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PHOTOCLINOMETRIC ANALYSIS OF WRINKLE RIDGES ON LUNAE PLANUM, MARS:

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Wrinkle ridges are common morphologic features on Mars. Both volcanic and tectonic mechanisms have been suggested to explain their origin (e.g., Quaide, 1965; Strom, 1972; Scott, 1973, Muehlberger, 1974; Lucchitta, 1976, Bryan, 1973); recent work has focused on a compressional origin (Maxwell et al., 1975; Lucchitta, 1977; Sharpton and Head, 1982, 1988, Watters, 1988; Plescia and Golombek, 1986). Analysis of terrestrial analogs has greatly influenced and aided the understanding of wrinkle ridge formation (Plescia and Golombek, 1986). An important aspect necessary to interpret structure is topography. Topographic profiles across ridges can provide important constraints for models of internal structure and analyzing deformation associated with ridges.

Topographic maps for Mars are too coarse (contour interval 1 km) to resolve the topography of individual ridges, therefore, monoscopic photoclinometry (Davis and Soderblom, 1984) was used to derive topographic profiles for the ridges in. Profiles spaced a few kilometers apart were obtained for each ridge; the number depended on ridge length, morphology and albedo variation. Photoclinometry relies on pixel brightness variations which results from topography (the assumption of the technique), albedo, or both. Because of the albedo variations, photoclinometric profiles can not be extended across large distances, such as between adjacent ridges (about 20-80 km). However, the technique is applicable to shorter distances, such as the distance across typical ridges. Profiles were measures across the ridge and extended a few kilometers on either side, including all visible components of the ridge.

The data indicate that ridge relief varies from 27-370 m; average relief is 130±74 m; mean width measured is 5±2 km; the maximum width measured is 14 km. The superposed hill and crenulation are well-defined by the topographic profiles of the wrinkle ridges. The superposed hill and crenulation have slopes of 1° to 9°; in a few locations the slopes locally exceed 10°. The profiles are generally asymmetric, with slopes steeper on one side than on the other. Lunae Planum ridges are characterized by an elevation offset, that is, the plains on one side of the ridge have an elevation distinctly different from the elevation of the opposite side. The offset is similar to that observed for lunar ridges. Measured offsets vary from 0 to as much as 250 m; the average offset is about 30 m to 100 m, with a mean of 57±46 m. The sense of offset does not change abruptly or randomly. Locally, changes in the direction of offset are observed, but these are characterized by a corresponding change in the ridge morphology and a decrease in both ridge relief and width. The elevation offset is generally continuous away from the ridges for at least several kilometers (the length of the photoclinometric profiles).

The elevation offset is an important point in the consideration of models of their internal structure (c.f. Watters, 1988 and Plescia and Golombek, 1986). The offset is most easily explained by a fault beneath the ridge separating structural blocks at different elevations. The study of earth analogs suggests that the broad, low-relief structure characteristic of wrinkle ridges is most compatible with folding and faulting over thrust faults. In this model, a thrust fault at depth dips beneath the high side of the ridge producing the elevation offset. Since the elevation offset persists away from the ridge, the fault producing the offset must be uniform over these scales (kilometers to tens of kilometers) and the fault dip can not decrease at a shallow depth. The complex surface morphology of wrinkle ridges in which different morphologies are observed for each ridge and at different points along the same ridge is interpreted to be the result of splays from the master thrust fault. These splays have a variety of dips and senses of displacement and deform the surface in a unique manner.

Using such a model for the internal structure and the topographic profiles it is possible to estimate the shortening due to folding and faulting (Table 1). Shortening due to folding is estimated by simply unfolding the surface profile across the ridge, assuming conservation of line length; shortening due to faulting at depth is proportional to fault dip. Although the fault dip at depth is not directly observable, theoretical failure criteria and observed angle of normal faults on the moon and Mars suggest a dip of about 25° for thrust faults.

Data (Table 1) indicate that folding shortening varies from <1m-75m; mean 10±10 m. Assuming fault dips of 25°, faulting shortening varies from 0-540m, mean 122±98 m. The average ratio of shortening due to faulting versus folding is about 12. Shortening due to faulting significantly exceeds that due to folding; shortening due to faulting would exceed that due to folding by a factor of 3 to 6 even for fault steeper dips (i.e., 35°). These estimates suggest that a model wherein the fault breaks the surface and a substantial portion of the shortening is expressed by slip on faults at the surface is appropriate for martian ridges.

The shortening data can be used to estimate strain. Individual ridges exhibit a local (single ridge) folding strain of 0.05% to 0.5%, a faulting (displacement) strain of 1.0% to 5.0%, to produce a total strain of 1.4% to 5%. These estimates are broadly consistent with previous estimates of strain of a fraction of a percent to a few percent (e.g., Bryan, 1973; Muehlberger, 1974; Watters, 1988). Ridges on Lunae Planum generally trend north-south indicating an east-west compressional stress field. At 20°N latitude, there are 12 major ridges between Echus Chasma-Kasei Vallis on the west and the heavily cratered terrain on the east. Assuming each ridge is typical (131 m total shortening/ridge), the total shortening across Lunae Planum is 1600 m; corresponding regional compressive strain is 0.2% to 0.5%.

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TABLE 1

RIDGE LOCATIONS (number of profiles)	HEIGHT (M)	WIDTH (KM)	OFFSET (M)	HIGH SIDE	SHORTENING FOLD (M)	SHORTENING FAULT (M)	SHORTENING COMBINED (M)
MC10NW							
20.5°N; 71°W (27)	204±52	5.3±1.0	105±44	E	17±10	225±95	242±101
20.5°N; 70.5°W (26)	197±81	5.0±1.5	94±65	E	22±19	209±142	232±153
20°N; 69°W (13)	152±31	6.4±1.5	58±32	E	9±3	25±52	134±52
17°N; 71.3°W (23)	146±41	6.8±1.9	75±32	E	7±3	160±70	168±71
MC10NE							
20.5°N; 66°W (13)	69±29	5.1±2.4	30±22	E	3±1	63±47	65±48
21°N; 65°W (6)	102±20	4.7±1.3	48±28	E	5±2	103±61	108±62
21°N; 64.5°W (7)	131±106	5.0±3.9	52±38	W	9±9	112±81	121±87
21.5°N; 62.5°W (6)	55±14	3.0±0.8	19±12	W	3±2	41±2	44±24
22°N; 62°W (7)	147±46	5.8±1.5	64±22	E	8±5	136±48	142±49
22°N; 59.5°W (4)	169±41	4.0±1.0	68±45	E	10±5	90±6	100±2
17°N; 66.2°W (6)	79±36	3.7±0.9	33±16	W	5±4	71±31	76±33
MC10SE							
14°N; 66.5°W (7)	75±19	3.3±1.1	39±20	W	3±1	84±44	87±44

(±standard deviation of measurements around means)