STRUCTURAL AND GEOLOGIC MAPPING OF SOUTHERN TELLUS REGIO, VENUS: IMPLICATIONS FOR CRUSTAL PLATEAU FORMATION.

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Introduction: Crustal plateaus are quasi-circular, flat-topped plateaus with heights ranging 1-4 km. These crustal plateaus are host to distinctive tectonic terrain, referred to as ribbon tessera terrain. Crustal plateau formation on Venus is subject to animated debate, centered on plateau support and resulting surface deformation. Four formation hypotheses exist, mantle downwelling [1-3], mantle upwelling [4-8], pulsating continents [9] and the lava pond hypothesis [10]. Detailed mapping of southern Tellus Regio provides critical clues for plateau evolution. Tellus Regio is one of two isolated crustal plateaus on Venus. Tellus Regio, centered at 42.6N/76.8E, is nearly oval with a slightly smaller and tapered southern part, has a long axis dimension of ~2300 km, is bordered by lowlands, and sits ~2-3 km above the regional plains with the highest elevations in the eastern, western, southern portions, and steep eastern and western margins and gently sloping northern and southern margins [11, 12]. The northern margin of Tellus Regio is not well defined and may represent a transitional area with the lowlands. North-central Tellus is host to a low-lying interior showing complex surface deformation. High resolution SAR data reveals an overall rough surface topography on Tellus Regio marked by ribbon tessera terrain. Structural and geologic mapping of southern Tellus Regio (43N/73-90E, 26N/74-86E) provides an excellent opportunity to examine the rich surface deformation history, preserved during crustal plateau formation, enabling the evaluation of crustal plateaus hypothesis.

Regional Geologic Relations: Geologic and structural mapping revealed that tessera terrain includes various combinations of long-, intermediate-, and short-wavelength (λ) folds, intra-tessera basins, ribbon structures, graben complexes, fault scarps, and undefined lineaments. Long- λ folds (20 km to >150 km) dominate the plateau generally occurring along the margins of Tellus Regio, although a few long, NW-trending wavelength folds occur in the center of the plateau. Intratessera basins are broadly distributed across the plateau, and occur at a range of sizes, shapes and orientations. Large intratessera basins are widely distributed across the plateau and commonly represent fill of long-λ fold troughs. Intermediate-λ folds (5 - 15 km) occur across the plateau defining a general fluid pattern [13]. Relatively broad elongate embayments also form in the troughs of intermediate-λ folds. Along the limbs and crests of long-and intermediate-λfolds short, narrow basins occur within the troughs of short-λ folds (λ<1 km) and ribbon structures. Ribbon structures occur across the plateau, whereas graben complexes generally appear in suites throughout the central and western regions of southern Tellus Regio. The regional distribution and orientation of structural elements collectively define a fluid-like pattern across the southern Tellus map area. Detailed analysis of targeted regions provides detailed temporal constraints.

Detail Map areas: Six detail map areas contribute to provide a detailed geologic history of the crustal plateau. Each area was selected for characteristic structural elements and was mapped using full-resolution Magellan cycle-1 and -2 SAR data, in normal and inverted modes, and combined for true stereo views [14]. Generally short- and intermediate-λ folds, ribbon structures and basin fill material occur throughout each of the detailed map areas. Fewer long-λ folds, graben and fault scraps occur throughout the areas. Broadly, all detail map areas record generally parallel short-, intermediate and long-λ folds, and ribbon structures that trend orthogonal to fold axes. Troughs of short-, intermediate-, long-λ folds and ribbons are commonly filled with flood deposit material. Although short-λ folds were previously associated with local intra-tessera basins within Tellus Regio [15, 16], the extent and abundance of short-λ folds across Tellus has not been previously documented. Each of the detail map areas record similar geometric structural relations, and relative timing of strucutractral elements, yet each region highlights different structural orientations and 2D bulk strain. The geologic mapping results are broadly in accord with previous studies on portions of Tellus Regio [15-18].

Broadly, fold λs show a progression from short-, to intermediate-, and long-λ over time, ribbon structures occur early, shortly after short-λ folds. Graben and fault scarp formation occurs late. Deposition of flood material occurred throughout the progressive deformation filling the troughs of all types of structural elements.

Structural wavelengths recorded for contractional and extensional structures for the detail map areas place estimates on layer thickness operative during structural-element formation; empirical λ:layer thickness ratios of 3 to 6 for contractional structures and 4 to 2 for extensional structures constrain the layer thickness estimates [10, 19-20]. Average layer thicknesses for short-λ folds and extensional ribbons structures show broadly overlapping average layer thicknesses, ranging from range from 0.1 to 1.15 km, and 0.76 to 1.33 km, respectively. Average layer thickness estimates associated with intermediate-λ fold formation range from 1.0 to 2.15 km and 1.45 to 3.83 km, depending on location; whereas long-λ folds deformed layers ranging in thickness from ~5 to 15 km. All six areas record similar increases in layer thickness over time, as well as overlapping thickness estimate between short-λ folds and ribbon structures. The progression of structures based on layer thickness estimates is consistent with the broad structural temporal relationships interpreted across the entire plateau with short-λ structures forming early and long-λ structures forming later. An increasing layer thickness over time also places a strict requirement on the evolution of the rheological structure across the plateau [10]; the presence of a thin initial layer, with an increase of layer thickness over time, requires a sharp viscosity gradient with depth in order to form short-wavelength fold and ribbon structures.

Histories and Implications: A general evolution arises from the geologic histories interpreted from each map area. Short-λ folds formed early followed or accompanied with, ribbon structure formation, deforming a thin (0.1-1.3 km) layer with a sharp viscosity change at depth. Low-viscosity flood material locally flooded structural lows. Fold formation and local flooding resulted in an increase in layer thickness. These early formed structures and their respective basin fill, were uplifted during the formation of intermediate-λ folds. Troughs, limbs and crests of intermediate-λ folds preserve these previously formed structures. Intermediate-λ fold troughs were then filled by more flood material, resulting in further layer thickening. During formation of long-λ folds the previously deformed terrain was again uplifted (and down warped), the troughs of which were locally filled by flood material, locally experiencing major flooding. During the latest stage of surface evolution graben complexes, and similar trending fault scarps, cut all other structures, with late local flooding in the troughs of some graben complexes.

The temporal relations and spatial orientations of structures provide equally valuable information about the evolution of the surface, and possible mechanisms. The interpretation of the 2D bulk strain ellipses provide clues to how 2D bulk strain changed over time. During "thin-layer-time" all six map areas record different orientations of local 2D bulk strain, consistent with the interpretation that the early surface deformation recorded a high structural fluidity at a regional scale. As the structural wavelengths increased with time, the fluidity of the surface deformation decreased, and the area deformed in a more coherent manner. Overall the orientations, spatial relations and temporal relationships of structural elements over the entire southern Tellus Regio map area depict: 1) layer thickness increased over time, allowing for short-wavelengths and ribbons to form early and then progressively increase wavelengths; 2) deformation and flooding occurred broadly synchronously, locally preserving early-formed structures and thickening the layer over time; and 3) 2D bulk surface strain changed over time, recording an early regional-scale variations that record a sort of surface fluidity, which evolved to a regionally consistent pattern, reflecting a change in regional strength and coherence across the southern Tellus Regio. This sequence of events calls for a high geothermal gradient over the entire region that decreased over time. Even though the overall geothermal gradient decreased over time, it has to be initially high enough to allow for a sharp viscosity gradient beneath the initial thin layer, and to remain hot enough to allow low-viscosity material to fill structural lows [10, 21-22]. In addition, a high geothermal gradient would provide the surface with enough ductility to deform in a fluid-like manner across the regional map area, as evident in early 2D bulk strain ellipses. This fluidity in structural elements ceased as the geothermal gradient decreased and the layer thickness increased with time.

Evaluations of crustal plateau formation hypothesis: The pulsating continents, mantle downwelling and mantle upwelling formation hypotheses are somewhat difficult to reconcile with the geologic evolution documented herein and the implications for southern Tellus Regio. On the contrary, the lava pond hypothesis and, by the association the bolide impact hypothesis, depicts an environment that creates similar surface deformation and evolution as documented for southern Tellus Regio.

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