A NEW BASALTIC-BEARING LUNAR METEORITE MILLER RANGE 13317. N. M. Curran[1], K. H. Joy[1], J. F. Pernet-Fisher[1] and R. Burgess[1]. [1]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK (natalie.curran@manchester.ac.uk).

Introduction: Miller Range 13317 (MIL 13317) is a new lunar meteorite found in the Miller Range region of Antarctica during the 2013 field season [1]. It was initially classified as an anorthositic breccia [1]; however, our preliminary examination of the sample shows it to be a mingled anorthositic-bearing basaltic breccia. Here we present mineralogy and mineral chemistry data for MIL 13317, discuss parent rock lithologies and investigate links between other lunar meteorites.

Sample and methodology: A polished thin section of MIL 13317,7 (2 × 2 cm) was provided by NASA's Meteorite Working Group and carbon coated at the University of Manchester. We used a Phillips FEG-SEM with EDAX Genesis EDS software to produce back-scatter electron images and false colour element maps and a Cameca SX 100 EMPA to determine mineral chemistry.

Confirmation of lunar origin: Olivine and pyroxene in MIL 13317 have Fe/Mn ratios (Ratios: pyroxene 33-86, olivine 70-97) that are consistent with previously determine lunar trend lines [2, 3].

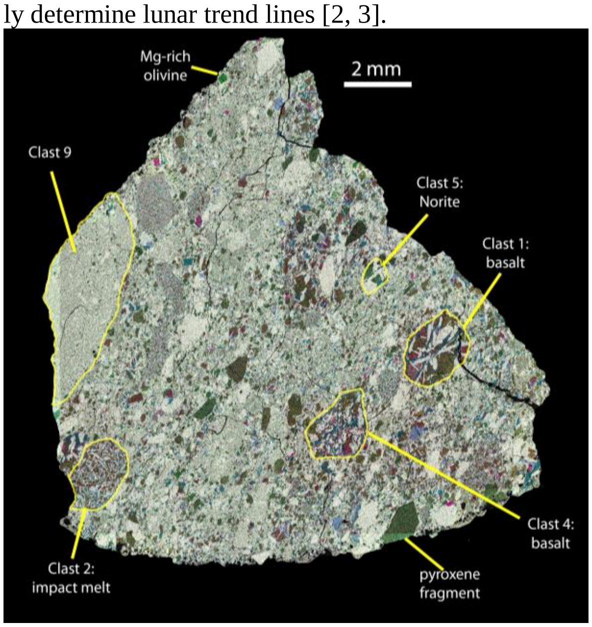

Figure 1: False colour element maps of MIL13317,7 where Al=white (feldspathic material), Ca=Yellow (phosphates), Mg=green (pyroxene, Mg-rich olivines), Fe=red (pyroxene rims), Ti=pink (ilmenite), Si=blue (silica), K=cyan (K-fsp). A variety of clasts are denoted with a yellow boundaries.

Petrology and Mineralogy: MIL 13317 is a polymict breccia containing a diverse array of both mare basalt and highland material in a heterogeneous matrix comprised of mineral and glass fragments (Fig. 1). The sample contains a variety of lithic clast up to 7 mm in size that include mare basalts, highland fragments, symplectites, norites and granulites, as well as impact melt breccia clasts. Mineral fragments, up to 2 mm, are mainly plagioclase (An_{93-99}: Fig. 2d) and pyroxene (Wo_{2-44} En_{3-66} Fs_{12-79}: Fig. 2a) with minor amounts of ilmenite (up to 300 µm), olivine and silica. Some pyroxene exhibit fine exsolution lamellae from 1 to 2 µm in width (composition are shown in Fig. 2a). Accessory mineral are Ca-phosphates and zircons.

No glass beads or agglutinates were found in this section to suggest that the sample contains regolith components. There is a vesicular fusion crust 50 to 250 µm wide found on two sides of the sample. The average composition of the homogeneous regions of this fusion crust glass is SiO_2 = 49.8 wt%, TiO_2 = 1.2 wt%, Al_2O_3 = 15.2 wt%, FeO = 13.2 wt%, MgO = 5.8 wt%, CaO = 11.4 wt%, Cr_2O_3 = 0.13 wt%, Na_2O = 0.34 wt%, K_2O = 0.3 wt%, P_2O_5 = 0.02 wt%, which we use as an estimate of the bulk composition of the meteorite.

Lithic clasts are described below in more detail:

Basaltic clasts: There are a number of coarse grained subophitic evolved quartz-normative basaltic clasts, the largest two being ~ 2 × 1.5 mm in size (clast 1 and 4: Fig 1). Basaltic clasts are mainly composed of pyroxene, plagioclase and silica. Late-stage crystallised residual melt of the MIL 13317 basaltic clasts are found in association with symplectite assemblage and pyroxene. These mesostasis areas are composed of fayalitic olivine, apatite, ilmenite and silica. Pyroxene grains show complex chemical zoning trends mainly from an Mg-richer core to Fe-rich rims, with chemical compositions of Wo_{8-35} En_{4-54} Fs_{28-79}. Plagioclase (An_{89-94}) and silica are present as elongated laths. Some small clasts, such as clast 15 (0.5 × 0.7 mm) are formed from solely late stage basalt melt components where pyroxene compositions (Wo_{17-27} En_{6-10} Fs_{66-75}) are similar to the most evolved pyroxene in the other basaltic clasts (Fig. 3a).

Impact melt breccia clasts: The predominant impact clast varieties include clast-rich and basaltic crystalline impact melts. There is a large 2 × 7 mm feldspathic impact melt breccia (clast 9) which is composed of plagioclase (An_{97-99}), pyroxene and minor triolite. Basaltic crystalline impact melts (clast 2, 7 and 8) consist of plagioclase, pyroxene and silica. Pyroxene are equilibrated and plagioclase are K-richer (An_{78-92} $Or_{0.7-15}$) than the mare basalt and highland lithologies (Fig. 3c).

Highland material: Highland rock types are represented by a range of norites, granulites, Mg-rich olivine fragments (Fo_{80-91}) and highly anorthitic ($An_{>97}$) plagioclase fragments in the sample matrix. A 0.6 × 1.2 mm igneous noritic clast (clast 5) contains plagioclase (An_{97-99}) and Mg-rich orthopyroxene (Mg#$_{72-75,}$ Wo_{2-4} En_{68-72} Fs_{24-27}) similar to rocks from the lunar Mg-Suite.

Discussion: MIL 13317 is a mingled fragmental breccia of lunar origin that is dominated by mare basalt assemblages. All basaltic clasts show similar mineral components, compositions and fractionation trend (co-crystallisation of plagioclase with pyroxene and late stage precipitation of ilmenite and silica) typical of very low-Ti (VLT) to low-Ti mare basalts (Fig 2b). The similar mineral chemistry suggests they all originated from the same source lava flow, but the slightly different textures reflect different cooling histories. The plagioclase in the matrix are highly anorthositic ($An_{>97}$) indicating a highland (FAN or Mg-suite) affinity, indicating mixing with ancient crustal lithologies.

Similarity to other lunar meteorites: There have been six other lunar meteorites found in the Miller range region. The MIL 090034/36/70/75 stones are feldspathic regolith breccias with little or no evidence of basaltic material [4, 5] and, therefore, are not likely paired with MIL 13317. We also rule out MIL 07006 as a possible paired stone as MIL 07006 is more feldspathic than MIL 13317, and contains VLT basalt clasts that originated from a more primitive and Ti-depleted melt than the MIL 13317 source lava flow (Fig. 2b).

MIL 13317 is petrographically most similar to Meteorite Hills (MET) 01210 which is paired with the MIL 05035, Yamato 793169 and Asuka 881757 basalts (collectively known as the YAMM group [6, 12]). Using the MIL 13317 fusion crust as a first-order estimate of bulk-rock composition; MIL 13317 like MET, is low-Ti (MIL 13317: 1.2 wt% TiO_2; MET: 1.53 wt% TiO_2 [7]), but has lower FeO than MET (MIL 13317: 13.2 wt% FeO; MET:16.4 wt% FeO [7]). Pyroxene in MIL 13317 are from a more Ti-depleted (i.e., VLT) source than those of the YAMM basalt group (Fig. 2b). Therefore, we suggest that a grouping between these samples is unlikely, although needs further testing.

Future work: Bulk-rock chemistry and noble gas analysis help further constrain the basaltic source region and determine the cosmogenic history of MIL 13317. In particular, the noble gas inventory will be used to determine i) exposure age, ii) breccia formation age (closure age), and iii) characterise trapped gases contained in the sample. As no regolith components were found in this sample, determining if there are trapped gases from solar wind implantation will indicate whether MIL 13317 is indeed a regolith breccia or not and cosmogenic histories will help further decipher pairing relationships.

References: [1] *Antarctic Meteorite Newsletter* 38(2) (2015), JSC, Houston [2] Karner J. et al. (2003) *Am. Min.t* 88, 806-816. [3] Karner J. et al. (2006) *Am. Min.*, 91, 1574-1582. [4] Martin D. (2014). *77th Met. Soc.* #5191. [5] Zeigler R. et al. (2012) *LPSC XLIII*. #2377. [6] Arai T. et al. (2010) *GCA*, 74, 2231-2248. [7] Korotev R. L. and Zeigler R. A. (2014) *35 Seasons of US Antarctic Meteorites* (1976-2010), 101-130. [8] Arai T. et al. (1996) *Meteor. & Planet. Sci.*, 31, 877-892 [9] Joy K. H. et al. (2010) *LPSC XLI*. Abstract #1793. [10] Robinson et al. (2012) *Meteor. & Planet. Sci.*, 47, 387-399 [11] Curran N. M. et al. (2014) *LPSC VL*. #1467. [12] Joy et al., (2008) *GCA*, 72, 3822-3844. [13] Joy K. H. et al. (2010) *LPSC XLI*. #1793.

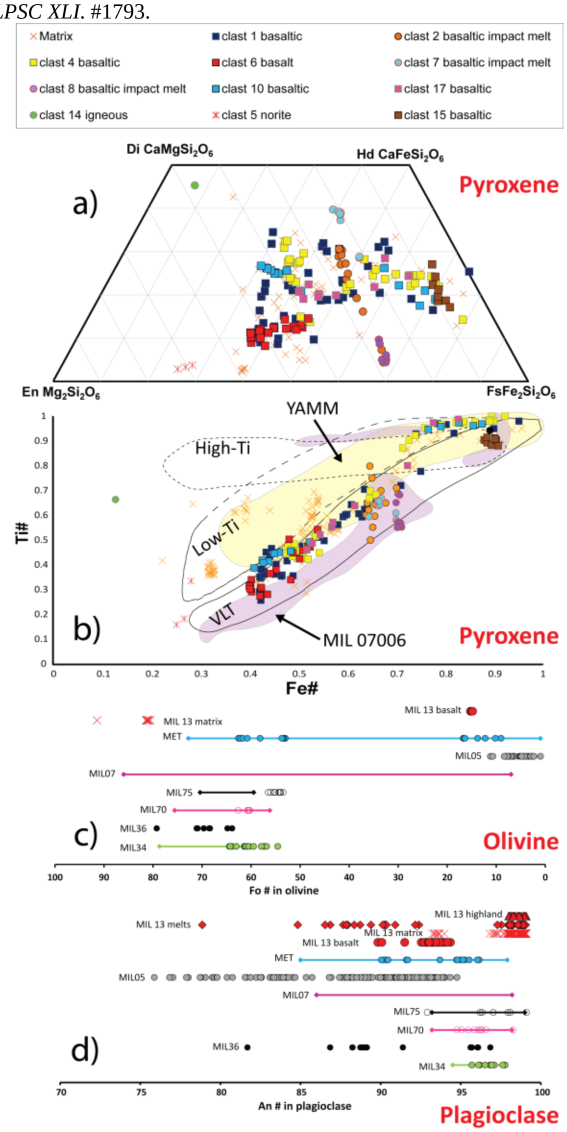

Figure 2: a) MIL 13317 pyroxene compositions. b) Fe # (atomic Fe/Fe+Mg) vs. Ti # (atomic Ti/Ti+Cr) for different clast and matrix in MIL 13317. Coloured fields represent YAMM meteorites (peach [8]) and MIL 07006 (purple, [9]). Black lined fields show the extent of Apollo VLT, Low-Ti and High-Ti mare basalts [9, 10]. c) Forsterite number in olivine found in matrix fragments and basaltic clasts and d) Anorthite number in plagioclase in MIL 13317. Data in c) and d) are compared with the other MIL meteorites and MET 01210 [4, 11, 12, 13].