ELLIPSES OF THE SOUTH POLE-AITKEN BASIN: IMPLICATIONS FOR BASIN FORMATION.

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Introduction: The South Pole-Aitken (SPA) basin is believed to have stripped away a portion of the Moon's upper crust, possibly exposing mantle material [1]. The SPA basin is characterized by a topographic depression, iron enriched mafic material, and higher thorium abundances than the surrounding Feldspathic Highland Terrane [2]. The shape of SPA's topography, iron, and thorium features can give insight into how the basin was formed, and how the thorium was emplaced. Fitting ellipses to these features provides a quantitative method for characterizing their shapes.

Data sources: The topography map of the Moon used is the 0.25 degree/pixel resolution map from the Clementine laser altimeter [3]. The thorium and iron abundance maps are 0.5 degree/pixel maps produced by the Lunar Prospector gamma-ray spectrometer [4,5].

Ellipse fitting methods: Each map was plotted using a stereographic (conformal) projection with the origin at the purported center (56°S, 180°E). Ellipse data points for each map were collected manually by displaying the map on a computer, and moving an on-screen marker along portions of the map that visibly showed the steepest gradient. For iron and thorium, the gradient was required to be negative moving out of SPA, and for topography it had to be positive. A key assumption was that a roughly elliptical pattern was behind the features, which is substantiated by the results in Figs. 1-3. With this assumption, the tracing process was part art and part science, requiring that a few jagged areas be smoothed over with a curved line that appeared to best represent the overall local structure. For the topographic map this was more difficult, since post-SPA impacts make the gradient lines more variable. Topographic data were collected around the deepest parts of SPA, and no topographic data were collected below 75°S since distortion becomes significant below this latitude.

120 data points were collected for each sampling trial, and 25 ellipses were fit to each of the three maps. The calculated parameters of the 25 best-fit ellipses, including center location and tilt angle, were then averaged to yield the final estimates.

Sources of error: The most significant source of error in these calculations is the personal bias towards what data points best represent the local structure. Since we are concerned here with changes in gradient, any large-scale dataset errors in absolute abundance or topography should not affect the results.

Results: The average best-fit ellipses are shown in Figs. 1-3, and their parameters with standard deviations in parentheses are shown in Table 1. Fig. 4 shows the three ellipses plotted over each other in transformed Cartesian coordinates, with a linear regression line (r^2 = 0.84) fit to the three ellipse centers. The locations of the ellipse centers roughly follow a line running SE-NW with a slope of –4.4, or an angle of –12.8° from north. All ellipses are also negatively tilted from north, with an average tilt of –8.5°.

Table 1. Average parameters for all ellipses (s.d.).

Parameter	Thorium	Iron	Topography
Center lat. °South	-48.3 (.4)	-52.8 (.2)	-54.2 (.4)
Center lon. °West	172.1 (.6)	170.5 (.6)	168.7 (.8)
Tilt angle°	-10.2 (1.6)	-7.9 (1.9)	-7.5 (2.1)
Eccentricity	0.70 (.02)	0.75 (.01)	0.69 (.02)
Mean tilt of all ellipses	-8.5°		
Angle connecting centers	-12.8°		

Discussion: Most strikingly, all ellipses are tilted west of north between 7.5° and 10.2°, and they are also laid along a line with western tilt of 12.8°, Fig. 4. A possible mechanism to explain this unusually ordered occurrence is an oblique impactor arriving from the south at an angle roughly 5-15° west of north. Because of the obliquity of the impact, excavation in the northwest could have accessed crust deeper than in the southeast, as the impactor plowed northwestward into the Moon. Ejecta and subsurface exposures from the lower crust, which are higher in thorium [6,7], would thus be shifted northwestward. The thorium ellipse would be the most northwestward since it came from the deepest portions of crust. This mechanism of emplacement would also explain the higher amount of thorium in the northwestern portion of the thorium ellipse, Fig. 2 [7]. The anomalously positive topography-thorium relation observed in the northwest [7] could then be a result of asymmetrical northern uplift of deeper materials. Note that the impactor's obliquity (suggested elsewhere, [8,2]) is also substantiated by the non-zero eccentricities of all ellipses, Table 1.

The iron ellipse center may be slightly northwest from the topography center for the same reason, i.e. progressively more iron-rich material was encountered at deeper, more northwestward excavation depths. Indeed, as in the case of thorium, the iron ellipse also has higher amounts of iron north of the ellipse centerline (not considering mare). Furthermore, the thorium ellipse is smaller than the iron ellipse, suggesting that the thorium was deeper and thereby not excavated as fully as iron was in the mid and upper crust.

The above process also implies that the SPA thorium features are indigenous SPA floor materials exposed by the impact event, and not derived from ejecta of other basins such as Imbrium [9]. The high northwestern thorium components are well contained by the ellipse, and even appear to curve around the basin with the ellipse. But if the oblique impact caused uplift and excavation of thorium in the northwest, why isn't it present in the northeast as well? If one looks to where the thorium highs in the northwest would appear if reflected to the east across the thorium tilt axis, one finds an analogous but smaller thorium enrichment at approximately (27°S, 170°W), but no analogous high for the lower component, expected at approximately (35°S, 158°W), Fig. 2. However, the mirror image of the more southern component lies within the Apollo basin centered at (36°S, 152°W), and Apollo basin formation and mare infilling may have eliminated any such thorium signature ([7] explores Apollo's thorium feature). A reflected version of the northwestern thorium may have once been present, but may now be undetectable.

The center of the topography ellipse is close to exposures of nonmare gabbroic rock described in [1], and could represent a location where central uplift took place, Fig. 1. Additionally, two exposures of high-Ca pyroxene from [1] appear in the northwest, and lie almost exactly on the best-fit topography ellipse, perhaps indicating where material was uplifted in a ring. These northwestern exposures are also nearby the high thorium abundances, offering support for the asymmetrical excavation and uplift of northern parts of the basin.

Conclusions: The thorium, iron, and lower-topography best-fit ellipses suggest that the SPA impactor was oblique, and from the south at an angle of 5-15° west of north. Asymmetrical excavation and uplift may be responsible for northwest-shifted iron and thorium ellipse centers, as well as greater northern abundances of both elements in their own ellipses. The thorium in SPA was likely emplaced by the SPA event itself, based on ellipse parameters that are similar to the iron and topographic ellipses. Exposures of potential lower crustal rocks help reinforce the proposed formation mechanism. All of these conclusions are tentative.

Acknowledgements: The author is most grateful to Maria Zuber for the helpful suggestions, and to David Lawrence for providing the most recent small area thorium dataset and answering my questions.

References: [1] Pieters, C. M. et al. (2001) *JGR, 106*, 28,001-28,022. [2] Jolliff B. L. et al. (2000) *JGR, 105*, 4,197-4,216. [3] Smith, D.E. et al (1997) *JGR, 102*, 1591-1611. [4] Lawrence, D. J. et al. (2003) *JGR, 108*, 5201. [5] Lawrence, D. J. et al (2002) *JGR, 107*, 5130. [6] Ryder, G. and Spudis P. D. (1977) *Proc. Lunar Sci. 8th Conf.*, 655. [7] Lawrence, D. J. et al (2000) *JGR, 105*, 20,307-20,331. [8] Shultz, P. H. (1997) LPS XXVIII, Abstract #1787. [9] Haskin, L. A. (1998) *JGR, 103*, 1679.

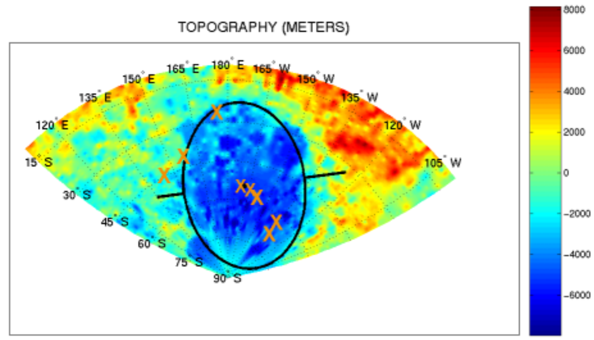

Figure 1. Best-fit topography ellipse with orange Xs marking nonmare gabbroic points from [1].

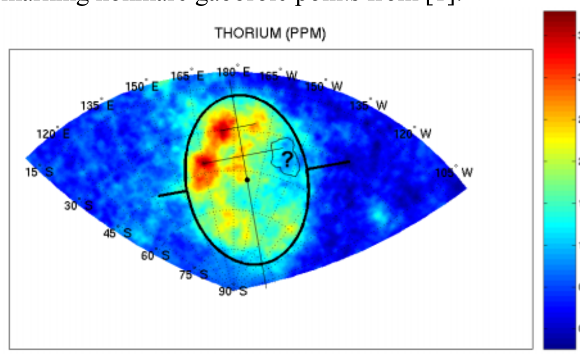

Figure 2. Best-fit thorium ellipse with angle of tilt, and a mirror image outline of the northwestern thorium highs, possibly removed by Apollo and its mare.

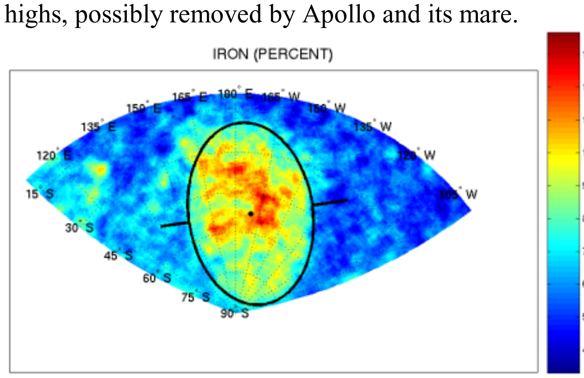

Figure 3. Best-fit iron ellipse.

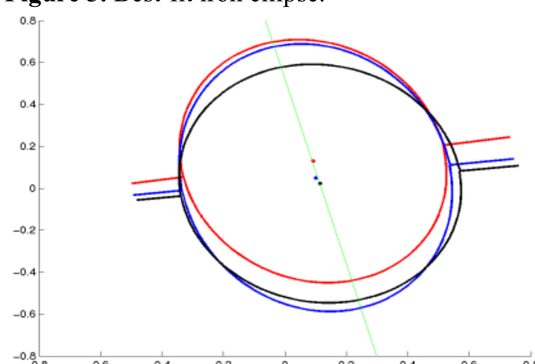

Figure 4. Best-fit ellipses: thorium (red), iron (blue), and topography (black), with a green line indicating the best-fit for their centers. Ellipses tilt in nearly the same direction as the best-fit line.