TRAVERSE PLANNING FOR ROBOTIC RECON AND HUMAN EXPLORATION OF HADLEY RILLE.

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Overview: On November 6, 2008, we conducted a short lunar traverse planning exercise at the NASA Ames Research Center [1]. The objective was to plan an EVA traverse for a hypothetical, manned mission to the Apollo 15 region and then identify where ground-level data would help refine the plan. The planning for this mission, which we named "Apollo 15B", focused on the region of Hadley Rille and Montes Apenninus.

During the exercise, we used a variety of lunar data including base maps, digital elevation models and other (e.g., geologic) maps. All data were registered to the ULCN 2005 control network and viewed in a version of the Google Earth geospatial browser, which we modified to provide lunar distance measurements.

Science Rationale: For "Apollo 15B", we selected a landing site south of Hadley C at 25.3N, 2.9E. From this location, both Hadley C and Hadley Rille are directly accessible. In addition, the ejecta blanket from Hadley C, which is deposited on to Hadley Rille, provides a deep sampling of crater materials and serves as a natural bridge across the rille to Montes Appeninus.

Our interest in this area is best summarized by [6]:

> *"The Apollo 15 landing was targeted next to a large sinuous rille, Rima Hadley. Several other rilles were considered for landings to determine their formation and to collect samples of volatiles or other exotic erupted materials."*

and

> *"One of the major objectives of the Apollo 15 mission in July 1971 was to collect samples of the Montes Apenninus. According to impact models based on simple craters, this basin rim material might have come from deep within the Moon."*

Robotic Recon: NASA currently plans to return to the Moon with a campaign of regularly spaced surface missions. Crewed missions will initially be "extended sortie" (e.g., 1-2 week) missions. This means that during the first few years of the new lunar campaign, humans will be on the Moon less than 10% of the time. However, during the 90% of time between crew visits, robots could perform tasks under ground control.

Prior to these surface missions, spacecraft (e.g., LRO) in lunar orbit will map the Moon. Additional data is available from past orbiters (e.g., Clementine) and the continued enhancement of data from these missions. However, remote sensing data may not be of sufficient resolution, lighting, nor view angle, to fully optimize mission planning (e.g., field geology traverses). Thus, it will be important to acquire supplemental and complementary data from ground-level (i.e., directly on the lunar surface).

Robotic recon (i.e., using a planetary rover to scout planned sorties) can perform this task prior to human surface activity [3-5]. Scouting is an essential phase of field work, particularly for geology, and can be: (1) traverse-based (examining stations along a route); (2) site-based (examining an area); (3) survey-based (systematically collecting data) or (4) pure reconnaissance.

During robotic recon, robot-mounted instruments can be used to examine the surface and subsurface at resolutions (e.g., micron to cm scale) and at viewpoints not achievable from orbit. The data can then be used to prioritize targets of interest to improve the productivity of crew traverses. In addition, robotic recon can help identify and assess terrain hazards, as well as evaluate alternate routes to help reduce operational risk [5].

Traverse Routes: We planned two traverses to explore the "Apollo 15B" site (Figures 1 and 2).

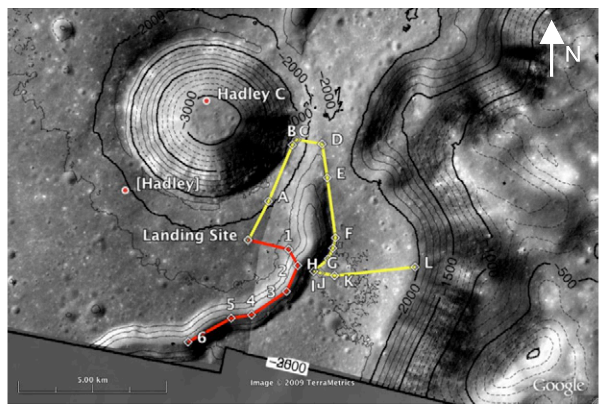

Figure 1. "Apollo 15B" traverses: EVA (red, stations 1 to 6) and robotic recon (yellow, stations A to L).

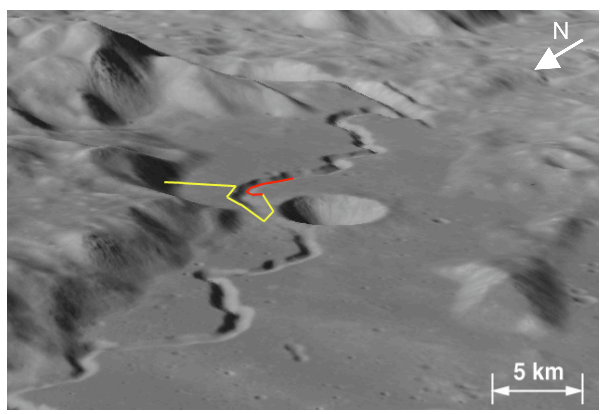

Figure 2. Traverses shown on an oblique view of Hadley C, Hadley Rille, and the Apennine mountains.

EVA Traverse: The planned EVA traverse is approx. 7 km one-way. The primary objective for this traverse is to descend from the landing site into Hadley Rille and then continue along the bottom. We designated six stations (numbered 1 to 6) as navigational via points and sampling locations (Table 1).

Table 1. EVA traverse objectives

Station	Tasks	Objectives
Landing site	Sample and document the mare and regolith materials.	Sample the outer ejecta blanket of crater Hadley C.
1 edge of rille	Sample and document lava flow materials to edge of Hadley Rille.	Prepare for descent (use data from recon F to I).
1 to 3 traverse into rille	Document along and across (to east side) rille wall.	Observe Hadley Rille structure.
3 to 6 rille bottom	Sample rille bottom. Document wall structure and layering.	Describe notable changes in rille structure.

To plan the EVA traverse, we assumed that the crew would perform the traverse in Apollo style (i.e., on foot or riding on an unpressurized crew rover). This constrains the one-way distance to a maximum of 10 km for unassisted walkback.

Robotic Recon Traverse: The robotic recon traverse, which is performed prior to the EVA traverse, is 13 km one-way. The traverse objectives are: (1) scout Hadley C for possible EVA; (2) cross ejecta blanket and assess alternate route into Hadley Rille; (3) acquire imagery of the EVA traverse from the opposite side of Hadley Rille; and (4) scout approach to Apennine Front. We designated twelve stations (lettered A to L) as via points and measurement locations (Table 2).

To plan the robotic recon traverse, we assumed: (1) planetary rover (100 kg, 30 deg slope and 20 cm obstacle capable, lunar night survivable, 50 cm/s max speed); (2) non-contact instruments: 3D lidar (Optech ILRIS-3D equivalent), color panoramic imager (MER pancam equivalent), multi-spectral imager (MER pancam equivalent), terrain imager (MER Microscopic Imager equivalent), ground-penetrating radar (CRUX GPR equivalent); and (3) Earth-based ground control operations.

Traverse Planning Datasets: For planning, we used several lunar datasets, which were all registered to the Unified Lunar Control Network (ULCN) 2005. The primary datasets were: (1) recent high-res digital scans of Apollo Metric Camera (AMC) images, (2) digital elevation models (created from the AMC images using the Ames StereoPipeline processing system [2]), (3) Clementine UV-VIS image base map, (4) Montes Appeninus lunar chart and geologic map, and (5) Apollo Panoramic Camera images.

Table 2. Robotic recon traverse objectives

Station	Tasks	Objectives
Landing site	Panoramic and terrain images. Ground-penetrating radar (GPR) scans.	Document landing site, including subsurface.
A	Document contact zones with stereo, panoramic, and multi-spectral images.	Examine ejecta material from Hadley C.
B and C Hadley C rim	Document surface with stereo, panoramic, and multi-spectral images.	Examine ejecta. Scout possible descent route into Hadley C.
D and E ejecta blanket	Document with stereo, panoramic, and multi-spectral images. Conduct GPR survey.	Examine ejecta. Scout route to Palis Putredinis & Apennine Front.
F and G West rim of rille	Acquire 3D lidar scans of ejecta blanket (top to rille floor).	Scout alternate route for crew into Hadley Rille.
H and I: west rim of rille	Acquire images and lidar scans of planned EVA stations. Document rille wall.	Scout planned crew descent (look across rille to crew traverse 1 and 2).
J and K: lava plans of Palis Putredinis	Document surface with stereo, panoramic, and multi-spectral images. Conduct GPR survey.	Examine lava material on Palis Putredinis. Scout possible crew traverse.
L: towards Apennine Front	Document contact zones with stereo, panoramic, multi-spectral, and 3D lidar.	Examine variety of rock types for sampling (possible crew traverse).

Conclusion: When the new lunar surface campaign begins around 2020, it will be important to make use of technological developments (high-resolution remote sensing, teleoperated planetary rovers, etc.) that have occurred since the end of the Apollo program. Robotic recon, for example, has the potential to significantly improve science return from the lunar surface. In particular, our planning exercise for “Apollo 15B” demonstrates how recon can aid plan prioritization, can supplement and complement remote sensing, and can assess hazards and routes to reduce operational risk.

References: [1]M. Broxton, et al. (2009) “Traverse planning for human and robotic missions to Hadley Rille”, NASA TM. [2] M. Broxton and L. Edwards (2008) Abstract 2419, LPSC. [3]T. Fong, et al. (2008) AIAA-2008-7886. [4]T. Fong, et al. (2008) Abstract 4049, LEAG. [5]M. Deans, et al. (2009) “Robotic recon for human exploration”, Tech. rep. NASA Ames. [6]D. Wilhelms (1987). Paper No. 1348, USGS.

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