USE OF ROBOTIC PRECURSOR MISSION FOR FOLLOW-ON HUMAN EXPLORATION: CASE STUDY LUNAR ANALOGUE MISSION AT THE MISASTIN LAKE IMPACT STRUCTURE

M. M. Mader[1], G. R. Osinski[1], I. Antonenko[1], T. Barfoot[2], M. Battler[1], M. Beauchamp[1], A. Chanou[1], E. Cloutis[3], M. Daly[4], R-D. Capitan[1], R. Francis[1], N. Ghafoor[5], R. A. F. Grieve[1], K. Hodges[6], B. L. Jolliff[7], M. Kerrigan[1], E. McCullough[1], J. Moores[1], C. Otto[8], A. Pickersgill[1], A. Pontefact[1], L. Preston[1], D. Redman[9], H. Sapers[1], B. Shankar[1], A. Singleton[1], P. Sylvester[10], L. L. Tornabene[1], T. Unrau[1], K. Young[6], and M. Zanetti[7]. [1]Centre for Planetary Science and Exploration/Canadian Lunar Research Network, Depts. Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON, Canada, [2]Institute for Aerospace Studies, Univerisity of Toronto, ON, Canada, [3]Dept. of Geography, University of Winnipeg, MB, Canada, [4]Dept. Earth and Space Science & Engineering, York University, ON, Canada, [5]MDA Space Robotics, Brampton, ON, Canada, [6]School of Earth and Space Exploration, Arizona State University, AZ, USA, [7]Dept. Earth & Planetary Science, Washington University, MO, USA, [8]NASA Johnson Space Center, TX, USA, [9]Sensors & Software, Toronon, ON, Canada, [10]Dept. of Earth Sciences, Memorial University, NL, Canada. (marianne.mader@gmail.com, gosinski@uwo.ca).

Introduction: Sample return from the Moon and Mars is a high priority for the international scientific community, in order to ground truth theories of planetary formation and surface processes. Robotic missions followed by human exploration missions have been proposed as an effective strategy for surface exploration (e.g., [1, 2]).

In order to prepare and test protocols for future lunar sample return missions, our team carried out two analogue missions at the Mistastin Lake impact structure, Canada, funded by the Canadian Space Agency. The first mission took place over three weeks in August and September 2010 and involved robotic surveying of proposed "landing sites". This was followed by a second, two-week mission, at the same location in 2011, which included simulated astronaut surface operations.

For each deployment a mission control team was based at the University of Western Ontario located in London, Ontario, over 1900 km away; communication was via satellite terminal in the field, with daily data budgets of ~100 MB. Neither the mission control team nor the 'astronauts' had *a priori* knowledge of the site.

To determine how to optimize a robotic precursor mission for field reconnaissance for augmentation of a follow-on human mission, several important questions were addressed by our study:

- What key instruments and scientific data are needed from a robotic precursor mission to support human operations/sample return?
- How do we adapt robotic precursor mission to the science needs of a specific landing site?
- What surface mobility system is best-suited for a robotic precursor mission with a human follow-on/samle return?

Our analogue mission campaign was driven by the paradigm that the operational and technical objectives are conducted while conducting new science and addressing real overarching scientific objectives. Without such scientific focus, operational and technical lessons learned may have been applied out of context.

Lunar Analogue Site: The Mistastin Lake impact structure, in northern Labrador, Canada (55°53'N; 63°18'W), was chosen because it represents an exceptional analogue for an a lunar highland crater [3]. This site includes both an anorthositic target and preserved ejecta deposits (including melt and breccias) [4]. The intermediate-size crater formed by a meteorite impact ~36 million years ago. The original crater has been differentially eroded; however, a subdued rim (diameter ~ 28 km) and distinct central uplift are still observed [5]. The inner portion of the Mistastin Lake impact structure is covered by the Mistastin Lake and the surrounding area is locally covered by soil/glacial deposits and vegetation. The topography directly surrounding the lake is slightly elevated in plateaus extending up to 5 km away from the shoreline (Fig. 1).

The overarching mission objectives for the analogue mission were to further our understanding of impact chronology, shock processes, impact ejecta and potential mineral resources.

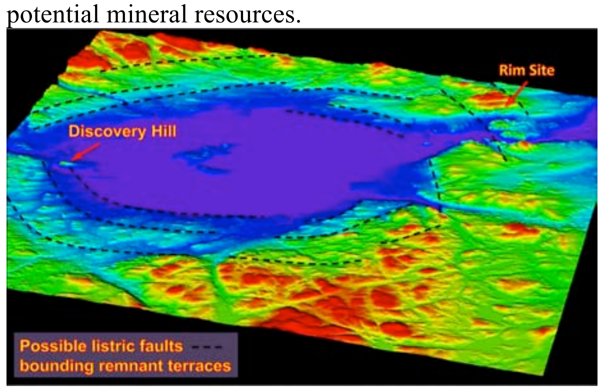

Figure 1:A colorized shaded relief model of Mistastin. Possible listric faults defining the terrace region are outlines in black dashed lines.

Overview of Analogue Mission Campaign: Our scientific approach mirrors exploration strategies for traditional geological exploration and field campaigns conducted on Earth, by 1) Using orbital and aerial data sets to assess geologic diversity, landing site selection, and accessibility/traverse planning; 2) Conducting reconnaissance surface mapping to get an overview of the site from the ground; 3) Follow-up detailed traverses, to study sites of interest in detail. Here we highlight this scientific process for a single landing site, Discovery Hill, situated on the southwest edge of Mistastin Lake (Fig. 1).

Site Selection Workshop, 2010: A site selection workshop was conducted prior to the deployments (results detailed in [5]). Three separate regions around the Mistastin Lake were chosen for reconnaissance exploration by the rover.

Robotic Precursor Mission, Mistastin 2010: No mechanical robot was used on this deployment; instead, a field team of up to five people acted collectively as the robot – they made traverses with the instruments, collected data as requested by mission control, and sent the data to the remote mission control team using satellite communication [6]. At each site, instruments used in the field to characterize the regional context and then progressively focus the geographic area of study, included lidar, Gigapan camera, ground penetrating radar (GPR), mobile scene modeller (mSM), and X-ray fluorescence spectrometer (XRF).

Planning for a Human follow-on Mission: Following the robotic precursor mission, the data collected from the sites were reviewed. Two sites were chosen for further detailed work by human exploration: one site was located within the topographic high area surrounding Mistastin Lake, and the other was closer to the lakeshore and included a distinct topographic feature locally called Discovery Hill (see Fig. 1). Each of these regions are characterized by rugged terrain, and steep topographic relief.

Through the review of precursor data, Discovery Hill was determined to consist in part of a large outcrop of impact melt. The science team therefore focused on two hypotheses: 1) Discovery Hill melt is a portion of the continuous "melt sheet" from the crater floor, or 2) it is a discrete melt unit within the terraced rim section of the crater.

Human Exploration Mission, Mistastin 2011: Two PhD students acted as astronauts and explored the Discovery Hill site – one a geology graduate student with prior geological mapping field experience and specializing in impact cratering products (i.e. impactites), and the other a pilot with an engineering background and some geologic training (similar to many lunar astronauts). With only five days to explore the Discovery Hill area, a focused traverse strategy was developed for the human exploration that allowed for flexibility and adaptability to allow input from the astronauts.

Lessons Learned: Robotic reconnaissance has the potential to significantly improve scientific return from lunar surface exploration. In particular, data from robotic precursor missions can be used to narrow the scientific focus of a human mission (i.e. develop specific research questions and hypotheses to test), improve traverse planning, reduce operational risk, and increase crew productivity.

What key instruments and scientific data are needed from a robotic precursor mission to support human operations/sample return? We found that the main scientific value of a reconnaissance mission is providing surface geology visualization at resolutions and from viewpoints not achievable from orbit. High resolution surface imagery of surrounding areas on the scale of 10's of meters up to several km in extent. The most used data sets included large scale panoramic images that allowed a full contextual view of the surrounding area including exposure of rocks and traversibility of the area and lidar scans that provided range and scale information.

How do we adapt robotic precursor mission to specific site and science needs? The most useful data products were panoramic images and lidar scans taken from 'safe' vantage points looking at 1) steep topography (which allows would allow a cross-sectional view of stratigraphy within rocks) taken from below the rock exposure, 2) overview of landscape taken from a topographic high.

What surface mobility system should be used for a precursor mission? From this experience, it is suggested that the reconnaissance mobility can be more reduced then the mobility needed later for crew transport (i.e. crewrover). A 'small' rover with the ability to collect panoramic photography and lidar scans would meet baseline needs.

- Design rover to access low lying areas to view side of steep topography and reach high points to get pano of region

Recommendations: Focus reconnaissance science instrument/software development on 1) Visualization tools (m to km scale) including seamless data integration of high resolution imagery with lidar to measure distance and scale (e.g., imagery draped over high resolution lidar to create 3D scenes of landscape). Suggest including scale bar (e.g. by laser) in all collected imagery. 2) Instruments such as a multispectral sensor on the rover could further enhance the site selection process, provide remote mineralogical information, and provide scientific rational for prioritization at outcrop and sub-outcrop scales. 3) Data compression of high resolution imagery products (e.g. Gigapan and lidar) and/or communication architecture that allows for greater bandwidth to allow transfer of large files.

References: [1] Global Exploration Strategy (2007), The framework for coordination. [2] Fong et al. (2010). *Acta Astronautica 67*, 1176-1188. [3] Mader et al. (2010), Lunar Science 2010 Forum, Abstract. [4] Mader et al. (2011), LPSC abstract. [5] Grieve (1975) *Geol.Soc.of America Bull. 86*, 1617-1629. [5] Shankar et al. (2011), LPSC abstract. [6] Mader et al. (2011) The Importance of Solar System Sample Return Missionsto the Future of Planetary Science, Abstract.

Acknowledgments: Funding from the Canadian Space Agency (CSA) and the Northern Research Training Program (NSTP) are gratefully acknowledged. We'd like to thank Danielle Cormier, Allan Bassi, Alex Ozaruk, Salma Abou-Aoy, Jacky Clayton, Stephanie Blain and Nicky Barry for their participation during the 2011 deployments.