Petrography and bulk composition of Miller Range 05035: a new lunar VLT gabbro

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PETROGRAPHY AND BULK COMPOSITION OF MILLER RANGE 05035: A NEW LUNAR VLT GABBRO. K. H. Joy, M. Anand, I. A. Crawford, and S. S. Russell. k.joy@ucl.ac.uk

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Introduction: Miller Range (MIL) 05035 is a crystalline lunar mare gabbroic meteorite collected in Antarctica in 2005 [1]. It is an important new sample in the lunar meteorite (LM) collection as it is only one of ~8 to be classified as basaltic in nature. MIL 05035 is coarsely grained with large pyroxene grains (<8mm) subophitically enclosing plagioclase grains (<6mm), and accessory ilmenite, spinel, silica, and sulphide phases.

Methods: Minerals in MIL 05035 were investigated using a Cameca SX50 Wavelength Dispersive electron microprobe. Mineral X-ray maps were made using a LEO 1455VP SEM fitted with Oxford Instruments INCA energy dispersive X-ray spectrometer and bulk major- and trace-element chemistry was obtained using ICP-AES and ICP-MS techniques on 140 mg chip of MIL 05035 (Table 1).

Lunar Origin: Fe to Mn ratios in the bulk rock (62), and in pyroxene (average: 60) and olivine phases (average: 80), bulk rock Co/Cr (0.014), and a typical lunar anhydrous mineralogy confirm lunar origin for this meteorite. We will report the results on ongoing oxygen isotope analysis at the LPSC 2007 meeting.

Petrography: MIL 05035 is an unbrecciated, holocrystalline lunar gabbroic meteorite. Its coarse-grained nature suggests a slow cooling history in a thick lava flow.

Pyroxenes: are the dominant mineral phases in MIL 05035 (~54% of sample by mode). They are typically large with compositional zoning from calcic-augite and pigeonite cores to Fe-rich calcic-augite rims: Fs<sub>39</sub>–Fs<sub>68</sub>, Wo<sub>14</sub>–Wo<sub>41</sub>, En<sub>2</sub>–En<sub>42</sub> (Fig. 1a,2).

Fig. 1. Mineral compositional variation in MIL 05035 (a) pyroxene variations where the melt evolution is tracked with the black arrow, (b) olivine, and (c) plagioclase compositional variations.


Fig. 2. False-colour X-ray map of section MIL 05035.1. Mineral phases are indicated. Colour correspond to abundance of elemental concentration and can be used to delineate mineralogical phases: White = Al (plagioclase), Red = Fe (fayalite olivine, troilite, pyroxene rims and symplectite assemblages), Blue = Si (silica), Yellow = Ca (phosphates), Green = Mg (pyroxene cores), Pink = Ti (ilmenite and spinels).

Extreme fractionation is evident in terms of Fe-rich rims associated with late stage crystallization products. Ferrosilite breakdown symplectite assemblages (silica + fayalite olivine + hedenbergitic pyroxene) occur at the rims of many pyroxene grains in a similar texture observed in LM Asuka-881757 [2,3,4,5,6]. These aggregates in places cover broad areas of MIL 05035 (~6% by mode: Fig. 2), and suggest that the sample may have crystallized at low-pressure [4].

Plagioclases: are generally large (500μm – 6mm: Fig. 2) sub-rounded grains (36% by mode) with a typical mare basaltic compositional range: An<sub>46–50</sub>, Or<sub>55–60</sub> (Fig. 1c). The vast majority of grains appear to have been completely shock metamorphosed to maskelynite.

Olivine: grains are fayalitic in composition (Fig. 1b: Fo<sub>10</sub>–Fo<sub>11</sub>) and form anhedral aggregates of varying sizes (<500μm – 2μm) as part of the late-stage mineral assemblage (<1% by mode: Fig. 2).

Ilmenite: is rare in MIL 05035 (~1%) and found in association with pyroxene-rim compositions and
symplectite assemblages. It occurs as euhedral elongate crystals (10 µm – 500 µm), and also as smaller anhedral aggregates in proximity to mesostasis areas. The very low modal abundance of ilmenite is evidence that this sample crystallized from a melt poor in TiO₂.

Spinel: occur occasionally as large grains (<700 µm) that have a limited compositional range of late-stage crystallizing ulvöspinel (2*Ti77-90,Al4-7,Cr4-16). These large anhedral grains occupy an intergrowth with host ilmenite and fayalite phases. Smaller grains also occur as intergrowths in mesostasis regions.

Mesostasis: areas are found adjacent to evolved pyroxene rims and associated with the symplectite assemblage described above. Associated with these regions is fayalitic olivine, silica phases (occurring as elongate laths (<1mm) and smaller (<300µm) grains), anhedral troilite (Fe 61-63S 33-37) blebs, apatite, whitlockite, and occasional aggregates of small Si-rich and K-rich glass intergrowths.

**Bulk composition and Lunar context:** according to our measurements (Table 1) MIL 05035 can be classified as a VLT (0.9 wt. % TiO₂) low-Al (8.85 wt. % Al₂O₃), low-K (124 ppm K) mare gabbroic meteorite (Fig.3b) following the scheme proposed by [7]. It has a very high Sc-content (109 ppm) and is evolved (Mg# 40), but has low bulk ITE concentrations, and a very low Th-content (0.28ppm Th; Fig.3c) implying that it was likely crystallized distally to the Procellarum KREEP Terrane [8].

Our sample of MIL 05035 does not have a negative Eu-anomaly (Fig.3a) typical of the majority of mare basalts. It also has a low REE content, with a C1-normalised profile [9] typical of being dominated by pyroxene phases (positive LREE slope, and a relatively flat HREE profile: (La/Lu)ₙ=0.4. (Tb/Lu)ₙ=1.4). This profile is similar to that measured in the LM Yamato-793169 and Asuka-881757 [3,5] (Fig.3a), although in comparison MIL 05035 is depleted in REE concentration and also notably lower in bulk TiO₂ content (Y and A are reported to have 1.5-2.5 wt. % TiO₂ [3,5]). MIL 05035’s bulk REEs are also much lower than those in Apollo and LM low-Ti samples, but are akin to concentrations measured in A17 and Luna 24 VLT mare basalts.

Mineralogically, pyroxene and symplectite textures in MIL 05035 are similar to those reported in Asuka-881757 and to some large monomict pyroxene fragments and symplectite assemblage clasts observed in the LM regolith breccia MET 01210 [11,12].

**Summary:** MIL 05035 is an unusual holocrystalline, coarsely grained VLT mare gabbro sample. We propose that it is possibly paired with A-881757 and Y-793169 in terms of petrography, mineral chemistry and bulk composition.

**Table.1.** Bulk chemical composition of MIL 05035, 19 measured using ICP-AES and ICP-MS (elements denoted with a *). Elements from Li onwards are listed in ppm. Errors are reported as 2 sigma.

<table>
<thead>
<tr>
<th>Element</th>
<th>MIL 05035.19</th>
<th>MET 01210</th>
<th>Yamato 793169</th>
<th>Asuka 881757</th>
<th>LAP 02224</th>
<th>LAP 02205</th>
</tr>
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<tbody>
<tr>
<td>SiO₂</td>
<td>58.59 ± 0.279</td>
<td>Li</td>
<td>6.03 ± 0.052</td>
<td>Na</td>
<td>1.15 ± 0.030</td>
<td>La</td>
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<tr>
<td>Fe₂O₃</td>
<td>0.60 ± 0.008</td>
<td>Rb</td>
<td>0.76 ± 0.963</td>
<td>Mg</td>
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<td>Ce</td>
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<td>MgO</td>
<td>6.89 ± 0.070</td>
<td>Sr</td>
<td>4.98 ± 0.679</td>
<td>Mn</td>
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<td>CaO</td>
<td>2.00 ± 0.002</td>
<td>Y</td>
<td>10.00 ± 0.579</td>
<td>Fe</td>
<td>0.16 ± 0.015</td>
<td>Nd</td>
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<tr>
<td>P₂O₅</td>
<td>20.68 ± 1.030</td>
<td>Ca</td>
<td>25.07 ± 1.644</td>
<td>Cr</td>
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<td>Na₂O</td>
<td>0.23 ± 0.003</td>
<td>Ti</td>
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<td>MgO</td>
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<td>Mn</td>
<td>5.64 ± 0.546</td>
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<td>CaO</td>
<td>12.13 ± 0.112</td>
<td>Fe</td>
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<tr>
<td>Na₂O</td>
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<td>Cr</td>
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<td>K₂O</td>
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<td>Mn</td>
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<td>P₂O₅</td>
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<td>K</td>
<td>0.01 ± 0.002</td>
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<td>Total</td>
<td>99.31</td>
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<td>0.02 ± 0.001</td>
<td>Eu</td>
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<td>Tm</td>
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<tr>
<td>Mg#</td>
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<td>Tb</td>
<td>0.28 ± 0.040</td>
<td>Yb</td>
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</tbody>
</table>

Table 1. Bulk chemical composition of MIL 05035, measured using ICP-AES and ICP-MS (elements denoted with a *). Elements from Li onwards are listed in ppm. Errors are reported as 2 sigma.