LITHOSPHERIC FLEXURE BENEATH THE FREYJA MONTES FOREDEEP, VENUS: CONSTRAINTS ON LITHOSPHERIC THERMAL GRADIENT AND HEAT FLOW. Sean C. Solomon, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, and James W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912.

Introduction. The heat budget of Venus is poorly known. On the basis of the ^{40}Ar abundance in the atmosphere [1] and the U,Th, and K concentrations in surface soils [2], heat production within Venus has been commonly scaled from estimates for the Earth. Under the assumption that Venus presently loses heat at the same rate per mass as the Earth, the heat flx is 74 W/m^2 s and the average vertical thermal gradient in the lithosphere is 20-25 K/km if conduction is the dominant heat transport mechanism in the outer layer of the planet [3]. It is important to seek tests of the premise that heat flux on Venus may be scaled from the Earth. One means to do so is to determine the thickness of the elastic lithosphere on Venus from the flexural response to surface loads, since the lithospheric thickness is limited by the temperature-dependent depth at which ductile behavior dominates brittle behavior at flexural strain rates [4]. Janle et al. [5] inferred an elastic lithosphere 30-100 km thick beneath the volcano Tepev Mons in Bell Regio from the radial position of a circumferential depression interpreted to be of flexural origin. As described below, even the lower limit of this range places a strong constraint on the lithospheric thermal gradient in this region.

An additional opportunity to estimate elastic lithosphere thickness is afforded by the Freyja Montes region of Ishtar Terra. Analysis of Venera 15 and 16 radar images and topographic data suggest that this mountain belt formed as a result of a sequence of southward underthrusts of the lithosphere of the North Polar Plains beneath Ishtar Terra [6]. To the north of a steep boundary scarp 1-3 km in height is a closed depression several hundred meters in relief. In cross section the topographic profile of the depression [6] is remarkably similar to that of a foreland deep formed by the flexure of the underthrusting plate beneath a terrestrial mountain range [e.g., 7,8]. While terrestrial foredeeps are typically filled with sediments, the much lower rates of erosion and sedimentation on Venus and limited infilling by young volcanic deposits [6] have apparently left the flexural signature of the topography at least partially intact. In this paper we employ that flexural signature to constrain the elastic lithosphere thickness and thermal gradient beneath the North Polar Plains.

Elastic Lithosphere Thickness. We have estimated the thickness T_e of the effective elastic lithosphere and the depth T_m to the base of the mechanical lithosphere [9] from Venera 15 and 16 topographic profiles of the unloaded portion of the underthrusting lithosphere of the North Polar Plains. Estimates of T_e are obtained by fitting individual topographic profiles to deflection curves for broken elastic plates [10]; free parameters in the fit are the flexural parameter α, the magnitude of the vertical load applied to the end of the plate, and the horizontal position. The principal source of uncertainty in estimating α arises from errors in the zero datum for deflection remaining after correcting for the long-wavelength topography of the North Polar Plains. For all of the Venera 15/16 orbits yielding topographic data for this region (orbits 85-91), there is a pronounced linear slope to the topographic profile between the Freyja Montes foredeep and the high-latitude culmination point of the orbit; the opposite-side data display a long-wavelength linear slope of opposite sign, with the break in slopes approximately coinciding with the culmination point. Since all of these data correspond to locations northward of Pioneer Venus altimetry coverage, we do not presently know if these long-wavelength linear slopes are real or are artifacts of the data reduction. In the absence of better information, we have removed from the topographic profiles a linear trend obtained by least squares from the portion of each profile between the orbit culmination point and a position 250 km northward of the Freyja Montes foredeep. One such profile is shown in Figure 1.

The flexure models fit the topographic profiles, corrected for long-wavelength slope, to within an rms misfit of about 50 m, comparable to the stated error in relative along-track elevations at short wavelength in the Venera data [11]. The best-fitting values for the flexural parameter α for the three profiles (orbits 89-91) with the best-developed signature of the foredeep are in the range 37-52 km, corresponding to flexural rigidity D in the range $(1\text{-}5) \times 10^{22}$ N m. Flexural rigidity may be

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converted to T_e for assumed effective values of Poisson's ratio ν and Young's modulus E. We take $\nu = 0.25$ and E in the range 10 - 100 GPa; the extreme values for E correspond to T_e in the ranges 25-37 km and 12-17 km, respectively. We favor higher values of E, and thus lower values of T_e, within these ranges.

Thermal Gradient. These values of T_e may be converted to the mean lithospheric thermal gradient dT/dz, given a representative strain rate and a flow law for ductile deformation of material in the lower lithosphere. This conversion is accomplished by constructing models of bending stress consistent with the strength envelope and finding for each model the equivalent elastic plate model having the same bending moment and curvature K [9]. We take $10^{-16}\ s^{-1}$ as the representative strain rate, and we assume that ductile flow is limited by the creep strength of olivine [12], consistent with the inference from the depths of impact craters and the characteristic spacing of tectonic features that the crust beneath plains units on Venus is no more than 10-20 km thick [13,14]. The conversion from T_e to T_m and dT/dz as functions of K is illustrated in Figure 2. The curvature K at the zero crossings of the flexural profiles for the uniform elastic plate model (e.g., Figure 1) is $(1\text{-}1.5) \times 10^{-7}\ m^{-1}$. From Figure 2, the values of T_e for E = 10 and 100 GPa correspond to mean lithospheric thermal gradients of 7-12 K/km and 16-25 K/km, respectively.

Implications. For a lithospheric Young's modulus at the upper end of the range considered here, the flexural topographic profile of the Freyja Montes foredeep is consistent with a lithospheric thermal gradient similar to that expected for the global mean gradient on the basis of scaling from Earth [3]. This is a reasonable result in that the elevation of the North Polar Plains to the immediate north of the foredeep and associated outer rise [6] is similar to the mean elevation of the planet [15]. In contrast, the thermal gradients if E is at the lower end of the range considered, and that implied (see Figure 2) by the least value of T_e inferred by Janle et al. [5], are no more than half that expected from scaling arguments. We suggest that an internally consistent description of the current internal structure and tectonics of Venus includes a strong (E ≈ 100 GPa) but thin (T_m ≈ 15-20 km) mechanical lithosphere, a thin (10-20 km) crust, and a thermal gradient appropriate to scaling global heat loss from the Earth (20-25 K/km) beneath typical plains regions of the planet.

References. [1] J.H. Hoffman et al., *JGR, 85*, 7882, 1980; [2] Yu.A. Surkov, *PLSC 8th*, 2665, 1977; [3] S.C. Solomon and J.W. Head, *JGR*, 9236, 1982; [4] C. Goetze and B. Evans, *GJRAS*, *59*, 463, 1979; [5] P. Janle et al., *Earth Moon Planets, 41*, 127, 1988; [6] J.W. Head, *LPS, 19*, 467, 1988; [7] G.D. Karner and A.B. Watts, *JGR, 88*, 10449, 1983; [8] L. Royden, *JGR, 93*, 7747, 1988; [9] M.K. McNutt, *JGR*, *89*, 11180, 1984; [10] D.L. Turcotte and G. Schubert, *Geodynamics*, p. 127,Wiley, 1982; [11] Yu.N. Alexandrov et al., *Science, 231*, 1271, 1986; [12] C. Goetze, *Phil. Trans. Roy. Soc. Lod., A288*, 99, 1978; [13] R.E. Grimm and S.C. Solomon, *JGR, 93*, 11911, 1988; [14] M.T. Zuber, *JGR, 92*, E541, 1987; [15] P. Ford, *Pioneer Venus Hypsometry*, MIT CSR rept., 1986.

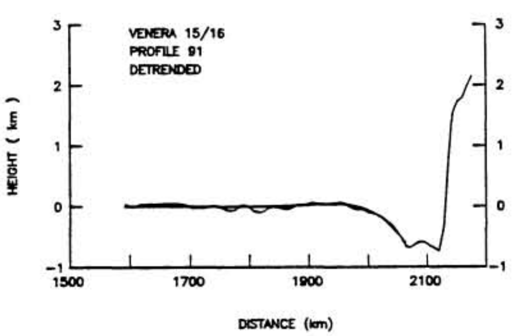

Figure 1. Topographic profile across Freyja Montes (Venera orbit 91), after correcting for long-wavelength slope. Also shown is a model profile for flexure of a uniform plate subjected to an end vertical load.

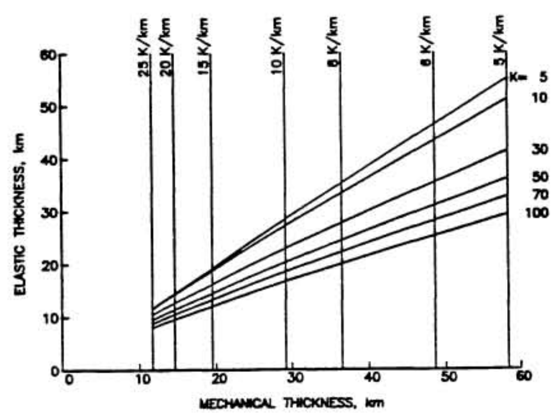

Figure 2. Conversion of T_e to T_m and dT/dz as functions of curvature K (in units of $10^{-8}\ m^{-1}$), after [9]. Mean thermal gradients shown correspond to a strain rate of $10^{-16}\ s^{-1}$.

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