LITHOSPHERIC STRUCTURE ON VENUS FROM TECTONIC MODELLING OF COMPRESSIONAL FEATURES

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Introduction. Spacecraft and Earth-based radar imagery of Venus, along with low resolution altimetry, have revealed a wide variety of landforms, many of which appear to be of tectonic origin. Features with a presumed tectonic origin tend to have broadly linear trends and characteristic widths or spacings within a group. The widths and spacings generally fall into one of two groups: one with a scale of 15-25 km, and the other with a scale of 100-300 km, with both sizes of features sometimes occurring in the same location.

Inasmuch as the detailed characteristics of surface deformation depend on the mechanical properties of the shallow interior, these tectonic features may be used to constrain models of Venus's lithosphere [e.g. 1,2,3]. In previous studies we used extensional models that incorporated realistic rheologies in order to constrain lithospheric structure [2,4]. Here we consider lithospheric modelling from the standpoint of compressional deformation. In this abstract we will review features of presumed compressional tectonic origin and present a model for compressional folding based on lithospheric strength envelopes that include the effects of both brittle and ductile yielding as well as finite elastic strength. Model predictions are then compared with the widths and spacings of observed tectonic features and we conclude that the results are consistent with a thin crust overlying a relatively stronger mantle, with thermal gradients probably in the range of 10-15$^{o}$/km.

Observations. Earth-based radar images of Ishtar Terra at 2 km resolution have revealed regions of high backscatter that are characterized by sets of linear bands of greater and lesser backscatter striking generally parallel to the long axes of the Maxwell, Akna, and Freyja mountain ranges [5]. These features have characteristic spacings between individual bands of 15-20 km [1]. Subsequent Venera data have shown that the bands correspond to subparallel ridges and grooves [6]. On the basis of its close correlation with mountainous topography and the continuity, regular spacing, and detailed morphology of the bands a compressional tectonic origin for the banded terrain is considered likely [1,5,7]. Venera mapping of the northern plains and Atalanta Planitia has also revealed ridge belts, which appear to be of tectonic origin [6]. These belts are several hundred to a thousand km long and up to 150 km wide, and trend roughly north-south with a mean spacing of 200-300 km [3]. The belts are composed of subparallel ridges and troughs that are continuous for 100-200 km along the strike of the belt and that are each 10-15 km wide [6], giving a mean spacing of about 25 km. The morphological similarity of these ridges to those surrounding Lakshmi Planum suggests that they are the result of compressional deformation [7].

The features discussed above are characterized by their continuity, linearity, and characteristic spacings and subparallel strikes within a group. These traits imply that the stress field and mechanical properties involved in their formation were relatively homogeneous, suggesting that simple deformational models may yield some insight into the structure of the lithosphere. It can also be seen that these features tend to fall into two groups: one with characteristic wavelengths (i.e. spacings) of about 15-25 km and the other with characteristic wavelengths of approximately 100-300 km. In addition, the ridge belts have both scales of deformation superimposed on one another, an observation for which any successful model must account.

Folding Model. When an elastic layer overlying an inviscid fluid is subjected to a sufficiently large compressive edge load it will deform by buckling with a dominant wavelength that depends primarily on the elastic properties and thickness of the layer. This simple model has been applied to Venus [1] in an attempt to use the observed spacing in the banded terrain to constrain the structure of the lithosphere. A layer thickness of the order of a few kilometers was derived, in good agreement with estimates of the elastic lithosphere thickness based on thermal arguments. However the critical stress required to induce the buckling instability was greater than 500 MPa, in excess of the yield strength of rocks. This discrepancy is even larger if it is assumed that the ridge belts of the northern plains formed by a compressional instability of an elastic plate, although again the plate thickness (about 25 km) is reasonable on thermal grounds if an olivine-rich lithosphere is assumed.

The problem of unreasonably high critical buckling stresses can be eliminated if a more realistic model is used that incorporates both frictional and ductile yielding of the lithosphere [e.g. 8]. A model incorporating such a rheology has been developed by McAdoo and Sandwell [9] in a study of periodic undulations observed in the topography and geoid of the northern Indian Ocean. They linearized the moment-curvature equation for small moments and found that the onset of folding is described quite well by the classical buckling equations with the plate thickness given by the "elastic core" of the lithosphere, the depth interval for which the yield stress is not exceeded and the material behaves elastically. The folding instability occurs well before the yield strength of the lithosphere is reached. Applying this model to Venus, we find that the critical buckling stress is less than 100 MPa for typical crustal materials and a few hundred MPa for dunite. Thus the basic physical objection of unreasonably high stress levels for lithospheric folding is removed.

Folding wavelengths as a function of thermal gradient for various materials are shown in Figure 1. The bottom four curves represent the deformation of a 10 km thick crust, while the top two curves show the behavior of a dunite mantle with and without such a crust. The two pairs of horizontal dashed lines denote the two ranges of wavelengths observed, as discussed above. The curve for dunite under a 10 km crust assumes that mantle deformations are decoupled from those in the crustal layer by a ductile lower crust (which is a natural consequence of the high surface temperature and the assumed range of thermal gradients), while the "no crust" curve is equivalent to assuming a crust thin enough so that ductile flow within it does not contribute significantly to the extensional strain. Thicker crusts have no significant effect on the crustal material curves and result in dunite curves with somewhat shorter wavelengths at a given gradient.

For the shorter wavelength features an anorthositic crust implies relatively low thermal gradients of 5-15$^{o}$/km, while a more likely basaltic composition gives higher gradients of 10-28°/km. The longer wavelength features put tighter bounds on the gradient, requiring 9-14°/km to satisfy observations.

Conclusions. These results imply that a thin (~10 km) crust overlying a stronger mantle with thermal gradients of the order of 10-15°/km is required in the northern plains of Venus if the observed features formed by elastic buckling of the lithosphere. The banded terrain in Ishtar Terra is consistent with a thicker crust and either a basaltic composition with higher gradients (10-30°/km) or a more ductile composition such as anorthosite with a thermal gradient similar to that found for the northern plains.

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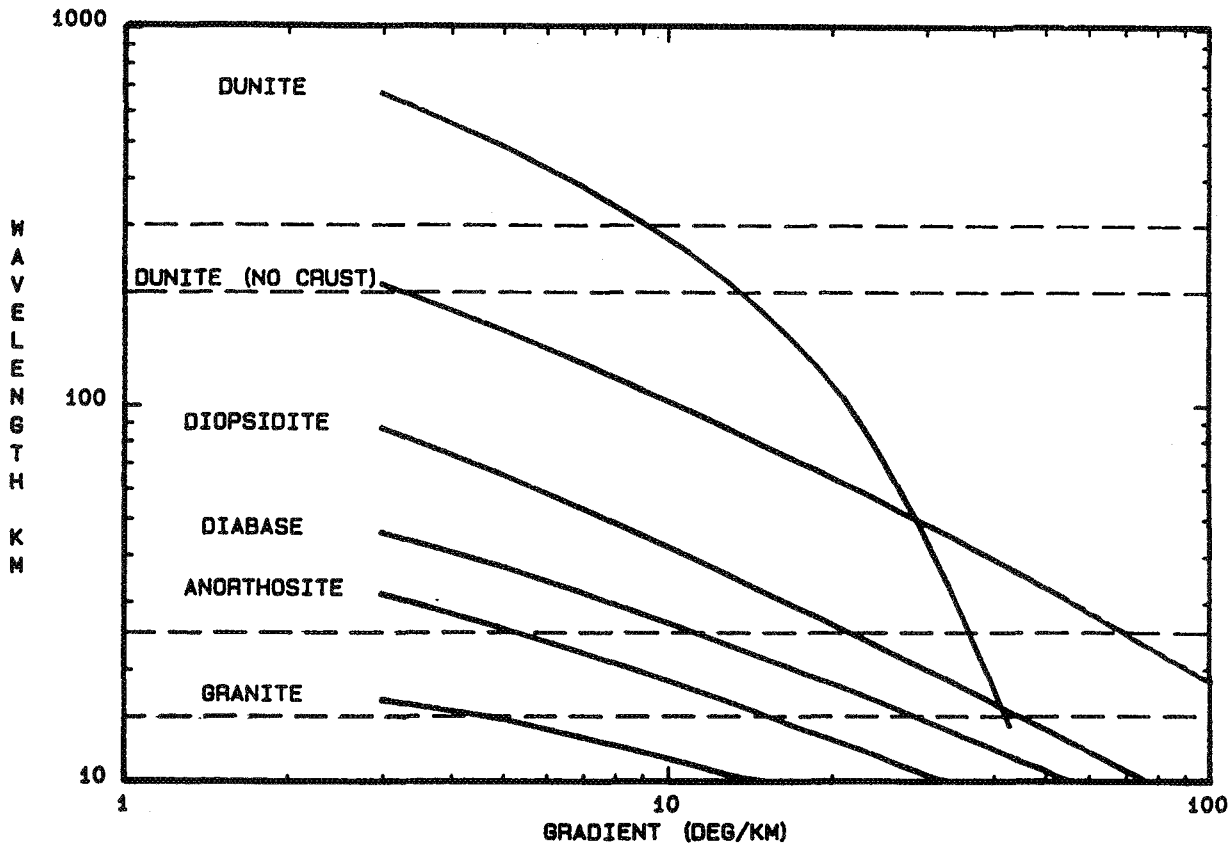


Figure 1. Characteristic folding wavelength versus thermal gradient for a number of geologic materials. A surface temperature of 720°K and a crustal thickness of 10 km (except for the "no crust" curve) is assumed. The frictional law from [10] is used along with flow laws from [11-13].