

The Textural Pristinity of KREEP Basalts: The Role of Impact Melting and Volcanic Eruptions. K. Cronberger¹ and C. R. Neal¹, ¹Dept. Civil Eng. & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA [kcronber@nd.edu; neal.1@nd.edu].

Introduction: KREEP, first described by [1] (but not given its name until 1971 [2]), is a descriptor added to any lunar rock enriched in [K] potassium, Rare Earth Elements and Phosphorus (hence the name) as well as other incompatible trace elements [1]. The origin of the “KREEP” geochemical signature is considered to be as the final dregs of residual magma from the crystallization of the lunar magma ocean, affectionately termed “urKREEP” or primordial KREEP (e.g., [3-5]). However, recognition of “urKREEP” in the existing sample collection is difficult and is usually present in a diluted form as KREEP basalts and extreme fractionates of basaltic melts. KREEP basalts are distinct from mare basalts in that they generally have higher Al₂O₃ contents and lower Ca/Al ratios, which reflect lower modal abundances of Ca-rich pyroxene (e.g., [6]). KREEP basalts have been termed “non-mare” or “very high alumina (VHA)” because of these compositional differences (e.g., [7-11]).

Two hypotheses for the formation of KREEP basalt 1: KREEP basalts are pristine, primary melts [12-18], and 2: KREEP basalts are the result of impacts that mix different “KREEPy” materials [19-22]. Warren and Wasson [5] proposed criteria for differentiating between impact and pristine lunar samples setting a threshold for extra lunar siderophiles at $<3 \times 10^{-4}$ times C1 chondrites, for a sample to be considered pristine. However sample 15386 is generally defined as a pristine KREEP basalt, but using the criteria of [5] is defined as pristine using some criteria and non-pristine using others. For example, it contains 0.61 ppb Ir and 0.22 ppb Au [23,24]. However the pristinity criterion for these elements is <0.1443 ppm Ir and <0.042 ppm Au. In addition to chemical methods petrographic methods have also been used to identify “pristine” melts as well. Ryder et al. [25] for example used orthopyroxene phenocrysts surrounded by a fine grain ground-mass reasoning that static environments such as those expected of an impact melt cannot form porphyritic textures in KREEP basalts. However a porphyritic texture could form in such an environment if a phase was on the liquidus long before the others. (e.g., [23]).

This study is to examine the nature of KREEP basalts from a pristine (basalt lava) vs. non-pristine (impact melt) standpoint. The issue with KREEP basalt samples in the current collections is that many of them are small, thus precluding determination of highly siderophile elements to determine pristinity. Therefore, other methods need to be used. Therefore, following on from [26], textural evidence will be used to define the origin of a given sample as either from a pristine or impact melt.

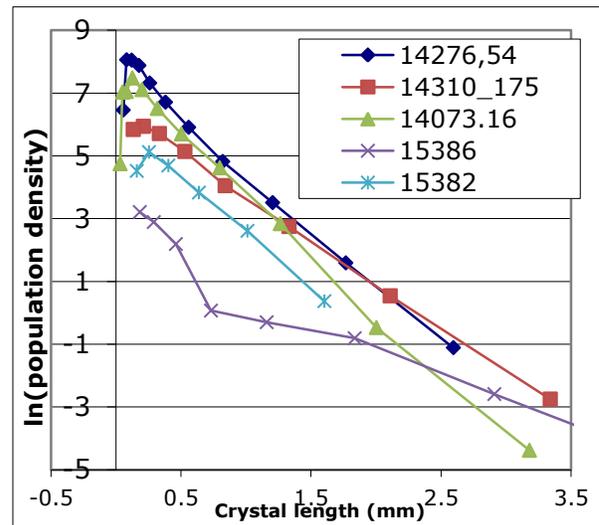


Figure 1: Plagioclase crystal size distributions calculated for KREEP melt samples.

Method: The use of quantitative petrography to discern between impact and pristine melts was proposed by [26]. This allows the provenance of samples too small for siderophile element abundances to be determined to be classified as either pristine or not. This method also preserves valuable sample mass as the destructive geochemical analyses are not needed for such a classification. Crystal size distributions (CSDs) measure the number of crystals of a characteristic size per unit volume of rock (e.g., [27-29]). In order to perform a CSD analysis, each sample must first be digitally photographed and the images imported into *Adobe Photoshop*, where the entire sample and each crystal is digitally outlined and filled-in. After conversion to a bitmap, the crystal and sample fill images are imported into *ImageJ* [30], which measures the major and minor axes, roundness, and area of each crystal as well as that of the entire sample. *ImageJ* is used in preference over *ImageTool* [31] because *ImageJ* can handle larger image file sizes. The major and minor axes are imported into *CSDslice* [32] to determine the 3-D crystal habit: short, intermediate, and long axes. The output gives the five best-match curves and corresponding crystal habits based on a least-squares fit between sample and the assembled database. Morgan and Jerram [32] state that 200-250 crystals are required in order to give good fits in crystal shape ($R^2 > 0.8$). These data, in conjunction with the major and minor axes, individual crystal area, average crystal roundness, and total sample area, are used in *CSDcorrections 1.3* [30,31] to determine the 3-D crystal size distribution. Finally, crystal size distributions are plotted as the natural log of the population density

against the corrected crystal size length [33]. The plagioclase CSDs for 5 KREEP basaltic samples are plotted in Fig. 1. Unfortunately, the CSD for 15386 does not meet the criteria for a statistically relevant CSD (number of crystals <200 ; $R2 <0.8$), but it is included here for illustrative purposes.

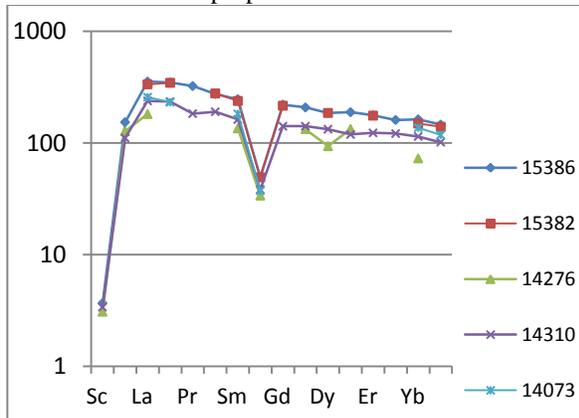


Figure 2: REE plots for the 5 KREEP samples used in this study. Data from the Mare Basalt Database (www.nd.edu/~cneal/Lunar-L/).

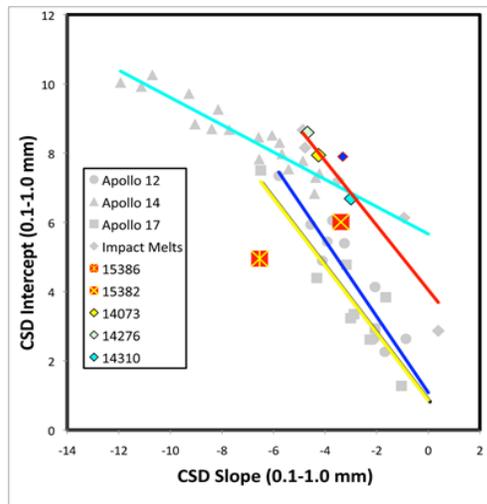


Figure 3: Plot of plagioclase CSD slope vs. CSD intercept (using the 0.1-1 mm size range (see Fig. 1) to discriminate between pristine and impact basaltic samples. After [26].

Discussion: The KREEPy nature of the samples included in this study can be seen in the REE profiles (Fig. 2). These samples have been incorporated into the plot developed by [26] to attempt to discriminate between pristine and impact melts (Fig. 3). This plots the slope and CSD intercept over the .1 to 1 mm interval, and basically represents nucleation density vs. growth/nucleation density [26]. 15386 appears to be pristine as it plots well away for the red “impact melt” regression line (defined by Apollo 16 impact melts), but note that the 15386 plagioclase CSD needs to be redone using a larger thin section with more plagioclase crystals. 15382 plots between the impact melt and Apollo 12 regression lines, requiring another CSD to

be constructed to remove any ambiguity. All Apollo 14 impact melts fall on the impact melt regression line. Additional plagioclase CSDs will be constructed for more KREEP melt samples and “crystal stratigraphy” will be applied to the constituent phases (major and trace elements), especially any phenocrysts/xenocrysts.

Summary: Initial plagioclase CSD data for KREEP samples show promise for defining those that are pristine vs. those that formed as impact melts, but verification is needed. More plagioclase CSDs from KREEP melt samples are currently being constructed. Application of crystal stratigraphy (major and trace elements) across constituent phases, especially phenocrysts/xenocrysts, will greatly help in deciphering the petrogenesis of these enigmatic samples. Such data will be presented at LPSC 43.

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