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Introduction: The next human landings on the Moon may be targeted for the South Polar region, with the investigation of ices on the floors of permanently shadowed craters one of the high priority objectives. Landing and exploring areas close (within ~5 degrees) to the Pole will, however, bring many challenges not experienced during the Apollo Program. We contend that a new generation of maps, both for landing site safety and trafficability, as well as the identification of science targets (potential resources and other geological objectives) will be required before new landings on the Moon can take place. Here we describe some of the challenges of mapping the polar regions of the Moon, as well as advocate that a formal mapping program should be started soon (i.e., in 2020) in order to provide the planetary community with time to produce the required map products.

Existing Maps: Early lunar South Pole maps were produced at a scale of 1:5M by the Aeronautical Chart and Information Center [1] and Wilhelms et al. [2]. An image of the South Pole (Fig. 1) has been prepared by the USGS using Wide Angle Camera (WAC) images from the Lunar Reconnaissance Orbiter (LRO) at a scale of ~1:6M. Map products at ~1:300,000 derived from LRO data sets are available from LPI: https://www.lpi.usra.edu/lunar/lunar-south-pole-atlas/. However, much more detailed maps will be needed prior to any future landings. A few years after the Apollo landings, the Defense Mapping Agency (DMA) prepared maps of traverses at the Apollo landing site at a scale of 1:25,000 [e.g., 3], which approximates the most likely scale for maps for future exploration. Speyerer et al. [4] have developed a traverse planning tool for future polar prospectors based on lunar topography derived from Lunar Orbiter Laser Altimeter (LOLA) (Fig. 2), but this map is based upon topographic data rather than image data, and thus does not actually portray what an astronaut would see on the ground.

Unique Mapping Issues for the Lunar Poles: Shackleton crater (89.66ºS, 129.20ºE) may well be one of the primary targets for a future lunar landing. LRO Narrow Angle Camera (NAC) images illustrate some of the challenges of mapping this crater (Figs. 3 and 4), including: (1) Extensive long shadows; (2) lighting from multiple azimuths; and (3) the enhancement of structural features perpendicular to the lighting direction.

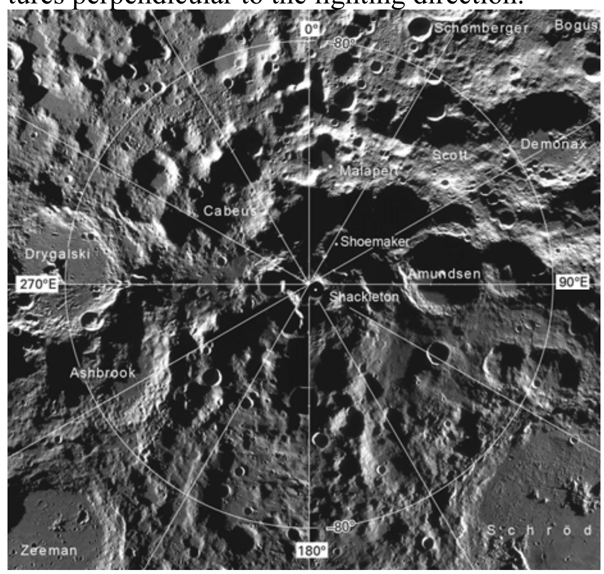

Fig. 1: LRO mosaic of the South Pole of Moon from LRO WAC, prepared by the USGS. Notice the wide variety of illumination directions at different parts of this mosaic.

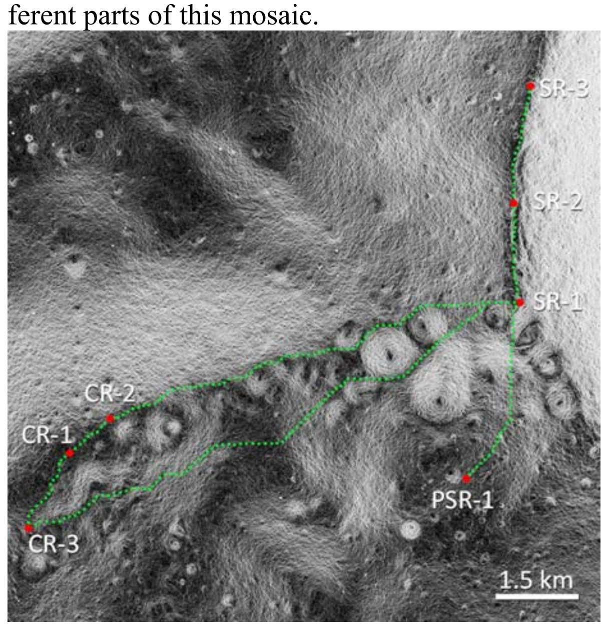

Fig. 2: Potential traverse on rim of Shackleton crater (at right) projected onto a NAC/LOLA slope map. From Speyerer et al. [4].

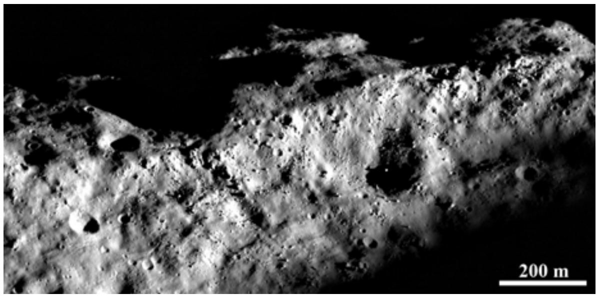

Fig. 3: Boulders litter the rim of Shackleton crater, close to SR-3 in Fig. 2. These might represent excellent sampling sites, but would also represent hazards to any rover crossing this area. Boulders ~4-25 m dia. are easy to identify in images such as these with very low illumination angles, but many parts of the surface are buried in shadows and so may hide other hazardous features. NAC image M1195011983LR.

Fig. 4: The peaks between Shackleton and de Gerlache craters (between points CR-2 and SR-1 in Fig. 2) show enhanced relief under very low light conditions, which would change dramatically during the lunar day. Note the lack of stratigraphic information in this image, making selection of interesting geologic targets particularly challenging. Part of NAC image M119501183LR.

Timeframe for Map Production: Experience has shown that most planetary maps take years to advance from the proposal stage to final publication as a U.S. Geological Survey map. If plans hold to land in the lunar polar regions by 2024, maps showing where to land for resource access, as well as details of landing hazards and ease of surface trafficability, will need to be available well in advance. Assuming that working copies of maps will be needed before the end of 2023, there is now <48 months for their preparation. Pushing the first landing back until 2028 would provide extra time, but still requires a new high-resolution mapping initiative be started soon.

While preparation of maps in that timeframe will require a streamlined process, maps supporting continued exploration can be prepared more systematically and involve individuals with both geologic and engineering perspectives, drawing on the skills of the planetary mapping community (e.g., https://planetarymapping.wr.usgs.gov/). Map scales from 1:25,000 (an area ~12.5 x 14 km in size) to 1:100,000 (~50 x 60 km) for individual sites will likely be needed, accompanied by regional scale maps at 1:1M scale to provide context for those sites. The number of community members involved in this mapping should be scoped based on the number and type of maps, as well as a firm timeline required for their completion. Rather than focusing primarily on image data as in the past, these new lunar maps must include a diverse suite of remote sensing information not only from the LRO Camera (LROC) at ~2 m/pixel, but also from Diviner thermal data (for boulder field mapping) at 240 m/pixel, Mini-RF radar data (for surface roughness) at 30 m/pixel, and slope and roughness from Lunar Orbiter Laser Altimeter (LOLA) topographic data.

If investigating polar ices is a priority for future lunar landings, lighting geometry will make mapping (of any type) challenging, with compositional maps (for sampling site selection) particularly difficult to produce. Similar to maps of potential landing sites anywhere on the Moon, polar maps should be placed into a regional context, **as only through a global review of new data sets can the most scientifically interesting sites be identified**. Many parts of the Moon have only been formally mapped at 1:5M scale back in the 1970s, and no maps at the required new scale(s) exist. We therefore conclude that a new lunar mapping program be established to identify the most important scientific objectives, and provide support for mission planning for future lunar polar exploration.

Acknowledgments: Images used here come from the LROC web site: http://wms.lroc.asu.edu/apollo/

References: [1] ACIS (1970) Lunar Polar Chart (LMP-3). [2] Wilhelms, D.E., Howard, K.A., Wilshire, H.G. (1979) Geologic map of the South Side of the Moon. USGS Map I-1162. [3] Defense Mapping Agency (1975) Lunar Photomap Sheet 41B4S4. [4] Speyerer, E.J. et al. (2016). *Icarus* 273, 337 – 345.