LUNAR HIGHLAND BRECCIAS MIL 090034/36/70/75: A SIGNIFICANT KREEP COMPONENT. Yang Liu[1], Allan Patchen[1], and Lawrence A. Taylor[1], [1]Planetary Geosciences Institute, Dept. of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 (yangl@utk.edu).

Introduction: Lunar highland breccias carry diverse mineral fragments that offer important information of the stratigraphy of the highland crust [1, 2]. Four lunar anorthositic breccias were recently found on the Miller Range (MIL) Ice Field in Antarctica [3], including MIL 090034 (195.6 g), 090036 (244.8 g), 090070 (137.5 g), and 090075 (143.5 g). The last two, MIL 090070 and 090075, were paired owing to their close proximity in the field [1]. Because all four samples display similar mineral chemistry, we present them as a group. Results of mineral chemistry and petrography suggest that these melt breccias contain a significant contribution of Mg-suite rocks, with significant addition of a mare (KREEP) component.

Petrography: All samples are dominated by mineral fragments sitting in a dark glassy matrix. Lithic clasts mainly consist of impact melt and regolith clasts of 0.5-5 mm. Small crystalline rock clasts include troctolite, gabbro, and granulite (Fig. 1). All samples also contain devitrified melt pockets. *No basalt clasts were observed in sections of four samples studied.*

Mineral fragments mainly include large plagioclase grains (>0.5 mm), pyroxene and olivine grains (<0.5 mm). Ilmenite commonly occurs as individual chips (≤10 μm) or clusters and also as minute grains (<1 μm) associated with silica or impact-formed glass. Both chromite and pink spinel were observed in all sections. There are no large metal grains, although micron to sub-micron Fe/FeNi grains occur in the matrix and in regolith breccias. Phosphates occur occasionally in lithic clasts.

MIL 090034. This sample contains a large gabbroic anorthosite clast (~5 mm) consisting of olivine and pyroxene fragments in a fine grained matrix (Fig. 1a). An unusual clast (granite clast) was also observed, containing cristobalite and anorthite (with ~0.32 wt% FeO) rimed by pigeonite (Fig. 1b). This sample also contains more pink spinel grains than other samples.

MIL 090036. This sample contains the most abundant lithic clasts (0.2-3 mm), including troctolite (Fig. 1d) and noritic anorthosites, impact melt, and regolith breccias. A small clast (~60 μm) of cristobalite, orthoclase, and zirconolite was observed in the thin section. Compared to the other three samples, MIL 090036 contains a significant amount of SiO_2, and K-rich phases (2 vol%, glass and orthoclase).

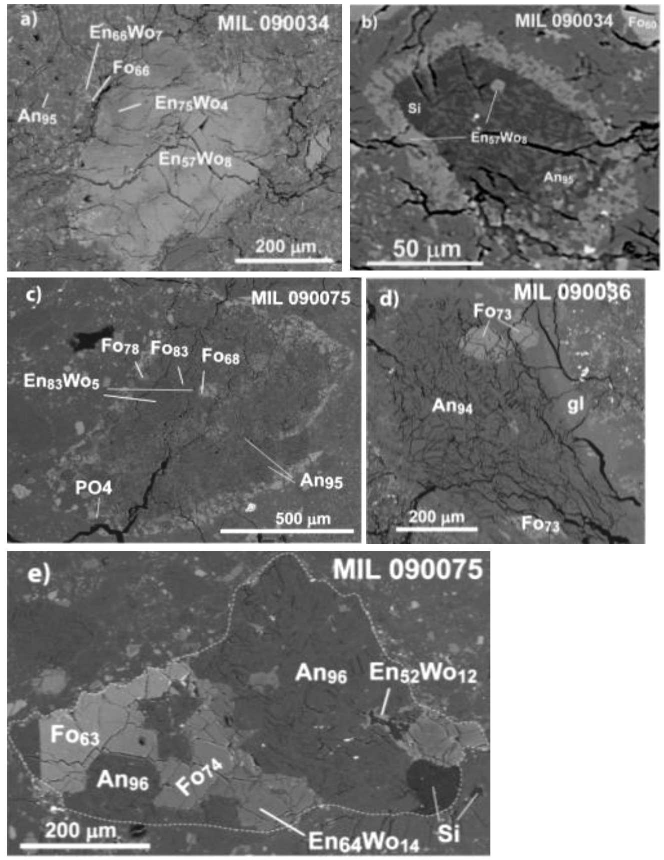

Fig. 1. BSE images of lithic clasts in MIL 090034/36/75. A) a large gabbroic clast of 5 mm size in MIL 090034. Here shows the Mg-rich pyroxene. B) A small "granite" clast [cristobalite (Si) + pigeonite + anorthite] enclosed by pigeonite. C) A granulite clast consiste of anorthosite (An95), olivine (Fo_{68-83}), and enstatite ($En_{83}Wo_5$). D) A troctolite anorthosite clast consisting olivine and anorthite. E) A gabbro clast consisting olivine, anorthite, and cristobalite (Si). Note the difference in scales.

MIL 090070. No large lithic clasts were observed in this sample. Mineral fragments mainly include anorthite, pyroxene, olivine, and pink spinel.

MIL 090075. A large granulite clast (Fig. 1c) was observed (56 vol% plag, 28 vol% ol and 16 vol% opx). Small gabbroic clasts were also observed in the sample (Fig. 1e).

Mineral Chemistry: Major- and minor-element chemistry of minerals and glasses were analyzed with a Cameca SX100 electron microprobe. All olivines and pyroxenes contain molar Fe/Mn of 84 -108 and 41 - 68, agreeing within error with the lunar values [4].

Olivines. All olivine grains analyzed show intra-grain homogeneity. Composition of olivine ranges from Fo_{59}-Fo_{91}. Thin Fe-rich rims (Fo_{77}) of ~3 μm occur on some olivine fragments (Fo_{90}) that are otherwise homogeneous, an indication of re-equilibration of the existing olivine core to a secondary chemical environment.

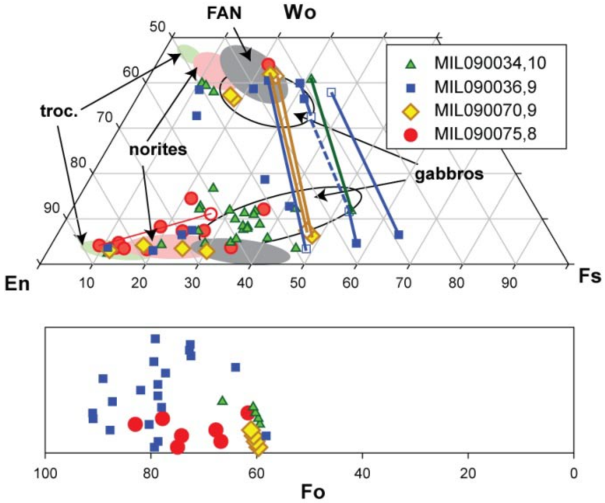

Fig. 2. Composition of olivine and pyroxene in mineral fragments and in lithic clasts. Solid tie lines connect host (filled symbols) to lamellae (open symbols). The dashed line connects symbols of one pyroxene grain of intergrown augite and pigeonite, each of which contains thin lamellae. Fields in the pyroxene quadrilateral are from [1].

Pyroxene. Pyroxene compositions range from enstatite ($En_{87}Wo_4$) to pigeonite to augite. Some pyroxene fragments contain two sets of lamellae of <1 μm and 2-5 μm width, respectively. Some fragments also contain Fe-rich rims. The most Fe-rich pyroxene was observed in a pigeonite fragment ($En_{29}Wo_6$) with augite lamellae ($En_{26}Wo_{38}$) in MIL 090036.

Feldspars. Anorthite in lithic clasts or as mineral fragments has a fairly uniform composition of An_{91-97}. The orthoclase in the small lithic clast in MIL 090036 has a composition of An_7Or_{88} with 1 wt% BaO.

Spinels. Pink spinels contain Al# [= molar Al/(Al + Cr + 2Ti)] of 81-97, Cr# of 16 to 3, and Mg# of 50-89. Some pink spinels also contain a thin Fe-rich rim of ~1 μm. Chromite grains contain a significant hercynite component (Al# = 32, Cr# = 62, Mg# = 23).

Glass. Impact melt pockets and melt veins are of feldspathic composition, with 0.8-4.5 wt% FeO and 2-4 wt% MgO. Matrix glass is also feldspathic with 1.5-2 wt% MgO and 1.5 wt% FeO. K-rich glass contains up to 5 wt% K_2O.

Minor phases. All samples contain cristobalite, ilmenite, chromite and troilite. MIL 090036 also contains large ilmenite (90 μm), rutile (up to 60 μm), zirconolite (~15 μm), baddeleyite (~20 μm) and large zircon (~40 by 200 μm). These minor phases are indicative of mare mineralogy.

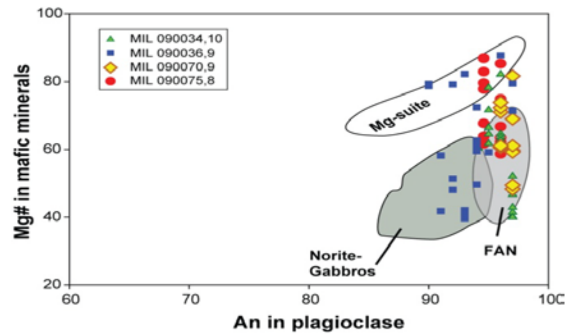

Fig. 3. Compositional ranges of plagioclase and mafic minerals in some lithic clasts in four samples. Fields are from [5].

Discussion: Compositions of pyroxene and olivines in MIL 090034/36/70/75 are similar to Apollo 16 and 17 breccias [1, 6], and other highland breccia meteorites [e.g. 7, 8]. The granulite clast in MIL 090075,8 is similar to those in ALHA 81005 and Dhofar 309 [9].

Mineral fragments in MIL 090034/36/70/75 suggest different thermal histories. Pyroxene with exsolution lamellae is derived from rocks that underwent slow cooling [10,11], which is consistent with their formation as plutonic rocks. Some, but not all, mineral fragments contain thin Fe-rich rims suggesting that some of the clasts and grains experienced generations of modifications.

Mineral fragments and crystalline clasts in MIL 090034/36/70/75 are mainly derived from high-Mg suites and ferroan anorthosites (Figs. 2 and 3). The presence of mineral fragements of mare mineralogy, and the lack of basalt clasts indicate that the mare basalt is a minor consitituent for these highland breccias. The presence of Zr-rich and K-rich phases in these breccias also indicate that the mare sources are likely highly fractionated (KREEP rich).

References: [1] Ryder G. et al. (1997) *GCA*, 61, 1083-1105. [2] Spudis P.D. et al. (1991) *LPSC*, 21st, 151-165. [3] Ant. Met. News Lett. (2008) 33(2). [4] Papike J.J. et al. (2003) *Am. Min.* 88. 469-472. [5] Lucey P. et al. (2006) *Rev. Mineral., 60*, 83-219. [6] Norman M.D. et al. (1995) *GCA*, 59, 831-847. [7] Cahill J.T. et al. (2004) *Meteoritics & Planet. Sci.*, 39, 503-529. [8] Zhang A. and Hsu W. (2009) *Meteoritics & Planet. Sci.*, 44, 1265-1286. [9] Treiman A.H. et al. (2010) *Meteoritics & Planet. Sci.*, 45, 163-180. [10] McCallum I.S. et al. (2006) *GCA*, 70, 6068-6078. [11] McCallum I.S. and O'Brien H.E. (1996) *Am. Min.*, 81, 1166-1175.