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.


CONSTRANTS ON THE THERMAL EVOLUTION OF VENUS INFERRED FROM MAGELLAN DATA. J. Arkani-Hamed, G. G. Schaber, and R. G. Strom, Department of Geological Sciences, McGill University, Montreal, Canada, H3A 2A7. U.S. Geological Survey, Flagstaff AZ 86001, USA, 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 the viscous lithosphere.
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 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 downwellings of cold plumes, whereas the
upwellng zones are relatively diffused [8]. Such a mantle convec-
tion 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
the 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 a 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 flow 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 $\geq 35$ km is con-
sistent with a "production" population with an age of $500 \pm 250$ 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 $\approx 40\%$ 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 $\approx 500$ 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 ther-
mal expansion coefficient, and time-dependent internal heat pro-
duction 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 radial-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 circula-
tions could become quasisteady and slow. A strong thermal bound-
ary 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.

Convection: Plate Tectonics and Global Dynamics (W. R. Peltier,

SURFACE PROCESSES ON VENUS. R. E. Arvidson,
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Magellan synthetic aperture radar (SAR) and alunetry 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) are available. In Sedna Planitia,
where clear stratigraphic relations can be discerned among volcanic
flow units, the youngest unit has plainform and microwave charac-
teristics indicative of pahoehoeholeike 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 backsscatter 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.