MAIN FAULT TECTONICS OF MESHKENET TESSERA ON VENUS

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Abstract. The lengthy Meshkenet Tessera highland located between Ishtar Terra and coronae of the Nightingale group provides evidence of large-scale crustal movements. Its complex tectonic structures have various deformation geometries, thus indicating different tectonic sequences. The main parallel faults, first explained as rotational bookshelf faults, are more likely due to relative dextral direct shear movements of rectangular blocks. These faults have been active, possibly due to endogenic stresses, as indicated by mid-size ridge ranges which connect them to some of the large coronae. There are some compressional ridge belts around Meshkenet Tessera, while deformation within the tessera blocks has mostly been extensional.

1. Introduction

Meshkenet Tessera (Figure 1a; Barsukov *et al.*, 1986, Basilevsky *et al.*, 1986) is a highly elongated tessera terrain of the Plains-Corona-Tessera Assemblage (Head, 1989) in the Tethus Regio between 65° to 68° N and 92° to 128° E (Burba, 1988; Vorder Bruegge and Head, 1989). It is located 480 to 800 km to the east and southeast of the eastward-facing scarps of the eastern Fortuna Tessera (USGS Map, 1989; Raitala and Törmänen, 1989) and 700 km east of Audra Planitia and Manto Fossae (USGS Map, 1989; Raitala and Törmänen, 1989). The Earhart and Nightingale Coronae, Melia Mons and Fakahotu and Vacuna Coronae are located to the east, southeast and south of Meshkenet Tessera, respectively. Low volcanic plains with clusters of domes (Slyuta *et al.*, 1988) and ridges surround the tessera, but there are also high areas covered by lavas between Meshkenet Tessera and Tusholi Corona (Figure 1b).

The 1600 km long and 50 to 340 km wide Meshkenet highland is cut by major parallel faults into blocks with an en echelon arrangement (Figure 1). All individual, bar-like blocks have a distinct pattern (cf. Ansan *et al.*, 1991) of high angle ridges and valleys which, even if the orientation varies from one area to another, mostly parallel and perpendicular main faults. Most structures display complex cross-cutting relations. The surrounding lava plains may hide long stretches of faults as well as patches of the tessera terrain.

Fault and ridge locations, shapes, geometries and dimensions were examined using Magellan and Venera 15/16 radar data. The tectonic development was evaluated based on the topography, morphology and mutual relations of the structures. The conclusions based on these observations are discussed with respect to their implications for the Cytherean tectonics.

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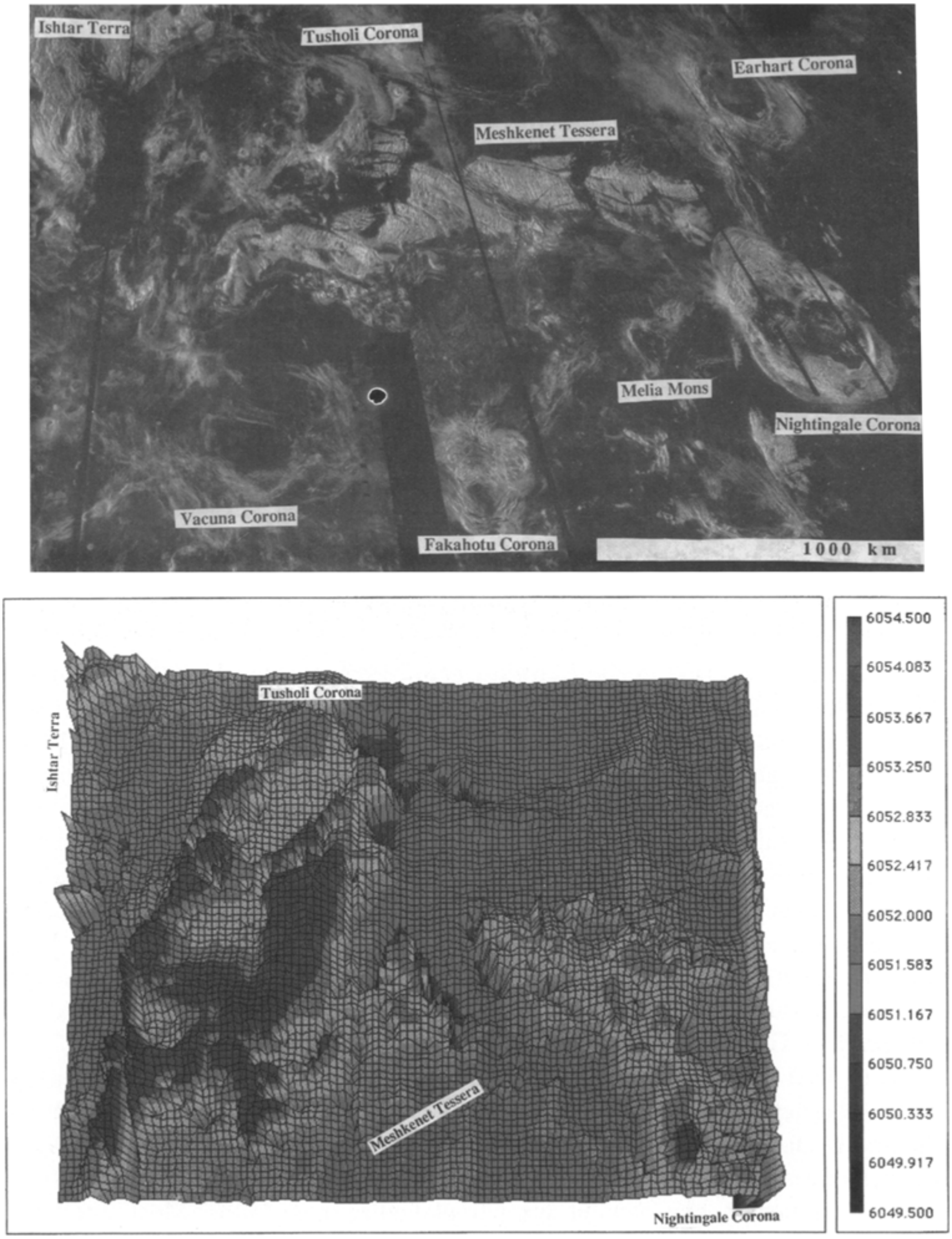

Fig. 1. **(a) The main faults of Meshkenet Tessera contribute to a bar-like en echelon tessera** block appearance. The spacing of the major faults is less than 100 km, while the width of an individual faults can be up to 10 kilometres. Earhart and Nightingale Coronae are located in the east, Melia Mons, Fakahotu and Vacuna Coronae in the south, and Tusholi Corona in the north. (b) Colour-coded topographic data on Meshkenet Tessera indicate large variations in terrain elevations. Gabie Rupes divides Meshkenet Tessera into two parts. There are deep troughs along parallel edges of Gabie Rupes and beside the scarp of Tusholi Corona. The large doughnut-shaped high area between Tusholi Corona and the western Meshkenet Tessera is not this prominent in the radar data (Figure 1a).

Fig. 2a.

2. Subareas of Meshkenet Tessera

2.1. THE WESTERNMOST AREA

The western Meshkenet Tessera between 92° to 104° E is topographically the highest, rising to 2.5 to 3 km above the lowlands (Figure 1; USGS Map, 1989). Its lengthy megablock is sliced into a few major parts by main faults. There are landslides in places along the edges (Figure 2a), forming terraces that cut or follow the fracture strikes of the tessera terrain. This is well displayed along the northern neck-like border area of the western Meshkenet Tessera, where roughly N–S oriented faults are intersected abruptly by a border-parallel scarp and a series of slump terraces. The western end of the landslide is defined by the deflected NNW–SSE strike of a tessera fault. To the east of this area a conjugate fracturing of the tessera terrain may also indicate landslide-like fracturing of the tessera promontorium.

The westernmost part of Meshkenet Tessera has an elongated form in the shape of a dog's head (Figure 1). It consists of massif-like parts which are separated either by distinct troughs or by lava-filled areas, the lava being assumed to cover underlying faults or depressions. Its structures differ from those of the main bar-like block, however, in spite of having roughly the same main orientation. These fault-like structures have conjugate NE–SW and NW–SE orientations in the north. A major NE–SW scarp defines the western border of the western Meshkenet

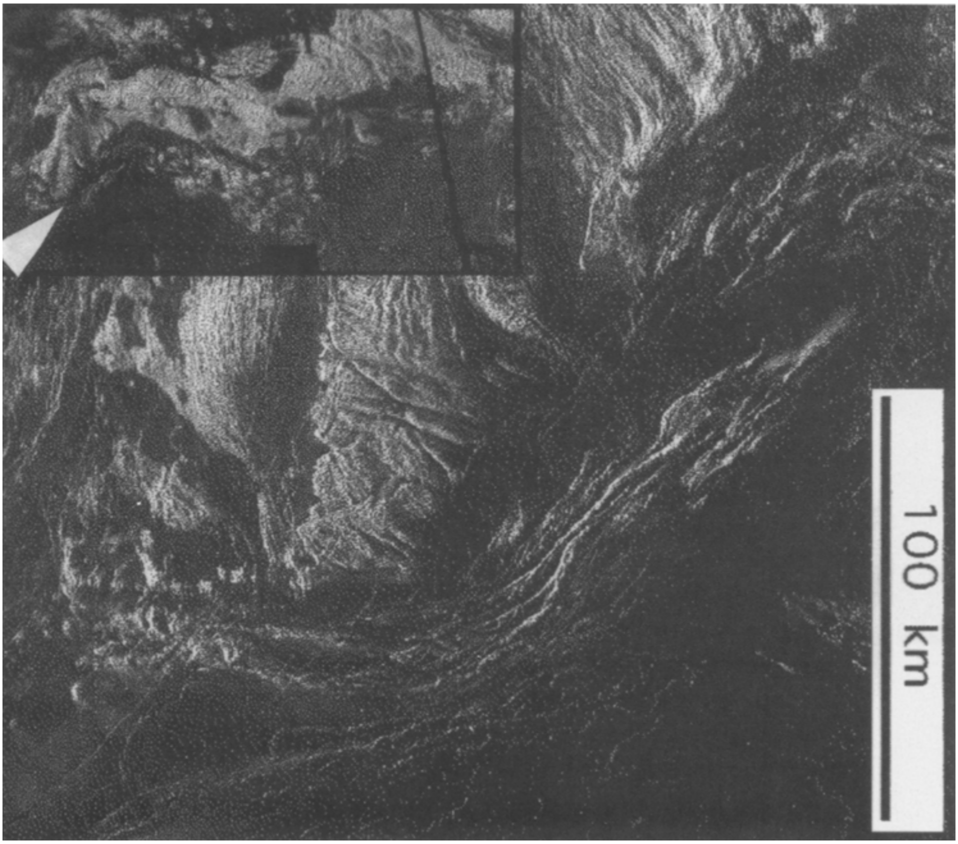

Fig. 2. (a) Overview of the middle western Meshkenet Tessera. While the main fractures of westernmost Meshkenet Tessera assume roughly a N–S orientation with offsets possibly denoting strike-slip movements along the faults, the two cross-cutting sets of ridges are evident within the middle western area. Surface collapse faults, or landslides, located in upper left part on the tessera edge cut across or are diverted by these older tessera fractures. Along the lava-filled main fault trough (arrows 1) which divides the western block into two pieces there are cross-cutting linear structures, crossing small ridges, linear small ridges, and a pull-apart-like depression in the branch of the fault. Some of these structures along its strike indicate sinistral, or multiple, movements. The dividing fault (arrows 2) between the western and middle parts of Meshkenet Tessera has a set of conjugate ridges and valleys, the orientation of which is deflected by the fault, indicating its dextral strike-slip nature. (b) The ridge belt orientation on the adjoining southern, lava-flooded Meshkenet lowlands is roughly E–W, but these wrinkle ridges strikes mostly follow the tessera edge. There are also places where these ridges continue the tessera structures.

Tessera, cutting off a long, narrow tessera strip. Several conjugate or high-angle NW-SE faults in the tessera highland cross this primary fault and its parallel structures, extending only slightly into the lava-covered lowland, where they assume a more northern orientation. These conjugate faults have small offsets in places where they cross the NE–SW structures. This may be partly due to the radar imaging geometry, but it may indicate a SE to E tilting of fault-bounded blocks. If real, the offsets of the NW-SE faults indicate that they were deformed by conjugate NE–SW faults. The NW–SE fault set crosses small lava-flooded patches and merges southwards in a broad zone with its strike turning towards N–S in the south.

The orientation of the main fault which runs through most of the western block is mainly N40°-80° W (Figure 2a). This large NW–SE fault splits the tessera area into two parts with slightly different ridge-valley orientation and surface morphology. Its straight northwestern part cuts through the NE–SW ridges and valleys of the tessera surface allowing only a few younger ridges to continue over it. Its strike may continue for some distance onto the adjoining lava plains. It has several crossing structures with NE–SW to ENE–WSW strikes. Some of the NE–SW trending structures seem to be offset by this block-dividing NW–SE fault, which may indicate sinistral strike-slip characteristics. Some of the high-angle ridges extend however, into the lavas, filling the fault, and are thus younger than these. There are numerous trough-parallel faults on the adjoining tessera terrain, and some of these are located beside or even on the trough lavas. Actually, the whole tessera area is patterned by these two conjugate structure systems, which seem to have various cross-cutting relations. At the southeastern end the NW–SE fault bends and becomes divided into two branches, with a lava-filled depression between them. Some minor conjugate structures on the lava plain seem to continue the adjoining tessera structures. This large depression displays the shape, orientation and location of a pull-apart basin. Fault development must have proceeded in at least three phases: (a) formation of the two conjugate sets, (b) left-hand faulting and adjoining pull-apart depression formation, (c) activation of the crossing faults with (d) formation of fault-parallel structures along the original fault.

The slightly arcuate main NWW–SEE fault largely defines the NE border of the block and the border between the western and middle Meshkenet Tessera (Figure 2a). The northwestern part of the fault is defined by a lava-filled trough. The course of the lava-covered fault is also defined by linear ridges. The fault is sharp and well-defined in the middle of the southeastern part, where it cuts through the tessera terrain. It is penetrated by numerous conjugate structures which have a N–S or NE–SW orientation. These ∫-shaped ridges indicate ridge-fault interaction. Even if part of the bending may be caused by the Magellan radar imaging geometry, in which high ridge crests appear to be moved towards the imaging radar (westward) while the lower parts of these crests appear to be farther from the radar (eastward), careful inspection reveals that a case can be made for the dextral nature of the movement along the fault. The ridges have been deformed by the fault's dextral strike-slip movement. The ridges to the southwest of the large NWW–SEE fault have a N–S orientation, while those to the northeast have a more NE orientation. The crossing ridges in the middle of the fault indicate conjugate activity after the formation of the main fault, while the set of parallel ridges illustrate the sequential nature of the movements along the fault. The easternmost section of the main fault is bent in a SE direction.

Zones of wrinkle ridges parallel the tessera edges on the lava plains south of the western Meshkenet Tessera (Figure 2b). Most of these are independent compressional structures, the strike of which on the low lava plains follows the overall strike of the high-lying tessera border. Some of the ridges continue fractures of the tessera terrain, however, as if the faults were continuing from the tensional tessera environment onto the compressional lava plains.

2.2. THE MIDDLE AREA

The roughly triangular middle part at 66° N/104° E rises to a height of 2 km (Figure 1; USGS Map I-2041, 1989). It is surrounded by lavas in the west and east-southeast and by the Gabie Rupes trough in the northeast. Slightly arcuate main NW–SE or N40–70° W faults divide the middle tessera into a few en echelon bar-like blocks. The border with the western lava plains is fairly distinct. The tessera terraces rise up from the plain, while the NW–SE faults end at the tessera-planitia contact, indicating local emplacement of the uppermost lava after the tessera faulting. The northeastward concave main fault troughs, semiparallel to the Gabie Rupes trough, are wider at their southeastern end, as is the latter. There are offsets in the structures on opposite sides of the troughs, and they are crossed by linear ridges in places.

The blocks are patterned by alternating ridges and valleys perpendicular and parallel to the main fault troughs (Figure 3). These may vary slightly in orientation between the blocks, with the perpendicular ridge orientation in the range N0°–40° E. The southwesternmost area of the middle Meshkenet Tessera is cut by alternating ridges and valleys at high angles to faults and grabens parallel to the border faults. This two-directional fault pattern is distributed widely over the whole middle Meshkenet Tessera area. In places the fractures parallel to the border faults dominate over the perpendicular ones, while in other areas the situation is reversed. The parallel faults are usually straighter, while the ridges and valleys in the perpendicular direction assume a slightly more winding orientation. This may be due to the topography and the radar imaging geometry. Some perpendicular structures have counterparts on both sides of the troughs, indicating horizontal displacements.

There are the two distinct fault sets, especially at the easternmost end of the middle Meshkenet Tessera. Some of the bar-parallel faults are younger than the cross-cutting ones and others are older, the youngest ones being found in the tessera area just beside Gabie Rupes. Some of these faults bend into the Gabie Rupes trough, as part of its fault system. It is difficult to find any systematic age differences between block-parallel and -perpendicular fractures. A few rectangular or rhomboid lava-flooded depressions along the main faults may have been caused by collapses between two orthogonal sets of (strike-slip) faults, resulting in pull-apart basins (Figure 3). At the very easternmost tip of the bar-like

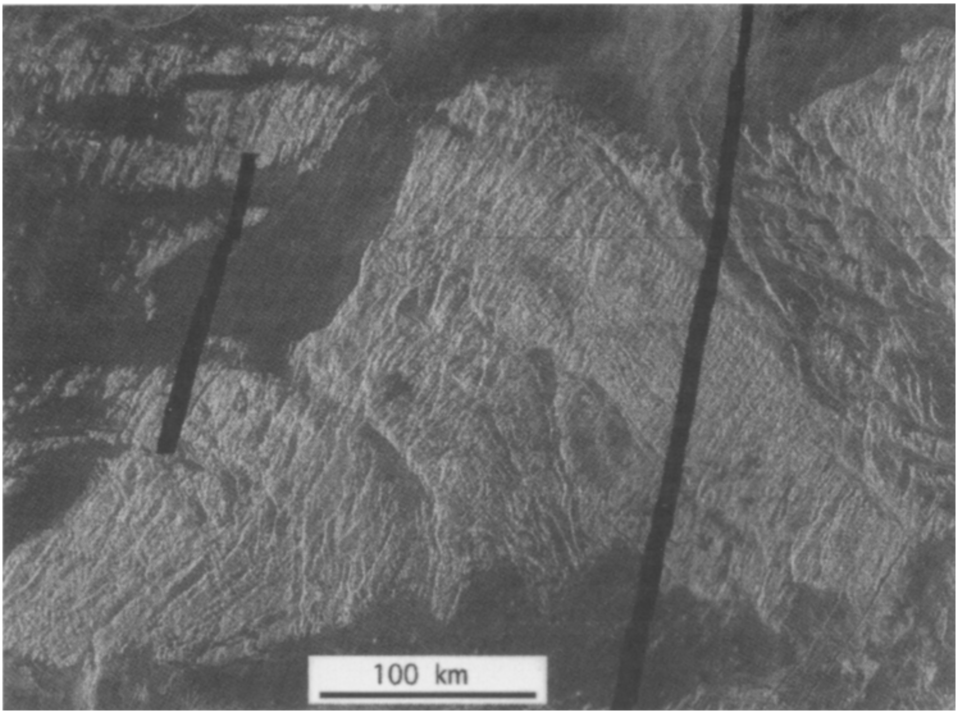

Fig. 3. The two high-angle tessera fracture sets of various ages are mostly parallel to the long and short edges of the bar-like blocks in the middle Meshkenet Tessera area. The main crossing faults contribute to bar-like block formation and the largest faults have lava-filled depressions along their strikes. High-angle linear structures cross the fault-parallel troughs. The spacing and intensity of both fracture sets vary from place to place. The more recent faults most clearly run across the previous ones and may be partly diverted along them. The obviously most recent set of ridges even crosses one of the main fault trough (middle). This ridge belt forms a winding, roughly N–S zone. Gabie Rupes (middle right) is the main trough between middle and northern Meshkenet Tessera. A ridge belt runs to the north from Gabie Rupes.

block there is a set of perpendicularly oriented grabens, which nevertheless seem to belong to a wide graben system extending over areas from the northeastern Meshkenet Tessera to the southern lava plains. The wide areal dimensions, arcuate shape and slight concentricity with respect to some of the coronae allow us to identify these grabens as belonging to a tectonic phase of their own.

Some slightly sinuous N–S fractures are younger than the structures they cross (Figure 3). The southern area in particular is cut across by numerous fresh-looking extensional, arcuate graben faults which have a NNW–SSE orientation at their southeastern end and turn more towards a NWW–SEE orientation in the west. Arcuate graben faults together with winding young faults indicate the youngest fault movements after the initial block formation and orthogonal faulting. The youngest winding faults have interacted with older fractures, the winding ones assuming the strike of the older structures for short distances. Several fresh-looking N–S ridges cross both the previous conjugate fault sets and the main troughs in places. These cross major dividing troughs in the form of zones consisting of several wrinkled ridges and fractures. In the western part of middle Meshkenet Tessera the major arcuate NW–SE fault trough, well defined by sharp northern scarp and trough-filling lavas, is transsected by numerous fault-ridges which continue over the trough (Figure 3). The ridge bending beside the trough may be due to strike-slip fault-related drag. This adds a further set of complicating cross-cutting relations and indicates a multitemporal deformation history for the area.

Although the majority of the ridge- and valley-related fractures do not give any clear systematic indications of horizontal movements along the faults (Figure 3), a few ridges seem to indicate dextral NNW-SSE shear. The structures may reflect tensional rupture or gravitational relaxation of the high-lying surfaces, and the shearing may have bent some of the ridges along the faults. Possible anticlockwise rotation may have increased the dextral strike-slip faulting, but this could not have produced most of the observed block geometries, fracture orientations and trough openings. The en echelon arrangement of the blocks indicates that the northern blocks of the middle Meshkenet moved to the east relative to the westward-sifted southern parts. The areal deformation may have taken place during a series of strike-slip movements.

2.3. GABIE RUPES

The 70 km wide Gabie Rupes fault trough (Basilevsky *et al.*, 1986) separates the middle and eastern parts of Meshkenet Tessera. Striking from the Melia Mons in the southeast to Tusholi Corona in the northwest Gabie Rupes (Figures 1, 3) is a major depression through Meshkenet Tessera. Especially its SE end has numerous ridges and elongated hills. Smooth lavas partially cover areas between them. The deepest areas parallel just its edges, while the ridge-patterned middle trough is higher. The wrinkle ridges continue into lava plains in the north. The parallel edge-related troughs of Gabie Rupes may indicate segments of the most recent tensional shear faulting or crustal bending. The middle ridges may be folds or thrust faults, but their discontinuous pattern reflects variations in the deformation of the lava cover.

2.4. THE EASTERN AREA

The northeastern Meshkenet Tessera complex, up to 1.5 km high and lying between 112° and 128° E (Figure 1; USGS Map I-2041, 1989) is characterized by sets of linear E–W, N60°–80° W and N 50°–70° E troughs resulting in several bar, triangle and wedge-shaped blocks. The ENE-trending troughs are the freshest-looking linear features, while the WNW–ESE, or E–W, troughs are wider and look older. The angle between the trough systems varies from 40° to 60°, and the individual troughs are straight, narrow lineaments resembling lava-flooded grabens or depressions. The NE–SW fault set in the middle area has an

Fig. 4. Several fracture patterns are found within the northern Meshkenet Tessera highland with both low and the high-angle faults and lavas filling the main troughs. In addition to long, parallel, fault-related troughs there are more inclined NE–SW troughs and grabens which cut the bar-like blocks into wedge-shaped subareas. The tessera structures within the blocks again consist of two high-angle fracture sets. Faults may have complicated orientations and cross-cutting relations. There are compressional E–W ridges on the northern lowland between Earhart Corona and Ishtar Terra.

especially fresh appearance, and cuts through the area as a distinct scar, while all the NW-SE troughs are much wider.

The major blocks of the northeastern Meshkenet Tessera have distinct alternating orthogonal ridge-valley-trough patterns (Figure 4). The majority of the ridges and valleys of the eastern Meshkenet Tessera are largely linear, with N–S or NNE–SSW trends. Numerous faults and troughs are oriented along the bar-like blocks, or NWW–SEE. Located in parallel bands or ridge swarms with alternating ridges and valleys of similar size, the conjugate structures are as complicated as in other parts of Meshkenet Tessera, and there are various signs of cross-cutting relations. The troughs may differ in age, and some of them are crossed by numerous ridges, being in a process of deformation due to later tectonic activity, while others are only partly penetrated by younger fault-related ridges. A few fresh grabens strike through all the previous structures and are obviously independent of them.

The southern part of the eastern Meshkenet Tessera is cut by several wide, lava-flooded NWW-SEE troughs. The long bar-like blocks are patterned by two orthogonal sets of ridges, valleys and troughs. The ridges are the most prominent features in places and tend to penetrate into the wide troughs. The tessera blocks may have been moved relative to each other along the faults because the ridges may be matched across troughs in places. Some ridges seem to bend beside the troughs as if they were drag structures. This ʃ-shaped deflection in their orientation cannot be due only to the radar imaging geometry of certain topographic characteristics, but is most probably caused by dextral strike-slip movements along the main trough-related fault. Some of the ridges reach over the trough as if they were younger than the lavas which fill the troughs, and indicate late ridge development. The last tectonic phase is defined by straight, narrow grabens which cut through the lava plains and tessera terrain (Figure 4).

Two perpendicular sets of structures are to be found on the easternmost block. The N–S faults at high angles to the longer block edges are far more numerous, and several ridge-valley bands extend through the northern block boundary into the northern lava plains. In the southern block area linear E–W depressions become more numerous, and they tend to be filled by lavas, the more so the further south they are located (Figure 4).

At least six deformation geometries and probably many more local deformation phases can be identified in some areas of the northeastern Meshkenet Tessera. (A) Long parallel faults divide the tessera areas into bar-like blocks, and these fault-bounded depressions are filled with lavas. These lavas cover most of the (B) conjugate or high-angle structures while (C) zones of extensive fault-related ridges cross the lava surfaces in places. Located in the main troughs, these lavas also cover most of the low-angle, or semiparallel, faults (D), which are seen to cross the lava surface only in a few places (E). Finally (F) arcuate and narrow young grabens cross all the above structures, although they, too, are covered by lavas as they penetrate further into the northern lava plains (Figure 4), with linear, mainly E–W-trending wrinkle ridges.

2.5. THE TUSHOLI AREA

The tessera blocks close to Tusholi Corona (Figure 5) are separated from the main Meshkenet Tessera by lava plains (cf. Ansan *et al.*, 1991). The northern Tusholi arch, with an eastward-facing scarp and an adjoining trench, continues to the south as a fan-like ridge pattern. The northernmost tessera blocks are in immediate contact with the Tusholi scarp, as being in the process of moving against it. They are separated from each other by lava-filled fault troughs. These structures continue approximately the same E–W trend of the northeastern Meshkenet Tessera trough, and thus are related to the fault troughs of the Meshkenet Tessera. The surface texture of these tessera blocks consists of alternating high-angle ridges and valleys which adopt an ʃ-shape, especially beside the troughs. These structures are fairly straight in the middle of the block but bend close to the troughs, as if influenced by drag forces along a dextral shear fault. The tessera ridge orientations match well with the influences of the dextral strike-slip movements along trough-related faults. This is the case on both sides of all the troughs, which evidently indicates that the relative movement has

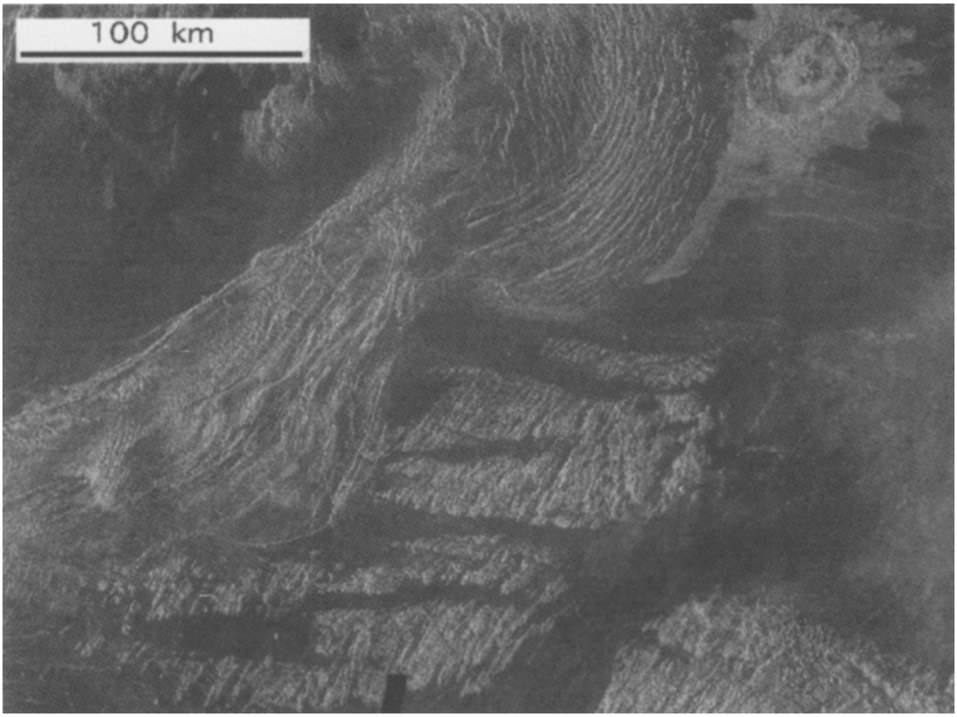

Fig. 5. Tusholi Corona has a foredeep depression as seen from the lava flow on the eastern side of the scarp. Parallel E–W troughs divide small tessera areas into units which have ∫-shaped ridges at high angles to the faults. These troughs may reflect the dextral E–W shear movements of the tessera blocks (cf. Raitala and Törmänen, 1989a).

been dextral in all cases. The southernmost blocks may thus have had the largest relative movement from east to west. There are no indications that the troughs continue over the scarp into Tusholi Corona, and we can thus make a strong case for underthrusting of the tessera terrain below the scarp. The tessera blocks may still be in a process of underthrusting below the Tusholi scarp (Figure 5).

2.6. ADJOINING STRUCTURES

The areas around Meshkenet Tessera are covered by lava fields and only a few tectonic structures can be found (Figure 1). Wrinkle ridges extend from the direction of Melia Mons to Gabie Rupes, with a NW–SE orientation, like the main fault trough. The rim of the western Meshkenet Tessera is bordered by planitia ridges on its southern side (Figure 2). To the north of Gabie Rupes the ridges have mainly a northern orientation, while the ridges on the northern Louhi Planitia plains adopt a NNE–SSW orientation. There is a well-defined E–W ridge belt at least 600 km long on the planitia between Tusholi scarp and

Earhart Corona. Being several tens of kilometres wide, it strikes through the other ridges and displays N–S compression.

Some gravitational relaxation in the highest, westernmost blocks of Meshkenet Tessera may have increased wrinkle ridge formation on the nearby plains by deforming the lava surface along the southern edge of the western Meshkenet Tessera. These features are concentrated in a few parallel sub-belts. The large differences in the ridge spacings may indicate the influences of different discontinuities in the uppermost crust (Raitala and Kauhanen, 1990).

Manto Fossae of Audra Planitia, over 600 km long and oriented roughly E–W, is a major en echelon fault arrangement, the most prominent NW branch of which reaches towards Fortuna Tessera. Its main E–W orientation along the southern border of Fortuna Tessera roughly continues the E–W strike of the western Meshkenet Tessera. Melia Mons (Figure 1) has distinct radial or subradial ridges, which are found as far as 200 km from the central structure. The Gabie Rupes fault-related ridges and adjoining tessera blocks are radial to Melia Mons.

Some faults of the eastern Meshkenet Tessera are connected geometrically with Nightingale Corona (Figure 1), but the lava flows allow only a few structures to be seen close to the corona which has both radial and concentric patterns. The northern latitudinal ridge connects Tusholi and Earhart Coronae. Another major ridge belt which runs between Earhart and Nightingale Coronae has a deformed caldera depression in the middle. Ridge belts also continue to the north of Earhart and to the south of Nightingale as if stress fields of the two coronae had interacted, giving rise to major ridge belt formation. The linear extension of fissures between two diapirs has been proposed as the origin for ridges between a corona pair (Pronin and Borodzin, 1989). Corona formation has been able to induce or reinforce radial stresses in the crust in the immediate vicinity of the coronae, where the radial and concentric ridges are located (Raitala and Kauhanen, 1990). Even if the lava flows do not allow us to map all the actual relations between coronae and fault zones, Nightingale Coronae, for example, may have promoted the fault development in the eastern Meshkenet Tessera area, or at least interfered with it.

3. Main Fault Tectonics

3.1. RIDGE BELTS AROUND MESHKENET TESSERA

The E–W ridge belt on the 70th latitude between 68°–72° N on Louhi Planitia is a compressional zone (Ansan *et al.*, 1991; cf. also Sukhanov, 1987, 1989; Sukhanov and Pronin, 1988, 1989) in which compressional ridges have developed parallel to the main zone under high normal compression (Lajtai, 1969). A N–S compression may have additionally been important within the northeastern Meshkenet Tessera. Some conjugate NW–SE and NE–SW fault sets in the eastern Meshkenet Tessera support the idea of a N–S compression, which could also have caused some of the proposed offsets along them.

A compressional aspect is visible in all the main ridge belts of the area (cf. Ansan *et al.*, 1991). The ridge belts along the southern border of the western and middle Meshkenet Tessera have developed due to folding and faulting of the uppermost surface, and may indicate shortening of the surface layers (Figure 2b), possibly of gravitational origin due to the large topographic differences between the high Meshkenet Tessera and its southern volcanic lowlands. This will have resulted in fold and fault formation in places where the uppermost surface layers of the volcanic planitiae were thin and easily deformed. This process was repeated, finally resulting in formation of a ridge belt.

3.2. POSSIBLE SHEAR FAULTS OF MESHKENET TESSERA

The dimensions and regularity of the fracture spacing may be used as an indication of the degree of uniformity of the tectonic forces across the area (Figures 1, 6). A regular fracture spacing over wide areas indicates an increase in the homogeneity of the forces involved. The main dividing faults were caused by a larger, more large-scale or wider force, while individual lineaments and faults may display more local deformation of the uppermost crust.

Three tectonic forces have previously been proposed as having contributed to the deformation of Meshkenet Tessera: N–S compression (Barsukov *et al.*, 1986), E–W compression (Basilevsky *et al.*, 1986) and horizontal forces (Head, 1989). Its en echelon configuration could have resulted from two mechanisms: pure right-handed strike-slip faulting caused by N–S compression (Barsukov *et al.*, 1986) and various other compressional phases (cf. Ansan *et al.*, 1991), or a ‘bookshelf’-type mechanism of dextral faulting and anticlockwise rotation in N–S compression and E–W directed shearing (Basilevsky *et al.*, 1986). Strike-slip and rotational faulting together with compressional and tensional stresses have influenced the tectonics of Meshkenet Tessera, and pure strike-slip faulting with some block rotation is highly probable. The ridge and valley orientations vary between the blocks, and the block geometries do not quite match if the movements along the faults are reversed. A partial ‘bookshelf’-type mechanism may be possible in addition to the more important E–W directed dextral shear. Lateral faulting and accompanying block rotations may explain some of the features observed (e.g. Freund, 1974; Ron *et al.*, 1984; Garfunkel and Ron, 1985).

The prominent Tusholi scarp is an overthrust-like feature formed by E–W movements, in which tectonic forces originating from the surrounding volcanic areas may have contributed to an effective compressional environment. Indications of N–S and E–W compressions have been found (cf. Ansan *et al.*, 1991) also in the northern Fortuna Tessera (Vorder Bruegge and Head, 1989; USGS Map, 1989) and Audra Planitia (Raitala and Törmänen, 1989).

3.3. STRUCTURES WITHIN BLOCKS

The fractures inside the Meshkenet Tessera blocks may be associated with extensional chocolate tablet structures developed by boudinage formation during partial relaxation of the high topography. The plan-view of the chocolate tablet boudinaging is well-displayed within the Meshkenet Tessera blocks, which are cut by long parallel faults and by ridges and valleys at high angles to the faults. In spite of some local variations, the majority of the area displays the two sets of fractures and boudin axes. Long faults parallel block boundaries, while neck fractures transverse them, as seen from the prominent structure directions.

The very first initiation of the deformation of Meshkenet Tessera was probably a dextral shear faulting resulting in parallel block formation. A uniform layer-parallel strain may have resulted in extensional fractures which depended on the pre-existent lineations, the stress rate and the dimensions and physical properties of the surface rocks. Possible deformation due to the partial relaxation of the high topography may have caused the two fracture sets to develop. Fault-parallel fractures may represent the first boudinaging phase of the uppermost surface, influenced by pre-existent structural anisotropies. Additional boudin sets may have developed during a progressive deformation, or else the continued activity may have resulted in fracture formation by superposed deformations with the development of a second, third etc. generation of boudins. The later superposed fractures were thus alternatively perpendicular and parallel to the first one. All the boudin sets depended on the shape and orientation of the previous ones which were originally controlled by the main block properties and geometry.

4. Conclusion

The main fault history of Meshkenet Tessera has been complex, with several superimposed processes active within the area, as revealed by the radar data. There are several parallel and subparallel major dextral shear faults across Meshkenet Tessera, resulting in a number of bar-like blocks (Figure 6). These blocks are relatively narrow, representing re-located remnants of a previously more uniform tessera area. The en echelon block geometry was defined by dextral shearing together with an additional rotational or bookshelf component related to compressional shortening of the area. The conjugate faults of the northeastern Meshkenet Tessera indicate N–S compression and adjoining shear movements in which triangular blocks were caused by an extra set of faults. The ridges and valleys within the blocks are explained by extensional forces, and the planitia ridge belts around tessera edges are due to compressional surface wrinkling.

The Meshkenet Tessera blocks have cross-cutting fractures similar to a two-dimensional chocolate tablet boudinage in an environment with pre-existing lineation. The long boudin axes run parallel to the original faults of Meshkenet Tessera, and the neck lines are at a high angle to these faults. The strain rate

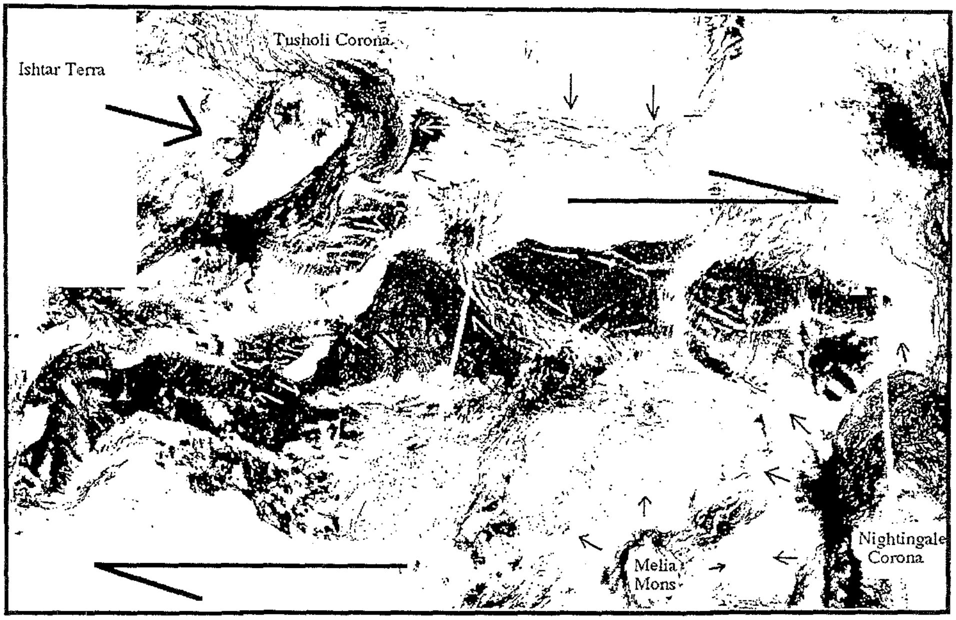

Fig. 6. Simplified sketch of the tectonic history of Meshkenet Tessera. The faults across it show E–W strike-slip components. The ridge belt orientation in the southern lowlands displays the effects of gravity sliding of the high tessera areas, which, in contrast, have mostly tensional internal structures.

may have been different parallel and perpendicular to the faults, but this was not necessarily the case. Relaxation or flattening deformation is able to produce tensional fractures in two directions in an environment of pre-existing faults or fault-induced lineation, even if the maximum extension is not normal to this lineation. Although Meshkenet Tessera has effective fault-parallel fractures, its perpendicular ones are also well-developed, indicating at least a two-phase boudinage formation. The varying cross-cutting relations nevertheless accentuate the existence of a multiphase boudinaging process (Figures 2a, 3, 4).

The main faults were controlled by the active centres around the area, and some faults were geometrically related to certain coronae (Figure 6). Fault sets which connect two adjoining coronae reveal a definite corona-related aspect in their formation. Thus the regular en echelon arrangement of the main faults which cut Meshkenet Tessera into bar-like blocks indicates that these were formed by a large-scale force. Since they retain their orientation remarkably well over large areas, a common explanation is needed for their formation. Fortuna Tessera and the major volcanic structures surround Meshkenet Tessera, and their development may have contributed to major lateral movements. E–W stresses from Ishtar Terra and large coronae, acting against the probable elongated shape of the original tessera may have broken it into pieces, resulting in block formation under continuous stresses and direct shear conditions. The en echelon block orientation indicates a dextral shear, but a slight rotational component cannot be excluded (Figure 6; cf. also Ansan *et al.*, 1991).

The driving force for main faulting remains partly masked by volcanism, resulting in an incomplete understanding of Cytherean endogenic processes. The eastward spread of Ishtar Terra and the mantle activity beneath the coronae may be appropriate candidates for moving and deforming the crustal blocks, but the results do not exclude the existence of Venusian spreading zones, although they accentuate the effects of hot spots. The evidence of N–S compression complicates the sequential geometry of the major faults and needs to be studied in more details.

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