

# SAMPLING THE SOUTH POLE-AITKEN BASIN: OUTSTANDING ISSUES AND OPPORTUNITY FOR INTERNATIONAL LUNAR EXPLORATION

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The ~2500 km diameter South Pole-Aitken Basin (SPA) which dominates the lunar farside is widely recognized as the largest and oldest impact basin on the Moon, perhaps in the entire Solar System. As such, SPA presents a focal point for a wide range of fundamental issues in planetary science and exploration [1, 2]. Highlighted below are major outstanding science questions derived from what is currently known about SPA. Implementation strategies for detailed exploration of Earth's nearest neighbor by the international community are underway, and we recommend a focus that leads to return of a diverse suite of samples from the SPA farside basin for extended analyses. While much groundwork remains to be accomplished, fundamental questions are answered with documented samples returned to Earth-based laboratories.

## Outstanding Science Questions at SPA:

*The SPA Event:* 1. When did the SPA impact occur during lunar evolution, specifically with respect to magma ocean solidification, residual KREEP layer formation and predicted mantle overturn? 2. What is the absolute age of the SPA impact and implications for the lunar and planetary impact flux record? 3. What was the nature of the impactor that produced the SPA basin? 4. If SPA was an oblique impact event as the current patterns imply, to what depth did it excavate and sample, and where is the original anorthositic crustal material? 5. Did SPA excavate material from the lunar mantle, and if so, where is it exposed within SPA? 6. What is the nature and volume of impact melt deposits associated with the SPA event? 7. Did the giant SPA event cause mantle geotherm uplift and short-term pressure-release melting?

*The SPA Effects:* 1. What were the effects of the SPA impact on the lunar interior and did it cause large-scale nearside-farside reorganization of the mantle and residual crustal layers? 2. Is the early SPA basin event directly related to formation of the Procellarum-KREEP Terrane? 3. How did the SPA impact affect subsequent nearside-farside history?

*The SPA Context:* 1. Even though central SPA retains the lowest elevations found on the Moon, what accounts for the general lack of topographically distinctive ring structures associated with the basin? 2. Since SPA is old, why is the topography not more viscously relaxed like smaller nearside basins (Tranquillitatis, Fecunditatis)?

*Post-SPA Event History:* 1. How has the interior of SPA retained its distinctive compositional signature after 4 Gy of bombardment history? 2. What are the implications of the elevated thorium values observed in the SPA interior and in specific post-SPA craters? 3. What do post-SPA basins (Schrodinger, Apollo, Ingenii) reveal about the lunar farside composition and thermal structure? 4. Why is there a distinct paucity of lunar mare basal

deposits within SPA, compared to nearside younger basins? 5. Can the distribution, thickness and age of cryptomeria within SPA be constrained? 6. What is the distribution and character of later Orientale basin ejecta deposits within SPA and does this complicate knowledge of SPA interior basin deposits? 7. What is the role of post-SPA impact events within SPA in providing information on the structure of the lunar deep interior?

## International Lunar Exploration Strategy:

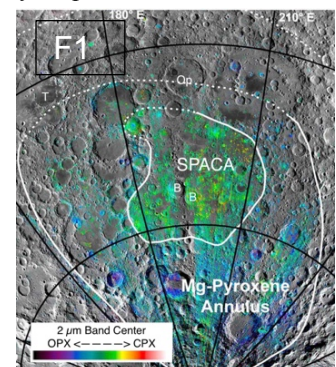
Serious lunar exploration is in formative years of a broadly based international endeavor that has evolved over the last several decades and is poised to move forward as modern capabilities continue to improve. Several individual nations, as well as coordinated efforts among several countries, are now highly capable of leading lunar exploration efforts. Although much current emphasis has naturally focused on the unique environment of the lunar poles [3], we recommend detailed *exploration and sample return across the enormous South Pole-Aitken basin. Such coordinated activity will provide a major step forward in understanding conditions and processes affecting the early evolution of terrestrial bodies.*

*Essential Elements:* **A.** Coordinated stable infrastructure is essential. This includes regular access to the farside as well as robust data and communication links. **B.** Continued supporting exploration data from modern orbital sensors. Instrument capabilities regularly improve and expand our understanding of the spatial extent of surface materials. **C.** Landing sites should target sampling *diverse* surface units. SPA is huge, but provides an exquisite window into processes affecting the early evolution of the Moon and terrestrial planets.

## SPA Sample Sites (and rationale):

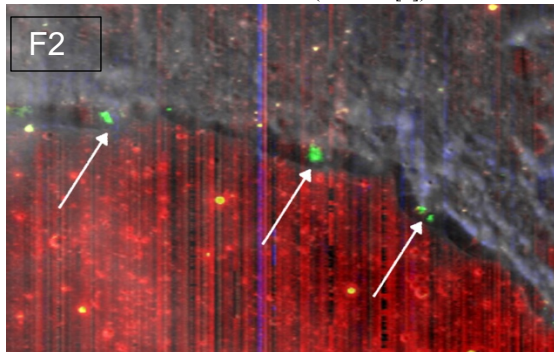
Provided below are example SPA terrains recommended for study and sample return based on their distinctive composition and setting. They are selected to represent a diversity of sites that together will provide a foundation for constraining the early evolution of this small but representative terrestrial planetary body.

➡ *SPA Mg-pyroxene feldspathic breccia terrain* (farside bulk crust components). These are abundant throughout the interior of SPA [4, 5], except for the centermost part of the basin (see MM and SPACA below). These Mg-pyroxene breccias are thought to represent the principal crust/mantle rock type excavated by the impact.



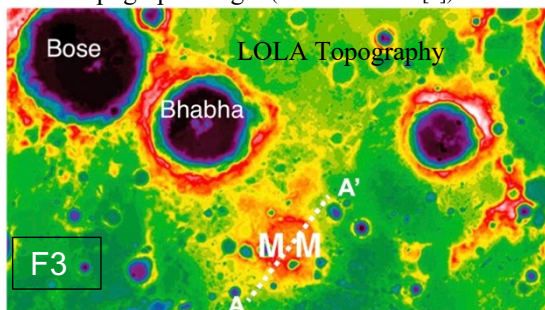
F1: Op= Openheimer; T= Thomson; B & B = Bose & Bhabha (see MM and SPACA below). (F1 derived from [5])

➡ *Mg-Spinel anorthosite* (exposed unsampled lower crust component). These materials [6] are found in SPA only along the rim of the 117 km Thompson Crater that post-dates the Ingenii Basin which occurs along a SPA basin ring (see T in F1 for location). These three sequential major impacts (SPA, Ingenii, Thomson) have exposed unusual but yet unsampled material from the lunar interior. Prominent Mg-spinel outcrops are highlighted in green in F2 along the northern wall of Thomson; later mare basalts are shown in red. (F2 from [6])

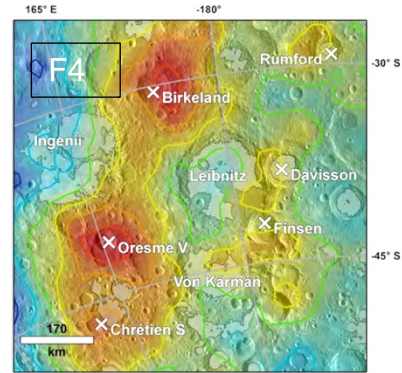


➡ *SPA impact melt* (necessary to date this giant earliest recognized basin forming event). SPA impact melt is expected to be abundant and pervasive across the basin interior, but it has been reworked for over ~4 Ga and may require an iterative approach to identify from samples in Earth-based laboratories.

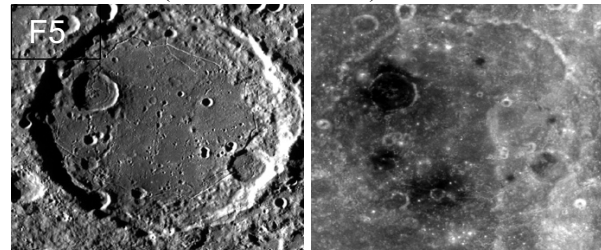
➡ *Mafic Mound (MM, Mons Marguerite) and SPACA* (early response to the SPA event?). The distinct CPX-bearing composition that characterizes such SPACA material is found across the central and deepest part of SPA basin [4, 5, 7] (extent shown in F1). It post-dates the impact, but pre-dates later basalts. In F3 MM is a notable SPACA topographic high. (F3 derived from [7])



➡ *Thorium 'Hotspots' within NW SPA interior* (assessment essential for direct comparison with materials associated with the pervasive near-side KREEP terrain). The best SPA Th exposures are associated with two Eratosthenian to Upper Imbrium craters: Birkenland (82 km) and Oresme V (51 km) [e.g. 8].



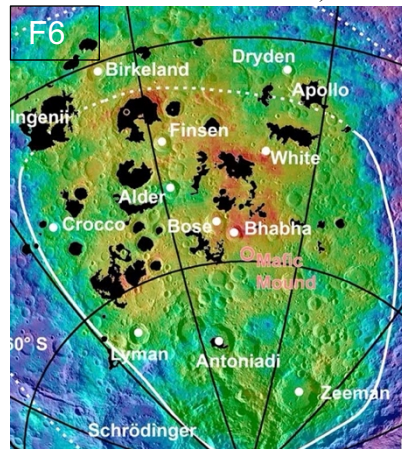
➡ *SPA farside pyroclastic deposits* (volatile-driven). Abundant localized pyroclastic deposits occur within **Oppenheimer** [9], a ~200 km floor-fractured crater in northern SPA (see F1 for location).



WAC Deep shadows.

WAC No Shadows

➡ *SPA farside basalts* [e.g. 10, 11, 12, 13] (reflect the products of farside mantle and thermal evolution). Compared to the near-side, SPA mare basalts (shown in black) are not as voluminous as those that fill basins across the nearside. Background color scale depicts FeO abundance as measured by Lunar Prospector. (F6 derived from [5])



**References:** 1] NRC 2007, Scientific Concept for Exploration of the Moon; NRC 2011, Vision & Voyages, Planet. Sci. Decadal. 2] Jolliff B et al, 2010 LPSC41, #2450. 3] Weber RC et al, 2021 LPSC52 #1261;---- NASA/SP-20205009602 4] Ohtake et al, 2014, *GRL* 41 5] Moriarty & Pieters, 2018, *JGRP* 123. 6] Pieters et al. 2014, *Am Min* 99. 7] Moriarty & Pieters, 2015, *GRL* 42. 8] Moriarty DP et al 2021, *JGRP* 121 9] Bennett KA et al. 2016, *Icarus* 273 10] Yingst and Head 1999, *JGR* 104. 11] Haruyama, J et al. 2009, *Science* 323. 12] Huang J et al. 2020, *Geology* 48. 13] Yuan Y. et al. 2021, *EPSC* 569.