DOUBLE-RINGED CIRCULAR GRABENS AND THICKNESS OF COVER MATERIAL IN UTOPIA PLANITIA, MARS.

D. L. Buczkowski, M. L. Cooke and G. E. McGill, Dept. of Geosciences, University of Massachusetts, Amherst, MA 01003, (emails: dbucz@geo.umass.edu, cooke@geo.umass.edu, gmcgill@geo.umass.edu).

Introduction: A number of hypotheses for the origin of the giant martian polygons of Utopia and Acidalia Planitiae have been proposed, from the cooling of lava to frost wedging to the desiccation of wet sediments [1,2,3,4]. However, these giant polygons are 1-2 orders of magnitude larger than the largest polygonal structures found on Earth, and none of the familiar processes can be scaled up to martian dimensions [5]. Two models for polygon origin [6,7,8] attempt to explain the scale of the martian polygons by postulating drape folding [9,10] of a compacting cover material, either sedimentary or volcanic, over an uneven, buried surface. The drape folding would produce bending stresses in the surface layers that increase the probability of fracturing over drape anticlines and suppress the probability of fracturing over drape synclines. In addition to bending, overall shrinkage of the cover material would provide the additional horizontal extensional strain needed to produce the observed polygonal troughs [7].

Throughout the polygonal terrain of Utopia and Acidalia are circular grabens that are inferred to lie over the rims of buried impact craters [11,4]. These features are the most logical place to test drape-fold models of polygon formation [12], because the buried topography can be estimated using published empirical equations that describe martian craters [13]. The 27 circular grabens found to the southwest of the Utopia Basin [22º-42ºN, 95º-120ºE] bound topographic depressions whose surface relief scale directly with diameter, as predicted by drape-fold models [12] (Fig. 1).

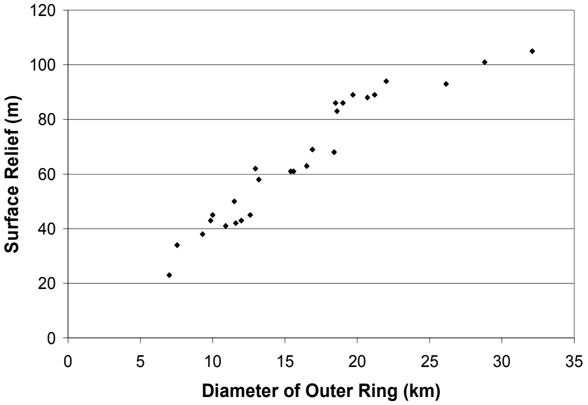

Figure 1. Diameter of the outer ring of circular grabens vs. the surface relief of the enclosed depression, as determined by MOLA. Surface relief is defined as the absolute value of the difference between the highest point on the ring's rim and the lowest point it surrounds.

Of the 27 circular grabens studied for surface relief, 25 are double-ringed, and the published drape-fold models [6,7,8] do not provide an explanation for this. The spacing between the concentric rings does not correlate with diameter of the circular graben but does correlate with its proximity to the center of the Utopia basin (Fig. 2). Cover thickness should increase towards the center of the basin, thus suggesting a correlation between ring spacing and thickness of cover material.

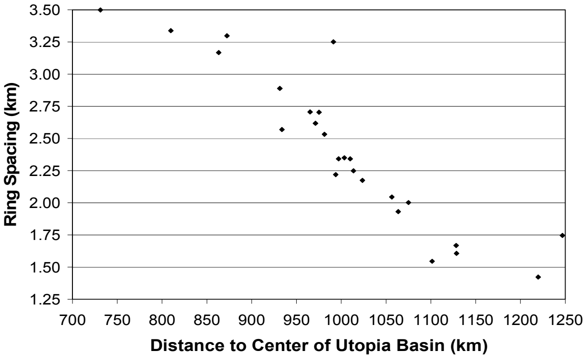

Figure 2. The spacing between the two ring grabens vs. the distance to the center of the Utopia Basin. Center of the Utopia Basin is assumed to be 44ºN, 113ºE, the center point of the 17º circle that circumscribes the Utopia polygonal terrain [7]. Alternatively, the lowest topographic point as determined by MOLA [14] is located at 45ºN, 112ºE. Although there are small variations in the plot when using this location, the trend is the same.

The work presented here determines if analytical and/or numerical models of compaction, drape folding and horizontal extension could 1) explain the doubling of circular grabens and 2) explain the observed dependency of graben spacing on cover thickness. We postulate that two separate mechanisms act to produce the two grabens; drape folding associated with differential compaction yields a graben just inside of the crater rim and extension of the shrinking material covering the buried crater yields a second graben outside of the crater rim.

Procedures and Results:

Folding associated with simulated compaction over buried topography: The analytical model of drape folding [7] assumes that the cover layer could be represented as an elastic plate overlying a compacting substrate. The compaction load q(x) is assumed to be sinusoidally distributed ($\sin(^{\pi}/_{L})x$) and elastic plate theory is used to derive the deflection of the cover material over a buried crater rim [7]:

$$w(x) = \frac{w_m}{(\frac{1}{\pi}-\frac{1}{4})}\frac{(\frac{L^2}{\pi})\sin(\frac{\pi}{L})x + x^2 - Lx}{L^2} \qquad 1)$$

where x=0 is over the crater rim, x=L/2 is the width of the crater wall and w_m is the maximum deflection. This particular equation depends greatly on the function q assumed, as it doesn't result directly from elastic bending formulations [eg. 15]. In this case the maximum deflection is the surface relief; the slope of the linear best fit through the surface relief vs. ring diameter data can be used to relate w_m to crater diameter. The width of the crater wall, L/2, can be determined from empirical equations [13], and also depends on diameter.

We are thus able to model the deflection over craters of different diameters. The horizontal normal stress at the surface due to flexure (tension positive) is:

$$\sigma_{xx} = \frac{-\frac{T}{2}E}{(1-\upsilon^2)}\frac{d^2w}{dx^2} \qquad 2)$$

where E is Young's modulus (MPa), υ is Poisson's ratio and T is the thickness of the cover material (m). In the analytical model, the maximum horizontal tensile stress occurs a short distance inside of the crater rim, and this location is independent of crater size and cover thickness. However, preliminary numerical modeling indicates that the location of the maximum may move slightly towards the crater center with increasing cover thickness.

Stretching over buried topography: Compaction of a material whose boundaries are pinned has been shown to form grabens, with extension due to volume loss [16]. The Boundary Element Modeling (BEM) code FRIC2D models slip along the crater wall due to remote extension, which simulates material shrinkage. The relief of the crater wall is modeled using control points provided by the published empirical martian crater equations [13] and studies of MOLA profiles through the centers of fresh craters in Utopia. At the surface, maximum horizontal tension occurs outside of the crater, and moves away from the rim as cover thickness increases. The location of the maximum tension also moves away from the rim as crater size increases.

Conclusions:

1. Circular grabens within the polygonal terrain of Utopia Planitia enclose areas that are topographic depressions, as predicted by drape-folding models. The maximum topographic relief across these depressions scales directly with ring diameter, also as predicted by drape-folding models.
2. The development of two ring grabens can be explained by a combination of folding of a compacting cover material over buried crater topography and extension of the cover material (ie. shrinkage). The drape folding yields maximum horizontal normal stress just inside the crater rim, while extension of the cover produces maximum horizontal tension outside of the crater rim, which can produce a second graben.
3. The observed relationship between graben spacing and cover thickness may also be a consequence of the combined drape folding and extensional models. While the maximum horizontal tension for drape folding may or may not remain fixed, the location of the maximum outside the crater rim due to extension over buried crater topography moves away from the rim with increasing cover thickness and crater size. Thus, the spacing between these grabens will increase with cover thickness.
4. One of the two single-fracture circular grabens studied is the smallest circular graben observed, while the other is the farthest away from the center of the Utopia Basin, and thus is assumed to be in the thinnest cover material. Since spacing of ring graben depends upon both crater size and cover thickness, it is possible that the two tensional maxima that formed over these craters were close enough to form only one graben.
5. As the model is refined, estimates of the cover thickness in Utopia Planitia, and anywhere else circular grabens are found, will be possible.

References: [1]Carr M.H. et al. (1976) *Science, 193*, 766-776. [2]Masursky H. and Crabill N.L. (1976) *Science, 194*, 62-68. [3]Carr M.H. and Schaber G.G. (1977) *JGR, 82*, 4039-4054. [4]Morris E.C. and Underwood J.R. (1978) *NASA Tech. Memo., TM-79729*, 97-99. [5]Pechmann J.C. (1980) *Icarus, 42*, 185-210. [6]McGill G.E. (1986) *GRL, 13*, 705-708. [7]McGill, G.E. and Hills L.S. (1992) *JGR, 97*, 2633-2647. [8]Lane, M.D., and Christensen P.R. (2000) *JGR, 105*, 17,617-17,627. [9]Nevin C.M. and Sherill R.E. (1929) *AAPGB, 13*, 1-22. [10]Hedberg H.D. (1936) *AJS, 31*, 241-287. [11]Carr M.H. *The surface of Mars*, Yale Univ. Press, 1981. [12]Buczkowski D.L. and McGill G.E. (2002), *GRL, 29(7)*, 10.1029/2001GL014100. [13]Pike R.J. and Davis P.A. (1984), *LPS XV*, 645-646. [14]Thompson B.J. and Head J.W. (1999), *LPS XXX*, #1894. [15] Turcotte D.L. and Schubert G. *Geodynamics*, John Wiley, 1982. [16] Cartwright J.A. and Lonergan L. (1996) *Basin Res., 8*, 183-193. [17] Cooke M.L. and Pollard D.D. (1997) *JSG, 19*, 567-581.