OPERATIONAL AND SCIENTIFIC ASSESSMENT OF LUNAR EXPLORATION SITES.
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Introduction: New observations from Kaguya, Chandrayaan-1, and the NASA Lunar Reconnaissance Orbiter (LRO) are advancing our understanding of the lithologies present in the lunar crust [e.g., 1-4], the distribution and timing of lunar volcanic features [e.g., 5-10], the surficial nature of lunar swirls [e.g., 11], and the nature of lunar tectonism [12-14].

While the LRO mission continues to produce important advances in lunar science, the original goal of LRO was to collect observations required to facilitate planning and operations of future human lunar and robotic exploration missions. Relatively few analysis efforts have leveraged LRO data for exploration planning [15-19], and these have in general focused on the Constellation lunar surface exploration architecture [20]. The Constellation Regions of Interest encompass a diverse range of exploration sites, but recent discoveries have identified additional sites of high exploration and science value that should also be studied in an exploration context...

To address this issue, we are complementing other lunar exploration site studies by systematically assessing (from both scientific and operational perspectives) fifteen places on the Moon considered to be likely locations for near-term robotic precursor missions (Table 1). In order to maximize the near-term utility of the proposed 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 [21]. However, the results of this study will also be applicable to future human lunar exploration.

Objectives: This study has three main goals:

Define optimal landing sites for future robotic precursor lunar missions: Using morphology, topography, temperatures, illumination, roughness, slopes, and rock abundances we are identifying landing sites optimized for scientific exploration of the lunar surface and/or the achievement of specific exploration objectives (i.e., In-Situ Resource Utilization [ISRU] demonstrations).

Identify meter-scale traverses and focused investigation stations: Using LRO NAC images and NAC-derived digital terrain models (DTM), we are identifying outcrops, specific boulders, craters, and other lunar geologic features and evaluating how these locations as traverse stations will satisfy scientific or engineering objectives. We are deriving slope and roughness parameters to automatically determine the navigability of a proposed traverse. Planning at this level was not generally enjoyed by the Apollo missions; however, by beginning the process now, the results of this and similar studies can inform and enable future exploration destinations and enhance science return.

Develop Concept of Operations for Teleoperated Spacecraft to Inform Future Hardware Decisions: Assessments for each study region will produce results directly addressing critical questions about rover, lander, and/or human exploration concepts of operation, including: distances required to reach scientifically interesting locations from landing sites, accessibility of specific locations, ability of wheeled mobility systems to fulfill mission objectives, and measurement objectives needed to fulfill investigation goals.

Reference Missions: In order to frame decisions about how to assess the scientific targets within a given study area, we define three use cases that are designed to be responsive to lunar surface activities recommended in the Lunar Exploration Roadmap [21] and that can be executed within the next decade as either competed Discovery/New Frontiers missions or human exploration precursor missions.

Automated Sample Return: The first use case is an automated sample return similar to the recent proposed MoonRise mission [16]. Automated sample returns have been suggested as a mechanism to answer key science questions about the timing and nature of lunar volcanism and lunar resource potential [16, 22-23].

Limited Duration Rover: This use case envisions a teleoperated, solar-powered rover with capabilities comparable to the Mars Exploration Rovers [24] designed to address specific objectives during a single lunar day. Under this use case, a single rover would travel several kilometers at a single site, visiting preselected science targets to answer specific science questions.

Long-Duration Mobile Prospector: This use case has mobility capabilities analogous to the Mars Science Laboratory, designed to travel a minimum of 5-20 km and powered by a radioisotope generator. This would be a long-duration roving mission to prospect for lunar resources and provide ground truth for orbital observations. This mission requires the ability to travel 10s-100s of km with a mission duration of at least six months to assay resources at several sites and determine the lateral and vertical distribution of prospective lunar resources while accomplishing key science objectives [25].

Study Area Selection: The study areas involved in this project (Table 1) were selected to address lunar science and exploration goals defined by community reports [21,23,26-28], particularly the need to determine the extent and compositional variations in lunar volcanism and to assess lunar resource potential. In order to maximize the near-term utility for exploration missions, nearly all of the proposed sites are located on the lunar nearside, where a communications relay will not be necessary.

Methods: We are coregistering 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. The integrated datasets are being used to determine important lithologies and geologic units, identify productive exploration locations and resources such as pyroclastic deposits, and then identify candidate landing sites. NAC DTMs are being used to assess the accessibility of each site in terms of the Terrain Ruggedness Index [29] and slopes. Finally, we have developed a preliminary path planning algorithm [30] based on a generalized least-energy model for planetary rovers, altered for the lunar use case [31]. This algorithm identifies least energy traverse paths and allows us to determine capabilities (rolling resistance, turning capability, maximum slopes) that are required to reach specific targets.

Conclusions: 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.

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Table 1. Study Area Locations

Site Name	Center Lat	Center Lon	Rationale	Use Case
Mairan Domes	41.7	312	Silicic Volcanism	Rover/Sample Return
Ina D	18.5	5.2	Unique Volcanism	Rover
Marius Hills	13.7	304.1	Non-Silicic Volcanism	Rover
Isis/Osiris	18.8	27.6	Non-Silicic Volcanism	Rover
Rima Parry V	-7.1	343.2	Non-Silicic Volcanism	Rover
Compton-Belkovich	60	99.6	Farside Silicic Volcanism	Rover/Sample Return
Dewar	-2.1	166.7	Farside Volcanism	Rover/Sample Return
Procellarum Basalts	18.9	308.3	Young Volcanism	Sample Return
Marius Hills Pit	14.1	303.2	Volcanic Terrain and Subterranean Voids	Rover
Aristarchus-1	24.4	311.5	Complex Geology and ISRU Prospecting	Rover/Sample Return
Sulpicius Gallus	19.7	10.2	Pyroclastics	Rover/Sample Return
Sinus Aestuum	5.6	344.8	Spinel Composition	Rover/Sample Return
Reiner Gamma	7.3	300.9	Lunar Swirl	Rover
North Polar PSR	89.3	130.9	Polar Volatiles	Rover
South Polar PSR	-89.7	201.2	Polar Volatiles	Rover