IMPLICATIONS OF FOLDING FOR THE RHEOLOGICAL STRUCTURE OF THE CRUST OF VENUS; Raymond C. Fletcher, Dept. of Geo. Sci., Brown Univ., Providence, RI 02912 (permanent address: Department of Geophysics, Texas A&M University, College Station, TX 77843)

Highly regular and extensive arrays of symmetrical ridges and troughs, with a spacing of $\approx$ 5 - 20 km, which are interpreted as folds (1), are formed at sites of compression on Venus. In the present study, we consider the process of formation of these folds and its implications for the rheological behavior of the Venus crust (2).

Folding Model. The folding occurs in a tectonic setting where thin-skinned deformation of crust overlying a subducting or underthrusting lithosphere is a likely process. This suggests that the folds may form in shortening of crust above a weak detachment surface at a depth, H. Material beneath the detachment may shear, but not shorten appreciably.

We assume, because of the lack of processes, such as erosion and sedimentation, that would produce regionally persistent weak layers, that the crust will be vertically homogeneous prior to tectonic deformation. The presence of a detachment surface, therefore, cannot be attributed to a pre-existing weak layer, and we suppose that such a surface is formed in the process of deformation. We investigate the possibility that the detachment surface is formed at or near the brittle/ductile transition (BDT) for the following three reasons: (1) even though it is a region of maximum initial strength, the interplay of brittle and ductile deformation processes near the BDT favors rapid strain-softening and the production of a detachment surface; (2) it is the only regionally-persistent feature in the structure of the crust that controls deformation; and (3) permissible estimates of the depth to the BDT are consistent with the observed fold wavelength.

We then assume that the behavior of the layer above the detachment is that of a cohesive Coulomb solid. In the model, this is approximated by a power-law fluid with stress exponent $n \to \infty$, whose strength increases exponentially with depth. The surface strength, τ_0, and the strength at the detachment, $\tau = \tau_0 \exp(\gamma H)$, are equated with the strengths derived from a Coulomb yield condition; this implies $\gamma H = \ln(1+2S)$, where $S=\rho gH/2\tau_0$. At the basal detachment, the velocity of slip associated with folding is taken to be linearly proportional to the shear stress, and the vertical component of velocity is zero. If, for concreteness, the slip is supposed to be mediated by a thin, weak layer of thickness δ and viscosity η, then the behavior of the detachment is described by the dimensionless parameter $\Omega = (|\varepsilon_{xx}|/\tau_0\eta)(\delta/H)$. The rate of growth of a sinusoidal perturbation in the layer surface with amplitude A and wavelength L is found to be $dA/dt = q|\varepsilon_{xx}|A$. The quantity q takes its maximum value at the dominant wavelength L_d. Hence, ignoring subsequent shortening, the observed spacing of folds should be approximately equal to L_d. The model shows that Ld/H is a function of S alone. It varies over a narrow range of from 2.5 to 2.0 as S varies from values much less than unity to values much greater than unity. The observed fold spacing therefore requires that $H \approx 4$ - 5km. If Ω is sufficiently large, the folding instability will be strong at any S.

Implications for conditions of Venus crust in regions of folding. If folds form by the mechanism proposed here, then it is required that the BDT in the regions undergoing folding have a depth of $H \approx 5$km. The depth to the BDT depends on (1) the rheological properties in creep: n, the power-law stress exponent, B*, the pre-exponential factor, and Q, the activation energy; (2) the surface strength, τ_0 and ρg; and (3) the conditions of deformation: T_0, the surface temperature, θ, the temperature gradient, and $|\varepsilon_{xx}|$, the absolute value of the strain-rate. The depth to the BDT in shortening is given by the relation

$$|\varepsilon_{xx}| = B^* \exp(-Q/RT)(\tau_0 + \rho gH)^n,$$

where $T = T_0 + \theta H$, and R is the gas constant. The surface temperature is $T_0 = 450^oC$ (723^oK). We take $\tau_0 =$ 50MPa and $\rho g = 30$ MPa/km. Creep parameters for diabase(3) are $B^*=2\times10^{-2} MPa^{-n} s^{-1}$, $n = 3.05$, and $Q = 276$ kJ/mol^{-1}. We may then determine H as a function of the two remaining parameters, θ and $|\varepsilon_{xx}|$. The result is shown in Figure 1.

As might be expected from the high surface temperature, the BDT is substantially shallower on Venus than it would be on Earth for this material. These values are specific to the material assumed. If, by way of contrast, we consider the same results for olivine (4), with $B^*=4870 MPa^{-n} s^{-1}$, $n = 3.3$, and $Q = 460$ kJ/mol^{-1}, the dashed contours for H = 5 and 10 km are obtained. If, as the folding model requires, $H \approx 5$ km, a crust of basaltic composition (diabase) must have deformed at relatively high strain rates and a low thermal gradient. By contrast, a crust with the properties of the dunite would have to have deformed at implausibly low strain rate and high thermal gradient. Modest changes of the parameters B* and Q used for diabase could enlarge the range of thermal gradient substantially, making the folding model more generally applicable to the observed structures. We see, however, that the dependence of H on strain-rate would not permit the variation in fold wavelength to be interpreted solely in terms of the thermal gradient.

Conclusions.

(1) The depth to the BDT on Venus will be substantially less than that on Earth, for the same rheological parameters. The presence of relatively small-scale structures, such as the folds considered here, is a likely consequence of this.

(2) Because of uncertainties in mechanism, mineralogical constitution, and rheological properties, the interpretation of systematic variations in fold wavelength is likely to be qualitative, at best.

References. (1) Crumpler, L. *et al., Geology, 14*, 1031, 1986. (2) Zuber, M., *J. Geophys. Res.. 92*, E541-E551, 1987. (3) Caristan, Y., *J. Geophys. Res., 87*, 6781-6790,1982. (4) Fletcher, R.C., and B. Hallet, *J. Geophys. Res., 88*, 7457-7466, 1983.