DISPLACEMENT-LENGTH RELATIONSHIP OF THRUST FAULTS ASSOCIATED WITH LUNAR LOBATE SCARPS: COMPARISON WITH LOBATE SCARPS ON OTHER BODIES.

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Introduction: Small lobate scarps, formed by thrust faults, are one of the most common tectonic landforms on the Moon. They are observed predominantly in highland material [1-4]. Images acquired by the Lunar Reconnaissance Orbiter Camera (LROC) [5] and LROC stereo-derived digital terrain models (DTMs) enable widespread detection and detailed morphometric analysis of lobate scarps [6-7] previously not possible due to the small-scale of these tectonic landforms. Over 3200 globally distributed lunar scarps have now been identified and mapped [6-8].

Data and Methods: DTMs derived from LROC Narrow Angle Camera (NAC) stereo pairs are used to measure the maximum relief (h) and horizontal length (L) of >40 individual lobate scarp segments (Fig. 1). Measurements of h can be used to estimate the maximum displacement (D_{max}) on associated thrust faults using the relationship $D = h/\sin\theta$, where θ is the dip of the surface-breaking fault-plane [e.g., 9-10] and assumes the total displacement from cumulative slip on the thrust fault is expressed by h. Studies of terrestrial fault populations formed in uniform rock types indicate that the maximum D on a fault scales with L as a linear function such that $D = \gamma L$, where γ is a constant determined by tectonic setting and the mechanical properties of the near-surface crustal materials [e.g., 11].

Here we use measurements of D_{max} and L to improve estimates of the value of γ for the population of lunar thrust faults, and to compare this with γ values of thrust fault populations on other bodies. When the displacement-length (D-L) relationship of a certain fault population is known, it can be used to estimate contractional strain using fault lengths alone [e.g., 12]. The D-L relation also provides insight into the tectonic setting of a fault population, and mechanical properties, particularly strength, of faulted materials.

Results and Discussion: Maximum relief of scarp segments ranges from ~4 to 165 m with lengths ranging from ~0.3 to 14 km. D_{max} ranges from ~10 to 390 m assuming a range in θ of 25° to 40°. Creating log-log plots of D_{max} as a function of fault length, γ is obtained by a linear fit to the D-L data (Fig. 2). The value of γ for the lunar lobate thrust fault scarp population ranges from ~2.1×10^{-2} to ~1.4×10^{-2} for θ = 25° to 40° (~1.8×10^{-2} for θ = 30°). Standard deviation of γ is (~0.2 to 0.3) x 10^{-2} for our range in θ (0.24 x 10^{-2} for θ = 30°).

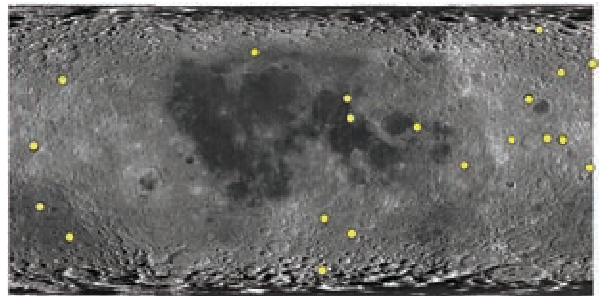

Fig. 1. Locations of lobate scarps measured for their relief in this study (white dots) plotted on a global LROC Wide Angle Camera (WAC) mosaic of the Moon. Map is centered at 0° longitude. Multiple scarp segments were measured at most locations.

Comparison with other bodies: The lunar scarps are about an order of magnitude smaller in scale compared with lobate scarps on Mars and the large-scale lobate scarps on Mercury (scarps on both planets may have >1 km of relief) [13-15] consistent with large amounts of contractional strain. The range in γ for the lunar thrust faults is higher than estimates of γ for lobate scarp populations on Mars (~6.2×10^{-3} for θ = 30°) [e.g., 13] and the large-scale scarps on Mercury (~8.2×10^{-3} for θ = 30°; Fig. 3) [16], but lower than the γ for typical thrust faults on Earth (~8.0×10^{-2} for θ =30°) [9]. However values of γ for lunar scarps are comparable to recently discovered small (<100 m relief) scarps on Mercury (γ ~5.4×10^{-2} for θ =30°) [16]. D-L data for populations of thrust faults on the Moon, Earth, Mars, and Mercury are plotted in Fig. 3. For further comparison, displacement and length for lobate scarp segments on asteroid 433 Eros (relief = ~25-50 m) [e.g., 7,17] are shown in Fig. 3 and plot within the cloud of data points for the lunar scarps and small-scale Mercury scarps.

The differences in γ for thrust faults on these bodies likely reflects differences in both tectonic setting and the mechanical properties of the near-surface rock. Terrestrial thrust faults localized at convergent plate margins accumulate large amounts of strain. In contrast, thrust faults on the Moon, Mars, and Mercury, indicate more distributed deformation [9]. In addition, the lower γ values estimated for the large-scale scarps on Mars and Mercury may indicate that these faults extend into their mechanically strong lithospheres [see 16]. The smaller scale scarps on the Moon which extend to depths of ≤1 km [18] are confined to mechanically weaker megaregolith. Mercury's small scarps are also likely shallowly rooted in the megaregolith [16]. Indeed, results from the Gravity Recovery and Interior Laboratory (GRAIL) mission indicate a fairly weak lunar regolith that is more propous and lower in density than previously thought [19]. Likely a similarly weak and porous megaregolith is present on Mercury [16]. The presence of abundant water on Earth reduces the friction on faults which may also contribute to higher γ values compared to faults where water is absent [1]. It has been suggested that γ scales with the acceleration due to gravity [20]. Our results suggest the principal influence on γ is the accumulated strain.

The small lunar thrust faults are almost always observed in clusters or complexes of multiple individual scarps with parallel/subparallel orientations; some clusters can extend for large distances, such as a ~250 km long cluster south of Mare Humorum. This is in contrast with the large more solitary scarps observed on Mars and Mercury. However, the small scarps on Mercury are also often observed in clusters [16]. It is likely that as Mercury's small scarps grow, clusters of small faults merge and form larger faults that extend in length and depth into the stronger mechanical lithosphere. The difference in γ between Mercury's large and small thrust fault populations may reflect the transition from small, dominantly shallow depth faults to deeper faults that extend perhaps to the base of the mechanical lithosphere on Mercury [16]. Thrust faults in lunar clusters have not developed sufficient linkage to become larger scale structures. This is likely due to insufficient cumulative contractional strain [see 8]. On Mercury, contractional strain accumulated over a long period of the recorded geologic history. Indeed analyses of relative and absolute ages of Mercury's scarps reveal that widespread contractional deformation has continued over much of the last ~3-4 Gyr, and may be ongoing [16, 21]. Nearside basin-related extensional tectonism on the Moon is believed to have ended ~3.6 Ga, transitioning to a predominantly compressional stress state [e.g. 22]. However, characteristics of the lunar lobate scarps (i.e. crisp morphologies, few or no superposing craters, etc) indicate that they have all been active very recently (likely with the last 50 Ma) [8, 23]. The amount of contractional strain expressed by the population of young lobate scarps on the Moon is small [15]. The lack of larger scale lunar scarps is a clear indication that large amounts of global contraction have not occurred over the past several billions of years.

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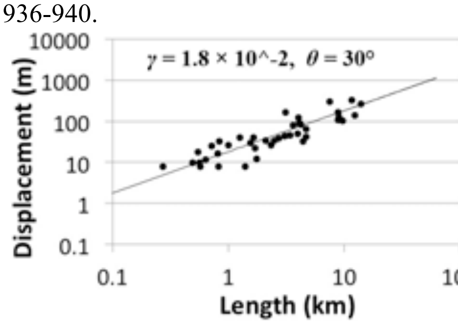

Fig. 2. Log-log plot of maximum displacement as a function of fault length. Slope (γ) for the lunar thrust faults was obtained by a linear fit with the intercept set to the origin.

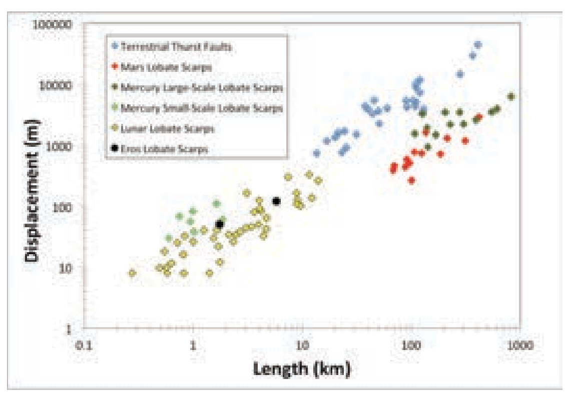

Fig. 3. Log-log plot of maximum displacement as a function of fault length for faults on the Moon, Earth, Mars, Mercury, and Eros.