THORIUM ABUNDANCES OF BASALT PONDS IN SOUTH POLE-AITKEN BASIN: INSIGHTS INTO THE COMPOSITION AND EVOLUTION OF THE FAR SIDE LUNAR MANTLE, J. J. Hagerty, D. J. Lawrence, and B. R. Hawke, U.S.G.S. Astrogeology Science Center, Flagstaff, AZ 86001, Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, and University of Hawaii, Hawaii Institute of Geophysics and Planetology, Honolulu, HI email: jhagerty@usgs.gov.

Introduction: Lunar basalts have been used as probes into the underlying lunar mantle by numerous researchers [e.g., 1, 2, 3]. In this investigation, we use basalt ponds within the South Pole-Aitken (SPA) basin to gain access into the far side lunar mantle. One complicating matter is that without unambiguous samples from SPA basin, we are reliant upon low-resolution, remotely sensed compositional data. Fortunately, thorium (Th) data derived from the Lunar Prospector Gamma Ray Spectrometer (LP-GRS) serves as a useful tool in investigating the SPA basalts.

Th is the focus of this study because Th has several characteristics that make it a critical element for understanding lunar geochemistry and evolution. For instance, Th is commonly used as a proxy for the abundance and distribution of KREEP [4]. Th is also one of the few elements that can be easily and accurately detected by both remote sensing and sample analysis techniques, which means that there are comparable data sets of different scales that can be combined to provide a wealth of information about the Moon.

Previous studies of Th abundances within SPA basin [e.g., 4, 5, 6, 7] have shown that the basin floor contains more Th than the surrounding Feldspathic Highlands Terrane [4]. The LP-GRS Th map for SPA basin (Fig. 1) shows that the basin has an average Th content of 2 to 3 ppm, with a regional high approaching 6 ppm Th (Fig. 1). However, due to the resolution of the LP-GRS Th data, it is difficult to determine which lithologies control the distribution of Th.

Fortunately, we have demonstrated that it is possible to use forward modeling of the LP-GRS Th data to determine Th abundance distribution at a finer scale [e.g., 7, 8, 9, 10]. Given this information, we sought to determine the Th composition of the basalt ponds within SPA, which not only provides information about the Th content of the underlying lunar mantle, but can also provides constraints on the Th abundance distribution within the basin and possibly for the entire Moon.

Forward Modeling: The regions being investigated in this study have characteristically low Th concentrations and therefore have larger statistical uncertainties than regions with larger Th concentrations. Fortunately, we can use the spatially adaptive image restriction method known as Pixon [11, 12, 13], to derive the smoothest possible image as constrained by both the original data and the data uncertainty (or noise). The use of the Pixon-processed maps is advantageous for this study, as Pixon reduces the statistical uncertainties for regions with low Th concentrations.

Due to the spatially variable nature of the Pixon algorithm, the spatial response function has not been directly calculated for the Pixon-derived Th maps of the Moon. Therefore, in this study we are making the approximation that the spatial footprint used in previous studies [8, 14] is valid here. Due to the slowly varying nature of these response functions (i.e., they are not step functions), this is likely a good approximation for the purposes of this study. Earlier analyses of SPA mare basalt ponds using non-Pixon data [7] yielded qualitative results similar to those given here. The validity of this methodology is further enhanced by the fact that the Pixon processed maps match astonishingly well with and reinforce our forward modeling results for all other portions of the Moon [e.g., 9].

As part of the forward modeling process, we create a hypothetical geologic environment in which we can control the Th abundances of specific geologic features. However, in order to reconstruct a specific portion of the lunar surface, we must have certain information about the region of interest. For example, we need to account for the various types of lithologies that could be present in the region by incorporating information from geologic maps and other remote sensing data sets (e.g., Clementine Spectral Reflectance (CSR) [15]). We must also know what Th abundances can be logically assigned to any given feature and/or lithology, which is why we use analyses from the lunar sample suite to constrain our Th estimates.

Once we have reconstructed a specific geologic environment, we allow the expected gamma ray flux from this geologic environment to be propagated through the spatial response of the LP-GRS, which produces a simulated Th abundance distribution. We then compare the simulated Th distribution to the Pixon processed data and iteratively adjust the simulated distribution until we achieve a match with the Pixon processed data. This methodology allows us to estimate the Th content of specific geologic features, and it allows us to determine how the Th content of a specific feature can influence the Th distribution for the entire region.

Results and Conclusions: As part of a comprehensive survey of multiple basalt ponds in SPA we used LP-GRS, LP neutron spectrometer, and CSR data to determine if there were large expanses of uncontaminated basalt that could be reliably used to obtain com-
positional information about the underlying mantle sources. We considered thirteen different ponds for this study (Fig. 2), but for the sake of brevity we only present detailed discussion of regions that were good candidates for the forward modeling process (i.e., three ponds in Apollo basin, as well as the ponds in Rumford crater and Chrétien crater).

Our results show that uncovered expanses of five basalt ponds in SPA basin are consistent with having < 1 ppm Th, indicating that the basalt ponds are not the source of the regional Th enhancement in the SPA basin. Conversely, we find that the nonmare mafic material on top of many of the basalt ponds is spatially correlated with local Th enhancements (8-10 ppm Th). These nonmare lithologies have compositions that are consistent with noritic to gabbronoritic lithologies in the lunar sample suite. Therefore, our results corroborate previous assertions that noritic to gabbronoritic lithologies, which dominate the floor of SPA basin [e.g., 16, 17, 18], are the most likely source(s) of the regional and local Th enhancements.

The observation that the SPA basalt ponds contain little or no Th indicates that they did not assimilate Th-rich materials during their ascent, and therefore reflect the Th compositions of the mantle source regions from which they were derived. The low Th abundances of the basalt ponds indicate that the mantle under SPA contained very little Th as of the Imbrian (the mapped age of the basalt ponds in SPA basin). Conversely, the presence of Th-rich norites, Ti-rich basalts, and regional, indigenous Th enhancements within SPA indicates that the far side mantle experienced extensive fractional crystallization, resulting in the formation of a KREEP-like component. However the KREEP-like component is not evident in later episodes of basaltic volcanism (i.e., the basalts analyzed in this study).

Given the information presented above, there are several key observations that must be explained in any model for lunar evolution: 1) A Th-rich noritic to gabbronoritic crust must be produced on the far side of the Moon prior to the SPA impact event; 2) Regional Th abundances of at least 6 ppm and local abundances of 8-10 ppm Th must be explained; 3) Ti-rich, Th-poor basaltic source regions must be produced in the far side mantle; 4) Ti-rich basalts must be generated by 3.9 Ga without significant energy input from the decay of radioactive elements. In an attempt to incorporate these constraints into a single model, we propose that the SPA impact event not only exposed the early formed noritic lower crust but also mobilized and concentrated a molten urKREEP layer on the near side of the Moon while also inducing the sinking of ilmenite pods on the lunar far side [e.g., 19], producing Ti-rich, Th-poor source regions for later episodes of basaltic volcanism on the far side of the Moon.

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Figure 1. LP-GRS Th abundance map for SPA basin (outlined in white), deconvolved using Pixon method.

Figure 2. CSR albedo map of SPA basin, showing the location of all of the basalt ponds investigated in this study.