LUNAR METEORITE MIL 05035: MARE BASALT PAIRED WITH ASUKA-881757. T. Arai, K. Misawa, and H. Kojima. Antarctic Meteorite Research Center, National Institute of Polar Research, 1-9-10 Kaga, Itabashi, Tokyo 173-8515, Japan (tomoko@nipr.ac.jp).

Introduction: Miller Range (MIL) 05035 is a new lunar meteorite, which is a crystalline mare basalt of 4.5 × 4.0 × 3.5 cm in dimension, weighing 142.2 g [1]. The mineralogy was studied to discuss the petrogenesis and pairing with known lunar meteorites.

Sample and Method: Three polished thin sections (MIL 05035, 29, MIL 05035, 33 and MIL 05035, 36) were provided by NASA JSC. Mineralogical analyses were done by JEOL 8200 Electron Microprobe at National Institute of Polar Research.

Results: MIL 05035 is a crystalline mare basalt with an extremely coarse-grained gabbroic texture (Fig. 1). Pyroxene crystals are 2 – 10 mm across, typically showing elongated shapes toward c-axis. Plagioclases are 1 – 4.5 mm across. Due to the coarse-grained texture, the modal abundances among the three thin sections are variable (Fig. 1). It consists of dominantly pyroxene and plagioclase with dark mesostases including fayalite, ilmenite, Cr, Al-bearing ulvöspinel, troilite, Fe metal, silica, k-feldspar and Ca phosphate. Symplectic intergrowths of silica-fayalite-hedenbergite are closely associated with mesostases and grain boudaries (Fig. 2a). Vesicular fusion crusts, 30 – 240 μm thick are found in one thin section (, 36). The compositions vary in places, depending on the mineral in contact with the fusion crust (Table 1). Pyroxene are highly fractured and plagioclase are all converted into maskelynite due to shock effect. Heterogeneous glasses in mesostasis and grain boundaries, and embayed grain boundaries indicate shock-induced melting (Fig. 2b). The composition represents mixtures of plagioclase and pyroxene with or without minor ilmenite.

Table 1 Averaged composition of fusion crusts.

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	P_2O_5	Total
FC 1	46.6	1.14	8.18	24.4	0.34	5.05	12.3	0.37	0.05	0.15	0.07	98.7
FC 2	46.4	1.61	9.17	22.6	0.36	6.57	11.8	0.29	0.03	0.22	0.05	99.1
FC 3	43.1	5.13	10.8	22.9	0.31	4.32	11.9	0.49	0.04	0.22	0.05	99.4

FC1: Contact with plagioclase, FC2: pyroxene, FC3: ulvöspinel.

Pyroxenes show complex chemical zonings from large (up to 2 mm) cores to rims. While the cores exhibit limited Fe/(Fe+Mg) value (= Fe#) variation (0.45 – 0.55), the rims shows the greater range (0.55 – 0.94). Though Ca seems to abruptly decrease toward the rims in the cores (Fig. 3a), most of the cores show cyclic Ca zoning between augite and pigeonite. In one pyroxene grain, pigeonite ($Wo_{11-13}En_{44}$) and augite ($Wo_{33-36}En_{35-36}$) co-exist in the core. These compositions indicate crystallization at 1100 – 1000 ºC. In the rim, Ca content gradually increases with enrichment of Fe, eventually rises toward the hedenbergitic composition. In the Al vs. Ti plot (Fig. 3b), Ti/Al values of the most cores are near 1/4, indicating the crystallization without plagioclase, whereas those of some cores and the rims are near 1/2, indicative of simultaneous crystallization of plagioclase. In a plot of Fe# and Ti/(Ti+Cr) (= Ti#) ratio, pyroxenes display a series of crystallization trend (Fig. 3c). The trend shows a change in the slope at Ti# = 0.7, indicating incoming of Ti-bearing phases, such as ilmenite and ulvöspinel. Based on the empirical correlation between the Ti# and bulk-rock TiO_2 [2], the bulk TiO_2 is estimated to be 1.9 ± 2 wt%. Pyroxenes are typically exsolved in sub-micron scale (Fig. 2c).

Maskelynite plagioclases show chemical zonings from cores to rims ($An_{94-77}Or_{0-3}$). Fayalite (Fo_{2-12}) is present both in mesostasis and symplectite. The Fe/Mn ratios (78 – 105) are comparable to lunar range. Cr, Al-bearing ulvöspinels occur with ilmenite and fayalite. They show compositional variations both within grains (zoning) and among grains (Fig. 4). Chromite is not present in the three sections studied.

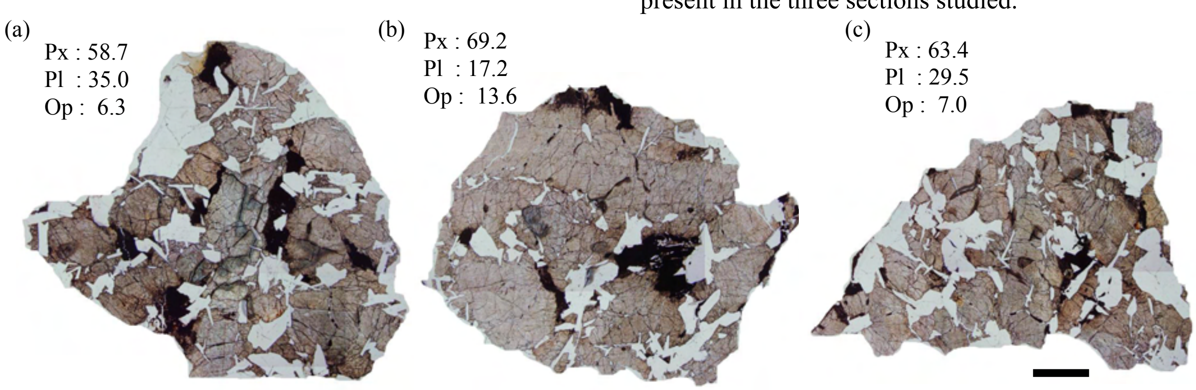

Fig. 1 Photomicrographs of thin sections studied. (a) MIL 05035, 29, (b) MIL 05035, 33, and (c) MIL 05035, 36. Scale bar is 2 mm. Due to the coarse grain size, the modal abundances (vol%) are variable amongst the three: Px (pyroxene in pale brown), Pl (plagioclase in white), and Op (opaque phases / mesostasis in black).

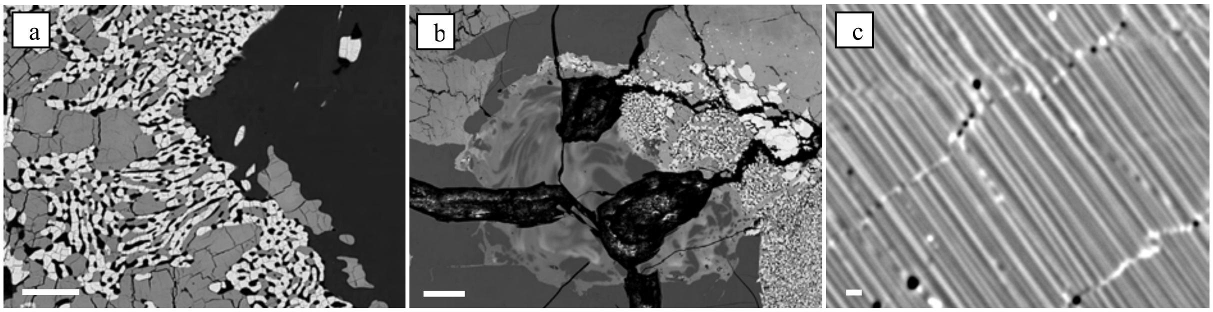

Fig. 2. Backscattered electron images (a) symplectic intergrowth in the embayed grain boundary of pyroxene and maskelynite plagioclase. Scale bar = 30 µm. (b) Heterogenesou shock melt in mesostasis. Scale bar = 100 µm. (c) Sub-micron pyroxene exsolution lamellae. Scale bar = 1 µm.

Discussions: MIL 05035 shows atypical mineralogical traits compared to Apollo and Luna mare basalts, such as unusually coarse grain size and unique pyroxene crystallization trend. Yet, a crystalline mare basalt, Asuka (A)-881757 exclusively shares the unique characteristics. With remarkable coincidences in the pyroxene compositional trends (Fig. 3a-c), modal abundance (40 - 60 vol% pyroxene), rock texture [3], crystallization sequence [2, 4], pyroxene crystallization temperature [4], subsolidus cooling history (sub-micron pyroxene exolution and symplectites), bulk-rock TiO_2 (~ 2.0 wt %) [e.g. 5] spinel composition (Fig. 4) [2], shock records (maskelynite and shock melting) [6], they are almost certainly derived from a single basalt flow. Due to the 2500 km separation of their find sites, they should be paired in a sense of launch from a single source crater. The reported source-crater pairings with A-881757, Yamato (Y-) 793169 [5, 7], and MET 01210 [8] further link MIL 05035 with these three. The Sm-Nd age and the ^{39}Ar - ^{40}Ar age of A-881757 [9] indicate their source basalt flow crystallized at 3870 Ma and was impacted at 3800 Ma. With the CRE ages of the above three [e.g. 10, 11], MIL 05035 was likely launched off the Moon simultaneoutly with them at 1 Ma. The U-Pb isotopic systematics of A-881757 indicate their derivation from a source mantle with extremely low $^{238}U/^{204}Pb$ (μ) value (10 ± 3), relative to typical Apollo basalts (100 – 300) [9]. Thus, these four basalts represent an unexplored ancient mare basalt.

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References: [1] Satterwhite C. and Righter K. eds. (2006) *Antarctic Meteorite Newsletter* 29(2) [2] Arai T. et al. (1996) *MPS, 31*, 877-892. [3] Yanai K. (1991) *PLPSC* 21th, 31-324. [4] Arai T. et al., (2006) *AMR* 19, 1-19. [5] Warren P. H. and Kallemeyn G. W. (1993) *AMR 6*, 35-57. [6] Mikouchi T. (1999) *AMR* 12, 151-167. [7] Takeda H. et al. (1993) *Proc. NIPR Antarct. Met. 6*, 3-13. [8] Arai T. et al. (2005) *LPS XXXVI*, #2361. [9] Misawa K. et al. (1993) *GCA* 57, 4687-4702. [10] Nishiizumi K. et al. (2006) *LPS XXXVII*, #2369. [11] Nishiizumi K. et al. (1992) *Papers presented to the 17th symposium on Antarctic Meteorites*, 129-132.

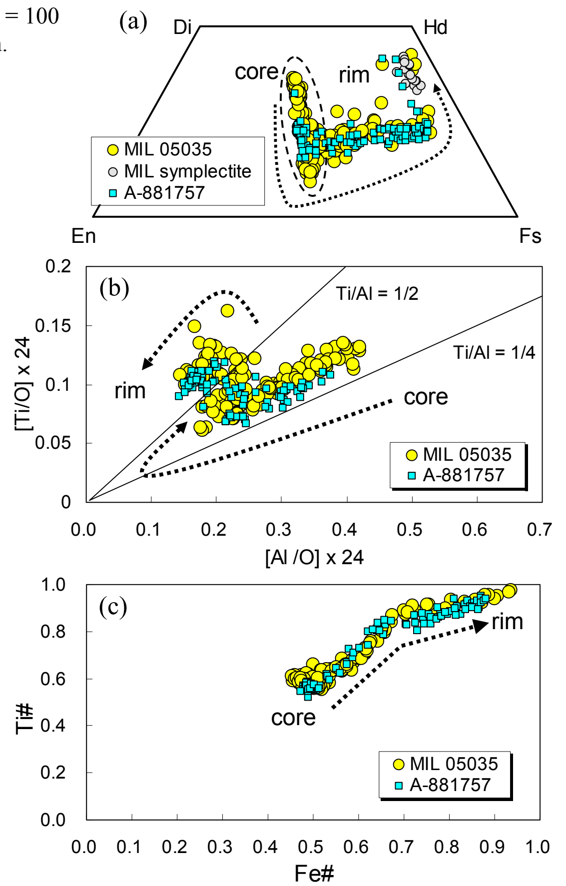

Fig. 3. Pyroxene compositions. (a) Ca-Fe-Mg variation, (b) Al vs. Ti systematics, (c) Fe# vs. Ti# crystallization trend.

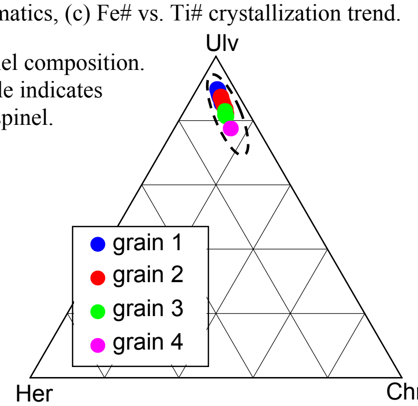

Fig. 4. Spinel composition. Dotted circle indicates A-881757 spinel.