ASSESSMENT OF FUNDAMENTALLY DIFFERENT LUNAR TERRAINS FOR FUTURE LONG-DURATION SURFACE EXPLORATION.

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Introduction: Data from the Lunar Reconnaissance Orbiter (LRO) mission have unquestionably contributed to recent scientific advancements; however, the application of LRO data is, as of yet, underutilized in support of the mission's original primary purpose: enabling future exploration and site assessment activities. Therefore, as part of a larger effort, Lawrence et al. [this vol] identified 15 high-priority sites for characterization to address key lunar science and exploration goals that primarily focus on volcanic and polar processes and complement similar recent analyses [1-4]. The goals of the Lawrence et al. study are to define optimal landing sites for future robotic missions, provide meter-scale traverses and site assessments for future exploration planning, and synthesize concepts of operations to inform future hardware decisions.

While there are many potential surface exploration scenarios ranging from static landers, limited-duration rovers, and long-duration rovers, Robinson et al. [5] proposed that a long-duration lunar prospecting rover might provide a wide-ranging mission that could investigate high priority nearside targets, for example. This mission scenario would exceed past and current missions (Lunokhod; MERs; Curiosity) in design for distance and rate of travel. Such a mission, however, will encounter a variety of terrains and be tasked with numerous science objectives. In order to define notional hardware requirements for such a mission, parameters including wheel traction, power, component lifetimes, and temperature survivability must be rigorously defined. Therefore, we have characterized the topography and illumination conditions of several key representative landforms including impact craters, volcanic constructs, and plains units in order to determine how mission objective will affect the design of the surface explorer platform (i.e., rover). Key questions include: Can the most engaging locations in a particular terrain be easily accessed? How far apart are crucial study areas? Are surfaces navigable and what are the meter-scale hazards? What are the illumination considerations over time?

Methods and Results: LROC NAC map-projected and mosaicked images allow evaluation of meter-scale hazards [6]. Where available, NAC images of each location collected under a variety of illumination geometries allow characterization of surface materials and illumination considerations (including persistence of shadows) [e.g., 3]. PDS-archived NAC-derived Digital Terrain Models (DTMs) allow determination of local slopes and surface roughness over a range of scales from meter to decameter as well as potentially impassable topographic obstacles. Roughness was defined for the purposes of this study as the average standard deviation in slope (°) over a 30-m length scale. Identification of key science waypoints in each terrain type was carried out using a variety of geologic datasets (Clementine UVVIS, LRO Diviner, LRO LROC), and each point was geospatially tagged using ArcMap in order to compute first-order distances between each waypoint (**Fig.1**). Calculated slopes (mean and maximum) likely encountered, maximum 30-m length scale roughness, potential hazards, and travel distances between key waypoints are presented in **Table 1** for 14 sites that represent plains units, impact craters, and volcanic terrains.

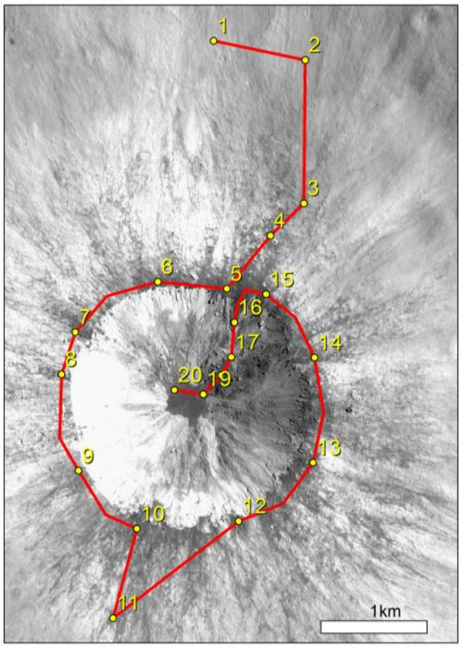

Figure 1. Example of waypoints selected for a 2.5-km Copernican crater to assess the composition and diversity of impact melt. Descent into crater requires traverse of 30° slopes.

Discussion and Summary: The results presented here represent an initial phase of site assessment and path planning and evaluation processes. Results will continue to be improved and refined through integration with trafficability metrics including a least-energy algorithm that will include the topographic parameters investigated here (slope, roughness, hazards, and illumination) [7]. Topography and objective definition play prominent roles in mission design. For example, minimum travel distances, minimum mission duration, wheel slip tolerance, and maximum approach and departure angles are fundamental for defining hardware as well as instrument-suite selection.

In general, exploration of impact craters, particularly fresh ones, may best be accomplished from a rover platform by sampling ejected materials scattered near the crater; however, this strategy would preclude exploration of any subsurface voids in impact melt on the crater floor [e.g., 8]. The interiors of fresh craters can also have extensive shadows during significant periods of time. While older craters generally have easier egress paths and reduced shadow effects, the identification of geologic units and materials can be difficult owing to extensive degradation.

Typical lunar mare domes (e.g., Hortensius) have flank slopes of a few degrees with few meter-scale hazards. However, in-situ outcrops are more common in association with more irregular domes (e.g., Marius Hills), but navigation of steep slopes and irregular topography may require more aggressive rover hardware at these sites when “rolled boulders” do not provide adequate samples from higher topographic units.

Plains units such as regional pyroclastic deposits, mare plains, and other smooth plains units have gentle slopes and few topographic obstacles; however, due to large (apparently) homogeneous areas, travel distances between waypoints may be greater. Excavated blocks can potentially provide subsurface samples from the panoply of geologic materials located beneath a relatively thin plains unit; these blocks are generally derived from small recent impact craters, including secondaries from relatively recent cratering events [e.g., 9-10].

Owing to the various hazards, slopes, and surface materials likely faced by a long-lived roving exploration platform crossing different terrain types, including volcanic edifices and fresh impact craters, prior delineation of mission objectives is critical for definition of minimum hardware requirements.

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References: [1] Jolliff et al. (2010) AGU Fall Mtg. #P53D-1550. [2] Jolliff et al. (2010) LPSC #2412. [3] Speyerer and Robinson (2013) Icarus, DOI: 10.1016/j.icarus.2012.10.010. [4] Mest et al. (2013) LPSC #2630. [5] Robinson et al. (2011) Ann. Mtg. LEAG #2042. [6] Robinson et al. (2010) Space Sci. Rev., DOI: 10.1007/s11214-010-9634-2. [7] Speyerer et al. (2013) LPSC #1745. [8] Robinson et al. (2012) Planetary Space Sci., DOI: 10.1016/j.pss.2012.05.008. [9] Basilevsky and Head (2012) Planetary Space Sci., DOI: 10.1016/j.pss.2012.08.017. [10] Robinson et al. (2012) Planetary Space Sci., DOI: 10.1016/j.pss.2012.03.013.

TABLE 1. PRELIMINARY RESULTS OF ACCESSIBILITY, NAVIGATABILITY AND HAZARD ANALYSIS FOR DIFFERENT TERRAINS

SITE	DEM RES (MPP)	NOMINAL SCIENCE GOAL	PRIMARY TARGET/FEATURE	AVG SLOPE (°)	MAX SLOPE (°)	MAX 30-m "ROUGHNESS" (°)	POTENTIAL HAZARDS	TRAVEL DISTANCES (KM) BTWN KEY WAYPOINTS
Plains								
Bhabha Plain	2	Composition and Origin of Non-mare Smooth Plain	Small crater ejecta	4	11	4	Minimal	5-15
Sulpicius Gallus FM	2	Composition and Origin of Pyroclastics	Pyroclastic deposits, vent structure	6	11	4	Descent into "vent" includes slopes >20°	1-10
Reiner Gamma	2	Composition and Origin of Albedo Anomaly (Swirl)	Regolith, small crater ejecta	4	6	2	Minimal	1-5
Imbrium Flows	5	Structure and Composition of Mare Flow Fronts	Flow surfaces	2	9	2	Minimal	2-10
Craters								
Fresh 2.5-km Impact Crater Near Denning	2	Composition and Distribution of Impact Melt	Impact Melt Deposits	6	13 (rim); 30 (wall)	4 (rim); 13 (wall)	Large dm-scale blocks near rim; 30° slope descending into crater; steep slopes near rim	0.5
Linne	2	Impact Mechanisms and Ejecta Distribution	Ejecta, Boulders	4 (ejecta); 14 (rim)	10 (ejecta); 35 (wall)	4 (ejecta); 7 (rim)	Some large dm-scale blocks near rim; >30° slopes descending into crater	0.1-1
Giordano Bruno	2	Age and Composition of Extremely Young Impact Crater	Ejecta, Impact Melt Deposits	4 (melt); 9 (rim)	20 (rim); 35 (wall)	6 (rim); 13 (boulder fields)	Areas along rim with dense boulder populations	0.1-3
"North Crater"	6	High Latitude Crater Materials	Crater Walls and Floor	27 (wall)	30 (wall)	5 (wall)	Polar illumination; slopes ~30° inside crater	0.5-1
Volcanic Constructs								
Hortensius	2	Composition of Lunar "Mare" Dome	Volcanic Domes and Vents	5 (flank)	9 (flank); 30 (vent)	3 (flank)	Up to 30° slopes descending into "vents"	0.5-10
Isis and Osiris	5	Composition of Lunar Cones	Volcanic Cones	5	23	4	>20° slopes ascending cones	0.1-5
Marius Hills	2	Composition and Structure of Complex Lunar Volcanism	Volcanic Domes, Cones, and Vents (Including Rilles)	5	20	3	Minimal	0.1-5
Sosigenes Rille	2	Composition and Age of "Ina-Style" Volcanism	Volcanic Deposits and Rille Structure	4	13	3	Ascent from rille floor includes slopes up to 30°	0.1-0.5
Gruithuisen Domes	2	Composition and Age of Silicic Volcanism	Volcanic Domes	9	20	5	Minimal	1-10
Mairan T	2	Composition and Age of Silicic Volcanism	Volcanic Dome (rolled blocks)	5 (base); 30 (flank)	3 (base); 40 (flank)	6 (flank)	>30° slopes ascending dome	0.5