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. Early ideas for their origin suggested that they result from volcanic intrusion and extrusion of high viscosity lavas (1); these early ideas were countered with suggestions that wrinkle ridges formed from tectonic processes involving folding and faulting (2,3). Combined volcanic and tectonic mechanisms have also been suggested (4). 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 (5). 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 (5) and support the hypothesis that wrinkle ridges form from thrust faults that deform surface rocks.

We have constructed a total of 76 detailed topographic profiles from a comprehensive survey of the entire collection of high-resolution Lunar Topographic Orthophoto Maps (10-20 m contour interval) that cover wrinkle ridges. 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. 2) Superposed hill or arch - generally narrower and steeper in slope than the broad rise and located toward the center of the ridge. 3) Crenulation - complex, narrow, low-relief wrinkles or crumples in the surface that are found at various locations across the structure. 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 (6,7) all of the profiles across the ridges show 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. Thus wrinkle ridges accommodate a vertical offset between structural units or blocks of the mare that are at different elevations.

The 76 profiles fall into 7 basic profile types (Fig. 1), based on the presence and arrangement of the 3 elements, ridge asymmetry and asymmetry of the regional elevation change. 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 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). Linear regression analyses reveal that a number of these quantities appear related. 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 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 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. Simple fold structures without faults 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 (5) 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. We expect that this detailed physiographic analysis will help provide data-constrained estimates of tectonic shortening across these complex structures.

References (1) Quaide 1965 Icarus 4, 374. (2) Bryan 1973 Proc. Lun. Sci. Conf. 4th, 93. (3) Howard & Muehlberger 1973 Ap. 17 Pre. Sci. Rep., NASA SP-330, 31/22. (4) Colton et al. 1972 Ap. 16 Pre. Sci. Rep., NASA SP-315, 29/90. (5) Plescia & Golombek 1986 GSA Bull. 97, 1289. (6) Maxwell et al. 1975 GSA Bull. 86, 1273. (7) Lucchitta 1977 Proc. Lun. Sci. Conf. 8th, 2961.

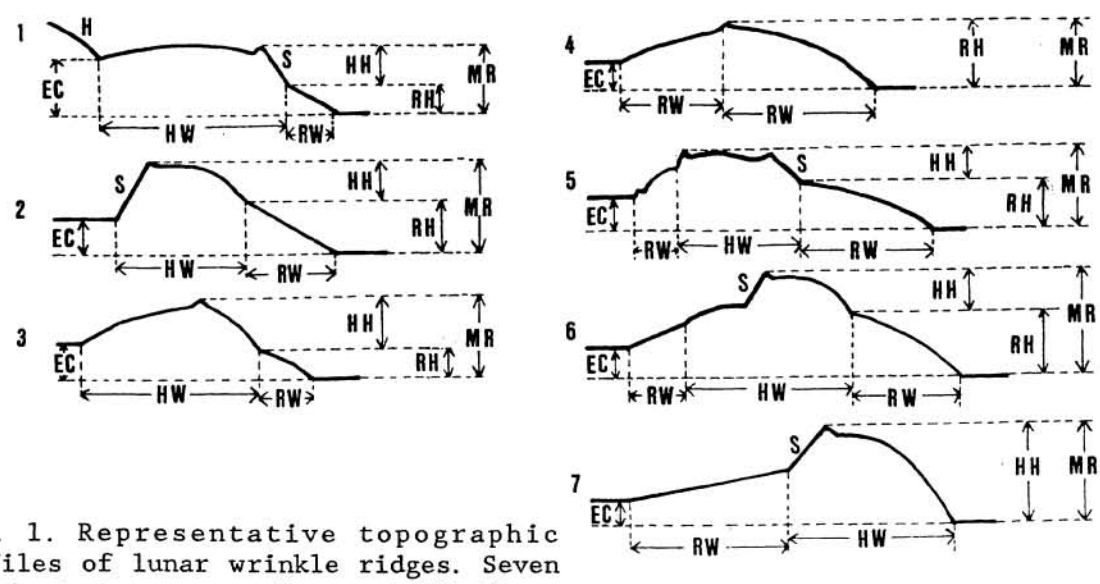

Fig. 1. Representative topographic profiles of lunar wrinkle ridges. Seven distinct types are shown at 10 times vertical exaggeration. Physiographic elements measured in this study are: RW-broad rise width, HW-superposed hill width, RH-broad rise height, HH-superposed hill height, MR-maximum relief,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