TRACE ELEMENT GEOCHEMISTRY OF APOLLO 17 MAFIC IMPACT MELT BRECCIAS.

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Introduction: Poikilitic and aphanitic impact melts from the Apollo 17 site are thought by most investigators (e.g., [1]) to have been produced by the impact that formed the Serenitatis basin (although an Imbrium origin has been proposed by [2]). Ryder et al. [3] determined by electron microprobe the major and minor element concentrations in hundreds of mineral clasts in fine-grained Serenitatis melts to characterize the crustal rocks in the target area, an approach used successfully on a terrestrial analog [4]. To extend the previous work by [3], we have collected extensive trace element geochemistry data using laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) as part of a petrologic study of Apollo lunar samples 72435, 76315, 76295, and 76035 so we can more fully characterize the source rocks making up the clast population. Here, we present some of the preliminary results of this study.

Methods: Polished sections 100-µm thick of Apollo lunar samples 72435, 76315, 76295, and 76035 were studied using optical microscopy, X-Ray elemental mapping, electron probe microanalysis, and laser ablation ICP-MS.

Each of the thin sections were mapped in P, Ni, Na, K, Ca, Ti, Si, Mg, Fe, and Al Kα at a resolution of 10 µm/pixel using the five wavelength dispersive spectrometers (WDS) of the University of Hawaii's Cameca SX-50 microprobe. These data were reduced using the technique of [5]. The resulting mineral maps were used to identify different mineral types, produce estimates of the modal mineralogy of these samples, and to provide targeting information for the quantitative microprobe analyses and ICP-MS laser points.

Major element compositions of selected plagioclase, olivine, and pyroxene mineral fragments larger than 50 µm in diameter from each thin section were determined using the University of Hawaii at Manoa's Cameca SX-50 electron microprobe. Analyses were conducted at the center of the mineral fragments at least 50 µm from grain boundaries to minimize the secondary florescence effects from adjacent grains. Trace elements were measured for a subset of the microprobed mineral clasts by LA-ICPMS using the Australian National University's custom-built 193-nm excimer laser system ([6]-[8]) and an Agilent 7500 quadrupole ICPMS operated in time-resolved mode using a dwell time of 20 ms per mass. A conventional suite of petrogenetic trace elements was measured using a 70 µm diameter laser beam and a laser repetition rate of 4 Hz. The CaO content of each sample was used for internal normalization of the lithophile element analyses. Replicate analyses of the NIST 612 glass were used for external calibration of relative element sensitivity using the concentration values given by [9] and demonstrate an external precision of 2-5% (1-σ relative standard deviation). Microprobe and LA-ICPMS results for individual mineral clasts were combined to obtain a comprehensive suite of major, minor, and trace element data for all four samples.

Results: A combined total of 127 individual olivine, pyroxene, and plagioclase clasts were examined.

Olivines: 26 olivine clasts ranging from Fo_{74-93} were analyzed. Based on their REE distributions, three distinct types of olivine can be distinguished, as shown in class averages provided in Fig. 1. Olivine class 1 has a large negative europium anomaly and is slightly enriched in the heavy rare earth elements (HREEs). Olivine classes 2 and 3 have lower REE concentrations than class 1 and are enriched in HREEs and depleted in LREEs, but each has a distinctive LREE patterns. The olivine REE distribution is not correlated with the olivine composition. The Co/Ni ratios indicate that these are predominantly Mg-suite materials, confirming the results of [3]. Ryder et al. [3] drew attention to highly magnesian olivines in Serenitatis melts. Two of the olivine clasts studied here are Fo_{93}. Their REE concentrations differ by about a factor of 10, implying that their parent magmas differed significantly in REE, perhaps because of different amounts of KREEP assimilation.

Pyroxene: 20 pyroxene clasts were analyzed during the course of this study. Two pyroxene classes can be distinguished on the basis of REE patterns (Fig. 2). Pyroxene class one ($En_{42-85}Fs_{10-31}Wo_{3-34}$) is characterized by a positively sloping LREE pattern and a negative Eu anomaly. The second pyroxene class, ($En_{71-81}Fs_{16-25}Wo_{1.7-8.0}$) is characterized by higher REE concentrations, positively sloped LREE patterns, negative Eu anomalies, and negatively sloped HREE patterns. Our major element data agrees very well with the data from [3]; most of the pyroxenes are Mg-suite materials. However, a comparison of key trace element concentration ratios (e.g., Sc/Ce, Y/Ce) from this study to results from previous work [e.g., 10] indicate that some of the low- and high- calcium pyroxenes have compositions similar to pyroxenes from the ferroan anorthosite suite.

Plagioclase: 81 plagioclase clasts ($An_{71-99}Ab_{1-27}Or_{0-17}$) were analyzed as a part of this study. The average, minimum, and maximum plagioclase REE distributions are shown in Fig. 3. Eight of the analyses are in the range of

typical ferroan anorthosites. A comparison of key trace element concentration ratios from this study to results obtained from previous work indicates that about 10% of the plagioclase grains sampled during this study have characteristics similar to the FAN population (Figs. 3, 4). This contrasts with the observations of [3], who found no evidence for plagioclase derived from FAN rocks. Thus, there appears to have been some FAN in the target for the Serenitatis event. Fig. 4 also shows that many plagioclase clasts are much richer in La than either FAN, Mg-suite, or alkalic suites of pristine lunar rocks, which have La of < 8 ppm. These come from magmas with high concentrations of incompatible elements.

Conclusions: Mineral clasts in these Serenitatis melt breccias come from known pristine rock types, including a small percentage from ferroan anorthosites. Many clasts have compositions outside the ranges of analyzed pristine minerals, implying a diversity of rock, hence magma, types present. This reinforces the previous conclusion of [3] that the lunar crust in the vicinity of Serenitatis was heterogeneous and composed of rocks from many parent magmas.

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References: [1] Wilhelms D. E. (1987) *The Geological History of the Moon,* U.S. Geological Survey. [2] Rockow, K. M., and L. A. Haskin (1996), *Proc. LPSC XXVII*, p. 1089-1090. [3] Ryder, G., et al. (1997) *GCA*, *61*, 1083-1105. [4] McCormick, K. A., et al. (1989) *Proc. LPSC XVIIII,* p. 691-696. [5] Hicks, T. L. (2002), *Automated mapping and Modal Analysis of Meteorite Thin Sections Using Image Processing Software*, Master's thesis, University of Hawaii at Manoa, Honolulu. [6] Eggins S. M. et al. (1998) *Appl. Surf. Sci.,* ***127-129,*** 278–286. [7] Eggins S. M. and Shelley J. M. G. (2002), *Geostandards Newsletter, 26*, p. 269–286. [8] Norman M. D. et al. (2004), *GCA,* 68, 18, pp. 3761–3777. [9] Norman M. D. et al. (1996), *Geostandards Newsletter 20*, 247–261 [10] Cahill J. T. et. al. (2004) MAPS 39(4), 503-529, and references therein. [11] Anders E. and Grevesse N. (1989) GCA 53, 197-214.

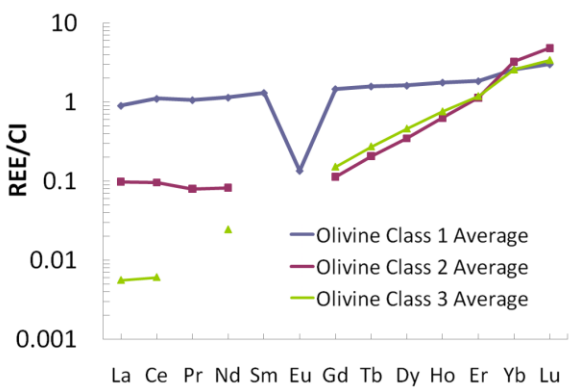

Figure 1. The average REE patterns for the olivines analyzed during this study, normalized to the CI chondrite values of [11].

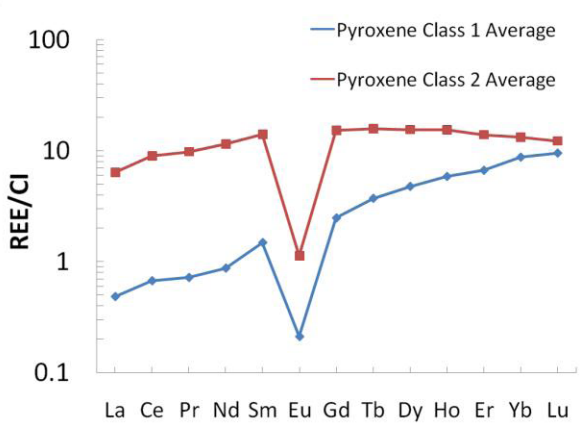

Figure 2. The average REE patterns for the pyroxenes analyzed during this study, normalized to the CI chondrite values of [11].

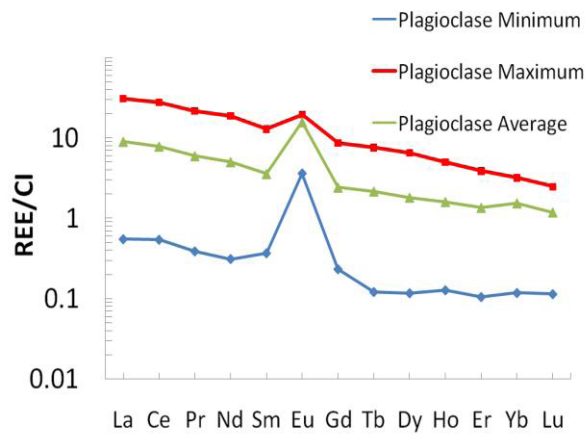

Figure 3. The minimum, maximum, and average REE patterns for the plagioclases analyzed during this study, normalized to the CI chondrite values of [11].

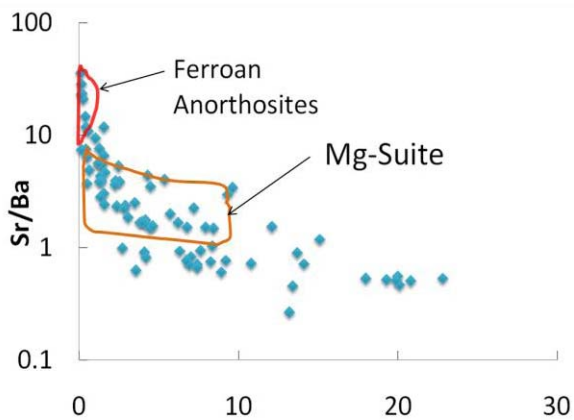

Figure 4. A plot of the La concentration vs. the Sr/Ba ratio in the plagioclase clasts measured during this study. Known lunar sample compositions from previous studies have been highlighted for reference.