Geofísica Internacional (1996), Vol. 35, Num. 1, pp. 83-86

Coronae on Venus: formation by lithospheric drag from convective cells in the mantle

Hector J. Durand-Manterola
Depto. de Física Espacial, Instituto de Geofísica, UNAM., México, D. F., México.

Received: 27 October, 1994; accepted: 21 August, 1995.

RESUMEN
Propongo un nuevo modelo de formación de coronas en Venus. Se supone una celda convectiva cilíndrica centrada en un punto caliente. La litosfera es arrastrada radialmente en la parte superior de la celda por el movimiento horizontal del manto produciendo el anillo de colinas y la cavidad interior. Conforme el material se enfria, desciende plegando la litosfera en el borde de la corona y creando un foso circular. Este mecanismo no puede ocurrir en la Tierra a causa del movimiento de las placas litosféricas, ni en la Luna, Mercurio o Marte por el grosor de sus litosferas.

PALABRAS CLAVE: Geología planetaria, coronas, Venus.

ABSTRACT
I propose a new model of coronae formation on Venus. It assumes a cylindrical convective cell centred on a hot spot. Lithosphere is dragged down radially at the top of the cell by the horizontal movement of the mantle producing the ring of hills and the interior cavity. As the material is cooled it descends, folding the lithosphere at the rim of the corona and creating a circular moat. This mechanism cannot occur on the Earth, because of the motion of lithospheric plates, nor on Mercury, Moon or Mars because of the thickness of their lithospheres.

KEY WORDS: Planetary geology, coronae, Venus.

INTRODUCTION

Coronae are tectonic features on the surface of Venus. These structures are circular for the most part, with a typical ring of concentric fractures. Their size is 75 to 2600 km and they are related to volcanism (Stofan *et al.*1992). Their topography varies; but usually there is a concave centre surrounded by hills and a moat around the hills. Generally the concavity in the centre of the corona is higher that the surrounding plains.

Squyres *et al.*(1992) and Janes *et al.*(1992) propose a model to explain corona formation as follows. A mantle diapir rises toward the surface producing a dome-shaped uplift of the surface. As the diapir reaches the base of the lithosphere it spreads radially thus flattening and transforming the shape of the surface from dome-like to plateau-like. Finally the diapir cools, removing thermal support of the topography and forming a moat rim and an interior depression. This model would work on Venus and on other planets, yet coronae exist only on Venus. Thus we need a mechanism that works only on Venus.

I propose an alternative model for corona formation as follows. Fluid material, from a convective cell in the Venusian mantle, ascends as a hot spot. As the material reaches the base of the lithosphere the fluid motion becomes horizontal and radial, dragging the Venusian lithosphere. The fluid gradually loses heat by conduction to the adjacent lithosphere and becomes more dense. When the density exceeds that of the medium, the fluid descends and folds the lithosphere forming a circular moat. This mechanism creates the concentric fractures and the topography characteristic of coronae. Thus the model of Janes *et al.* (1992) is a static model and the present is a dynamic model.

My model provides an improved fit to the measured topography of coronae and is only appropriate to the conditions which prevail on Venus.

THE MODEL

Suppose that we have in the mantle of Venus a convective cell with steady flow (Figure 1). Imagine a volume in the mantle bounded by four surfaces as follows. The top surface is the base of the lithosphere AD (Figure 1), the bottom surface is parallel to the previous one (BC), and the third and fourth surfaces are vertical cylindrical surfaces centred on the axis of the convective cell (AB and DC). The flux of the mantle enters the volume ABCD through DC and leaves through AB (see arrows). If the distance between AD and BC is small we may assume that the density ρ and the velocity v are constant across AB, and that the corresponding values, ρ_o and v_o are constant across DC. Thus, integrating the continuity equation, the velocity v may be found from

$$v = \frac{\rho_o v_o r_o}{\rho\, r} , \qquad (1)$$

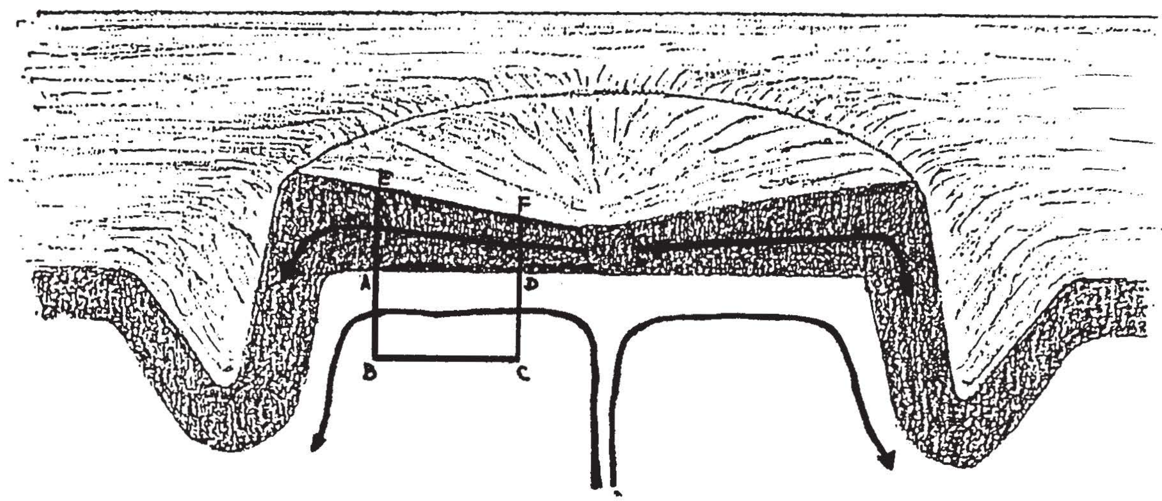

Fig. 1. In a hot spot, in the mantle of Venus, we have a convective cell. The material of the mantle rises and when it moves horizontally, in the base of the lithosphere, it drags lithosphere radially forming the concavity and the hilly ring of coronae. In the place in which the material of the mantle descends, lithosphere is folded in a circular zone forming the moat.

in which r, r_o are the radial distance to AB and to DC. This is the drag velocity of the lithosphere.

Similarly, if we consider the volume EADF at the free surface, the lithosphere thickness H at a radial distance r is given by

$$H = \frac{v_o r_o H_o}{v\ r} \tag{2}$$

where H_o is the thickness of the lithosphere at distance r_o. From (1) and (2) we find

$$H = \frac{H_o}{\rho_o}\rho\ . \tag{3}$$

If ρ depends only on temperature $T(r)$ and pressure $P(r)$, we have

$$\rho = \rho_o \exp(\beta(P - P_o) - \alpha_v(T - T_o))\ , \tag{4}$$

where β is the isothermal compressibility, α_v is the thermal expansion coefficient and P_o and T_o are the pressure and temperature at r_o.

But $P\text{-}P_o = \rho_l\, g(H\text{-}H_o)$ and $T\text{-}T_o = Ir$, where ρ_l is the lithospheric density, g is gravity and I is a constant. Substituting all these in (4) and the result in (3) and we obtain:

$$H = (1 - \beta\rho_1 g H_o - \alpha_v I r)/(\frac{1}{H_o} - \beta\rho_1 g) \tag{5}$$

which yields the thickness of the lithosphere as a function of r.

Suppose the interface between the lithosphere and the mantle is given by

$$z_a = \begin{cases} J(r - r_m)^2 & r < r_m \\ -D(r - r_m)^2 & r \geq r_m \end{cases} \tag{6}$$

in which r_m is the radial distance at which the fluid material of the mantle descends, and J and D are constants. Then the topography of the surface of the corona is

$$H_r = H + z_a =$$

$$\begin{cases} (1 - \beta\rho_1 g H_o - \alpha_v I r)/(\frac{1}{H_o} - \beta\rho_1 g) + J(r - r_m)^2 & r < r_m \\ (1 - \beta\rho_1 g H_o - \alpha_v I r)/(\frac{1}{H_o} - \beta\rho_1 g) - D(r - r_m)^2 & r \geq r_m \end{cases} \tag{7}$$

This value may be compared with the level found from the initial lithospheric thickness:

$$L = \frac{H_o}{(1 + \alpha\ \Delta T)} \tag{8}$$

where α is the linear expansion coefficient.

RESULTS

In Figures 2 and 3, I show the topography of Kuan-Yin corona and Eve corona with the predictions from the model. The parameters are given in Table 1. A good fit is obtained for Kuan-Yin topography. Notice that the internal slope and the slope from hills to moat are quite similar to the real ones. In the case of Eve (Figure 3), the fit is not as good as for Kuan-Yin.

Using other values for parameter J we may obtain a wide values of range of topographies. Thus $J = 10^{-8}\text{m}^{-1}$ yields a plateau-like topography as for Selu corona (Janes *et al.* 1992). Negative values of J predict an interior depression below the level of the surrounding plains, as in Bhumidevi corona (Stofan *et al.*, 1992).

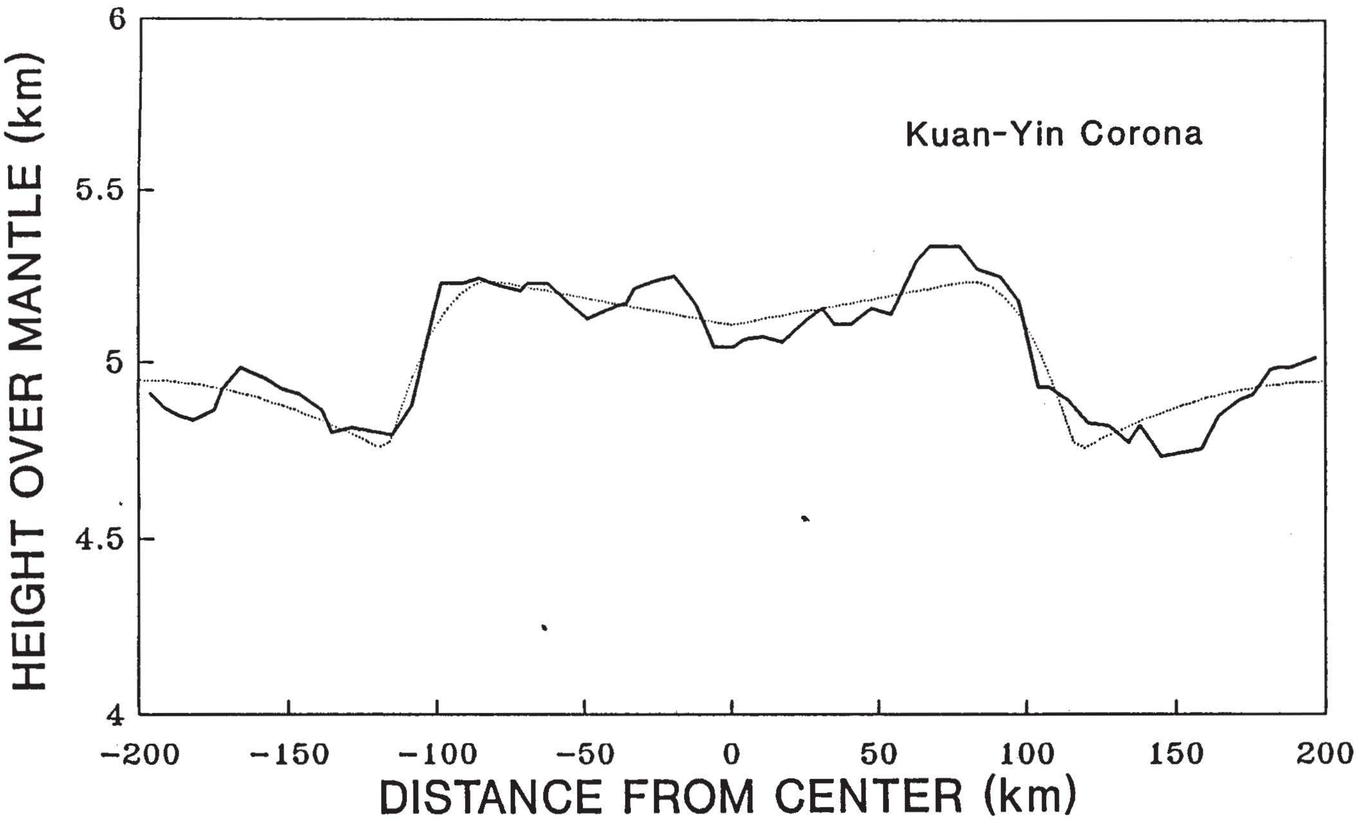

Fig. 2. Comparison between the altimetric profile of Kuan-Yin corona (thick line) and that predicted by the model (dotted line). (Data of topography from Janes *et al.*, 1992).

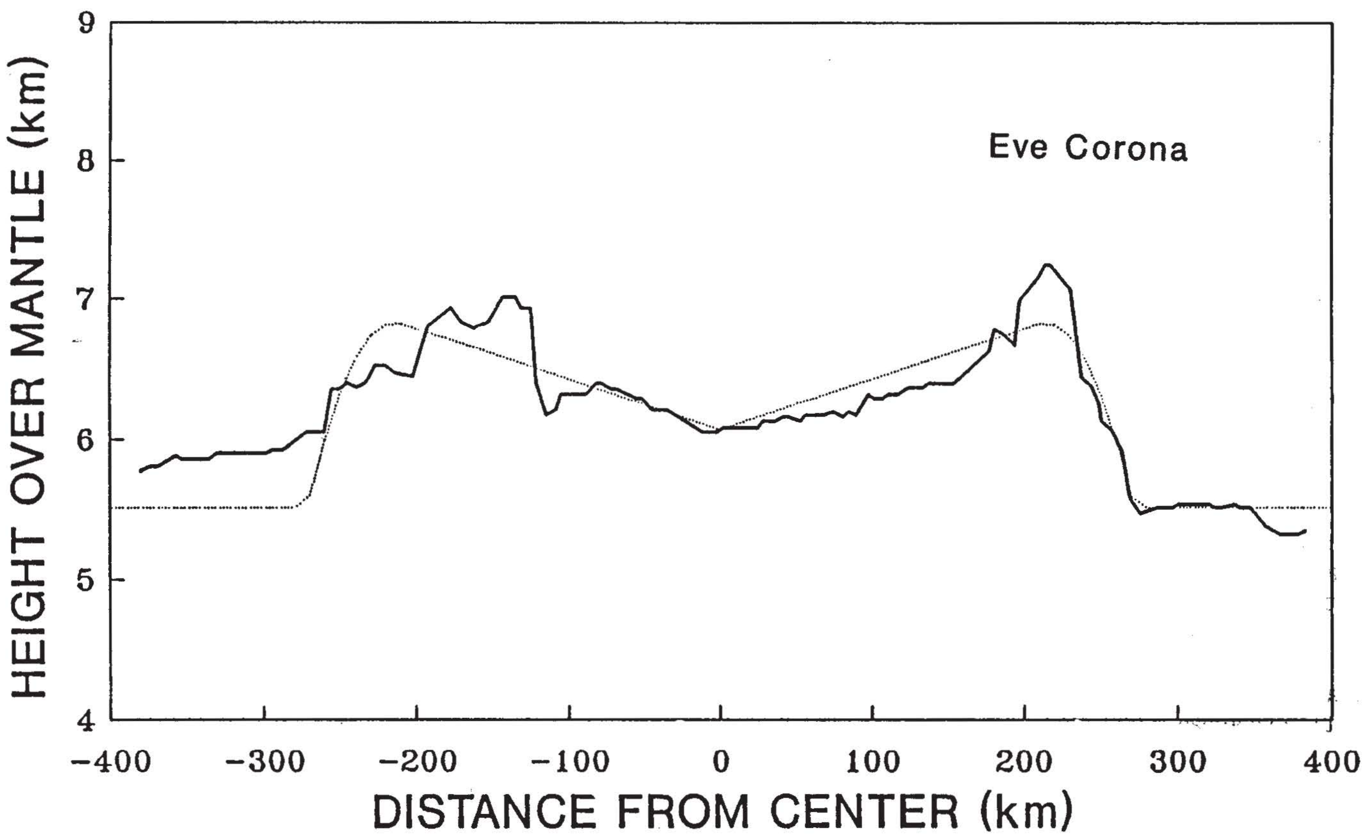

Fig. 3. The same of Figure 2, but with Eve corona. (Data of topography from Janes *et al.*, 1992)

Table 1

	Kuan-Yin	Eve
α	2.5×10^{-5}mK^{-1}	2.5×10^{-5}mK^{-1}
g	8.87 m/s^2	8.87 m/s^2
H_o	5.08×10^3m	6.06×10^3m
I	-1.1×10^{-2} K/m	-1.2×10^{-2} K/m
J	0 m^{-1}	0 m^{-1}
D	4×10^{-7}m^{-1}	4×10^{-7}m^{-1}
r_m	7.9×10^4 m	2.2×10^4 m
α_v	3.1×10^{-5} K^{-1}	3.1×10^{-5} K^{-1}
β	1×10^{-11} Pa^{-1}	1×10^{-11} Pa^{-1}
ρ_o	3×10^3 Kg/m^3	3×10^3 Kg/m^3
ρ_1	2.9×10^3 Kg/m^3	2.9×10^3 Kg/m^3

DISCUSSION

The differences between Kuan-Yin and Eve coronae may suggest that Kuan-Yin is an active corona, i.e., that a convective cell still exists under it in the mantle. In the case of Eve, which lacks a moat, this may be an older corona where the convective cell doesn't exist and the lithosphere has relaxed, the moat has disappeared and the hilly ring has been deformed. Hence the fit is not as good. However in both cases the fit is better than provided by the model of Janes *et al.* (1992).

As for the trenches of the great coronae (McKenzie *et al.* 1992), the weight of the hills may break the lithosphere in the region of the moat and the drag of the moving mantle might subduct the lithosphere.

Unlike Janes *et al.* (1992), nova structures are not explained by this model. Coronae and novae are assumed to be structures of different origins.

The model of Janes *et al.* is applicable to Earth and planets of thick lithosphere, however in those planets there are no coronae. The present model only works on Venus for the following reasons. Venus has no plate tectonics. Some authors (McKenzie *et al.* 1992; Sandwell and Schubert 1992) report features that could be attributed to plate tectonics, but this is not a general feature of the lithosphere of Venus. The lithospheric thickness (Ho) needed to reproduce coronae topography are similar to the oceanic lithosphere on Earth (Table 1). But here the displacement of the plates breaks the cylindrical symmetry and coronae do not form.

On the other hand, with a very thick lithosphere the drag is impeded. Therefore Moon, Mercury or Mars could not form coronae even when they have an active tectonics.

CONCLUSIONS

(1) The proposed model provides a good fit to the topography of coronae on Venus.

(2) The mechanism works only on Venus and coronae cannot form on other planets.

(3) The model predicts that the lithosphere of Venus has a thickness similar to the oceanic lithosphere on Earth.

BIBLIOGRAPHY

JANES, D. M., S. W. SQUYRES, D. L. BINDSCHADLER, G. BAER, G. SCHUBERTH, V. L. SHARPTON and E.R. STOFAN, 1992. Geophysical Models for the Formation and Evolution of Coronae on Venus. *J. Geophys. Res., 97,* E10, 16055-16067.

McKENZIE, D., P. G. FORD, C. JOHNSON, B. PARSON, D. SANDWELL, S. SAUNDERS and S. C. SOLOMON, 1992. Features on Venus Generated by Plate Boundary Processes. *J. Geophys. Res., 97,* E8, 13533-13544.

SANDWELL, D. T. and G. SCHUBER, 1992. Flexural Ridges, Trenches and Outer Rises Around Coronae en Venus. *J. Geophys. Res., 97,* E10, 16069-16083.

SQUYRES, S. W., D. M. JANES, G. BAER, D. L. BINDSCHADLER, G. SCHUBERT, V. L. SHARPTON and E. R. STOFAN, 1992. The morphology and evolution of coronae on Venus. *J. Geophys. Res., 97,* E8, 13611-13634.

STOFAN, E. R., V. L. SHARPTON, G. SCHUBERT, G. BAER, D.L. BINDSCHADLER, D.M. JANES and S. W. SQUYRES, 1992. Global distribution and characteristics of coronae and related features on Venus: Implications for origin and relation to mantle processes. *J. Geophys. Res., 97,* E8, 13347-13378.

Hector J. Durand-Manterola
Depto. de Física Espacial
Instituto de Geofísica, UNAM.,
Del. Coyoacán, 04510 México, D. F.
México.
E-mail: hdurand@quetzalcoatl.igeofcu.unam.mx