LROC OBSERVATIONS OF PERMANENTLY SHADOWED REGIONS. S. D. Koeber and M. S. Robinson. Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (skoeber@ser.asu.edu).

Introduction: Permanently shadowed regions (PSRs) exist near the lunar poles because the Moon's spin axis is tilted only ~1.5° with respect to the ecliptic normal. The Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) [1] were designed to image the illuminated surface of the Moon. However, reflected light from crater walls and nearby massifs enable imaging within PSRs. From the point-of-view of the NACs, polar secondary lighting is optimal for imaging around respective summer solstices and when the LRO orbit is nearly coincident with the sub-solar point (low spacecraft β angles). The goals of PSR imaging are to support ongoing studies (utilizing numerous datasets) investigating the distribution of cold-trapped volatiles. NAC images will be analyzed for evidence of surface frosts, unusual morphologies from ice rich regolith, and potential landing sites for future in-situ work.

Long Exposure NAC Images: Most NAC images of the polar regions have exposure times (0.7 to 2.0 ms) designed to provide optimal signal-to-noise ratio (SNR) and spatial resolution for illuminated terrain. When the altitude of the spacecraft is below ~70 km, polar NACs are usually acquired in summed (two pixel cross-track average) mode to compensate for the longer exposure times and challenged signal conditions (incidence >80°). As a result of summing the angular size of a pixel increases and SNR increases (both through pixel averaging and 2x increase in exposure time). For the nominal polar exposure times there is not enough signal to make out surface details within heavily shadowed terrain.

When secondary illumination within PSRs is optimal, NAC observations with increased exposure times reveal surface details within PSRs (**Fig. 1**) [2]. Because of the high latitudes of most PSRs only small portions of their interior crater walls are illuminated even during the best of conditions, thus limiting the amount of secondary illumination and requiring NAC exposure times more than ten times greater than nominal imaging. The increased exposure times result in downtrack smear, which decreases the realized spatial resolution of the NAC PSR images.

Campaign 1. The first campaign acquiring long exposure (>11.8 ms) NAC images of the lunar south pole region occurred between Jul. 22 and Nov. 4, 2009. The longer exposure resulted in images with pixel sizes of ~1 m crosstrack (summed) by 20 m downtrack. The images were map projected to 10 m square pixels, which resulted in images with recognizable terrain features within large extents of PSRs. Cabeus, Schackleton, and Faustini craters being the most notable PSRs successfully imaged during this campaign.

Campaign 2. The second campaign acquiring long exposure NAC images of PSRs occurred between Jul. 27 and Oct. 16, 2012. During the first half of the campaign, NAC images were acquired with exposure times of 11.8 ms, and for the second half the exposure time was increased to 24.2 ms to further increase SNR and thus reveal more details within PSRs. The longer exposure times overcame a low signal threshold non-linearity [1] increasing the SNR significantly more than 2x, but reduced the spatial resolution of the image in the down track direction (pixels 1 m by 40 m, sampled to 20 m during map projection).

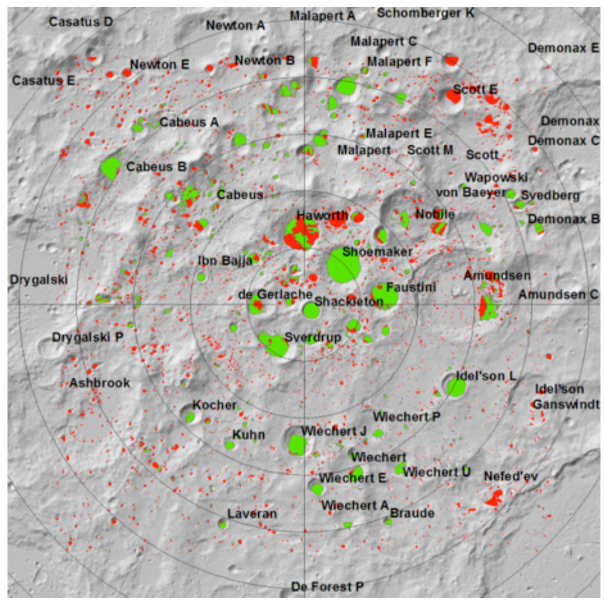

Fig. 1. Shaded relief map of the lunar south pole derived from LOLA altimetry (80° to 90°S). PSRs [3] with no NAC coverage are red. PSRs with acceptable SNR NAC coverage acquired during both campaigns are green.

Interior of PSRs: *Fresh Craters.* Lighting within PSRs is more diffuse than normal surface illumination and at grazing angles. Such conditions tend to reduce albedo contrasts complicating identification of patchy frost or ice deposits. Within the long exposure PSR images only a few small craters (< 200m) with highly reflective ejecta blankets have been identified (**Fig. 2**). Based on our knowledge of small fresh craters on the Moon there are likely many more, however the oblique lighting and low SNR inhibit albedo contrasts.

The identification of a few fresh craters by long exposure NAC images indicates strong reflective anomalies (contrast ~2x) can be found in the PSRs. Lunar highland material has an albedo of ~0.2, while pure water frost has an albedo of ~0.9. If PSRs have an albedo similar to lunar farside average, significant surface frost deposits should result in noticeable reflective anomalies in the NAC images. However, currently no reflective anomalies have been identified in PSRs that can be attributed to water frost. However acquisition and analysis is preliminary and proceeding.

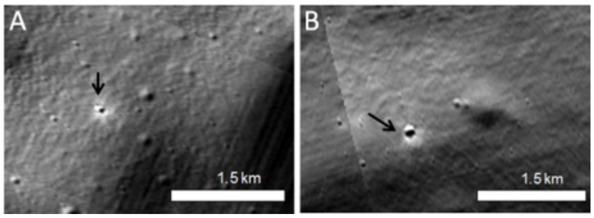

Fig. 2. Mosaics of long exposure (24 ms) NAC images of small craters in PSRs that have high reflective material (likely ejecta) adjacent to them. The craters are located in Cabeus (A) and Shoemaker (B).

Shoemaker crater. Lunar Exploration Neutron Detector (LEND) results show two extensive PSRs (Shoemaker and Cabeus) near the south pole with significant interior hydrogen deposits [5]. Lyman Alpha Mapping Project (LAMP) results indicate that ~0.3% water surface frost exists in the Shoemaker crater PSR, compared to ~1-2% for Faustini, Haworth and Shackleton craters [6]. The contradiction between the LEND and LAMP hydrogen estimates for Shoemaker crater is proposed to be the result of a thin layer of regolith on a water-ice deposit that in effect hides the volatiles from LAMP [6].

An ice rich regolith on the floor of a PSR may create an unusual surface morphology. NAC images reveal that most craters in PSRs have a simple bowl shape morphology. An exception is a crater on the floor of Shoemaker (**Fig. 3A,B**: arrow# 2 to #3), corresponding to significant H deposits and the coldest temperature in the PSR (Fig. 4: arrow# 3 to #4). The crater depth (~280 m) and rim height (~110 m) relative to diameter (~6.5 km) are low for a fresh crater [7]. The location and shape of the degraded crater (**Fig. 3B**) in the PSR and the H deposits may be fortuitous or indicate unusual regolith properties. Further studies of crater morphologies in PSRs are needed to categorize and compare them with illuminated examples.

The NAC mosaic (**Fig. 3**) and data profile (**Fig. 4**) are well correlated. For example, the crater wall at arrow #2 (Fig. 3B) is well illuminated by secondary illumination in **Fig. 3** and corresponds to an increase in temperature (**Fig. 4**). The temperature decreases and does not rise significantly until arrow #4.

Future Campaigns: The existing PSR image coverage will be expanded in future campaigns filling in areas of no coverage (**Fig. 1**) and following up on discoveries with images of higher SNR, higher resolution and varying secondary illumination conditions. Currently, a model using LOLA data predicts periods of optimal secondary illumination within in PSRs and will be used for future campaigns.

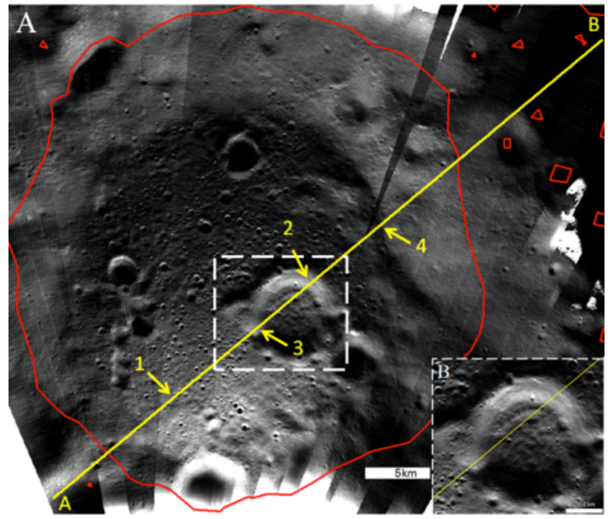

Fig. 3. A) NAC mosaic of Shoemaker crater PSR. Red lines are PSRs from LOLA illumination model [3]. Yellow line and arrows correspond to profile in Fig. 4. Sun is from the top image and reflects off the wall at the bottom (illuminated wall is saturated in the image). B) 6.5 km diameter crater.

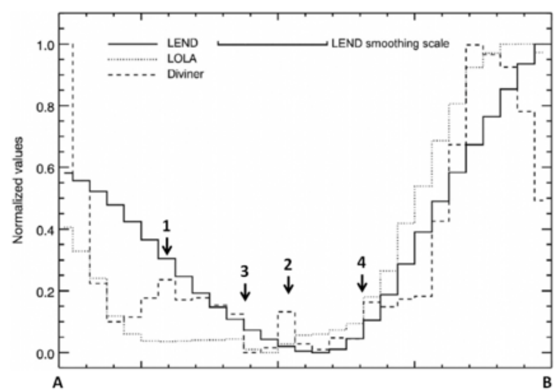

Fig. 4. Data profile across floor of Shoemaker crater from [5]. Yellow line in Fig. 3 shows location of profile in NAC mosaic.

References: [1] Robinson M.S. et al. (2010) *Space Sci. Rev., 150,* 81–124. [2] Speyerer E. J. and Robinson M.S. (2013) *Icarus, 222*, 122-136. [3] Mazarico E. et al. (2011) *Icarus, 211*, 1066-1081. [4] Marshall W. et al. (2012) *Space Sci. Rev.*, 167, 71-92. [5] Sanin A.B. et al. (2012) *JGR*, 117, E00H26. [6] Randall G. et al. (2012) *JGR*, 117, E00H04. [7] Pike R. J. (1977) *Proc. Symp. Plan. Cratering Mech*., 489-509.