LUNAR SURFACE TRAVERSE AND EXPLORATION PLANNING: DESTINATIONS FOR AUTOMATED SAMPLE RETURN. S. J. Lawrence[1], J. D. Stopar[1], B. L. Jolliff[2], M. S. Robinson[1], E. J. Speyerer[1]. [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

Introduction: We are systematically assessing (from both scientific and operational perspectives) locations on the Moon [1] considered to be likely locations for near-term robotic precursor missions. In order to maximize the practical utility of the research, our goals are directly traceable to three generalized examples of robotic missions (short-duration rover, long-duration rover, and automated sample return) that have been recommended as desirable precursor missions [2].

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. Here, we focus on five potential sample return sites that are of high community scientific interest: the Compton-Belkovich volcanic complex, the Dewar cryptomaria, Giordano Bruno crater, the Sinus Aestuum pyroclastic deposit, and the Sulpicius Gallus formation.

Background: The Lunar Reconnaissance Orbiter (LRO) mission continues to produce data sets that are essential for lunar science and exploration [3-7]. There are numerous locations on the Moon where targeted sample return is required to address Solar System research priorities, including:

Understand the evolution of the lunar interior: Significant questions exist regarding the origin and evolution of rock types that were not sampled during the Apollo mission (Compton-Belkovich volcanic complex, Dewar cryptomaria, Sinus Aestuum).

Understand lunar volcanic processes: Sample return from unexplored volcanic units will address key gaps in our understanding of the Moon's volcanic history (Compton-Belkovich, Sulpicius Gallus, Sinus Aestuum).

Understand lunar time-stratigraphy: Determining the chronology of geologically recent (i.e., Copernican) lunar events is required to calibrate the cratering statistics used to age-date surfaces on other terrestrial planets (Giordano Bruno)

Evaluate lunar resource potential: Regional dark mantling deposits are primitive materials from the mantle and are some of the most accessible lunar ores. Lunar pyroclastics are excellent locations to assess the physical properties and the compositional variability of these resources; and facilitate flight qualification of in-situ resource utilization hardware to expand the capabilities and reduce the cost of Solar System exploration (Sulpicius Gallus, Sinus Aestuum).

Each of these science objectives require detailed analysis of compositions, mineralogy, rock textures, and physical properties in addition to laboratory-determined radiometric ages. 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. 8].

Notional Mission Strategy: An automated sample return mission functionally similar to the proposed MoonRise mission [9] is required. The notional 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 would be less than a lunar day; long-duration survival for the landed element is not required, and any nearside location would not require a communications relay.

Methods: We are integrating LROC (NAC, WAC, and DTMs), Diviner, and LOLA datasets with moon Mineralogy Mapper (Chandrayaan-1), Kaguya Terrain Mapping Camera, Clementine, and Apollo Metric Camera frames to determine important lithologies and geologic units, identify productive exploration locations and resources such as pyroclastic deposits, and identify candidate landing sites and traverses. LROC DTMs are being used to assess the accessibility of each site in terms of the slopes and the Terrain Ruggedness Index (TRI), which is the mean elevation difference between the central DTM pixel and its surrounding cells [10], and slopes. Finally, we have developed a preliminary path planning algorithm [11] based on a generalized least- energy model for planetary rovers, altered for the lunar use case [12], to explore and define mobility options. In all cases presented here, the overriding goal is to identify Regions of Interest where a safe landing can be readily achieved, but which also satisfy the stated science objectives with automated science return. Since we are not making any assumptions about the capabilities of the spacecraft, our approach is to simply identify 1km circular RoIs that meet the criteria defined below.

Site Selection Criteria: For the purposes of this study, we have defined a site selection strategy for automated sample return without surface mobility.

Proximity: The proposed landing site(s) must be close enough to provide a reasonably high probability of collecting the desired sample.

Representative: The proposed landing site must be geochemically representative of the targeted sample type.

Characterized: The availability of LRO data (particularly Narrow Angle Camera Digital Terrain Models) is required for terrain referenced navigation systems and enhances mission success probability.

Accessibility: The selected location must have fairly level slopes (GLD100 slope < 5°), traversable TRIs, and be relatively free of large boulders. To determine boulder abundance, we use the rock abundance estimates produced by the LRO Diviner instrument [13] which are sensitive to

1 m diameter boulders. By way of comparison, in the Diviner rock abundance parameter space, landing locations like the Apollo 12/Surveyor 3 landing site at Statio Cognitum have a rock abundance of 0.003; the landing site of the recent Chang'e 3 mission has a rock abundance of 0.005.

Results: From the five science destinations, we identified fourteen Regions of Interest (**Table 1)** that meet the requirements for proximity, representation, and characterization. The characteristics of each RoI are consistent across at least a nominal 1 km diameter landing area. Table 1 includes the location of each Region of Interest, as well as the physical parameters determined for each site. Each Region of Interest represents a discrete site (**e. g., Fig 1)** where an automated sample return mission could reasonably be executed. Regions of interest with comparable rock abundances, slopes, and TRI values to those of previous landing sites can at least be demonstrated to satisfy accessibility requirements. However, all of the studied Regions of Interest are feasible locations for sample return.

Implications: While near-side locations are more feasible near-term destinations for surface exploration, the importance and number of key far side targets like Compton-Belkovich and Dewar means that technologies required to enable farside communication must remain part of the Lunar Exploration Roadmap moving forward.

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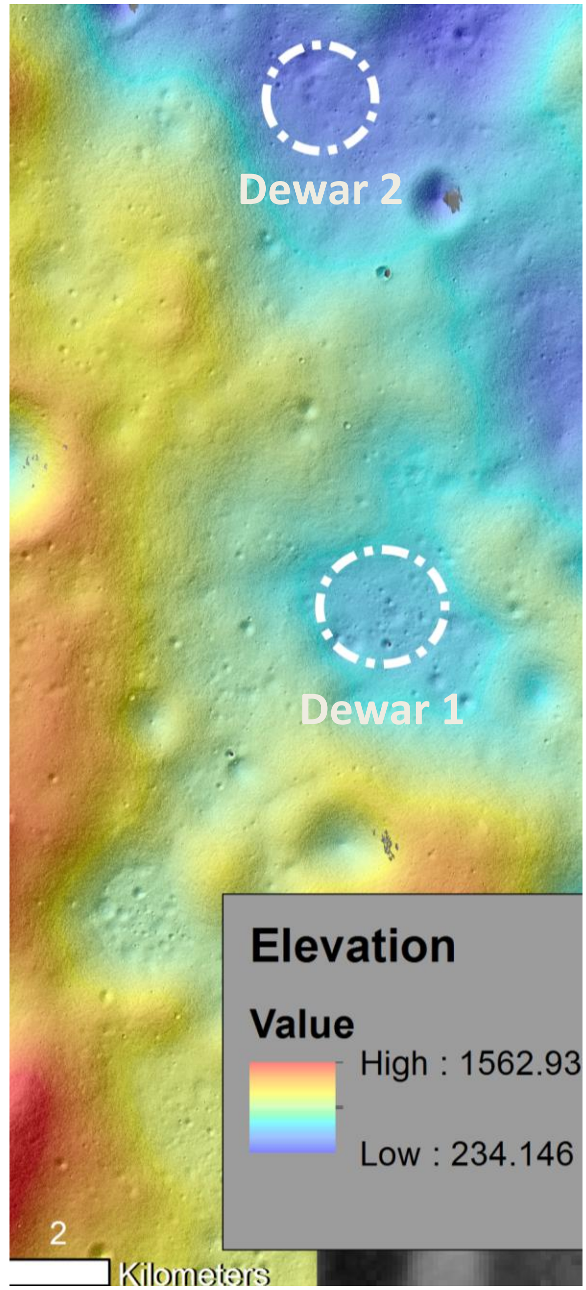

Figure 1. LROC NAC Digital Terrain model highlighting locations of the Dewar 1 and Dewar 2 RoIs**.**

Table 1. Locations and Physical Properties of Sample Return Regions of Interest

Name	Latitude	Longitude	NAC TRI (6m scale)	WAC TRI (300m scale)	DRA	Mean WAC Slope (Degrees)	Max WAC Slope (degrees)	Mean NAC Slope (degrees)	Max NAC Slope (degrees)
Dewar 1	-2.48	166.86	0.1±0.07	4.3±1.7	0.003	3.9	7.6	4.3±3.2	64
Dewar 2	-2.16	166.84	0.09±0.05	3.7±1.6	0.004	3.23	6.9	1.2±2.6	31
Dewar 3	-1.94	166.77	0.09±0.05	2.4±1.05	0.002	1.8	3.8	3.5±2.5	30
Compton-Belkovich 1	61.45	99.72	0.05±0.03	3.1±0.91	0.003	2.3	3.8	1.8±1.2	27
Compton-Belkovich 2	61.42	99.72	0.06±0.03	4.5±0.5	0.002	3.4	4.3	2±1.2	18
Compton-Belkovich 4	61.47	99.86	0.05±0.03	3.3±1.6	0.004	2.3	3	1.9±1.2	24
Comtpon-Belkovich 5	61.47	99.82	0.06±0.03	2.9±0.62	0.003	1.1	1.8	2.4±1.3	13
Compton-Belkovich 3	61.35	99.77	0.06±0.04	1.5±0.39	0.003	2.4	5.1	2.2±1.5	19
Giordano Bruno 1	36.10	102.34	0.1±0.06	3.4±1.5	0.048	2.5	5	3.6±6.4	35
Sulpicius Gallus 1	19.97	10.39	0.09±0.07	2±0.87	0.0023	1.5	2.9	3.4±2.5	38
Sulpicius Gallus 2	20.06	10.41	0.07±0.05	0.9±0.36	0.002	0.7	1.5	2.6±1.9	30
Sinus Aestuum 1	5.54	344.80	NA	2.4±1.28	0.0024	1.8	5.1	NA	N/A
Sinus Aestuum 3	5.74	344.80	NA	1.5±0.79	0.0028	1.1	2.8	NA	N/A
Sinus Aestuum 4	6.06	344.77	NA	1.4±0.62	0.0036	1	3.1	NA	N/A
NA=Not Available									