PETROGRAPHY OF LUNAR METEORITE MET 01210, A NEW BASALTIC REGOLITH BRECCIA.

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Introduction: Lunar meteorite MET 01210 (hereafter referred to as MET) is a 22.8 g breccia collected during the 2001 field season in the Meteorite Hills, Antarctica. Although initially classified as an anorthositic breccia [1], MET is a regolith breccia composed predominantly of very-low-Ti (VLT) basaltic material. Four other brecciated lunar meteorites (NWA 773, QUE 94281, EET 87/96, Yamato 79/98) with a significant VLT basaltic component have been identified [2-3]. We present here the petrography and bulk major-element composition of MET and compare it to previously studied basaltic lunar meteorite breccias.

Methods: We determined mineral compositions by electron microprobe analyses (EMPA) on a polished thin section of MET using a JEOL 733 Superprobe at 15 keV accelerating voltage, 20-40 nA beam current, and a 1-20 μm beam size. The bulk major-element composition of MET is estimated based on EMPA analyses on the fusion crust of MET (Table 1).

Results: MET is a lunar breccia composed predominantly of lithic and mineral clasts set in a glassy matrix (Fig. 1f). There are no obvious regolith components, e.g. spherules or agglutinates, apparent in MET. A narrow vesicular fusion crust is present along one edge of MET. Most lithic clasts in MET are either "coarse" grained VLT basalt-gabbro clasts or very fine-grained granulite clasts, with a few symplectite grains

Table 1: Bulk composition of MET

SiO_2	44.8	Cr_2O_3	0.19	MgO	5.97
TiO_2	1.58	FeO	16.2	CaO	13.6
Al_2O_3	17.0	MnO	0.26	Na_2O	0.26

All values in wt%. K2O (not listed) is <0.2 wt%.

also present. The basalt-gabbro clasts (Fig. 1a-b) are composed mainly of pyroxene and plagioclase with lesser amounts of olivine and almost no detectable Fe,Ti oxides. The pyroxene grains range wildly in composition ($Fs_{12-61}Wo_{3-39}$; Fig 2a), are commonly well equilibrated, and in some places have 1-2 μm exsolution. The olivine (Fo_{37-76}; Fig 2b) and plagioclase (An_{90-97}) grains also range in composition, neither showing appreciable zoning trends. Several symplectite grains, silica-fayalite-hedenbergite intergrowths resulting from the break-down of pyroxferroite, are observed (Fig. 1c). The granulitic clasts (Fig 1d-e) are composed of plagioclase (An_{93-98}) and glass with very few pyroxene and olivine grains present (Fig. 2a). The granulite clasts are highly feldspathic, with >80% modal plagioclase.

Mineral clasts in MET are predominantly pyroxene, with lesser amounts of plagioclase and olivine. The pyroxene clasts have a wide range of compositions ($Fs_{25-82}Wo_{6-39}$; Fig 2c) and are commonly exsolved (1-2μm). The olivine clasts also range widely in composition

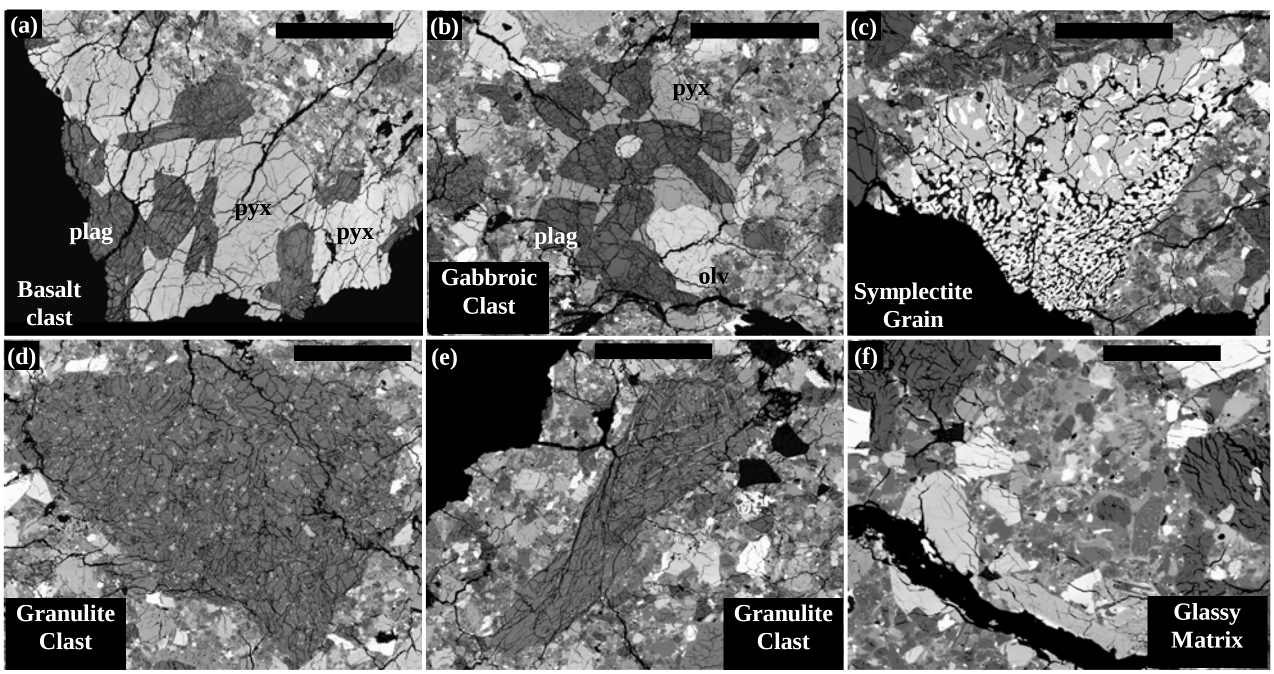

Figure 1: Back-scattered electron images of various lithic clasts in MET (a-e) and the glassy matrix (f). Plag = plagioclase, pyx = pyroxene , olv = olivine. **(a)** Basaltic lithic clast. Scale bar = 300 μm. **(b)** Gabbroic lithic clast. Scale bar = 300 μm. **(c)** Symplectite grain. Brightest phase is fayalite, middle brightness is pyroxene, and silica is the darkest phase. Scale bar = 300 μm. **(d)** Granulitic clast with a plagioclase hosting small amounts of glass and olivine (bright blebs). Scale bar = 150 μm. **(e)** Granulitic clast with larger proportion of glass. Scale bar = 150 μm. **(f)** Close up view of the matrix. Scale bar = 80 μm.

(Fo_{44-98}; Fig 2d) with a high proportion of fayalite observed (55% of olivine clasts have a composition <Fo_{10}). The plagioclase clasts are typically highly fractured, are not maskelynitized, and almost all have a composition in the range An_{92-96} (four grains have compositions in the An_{85-88} range). A few irregularly shaped glass clasts are observed, as well as one large glass grain that appears to have undergone silica volatilization (similar to the HASP glasses of [4]). Trace amounts of ilmenite, ulvöspinel, troilite, Fe,Ni metal clasts are also observed.

The bulk composition of MET is ferroan (Mg' of 40), moderately Fe-rich and Al-rich (16 and 17 wt% respectively), and relatively low in TiO_2 (1.6 wt%). The normative composition of MET is 48% plagioclase (An_{95}), 22% orthopyroxene, 19% clinopyroxene, 8% olivine, and 3% ilmenite.

Discussion: Despite the lack of spherules and recognizable agglutinates, the presence of a vesicular fusion crust (typically attributed to escaping solar wind implanted gases [5-6]) as well as reworked granulite clasts indicates that MET is a regolith breccia, albeit a very immature one [7]. Also, our chemical analysis of the meteorite [8] yielded 25 ppm Zn, a high value which is more consistent with a regolith breccia than an impact-melt breccia [9].

The meteorite contains both basaltic lithic clasts (e.g., the symplectite grains, the clast in Fig. 1a) as well as somewhat deeper seated, hypabyssal gabbroic lithic clasts (e.g., the clast in Fig. 1b). The basaltic clasts are typically more ferroan, have less well equilibrated pyroxene, and typically lack the exsolution observed in the hypabyssal clasts (Fig. 2a). The compositional range in the mineral clasts is similar to the compositional range seen in the constituent minerals of the lithic clasts. The mineral clasts do show a greater variety of compositions and are somewhat more ferroan on average than the lithic clasts, however.

The basaltic and gabbroic lithic clasts in MET are clearly VLT, all have less than 0.6 wt% TiO_2 (typically much less) based on modal recombination. The bulk TiO_2 concentration of MET (1.6 wt%) is right at the border of very-low-Ti and low-Ti lunar basalts, however. This excess TiO_2 is present as small ilmenite and ulvöspinel clasts. The bulk major-element composition of MET (e.g., 16 wt% FeO) is consistent with it being composed predominantly of basaltic material. The only material in MET with an obvious highlands provenance are the granulitic clasts, which with >80% modal plagioclase would be difficult to produce from reworked basaltic material.

In detail, the trace-element geochemistry of MET appears to preclude any obvious connection to the previously studied lunar meteorite basaltic regolith breccias [8], all of which (except NWA 773) are likely source-crater paired [2]. Many of the petrographic features observed in MET are also observed in the previously studied basaltic regolith breccias, however. For example, all of the lunar meteorite basaltic regolith breccias have a basaltic component that is VLT, all have pyroxene and olivine compositions spanning a similar range, all have relatively coarsely exsolved pyroxene (~2 μm), and most contain symplectite grains [3,9-10]. One must be careful not to over interpret petrographic similarities, particularly in breccias, however, as chemical composition is a much more diagnostic tool for pairing meteorites than petrography.

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Acknowledgements: We would like to thank Gretchen Benedix for her help with the EMPA. This work was funded by NASA grant NNG04GG10G (L. Haskin).

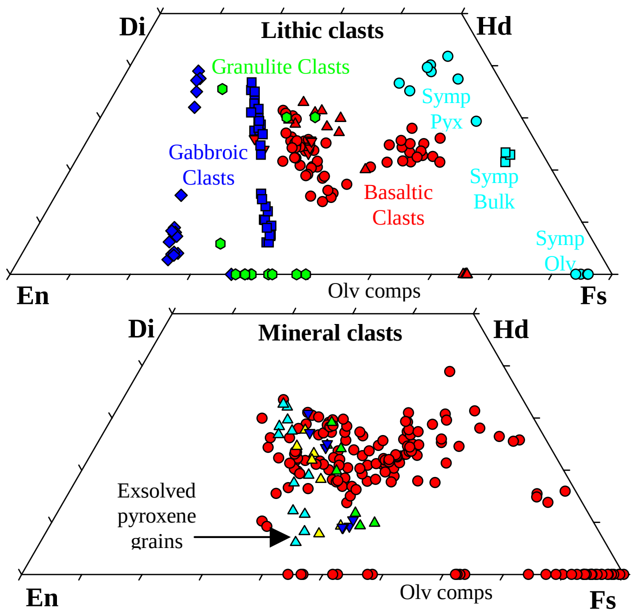

Figure 2: Pyroxene quadrilaterals showing the composition of the MET pyroxenes in the lithic clasts (a) and the mineral clasts (b). **(a)** Each type of lithic clast (e.g, basaltic clast) is a different color, with individual clasts of a given type shown as different symbols. The compositions of olivine in the lithic clasts are shown along the bottom axis. **(b)** The average composition of each pyroxene mineral clast (1 to 5 spots per grain, average of 3) are shown in the red points. Each set of colored triangles corresponds to an individual analysis on an exsolved pyroxene clast. The composition of olivine mineral clasts is shown along the bottom axis.