Mass wasting on the Moon: Implications for seismicity

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Overview

Seismicity estimates play an important role in creating regional geological characterizations, which are useful for understanding a planet's formation and evolution, and are of key importance to site selection for landed missions. Here we investigate the regional effects of seismicity in planetary environments with the goal of determining whether such surface features on the Moon, could be triggered by fault motion (Fig. 1).

Fig. 1: (left) Landslide deposits (granular flow) on an interior slope of Marius crater (11.9° N, -50.8° E).

(right) Boulder track emanating from the central peak complex of Schiller crater (-51.8° N, -40.0° E).

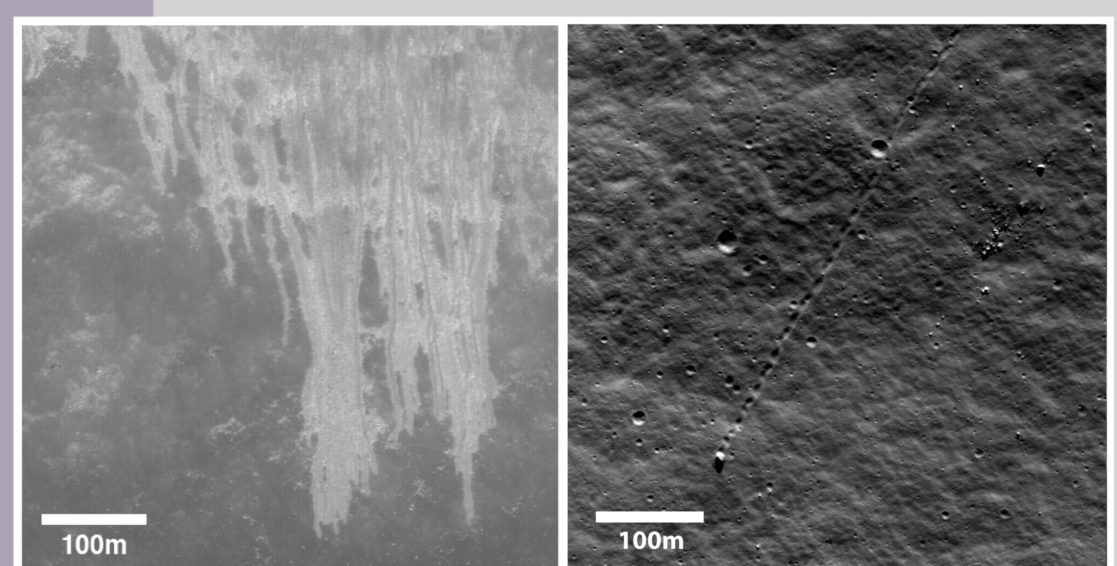
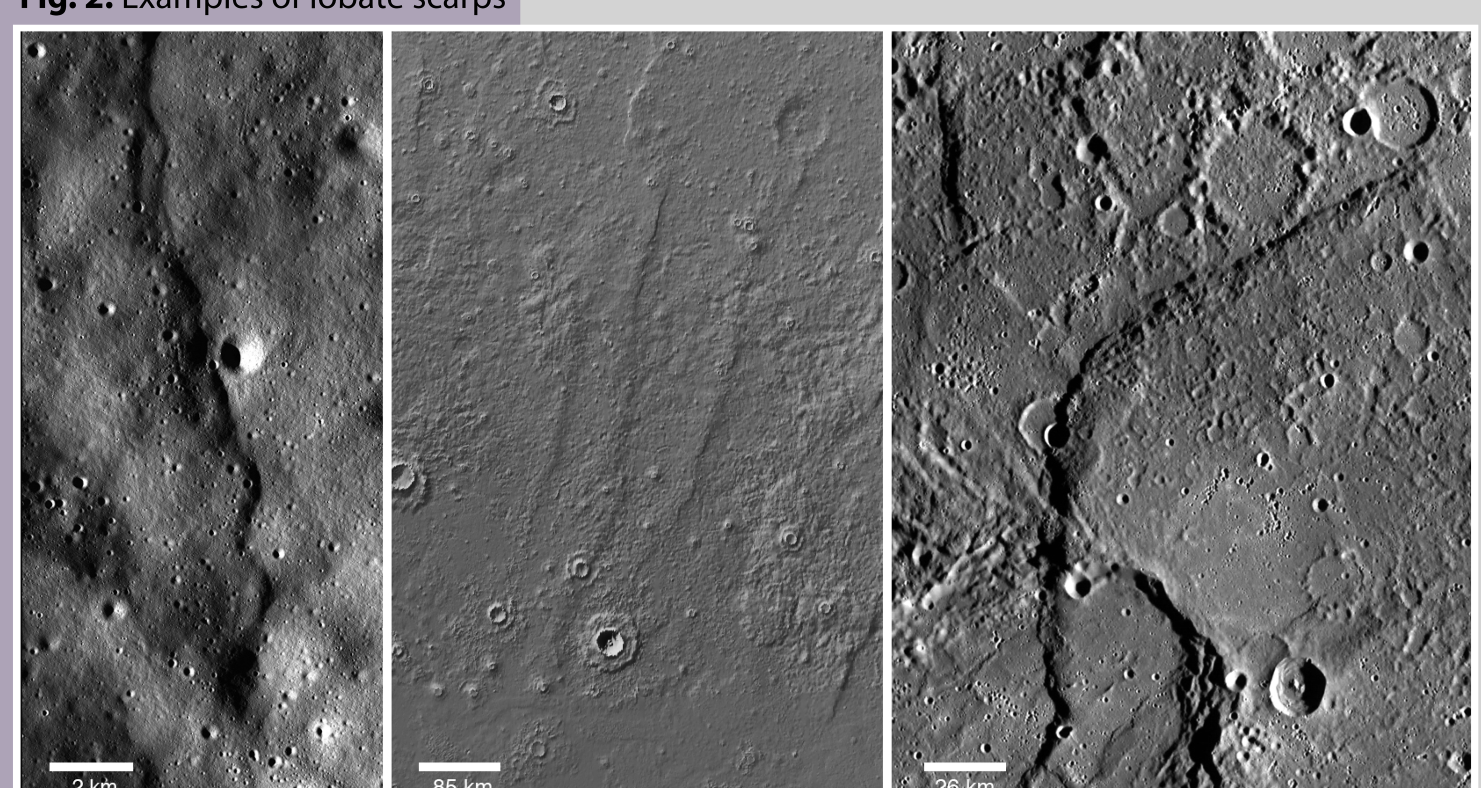


Fig. 2: Examples of lobate scarps



Evershed S1 center lat/lon 33°N/197.1°E	Utopia Planitia #s 1801, 1802, 1804 center lat/lon 52.9°N/119.2°E	Beagle Rupes center lat/lon -3.5°N/100.7°E

Lobate scarps

Lobate scarps, the typical surface expressions of thrust faults resulting from tectonic compression, are widely observed on the Moon (Figs. 2&3). Compared to other types of faults, surface-cutting thrust faults require the largest amount of stress to form and/or slip, so they could possibly generate large quakes. While normal faults, graben, and wrinkle ridges may be more abundant on Mars, the Moon, and Mercury respectively, these structures would create smaller theoretical maximum quakes than lobate scarp thrust faults. Thus, we optimize our chances of finding mass wasting associated with faults by studying lobate scarps.

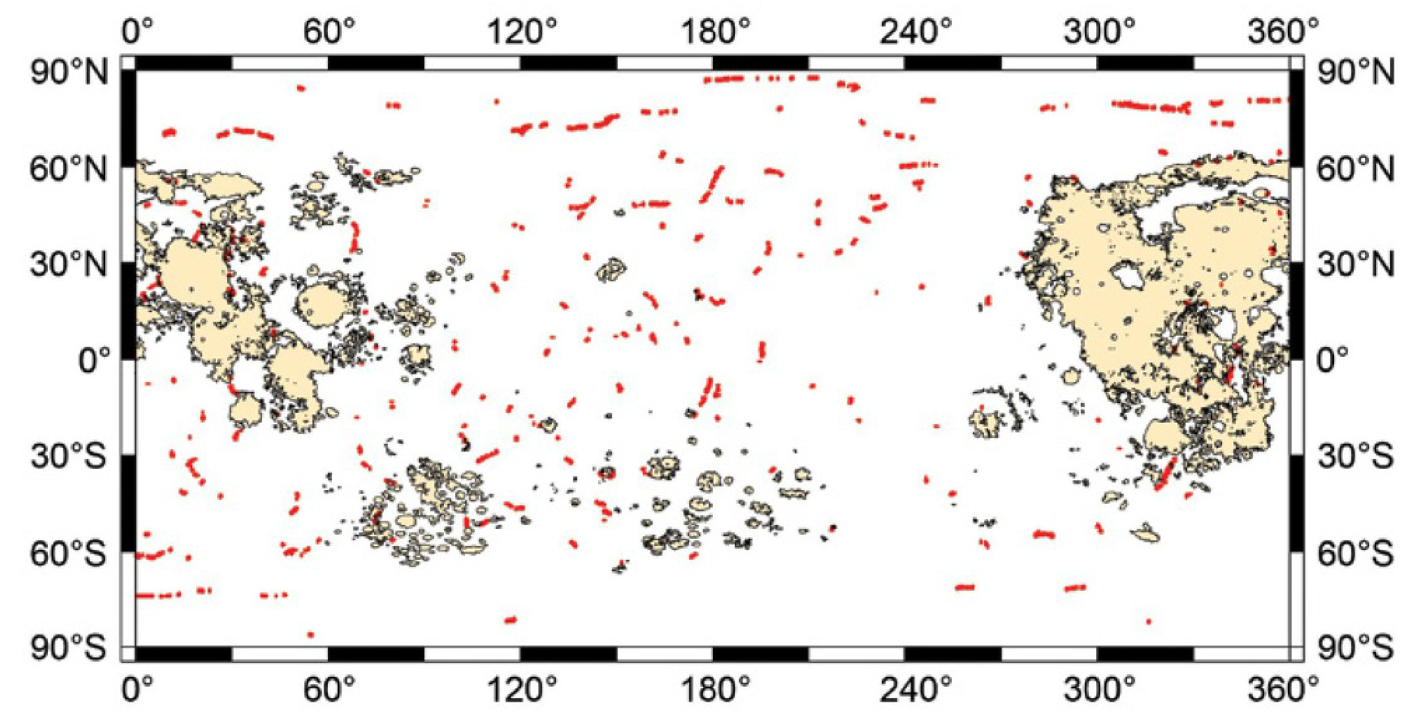
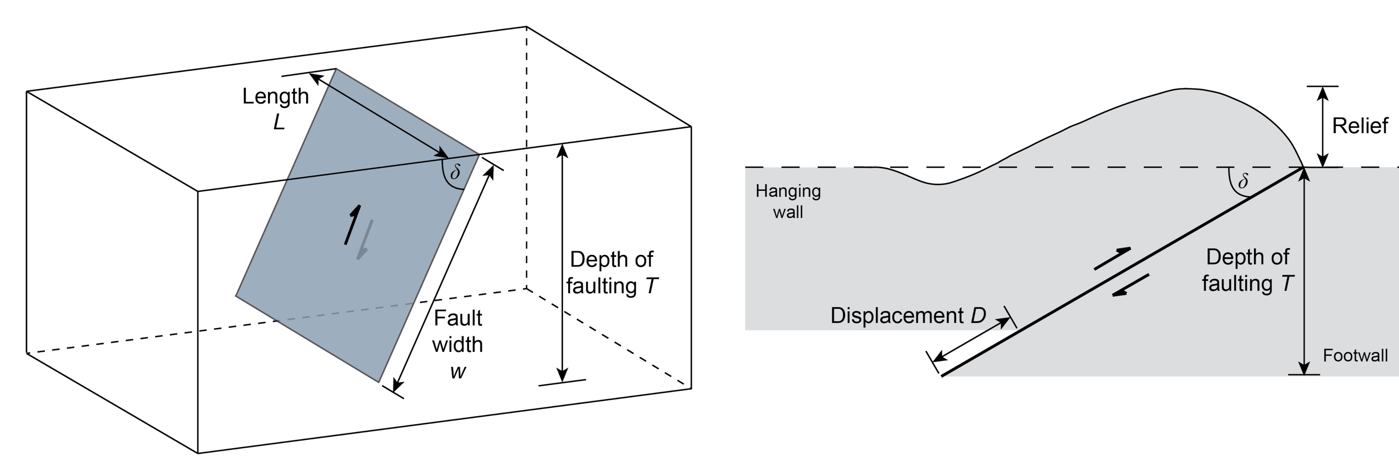


Fig. 3: Map of digitized locations of lobate scarps on the Moon. Over 3200 lunar scarps (red) have been mapped. Mare basalt units are shown in tan. From Watters et al., 2015. (Geology Vol. 43 No. 10)

Methodology



Following the method outlined in Nahm & Velasco, 2013 (LPSC 44th Abstract #1422), we derive a theoretical quake magnitude from basic fault properties. These are estimated either from imagery, laboratory rock experiments, or elastic dislocation models, and include the length (L), dip angle (δ), depth of faulting (T), displacement (D), and fault width (w). Fault displacement is calculated using displacement-length scaling such that D=γL, where γ is determined by rock type and tectonic setting.

To determine the dimensions of an area affected by seismic shaking, we model the ground motion resulting from the theoretical maximum quake along a given fault (Figs. 4&5). We use a numerical code for simulating seismic wave propagation through a 3-D structure model including topography. Peak vertical ground motion typically occurs within a few kilometers of the main shock and drops off rapidly from there. This implies that we should expect most of the mass wasting phenomena to occur in the immediate vicinity of the fault. However, this result may depend on regional effects like surface slope and megaregolith thickness. A thicker megaregolith (as might be expected in the vicinity of craters) would tend to focus shaking in some of the crater basins.

Wavefield modeling

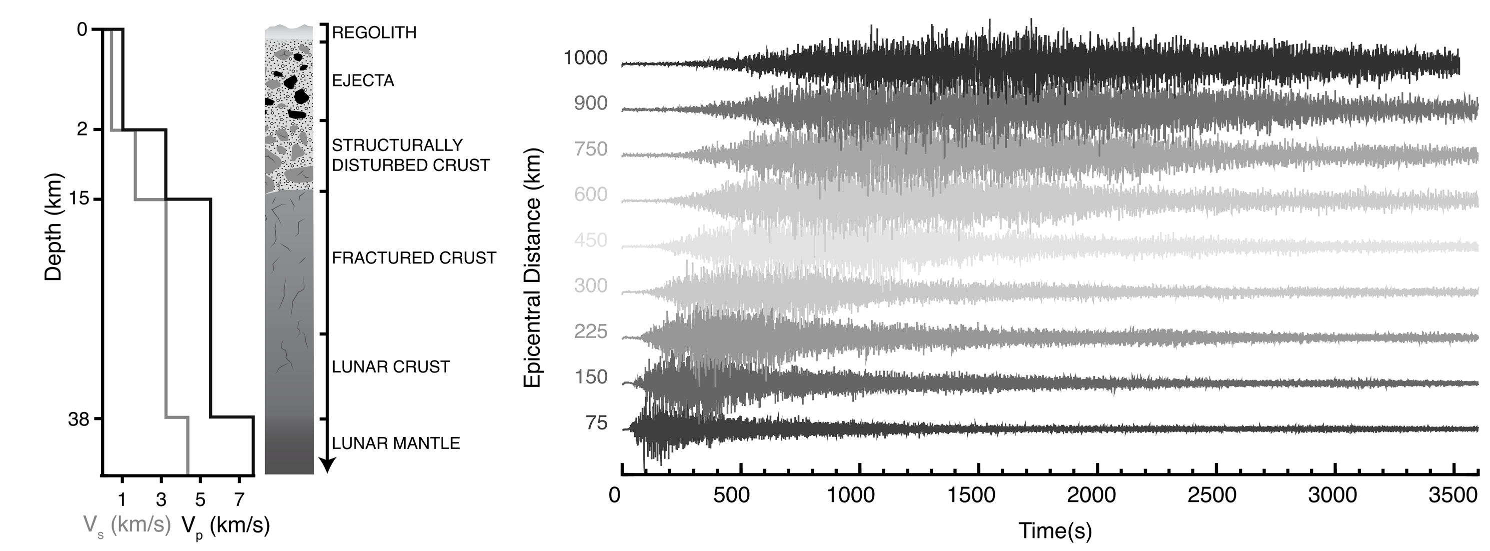


Fig. 4: Seismic structure of the lunar crust and megaregolith. (left) The crustal velocity model after Weber et al., 2011 (Science Vol. 331), showing the geology of the subsurface. The megaregolith extends from the surface to just above the structurally disturbed crust. (right) Wave propagation for a model with a 1 km thick layer of low-velocity megaregolith showing the development of surface waves and reverberations trapped in the layer. From Weber et al., 2015 (Extraterrestrial Seismology, Cambridge Univ. Press).

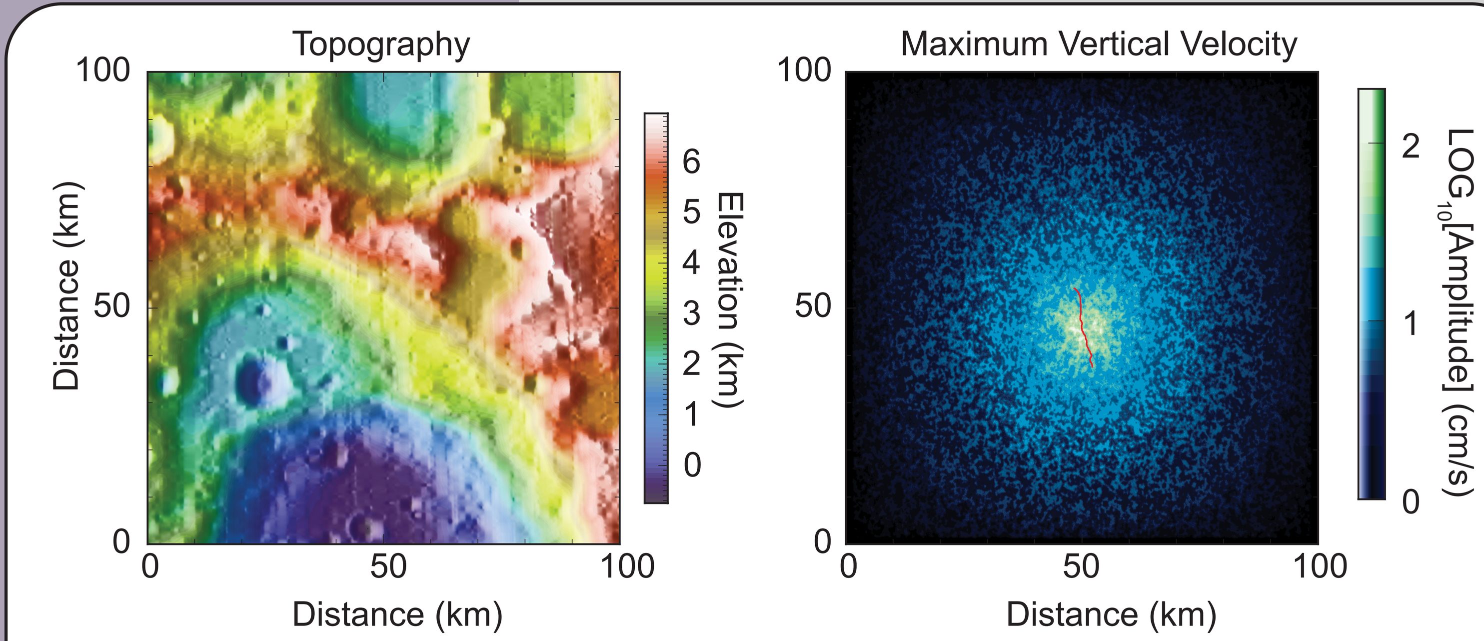


Fig. 5: (left) LOLA surface topography input into the wave propagation simulation. The Evershed scarp is centered in the image (see Fig. 2). (right) Predicted maximum vertical ground motion for a M_W=7.8 quake on a subjacent reverse fault, with a 2.25 km depth of faulting. The surface trace of the scarp is marked with a red line. A random distribution of heterogeneity of 25% in S- and P-wave velocity with 100 km scale length scatterers is placed in the megaregolith to simulate the scattering observed on Apollo seismograms. The expected damage area indicated by seismic wavefield modeling is compared to mapped imagery to determine the likelihood of a quake having triggered mass wasting.

Future work