CLASTS IN LUNAR IMPACT MELTS AND THE ORIGIN OF LOW-K FRA MAURO BASALT

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Although "low-K Fra Mauro basalt" (LKFM; [1]) has been recognized as an impact-produced mixture (e.g., [2]), several aspects of its occurrence remain poorly understood. The term LKFM, originally used to describe soil agglutinates [1], is now applied to a variety of impact-melt breccias of basaltic composition that were assembled around 3.8 to 3.9 Ga [2, 3]. More than 90 % of melt breccias in the Apollo sample collections have LKFM composition, but regionally it is rare on the lunar surface [4]. LKFM melt rocks contain clasts of crystalline rock and mineral fragments (no regolith products) and cannot be made by mixing any combination of known pristine rocks [5]; the one or more missing components are rich in transition metals (e.g., Ti, Sc) and KREEP and have a high Mg*. Through an analog study of melt rocks from the terrestrial Mistastin Lake crater [6], we have shown that clasts in impact melts contain information on the path followed by the melt as it traversed the pre-existing target rocks during cratering flow. We here describe results from an ongoing study [7] that uses the same methodology for lunar impact melts.

Bersch [8] has assembled high-precision electron microprobe analyses for the minor-element concentrations in the mineral phases of virtually all known lunar pristine rocks. We analyzed (by microprobe) olivine and pyroxene clasts in lunar impact melts 15445 and 15455 for minor elements, using Bersch's database to establish the affinities of these clasts to the known pristine rock types. We also examined these same data in an attempt to understand the chemical nature of unknown rock types that contribute to the LKFM composition. We chose samples 15445 and 15455 for initial study because they are aphanites, and their entrained clasts can be easily and unambiguously distinguished from the matrix [9]; moreover, they have been interpreted as fragments of the melt sheet of the Imbrium basin [9]. We plan to extend our study of clast compositions to other melt groups from other landing sites, including the Apollo 17 aphanites and the Apollo 16 VHA melts (which could represent Nectaris basin impact melt; [3]).

The dominant mafic mineral occurring as clasts in both 15445 and 15455 is olivine (the olivine/pyroxene ratio in both rocks ~ 5:1). Results of analyses of Cr and Fe in olivine clasts in the two samples are shown in Figure 1. A wide variety of compositions is present; moreover, the composition of clastic olivines falls only partly within the fields defined by the analyses of known pristine rocks [8]. Because even these fields encompass rocks derived from more than one magma source, the olivine clasts in 15445 and 15455 probably are derived from rocks of many different intrusions. The fields defined by the known pristine rocks are probably incomplete; many of the points lie just outside the boundary of the known fields. Some olivines appear to possess high Cr (Fig. 1), an expected characteristic of the "missing" matrix component of LKFM (which has a high concentration of transition metals). However, these clasts probably are *not* derived from a "missing" rock type, because they have no accompanying high Ti (as expected for a transition metal-rich rock type) nor high P (as expected for a KREEP-rich rock). We interpret these clasts as derived from Mg-suite rocks produced by magmas enriched in Cr that have not been sampled as pristine plutonic rocks. The bulk of the olivine clasts appear to be derived from Mg-suite troctolites, with lesser amounts from Mg-suite norites. Only three clasts occur close enough to the ferroan field (Fig. 1) to indicate their derivation from ferroan anorthosites; these clasts (and others that plot directly above them; Fig. 1) may be pieces of unsampled, mafic members of the ferroan suite, such as ferroan troctolite or gabbro. Finally, the proportions of clasts representing identified rock types differ in the two samples; if we generously extend the fields of the known rock types to include the "orphan" points, sample 15445 consists of 79.6 % troctolite and 12.9 % olivine-bearing norite, whereas sample 15455 consists of 62.6 % troctolite and 31.6 % olivine-bearing norite.

As previously observed in the impact melt rocks of Mistastin Lake crater [6], the clasts contained in 15445 and 15455 are derived from a variety of rock types whose proportions differ within samples from the same melt sheet. The clasts appear to be derived largely from a variety of Mg-suite plutonic rocks, only a few of which are represented by samples in the Apollo collections. The Mg-suite probably comprises a wide variety of rocks produced over a long period of time from many magmas that ranged widely in composition. The lithic clasts of 15445 and 15455 are Mg-suite troctolites and norites, the same rock types from which their mineral clasts are derived. These observations support our model for melt formation, whereby the clast population of impact melts reflects the path that the melt followed during cratering flow and its final emplacement [6],

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rather than containing a representative population of rock types that have participated in the melt petrogenesis (e.g., [10]). LKFM may represent impact melt produced during the formation of multi-ring basins [3, 9, 11]. In these large events, the scale of crater formation is greater than the curvature of the Moon; impact melt generated at depth that moves laterally outward during crater growth encounters progressively higher stratigraphic levels. Thus, clasts are entrained in the LKFM basin melts during the later stages of crater growth, and they are derived from crustal levels above the mafic, KREEP-rich zone of melt generation. In our model, the "missing" components of LKFM are plutonic rocks that occur in lower parts of the crust, perhaps as deep as its base. We can only infer their properties from geochemical modeling; they are unlikely to be observed as clastic components within the melt breccias.

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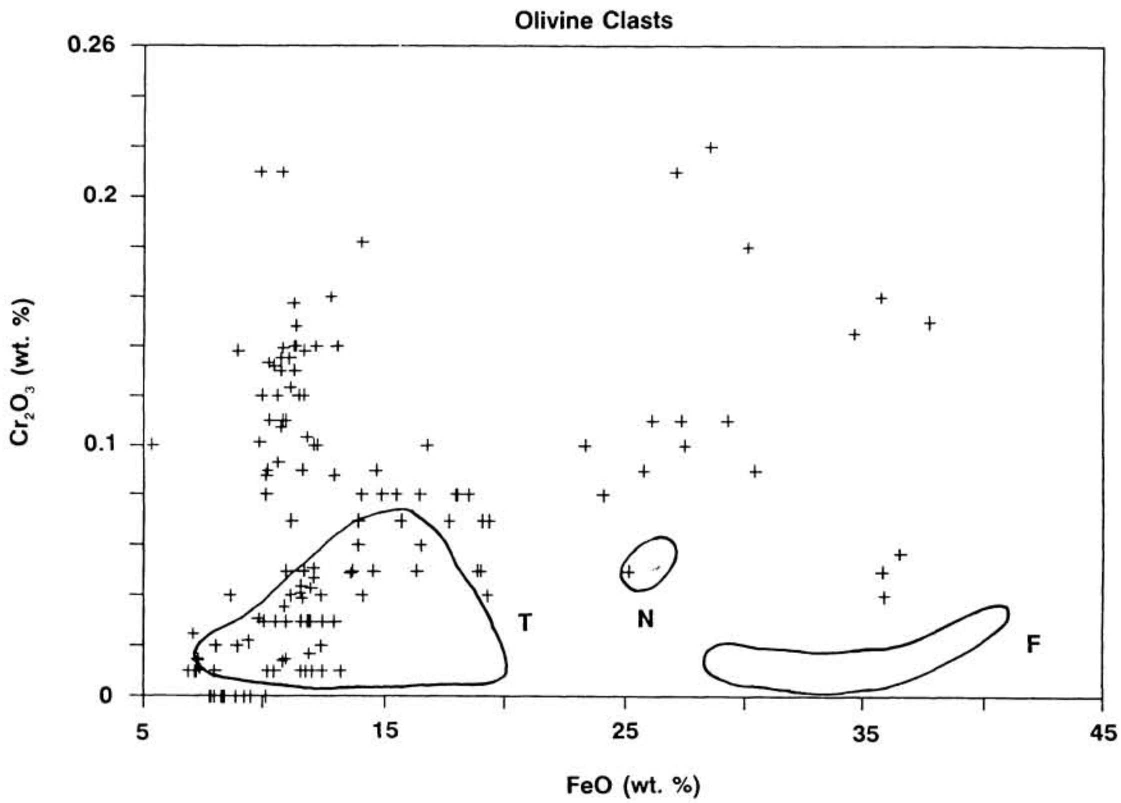

Figure 1. Cr and Fe concentration data for clastic olivines in impact-melt breccias 15445 and 15455. Fields for pristine lunar rocks are taken from the data of Bersch [8]; "T" - Mg-troctolites, "N" - Mg-norites, "F" - ferroan anorthosites.