SM-ND SYSTEMATICS OF "KREEP". G.W. Lugmair and R.W. Carlson, Univ. of Calif., San Diego, B-017 Chemistry and SIO, La Jolla, California 92093.

One of the fundamental problems of lunar petrogenesis is the origin of the highly differentiated materials enriched in incompatible elements, termed KREEP by Hubbard et al. (1). Many of the basic questions as to the mechanism of production, the selenographic site and time of generation surrounding this, what used to be called "magic component", were addressed by many authors in the past (2-6). In order to shed some light on some of these unsolved problems, we are currently studying the whole rock Sm-Nd systematics of KREEP from a variety of landing sites. So far, samples from three different Apollo sites have been measured. The results are listed in Table 1.

15382 is a rock fragment of crystalline KREEP of relatively fine grain size. Sample a was a 26.2mg split of the finely crushed rock fragment, which was split after dissolution and ∿ 1/3 of it spiked. Sample b, a 10.4mg split of the crushed sample, was totally spiked. The Sm-Nd concentrations for the two samples listed in Table 1 are in reasonable agreement. 14307 is a KREEP breccia studied extensively by the St. Louis group (7,8). One sample analyzed was a 6.8mg aliquot of a very compact KREEPy white clast containing ∿ 6% K-rich interstitial glass (8). The sample labeled MTX consisted of 10.2mg of brown, glassy matrix material with intermixed lithic fragments of the white clast variety. 12034 is a breccia which, as described by McKay et al. (9), contains the highest KREEP content of any of the Apollo 12 breccias. From this rock, we analyzed two samples so far: a 2.9mg piece of maroon glass (MG) and a 3.7mg chip of a light grey clast (CL8).

As discussed before by numerous authors, the relative chondrite normalized REE abundance pattern for KREEP-rich samples is very similar for samples from different landing sites and varying REE concentrations. What becomes apparent from our high precision measurements, however, is the fact that despite a variation of the REE concentration in our samples by a factor of ∿ 2.7, the relative REE abundance, as expressed by $^{147}Sm/^{144}Nd$, varies only by ∿ 1.2% (Table 1 and Figure 2). Also, concentration and $^{147}Sm/^{144}Nd$ have a roughly inverse relationship as shown in Figure 2 which may provide important constraints on the genetic history of KREEP. The total variation in $^{143}Nd/^{144}Nd$ is 1.4 parts in 10^4, only ∿ 3 times the typical uncertainty of the individual values. This remarkably close agreement in Sm/Nd and $^{143}Nd/^{144}Nd$ between samples from different selenographic sites is illustrated in Figure 3.

Two reference isochrons are given in this Sm-Nd evolution diagram. One is that of the basaltic achondrite Juvinas representing an age of 4.56AE, the other is that of the troctolite 76535, corresponding to an age of 4.26AE (10). Also shown are the data points for OPX and PL from 76535, exhibiting the largest variation in $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ in any lunar material observed so far. The small rectangle designated "KREEP" contains all the data pairs listed in Table 1. The insert in Figure 3 is a 60X enlargement of this data field. Figure 3 reveals that the data points line up roughly along the 4.26AE reference isochron of the troctolite. Resolution from the 4.56AE reference isochron is suggested, but is only marginal in this representation considering the uncertainties involved.

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Many workers have argued for an ancient origin of KREEP material on the basis of chemical, isotopic and petrologic evidence (e.g. 3,11,12). We have shown previously (10,13) that the differential Sm-Nd evolution of crustal and mantle derived lunar materials appears to be roughly complementary. This result is again illustrated in Figure 1 which shows the differential evolution of ^{143}Nd versus time in various lunar rock types and their source regions relative to a "chondritic" Sm/Nd reservoir as represented by Juvinas [$\varepsilon_{JUV}(T) \equiv 0$]. The basalt field occupies the half space of positive $\varepsilon_{JUV}(T)$ while crustal materials (i.e. ANT rocks and KREEP) evolved with negative $\varepsilon_{JUV}(T)$. The intersection of an evolution line of a sample with the chondritic evolution line determines the model age (T_{ICE}) of this sample. This type of model age, therefore, is based on the assumption that negligible Sm/Nd fractionation and/or dilution with materials of different Sm/Nd occurred at the time of extrusion and crystallization. Furthermore, the average "whole moon" Sm/Nd ratio is assumed to be chondritic and homogenous throughout the moon before the onset of the early melting. The line in Figure 1, labeled "KREEP", denotes the ^{143}Nd evolution of all samples listed in Table 1 under these model assumptions. As discussed above, the Sm/Nd and ^{143}Nd/^{144}Nd data are so tightly clustered that representation by a single evolution line appears justified. The actual T_{ICE} model ages and their overall uncertainties are given in the last column of Table 1. The model ages for KREEP materials from at least three different landing sites agree well within their error limits. From the close agreement of the Nd isotopic data and the Sm/Nd ratios, it appears rather unlikely that significant relative fractionation of the REE has occurred since the establishment of the relative REE pattern. If this is true, then the range of model ages reflects the time of generation of the source material of these rocks. This time is in very good agreement with earlier estimates based on Rb-Sr and U-Pb systematics, especially when adjusted for the new ^{87}Rb half-life (see e.g. 12 and references therein). Whether this close grouping which very strongly suggests a common source reservoir and closed system behaviour of Sm-Nd in KREEP holds true for samples from other lunar landing sites is still under investigation.

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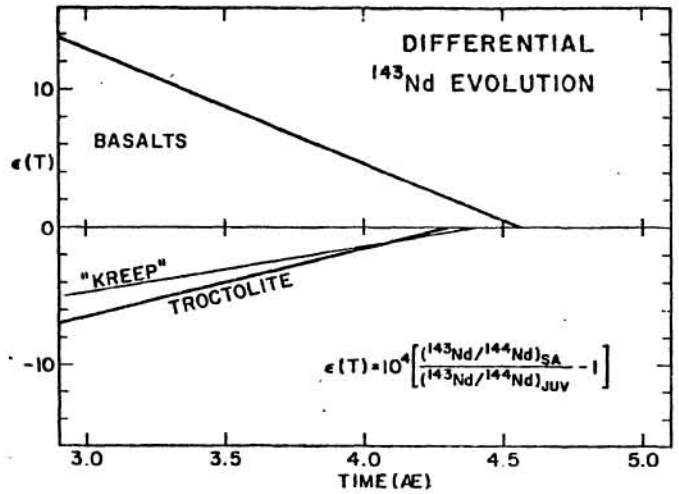
Fig. 1: Differential ^{143}Nd evolution of crustal and mantle derived lunar rocks relative to that of a chondritic source reservoir.



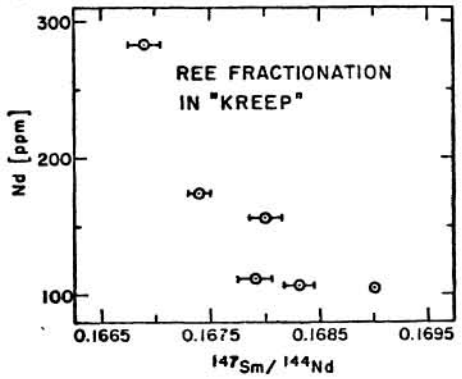
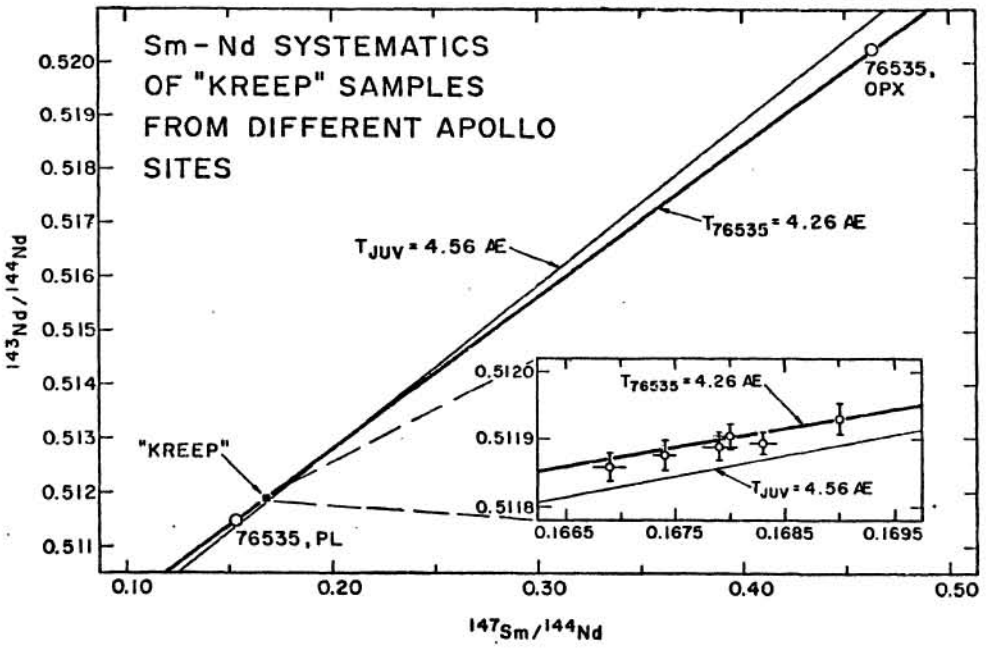


Fig. 2: Correlation of REE concentrations in KREEP samples with relative REE abundances.

Table 1: Analytical Results for KREEP Samples.

SAMPLE	Sm ppm	Nd ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T_{ICE} (AE)
15382 a	31.06	111.8	0.1679	0.511 889 21	4.38 ± 0.14
15382 b	29.84	107.2	0.1683	0.511 894 16	4.42 ± 0.1
14307 MTX	29.38	105.1	0.1690	0.511 931 23	4.32 ± 0.16
14307 CLAST	48.30	174.4	0.1674	0.511 876 22	4.37 ± 0.14
12034 MG	43.41	156.2	0.1680	0.511 905 18	4.30 ± 0.12
12034 CL8	78.38	283.8	0.1669	0.511 859 21	4.39 ± 0.14

Fig. 3: Sm-Nd evolution diagram. A remarkably close clustering of Sm-Nd data from KREEP samples is revealed and a close genetic relationship with other crustal materials is suggested.



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