DID A KREEP-LIKE COMPONENT EXIST ON THE FAR SIDE OF THE MOON?: INSIGHTS FROM THE THORIUM ABUNDANCE DISTRIBUTION IN SOUTH POLE-AITKEN BASIN.

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Introduction: Most models for the evolution of the Moon predict that 99% fractional crystallization of a lunar magma ocean will produce a layer of melt enriched in incompatible elements such as K, REE, and P (i.e., KREEP) [1]. The lateral extent and distribution of this "KREEP" layer, which contains an abundance of heat-producing elements such as Th and U, is currently a matter of debate. However some workers [2] have proposed that the surficial distribution of Th, which has been measured on a global-scale [3,4,5], can be used as a proxy for determining the global distribution of KREEP. Assuming that the surficial distribution of Th mimics the distribution of Th in the underlying mantle, workers have suggested that KREEP was almost entirely concentrated on the nearside of the Moon, primarily in and under the Procellarum KREEP Terrane (PKT) [2,6,7].

We use new data from forward modeling of the Th abundance distribution in South Pole-Aitken (SPA) basin, as well as newly deconvolved Th data [5], to suggest that a KREEP-like component may have once existed on the far side of the Moon. More specifically, we provide information about the distribution of Th in the crust and mantle on the far side of the Moon at two distinctly different periods in lunar history (i.e., prior to the SPA impact event and during Imbrian volcanism). Determining if a KREEP-like component ever existed on the far side of the Moon has potential ramifications for the evolution of the lunar mantle.

SPA Background: Previous studies of the Th abundance distribution in SPA [2,3,4,8] have shown that the basin floor contains more Th than the surrounding Feldspathic Highlands Terrane [2]. Additional studies have shown that the Th enhancements in the basin are not associated with antipodal ejecta from Th-rich basins on the near side of the Moon [9,10] and are most likely affiliated with ancient lithologies inherent to the basin [11]. The question is, what lithologies are responsible for the Th enhancements?

We initially addressed this question by using forward modeling of the Lunar Prospector Gamma Ray Spectrometer (LP-GRS) Th data to investigate the Th content of several basalt ponds in SPA basin [12]. Our preliminary results indicated that there was little or no Th in these basalt ponds. Because the basalt ponds represent partial melts from the lunar mantle, we concluded that the underlying mantle was also Th poor. Since that time, we have obtained results for additional ponds and have estimated the composition of nonmare materials on top of those basalt ponds. These results provide important information that help us to evaluate the source of Th enhancements in SPA basin.

Forward Modeling: As part of the forward modeling process, we re-create a specific portion of the lunar surface in which we can control the Th abundances of specific geologic features [12,13]. We must also know what Th abundances can be reasonably assigned to any given feature and/or lithology, which is why we use analyses from the lunar sample suite to constrain the upper and lower bounds of our Th estimates.

Once we have reconstructed a specific geologic environment, we propagate the expected gamma ray flux from this geologic environment through the LP-GRS spatial response, which produces a simulated Th abundance distribution. We then compare the simulated Th distribution to the measured Th data and iteratively adjust the simulated distribution until we achieve a match with the measured data. This type of forward modeling has been carried out for other gamma-ray measurements of the Moon [12,13,14].

Results: We have used forward modeling to estimate the Th abundances of 12 different basalt ponds in SPA basin (Fig. 1). Our results show three definitive trends. 1) Th abundances increase from east to west across the basin. 2) Basalt ponds that have little or no nonmare cover on top of them (7 ponds in all) have < 1 ppm Th. 3) There is a direct spatial correlation between nonmare cover and Th enhancements on basalt ponds in SPA. Our results show that the nonmare cover on the basalt ponds appears to have relatively high Th abundances (2 to 9 ppm, with a mean of 3 ppm), as well as moderate FeO abundances (9 to 12 wt.%) and moderate TiO_2 abundances (2 to 4 wt.%). The FeO, Th, and TiO_2 abundances are consistent with noritic/gabbronoritic materials [15] that appear to dominate the floor of SPA [16].

Discussion and Conclusions: Clementine spectral data indicate that the majority of the SPA floor consists of noritic/gabbronoritic materials [16]. LP-GRS Th data indicate that the SPA floor is enriched in Th relative to the surrounding terrain [2,3,4,5]. This information, in conjunction with the fact that norites in the lunar sample suite tend to be Th-rich [15], indicates that norites are the likely source of Th in SPA. Our study supports this conclusion by first showing that the basalt ponds are not the source of Th in SPA and second, that the noritic cover on the ponds is indeed Th-rich (2 to 9 ppm). Because norites are the intrusive equivalents of basalts, we can infer that Th-rich norites were produced by ancient basaltic magmas that were also Th-rich. Given billions of years of regolith processing and the observation that the floor of SPA has an average of > 2 ppm Th and a regional high of > 5 ppm [4,5], it is logical to assume that the initial source lithology contained > 5 ppm Th. The source of Th is debatable, but it is clear that a source of Th did exist in this part of the Moon at the time of lower crust formation. Additional evidence for this assertion has been provided by studies of Dewar and Moscovience craters [17,18]. These studies show that Th enhancements within or adjacent to Dewar and Moscoviense are associated with basaltic materials. The newly deconvolved Th data [5] show that the Th anomalies in these areas exceed 3 ppm Th, thus indicating that basaltic magmas interacted with a source of Th.

The observation that the relatively uncontaminated basalt ponds in SPA have little or no Th, indicates that their parental magmas did not assimilate the Th-rich, lower crust and therefore the basalt ponds provide compositional information about their basaltic source regions (at least with respect to Th). The uncontaminated ponds are widely separated, have different major element compositions, and different relative ages. This information, along with assumption that the partial melts were likely derived from various depths, indicates that the seven basaltic ponds represent seven unique portions of the far side lunar mantle. Because the ponds are Th-poor, their source regions must have also been Th-poor, indicating that at least seven different portions of the far side mantle had little or no Th as of the Imbrian. In summary, we have evidence that a KREEP-like component existed on the far side of the Moon prior to the formation of SPA and that as of the Imbrian, there was little or no Th in the mantle below SPA.

We use the results from this study to make the following implications for the evolution of the far side mantle. 1) Some form of magmatic fractionation took place on the far side of the Moon producing a Th enrichment similar to that of near side KREEP, albeit at a smaller scale. 2) If magmatic fractionation did occur on the far side of the Moon, it does not appear to have been incorporated into deeper portions of the far side mantle. From these implications, we propose two potential scenarios: 1) The end product of magmatic differentiation (i.e., the Th-rich, KREEP-like component) was removed from the far side after the SPA impact event [7,19], leaving behind a barren, Th-poor mantle that was subsequently melted to produce Th-poor basalt ponds. 2) The KREEP-like component remained just below the lunar crust and reacted with the lower crust and/or crystallized in-situ. In this model, the far side mantle remained stratified, similar to the model of Snyder et al. [20], with no evidence for cumulate overturn [e.g., 7]. Deep portions of the stratified mantle were partially melted to produce Th-poor basalts. In either of these scenarios, a KREEP-like component must have been located on the far side of the Moon in order to explain the Th-rich noritic lower crust, which in turn indicates that KREEP-like fractionation was not limited to the near side of the Moon.

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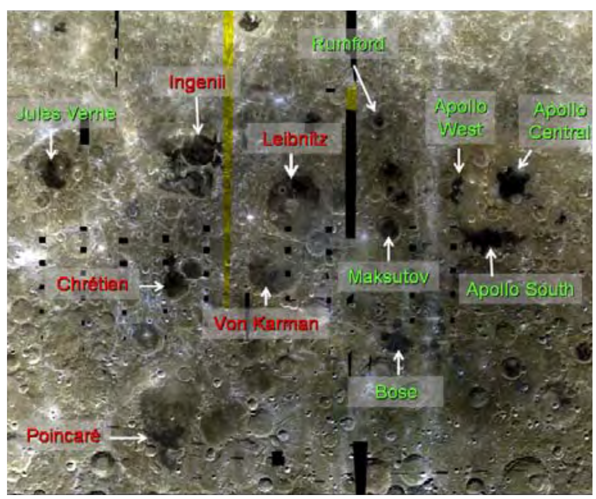

Fig. 1. Clementine albedo (natural color) map (from USGS map-a-planet) showing the results from the forward modeling of Th abundances in basalt ponds in SPA basin. The ponds labeled in green are relatively uncontaminated and have Th abundances < 1 ppm. The red labels represent ponds that have no uncontaminated exposures of basalt. The modeled Th values in these ponds represent the noritic cover on top of the ponds, which has between 2 and 9 ppm Th.