

**Geometry of Thrust Faults beneath Amenthes Rupes, Mars** A. Vidal<sup>1</sup>, K. M. Mueller<sup>1</sup>, and M.P. Golombek,  
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**Introduction:** Amenthes Rupes is a 380 km-long lobate fault scarp located in the eastern hemisphere of Mars near the dichotomy boundary. The scarp is marked by about 1 km of vertical separation across a northeast dipping thrust fault (top to the SW) and offsets heavily-cratered terrain of Late Noachian age, the visible portion of which was in place by 3.92 Ga and the buried portion in place between 4.08 and 4.27 Ga [1]. The timing of scarp formation is difficult to closely constrain. Previous geologic mapping [2] shows that near the northern end of Amenthes Rupes, Hesperian age basalts terminate at the scarp, suggesting that fault slip predated the emplacement of these flows at 3.69 to 3.9 Ga. Maxwell and McGill [3] also suggest the faulting ceased before the final emplacement of the Late Hesperian lavas on Isidis Planitia.

The trend of the faults at Amenthes, like many thrust faults at the dichotomy boundary, parallels the boundary itself. Schultz and Watters [4] used a dislocation modeling program to match surface topography and vertical offset of the scarp at Amenthes Rupes, varying the dip and depth of faulting, assuming a slip of 1.5 km on the fault. They modeled faulting below Amenthes Rupes as having a dip of between 25 and 30 degrees and a depth of 25 to 35 km, based on the best match to topography. Assuming a 25 degree dip and surface measurements of vertical offset of between 0.3 and 1.2 km, Watters [5] later estimated the maximum displacement on the Amenthes Rupes fault to be 2.90 km. However, these studies did not determine the geometry of the thrust using quantitative constraints that included shortening estimates.

Amenthes Rupes deforms large preexisting impact craters. We use these craters to constrain shortening across the scarp and combine this with vertical separation to infer fault geometry. Fault dip was also estimated using measurements of scarp morphology. Measurements were based on 460 m ( $1/128^\circ$  per pixel) digital elevation data from the Mars Orbiter Laser Altimeter (MOLA), an instrument on the Mars Global Surveyor (MGS) satellite [6].

**Methodology:** Axial surface mapping was undertaken to analyze backlimb and forelimb morphology and to estimate backlimb width. Axial surface mapping uses changes in topography to map axial fold surfaces at depth [7,8]. This technique is used for terrestrial fault-related folds to assess slip budgets across blind thrust ramps. Axial surface mapping was completed using first and second derivatives of the topography as

obtained from MOLA data. The second derivative maps were used to identify inflection points in topography which are interpreted as axial surfaces formed above bends in underlying blind thrusts.

Fault surface ruptures also provide independent information on underlying fault dip. Topographic transects across the deformed crater were used to estimate vertical separation. This was coupled with mapping of offset crater rims (Fig. 1). The slopes of undisturbed rims ranged from 10 to 19 degrees; these features steepened to 15 to 27 degrees where they were deformed across the Amenthes scarp. Horizontal shortening along the scarp was measured by mapping the location of the crater rim on either side of the scarp and then calculating the offset between the two segments of the shortened crater, that was assumed to be initially concentric.

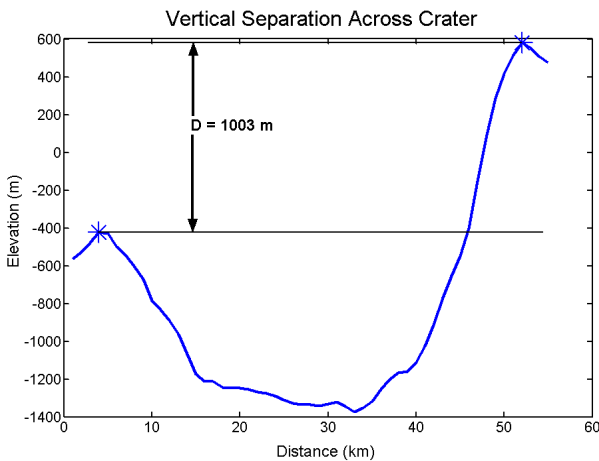
To forward model scarp formation, a mechanical modeling program was used to estimate fault dip, backlimb geometry, and slip along the fault that were consistent with observed fold morphology [9]. Given measurements of the backlimb of the fault-related fold formed above Amenthes and the width and height of the scarp, we interpret the underlying thrust fault to have a listric geometry. Alternatively, a planar thrust ramp stepping up from a decollement would have produced a much different fault-related fold that was characterized by a broad, flat top bounded by a narrow backlimb.

**Results:** Axial surface mapping (Fig. 2) suggests the backlimb at Amenthes is a maximum of 58 km wide. Topographic transects across the offset crater suggested vertical separations of 910 to 1080 m, with an average of 1000 m. The average horizontal separation between the crater rims across the scarp was  $3 \pm 0.15$  km (error represents standard deviation resulting from several iterations of measurement of separation, which is propagated through the calculations for slip and dip). This yields a slip estimate of  $3.16 \pm 0.15$  km and a fault dip of approximately  $18.4 \pm 0.9$  degrees.

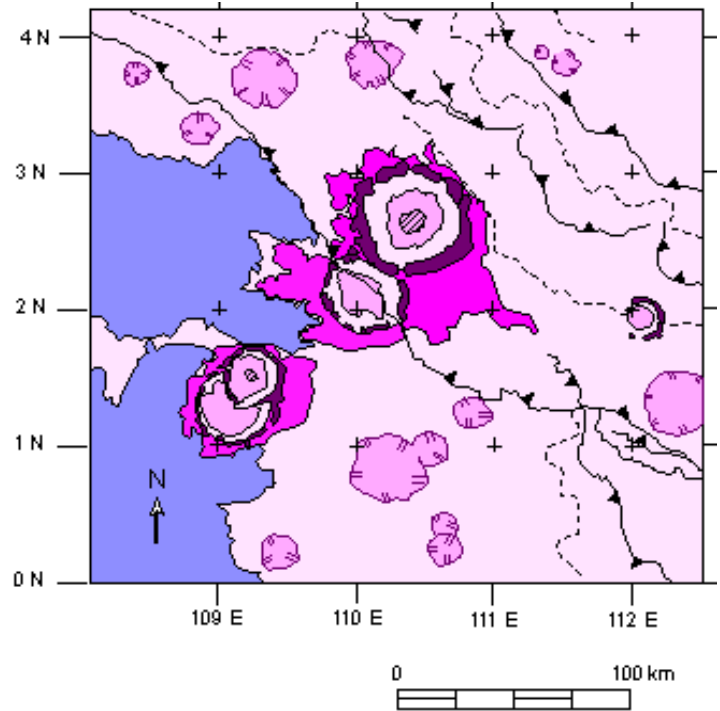
The parameters for the mechanical modeling are as follows: backlimb width = 58 km, backlimb slope = 1 degree, slip =  $3.16 \pm 0.15$  km, fault dip =  $18 \pm 1$  degrees. Mechanical solutions for fault geometry based on these values and a non-layered substrate suggest the thrust fault that underlies Amenthes soles at a depth of  $8.9 \pm 0.5$  km.

**Conclusions:** Our structural model of the thrust fault underlying Amenthes Rupes suggests it dips shallowly in comparison to thin-skinned terrestrial analogs. Faulting depth is indicative of a rheological change; a weak layer must exist at these shallow levels. This implies a crustal strength column with onset of crystal plasticity at shallow depth, suggesting a high heat flow for this region.

**References:** [1] Frey, H.V. (2004) *Workshop on Hemispheres Apart*, 19-20. [2] Hiller, K.H., (1979) USGS Map I-1110 (MC-14). [3] Maxwell, T.A. and McGill, G.E. (1988) Proc. Lunar Planet. Sci. Conf. XVIII, 701-711, [4] Schultz, R.A. and Watters, T.R. (2001) *LPSC XXXII*, Abstract #1736. [5] Watters, T.R. (2003) *JGR*, 108, doi:10/1029/2002JE001934. [6] Smith, D.E., et al. (2001) *JGR*, 106, 23,689-23,722. [7] Shaw, J.H. et al. (1994) *AAPG Bull.*, 78, 700-721. [8] Vidal, A. and Mueller, K.J. (2004) *LPSC XXXV*, Abstract #2086. [9] Johnson, K.M., and Johnson, A.M. (2002) *J. Struct. Geol.*, 24, 277-287.



**Figure 1.** Vertical separation is measured using the location of the deformed crater rim. Separation values ranged between 910 to 1080 m, with an average of 1000 m. In this diagram the fault breaks the surface between 32 and 40 km on the horizontal axis.



**Figure 2.** Map of the Amenthes Rupes region. Legend appears below. The main scarp deforms a crater in the center of the mapped region. Trace of fault marks base of scarp.

