Janle et al. [1984] reported stress calculations similar to that shown in Figure 8. They argued that such stress fields can account for the formation of the tectonic features in Figure 1, and on the basis of this argument they made further inferences as to the thickness of the lithosphere and its lateral variation. In their comparison of predicted stresses with tectonic features, however, *Janle et al.* [1984] examined only the second invariant of the deviatoric stress tensor, which is a measure only of the magnitudes and not the directions of the principal deviatoric stresses. Although the regional stress models for a thickness of the elastic lithosphere less than about 200 km do predict stress differences sufficient to induce faulting at shallow depths [*Brace*, 1964; *Brace and Kohlstedt*, 1980], the calculated stress trajectories are not consistent with the orientations and types of tectonic features observed.

We recognize the possibility that our loading models, based on the approximation of *Brotchie* [1971] in which the dimension of the load is small compared with the planetary radius, may tend to underestimate the magnitude of membrane stresses for loads of large lateral extent. Membrane stresses support topography of long wavelength [*Turcotte et al.*, 1981; *Willemann and Turcotte*, 1981, 1982], while bending stresses are dominant in the support of short-wavelength topography. For Mars the transition between bending-dominated and membrane-dominated stress fields occurs for loads with horizontal dimensions greater than about 2000 km [*Willemann and Turcotte*, 1981]. While the Elysium rise has approximately this dimension, the portion of the rise that may exert a load on the lithosphere is substantially smaller in extent, perhaps 900 km across [*Janle and Ropers*, 1983]. The analysis of *Willemann and Turcotte* [1981] indicates that for a load of this dimension the membrane stresses are not likely to be the dominant support of the load.

On the basis of a comparison of the stress models in Table 1 with the distribution of tectonic features in Elysium there appears to be no evidence for downward loading of the lithosphere by volcanic units at a regional scale. This implies either that the regional volcanic units are largely isostatically compensated [*Janle and Ropers*, 1983] or that the uncompensated portion of the load is supported by the strength of a very thick elastic lithosphere. The locally thinner lithosphere in the vicinity of Elysium Mons at the time of formation of concentric graben may have been the result of heating associated with the formation of the volcano. Similar lateral variations in lithospheric thickness have been inferred for the Tharsis region [*Solomon and Head*, 1982; *Comer et al.*, 1985].

Regional Uplift

As an alternative to volcanic loading models, we next consider the possibility of flexural uplift on a regional scale. The primary constraints are the positions and orientations of the extensional tectonic features in Elysium Planitia. These features are found to a radial distance of approximately 500 km from the center of the rise. This suggests that the area of uplift was also of the order of 500 km in radius because extensional stress is predicted only over the uplifted area. The pattern and magnitude of uplift, or of equivalent upward load on the lithosphere, are otherwise poorly constrained. Presumably, this upward load represents an excess pressure exerted on the base of the lithosphere by a mechanism such as thermal expansion of a volume of underlying mantle material. Flexural uplift of the lithosphere creates stresses which balance the excess pressure; if the uplift is due to differential thermal expansion, the volume of thermally anomalous material and the percent volume change are not separately resolvable.

For an upward lithospheric load equal in magnitude, distribution, and location to the volcanic load JR1 in Table 1, the resulting stress field (Figure 9) is generally consistent with the positions of radial extensional features. We have taken the thickness of the elastic lithosphere to be 100 km for this model; a thicker lithosphere would require greater excess pressures in order to produce surface stresses of a given magnitude. As shown in Figure 9, the greatest extensional stresses are approximately circumferential to the center of the Elysium rise and are significant in magnitude ($\sigma \simeq 0.2$–0.6 kbar) over the area in which those features are found. Also, because the extensional stress field produced over the regional uplift adds constructively to the local extension produced by flexure in response to the Elysium Mons shield, the regional uplift model of Figure 9 is also consistent with the formation of graben concentric to Elysium Mons. The predicted maximum upward deflection of the lithosphere for the assumed values of upward load and lithosphere thickness is approximately 1 km. Such an uplift could be the result of mantle thermal expansion for a temperature contrast of about 300°C extending to a depth of 100 km, values not unreasonable in comparison to thermal anomalies associated with mid-ocean ridges on the earth [*Parsons and Sclater*, 1977].

Because this model is offered as a mechanism of formation of tectonic features rather than as an explanation of the regional topography and gravity, any causative mantle thermal anomaly is not required to persist to the present. An uplift model in which the deformation matched the present topography ($\sim$4 km over the center of the rise) would predict very large (several kilobars) extensional stresses over most of the surface of the rise. With such high stresses it would be difficult to account for the relatively small numbers of radial extensional tectonic features. It is thus likely that much of the present regional topography is due to some combination of volcanic construction and isostatic support.

If significant volcanic construction of Elysium Planitia postdated regional uplift and the formation of radial extensional fractures, an important question concerns the extent to which the evidence of such fracturing would have been preserved. One mechanism for preserving the tectonic signature of an early uplift phase would be if the radial extensional fractures later served as preferred sites for lava tube collapse or for fluvial channel formation. This idea is consistent with the observation [*Carr*, 1981; *Mouginis-Mark et al.*, 1984] that the wide grabenlike depressions of central Elysium Fossae grade downslope into sinuous channels of volcanic or fluvial origin.

The uplift model of Figure 9 does not reproduce the azimuthal asymmetry in the distribution of extensional features, which are preferentially oriented NW-SE (Figure 1). The observed distribution of faulting could be due to corresponding asymmetries in the distribution of uplift (which need not match the present topography) or in lithospheric thickness, but there is no means to test these possibilities at present. Since Elysium lies near the boundary between the ancient southern uplands and the northern lowland plains of Mars, one potential source of heterogeneity in lithospheric thickness or of preferred zones of weakness was the process that gave rise to the Martian hemispherical asymmetry. *Wilhelms and Squyres* [1984] have recently suggested that the upland-lowland boundary marks the rim of a 7700-km-diameter impact basin centered about 50°N, 190°W. While the formation of such a huge impact basin might be expected to have left a strong signature on the distribution of later formed tectonic features, neither the Elysium Fossae nor the Cerberus Rupes are concentric to the proposed location of the basin center.