Artemis III EVA Opportunities in the Vicinity of the Lunar South Pole on the Rim of Shackleton Crater

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Introduction. The south pole is located on impact ejecta covering the rim of a 4.2 km-deep, 21 km-diameter Shackleton crater (Fig. 1). Ejecta on the rim is ~150 m thick [1] and covers target material uplifted >1 km to form the crater rim. Shackleton crater penetrated and excavated debris from at least two types of terrains. In the immediate vicinity of the south pole, the crater excavated nearly pure anorthosite and potentially other crystalline crustal lithologies, large blocks of which remain visible in the upper crater walls [1-3]. This material appears to be part of a massif displaced by the South Pole-Aitken (SPA) basin impact event [4]. The opposite side of the crater excavated a layered terrain that may be the product of multiple impact ejecta blankets from older craters that partially covered the massif [3].

Operational Context. For purposes of evaluating opportunities available to Artemis III astronauts, we take the mission duration to be 6.5 days [5]. The sun will be low in the sky, slightly less than the 5.1° during the Apollo 12 landing and the 7.5 to 9.5° during extravehicular activity (EVA) 1 by Apollo 12 crew, neither of whom reported any visual degradation or enhancement at those sun angles. If crew are limited to walking EVAs, then the Apollo 12 and 14 missions, albeit with shorter surface stays (1.3 and 1.4 days, respectively), may provide some operational guidance. Apollo 12 crew conducted two EVAs, the second of which was nearly 1.6 km-long, reaching a distance ~400 m from the lander, and included an ~100 m segment up a 14° slope, in under 4 hours. That EVA recovered ~18 kg of geological samples, including core ~60 cm deep, supplemented with a ~20 cm deep trench. Apollo 14 crew also conducted two EVAs, the second of which was ~2.9 km long, reaching a distance ~1.4 km from the lander in about 4.5 hrs. That EVA recovered ~22 kg of geological samples, including core ~60 cm deep, and produced an ~30 cm deep trench. The capability of the Artemis Exploration Extravehicular Mobility Unit (xEMU) is not yet fully known, but it should provide crew with greater capability than Apollo-era units. Thus, we consider here walking EVAs up to 2 km from the lander, which is consistent with planning given to us by the Human Exploration and Operations Mission Directorate (HEOMD) in June 2019, and we anticipate at least three EVAs exceeding 4 hours duration each.

EVAs: Rather than providing abstract suggestions for EVA targets, we illustrate opportunities with actual geologic sites distributed within 2 km of a landing site at the south pole (Fig. 1). Traverses will be limited to the rim crest, which is bounded by a crater wall with slope ~30° on one side and crater ejecta with slope ≥15° on the other side. If EVAs are limited to the rim crest, most of the samples available to them will be Shackleton ejecta [6]. Potentially, that will include Shackleton impact melts, from which an age can be ascertained. The regolith may also contain impact melt from the SPA basin and other pre-Nectarian and Nectarian-age impacts, plus fragments of the original highland crust, with components from the lunar magma ocean and later intrusives, plus cryptomaria from SPA. Rock exposures tens to a hundred meters in size, far larger than any Apollo exposure, have been detected in that ejecta (Fig. 1) [3]. Boulders may be composed of nearly pure anorthosite [2,3] or deeper lithologies excavated from the massif. In addition, fresh blocks of rock from the Shackleton ejecta blanket have been distributed around smaller, younger craters (Fig. 1). EVAs will provide an opportunity to study polar regolith processes and collect samples for Earth-based assessments of *in situ* resource utilization (ISRU) potential. Although the crater rim is illuminated, with one site being illuminated 86.7% of the time [7], a few shadowed areas adjacent to ridges and boulders along the rim may have regolith sufficiently cold to stabilize ice within 2.5 m of surface [8]. Thus, trenching and coring to test those model calculations would be valuable. Regolith samples can be augmented by several mechanical property tests, such as lander and footstep penetration, stability of trench walls, cone penetrometer measurements, and vane shear device measurements. Other instruments can potentially be deployed: a seismic station; a meteoroid detector that can also be used to evaluate dust pluming by the Artemis III ascent vehicle and future descent

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vehicles; and a low-light imaging system, potentially with a spectrometer, that can produce a mosaic of the Shackleton crater permanently shadowed region (PSR) during or after the mission.

Relevance. EVAs in this location can begin to address science objectives 1c, 2a, 3a, 3b, 3d, 4a, 4d, 6c, and 7b, and potentially address objectives 1a, 1b, 4b, 5a-b, and 7d [9]. EVAs can also help address strategic knowledge gaps (SKGs) I-D, I-G, II-D-3, III-C-2, III-D-1, III-D-2, III-D-4, and III-J-4.

Contingency planning. An EVA from the south pole, along the rim towards the lower left quadrant of Fig. 1a, requires a climb of about 140 m over a distance of 2 km. If one continues along the rim crest, then an elevation change of ~470 m is required. A ridge that abuts the crater rim rises to ~1900 m or ~600 m above the south pole. That type of elevation change may be difficult for crew without an unpressurized or pressurized rover. Because of that topography along the rim, a mission limited to walking EVA may want to target a landing site closer to a ridge that abuts Shackleton crater. Our studies show (e.g., [3]) that similar types of science and exploration targets occur along Shackleton crater rim in the direction of the lunar farside where the crater crosscuts a massif ridge.

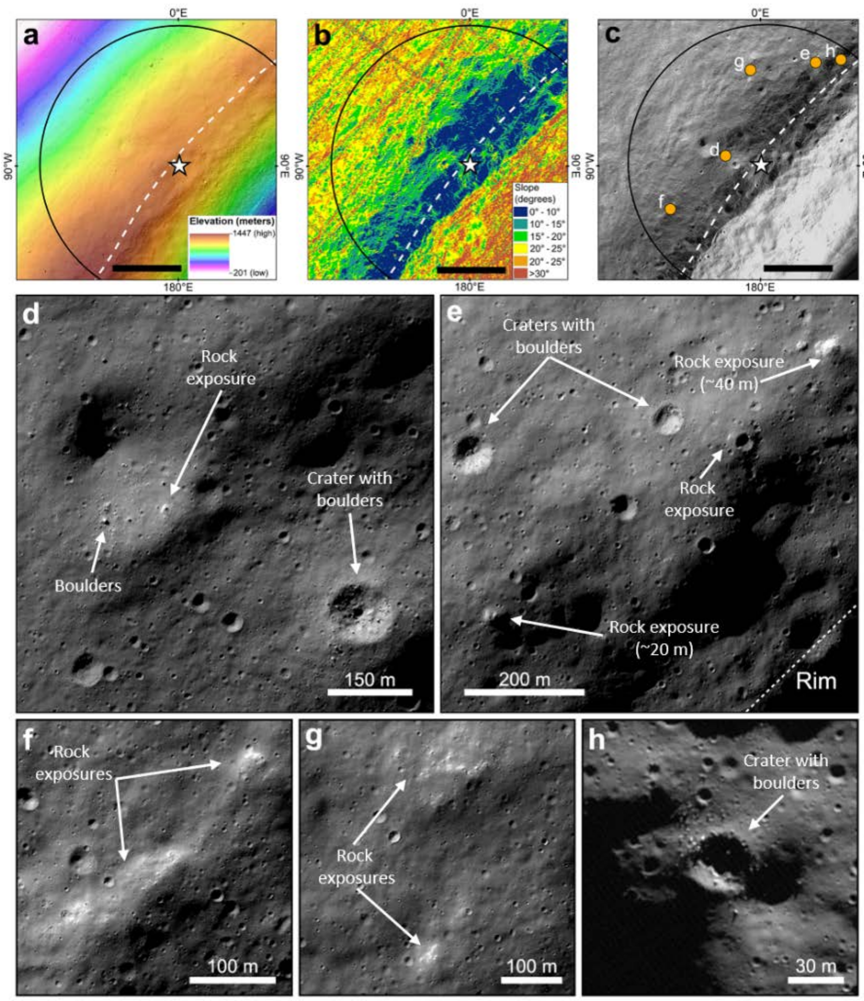

*Figure 1. Potential EVA targets in a 2 km radius exploration zone around the south pole. (a) LOLA DEM (5 m/pixel) overlaid on hillshade showing the topography within the 2 km radial boundary. Dashed white line represents the rim of Shackleton crater. (b) LOLA-derived slope map of the same extent. (c) Averaged NAC mosaic (Moon Trek) showing the locations of annotated images **d** to **h**. Targets in figures **d**, **e**, and **f** are on the edge of slopes >15° and require additional study to fully evaluate their accessibility during a walking EVA. Extracted from [3].*

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