A MODEL FOR VENUSIAN CORONAE AS RELAXED SILICIC FLOWS

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Venera radar images of the Venusian surface [1-2] reveal a number of features termed "coronae" or "ovoids" which are apparently unique to Venus. Coronae (Fig. 1) are roughly circular features 390-530 km in diameter, and 0.7-2.5 km high [1], under 1.5 km high according to Pioneer altimetry; they may be lower toward their centers, but still above the surrounding plains. Only one of the five coronae shows a radial structure and a possible small volcanic peak. Instead, a set of concentric ridges near their edges is their common, dominant structure. A depression and further concentric ridges usually surround the coronae. The largest of the features is bilaterally symmetric, having a teardrop shape. Various indistinct, internal morphologies are observed. Other radar data show that two of the coronae appear prominently in previously published images; the data sets suggest rough, somewhat porous surfaces with ridges rougher than centers.

The general forms and radar signals of the coronae suggest a volcanic origin. Their subcircular form appears to result from a unified flow, rather than from lobate flows typical of composite structures on the Earth. On the other hand, their sharp edges and concentric ridges are not typical of ash-flows or air-fall deposits in general, but rather of viscous flows with pressure ridges. Since separate flows are not seen, a single effusion is more likely than numerous smaller flows.

It is proposed, therefore, that coronae are formed by the viscous flow of rapidly extruded volcanic material. To test this, a model was derived as follows: a cylindrically symmetric body of constant viscosity is allowed to relax under its own weight on a flat, rigid surface; it is similar to the spreading of fluid in a porous body, as described in [3]. The solution is given in detail elsewhere [4]; the result is a cross-sectional form very close to a half-ellipse (Fig. 2). The equations for surface height are

$$h = (V/4.19)^{1/4}\, t^{-1/4}\, (\rho g/\eta)^{-1/4}\, H(s), \quad (1) \qquad s = (V/4.19)^{-3/8}\, t^{-1/8}\, (\rho g/\eta)^{-1/8}\, r, \quad (2a)$$

$$V = 2.36\, r_e^2\, h_{max}, \quad (2b) \qquad H(1.33) = 0, \quad (2c)$$

$$\eta = 0.133\, V^3\, r_e^{-8}\, \rho g t, \quad (3)$$

where h = thickness of flow, V = volume of flow, t = time, ρ = density, g = gravity, $H(s)$ = universal height profile, and r = radius, r_e = radius at flow edge, η = viscosity. The solution thus gives a body which expands in radius as $t^{1/8}$, while flattening by $t^{-1/4}$.

The model has several drawbacks. The viscosity structure is unrealistic and the slope approximation fails near the edge. Moreover, lava can be either a Newtonian viscous fluid (above its liquidus), or a Bingham material (below its liquidus). In its favor, the model is simple and reduces to an analytic approximation whose solution applies to a wide range of initial conditions: because the flow radius varies as $t^{-1/4}$, the last 10% of spatial relaxation requires the vast majority of the flow time, so that a slow effusion of materials or a rapid release will have much the same final form for long times. Thus, it seems a good choice for a first-order approximation.

Regardless of the shape at early time, the form approaches a flat, sharp-edged pancake (Fig. 2). As the flow relaxes, it cools, and a chilled, brittle surface layer forms. Its buckling in regions where $\partial v_r(r,h)/\partial r < 0$ will form pressure ridges near the edges. The model [4] indicates that such ridges will form in the outer 27% of the flow. The surface of such a flow is presumably cracked, possibly covered with pumice, and (at least initially) rough. These features match the coronae well. Last, subsequent volcanism could produce minor internal peaks, flows, or collapsed regions, such as are seen indistinctly in the images. It is also possible that the symmetrical, teardrop-shape of one corona is due to flow down a regional slope. We may also expect a separate set of phenomena due to isostatic compensation of the coronae loads and/or collapse of the magma chambers which produced them. In particular, based on similar isostatic compensation problems on the Earth, the total volume extruded might be as much as 7 times the observed topography.

We may use (3) to solve for viscosity of the flowing material. The size of the coronae determines their model viscosity, and the absolute scale of the features (topography ~1 km, radius 175-265 km) is a very strong constraint on their nature. Using $\rho = 3000$ kg/m^3, $g = 10$ m/s^2, h_{max} = 1000-

1500 m, and computing volume from the model height profile times a factor of 1-7 (to allow for the possibility of isostasic collapse), we find

$$\eta = r_e^{-2}\, t\, (5.22 \times 10^{14} - 6.04 \times 10^{16}). \qquad (4)$$

The time of relaxation is approximated by the time to cool a thick skin on the flow; once such a skin forms, effective viscosity rises by several orders of magnitude. Cooling times for lavas on Venus [5] for a 50-150 m crust, which we estimate is appropriate to halt a ~1 km thick flow, $t=10^8$-10^9 sec (3-30 years). The most reasonable subset of this range is for ~30 year cooling times, 200-250 km flows (most coronae are of this order), and initial volumes 7 times the present topography; these considerations suggest 10^{11} to 10^{13} Pa-s as the effective viscosity.

The viscosities required by the model are clearly too high for basaltic magmas. Equation 3 implies that viscosities typical for basalt (under 10^6 Pa-s) would form significantly wider or flatter structures; moreover, the large pressure-ridges observed are not typical of [6] in the laboratory: viscosities of 10^{10}-10^{16} were observed. It is therefore proposed that coronae are siliceous flows.

On Earth, siliceous magmas tend to be explosive. However [5], temperature and atmospheric pressure are sufficiently high on Venus to prevent gas exsolution except very near the surface. This will preclude explosive behavior in the lowlands (where coronae form) for under ~4-5% volatiles. Hence, a small quantity of volatiles could exist in Venusian rhyolitic magmas; this gas would exsolve to produce slightly more viscous material. 1-5% volatiles and a slightly elevated geothermal gradient (>35°/km) are required -- though the importance of this limit depends on the rapidity of ascent. Certainly it is reasonable to expect a high geothermal gradient in the Mnemosyne regio, where four coronae are clustered together.

In conclusion, a simple model for Venusian coronae as relaxed volcanic flows has been developed. This model is consistent with reasonable geological parameters, and indicates: (1) coronae are high-silica flows; (2) a small fraction of volatiles was probably present in the corona magmas; (3) corona eruptions may be restricted to areas of elevated geothermal gradient.

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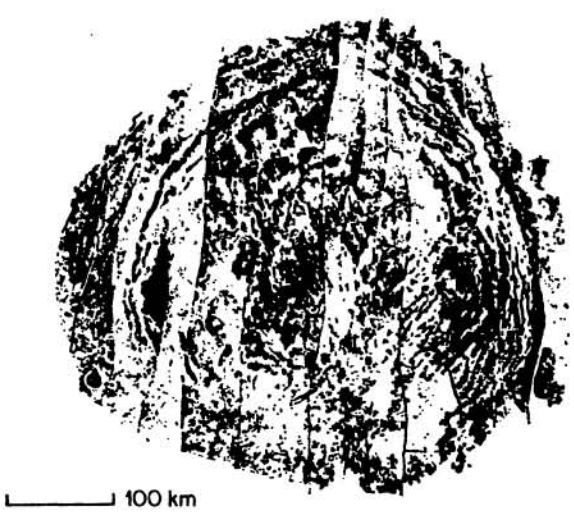

Figure 1: Corona at 77°N,279°E, in the Mnemosyne Regio area. Note concentric ridges to left and right.

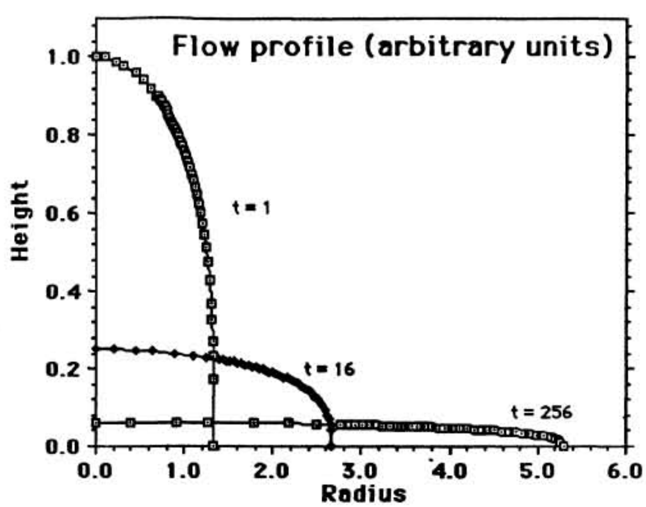

Figure 2: Flow profile of a relaxing body in arbitrary units shows rapid collapse of a peak into a flat, pancake-shaped form, followed by very slow outward expansion.