How Artemis Can Accomplish Major Lunar Exploration Scientific Goals and Objectives: A Sampling Strategy and the "Artemis Rake".

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Overview: For the Artemis-targeted unique lunar *South-Circumpolar Region*, we outline its Moon-wide context and major scientific problems and assess the optimal sampling strategy for initial and early Artemis human exploration missions to obtain a *representative sample* of the igneous (differentiation/petrogenesis) and metamorphic (impact-modified) history and cratering chronology of this unique lunar region.

1. Geologic Context and Importance of the Artemis Landing Site Region: The Artemis III landing site and subsequent Artemis Base Camp are targeted to the *South-Circumpolar Region (SCR)*, within 6° of the pole. This area is located at the southern rim of the South Pole–Aitken (SPA) basin, the largest and oldest lunar impact basin, and offers key opportunities to address fundamental questions in lunar and planetary science that can be studied by careful human exploration and return of samples for analysis in Earth laboratories. Here we focus on the non-volatile-related goals: 1) Crustal Provinces: Of the major global terrane types [1], the SCR is located in the Feldspathic Highlands Terrane (FHT), adjacent to the South Pole-Aitken (SPA) Terrane, and south of the Procellarum KREEP Terrane (PKT); SCR is outside the Apollo-Luna zone, over 90° south of the Apollo 11 site, and will provide significant insights into the nature of nearside-farside (NS-FS) differences. 2) Crustal-Subcrustal Stratigraphy: SCR provides a unique location to assess variations in crustal layering, magma ocean lateral heterogeneity, and provides potential access to mantle materials. 3) Magmatism: SCR location can provide access to samples to establish NS-FS differences in mare basalts, pyroclastics, KREEP, and different magmatic rock types. 4) Magnetism: The possibility of obtaining and dating a wide array of igneous and metamorphic rocks provides access to critical information on magnetic field magnitude and history. 5) Chronology and Flux: Radiometric dating of a wide and representative variety of SCR samples will yield ages of impact basins in the region (e.g., Schrödinger, Orientale, Mendel-Rydberg, SPA) and provide links to the bombardment history of the Earth-Moon system. Dating of SCR crater-associated cold traps (e.g., Shackleton, Cabaeus, Haworth, Faustini, Shoemaker) can significantly enhance our understanding of the origin and evolution of the SCR volatile inventory and enhance exploration strategies. 6) Lunar Origin and Evolution: Just as Apollo-Luna exploration in the Imbrium-dominated zone provided a foundational basis for our current lunar paradigm, obtaining and analyzing representative samples of the SCR will surely result in a fundamental change in our understanding of lunar origin and evolution.

2. Artemis Scientific Goals and Objectives: The NASA Human Exploration & Operations Mission Directorate (HEOMD) has articulated broad scientific and exploration goals for Artemis (Artemis Science Plan), and a Science Definition Team formed by the Planetary Science Division of NASA's Science Mission Directorate will draw from community goals documents (LEAG Roadmap, Decadal surveys, SCEM report, ASM report) to develop the detailed Artemis science objectives. Among the major Artemis Science Plan goals are *Processes* (differentiation, magnetism, volcanism, impact cratering), *Earth-Moon System Impact Flux*, *Volatile Cycles* and *Fundamental Lunar Science*. Landing in the SCR has the potential to make significant scientific progress on all of these major goals.

3. Strategies for Accomplishing Scientific Goals and Objectives: Sampling strategies for geologic field investigations focus on three components: 1) identification and sampling of the diversity of rock types and lithologic units in a field area, 2) focus on representative sampling of the most common rock types, 3) attention to sampling any unusual rock types. On Earth, typical sampling is from bedrock outcrops, and only rarely from 'float" (rocks detached from their bedrock source). For the Moon, the formation and evolution of an impact-generated, meters-thick regolith typically precludes sampling of bedrock. Although mare regolith is dominated by the mechanical and chemical alteration of generally underlying basaltic lava flow units (Apollo 11, 12, 15, 17), older highlands units are characterized by a very wide variety of crater ejecta deposits derived from a range of crater sizes up to multi-ringed basins (Apollo 14, 15, 16, 17) and the provenance (location and unit of origin) of highland rock types is much less clear. Nonetheless, even at the Apollo 11 mare site, numerous regolith soil grains transported to the site from great distances (the surrounding highlands), permitted an understanding of the nature of the highlands and the proposal of an initial "magma ocean" hypothesis. Due to the realization, following the Apollo 11, 12 and 14 missions, that the regolith was very likely to contain a treasure trove of pebble-sized fragments transported from greater distances, a proposal (by L. T. Silver) was made to include a "rake" on the J-missions (Apollo 15-16-17).

The Apollo rake (Fig. 1), constructed at NASA JSC and carried on Apollo 15-16-17, consisted of a collection basket of parallel, 1 cm-spaced stainless steel wire tines, spout-like aluminum sidewalls, and was connected to an adjustable angle extension handle [2]. Following collection of an undisturbed bulk regolith sample, Astronauts raked an approximately 1 m^2 surface area to collect a representative sample of all pebbles >1 cm from the regolith; shaking of the rake (Fig. 1) caused small particles to fall through the tines and the concentration of larger pebbles was emptied into sample bags. Experience with Apollo mission sample return confirmed the rake strategy for obtaining a diverse and regionally representative sample. Of the 665 rake samples collected, the vast majority were crystalline rock samples (A15-94%, A16-80%, A17-86%) [3].

4. Artemis Mission Profile and CONOPS: NASA is scheduled to launch the Artemis III mission to the SCR in 2024, landing a crew of two to undertake scientific instrument deployment, surface exploration, and sample documentation and collection (for return to Earth for detailed laboratory petrologic, geochemical and chronologic analyses). Artemis III astronauts will undertake several periods of extravehicular activity (EVAs) within walk-back distance of the lunar lander. Astronauts on the earliest Artemis missions will be unassisted by the mobility typical of the Apollo J missions (the Lunar Roving Vehicle, LRV, on Apollo 15-16-17) and the sample return mass will be limited to a few tens of kilograms. Thus, the Artemis III mission surface exploration profile (Concept of Operations; CONOPS) is best thought of in the context of early Apollo missions (Apollo 11, 12, 14), with walking traverses (<4 km) and small sample return mass (<42 kg). Later Artemis missions will hopefully exceed Apollo 15-16-17 traverse distances (>30 km each) and sample return mass (77-111 kg).

A notable difference between Artemis III CONOPS and Apollo 11-12-14 surface operations is that the Artemis III EVA total surface exploration time is likely to far exceed that of early Apollo missions (<10 hours each), while the sample return mass will remain comparable (<42 kg). This places a major emphasis on returning a representative sample of the rocks that provide the key to the distinctive history of the *South-Circumpolar Region*. Because of landing safety constraints, Astronauts undertaking Artemis III walking traverses are much more likely to encounter highland impact ejecta and regolith breccias of small, hand-sample sizes (similar to those at Apollo 14) than the large breccia boulders encountered several km away for the landing points of Apollo 16 and 17. These early Artemis CONOPS, and returned sample up-mass constraints, translate into two important guidelines for overall mission planning in order to accomplish the fundamental Artemis scientific goals and objectives: 1) Hand-specimen-sized samples must be analyzed in situ and triaged very carefully before being allocated to the limited sample return mass, and 2) Other techniques must be utilized in order to assure that the limited early Artemis sample return mass contains a *representative sample* of the distinctive history of the *South-Circumpolar Region*. We call on the collective experience from the Apollo Lunar Exploration Program to address the second point, how to obtain a *representative sample* of the distinctive history of the *South-Circumpolar Region* in the early Artemis mission profile.

Four guidelines are important in obtaining pebble and larger-sized rake samples [3,4]: 1) optimizing the content of crystalline samples (as opposed to regolith breccias), 2) maximizing both the representativeness and the diversity of collected samples (primarily by increasing the number of samples), 3) understanding variability within crystalline samples, and 4) providing samples large enough for multiple characterization and dating analyses. Post-Apollo analyses of the lessons learned from lunar sample curatorial statistics, and the sub-samples allocated for scientific research, underlined the effectiveness of Apollo sampling devices such as the lunar rake in recovering the desired specimens [3,4].

6. Conclusions and Recommendations: In order to optimize the sampling and sample return strategy for Artemis Missions landing in the scientifically unique *South Circumpolar Area*, we recommend: 1) Tools be developed to ensure a representative sample of the petrologic diversity of the broad SCA and vicinity. 2) Primary among these is the inclusion for surface operations of a sampling device to concentrate the collection of pebble-rock-sized samples. 3) On the basis of Apollo exploration experience, the basic design concept of an "Artemis Rake" device will accomplish this objective. 4) The "Artemis Rake" device design should build on the basic successful Apollo design [2], but take advantage of the array of post-Apollo curatorial experience [3], and laboratory sample analysis experience [4] to adjust the design to optimize the scientific return. Issues to revisit are the optimum tine spacing and the potential innovation of an adjustable tine setting, as suggested by Schmitt, utilized to accommodate in situ sampling experience at different sampling stations.

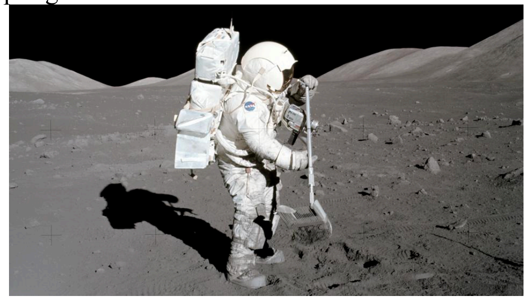

Fig. 1. Apollo 17 LMP H. H. Schmitt undertaking lunar rake sampling in the lunar Taurus-Littrow Valley.

References: [1] Jolliff, B., et al. (2006) New Views of the Moon, *Rev. Min. Geochem.* 60, 721p. [2] Allton, J. (1989), *NASA JSC-23454*, 97p. [3] Allton, J. & T. Bevill (2003) *Adv. Space Res.* 31, 2305-2313. [4] Shearer, C., J. Papike, & L. Borg (2002) Future lunar sampling missions: Big returns on small samples, *In The Moon Beyond 2002: Next Steps in Lunar Science and Exploration* 54, LPI Contribution 1128.