A CANADIAN SCIENCE MATURATION STUDY FOR THE PRECURSOR TO HUMAN AND SCIENTIFIC ROVER (PHASR) AS PART OF THE HERACLES MISSION CONCEPT. G. R. Osinski[1], M. Bourassa[1] , M. Cross[1], P. Hill[1], D. King[1], Z. Morse[1], E. Pilles[1], G. Tolometti[1], L. L. Tornabene[1], M. Zanetti[1]. [1]Centre for Planetary Science and Exploration, University of Western Ontario, London, ON, Canada (gosinski@uwo.ca).

Introduction: The focus on exploration of the Moon by the world's space agencies has been recently renewed in an effort to return humans to the lunar surface. Such efforts are taking shape in the form of the Lunar Gateway, a small periodically-habited space station orbiting near the Moon. The Gateway would not only provide a critical testbed for demonstrating necessary technologies for lunar exploration but would also facilitate a variety of science investigations both in orbit and on the lunar surface. The European Space Agency (ESA), along with the Japanese Aerospace Exploration Agency (JAXA) and the Canadian Space Agency (CSA) have partnered in an international mission concept proposed to test lunar exploration technologies and perform a science investigation called the Human Enabled Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES) [1].

The first component of HERACLES is called the Precursor to Human and Scientific Rover (PHASR). PHASR would land on the lunar surface to test technologies such as a lunar night survival and would perform a 70-day sample return mission to return lunar samples back to Earth via the Lunar Gateway. After the sample return phase, the rover would continue to explore the landing site area for one year to continue its science investigation. To prepare for the international science team discussions for HERACLES, CSA awarded a contract to our team at the University of Western Ontario to perform a Science Maturation Study for PHASR. This study focused on maturing the science requirements for the mission and to develop a Baseline Science Investigation involving identifying the science goals/objectives, choosing the suite of science instruments for the rover and designing a nominal traverse plan [2]. An analogue mission to test the science investigation and operations concept was developed as part of this contract. The deployment is planned to take place in the summer of 2019 in Lanzarote. The study also involved recommending an instrument to CSA that could be Canadian contribution to the mission and creating a science plan for the corresponding instrument team [3].

Goals and Objectives: CSA initially provided seventeen relevant science themes for our PHASR study as a starting point ranging from planetary evolution to identifying potential lunar habitats. We downsampled the list to four science goals. (1) Lunar Chronology: to return lunar samples to the Earth in order to constrain the early bombardment history of the solar system, characterize the lunar crust, and constrain the thermal evolution of the Moon. The specific objectives are to acquire chemical data and return samples of: clast-poor impact melt rock, ejected impact melt rock, peak ring material, and material from secondary craters. (2) Impact cratering: acquire samples and in-situ measurements of impactites to provide insight into peak ring basin formation, impact melting, and shock metamorphic processes, and to understand the provenance of uplifted and excavated lunar crustal material. The objectives are to acquire mineralogical/chemical data and return samples of impactites, peak ring material, and impact melt material, and to investigate shock effects and characterize geology of secondary craters. (3) Volcanism: acquire samples and in-situ measurements of mare and pyroclastic volcanic deposits to provide a clear view of the overall history of lunar volcanism and its relation to the Moon's thermal and compositional evolution. The objectives are to acquire chemical data and return samples of pyroclastic and mare deposits, and other volcanic material. (4) Human lunar exploration: to provide essential information for future human activity on the Moon. The science objectives are to measure the radiation and surface thermal environments, and to create geologic and terrain maps of the area.

Baseline Science Investigation: The first task for developing the Baseline Investigation was to select the suite of payloads that would satisfy the aforementioned science goals/objectives for PHASR. Two mast-mounted instruments were chosen: an Integrated Vision System (IVS) and a combined Raman/LIBS/Zoom Camera (e.g., Supercam on Mars 2020 [4]). The IVS combines a science camera (e.g., Pancam on ExoMars [5]) with a LiDAR and a spectral imager in the 1000 nm to 2500 nm range. It would provide high resolution panoramic colour images, 3D mapping, and textural information and spectral data to interpret mineralogy. The Raman/LIBS/Zoom camera collects spot data to identify chemical composition of rocks and soil and can also be used to interpret mineralogy. A radiation detector and thermopile are two body-mounted instruments used to measure a broad spectrum of radiation and to measure the lunar surface temperature. PHASR would also have two instruments mounted to a robotic arm: a microscopic imager and an in-situ geochemical spectrometer (e.g. APXS [6]). The microscopic imager would provide images of grain sizes and small-scale textural information. The in-situ contact spectrometer would analyze the chemical elements in rocks and soils to a higher fidelity than capable by the mast-mounted instruments. A set of sampling tools were also selected for the rover to cover the range of expected samples desired by the scientific community. The reference design for PHASR used for this study assumed that up 16 kg of sample material could be collected. A simple scoop device would be included to collect regolith and any loose rock fragments. A sieve would be implemented to also collect loose rock fragments and chips, but that can discard the regolith. Finally, a percussive chisel would be used to break off in-situ samples from larger boulders or outcrops to ensure the source of the sample and collect the appropriate context data.

With these instruments and sampling tools, a concept of science operations for PHASR was formed (Fig. 1). The operations would begin well before launch with a pre-landing traverse plan to identify sites of interest and the select the landing site [2]. Upon landing, the rover would traverse to the first site of interest. A site survey would be performed using the IVS to scan the surrounding environment to identify features of interest not visible in orbital imagery. These features would then be targeted by the stand-off Raman/LIBS/Zoom Camera for further analysis. The combined survey and stand-off data would be combined and discussed by mission control to down-select the features of interest to those that require further analysis. The rover would re-position itself and drive to a feature and deploy its robotic arm to collect microscopic images and in-situ geochemical data. A sample would then be acquired if the science team agrees the feature is suitable for sampling and meets the mission science objectives. If there is no further analysis or samples to collect, the rover would then drive to a new site and repeat the procedure. As indicated in Fig. 1, there are multiple exit options during the operations procedure. If no features are found at any stage, the rover could repeat the measurements to collect additional data or proceed to a new site.

Threshold and Augmented Science Investigations: The Threshold Science Investigation represents the minimum acceptable data and scientific return, below which the science mission would not be worth pursuing. For PHASR, the Threshold Investigation shall descope the mission by removing some arm-mounted payloads to simplify the system. The percussive chisel will be removed along with the microscopic imager and contact geochemical spectrometer. This would limit sampling abilities to just using the scoop and sieve, but would simplify and expedite mission operations procedures, and reduce mission cost and complexity. The next descope pathway is to remove the stand-off Raman from the mast-mounted instrument. This limits the ability to determine shock levels, but the IVS would still be able to provide measurements used to determine mineralogy. The Augmented Science Investigation identifies additions to the Baseline Mission if additional resources became available. In this scenario, the payload suite would be expanded to aid with collecting data during the extended 1-year traverse after the samples have been returned. A ground-penetrating radar (GPR) would be added to enable the study of the internal lunar structure and the thickness of basalt flows. A neutron detector would also be added to detect volatile-bearing species within the pyroclastic deposits.

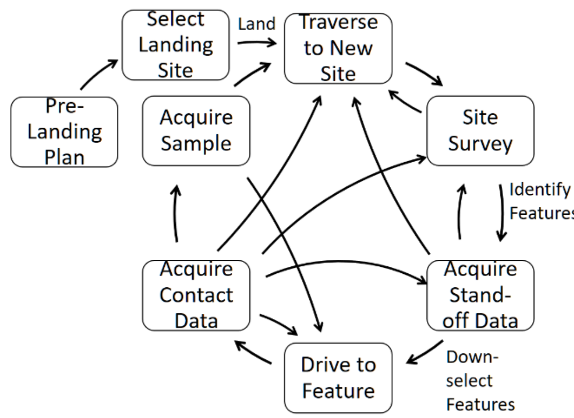

Figure 1: Science operations flow chart.

Conclusions: PHASR is a proposed rover that would land on the lunar surface to prepare for the eventual return of humans to the Moon by testing critical technologies and performing a sample return mission. We designed a science investigation that would help provide answers to fundamental geological questions regarding the formation of the Moon and the processes that dominate it. Our proposed scenario for PHASR will be one of many that feeds into the HERACLES international science definition team that will lead development of the PHASR science mission.

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