The primary dependence of viscosity on depth is through the variation of temperature $T(z)$. In most empirical flow laws determined from laboratory measurements of creep in crustal materials the temperature dependence of effective viscosity is given by the factor exp (A/RT), where A is an activation energy, R is the gas constant, and T is absolute temperature [e.g., *Tullis*, 1979]. Within a limited range of confining pressures, and for a single mechanism limiting the rate of creep, A is approximately constant at values ranging from 0.15 to 0.35 MJ/mol for various crustal materials (polycrystalline feldspar, pyroxenite, quartzite, diabase) at conditions appropriate (low confining pressure, $T > 700°K$, dry) to the upper crust of Venus [*Tullis*, 1979; *Shelton and Tullis*, 1981]. Then

$$\frac{1}{s} = -\frac{1}{\eta}\frac{d\eta}{dT}\frac{dT}{dz} = \frac{A}{RT^2}\frac{dT}{dz} \tag{26}$$

where dT/dz is the near-surface thermal gradient. While the crustal thermal gradient has not been measured on Venus, a reasonable range is 10°–20°K/km; the first figure roughly corresponds to the average thermal gradient in terrestrial oceanic lithosphere at thermal equilibrium [*Sclater et al.*, 1980], while the second corresponds approximately to the average thermal gradient in the Venus lithosphere if Venus has a global heat loss per mass equal to that of the earth and if lithospheric heat transport on Venus occurs predominantly by conduction [*Solomon and Head*, 1982]. With the indicated ranges in both A and dT/dz, (26) gives $1/s = 0.3$–1.5 km^{-1}, or $s = 0.7$–3.0 km.

With this range of possible values for s we may use (24) to estimate the magnitude of compressive stress necessary to induce folding at a dominant wavelength equal to the spacing between adjacent bands. For $\lambda = 15$–20 km, (24) then gives $\sigma_0 = 2$–9 kbar, with the higher values of stress corresponding to larger values of λ and smaller values of s. These values of stress are similar to those obtained in the model of a uniform viscous layer, a reasonable result in view of the qualitative similarity of that model to the case with continuously varying viscosity treated here. As with the uniform layer model, compressive stresses of at least 1 kbar are difficult to avoid unless s has been seriously underestimated. Since A is unlikely to be significantly less than 0.15 MJ/mol for crustal materials [*Tullis*, 1979], only a thermal gradient substantially less than 10°K/km (i.e., by more than a factor of 2) could give large enough values of s for σ_0 to be less than 1 kbar. While this possibility cannot be completely rejected for highland regions on Venus, particularly over what may have been a limited time interval during which banding formed in any given unit of banded terrain, we do not regard it as likely.

Assessment of folding models. A variety of simple mechanical models for folding can be made to be consistent with the hypothesis that banded terrain on Venus consists of large-scale folds of surficial rock units produced as a result of horizontal compression during formation of Venus mountain ranges. The models have included both elastic and viscous layers overlying interior regions of much lower viscosity. While uniform elastic and viscous plates of, at most, a few kilometers thickness give fold wavelengths equal to the observed spacing between bands, the required compressive stresses are several kilobars in magnitude, comparable to or larger than the stress differences likely to be supported in the near-surface portions of the Venus crust. Such models might accommodate compressive strain by faulting rather than folding. Layered elastic or high-viscosity plates, however, can fold at the required wavelength with subkilobar stresses, and there are grounds for believing that layering of mechanically distinct units within the crust may commonly occur on Venus [e.g., *Warner*, 1983]. Such layered models are therefore favored.

According to these folding models, banded terrain is a primary feature of Venus mountain ranges, and the distinctive physiographic or morphologic characteristics of banding date from the time of formation of the mountains. In a parallel study [*Stephens et al.*, 1983] we investigate the proposal of *Weertman* [1979] that the age of mountain ranges on Venus may be constrained by the time scale for significant viscous relaxation of topographic relief. Using conservative assumptions as to the effective viscosity of the Venus crust, the extent of isostatic compensation immediately following mountain formation, and the efficiency of other geological processes that may also act to reduce relief, we conclude that the high topography of the mountain ranges of Ishtar Terra is not likely to be older than a few hundred million years. Banded terrain, if a primary feature of mountain formation on Venus, must similarly be geologically young.

EXTENSIONAL MODELS FOR BAND FORMATION

We next consider the alternative hypothesis that banded terrain formed by horizontal extension of the Venus lithosphere. By this hypothesis each distinct high backscatter band or pair of bands would correspond to a crustal block bounded by normal faults. Banded terrain may be characterized by a basin and range structure, though the broader-scale topography of Venus mountain ranges and highlands probably precludes a strict analogy to the terrestrial Basin and Range Province [e.g., *Eaton*, 1982]. Lithospheric extension may arise from the lateral spreading of mountain units under the influence of gravity. Because of the high surface temperature of Venus, as noted above, such spreading may occur by viscous creep at rates much more rapid than on the earth [*Weertman*, 1979; *Stephens et al.*, 1983]. By this explanation the bands would not be primary features associated with the origin of the mountain ranges but rather secondary features produced during their later modification.

We consider several simple models for the formation of Venus banded terrain by extension. These include graben and horst formation in an elastic-brittle layer over a fluid substrate, imbricate normal faulting in a similar layer, and necking of a surficial plastic layer. As with the folding models we seek the range of physical parameters for each type of extensional model that is consistent with the observed spacing between bands. The simplifying assumption that topography at wavelengths much greater than the spacing between bands may be neglected in the analysis is also retained for these models.

Graben and horst formation. As a basis for several extensional models we begin with the hypothesis of *Vening Meinesz* [1950] that once an elastic-brittle layer under extension fails along a throughgoing normal fault, slip on that fault will induce bending stresses in the plate on either side. If extension continues, by this hypothesis, the next fault will form where the surface horizontal bending stress is most extensional. This theory has been used successfuly to predict the widths of continental rifts and some of the characteristics of major extensional fault zones on the earth [*Vening Meinesz*, 1950; *Heiskanen and Vening Meinesz*, 1958; *Bott*, 1976; *Zandt and Owens*, 1980].

The basic model is shown in Figure 6. An elastic-brittle plate of thickness h, Young's modulus E, and Poisson's ratio ν