MINERALOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF LUNAR METEORITES FROM THE DOMINION RANGE, AND THEIR PAIRING RELATIONSHIPS.

T. S. Hayden[1], T. J. Barrett[1], M. J. Whitehouse[2], H. Jeon[2], X. Zhao[1], M. Anand[1,3], 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]Swedish Museum of Natural History (NordSIMS facility, Stockholm, Sweden), [3]Department of Earth Sciences, The Natural History Museum, London, SW7 5BD, UK).

Introduction: Lunar basaltic breccias Dominion Range (DOM) 18262 and 18666 were collected by the 2018 ANSMET program [1–2]. The DOM pairing group (which includes 18262 and 18666) is observed to have textural similarities to Meteorite Hills (MET) 01210 [3], which is one of the YAMM group of lunar meteorites — including Yamato (Y)-793169, Asuka (A)-881757, and Miller Range (MIL) 05035 [4]. The YAMM group is thought to represent an ancient low-Ti mare basalt flow, with crystallization ages ~ 3.8–3.9 Ga [4–5], permitting insight into the conditions on the Moon at the time of their formation. The mare basalt flow represented by the YAMM group has been termed 'cryptomare' due to a deep provenance in the lunar surface and significantly older crystallization ages compared to Apollo low-Ti basalts (3.2–3.5 Ga) [6]. Here we report on petrographical, geochemical, and geochronological analyses of DOM 18262 and DOM 18666 to assess their pairing relationship with the YAMM group.

Methods: The polished thin sections were studied using optical microscopy and a FEI Quanta 200 3D Scanning Electron Microscope (SEM) at The Open University (OU), using an electron beam current of 0.60 nA and accelerating voltage of 20 kV.

Quantitative geochemistry of a range of lithic and mineral clasts was collected at the OU using a CAMECA SX100 electron microprobe using a 5 µm spot size with a defocused beam, a beam current of 20 nA, and accelerating voltage of 15 kV.

Pb dating of apatite and merrillite in the sections were collected using a CAMECA IMS 1280 ion microprobe in multicollection mode at the NordSIMS facility in the Swedish Museum of Natural History (Stockholm), using an accelerating voltage of 30 kV and beam current of ~ 2.5 nA — following an established protocol [7].

Results: *Petrography*: DOM 18262 is comprised of lithic and mineral clasts (~ 100–400 µm in the longest direction) within a fragmental matrix. The lithic clasts comprise quartz monzodiorites (QMDs) dominated by K-feldspar (Fig, 1 Clast 1), coarse-grained low- and high-Ti basalts (Fe# (Fe/Fe+Mg) = ~ 94, Ti# (Ti/Ti+Cr) = ~ 97; $Fs_{13–85}En_{1–57}Wo_{4–44}$; see Fig. 1–3), symplectite clasts and clasts showing reduction breakdown textures of olivine grains, clasts with granoblastic textures, and abundant impact melt breccias exhibiting fine-grained recrystallisation textures and melt veins ~ 50 µm thick. Larger (100–200 µm thick) isotropic shock veins run through the section. DOM 18262 is, therefore, likely to be moderately shocked (M–S3/4) [8].

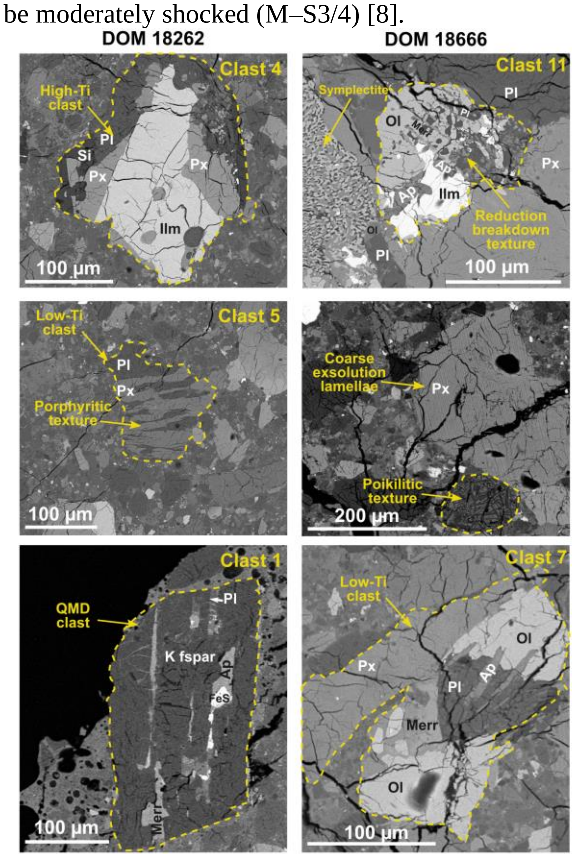

Fig. 1: BSE images of a sample of lithic clasts in DOM 18262 and DOM 18666

DOM 18666 is comprised of a dark fragmental matrix enclosing ~ 50–500 µm (longest dimension) lithic and mineral clasts. Lithic clasts comprise low- and high-Ti basalts with similar pyroxene compositions and compositional trends (i.e., Fe# = 29.1–99.3; Ti# = 47.3–100.0; $Fs_{26–98}En_{1–68}Wo_{1–42}$) to MET 01210 (Fe# = 24.4–94.2; Ti# = 49.2–98.2; $Fs_{30–86}En_{1–49}Wo_{1–42}$ in basaltic clasts; $Fs_{4–57}En_{21–53}Wo_{18–73}$ in anorthositic clasts) [9] (see Fig. 1–3). Symplectite clasts are more prevalent in DOM 18666 than 18262, and clasts exhibiting reduction breakdown textures of varying levels of completion are also more dominant (Fig.1 Clast 11). Microbreccias with fine-grained groundmass encompassing coarser plagioclase and pyroxene grains (~ 50–60 µm in the longest dimension) indicate that DOM 18666 possibly samples several brecciation events. Mafic minerals in DOM 18666 show mosaicism and melt veins ~ 1 mm width are also present. DOM 18666 may, therefore, be moderately shocked (M–S4) [8]. Accessory minerals in both clasts and isolated in the matrix include apatite, merrillite, ulvöspinel, K-feldspar, ilmenite, and sulfide. Glassy spherules are also present — indicating this is a regolith breccia.

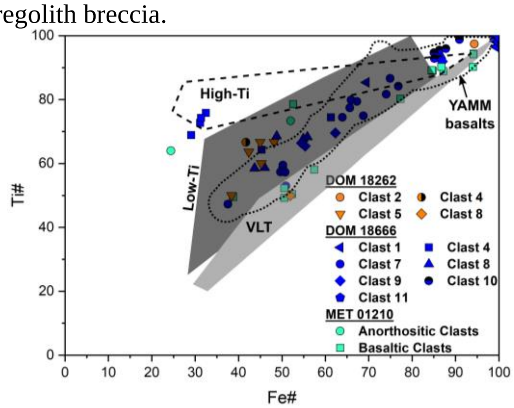

Fig. 2: Fe# vs Ti# of pyroxene in basaltic clasts in DOM 18262, DOM 18666, MET 01210, and YAMM basalts [4, 9].

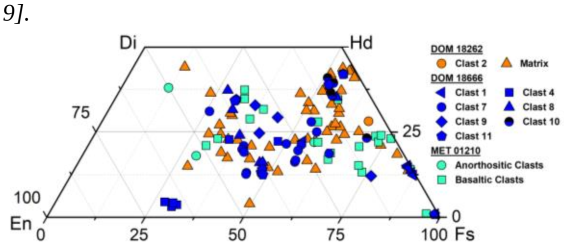

Fig. 3: Pyroxene quadrilateral for basaltic clasts in DOM 18262 and 18666, compared to anorthositic and basaltic clasts in MET 01210 [9].

Geochronology: Analysis of apatite grains associated with basalt clasts in DOM 18262 and 18666 yield terrestrial common Pb corrected $^{207}Pb/^{206}Pb$ ages between 3.86 and 3.96 Ga. These ages are interpreted to be crystallization ages and are comparable to those of the YAMM group (~ 3.8–3.9 Ga) [4]. No correlation between clast type and crystallization age is apparent.

Discussion: The texture and clast inventory of DOM 18262 and 18666 are comparable with MET 01210 and the YAMM group — with a predominance of symplectite and low-Ti basalt clasts, the coarse-grained nature of basaltic clasts, and the presence of glassy spherules [4]. Pyroxene exhibits coarse exsolution lamellae (up to 2 µm thickness; see Fig. 1) in DOM 18262 and 18666, however, this is not as prominent as in the YAMM samples. Coarse exsolution indicates the origin of the YAMM group from an unusually thick lava, or possible burial of mare material [4, 10–13]. The lower frequency of exsolution lamellae in DOM 18262 and 18666 may be a result of sampling bias. MIL 05035 was assigned a shock stage of 2b according to IUGS 2007 [14], which corresponds to a shock stage of M–S3/4 [8] — a characteristic also shared by DOM 18262 and 18666.

The age of phosphates in DOM 18262 and 18666 (3.86–3.96 Ga) correspond to the ages of YAMM samples (3.8–3.9 Ga) [4]. This is older than many of the Apollo 12 and 15 low-Ti basalts (3.2–3.5 Ga) and Luna 24 very low-Ti (VLT) basalts (~ 3.2 Ga) [6]. The YAMM basalts are thought to sample a cryptomare basalt flow located in the Schiller-Schickard crater region with a pre-Orientale eruption age (> 3.8 Ga) [4–5]. The predominance of low-Ti material in cryptomare samples has been noted previously [15] and is supported by remote geochemical analyses on older mare deposits [16].

The Cl and H isotopes of apatite in DOM 18262 and 18666 are close to MIL 05035, further supporting a shared origin of these samples [17]. Further work on the CRE launch age and trace element geochemistry of DOM 18262 and 18666 would further support this.

Conclusions: The texture, clast inventory, and major element geochemistry of basaltic material in DOM 18262 and 18666 are similar to MET 01210. The shock stage of DOM 18262 and 18666 are also consistent with other YAMM group samples. These factors indicate that these samples may be part of the YAMM group of lunar meteorites, which is thought to sample an ancient basaltic lava flow. The Pb-Pb age of phosphates in the DOM samples (~ 3.86–3.96 Ga) is consistent with the YAMM group (3.8–3.9 Ga) [4]. Assuming DOM 18262 and 18666 are paired with the YAMM group, 'DYAMM' is proposed as an updated acronym for this group.

References: [1] Righter, K. (2019) *Antarctic Meteorite Newsletter 42(2)*. [2] Gattacceca, J. et al. (2020) *MaPS, 55,* 1146–1150. [3] Zeigler, R. A. et al. (2021) *84th Ann. Met. Soc.*, 2609. [4] Arai, T. et al. (2010) *GCA, 74,* 2231–2248. [5] Hawke, B. R. et al. (2006) *LPSC XXXVII*, Abstract #1516. [6] Nyquist, L. E. and Shih, C.-Y. (1992) *GCA, 56,* 2213–2234. [7] Snape, J. F. et al. (2016) *EPSL, 451,* 140–158. [8] Stöffler, D. et al. (2018) *MaPS, 53,* 5–49. [9] Day, J. M. D. et al. (2006) *GCA 74(24)*, 5957–5989. [10] Jolliff, B. L. et al. (1993) *18 Symp. Ant. Met.* [11] Takeda, H. et al. (1993) *Ant. Met. Res., 6,* 3. [12] Warren, P. H. and Kallemeyn, G. W. (1993) *Ant. Met. Res., 6,* 35. [13] Joy, K. H. et al. (2008) *GCA, 72,* 3822–3844. [14] Stöffler, D. and Grieve, R. A. (2007) *in Fettes, D. and Desmons, J. (Eds) IUGS.* [15] Terada, K. et al. (2007) *Nature, 450,* 849–852. [16] Hawke, B. R. et al. (2005) *LPSC XXXVI*, Abstract #1642. [17] Hayden, T. S. et al. (2022) *LPSC, LIII*.