THE RELATIVE IMPORTANCE OF FAULTING VERSUS FOLDING IN THE FORMATION OF PLANETARY WRINKLE RIDGES; M. Golombek, J. Plescia, and B. Franklin (Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109)

Wrinkle ridges are linear asymmetric topographic highs, have considerable morphologic complexity, and are commonly found on the lunar mare and the smooth plains of Mars and Mercury. Interpretations of their origin include both volcanic (intrusion and extrusion) and tectonic (folding and faulting) mechanisms (e.g., see references in 1). Recent interpretations have focused on the tectonic origin of wrinkle ridges, although the relative importance of folding versus faulting remains controversial. We have constructed detailed topographic profiles from a comprehensive survey of the entire collection of high-resolution Lunar Topographic Orthophoto Maps. In addition, photogrammetry has provided information on the overall physiography and topographic relief of selected Martian wrinkle ridges in Lunae Planum (roughly 30 profiles). We use these data to estimate both the shortening due to folding and that due to faulting. Our analysis indicates that most of the shortening associated with wrinkle ridges is accommodated by displacement across one (or more) thrust faults and that folding is subsidiary. This conclusion is consistent with the recent interpretation of earth analogs (1).

Detailed analysis of these data (2,3) shows that in addition to the three physiographic elements that make up wrinkle ridges (broad rise, superposed hill or arch, and crenulation) almost all wrinkle ridges mark a regional elevation offset. That is, the regional surface elevation on one side of the ridge is different from that on the opposite side. This regional elevation change requires a fault beneath the ridge to produce the offset in surface elevation; simple fold structures cannot readily explain it. In addition, the fault beneath the wrinkle ridges cannot shallow with depth, or the regional elevation change would disappear beyond the point where the fault becomes horizontal. Although we do not know the dip of the fault, a vertical fault at depth does not appear capable of affecting a wide region at the surface producing a broad, low, positive relief structure, particularly when the edges of the structure are characterized by broad rises without apparent structural discontinuity or faulting that breaks the surface.

We believe that the origin of the broad, low, positive relief structure that characterizes wrinkle ridges is most compatible with displacement along low-angle thrust faults with the compression and folding of overlying surface units. Even though the dip of the thrust faults at depth is unknown, a shallow dip is suggested by a number of arguments. The most convincing argument is based on the failure criteria for the brecciated surface material of the moon (4), which suggests that deformation under compression will occur along pre-existing faults that dip at about 25°, for which the resistance to frictional sliding is minimized (5).

The above constraints for the subsurface structure of wrinkle ridges allow estimates of the compressional strain or shortening that they have accommodated. Two end-member models can be used to calculate the minimum and maximum shortening possible across wrinkle ridges. 1) All slip at depth on the fault is reflected in folding at the surface, so that the fault does not break the surface. In this case, the shortening due to faulting should equal that due to folding; this model results in a minimum value for shortening. 2) Folding and faulting both contribute to the total shortening. In this case, the thrust fault breaks the surface and the shortening due to faulting must be added to that due to folding; this model results in a maximum value for shortening. In this model, all strain at depth and at the surface is accommodated by slip on the fault and folding adjacent to the fault. An

intermediate case in which all the slip at depth on the fault is expressed as folding and slip of the fault at the surface can also be used to calculate the possible shortening. In this case, there is no folding of rocks at depth so that the thrusting at depth is the total shortening, which equals the sum of the folding and fault slip at the surface.

Calculations of the amount of shortening due to faulting and folding were made for 31 representative lunar wrinkle ridges. We calculated the shortening due to faulting by dividing the regional elevation change (2-280 m) by the tangent of the fault dip (25 ± 10°). This assumes that all of the shortening at depth on the fault is reflected as a regional elevation change at the surface. The shortening due to folding was determined by subtracting the line length of the surface profile from the present horizontal width of the wrinkle ridge.

Results indicate that the shortening due to folding varies from 2 to 121 m with an average of 40 m. Shortening due to thrusting varies from 3 to 1044 m. On average, the shortening due to thrusting exceeds the shortening due to folding by a factor of 7 indicating that the thrust faults associated with lunar wrinkle ridges break the surface and the total shortening is close to a sum of that due to faulting plus that due to folding (model 2). Model 1 is not reasonable because the shortening due to folding does not equal that due to thrusting as would be expected if the fault did not break the surface and all the shortening due to slip on the fault at depth was reflected by folding at the surface. Instead, the data indicate that the fault breaks the surface and a substantial portion of the shortening is expressed by slip on the fault at the surface, a situation closer to model 2 or the intermediate case. If some of the shortening at depth is accommodated by folding (in addition to the slip on the fault), then the total shortening across the structure is closer to the sum of the shortening due to faulting at depth plus that due to folding (model 2). This situation would result in a maximum shortening of 15-1101 m.

Although we have not completed analysis of the photogrammetric data of Martian wrinkle ridges, the overall form and relief are similar enough to lunar wrinkle ridges to allow a general characterization. In particular, the width (a few to tens of km), topographic relief (hundreds of m), and regional elevation change (tens to hundreds of m) across the lunar and Martian wrinkle ridges are very similar. This similarity in size, form and relief suggests that the shortening due to folding and that due to thrusting for Martian wrinkle ridges is close to that for lunar wrinkle ridges (tens of m and hundreds of m, respectively). This, in turn, suggests that the shortening due to faulting far exceeds the shortening due to folding in Martian wrinkle ridges as is the case for lunar wrinkle ridges. We will be analysing these data further to confirm this working hypothesis.

In conclusion, our calculations of shortening across lunar wrinkle ridges and estimates from Martian wrinkle ridges indicate that shortening across these structures is primarily accommodated along shallowly dipping thrust faults; folding is subsidiary. Thus our analysis of lunar and Martian wrinkle ridges is in agreement with our study of analog structures on earth (1) and indicates that this family of structures is primarily the result of thrust faults that break the surface.

References (1) Plescia & Golombek (1986) Geol. Soc. Amer. Bull., 97, 1289-1299. (2) Golombek & Franklin (1987) Lunar Planet. Sci. XVIII, 339-340. (3) Plescia (1988) this volume. (4) Brace & Kohlstedt (1980) J. Geophys. Res., 85, 6248-6352. (5) Byerlee (1978) Pageoph., 116, 615-626.