

AN INDIGENOUS ORIGIN FOR THE SOUTH POLE-AITKEN BASIN THORIUM ANOMALY.

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Introduction: The thorium anomaly at the northwest corner of the South Pole-Aitken (SPA) basin interior was first observed by the Apollo gamma ray spectrometers. Sections of the thorium anomaly were later found to be located near a mapped geologic unit of "grooves and mounds" and dissected crater walls [1]. Explanations for both the thorium anomaly and grooves include antipodal convergence of thorium-enriched Imbrium basin ejecta [1,2,3], local volcanic processes [4], and convergence of Serenitatis basin ejecta [5]. Based on analysis of a combination of datasets we propose that the thorium anomaly most likely reflects an indigenous process.

Data: The thorium data is updated from a preliminary version of data from [6], in a 0.5 degree/pixel map. We use UV-VIS Clementine images that are manipulated and displayed in an RGB color format for gross mineralogical information according to the method of [7]. Topography data is from the Clementine laser altimeter interpolated onto a 0.5 degree/pixel grid [8], and all geologic units are as mapped by [1].

Results: Anomaly characterization: The enhanced thorium region is separable into two northeast-southwest-trending oval-shaped regions in the northeast and southwest, which we refer to as North and South Lobe, respectively (Fig. 1). Thorium level contours ranging from 2.5-3.5 ppm in intervals of 0.5 ppm help illustrate this morphology, and will serve hereafter as a quantitative means of addressing the extent of the anomaly (Fig. 3). We note that the western edge of the two lobes is continuous with the western edge of the entire inner SPA thorium deposit (Fig. 1).

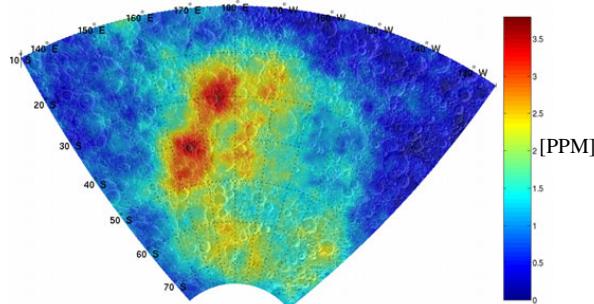


Fig. 1 Overview of the anomaly and SPA thorium deposit.

Correlation with mapped unit of grooves: The improved spatial resolution of our thorium data shows that correlation with the unit of grooves and mounds (unit Ig in [1]) is seen only in North Lobe (Fig. 2, 3a). The unit is hardly present in South Lobe except for several dissected crater walls (addressed in [5]). Additionally, to the northwest of North Lobe unit Ig is present over a

large area greater in size than the resolvable ~80 km diameter FWHM of the thorium dataset, yet thorium abundances here are less than ~1.5 ppm.

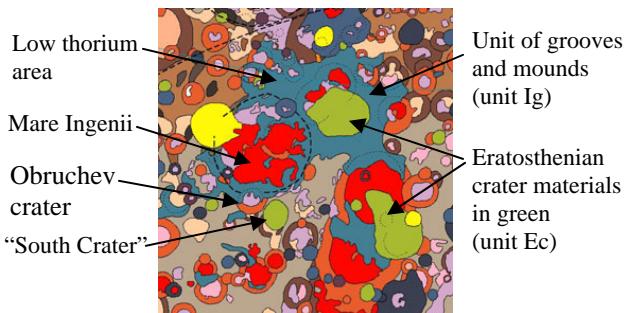


Fig. 2 Geologic map from [1].

Relations with Eratosthenian craters: The highest thorium in South Lobe is correlated with mapped crater materials of Eratosthenian age, herein named South Crater (40°S, 165°E, Figs. 2, 3b). Based on crater scaling laws we find that South Crater has a depth of excavation of 1.1 km [9]. This excavation depth is far greater than the median depth of expected regolith gardening [10]. Thus if ejecta from Imbrium is responsible for the thorium anomaly, the ejecta thickness is constrained to be least 1.1 km deep. Despite the fact that a purported ejecta blanket ~1.1 km thick fell in the vicinity of South Crater, there are no mapped Imbrian units bordering South Crater [1]. Dissected crater walls are not present in the pre-Nectarian crater underlying South Crater, or in the larger pre-Nectarian crater to the southeast (Fig. 2). In the crater Obruchev (38.9°S, 162.1°E) the northern walls bordering mare Ingenii show signs of dissection, but the walls closest to South Crater do not.

Topography: The western edge of the thorium anomaly is well aligned with topographic contours defining the entire inner part of the basin (Fig. 3b). Level contours between -1000 and -3000 m can be followed from approximately (-23°, 180°E) to (-47°, 158°E), over a distance of ~900 km. The northwest-trending orientation of the two lobes is most likely related to this topographic trend in the same direction. Such strong correlation and bounding by basin terrain would not be expected if material fell over the region, but is more consistent with a process related to the SPA basin structure.

Mare-thorium relations: The most visually prominent feature of the thorium anomaly is that it is well defined by the eastern border of mare Ingenii. We interpret this relationship to be due to thorium-poor mare cross-cutting an Ingenii basin floor of intermediate or elevated thorium. In a survey of all SPA mare volumes

and areas, we find that a large percentage of mare, 68% by volume, and 50% by area, is found within or closely bordering the thorium anomaly, based on values from [11]. We note that mare Ingenii has an approximate depth of ~1.6 km based on a variety of photographic techniques [11], placing an approximate upper limit on the thickness of Imbrium ejecta in this area of the Moon.

Multispectral images: We can compare the gross mineralogy of the anomaly to nearside geologic units that have been widely attributed to Imbrium basin ejecta, the Fra Mauro formation and the Apennine Mountains backslope region. Under the UV-VIS ratios of [7] the thorium anomaly appears mainly reddish with areas of green both inside and outside of mare regions, implying mafic rock types (Fig. 4a). The anomaly's lithologies are broadly similar to other regions in SPA. Under the same image stretch we see that the mineralogy of Fra Mauro and Apennine is distinctly different - much more anorthositic and/or weathered (Fig. 4b).

Discussion: We propose the anomaly is a province of slightly elevated thorium that was exposed at the surface by the SPA impact event. This scenario of origin would explain the correlation of thorium concentration with basin topography contours and the mafic lithologies characteristic of SPA's interior. An indigenous source does not invoke the contradictions arising from association with the mapped unit Ig, and explains the position and orientation of the lobes in relation to the entire SPA thorium region without requiring oblique nearside impacts [5]. South Crater could thus represent an excavation of indigenous material that had been covered by ejecta from distant basins (suggested in [6]).

Thorium and KREEP at depth could also provide the heating necessary to supply the large amount of mare flooding in the region, similar to the Procellarum KREEP terrain [12]. As in the Procellarum KREEP terrain, mare near the anomaly has a lower abundance of thorium than the surrounding non-volcanic regions (e.g. circum-Imbrium mountains). As for the mapped unit Ig, these complex features may be unique local disturbances related to early Imbrian volcanism [4], features associated with convergence of seismic energy [13], or a combination of both. A volcanic-linked mechanism is partially substantiated by the strong correlation with mass wasted crater walls around the entire rim of mare Ingenii, and lack of crater wall dissection near the thorium rich South Crater.

References: The authors are most grateful to David Lawrence and Rick Elphic of Los Alamos National Laboratory. [1] Stuart-Alexander, D.E. (1978) USGS Map I-1047. [2] Wilhelms, D. E. (1984) USGS Professional Paper 1348. [3] Haskin, L.A. (1997) JGR 103, 1679. [4] Hawke, B.R. and Spudis, P. D. (1980) in *Proc. Conf. Lunar Highlands Crust*, 467. [5] Wieczorek, M. and Zuber, M.T. (2001) JGR 106, 27825. [6] Lawrence, D. J. et al. (2003) JGR 108, 5102. [7] Pieters, C.M. et al. (2001) JGR 106, 28,001. [8] Smith, D.E. et al. (1997) JGR 102, 1591. [9] Stoffler, D. et al. (1975) JGR 80, 4062. [10] Quaide, W. and Oberbeck, V. R. (1975) The Moon 13, 27. [11] Yingst, R. A., and Head, J.W. (1997) JGR 105, 10,909. [12] Joliff, B.L. et al. (2000) JGR 105, 4197. [13] Schultz, P.H. and Gault, D.E. (1975) Moon 12, 159.

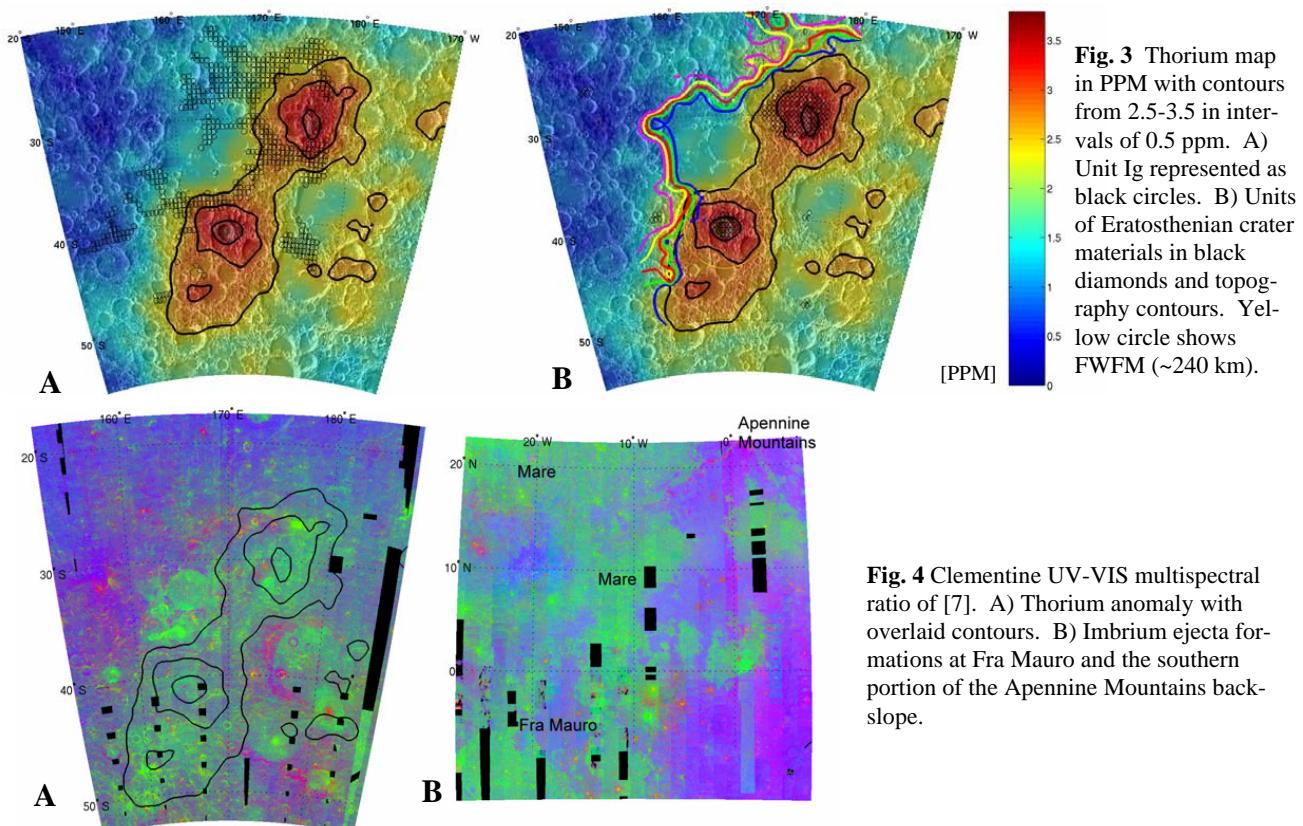


Fig. 4 Clementine UV-VIS multispectral ratio of [7]. A) Thorium anomaly with overlaid contours. B) Imbrium ejecta formations at Fra Mauro and the southern portion of the Apennine Mountains backslope.