Arguments for a Thick Venus Lithosphere

The main support for a thick lithosphere on Venus comes from analyses of gravity and topography over the volcanic highlands.

Beta Regio

Author	Lithosphere Thickness (km)
Smrekar and Phillips (1994)	270
Smrekar (1994)	225
Simons et al. (1994)	300
Kucinskas and Turcotte (1994)	369
Moore and Schubert (1995)	270
Moore and Schubert (1997)	264

Atla Regio

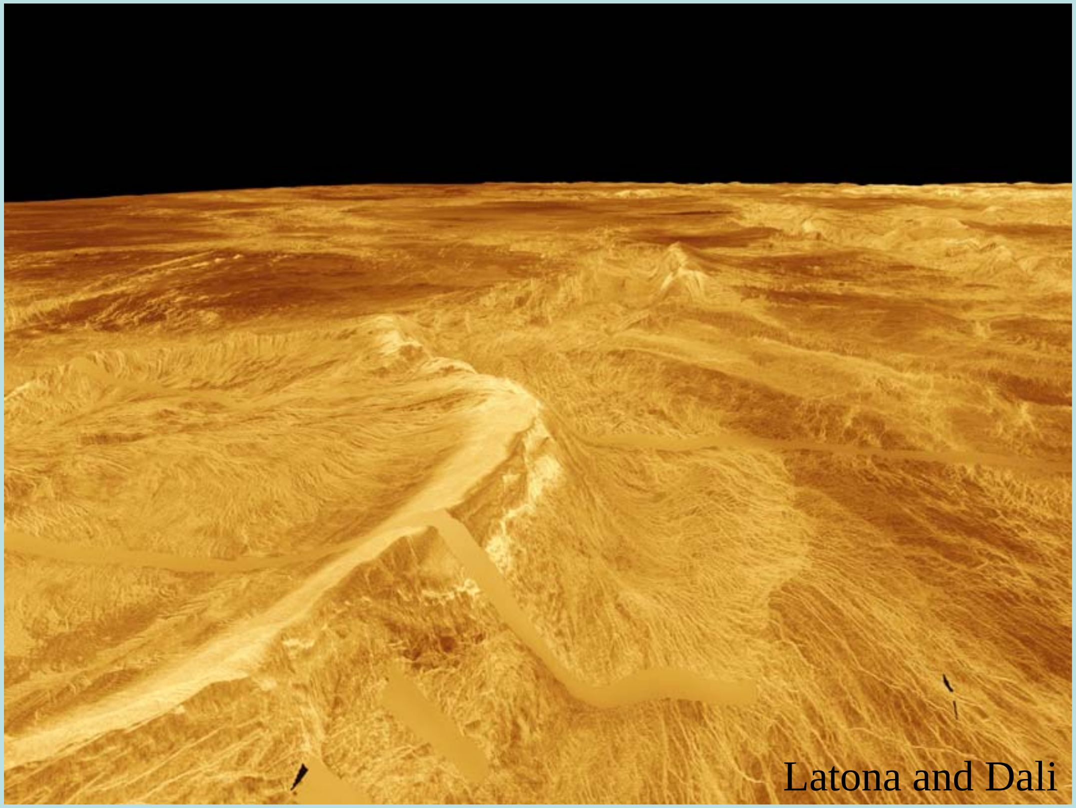
Author	Lithosphere Thickness (km)
Herrick et al. (1989)	240
Smrekar and Phillips (1991)	200
Phillips (1994)	350
Smrekar (1994)	175
Kucinskas and Turcotte (1994)	362
Moore and Schubert (1997)	221

Coronae

Schubert et al. (1994)

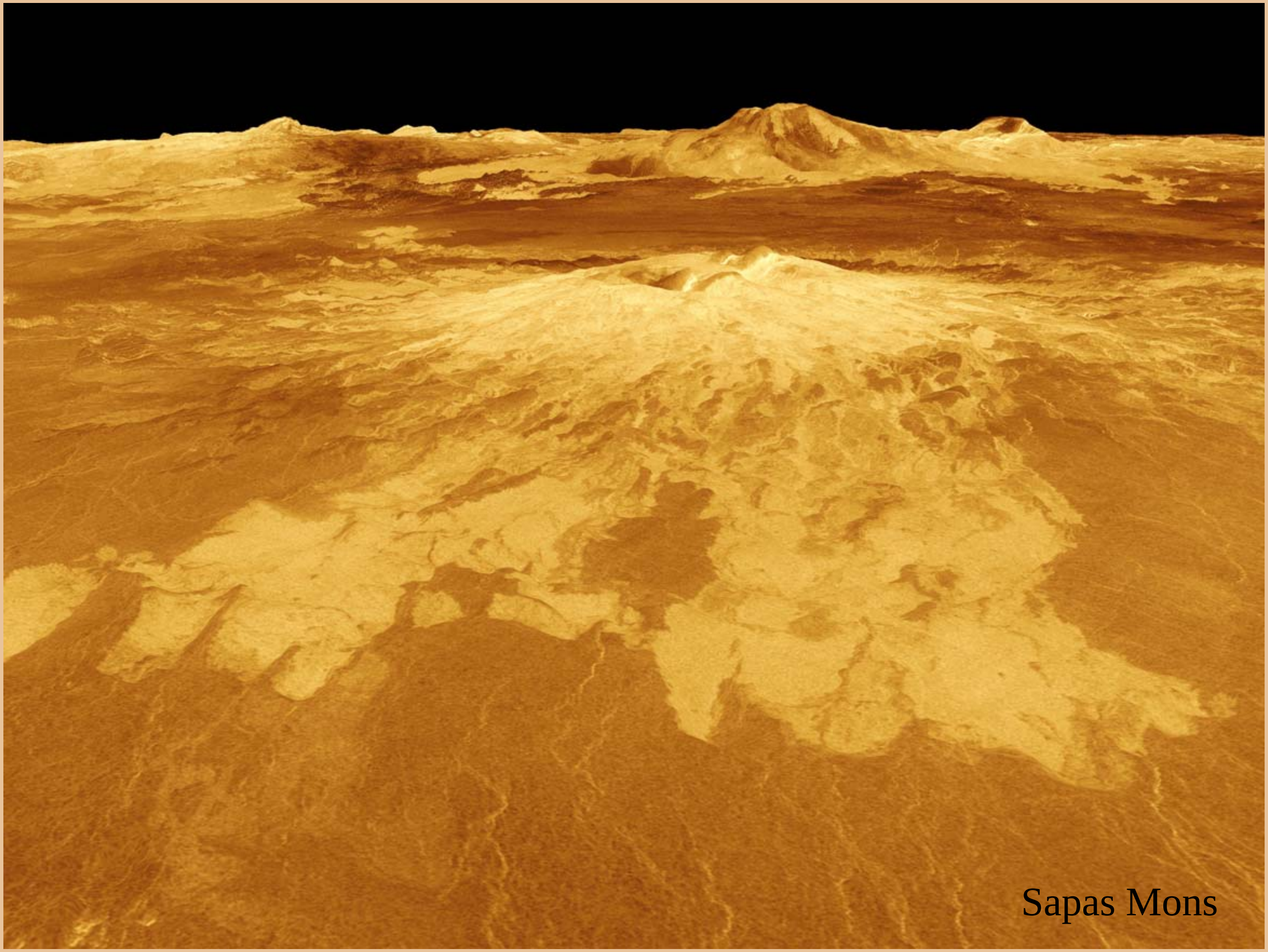
Feature	Admittance (mGal/km)	ADC (km)
Artemis	56	200
Latona, Heng-o	43, 76	150, 150

Stofan et al. (1997) point out that the peak gravity anomalies over Artemis, Latona, and Heng-o coronae are larger by factors of 1.8, 1.9, and 1.6, respectively, than used by Schubert et al. (1994) (due to improved resolution of 90 degree and order gravity field). This means that the ADCs of these coronae are even larger than the values on the previous slide. The additional power is at the shorter wavelengths, comparable to the values of the ADCs.



Latona and Dali

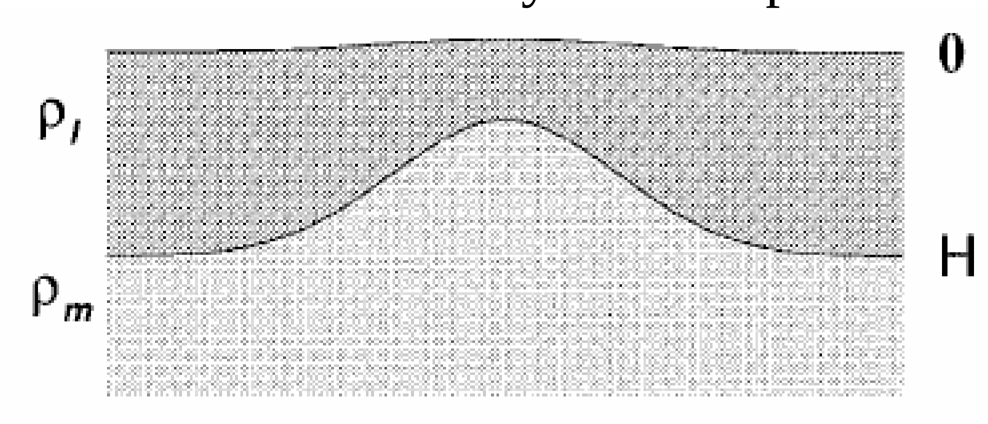
Analyses of geoid and topography over Atla and Beta show considerable lithospheric thinning directly under the rises and buoyant mantle below the lithosphere.



Moore and Schubert (1995)

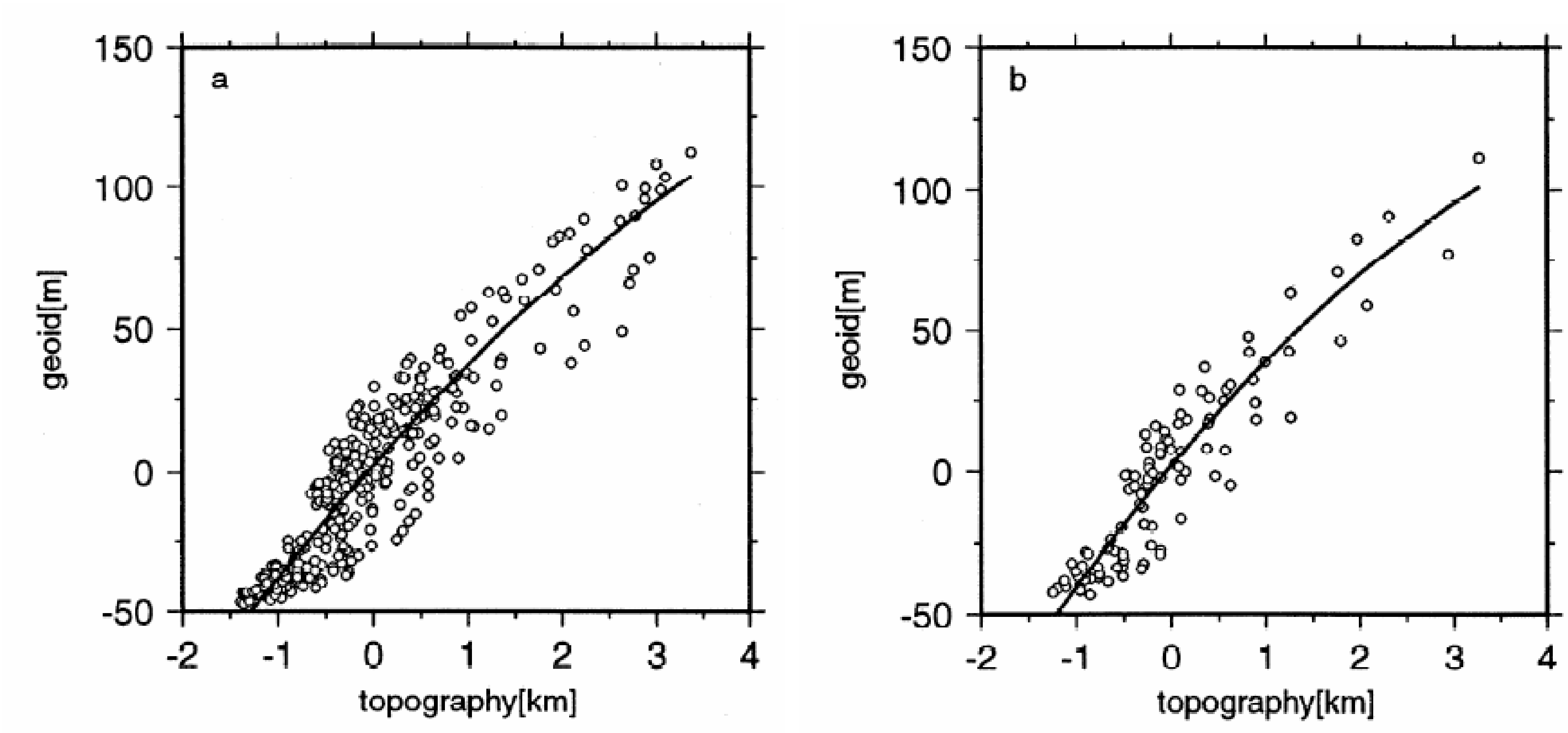
- Studied geoid and topography over Beta Regio.
- Inferred lithosphere thickness and density contrast from a quadratic regression of filtered (600 km < λ < 4000 km) geoid vs. topography data.
- Mean lithosphere thickness of 270 km.
- Density contrast -(2.5-3.0)%.
- Lithosphere thinning by 50-60% beneath the rise.

Assumed isostasy and compensation at a single depth (Airy).



$$\Delta N = \frac{\pi G \rho_l}{g} \left\{ 2Hh + \frac{\rho_m}{(\rho_m - \rho_l)} h^2 \right\}$$

- Topography convolved with the Gaussian filter $f(r)=\exp(-r^2/\sigma^2)$ (σ=180 km) to remove wavelengths less than 600 km and flexural effects without aliasing.
- Data averaged over box sizes 3º to 6º and a regional mean subtracted (to remove unrelated long wavelength power.
- Used orthogonal distance regression to fit data.



$$\Delta N = \frac{\pi G \rho_c}{g} \left\{ 2\mathrm{H}h + \frac{\rho_m}{\rho_m - \rho_c} h^2 \right\}$$

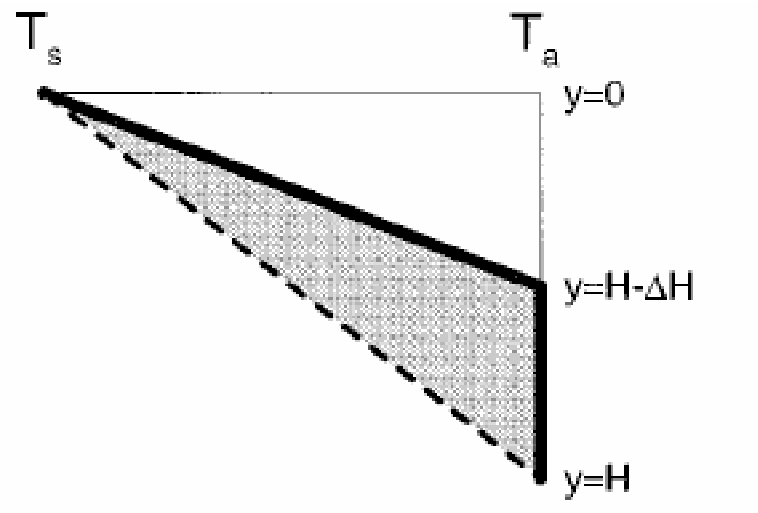
H = 270 km

Lithospheric thickness and mantle/lithosphere density contrast beneath Beta Regio, Venus, W. B. Moore and G. Schubert, Geophys. Res. Lett., 22, 429-432, 1995.

Moore and Schubert (1997)

Investigated quadratic relationship bewteen geoid and topography for volcanic and plateau highlands. Analysis is similar to Moore and Schubert (1995), but local long wavelength field, constructed by convolution with a boxcar function having the same width as the region in which the regression is performed, is subtracted out.

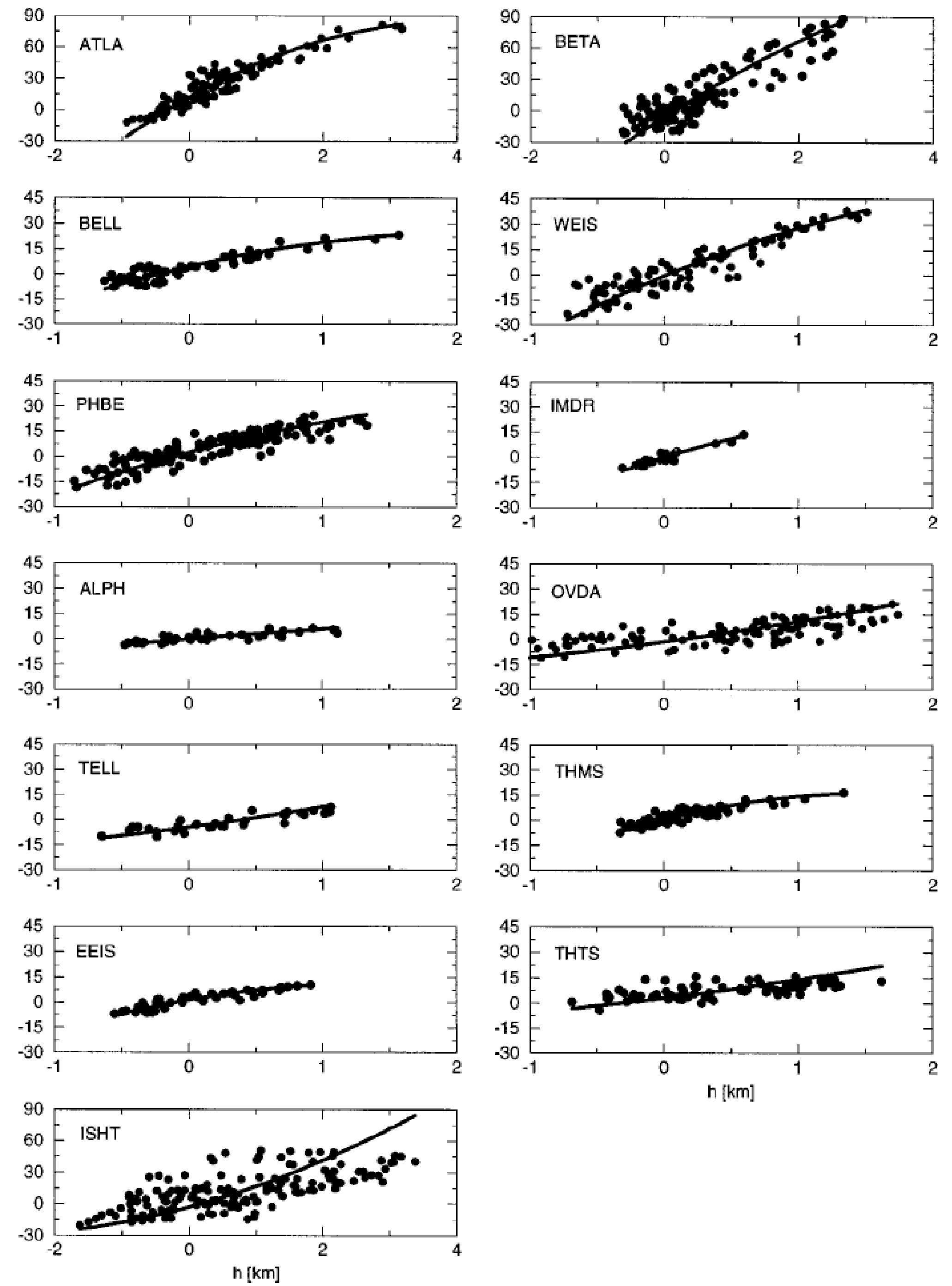
Slow Thinning Model



$$\Delta N = \frac{4\pi G\rho_l}{3g}\left(Hh - \frac{h^2}{\alpha(T_a - T_s)}\right)$$

H is 1.5 times as large as the Airy model H. It is the average depth to the asthenosphere.

Feature	H (km)	Percent Thinning
Atla Regio	331	76
Beta Regio	396	31


ATLA
BETA
BELL
WEIS
PHBE
IMDR
ALPH
OVDA
TELL
THMS
EEIS
THTS
ISHT
h [km]
h [km]

A Different Approach

McKenzie and Nimmo (1997)

Analyzed LOS Magellan acceleration data to calculate admittance (gravity/topography ratio) as a function of wavelength.
Long wavelength admittance over Atla Regio determined to be about **50 mGal km^{-1}**.
Attribute the long wavelength signal to dynamic support from convection.

Barnett et al. (2000)

Long wavelength admittance over Beta Regio is about **50 mGal km^{-1}**.

How are these admittance values related to lithosphere thickness?

The above studies determined an average elastic thickness of the lithosphere in these regions from short wavelength admittance to be about 30 km.
The thermal lithosphere must be much thicker.

Admittance and Lithosphere Thickness

Airy model, long wavelength: **Admittance = $4\pi^2\rho g(H/\lambda)$**

H = Lithosphere thickness

λ = Wavelength

ρ = Lithosphere density

g = Acceleration of gravity

50 mGal km^{-1} corresponds to H = 253 km for λ = 4000 km.

McKenzie and Nimmo (1997) assert that 50 mGal km^{-1} corresponds to convection beneath a 180 km thick lithosphere.

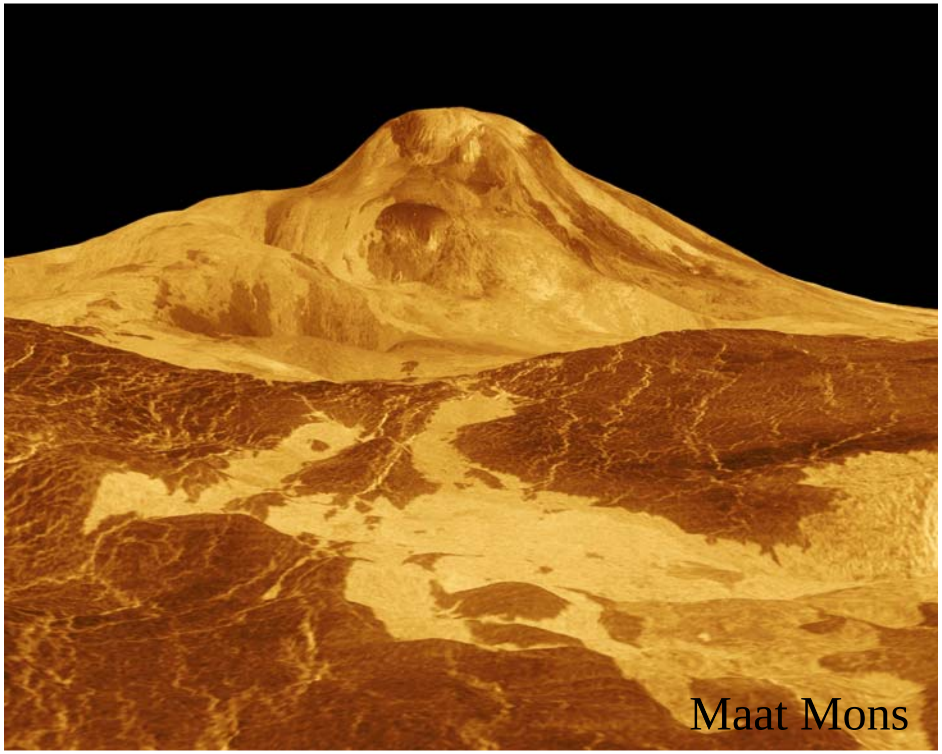
Convection Models

Solomatov and Moresi (1996)

Stagnant Lid Convection.
Lithosphere thickness- 400-550 km under Beta Regio
200- 400 km on average

Vezalainen et al. (2004)

Model topography and gravity of Beta Regio.
Lithosphere thickness- 400 km



Yet Another Approach

Lawrence and Phillips (2003)

- Gravity/topography admittance inversion using niching genetic algorithms.
- Fit data using theoretical admittance function for top and bottom loading of an elastic shell.
- **Find long wavelength admittance of around 50 mGal km^{-1}.**
- Infer a negative mantle density anomaly beneath Atla Regio.
- The mantle density anomaly extends 200 km below the crust-mantle boundary.
- Elastic plate thickness is about 80 km.

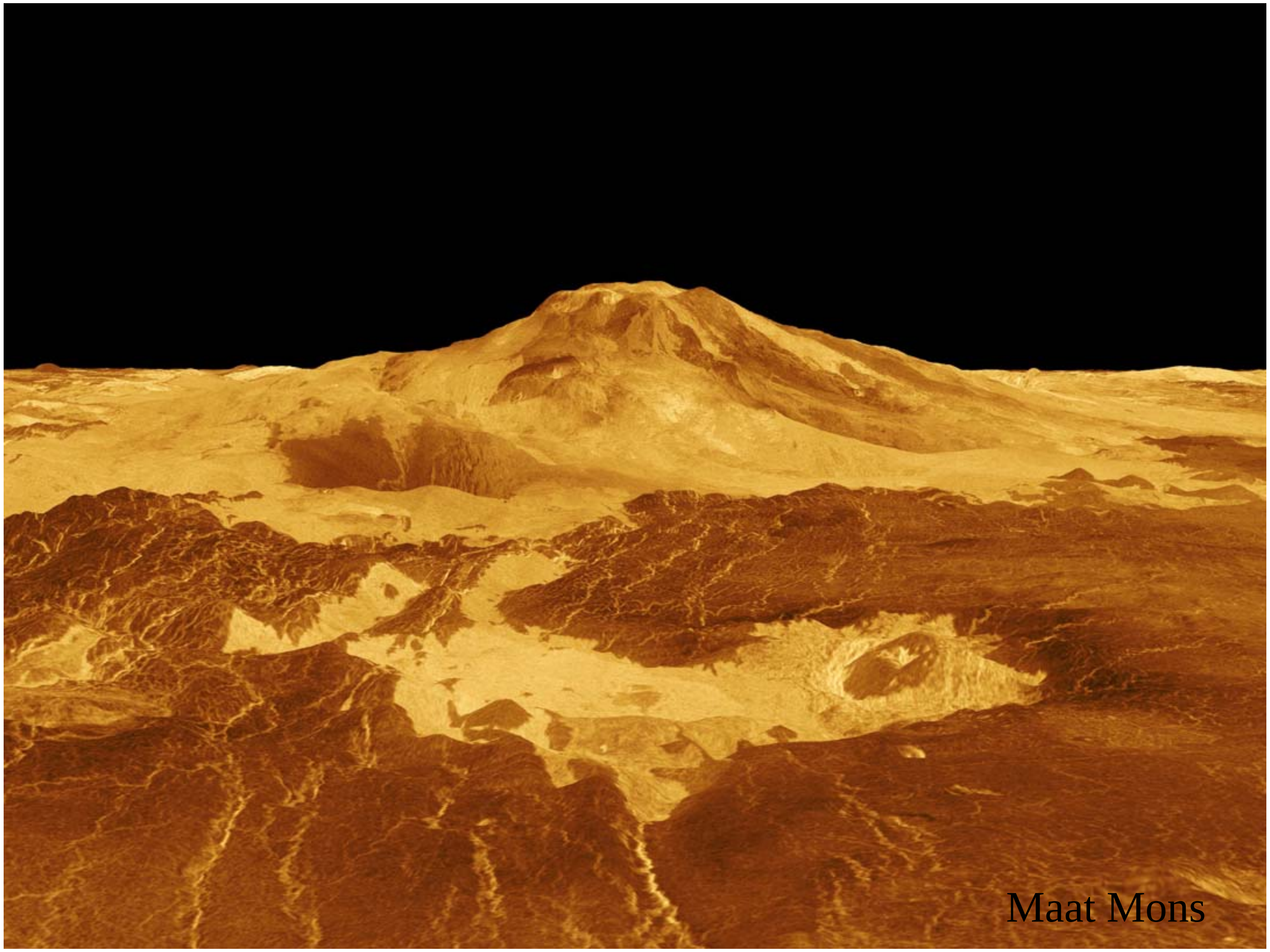
Elastic Lithosphere Thickness

There have been a large number of studies of the elastic thickness T_e of Venus' lithosphere. The results encompass a broad range of values.
Flexural studies of some coronae yield T_e of 40 km.
It is difficult to infer lithosphere thickness from T_e.

Certainly Venus' thick lithosphere is thinned in many places, e. g., beneath volcanic highlands, as the geoid-topography analyses show, so low values of T_e in particular locations place no constraints on the global average lithosphere thickness.

Theoretical Argument

If Venus underwent a global resurfacing event about 500 Myr ago, then it could have produced a lithosphere as thick as 300 km in the intervening time.



Plateau Highlands

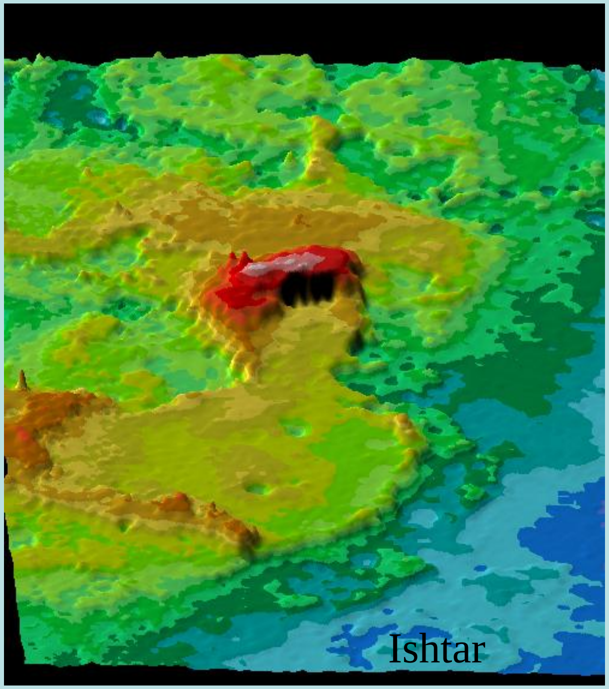
Plateau highlands (Alpha, Ovda, Thetis and Tellus Regiones) are supported by thick (45-85 km) crustal roots. The lithospheres under these highlands must be considerably thicker.

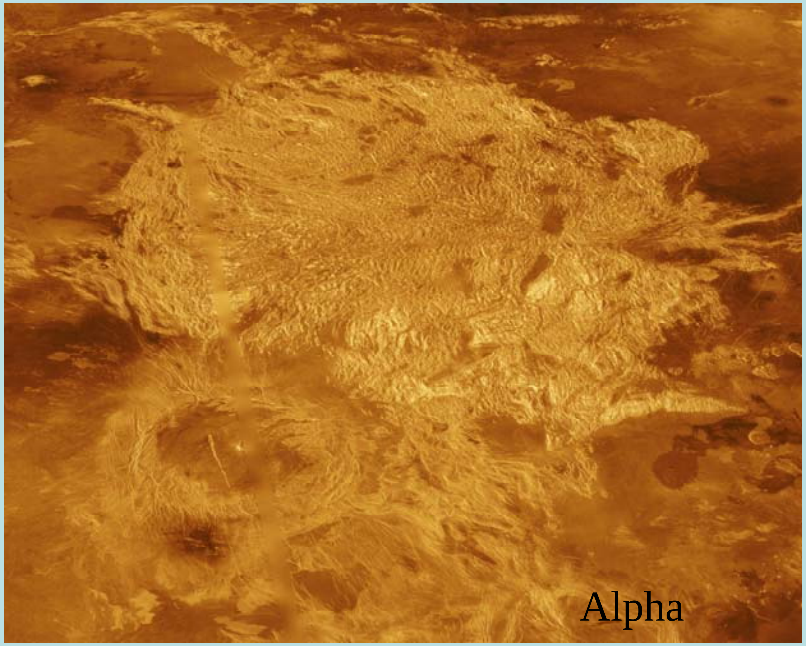
The long wavelength ADC of Ishtar Terra is 150-200 km. The compensation probably occurs through a combination of thick crust and the buoyant residuum of depleted mantle. Such a structure is likely imbedded in a thick lithosphere.

The high and steep escarpments around Ishtar Terra are likely supported by elastic stresses in a thick lithosphere.

Spherical Harmonic Analysis of Global Geoid and Topography
Kucinskas and Turcotte (1994)

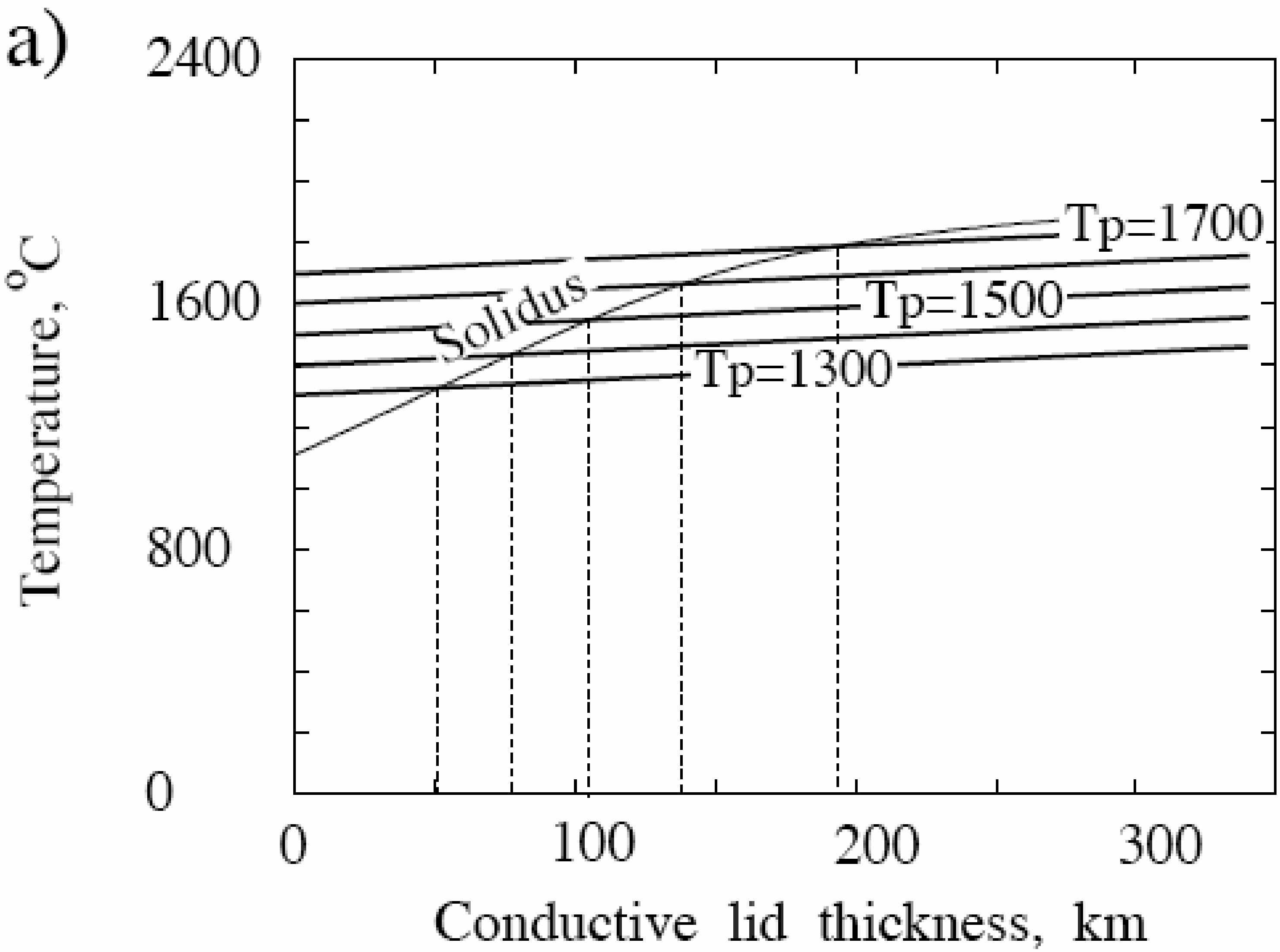
"Observed degree geoid to topography ratios (GTRs) on Venus are significantly smaller than degree GTRs for uncompensated topography, indicative of substantial compenstaion. Assuming a global Airy compensation, most of the topography is compensated at depths greater than 100 km, suggesting a thick lithosphere on Venus."





Nimmo and McKenzie (1998)

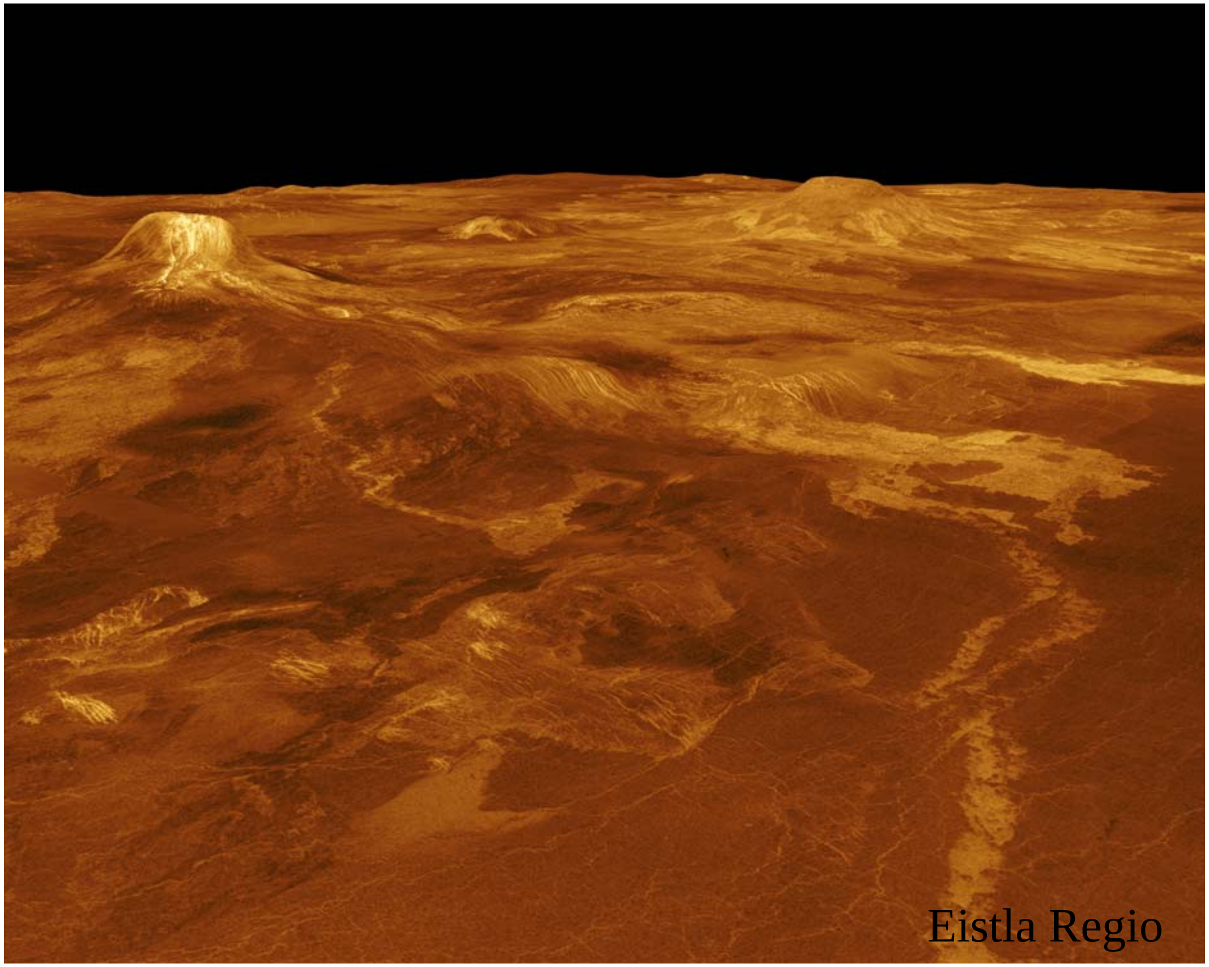
Our belief is that the mechanical boundary layer of Venus is not more than 200 km thick. This view is based on convection models that are required to match inferred melt generation rates, as well as gravity and topography anomalies, of the Hawaii-scale features referred to above (Nimmo & McKenzie 1996). Many of these sites show signs of melt production that are overprinting fractures and are therefore presumably recent; moreover, for the 4–20% resurfacing to have occurred over the last 500 Ma (Bullock et al 1993, Strom et al 1994, 1995), a melt contribution from plumes is probably required. A thick conductive lid inhibits melt production: Figure 3*a* shows that the mantle potential temperature (T_p) must exceed 1700°C to cause melt generation below a mechanical boundary layer that is thicker than 200 km. In general, peak plume temperatures on Earth are not more than 250°C hotter than the background temperature (White & McKenzie 1995). Therefore, even if the background mantle T_p on Venus were 1500°C, it is unlikely that any melt would be generated beneath a mechanical boundary layer thicker than 200 km. Smrekar & Parmentier (1996) have also used melt generation as an additional constraint on mantle properties, and they concluded that a lithospheric thickness of 100–150 km underlaid by a depleted mantle layer was consistent with their observations.

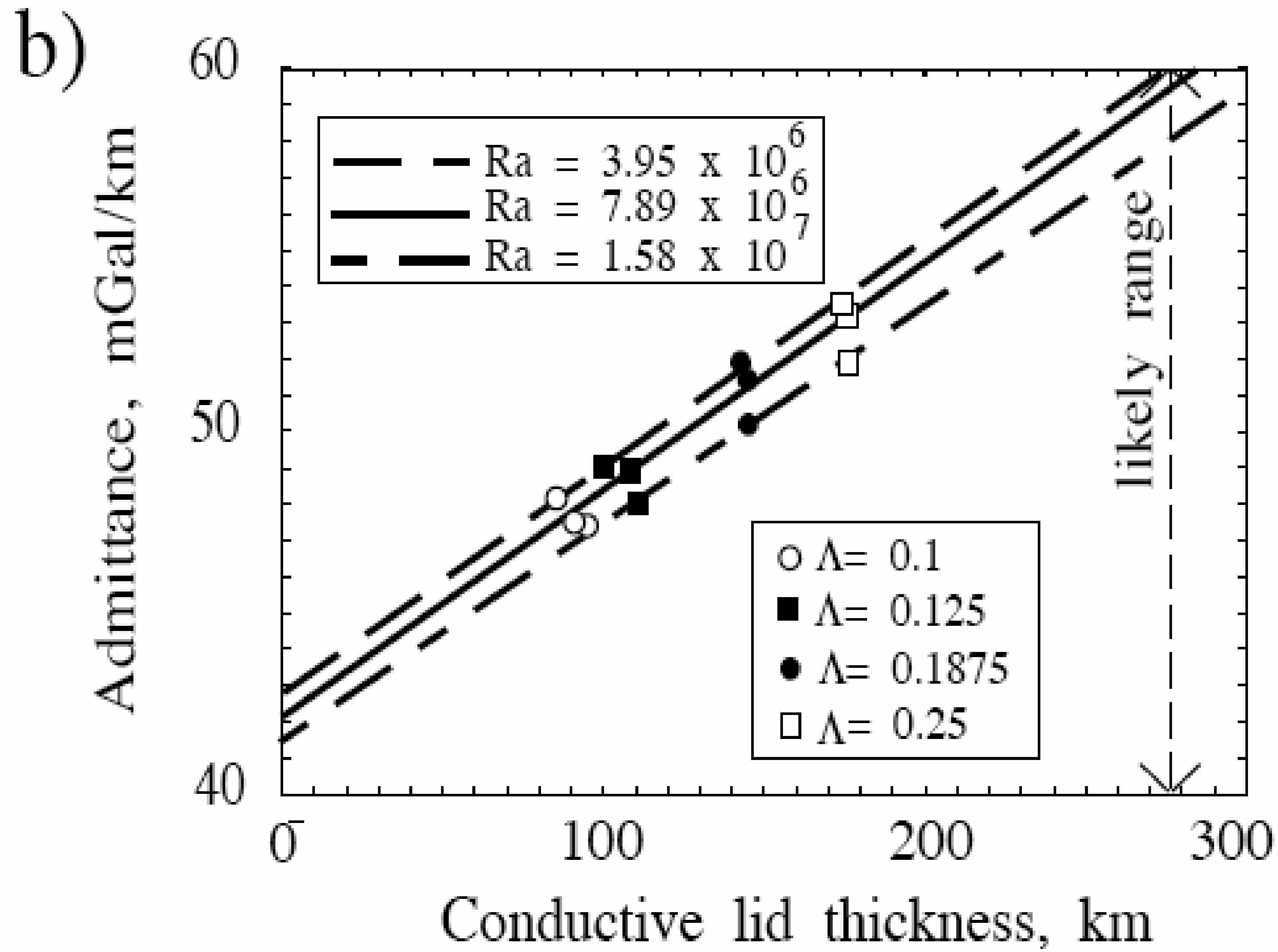


Nimmo and McKenzie (1998)

Nimmo and McKenzie (1998)

A less robust constraint is given by the values of admittance over plumes. As the mechanical boundary layer thickness increases, so does the admittance. For the observed range of admittance on Venus of 40–60 mgal/km over plume areas (Smrekar 1994, Phillips 1994, McKenzie & Nimmo 1997), Figure 3*b* shows that the mechanical boundary layer is unlikely to be thicker than 300 km.





Nimmo and McKenzie (1998)

A Thick Venus Lithosphere

Isostatic compensation models to interpret geoid vs. topography data.

Isostatic compensation of equatorial highlands on Venus, A. B. Kucinskas and D. L. Turcotte, Icarus, 112, 104-116, 1994.

The geoid/topography ratios for Atla and Beta Regiones require the thinning of a thick (300 km) thermal lithosphere.

A Thick Venus Lithosphere

Nonlinear regression of geoid vs. topography data. Isostatic models.

Lithospheric thickness and mantle/lithosphere density contrast beneath Beta Regio, Venus, W. B. Moore and G. Schubert, Geophys. Res. Lett., 22, 429-432, 1995.
Venusian crustal and lithospheric properties from nonlinear regressions of highland geoid and topography, W. B. Moore and G. Schubert, Icarus, 128, 415-428. 1997.

Venus has a thick (200-400 km) thermal lithosphere that is thinned beneath the volcanic highlands (Atla, Beta, Bell, Eastern and Western Eistla, Phoebe, and Themis).

TABLE I
Lithospheric Thickness and Compensating Density Contrast for Venusian Highlands: Two-Layer and Slow-Thinning Models

Region name[a]	Thickness H (km) Two-layer	Thinning	Density Contrast $\delta\rho/\rho$ (%)	$T_a - T_s$ [K]	Previous H estimates (km)[b]
ATLA	221 ± 15	331 ± 22	−1.7 ± 0.3	742 ± 117	200,[c,e] 175,[d] 240,[h] 167,[f] **362**,[f] **350**[g]
BETA	264 ± 36	396 ± 54	−3.0 ± 2.6	1341 ± 1137	270,[c] 225,[d] 300,[e] 223,[f] **369**,[f] 330[i]
BELL	130 ± 9	195± 14	−1.7 ± 0.5	766 ± 210	170,[c] 125,[d] 200[e]
WEIS	219 ± 16	329 ± 25	−1.5 ± 0.7	670 ± 292	90,[c] 200,[d,e] 210[j]
PHBE	144 ± 9	216 ± 13	−2.1 ± 0.9	931 ± 413	60[c]
IMDR	172 ± 19	257 ± 29	Uncertain	—	260[l]
ALPH	44 ± 8	—	Uncertain	—	50,[e] 20[k]
OVDA	83 ± 8	—	+5.4 ± 3.8	—	70,[c] 60,[d] 50[f,h,k]
TELL	75 ± 17	—	Uncertain	—	70[c]
THMS	129 ± 10	193 ± 14	−1.2 ± 0.2	512 ± 87	100[l]
EEIS	94 ± 8	141 ± 12	−1.4 ± 0.4	634 ± 195	65[l]
THTS	75 ± 22	—	Uncertain	—	90,[c] 50,[e] 67,[f] 80[h]
ISHT	144 ± 20	—	+2.8 ± 1.7	—	60,[e] 45,[k] 66[m]

[a] WEIS, Western Eistla Regio; PHBE, Phoebe Regio; ALPH, Alpha Regio; TELL, Tellus Regio; THMS, Themis Regio; EEIS, Eastern Eistla Regio; THTS, Thetis Regio; ISHT, Ishtar Terra.

[b] Boldface entries are estimates of background thermal lithospheric thickness.

[c] Smrekar and Phillips (1991).

[d] Smrekar (1994).

[e] Simons *et al.* (1994).

[f] Kucinskas and Turcotte (1994).

[g] Phillips (1994).

[h] Herrick *et al.* (1989).

[i] Esposito *et al.* (1982).

[j] Grimm and Phillips (1992).

[k] Grimm (1994a).

[l] Stofan *et al.* (1995).

[m] Kucinskas *et al.* (1996).

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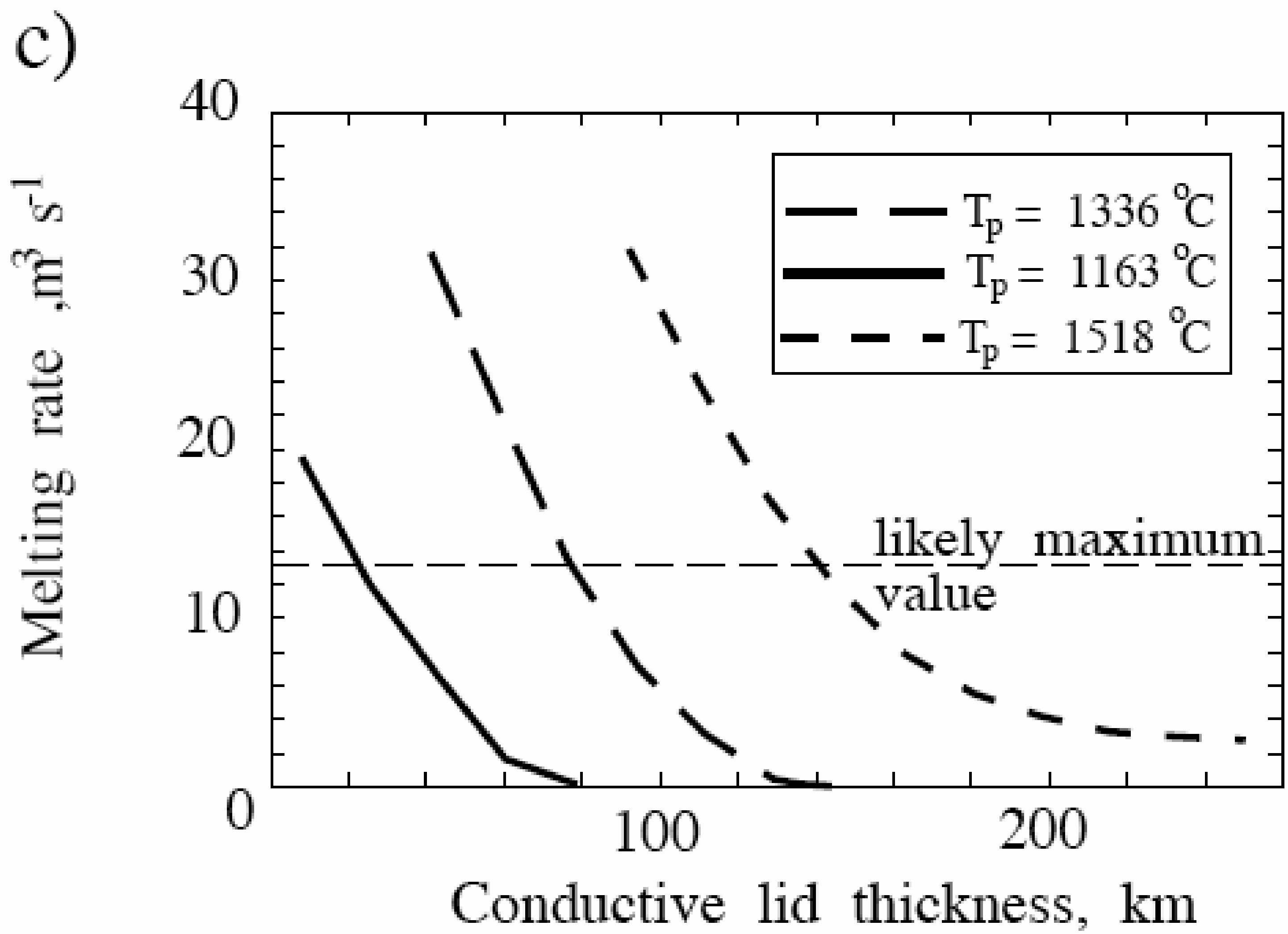

Nimmo and McKenzie (1998)

A Thick Venus Lithosphere

Fit geoid-topography data using isostatic models.

2-layer model

$$\Delta N = \frac{\pi G \rho_l}{g} \left\{ 2Hh + \frac{\rho_m}{(\rho_m - \rho_l)} h^2 \right\}$$

Thermal thinning model

$$\Delta N = \frac{4\pi G \rho_l}{3g} \left(Hh - \frac{h^2}{\alpha (T_a - T_s)} \right)$$