
As part of our continuing effort to understand the origin of KREEP-rich materials, six fragments (0.16-0.27 g) from soils 14150 and 14160 were subjected to petrographic, chemical, and isotopic investigation. Four of the fragments are crystalline matrix breccias while two are intergranular to subophitic basalts. These basalts are petrographically, chemically, and isotopically very similar to other A-14 KREEP basalts (1). Major minerals are plagioclase (54-55 vol. %) low-Ca pyroxene (33-36%), and augite (5-7%). Minor phases include ilmenite, Ca-phosphate, K-feldspar, Si- and K-rich mesostasis, troilite, and metal. Plagioclase cores are An93-95 Or0.2-0.5 in composition, while orthopyroxene cores are En79-81 Wo2-4. Orthopyroxene tends to be rimmed by and occasionally intergrown with pigeonite or augite. Zoning patterns are similar to those in other A-14 basalts. Metal grains contain 1-20 wt % Ni and 0.1-1.3% Co, similar to the range observed for 14310 and 14078 (1, 2), suggesting that these samples have high siderophile contents.

When projected in the Ol-Si-An pseudoternary system (F. 1), major element compositions of the breccia fragments fall within the range observed for Fra Mauro breccias (3). Basalts lie within the plagioclase liquidus field, but are slightly less plagioclase-rich than other A-14 basalts (e.g., 14078), possibly due to sampling errors (1). Ba and REE contents of the basalts are slightly lower than those of 14078 (F. 2), but similar to those of 14073, 14152, 5, 102, and 14310. Breccia fragment 14160.97.1 is the most KREEP-rich A-14 sample analyzed in our lab (Sm=48 ppm). All six fragments have similar characteristics "V-shaped" REE patterns which distinguish A-14 KREEP from KREEF at other landing sites (1). A mineral isochron for basalt 14150.7.3 (F. 3) yields an age similar to those of other A-14 KREEP basalts, but a marginally resolved initial Sr isotopic ratio (F. 4).

Data for the basalt fragments support our previous conclusion that A-14 KREEP basalts were all derived from the same impact generated melt (1). The impact target material was probably a mixture of two or more lithologies, one rich in incompatible elements and radiogenic Sr, and one rich in Al and poor in radiogenic Sr. Incomplete isotopic homogenization resulted in different volumes of melt having slightly different initial Sr isotopic ratios.

Several groups have proposed that KREEP-rich lunar samples represent mechanical or assimilative mixtures of late-stage residual liquid from the primary lunar differentiation with incompatible-poor highlands crustal material (e.g., 1, 4, 5). We have investigated the possibility of starting with a primitive magma ocean composition and generating, via a reasonable crystallization sequence (6), residual liquids with trace element patterns similar to those required to produce KREEP-rich samples. We obtain the primitive magma ocean composition from dunite 72415/7, which is probably a product of the primary differentiation (7, 8), and contains interstitial samples of the liquid from which it crystallized (9). Using olivine/liquid distribution coefficients determined for appropriate phase compositions (10, 11) we have refined the calculations of Laul and Schmitt (9), and placed narrow constraints on the composition of the trapped interstitial parent liquid (TL). Of the OL/Liq Ds for REE measured by McKay and Well (10, 11) for OL+PL saturated liquids, the most precisely determined is that for Yb. Assuming their 1200°C value for D(Yb) (10) to be applicable, we have used the data of Laul and Schmitt (9) for the most LIL-rich and LIL-poor dunite fragments to iteratively calculate abundances in the TL and resulting D(OL/Liq) for 17 trace elements. Maximum
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LIL abundances in the TL (F. 5) result if the most LIL-poor fragment contains no TL. Resulting Ds for Sr, Ce, Sm, and Eu are in general agreement with experimental values (F. 6). Slight fragment-to-fragment variations in La/Al (not shown) suggest either nonrepresentative sampling of TL or the presence of cumulus PL which would imply a PL saturated liquid. The minimum Al_2O_3 content of an OL+PL saturated liquid of appropriate Fe/Mg is ~16% (12), yielding intermediate LIL abundances in the TL (F. 5), and Ds which are also in general agreement with experimental values (F. 6). The stippled region (F. 5) shows the range of LIL abundances in OL+PL saturated liquids. As LIL abundances in the TL decrease, resulting values for D (Ce-Gd) also decrease (F. 6). Minimum possible LIL abundances in the TL (dashed line, F. 5) are those which result in D (Ce-Gd) > 0, well below experimental values (F. 6).

LIL abundances for all fragments (9) were modelled assuming OL+PL saturated TL, and using La to calculate the TL content of each fragment. Good agreement between calculated and observed abundances in the fragments (F. 5) and between calculated and observed Ds (F. 6) strongly support the model.

LIL abundance patterns calculated for the dunite trapped parent liquid are ~2X lower than those calculated by Laul and Schmitt (9), but are very similar in shape. Ba, Sr, and Eu are present in nearly chondritic proportions and are enriched relative to trivalent REE and Sc. The heavy REE slope in the TL is similar to that in KREEP and to that proposed for the magma ocean (13). Ca/Al of the TL is below chondritic values (F. 7), as proposed for the magma ocean by (6, 14). The non-chondritic compositional aspects of the TL probably could not be generated by fractionation of petrologically reasonable phase assemblages (6) from an initially chondritic liquid.

Relative LIL abundances observed in KREEP-rich samples, or calculated for their proposed ilmenite-saturated precursors (1, 5) are fractionated relative to the TL (F. 8). Extensive crystallization of PL and CPX from a magma ocean with LIL patterns similar to those of the TL appears necessary to generate observed fractionations. Neither magma ocean crystallization sequences nor D values are well constrained. However, sequences similar to that proposed by (6), with Ds for OL, OPX, and PL adapted from (10, 11) and Ds for CPX from (13) are capable of generating fractionations similar to those observed (F. 8).

REFERENCES