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Graben on the Lunar Nearside: Do Dikes Lie Beneath?

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On the Moon, tectonic structures are concentrated on the nearside, spatially associated with the maria (e.g., Watters and Johnson, 2010), or basalt-filled impact structures. Lunar graben (or rilles) are long, narrow troughs up to several hundreds of kilometers long and up to 5 km in width. The occurrence of graben on material that formed after basin formation and mare emplacement indicate that graben formed relatively recently (Lucchitta and Watkins, 1978). Current model ages suggest that graben formation ceased around 3.6 Ga (Boyce, 1976; Lucchitta and Watkins, 1978; Watters and Johnson, 2010) and contractional structures formed ~1 Ga (Watters et al., 2010; Watters and Johnson, 2010). Crosscutting relationships, however, indicate that some wrinkle ridges pre-date the graben (Quaide, 1965; Nahm et al., 2016) and recent work on Rupes Recta, a large normal fault in Mare Nubium, indicates that it is younger than 3.2 Ga (Nahm and Schultz, 2013). These contradictory observations indicate that a detailed, systematic study of the distribution and timing of graben formation is needed. Here, I present the results from the first part of this systematic study: the mapping campaign.

Mapping of graben on the lunar nearside (270° to 90° E, 70°N to 70°S) at a scale of 1:500,000 has been completed (Figure 1). The Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC) global morphologic map was used

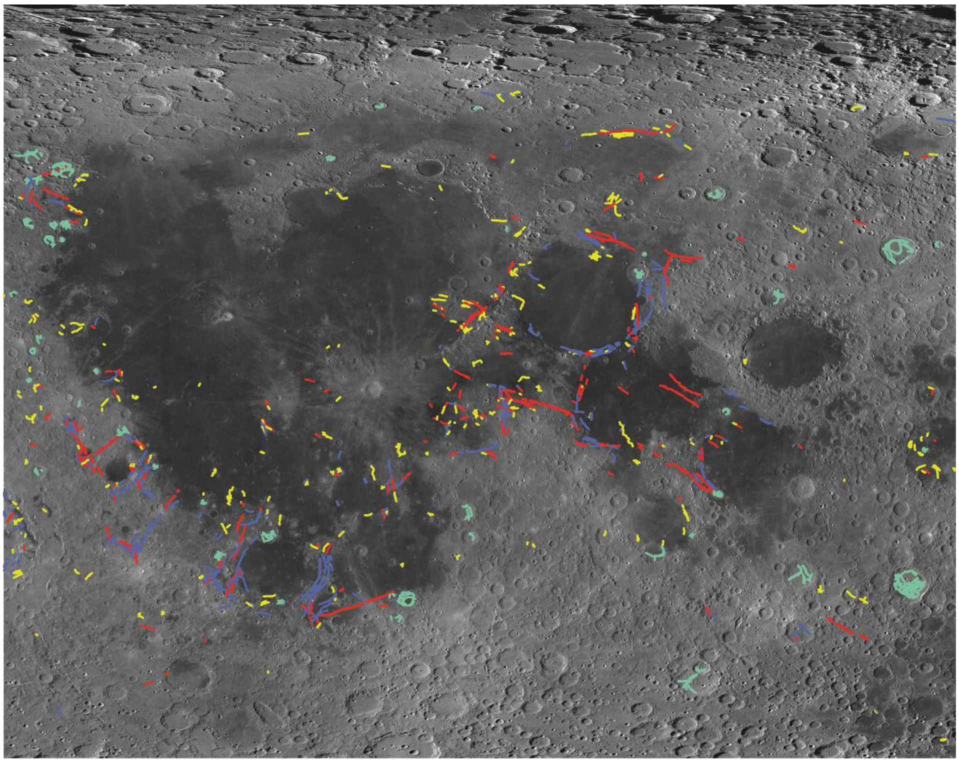

Fig. 1. Nearside of the Moon with mapped graben. Colors correspond to assigned classification group: red: linear graben, green: graben in floor fractured craters; blue: arcuate graben; yellow: lineaments. Graben mapped at 1:500,000 scale. Basemap: LRO WAC global morphologic map. Simple cylindrical projection centered at 0°.

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as the base map (100 m/px, available at http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GLOBAL). Graben and other fractures were identified primarily based on map view morphology. The primary characteristic was the presence of a pair of scarps with the portion between them down-dropped relative to the surroundings. In general, the scarps are subtle, with heights up to several hundred meters.

Based on morphology and map view orientation, the mapped graben have been divided into 4 categories: linear graben, arcuate graben, graben in floor fractured crater (FFCs), and lineaments. Linear graben are structures that are linear or nearly linear, have a relatively flat floor, roughly parallel walls, and approximately constant widths. In contrast, arcuate graben meet the criteria of linear graben, but have orientations that vary from linear by more than several degrees and are typically concentric about maria. Graben in FFCs are undifferentiated fractures or graben that are contained within a FFC identified by Jozwiak et al. (2012). Lineaments may have similar trends to identified graben in the area and are shallow curvilinear depressions. These structures may not be graben, but may have formed under similar stress fields and are thus useful for understanding the tectonic history of the nearside.

Several mechanisms have been proposed for the formation of the lunar graben mapped on the nearside. Because of the spatial association of lunar graben with the mare basins (e.g., Fig. 1), it has been suggested that the graben formed due to basin subsidence and lithospheric bending as a result of mascon loading, in which the bending of the lithosphere induces extension at the bend crest, forming normal faults and/or graben (Quaide, 1965; Solomon and Head, 1980). Lunar graben may also be contained within the lunar megaregolith and may be the result of extensional fracturing of the underlying lithosphere (Golombek, 1979; Golombek and McGill, 1983). Lastly, based on morphology (Klimczak, 2014), magnetic anomalies (Srnka et al., 1979), and volcanic materials associated with some graben (Head and Wilson, 1993), dike intrusion has been hypothesized as a formation mechanism for lunar graben (e.g., Schultz, 1972; Head, 1976; Head and Wilson, 1993).

Based on forward mechanical modeling of topographic profiles taken orthogonally to a subset of lunar graben, Klimczak (2014) identified dike-induced graben in several locations, including structures within Schrödinger basin (centered at 74° S, 132° E) and several graben identified here as linear: Rimae Daniell (centered at 37.5° N, 24.3° E), Rima Ariadaeus (centered at 6.5° N, 13.4° E), Rima Hyginus (centered at 7.6° N, 6.7° E), and Rima Hesiodus (centered at 30.5° S, 21.8° W). Dike apertures range between 100 and 550 m, with the dikes being between 100 m and 2.5 km below the surface and having heights of 5 to 18 km (Klimczak, 2014). These results suggest that many of the linear graben on the Moon may be related to dike intrusions. Further work will elucidate the abundance and properties of dikes on the Moon, adding yet another to the list of planetary bodies on which dike intrusions are known and form a significant fraction of the crustal materials.

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