MARTIAN FRACTURED TERRAIN: COALESCING POLYGONS, Paul Helfenstein, Department of Geological Sciences, Brown University, Providence, RI 02912

Poleward of 15°N latitude, the northern hemisphere of Mars is covered by extensive areas of fractured terrain, primarily in Acidalia, Elysium, and Utopia Planitia, near the polar cap (1,2), and to a lesser extent, in Lunae Planum (3). The regional settings of these features are described as smooth and cratered plains, lying at elevations 0-3 km below mean Mars datum(1). The detailed morphology of fractured terrain on Mars has been described elsewhere (1,2,3).

Several observations key to this analysis are 1) martian fractured terrain is frequently observed to be mantled by possibly aeolian and/or fluvial deposits; 2) individual polygons often exhibit upturned edges characteristic of terrestrial periglacial ice-wedge polygons (V0 frames 538A25-26, 560B42). It is suggested that the close proximity of (a) the north polar polygons to Borealis Chasma, (b) Acidalia polygons to a region which may have been fed by catastrophic outflow channels(4), and (c) Lunae Planum polygons to Vedra and Maumee Valles, which are believed to be fluvial in origin(5) indicate that fractured terrain is associated with a volatile rich environment.

Numerous analog terrestrial mechanisms have been suggested to explain the origin of martian fractured terrain: periglacial thermal contraction(6,7), dessication(8), lava contraction(9), lava loading of volatile rich sediments (10), and ice-heaving from buried aquifers(11). The chief objection to these mechanisms has been that the dimensions of martian polygons, which may exceed 20 km in diameter, are several orders of magnitude larger than terrestrial examples(12).

Using a physical model of contraction fracture formation developed by Lachenbruch(13), Pechmann(2) showed that the depths of tensile stress required to produce 10 km diameter polygons on Mars exceeds that which is realistic for seasonal contraction of permafrost, dessication, or lava contraction. Pechmann argues that such deeply seated tensile stresses would most likely develop from a martian tectonic environment and invokes this concept to explain the origin of martian polygons. Pechmann's tectonic hypothesis needs, however, to consider the following: (a) as will be shown in this paper, a significant number of polygons much smaller than 10 km are observed. Data by Evans and Rossbacher(3) on Lunae Planum yield a population of 400-1000 m diameter polygons which are near the range of dimensions exhibited by terrestrial playa polygons and periglacial polygons. (b) Pechmann uses a tensile strength of 50 bars for basalt, while data by Brace(14) suggest a value between 200-400 bars. In accordance with Lachenbruch's equations, a larger tensile strength would reduce the depth of tensile stress required to produce 10 km diameter polygons. (c) Fractured terrain is observed extensively in Acidalia, Utopia, and Elysium Planitia, but not in Arcadia Planitia, which is a geologically and spatially similar region of the northern hemisphere. Why do we not see the same tectonic manifestations in Arcadia as for Acidalia, especially when Arcadia is in regional proximity to the tectonically influence Tharsis bulge?

To characterize better the scale and geometry of martian polygons, measurements of the diameter and number of sides of closed polygons in Acidalia and Utopia Planitia were made from Viking Orbiter images, using a convention which compensates for irregularities in shape by converting the measured area of a polygon to the diameter of an equal area circle. It is important to note that polygons in the range of the 400-1000 m Lunae Planum features would not be visible at the resolution of the Viking Orbiter frames used. The results, shown in figure 1, demonstrate that in both Utopia and Acidalia Planitia, most polygons have about 5 to 6 sides and diameters less than 2 to 5 km. Polygons
larger than about 5 km have non-uniform geometries and comprise a more random component of the overall population.

The significance of the 5-6 sided nature of the smaller polygons is that this is the geometry expected from fracture of a medium exposed to a horizontally isotropic tensile stress (8, 12). On the basis of the above data, it is proposed that martian polygons with 5-6 sides and diameters of less than 5 km characterize a population from which larger, more randomly shaped polygons evolve. This is further indicated by morphologic observations that the meandering fracture outlines of large polygons tend to follow the intersection angles of smaller polygons and that small (<5 km) polygons are frequently seen within the borders of larger, partially enclosed polygons of ill-defined geometries (1).

Analysis of the observed upturned edges on martian polygons may constrain the mechanical properties of fractured terrain materials and suggest a mode of origin for the polygons. On Earth, upturned edges are associated with periglacial polygons and occur during seasonal warming periods, when thermal expansion of frozen soils induces horizontal compression of polygon edges against ice-wedges. This results in vertical plastic deformation of polygon edges closely resembling those seen on Mars. The required plastic flow is not characteristic of crystalline basalt, which behaves as a brittle solid. It is however, a notable characteristic of frozen soils under compression and in view of the association of martian fractured terrain with frozen, possibly volatile rich sediments, it is suggested that periglacial materials and mechanisms are candidate for the formation of small scale martian polygons.

Conclusions: It is proposed that large (>5 km) scale martian polygons evolve from the coalescence of smaller polygons with 5-6 sides. Constraints on terrestrial analog mechanisms for the origin of martian fractured terrain based upon scale are thus reduced to explaining 2-5 km diameter polygons, which themselves may originate from observed 400-1000 m scale polygons. The plastic mechanical properties of fractured terrain materials inferred from upturned polygon edges are suggested to indicate the presence of frozen, possibly volatile rich sediments rather than a brittle crystalline material, like basalt. The presence of volatiles is also suggested by the association of fractured terrain with fluvial features. It is concluded that periglacial origin of martian fractured terrain is still a viable hypothesis.

References:

Figure 1: Distribution of polygon size and shape in Utopia and Acidalia Planitia. Bin size is 2 km, "N" gives the number of polygons sampled.