

TABLE 1. Potential venusian stratigraphic markers (from youngest to oldest).

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- Relatively pristine lava-flow surfaces as indicated by radar backscatter characteristics
 - Preserved crater halos and surface splotches
 - Widespread fractures, grabens, and ridges
 - Plains material
 - Complex ridged terrain (tesserae)
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which local volcanic and tectonic features and units may be correlated. Finally, very young time markers may be defined by the degree of weathering or eolian modification of a surface. For example, lavas flows at Maat Mons show a decrease in radar contrast and brightness with increasing age (based on superposition relations) [10]. Also, some impact craters retain radar-dark (less commonly radar-bright) halos perhaps consisting of impact debris; apparently related to the halos are dark and light surface "splotches" that may represent relatively young debris and shock-induced surface roughness produced by impacting bolides of a narrow size range that disintegrated deep down in the dense venusian atmosphere [1]. As these features age, they may become less distinct relative to surrounding terrains.

Initially, superposition relations were difficult to ascertain among various geologic units on Venus because of the general difficulty in perceiving topography on the radar images. (Exceptions, such as thick lava flows or domes, were relatively rare). Still, many stratigraphic relations can be determined in plan view, because overlying materials tend to mute or embay the texture and structure of underlying surfaces. More recently, Magellan has produced repeated radar images of selected areas, which permits stereoradargrammetry [11]. In addition, synthetic-parallax stereo-images (produced from merged Magellan images and altimetry) commonly show the association between geologic/tectonic-terrain units and regional topography.

Magellan radar mapping shows that Venus has had a complex geologic history that can be unraveled to a large extent from available data. Even though exposed rocks apparently record only a small portion of the planet's history, stratigraphic markers are sufficient to permit the development of a useful scheme of time-stratigraphic units. Such a scheme should result from NASA's new Venus Geologic Mapping (VGM) Program, which will cover the entire planet.

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STRUCTURAL CHARACTERISTICS AND TECTONICS OF NORTHEASTERN TELLUS REGIO AND MENI TESSERA.

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Introduction: Tellus Regio-Meni Tessera region is an interesting highland area characterized by large areas of complex ridged

terrain (CRT [1]) or tessera terrain [2]: Tellus Regio and Meni Tessera areas and deformed plains areas between the highland tesserae. The area was previously studied from the Venera 15/16 data and typical characteristics of complex tessera terrain of Tellus Regio were analyzed and a formation mechanism proposed [3]. Apparent depths of compensation of ~30–50 km were calculated from Pioneer Venus gravity and topography data. These values indicate predominant Airy compensation for the area [4,5]. Regional stresses and lithospheric structures were defined from analysis of surface structures, topography, and gravity data [6]. In this work we concentrate on northeastern Tellus Regio and Meni Tessera, which are situated north and west of Tellus Regio. Structural features and relationships are analyzed in order to interpret tectonic history of the area. Study area was divided into three subareas: northeastern Tellus Regio, Meni Tessera, and the deformed plain between them.

Description of Areas and Interpretations of Structures: *Northeastern Tellus Regio.* Northeastern Tellus Regio is defined here as a roughly triangle-shaped area between longitudes 84° and 92°E and latitudes 46° and 53°N. The ridgelike northern end of northeastern Tellus Regio is cut by a fracture belt at 53°N, 85°E, but the overall trend of the CRT is continued by CRT of Dekla Tessera. Together these areas form a >2000-km-long south-concave arc of tesserae, which extends to Kamari Dorsa south of Audra Planitia and west of Laima Tessera.

The northernmost area of northeastern Tellus Regio is characterized by wide, arcuate ridgelike features, which form the major structural element of the CRT in this area. The longest one of these ridgelike features is oriented in a northwest-southeast direction and it forms the curving northeastern edge of the CRT of Tellus Regio ("A" in Fig. 1). It is ~660 km long, 4–40 km wide, and has gentle slopes. The east-facing slope is steeper and more pronounced. The other two ridgelike structures of the CRT are situated southwest of the first one ("B" and "C" in Fig. 1). They are less distinct and shorter: ~40 km wide and 280 km long ("B") and ~30–85 km wide and 230 km long ("C"). Their general orientation is west-northwest/east-southeast. These ridgelike features end abruptly in the northwest, but in the south and southeast they merge to more topographically flat-looking tessera surface. The large ridgelike features of northeastern Tellus Regio are composed of narrower (widths 1–2.5 km), closely spaced, linear, and generally ridges tens of kilometers in length.

The narrow ridges and the larger-scale ridgelike features comprising them appear to be the oldest structural elements of the CRT. In the topography data the widest ridgelike patterns can be distinguished. Their heights are typically several hundred meters below or about the mean planetary radius of 6052 km. The topography and morphology of ridges support compressional origin. There are oval-shaped intratessera plains depressions and troughlike features in between the major ridgelike structures of the CRT in several places (e.g., 49°N, 87°E, "D"). These postdate the ridgelike features of the CRT. The oval plains areas have smooth radar-dark surfaces and are obviously covered by lavas. There are narrow (1–3 km wide) ridges on the edges of the oval-shaped plains, which follow the curvature of the edges of the plains. These ridges appear to have formed in a later episode of compression in the area.

There is a 30-km-wide belt of narrow linear ridges adjacent to the northeastern tessera border. The widths of these ridges are 1–2 km and are several tens of kilometers in length. These ridges apparently formed due to compressional stresses oriented perpendicular to the border of CRT (approx. northeast-southwest). These ridges are not

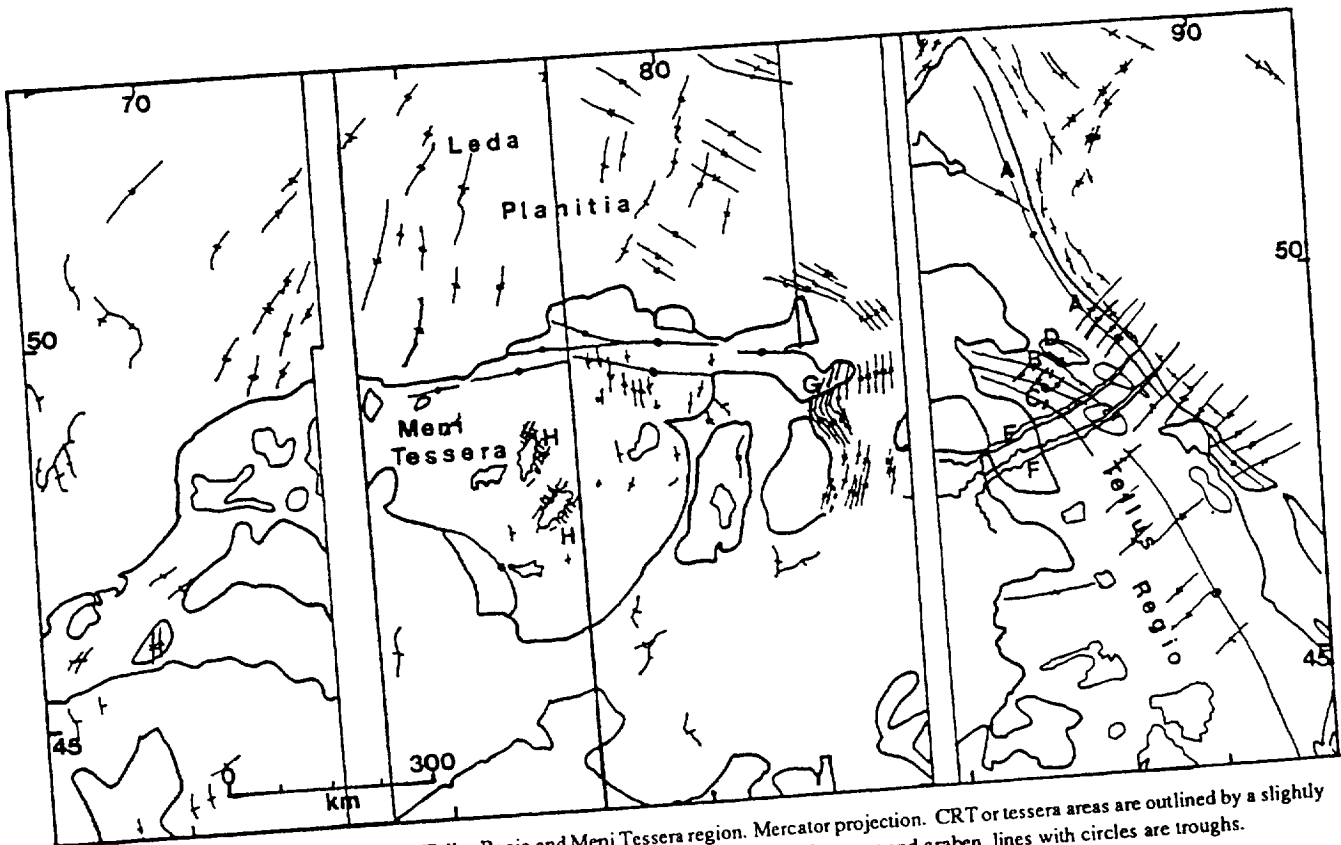


Fig. 1. Sketch of a map of northeastern Tellus Regio and Meni Tessera region. Mercator projection. CRT or tessera areas are outlined by a slightly thicker line. Lines with small cross lines represent ridges, lines with crosses represent fractures and graben, lines with circles are troughs.

part of the CRT because their spacing is larger and they do not form a similar structural pattern to the ridges of the neighboring CRT.

The ridges of the CRT are extensively cut by northeast-southwest-oriented flat-floored valleys. These features are interpreted to be graben and manifest moderate tensional strain in the area. The graben cut almost orthogonally both the ridges of the CRT and the ridges bordering the CRT but they rarely cut across the intratessera plains. Their typical widths are 1.5–3.5 km with lengths 20–150 km.

Two large, linear depressions in the area follow the strike of the graben ("E" and "F" in Fig. 1). Based on their distinct morphological characteristics (wide scarp-bounded openings on the plain, sinuous edges, widenings along the strike and up to 20 km long orthogonal to the strike-oriented segments) they are classified as valley networks of subtype III [7,8]. Valley networks of Venus resemble sapping valleys of the Earth and are interpreted to have formed by the fluid motion through an underground fracture system [9,10]. These two valley networks of northeastern Tellus Regio cut across the CRT, but are more pronounced on the plains within and adjacent to the CRT than on the CRT itself. They have similar orientation to the graben, which shows that the valley formation probably occurred along two large preexisting graben. The northeast-southwest-oriented Tellus Regio is cut by a 560-km-long northwest-southeast-striking linear trough (Medeina Chasma). Most of the northeast-southwest-oriented graben cross-cut it, which shows that the trough formed earlier.

Inferred Sequence of Deformation: (1) The narrow linear ridges and larger ridgelike structures of the CRT form in compressional folding and thrusting. (2) The ridge belt along the northeastern edge of Tellus Regio forms in northeast-southwest compression. (3) Extensional deformation results in widespread graben formation. (4) Formation of intratessera plains and subsequent compressional deformation occurs along the edges. (5) Valley networks and some extensional graben form. Medeina Chasma and other long troughs of the area probably formed during phase 2. This sequence agrees well with both earlier and other recent studies of the area [3,11] and analyses of deformation of many other regions of CRT or tessera [1,12,13].

The Deformed Area Between Northeast Tellus Regio and Meni Tessera: The troughlike area is characterized by several irregular patches of CRT, which seem to be remnants of an earlier continuous CRT connecting Meni Tessera and Northeastern Tellus Regio. The CRT areas near eastern Meni Tessera have very similar structures as adjacent Meni Tessera. Linear, narrow fractures form up to 45-km-wide belts on the plain between the CRT areas. These fractures are oriented northwest-southeast in the northern part of the trough and they follow the dominant strike of fractures to the southeast corner of northern Leda Planitia. They turn to a north-south direction in the trough. Fractures directed almost perpendicularly against a scarp-like, linear edge of the eastern extension of the Meni Tessera ("G" in Fig. 1) turn near the edge to the north-northeast and form a bend in the fracture pattern. The linear edge appears to be a fault (its strike can be traced also further to the west-southwest) and the bend in the fracture belt can be due to right-lateral shear. Fracture belts also cut into areas of CRT. Fractures are covered in some places by plains material, apparently lava flows. Fractures were probably formed by extensional deformation of the area, but later plains formation has covered them extensively.

Eastern and Central Meni Tessera: Meni Tessera is situated between latitudes 45° and 50°N and longitudes 67° and 83°E. It has narrow, topographically distinct extensions to the southeast and east. Its central part is composed of more equidimensional and topographically lower area of CRT. The northern part of Meni

Tessera is characterized by troughs, which define ~110–370-km-long and ~15–50-km-wide east-west-oriented segments of CRT. These elongated areas have some of the highest topography in the Meni Tessera. One of the segments forms the previously mentioned eastern extension of the CRT ("G" in Fig. 1). Although these elongated parts of the Meni Tessera do not have a similar strike as the ridgelike topography and morphology, and they are not composed of clear individual ridges, they do have a strike similar to the ridgelike components in northeastern Tellus Regio.

Structurally Meni Tessera CRT is more complex than northeastern Tellus Regio. The oldest underlying structures are curvilinear ridges, but they are wider and shorter (2–8 km wide and 10–30 km long) and more widely spaced than in northeastern Tellus. There does appear to be very fine ridgelike structures superposed on these ridges, but they can not always be distinguished from scarps and normal faults. The dominant direction of the ridges is to be north-south/northeast-southwest, but this orientation may be due to more later deformation and the original directions may not be observable any more. Near the eastern edge of central Meni Tessera the ridges follow the curving tessera border. The central parts of Meni Tessera are characterized by areas of orthogonal terrain of intersecting northeast-southwest and northwest-southeast graben ("H" in Fig. 1). This terrain has been partly covered by lavas of intratessera plains in the areas where it is visible. There are also places where graben cut across the border between the CRT and the plain, especially around western and northern edges of Meni Tessera.

The relationships between graben with different orientations is complex: North-south striking graben and individual scarps (probably normal faults) cut other features extensively in the eastern and northern parts of the central Meni Tessera. There are also graben oriented in the northeast-southwest direction, especially near the northwestern and southeastern borders, which cut ridges and northwest-southeast graben. In the central parts of the CRT there are northeast-southwest-oriented graben that cut other features, but these graben are frequently covered by lavas. There are also small areas where graben are not widespread or at least can not be distinguished from small-scale ridges or closely spaced faults. Deformation seems to have followed the same kind of basic sequence as in northeastern Tellus Regio except that there have been several different episodes of graben formation with both spatially and chronologically more complex relationships. Also, differences in orientation and morphology of ridges in Meni Tessera and northeastern Tellus Regio may reflect different original stress regimes. Although no major strike-slip faults were identified in Meni Tessera, there is evidence of probable shear deformation in nearby plains areas.

Discussion and Conclusions: Similarities in the topographic trends, especially the similar types of linear ridgelike features in northeastern Tellus Regio and corresponding elongated segments in northern Meni Tessera, which together form a roughly south-concave arc of topographically higher CRT, as well as some similarities with structures of the CRT of the easternmost Meni Tessera and western edge of northeastern Tellus Regio, indicate that these areas of CRT were probably earlier interconnected. The troughlike plain area between Meni Tessera and Tellus Regio is probably underlain by CRT, which has been disrupted and covered by lavas. The adjacent northern Leda Planitia is deformed by complex intersecting systems of fractures and ridges. Some of this deformation may reflect a presence of a covered basement of CRT. The arclike pattern of tesserae between Kamari Dorsa and northeastern Tellus Regio may also reflect an earlier larger area of tessera. Similar conclusions were earlier presented on the basis of analysis

of Venera data [14,15] and more recently by a comprehensive analysis of distribution and characteristics of tessera from Magellan images [16]. Based on this work, however, it is very hard to define exactly the original extent of the CRT in this region.

Tessera are proposed to form by hot-spot-related volcanism and tectonism [17,18] or by convection-driven tectonics above mantle downwellings [1,12,19]. The results of this work do not conclusively rule out either model. Analysis of structures and deformation shows that the earliest distinguishable deformation was compression, which was followed by widespread extension and volcanism (formation of intratessera plains). This result is in agreement with other studies [e.g., 1,3,11,13] and similar results have been used to support the mantle downwelling model [1,12], but in our opinion they do not leave out other possibilities.

The arclike arrangement of topographically higher ridgelike features in northeastern Tellus Regio and northern Meni Tessera is roughly similar in planform, but smaller than the Dekla Tessera–northeastern Tellus Regio arch in the north. These arcuate patterns of tessera are typical to the area between longitudes 0° and 150°E [16] and could tell us about the scales of deformation of the crust in these areas. Observed complex deformational sequences in the northeastern Tellus Regio–Meni Tessera region do support the idea that the CRT is probably a result of repeated deformation through different mechanisms [20]. We are currently analyzing in more detail structures in Meni Tessera and northern Tellus Regio and their relationships with topography, intratessera volcanism, and the deformation and volcanism on the adjacent plains.

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EPISODIC PLATE TECTONICS ON VENUS. Donald Turcotte, Department of Geological Sciences, Cornell University, Ithaca NY 14853, USA.

Studies of impact craters on Venus from the Magellan images have placed important constraints on surface volcanism. Some 840 impact craters have been identified with diameters ranging from 2 to 280 km. Correlations of this impact flux with craters on the Moon, Earth, and Mars indicate a mean surface age of 0.5 ± 0.3 Ga. Another important observation is that 52% of the craters are slightly fractured and only 4.5% are embayed by lava flows. These observations led Schaber et al. [7] to hypothesize that a pervasive resurfacing event occurred about 500 m.y. ago and that relatively little surface volcanism has occurred since. An alternative hypothesis has been