PHYSIOGRAPHIC CONSTRAINTS ON THE ORIGIN OF LUNAR WRINKLE RIDGES

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Wrinkle ridges are linear asymmetric topographic highs with considerable morphologic complexity that are commonly found on the lunar maria and the smooth plains of Mars and Mercury. The origin of planetary wrinkle ridges has been a much argued and debated topic in the literature. Early ideas suggested that wrinkle ridges resulted from volcanic intrusion and extrusion of high viscosity lavas (e.g. Quaide, 1965; Strom, 1972; Scott, 1973); these early ideas were countered with suggestions that wrinkle ridges formed from tectonic processes involving folding and faulting (e.g. Ronca, 1965; Bryan, 1973; Howard and Muehlberger, 1973; Muehlberger, 1974; Maxwell et al., 1975; Lucchitta, 1976, 1977; Sharpton and Head, 1982). Combined volcanic and tectonic mechanisms have also been suggested (e.g. Colton et al., 1972; Young et al., 1973). The identification and analysis of a number of morphologically similar structures on the earth has helped in the recent interpretation of wrinkle ridges as thrust faults that deform surface rocks (Plescia and Golombek, 1986). Nevertheless, in the literature there remains the uncertainty of the dominant role of thrusting versus folding in the formation of planetary wrinkle ridges. In this abstract, we present the detailed physiographic analysis of lunar wrinkle ridges in an effort to help distinguish the dominant deformation mechanism. Our results agree with the findings of the earth analog study (Plescia and Golombek, 1986) and support the hypothesis that wrinkle ridges form from thrust faults that deform surface rocks.

We have completed a comprehensive survey of the entire collection of high-resolution topographic data, Lunar Topographic Orthophoto Maps, that cover wrinkle ridges. These maps are at a nominal scale of 1:250,000 with 100 m contours; supplemental maps are at scales of 1:50,000 and 1:10,000 with 20 and 10 m contours, respectively. Identification of ridges was made on Lunar Orbiter and Apollo photographs. A total of 76 topographic profiles were constructed across suitable ridges on the supplemental high resolution topographic maps.

These profiles reveal that wrinkle ridges are composed of three physiographic elements. 1) Broad rise - a linear or convex upward, gentle slope that rises from an essentially flat mare surface toward the center of the ridge. The slope is so gentle that the broad rise is rarely visible on images of the lunar surface. 2) Superposed hill or arch - generally narrower and steeper in slope than the broad rise and located toward the center of the ridge. Because it has steeper slopes it is the physiographic element identifiable in images as the "ridge" of wrinkle ridges. 3) Crenulation - complex, narrow, low-relief wrinkles or crumples in the surface that are found at various locations across the structure, although they are preferentially found near the high point of the ridge. These wrinkles are quite visible, especially in low-sun angle images, and make up the "wrinkle" of wrinkle ridges. They can be paired or braided. All ridges investigated have a broad rise on one or both sides. Almost all ridges have superposed hills, and most have crenulations.

In addition to these previously noted elements (e.g. Strom, 1972; Maxwell et al., 1975; Lucchitta, 1977), every topographic profile across a wrinkle ridge shows a regional elevation change. That is, the elevation of the mare surface on one side of the ridge is always different from that on the other side. As a result, wrinkle ridges accommodate a vertical structural offset between structural units or blocks of the mare that are at different elevations.

The 76 profiles fell into 7 basic profile types (illustrated in Fig. 1), based on the presence and arrangement of the 3 elements, ridge asymmetry and asymmetry of the regional elevation change. The number of physiographic forms found underscores the complexity and diversity of wrinkle ridges. In an effort to quantify the contribution of the different elements of wrinkle ridges to the overall structural form, a group of 31 representative profiles was selected from the total for statistical analysis. The selection was made to mimimize the bias in the profiles created by the oversampling of particular ridges covered by high-resolution topographic maps. The following quantities (shown in Fig. 1) were measured from the profiles: regional elevation change (5-280 m), maximum relief (80-500 m), maximum broad rise height (25-300 m), maximum superposed hill height (25-410 m), steep face height (55-410 m), total ridge width (2.5-41 km), total broad rise width (1-35 km), and superposed hill width (1-29 km). Two-axis graphs of various combinations of these data reveal that a number of these quantities appear related through linear regression analysis. The most significant correlation (correlation coefficient of 0.77) is found between the total ridge width and maximum relief, indicating that wider ridges have greater relief. The maximum relief also relates to the height of the steep face (0.75 correlation coefficient), indicating that most of the maximum relief is accommodated by the steep face when it exists. The total ridge width has a correlation coefficient of 0.72 with the total broad rise width, indicating that most of the width of a ridge is taken up by the broad rises. Finally, the width and height of the superposed hill have a correlation coefficient of 0.71, showing that wider hills are also higher. These relationships suggest a continuity in form between small and large wrinkle ridges, regardless of the differences in the particular form of the ridge (i.e. the 7 types identified earlier). The simplest explanation is that continuing development of wrinkle ridges results in both wider and higher ridges and is suggestive that large ridges have experienced more deformation and shortening than smaller ridges.

Wrinkle ridges are complex structural features that exhibit a significant variability in the presence and arrangement of a few morphologic and physiographic elements. Our comprehensive analysis of the topographic profiles of lunar wrinkle ridges reveals that all ridges for which there exists high-quality topographic data have a change in regional elevation across the structure. This regional elevation change requires a fault beneath the ridge to accommodate the change in mare surface elevation. It is important to point out that simple fold mechanisms for wrinkle ridges cannot readily explain this regional elevation change. The relationship between ridge width and maximum relief suggests a tectonic process that progressively develops wider structures having greater structural relief and greater shortening. The similarity in morphology between planetary wrinkle ridges and analogous structures identified on earth (Plescia and Golombek, 1986) suggests that the faults are low-angle thrust faults that produce subsidiary folds near the surface. For lunar wrinkle ridges the thrust fault is required to dip beneath the high side of the change in regional elevation to produce the greater elevation of that mare block. This, in turn, suggests that the faults near the surface have an opposite vergence from the main fault at depth where wrinkle ridges change asymmetry along strike but have the same regional elevation offset, assuming that the asymmetry is created by the dip of the fault near the surface as is the case for the earth analogs (Plescia and Golombek, 1986). We expect that this detailed physiographic analysis will help provide data-constrained estimates of tectonic shortening across these complex structures.

References

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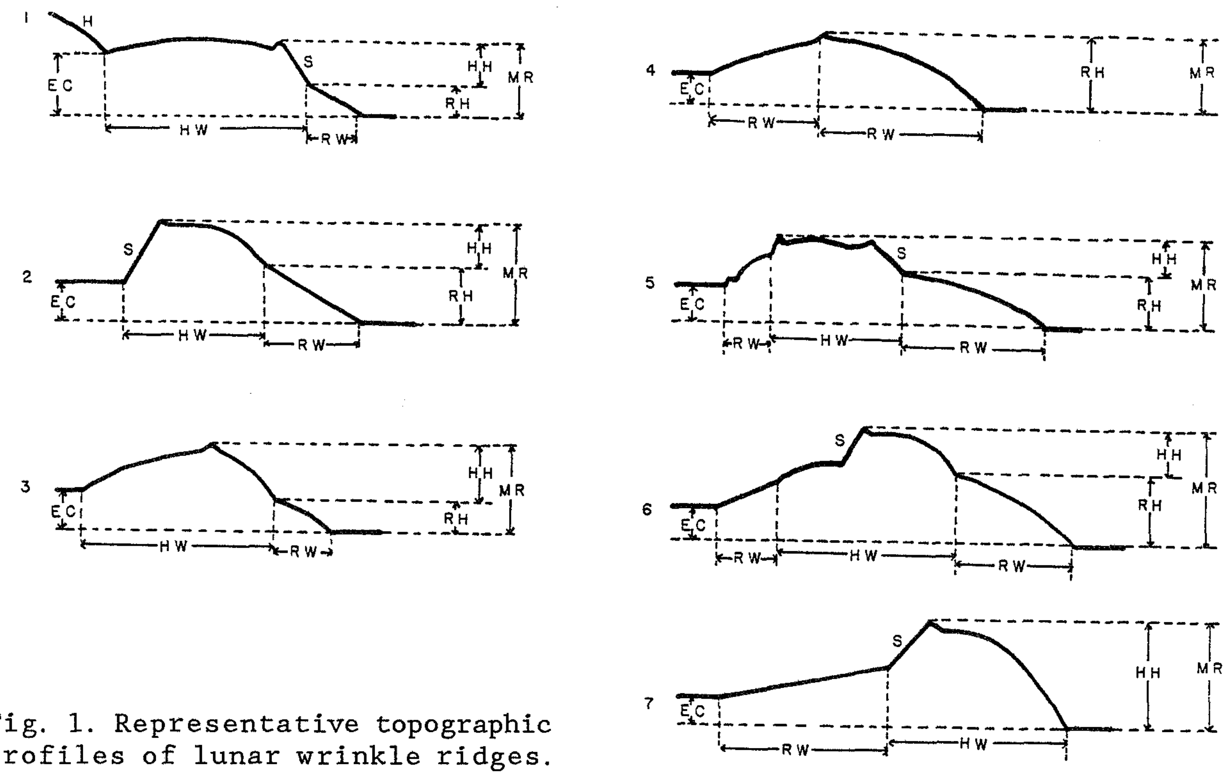

Fig. 1. Representative topographic profiles of lunar wrinkle ridges. Seven distinct types are shown at 10 times verticalexaggeration. Physiographic elements measured in this study are: RW-broad rise width, HW-superposed hill width, RH-broad rise height, HH-superposed hill height, MR-maximum relief, EC-regional elevation change, S-scarp height. Type 1 backs up against highlands (H).