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Length-Displacement Scaling of Lunar Thrust Faults and the Formation of Uphill-Facing Scarps

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Lobate scarps are straight to curvilinear positive-relief landforms that occur on all terrestrial bodies [e.g., 1-3]. They are the surface manifestation of thrust faults that cut through and offset the upper part of the crust. Fault scarps on planetary surfaces provide the opportunity to study the growth of faults under a wide range of environmental conditions (e.g., gravity, temperature, pore pressure) [4]. We studied four lunar thrust-fault scarps (Simpelius-1, Morozov (S1), Fowler, Racah X-1) ranging in length from 1.3 km to 15.4 km [5] and found that their maximum total displacements are linearly correlated with length over one order of magnitude. We propose that during the progressive accumulation of slip, lunar faults propagate laterally and increase in length. On the basis of our measurements, the ratio of maximum displacement, D, to fault length, L, ranges from 0.017 to 0.028 with a mean value of ~0.023 (or 2.3%). This is an order of magnitude higher than the value of ~0.1% derived by theoretical considerations [4], and about twice as large as the value of ~0.012-0.013 estimated by [6,7]. Our results, in addition to recently published findings for other lunar scarps [2,8], indicate that the D/L ratios of lunar thrust faults are similar to those of faults on Mercury and Mars (e.g., 1, 9-11], and almost as high as the average D/L ratio of ~3% for faults on Earth [16,23]. Three of the investigated thrust fault scarps (Simpelius-1, Morozov (S1), Fowler) are uphill-facing scarps generated by slip on faults that dip in the same direction as the local topography. Thrust faults with such a geometry are common (~60% of 97 studied scarps) on the Moon [e.g., 2,5,7]. To test our hypothesis that the surface topography plays an important role in the formation of uphill-facing fault scarps by controlling the vertical load on a fault plane, we simulated thrust faulting and its relation to topography with two-dimensional finite-element models using the commercial code ABAQUS (version 6.14). Our model results indicate that the onset of faulting in our 200-km-long model is a function of the surface topography [5]. Our numerical model indicates that uphill-facing scarps form earlier and grow faster than downhill-facing scarps under otherwise similar conditions. Thrust faults which dip in the same general direction as the topography (forming an uphill-facing scarp), start to slip earlier (4.2 Ma) after the onset of shortening and reach a total slip of 5.8 m after 70 Ma. In contrast, slip on faults that leads to the generation of a downhill-facing scarp initiates much later (i.e. after 20 Ma of elapsed model time) and attains a total slip of only 1.8 m in 70 Ma. If the surface of the model is horizontal, faulting on both fault structures starts after 4.4 Ma, but faulting proceeds at a lower rate than for fault, which generated the uphill-facing scarp. Although the absolute ages for fault initiation (as well as the total fault slip) depend on the arbitrarily chosen shortening rate (as well as on the size of the model and the elastic parameters), this relative timing of fault activation was consistently observed irrespective of the chosen shortening rate. Thus, the model results demonstrate that, for all other factors being equal, the differing weight of the hanging wall above the two modeled faults is responsible for the different timing of fault initiation and the difference in total slip. In conclusion, we present new quantitative estimates of the maximum total displacements of lunar lobate scarps and offer a new model to explain the origin of uphill-facing scarps that is also of importance for understanding the formation of the Lee-Lincoln scarp at the Apollo 17 landing site.

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