-2.2) (Fig. 3). AZ shows the greatest diversity of lithology types and displays a very consistent increase across 4 different alteration grades. The apparent high level of linearity is probably inconsequential as the magnitude level of alteration represented by each step may be different, although the result does indicate that the alteration index used here may be progressing in a usefully regular manner. However, what is striking is that the rate of change in O-isotope composition with changing alteration is different from meteorite to meteorite– indicating that each sampled a region of the parent body(s?) that experienced a unique set of alteration conditions. We infer that AZ, MP and KO must each sample a localised region.

The isotope alteration trend in KO appears to extend smoothly towards the C1 lithology (KO-03-A) for both $\delta^{18}O$ and $\Delta^{17}O$, and this may represent the final product of an alteration series. However, it should be noted that the relationship of C1 to CM2 alteration scales is poorly defined; positioned arbitrarily along the x-axis. In contrast, a CM1 clast (MP-05-A) in MP is isotopically lighter by ~3‰ in $\delta^{18}O$ than the most altered CM2 material present in the meteorite.

The tight-fitting linear relationships of clasts *within* each meteorite indicates sampling of a relatively restricted range of parent body material and a single dominating process. Each conforms to the limitations of a two component closed system model [4] (with one exception of CM1 material (MP-05-A)). However *between* meteorites, a singular closed system - and by extension, a common, homogenous parent body - is hard to accommodate with such different trends. Rather, the isotopic composition of the fluids or starting materials must be permitted to evolve in an open system [7], requiring a complex, heterogeneously altered asteroid. The CM1 clast has a high probability of being derived from the same parent body as its host and may provide evidence that open system behaviour existed on the MP asteroid. In conclusion, further studies on the oxygen isotopic composition of components and other clasts will help constrain the nature and number of CM parent bodies. Our study highlights the importance of careful interpretation when studying CMs, preferably making use of un-weathered falls with minimal terrestrial contamination.

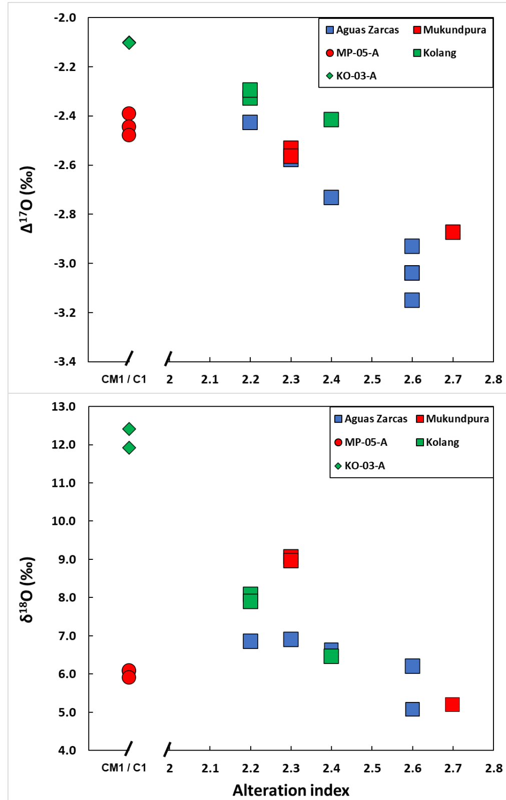

Fig. 3 *Top: $\Delta^{17}O$ vs petrologic subtype. Bottom: $\delta^{18}O$ vs petrologic subtype.*

References: [1] Bischoff et al., (2006) *MESS II* 679-712. [2] Rubin et al., (2007) *GCA 71,* 2361-2382. [3] Lentfort, S. et al., (2020) *MAPS* 56 127-147. [4] Clayton R. N. and Mayeda T. K. (1999) *GCA 63*, 2089-2104. [5] Greenwood R. C. et al., (2019) *LPSC 50* abst #3191. [6] King A. J. et al., (2018), *LPSC 49*, abst #2201. [7] Young E. D. et al., (1999) *Science 286*, 1331–1335. [8] Howard K. T. et al., (2015) *GCA 73,* 4576-89. [9] Starkey N.A. et al., (2016) *GCA 176,227-238.* [10] Kimura M. et al., (2020) *PS* 26 100565. [11] King A. J. et al., (2017) *MAPS 52*, 1197-1215. [12] Zolensky M. et al., (1997) *GCA 61*, 5099-5115. [13] Irving A. J. et al., *MAPS 44*, A96.