# SAMPLING THE SPA BASIN: SOME CONSIDERATIONS BASED ON THE APOLLO EXPERIENCE

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The evolution of the crust and the timing of early impact events is important in the scientific exploration of the Moon [1]. The recent National Research Council decadal study [2] made sampling the deposits of the South Pole-Aitken basin a major priority for planetary exploration. This basin, located on the southern far side, is the largest and oldest multi-ring basin on the Moon and may have excavated most, if not all, of the lunar crust in its target region [3-5]. Study of this feature can illuminate the early cratering history of the Earth-Moon system, lunar crustal composition and structure, and the nature of the large impact process [2,6].

The NRC study recommended a robotic mission to sample the SPA deposits [2]. The issue of robot samplers v. human geological field study in lunar exploration was considered by Ryder et al. [7]. They suggested that to collect samples relevant to the issues under study, complex, geological targets requires the guiding presence of human intelligence. Given the scientific questions about SPA and its evolution, where should the basin be sampled and how? I here review the Apollo experience with basin sampling and draw some parallels the South Pole-Aitken basin.

**Apollo Sites and Sampling Results** The Apollo landing sites were selected to advance our understanding of the composition and history of the lunar highlands, including the role of large multi-ring basins, particularly Imbrium, a dividing event in lunar history [8, 9]. Key objectives were to document the absolute age of the Imbrium impact and to characterize the deep lunar crust through the examination of basin ejecta [8]. The Apollo missions to the lunar highlands (14-17) returned carefully selected and documented samples [10], probably representing regional units, although dissenting opinions exist [11].

*Apollo 14*. The Apollo 14 mission was sent to Fra Mauro because: a) the context of the regional deposit was thought clear (i.e., Imbrium basin ejecta); and 2) a young, fresh crater (Cone) was available to provide a "drill hole" into the thick basin deposits recognized there, ensuring proper sampling. It was considered critical to sample the deposits of Cone crater to be certain that genuine Fra Mauro Fm. (Imbrium-related) was collected, not later surficial contamination [8]. The Apollo 14 samples are impact breccias of broadly basaltic composition; all are enriched in KREEP. True anorthosite (thought to be the principal component of the highlands) is uncommon. Plutonic rocks are norites and gabbronorites, with some granitic rocks. Mare basalt is surprisingly common, occurring as both loose samples (14053) and clasts within breccias. Granulites are fairly common, as they are at all sites.

*Apollos 15 & 17* The subsequent Apollo 15 and 17 missions were sent to the Imbrium and Serenitatis basin rims, respectively [8]. On these missions, emphasis was on sampling highland massifs, hypothesized to be blocks of uplifted crust, from which one could reconstruct stratigraphy. It was also hoped to find material from depth, as these sites are located closer to the basin rim than was Apollo 14; analogy with terrestrial craters suggested that the deepest ejecta would be concentrated closest to the crater (basin) rim.

Rocks from the Apennine front at Apollo 15 turned out to be mostly regolith breccias (containing local mare basalt.) However, both plutonic rocks (ferroan anorthosite 15415 and Mg-norite as clasts in melt) and impact melts were returned from Spur crater. The "black-and-white" rocks 15445/455 are probably basin melt rocks; Ryder and Wood [12] proposed that they are Imbrium basin melts and their mafic composition (rich in Mg) and age (~3.85 Ga) support this concept. Other melts found in the coarse fines from Spur crater probably represent at least 3-4 other impacts, including some possibly derived from the Serenitatis impact [13].

The Apollo 17 highland samples from Taurus-Littrow are remarkable in two respects. First, ferroan anorthosite is virtually absent and plutonic rocks are all from the Mg-suite, including norites and troctolites. Second, impact melts form at least two broad groups: the poikilitic melts are remarkably homogeneous, while the aphanites are more diffuse [14]. Nearly all the melt rocks formed at 3.87 Ga, commonly interpreted as the age of the Serenitatis basin [9].

*Apollo 16* The intervening Apollo 16 mission was sent to sample the Cayley plains (thought to be felsic ash flows) and wormy textured Descartes material (interpreted by some as silicic lavas.) In this case, the pre-mission interpretation was wrong: the samples are all impact breccias, causing a major reinterpretation of the origins of highland landforms. We now think that the Cayley and Descartes are facies of basin ejecta.

The Apollo 16 samples have provided an endless source of controversy since the pre-mission volcanic hypothesis was discredited. All the Apollo 16 samples are impact products, but from where? The samples are feldspathic breccias, with lesser amounts of mafic, KREEPy melt rocks [15]. These melt rocks differ in composition and age from both the Apollo 15 and 17 melts. If they are basin-related, do they come from Imbrium or Nectaris – or another basin, such as Serenitatis? They cannot be local because the local substrate is too aluminous and KREEP-poor to provide the necessary lithic precursors [15].

*Luna* Three Soviet robotic missions also returned samples from the Moon. Luna 16 and 24 were sent to maria; basaltic rocks found in these samples are assumed to represent local mare flows in Maria Fecunditatis and Crisium, from which much detailed knowledge has been gathered. The Luna 20 site is in the highlands, on the back slope of the Crisium basin. Thus, we might expect debris from that basin impact to be included in these samples. One melt rock may from the Crisium basin [16], but its relation to that event remains problematical.

**Consensus (in order of general acceptance)**

*The Apollo 17 poikilitic melts represent Serenitatis melt sheet* – Most workers who have studied the Moon agree with this conclusion. A tightly clustered compositional group, with identical ages and siderophiles, they contain deep-seated clasts and have a mafic, KREEP-enriched composition.

*The Apollo 15 highlands are Imbrium ejecta* – Both clastic (anorthositic and noritic) and melt rock (mafic, KREEPy) components are present. Imbrium basin melt is probably among the Apollo 15 samples, but we're not certain which ones represent this component.

*Apollo 14 breccias are (probably) Imbrium clastic ejecta, but we don't know which* – The crystalline breccias of Fra Mauro likely make up a large mega-breccia deposit associated with the Imbrium basin ejecta blanket. A model of ballistic sedimentation published after the Apollo program cast doubt on the presence of large amounts of primary basin ejecta, contending instead that the deposit is dominated by local materials [17]. Thus, although the Fra Mauro Fm. was emplaced by the Imbrium impact, it may not consist of material thrown out of the excavated basin cavity.

*Apollo 16 feldspathic clastic debris is largely local* – and here, local means the ejecta blanket of the Nectaris basin. Again, the issue of local substrate vs. excavated basin material, as at the Apollo 14 site, becomes contentious.

*Mafic melt breccias returned by all the Apollo missions are basin-related* – Although this conclusion is by no means completely accepted, it's hard to understand the genesis of these rocks from near-surface, local impact melts because no site possesses the appropriate composition to create them by small, local impacts. Accepting this conclusion, however, doesn't solve the problem of where they come from (except where noted above).

**Implications for sampling the South Pole-Aitken basin**
The experience from the Apollo missions provides us with some guidance on how to approach the problem of characterizing the SPA basin impact. In part, that experience is cautionary, with some specific implications for planning the best strategies to ensure that we obtain samples having maximum scientific utility.

*Bulk samples obtained at small local scales may reflect major units, but exactly which ones and how can be uncertain, even long after the mission*. Apollo was successful in sampling major regional units but sometimes, relating these samples to the units is difficult. There is broad agreement that mare basalts represent surface flows, but at some sites (e.g., Apollo 12), exactly which samples are pieces of the uppermost basalt can be unclear. Samples from highland sites tend to be even more obscure. It is thus important not to "oversell" the value of a sample return; while many problems are potentially addressable from a collected sample, the scientific value of a sample is dependent upon its context.

*Samples from older geological units have context that is less clear*. This may seem obvious, but as units age on the Moon, they collect deposits from subsequent events, usually by impact deposition. The oldest sites (highlands) are more difficult to understand than the post-basin maria.

*The best samples of basin impact melt obtained during the Apollo missions come from basin massifs.* The most unambiguous melt sheet sampled is the one at the massifs of the Apollo 17 site. These massifs make up the rim of the Serenitatis basin. Melt rocks sampled from continuous ejecta are problematic. While we did not visit and sample the interior melt sheet of a basin during Apollo, all basin melt sheets are very old, at least 3.8 Ga, and thus, sometimes have ambiguous context.

*Can a New Frontiers robotic sample return mission solve SPA problems?* I doubt it. Robotic missions can get samples from which major scientific questions can be answered. However, this depends strongly on obtaining the **correct** sample. Complicated sites offer less chance that the correct sample will be obtained or recognized. The geology of complicated highland sites remains contentious even with human field work and extensive sample collection. It's probably no accident that the best understood highland site (Apollo 17) was also studied and sampled by the geologically best trained crew with the most available time. Geological relations that seem clear from orbital data turned out to be anything but once we were on the ground. A single scoop of regolith contains more complexity than even the most complicated terrestrial field sites. Although some of this complexity can be unraveled and comprehended, much remains unclear about the highland sites that Apollo explored so productively.

*Can SPA questions be answered from a south pole lunar outpost?* Almost certainly. Extended human presence on the Moon offers unique scientific opportunities. The key to getting the right sample is careful field work, followed by revisit and re-sampling, neither of which is possible with current robotic missions. Moreover, we have tentatively identified a site near the south pole of the Moon [18]. This site is just inside the rim of the SPA basin [9], made up by numerous massifs. The Apollo experience indicates that these massifs probably contain impact melt created during the SPA basin-forming impact. As such, they are our best opportunities to both date the SPA impact and to understand the composition of the lunar crust in its target region.

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