VOLATILE INVENTORY OF LUNAR METEORITES FROM THE DOMINION RANGE. T. S. Hayden[1], T. J. Barrett[1], X. Zhao[1], M. Anand[1,2], I. A. Franchi[1] [1]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK (Email: tara.hayden@open.ac.uk), [2]Department of Earth Sciences, The Natural History Museum, London, SW7 5BD, UK.

Introduction: Lunar samples returned by various missions have significantly expanded our knowledge of the lunar geological history. These samples, however, are from an area that represents ~ 5 % of the lunar surface [1]. Upcoming sample return missions aim to collect material from previously unsampled regions of the Moon (e.g., Artemis and Chang'e 6). Until these samples are available, lunar meteorites potentially provide a more diverse and less biased sampling of the Moon. Lunar meteorites also provide insights into the distribution and abundance of volatile species (e.g., H, Cl), and a snapshot of the Moon's evolution by sampling some of the oldest material (e.g., cryptomare basalts) [2].

The Ca-phosphate mineral apatite is the primary volatile bearing phase in lunar samples and is ubiquitous in all lithologies except the ferroan anorthosites (FAN) [3]. The endurance of apatite through impact processing and thermal weathering during formation of lunar breccias [4] (apatite grains being present within lithic clasts or as isolated grains in the matrix) has broadened the sample set for analysis of lunar volatiles.

Lunar basaltic breccias Dominion Range (DOM) 18262 and 18666 were found in 2018 by the ANSMET program [5–6]. It has been suggested that the DOM pairing group (of which 18262 and 18666 are a part) has textural similarities to Meteorite Hills (MET) 01210 [7], one of the YAMM group of lunar meteorites — also including Yamato (Y)-793169, Asuka (A)-881757, and Miller Range (MIL) 05035 [8]. The YAMM group are thought to sample an ancient basalt flow [8–9], and to date volatile data has only been collected on one sample (MIL 05035) [10–13]. Assuming DOM 18262 and 18666 are paired with the YAMM group [14], analysis of their volatiles will provide greater context on processes taking place within and on the Moon at the time of their eruption (3.8–3.9 Ga) [8]. This can be compared to other ancient basalts (e.g., Kalahari 009) [2] to better constrain volatile evolution in the Moon's early history. Here we report on stable isotope analysis of Cl and H in DOM 18262 and DOM 18666 and assess their pairing relationship with the YAMM group.

Methods: Cl and H isotopic compositions and abundances were measured using the CAMECA NanoSIMS 50L at The Open University (OU), following modified protocols [9, 15–16]. Negative secondary ions of ^{13}C, ^{18}O, ^{35}Cl, ^{37}Cl, and $^{40}Ca^{19}F$ were acquired simultaneously on electron multipliers in imaging mode. Negative secondary ions of ^{13}C, ^{1}H, ^{2}H, and ^{18}O were collected in spot mode over Cl pits.

Results: The $\delta^{37}Cl$ values for apatite in DOM 18262 (− 1.0 to + 26.0 ‰) and 18666 (+ 5.5 to + 19.6 ‰; Fig. 1) [17] are similar to Apollo 11 high-Ti, Apollo 12 low-Ti [10–11, 18–19], and Apollo 14 high-Al basalts [20]. The lightest $\delta^{37}Cl$ (~ − 1 to + 1 ‰) is comparable to MIL 05035 ($\delta^{37}Cl$ down to − 4 ‰) [11]. Apatite in DOM 18262 and DOM 18666 display a range in Cl abundance from < 20 ppm to ~ 3.65 wt. % [17].

The δD values for apatite in DOM 18262 (~ − 830 to − 660 ‰) and 18666 (~ − 30 to + 340 ‰; Fig. 2) [17] are comparable to Apollo 15 QMDs (− 750 to – 600 ‰) [20] and low-Ti basalt apatite and melt inclusions (− 600 to + 1440 ‰) [10–12, 21–26]. Apatite in DOM 18666 have higher H_2O abundances (~ 1210–3790 ppm) than in DOM 18262 (~ 250–300 ppm) [17].

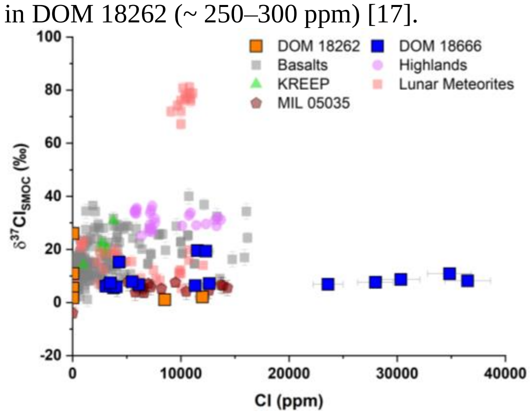

Fig. 1: $\delta^{37}Cl$ (‰) vs. Cl (ppm) of DOM 18262 and 18666 apatite compared to literature [10–11, 13, 18, 20, 27–28]

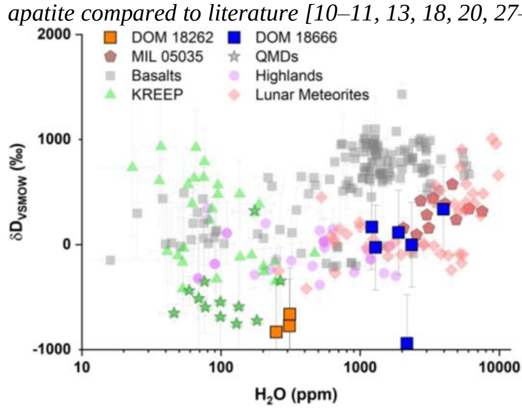

Fig. 2: δD (‰) vs. H_2O (ppm) of apatite in DOM 18262 and 18666 compared with literature [11, 21-22, 27-29]

Discussion: The $\delta^{37}Cl$ and δD values of MIL 05035 (− 4.0 to + 7.8 ‰ and + 90 to + 570 ‰, respectively [10–13]) are comparable to the low-Ti basaltic clasts with lighter δ^{37}Cl (− 1.0 to + 10.9 ‰) and heavier δD (− 28 to + 340 ‰) in DOM 18262 and 18666 (see Fig. 1 and 2). It has been proposed that the light δ^{37}Cl of MIL 05035 originates from an un-degassed or partially degassed lunar source [11]. The lightest Cl isotope composition is comparable to CAI sodalite in the carbonaceous chondrite Allende (δ^{37}Cl = − 2.09 to – 0.39 ‰ [30]), thought to have formed early in Solar System history [31]. Mixing of early Solar System materials of similar light Cl isotopic composition within the Moon-forming material with an initial δ^{37}Cl of ~ 0 ‰ could have produced a source with light δ^{37}Cl observed in DOM 18262 and 18666. Covariation between δ^{37}Cl and KREEP component has been observed in lunar samples [17], so it is possible that the light Cl isotopes in DOM 18262 and 18666 basaltic clasts do not have a KREEP component, and instead record a more primitive lunar signature with no apparent mixing of exogenous material. Further work on determining the trace element composition of these samples would be required to test this. More enriched Cl and H isotopes suggest significant degassing in the parental melt(s) of these apatites. The similarity in Cl and H isotopes to MIL 05035 supports the pairing of DOM 18262 and 18666 to the YAMM group. Detailed petrographical and geochronology work further supports these findings — with DOM 18262 and 18666 having similar textures, clast inventories, and crystallization ages (3.86–3.96 Ga) [14] to the YAMM group (~ 3.8–3.9 Ga) [8].

Apatite with the lightest H isotopes (δD = − 830 to – 660 ‰) in DOM 18262 are comparable to those from Apollo 15 QMDs (− 750 to – 600 ‰) [29]. The texture and geochemistry of the host clast of this apatite is similar to lunar QMDs, and it is, therefore, possible that DOM 18262 hosts the lightest recorded δD for this group. This signature may be inherited nebular hydrogen introduced by the incorporation of material from Theia into the lunar precursor — with Theia incorporating nebular hydrogen (δD = − 863 ‰) [32] through ingassing [33]. Solar wind H isotopes are also extremely light (− 988 ‰) [34]; however, this apatite is at a depth into the sample (> 100 µm) exceeding the penetration depth of solar wind (~ 1 µm) [29], and there is no surrounding impact melt to have supported diffusion of solar wind into this apatite. Additionally, any solar wind H would have had to rapidly diffuse through impact melt as it cooled and then diffuse through K feldspar. The diffusion coefficient for hydrogen in feldspar is lower than in other nominally anhydrous minerals [35], therefore, it is less likely that these low values reflect solar wind contamination. The Cl isotopes of this material are variable (+ 2 to + 26 ‰), however, these are within the range of δ^{37}Cl measured in more Cl-rich apatite grains in DOM 18262 and DOM 18666. The heavier Cl measurements are also comparable to Cl isotopes (+ 19 to + 29 ‰) measured in Apollo 15 QMDS [36]. The contrasting light H and heavy Cl isotopes in Apollo 15 QMDs was taken to suggest H and Cl were derived from different sources within the Moon [36].

Conclusions: The Cl and H isotopes of apatite in basaltic clasts in DOM 18262 and 18666 are comparable to apatite in MIL 05035, indicating that these basaltic breccias are part of the YAMM group, thought to sample an ancient lava flow. Cl and H isotopes may reflect a partially degassed source. A QMD clast in DOM 18262 shows similar Cl and H isotopes to Apollo 15 QMDs, which may reflect the indigenous H isotope composition of this suite and/or an inherited nebular hydrogen signature.

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