EVALUATION OF THE OROGENIC BELT HYPOTHESIS FOR THE FORMATION OF THE THAUMASIA HIGHLANDS, MARS.

Amanda L. Nahm[1] and Richard A. Schultz[1] [1]Geomechanics–Rock Fracture Group, Department of Geological Sciences and Engineering/172, University of Nevada, Reno, NV 89557–0138, nahma@mines.unr.edu

Summary: The orogenic belt hypothesis for the formation of the Thaumasia Highlands is tested using critical taper wedge mechanics. We find that conditions required for the presence of a basal décollement, which is required for orogenic belts on any planet, are improbable for Mars and thus render the formation of the Thaumasia Highlands as an orogenic belt unlikely.

Introduction: The formation of the Thaumasia Highlands (Fig. 1) has been of interest for over 30 years. The formation of the Highlands is an important question in Mars science because Thaumasia constitutes a significant and early portion of Tharsis, and understanding its history will contribute to the understanding of the volcanotectonic history of the Tharsis region [1]. Understanding the volcanotectonic history of Tharsis is critical to understanding the tectonic and geologic evolution of Mars [2]. Tharsis is the largest volcanotectonic province on Mars and has been active throughout Mars' history [1–4]. Unraveling its complex history will give new information about the evolution of Mars.

Regional and Geologic Setting: The Thaumasia region is a major volcanotectonic province of Tharsis that lies south of Valles Marineris and is at its southern edge (Fig. 1). It includes a tectonic plateau with high interior plains and surrounding highlands [1] and an arcuate region of high topography, known as the Thaumasia Highlands (Fig. 1).

The Thaumasia region consists of diverse rock types, tectonic structures, and erosional and depositional features [1]. The Thaumasia Highlands are the dominant feature, extending nearly 2900 km in length and rising ~4 km above the surrounding terrain [1, 5]. The Highlands have been mapped as mostly Noachian basement and Noachian and Hesperian fractured units [1, 6, 7]. The Highlands are fractured by several sets of graben [1] (Fig. 1) and the margin is characterized by thrust faults (either in the form of wrinkle ridges or lobate scarps). The surrounding plains consist of cratered highlands to the south, ridged plains to the east, and lobate lava flows from Daedalia Planum to the west [1]. For detailed stratigraphy see [1] and [7].

The geological and tectonic histories of the Tharsis and Thaumasia regions on Mars are complex. Thaumasia volcanotectonic activity occurred early in the development of Tharsis [1]. Tectonic activity in Thaumasia began and peaked during the Noachian and declined during the Hesperian through the Amazonian [1, 2]. The tectonic histories of Mars and Thaumasia are recorded as the distribution and ages of fault and ridge systems [1, 2]. Of the ~15,000 faults mapped over the entire planet [8], the majority occur in the vicinity of Tharsis. The majority of structures mapped by [8] were extensional (~65%), while a smaller fraction (~35%) were contractional.

Formation Hypotheses: Several hypotheses have been proposed for the formation of the Thaumasia Highlands. These define two categories: lateral movement as a block or a slide, or formation as an orogenic belt by plate tectonics. The orogenic belt hypothesis is tested here.

According to the orogenic belt hypothesis, the Thaumasia Highlands formed as a result of thrusting of the Thaumasia Plateau to the west, south, and east during a period of "lithospheric mobility," possibly caused by subduction and collisional tectonics along its western border [5]. The Thaumasia-Aonia Orogen, as it has been called, occurred sometime between Noachian and Early Hesperian times [5]. A north-south directed compression caused shortening of Thaumasia along this direction, triggering southward-directed thrusting along its southern margin [5]. The Thaumasia Highlands orogenic belt has been compared to orogenic belts on Earth (e.g. Alpine Cantabrian Belt in Spain).

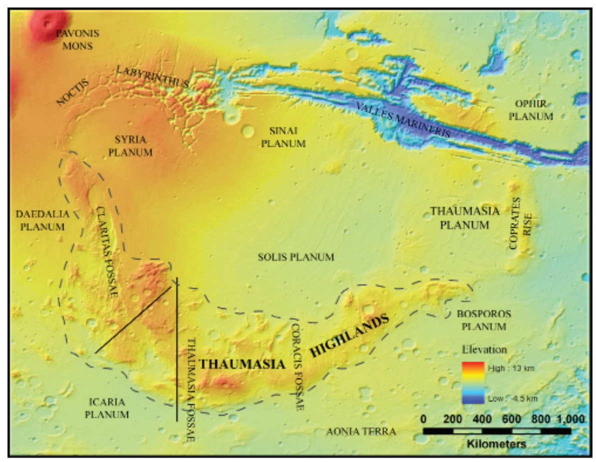

Figure 1. Index map showing the Thaumasia region, Mars. Key locations are labeled. Location of the Thaumasia Highlands outlined by dotted line. The Thaumasia Plateau encompasses the Highlands and the plains between them and Valles Marineris. Profile locations in Thaumasia Highlands shown as solid black lines in lower left portion of image. Base image is MOLA topography. MOLA topography scale shown in lower right portion of image.

Methods: We test the orogenic belt hypothesis by using critical taper wedge mechanics. Critical taper wedge mechanics (CTWM) has been used to describe the formation and mechanics of fold-and-thrust belts such as the Central Mountains of Taiwan and the Himalaya on Earth [9 – 12] and the Artemis Chasma fold belt on Venus [13]. Fold-and-thrust belts, or orogenic belts, exhibit common properties and geometries: (1) a basal detachment surface or décollement that dips toward the interior of the belt along which the wedge slides, (2) large horizontal compression in the material above the décollement, and (3) a wedge shape of the deformed material which tapers toward the margin of the belt (Fig. 2) [9]. As the material is subjected to a sufficiently large horizontal compression, it deforms internally, forming nested and duplexing thrust faults and thickening until a critical taper ($\alpha + \beta$ in Fig. 2) is achieved. The wedge then slides stably along the basal décollement.

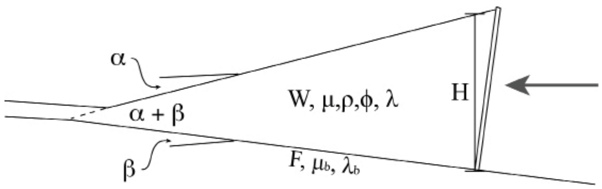

Figure 2. Schematic showing geometry of a generalized critical taper wedge. Arrow on right represents horizontal compression. Variables are discussed in text. After [11, 12].

CTWM can be described using equations that characterize the physical properties of the wedge material and the geometry of the wedge. The surface slope (α) of a mechanically homogeneous wedge is linearly related to the dip of the basal décollement (β) by [12]:

$$\beta = \frac{F - \alpha\left\{\left[1 - \left(\frac{\rho_f}{\rho}\right)\right] + W\right\}}{W}$$

$$F = \mu_b(1 - \lambda) + \frac{S_b}{\rho g H}$$

$$W = 2(1 - \lambda)\left[\frac{\sin\phi}{1 - \sin\phi}\right] + \frac{C}{\rho g H}$$

where F is the fault strength, W is the wedge strength, ρ_f is the density of the overlying fluid (in this case, the density of the Martian atmosphere), ρ is the density of the wedge material, μ_b is the basal coefficient of friction, λ is the pore fluid pressure in the wedge, S_b is the fault cohesion, g is the acceleration due to gravity, H is the thickness of the wedge, ϕ is the angle of effective internal friction for the wedge (where $\phi = \tan^{-1} \mu$), and C is cohesion of the wedge (Fig. 2).

MOLA profiles were measured across the Thaumasia Highlands in different orientations (Fig. 1). Average surface slopes (α) used to represent surfaces of potential orogenic wedges were measured from these profiles and used in the calculations. Physical properties, such as μ_b, ϕ, and λ, were varied within reasonable values of these variables. The dip of the hypothesized basal décollement (β) was calculated for each case using the known surface slopes. Values for $\beta < 10°$ were considered to be reasonable, since measured values of β on Earth have been found to be $\leq 10°$ [9]. To test the horizontal décollement case, β was set to equal zero and a corresponding α was calculated. When the calculated α was within ±50% of the measured value, this was considered a match and the parameters (μ_b, ϕ, and λ) were recorded.

Results: Values of μ_b, ϕ, and λ that match the measured surface slopes with a horizontal décollement are shown in the first column of Table 1. The second and third columns (Table 1) show the ranges of these values that, when put into the above equations, yield values of β = 1º – 5º and β > 5º.

The geometry of these potential orogenic wedges in the Thaumasia Highlands requires unusually low values of basal friction (μ_b = 0.1) if the Highlands were to have formed as an orogenic wedge. For comparison, wedges on Earth have strong décollements (μ_b = 0.85), consistent with Byerlee friction and frictional sliding along the base [9]. Also for comparison, the coefficient of fiction for serpentinite fault gouge has been found to be as low as 0.15 [14]. In general, these calculations are not dependent on particular values of pore fluid pressure (i.e., dry, hydrostatic, or higher).

Slope		$\beta = 0°$	$\beta = 1 - 5°$	$\beta > 5°$
0.418°	μ_b	0.1	0.1	0.1 - 0.85
	μ	0.2 - 1.0	1.0	0.2 - 1.0
	λ	0.9	0 - 0.36	0 - 0.9
0.437°	μ_b	0.1	0.1	0.1 - 0.85
	μ	0.2 - 1.0	0.2 - 1.0	0.2 - 1.0
	λ	0.9	0 - 0.9	0 - 0.9
0.773°	μ_b	0.1	0.1	0.1 - 0.85
	μ	0.2 - 1.0	0.4 - 1.0	0.2 - 1.0
	λ	0 - 0.9	0 - 0.9	0 - 0.9
1.017°	μ_b	0.1	0.1	0.1 - 0.85
	μ	1.0	0.4	0.2 - 1.0
	λ	0 - 0.36	0 - 0.36	0 - 0.9

Table 1. Results of CTWM calculations. For explanation, see text.

Conclusions: Conditions required for the formation of critical taper wedges on Mars are improbable, rendering the orogenic belt hypothesis unlikely. Contrary to the models that require slipping décollements beneath Thaumasia and/or its margin, the data imply instead formation models involving a mechanically continuous lithospheric section [15]. Additionally, the plate tectonics hypothesis for the formation of the dichotomy boundary [16] is not widely accepted as a valid model [17], and this also puts into question the formation of the Thaumasia Highlands as an orogenic belt formed through analogous lithospheric mobility and subduction. (i.e. plate tectonics).

References: [1] Dohm, J. M., and K. L. Tanaka, (1999) *Planet. Space Sci.*, **47**, 411–431. [2] Anderson, R. C., *et al.,* (2001) *J. Geophys. Res.*, **106** (E9), 20,563–20,586. [3] Phillips, R. J. *et al.,* (2001) *Science*, **291**, 2587–2591. [4] Solomon, S. C., *et al.,* (2005) *Science*, **307**, 1214–1220. [5] Anguita, F., *et al.,* (2006) *Icarus*, **185**, 331–357. [6] Scott D. H. and Tanaka K. L. (1986) USGS Misc. Inv. Series Map, I–1082-A. [7] Dohm, J. M., *et al*., (2001) USGS Misc. Inv. Ser. Map I–2650. [8] Knapmeyer, M., *et al*. (2008) EGU abstract 2008–A–03574. [9] Davis, D. *et al.,* (1983) *J. Geophys. Res.*, **88** (B2), 1153–1172. [10] Dahlen, F. A., *et al.*, (1984) *J. Geophys. Res.*, **89** (B12), 10,087–10,101. [11] Dahlen, F. A., (1990) *Annu. Rev. Earth Planet. Sci.*, **18**, 55–99. [12] Suppe, J., (2007) *Geology*, **35**, 1127–1130. [13] Suppe, J. and C. Connors, (1992) *J. Geophys. Res.*, **97** (E8), 13,545–13,561. [14] Paterson, M. S. and T-f. Wong, (2005) *Experimental Rock Deformation — The Brittle Field*, Springer. [15] Okubo, C. H., and R. A. Schultz (2003) *Geophys. Res. Lett.*, **30**, 2154, 10.1029/2003GL018664. [16] Sleep, N. H., (1994) *J. Geophys Res.*, **99** (E3), 5639–5655. [17] Pruis, M. J. and K. L. Tanaka, (1995) LPSC Abstract 1147.

Abstract published in Lunar and Planetary Science *XL*, CD-ROM (www.lpi.usra.edu/meetings), Lunar and Planetary Institute, Houston (2009).