MINERALOGY AND PETROGRAPHY OF A LUNAR HIGHLAND BRECCIA METEORITE, MIL 07006.

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Introduction: Lunar breccias provide a lithic buffet of delicious clasts revealing tidbits of lunar petrologic data. A small lunar breccia meteorite, Miller Range (MIL) 07006 (~1.4 g) was recently found on the Miller Range Ice Field in Antarctica [1]. This meteorite was tentatively characterized as a basaltic breccia [1]. However, upon detailed examination of mineral chemistry, we found that another chip (MIL 07006, 9) is a feldspathic regolith breccia, which is consistent with the classification based on the bulk-rock composition [2]. Mineral chemistry indicates the majority of lithic/mineral clasts a highland origin, some with possible basaltic affinity.

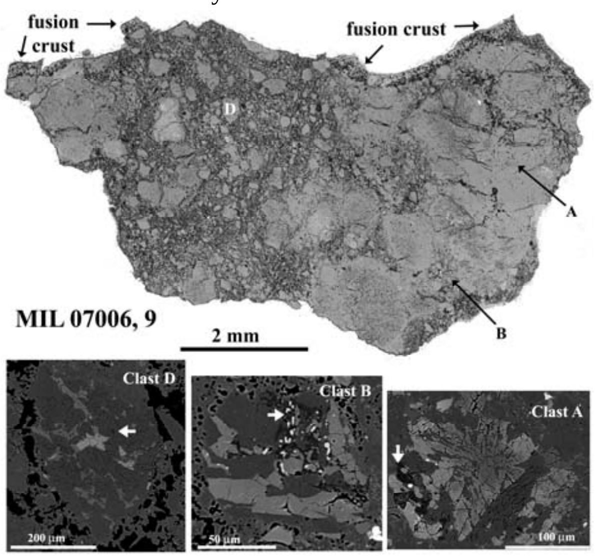

Figure 1. Photo mosaic of MIL 07006, 9. A, B, and D indicate some lithic clasts. All three contain silica (white arrows) while clasts A and B also contain ilmenite. Clasts A shows compositional zonation in pyroxene. Clast D is a gabbro clast.

Petrography: MIL 07006, 9 consists of angular lithic and mineral clasts welded in a dark matrix. The matrix consists of glassy material with abundant vesicles, which are typical for lunar regolith. Most clasts contain extensive fractures. Most lithic clasts, 0.5–2 mm in size, are feldspathic (breccia, ferroan anorthosite, impact-melt glass). Two small clasts (50–100 µm) are suspected to be basaltic (A and B in Fig. 1) based on its texture, zoned pyroxene, and presence of silica and ilmenite. However, the small size of the clast and similar mineral chemistry to highland rocks make the definition ambiguous (Figs. 2 and 3). Clast D is a gabbro. This sample also contains a highly ve-

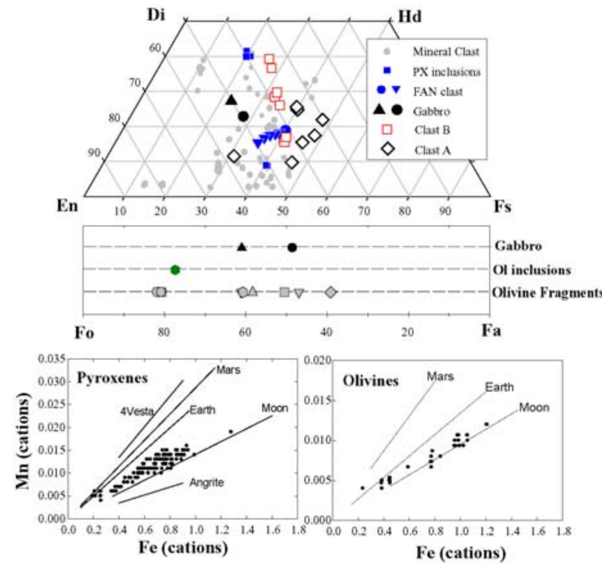

Figure 2. Compositions of pyroxene and olivine in MIL 07006, 9.

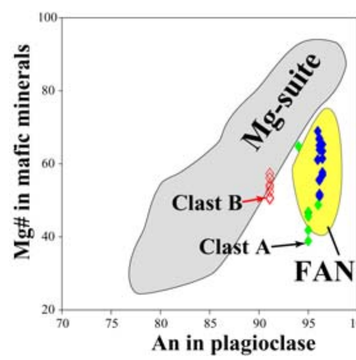

Figure 3. Compositional ranges of plagioclase and mafic minerals in some lithic clasts from MIL 07006, 9. Fields are from [3].

sicular fusion crust (0.12–0.30 mm thick), covering ~40 % of the outer surface of this meteorite.

Mineral fragments mainly include large plagioclase grains (~1 mm) and small pyroxene and olivine grains (<0.5 mm). Pyroxene fragments typically contain exsolution lamellae. Thickness of these lamellae varies from 0.5 to 2.5 µm. Olivine fragments are generally unzoned. Ilmenite commonly occurs as individual chips (≤10 µm), and also as minute grains (<1 µm) associated with silica or impact-formed glass. Chromian ulvöspinel, Ti-chromites and a Al-rich spinel are <50 µm in size. Troilite grains also occur as monomineralic fragments. Micron to sub-micron FeNi grains occur in the matrix and in impact-melt clasts. Several FeNi metal grains occur as anhedral grains of

<30 μm in size. Phosphates were not found in lithic clasts in this section.

Mineral Chemistry: Electron microprobe (EMP) analyses, with a Cameca SX100, were performed for major- and minor-element chemistry of minerals and glasses.

Feldspar: Anorthosite and gabbro clasts, as well as large monomineralic fragments, contain crystalline plagioclase. Maskelynite grains occur as small mineral fragments in the matrix. Plagioclase grains in anorthosites, gabbros, and fragments show inter- and intra-granular homogeneity with $An_{97\pm1}$, and with FeO content similar to highland plagioclase (<0.25 wt%, [4]). Plagioclase in clast A ranges from An_{93} to An_{96} and those in clast B is relatively uniform with lower An (An_{91}) .

Pyroxene: Compositions of pyroxenes in anorthosite and gabbro clasts range from pigeonite to augite with Mg# from 50 to 69 (Fig. 2). Pyroxenes in clasts A and B show compositional variations (Fig. 2). Pyroxene and plagioclase in clast A lie approximately in FAN field whereas those in clast B lie in Mg-suite field (Fig. 3). Pyroxene fragments show a wider range of composition from orthopyroxene ($En_{79}Wo_3$, Mg# = 82) to Fe-rich augite ($En_{28}Wo_{21}$, Mg# = 35). Fe and Mn concentrations in pyroxenes are distributed in the area between the Earth and the Moon lines (Fig. 2), similar to other feldspathic lunar breccias (e.g., Dho 025 and Dho 081 [5]), supporting the lunar origin for this meteorite.

Olivine: Olivine in two gabbro clasts (Fo_{61} and Fo_{51}) occurs as anhedral interstitial grains among plagioclase (An_{96}). Olivine inclusions in plagioclase have relatively higher Mg# (Fo_{77}). Olivine fragments show a compositional range from Fo_{82} to Fo_{39} (Fig. 2). Fe-Mn values in MIL 07006 olivines are consistent with a lunar origin.

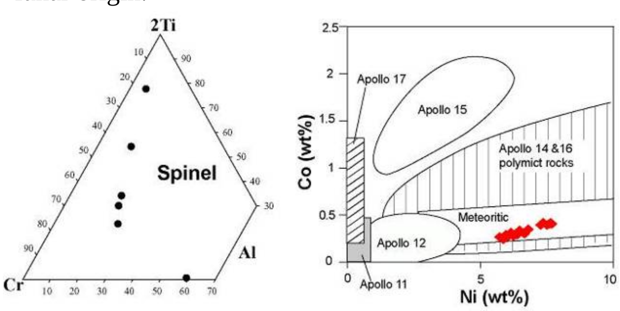

Figure 4. *Compositions of spinels and metal in MIL 07006. Fields in the Co-Ni plot are from [6].*

Oxides: Ilmenite grains large enough for EMP analyses contain MgO of 0.75-1.85 wt%. Compositions of spinel minerals show a wide variation from Ti-chromite to ulvöspinel (Fig. 4), with variable Mg# of 2.3-8.5. The Al-rich spinel grain (Mg# = 44) associated with Fo_{70} olivine contains ~33 wt% Al_2O_3, typical for highland rocks [6,7].

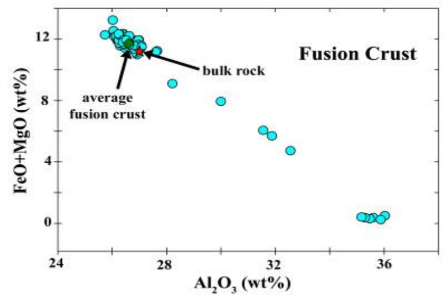

Figure 5*. Composition of fusion crust. Bulk rock data are from [2].*

Metal: Metal grains large enough to be analyzed by EMP contain <0.1 wt% Si and <0.4 wt% P. The contents of Co and Ni in these FeNi grains show a limited range of variation and plot inside the meteoritic range (Fig. 4), similar to Apollo 14 and 16 breccias and meteoritic [6]. A few FeNi grains are associated with akaganeite (β-FeOOH) grains that could have formed by terrestrial oxyhydration of lawrencite ($FeCl_2$). Lawrencite is indigenous in Apollo 16 highland rocks [8].

Fusion crust: Composition of the fusion crust is heterogeneous (Fig. 5) and depends to some extent on the substrate mineralogy [9]. The average composition of 93 analyses on fusion crust (26 wt% Al_2O_3 and 5.9 wt% FeO) are similar to the bulk rock data (~27 wt% Al_2O_3 and 5.6 wt% FeO) by [2] (Fig. 5).

Other phases: Silica-rich glass is found throughout the section as individual fragments or associated with ilmenite and Fe-rich pyroxene ($En_{27}Wo_{33}$, Mg# = 40). Silica-rich glass generally contains SiO_2 >93 wt% with <2 wt% Al_2O_3 and <0.03 wt% K_2O. The silica-rich glass associated with Fe-rich pyroxene contains 0.34 wt% K_2O.

Discussion: Mineral and bulk-rock chemistry and petrology suggest MIL 07006, 9 is a feldspathic regolith breccia. Bulk-rock chemistry of MIL 07006 is similar to feldspathic regolith breccias: ALHA 81005, DaG 262, DaG 400, Dho 025, NEA 001 and Yamato 791197 [2]. The scarcity of basaltic clasts in MIL 07006 is similar to DaG 262/400 and Dho 025 lithologies [4]. The high abundance of FAN clasts and the scarcity of basaltic clast in MIL 07006, indicate that the source area on the Moon is the highland terrain.

References: [1] Ant. Met. News Lett. (2008) 31(2). [2] Korotev R. (2008) http://meteorites.wustl.edu/. [3] Lucey P. et al. (2006) *Rev. Mineral., 60*, 83-219. [4] Taylor L.A. et al. (2009) this volume. [5] Cahill J. T. et al.. (2004) *Meteoritics & Planet. Sci.*, 39, 503–530. [6] Papike J. et al. (1991) *Lunar sourcebook*,121-182. [7] Haggerty S. (1978) Mare Crisium: The View from Luna 24. *GCA Supp. 9*, 523-535. [8] Taylor L. et al. (1973) *LPSC, 4*, 829-839. [9] Thaisen K.G. and Taylor L.A. (2009) *Meteoritics & Planet. Sci. (in revision).*