LUNAR SURFACE TRAVERSE AND EXPLORATION PLANNING: WHAT MAKES A "GOOD" LANDING SITE? S. J. Lawrence[1,2], J. D. Stopar[1], B. L. Jolliff[2], E. J. Speyerer[1], and M. S. Robinson[1]. [1]School of Earth and Space Exploration, Arizona State University [2] sjlawren@asu.edu [3]Department of Earth and Planetary Science, Washington University in St. Louis

Introduction: The Moon, with its abundant resources and vast surface area, represents the most logical destination for future human and robotic exploration [1]. An integrated strategy for lunar exploration involving both robotic and human exploration is required to build the capabilities, technologies, and experience base needed to enable enduring commercial cislunar opportunities and longer voyages beyond [2, 3]. Here, we discuss how LRO observations of legacy lunar landing locations inform future destinations for science and exploration, enabling a vigorous and productive program of precursor missions including automated sample returns [4-9] and extended operations rovers ([10]), as well as human missions [11].

A Cohesive Strategy: Thanks to the Apollo experience, we have an excellent first order understanding of the likely locations of prospective lunar resources. Lunar resources can broadly be characterized in terms of polar [12-14] and nonpolar [15–21] resources. Since the original purpose of LRO was to collect the dataset necessary to facilitate future human and robotic lunar exploration [22], LRO data is uniquely well suited to optimize the performance and science return of future lunar exploration missions intended to follow up on our Apollo-era understanding of useful lunar resources. [23] outlined how LRO data can be used to inform and guide an integrated strategy for lunar exploration that offers a focused path to render ambitious voyages to Mars and beyond feasible in an affordable and achievable way. Such a strategy involves a series of precursor missions building to human lunar surface operations that use the Moon to address strategic knowledge gaps [24] and test key technologies (such as automated landing) characterize the surface environment (including radiation), demonstrate teleoperations, determine the presence, grade, and tonnage of lunar resources, and validate key human exploration technologies while comprehensively addressing lunar and planetary science questions outlined by the planetary Decadal survey [25].

Purpose and Scope: To help enable future exploration missions, we are systematically assessing locations on the Moon considered likely locations for near-term robotic precursor missions [9]. Our goals are directly traceable to three examples of robotic missions (short-duration rover, long-duration rover, and automated sample return) recommended as desirable precursor missions [1]. Extended operation rovers analogous to the Mars Exploration Rovers are required to provide needed remote sensing ground truth and characterize resources, while automated sampling of key locations is particularly needed to address fundamental questions about the Moon (with implications for all of the terrestrial planets) and preparing for future human exploration. This project will further science and exploration objectives by identifying locations for future robotic precursor exploration, specific traverses designed to achieve science objectives, sampling stations, and resources to define hardware requirements for feasible lunar precursor missions.

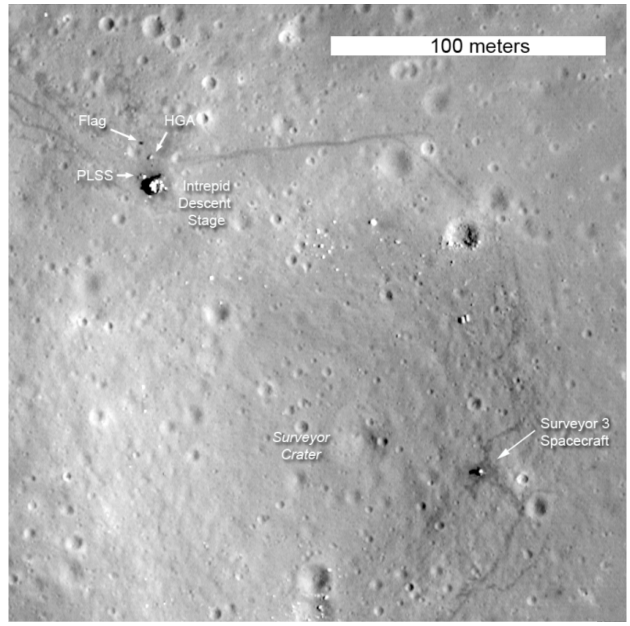

Figure 1. The Apollo 12 and Surveyor 3 Landing Sites.

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 [26], and slopes. Finally, we have developed a preliminary path planning algorithm based on a generalized least-energy model for planetary rovers, altered for the lunar use case [27] to explore and define mobility options. In all cases presented here, a necessary first step is to identify Regions of Interest (RoI) where a safe landing can be readily achieved to serve as either locations for automated sample return or initial points for rover traverses, but which also satisfy the stated science objectives with automated science return. Our approach is to simply identify 1 km circular RoIs that meet our criteria for these landing sites and initial points.

A key question: One of the most important questions to ask when considering future lunar exploration is "What makes a good landing site?" While the Moon can present the appearance of a challenging exploration target due to the presence of craters and boulders on the surface, in reality, vast portions of the lunar surface are undoubtedly accessible. Nevertheless, metrics are required to assess landing site suitability from an operational standpoint. This question is important because many high priority locations for future exploration are considered challenging landing sites from a morphometric perspective.

Approach: Our hardware-agnostic approach to develop defensible criteria for landing site selection is to determine the morphometric properties of missions that have successfully landed on the lunar surface. Accordingly, we created comprehensive data suites for previous lunar surface missions (e.g., Fig. 1) including NAC DTMs (scale: 2 m/pixel), GLD100 data, and Diviner rock abundance [28] to characterize these landing sites. NAC imagery was used to precisely position 200m regions of interest around the spacecraft, and NAC DTMs were used to calculate the TRI and determine slopes. These measurements allow us to quantify the range of morphometric parameters exhibited by regions where lunar landings have been successfully achieved (Figure 2):

- NAC TRI values between 0.077 and 0.462
- NAC DTM slopes < 10°
- Diviner rock abundances [DRA] between 0.003-0.011

Conclusions: This analysis serves as a useful starting point for judgments of landing site feasibility: If a given landing site has morphometric parameters derived using LRO data that fall within the envelope defined by the locations on the Moon where lunar landings have been successfully executed, then by definition, a lunar landing at that location can be shown to be achievable. Future mission concept proposals can use these results to inform site selection activities.

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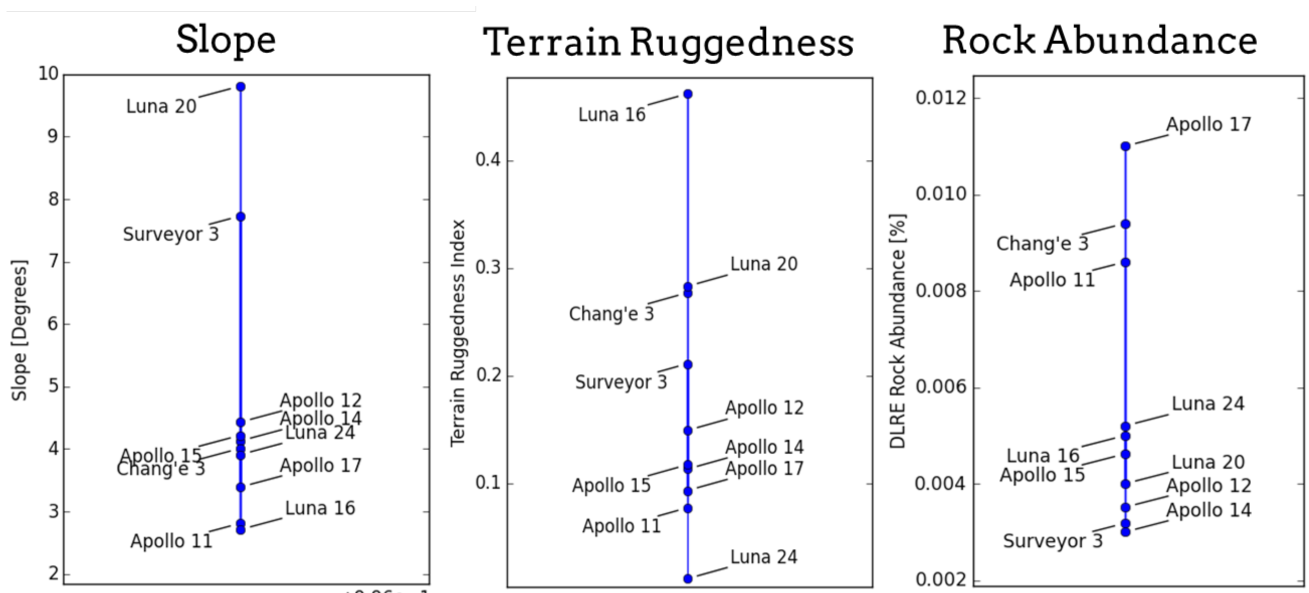

Figure 2: LRO-derived morphometric properties (NAC DTM Slope, surface roughness, and rock abundance) for historical lunar landings.