VOLATILES AT THE LUNAR SOUTH POLE: A CASE STUDY FOR A MISSION TO AMUNDSEN CRATER. K. D. Runyon[1], D. M. Blair[2], M. Lemelin[3], D. Nowka[4], C. E. Roberts[5], D. A. Paige[6], P. Spudis[7], and D. A. Kring[8]. [1]Dept. of Earth & Environmental Sci., Temple University, Philadelphia, PA 19122, kirby.runyon@gmail.com, [2]Dept. of Earth & Atmospheric Sci., Purdue University, [3]Dép. de Géomatique Appliqueé, Université de Sherbrooke, [4]Museum für Naturkunde, Leibniz Institut, [5]Dept. of Geology, SUNY at Buffalo, [6]Dept. of Earth and Space Sciences, UCLA, [7]USRA-LPI, [8]Center for Lunar Science and Exploration, USRA-LPI.

Introduction: The National Research Council (NRC) [1] places a high priority on studying lunar polar volatiles, and has outlined five goals related to the study of such volatiles. Our survey of the Moon's polar regions integrated geospatial data for topography, temperature, and hydrogen abundances from Lunar Reconnaissance Orbiter, Chandrayaan-1, and Lunar Prospector to identify several landing sites [2] near both the north [3] and south polar regions that satisfy the NRC's stated goals. Here we discuss Amundsen crater, one of the most attractive south polar sites.

Amundsen Description. Amundsen crater, centered at 84.6°S, 85.6°E, is a ~100-km-diameter complex crater with heavily terraced walls and prominent central peaks (Fig. 1). Amundsen formed in the late Nectarian (~3.92–3.85 Ga), though its floor is somewhat younger (Imbrian, ~3.85–3.8 Ga) [4]. The crater floor has relatively low slopes (< 5º), which are attractive for landing and rover operations. Amundsen sits on the southern limb of the South Pole-Aitken (SPA) basin (*D* ~ 2500 km), the oldest and largest discernible impact crater on the lunar surface [*e.g.*, 5]. Because of the great depth of SPA (~13 km), Amundsen's mineralogy is likely intermediate between mafic and felsic, due to mixing of lower crustal or upper mantle material with feldspathic highlands material [6]. As Amundsen is a complex crater, it likely contains a broad range of geologic units, such as impact melts or volcanic material on the crater floor, bedrock outcrops on the crater wall, slumped material from high on the crater's wall or rim, and uplifted basement rocks in the central peak. There are also many smaller (km-scale) craters in various states of degradation on Amundsen's floor.

Amundsen is a particularly attractive landing site due to its sizeable permanently shadowed regions (PSRs, which may thermally trap volatiles) and its relatively high hydrogen abundances (~100 to ~150 ppm [7]) set amongst diverse geologic units. Moreover, one can land on a relatively flat (safe) crater floor in sunlight, where solar power is available, and then make brief traverses into shadowed regions. To illustrate how a mission to Amundsen can be used to address the NRC's goals for volatile exploration [1], we discuss two areas of interest, with suggested landing sites and science stations in each.

Landing Site Requirements: A mission needs to access areas where the NRC's science goals can be addressed. These goals are (a) to determine the compositional state and distribution of volatiles in lunar polar regions, (b) to determine the sources for lunar polar volatiles, (c) to understand the transport, retention, alteration, and loss processes that operate on volatile materials at PSRs, (d) to understand the physical properties of the extremely cold polar regolith, and (e) to determine what the cold polar regolith reveals about the ancient solar environment [1].

From these criteria, we limited our search to sites with temperatures of 54–130 K (below the sublimation point of various volatiles) [8] where the slopes and local geology facilitate the study of all the goals. Thus, the focus of any measurements will be on the 9% of Amundsen's interior that is in permanent shadow, but will be facilitated by the power available in the remainder of the crater.

We identified two landing sites (A and B) on the floor of Amundsen crater that are lit up to ~25% of a lunation [9]. Those sites provide access to stations within PSRs while providing a base of operations in an illuminated region. Having the ability to establish stations in both sunlit regions and adjacent PSRs also has several scientific advantages. The stations outside of PSRs can serve as experimental controls for the processes that affect volatile distribution within PSRs. Contrasts between the two regions can also be used to evaluate transport mechanisms. Remotely observed circular polarization ratios (CPR) [10] also vary around both landing sites, providing an opportunity to ground-truth the global data set and test the effects of ground ice and surface roughness on those CPR values. Temperatures derived from the Diviner radiometer [11] also helped define station locations.

Area A (83.93°S, 90.45°E) consists of six science stations, all with elevated hydrogen levels (~110–123 ppm [7]), navigable slopes (< 15°) [9], and with temperatures [11] ranging from ~23–100 K and averaging ~40–50 K. A1 and A6 address three of the five NRC science goals (b, c, and e), while stations A2 to A5 address them all. The maximum temperature (T_{max}) distribution places constraints on stations' expected volatile abundance based on volatiles' sublimation points. Volatile sublimation temperatures [7] near the T_{max} of the stations include CO_2 and hydrogen sulfide (Stations A2 to A5); water and ammonium hydrosulfide (A1); and toluene (A6).

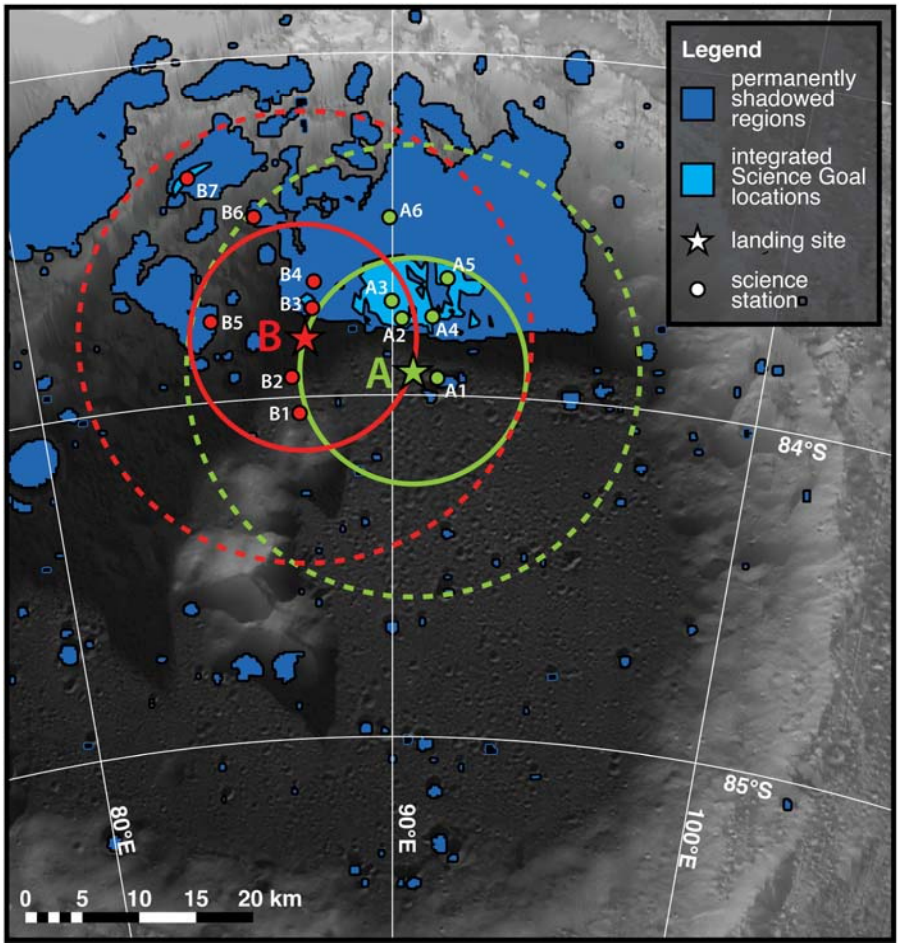

Fig. 1. Amundsen crater, showing PSRs (dark blue), sites where all five science goals can be met simultaneously (light blue), proposed science stations (circles), and proposed landing sites (stars). Radii of 10 and 20 km from the landing sites shown as solid & dashed lines. Base map is LRO/WAC/LOLA shaded relief.

These stations explore the distribution of volatiles in several geologic sites that will have variable regolith properties and potentially cavities for icy deposits, while also providing access to geology that address other NRC [1] goals. Station A1 is in a small PSR amidst an interesting complex of overlapping, asymmetric simple craters. A2 is on flat terrain while A3 and A4 are on degraded crater rims, though the latter is also near fresh craters and their ejecta. A5's location on a debris slump will allow sampling of a range of lithologies, particularly from higher on Amundsen's wall and rim, while A6 is on the terraced wall. All but Station A6 are within the 10 km astronaut walk-back safety zone.

Area B (83.82°S, 87.53°E) consists of seven science stations; all have elevated hydrogen levels (between ~98–125 ppm [7]), slopes < 6° [9], and temperatures [11] ranging from ~23–239 K with an average of ~37–73 K. Stations B1 and B2 address none of the science goals directly, but serve as controls. Stations B3, B6, and B7 address all five of the NRC goals, while stations B4 and B5 address goals b, c, and e.

Area B also allows sampling in various geologic regimes. Station B1 is in a diurnal region at the base of Amundsen's central peak. B2 is in a small PSR on the bottom of a small, fresh crater while B3 is on the flat Amundsen floor very near the terraced walls. Stations B4 and B5 are on different debris slumps, allowing for sampling of stratigraphically higher and laterally diverse material. B6 samples a simple crater on Amundsen's terrace. Station B7 also samples the terrace, though in a location that also satisfies all five NRC goals.

Summary: Amundsen crater is a prime area for studying lunar volatiles. Its geologic diversity, elevated hydrogen abundances, cold PSRs adjacent to warmer diurnal regions, and overall accessibility make it an appealing and interesting target for future lunar missions from both science and mission planning perspectives. This is in contrast to the more limited science opportunities at Shackleton crater, which has steeper walls, simpler geology, and whose interior is entirely in permanent shadow.

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