FELDSPATHIC LUNAR METEORITE GRAVES NUNATAKS 06157, A MAGNESIAN PIECE OF THE LUNAR HIGHLANDS CRUST.

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Introduction: To date, 49 feldspathic lunar meteorites (FLMs) have been recovered, likely representing a minimum of 35 different sample locations in the lunar highlands. The compositional variability among FLMs far exceeds the variability observed among highland samples in the Apollo and Luna sample suites [1]. Here we will discuss in detail one of the compositional end members of the FLM suite, Graves Nunataks (GRA) 06157, which was collected by the 2006-2007 ANSMET field team [2]. At 0.79 g, GRA 06157 is the smallest lunar meteorite so far recovered. Despite its small size, its highly feldspathic and highly magnesian composition are intriguing (Fig. 1). Although preliminary bulk compositions have been reported, thus far no petrographic descriptions are in the literature [3]. Here we expand upon the bulk compositional data, including major-element compositions, and provide a detailed petrographic description of GRA 06157.

Methods: Trace-element compositions were determined by INAA (instrumental neutron activation analysis) on 57 mg of GRA 06157. Major-element compositions were determined by electron probe microanalysis (EPMA) of fused beads (FB) prepared from the INAA samples [4]. Petrography was determined using backscattered electron (BSE) images, elemental x-ray maps, and quantitative EMPA on polished thin section GRA 06157,8 (~10 mm^2; Fig. 2).

Petrography: GRA 06157 is a glassy-matrix regolith breccia containing abundant lithic and mineral clasts and a few small impact spherules (Fig. 2 blue). All of the lithic clasts identified are granulite clasts. The mineral clast population is dominated by plagioclase, pyroxene, and olivine, with trace amounts of FeTiCr oxides, FeNi metal, and FeS. The meteorite has a discontinuous vesicular fusion crust on three sides.

The most abundant type of lithic clast is highly feldspathic granulite (>90% plagioclase) consisting of large plagioclase grains, up to 1 mm in their longest dimension, that contain tiny rounded inclusions of pyroxene, almost always less than 2 μm wide. All granulite clasts have highly calcic plagioclase (An_{94-97}). Rarely there are strings of larger pyroxene grains (up to ~20 μm wide) present along the borders of some plagioclase grains (Fig. 2 green). Augite is the dominant pyroxene ($En_{44}Wo_{42}Fs_{14}$; Fig. 3), with rare occurrences of hypersthene ($En_{64}Wo_3Fs_{33}$); there is no compositional difference between the different size pyroxenes. Minor olivine grains also occur, with a relatively wide range in compositions (Fo_{60-78}). There are also troctolitic granulite clasts, including the largest lithic clast in the section (~1.5 x 1.5 mm; Fig. 2 magenta). They contain up to 50% magnesian olivine (Fo_{85-90}), <5% magnesian augite ($En_{53}Wo_{37}Fs_9$), <5% near end member magnesian spinel (mg' = 83; 1.7 wt% Cr_2O_3), and trace amounts of bronzite ($En_{77}Wo_2Fs_{20}$). A few small (~150 μm) mafic granulite clasts (plagioclase is <20% by mode) are compositionally similar to the more feldspathic granulite clasts (Fig. 2 orange), albeit with more ferroan pyroxene compositions ($En_{39}Wo_{42}Fs_{19}$; $En_{55}Wo_2Fs_{43}$).

A single large (200 x 150 μm) basaltic spherule is present. It is partially devitrified with magnesian olivine (Fo_{78}) quenching out of the glass (Fig. 2 cyan). It has a bulk composition very similar to Apollo 15 yellow pyroclastic glass [5]. Plagioclase mineral clast compositions have a restricted range (An_{94-98}). In contrast, olivine mineral clasts span nearly the entire compositional range (Fo_{7-93}); most clasts are at the Mg-rich end of the range, however. Most pyroxene mineral clasts are exsolved, with augite ($Wo_{41-43}Fs_{18-40}$) and orthopyroxene ($Wo_{1.5-3}Fs_{34-72}$) lamellae ranging from sub-micron all the way up to nearly 100 μm thickness (5-10 mm is typical; Fig. 2 red, yellow).

Geochemistry: GRA 06157 is one of the most feldspathic meteorites (3.5 wt% FeO). With an mg' of 77 (molar Mg/[Mg+Fe]*100), it is distinct in being more magnesian than any other lunar meteorite from Antarctica and any other fragmental or regolith breccia lunar meteorite of which we are aware (Fig. 1). Additionally, GRA 06157 has low concentrations of incompatible elements (e.g., 0.23 ppm Th). Despite being a regolith breccia, GRA 06157 has low concentrations of siderophile elements compared to most regolith breccias [4].

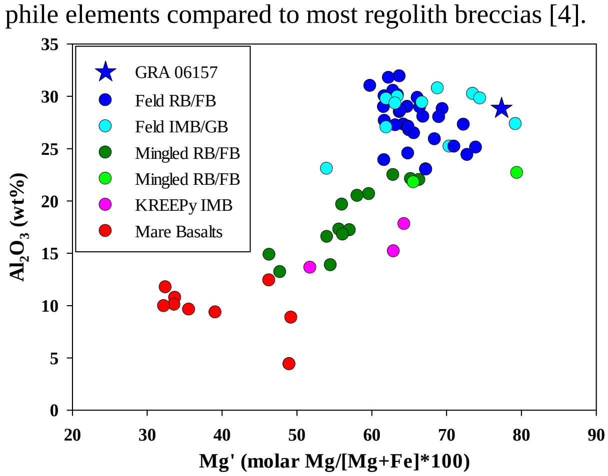

Figure 1: Al_2O_3 vs. mg' for 72 of 78 known lunar meteorites. Data from FB- EPMA at Washington University.

Discussion: On the basis of significant differences in mg', siderophile-element concentrations, and clast populations, GRA 06157 is not paired with any other FLM. The high Mg' of GRA 06157 is due to the overall magnesian nature of its clasts, in particular the presence of the highly magnesian spinel-bearing troctolitic granulite clasts and forsterite mineral clasts. The presence of spherules makes GRA 06157, by definition, a regolith breccia (this is also supported by the presence of a vesicular fusion crust). The paucity of impact spherules or glass clasts of any kind, coupled with low siderophile concentrations suggests it represents an immature regolith. Low concentrations of incompatible elements commonly associated with KREEP suggests that its provenance was distant from the Procellarum KREEP Terrane. Finally, the presense of a likely pyroclastic spherule indicates there is at least a minor basaltic component in GRA 06157. The absence of lithic basalt clasts, the coarse-grained nature of the pyroxene exsolution, and the overall magnesian nature of the sample suggest that the basaltic component is minor.

Acknowledgements: We thank ANSMET for collecting the meteorite and JSC for allocating it to us. This work was supported by NASA grants NNX10AI44G and NNX11-AB26G. **References:** [1] Korotev et al. (2012) *P2CLHC*, this volume. [2] McBride K et al. (2007) *Ant. Met. News.*, **30**(2). [3] Korotev RL et al. (2008) *LPSC* **39**, #1209. [4] Korotev RL et al. (2009) *MAPS* **44**, 1287–1322. [5] Shearer CK and Papike JJ (1993) *GCA* **57**, 4785–4812.

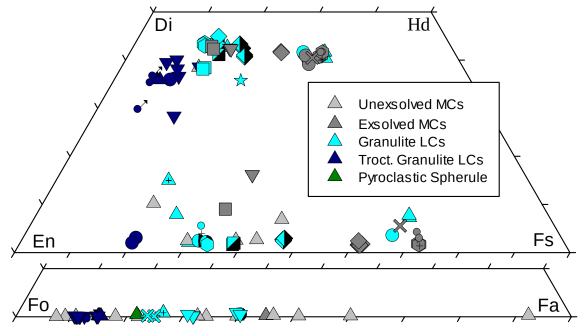

Figure 3: Pyroxene and olivine compositions in GRA 06157 mineral clasts (MC, grey) and lithic clasts (LC, blue,cyan). Different symbols in the same color represent different clasts.

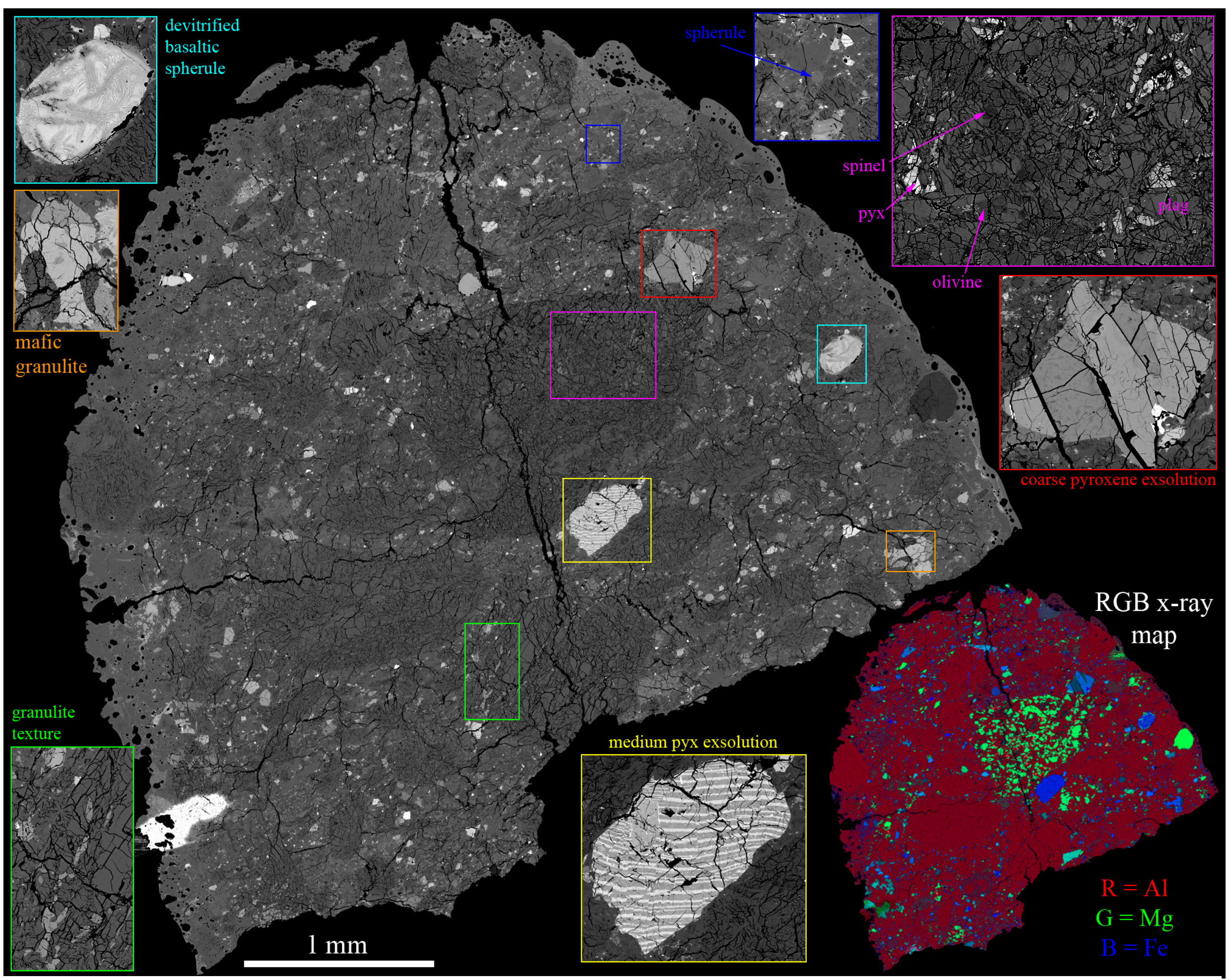

Figure 2: BSE images (grey scale) and an RGB elemental x-ray map of lunar meteorite GRA 06157. The scale bar applies only to the main image.