

INVESTIGATION OF LUNAR WRINKLE RIDGES AND BOULDER FIELDS IN A MULTI RING IMPACT BASIN, MARE SERENITATIS. L. Pauw¹, T. Frueh¹, C. H. van der Bogert¹, and H. Hiesinger¹,
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Introduction: Studies of wrinkle ridges, which are preferentially found in lunar maria basins or lowland-and plains-areas [e.g., 1-4], enables us to assess ancient and recent tectonic activity. Wrinkle ridges are contractional features formed by a combination of folding and thrust faulting in response to compressional stresses [e.g., 2, 4-8]. They deform both the oldest and youngest mare basalts, implying an extended period of localized crustal shortening [2, 4]. Serenitatis is a multi-ring impact basin that was filled with mare basalts and exhibits a mascon. It displays pre-mare topography similar to the current topography of Mare Orientale [9, 10]. Wrinkle ridges in this region occur in noticeable patterns that might indicate relationships between different types of stress systems, e.g., mascon tectonics or global contraction. Boulder fields near the wrinkle ridges are hypothesized to indicate reactivations by recent tectonic activities on the Moon [11, 12, 16]. Building on Head's reconstruction of the Serenitatis ring-system [10] and Yue's global survey of lunar wrinkle ridges [14], our work expands the mapping and classification of these features and gives interesting insights about basin-related lunar tectonics.

Methods: We classified the wrinkle ridges in Mare Serenitatis based on their orientation patterns into three categories: concentric, radial, and scattered. For relative age determinations we distinguished them by their morphology and degree of degradation into heavily, intermediate, and sparsely degraded. Thereupon we quantified the existence and frequency of boulder fields for each individual wrinkle ridge, which led to four groups: (1) absent, (2) few, (3) partly, and (4) many boulder fields. The mapping was done using Terrain Camera (TC; ~10m/pixel) image data provided by the Kaguya spacecraft (SELENE), Lunar Reconnaissance Orbiter Camera (LROC) NAC and WAC imagery and merged topographic data (SLDEM2015) from the Terrain Camera (TC) and Lunar Orbiter Laser Altimeter (LOLA). These datasets were imported into ArcGIS where we used tools like hill shading and slope maps, to select over 470 wrinkle ridges and map and classify them based on the previously described attributes at an average scale of 1:62,500.

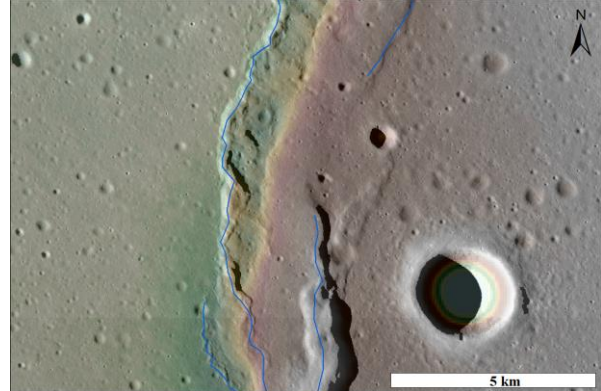


Figure 1: Example of the mapping method on TC data. (incidence ~270°W) with SLDEM2015 (75% transparency). Scale is 1:62,500.

Results: In total, 474 individual ridge segments were mapped in Mare Serenitatis with a total length of 5154.9 km, ranging from 0.9 km to 70.7 km in length with a mean length of 10.9 km.

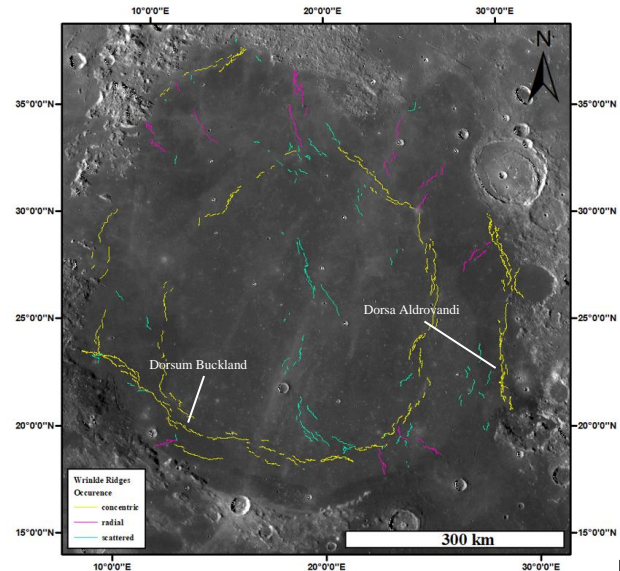


Figure 2: LROC WAC mosaic of mapped wrinkle ridge segments that are illustrated in three colors, indicative of their specific orientation pattern.

Morphology: We classified the wrinkle ridges in terms of their appearance to capture the degree of degradation and erosion. Such characteristics might indicate relative age relations, since the crests of old

wrinkle ridges seem to be heavier degraded than compared to younger ones [3, 14-16]. About 36 % of wrinkle ridge segments measured in this study exhibit a heavily degraded appearance corresponding to 64 % of the total length of all wrinkle ridges in Serenitatis. About 46 % of our measured segments show intermediate degradation states, which corresponds to 31 % of the total length and 18 % of all wrinkle ridges were classified as sparsely degraded representing only 4.5 % of the total length of wrinkle ridges. These measurements show that the heavily degraded wrinkle ridges seem to have the greatest extent, followed by intermediate degraded ones and lastly sparsely degraded ridges. One of our main observations is that the inner ring-system seems noticeably more heavily degraded than the outer ring-system. Furthermore, many wrinkle ridges in the NW display higher degradation states compared to other regions in the basin. Most wrinkle ridge segments associated with Dorsa Aldrovandi (SE) and Dorsum Buckland (SW) are sparsely degraded and occur with crisp and sharp morphologies, indicative for relatively younger ages [12, 16].

Boulder fields: As a measure of possible recent tectonic activity, our classification displays the frequencies of boulder fields and patches that are distributed over the whole length of each wrinkle ridge. For a specific boulder field class, we divided the number of wrinkle ridge segments with the total wrinkle ridge length of their associated orientation class. This enables us to infer that concentric wrinkle ridges seem to have higher boulder field abundances than ridges related to other orientation classes. Furthermore, we divided concentric wrinkle ridges into an inner and outer ring class and, thus, showed that the inner ring-system of Serenitatis has a ~20 % higher abundance of boulder fields than the outer ring-system, even though its degraded morphology would imply less tectonic activity at first glance. Additionally, we observed relatively low boulder field abundances in the north-western parts of Serenitatis and very high abundances along concentric wrinkle ridges in the southern regions.

Implications: Regional differences in the abundance of boulder fields along individual wrinkle ridges in Serenitatis could imply various stress fields beyond the homogenous influence of mascon tectonics and super-isotropic stresses. Thus, our study might indicate spatially heterogeneous tectonic activity of lunar wrinkle ridges at the nearside by the contrast in morphology and boulder field distribution. Various studies hypothesize that recent lunar tectonics could, e.g., reactivate geological features on the Moon's nearside [11, 12, 16]. Valantinas and Schultz [11] suggested that the level of ongoing tectonic activity along ridges expressed by blocky exposures could be

caused by two underlying processes. First, the nearside lunar lithosphere, which is still adjusting to an ancient "Procellarum Basin" that shaped the formation of the lunar nearside and resulted in radial and concentric tectonic patterns. However, the Procellarum basin is a heavily debated hypothesis for which there is little evidence given yet, because the surface would have been largely obscured by resurfacing events considering very old ages and poor preservation of geological features [17]. A second possibility is an active nearside tectonic system (ANTS) reflecting much later reactivation of faults, related to deep transient stresses generated by the South Pole-Aitken basin [13]. These ANTS spatially correlates with deep-seated ancient intrusions discovered by GRAIL [11, 17]. By comparing our mapping with the global map of GRAIL gravity gradients overlain by the wrinkle ridges mapped in the study of Valantinas and Schultz [11], we observe that many wrinkle ridges in Mare Serenitatis with sparsely or intermediate degradation states and boulder field classes 3-4, indeed, spatially correlate with the geography of ancient intrusions [17]. Watters et al. [12] hypothesized that, besides global contraction, tidal stresses are a strong influence on shallow seismic activity and young thrust faults. Diurnal tidal stresses at apogee and recession may help trigger co-seismic slip events on active thrust faults on the Moon [16]. Spatial distributions of investigated thrust fault scarps confirm that the Moon underwent global contraction, but tidal stresses seem to superimpose stresses from global contraction resulting in non-isotropic compressional stresses [12] possibly triggering outcrops and boulder fields along individual wrinkle ridges in Mare Serenitatis.

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