SCIENCE RATIONALE FOR SOUTH POLE-AITKEN BASIN LOCATIONS FOR SAMPLE RETURN.

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Introduction: Sample return from the South Pole-Aitken (SPA) Basin was identified as a high priority science goal for a future New Frontiers mission in the 2011 Planetary Science Decadal Survey [1]. The high priority is because appropriately collected rock samples from SPA could be used to determine the age of the SPA basin and the chronology of later, large impacts within the basin. The early, pre-4.0 Ga part of the lunar impact chronology is poorly known, and determining the SPA large-impact chronology would provide an anchor for the timing of impact-basin formation during the first 500 million years of lunar history. Determining this chronology and the age of the SPA event has implications for testing the Cataclysm hypothesis and for elucidating early Solar System orbital dynamics [2], and possibly for the timing and origin of major magmatic events on the Moon [3-6]. Benchmarking the age of SPA has the potential to resolve the uncertainties of current models of early Solar System evolution.

The SPA impact event melted and reset the ages of rocks over a huge area of the Moon and we anticipate that rock materials from the interior of the SPA basin contain geochronologic evidence of the reset. In other words, rocks containing impact melt or impact-melt breccia will reflect a range of ages spanning the interval of heavy bombardment with an abrupt cutoff and possibly a spike at the time of SPA basin formation. Moreover, the SPA basin is far from Imbrium, which may have dominated the production of impact melt that was sampled by Apollo and whose ages have been determined [7].

SPA provides many potential sample sites: The SPA basin is enormous, spanning over 2000 km east to west and ~2400 km north to south, forming an elliptical shape [8]. It is centered approximately 54 °S Lat and 191 °E Lon., in the vicinity of Bose Crater, with its long axis inclined slightly NW to SE (Fig. 1). The interior of the basin is marked by a prominent geochemical anomaly in FeO and Th; however, these geochemical signatures are smaller than the main topographic rim and offset to the north (Figs. 2, 3), extending approximately from 150-230 °E Lon. and 15-85 °S Lat. Thorium, determined by the Lunar Prospector gamma-ray spectrometer (LP-GRS) within SPA basin [9], exhibits a "background" value of ~2-3.5 ppm, excluding the highest-value anomalies located in the northwestern quadrant. FeO exhibits a range of values generally ~8-13 wt.% (LP-GRS) [9] or ~10-15 wt.%, excluding areas of mare basalt (Clementine UV-VIS data [10]). These "background" geochemical signatures are associated with SPA basin and not some other, more localized geologic formation or source.

Mixing of large impact crater and basin ejecta by ballistic sedimentation provides a first-order explanation for the shape and extent of the background geochemical signature of SPA basin. Mixing "in" of materials from large impacts outside the basin would tend to dilute the interior deposits whereas mixing and spreading of materials outward has resulted from large impacts into the interior of the basin. *The result of the period of heavy (post-SPA) bombardment was to produce a mixed deposit all over the basin, but one that retains a stronger geochemical signature in the interior, suggesting that the interior contains a higher proportion of original SPA-formed substrate.* The original substrate is likely to have been dominated by an enormous and thick impact-melt "sea" that may have undergone magmatic differentiation [11-13], but importantly, the age of this material was established or "reset" at that time. Subsequent smaller basin and large crater impacts would also reset ages locally, but the main effect would be to simply redistribute SPA substrate materials, and ejected material is expected to be largely brecciated and likely to contain clasts of original SPA substrate. Multiple chronometers and petrologic interpretations have the capability to decipher these events

Modeling of the makeup of SPA interior deposits based largely on the process of ballistic sedimentation and mixing by Haskin et al. [14] and Petro and Pieters [15] indicates that even after many subsequent large impacts, the deposits in the interior of SPA basin should remain dominated by SPA substrate materials. Thus the greatest likelihood of sampling this material is within the SPA basin, and within the present-day observable geochemical signature. Indeed craters that formed within SPA would tend to not contribute remelted material, but would instead reintroduce SPA melt material from depth or basement material. Numerous large impact craters have orthopyroxene-rich central peaks, consistent with SPA impact-melt-sheet differentiates [16], indicating that these materials have continued to be excavated and mixed into surface deposits by younger large impacts such as Bose, Bhabha, Stoney, Bellingshausen, Lemaître, Cabannes, Baldet, Lyman, Finsen, Abbe, and others. Key large impact and basin deposits include those from Poincaré, Von Kármán, Leibnitz, Oppenheimer, Antoniadi, Zeeman, and many others that impacted within the SPA geochemical signature. Materials from other basin impacts are expected to be present, e.g., Orientale on the eastern SPA side, Schrödinger in the southwest, and even Imbrium, whose antipode is in northern SPA, but these materials should be significantly less abundant than SPA substrate and evident by their younger ages. Other, smaller basins would not dominate surfaces near them in the same way as Imbrium did the near side (smaller transient cavity sizes, smaller volumes of impact melt generation, and less ejecta produced). Short of sampling within the continuous ejecta deposits of a basin within SPA (*e.g.*, Apollo, Ingenii) the same kind of single-basin dominance that occurs on the nearside with Imbrium is not predicted for regions within SPA.

At present there are no samples of impact melt collected from within a basin, the impact melts sampled by Apollo are largely from basin rims and in the form of ejected materials. The conundrum of tying samples to specific basins that occurs with many of the impact-melt breccias in the Apollo collection is not analogous to what we anticipate from the interior of SPA

Conclusions: The interior of the SPA basin covers many thousand square km. Abundant potential landing sites exist where SPA impact-melt materials, including the original substrate, ejecta material from other nearby large craters and basins, and SPA interior basalts can be sampled among the rock fragments present in the mixed regolith deposits. Such samples will significantly change our understanding of the early evolution of the lunar crust, the bombardment history of the inner Solar System, and the volcanic and magmatic history of the Moon.

References: [1] NRC (2011) *Vision and Voyages for Planetary Science in the Decade 2013-2022*, Nat'l Academies Press. [2] Marchi et al. (2012) *Earth & Planet. Sci. Lett. 325-326*, 27-38. [3] Grange et al. (2013) *Lunar Planet. Sci.* 44, #1884. [4] Borg et al. (2015) *Lunar Planet. Sci.* 46, #1563. [5] Schultz and Crawford (2015) *Lunar Planet. Sci.* 46, #2416. [6] Kring et al. (2015) *Early SS Impact Bombardment III*, #3009. [7] Haskin et al. (2003) *Meteorit. Planet. Sci. 38*, 13-33. [8] Garrick-Bethel and Zuber (2009) *Icarus 204*, 399-408, 2009. [9] Lawrence D., et al. (2003) *Lunar Planet. Sci.* 34, #1679. [10] Lucey et al. (1998) *J. Geophys. Res.* 103, 3701-3708. [11] Potter et al. (2012) *Icarus*, 220, 730-743. [12] Vaughan and Head (2013) *PSS* 91, 101-106. [13] Hurwitz and Kring (2014) *J. Geophys. Res.* 119, 1110-1133. [14] Haskin et al. (2003) *Lunar Planet. Sci. 34*, #1434. [15] Petro and Pieters (2004) *J. Geophys. Res.* 109, E06004. [16] Moriarty et al. (2013) *J. Geophys. Res.* 118, 2310-2322.

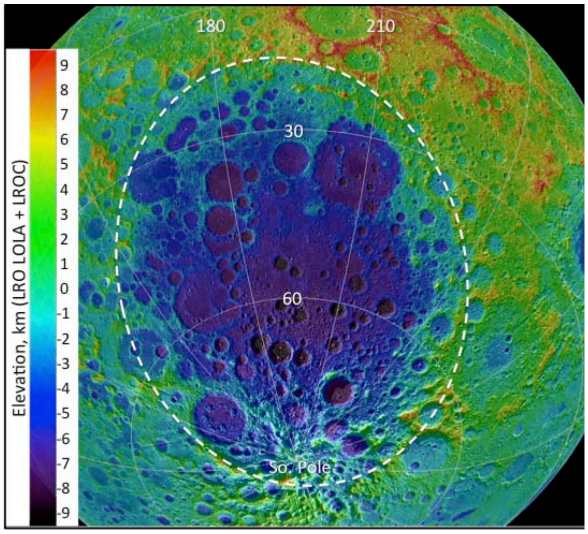

Figure 1. Topography of South Pole-Aitken Basin from LRO LOLA & LROC WAC (NASA/GSFC/MIT/ASU)

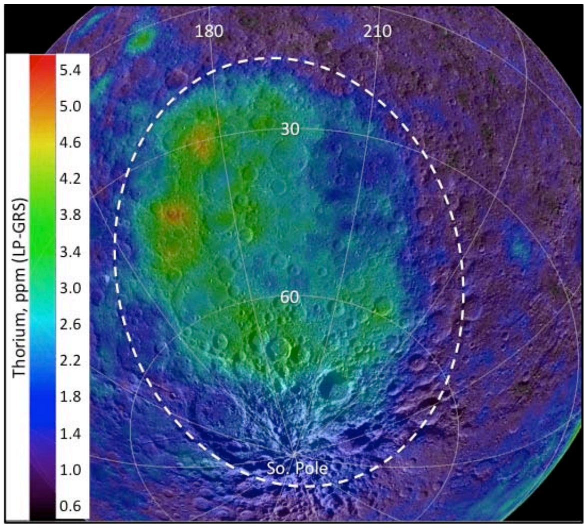

Figure 2. Thorium distribution in SPA Basin (LP-GRS).

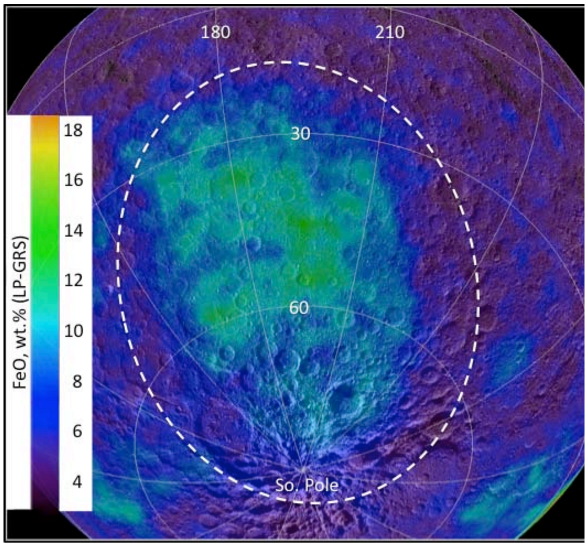

Figure 3. FeO distribution in SPA Basin (LP-GRS).