HOT SPOT HEAT LOSS, THERMAL ISOSTASY AND GRAVITY ON VENUS

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Similarities in the gross properties of Earth and Venus suggest that both planets might be expected to lose heat by similar processes. Terrestrial heat loss is dominated by the process of seafloor spreading in a framework of plate tectonics (e.g., 1). Available data do not resolve the dominant tectonic style of Venus (2-4), however, and other heat loss mechanisms, such as hot spot heat loss, have been suggested (e.g., 5). We have developed a model which gives a relationship among surface elevation, lithospheric thickness and heat flux with which to test the feasibility of the hypothesis that hot spot heat loss is the dominant form of heat loss on Venus, and that the gross features of the planet's topography and gravity field can be explained in terms of hot spot tectonics.

Our Venus hot spot/topography model (6) is based on the principle of thermal isostasy (see e.g., 7), in which elevation differences are explained primarily by thermally induced lateral density variations in the lithosphere/asthenosphere system. The lithosphere is assumed to be a steady state thermal boundary layer on convecting asthenosphere, its thickness controlled by the heat flow through the lithosphere such that its thermal gradient intersects the solidus at the top of the asthenosphere. The density structure of the lithosphere is assumed to be solely a function of thermal contraction from the asthenosphere density, and as a first approximation it is assumed that all heat transfer through the lithosphere is by conduction (i.e., insignificant magmatic activity), and that temperature and density variations within the asthenosphere are negligible. Lateral variations in heat flow from the asthenosphere into the lithosphere result in corresponding variations in lithospheric thickness and lateral density contrasts, and elevation variations are calculated from these density contrasts assuming the topography to be isostatically compensated.

To calibrate the model with respect to absolute elevations on Venus it was reasoned that if hot spot heat loss is the dominating factor controlling topography on Venus, then values estimated for the mean lithospheric thickness, heat flow and temperature drop across the lithosphere should be represented by the mean elevation of the planet. The mean radius of Venus is 6051.5 km (2), and we used published values (from 8 & 9) of 100 km, 50 mW/m^2 and 1000°C for the mean lithospheric thickness, heat flow and temperature drop across the lithosphere, respectively. In addition we assumed an asthenosphere density of 3.2 g/cm^3 and a constant volume coefficient of thermal expansion of 3×10^{-5} per °C. The relationship among elevation, lithospheric thickness and heat flow predicted by our model using these calibration parameters is illustrated in Figure 1.

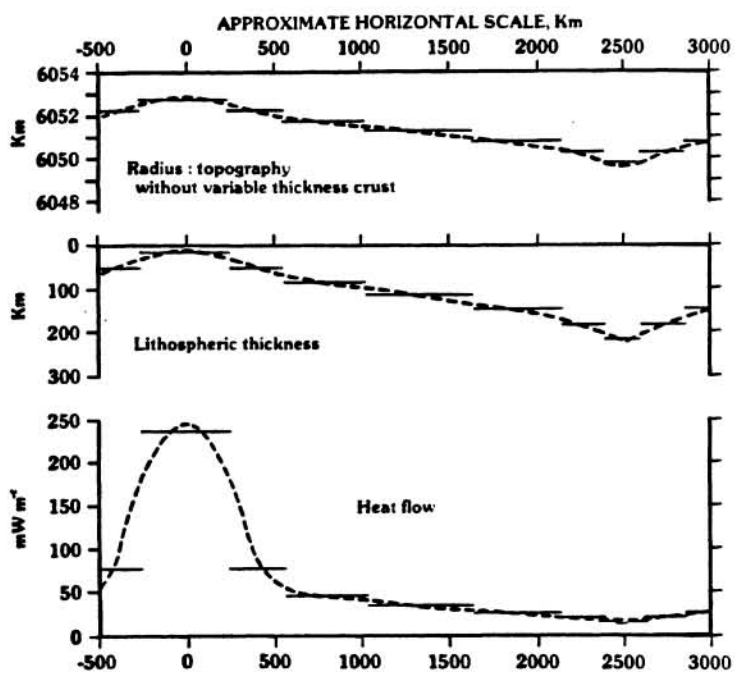

Figure 1. Relationship among elevation (planetary radius), lithospheric thickness and heat flow based on the hot spot/topography model. The horizontal scale is based on a topographic wavelength of 5000 km, and the length of each elevation increment is scaled according to the square root of the total area represented by the elevation (from 2), and the scale has an arbitrary zero. Horizontal lines represent actual model data and results; smooth curves show inferred relationships. (Adapted from 6).

This simple thermal isostasy model can be used for Venus elevations less than a radius of 6053 km, which accounts for approximately 93% of the mapped surface area of the planet. The model is also consistent with the strong correlation between gravity and topography for all resolvable wavelengths on Venus (10-13), as topography is supported by density contrasts in the upper mantle dynamically maintained by hot spot heat loss. The maximum depth of lateral density contrasts

predicted by the model (250 km, the maximum thickness of the lithosphere) is also consistent with the estimates of deep, relative to Earth, isostatic depths of compensation for the Venus topography at these elevations (5, 8).

Topography above a radius of 6053 km (approx. 7% of Venus) cannot be explained solely by the simple hot spot/topography model. We propose that in most of these higher elevation areas the topography, primarily supported by lithospheric thickness variations is augmented by the addition of a low density crust, or crustal thickening over the crests of the hot spots. This mechanism maintains the condition imposed by the gravity data that the primary isostatic depth of compensation is deep and may include density variations in the asthenosphere, and extends the model to include topography up to a radius of approximately 6055 km. This crust, localized on the hot spots could be generated by hot spot volcanism over a long time period with possible crustal recycling and further differentiation by burial and remelting (6, 14). Beta Regio and eastern Aphrodite Terra may be examples of terrain generated and maintained by this mechanism.

The only area of Venus inconsistent with the model of hot spot/topography with limited crustal augmentation is Ishtar Terra, which rises to a maximum elevation of 6062.1 km. Extensive crustal thickening, more than is likely to be directly generated on the crest of a hot spot, is required to isostatically support this terrain, an interpretation supported by available gravity data (5). How this thick crust was generated is undefined, although it is most likely the result of tectonic thickening during lateral compression. This thickening may be related to a different (earlier?) tectonic process than the postulated modern hot spot tectonic regime, or possibly is the result of gravity tectonics on the flanks of hot spots (14).

Our basic models for the relationships among topography, lithospheric and crustal thickness, and hot spot heat loss as applied to Venus are illustrated diagrammatically in Figure 2.

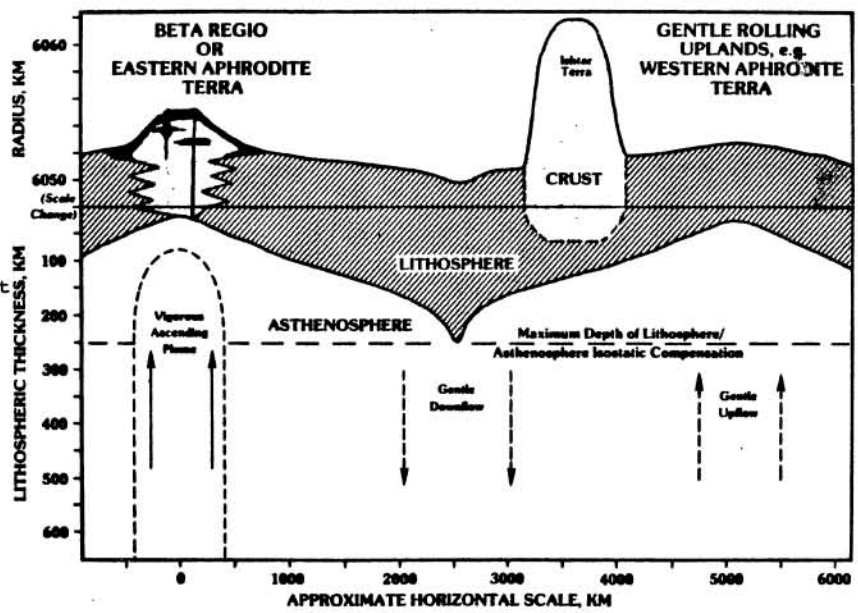

Figure 2. Diagrammatic representation of topographic compensation on Venus from hot spot topography model and crustal thickness variations. (From 6).

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