THIN CRUST IN THE SOUTH POLE-AITKEN BASIN AND SAMPLES FROM THE MANTLE? IMPLICATIONS FOR SOUTH POLE-AITKEN BASIN SAMPLING IN LIGHT OF RECENT GRAIL RESULTS.

N. E. Petro[1] and B. L. Jolliff[2], [1]NASA Goddard Space Flight Center, Planetary Geodynamics Laboratory, [2]Washington University. (Noah.E.Petro@nasa.gov)

Introduction: With each new dataset from lunar missions, new insights into the uniqueness of the South Pole-Aitken Basin (SPA) are gained. With each new insight, additional compelling reasons for sampling the interior of the basin are gained. In addition to learning the age of the basin [1, 2], well selected sample sites from inside SPA will also reveal unique compositions [3-5], the chronology of subsequent craters in the basin [6, 7], and now GRAIL data reveals areas of thin crust beneath two basins in SPA where mantle would have been excavated [8]. Here we assess the implications of GRAIL crustal thickness data on what would be sampled within SPA by a future robotic sample return mission.

GRAIL Crustal Thickness Results for South Pole-Aitken Basin: Recent results from the GRAIL mission indicate that two of the five regions with estimated crustal thickness values less than 5 km are found within the SPA [8]. The two basins, Poincaré and Apollo (diameters of 325 and 480 km respectively [9]), have crustal thicknesses less than 5 km and likely excavated into the mantle. Excluding these two regions, the crust is estimated to be less than ~20 km thick [8] across much of SPA's interior (Figure 1).
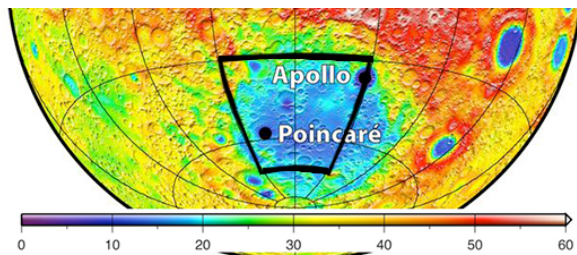

Figure 1. Lunar crustal thickness (in km) derived from GRAIL gravity and Lunar Reconnaissance Orbiter topography [8]. Subset of Figure 3 from Wieczorek et al. [8] in Lambert azimuthal equal-area projection covering SPA. Outline covers area illustrated in Figure 2.

Materials Excavated by Poincaré and Apollo Basins: Based on the size of both basins and using established crater scaling equations [10], we can estimate the depth of excavation and melting, and therefore how much mantle material may have been ejected by these craters. The depth of melting for large craters exceeds that of the depth of excavation [10]

suggesting that the deepest material either Apollo or Poincaré would excavate, as ejecta, would be as impact melt. Based on the sizes of the basins, and derived transient cavity sizes [11], we estimate a number of parameters that reveal the depths of origin for their ejected and melted materials.

Based on crater scaling relationships [10] we predict that both Apollo and Poincaré would have excavated into the mantle, and their impact generated melts would have penetrated deep into the mantle (Table 1). If we assume that the crust that both basins impacted into was ~20 km thick (Figure 1), their melts would be derived from depths from ~40-80 km *below* the crust. In addition to the melted component, ejected material would be derived from the thin crust as well as some portion, albeit small, of the mantle. Since both basins are largely melting mantle material, we would like to understand how much impact melt is ejected by these basins. Additional scaling relationships [6] suggest that while a ~40% of the melted component may be ejected by each basin, the percentage of the ejecta deposit of each basin contains ~5% melt.

Table 1. Derived excavation parameters for the Apollo and Poincaré Basins. DoM=Depth of Melting [10], DoE=Depth of Excavation [10], Eff%=Efficiency (fraction of melt ejected from a basin) [6], F_{Melt}%=Fraction of melt in ejecta deposit.

Basin	DoM	DoE	Eff%	F_{Melt}%
Apollo	98km	35km	42	6
Poincaré	63km	25km	44	4.5

In light of the GRAIL crustal thickness data, these derived parameters tell us two things. One, melt components of the ejecta from these basins would largely be derived from the mantle. Two, while the melt component is a small fraction of the total ejecta from the basins, the purely excavated portions of the ejecta deposits are tapping lower crust and upper-most portions of the mantle.

However, no exposures of olivine, an expected component of the lunar mantle, are observed in or directly around Apollo and Poincaré [12-14]. It has been observed, however, that the interior of Apollo is quite distinct compositionally relative to its surroundings [14]. It is possible that any mantle component is simply well-mixed within the ejecta

deposit from each basin, precluding detection by remote sensing instruments. It is unlikely however, that any material within SPA (such as ejecta from these basins) is significantly diluted by material from outside the basin (such as ejecta from the large nearside basins) [15].

Distribution of Ejecta from Poincaré and Apollo Basins: If the ejecta from both Poincaré and Apollo do indeed contain material from the lower crust and mantle, selecting a sampling site that may collect ejecta from both craters may be desirable. Using the same approach described in *Petro and Pieters* [15], we map the distribution of ejecta outside the basins in order to identify areas that may be enriched in their ejecta (Figure 2). While any ejecta from either basin would, after several billion years of regolith gardening, be well mixed within the regolith, such material is expected to still be present at the surface [11].
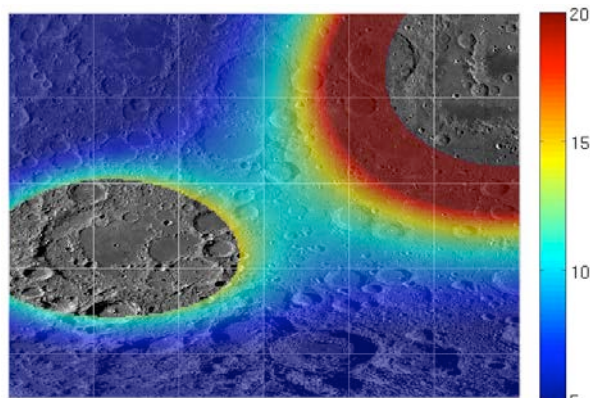

Figure 2. Estimated ejecta thickness (in meters) distributions around Apollo (northeast) and Poincaré (west) basins. Ejecta deposits within 1.5 crater radii of each basin are masked. Base image is 100mpp WAC mosaic, image extent is -30º to -75º S, 150º to 210º E. Ejecta scale is stretched to illustrate enhanced thicknesses between both basins, maximum thickness (outside Apollo) is ~50 m. The *Housen et al.* [16] ejecta scaling relationship was used to determine the thickness of ejecta.

Role of Smaller Craters in Excavating Mantle Material: While the above example focused solely on the role of two large basins in excavating mantle materials, smaller craters can also melt into the mantle. Following the previously described crater scaling relationships [10], melt zones from craters larger than ~100 km in diameter are expected to be deeper than 20 km, while craters larger than ~260 km will excavate deeper than 20 km.

There are a number of craters within SPA that are larger than 100 km in diameter (e.g., Antoniadi,

Oppenheimer, Von Kármán, Leibnitz) that would excavate melted material from the mantle, and far fewer larger than 260 km in diameter. Therefore we expect that any mantle material within the regolith of the SPA interior would largely be in the form of impact melt from craters larger than 100 km or from the original SPA impact melt itself [11, 17].

Conclusions: Given the recent findings from the GRAIL mission that the crust is generally less than 20 km thick across much of SPA, and less than 5 km thick beneath the Apollo and Poincaré basins, it is likely that those basins and several craters larger than 100 km in diameter melted mantle material. Such mantle material would then be incorporated into their ejecta deposits and distributed across the basin floor. However, this does not imply that a random sample site within SPA would necessarily sample such material. Taking into consideration such factors as the presence of mare volcanism and ancient volcanic deposits [18, 19] is an important consideration, and future mapping of such deposits is necessary. However, given our current understanding of the interior of SPA, we are confident that any future sample return mission [1] will not only determine the age of SPA, but also sample the material from the lower crust and mantle.

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