SUB-SURFACE LUNAR KREEP THICKNESS INFERRED FROM THORIUM ANOMALIES ASSOCIATED WITH IMPACT CRATERS.
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Introduction: Thorium abundance data collected by the Lunar Prospector Gamma Ray Spectrometer (LP GRS)[1] has provided us with insight regarding the composition of the lunar surface. Three lunar terranes are defined, in part, using thorium abundance– the Procellarum KREEP Terrane (PKT) around the Imbrium impact, with relatively high values of thorium concentration (> 5 ppm), the South Pole Aitken Terrane, with moderate abundances (2-5 ppm), and the low thorium levels in the Feldspathic Highlands Terrane (< 2 ppm) [2]. This high elevations of thorium associated with the PKT region indicate units enriched with **KREEP** (Potassium (**K**), Rare Earth Elements (**REE**), and Phosphorous (**P**). As KREEP has elevated abundances of incompatible elements, KREEP is thought to have crystallized as the dregs of the early lunar magma ocean [3]. Understanding the lateral and subsurface distribution of KREEP will provide insight into the evolution of the lunar magma ocean.

Patterns in surface thorium abundance do not necessarily correlate to the location of subsurface KREEP. In order to infer the thickness of subsurface KREEP, we examine thorium anomalies associated with impact craters. Impact craters can eject and disperse materials at the impact site when formed. Comparing the thorium abundance in the crater floor and the crater ejecta allows us to evaluate whether a given crater excavated completely or partially into a KREEP-rich layer (Fig. 1).

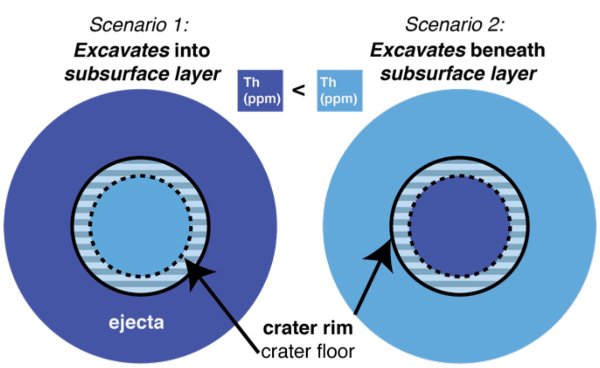

Figure 1: Simplified view of end-member scenarios of craters with identified thorium anomalies and the resulting assumptions.

Methods: We use the lunar crater survey conducted by Robbins, 2018[4] to select all lunar craters with diameters of 30 km – 140 km. This diameter range corresponds to craters with central peaks, but without central peak rings [5]. Analytical crater scaling relationships [e.g. [5][6]] are used to determine the diameters of the floor, and ejecta blanket of a given crater. These measurements are used to determine the boundaries of the floor and the continuous ejecta.

We create a forward model for each crater that uses the instrument response function of the LP GRS, as defined by Lawrence, 2003[7], and known locations of the floor and ejecta of a given crater. We use this model and Thorium abundance data at a resolution of 0.5-degrees [8][9] to estimate the true thorium anomaly values associated with the crater floors and ejecta for each crater in the survey. From those values, we calculate the difference between ejecta and floor thorium abundance for each given crater (Fig. 2a). When the difference is positive, i.e. the ejecta anomaly is greater than the floor anomaly (Fig. 1 (right)), we interpret that the crater excavated into or through a subsurface KREEP layer. On the other hand, a negative difference, where the floor anomaly is greater than the ejecta anomaly (Fig. 1 (left)), implies that the impact excavated into the KREEP layer, but not through it.

Implications: For a given location, the diameters of craters are compared with the sign and magnitude of their "difference" anomalies. These measurements are then used to characterize the inferred relative thickness of the subsurface KREEP layer in that area. For example, small craters with strong positive differences imply a thin subsurface KREEP layer, while larger craters with large, negative differences suggest a thick KREEP layer. Comparing the local distribution of crater diameters and anomalies allows us to infer the relative thickness of underlying KREEP layers. For example, Fig. 2c shows a location with a thinner KREEP layer than Fig. 2b.

Future Work: We will develop a systematic metric that considers the distribution of corresponding crater diameters and thorium anomaly differences within a given region and generates a rudimentary prediction of subsurface KREEP layer thickness. We plan to apply this metric to characterize the subsurface KREEP thickness of the whole Moon.

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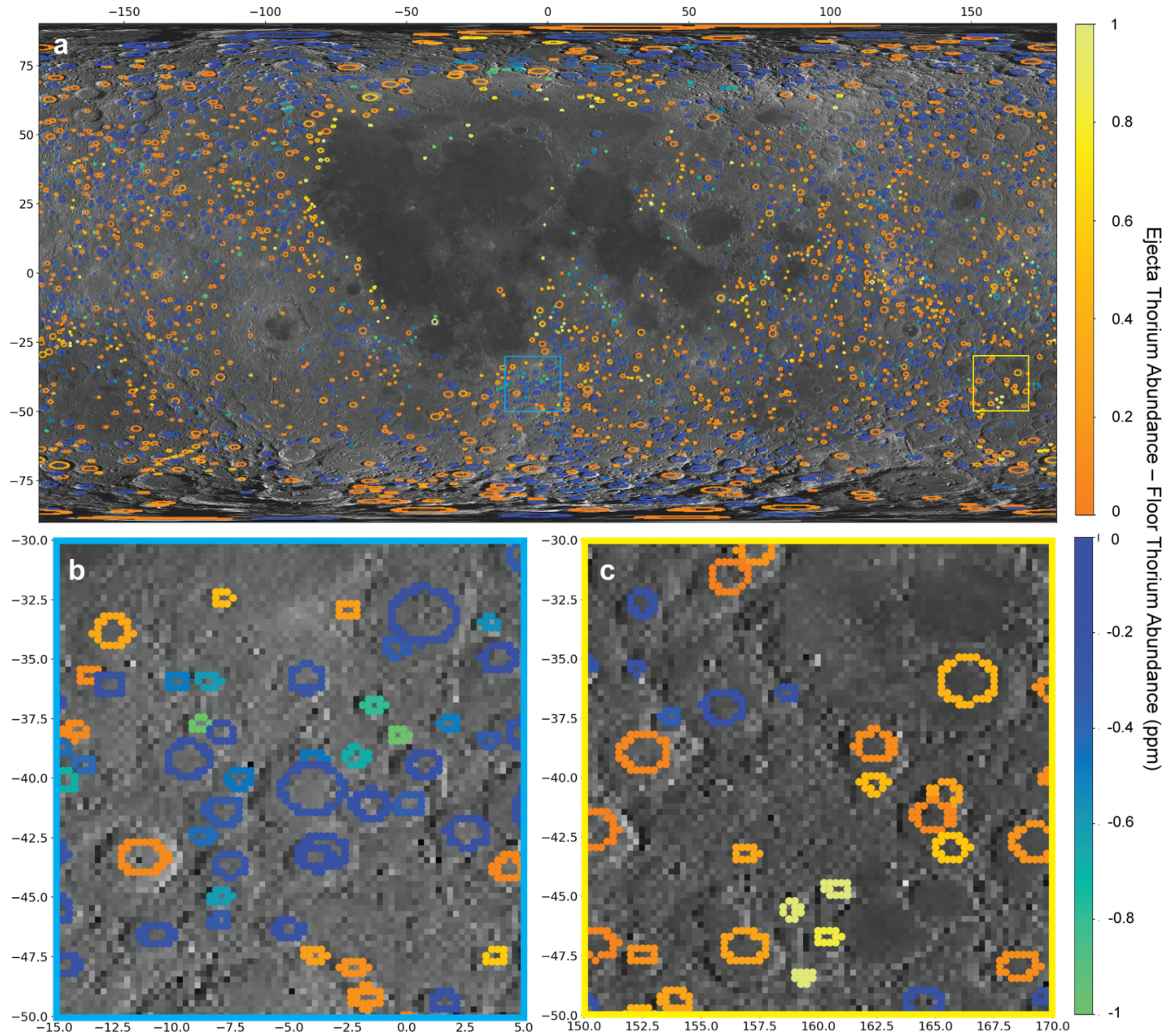

Figure 2: a) Measurements of thorium anomalies associated with craters between 30 – 140 km in diameter. b) A 20° x 20° area immediately below the Procellarum KREEP Terrane. A greater percentage of craters with negative anomalies, corresponding to a thicker underlying KREEP layer than in (c) are indicated. c) A 20° x 20° in the South Pole Aitken Terrane with more craters with positive anomalies, corresponding to a thinner underlying KREEP layer than in (b). (WAC Mosaic GSFC/ASU/MSSS)[10]