TECTONICS OF UTOPIA BASIN, MARS: RESULTS FROM FINITE ELEMENT LOADING MODELS .

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Introduction: The Utopia basin is one of the largest impact structures in the solar system. One of its striking features is the prominent system of faulting that appears within the region (see Fig 1). The tectonics within Utopia can be separated into two distinct subsets: along the eroded crater rim, basin concentric features dominate, and towards the center of the basin, the direction of faulting changes to predominantly radial. Both types of features have been interpreted as compressional reverse faults [1], which must have occurred in response to crustal stresses. Here we test the hypothesis that the tectonic features found within the Utopia region are due to stresses resulting from the deflection of the lithosphere under the weight of the material infilling the basin and also from stresses resulting from self-deformation of the fill material itself. The methods used here also allow us to explore the influence of differential compaction of the basin fill material as well as the role of gravitational slumping of the material on the stress regime in Utopia Planitia.

Model: For the modeling presented here we utilized a finite element package, MSC.Marc-Mentat, to portray the mechanics of Utopia basin. The basic structures of the initial meshes used in this study are taken from the thin-shell model results presented in Searls et al. [2]. In that work, the authors solved for the pre-fill basin depth of Utopia and the amount of fill needed to match the current observed topography after flexure. From these analytical model results, cross sections were created through the center of Utopia basin to obtain the starting geometry for the mesh.

Due to the long wavelength of the basin, a spherical axisymmetric mesh was used in order to incorporate membrane stresses. The depth of the mesh is set equal to the lithospheric thickness and a Winkler foundation at its base mimics the lithosphere-asthenosphere boundary. We employed an elastic rheology; in future studies we will explore the role viscous creep in the lower regions of the model lithosphere.

Results: The stress results were calculated along the top-most elements of the spherical mesh. As the surface of the mesh represents the contact between the ground and atmosphere, the shear stresses along this boundary are zero, so the local ground plane contains the two horizontal, orthogonal principal stresses (here described as the "radial" and "tangential" components in reference to the center of axisymmetry in the basin) Because the top of the mesh is a free surface (no overburden), the vertical principal stress is zero. The magnitudes of the radial and tangential stress components are shown as a function of the distance (in degrees) from the center of the load in Figure 2. Compressive stresses are negative and tensile stresses are positive.

A plot of the radial and tangential components of stress is extremely useful in predicting the style of faulting that one expects to see on the surface. In Figure 2, the dotted lines separate the predicted faulting styles into zones according to Anderson's theory of faulting [3]. The predictions are as follows: I - concentric reverse faults, II – radial reverse faults, III and VI – strike-slip, IV – circumferential grabens, V – radial grabens. In order to help facilitate comparisons between the predicted and the observed faults, radial distances have been included in Figure 1. A comparison of these figures shows that the predicted radial faults of zone II are in agreement with the observed tectonic features; however, concentric reverse faults are seen in the region where circumferential grabens (zone V) and strike-slip faults (zone VI) are predicted to occur. Also absent from the observed tectonics are predicted concentric reverse faults in the interior of basin (zone I) and the radial grabens predicted to occur between the observed radial and concentric reverse faults.

Discussion: Amazonian-age flows (outlined by the dashed line in Figure 1) from the Elysium volcanic province obscure evidence of faulting in the Utopia region [1,4]. These Elysium flows cover a good portion of the region of predicted concentric reverse faulting in the basin center leaving exposed the region where observed radial faulting is predicted to occur; however, this region of predicted radial faulting is relatively small. In addition, strike-slip faulting and extensional features are predicted where concentric reverse faults are found along the eroded crater rim. This leads us to consider the influence of outside sources of stress.

As Tharsis dominates the overall shape of Mars [5], the effect of this volcanic province on the Utopia region cannot be ignored. The Tharsis load contributes a global influence in the stress field of the planet [e.g. 6,7]. In the northern lowlands, Tharsis related reverse faulting extends in an arcuate pattern for ~7000 km around the volcanic province [8]. At the margins of the Utopia basin the ridges become more circumferential to Utopia indicating that the interplay between these features is an important part of the modeling of Utopia basin. *Sleep and Phillips* [7] estimate that this compressional stress is on the order of 25 MPa within the Utopia region; however, as this work was per-

formed prior to the current high resolution gravity and topography data, this value provides only a rough first-order estimate of the actual magnitude.

In addition to the compressional strains from the Tharsis load, it is likely that planetary contraction also contributed to the global compressive regime. After a brief period of extension after planetary accretion, model results indicate that secular cooling of the planet led to high compressional stresses in the lithosphere of Mars for approximately a billion years, with the strain magnitudes tapering off thereafter [9]. The formation of the Hesperian-aged wrinkle ridges within Utopia is within this timeframe of increased global compressional stress [10]. However, results presented by Hauck et al. [11] showed that, although global compression would occur, this mechanism would not lead to significantly high strains. As an alternative, they suggest that global climate change could have had a more pronounced impact on the global stress regime; however, this would require extended periods of elevated temperatures to result in the wrinkle ridges found in the Hesperian volcanic plains.

The combined effect of global compression mechanisms on the Utopia results would be to shift all of the stress results in the compressive direction. This would effectively widen the region of predicted radial wrinkle ridges (zone II), and hence, decrease the size of the region where radial normal faults are predicted but not observed (zone IV). This added compression could also change the strike-slip zone into a zone of dominantly radial compressive stresses, predicting circumferential wrinkle ridges, as are observed at the edge of the basin.

In the models, as the elastic thickness decreases, more compressive global input is required to shift the tectonic style into compression for the concentric ridges located at the edge of the basin. However, the combination of stresses from Tharsis, global cooling, and climate changes could be sufficient to provide the compression required to predict these features.

Although differential compaction can be an important process in small buried craters [12], our results indicate that differential compaction within Utopia does not affect the types of faulting predicted. These results also show that the gravitational slumping of material towards the basin center is not significant enough to shift the dominant prediction from concentric to radial faulting in the basin center. This is most likely due to the relatively low slopes within the basin. On average the slopes within Utopia basin are < 0.3°.

The results of the analysis also show that the global response to the Utopia mascon is small but not insignificant. The simulations show that Utopia contributes on the order of tens of MPa of compressive stress antipodal to the basin with the radial and tangential components of stress being approximately equal. However, this signal is effectively swamped by the larger stress of Tharsis.

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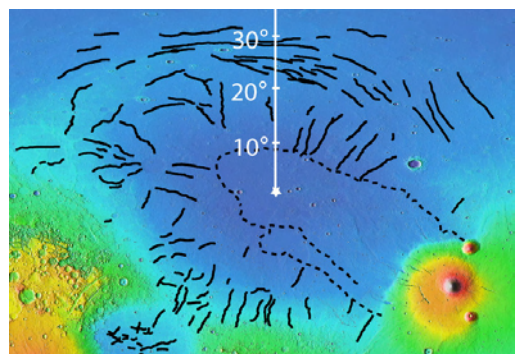

Figure 1. MOLA shaded relief map of Utopia basin. The observed faults are outlined in solid black.

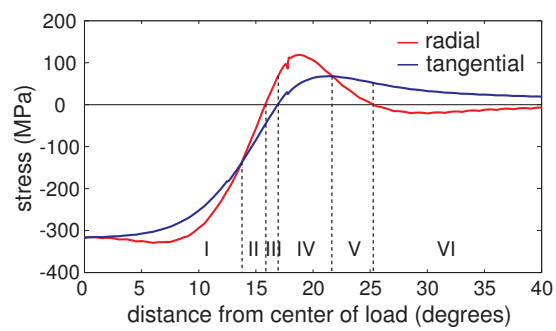

Figure 2. Magnitude of the principal horizontal stress components (radial in red and tangential in blue) as a function of the distance from the center of the load. Model parameters assumed are a crustal thickness of 35 km, a Young's modulus of 10^{11} Pa, a Poisson's ratio of 0.25, and densities for the crust and mantle of 2900 kg/m^3 and 3500 kg/m^3 respectively. Roman numerals indicate type of faulting according to Anderson's theory (see text).