

THE POTENTIAL FOR VOLATILES IN THE INTERCRATER HIGHLANDS OF THE LUNAR NORTH POLE. C. E. Roberts¹, D. M. Blair², M. Lemelin³, D. Nowka⁴, K. D. Runyon⁵, D. A. Paige⁶, P. D. Spudis⁷, and D. A. Kring⁷. ¹Department of Geology, University at Buffalo, SUNY, NY, carolynr@buffalo.edu, ²Department of Earth and Atmospheric Sciences, Purdue University, IN, ³Département de Géomatique Appliquée, Université de Sherbrooke, Québec, Canada, ⁴Museum für Naturkunde – Leibniz-Institut, Berlin, Germany, ⁵Department of Earth and Environmental Sciences, Temple University, PA, ⁶Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA, ⁷Center for Lunar Science and Exploration, USRA-LPI, Houston, TX.

Introduction: Lunar polar volatiles can provide clues about solar and planetary evolutionary processes [1]. In addition, local sources of water and other volatiles on the Moon may enable in-situ resource utilization (ISRU) for future permanent human bases. To address these science and exploration issues, we need to identify lunar landing sites where the distribution and physical properties of volatiles can be studied.

The National Research Council (NRC) identified five science objectives as being essential to understanding lunar polar volatiles [1]. These were to (a) determine the compositional state and distribution of volatiles in lunar polar regions, (b) determine the sources for lunar polar volatiles, (c) understand the transport, retention, alteration, and loss processes that operate on volatile materials at permanently shadowed regions (PSRs), (d) understand the physical properties of the extremely cold polar regolith, and (e) determine what the cold polar regolith reveals about the ancient solar environment [1].

Methods: To determine where the NRC's objectives can be met by human and/or robotic surface missions, a survey of both polar regions was conducted [2]. Here we focus on the Intercrater Polar Highlands region (IPH) near the lunar North Pole, which contains landing sites where all five NRC science objectives can be addressed. To study the region further and to evaluate specific landing sites within it, we integrated observations from Lunar Prospector, Lunar Reconnaissance Orbiter, and *Chandrayaan-1* spacecraft with existing USGS geologic maps. The outcome of our data integration is represented in Fig. 1.

Results—IPH Summary: Centered at 285°E, 89°N, the IPH is ~4000 km² in area and consists of rugged, hummocky terrain bounded by Peary, Rozhdestvenskiy, and Hermite craters. The IPH is relatively homogeneous due to its age and near-complete crater saturation [3]. The majority of the region has been characterized as pre-Nectarian (~4.60–3.94 Ga) and Nectarian (~3.94–3.86 Ga) in age [3], which is bounded by highly subdued pre-Nectarian crater material [3]. Within the IPH there are also a few young craters of Eratosthenian age (3.2–1.1 Ga), namely Hermite A [3].

The IPH contains abundant PSRs that are smaller, but more numerous, than those at the South Pole [see

2]. PSRs within the IPH are typically <10 km in diameter (Fig. 1), occupying small topographic lows that are often degraded simple craters. These regions have not been illuminated by the Sun in at least 2 Ga [4] and, thus, act as 'cold traps' for volatiles migrating from other regions on the lunar surface [5]. Orbital measurements indicate that the IPH region has enhanced hydrogen abundances (>150 ppm; [6]), low average temperatures (<54 K; [7]), and high circular polarization ratio (CPR) values [8]. The Mini-SAR CPR data suggest that ice may be heterogeneously distributed within many small craters near the North Pole and be at least tens of wavelengths (~2–3 m) thick [8].

Because the IPH region lacks substantial topographic highs, temperatures remain consistently cold (~23–54 K average annual temperatures), and there is little direct sunlight. Models suggest the entire region experiences ~0–25% illumination over a period of four full (18.6 earth-year) cycles [9]. While this is sub-optimal for generation of solar power during a mission, the situation can be improved by installing solar panels in nearby well-lit areas or mounted on ~10-meter-high masts [9]. Alternatively, radiogenic power sources could be used. Because of the patchwork nature of the PSRs in the IPH, landing can occur in sunlit regions (attractive for solar power) and short drives can then access the PSRs for measurements and sample collection.

Results—Specific Landing Sites: We have identified two sites (Fig. 1) that can provide access to areas with overlapping science objectives and that have slopes suitable for rover operations. Each area consists of 3 to 5 geologic stations located within a 10 km radius (for extravehicular activity safety reasons; [10]) of a flat ($\leq 1^\circ$ slopes) landing site. All stations can be reached following rover-accessible paths (slopes <20°; [11]), and are located in areas where all science objectives can be addressed. Multiple core samples (to depths of 3 m) collected in a grid-like fashion would address science objective (a) locally, as well as objectives (d) and (e) due to the stations' low annual average temperatures of ~31–39 K. Sampling regolith to depths of 3 m is required to verify potential subsurface water ice as suggested by high CPR values at some stations. Samples collected at stations situated in variable terrains (e.g. crater rim/floor) partially address objectives

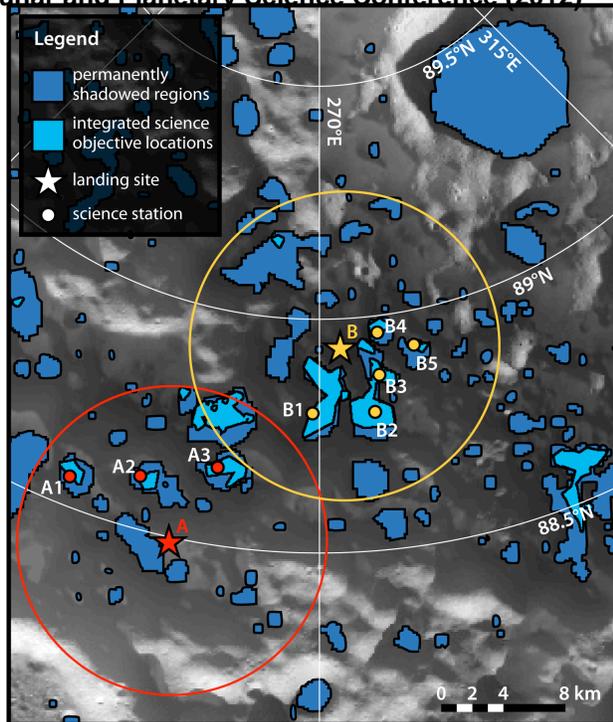


Figure 1: Case study for the IPH near the lunar North Pole. Science areas A (red) and B (yellow) include a landing site (stars), 3–5 stations (dots), and 10-km exploration radius (large empty circles). PSRs are in dark blue, while areas fulfilling all science objectives are in light blue. See text for details.

(a) and (c). To address science objectives (b) and (c), ion and particle collectors could be set up to assess volatile flux at the boundary of the PSR in which each station resides. In order to fully address science objective (c), regolith core samples could be collected not only at each station, but also outside and on the borders of their respective PSRs.

Area A (258°E, 88.5°N) consists of 3 science stations. Station A1 never experiences temperatures >54 K, thus providing an opportunity to sample regolith that could contain volatile compounds with sublimation temperatures above 54 K (CO₂, SO₂, NH₃, C₅H₁₂, HCN, C₇H₈, H₂O, and S; [12]). This station exhibits some of the highest hydrogen abundances in the IPH region (>155 ppm), further supporting the potential for hydrogen compounds within the regolith at this location. The low CPR values observed at A1 would permit ground truth for the global CPR dataset, which could prove to be immensely useful for locating subsurface ice in the future. At station A2 there is an opportunity to sample volatiles with sublimation temperatures >50 K (like H₂S and the compounds listed for A1), as the maximum annual temperature is ~50 K at this location. Station A2 is located within a degraded simple crater and would enable access to deeper deposits from the crater floor. Enhanced hydrogen abun-

dances (>154 ppm) are observed at A2, as well as high CPR values (suggestive of subsurface water ice). Station A3 is similar to A2 in that it has similar hydrogen abundances, and would provide an opportunity to sample volatiles that sublime above 50 K. On the other hand, A3 exhibits medium CPR values, in contrast with A2. The hills near the southern edge (towards the bottom in Fig. 1) of area A experience ~35–45 % illumination over four full lunar cycles [9] and have the greatest solar power collection potential for a mission to the IPH.

Area B (273°E, 89°N) stations exhibit hydrogen abundances of 152 ± 1 ppm and temperatures (<49 K maximum annual) similar to stations in A, so they provide the same potential volatile sampling opportunities. All five B stations have minimum annual temperatures <20 K (with B1 and B4 being <15 K) and could more completely address objectives (d) and (e). Station B4 is within a steep-walled (20°–35°) crater, enabling the sampling of the crater rim/wall material, and providing access to deeper deposits from the crater floor (similar to A2). As with area A stations, B stations sample a range of CPR values.

Summary: The IPH is an ideal location to study lunar polar volatiles due to the prevalence of PSRs, consistent low temperatures, high hydrogen abundances, and very old terrain. Two landing sites within the IPH provide access to stations that can address all of the NRC objectives for the study of polar volatiles. Mission logistics will likely be challenging because of illumination conditions (i.e., access to solar power) and extremely cold temperatures [1]. The small size and patchy distribution of PSRs, however, provide an opportunity to base operations in sunlit areas and limit exploration of the PSRs to short-duration traverses.

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