SURVEY OF THE LUNAR SOUTH POLE FOR CANDIDATE NASA ARTEMIS BASE CAMP SITES

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Introduction: We present a survey of the lunar south pole identifying candidate sites for NASA's Artemis Base Camp (ABC) using a series of safety, logistical, and science access criteria. Drawing from NASA's Lunar Exploration Program Overview [1] and experience from Antarctic and Arctic polar research stations, *e.g.,* McMurdo and the NASA Haughton-Mars Project, site criteria include: 1) Extended solar illumination (> 65% of the time); 2) Substantial direct-to-Earth (DTE) visibility (> 50% of the time); 3) Continuous flat *Hab Area* (slope < 5°, > 1 km^2) for habitat structures; 4) Separate flat landing/launch *Pad Area* (slope < 5°, 100 m in radius, and 1-3 km away), separated from the Hab Area by a topographic obstacle > 100 m in height, but linked to the Hab Area by a safely trafficable (< 10° slope) path; 5) Proximal access to water-ice bearing PSRs. We present our approach and discuss several end-member candidate ABC sites.

1. Solar Illumination: Quasi-permanently lit areas areas at the lunar pole allow for maximizing solar energy. A solar array area of ~ 5000 m^2 on the Moon will produce ~ 200 kW average power if solar illumination is available 50% of the time (~0.04kW/m^2, similar to ISS). We set a >65% solar illumination threshold to add additional margin on this estimate. Using Python GDAL (Geospatial Data Abstraction Library), we identify all points with > 65% solar illumination at > 75°S latitude on a 120 m resolution solar illumination dataset [2]. We group these points into candidate sites 2.5 km in radius, centered on the point of maximum illumination serving as solar array location. This yields 65 candidate sites: 11 sites > 80% solar illumination; 23 sites at 70-80%; 31 sites 65-70%.

2. Earth Visibility: Maximizing Earth visibility time for direct-to-Earth (DTE) communications minimizes reliance on orbital comms. For each 2.5 km radius site above, we identify its maximum DTE visibility time percentage. Requiring DTE visibility > 50% eliminates 14 sites (mostly far side); 51 sites remain. It should be noted that several far side sites that have good DTE visibility.

3. Habitat Area: From experience with terrestrial polar bases, the ABC will require a minimum of 1 km^2 of continuous flat area (< 5° slope) for habitat structures and some expansion options. Using a 20 m resolution slope map, 13 sites are found to offer < 1 km^2 of flat area (< 5° slopes) and are eliminated. Additionally, requiring continuity of the 1 km^2 flat areas and safe accessibility of the local point of maximum illumination (path < 10° slope) eliminates 8 additional sites. 30 sites remain.

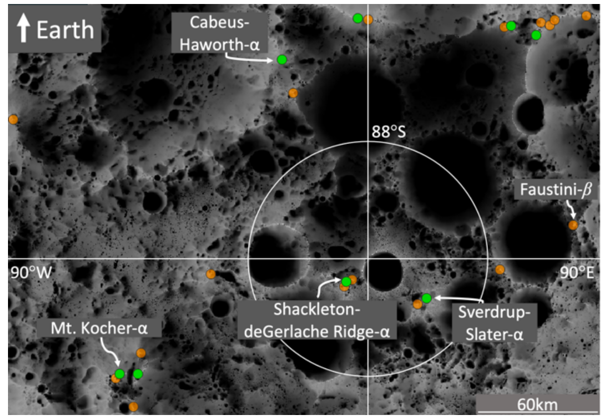

Figure 1: Candidate Artemis Base Camp Sites – This Study. Sites meeting our criteria 1-4. *Green:* Optimal sites with >75% solar illumination. *Orange:* Other viable sites with 65-75% solar illumination. Sites discussed here are named.

4. Landing/Launch Pad Area and Access: The ABC will require at least one landing/launch Pad Area safely separated from the Hab Area. We applied five Pad Area requirements: a) < 5° slopes; b) ≥ 100 m radius area; c) 1-3 km away from Hab Area; d) a topographic barrier or elevation difference of > 100m between Pad and Hab areas; e) easy path (slope <10°) to Hab Area, if possible via a flat (<5°) Staging Area. Criteria a and b are derived from the NASA Human Landing System (HLS) Requirements Document (SRD) (requirements HLS-R-0071 & HLS-R-0021, resp.) [3]. Criteria c and d aim to reduce risk from engine exhaust ejecta (official requirements not yet available).

On a 20 m resolution slope dataset, we use a Python algorithm to apply criteria a, b, and c, yielding possible Pad Area locations; we then analyze each location in ArcGIS with a 20m LOLA DEM to apply criteria d and e. Four sites are eliminated; 26 remain (Fig. 1).

5. Accessibility to Water-Ice Bearing PSRs: We consider ready access to water-ice bearing PSRs (hereafter "H_2O-PSRs") to be a primary science requirement for any good ABC site. Lemelin et al. (2021) identify 169 H_2O-PSRs [5]. We conduct a Least-Cost-Path analysis, using QGIS, between each candidate site's Hab Area and each H_2O-PSR at three slope thresholds (10°, 15°, & 20°) on a 120m (low-res for computation time) slope dataset to estimate traverse distances (Fig. 2).

Several sites stand out with respect to H_2O-PSR accessibility: Sverdrup-Slater and Shackleton Ridge have the best overall H_2O-PSR access, *i.e.,* are closest to multiple H_2O-PSRs and allow for shallower slope traverses. Cabeus-Haworth and Mt Kocher have above average H_2O-PSR access while being lower in latitude. Malapert and Nobile have excellent solar illumination and DTE visibility, but access to H_2O-PSRs from these sites is poor, requiring distant traverses via steep slopes.

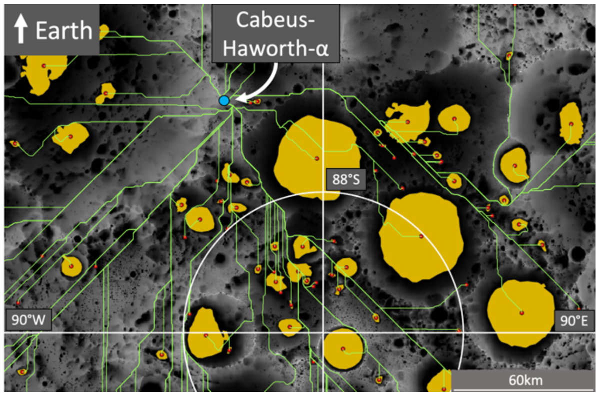

Figure 2. Access to H_2O-PSRs from the Cabeus-Haworth-α Site. Example H_2O-PSR access analysis for the Cabeus-Haworth-α candidate ABC site (*blue dot*) at 15° slope threshold. *Yellow polygons with red centroids*: H_2O-PSRs [5]. *Green paths*: minimum traverse distance from ABC site to PSR, via terrain of < 15° slopes.

Table 1: Candidate ABC Sites Discussed Below

Candidate ABC Site	Lat, Lon	Solar	DTE	Best Quality
Shackleton-deGerlache Ridge α	-89.48, -137.45	85%	58%	Solar/H_2O-PSR
Sverdrup-Slater α	-88.81, 123.77	78%	61%	H_2O-PSR
Mt. Kocher β	-85.41, -114.92	77%	60%	H_2O-PSR/SPA B.
Cabeus-Haworth α	-86.37, -23.26	75%	82%	DTE/H_2O-PSR
Faustini β	-86.50, 80.79	66%	51%	H_2O-PSR

Case Studies: Several strong ABC candidate sites stand out in our study, depending on criteria priority. We discuss a few end-member cases here **(Table 1)**.

Shackleton-deGerlache Ridge-α (SGRα): All the Shackleton rim sites (incl. Site 004 in [1]) were eliminated based on one or more criteria not being met, but the *SGRα* site (Site 001 in [1]) is on the connecting ridge between Shackleton and de Gerlache craters. It excels in solar illumination and access to H_2O-PSRs. DTE visibility, however, is only 58%.

Sverdrup-Slater-α (SSα): Similar to *SGRα,* with somewhat lower solar illumination, but more forgiving given closer and shallower access to H_2O-PSRs. It has the closest access to an H_2O-PSR of any high solar illumination (> 75%) sites at just 5.8 km away **(Fig. 3)**.

Mt. Kocher-β (MKβ): This site, presented by our team in [9], offers access not only to H_2O-PSRs, but uniquely to South Pole-Aitken Basin (SPA B) materials as well. It is located at the boundary between the SPA B's outer heterogenous annulus and its inner Mg-rich pyroxene annulus, thus allowing sampling of both [9].

Cabeus-Haworth-α (CHα): This site sits on the dividing ridge between Cabeus and Haworth craters. Its near-side location gives it > 80% DTE visibility and strong solar illumination; it has above average H_2O-PSR accessibility, while also being the only high solar illumination site with access to Cabeus crater, unique as it contains a proven diversity of volatiles [6] and is the site of a lunar paleopole [7].

Faustini-β (Fβ): This site on the rim of Faustini crater is at the lower threshold for solar illumination & DTE visibility, but has proximal access (< 10km) to an H_2O-PSR with > 150 ppm hydrogen content, *i.e.,* a high-value H_2O-PSR target [5].

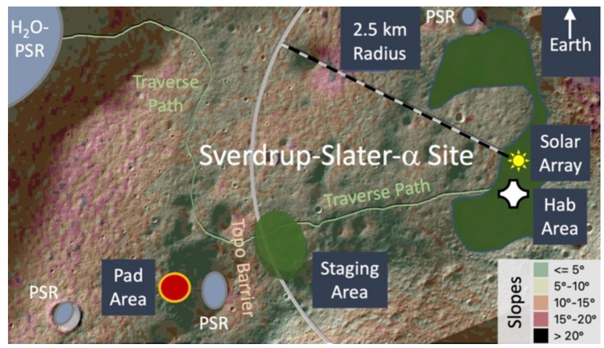

Figure 3. The *Sverdrup-Slater-α* candidate ABC Site. *Yellow Sun Dot*: Site centered on local elevation peak with local max 78% solar illumination, 61% DTE visibility. *Green areas*: Hab & Staging Area options (< 5° slopes) *Red*: Pad Area, separated from Hab Area by topographic barrier. *Blue-Gray*: PSRs. The PSR at upper left is an H_2O-PSR [5]. *Light Green*: Low slope traverse path from Hab Area to H_2O-PSR: ~12 km at 10° slope threshold (~ 6 km option at 15°; not shown).

Future Exploration: These candidate ABC sites offer exciting opportunities for further characterization, scouting, and validation, and could be ideal targets for future NASA CLPS (Commercial Lunar Payload Services) missions combining high-priority lunar science and Artemis reconnaissance. Sverdrup-Slater-α, Faustini-β, and Mt. Kocher offer proximal H_2O-PSRs, ideal for CLPS-delivered robotic rover missions [8,9].

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References: [1] NASA's Lunar Exploration Program Overview (2020); [2] Mazarico E. *et al.* 2011, *Icarus*, *211*,1066-1081; [3] NASA HLS Requirements Doc. (SRD), *HLS-RQMT-001* 2019; [4] Metzger P. 2020, *LPI Lunar Dust Workshop*, *#2141;* [5] Lemelin M. *et al.* 2021, *PSJ, 2:103;* [6] Colaprete A. *et al.* 2010, *Science*, 330, 463-468; [7] Siegler M. *et al.* 2016, *Nature*, *531,* 480-484; [8] Willard C. *et al.* 2021, *LSSW XII, CLPS Landing Sites;* [9] Pimentel E. *et al.* 2021, *LSSW XII, CLPS Landing Sites.*