MODELS FOR CORONAE: DEFORMATION DUE TO MANTLE UPWELLING.

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Introduction. Coronae and ovoids (1,2) represent one possible manifestation of mantle plumes or hotspots on Venus (3). Squyres et al. and Stofan et al. (2) discuss the characteristics of these features as observed in Magellan images. Stofan and Head (3) have proposed a sequence of events in the evolution of coronae which proceeds from uplift and volcanism, to formation of an annulus of tectonic features and annular trough, to topographic degradation and volcanic burial. They suggest that mantle upwelling, perhaps in the form of a rising diapiric body, followed by gravitational relaxation due to removal of dynamic support and/or volcanic loading are the primary processes of corona formation. Results from Magellan investigations at this point (2) are largely consistent with the suggested sequence of events, although much detailed examination of coronae and ovoids remains to be performed. The purpose of this study is to test models for corona formation on the basis of their ability to match the observed characteristics of coronae. At present, these characteristics include the formation of a domical topographic high characterized by radial and/or azimuthal faulting, the formation of a topographic trough and an annulus of compressional or extensional structures surrounding the dome, and an evolution of topography and stresses that is consistent with the evolutionary sequence of events inferred from Magellan data of coronae and ovoids.

Models. To investigate these hypotheses we have begun to consider quantitative models for the formation of coronae and ovoids due to diapiric upwelling in the mantle and for the modification of these features due to gravitational relaxation. Two upwelling models are being examined. The first model (4,5) treats the crust and mantle as a layered halfspace with temperature dependent Newtonian viscosity and cylindrical symmetry. Viscosities are found from flow laws for olivine (for mantle material) and diabase (for crustal material). The rising diapir is modeled as a Gaussian-shaped density anomaly which rises through the mantle according to Stokes' Law. The presence of this density anomaly results in topography and horizontal stresses and strains within near- surface layers. In the second model (6), the mantle is treated as a spherical shell of Newtonian viscous fluid bounded below by a rigid core and above by an elastic shell (the lithosphere). Flow is driven by a point mass anomaly representing a diapir; more complex diapir shapes can be modeled by superposing solutions for a number of point masses. Stresses exerted at the base of elastic lithosphere by flow of the underlying viscous material result in uplift and both flexural and membrane stresses within the elastic layer. Results of both models are sensitive to the density anomaly, shape, and depth of the diapir. The viscous halfspace model and elastic-viscous shell models parameterize lithospheric strength in terms of thermal gradient and crustal thickness, and shear modulus, respectively. In addition, the viscous model may also be affected by the choice of flow laws.

Both models predict the formation of a domical uplift characterized by extensional radial and hoop (or azimuthal) stresses near the surface. Hoop stresses are greater, suggesting that most extensional features will trend radially to the dome. Extensional hoop stresses extend beyond the topographic limit of the dome. This is consistent with the observation that some corona and ovoids exhibit radial fractures that extend considerably beyond the topographic high. Radial stresses become compressional at the edge of the uplifted region and under some conditions in the elastic-viscous shell model are much greater in magnitude than hoop stresses, resulting in the formation of azimuthal compressional features (7) near the base of the uplifted region. Further investigation of the viscous halfspace model is required to delimit the conditions under which an annulus of compressional features is predicted. Neither model predicts an annulus of extensional features as observed in a number of coronae (2).

We also consider a gravitational relaxation model for modification of the corona following withdrawal of dynamic support and/or loading of the surface due to volcanism. The mathematical formalism involved in this model is identical to that of the viscous halfspace model above, with the exception that the source of stress is a topographic load and is thus located at the surface (4). The model is sensitive to the shape and magnitude of the load, the thermal gradient, crustal thickness, and assumed flow laws. Preliminary results suggest that this process is expected to result in the loss of relief of the domical high and the formation of an annular trough. The types and locations of deformational features caused by relaxation will be investigated as part of this study.

Application. Some aspects of the sequence of events involved in corona/ovoid formation and inferred from Venera (3) and Magellan images (2) are consistent with a combined diapiric upwelling/gravitational relaxation model. The formation of a domical high characterized by predominantly radial extension is a robust result of models for diapiric upwellings and explains the presence of these features in coronae and ovoids. This model also predicts that the oldest deformational features seen in coronae should be radial fractures, as is observed in Magellan images (2). The loss of topographic relief inferred to occur as part of corona evolution is the result of the combined loss of dynamic support that occurs as the diapir encounters the rheological lid, and loading of the surface due to volcanism and near-surface intrusion within the corona. Such relaxation also causes the formation of an annular trough.

It is not yet clear that either a diapiric upwelling model or a relaxation model adequately explains the formation of the deformed annulus which define coronae. Venera images of coronae appeared to show that most corona annuli were compressional in nature (3). To date, most coronae seen in Magellan data (which generally do not include coronae imaged by Venera) appear to manifest an annulus of extensional features only (2); the only possible exception is Quetzalpetlatl (8,9). This suggests that the radial compression predicted by the elastic-viscous shell model may not be an important process in corona formation. Magellan observations of northern hemisphere coronae with annuli which have been interpreted as compressional (3,1) will be critical in resolving this issue.

Annuli of extensional features are not predicted by diapiric upwelling models. They may be a result of gravitational relaxation; the formation of the trough caused by relaxation is likely to be accompanied by deformation, but the type of features formed and their relationship to topography remain to be determined. Several other processes could be important in the formation of such an annulus. These include flexure of the brittle upper crust during relaxation, gravity sliding of material off the sides of a corona, and deformation caused by mantle flow that occurs as a rising diapir or plume head flattens and spreads horizontally beneath the rheological lid of the lithosphere. Numerous constraints on models remain to be obtained from Magellan data, including details of the shape of the topography of coronae and ovoids, the depths, widths, and radii of topographic troughs, and the widths and radii of annuli of structures that define coronae, their association with topography, and the type(s) of deformation they manifest.

References. (1) Pronin and Stofan, *Icarus, 87,* 452-474, 1990; (2) Stofan *et al.,* this volume, Squyres *et al.,* this volume; (3) Stofan and Head, *Icarus, 83,* 216-243, 1990; (4) Stofan *et al.*, Corona structures on Venus: Models of origin, in review, *J. Geophys. Res.,* 1991; (5) Bindschadler and Parmentier, *J. Geophys. Res., 95,* 21,329-21,344, 1990; (6) Janes and Melosh, *J. Geophys. Res., 93,* 3127-3143, 1988; (7) Janes and Squyres, *EOS, 71,* 1423, 1990; (9) Solomon et al., Venus Tectonics: Initial analyses from Magellan, in prep., 1991; (10) The name "Quetzalpetlatl" is provisional and has not yet been approved by the IAU.