

SM-ND STUDY OF PRISTINE KREEP BASALT 15386, R. W. Carlson and G. W. Lugmair, B-017, Chemistry Dept. and Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California 92093.

Chemical and chronological studies of the incompatible element rich component of lunar materials have yielded somewhat enigmatic results with respect to theories of its origin and evolution. This component termed KREEP for its high abundances of K, REE and P has been described alternately as a product of the partial melting of ANT (Anorthosite, Norite, Troctolite) (e.g. [1,2]) or low-K Fra Mauro rock types [3], and as a final residue of the differentiation of a lunar magma ocean. Arguments against a partial melting origin for KREEP are based mainly on the degree of consistency of relative lithophilic trace element abundances [4]. This feature is particularly evident in the Sm-Nd systematics of the KREEP-rich samples reported by Lugmair and Carlson [5]. These samples from four lunar landing sites display a total variation of only 1.2% in Sm/Nd despite a factor of 2.7 variation in the concentration of Sm and Nd.

Chronological information on the origin of KREEP-rich rocks indicates at least two significant ages in the history of KREEP evolution. Ages of  $\sim 3.9$ AE are repeatedly indicated by Rb-Sr internal isochrons of KREEP-rich samples, while, on the other hand, their Rb-Sr model ages fall in a rather limited range at  $\sim 4.4$ AE [6,7,8,9]. In addition, we have recently shown [5] that Sm-Nd (TICE) model ages of a variety of KREEP-rich samples cluster between 4.3 - 4.4AE. While it seems evident that the  $\sim 4.4$ AE age represents the original formation of the incompatible element characteristics of KREEP, the 3.9AE age can be variously interpreted as either a solidification or metamorphic age. The importance of Sm-Nd age information for KREEP samples lies in the demonstrated resistance of this system to disturbance in metamorphic events [10,11]. For this reason, we are currently attempting to obtain a Sm-Nd internal isochron for KREEP basalt 15386. This sample was chosen for study based on evidence which suggests that it formed from a pristine flow of KREEP magma, notably characterized by its decidedly igneous texture [12] and low siderophile element content [13].

From a 165 mg original allocation, to date five samples have been measured: (i) a 10 mg whole rock aliquot (TR-1B) split from the total sample after crushing, (ii) one 2.65 mg separate of optically clean, yellow-green pyroxene (Px-1) (iii) 2.51 mg of pure plagioclase (PL-1) without obvious adhering contamination (iv) a 9.42 mg plagioclase separate (PL-2) which contained  $\sim 1\%$  adhering and included dark grains and flakes, (v) a totally spiked aliquot (0.40 mg) of a separate of frosty-grey mesostasis phases with minor ilmenite (Mes-1). Results of Sm-Nd measurements for these samples are given in the Table. An isochron fitted to the data yields an age of  $3.87 \pm 0.12$ AE. This value is consistent with the Rb-Sr age of  $3.94 \pm 0.04$ AE ( $\lambda_{Rb} = 1.39 \times 10^{-11} \text{y}^{-1}$ ) reported for 15386 by Nyquist *et al.* [9]. The agreement between the Sm-Nd and Rb-Sr age implies that the  $\sim 3.9$ AE age reported for many KREEPy rocks may indeed represent the time of solidification rather than metamorphism. The relatively large error of the Sm-Nd age of 15386 is due to the small spread in Sm/Nd obtained in the mineral separates and non-optimal analytical error resulting from the very small sample size measured. The low REE abundances of the major mineral phases of 15386 indicate that the total rock REE pattern of this sample is dominated by the volumetrically minor mesostasis phases (Table). Inhomogeneous distribution of these mesostasis phases would account for the discrepancy between the whole rock Sm and Nd abundances reported here, and those of Warren *et al.* [13] who report 25.5 and 80 ppm respectively for 15386. However, as shown by

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Lugmair and Carlson [5], the Sm/Nd ratio of whole rock samples is insensitive to variations in the abundances of these elements. Abundances of Sm and Nd in Pl-1 are roughly 50% higher than would be expected, based on measured plagioclase-liquid distribution coefficients. This discrepancy can easily be the result of a very small (< 1%) amount of contamination by adhering or included mesostasis. However, pyroxene (Px-1) Sm/Nd abundances are not in agreement with those predicted for orthopyroxene, which suggests that much of the REE's in the pyroxene separate were contained in the pigeonitic rims of OPX grains [14] or that the REE in the pyroxene separates were severely affected by mesostasis contamination.

The relatively low abundances of REE in the major minerals of 15386 emphasize the possible genetic relationship between KREEP and ANT suite materials. Plagioclase and orthopyroxene in troctolite 76535 have Sm and Nd abundances [15] similar to those found in our 15386 separates. Apparently, the minerals comprising the troctolite were at one time in equilibrium with a liquid which was approaching KREEP-like abundances of incompatible elements. This suggests that the final characteristics of the KREEP incompatible element abundances may be intimately related to the degree of late-stage differentiation which occurred in the interaction between incompatible element-rich liquids and the formation of deep lunar crustal rocks such as the troctolite 76535. This differentiation was completed at about 4.3AE, as evidenced by Rb-Sr and Sm-Nd model ages. Ages of 3.9AE must then represent the time of extrusion of measured KREEP samples. However, the events occurring at 3.9AE did not disturb the relative incompatible element pattern which was established much earlier. The constraints imposed by the Sm-Nd data strongly support the idea that KREEP basalts may have originated as disequilibrium melts of interstitial materials associated with ANT rocks in the deep lunar crust at 3.9AE, as suggested by Dowty *et al.* [16].

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Table 1: Analytical Results For 15386.

Sample	[Sm] <sub>ppm</sub> <sup>a</sup>	[Nd] <sub>ppm</sub>	<sup>147</sup> Sm/ <sup>144</sup> Nd <sup>b</sup>	<sup>143</sup> Nd/ <sup>144</sup> Nd
P1-1	1.68	7.68	0.1319 ± 4	0.51102 ± 24
P1-2	2.17	8.95	0.1466 ± 2	0.511338 ± 27
Mes-1	99.01	361.7	0.1655 ± 1	0.511858 ± 34
TR-1B	36.04	129.6	0.1681 ± 1	0.511909 ± 18
Px-1	2.91	8.34	0.2113 ± 5	0.512996 ± 41

(a) Calculated using measured Sm isotopic composition. (b) Errors correspond to last digit and include 50% uncertainty in blank correction.