**LUNAR METEORITE MILLER RANGE 07006: PETROGRAPHY AND VLT BASALT CLAST INVENTORY.** K. H. Joy[1,2], I. A. Crawford[1] and J. F. Snape[1], [1]UCL/Birkbeck Research School of Earth Sciences, UCL, Gower Street, London, WC1E 6BT, UK. [2]The Natural History Museum, Cromwell Road, London SW7 5BD, UK. (Email: K.Joy@ucl.ac.uk).

**Introduction:** Miller Range (MIL) 07006 is a basalt bearing, feldspathic, regolith breccia meteorite with a lunar origin [1,2]. Our section (MIL 07006,12) is bound on two sides by a heterogeneous fusion crust (Fig. 1) and contains abundant lithic and mineral clasts bound in a vesiculated glass matrix. The meteorite is reported by Korotev et al. [2] to be paired with the Yamato-791197 regolith breccia stone [3-5] on the basis of bulk composition and sample texture, and is also compositionally akin to the Dhofar 1436 impact melt breccia [2].

**Methods:** Mineral chemistries were investigated using a Cameca SX100 Wavelength Dispersive Spectrometer. Element maps (Fig. 1) and BSE images were collected using a JEOL 5900LV SEM at the NHM fitted with Oxford Instruments INCA energy dispersive spectrometer.

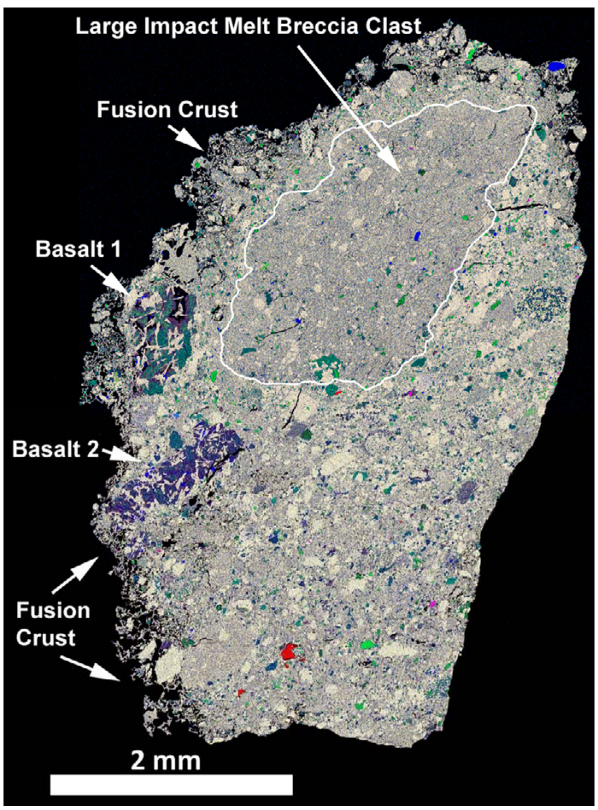


**Figure 1.** False-colour element map of MIL 07006,12. Colours correspond to abundance of elemental concentration and can be used to identify mineral phases and rock types: White = Al (feldspathic material), Red = Fe (FeNi metal, pyroxene rims), Blue = Si (silica), Yellow = Ca (phosphates), Green = Mg (pyroxene and olivine cores), Pink = Ti (ilmenite and spinels) and Turquoise = K.

**Petrography:** MIL 07006,12 has a serrate clast inventory from large (up to 3.5 mm diameter) subangular lithic fragments to small mineral grains indistinguishable from the dark glassy matrix. Some regions of the matrix are very well consolidated indicating high degrees of shock welding. However, other areas affiliated with the sample boundary (i.e. fusion crust) contain many vesicles suggesting that widespread degassing may have occurred when the sample passed through the Earth's atmosphere.

Clasts are typically feldspathic including a diverse range of impact melt and impact melt breccia material, plagioclase grains ($An_{86-98}$) and ferroan anorthosite lithic fragments. Mafic clasts include very low-Ti (VLT) to low-Ti basaltic assemblages. Comminuted mineral fragments derived from a range of protoliths are distributed throughout the matrix. These include silica, pyroxene ($En_{6-82}$ $Fs_{9-73}$ $Wo_{2-44}$: Fig. 2a), olivine ($Fo_{7-89}$), ilmenite and spinel (chromian plenoaste to aluminous chromite) fragments. Our olivine and pyroxene compositions extend to more Fe-rich varieties than the range reported by Lui et al. [1] for MIL 07706,9. Notable large clasts in MIL 07006,12 are discussed in detail below:

*Large Impact Melt Breccia:* The largest clast (3.5 × 2.5 mm) in the section is a fragment laden feldspathic impact melt breccia (Fig. 1). Clasts of mineral grains (plagioclase, olivine, pyroxene, silica) and lithic fragments (norite: $An_{95-97}$, $En_{67-71}$ $Fs_{21-23}$ $Wo_{6-12}$) are bound in a heterogeneous matrix of feldspathic and mafic glass.

*Metal Assemblage:* A 200 × 100 µm clast of FeNi (5.9-7.4 wt. % Ni, 0.39-0.44 wt. % Co) metal (see the bright red region in Fig. 1), which is similar in composition to metal described by [1], surrounds a silicate assemblage of Cr-rich (0.38 wt. % $Cr_2O_3$) forsteritic olivine ($Fo_{89}$) and anorthite ($An_{96-97}$).

**Basalt Clast Component:** Basaltic fragments found in predominantly feldspathic lunar meteorites provide an insight into basalt petrogenesis from regions not sampled by the Apollo and Luna sample return missions. Korotev et al. [2] suggest on the basis of sample major element composition that the MIL 07006 meteorite has a ~8 to 10 % basaltic clast component, and our petrographic observations agree with their finding. Basaltic clasts in MIL 07006,12 are discussed below:

*Basalt 1:* Large VLT subophitic basalt consisting of laths of plagioclase ($An_{95-98}$, $Mg\#_{11-41}$) partially enclosing tabulate pyroxene grains. Pyroxenes are zoned ($En_{6-62}$ $Fs_{27-71}Wo_{9-30}$: Fig. 2a) from pigeonite cores with Al/Ti ratios of 22.2 to Fe-rich rims with Al/Ti ratios of 1.8. Al/Ti vs. Fe# trends (Fig. 2b; blue symbols) indicates that plagioclase and pyroxene cotectically crystallized from a VLT melt, but did not co-crystallize with ilmenite. Accessory phases associated with small mesostasis regions include fayalitic olivine ($Fo_{7-18}$), silica and ilmenite. The clasts is heavily shocked, but has not been remelted: several large (< 200 µm) interconnected pores are present throughout the clast and fractures cutting through mineral phases are frequently infilled with melt. We interpret this melt to have been injected into the fractures during fusion crust formation.

*Basalt 2:* Elongate VLT basalt fragment that is comparatively finer grained than Basalt 1 (Fig. 1). Plagioclases ($An_{96-97}$, $Mg\#_{10-20}$) subophitically enclose pyroxenes ($En_{23-55}$ $Fs_{28-60}$ $Wo_{11-32}$: Fig. 2a). Al/Ti ratios in pyroxenes (Fig. 2b; red symbols) indicate that plagioclases and pyroxenes were cotectic phases, but ilmenite was not being simultaneously precipitated from the melt. Late stage silica, small ilmenite and ulvöspinel grains are associated with, and found within, late stage plagioclase.

Other smaller (<700 µm) basalt fragments in MIL 07006,12 are affiliated with the VLT suite (i.e. Basalt 4, Metabasalt: Fig. 2) and with an evolved low-Ti suite (i.e. Basalt 3: Fig 2).

Pyroxene compositions (Fig. 2a) and An# and Mg# in plagioclases indicate that these two large basalt clasts (Basalt 1 and 2) in MIL 07006 are compositionally similar (VLT, high plagioclase An#) with similar crystallization sequences (co-crystallizing plagioclase and pyroxene, with late stage ilmenite and silica precipitation). However, Al/Ti ratio trends and Mg# (Fig. 2b) suggest that Basalt 1 originated from a slightly more magnesian melt and underwent more fractionation than Basalt 2, indicating that they were likely sourced from different parent magmas.

**Comparison with lunar VLT Basalts:** VLT basalt fragments found within predominantly feldspathic lunar meteorites likely represent a range of lavas erupted in and around the Outer-Feldspathic Highlands Terrane. VLT basalts such as these are thought to form a significant component of cryptomaria deposits and likely represent some of the oldest volcanism on the Moon [6].

The VLT basalt clasts in MIL 07006,12 have mineral chemistries within the range VLT lithologies in Yamato-791197 [4,5], supporting the pairing relationship proposed by Korotev et al. [2]. Pyroxene Al/Ti ratios and Mg# (Fig. 2b) also follow similar trends to VLT basaltic material seen in Kalahari 009 [7] and NEA 001 [8] but, at onset of crystallization, are more ferroan and/or Ti-poorer compared with VLT basalt pyroxenes in MAC 88104/5 (Fig. 2b). However, plagioclases in MIL 07006 VLT basalts are more anorthite-rich than Kalahari 009 VLT material (typically $An_{93-94}$: [7]) and are more ferroan than NEA 001 VLT plagioclases ($An_{96-97}$, $Mg\#_{51-62}$: [8]), indicating that these meteorite VLT basalt fragments must represent discrete petrologically distinct lava flows.

**References:** [1] Lui et al. (2009) *LPS XL*, Abstract #2105. [2] Korotev et al. (2009) *LPS XL*, Abstract # 1137. [3] Yanai and Kojima (1984) *Mem. Nat. Inst. Polar Res., Spec. Iss. 35*, 18–34. [4] Lindstrom et al. (1986) *Mem. Nat. Inst. Polar Res., Spec. Iss.* 41, 58–75. [5] Goodrich and Keil (1987) *Mem. Nat. Inst. Polar Res., Spec. Iss.* 46, 56-70. [6] Terada et al. (2007) *Nature.* 450, 849–853. [7] Sokol et al. (2008) *Geochim. et Cosmochim. Acta.* 72, 4845–4873. [8] Snape et al. (2008) *LPS XXXIX*, Abstract # 1316. [9] Joy et al. (2006) *MAPS.* 41, 1003–1025. [10] Joy et al. (2008) *Geochim. et Cosmochim. Acta.* 72, 3822–3844.

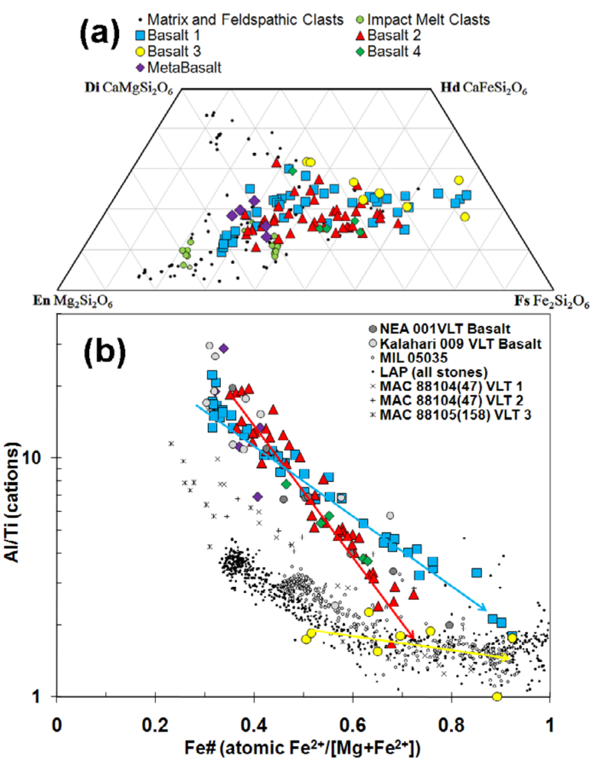


**Figure 2.** (a) Pyroxene compositions of clasts and matrix fragments in MIL 07006,12 projected onto a pyroxene quadrilateral. (b) Pyroxene Al/Ti pyroxene cation ratios in basalt clasts from MIL 07006 compared with (i) pyroxenes in the low-Ti LAP stones [9], (ii) pyroxenes in the low-Ti MIL 05035 stone [10], (iii) pyroxenes in VLT basalt clasts from Kalahari 009 [7], NEA 001 [8 and J. Snape unpublished data] and three VLT basalt clasts in MAC 88104,47 and MAC 88105,158 [K. Joy unpublished data]. Blue, Red and Yellow arrows denote crystallization trend in Basalt 1, 2 and 3 clasts respectively.