SPATIAL RELATIONS BETWEEN SHORTENING STRUCTURES AND MASCONS IN LUNAR MARE BASINS.

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Introduction: Wrinkle ridges, one of the most common types of tectonic structure in the Solar System, are broad, low-relief topographic landforms thought to reflect crustal shortening by some combination of thrust faulting and folding [e.g., 1]. Wrinkle ridges observed on Mercury [2], Mars [3] and the Moon [4–6] likely accommodated, to various extents, both global contraction [2] and shortening related to basin subsidence [5].

On the Moon, wrinkle ridges are abundant within the mare deposits and, in the case of Mare Crisium, demarcate the inner edge of an annulus of elevated terrain [6–8]. In an earlier study that motivates this work, the bench-bounding ridges were found to be situated atop radial, outward-dipping, large (~20 km-deep) thrust faults [5]. Moreover, these structures delineate the highest Bouguer gravity anomaly values within the basin, which correspond to the mass concentration ("mascon") beneath Mare Crisium [6,9].

A comparison of modeling results and the crust–mantle interface beneath Crisium [10] indicated that the thrust faults there bound and likely control the geometry of the superisostatic mantle responsible for the Crisium mascon signature [5]. Here, we build upon that earlier study by extending this approach to an additional five lunar mascon basins—Maria Moscoviense, Serenitatis, Imbrium, Humorum, and Nectaris—to determine if this structural architecture is present beneath these other basins, too.

Methods: We start by mapping the populations of wrinkle ridges within each of our target basins. All mapping is performed at a 1:200,000 scale within an ArcMap GIS environment. Wrinkle ridges are identified with a Lunar Reconnaissance Orbiter Camera (LROC) wide-angle camera (WAC) 100 meters-per-pixel (m/px) global mosaic [11], from which morphometric properties such as length and orientation are acquired. Topographic measurements of offset between the elevated bench and the basin interior are taken from a Lunar Orbiter Laser Altimeter (LOLA) digital elevation model (DEM) at a resolution of 118 m/px [12], as well as from the combined LOLA and Kaguya Terrain Camera Merge (SLDEM2015) DEM (59 m/px) [13] and a LROC WAC-derived DEM (100 m/px) [14]. Hillshade maps generated from the LROC-derived DEM with illumination azimuths of 0°, 90°, 180°, and 270° supplement the photogeological data to aid in the identification of structures not otherwise readily visible [5]. Shortening structures are identified on the basis of a morphology generally characterized by a steeply-dipping forelimb and tapered backlimb [1] unrelated to cratering, ejecta blanketing, or normal faulting. A degree-and-order 660 Bouguer gravity anomaly map from the Gravity Recovery and Interior Laboratory (GRAIL) mission [15] is used for analyzing two- and three-dimensional spatial relationships between tectonic structures and the mascons.

Mapping Results: Wrinkle ridges are common in these study basins; we have mapped to date a total of 820 ridges in all five mascon basins. Each basin features at least a partial annulus of elevated terrain inside its perimeter. In each case, the inner edge of the annular "bench" is marked by wrinkle ridges, as has been reported for Mare Crisium [5,6]. Large, concentric, bench-bounding wrinkle ridges in the study basins tend to have several hundred meters of relief, whereas smaller ridges within the basin interiors are typically tens of meters in height, diverge from this concentric pattern, and show no preferred orientations. The smaller of our target basins, Maria Nectaris and Moscoviense, host topographic benches that are demarcated by fewer wrinkle ridges and are frequently blanketed by crater ejecta.

Tectonic Structures and Gravity Signature: Numerical modeling revealed that the collocation in plan view of bench structures and the mascon in Mare Crisium corresponds to a structural architecture in which the elevated mantle is encircled by an outward-dipping reverse ring fault [5]. In our mapping of Maria Serenitatis and Moscoviense, that same plan-view spatial collocation is present—suggesting that so, too, is this mantle–fault geometry.

For example, within Mare Serenitatis, the inner edge of an annulus of elevated terrain is delineated by wrinkle ridges with more than 500 meters of relief. When compared with the Bouguer gravity field for the basin (Figure 1a), it is clear that these concentric ridges mark the perimeter of the highest gravity anomalies, the shape of which, as for Crisium, mirrors the overall geometry of the basin. In Mare Moscoviense, an elevated topographic bench is also present. The southern and western portion of the bench is demarcated by wrinkle ridges that offset the bench and basin interior by 200–500 m. The topographic bench in the

northeast quadrant, however, is about 100 km offset radially from the established, concentric pattern, and bench-bounding wrinkle ridges there are less pronounced. The mascon boundary (i.e., the area with the highest gravity anomaly values) beneath this basin matches well the positions of the wrinkle ridges along the inner edge of the elevated bench to the south and west, but, as for the overlying topography, the distinctive gravity signature disperses radially outwards towards the northeast (Figure 1b).

Outlook: These observations imply that the mapping and modeling results for Crisium [5] hold at least for Maria Serenitatis and Moscoviense. Mapping for our remaining study basins (Maria Imbrium, Humorum and Nectaris), together with modeling of the geometries of the underlying faults, will help determine if deep-seated structures underlie these basins, too. If so, then the bounding of impact-uplifted mantle portions by large thrust faults may be the rule, not the exception, for major impact basins on terrestrial planets, with attendant implications for those such features on Mars [16], Mercury [17], and elsewhere.

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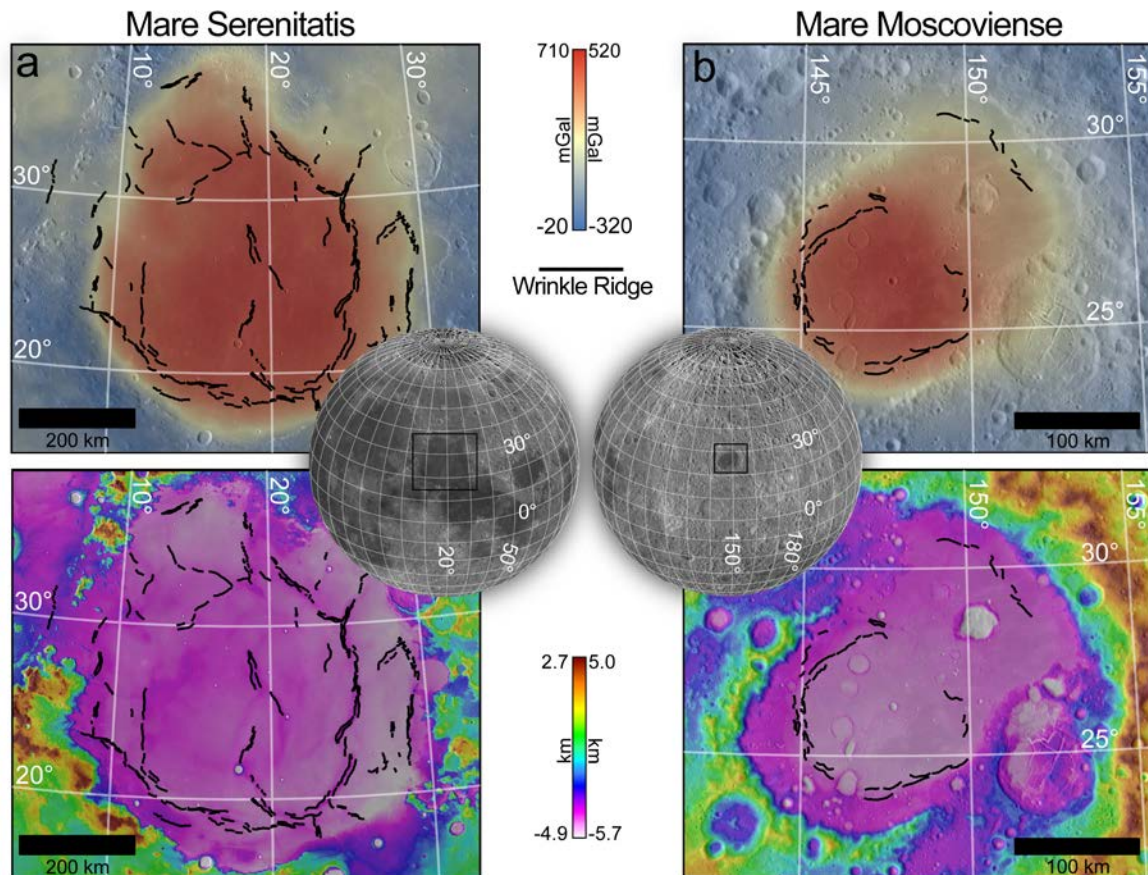
Figure 1. The spatial distribution of wrinkle ridges (black lines) in Mare Serenitatis (a) and Mare Moscoviense (b), compared with degree-and-order 660 Bouguer gravity anomaly maps (top) and SLDEM2015 digital elevation maps (bottom) for each. The highest Bouguer gravity anomaly values are encircled at almost all azimuths by bench-bounding structures in Mare Serenitatis, whereas the Mare Moscoviense mascon is less well defined to the northeast, where wrinkle ridges are notably lacking.