DID METEORITE BOMBARDMENT SAMPLE DEEP LUNAR CRUST?: MAJOR AND TRACE ELEMENT COMPOSITIONS OF GRANULITE CLASTS IN LUNAR REGOLITH BRECCIA MAC 88104.

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Introduction: The origin of lunar granulite clasts remains controversial. Different works suggest a range of roughly 3 orders of magnitude (>40 km to <40 km) for the source depth of these granulite clasts [1,2]. This range of possible burial depths for lunar granulites corresponds to significantly different portions of the lunar crustal assemblage. It is suggested that the lower crust (roughly >30 km) may be more mafic and contain higher thorium contents than the feldspathic upper crust [3]. Additionally, between the crust-mantle boundary, a "sandwich horizon" rich in potassium and rare earth elements (KREEP) may be present [5].

The proposed depths of formation of lunar granulite clasts should therefore match the associated geochemical signatures for the lunar crustal assemblage. Therefore, deeper formed granulites should be more mafic and may even potentially have a KREEP signature, whereas shallow formed granulites should be more reminiscent of typical FAN chemistry.

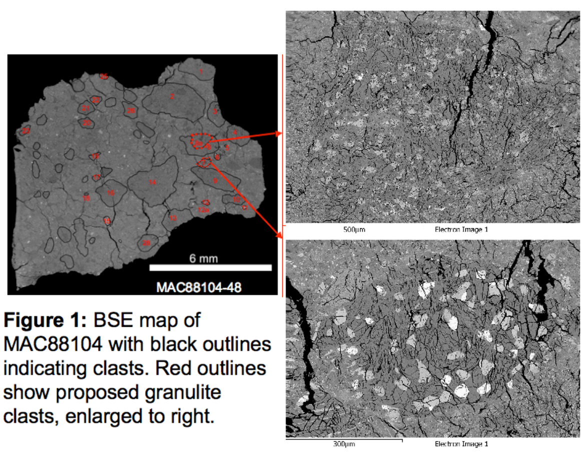

Figure 1: BSE map of MAC88104 with black outlines indicating clasts. Red outlines show proposed granulite clasts, enlarged to right.

This work seeks to ascertain the source material of two granulite clasts identified in lunar regolith breccia MAC 88104 (48). These clasts are distinguished from impact melt clasts by the well-defined 120° angle crystals faces of both olivine and pyroxene minerals within the clast (*e.g.,* see Fig. 1). The olivine and pyroxene minerals are surrounded by a fine-grained plagioclase chadocrysts of nearly uniform composition. These features are suggestive of relatively high heatflux and sustained growth [6]. By analyzing the major and trace element composition of these clasts and their respective mineral phases, a more clear picture of source material and therefore the depth of formation of these granulites clasts should be constrained, providing additional clarity to the range of depths previously suggested.

Methods: To analyze the major and trace element compositions of two granulite clasts in MAC 88104 (48) were measured by electron microprobe and laser ablation-ICPMS. For comparison 5 impact melt clasts from the same section were also measured. Major element compositions were measured on an SX-100 electron microprobe at the Johnson Space Center. All measurements were made using standard protocols with machine conditions between 15 kV-20 kV, 10-20 nA, and 1-10 micron beam sizes with count times between 10-30 s. All LA-ICPMS measurements were made on a Varian 810 quadrupole ICP-MS using a Photon Machines 193 nm excimer laser at the University of Houston. Measurements of natural basalt standards, BHVO and BIR, and the synthetic NIST 612 standard bracketed each series of granulite analyses to monitor machine performance. A spot size of ~24 microns was used for all ablations. All major element chemistry data was processed in EXCEL and all trace element data was reduced using the Glitter software package and exported to EXCEL for review. In total 51 elements were analyzed using these combined procedures.

Results/Discussion: A total of 76 defocused beam microprobe analyses from the two MAC88104-48 granulite clasts yielded data taken from a single mineral, as confirmed by stochiometric calculations. Four of these analyses are from olivines, 12 from pyroxenes, 59 from plagioclase, and 1 potentially from an apatite. After averaing mineral compositions from each clast, the two granulite clasts, when averaged, plot in the same plagioclase An# vs mafic mineral Mg# field as typical FAN material [7] (see Fig. 2). All impact

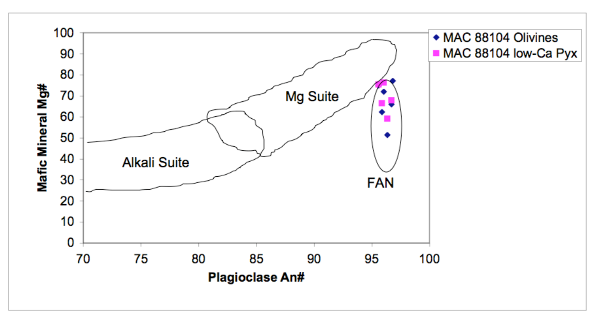

Figure 2: The bulk clast mineral averages for both granulite and impact melt clasts all plot within the FAN field reproduced from Wieczorek et al. 2006.

melt clasts measured also plot within this same field. The compositions of pyroxenes within the granulitic clasts plot comparably with other pyroxenes measured in MAC88104 impact melt clasts (see Fig. 3).

A total of 24 laser ablation spots were taken from the two granulite clasts. However these analyses are inhibited by high detection limits (>1.45ppm) and large 2σ errors (1.5-11ppm) in the REE. This makes these data only useful for first order identification of granulite clast provenance. When the REEs patterns from each spot are averaged in these clasts and normalized to chondritic values, they plot above the feldspathic terrains and near more mafic values and do not generally resemble literature values for KREEP like terrains [4] (see Fig. 4). However, this could be the result of large analytical errors as well as biased sampling of pyroxenes, which tend to have higher REE concentrations.

Though the portrait painted by the LA-ICPMS data yields insufficient evidence to deduce with certainty the target material of these granulite clasts, initial results suggest that a mixure of terraians may be present. Much of the microprobe work suggests that these clasts have the composition of typical FAN suite, yet the REE chemistry of the clasts indicates that the clasts may have some contribution from more mafic material. These preliminary findings agree with conclusions drawn in Joy et al. [4] for impact melts clasts in MAC88104 and 88105.

Further Work: In light of the limited use of the present LA-ICPMS results for this study, a new method for measuring the compositions of the granulite clasts is currently being implemented. New microprobe data has already been acquired across multiple transects across the two clasts. These transects will be averaged to yield a bulk composition of the clast for each particular transect. Then, our group will reanalyze the granulite clasts utilizing a scanning, larger (~50-75 micron) laser ablation pattern across the same transect to acquire better bulk clast average REE data.

References: [1] Hudgins J. A. and Spray J. G. (2006) *AMSM LXIX,* Abstract 5256. [2] Cushing et al. (1999) *Meteoritics & Planet. Sci., 34,* 185-195. [3] Spudis P. D. et al. (1999) *Workshop on New Views of the Moon II,* Abstract 8021. [4] Joy K. H. et al. (2010) *Meteoritics & Planet. Sci.,* 45, 917-946. [5] Joliff B. L. (2006) *LPS XXXVII*, Abstract 2346. [6] Hudgins J. A. and Spray J. G. (2005) *International Lunar Conference* [7] Wieczorek et al. (2006) *New Views on the Moon*, p. 221.

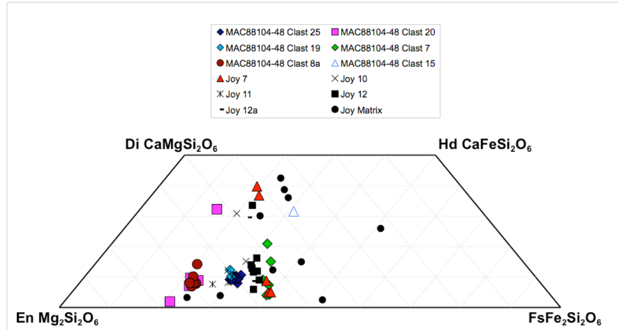

Figure 3: All pyroxene data are from clasts in MAC88104-48. Data in colored symbols are from this work and those in black are were collected by K. Joy (unpublished data). Granulite clasts 8a and 7 plot similarly to the impact melt clasts. This may suggest similar sources for both impact melt clasts and granulite clasts.

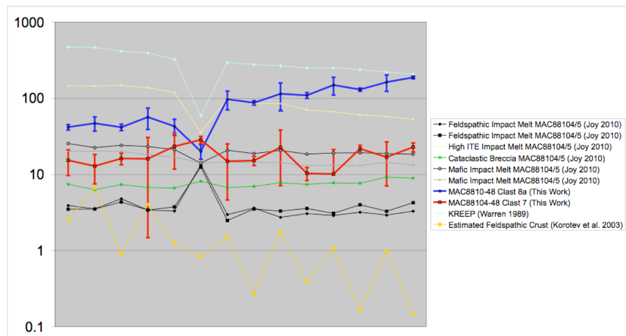

Figure 4: Averaged granulite clast REE patterns [blue and red] are plotted against Impact Melt Clasts [black and grey] (Joy 2010), KREEP [light blue] (Warren 1989), and estimated Feldspathic Crust [orange] (Korotev et al. 2003). The standard deviation of errors for each element have been the average clast values. All data relative to chondrite values from Anders and Grevesse (1989).