ROVER TRAVERSE PLANNING TO SUPPORT A LUNAR POLAR VOLATILES MISSION. J. L. Heldmann[1], A. C. Colaprete[1], R. C. Elphic[1], B. Bussey[2], A. McGovern[3], R. Beyer[1,4], D. Lees[1], M. C. Deans[1], N. Otten[5], H. Jones[5], and D. Wettergreen[5]. [1]NASA Ames Research Center, Moffett Field, CA, [2]NASA Headquarters, Washington, DC, [3]Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, [4]SETI Institute, Mountain View, CA, [5]Carnegie Mellon University, Pittsburgh, PA.

Introduction: Studies of lunar polar volatile deposits are of interest for scientific purposes to understand the nature and evolution of the volatiles, and also for exploration reasons as a possible in situ resource to enable long term exploration and settlement of the Moon. Both theoretical and observational studies have suggested that significant quantities of volatiles exist in the polar regions, although the lateral and horizontal distribution remains unknown at the km scale and finer resolution. A lunar polar rover mission is required to further characterize the distribution, quantity, and character of lunar polar volatile deposits at these higher spatial resolutions. Here we present two case studies for NASA's Resource Prospector (RP) mission concept for a lunar polar rover and utilize this mission architecture and associated constraints to evaluate whether a suitable landing site exists to support an RP flight mission.

Resource Prospector: RP is a robotic mission currently in formulation (Phase A) by NASA's Human Exploration and Operations Mission Directorate (HEOMD) to both prospect for water resources and conduct ISRU (in situ resource utilization) on the Moon [1,2,3]. For prospecting, RP is designed to characterize the distribution of water and other volatiles at the lunar poles. RP aims to map the surface and subsurface distribution of hydrogen-rich materials within the upper 1 meter of the Moon, determine the constituents and quantities of volatiles, and provide limits on key isotope ratios (e.g., D/H, $^{18}O/^{16}O$, $^{36}S/^{34}S$, $^{13}C/^{12}C$). RP is also an ISRU processing demonstration mission, using a hydrogen reduction process to extract oxygen from lunar regolith. RP will both demonstrate the hardware in the lunar setting and also capture, quantify, and display the water generated from the ISRU processing [1,2,3].

The RP surface conops has multiple modes of operation critical to mission success including 1) Prospecting, 2) Mapping 3) Excavation, and 4) Demonstration [4,5,6,7]. In Prospecting mode, the RP rover is traversing across the lunar surface as the prospecting instruments search for enhanced H_2O/OH, other volatiles, and/or volumetric hydrogen in the form of ice or other H-bearing compounds. When enhancements of volatiles are detected, a decision is made whether or not to map the area at higher spatial resolution (e.g., area of interest mapping, AIM) or immediately auger or collect subsurface samples. Once a decision has been made to collect samples, the rover enters Excavation mode where samples are acquired from the subsurface, processed by the onboard payload, and evolved gases are measured. Prospecting mode can continue throughout the primary mission as the rover maps volatiles and samples across a variety of environments, testing theories of emplacement and retention, and constraining the economics of extraction. Demonstration mode occurs at the end of the RP primary mission when oxygen extraction from the regolith is demonstrated using hydrogen reduction, thus testing two possible ISRU pathways: ISRU from local volatiles and water production from "dry" regolith [7].

A specific concept of operations (conops) has been developed for RP to achieve the mission objectives. RP is envisioned as a low cost mission and is reliant on solar power for operations [1,2,3]. This constraint requires either operations in sunlight or sufficient battery power to enable operations in shadow. The nominal mission profile includes the rover landing in an area illuminated by the sun and then traversing across the lunar surface to achieve the RP success criteria.

In addition to operating in the sunlit regions, RP must also collect measurements in shadowed areas to provide information on volatile content in these colder regions. Thus both sunlit and shadowed operations are an integral element of the RP operations architecture. RP also requires direct to Earth (DTE) communications given the low cost nature of the mission concept.

The RP measurement requirements can be broken into categories to achieve minimum success, full success, and stretch goals. Minimum success requires RP to make measurements from two places on the Moon separated by at least 100 meters, and these can include surface or subsurface measurements. Full success requires measurements from two locations on the Moon separated by at least 1000 meters, surface and subsurface measurements (where subsurface measurements are specifically obtained with a drill for sample collection), measurements in and a sample acquired from a shadowed area, and demonstration of ISRU. Stretch goals include making subsurface measurements (with an auger) in at least eight locations across 1000 m (point-to-point) distance, making subsurface measurements (sample and processing) at least four locations across a 1000 m point-to-point distance, and providing geologic context.

To achieve the mission objectives and operate within the given mission constraints, RP requires only 4-10 days of operations. The mission duration is a balance between targeting the most scientifically compelling region(s) that have high hydrogen abundances and are located in proximity to shadowed areas which also possess benign slopes and topography for rover trafficability plus access to DTE communications for the duration of the mission. These areas are by default relatively cold (e.g., high polar latitude) and only experience a few (~4-10) days of sunlight each month.

Site Selection: The success of a lunar polar rover mission such as RP is highly dependent upon selecting the optimal landing site. We have attempted to identify candidate polar landing sites based on the following four criteria: 1) presence of surface/subsurface volatiles, 2) reasonable terrain for traversing, 3) direct view to Earth for communication, and 4) sunlight for the duration of the mission (power constraints).

Traverse Planning: We use the Exploration Ground Data Systems (xGDS) platform to create traverse plans. xGDS is a suite of software tools developed to support mission planning, monitoring, visualization, documentation, analysis, and search functionalities [8]. We also use novel software developed by Carnegie Mellon University to test automated traverse planning capabilities [9]. Below we summarize two notional traverse plan options at Haworth Crater and the Nobile region near the lunar south poles.

Haworth Crater. Haworth Crater has been shown to meet the high-level RP site selection criteria of elevated hydrogen abundances, acceptable slopes, DTE, and sunlight availability. Figure 1 shows a notional traverse plan for the Haworth region. The landing site is chosen in a region of low slope and in sunlight. We choose this site such that the traverse path can proceed towards the east as the sunlight (terminator) also moves to the West such that shadows cast by topographic relief swing to the East. The plan then fulfills the minimum and full success criteria of RP, followed by the stretch goals.

Nobile. The Nobile region has been explored as a potential option for a longer duration lunar polar mission to study volatiles. Figure 2 shows a notional 60+ day traverse plan for Nobile, where the rover lands on a ridge of sunlight and ventures down into the colder plains below (which also contain shadowed areas) to explore volatiles, returning to the ridge when necessary for sunlight and/or communications to extend the duration of the mission.

Conclusions: This work demonstrates that viable traverse plan options exist to meet the success criteria (and stretch goals) for the RP mission. We also find that the landing site chosen for this mission is critical to all future surface planning and activities. Illumination conditions vary significantly over time and are strong drivers in terms of traverse planning. The presence of shadow (both transient and permanent) also have substantial implications for traverse planning and the mission timeline. Advanced planning tools will be required to support real-time operations for a mission with a real-time operations concept. Finally, traverse plan options exist which can significantly extend the length of a lunar polar rover mission.

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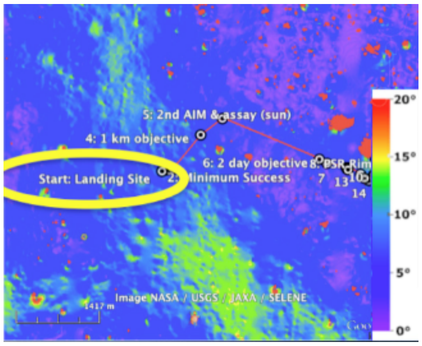

Figure 1. Sample traverse plan near Haworth Crater.

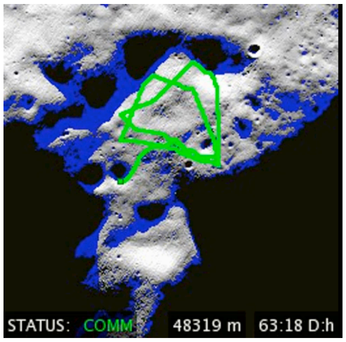

Figure 2. Example of long duration traverse plan near Nobile. Green represents the rover path.