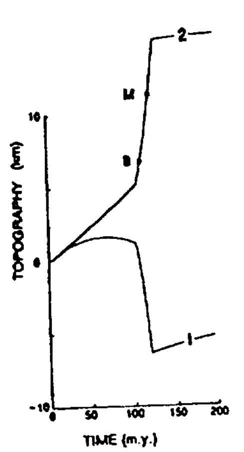

Fig. 2. The surface topography produced by the crustal shortening of the cold Venus model with (curve 1) and without (curve 2) taking the BGET into account. Point B approximates Bindschadler et al.'s [8] model and point M is the approximate height of Maxwell Montes.

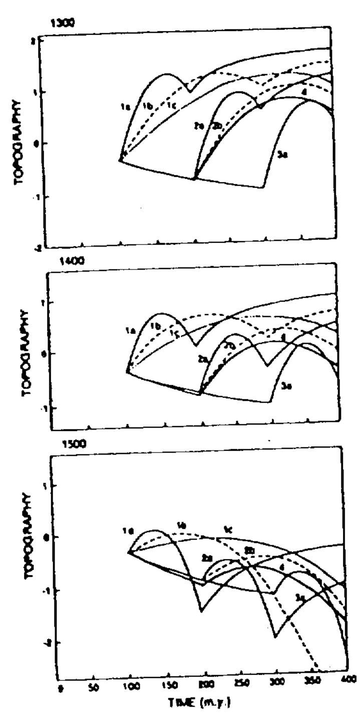

Fig. 3. The surface topography produced by the crustal thickening of the cold (1300), the Earth-like (1400), and the hot (1500) Venus models. The curves a, b, and c denote the thickening rates of 0.5, 0.25, and 0.167 km/m.y., respectively. The compensation depths are at 150 km, except for the curve 4 whose compensation depth is at 200 km.

rebound to produce a significant surface elevation. Not only is it impossible to produce a high plateau, but it is quite possible to produce a basin.

The factors that could affect the surface topography of a thickening crust are (1) the initial temperature distribution in the lithosphere, (2) thickening rate of the crust, (3) depth of compensation, and (4) total thickness of the crust. Figure 2 shows the surface topography produced by lithospheric models assuming linear thickening of the crust. There are three sets of curves in each figure. Sets 1, 2, and 3 show the effects of the initial temperature distributions corresponding to lithospheres 100, 200, and 300 m.y. old. Within a given set, the curves a, b, and c are for thickening rates of 0.5, 0.25, and 0.167 km/m.y. respectively. In 1a and 2a the thickening was halted after 100 m.y., and in 1b after 200 m.y., allowing the lithosphere to reach thermal equilibrium. Curve 4 shows compensation at 200 km depth. None of these factors have a significant effect on the maximum height of the surface topography. The controlling factor, however, is the total thickness of the basaltic crust. The maximum topographic height is achieved when the crust reaches its critical thickness of ~38 km, beyond which the crustal shortening actually depresses the surface due to creation of high-density granulite and eclogite in the deeper parts that readily sink into the mantle. The crust of the cold Venus model requires significant thickening before it reaches the critical thickness, whereas those of the Earth-like and especially the hot Venus models need less thickening. Consequently, the cold Venus model produces a surface topography that is ~1.5 times higher than that of the Earth-like Venus model and ~3 times higher than that of the hot Venus model.

Lakshmi Planum is higher than 4 km above the mean surface of Venus and Maxwell Montes stand ~6 km higher. These prominent features are ~2–6 times higher than the maximum height that could be achieved by thickening a basaltic crust, no matter which lithospheric model is used. These features probably contain relatively less dense materials and represent analogues of continental masses on Earth.

References: [1] Solomon S. C. and Head J. W. (1984) *JGR, 89*, 6885–6897. [2] Vorder Bruegge R. W. and Head J. W. (1989) *GRL, 16*, 699–702. [3] Kiefer W. S. and Hager B. H. (1991) *JGR, 96*, 20967–20980. [4] Morgan P. and Phillips R. J. (1983) *JGR, 88*, 8305–8317. [5] Vorder Bruegge R. W. and Head J. W. (1991) *Geology, 19*, 885–888. [6] Janle P. and Jansen D. (1984) *Earth Moon Planets, 31*, 141–155. [7] Solomon S. C. and Head J. W. (1990) *GRL, 17*, 1393–1396. [8] Bindschadler D. L. et al. (1990) *GRL, 17*, 1345–1348. [9] Ito K. and Kennedy G. C. (1971) *Am. Geophys. Union Mon., 14*, 303–314. [10] Green D. H. (1967) *The Poldervaart Treatise on Rocks of Basaltic Composition, Vol. 1* (H. H. Hess and A. Poldervaart, eds.), Wiley-Interscience, New York. [11] Ahren T. J. and Schubert G. (1975) *Rev. Geophys. Space Phys., 13*, 383–400. [12] Schaber G. G. et al. (1992) *JGR*, in press. [13] Phillips R. J. et al. (1992) *JGR*, in press. [14] Sjogren W. L. et al. (1984) *GRL, 11*, 489–491.

CONSTRAINTS ON THE THERMAL EVOLUTION OF VENUS INFERRED FROM MAGELLAN DATA. J. Arkani-Hamed[1], G. G. Schaber[2], and R. G. Strom[3], [1]Department of Geological Sciences, McGill University, Montreal, Canada, H3A 2A7, [2]U.S. Geological Survey, Flagstaff AZ 86001, USA, [3]Department of Planetary Sciences, University of Arizona, Tucson AZ 85721, USA.

A surface topography produced through viscous deformation of a mantle by internal loadings correlates with the resulting gravity anomaly if the mantle has an almost uniform viscosity [1]. The high correlation over low-degree spherical harmonics of surface topography and gravity anomalies of Venus and the greater apparent depth of compensation of the topography imply a high-viscosity upper mantle for Venus [2] that probably results from dehydration effects of the high surface temperature [3] and from the colder interior of

Venus [4]. The convecting mantle that is tightly coupled to the high-temperature weak lithosphere through the high-viscosity upper mantle [2] may strongly deform the lithosphere, producing a mobile and semifree boundary layer on top of the convecting mantle.

The thermal convection models of a mantle that convects under a stress-free surface boundary condition [5] and is mostly heated from within, as favored for Venus by many investigators [e.g., 3,4,6], develop a strong thermal boundary layer at the surface but a weaker one at the base [7]. Strong instabilities in the near-surface boundary layer result in downwelling of cold plumes, whereas the upwelling zones are relatively diffused [8]. Such a mantle convection may not create sharp oceanic-type ridge systems, but it may result in distinct compressional features at the surface associated with the downwellings. The lack of distinct ridge systems on Venus, and the almost axisymmetric geometry of Lakshmi Planum and surrounding mountains that are interpreted as thickened crust over downwelling mantle convection [6], are in good agreement with the surface expressions of a convecting mantle that is mainly heated from within.

Another major characteristic of the mantle convection models is their time dependence. A time-dependent oscillatory convection at high Rayleigh numbers reduces to a steady-state slow convection as the Rayleigh number is decreased below a critical value. In Venus' mantle the local Rayleigh number probably decreases with depth due to decrease in the thermal expansion coefficient with depth [4,7]. The secular cooling of the core decreases the temperature drop across the mantle, and the secular cooling of the mantle increases its effective viscosity. It is therefore possible that the Rayleigh number decreases with time as the mantle cools. This would increase the thickness of the thermal boundary layers, especially the lower one, decrease the heat flux out of the core, and hamper the instability of the lower layer. The mantle becomes more like one that is heated mainly from within. The Rayleigh number may decrease below the critical value and a time-dependent, vigorous convection may suddenly change to a quasisteady and slow circulation [4].

The impact craters with diameters from 1.5 to 280 km compiled from Magellan observations indicate that the crater population on Venus has a completely spatially random distribution [9] and the size/density distribution of craters with diameters ≥35 km is consistent with a "production" population with an age of 500 ± 250 m.y. [10]. The similarity in size distribution from area to area indicates that the crater distribution is independent of crater size. Also, the forms of the modified craters are virtually identical to those of the pristine craters. These observations imply that Venus reset its cratering record by global resurfacing 500 m.y. ago, and resurfacing declined relatively fast. The fact that <40% of all craters have been modified and that the few volcanically embayed craters are located on localized tectonic regions [11] indicate that only minor and localized volcanism and tectonism have occurred since the latest vigorous resurfacing event ~500 m.y. ago and the interior of Venus has been solid and possibly colder than Earth's. This is because the high-temperature lithosphere of Venus would facilitate upward ascending of mantle plumes and result in extensive volcanism if Venus' upper mantle were as hot as or hotter than Earth's [12]. Therefore, the present surface morphology of Venus may provide useful constraints on the pattern of that vigorous convection, and possibly on the thermal state of the Venus' mantle.

We examine this possibility through numerical calculations of three-dimensional thermal convection models in a spherical shell with temperature- and pressure-dependent Newtonian viscosity, temperature-dependent thermal diffusivity, pressure-dependent thermal expansion coefficient, and time-dependent internal heat production rate. Both rigid and free boundary conditions are considered at the surface, whereas the boundary condition at the core/mantle boundary is assumed free as long as the core has not become completely solidified. Otherwise it is assumed to be rigid. The lateral dependence of the governing equations of motion, heat transfer, and continuity is resolved through spherical harmonic representations of field variables and the resulting radially dependent differential equations are solved numerically using the Green function method [4]. Among all parameters affecting the pattern of convection circulations, the free boundary condition at the surface and the secular decrease of temperature at the core/mantle boundary have by far the most dominant effects. These two factors result in fast cooling of the mantle and sharp reduction in its effective Rayleigh number, so that oscillatory vigorous convection circulations could become quasisteady and slow. A strong thermal boundary layer is developed near the surface, whereas that near the core/mantle boundary is relatively weak. Consequently, major lateral variations in temperature exist in the upper mantle, but they are subdued near the core/mantle boundary.

References: [1] Richards M. A. and Hager B. H. (1984) *JGR, 89*, 5987–6002. [2] Phillips R. J. (1990) *JGR, 95*, 1301–1316. [3] Kaula W. M. (1990) *Science, 247*, 1191–1196. [4] Arkani-Hamed J. and Toksoz M. N. (1984) *PEPI, 34*, 232–250. [5] Schubert G. et al. (1990) *JGR, 95*, 14105–14129. [6] Bindschadler D. L. et al. (1990) *GRL, 17*, 1345–1348. [7] Leitch A. M. and Yuen D. A. (1991) *JGR, 96*, 15551–15562. [8] Jarvis G. T. and Peltier W. R. (1989) in *Mantle Convection: Plate Tectonics and Global Dynamics* (W. R. Peltier, ed.), 479–595, Gordon and Breach. [9] Phillips R. J. et al. (1992) *JGR*, submitted. [10] Schaber G. G. et al. (1992) *JGR*, submitted. [11] Strom R. G. et al. (1992) *LPSC XXIII*, 1065–1066. [12] Erickson S. G. and Arkani-Hamed J. (1992) *GRL*, in press.

N93-[illegible]

SURFACE PROCESSES ON VENUS. R. E. Arvidson, McDonnell Center for the Space Sciences, Earth and Planetary Sciences, Washington University, St. Louis MO 63130, USA.

Magellan synthetic aperture radar (SAR) and altimetry data were analyzed to determine the nature and extent of surface modification for venusian plains in the Sedna Planitia, Alpha Regio, and western Ovda Regio areas. Specific cross sections derived from the SAR data were also compared to similar data for dry terrestrial basaltic lava flows (Lunar Crater and Cima volcanic fields) and playas (Lunar and Lavic Lakes) for which microtopographic profiles (i.e., quantitative roughness information) were available. In Sedna Planitia, where clear stratigraphic relations can be discerned among volcanic flow units, the youngest unit has planform and microwave characteristics indicative of pahoehoelike flows. The second youngest flow exhibits cross-section values similar to fresh a'a flows at the Lunar Crater and Cima fields. Older flows have the same planform shapes as the youngest a'a flow, but exhibit backscatter signatures similar to degraded terrestrial flows. We suggest that flows with a variety of surface textures have been emplaced at Sedna Planitia and elsewhere and that initial properties have been removed by surface processes for the older units. Degradational effects of ejecta are directly evident in deposits from the nearby impact crater Lind mantle sections of the Sedna flows. Differences in cross sections between mantled and unmantled flows are consistent with ejecta thicknesses of centimeters. Similar thicknesses are inferred for the extensive parabolic ejecta deposit from Stuart Crater, which is located on plains to the east of Alpha Regio. Ejecta deposits are inferred to accumulate during impact events and to be dispersed