SCIENCE OPTIONS FOR SAMPLING SOUTH POLE-AITKEN BASIN

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Introduction: Sample return from the huge South Pole-Aitken basin is one of the highest priority science missions recommend by the NRC/NAS for solar system exploration by NASA's New Frontiers program, second only to Kuiper Belt/Pluto exploration [1]. The envisioned SPA mission is to address several key science issues concerning early evolution of solid bodies in the solar system. Since the Moon is a differentiated planetary body that shares the 1 AU environment with Earth, and SPA is among the largest basins in the solar system, mission goals identified by the NRC report include:

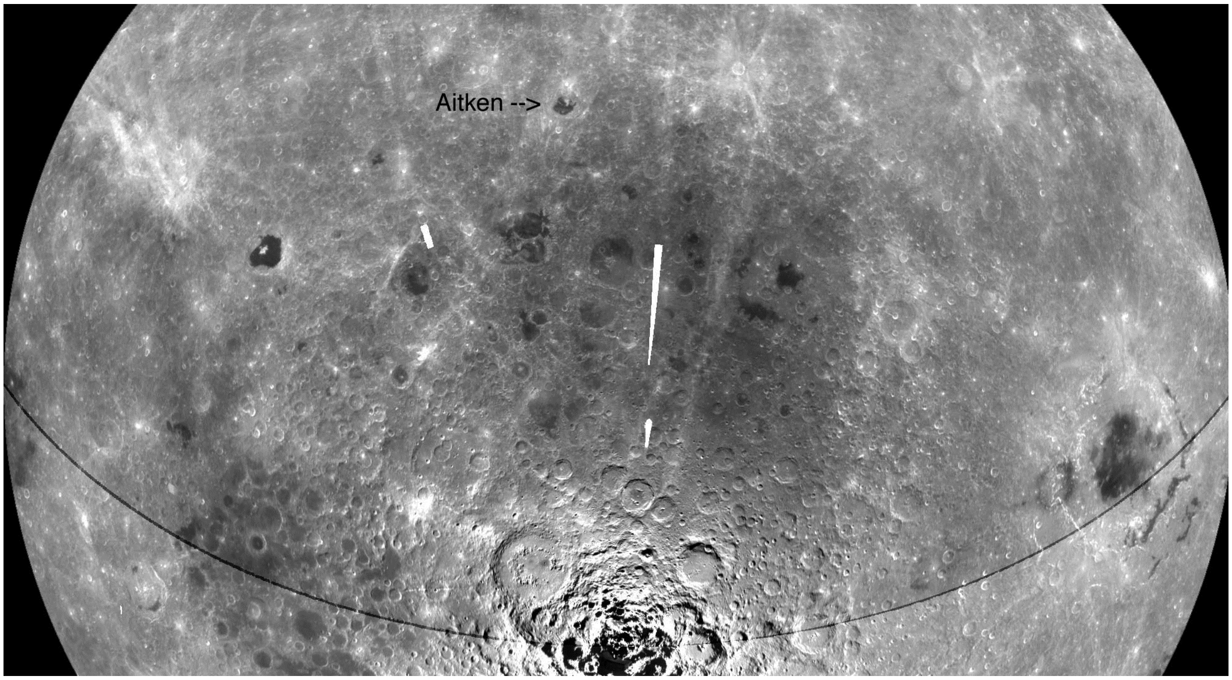
- Obtain samples to constrain the early impact history of the inner solar system (including the possible 4.0 By "cataclysm").
- Assess the nature of the Moon's interior and the style of the differentiation process.
- Develop robotic sample acquisition, handling, and return technologies.

Implementation of New Frontiers missions will be competed through a NASA AO process. The sample return mission to South Pole-Aitken Basin (SPA-SR) could be flown as early as 2008/9 [2]. Several aspects of this science opportunity involve community participation, most importantly analysis of the returned samples. Optimization of the specific site(s) selected for sampling also benefits from broad input, and several site selection options are discussed here.

Minimum Science Requirements. In order for any SPA-SR mission to be selected, the science goals outlined by the NRC report must be met. These goals relate to the type of samples returned and translate into specific criteria. 1) Since SPA is the oldest known basin identified on the Moon [3], dating it will place substantial limits on the early impact history and the timing and duration of basin forming events in the inner solar system. Thus, samples of the SPA melt breccia must be returned to be dated. 2) As the largest, and deepest, accessible basin in the solar system, SPA basin interior would have originally exposed debris excavated from the lower portions of the crust or upper-mantle. Returned samples should be selected to contain a significant portion of such material for analysis.

The lack of extensive mare basalt fill [3, 4, 5] provides an unprecedented opportunity to sample this ancient basin interior. It is expected that 4 b. y. or more of surface reprocessing has occurred since basin formation and the actual challenge may be to recognize the original SPA melt breccia and lower crustal material. However, based on the assessment of SPA with remote data from Clementine and Lunar Prospector and the ground truth experience gained from Apollo and Luna for regolith evolution, the above requirements are easily met for a large number of regions within SPA. Key elements supporting this proposition are outlined here.

SPA interior has not been later filled or covered by foreign material. Clementine images provide global



Clementine 750 albedo mosaic centered on 180° E and the 2300km South Pole-Aitken Basin (SPA). The small thin line separates the lunar near side from the far side. SPA was first named because the basin appeared to extend from the south pole to the crater Aitken at 16° south of the equator on the lunar farside. The basin interior contains the lowest topography on the Moon [6] and regionally exhibits a distinctly low albedo [7]. Unlike basins on the near side and the Orientale Basin to the east, most of the ancient interior of SPA has not been covered by mare basalts [3, 4, 5].

albedo data and clearly show SPA interior remains distinct from its surroundings. The low albedo of SPA interior has not been masked by redistribution of lunar materials during subsequent basin impacts. The current surface is not pristine, of course, but estimates of the foreign component can be modeled [8, 9].

SPA interior remains a compositional anomaly. From the first look at SPA with modern sensors, the interior is recognized as compositionally distinct from its surroundings. It is notably more iron-rich [10, 11, 4] and slightly more radiogenic [12].

SPA melt breccia is compositionally distinct from the original anorthositic upper crust as well as later mare basalts [e.g. 4]. Except for a few exposures near the edges, SPA is largely devoid of crustal anorthosite . Two principal mafic rock types are identified in SPA interior: a) small ponds of mare basalts and cryptomaria, both of which contain abundant high-Ca pyroxene and b) an older, more pervasive noritic composition characterized by abundant low-Ca pyroxene. These stratigraphic relations indicate the noritic mineralogy represents the melt breccia of SPA interior.

SPA melt breccia consists of a significant fraction of lower crust and/or upper mantle material. It appears the anorthositic portion of the upper crust was removed by the SPA impact (and may contribute to the elevated anorthositic-rich terrain to the north of SPA [6]). The formation of impact-melt breccia involves mixing of the column of material excavated near the center of the basin. For large impacts, the melt taps the deepest portion of the target material and the resulting melt breccia remains largely within the excavation cavity [13].

In a well-developed regolith, the principal rock types of the region can be identified in a suite of representative regolith rock fragments. This is well demonstrated from returned lunar samples [14] and results from random, but long term, impact processes active on the lunar surface that redistribute and mix materials locally.

Samples of the SPA-MB. Interior SPA sites with regolith of the above properties are abundant and readily identified with available data. SPA melt breccia is easily recognized in a representative sample of regolith rock fragments because either SPA-MB dominates the sample or it is of a distinctive mafic composition:

Limits on the composition of the original SPA melt breccia are estimated from current remote sensing data and a linear mixing calculation as shown in Table 1. Values of FeO for the non-mare component of SPA (~9% FeO) are derived from calibrated LP-GRS [15, 16]. Estimates of the composition of external foreign debris ranges from a) typical composition of highlands surrounding SPA (4% FeO) to b) typical highland soil from Apollo 16 (6% FeO). These known values constrain the composition of the original SPA melt breccia (SPA-MB). If the foreign fraction in current regolith is high (e.g. 80%), the melt breccia itself must have an exceptionally high FeO content making those regolith rock fragments readily identified. On the other hand, if the foreign fraction is low (e.g. 30%), then the majority of the fragments represent the original SPA material.

Thus, if returned samples contains a statistically significant number of representative regolith rock fragments, the SPA melt breccia component is readily identified from fragment statistics and available for analysis. These constrain the composition of lower crust/upper mantle. The age of the basin should correspond to the oldest peak in the distribution of ages of mafic melt breccia, and a detailed time-stratigraphic sequence of subsequent events could be constructed from integrated petrologic and geochronologic analyses of the samples. [see 17].

Table 1. Composition of SPA melt breccia (SPA-MB) calculated for various fractions of foreign material mixed with local SPA-MB in current regolith.

Foreign Fraction	**Observed* %FeO**	**SPA-MB %FeO a**	**SPA-MB %FeO b**
0.30	9.0	11.1	10.3
0.50	9.0	14.0	12.0
0.80	9.0	29.0	21.0

*LP-GRS for non-mare SPA [15, 16]

Science Options. The SPA basin is nevertheless very complex due to its age and long post-basin history. In addition to accomplishing the primary science requirements above, there is a long and exciting list of secondary objectives to choose from to narrow the specific site to be sampled. This is particularly important if more than one site is to be sampled to assure science objectives are met. Formal discussions of these options among the community are planned. Examples of other terrain that could contribute to the regolith rock fragment population based on proximity include:

Cryptomaria. Ponds of ancient mare basalt have been identified within the basin. These could help constrain the unusual thermal history of SPA and mantle composition.

Olivine Hill. This central region [4] may represent a deposit of the deepest (unhomogenized) melt breccia.

Th Anomaly. The NW zone of enriched Th [12] is an enigma and may represent a concentration of Imbrium antipodal deposits [18].

Pristine lower crust. Material in the central peaks of the largest craters could represent lower crust excavated from beneath the melt breccia.

References: [1] SSB/NRC/NAS, New Frontiers in the Solar System, 2002. [2] M. Duke COSPAR 2002. [3] Wilhelms D. E. USGS Prof Paper 1348, 1987. [4] Pieters et al. JGR 106 E11, 28001, 2001. [5] Yingst and Head JGR 102 10909, 1997; --104, 18957, 1999.[6] Zuber et al. Science 266, 1839, 1994. [7] Eliason E. M.,NASA-PDS CD-Rom Archive CL-4001-4078. [8] Haskin et al. LPS34 these volumes, 2003. [9] Petro and Pieters, LP34 these volumes, 2003. [10] Belton et al. Science 255, 570, 1992. [11] Lucey et al. Science 268, 1150,1995. [12] Lawrence D. et al. Science 281, 1484, 1998. [13] Cintala and Grieve MaPS 33, 889, 1998. [14] Jolliff B. et al. LPS33 #1156, 2002. [15] Lawrence D. et al. JGR in press. [16] Lawrence D. et al. LPS34 these volumes 2003. [17] Jolliff et al. LPS34 these volumes 2003. [18] Haskin et al. JGR 103, 1679, 1998.