ROBOTIC SAMPLE RETURN II: ADDRESSING FUNDMENTAL EXPLORATION THEMES.

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Introduction: Lunar sample return is a critical aspect of an integrated lunar exploration strategy that includes sample return [1] and rovers [2] designed to address fundamental Solar System science goals and objectives expressed in the Planetary Decadal Survey [3] and the Lunar Exploration Roadmap (LER) [4]. Automated sampling of key locations will address fundamental questions about the Moon (with implications for all of the terrestrial planets), and prepare for future human exploration and resource utilization.

Background: The Moon preserves a record of time erased on other terrestrial planets [5]. The Moon is the only other planet from which we have contextualized samples, yet critical issues need to be addressed: we lack important details of the Moon's early and recent geologic history, the full compositional and age ranges of its crust, and the bulk composition of the crust, mantle, and whole Moon.

The ongoing Lunar Reconnaissance Orbiter (LRO) mission continues to produce data sets that are essential for lunar science and exploration, particularly exploration planning [6-10]. LRO data enables the preliminary identification of key sites for in-situ exploration, an activity useful for defining hardware and mission design choices [11-15]. While the importance of a sample return from South Pole-Aitken basin is well-established [16], there are numerous additional locations on the Moon where targeted sample return is also required to address Solar System research priorities with relatively low risk. A companion abstract by C. Shearer discusses the role of lunar sample return for advancing our knowledge of the early differentiation of the Moon and other planetary bodies. Here, we outline how themes outlined in the LER can be readily addressed through sample return missions to specific locations.

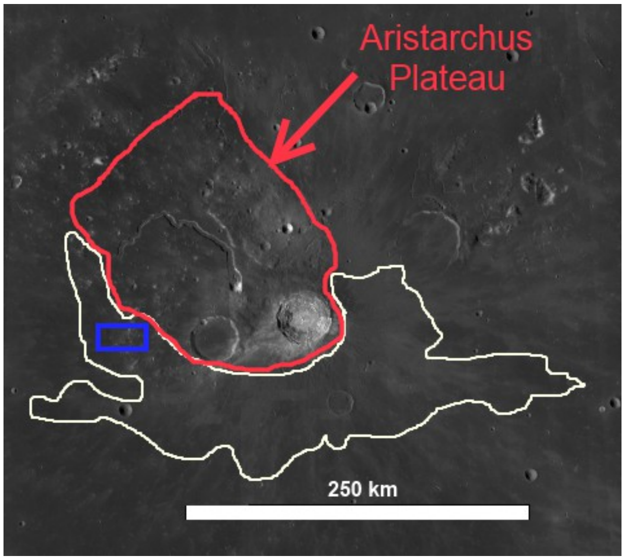

Figure 1: *LROC WAC base map highlighting the P60 area of [26] (white line), along with the crater counting region used to derive the model basalt age (in blue). The Aristarchus Plateau is highlighted in red for reference.*

Understand the Evolution of the Lunar Interior: Science results from the LRO mission confirmed the presence of nonmare, silicic volcanic constructs on the lunar surface [17-21]. Significant questions exist regarding the origin and emplacement of these evolved lithologies. Sample collection at Hansteen Alpha, the Lassell Massif, the Gruithuisen Domes, and Mairan T will dramatically expand our knowledge the compositional diversity, age, and differences in emplacement style of nonmare lunar volcanism.

Understand Lunar Volcanic Processes: In-situ investigations of lunar maria are needed to fill out our understanding of the Moon's volcanic history. For example, what processes produced low shield volcanoes within the lunar mare? Although morphologically distinct, many mare low shields cannot be distinguished on a compositional basis from surrounding mare plains. Low shields are ideal locations for targeted sample return to determine compositional or other differences between low shields and mare basalts that form plains [22-24]. Excellent candidate locations include the Marius Hills, Mons Rümker, Hortensius Domes, and the Isis and Osiris cones.

Understanding Lunar Time-Stratigraphy: Determining the chronology of geologically recent (i.e., Copernican and Eratosthenian) lunar events requires sample return [1] and is required not just for lunar exploration, but for calibrating the cratering statistics used to age-date surfaces on other terrestrial planets [e.g., 25]. Sample return locations with high-prioirty, geologically recent materials for age-dating include: the youngest (~1 Ga) Procellarum basalts defined by [26]; Lichtenberg Crater; the Ina-like Irregular Mare Patches [27]; Copernicus (the defined division between the Eratosthenian and Copernican epochs); and Tycho, Aristarchus, and Giordano Bruno craters.

The Youngest Basalt Example: Some mare basalt flows dated by crater counting methods provide significantly younger model ages than any Apollo basalt [28]. Hiesinger et al. [26] mapped 60 spectrally homogenous basalt units in Oceanus Procellarum. Crater counting methods determined that 5 of these units have model ages ranging from ~1.5-2.0 Ga. Unit P60 (**Fig. 1**) directly south of the Aristarchus Plateau has the youngest model age (1.2 Ga; uncertainty +0.32/-0.35 b. y.).

The analysis of returned samples from the P60 region would provide knowledge about isotopic and trace-element variations in lunar basalts, distinguish differences in basalt source regions/reservoirs and eruption rates over time, and redefine knowledge of the Moon's absolute chronology.

Understanding Lunar Resource Potential: Regional lunar dark mantling deposits are not only primitive materials that yield insights into the lunar mantle, but are some of the most common and accessible lunar ores and can be processed to produce key lunar resources, particularly oxygen [29,30]. The Aristarchus-1, Aristarchus-2, and Sulpicius Gallus Constellation Regions of Interest offer excellent locations to assess the physical properties and compositional variability of these resources [31]. Sample return from these deposits will greatly facilitate design and flight qualification of in-situ resource utilization hardware to expand the capability and reduce the cost of Solar System exploration.

Notional Mission Strategy: An automated sample return mission functionally similar to the Soviet Luna 24 mission and the recently proposed MoonRise mission [32] can meet the return requirements. The advanced scouting capabilities provided by LRO enable precisely targeted landings. The required spacecraft would consist of a single landed element with sampling capabilities, an ascent vehicle, and a sample return system. After landing, a robotic arm collects and stores a scoop of bulk regolith, then collects a kilogram of 3-20 mm rocklets by raking or sieving. Following collection, the samples are returned to Earth. The mission duration is less than a lunar day; no-long-duration survival for the landed element is required, and any nearside location would not require a communications relay.

Sample Return is Required: The Apollo experience demonstrates the importance of returning planetary samples to Earth [33]. The science objectives discussed here require detailed analysis of compositions, mineralogy, rock textures, and physical properties in addition to laboratory-determined radiometric ages. In-situ measurements can provide important data points, but terrestrial laboratories offer more capability for the foreseeable future, and to date, the only method with sufficient precision to adequately answer the question of the age of the youngest lunar materials. Furthermore, samples become resources, so new measurements can be made as analytical techniques improve, as indicated by recent reanalysis of lunar water in Apollo materials [e.g. 34]. Sample return missions will also play an important complementary role towards human lunar return by providing experience to the next generation of lunar scientists prior to the seventh human lunar landing.

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