# TECTONIC HISTORY AND SEISMICITY IN THE LUNAR NORTH POLAR REGION.

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**Introduction:** Lunar polar regions host various tectonic features such as, wrinkle ridges, grabens and lobate scarps but lobate scarps are the predominant tectonic landforms of both the polar regions. Lobate scarps, being the youngest tectonic landforms of the moon [1, 2] which are formed due to active lunar contraction [3], are important tool to understand the active seismicity, amount of crustal shortening and period of global contraction on the moon. Past studies reported several thousands of lobate scarps on the moon, globally [1-5]. Our previous work [1] presented the study of lobate scarps from the lunar south polar region (LSPR) and in the current study we are focusing on the lunar north polar region (LNPR). We have identified a few hundred individual lobate scarp segments from the LNPR (Figure 1) while the previously reported scarps by [3] have also been considered in this study.

The geometry (lengths, depths and orientations) and kinematics (movement directions) of all the lobate scarp segments from LNPR are measured. Lengths of the scarp segments are used to calculate the seismic hazard potential of the thrust faults [1, 6]. The absolute formation ages of newly detected scarp segments are determined to know the tectonic history of LNPR.

Association of young faults and mass wasting features indicates active seismicity on lunar surface [4, 5, 7]. Boulder falls are distributed throughout the lunar globe and are formed due to rolling, bouncing or sliding movement of boulders (Figure 2c). Down slope movement of boulders require intense ground vibration that can be generated either due to meteorite impacts or due to the shallow moonquakes. We report few locations in the LNPR showing evidence of lobate scarp - boulder fall associations (Figure 1 and 2) which indicates seismic origin of these boulder falls. Seismic hazard map of the LNPR is produced by creating buffer zones around the scarps, considering the seismic shaking originating from $M_W$ 1 to 4 shallow moonquakes [1, 7], that may occur along the scarps.

**Data and Methods:** The lobate scarps and boulder fall sites are located using LROC Quickmap browser (https://quickmap.lroc.asu.edu/), initially. USGS-PILOT (https://pilot.wr.usgs.gov/) web portal and Map projection on the web (https://astrocloud.wr.usgs.gov/) interface are used to download and process high resolution Lunar Reconnaissance Orbiter Camera (LROC) - NAC (Narrow Angle Camera) images. The images are then imported to ArcGIS desktop 10.7 software for digital mapping and analysis. We have used 280 LROC-NAC images of 0.5m/pixel resolution in this study for mapping the scarps and boulder falls. LROC-WAC (Wide Angle Camera) images that provides 100m/pixel images in seven colour bands are used for representing the scarps and boulder fall sites and analysing their distribution pattern. Dating of the lobate scarp segments are carried out using conventional crater counting method with the help of *Crater Tools* [8] and *Craterstat* software [9]. The statistical analysis is performed and the cumulative size-frequency distributions (CSFD) of the mapped craters are derived. The lunar production and chronology functions [10] are applied for obtaining the absolute ages.

**Initial Results and discussion:** 224 individual lobate scarp segments from 22 sites are identified in this study (Figure 1). Including the previously identified scarps [3], a total of 788 lobate scarp segments are considered. We have found 443 scarp segments (56%) located within crater interiors, and remaining 345 segments (44%) are present in the inter-crater highlands. The occurrences of lobate scarps in the impact craters suggest the roles of pre-existing impact structures (e.g., [1]). The size range of host impact craters is found to be 11 km diameter simple crater to 211 km complex crater. The morphology of scarps indicate there young ages. Lengths of individual scarp segments are ranging from 21 m to 23 km (mean- 2.16 km) (Figure 3) and the depth of the faults range from 7 m to <8 km (mean- 0.7 km) (e.g., [1]). Lengths of scarp segments indicates that they are capable of producing $M_W$ 3 to 7 shallow moonquakes. Measurement of orientations and movement directions of the 788 scarp segments are under progress.

30 newly identified scarp segments suggest ages ranging from 6.7 to 35 Ma (mean- 15.5 Ma) (Figure 1). Out of them 22 scarp segments (73%) are giving ages ≤20 Ma. The CSFDs of a few dated scarps from LNPR are showing mild to strong resurfacing signatures. The age distribution suggests recent tectonic activity (<50 Ma) in and around the LNPR irrespective of the latitude unlike the LSPR [1]. However, dating of the scarps in the LNPR is still under progress.

We have identified 5 sites showing scarp - boulder fall associations (Figures 1 and 2), indicating the scarps are seismically active and may be the possible triggering source for the formation of the boulder falls. This also supports the relocation of May 16, 1976 ($M_W$

2.7) shallow moonquake epicenter [11] to the lobate scarps in LNPR (Figure 1) by [12]. For example, figure 2a shows the location of boulder falls on the eastern crater wall slope of a 3.5 km diameter simple crater to the north of the lobate scarp located along the southern wall of Meton C crater. The site contains more than one generation of boulder falls (e.g., [7]). Figure 2d shows one example of superposition of boulder tracks.

Following, [1, 7] We have generated a seismic hazard map of the LNPR by creating buffers around all the lobate scarp segments [1] and considering the ground motions produced from expected shallow moon quake magnitudes of $M_W$ 1 to 4 [7]. Considering 0.03 lunar g as the threshold PGA (peak ground acceleration) and magnitude $M_W$ 4 shallow moon quake, 22% area of the LNPR is falling in high seismic risk zones.

Comparing the lobate scarp distributions in LSPR [1] and LNPR (This study), the scarps are more or less evenly distributed throughout the LNPR where as a paucity of scarps is noticed inside the SPA basin in LSPR. However, absence of scarps within 2° latitude from the pole is common in both LNPR and LSPR. Morphology, morphometry and seismic potential of the lobate scarps are comparable in both the regions. Ages of scarps obtained from both the polar regions show that the scarps are dominantly younger (<50 Ma). However, 10% of the scarp ages from the LSPR are >50 Ma, which is not observed in LNPR, so far, including the latitudinal age variation. Seismically high risk zones are comparatively higher in the LNPR because of wider scarp distribution than LSPR. Further analysis is in progress.

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**References:** [1] Mishra and Kumar (2022) *Geophys. Res. Lett.*, 49. [2] Binder, A. B., and H. C. Gunga (1985), *Icarus*, 63, 421–441. [3] Watters, T. R. et al. (2015) *Geology* 43, 851–854. [4] Kumar, P. S. et al. (2016) *Journal of Geophysical Research : Planets*. 147–179. [5] Kumar, P. S. et al. (2019) *Geophys. Res. Lett.*, 7972-7981. [6] Wells and Coppersmith (1994) *BSSA*, 84 (4), 974–1002. [7] Mohanty, R. et al. (2020) *J. Geophys. Res. Planets* 1–29. [8] Kneissl et al. (2011) *Planetary and Space Science*, 59 (11–12), 1243–1254. [9] Michael, G. G., and Neukum, G. (2010) *Earth and Planetary Science Letters*, 294(3–4), 223–229. [10] Neukum, G. et al. (2001) *Space Science Reviews*, 96 (1–4), 55–86. [11] Nakamura et al. (1979) in *10th lunar and planetary science conference proceedings* (pp. 2299–2309). [12] Watters et al. (2019) *Nature Geoscience*, 12(6), 411–417.

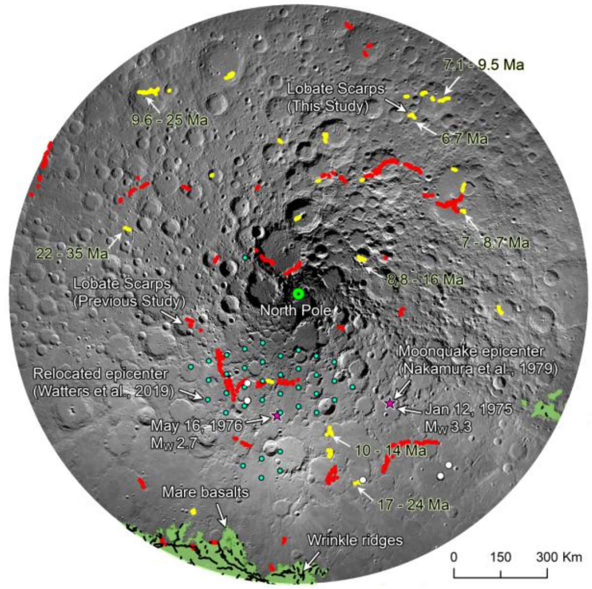


**Figure 1.** LROC-WAC mosaic showing the lobate scarp distribution in the LNPR. The boulder fall sites are marked by white circles. Ages of the dated scarps are shown.

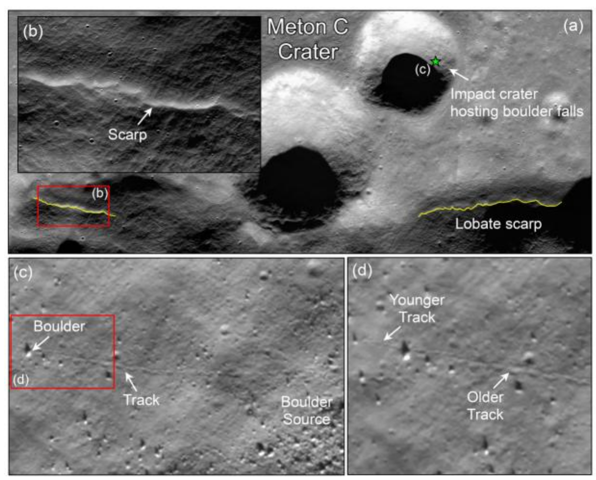


**Figure 2.** LROC NAC image mosaic showing the lobate scarps located along the southern wall of Meton C crater and the associated co-seismic boulder falls.

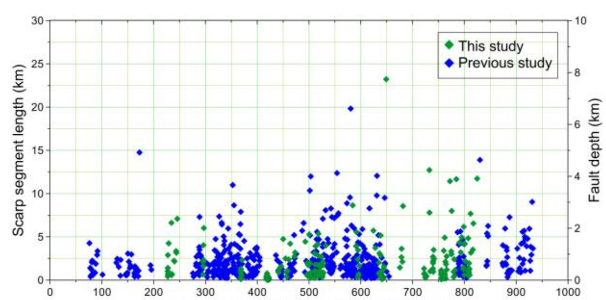


**Figure 3.** Scarp length vs. distance from LNPR for 788 individual scarp segments reported, thus far.