**LUNAR POLAR HYDROGEN CORRELATIONS WITH IMPACT CRATER GEOMETRY FROM LRO LEND AND LOLA OBSERVATIONS.**

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**Introduction:** The Lunar Reconnaissance Orbiter spacecraft (LRO) enables quantitative studies of the distribution of lunar polar region hydrogen (H) content associated with the geometric characteristics of a reference set of impact craters in these regions. As impact crater geometric properties measured from newly-available LOLA topography are related to crater degradation state and hence surface age, if there are correlations between H content and crater geometric properties then these may reflect age-relationships associated with H deposition.

Using divisive, omnithetic clustering methods (DOCTDA) [1], we have investigated the association of enhanced regions of polar H with geometric parameters that are potential proxies for crater age.

Given the availability of 10km scale LEND neutron flux information (from which H can be measured) as well as 100m (horizontal) LOLA topography for the polar regions, detailed assessment of spatial clustering is amply warranted at this time.

***Lunar Orbiter Laser Altimeter (LOLA)***: LOLA produced 100m scale digital elevation model (DEM) topography of the lunar polar regions under the leadership of PI, David Smith and DPI, Maria Zuber. The 100m horizontal scale DEM's enable extremely detailed geometric property measurements of polar region impact craters, including such normalized parameters as:

1. depth/Diameter (d/D). [aspect ratio]
2. cavity cross-sectional shape as a 3D power function (exponent n).
3. Average crater cavity wall slopes.
4. Ejecta Thickness Function power functions (exponent b and coefficients).
5. Cavity Volume normalized to cavity surface area (V/SA)
6. Others (V/SA/d, Ejecta V/SA, Central uplift volume, etc.)

These parameters were measured using a semi-automated system developed and tested using Mars MGS MOLA data on 10,000 impact craters, as well as using SRTM DEM data for Earth [2].

***Lunar Exploration Neutron Detector (LEND):*** LEND maps the flux of neutrons from the lunar surface to infer the hydrogen (H) content of upper meter of lunar regolith, as well other properties. The PI, Igor Mitrofanov, Institute for Space Research, and Federal Space Agency, Moscow has provided normalized measurements of the neutron flux for the representative set of north and south polar impact craters that have been characterized using LOLA topography (geometric properties).

The LEND neutron fluxes have been normalized to polar region latitude bands [3] so that the statistical confidence of the values for impact craters from 10km to 100km in diameter is maximized. The joint clustering analysis of the LEND neutron flux (as a proxy for H content within the craters) involves the use of various sets of specific attributes (associated with each crater), as follows:

1. LEND neutron flux (normalized to the latitude band that includes the particular crater)
2. LOLA-derived geometric parameters:
   a. d/D
   b. Cavity shape
   c. Ejecta Thickness Function "shape"
   d. Avg. crater cavity wall slopes
   e. Cavity Volume normalized to Surface area
   f. V/SA/d (normalized to crater depth)
   g. Whether a given crater is within or includes a PSR or not (permanently shadowed region) on the basis of LOLA estimations (from the LOLA team) [4].

Using these parameters we have investigated an index set of polar region impact craters from both lunar polar regions (from 70 degrees to the pole for N and S). For the South polar region (SP), we measured 49 craters using both LEND and LOLA and conducted multiple clustering analysis "runs" to ensure reproducibility and to investigate sensitivities. Craters were selected on the basis of the quality of LOLA and LEND measurements and to accommodate a range of diameters and degradation states. All craters measured were between 10km and 100km in diameter.

***Spatial Clustering Results:*** Preliminary results from the ongoing study are summarized below (see Figure 1). There are clearly differences between the SP and the NP crater populations considered. Here we focus on the south polar (SP) region. Figure 2 illustrates the results.

SP Crater Population Clustering observations:

1. A cluster has been identified that includes the craters with the lowest LEND neutron fluxes (highest potential H content) and the most "conical" cavities (which may be a proxy for minimal post-impact degradation) – this cluster (A in Figure 1) is not confined to PSR's.
2. All of the higher LEND neutron flux craters display parabolic cavities with higher V/SA properties (most of these are associated with PSR's).
3. Cavity "shape", including aspect ratio (d/D) serves to classify craters measured from high resolution LOLA DEM's to first order such that parabolic craters are clearly separable from conical and more U-shaped craters – this suggests that cavity geometry is a first order discriminator in association with modeled H content for the population of 49 south polar craters studied.

***SUMMARY***: Preliminary divisive omnithetic clustering analysis of populations of representative impact craters from the NP and SP regions on the basis of LEND neutron flux information and LOLA-based geometric properties indicates that H content appears to be associated with a sub-population of craters with fresh-appearing conical cavities. Whether this association is related to how H content within the polar craters is related to absolute age or to other factors is the subject of ongoing study using control regions from mid-latitude regions. Incorporation of other parameters as attributes in the continuing clustering analysis is under consideration, including thermal inertia (Diviner) and Circular-Polarization Ratio from MiniRF.

**Acknowledgements**: Special thanks to the LRO project (Tooley, Vondrak, Keller), ESMD, and the LRO instrument teams.

**REFERENCES**: [1] Garvin J. (1984) *PhD Thesis*, Brown University, Geological Sciences; [2] Garvin J. (2000) *Icarus 144*, 329-352; [3] Mitrofanov I. et al. (2009) submitted to *Science*, Dec. 2009. [4] D. E. Smith et al., *Space Sci. Rev.*, in press (2009) .

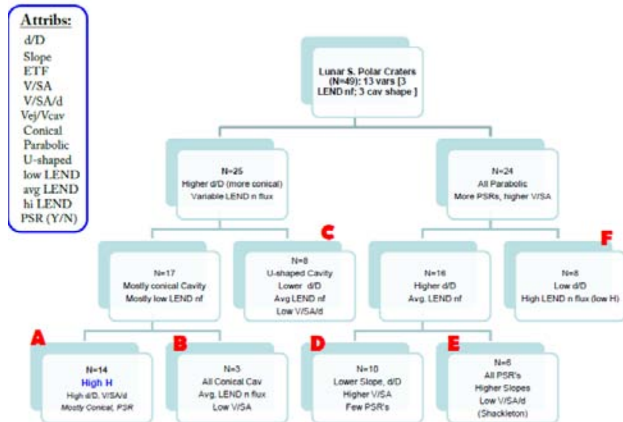


**Figure 1**: Hierarchical clustering diagram (SP).

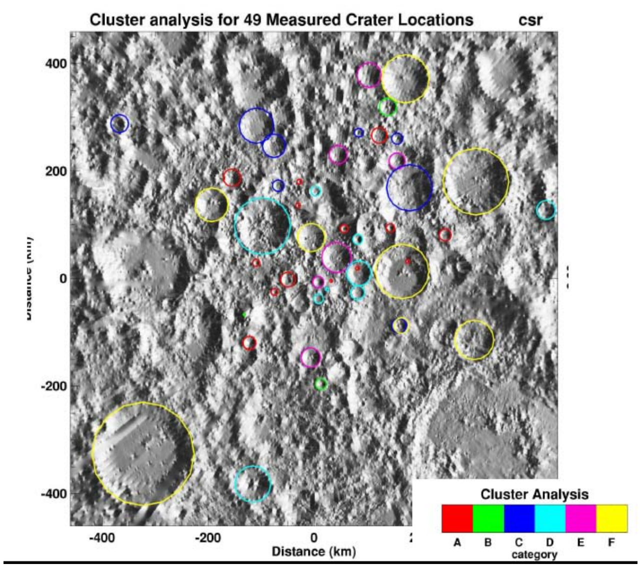


**Figure 2**: Shaded relief map (from LOLA) of the lunar south polar region (SP) illustrating the 6 clusters using color (see color bar); craters within clusters are identified on the basis of the color shown as a ring around their rim crests. Cluster A (red) is that with the highest H content and the most conical cavity geometries.