REGIONAL HETEROGENEITY OF KREEP: IMPACT MELTS FROM APOLLO 16 AND 17.

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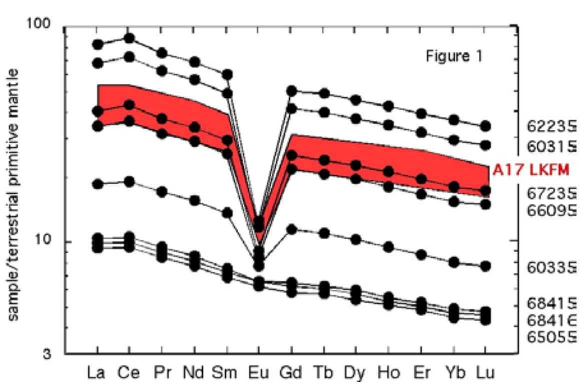
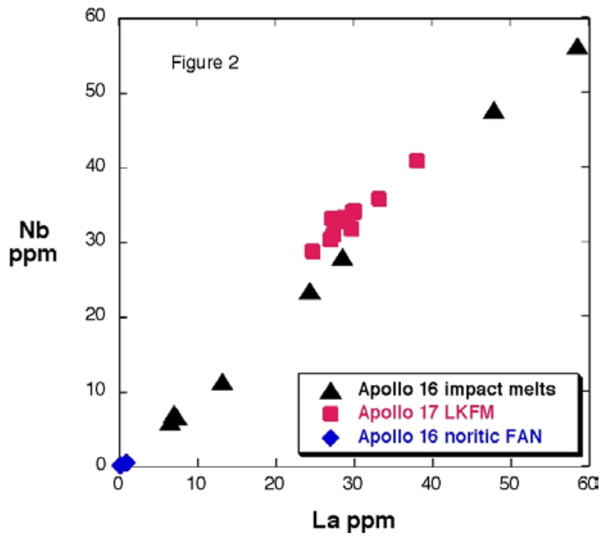
Introduction: Impact melt breccias from Apollo 16 and 17 show subtle but resolvable differences in trace element composition between the two sites, possibly indicating regional heterogeneity in the KREEP component contributing to these breccias. The compositional differences are most apparent in the high-field strength elements (HFSE; e.g., Zr, Hf, Nb, Ta), which are fractionated in KREEP relative to the bulk Moon. Compatible trace elements such as Cr, V, and Sc further document compositional differences in target lithologies. These trace element signatures appear to reflect multiple impact events into compositionally distinct crustal terranes during the Nectarian (3.8-3.9 Ga) episode of intense bombardment.

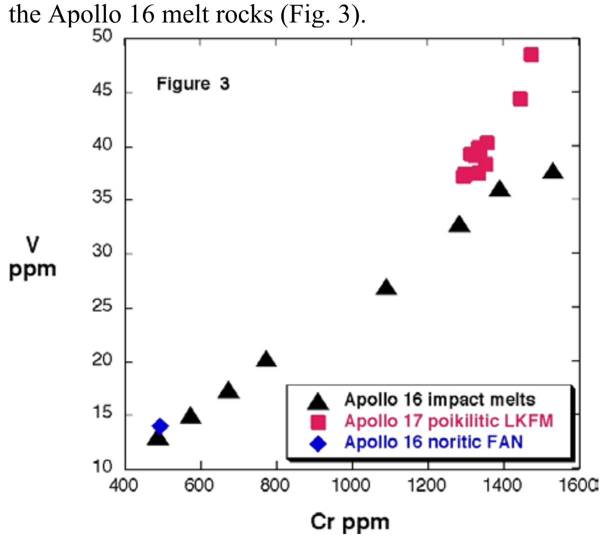
Samples and Methods: Samples of Apollo 16 impact melt breccias weighing approximately 3 g each were crushed to a fine powder using a steel piston and agate mortar and pestle. 30 mg aliquots of the powder were dissolved in distilled HF-HCL-HNO_3, and analysed for trace element compositions by quadrupole ICP-MS using solution nebulization. Samples analysed for this study include 60315, 60335, 62235, 65055, 66095, 67235, 68415, and 68416. These samples span most of the range of bulk compositions observed in Apollo 16 impact melts, representing Groups 1 (60315, 62235), 2 (60335, 66095), and 3 (68415, 68416, 65055) of Korotev [1]. The results are compared with data from our lab for Apollo 17 poikilitic LKFM impact melts [2; excluding 77035] and noritic anorthositic rocks 62236 and 67215 [3] in order to minimize inter-laboratory bias. Replicate analyses of USGS rock standards analysed with the Apollo 16 breccias demonstrate a precision of <2% RSD (1σ, n = 3-6) for the REE and HFSE concentrations and trace element ratios considered here.



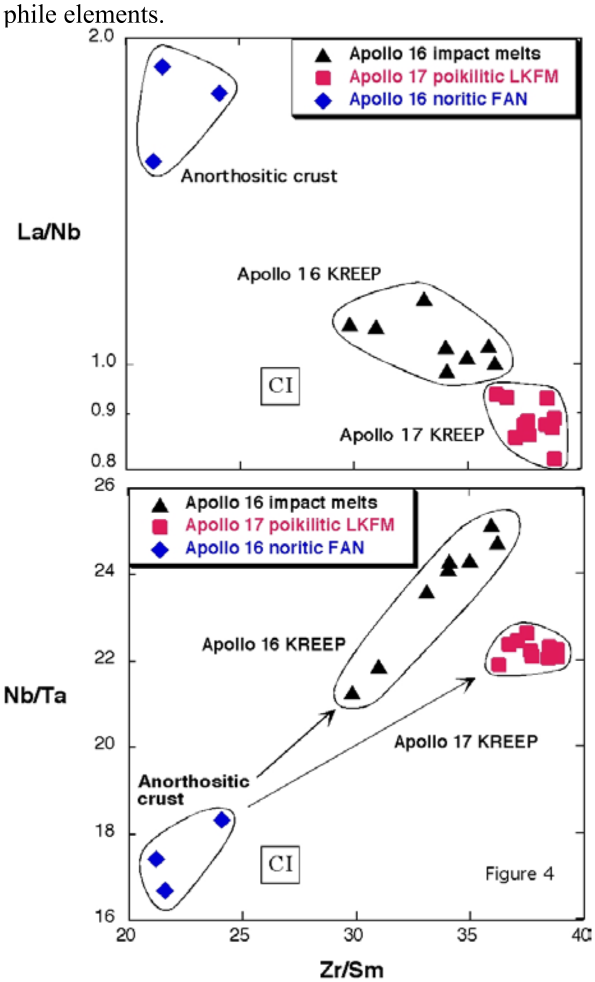
Results: Incompatible lithophile element abundances in the Apollo 16 melt breccias span about an order of magnitude, e.g., Zr 90-960 ppm, Nb 6-56 ppm, Hf 2-19 ppm, Ta 0.3 – 2.2 ppm, Ce 17-160 ppm, and show excellent linear correlations among the REE and HFSE (Figs. 1, 2). Compared to the Apollo 16 impact melt suite, Apollo 17 poikilitic breccias have intermediate lithophile element abundances and a more restricted range of compositions (Figs. 1, 2).



Compatible lithophile elements (e.g. Cr, V, Sc) in the Apollo 16 impact melts show a more limited compositional variation, with ~ 3x range in abundance (Fig. 3). Compatible lithophile element abundances in the Apollo 17 poikilitic breccias form a tight cluster, with higher V and Sc at a given Cr content relative to the Apollo 16 melt rocks (Fig. 3).

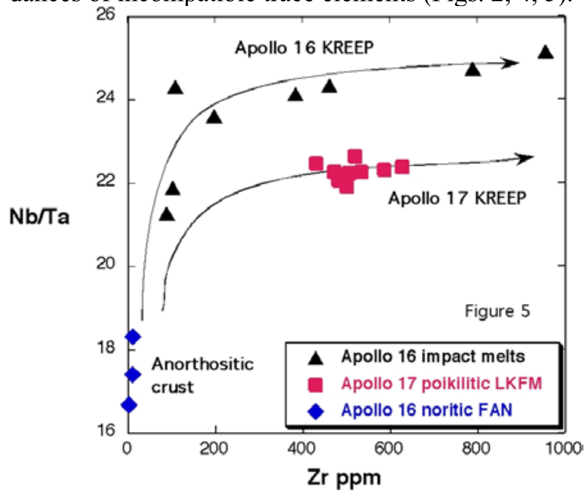


Discussion: Although the Apollo 16 and 17 melt rock suites fall along generally similar compositional arrays (Figs. 2, 3), in detail the Apollo 16 breccias have diagnostic trace element signatures that are distinct from those of the Apollo 17 poikilitic LKFM breccias. These differences are expressed in the relative abundances of HFSE, REE, and compatible lithophile elements.



Characteristic incompatible element signatures of the Apollo 16 breccias include systematically higher La/Nb and lower Zr/Sm ratios (Figs. 2, 4). These differences in trace element composition cannot simply result from mixing different proportions of a common KREEP endmember into the breccias, as the mixing trends between KREEP and anorthositic crust are very steep such that nearly constant trace element ratios are obtained with only a few percent KREEP in the mix. The Apollo 16 breccias show a trend similar to that expected for two component mixing (Fig. 5).

At the elevated lithophile element concentrations present in the Apollo 17 poikilitic breccias and most of the Apollo 16 melt breccias, mixing between a KREEP-poor anorthositic crust and a single KREEP endmember composition would produce breccias with constant lithophile trace element ratios. This, however, is not observed. The Apollo 17 LKFM melt breccias have higher Zr/Sm and lower La/Nb and Nb/Ta ratios than those of Apollo 16 breccias with similar abundances of incompatible trace elements (Figs. 2, 4, 5).



In addition to having distinctive incompatible element signatures, the Apollo 16 and 17 impact melt suites are also distinguished by their compatible lithophile element compositions. Higher concentrations of V and Sc at a given Cr content in the Apollo 17 poikilitic suite (Fig. 3) probably reflects different proportions and petrologic characteristics of mafic lithologies in the crustal source terranes [1].

Trace element compositions of Apollo 16 and 17 impact melt suites suggest the impacts which created these breccias occurred in crustal terranes which were lithologically and geochemically diverse. Variations in the incompatible element signatures may reflect regional heterogeneity in a component identified specifically as KREEP, or variable compositions and proportions of other evolved, ITE-rich lithologies. When the compositions of impact melts from all the lunar landing sites are considered, it is apparent that significant regional heterogeneity exists in the composition of KREEPy components from different crustal source terranes [4]. This may be revealing subtle variations in style or extent of fractionation in a magma ocean, or petrogenesis of KREEPy compositions in more localized events.

Integrated studies of lithophile element compositions, siderophile element signatures, and chronologies of lunar impact melts can be linked to provide a better understanding of the impact history and crustal evolution of the Moon.

References: [1] Korotev RL (1994) GCA 58, 3931. [2] Norman MD, Bennett VC, and Ryder G (2002) EPSL. [3] Norman et al. (2003) MAPS, submitted. [4] Jolliff B.L. (1998) Int. Geol. Rev. 40, 916.