VENUS: GRAVITY, TOPOGRAPHY AND ISOSTASY

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Gravity and topography provide important constraints on the tectonics and internal structure of a planetary body. Recently derived spherical harmonic models of Venusian topography (Bills and Kobrick, 1984) and gravity (Bills et al., 1984) reveal a number of interesting features. The variance spectra are generally similar to those previously found for the Earth, Mars and Moon (Bills, 1979) in that there is a rapid decrease with increasing harmonic degree:

$$V(H;n) = O(n^{-2}) \qquad V(G;n) = O(n^{-4}).$$

However, Venus most closely resembles the Earth, both in terms of a significant low degree deficit (relative to the extrapolated trend of the higher degree terms), and a small topography/gravity spectral ratio. Venus differs from the Earth, though, in that it exhibits a significant correlation between long wavelength topography and gravity (figure 1).

Bills and Kobrick (1984) have recently argued that the basic spectral similarity of the topography of these four, rather diverse, bodies simply reflects the fact that, in each case the observed topography results from a statistical balance between "constructional" processes, which roughen the surface more or less uniformly at all wavelengths, and "degradational" processes, among which "erosion" selectively attenuates short wavelength features, and viscous relaxation preferentially attenuates the long wavelengths. With reasonable material properties and process rates, this model satisfactorily explains the observed low degree spectral deficit on the large, dense bodies (Earth, Venus) and the essentially monotonic spectra on small, low density bodies (Mars, Moon).

Explanation of the gravitational spectra is somewhat more complex, in that they reflect both a "coherent" component, due to topography plus any compensating mass, and an "incoherent contribution from those internal density variations wich do not correlate with topography. If we assume that the compensation mechanism is linear, the relationship between harmonic coefficients of gravity (G_{nm}) and topography (H_{nm}) can be expressed as

$$G_{nm} = \Phi_n H_{nm} + I_{nm}$$

where Φ_n is a spectral admittance, whose value will depend on details of the compensation mechanism (Dorman and Lewis 1970, Banks et al., 1977), and I_{nm} is the isostatic anomaly. Figure 2 compares the empirically determined admittance with theoretical values for a local Airy type compensation model. In that case we have

$$\Phi_n = \frac{3\tau}{2n+1}(1 - \xi^{n+2})$$

where τ is the density of surface material and ξ is the mean radius of the compensating density anomalies (normalize by mean planetary density and radius, respectively). The small admittance for degree n=10 is due principally to aliasing errors in the gravity model. With that one exception, the observed admittance values are all reasonably consistent with a globally averaged, effective depth of compensation of 160 ± 20 km. The effect of an elastic lithosphere in producing regional, rather than local, compensation is difficult to discern at the wavelengths present in these harmonic models. We can only place a rough upper bound of 100 km on the effective elastic thickness of the lithosphere (Reasenberg and Bills, 1983).

Despite the impressive correlation between topography and gravity, the isostatic anomaly accounts for fully 49% of the variance in the observed gravity field. An isostatic anomaly map reveals fairly significant regional departures from the global average compensation mechanism. In particular, there are positive isostatic anomalies associated with the elevated terrains of Beta, Atla, Thetis and Tethus regiones, there is no appreciable anomaly at all over most of Ishtar terra, and negative anomalies are associated with both the low lying Helen and Aino planitia and with the highlands of Ovda regio. These positive and negative anomalies respectively imply compensation at depths greater than and less than the global average. Another interesting aspect of the isostatic anomaly distribution is its extreme anisotropy. The most pronounced regions of positive anomaly are arrayed in linear bands at low inclination to the equator. Though a similar tendency is evident in the topography and free-air gravity, it is much more obvious in the isostatic anomaly. It is tempting to speculate that this pattern is related to despinning from a past, more rapid rotation (Melosh, 1977).

The second degree gravity harmonics also provide valuable new insights into Venus' present rotational state, via the inertia tensor. That Venus is dynamically triaxial is manifest by the ratio (C-B)/(B-A) = 1.2, where A B C are th principal moments. The orientation of the principal axes is

A:	-1°.67 ± 0°.19	N	6°.26 ± 0°.37	E
B:	-2°.02 ± 0°.30	N	96°.32 ± 0°.37	E
C:	87°.38 ± 0°.26	N	56°.65 ± 5°.09	E

The significant departure (≈3°) of the axis of greatest inertia from the rotation axis is apparently unique among the planets. However, the extremely slow rotation of Venus makes this large amplitude wobble energetically comparable to the 0.3 arcsecond Chandler wobble of the Earth (Yoder and Ward, 1979).

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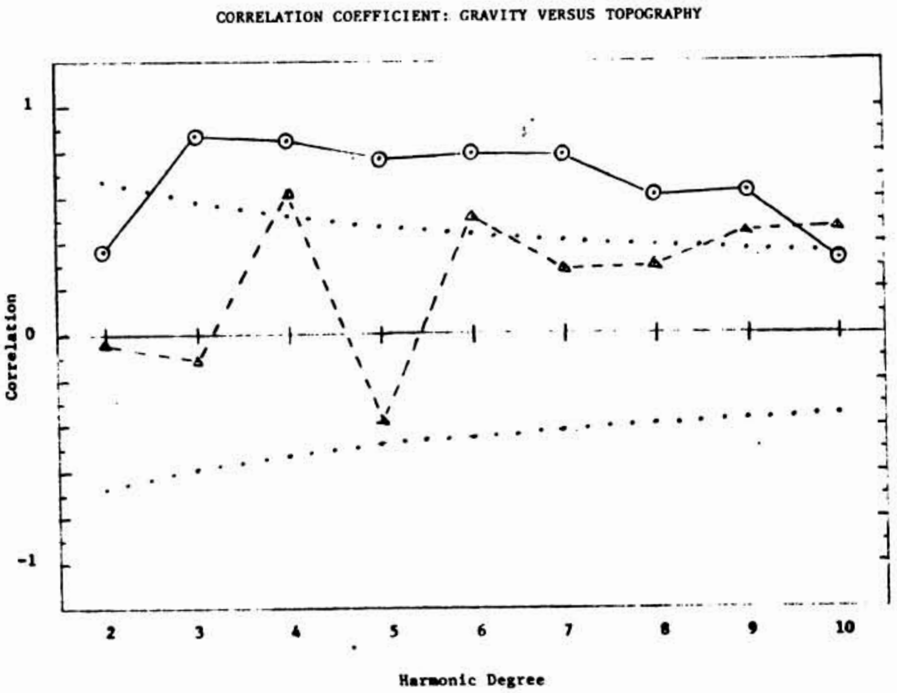

Figure 1. Correlation coefficients for gravity versus topography are compared for Venus (solid line) and Earth (dashed line). Also shown are 95% confidence limits for these coefficients (dotted lines).

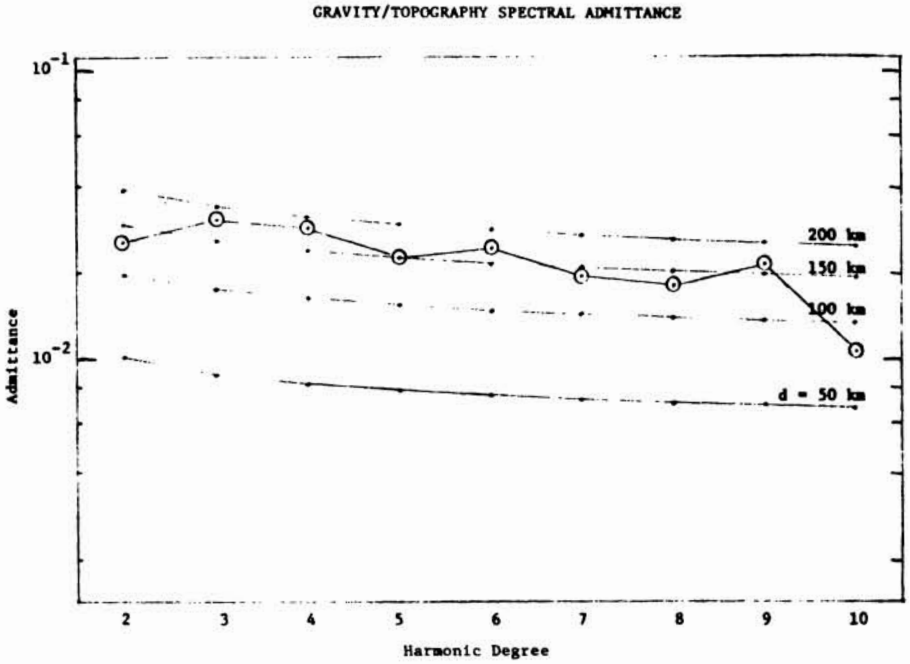

Figure 2. Empirical gravity/topography spectral admittance for Venus is compared to theoretical values for the case of local (Airy) isostatic compensation at various mean depths (d). The density of surface material is assumed to be 2.70 g cm^{-3}.