MAPPING AND CHARACTERIZATION OF NON-POLAR PERMANENT SHADOWS ON THE LUNAR SURFACE. J. A. McGovern[1], D. B. J. Bussey[1], B. T. Greenhagen[2], D. A. Paige[3], J. T. S. Cahill[1], M. Siegler[2,3], and P. D. Spudis[4], [1]Applied Physics Laboratory, Laurel MD 20723, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, [3]University of California, Los Angeles, Department of Earth & Space Sciences, Los Angeles CA 90095, [4]Lunar & Planetary Institute, Houston TX 77058.

Introduction: Using an illumination-simulation tool, together with the latest data sets from the Lunar Reconnaissance Orbiter Camera (LROC), the Diviner radiometer, and the Lunar Orbiter Laser Altimeter (LOLA), we have discovered permanent shadows as far from the pole as +/-58^o of latitude. Here we report the results of our analyses of these areas specifically evaluating whether they are cold enough to harbor volatile deposits. The existence of ice deposits at long distances from the poles would represent an exciting resource for future surface missions.

Methodology: We have produced a software tool, called LunarShader that can precisely simulate lunar illumination conditions. Each simulation is run with a fixed Sun position and a gridded topographic image file. The output of the simulation is another gridded image file, with the same dimensions as the input file, containing percentage of Sun visible to each pixel. The Sun location can either be defined by sub-solar latitude and longitude, or by choosing a date and time.

To find the permanent shadows we used the gridded images at resolutions of 100 and 200 meters per pixel extending from the North Pole to 45 degrees north latitude and from the South Pole to 45 degrees south latitude. Since no permanent shadows were found on the equator side of +/-58^o we believe these data products have sufficient coverage for finding all the permanent shadows on the lunar surface. Although the LOLA shot density decreases dramatically away from the pole the gridded topography shows a good amount of detail around the permanent shadows that are farthest from the pole. The analysis was repeated using the Lunar Reconnaissance Orbiter Camera's (LROC) global 100-meter models that only recently became available. We filled missing polar data in the LROC digital terrain models (DTMs) with LOLA gridded data. The results of the analyses using these two datasets were essentially identical.

Temperature information was determined using data collected by the Diviner instrument [1]. Analyses were conducted for a few select permanent shadows on the equator side of +/- 65^o. Two non-polar permanent shadows in each hemisphere were selected for analysis. At each point a nearby (non-permanently shadowed) spot was selected for comparison purposes.

Results: The goal of this study was to map the locations of ALL permanently shadowed regions on the lunar surface using the best available data, with a specific goal of locating those localities that exist at the furthest distance from the poles. To find these permanent shadows we simulate the Sun location at 1440 longitudes (1/4^o increments) and at the highest sub-solar latitude (closest to the pole we are studying) that the Sun ever reaches. Over geologic time the Sun will eventually be at the closest sub-solar latitude (to each pole) at every longitude. So, for a point to be in permanent shadow it must be shadowed from the Sun at the highest possible elevation angles for all azimuths.

Figure 1 shows a shaded relief map of the Moon's northern polar region, from 65 ^{o} to 90^o latitude, containing hundreds of permanent shadows (in red). Figure 2 shows a portion of a shaded relief map from 58 ^{o} to 65 ^{o}N latitude.

Figure 3 shows a small area of permanent shadow inside the 13 km diameter crater Dugan J located at 61.6°N 108.0°E. The permanent shadow is located at the base of the north-facing slope of the crater. The shape of the permanent shadow is in good agreement with predictions from previous work [2,3] we have found multiple craters far from the poles that also exhibit a similar oval shaped shadow pattern similar to that seen in Dugan J.

We have been looking at Diviner temperature data of these low latitude regions, comparing areas of permanent shadow with nearby areas that are sunlight the usual half of a lunar day. We find that the permanently shadowed non-polar regions have max temperatures approximately half those of nearby illuminated regions. The maximum temperature is typically ~175K. This is too warm for ice to exist at the surface but we are determining the depth of regolith required in these regions for long-term sequestration of volatiles.

Conclusions: We have discovered the existence of permanently shadowed regions at distances further from the pole than previously known. Analysis of the temperature regime with these areas reveals that they are significantly colder than neighboring illuminated regions. Further research will determine the habitability for volatiles in these areas.

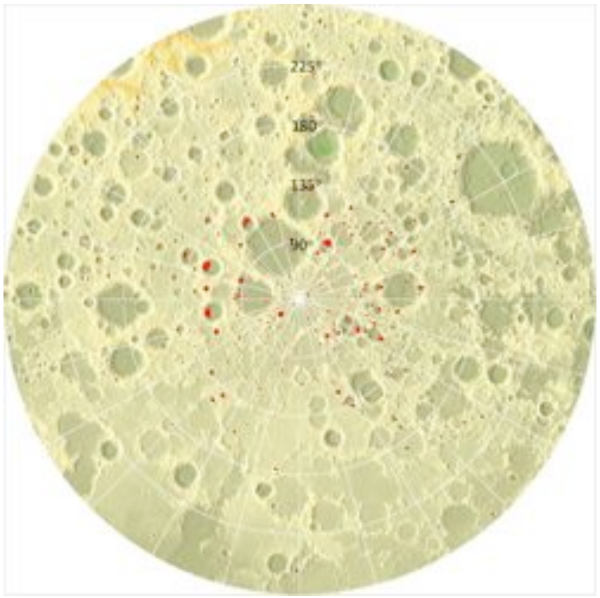

Figure 1. Shaded relief image covering 60° to 90°N with permanently shadowed regions in red.

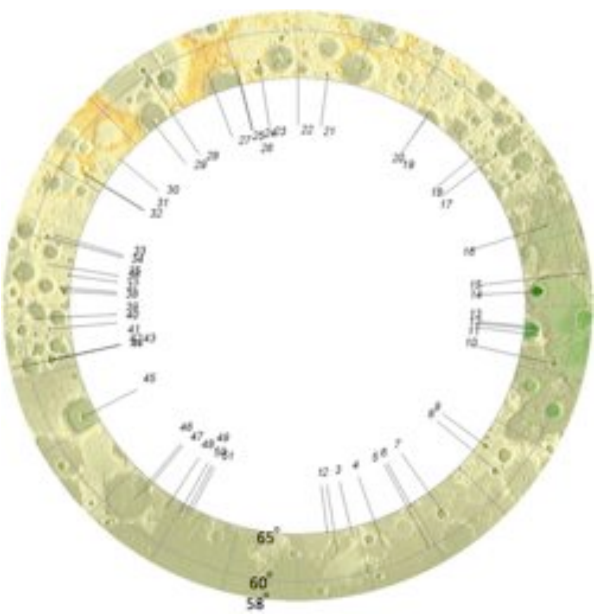

Figure 2. Shaded relief image covering from 58°N to 65°N. Areas of permanent shadow are numbered.

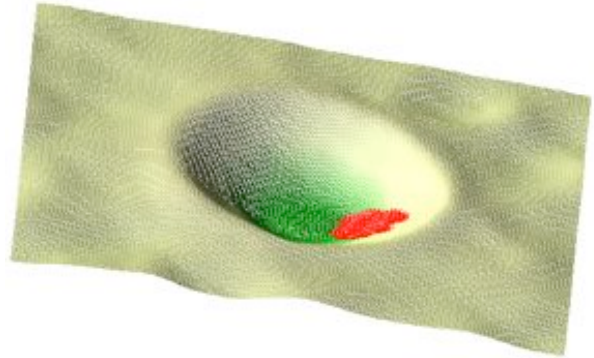

Figure 3. Three-dimensional rendering of the 13 km crater Dugan J, with the area of permanent shadow marked in red. The shadow exists in the inner rim facing towards the north (pole).

References:

[1] Paige, et al., 2009. [2] Vasavada et al., 1999. [3] Bussey, et. al. 2003