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Morphological Analysis of Lunar Lobate Scarps Using LROC NAC and LOLA Data

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1. Introduction

Lobate scarps on the Moon are relatively small-scale tectonic landforms observed in mare basalts and more commonly, highland material [1-4]. These scarps are the surface expression of thrust faults, and are the most common tectonic landform on the lunar farside [1-4]. Prior to Lunar Reconnaissance Orbiter (LRO) observations, lobate scarps were largely detected only in equatorial regions because of limited Apollo Panoramic Camera and high resolution Lunar Orbiter coverage with optimum lighting geometry [1-3].

Previous measurements of the relief of lobate scarps were made for 9 low-latitude scarps (<±20°), and range from ~6 to 80 m (mean relief of ~32 m) [1]. However, the relief of these scarps was primarily determined from shadow measurements with limited accuracy from Apollo-era photography. We present the results of a detailed characterization of the relief and morphology of a larger sampling of the population of lobate scarps. Outstanding questions include what is the range of maximum relief of the lobate scarps? Is their size and structural relief consistent with estimates of the global contractional strain? What is the range of horizontal shortening expressed by lunar scarps and how does this range compare with that found for planetary lobate scarps?

Lunar Reconnaissance Orbiter Camera (LROC) images and Lunar Orbiter Laser Altimeter (LOLA) ranging enable detection and detailed morphological analysis of lobate scarps at all latitudes. To date, previously undetected scarps have been identified in LROC imagery in 75 different locations, over 20 of which occur at latitudes greater than ±60° [5-6]. LROC stereo-derived digital terrain models (DTMs) and LOLA data are used to measure the relief and characterize the morphology of 26 previously known (n = 8) and newly detected (n = 18) lobate scarps. Lunar examples are compared to lobate scarps on Mars, Mercury, and 433 Eros (Hinks Dorsum).

2. Data and Methods

The LROC Narrow Angle Cameras (NACs) provide up to 0.5 meter-scale panchromatic images [7]. Five DTMs derived from LROC NAC stereo pairs, with vertical precision errors ranging from ~2 to 5 m [8], were analyzed to obtain measurements of maximum relief for 5 lobate scarps (Fig. 1).

The LOLA instrument transmits 5 beams, each illuminating a 5 m spot from a 50 km altitude orbit, creating individual observations separated by ~56 m along each profile [9]. LOLA ranging has a vertical precision of up to ±0.1 m. Because of LRO's polar orbit, only primarily E-W trending scarps were examined with LOLA topography. Multiple LOLA profiles were analyzed to measure the relief in several locations along 21 scarp segments where the profiles traverse the scarps at orthogonal or near to orthogonal angles (Fig. 2). Here we report the greatest measured relief for each scarp, as opposed to the maximum relief, due to incomplete LOLA coverage along the full scarp lengths.

3. Results

The lobate scarps typically exhibit asymmetric profiles with relatively steeply sloping scarp faces and more gently sloping back scarps [1, 10] (Fig. 1-2). They share similar basic morphological elements with lobate scarps observed on Mars, Mercury, and Eros. Maximum scarp-face slopes range from ~4° to 27° with a mean of ~11° and are also comparable to slopes reported for planetary lobate scarps (up to 17°) [i.e. 10-11] and Hinks Dorsum (~20°) [12].

Measured relief of the lobate scarps ranges from ~5 to 150 m with a mean relief of ~35 m (median = ~20 m) (Fig. 3). Racah X-1, a newly identified scarp at 10.06° S, 178.10° E, is the largest scarp measured to date with a relief of ~150 ± 5 m (Fig 1). All but five of the measured scarps have a relief of less than 41 m and scarps with a relief up to ~20-30 m are observed at nearly all latitudes (Fig. 3). The current data indicate that the lobate scarps, as a whole, typically exhibit tens of meters of relief, consistent with previous work [1]. Lunar lobate scarps are typically smaller than those on Mercury [13-16] and Mars [17], some with maximum reliefs >1 km, but are comparable to Hinks Dorsum (25-60 m) [12].

Using the relief (h) and a range of 20°- 40° for the fault plane dip (θ), we can estimate a range for the lower limit of horizontal shortening (S) expressed by the lobate scarp thrust faults by assuming it is a function of the relief of the scarp and the dip of the surface-breaking fault-plane ($S = h/\tan\theta$) [i.e. 10, 18-19]. Estimated lower limits for S range from 0.006 to 0.412 km. The horizontal shortening of individual lobate scarps is an expression of either the regional or global contractional strain. The range in S estimated for the lunar examples is thus consistent with a small amount of global contractional strain. This range in S is comparable to Hinks Dorsum (~0.072-0.165 km) [12], a surprising result due to the small size of Eros (34 by 11 by 11 km) [20]. The lunar results are roughly an order of magnitude lower than estimates of S for planetary thrust faults (up to ~3-4 km), consistent with larger amounts of regional and global contractional strain associated with the lobate scarps on Mars and Mercury respectively [10-11, 16-17, 19].

6. Summary and Conclusions

LOLA profiles and NAC DTMs are used to characterize 26 globally distributed lobate scarps.

- Relief of the lobate scarps ranges from ~5 to 150 m with a mean relief of ~35 m.
- Estimated lower limits for the horizontal shortening expressed by the lobate scarp thrust faults range from 0.006 to 0.412 km.
- Lunar scarps have similar morphology to planetary lobate scarps and Hinks Dorsum.
- The relief and horizontal shortening of lunar scarps is generally an order of magnitude lower than planetary lobate scarps, but comparable to Hinks Dorsum on Eros.
- The current data indicate that lunar lobate scarps, as a whole, typically exhibit tens of meters of relief, consistent with previous estimates [1].
- The small amount of horizontal shortening estimated for the growing number of well-characterized scarps is consistent with a small amount of global contractional strain manifested by the population of lunar lobate scarps.

References

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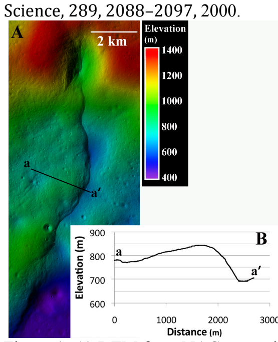

Figure 1: A) DTM from NAC stereo images of lobate scarp Racah X-1. The black line marks the location of the profile. B) Profile across Racah X-1 derived from the NAC DTM.

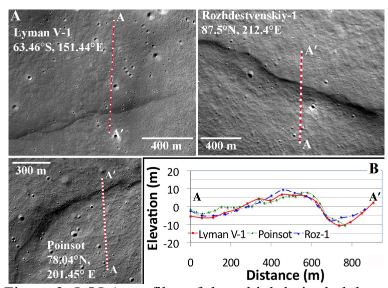

Figure 2: LOLA profiles of three high latitude lobate scarps newly identified in LROC imagery. A: The location of the LOLA track is indicated by a red line where it traverses each lobate scarp. White dots indicate individual data points. B: Detrended LOLA profiles.

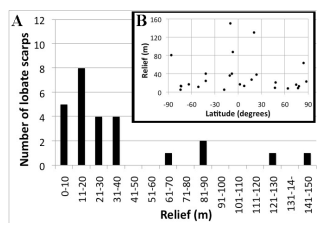

Figure 3: A) Histogram showing the distribution of measured lobate scarp relief. B) Distribution of lobate scarp relief by latitude.