SAMPLING THE YOUNGEST LUNAR BASALTS. S. J. Lawrence[1], M. S. Robinson[1], B. L. Jolliff[2], B. R. Hawke[3], G. J. Taylor[3], J. J. Hagerty[4], and B. W. Denevi[5] [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA (samuel.lawrence@asu.edu) [2]Department of Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO, USA [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA. [4]Astrogeology Science Center, United States Geological Survey, Flagstaff, AZ, USA [5]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

Introduction: Determining the timing and compositional range of basalts on the lunar surface is key information for interpreting the origin and geologic evolution of the Moon, with implications for comparative terrestrial planetology. Here, we advocate an automated sample return mission to key basaltic sites, addressing fundamental questions about the composition of the lunar crust and the time-stratigraphy of lunar volcanic processes, with implications for all of the terrestrial planets. Sampling these basaltic materials complements currently proposed missions [e.g., 1] and helps prepare for future human exploration.

Background: The Moon preserves a record of time that were erased on other terrestrial planets, such Earth and Venus [2]. The Moon is the only extraterrestrial body from which we have contextualized samples, yet unanswered questions remain: we lack important details of the Moon's early igneous history, the full compositional and age ranges of its crust, or the bulk composition of the crust, mantle, and whole Moon.

Lunar mare basalts form through partial melting of the mantle and are the most direct window into the composition of the interior. Mare basalts cover ~17% of the lunar surface, primarily contained within topographic lows on the nearside [3]. Analysis of remote sensing data sets shows that the full range of mare basalt compositions and ages has not yet been sampled [4,5]. Knowledge of the duration of mare volcanism comes from (a) radiometric dating of Apollo and Luna samples and lunar meteorites and (b) crater counting of mare surfaces from remote sensing data (an imprecise method). Mare volcanism reached its maximum volumetric output between 3.8 and 3.2 Ga [6], but began as early as 4.3 Ga [7-9] and may have persisted until as recently as 1.2 Ga [5,10]. This uncertainty needs to be addressed.

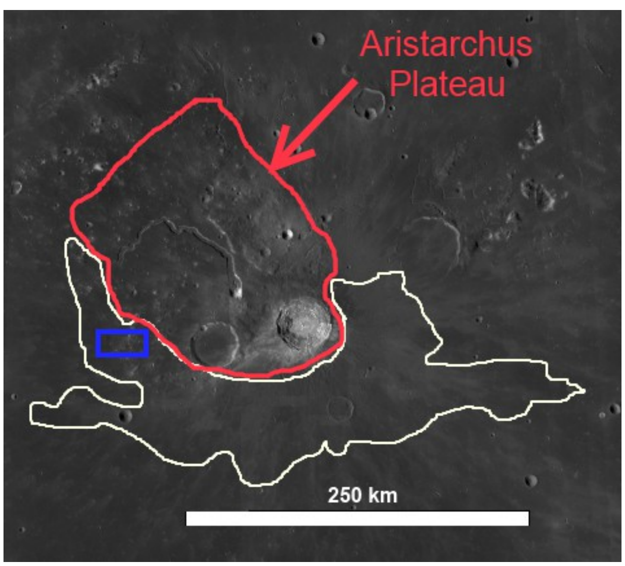

Figure 1: LROC WAC base map highlighting the P60 area of Hiesinger et al., 2003 (white line), along with the crater counting region used to derive the model basalt age (in blue). The Aristarchus Plateau is highlighted in red for reference.

Some of the basalt flows on the Moon are significantly younger than the youngest Apollo basalts [10]. Hiesenger et al. [5] 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 increase knowledge about isotopic and trace-element variations in lunar basalts, help to distinguish differences in basalt source regions/reservoirs and eruption rates over time, and significantly improve knowledge of the Moon's absolute chronology. The nearside location of the sampling location makes this an ideal site for an automated sample return. In addition, the proximity of the proposed sampling station to the Aristarchus Plateau (a high-priority target for future human exploration and development) also makes this an attractive site as a precursor mission for human lunar return.

Mission Strategy: An automated sample return mission functionally similar to the Soviet Luna 24 mission and the recently proposed MoonRise mission [1] can meet the return requirements. The advanced scouting capabilities provided by the NASA Lunar Reconnaissance Orbiter enable precisely targeted landings. The required spacecraft consists 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 3-10 cm 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.

Traceability: Sampling the youngest lunar basalt unit is directly responsive to science goals outlined in [11], especially Goal 5b: Determine the age of the youngest and oldest mare basalts. Sampling the youngest lunar basalts is also responsive to other goals outlined in that report, including establishing a precise absolute chronology for the Moon, characterizing the thermal state of the interior and elucidating the workings of the planetary heat engine, quantifying the local and regional complexity of the current lunar crust, determining the origin and variability of lunar basalts, and investigating the flux of lunar volcanism and its evolution over time.

Implications:: Collecting samples of the basalts thought to be the youngest on the lunar surface offers a low-risk, high-reward pathway to address fundamental questions in planetary science, including: understanding the lunar interior, the flux of mare volcanism, and improving the absolute chronology for the inner Solar System.

Understanding the lunar interior: The Apollo samples and lunar meteorites only sample a limited range of lunar basalt compositions and ages, which limits our understanding of the lunar interior and the full extent in space, time, and composition of lunar basaltic volcanism. Returning samples from the youngest lunar basalts will increase our knowledge about isotopic and trace element variations in lunar basalts, and in principle will distinguish prospective differences in basalt source regions and reservoirs over time.

Understanding the flux of mare volcanism: An important measure of the thermal history of a planetary body is the changes in the rate of lava eruption with time. Age determinations of samples from the maria indicate that most mare volcanism took place between 3.7 and 3.1 Ga [12]. If sample return from the youngest mare basalts shows that volcanism did, in fact, continue to as recent as 1.2 Ga, then that information would help to unravel how mare eruption rates varied with time.

Improve the absolute chronology for the Inner Solar System: The fieldwork and samples from the Apollo and Luna missions yield an absolute chronology that extends to the rest of the Solar System [12-16]. Collecting samples from the youngest mare basalts will therefore have important ramifications for planetary science [11,17]. Current cratering flux calibration curves from the Moon are anchored by dates from mare surfaces near Apollo landing sites (3.8-3.2 Ga), and very few young dates establish the more recent (<2 Ga) cratering flux [13].

If the Procellarum basalt samples have older or younger absolute ages than expected, than we will have significantly improved our knowledge of the surface ages on the Moon, and by extension, the other terrestrial planets. No matter what the age date of the Procellarum samples is determined to be, the result will still provide new knowledge for Solar System history and exploration.

Sample Return is Required: The Apollo experience demonstrates the importance of returning planetary samples to Earth [18]. To achieve the objectives discussed here, detailed analysis of compositions, mineralogy, rock textures, and physical properties in addition to laboratory-determined radiometric ages are required. Important measurements could be made using in-situ instrumentation, 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 basalts. Samples become resources, so new measurements can be made as analytical techniques improve. For sample return missions to be successful, the scientific community must maintain key capabilities, including lunar sample curation, lunar remote sensing data analysis, and laboratories staffed with experienced planetary scientists. Sample return missions will also play an important complementary role towards human lunar return by giving the next generation of lunar scientists experience analyzing new lunar samples prior to the seventh human lunar landing.

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