GRAVITY INDUCED COMPRESSIVE STRESS IN THE THARSIS REGION OF MARS.

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Models for the origin of the stresses that generated the tectonic features in the Tharsis Region of Mars involve three basic concepts: 1) isostatically-compensated uplift (1,2); 2) simple loading (3,4); and 3) a combination of isostatically-compensated uplift and flexural loading (5). To a large extent these models focus on the origin of the extensional features in the Tharsis Region but are much less clear on the origin of the compressional ridges.

Models invoking loading suggest that ridges formed as a result of a long term viscoelastic response of crust to the volcanic loading of the region. Based on ridge-fault cross-cutting relationships on the ridged plains units in the Tharsis region, Watters and Maxwell (6) concluded that the major compressional ridge forming events were roughly coincident with, and in some cases prior to, the period of extension that generated the faulting of the ridged plains and the rifting of Valles Marineris. Further, the presence of embayed and buried ridges in SW Coprates and the complete absence of compressional ridges on the stratigraphically younger Syria Planum flow units, as well as the Alba Patera flow units in W Lunae Planum, indicates that the deformational events that generated the ridges occurred after the emplacement of the ridged plains units and did not extend beyond the emplacement of these flows. These observations suggest that the compressional deformation responsible for the ridges occurred during an isolated period in the tectonic history of the region thus constraining models for the origin of the compressive stresses.

A model involving an early period or periods of isostatically-compensated uplift followed by relaxation and crustal subsidence could generate circumferentially oriented compressive stresses (see 6). Such a model would satisfy the ridge-fault cross-cutting relationships as well as the apparent relative age of the ridge forming events. However, if subsidence were rapid, compressive stresses may have grown in excess of the finite strength of the ridged plains material resulting in thrust faulting rather than folding.

Wise et al. (1) suggested minor radial gravity induced motions of surficial layers off an isostatic rise to produce the radial fault system in Tharsis. An alternative for generating compressional stress in the Tharsis region that will be explored here is the down-slope stress due to gravity. During an early period of uplift the regional slope was undoubtedly greater than at present. The question is whether the down-slope stress was large enough to generate the observed compressional features. The down-slope stress can be defined as equal to the basal shear stress (τ) expressed as,

$$\tau = \rho g T \sin \theta \qquad (1)$$

where T is the thickness of the unit and θ is the average regional slope. Here θ can be defined as the basal slope assuming the ridge plains unit was emplaced on a relatively flat planar surface. However, as demonstrated by Elliott (7), θ may equally well represent the down-surface topographic slope eliminating the need for assumptions of basal slope. In his study of the thrusts in the Canadian Rockies, Elliott suggested that thrusts move in the direction of surface slope even if this involves movement up the basal dip, and that the shear stress of the sole thrust beneath the Canadian Rockies was on the order of 50 bars. Using topography obtained from radar altimetry data from Roth et al, (8) the regional topographic slope was measured on the ridged plains of western Coprates. The average slope in this area is less than 0.3 degrees. Measurements using radar data from Downs et al. (9) for the ridged plains of Lunae Planum indicate similar slopes in this region. Using equation 1, the down-slope stress was calculated assuming $\rho = 2.9\ gm/cm^3$ (ρ = terrestrial basalts) and a unit thickness of between 1-1.5 km. Assuming that during an early period of uplift the paleo slope was 1-3 degrees greater than at present the down-slope stress on the ridged plains unit would have been 3-10 bars.

If we assume the ridged plains unit deformed as a viscous solid, the time required to generate the observed stain can be estimated by,

$$\sigma_{xx} = 4\eta\ (\partial e_{xx}/\partial t) \qquad (2)$$

where η is the viscosity coefficient of the unit, e_{xx} is the strain, t is the time and σ_{xx} is the stress (for a detailed derivation of this equation, see 10). The upper limits of strain in the ridged plains units of SW Coprates have been estimated to be 2% based on a simple folding model and elevation measurements. With stresses of between 3-10 bars and assuming $\eta = 10^{22}$ poises (the highest reported value for a terrestrial rock that the author could locate; 11), the observed ridges could have been generated in 2.6 - 8.5 M.Y.

A problem that arises from a gravity induced stress model is the magnitude of uplift necessary to produce a 1-3 degree increase in the regional slope. This is largely dependent on the geometry of the uplift. If the total uplift was on the order of 10 km with its center located in Syria Planum, slopes in western Coprates would have approached 1 degree. This assumes the uplift was symmetric about a point in Syria Planum. If, however, a broad zone encompassing, for example, the whole of Syria Planum was uplifted to roughly 10 km, then slopes would have been greater than 1 degree. After uplift, a period of crustal relaxation would have led to subsidence and a reduction in regional slope. This would reduce the gravitation potential energy and compressional folding would have ceased.

In conclusion, I would like to suggest that down-slope stress due to gravity may have played an important role in the generation of compressional stress during early periods of isostatically-compensated uplift. Measured slopes in the ridged plains are in agreement with this model and are compatible with either relaxation-subsidence or later loading of the crust after uplift. The magnitude of the uplift and, therefore, the original slopes are, however, unconstrained estimates.

References: (1) Wise et al. (1979) Icarus 38, 458-472. (2) Finnerty, A.A. and R.J. Phillips (1981) 3rd Intern. Coll. on Mars, 77-79, Lunar and Planet. Inst., Houston, TX. (3) Solomon, S.C, and J.W. Head (1982) JGR 87, 9755-9774. (4) Willemann, R.J. and D.L Turcotte (1982) JGR 87, 9793-9801. (5) Banerdt et al. (1982) JGR 87, 9723-9733. (6) Watters, T.R. and T.A. Maxwell (1983) Icarus 56, 278-298. (7) Elliott, D. (1976) JGR 81, 949-963. (8) Roth et al. (1980) Icarus 42, 287-316. (9) Down et al. (1982) JGR 87, 9747-9754. (10) Biot, M.A. (1961) Bull. GSA 72, 1595-1620. (11) Griggs, D.T. (1939) Jour. Geol. 47, 225-251.