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Newly discovered thrust fault cluster in the lunar northern high latitudes

T.R. Watters (1), M.S. Robinson (2) and the LROC Team
(1) Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA (watterst@si.edu),
(2) School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85251, USA

1. Introduction

The tectonics of the Moon are dominated by contractional wrinkle ridges and extensional rilles or graben directly associated with the nearside mare basins [see 1, 2]. In addition to basin localized tectonic features, however, are relatively small-scale lobate scarps that were only easily detected in the Apollo Panoramic Camera and the highest resolution Lunar Orbiter images [2, 3, 4]. Lobate scarps are found in both mare basins and highlands, but they most often occur in the highlands and are the dominant tectonic landform on the farside [2]. These landforms are interpreted to be the surface expression of thrust faults [2, 3, 4]. Many lunar scarps consist of a series of en echelon stepping segments while other scarps occur in clusters that cover relatively small areas [4]. Prior to Lunar Reconnaissance Orbiter (LRO) the global spatial distribution of the lobate scarps was unknown because of limited high resolution image coverage with optimum lighting geometry. Newly obtained high resolution 0.5 to 2 m/pixel images from the LRO Camera (LROC) reveal previously undetected lobate scarps [5]. The detection of lunar scarps in LROC Narrow Angle Camera (NAC) images was initially limited to individual landforms because of the lack of large-area NAC coverage.

2. North Polar Region Scarp Cluster

Cumulative imaging of high northern latitudes reveals a previously unknown lobate scarp cluster (Fig. 1) located (~74.7°N, 148.0°E), in the floor of Seares crater (100 km diameter). There are seven scarps in the Seares cluster that occur over an area of ~250 km^2. The lobate scarps range in length from ~1 to 10 km with some scarp segments <1 km long. The scarps are generally linear with NE-SW orientations. Two of the scarps, however, are distinctly curvilinear (Fig. 1). The longest scarp in the Seares cluster is curvilinear with numerous, complex lobate segments. Several small boulder fields are associated with the scarp face and back-scarp area. The smaller curvilinear scarp is made of multiple, en echelon stepping segments that extend for ~2 km. The southern terminus of the scarp is made up of a series of splay faults expressed by multiple scarp segments (Fig. 2). Splay faults have been found with other newly detected lobate scarps [5]. A set of small-scale, en echelon stepping, narrow extensional troughs are associated with the core of the cluster of lobate scarps (Fig. 3). The largest troughs or graben are several hundred meters in length, tens of meters wide, and occur in an area of <1 km^2.

3. Scarp Crosscutting Relations and Relative Age

A general lack of superposed, relatively large-diameter (>500 m) impact craters and their generally crisp morphology led previous to workers to infer relatively young ages for these features [2-5, 7]. NAC images have revealed that known and newly detected scarps crosscut impact craters with diameters as small as ~10 m, further evidence of a young age. One of the scarps (>4-km in length) in the Seares cluster crosscuts the steep interior slope of ~5-km diameter crater. Lunar Orbiting Laser Altimeter (LOLA) [6] profiles across the crater show a depth of ~350 m. This is the largest diameter known lunar impact crater that is crosscut by a scarp. Crosscut kilometer to meter-scale craters indicate a very young age for lunar scarps. In the former case, scarps traversing craters of this size with relatively steep wall slopes are expected to prematurely degrade due to downslope processes. Since the Moon is saturated at small crater sizes, any lobate scarps that deform small-diameter craters must be relatively young.

4. Spatial Distribution of Lunar Scarps

Most of the previously known lobate scarps are located in the equatorial zone photographed by the Apollo Panoramic Cameras [2, 4] (Fig. 4). Prior to the discovery of the Seares scarp cluster, seven lobate scarps were known at latitudes greater than ±60° [5] from LROC NAC images. The discovery of the Seares cluster thus doubles the number of known, high-latitude lobate scarps and is further evidence that lunar scarps are globally distributed (Fig. 4).

5. Lobate Scarps and Lunar Thermal History

Very young, globally distributed, small-scale thrust faults are evidence of late-stage radial contraction [5]. The Moon's initial temperature and thermal evolution can be constrained by knowledge of radial contraction [8-10]. The absence of large-scale lobate scarp thrust faults (hundreds of kilometers in length and hundreds of meters of relief) similar to those found on Mercury, attributed to significant radial contraction [11, 12], argues against secular cooling of a nearly or completely molten early Moon [8, 9]. The small amount of contraction expressed by lunar scarps supports thermal history models that predict low-level, late-stage compressional stresses and a relatively small change in lunar radius in the last 3.8 Ga. Solid body tides are another source of global stress. Stresses resulting from a tidally locked satellite undergoing orbital recession and relaxation of an early tidal bulge would likely form thrust faults [12]. Thrust faulting, however, is thought to be limited to the region around the sub-Earth point and its antipode with extension predicted at the poles [12]. Earth-raised tidal forces also induce crustal stresses, and although the magnitude of the stress is low, they contribute to the total state of stress. Thus, the total state of stress in the lunar crust when the thrust faults formed, likely consists of a combination of stresses from radial contraction and tidally induced stresses.

The contractional strain and the global radial contraction will be determined when the total population of lunar scarps is known from a global survey of LROC NAC images obtained over the life of the LRO mission.

References

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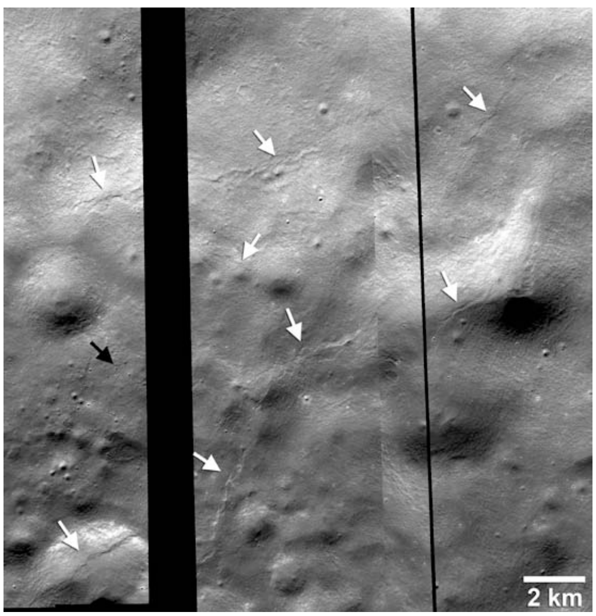

Figure 1. NAC mosaic of an area on the floor of Seares crater. At least seven lobate scarps (indicated by white arrows) occur in cluster. A series of small-scale extensional troughs are located in the core of the cluster (black arrow).

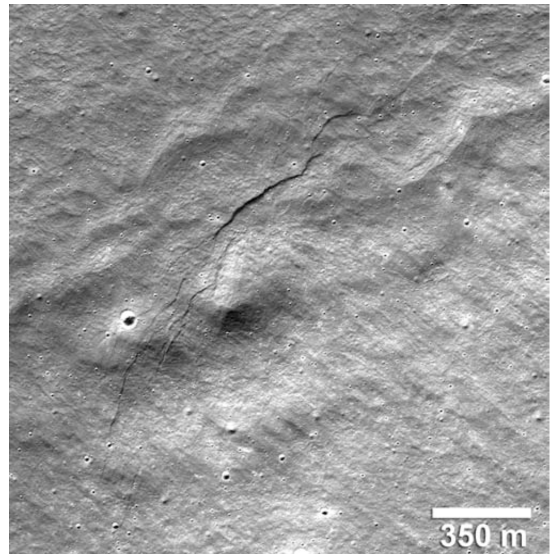

Figure 2. Curvilinear scarp in the Seares scarp cluster. At least three splay faults form the southern segment of scarp.

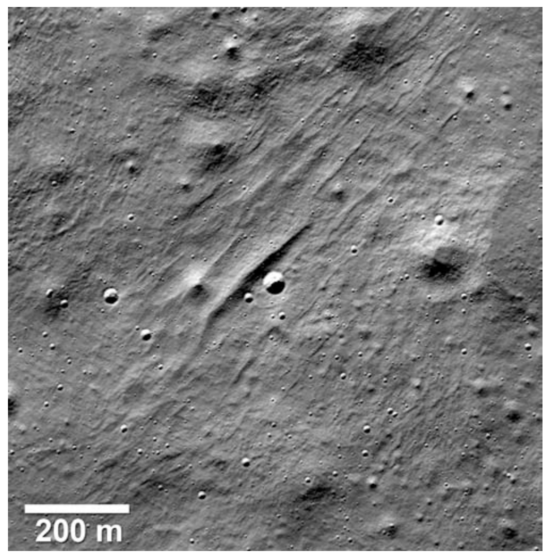

Figure 3. Small-scale, linear troughs in the Seares crater. The troughs are interpreted to be graben associated with the scarp cluster.

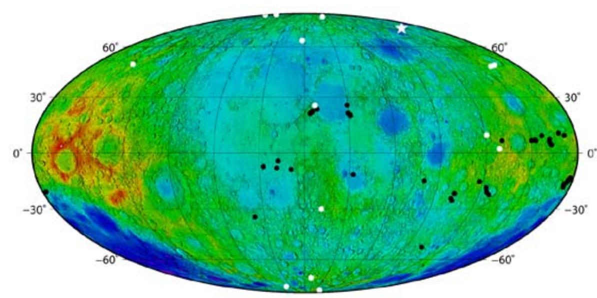

Figure 4. Distribution of previously known (black dots) and newly discovered (white dots) lobate scarps. Star indicates location of newly discovered Seares scarp cluster.