TWO TYPES OF TERRAIN EXPOSED IN THE UPPER CRATER WALL OF SHACKLETON CRATER, LUNAR SOUTH POLE: IMPLICATIONS FOR FUTURE LANDINGS. Harish[1], N. Barrett[2], S. J. Boazman[3,4], A. J. Gawronska[5], C. M. Gilmour[6], S.H. Halim[7], K. McCanaan[8], A. V. Satyakumar[9], J. Shah[10] and D. A. Kring[11,12]. [1]Physical Research Laboratory, India (email: harish@prl.res.in). [2]University of Alberta, Edmonton, Canada. [3]Natural History Museum, London, UK. [4]University College London, UK. [5]Miami University, Ohio, USA. [6]York University, Toronto, Canada. [7]Birkbeck, University of London, UK. [8]University of Manchester, UK. [9]CSIR – National Geophysical Research Institute (CSIR-NGRI), India. [10]The University of Western Ontario, London, Canada. [11]Lunar and Planetary Institute, Universities Space Research Association, Houston, TX, USA. [12]NASA Solar System Exploration Research Virtual Institute.

Introduction: Shackleton is an Imbrian aged (~3.5 Ga), ~20 km diameter, and ~4 km deep impact crater at the lunar south pole (Fig. 1) along the margin of the South Pole-Aitken (SPA) basin [1,2]. The site is the target of the next human mission to the lunar surface [3] and one of five proposed landing sites of potential scientific interest [4]. It is an attractive landing site because of its proximity to permanently shadowed regions (PSRs) that may contain water and other volatiles suitable for scientific exploration [5] and in situ resource utilization (ISRU) [6]. Moreover, the rim of Shackleton crater is elevated, with illuminated topographic highs suitable for solar power [7,8,9]. Shackleton ejecta on the rim and flanks of the crater may provide [10] samples of Shackleton impact melt, plus regolith with a mixture of SPA and other pre-Nectarian impact melts, fragments of the original highlands crust, and cryptomare that can address several lunar science goals [5]. Here, we examine rock exposed in the crater walls to further deduce the geologic potential of this landing site.

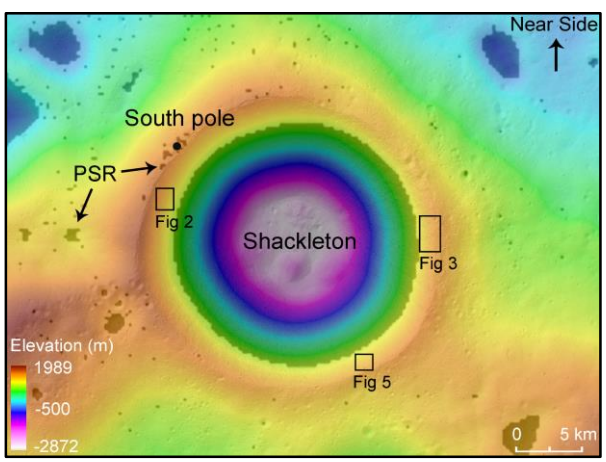

Figure 1: Topography map of Shackleton crater showing the locations of PSRs (shadowed areas) [6]. Black boxes shows the location of figures 2,3 and 5.

Data and Methods: Data is derived from the NASA Lunar Reconnaissance Orbiter (LRO) [11]. Topographic analyses were completed using a LRO Lunar Orbiter Laser Altimeter (LOLA) DEM (Digital Elevation Model) with a resolution of 5 m/pixel [12]. Photogeological analyses of the Shackleton region were done using LRO Narrow Angle Camera (NAC) images [13]. The NAC images were processed and projected to a lunar polar stereographic perspective using the Integrated Software for Imagers and Spectrometers (ISIS) 3 software.

Results and discussion: Shackleton crater penetrates at least two types of terrains: one dominated by crystalline crustal rocks, including purest anorthosite (PAN), and the other composed of strata. Both units are crosscut by boulder tracks and rock falls.

PAN exposures: Remote sensing of the area had previously detected PAN within the wall of Shackleton using 500 m spatial resolution Kaguya Spectral Profiler (SP) and 20 to 60 m spatial resolution Multiband Imager (MI) data [14,15]. To further investigate that occurrence, we surveyed the inner wall using high resolution NAC (~1 m/pixel) images. Large (~100s of meters), high-albedo rock exposures were located ~1 km below the crater rim (Fig. 2) and, in some cases, could be spatially linked directly to Kaguya spectra of PAN. They appear to be part of a crystalline crustal terrain that is either intact or forms a megabreccia beneath the south pole akin to the schematic cross-section shown in Fig 4.

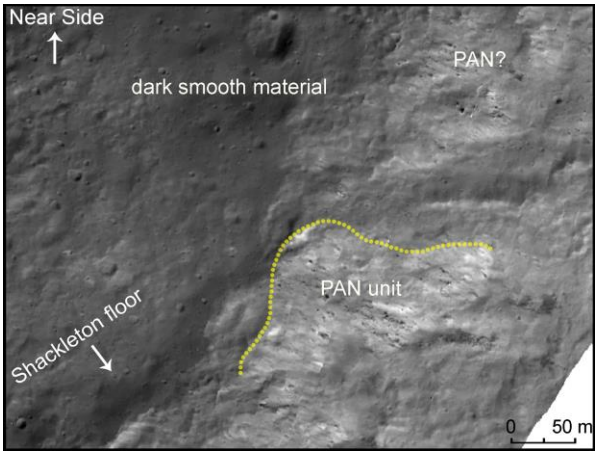

Figure 2: PAN unit rock exposures on the inner wall of Shackleton crater. Detail of NAC ID M133786042L.

Layered terrain: Strata are exposed in the wall of Shackleton crater opposite the side of the crater where the south pole is located. The strata occur ~10 m below the crater rim (Fig. 3). Vertical thickness of individual

layers ranges between 10 and 50 m, and the thickness of the entire sequence varies between 100 and 200 m. These layered sequences possibly represent: (1) pre-existing target strata deposited by the ejecta of surrounding craters older than Shackleton or (2) volcanic lava flows [16].

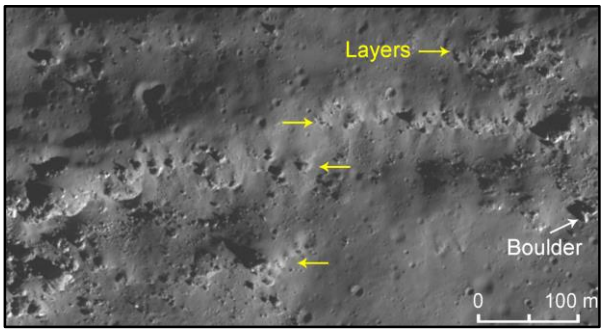

Figure 3: Layers in the wall of Shackleton located opposite of the south pole (crater rim ~10 m above image). Detail of NAC ID M133154995R.

As the south polar region is a heavily cratered landscape with no other evidence of volcanism, option (1) is more likely. Impact ejecta from Amundsen, de Gerlache, Nobile, Slater, Sverdrup, and Cabeus are among the candidate sources for the layers (Fig. 3). Calculated thicknesses of ejecta [17] produced by surrounding craters imply ejecta blanket thicknesses from 10's to 100's of meters. Additionally, if ejecta produced from surrounding craters was deposited at adequate speeds, mixing of ejecta via ballistic sedimentation would have occurred [18]. Speeds of order of 1000 km/h were possible.

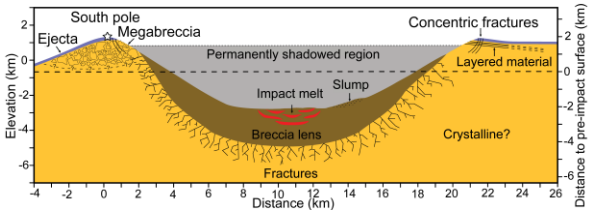

Figure 4: Schematic cross-section of Shackleton crater.

Boulder tracks: Boulders and associated tracks (hundreds of meters long) occur on the inner wall of Shackleton crater (Fig. 5). Boulder tracks correspond to rock falls that were a consequence of erosion via impact or seismic activity in the region [19]. Prominent boulder tracks shown in Fig. 5 are associated with a fresh crater superposed on the rim of Shackleton and were likely generated by that impact event.

Summary: Exposures of PAN hundreds of meters long were identified within the inner wall of the crater in the vicinity of the south pole. This implies PAN may exist in ejecta on the flanks of Shackleton crater.

Elsewhere around the crater, a layered terrain is exposed in the wall of Shackleton, demonstrating the crust in the south pole region is heterogeneous. The layers may be a sequence of ejecta deposits from other, older craters in the region.

Boulders tracks, or rock falls, found on the inner wall of Shackleton crater require more investigation to identify the frequency of this type of erosional process and any associated hazards in the region.

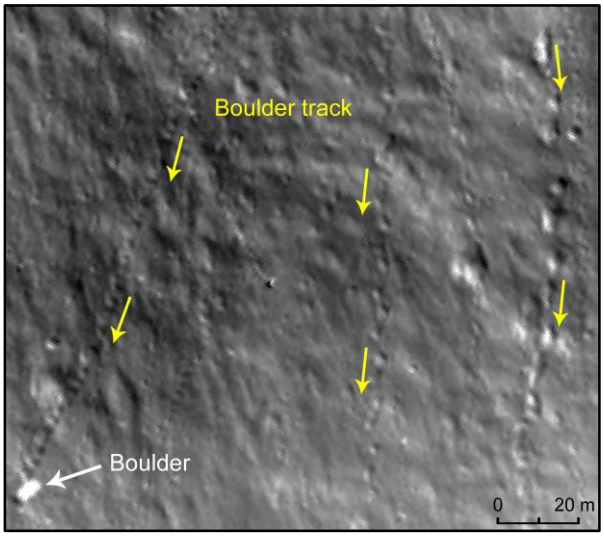

Figure 5: Boulders associated with a boulder tracks on the Shackleton wall. Boulder tracks are marked by yellow arrows (also pointed towards crater floor). Detail of NAC ID M142504842L.

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