MODELS FOR THE ORIGIN OF LAKSHMI PLANUM, VENUS; Kari M. Roberts, James W. Head, Dept. of Geological Sciences, Brown University, Providence, R. I. 02912

Models describing the evolution and formation of Lakshmi Planum in Western Ishtar Terra must explain the origin of the following characteristics: 1) its 3-5 km elevation; 2) its plateau-like nature and irregular polygonal outline; 3) the surrounding compressional orogenic belts; 4) the abundant volcanism which dominates the surface of Lakshmi and occurred synchronously with the regional tectonic activity; and 5) the presence of ridged terrain units (previously defined; [1]). We will evaluate models of the formation of Lakshmi Planum first on their ability to produce the elevation of the plateau and then on their ability to explain the remaining characteristics listed above.

There are several different types of geological processes which are known to produce uplift. We focus on two mechanisms which have been proposed for the uplift of Lakshmi Planum/Ishtar Terra: thermal expansion due to the rise of a deep mantle plume [2] and crustal thickening as the result of horizontal convergence [3-5]. In addition, we will examine the mechanisms of lithospheric delamination as discussed for the uplift of the Colorado Plateau [6] and crustal underplating as discussed for the uplift of tessera terrain [5].

Thermal uplift due to the rise of a deep mantle plume (Fig. 1a) has been proposed for the origin of other highland regions on Venus such as Beta, Atla, Bell, and Western Eisila Regiones [7-9]. These regions are characterized by domal rises, shield-building volcanism, and prominent extensional features (*e.g.*, Devana Chasma in Beta Regio). Although it offers a possible explanation for the elevation and abundant volcanism of Lakshmi Planum, thermal uplift does not appear to be able to account for its plateau-shaped configuration nor its surrounding orogenic belts and compressional tectonic environment. It has been proposed [2] that mantle upwelling beneath Lakshmi could produce the surrounding mountains as a result of shear along the base of the lithosphere due to the flow of material away from the upwelling (Fig. 1b). However, a recent analysis [5] illustrates that if the mountains surrounding Lakshmi are the result of crustal thickening due to mantle flow then crustal thinning of similar or greater magnitude is expected in the center of the plateau. The notable absence of large-scale extensional features within the plateau indicates to us that thermal uplift models are not wholly appropriate in explaining the formation of Lakshmi Planum. Gravitational relaxation of an uncompensated plateau (such as a thermal rise) is also unlikely to produce the surrounding orogenic belts as it has been shown to result primarily in extensional horizontal strains [10]. The topography associated with the thermal rise is required to have been initially as high as the mountains are today to have created them by gravitational relaxation. Another study [11] has shown that such altitudes are unlikely to be produced by thermal effects alone.

Crustal underplating involves the emplacement of a large volume of low density material at or near the crust-mantle boundary. The gravitational relaxation of such an event causes the surface elevation to increase until the topographic load balances the buoyancy forces at depth (Fig. 1c). A plateau-shaped uplift may be produced over time but strains within and near the plateau are strictly extensional -- no compressional deformation is produced [10]. Thus, this model is unable to explain the orogenic belts surrounding Lakshmi Planum.

Lithospheric delamination due to a gravitationally unstable density stratification has been described for the uplift of the Colorado Plateau [6]. As the mantle portion of the lithosphere pulls away from the crust and sinks, hot buoyant asthenosphere rises in its place, producing uplift and volcanism (Fig. 1d). This model suffers from the same disadvantages that characterize the models mentioned above. Although capable of explaining many of the features of the Colorado Plateau, including uplift and volcanism, it is unable to explain the compressional environment of Lakshmi Planum. A variation of the delamination model has also been proposed [5] (Fig. 1e). If an episode of lithospheric delamination is of sufficient scale, it may initiate large-scale mantle downwelling. If a ductile lower crust is present in the lithosphere of Venus, then mantle flow may be coupled with the crust, producing horizontal convergence and crustal thickening above the area of downwelling. This will produce uplift and compressional deformation. Concentric mountains may result from radial compression. Conductive heating of the thickened crust will produce basal melting and surface volcanism. This model is able to explain the elevation, compressional tectonic environment and volcanism which characterize Lakshmi Planum. However, it is unlikely that orogenesis would be restricted to the periphery of the plateau. More probably, mountain building would procede outwards from a central core. Therefore, the relatively flat interior surface of Lakshmi is unaccounted for unless the regions of ridged terrain represent gravitationally relaxed or otherwise degraded ancient mountain ranges.

Many of the features associated with Lakshmi may be accounted for by a model involving horizontal convergence and crustal shortening as a result of the collision, imbrication, underthrusting and possible subduction of crustal and lithospheric segments. These processes have been proposed for the formation of Akna, Freyja, and Maxwell Montes (*e.g.*, [4]) and can account for the architectural features (including outer rise, foredeep, scarp, outboard plateau and fold belt) of these orogenic belts [12]. If assumed to have occurred during episodes of differing duration, orientation and magnitude about the periphery of Lakshmi Planum, a model consisting of such processes can also explain the elevation, volcanism (basal melting of thickened crustal root) and irregular outline of the plateau. The difficulty lies in explaining the flat, plateau-shaped configuration of Lakshmi and the presence of ridged terrain units. Two variations of this model exist. The first (Fig.1f) proposes that Lakshmi was pieced together by multiple collisional events and that its entire history is composed of repeated sequences of convergence, crustal thickening and mountain building, cessation of convergence and reduction of mountainous topography. Thus, ridged terrain would represent ancient tectonic seams which have been partially reduced through some mechanism of erosion, gravitational relaxation, and/or volcanic burial. Such rapid degradation of topography between episodes of convergence seems implausible given the slow rates of erosion proposed for Venus [13]. This model differs from the model of mantle downwelling discussed above in that the forces driving convergence are not associated with broad downwelling but

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with external activity.

The second alternative to this model (Fig. 1g) proposes that Lakshmi Planum is composed of a large block of tessera (stipled pattern) which has been subjected to compressional deformation about its perimeter and volcanically resurfaced within its interior. The plateau-like nature of Lakshmi would then be the result of volcanic resurfacing of pre-existing topography (blocks of tessera are typically plateau-like in cross-section [14]) that resisted internal deformation and responded to exterior compression by the production of the surrounding orogenic belts, which also served to confine volcanic resurfacing. In this case, regions of ridged terrain represent exposed islands of the underlying tessera block which have not been buried by volcanic deposits. This is consistent with the morphological similarity ridged terrain has to tessera. In terms of height and area, Lakshmi Planum as a whole falls well within the range of values reported for tessera terrain. Tessera terrain ranges up to 6 km in height, with an average elevation of 2 km, and ranges in area from ~2×10^5 km^2 to ~47×10^5 km^2 [10,14]. Lakshmi Planum is 3-5 km in elevation with an area of ~20×10^5 km^2, very similar to the size and elevation of Laima Tessera. Thus, if Lakshmi was initially a typical piece of tessera, the amount of uplift required for it to attain its present height would be about 2 km, with the most extreme uplift occurring at the borders of the plateau. The similarity in orientations of all lineations observed on Lakshmi to those mapped within the ridged terrain supports the idea that regions of ridged terrain represent the surface of the plateau beneath the volcanic deposits and not merely isolated units. This model is further supported by the fact that the plateau of Lakshmi rises 2-4 km above the plains of Snegurochka Planitia, located north of Freyja Montes and Uorsar Rupes. On the basis of this observation it has been proposed that the orogenic belt of Freyja Montes represents a boundary between crusts of two different thicknesses [12]. This would be expected if Lakshmi is a block of tessera which has been deformed by crustal convergence about its periphery.

To summarize, all of the models discussed above appear to be able to account for some of the features which characterize Lakshmi Planum (*e.g.*, its elevation and volcanism). However, we do not feel that the models of thermal uplift or delamination can adequately explain the plateau-like nature nor the compressional environment of Lakshmi and therefore discount them as potential models solely responsible for the formation and evolution of Lakshmi Planum. A model consisting of a continuous sequence of crustal convergence and horizontal shortening is able to explain the irregular outline and compressional environment of Lakshmi but requires that older, interior mountain belts have been degraded sufficiently to produce the flat central plateau and units of ridged terrain. Crustal convergence occurring on a preexisting block of tessera terrain is able to account for the plateau-like nature of Lakshmi as well as the presence of ridged terrain and its general similarity to tessera. Therefore, we conclude that the latter model is the most likely candidate to explain the formation and evolution of Lakshmi Planum.

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Figure 1. Schematic diagrams illustrating models of origin for Lakshmi Planum; see text for discussion.