

TRACE ELEMENT GEOCHEMISTRY OF MINERAL CLASTS IN APOLLO 16 IMPACT MELT BRECCIAS. S. J. Lawrence¹, G. J. Taylor², M. D. Norman³, ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (Samuel.Lawrence@asu.edu) ²Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, USA ³Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia

Introduction: Crystalline impact melt breccias can preserve mineral clasts disaggregated from rocks that were originally located in the target volume of bolide impacts; the disaggregated clasts then were incorporated into the impact melt [1]. Detailed petrologic investigations of these clasts provide important insights into the lithologies present in the crustal section prior to the impact [2]. Studies of the mineral clasts within Apollo 17 crystalline impact melts have shown the compositional diversity of pristine lunar igneous materials [2–5]. The crystalline impact melts collected at the Apollo 16 landing site selected for this study are either products of large basin-forming impacts (Imbrium [6,7] and/or Nectaris [8,9]) or, alternatively, were produced locally by smaller impacts [10]. To assess the compositional variability of the clast populations in these samples, we are systematically analyzing individual mineral fragments contained in the melt matrices of Apollo 16 crystalline impact melts.

Previous studies have determined the geochemistry [11] and ages of similar clasts [12]. Here, we employ the approach of [3–5] and [13] to characterize the trace element geochemistry of individual mineral fragments in a suite of carefully chosen Apollo 16 crystalline impact melts, with a focus on the rare-earth elements (REEs), which are uniquely useful for facilitating petrogenetic understanding of lunar highlands materials [14,15]. We discuss trace element concentrations obtained from plagioclase mineral fragments in the following Apollo samples:

61156,62: This is a poikilitic impact melt collected 25 m northeast of Plum crater [16] that has undergone some thermal metamorphism [17]. Classified as group 2F [10] and aluminous poikilitic [12].

62235,124: This is a poikilitic impact melt collected on the rim of Buster crater [18]. This is classified as Group 1F [10] and mafic poikilitic [12].

62295,78: This is a basaltic impact melt collected 35 m SW of Buster crater [18]. Classified as group 2MO [10] and as a troctolitic vitrophyre [12].

66095,78: This is a basaltic impact melt collected near the base of Stone Mountain [18]. Classified as Group 2DB [10].

These are among the most fragment-rich and fine-grained Apollo 16 impact melts, and so the clasts are

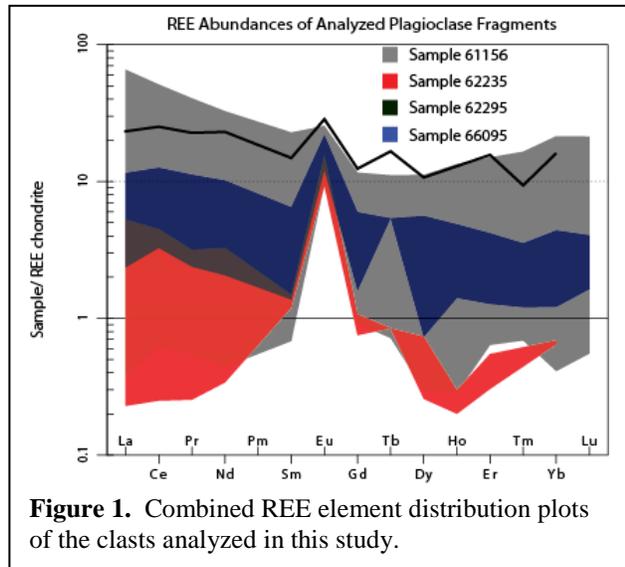
less likely to have reacted with the melt, and therefore more likely to have preserved the original compositions of the mineral fragments [11, 19, 20].

The goals of this study are to (1) characterize the clast population geochemistry in these samples, (2) assess whether geochemical trends exist amongst these Apollo 16 clasts in order to determine the nature of the pre-impact lithologies, and (3) ultimately, compare the geochemical results produced from this study to similar studies from other Apollo landing sites in order to investigate basin-forming processes.

Methods: We used optical microscopy, electron probe microanalysis, and laser ablation inductively coupled mass spectrometry (LA-ICPMS) on polished thick sections (>60 microns thick). Major elements were determined through point analyses of individual mineral clasts using ASU's JEOL-8200 electron microprobe with a focused beam at 30 nA and an accelerating voltage of 15 kV, counting for at least 15 s on each peak and 15 s on each background. Matrix effects were corrected using PAP-ZAF [21]. Additional major element point analyses and X-ray elemental abundance maps (Al, Ca, Cr, Fe, K, Mg, Mn, Na, Ni, S, Si, and Ti K α) were collected using the JEOL JXA-8200 electron microprobe at Washington University in St. Louis. Microprobe point analyses proximal to the laser ablation points provide accurate compositional information for the calibration required by the LA-ICPMS analysis.

Trace element data were collected via LA-ICPMS using a New Wave UP-213 laser ablation system coupled with a ThermoFinnigan Element2 ICPMS at the University of Notre Dame using a repetition rate of 5 Hz and a spot size of 60 μ m. Clast results were processed using the microprobe-derived CaO content and the NIST 612 glass [22–24] as the internal and external standards, respectively.

Experiments performed by [19] demonstrated that mineral fragments immersed in impact melt react with the melt, which causes zoning within the individual mineral fragments. Therefore, in order to minimize the possible contributions of zoning or melt reactions to these results, the analyses from this study were specifically targeted at the center of large mineral fragments, and every effort was made to avoid obvious inclusions in these clasts.

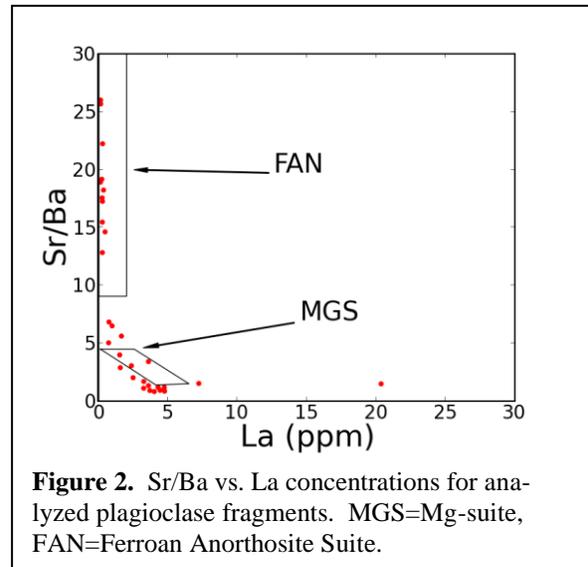


Results: Geochemical data were acquired from 19 plagioclase fragments in 61156 (An₉₇₋₉₈), 10 plagioclase fragments in 62235 (An₉₆₋₉₉), 1 plagioclase fragment from 62295 (An₉₇), and 4 plagioclase fragments from 66095 (An₉₆₋₉₉). REE abundances vary from less than 1 up to 100 times chondritic (Fig. 1). Observed La concentrations range from 0-21 ppm (61156); 0.07-1.63 ppm (62235); 7.2 ppm (62295); and 0.7-3.5 ppm (66095), which is within the compositional range determined for the plagioclase clast populations in the poikilitic Apollo 17 melts [4]. Sr/Ba ratios for Apollo 16 plagioclase fragments range from 0.8-26, which is again within the range determined for plagioclase clasts at the Apollo 17 site (0.5-37) [4].

Conclusions: These results are consistent with contributions from both ferroan anorthosite [FAN] (high Sr/Ba, low REE) and Mg-suite rocks [MGS] (low Sr/Ba, high REE) in the Apollo 16 clast population (Fig. 2) [14,15].

Despite the fact that the Apollo 16 rocks have different whole-rock Al₂O₃ (61156: 22.9 wt%; 62235: 18.6 wt% [12]; 62295: 19.2 wt% [12]; 66095 24.0 wt% [12]) and La (61156: 21.5 ppm; 62235: 60.3 ppm; 62295: 19.2 ppm; 66095: 22.66 ppm [25-27]) concentrations, MGS and FAN materials are both present in this clast population, which implies the presence of both types of lithologies in the pre-impact target regions of all of these breccias.

35% of the clasts are FAN and 50% are MGS on the basis of trace element geochemistry. This differs from the Apollo 17 plagioclase clast population, which is somewhat more compositionally diverse (10% FAN, 33% MGS, 57% uncertain affinity) [4]. Assuming that the relative clast proportions reflect the proportion of lithologies in the target regions, this finding implies that the relative abundances of FAN and MGS materi-



als in the targets of the Apollo 16 and Apollo 17 crystalline impact melt breccias were different.

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References: [1] M. D. Norman, *Aust. J. Earth Sci.*, 52, 711-723, 2005. [2] G. Ryder et al. *GCA*, 61, 5, 1083-1105, 1997. [3] S. J. Lawrence, PhD Dissertation, University of Hawaii at Manoa, 2007. [4] S. J. Lawrence et al. *LPSC 38*, 1696, 2007 [5] S. J. Lawrence et al., *LPSC 39*, 1521, 2008, [6] R. L. Korotev, *MAPS*, 32, 447-478, 1997. [7] L. A. Haskin et al. *MAPS*, 33, 959-975, 1998. [8] P. D. Spudis, *Proc. LPSC 15*, 1984, p. 95. [9] D. E. Wilhelms et al. *USGS Prof. Pap.* 1348. 1987. [10] R. L. Korotev, *GCA*, 58, 18, 3931-3969, 1994. [11] C. Meyer et al., *Proc. LPSC 5*, 685-706. [12] M. D. Norman et al. *GCA*, 70, 24, 6032-6049, 2006. [13] K. A. McCormick et al., 1989, *Proc. LPSC 19*, 691-696. [14] J. T. Cahill et al. *MAPS* 39, 4, 503-529, 2004. [15] C. Floss et al. *GCA*, 62, 7, 1255-1283, 1998. [16] M. D. Norman and G. Ryder, *Proc. LPSC 11*, 1980, 317-331. [17] A. L. Albee et al. *Proc. LPSC 4*, 1973, p. 569. [18] G. Ryder and M. D. Norman, *Curatorial Branch Publication* 52, 1980. [19] C. R. Thornber and J. S. Huebner, *Proc. Conf. Lun. High. Crust.*, New York, NY, 1980, 233-252. [20] G. Ryder et al. *Moon*, 14, 327-357, 1975. [21] S. J. B. Reed, *Electron Microprobe Analysis*. Cambridge, UK: Cambridge University Press, 1993. [22] N. J. G. Pearce et al. *Geostd. Nwsltr.*, 21, 1, 115-144, 1997. [23] M. D. Norman et al., *Am. Min.*, 90, 5-6, 888-899, 2005. [24] M. D. Norman et al. *J. Anal. At. Spectrom.*, 13, 5, 477-482, 1998. [25] H. Wänke et al., *Proc. LPSC 5*, 1974, 5, 1307-1335. [26] H. Wänke et al., *Proc. LPSC 7*, 1976, 3479-3499. [27] N. Nakamura et al. *Proc. LPSC 4*, 1973, 1407.