MECHANICAL MODELING OF THE DISCOVERY RUPES THRUST FAULT: IMPLICATIONS FOR THE THICKNESS OF THE ELASTIC LITHOSPHERE OF MERCURY.

T. R. Watters, R.A. Schultz, M. S. Robinson, and A. C. Cook,

1Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560 (twatters@nasm.si.edu);
2Geomechanics–Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno; 3Department of Geological Sciences, Northwestern University, Evanston, Illinois 60208.

Introduction: One of the most remarkable discoveries of the Mariner 10 mission to Mercury was the existence of hundreds of landforms described as lobate scarps [1, 2, 3]. Based on morphology and offsets in crater wall and floor materials, lobate scarps are interpreted to be the surface expression of thrust faulting [1, 2, 3, 4, 5]. The largest lobate scarp on the hemisphere imaged by Mariner 10 is Discovery Rupes. Located in the southern hemisphere, Discovery Rupes is over 500 km in length [1, 2]. New topographic data for Mercury, derived from digital stereoaanalysis, using updated Mariner 10 camera orientations [6, 7], indicates that Discovery Rupes is up to ~1.5 km high [4, 5]. These data are also providing the first quantitative measurements about the morphometry of Discovery Rupes. Using the new topographic data, it is possible to test the validity of kinematic models proposed for lobate scarps by mechanically modeling the long and short wavelength topography across Discovery Rupes.

Topography and Analysis: Topography of Discovery Rupes was obtained using an automated stereo matching process that finds corresponding points in stereo images using a correlation patch [cf. 8]. A stereo intersection camera model is then used to find the closest point of intersection of matched points which specifies their location and elevation. The derived digital elevation model (DEM) has a grid spacing of 2 km/pixel (Figure 1) [also see 9, 10].

The greatest relief on Discovery Rupes occurs roughly midway long the length of the scarp (south of the 60-km-diameter Rameau crater, Figure 1). The average relief of the scarp in this area is about 1.3 km (Figure 2) [4]. The new topographic data reveal a shallow trough roughly 100 km west of the base of the scarp (Figure 1). This trough is interpreted to be evidence of a trailing syncline and the distance between it and the surface break defines the cross-strike dimension of the upper plate of the Discovery Rupes thrust fault.

Mechanical Model: The 3-D boundary element dislocation program Coulomb 2.0 was used to predict the surface displacements associated with the Discovery Rupes thrust fault. The dislocation method has been successfully applied to terrestrial faults [11, 12] where the magnitude of offset along the fault is known and when the remote stress state or frictional/constitutive properties of the fault are unknown [13, 14]. The magnitude and sense of offset are specified along the fault, then the stresses and material displacements are completely determined using the stress functions for an elastic halfspace [15]. An acceptable match between the model and the topography constrains admissible values. We then calculate the displacement vectors to predict changes in topography due to the surface-breaking thrust fault beneath Discovery Rupes.

Results and Implications: Iteratively adjusting the displacement D, fault dip θ, and depth of faulting T, good fits to the topography are obtained for a relatively narrow range of the fault parameters (Figure 2, 3). Depths of faulting T < 30 km and T > 40 km (Figure 2) produce unacceptable fits to the topography. The best fits to the topography across Discovery Rupes are for a depth of faulting T = 35 to 40 km, fault dip angle θ = 30° to 35°, and D = 2.2 km (Figure 4). A tapered displacement distribution with minima at the fault tips is assumed based on examining the offset where the fault breaks the surface. Where the Discovery Rupes thrust fault cuts the floor of Rameau crater (Figure 1), there is no significant offset suggesting that the cumulative structural relief developed while the fault was blind and propagating up toward the surface.

Our results suggest that the Discovery Rupes thrust fault cuts the mercurian crust to a depth of up to ~40 km. There are examples of terrestrial thrust faults that cut to comparable depths. The Wind River thrust in the Rocky Mountain foreland in Wyoming extends to a depth of 36 km (with a uniform dip of 30° to 35°) [16], cutting the entire elastic lithosphere. On Earth’s continents, Tc typically coincides with the thickness of the seismogenic crust T, (ranging from ~10-40 km), with Tc often less than T [17, 18]. On Mars, the Ammonites Rupes thrust fault extends to a depth comparable to estimates of Tc for the highlands [19] (~20-30 km) [20, 21]. If the Discovery Rupes thrust fault extends to a depth of ~40 km, it may cut the entire mercurian elastic and seismogenic lithosphere. An estimate of Tc from depth of faulting provides insight into the thermal structure of the mercurian crust at the time the faults formed. The effective elastic thickness is though to be controlled by the depth of the 450°C to 600°C isotherm below which the lithosphere is too weak to support long-
term stresses [17, 22]. Our results suggest a thermal gradient of \( -8^\circ \text{K km}^{-1} \) and a heat flux of \( \sim 24 \text{ mW m}^{-2} \) at the time Discovery Rupes formed. These estimates will be testable when MESSENGER [23] and Bepi Colombo returns new gravity and topographic data.


Figure 1. Color-coded DEM generated using Mariner 10 stereo pair 27399 and 166613, overlaid on an image mosaic. The white line indicates the location of the topographic profile across Discovery Rupes (white arrows) shown in Figure 2 and 3. The black arrow and dashed line shows the location of a shallow depression. Rameau crater is indicated by an R on the image. Elevations relative to 2439.0 km reference sphere.

Figure 2. Comparison between predicted structural relief and a topographic profile across Discovery Rupes. Depth of faulting \( T \) is varied while the fault-plane dip and displacement are constant. Profile location is shown in Figure 1. Vertical exaggeration is 30X.

Figure 3. Comparison between predicted structural relief and a topographic profile across Discovery Rupes. Fault-plane dip \( \theta \) is varied while the depth of faulting and displacement are constant. Profile location is shown in Figure 1. Vertical exaggeration is 30X.

Figure 4. Difference between topography and predicted structural relief for model runs shown in Figure 2. Plots indicate that the best fit is obtained for depth of faulting \( T = 35-40 \) km. Vertical exaggeration is 30X.