Polygonal Terrain of Utopia Planitia, Mars: The First MOLA Results

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Abstract
New data obtained by the Mars Orbiter Laser Altimeter (MOLA) allow highly precise analysis of the morphology of polygonal terrain. We found that the widths of polygonal troughs are considerably larger than previously published and the very shallow slopes of the trough walls suggest a modification of the trough morphology after their formation. The depth of the troughs is in the range of 35 m and therefore in good agreement with data derived from shadow measurements. Polygonal terrain in Utopia is located at the slopes of a basin structure and appears over a wide range of elevations.

Introduction
Polygonal terrain on Mars was first observed in Mariner 9 and Viking Orbiter images and its origin, formation, and evolution remained enigmatic since that time. Polygonal terrain is a major morphologic constituent of the Utopia Planitia region of the Northern plains on Mars. These polygons formed during the Late Hesperian and are thought to be in close genetic relation to outflow channels and a possible ancient martian ocean. However, it is still under discussion whether polygonal terrain formed on volcanics or sediments. As the formation process of these polygons is also still under discussion, we tested previously published models in the light of the new MOLA data.

Numerous models have been suggested for the formation of polygonal terrain on Mars and all models involve cracking in response to tension. Tension-generating processes are: (1) cooling of lava flows [1,2,3], (2) desiccation of wet sediments [3], (3) thermal contraction [4], (4) loading of sediments with volatile-rich lavas [5,6], (5) coalescence of smaller polygons [5], (6) tectonic bending over a rough subsurface [7], (7) tectonic processes [8] and finally convection [9]. We reviewed these models, their predictions and constraints, and describe key characteristics of mid-latitude (27˚-39˚ N, 247˚-265˚ W) martian polygonal troughs in Utopia Planitia which allow us to test the plausibility of each model. Key characteristics of troughs are the location relative to the Utopia basin structure, geometry (width, depth, slope), morphology, and topography.

Lucchitta [10] noted that polygonal terrain occurs in close proximity to the major outflow channels and in low reentrants of the northern lowlands projecting into the southern highlands. The size of martian polygons is in the range of 2-32 km [5,11,12,13,14,15]. Helfenstein and Mouginis-Mark [5] measured the size of 383 polygons in Utopia, Acidalia and the polar regions and found that the largest polygons occur in Utopia (ø=7.4 km) and the smallest in the polar regions (ø=3.5 km). The width of the fractures which form the polygons is about 200-800 m [13], consistent with data from McGill [11] which indicate a width of 250-1000 m with some fractures much larger than 1 km. According to Morris and Underwood [3] the fracture width can vary up to 2 km. Pechmann [13] noted that the depth of four representative troughs varies between 30±10 m and 107±10 m. Morris and Underwood [3] mention that polygonal troughs are typically a few hundred meters deep.

Based on investigations of buried impact craters McGill [7,12] proposed a thickness of the polygonal terrain of 500-600 m.

Results
The MOLA instrument has a vertical shot-to-shot resolution of ~30 cm, an absolute vertical precision of 10 m, and along-track spatial resolution of 300-400 m [16]. The surface spot size in mapping orbit is about 130 m. These specifications allow one to resolve narrow graben- or fault-like features in the MOLA profiles. So far, we have investigated the geometry of 96 troughs forming parts of the polygonal terrain of Utopia Planitia. We used the data obtained during aerobraking (hiatus-orbits) and from the first science phasing orbit (SPO1-orbits). Four orbits which cross the investigated area, 27, 251, 232, and 213 (sorted by increasing longitude), were studied in detail. From the MOLA hiatus and SPO-1 orbits we generated a global topographic map and combining this map with the map of Lucchitta [10] we see that the polygonal terrain in Utopia Planitia is located on the slopes of a topographic depression or basin [also see 17]. We conclude that the formation of polygonal terrain is closely related to the transport and deposition of sediments/volcanics into this local basin. Using the geologic map [18] we see that polygonal terrain consists mainly of material of the Vastitas Borealis Formation which is of Hesperian age. Polygonal terrain is tilted to the north and therefore follows the general trend observed in all MOLA profiles, independent of the geologic unit. In other words: polygons occur at different topographic levels along the general north-facing slope and do not mark a single horizontal topographic level nor do they occur at the deepest topographic positions of a basin. In the case of the polygonal terrain this slope is about 0.1˚ and appears to be very similar for all investigated MOLA orbits.

A typical cross-section of a polygonal trough is displayed in Fig.1 which also shows how we measured the width and depth of a trough. To have consistent criteria for the determination of the width and depth of all troughs, the width was measured at a level were a hypothetical trough-filling fluid would spill over into an adjacent depression. The depth was measured between the lowest point and the level where the width has been determined. MOLA profiles usually do not cross the polygon fractures perpendicularly. Therefore, the width measured in the profiles has to be corrected for widening due to oblique cross-cutting. Even after this correction our widths are considerably larger than previously published fracture widths of polygonal terrain of 200-800 m [11,13]. MOLA data show that the trough width varies between 0.5 km and 6 km. 20% of all fractures show a width of 1-1.5 km and 57% of all troughs exhibit a width of 1-2.5 km. Only 9% of the investigated troughs are smaller than 1 km in width. The mean fracture width is ~2.3 km with a standard deviation of 1.2.

The depths derived from the MOLA profiles are in excellent agreement with the previously published data [13] and vary between ~5 m and ~110 m. The mean depth of the investigated troughs is ~35 m with a standard deviation of 23.6. The
A formation of polygonal terrain due to basalt loading onto water-saturated sediments can be clearly ruled out because martian polygons are bounded by troughs instead of ridges as predicted in the model by Needham [6].

A major argument against a formation of polygonal terrain related to desiccation of wet sediments was the depth of the associated fractures [13]. However, MOLA data show that 34% of the troughs are less than 20 m deep and 54% are less than 30 m deep. We conclude that a large number of troughs exhibit depths which are very close to or slightly above the upper limit of 15-20 m for the stability of tension cracks on Mars [13]. Therefore a formation due to desiccation may not be rejected before further investigation has been undertaken.

Similar arguments concerning the depth of polygonal fractures were made for a formation by thermal contraction. Pechmann [13] noted that thermal contraction is confined to the uppermost 10 m of the surface and can’t produce deep fractures. The statistical distribution of fracture depths seen in the MOLA data is too close to the predictions of Pechmann [13] to reject this hypothesis at the present state of knowledge.

Coalescence of smaller polygons which formed by ice wedging remains a plausible possibility even if the process is not yet well understood. Argument against such a formation process is that it is difficult to explain flat-floored steep-sided trough cross sections [13]. As we do not frequently see such geometries at the resolution of the MOLA data, we think that Pechmann’s argument is not necessarily applicable to the polygonal fractures in Utopia Planitia. We conclude that a formation due to coalescence can not be ruled out.

The convection model is complex and to test its predictions further data are required. A tectonic formation due to phase changes in the interior, which would result in an increase of the martian radius [8] may be ruled out because of the localized appearance of polygonal terrain. Differential compaction, which would cause bending of the compaction layer over pre-existing topography [7] is plausible. There are hints in the MOLA data which show that polygonal fractures occur preferentially on steeper slopes of local topographic highs where tensile stress induced by bending is assumingly larger. As a tectonic origin in combination with shrinkage of wet sediments can explain most of the MOLA observations, we favor this model at the present stage of our investigation.

References