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Morphology and deformational history of Tellus Regio, Venus: Evidence for assembly and collision

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ABSTRACT

Tessera terrain is the oldest stratigraphic unit on Venus, but its origin and evolution are inadequately understood. Here we have performed detailed mapping of Tellus Regio, the third largest tessera plateau on Venus. Tellus Regio is shown to have distinct marginal and interior facies. The east and west margins of Tellus rise up to 2 km above the interior and include ridges and troughs ~5–20 km across, oriented parallel to the present plains-tessera boundary. Structures characteristic of the interior of Tellus are found within the eastern and western margins and are deformed by the margin-parallel ridges indicating their presence during the time of the formation of the current margins. These relationships suggest that the margins formed by the application of external horizontal compressional stresses at the edges of an already-existing tessera interior. Structural and stratigraphic relationships in southwest Tellus show the assembly of three structurally distinct tessera regions and intervening plains that are consistent with the collision of the southwest margin into the plateau interior. This requires that tessera terrain was formed regionally and collected into the present day Tellus plateau. The latest stages of activity in Tellus include volcanism and pervasive, distributed, 1–2 km wide graben, which may have been formed due to large-scale gravitational relaxation of the plateau topography. A large intratessera plains unit may have formed via crustal delamination. The collisional oroclinal deformation of the margins are most consistent with models that invoke mantle downwelling for the origin of Tellus Regio and other tessera plateaus with similar structural relationships.

1. Introduction

Tessera terrain is characterized by complex deformation comprising at least two sets of intersecting ridges and grooves which contribute to high radar backscatter and high elevations relative to local plains (Sukhanov 1992; Barsukov et al., 1986; Ivanov and Head, 1996a). Stratigraphic studies of tessera terrain have shown them generally to be embayed by the volcanic plains that cover the majority of the planet (Bindschadler and Head, 1991; Bindschadler et al., 1992a; Solomon et al., 1992; Sukhanov 1992; Basilevsky and Head, 1995a, b; Ivanov and Head, 1996a); however, the density of craters on both terrains is similar where the tesserae yield a surface crater retention age of 1 (Strom et al., 1994) to 1.4 times (Ivanov and Basilevsky, 1993) the average age of the surface of ~300 (Strom et al., 1994) to ~800 Ma (McKinnon et al., 1997). The apparent spatial randomness of the crater population on the surface of Venus and rarity of embayed craters (Phillips et al., 1992; Schaber et al., 1992) can be produced by a geologically rapid volcanic and tectonic emplacement of that surface (e.g., Schaber et al., 1992; Bullock et al., 1993), provoking several theories of catastrophic formation of the crust by varying methods (e.g., Turcotte, 1993; Arkani-Hamed et al., 1993; Parmentier and Hess, 1992). The crater record is satisfied if both the latest stages of tessera formation and the emplacement of the plains were formed within a geologically short period of time of approximately 10% of the crater retention age of the surface (Gilmore et al., 1997), requiring a decline in surface strain rates of two orders of magnitude during that interval (Grimm, 1994). Alternatively, the crater record has been modeled to result from steady state geologic processes that are a consequence of secular cooling of the planet (Phillips et al., 1992; Solomon, 1993; Herrick, 1994). The “catastrophic” vs. “equilibrium” models depend critically on the number of geologically modified craters and the assumptions made about the rate and extent of volcanic resurfacing in models of the crater size-frequency distribution. Perhaps the most critical observation is whether dark-floored craters have suffered volcanic infilling and embayment, supporting continuous resurfacing (Herrick and Sharpton, 2000; Herrick and Rumpf, 2011).

The sequence of events in the tesserae is the only record of the history prior to and during plains emplacement, and constrains the character, magnitude and direction of surface strain at this time. Tessera terrain covers approximately 8% of the surface of Venus, and is generally elevated relative to the local plains, having bimodal hypsogram with peaks at ~1 and ~3 km above mean planetary radius (MPR, 6051.84 km; Ivanov and Head, 1996a, 2011). Higher elevations are associated with

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the largest tessera occurrences; small outliers of tessera scattered throughout the plains may have elevations below MPR (Ivanov and Head, 2011). The largest areas of tesserae are plateau-shaped in topographic profile, often having sharp contacts with the adjoining plains indicating embayment by the plains. The edges of these plateaus tend to stand higher than the interiors and may be marked by ridge belts (Ivanov and Head, 2011, 2015) parallel to the tessera margins (e.g., Törmänen, 1993, 1995; Romeo and Capote, 2011). Such ridge belts yield in both their form and orientation to more complex fabrics in tessera interiors, frequently containing ridges and graben consistent with polyphase deformation (Solomon et al., 1992; Ivanov and Head, 1996a; Hansen and Willis, 1996). These graben are found in several stratigraphic studies (Solomon et al., 1992; Bindschadler and Head, 1991; Bindschadler et al. 1992a, b; Ivanov and Head, 1996a, 2011; Romeo and Capote, 2011) to overlie the ridges and thus are the youngest features of the tesserae, and may deform the oldest plains units adjoining the tesserae (Basilevsky and Head, 1995a, b; Gilmore and Head, 2000). Such a sequence of features (compression followed by extension, margin parallel high-standing ridge belts, plateau shape) have been predicted to occur as the result of large-scale mantle downwelling (Bindschadler and Parmentier, 1990; Bindschadler et al., 1992b) which may have direct implications for the nature of the event that formed the tesserae and the subsequent emplacement of the plains (e.g., Head et al., 1994). A different sequence of events has been suggested for tessera terrain where extensional structures predate compressional structures (e.g., Hansen and Willis, 1998; Phillips and Hansen, 1998). Such a stratigraphy supports the theory that tessera terrain forms by magmatic thickening of the crust over regions of mantle upwelling (see Bindschadler (1995); Phillips and Hansen (1994) for overviews of downwelling vs. upwelling hypotheses) or by cooling of magma at the site of large impacts (Hansen, 2006). The upwelling model predicts that radial extensional structures should form due to uplift over a mantle plume, followed by the production of concentric ridges by gravity sliding as the plume recedes (Phillips et al., 1991; Phillips and Hansen, 1994; Ghent and Hansen, 1997). Thus each model outlines fairly specific predictions of the type and distribution of tessera structures. The models also have implications for tessera composition as mantle plume models would presumably yield basaltic lavas, while downwelling models allow a range of tessera rock compositions. These predictions can be tested by the rigorous documentation of the stratigraphy of tessera structures.

In this paper, we present some of the results of structural mapping of the tessera plateau Tellus Regio and Meni Tessera (centered at ~37°N, 81°E, Fig. 1).

Tellus was selected because it is an individual large tessera plateau with good coverage in Cycle 1 left-looking, Cycle 2 right-looking, and Cycle 3 left-looking SAR data yielding stereo. Our goal is to map the type and orientation of the dominant structures within the plateau and develop a sequence for their formation. Each of these observations yields information about the large-scale events that produced Tellus Regio, which can be used to assess predictions of models for the formation of tessera terrain on Venus.

2. Methodology

2.1. Classification of structures

The Magellan mission has provided us with near-global imaging of the surface using side-looking, synthetic aperture radar (SAR) at approximately 100–250 m resolution (Saunders et al., 1992). The brightness of each radar image is controlled by the strength of the radar return from the surface, which is largely a function of topographic slope, orientation and surface roughness. The appearance of surface features in the radar is also highly dependent on the size of the feature relative to the image resolution and its orientation with respect to the viewing geometry of the radar, where topographic features tend to be enhanced when oriented perpendicular to the radar look direction and/or at low incidence angle. In general, extensional features, such as normal faults and fractures, have a linear planform, in contrast to ridge and fold structures which tend to be sinuous in planform. As graben are defined by having two inward-dipping normal faults, in the side-looking radar, graben (and troughs) are identified by a bright wall facing the illumination (spacecraft) direction and a dark wall facing away from the illumination direction, closer to the spacecraft. The relative steepness of a graben wall relative to its floor should produce a change in radar brightness across the feature that is sharp, which is observed to be the case generally on Venus (Hansen and Willis, 1996). Steep sided (vertical walled) graben are

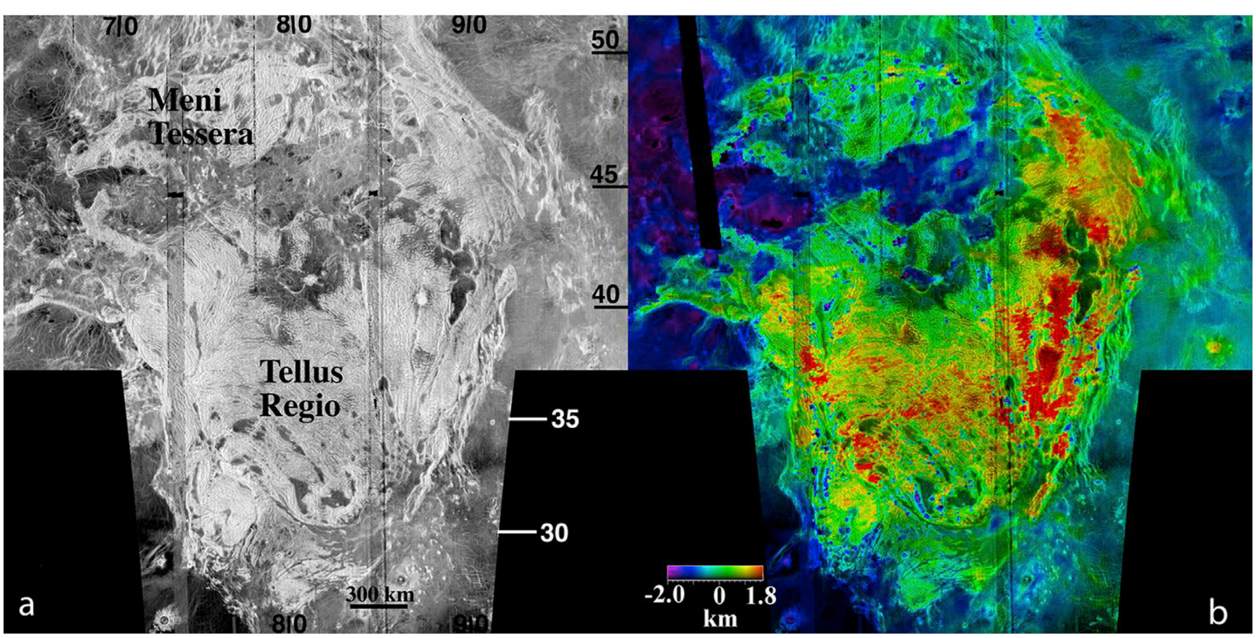

Fig. 1. (a) Magellan image of Tellus Regio and Meni Tessera. Mosaic of C145N074, C145N096, and C130N081. As is the case for this and subsequent figures, Cycle 1 image gaps are filled in by Cycle 3 and Cycle 2 data. (b) Magellan altimetry data overlain onto SAR image. The elevation scale is relative to mean planetary radius (MPR) = 6051.84 km.