New Lunar Meteorite MIL 05035: Petrography and Mineralogy.

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Introduction: MIL 05035 is a 142.2 g lunar meteorite found on the Miller Range Ice Field, Antarctica, during the 2005 meteorites season [1]. A polished thin section, MIL 05035,6 (~0.75 cm^2, Fig. 1), was used for the petrographic and mineralogic study. Results suggest that this new lunar meteorite is derived from a highly fractionated, low-Ti magma.

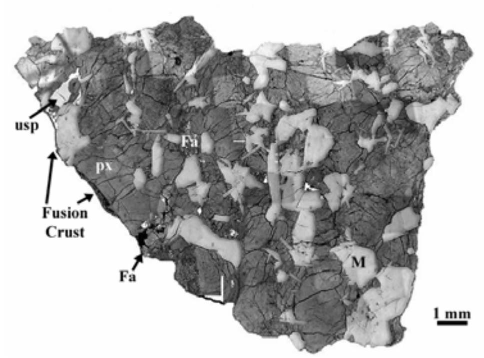

***Figure** 1. MIL 05035,6 (reflective light). Abbreviations are Px for pyroxene, M for maskelynite, Fa for fayalite, and Usp for ulvöspinel.*

Petrography: MIL 05035,6 is conspicuous for the abundant break-down assemblages (~1.4 vol%) and the large grain size. It has a holocrystalline texture and is mainly composed of coarse-grained pyroxene (>2 mm, ~66 vol%) and maskelynite (>1 mm, 29 vol%). The rest of the sample consists of interstitial minerals (fayalite, troilite, ulvöspinel intergrown with ilmenite, and SiO_2), Fe-rich pyroxene break-down assemblages (intergrowths of olivine, SiO_2, and ferroaugite), and mesostasis (K-rich glass, fayalitic olivine, merrillite, baddeleyite, and SiO_2). Mesostasis accounts for <1 vol% of the section. Also present is a small section of highly vesiculated, heterogeneous fusion crust. All minerals are subhedral to anhedral.

Mineral Chemistry: *Pyroxene*: Primary pyroxenes have augite cores ($En_{35-40}Fs_{30-42}$) and grade toward Fe-rich rims (Fig. 2). The extreme Fe-enrichment of pyroxene rims places these compositions in the "forbidden zone" for terrestrial pyroxenes, and they are, therefore, metastable [8]. Secondary pyroxenes in the break-down regions are close to hedenbergite ($En_{11\pm2}Fs_{52\pm3}Wo_{37\pm3}$).

Maskelynite: Maskelynite is zoned from An_{94} in cores to An_{91} in rims. However, rims in contact with the mesostasis have An_{85-86}.

Olivine: All olivines are fayalitic in composition. The most extreme composition is that of two large (> 1 mm) fayalite grains (Fa_{98}) associated with late stage

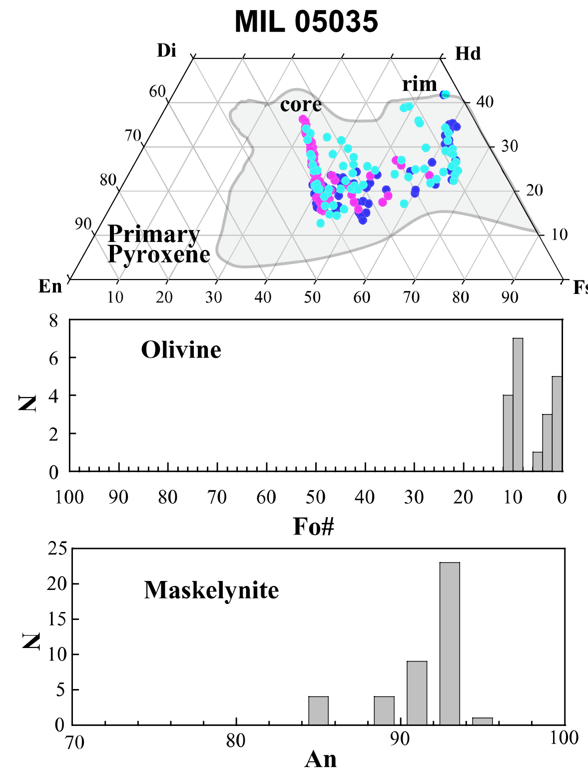

***Figure 2.** Mineral Compositions in MIL 05035. The field in pyroxene quadrilateral corresponds to pyroxene compositions in other lunar meteorites, e.g. EETA 96008 [2], MET 01-020 [3], LaPaz [4, 5], Asuka [6], Yamato-793169 [7].*

phases (e.g., K-rich glass, Cr-rich usp, baddeleyite). Small fayalite grains in mesostasis have a composition of Fa_{90}. Secondary olivine, in the break-down textures, has composition $Fa_{94\pm1}$.

Oxide Phases: Interstitial ulvöspinel (>1 mm) contains 5-7 wt% Cr_2O_3, and ilmenite contains ~0.2 wt% Cr_2O_3. Ilmenite has detectable ZrO_2 (~0.2 wt%).

Miscellaneous Phases: Silica occurs as lath shaped grains (~ 1 mm long), as well as small grains (<20 μm) in the break-down assemblages. K-rich glass contains up to 8.5 wt% K_2O and ~0.9 wt% BaO.

Bulk Composition: The bulk composition of the rock was estimated using the modal analyses of minerals, mineral compositions, and density. The estimated composition is low Ti basalt: 47.2 wt% SiO_2, ~1 wt% TiO_2, 10.5 wt% Al_2O_3, 0.4 wt% Cr_2O_3, 5.9 wt% MgO, 13.7 wt% CaO, and 20.7 wt% FeO.

Discussion:

MIL 05035,6 has an unusually high proportion of break-down assemblages (~1.4 vol%). Most

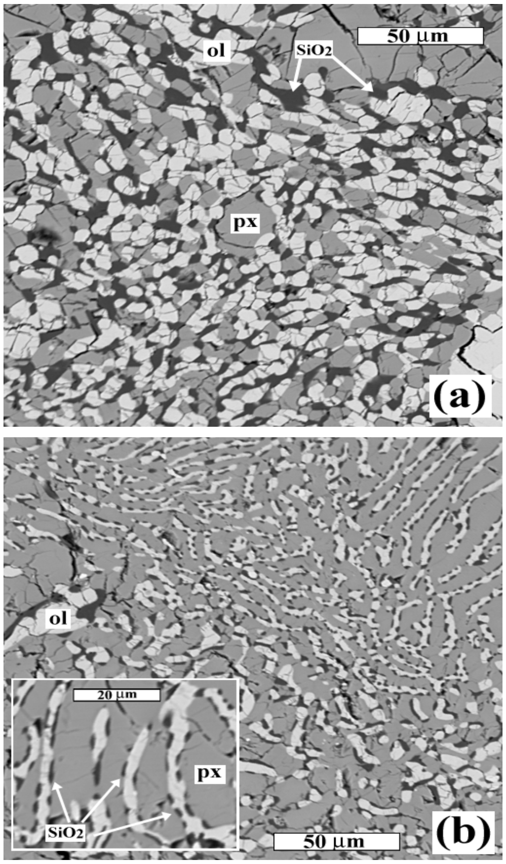

***Figure 3**. BSE images of the break-down textures. (a) Minerals are uniformly distributed. (b) Myrmekitic texture with SiO_2 along the boundary between pyroxene and olivine.*

assemblages contain a uniform distribution of minerals (Fig. 3a). However, a few assemblages have distinctive myrmekitic textures (Fig. 3b).

This intergrowth feature of augite, fayalite, and SiO_2 is indicative of the **break-down of pyroxferroite** [9-10] **or pyroxenes with compositions in the "forbidden zone"** (Fig. 4) [8]. The pre-break-down pyroxenes or pyroxinoids were reconstructed using the modal percentage of minerals (analyzed on the BSE image using image analysis software, ImageJ from NIST), the composition of minerals, and their corresponding densities.

For the uniformly distributed texture (Fig. 3a), the reconstructed composition (Fig. 4) lies near the range of lunar pyroxferroite [8]. Pyroxferroite can form metastably at low P and then break-down during slow cooling [9]. In this sample, the lack of pyroxenes with pyroxferroite composition (Fig. 4) suggests that all pyroxferroites broke down due to a homogeneous process affecting the entire rock e.g., cooling.

For the myrmekitic break-down, the reconstructed Fe-rich pyroxene, in the "forbidden zone" (Fig. 4), is similar in composition to the rim of primary pyroxenes. The preferential alignment of olivine and SiO_2 suggests the pyroxene ($En_{12}Fs_{65}$) decomposed to ferro-augite and metastable "ferrosilite", and the "ferrosilite" subsequently broke down to fayalite + SiO_2.

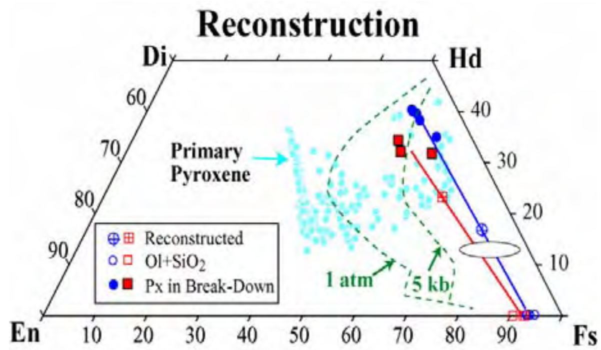

***Figure 4.** Reconstruction of the bulk composition for break-down assemblages. Blue symbols are data for uniform assemblage – pyroxferroite breakdown. Red symbols are data for myrmekitic texture. The ellipse is the composition of lunar pyroxferroite [9]. Dashed curves are the left boundary of "forbidden zone"[8].*

The textual and chemical differences between the two types of break-down suggest a different process may have been involved in the formation of the myrmekitic assemblages. **An obvious candidate to provide the activation energy required to initiate this process would be the impact shock that launched this lunar rock into space.** The full conversion of plagioclase to maskelynite involves pressures in the upper end of the vitrification range (30 – 45 GPa [11]), and the mosaicism of pyroxenes involves pressures of 30 – 75 GPa [12]. This may have been sufficient energy to cause the breakdown. That not all pyroxenes with this composition broke down is further evidence for the mechanical nature of the activation of this process.

Comparison with Other Lunar Meteorites: Compared to other lunar gabbroic meteorites (Asuka-881751 [6], Yamato-791369 [7]), MIL 05035 is similar to Asuka-881751 in that primary minerals have similar compositions. However, MIL 05035 contains more Fe-rich pyroxenes and less ilmenite than Asuka-881751. The break-down textures have been reported for other lunar meteorites, but not to the degree observed here.

References: [1] Ant. Met. News Lett. (2006) 29, 37. [2] Anand et al. (2003) GCA, 67, 3499-3518. [3] Patchen et al. (1995) *LPS XXXVI*, Abstract #*1411*. [4] Day et al. (2006), GCA, 70, 1581-1600. [5] Hill et al. (2007), this volume. [6] Yanai (1991) *Proc. LPS XXI*, 317-324. [7] Takeda et al. (1993) *Proc. NIPR Symp. Antarct. Meteo. 6*, 3-13. [8] Lindsley (1983) Am Min. 68, 477-493. [9] Lindsley et al. (1972) *LPS III*, 483–485. [10] Burnham (1971) *LPS II*, 47-57. [11] Ostertag et al. (1983) *LPS XXIV, 364-376*. [12] Schaal et al. (1979) *LPS X*, 2547-2571.