LROC OBSERVATIONS OF PERMANENTLY SHADOWED REGIONS ON THE MOON.

S. D. Koeber, M. S. Robinson and E. J. Speyerer. School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (skoeber@ser.asu.edu).

Introduction: Permanently shadowed regions (PSRs) exist at high latitudes 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, indirect illumination from crater walls and nearby massifs reflect light into PSRs thus allowing opportunities to image. PSR secondary lighting is optimal for imaging around the respective solstice and when the LRO orbit is nearly coincident with the sub-solar point (low spacecraft β angles). The goal of PSR imaging is to support ongoing studies (using numerous datasets) to investigating the possibility of cold-trapped volatiles; potentially in the form of surface frosts and unusual morphologies from an ice rich regolith. The PSR images also serve to delimit potential landing sites for future in-situ field work.

Campaign Update: *South Pole Campaigns:* LROC undertook three south pole PSR imaging campaigns (2009, 2012, 2013) by acquiring long exposure (>11.8 ms) NAC images. During the initial and first-half of the second campaign, NAC images were acquired with exposure times of 12-ms and an effective pixel scale of 10-m (nominal polar exposures are 0.7 ms). However, these images had non-optimal signal to noise ratio (SNR) within the PSRs in many cases.

During the second-half of the second campaign, exposure times was increased from 12-ms to 24-ms. The longer exposure times overcame a low signal threshold non-linearity [1], increasing the SNR significantly more than 2x, but reduced the pixel scale in the down track direction (pixels 1-m by 40-m, down track, sampled to 20-m during map projection). During the third campaign, higher effective NAC resolutions for craters with previous high SNRs were obtained by applying an optimized line time (Table 1).

Craters with PSR	Previous Pixel Scale	Latest Pixel Scale
Idel'son L	20 meter	8 meter
Faustini	20 meter	15 meter
Ibn Bajja	20 meter	5 meter
Shoemaker	20 meter	15 meter
Cabeus A	20 meter	7 meter

Table 1. Effective pixel scale of NAC PSR images from the first and second campaign (previous) to the third (latest) in which an optimized line time for each crater was applied.

North Pole Campaigns: The first campaign began in Feb. 2013 and ended in April 2013, while the second campaign started in January 2014. Relative to the south polar region, PSRs near the north pole are generally smaller (diameter <24-km) and located in simple craters. Relative to complex, craters with PSRs, simple craters are often better illuminated by secondary light reflected from steep Sun-facing crater walls at shorter distances. During the northern summer solstice, the smaller northern craters are imaged with shorter exposures 12-ms (resampled to 10-m) resulting in higher effective pixel scales without sacrificing SNR. With the exception of some craters in Peary crater, most northern PSRs with diameters >6-km was successfully acquired (i.e. Whipple, Hermite A and Rozhestvenskiy U craters).

Interior of PSRs: The identification of fresh crater ejecta, boulder tracks, fallback breccia by NAC images inside of PSRs indicates strong reflective anomalies (contrast ~2x) can be confidently identified in PSRs [2]. 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 the highland average, significant surface frost deposits should result in detectable reflective anomalies in the NAC images. However, currently no reflective anomalies have been identified in PSRs that we attribute to water frost.

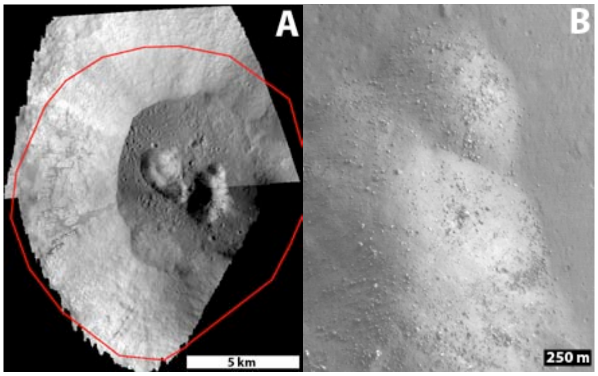

Fig. 1. A) NAC images of Sylvester N, a fresh Copernican-age crater (D: 20 km, 82.4°N, 291.4°E), displaying debris flow on the wall of the crater. B) Sylvester N central peak covered in boulders. Red lines denotes PSR boundaries derived from LOLA illumination model [3]. Saturated pixels are blacked out.

Analysis of CPR anomalous craters: Most fresh lunar craters display high Circular Polarization ratio (CPR) values in their interiors and exteriors [4,5]. The high CPR values are associated with the presence of boulder fields, impact flows, and fallback breccia, which have high levels of wavelength-scale (12.6 and 4.2 cm) surface roughness. Mini-SAR and LRO Mini-RF imaging radar data reveal 71 polar craters exhibiting elevated CPR values in the crater interiors, but not their exteriors (**Fig. 2B**) [4,5]. These craters (3 to 20 km in diameter) were identified as "anomalous" and interpreted as potential locations for water ice deposits based on their correlation with Lunar Prospector neutron data, PSR location, and their thermal environment [5]. Figures 3B and 4 are NAC images of the interior of CPR-anomalous craters with PSR.

Rozhdestvensky N is a CPR-anomalous crater displaying elevated CPR values throughout the crater interior, from the rim to the floor (**Fig. 2B**). NAC images and illumination simulations reveal that the north crater wall receives direct sunlight, indicting that the location of PSR and elevated CPR values are not completely coincident in this crater. We are currently investigating the spatial relations between elevated CPR values in anomalous craters and their PSR.

Preliminary analysis of NAC images of the interiors of CPR-anomalous craters in the polar regions, reveal that these craters are not as heavily cratered as their “nonanomalous” counterparts (**Fig. 3**). Faustini and Idel’son L (**Fig. 3A**) are craters with PSRs that do not display elevated CPR values in their interiors or exteriors. These craters are heavy cratered compared to CPR-anomalous craters with PSRs. Indicating an association with degradation state of a crater and anomalous craters (CPR-anomalous craters are relatively young).

Preliminary results from high-resolution PSR images (pixel scale < 6-m) reveal that some (some but not all) CPR-anomalous craters contain boulder fields and landslides along the crater walls. Figure 4 shows boulder fields inside the PSR of Kocher crater, a CPR-anomalous crater. The boulders range in size from 50 to 20 m. Perhaps, many smaller boulders also exist in the crater but cannot be resolved with the current pixel scales. The presence of many smaller boulders in the interior crater could attribute to higher CPR values

Future Campaigns: The existing PSR image coverage will expand in future campaigns filling in areas of no coverage 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.

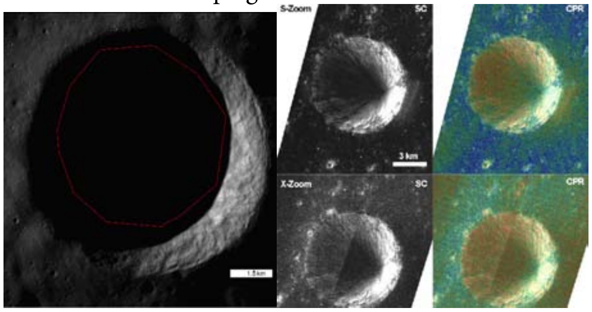

Fig. 2. A: Nominal exposure NAC image of Rozhdestvensky N crater (D:9 km) , red line denotes PSR. B: Rozhdestvensky N displays the same CPR pattern in S and X bands [6]. Note that elevated CPR does not correspond to the PSR location.

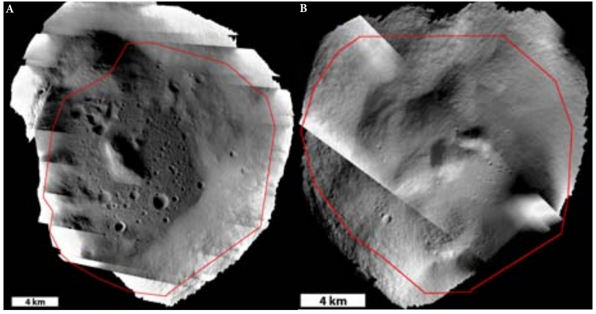

Fig. 3. A) NAC mosaic of the interior of Idel’son L (D: ~27 km, 118.8 E, 84.0 S) **B)** NAC mosaic of the interior of Hermite A (D: 20 km 51.622°W 87.96°N) an CPR-anomalous crater. In both images, red lines are PSRs derived from LOLA illumination model [3]. Saturated pixels are blacked out.

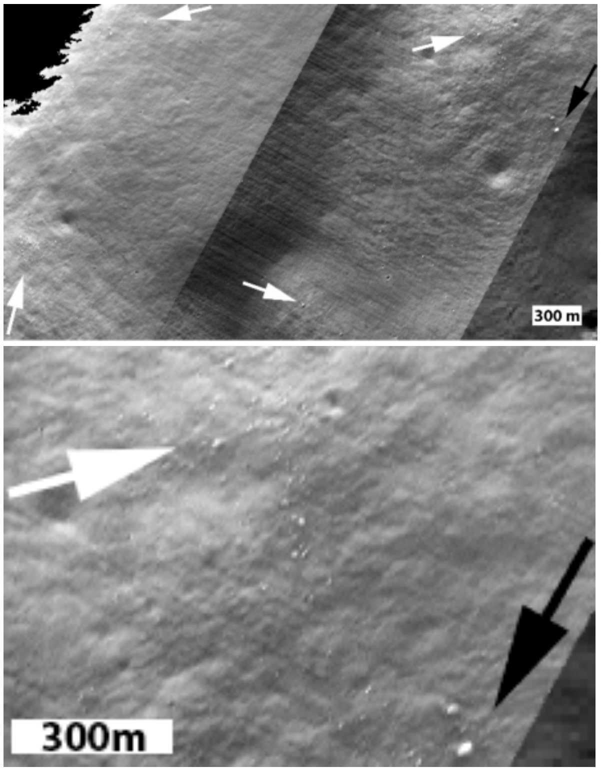

Fig. 4. Top: NAC mosaic of the Kocher crater PSR (D:24 km, 225.8°E, 84.5°S). Bottom: Zoom area near black arrow, which marks the same 50-m diameter boulder in both images. White arrows denotes smaller boulders. Saturated and no data value pixels are blacked out.

References: [1] M.S. Robinson et al. (2010) *Space Sci. Rev., 150,* 81–124. [2] S. D. Koeber et al. (2013) LPS XLIV Abstract# 2588. [3] E. Mazarico et al. (2011) *Icarus. 211*, 1066-1081. [4] P. D. Spudis et al. (2010) *Geophys Res. Lett.* 37, L06204. [5] P. D. Spudis et al. (2013) *JGR*, 118, 2016-2029.