EXPLORATION OF SOUTH POLAR REGION OF THE MOON: TELE-OPERATED TRAVERSES.

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Introduction: The International Space Exploration Coordination Group (ISECG) has been examining mission scenarios that are consistent with its Global Exploration Roadmap (GER) [1]. Hufenbach et al. (2015) outlined a Design Reference Mission (DRM) architecture for humans to the lunar surface. In this concept, there are five landing sites for crew. At the first landing site they utilize two Lunar Electric Rovers (LERs), which are then tele-operatively driven to each of the next four landing sites. The five human landing sites [2] are: Malapert Massif, South Pole (Shackleton), Schrödinger Basin, Antoniadi Crater, and South Pole-Aitken (SPA) Basin Center. The time constraint for the traverse between these human landing sites is 365 Earth days. It is assumed that the LERs can only be moved during lunar daylight and with communications with Earth relayed through the eDSH during the tele-operated traverse. Here we evaluate the feasibility of a traverse between those landing sites and optimize that traverse to address lunar science and exploration objectives [3]. In a companion abstract [4], we explore crewed LER traverses at each landing site.

Traverse Conditions: A speed of 0.36km/h (0.1m/s) is assumed, based on the planned driving speed of the Resource Prospector rover, which is consistent with the bandwith of the Deep Space Network and the speed where a neutron detector and Ground Penetrating Radar (GPR) can survey the surface. We also assign a 30% margin to that speed. The maximum accessible slope is restricted to 25º, with a preferred slope of less than 15º [5].

Accessibility: The maximum driving distance is calculated with the following constraints. It is assumed that the surface is illuminated half of the year because of the day and night transition. Communication coverage via an asset in a large halo orbit around the Earth-Moon Lagrange point 2 (EM-L2) changes from 84.5% of the time per orbital period of 10.6 days from Malapert Massif to South Pole (Shackleton Crater) to 86% between Antoniadi Crater and SPA Basin Center (based on an unpublished study shared with us by the Lockheed Martin Corporation). For a 0.36 km/h speed and a 30% contingency margin, we calculate the maximum drivable distance (**Table 1**). The most efficient tele-operated traverses between the human landing sites were designed using slope maps from the highest resolution LOLA Digital Elevation Model (DEM) available at each landing site. The resolution of the DEMs changes from 5 m/px near the South Pole to 100 m/px at lower latitudes. In areas with steep slopes and low resolution DEMs, Narrow Angle Camera (NAC) images (1 m/px) were used to provide a better assessment of the terrain. That analysis revealed that there is sufficient time to conduct a more complex science traverse to address NRC goals [3] and evaluate the potential for in situ resource utilization (ISRU). The resulting efficient and science traverses are shown in **Fig. 1** and their lengths listed in **Table 1**.

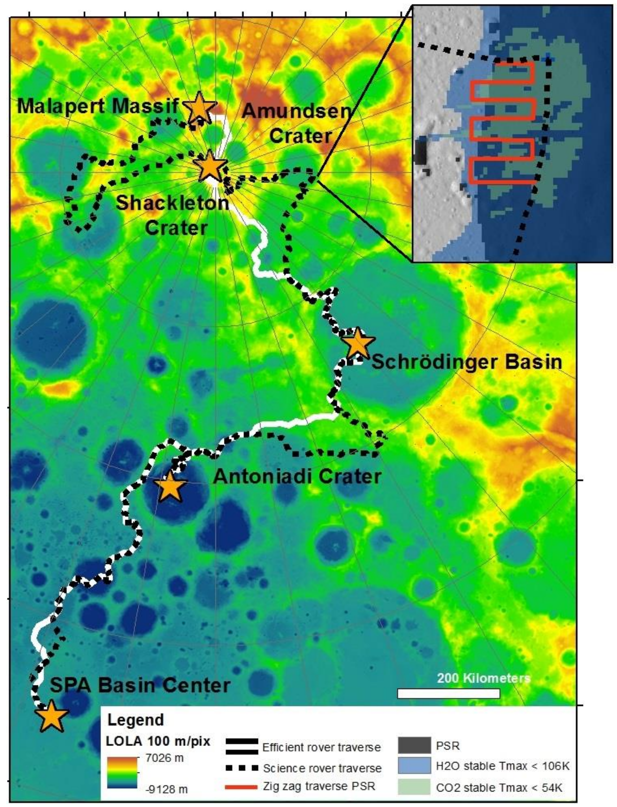

Fig. 1: *Science and efficient traverses between the five human landing sites. Zoom in shows a traverse on the edge of a PSR in Amundsen Crater to survey for volatile elements and their spatial distribution.*

Discussion: To accomplish science during the traverses, the study assumed the LERs had GPR, a neutron detector, and cameras. To increase scientific return, one or more tools for in-situ chemical analyses could also be installed. It would also be useful to have the ability to tele-robitically collect samples.

Malapert Massif to South Pole (Shackleton Crater) Traverse: Two highlights of this traverse are the ability to better understand early Solar System bombardment and the distribution of volatile resource deposits. The science traverse includes some of the largest craters in the SPA Basin, such as Drygalski and Ashbrook craters, where impact melt can be sampled for radiometric analyses. Additionally, it is possible to conduct a thorough sub-surface survey of ice deposits in Cabeus Crater and nearby regions. Temperature maps indicate the maximum temperatures in Cabeus Crater are low enough to host stable CO_2 ice [6], and the Lunar Prospector Neutron Detector (LPND) reported high concentration of hydrogen there [7]. An oscillating survey pattern across Cabeus Crater will provide a better spatial understanding of the volatiles in Permanently Shadowed Regions (PSRs).

South Pole (Shackleton Crater) to Schrödinger Basin Traverse: Here, the science traverse includes Amundsen Crater, which may be the best site to study volatiles [8,9]. Amundsen Crater has a relatively flat crater floor, making it possible to perform a search pattern along the edge of a PSR where the maximum temperature does not exceed the sublimation temperature for water and CO_2 (**Fig. 1**).

Entering and departing Schrödinger Basin with the LERs is possible in two locations based on an analysis of the 30 m/pix LOLA DEM, in which the slope does not exceed the 15º. NAC imagery of the proposed traverse were used to study potential obstacles smaller than the LOLA DEM resolution.

Schrödinger Basin to Antoniadi Crater Traverse: The science traverse to Antoniadi Crater focuses the crater walls which have the potential to expose the SPA impact melt sheet. Close to Schrödinger Basin, a secondary impact field originated from the emplacement of Antoniadi Crater along with impact melt ponds from Schrödinger Basin [10].

There is only one possible way to access the floor of Antoniadi Crater based on a slope map from a 60 m/pix LOLA DEM. There the maximum slope is 17º.

Antoniadi Crater to SPA Basin Center Traverse: Due to the large distance between these two human landing sites, the science and efficient traverses only differ slightly. The science traverse visits a side of Mafic Mound that may not be accessible to crew. Additionally, more mare and cryptomare basalts in the vicinity of the human landing site can be studied.

Conclusion: Based on this feasibility study, and given the constraints of time, communication, illumination, and speed, the five human landing sites proposed in [2] are all accessible with tele-operated LERs. The proposed science traverses in this study provide valuable opportunities to address NRC (2007) goals [3]. In particular, these science traverse provide an opportunity to study complex impact craters and conduct a comprehensive survey of volatiles suitable for ISRU in two locations. To accommodate trafficability of those shadowed, potentially volatile-rich areas, the LERs will need to have the capability of accessing PSRs for short periods of time.

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References: [1] ISECG (2013) *The Global Exploration Roadmap*, NASA NP-2013-06-945-HQ, 42p [2] Hufenbach B. et al (2015) *Proc. of 66th Int. Astro. Congress*, IAC-15-A5-1-1-X30756. [3] NRC (2007) *The Scientific Context for Exploration of the Moon*,107p. [4] Ende J. J. et al. (2017) *LPS XLVIII, submitted.* [5] Öhman T. and Kring D. A. (2012) *JGR, 117*, E00H08. [6] Paige D. A. et al. (2011) *Science, 330*, 479–482. [7] Elphic R. et al. (2007) *GRL*, *34*, L13204, 5p., doi:10.1029/2007GL029954 [8] Lemelin M. et al. (2014) *Planetary and Space Science, 101*, 149–161. [9] Runyon K. et al. (2012), *LPS XLIII*, Abstract #1619. [10] Kramer G.Y. et al. (2013) *Icarus*, 223, 131–148.

From	To	Maximum drivable distance (km)	Efficient Traverse (km)	Science Traverse (km)
Malapert Massif	South Pole/ Shackleton Crater	932.7	208.4	911.4
South Pole/ Shackleton Crater	Schrödinger Basin	938.2	739.7	923.5
Schrödinger Basin	Antoniadi Crater	943.7	681.9	935.8
Antoniadi Crater	South Pole-Aitken Basin Interior	949.2	939.5	946.9

Table 1: *Calculated maximum drivable distances and topographic lengths of efficient and science for each tele-operated traverse*