Eastern Olympus Mons Basal Scarp: A Landslide Story? M. B. Weller[1], P. J. McGovern[2], T. Fournier[1], J. K. Morgan[1] and O. Katz[3], [1]Department of Earth Science, Rice University, Houston, TX 77005, USA (matt.b.weller@rice.edu; thomas.fournier@rice.edu; morganj@rice.edu), [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, USA (mcgovern@lpi.usra.edu), [3]Geological Survey of Israel, Jerusalem, Israel (odedk@gsi.gov.il).

Introduction: Olympus Mons (Figure 1) is the tallest volcano in the solar system, extending up to a 23km height above its' base, and is nearly 600km in diameter. The volcanic edifice is located in the northwest portion of the Tharsis Rise on Mars, and is partially bounded by an escarpment of up to 10km height, known as the Olympus Mons basal scarp. Extending hundreds of kilometers out from much of the basal scarp are the aureole deposits. While the origin of the aureole lobes that surround Olympus Mons are still controversial, it is generally acknowledged that the basal scarp and the aureole lobes are related to one another. Explanations for these features range from gravitational spreading and thrust sheets [1,2,3], wave cut action and submarine processes [4,5], volcanic spreading [6,7], and mass wasting [5,8,9,10,11]. Previous works identified a set of parallel trending faults along the Eastern Olympus Mons basal scarp (EOMBS) [6,12] (e.g. Figure 2) that cut young surfaces, constraining deformation to be < 40 Myr [12].

In this work, we evaluate the potential for slope failure along the EOMBS and establish several successful scenarios for creating the southern portion of the parallel Olympus Mons east flank extensional and compressional fault systems (wrinkle ridges) via a single failure surface.

Method: We use Digital Terrain Model (DTM) data product 1089_0000 [13] that was derived [14] from the High Resolution Stereo Camera (HRSC) [15,16]. The data product has 75m/px grid spacing and 10m vertical resolution. We run slope profiles along the basal scarp, perpendicular to the fault traces (Figure 2) and analyze the stability of the slope through Janbu's method [16], a 2D limit equilibrium Factor of Safety (FS) calculation (Figure 3). The FS is the ratio of the static resisting to driving forces along a circular slip surface (Figure 3). Generally, a FS > 1 is stable, a FS < 1 is unstable and in failure, and a FS ~1 is critical. Several edifice stratigraphies are considered in the model setup: a homogeneous rock mass and a weak 1km thick sediment (phyllosilicate) layer [18] of varying depths (within the volcanic edifice, and at 1, 3, and 5km depths below the reference datum). Each modeled stratigraphy is run for dry, water saturated, and for layers at 3 and 5km depth, overpressured, conditions.

Results: Best fit stratigraphies indicate that pore fluid pressure is required and the subsequent detachment depth decreases northward along the Southern transects R1—R2 (Figure 2a) from 1 – 3km, and results in a slip surface that is marginally above the critical state, i.e. relatively stable (FS ~ 1.2), along the southern most transect R1, but in failure along the transect R2 (FS <=1). Along the Northern most transects (R4—R5), an overpressured weak stratigraphic layer at 3km depth results in a slip surface on the verge of failure, and broadly matches observed fault locations. These overpressured conditions however invoke unrealistically high pore fluid pressures.

Discussion: The FS analysis indicates that the EOMBS is relatively insensitive to changes in dry stratigraphic layer properties. In order to obtain failure/near failure conditions, a prescribed weakness, such as the existence of a phyllosilicate sedimentary layer [18] that is pore fluid saturated, may be required and acts as a mechanism that allows the volcanic edifice to spread laterally [7,10,19]. Additionally, this layer may create a weak detachment that places the EOMBS into a conditionally unstable state, that allows for the failure of the edifice to form the aureole lobes. Slope destabilization and possible collapse could further be triggered by such events as volcanic activity, impacts, or portions of the EOMBS failing. Circular and 2D failure geometries are non-ideal to examine the edifice, and quasi-circular to non-circular geometries should be allowed in order to examine such 3D structures as the slope breaking extensional fault trace and undulating wrinkle ridges in Figure 2.

The formation mechanism of martian wrinkle ridges is controversial, with both thin-skinned [20] and thick-skinned [21,22] deformation proposed. Our results indicate that the wrinkle ridges at the base of the EOMBS are shallow structures, i.e., consistent with thin-skinned deformation.

Conclusions: In the homogeneous state our FS analysis shows the EOMBS is a stable slope, suggesting an internal weakness is required to achieve failure. The FS of the slope traces are insensitive to changes in dry stratigraphic layer properties, suggesting that for failure of the southern EOMBS to be reached, it may need to have a weak, pore fluid saturated layer dipping northward from 1— 3km depth. The northern portions are indicated to require an overpressured (> lithostatic) weak layer at 3km depth. This unrealistic requirement, with the undulating expression of surface faulting, suggests the need for future investigations to explore the EOMBS stability in three dimensions. It would be difficult for the formation of the current regions of faulting of the EOMBS (Figure 2) to have occurred via a landslide process in the presence of free standing water (i.e. ocean) as the edifice would be in failure for most of the transects in Figure 2a, and the observed faulting locations would be inconsistent with formation under such conditions. In order to produce large volume failures, a weak layer with high pore fluid pressure (overpressured for larger volumes and consistent fault locations) are suggested. Potential failure volumes range from 3200km^3 – 8000km^3, or 18% – 45% of the estimated volume of the "East" Olympus Mons aureole lobe (Figure 1 blue box) [23].

References: [1] Harris, S. A. (1977) JGR, 82, 3099-3107. [2] Francis, P. W. and Wadge, G. (1983) JGR, 88, 8333-8344. [3] Tanaka, K. L. (1985) Icarus, 62, 191-206. [4] Mouginis-Mark (1993) LPSC, XXIV, 1021–1022. [5] Blasio, F. V. (2011) EPSL, 312, 26-139. [6] Borgia, A. et al. (1990) JGR, 95, 14357-14382. [7] McGovern, P. J. and Morgan, J. K. (2009) Geology, 37, 139-142. [8] Lopes, R. et al. (1980) M&P, 22, 221– 234. [9] Lopes, R. et al. (1982) JGR, 87, 9917-9928. [10] McGovern, P. J. et al. (2004) JGR, 109, E08008. [11] Shea, T. and van Wyk de Vries, B. (2008) Geosphere, 14, 657-686. [12] Basilevsky et al. (2006), GRL, 33, L13201. [13] HRSCview, http://hrscview.fu-berlin.de/. [14] Gwinner, K. et al., (2005) Geoinf., 5, 387–3942. [15] Neukum, G. et al., (2004) ESA Special Publications, SP-1240. [16] Jaumann, R. et al. (2007) P&SS, 55, 928-952. [17] Janbu, N. (1954) Proceedings of the European Conference of Earth Slopes, 3, 43–49. [18] Bibring, J. P., et al., (2006) Science 312, 400. [19] Morgan, J. K., and P. J. McGovern (2005) JGR, 110, B05402. [20] Watters (2004), Icarus, 171, 284-294. [21] Montesi and Zuber (2003), JGR, 108. [22] Golombek et al (2001), JGR, 106. [23] Griswold et al., (2008) LPSC, XXXIX, 2239

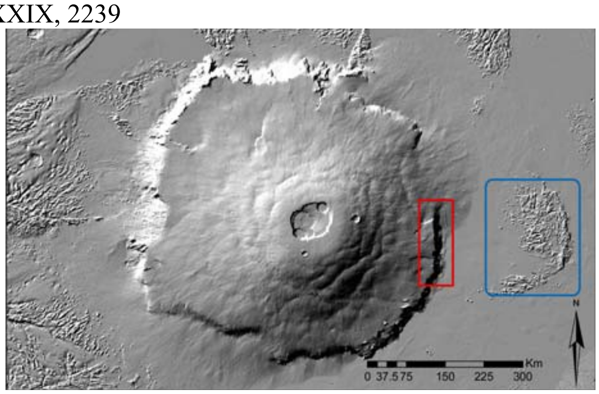


Figure 1: Themis daytime IR image of the Olympus Mons region. The study area in is highlighted in red box. Eastern Olympus Mons aureole lobe indicated by the blue box.

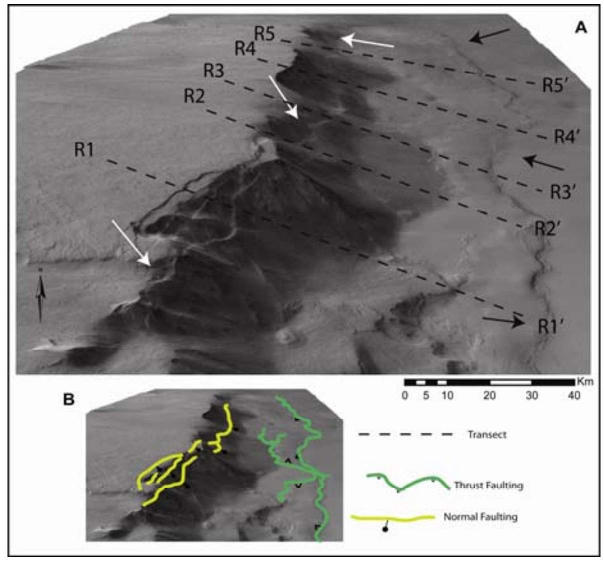
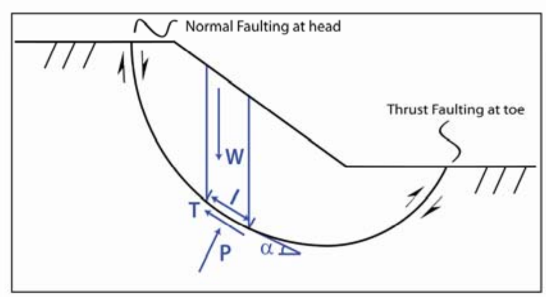


Figure 2: A) HRSC 3D DTM image of the Eastern Olympus Mons basal scarp (red box from Figure 1). White arrows indicate the extensional fault trace, and black arrows indicate the contractional fault (wrinkle ridges) trace. B) Structural map of eastern basal scarp.



$$F_s = \frac{\sum resisting\ force}{\sum driving\ force} = \frac{\sum \left(cl + (P - ul)\tan\phi\right)\sec\alpha}{\sum W \tan\alpha}$$

Figure 3: Calculating the Factor of Safety (FS) from driving and resisting forces using Janbu's simple method (force balance approach) and circular failure surfaces. Where, W = slice weight, T= resisting force acting on a slice, alpha = angle from horizontal to failure surface, P = normal force acting on a slice, l = length of slice along the failure surface, μ = pore fluid pressure, c = cohesion, and φ = angle of internal friction.

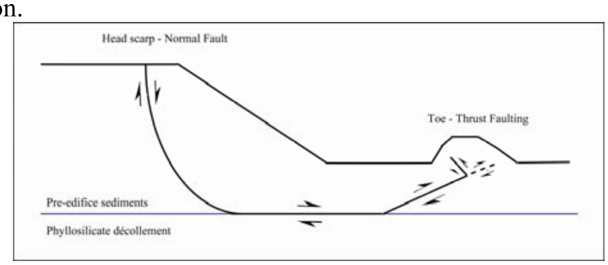


Figure 4: Schematic structural interpretation of the Southern EOMBS.