POTENTIAL IN SITU EXPLORATION OF SUBSURFACE ICE ON THE MOON USING EVA AND ROBOTIC FOLLOW-UP: THE HAUGHTON CRATER LUNAR ANALOG STUDY. Heggy E.[1], Helper M. A.[2], Fong T.[3], Lee P.[4], Deans, M.[5], Bualat M.[5], Hurtado J. M. Jr.[6] and Hodges K. V.[7], [1]NASA Jet Propulsion Laboratory, 4800 Oak Grove Drive, MS 300-243, Pasadena, CA 91109, heggy@jpl.nasa.gov, [2]Geological Sciences, Univ of Texas at Austin, Austin, TX 78712, [3]Intelligent Robotics Group, NASA Ames Research Center, Moffett Field, CA 94043, [4]SETI Institute / NASA Ames Research Center, Mars Institute, MS 245-3, Moffett Field, CA 94035-1000, [5]Intelligent Systems Division, Ames Research Center, MS 269-3, Moffett Field, CA 94035, [6]Department of Geological Sciences, University of Texas at El Paso, 500 West University Ave., El Paso, TX 79968, [7]School of Earth and Space Science, Arizona State University, University Drive and Mill Avenue, MC 1404, Tempe, AZ

Introduction. Recent orbital observations from the Lunar Crater Observation and Sensing Satellite (LCROSS) [1]**,** the mini-RF Synthetic Aperture Radar onboard the Lunar Reconnaissance orbiter (LRO) [2] and Moon Mineralogy Mapper (M^3) on board Chandrayaan-1 [3] all suggest that the lunar subsurface contains traces of cometary ice in the permanently shadowed areas at the lunar poles. Although the presence of ice in the lunar subsurface is supported by an increasing set of remote sensing observations, its depth, composition, and concentration remain poorly quantified. Quantifying these parameters will increase our understanding of the ice transport to the lunar surface and are vital to future plans to use it as a potential resource for long-term human presence. Future EVAs and robotic follow-up are hence crucial to characterize the ice budget at the lunar poles. To address this, a two-year analog experiment using simulated EVAs and robotic follow-up was designed to simulate geologic and geophysical fieldwork to map volatiles on the moon. In 2009, we simulated a 9-hour geophysical survey EVA in concept space suits and motorized traverses in a simulated rover at Haughton crater, Devon Island, Canada. The main objective was to explore for ice along the western crater rim. Two ground penetrating radars (GPR) with four antennas with different probing depths, resolutions, and operational constraints, were mounted on the rover and also deployed manually.

Traverses along the crater rim were designed to visit areas where gullies have been observed in high-resolution visible images and that have anomalous polarimetric signatures in L- and X-Band Synthetic Aperture Radar (SAR) images. Observations suggest the presence of ice in the subsurface. GPR has been used explore the depth and the state of this ice in the shallow subsurface and to optimize shallow sampling to better understand the presence of volatiles. In 2010, a follow-up mission was performed using the LiDAR, GPR, panoramic- and micro-imaging cameras, and XRF instruments on the Ames K10 robot to re-explore the sites. The main objective of the robotic follow-up was to provide measurements to quantify ice depth, concentration, and large-scale distribution. Both the LiDAR and panoramic images provided a correlation between gully depth, surface polygon sizes, and ice layer depth as determined with GPR.

Site Description. The Haughton meteorite impact crater is 20 km in diameter and formed 23 million years ago. It is one of the highest-latitude terrestrial impact craters in the arctic circle. It lies near the central part of Devon Island that is known to be the largest inhabited island with a polar desert environment. Haughte is the only crater known to lie within such an environment that offers several geological, geophysical and operational analogy to both the Moon and Mars [4].

Although Haughton Crater has undergone substantial erosion (also have different geological and vironemental factors that lead to the presence of subsurface ice), most of its impact related geologic features are well preserved. The good state of preservation is due mostly to the crater's geographic setting. Erosion processes in the polar desert of the High Arctic are particularly sluggish due to the extreme seasonality in the availability of liquid water and the presence of continuous permafrost [4]. The absence of any substantial vegetation cover in the structure has substantially limited the weathering of the surface materials, and allowed an excellent exposure of the geological structures from the ground and by remote sensing. Complex diversity of lithologies are exposed at Haughton, reflecting the fact that the impact event punched through the entire stack of Paleozoic sediments present at the time and excavated material from a depth of over 1.7 km, biting into the gneissic basement. Some shocked formations at Haughton have retained their integrity and are now exposed as tilted or down-faulted megablocks within the structure and at its periphery. However, particularly distinctive at Haughton is the crater's allochthonous impact breccia formation, a rubble deposit resulting from the launching, airborne mixing, fallback, and weak rewelding of impact-shattered fragments derived from the entire stack of excavated rocks. Thus at Haughton, (shocked) basement crystalline rocks can now be found in abundance at the surface. Haughton Crater has been identified as a scientific and tific and operational terrestrial analog for both the Moon and Mars. Haughton is similar in scale to Shackleton crater, one of the primary candidate sites for a lunar outpost. The impact structure is an excellent lunar analog for several reasons [4]: (1) extreme environment with a polar desert and frozen subsurface, (2) relevant geologic features (mixed impact rubble rich in ground ice, ejecta blocks, polygones and rock similar to materials and terrains found on the Moon), and (3) no vegetation coverage, with a dry surface during the summer July–August season. In addition, there is permafrost present at about 1-2 m beneath the surface.

Results. The 2010 robotic follow-up integrated Lidar, 850 MHz GPR, Panoramic and Micro-Imaging Cameras and XRF to re-explore the EVA sites visited in the 2009 field survey (a year ago) with the main objective of providing metric observations to quantify the ice depth, concentration and large-scale distribution a long the 2009-EVA tracks. Both PanCam (fig. 1) and Lidar (fig. 2) images provided a correlation between the polygons sizes, roughness and depth of the ice layer as measured by GPR (fig. 3).

Figure 1: The polygone patterned ground at ~800m to the west of the HMP base as imaged by the PanCam onboard K-10.

The PanCam camera revieled the different albedos in the patterned grounds. Darker materials where found to corroloate with rougth terrains with fragmented rocks that endured both thermal and water flow erosion. Larger polygons were found to corroloate with a deeper active layer that is proportioned to the paterns size (~1 to 2 m). Polygons occurrence were found to be correlated to soft slopes of the local topography. The depth of the active layer was measured to vary from ~0.9m at the shallowest site to 2.2 m for the deepest location. The depth of the active layer was also observed to vary with slopes and the occurrence of gullies on the Haugthon western crater walls. Lidar provided a metric assessment of the surface rougthness that constrained the understanding of the type and amplitude of erosions that occurred in the explored sites.

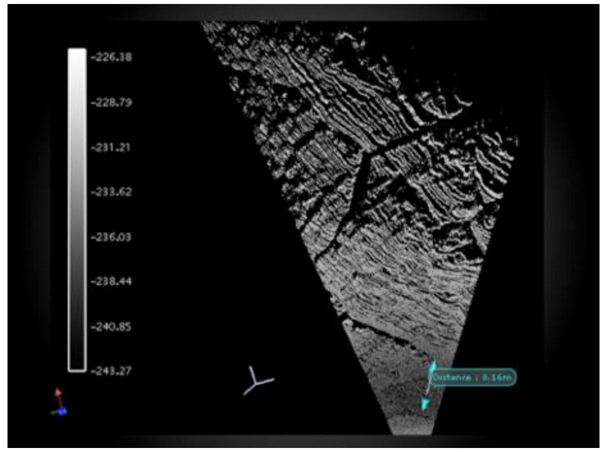

Figure 2: ground Lidar image from k-10 of the patterned ground with polygons ranging from few 10ths of cm's to meters large in local 9, located 500m north of the HMP base. Image shows a 45-degree segment of a Lidar scan with well defined sections of the polygons edges.

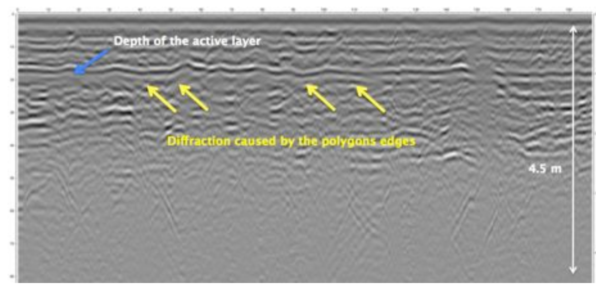

Figure 3: 850 MHz radargram on the local 9 site, representing a traverse of 130m long where the bottom of the active layer responsible for generating the polygons was identified to be at 1m deep from the surface. The depth was correlated with surface polygons sizes and roughness as measured by Lidar.

Further results and analysis on the implications of these observations in supporting EVA's science return, specialy for the purpose of understanding subsurface volatile distribution will be presented at the conference.

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