of the areal distribution of the load is essential. The load model of *Comer et al.* [1985] consisted of a stack of concentric cylinders approximating a conical volcano. We have repeated the calculation with an alternative model with the same excess mass but with a load distribution conforming more closely to the shape of the volcano, as given by the elevation contours of *Batson et al.* [1979], which indicate a pronounced north-south elongation to the topographic relief. We found that this load model predicts stresses not significantly different from those of the axially symmetric model for the same thickness (i.e., flexural rigidity) of the elastic lithosphere. The lithospheric thickness estimate of *Comer et al.* [1985] is therefore robust with respect to uncertainties in the areal distribution of the Elysium Mons load.

A further test of the hypothesis that the graben concentric to Elysium Mons are the result of flexure may be made by comparing the predicted stress magnitudes with the lithospheric strength. In the upper lithosphere of the terrestrial planets, strength is likely to be limited by friction on preexisting faults [*Goetze and Evans*, 1979; *Brace and Kohlstedt*, 1980]. *Byerlee* [1968] demonstrated that frictional strength is well approximated by piecewise linear functions of depth under both horizontal extension and horizontal compression, relations that are largely independent of temperature and rock type. The strength depends on the effective confining pressure and thus on the presence of pore fluids. Fluidized crater ejecta, chaotic terrain, and fluvial channels have been cited as evidence for extensive volcano–ground ice interactions within the Elysium region [*Mouginis-Mark et al.*, 1984]. Because there may have been extensive melting of permafrost and ground ice during the time of volcanic activity in Elysium, the strength in both "wet" and "dry" situations should be considered.

If a flexural origin for the concentric graben is correct, then normal faulting should occur at radial positions and over depth intervals for which the flexural extensional stress exceeds the frictional strength [*Solomon*, 1985]. *Golombek* [1979] has proposed a simple rule to estimate the maximum depth of extensional faulting from the widths of graben and of their bounding walls. This method is based on the assumptions that the graben are the product of simple extension, that the faults bounding the graben dip at approximately 60°, and that faulting does not extend below the projected intersection at depth of the two faults. We measured graben widths at nine locations on six different graben (Figure 6). The measurement points are located 150–215 km from the load center; they are distributed around Elysium Mons from the northeast (N30°E) to the southwest (S30°W). Graben widths range from 1.0 ± 0.5 km to 3.0 ± 0.5 km. Wall widths in all cases (both measured directly and determined by subtracting the floor width from the total graben width) are approximately 0.50 ± 0.25 km.

The inferred maximum depth of faulting ranges from 0.3 to 2.1 km for the various graben considered. These estimates have large uncertainties, however, particularly associated with uncertainties in the dip angles of the bounding faults. For assumed uncertainties of 10° in the fault dip and 5° in the slope of the graben walls the range of possible fault intersection depths varies from 0.1–1.6 km for the narrowest graben measured to 0.6–5.1 km for the widest graben.

For each graben the maximum depth of faulting may be compared with the depth at which flexural stresses fall below the extensional strength. The flexural stresses, including both bending and membrane stress contributions, are taken from the loading model for Elysium Mons of *Comer et al.* [1985]. As a measure of the uncertainties in the predicted stresses, we repeated the flexure calculations with a fixed flexural parameter while varying Young's modulus E and the load q by factors of 2 and 1.5, respectively, greater than and less than the values assumed by *Comer et al.* [1985]. These values represent our best estimate of the uncertainties in each of these quantities.

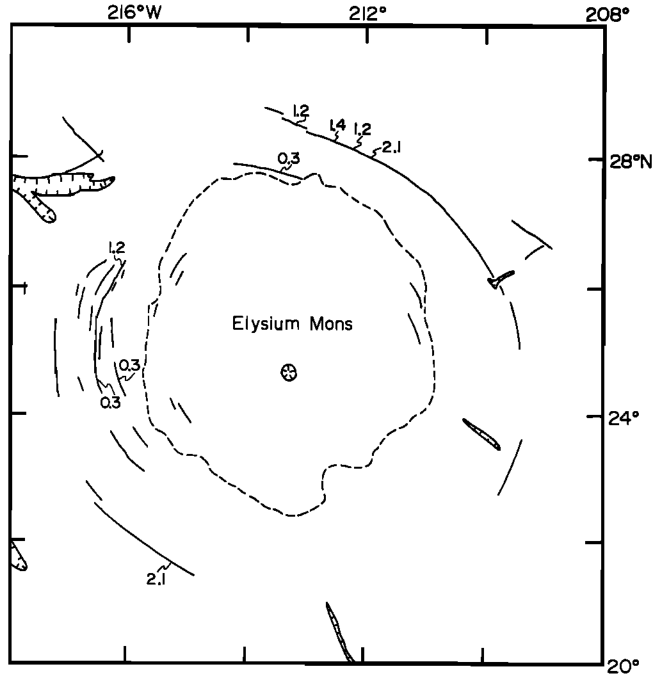

Fig. 6. Sketch map of Elysium Mons and vicinity showing locations at which graben widths were measured, and the inferred depths (in kilometers) at which the normal faults bounding each graben would intersect [*Golombek*, 1979]. Graben widths and wall widths were measured from Viking orbiter photographs (V0541A30, V0844A19, V0846A16).

One such comparison for one of the widest graben is shown in Figure 7. While the inferred maximum depth of normal faulting is somewhat shallower than that predicted from the intersection of the flexural stress distribution and Byerlee's law for extensional strength under "dry" conditions, the two predicted depths agree to within the estimated uncertainties in both the maximum fault depth and the flexural stress magnitudes. If the difference in these depths is real, it may be due to partial release of stress by the formation of neighboring graben, finite extensional strength of relatively unfractured surficial volcanic material, or a superposition of stresses from other sources. In all cases the faulting depth predicted from the intersection of the flexural stress curve with the extensional strength distribution under "wet" conditions is greater than that inferred from graben geometry. This comparison suggests that the depth of faulting inferred for the formation of concentric graben is consistent with a flexural origin as long as there was no significant reduction of maximum effective pressure by near-surface pore fluids during the period of graben formation. However, because of the large uncertainties in the predicted flexural stresses, the presence of pore fluids cannot be completely excluded.

Regional Scale Loading

The stresses due to any arbitrary surface load $q(\mathbf{r})$ on a thin shell may be obtained by convolving the load with the stress tensor $\boldsymbol{\sigma}_0$ resulting from a point load of unit magnitude:

$$\boldsymbol{\sigma}(\mathbf{r}) = \iint q(\mathbf{r}')\boldsymbol{\sigma}_0(\mathbf{r} - \mathbf{r}')\, dA' \quad (1)$$