DISPLACEMENT PROFILES OF WRINKLE RIDGE THRUST FAULTS ON MERCURY. A. M. Keebler[1,2] and T. R. Watters[2], [1]Department of Earth and Space Sciences, West Chester University of Pennsylvania, West Chester, PA 19383 (ak883682@wcupa.edu); [2]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560

Introduction: Compressional stresses that fault and fold the smooth plains volcanic units on Mercury are primarily expressed by tectonic features called wrinkle ridges [1, 2]. The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft returned image and topographic data that make possible morphometric studies of tectonic landforms.

Using high-resolution digital elevation models to conduct morphometric analysis of wrinkle ridges, the displacement profiles of associated thrust faults may be quantified [3, 4]. Displacement profiles facilitate the determination of displacement-length (D_{max}/L) relationships of faults. Displacement profiles provide insight into how the thrust faults develop and the D_{max}/L ratio of a fault population enables the quantification of strain. Estimates of the contractional strain of Mercury's smooth ridged plains are important because it allows a comparison with the strain expressed by the more broadly distributed lobate scarps in intercrater plains formed in response to global contraction [5]. This will enable the evaluation of the contribution of stresses due to subsidence of the smooth plains volcanics and stresses from global contraction due to interior cooling of the planet in the deformation of the ridged plains.

Wrinkle ridges are complex structures consisting of an assemblage of superimposed landforms [1, 2]. The ridges of Mercury's smooth northern plains exhibit a complex network pattern that often overprint ghost craters, shallow buried impact craters that have localized wrinkle ridge formation [6]. This project develops a careful method for measuring the relief along wrinkle ridges on Mercury to generate fault displacement profiles that can be used to determine the displacement-length relationship of wrinkle ridge thrust faults.

Data and methodology: Wrinkle ridges on the smooth northern plains of Mercury were identified in moderate- and high-incidence angle (55°-88°) images obtained by MESSENGER's Mercury Dual Imaging System (MDIS) [7]. Digital elevation models (DEMs) derived from the Mercury Laser Altimeter (MLA) provided the necessary elevation data [8]. Mapping and measurements were performed in an ArcGIS environment.

Typically, displacement-length studies of tectonic landforms assume that maximum relief and maximum fault displacement occur near the midpoint of the fault length and thus tend to concentrate measurements around that location. We measure relief along the entire length to unambiguously identify the maxima. The displacement profile provides an unambiguous location of D_{max} and shape of the profile provides insight into factors effecting fault growth [4].

To constrain the lengths and maximum displacements of the ridges identified in this study, we developed a series of displacement profiles for wrinkle ridges in the smooth northern plains. First, polylines were plotted following the midline and length of each ridge. The length of each ridge was determined from its digitized polyline. To determine the maximum displacement, a series of elevation profiles were extracted at regular intervals along each ridge, normal to the strike of each ridge (Fig. 1). Within each orthogonal profile, elevation data were examined to identify a high and representative low elevation from which to calculate the relief. Ridge relief is plotted with respect to distance along ridge (Fig. 2). The displacement necessary to restore the topography to a planar surface is roughly approximated by $D = h/\sin\theta$ where h is the measured relief and θ the fault plain dip, assumed to be 30°. However, current work on lunar wrinkle ridges (by T.R. Watters) suggests that this simple relation significantly underestimates the displacement. Thus, the displacements in the profile plots should be considered minimum values. Ultimately, the shape of the displacement profiles are not affected if the absolute displacements are underestimated. Displacement profiles clearly illustrate how displacement varies along the fault length (Fig. 2), and simplify an accurate estimate of D_{max}.

Observations and future work: The displacement profile of an unrestricted fault will be elliptically shaped as predicted by a simple linear elastic fracture mechanic (LEFM) model [4]. Such a profile suggests that much of the accumulated fault growth occurred along the length of a single fault [3, 4]. The displacement profile of a restricted fault, a fault where growth is limited by some mechanical factor(s), will not exhibit a symmetric displacement profile with maximum displacement at the center of the fault. We find wrinkle ridge displacement profiles that suggest both unrestricted and restricted fault growth (Fig. 2). Although most wrinkle ridges in the smooth northern plains are typically found in close proximity to other ridges that form complex, reticulate patterns where ridges abut other ridges, wrinkle ridges with unrestricted thrust faults (i.e., elliptically shaped profiles) (Fig. 2A) appear to be more isolated from other wrinkle ridges in the immediate area than ridges exhibiting restricted growth (Fig. 2B). Other likely examples of restricted fault growth are wrinkle ridge rings or ghost craters where ridges are localized by the rims of shallow buried craters. These will also be examined to create the broadest understanding of wrinkle ridge fault growth on Mercury.

Future work involves expanding the study to include wrinkle ridges located in other smooth plains, including the Caloris basin, to generate displacement profiles and determine the *D*/*L* ratio of the population of wrinkle ridges on Mercury. Displacement profiles may provide insight into how the complex, reticulate ridge patterns develop. This methodology may also be applied to wrinkle ridges in lunar maria. However, the complex patterns of wrinkle ridge and ghost crater pose a significant challenge in making accurate measurements. This investigation may benefit from the future application of machine learning techniques.

Conclusions and summary: Wrinkle ridges are a common surface expression of thrust faulting in Mercury's smooth plains. Displacement profiles of wrinkle ridges show evidence of both restricted and unrestricted fault growth and may facilitate the quantification of the contractional strain in these deformed volcanic units.

References: [1] Watters, T. R. (1988) J. Geophys. Res. 93, 10236–10254. [2] Schleicher L. S. et al. (2019) *Icarus, 331,* 226-237. [3] Cowie, P. A., and C. H. Scholz (1992) J. Struct. Geol., 14, 1133–1148. [4] Schultz R. A. et al. (2010) in *Planetary Tectonics,* Cambridge University Press, pp. 457-510. [5] Watters, T.R. (2021) Comm. Earth & Environment, in press. [6] Head, J. W., et al. (2011) Science, 333, 1853–1856. [7] Hawkins S. E. et al. (2007) *Space Science Reviews, 131,* 247-388. [8] Zuber M. T. et al. (2012) *Science, 336,* 6078, 217-220.

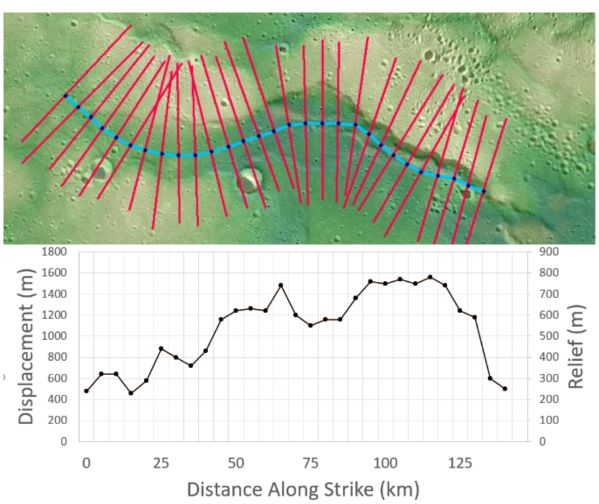

Figure 1: Wrinkle ridge (73.3°N, 46.1°W) topography shown in color-coded DEM derived from interpolated MLA altimetry data. The polyline for length measurements (blue) and orthogonal elevation profile locations (red) are shown on a wrinkle ridge in smooth northern plains. The graph below plots relief and displacement along the length of the fault. The irregular, asymmetric displacement profile may indicate restricted fault growth.

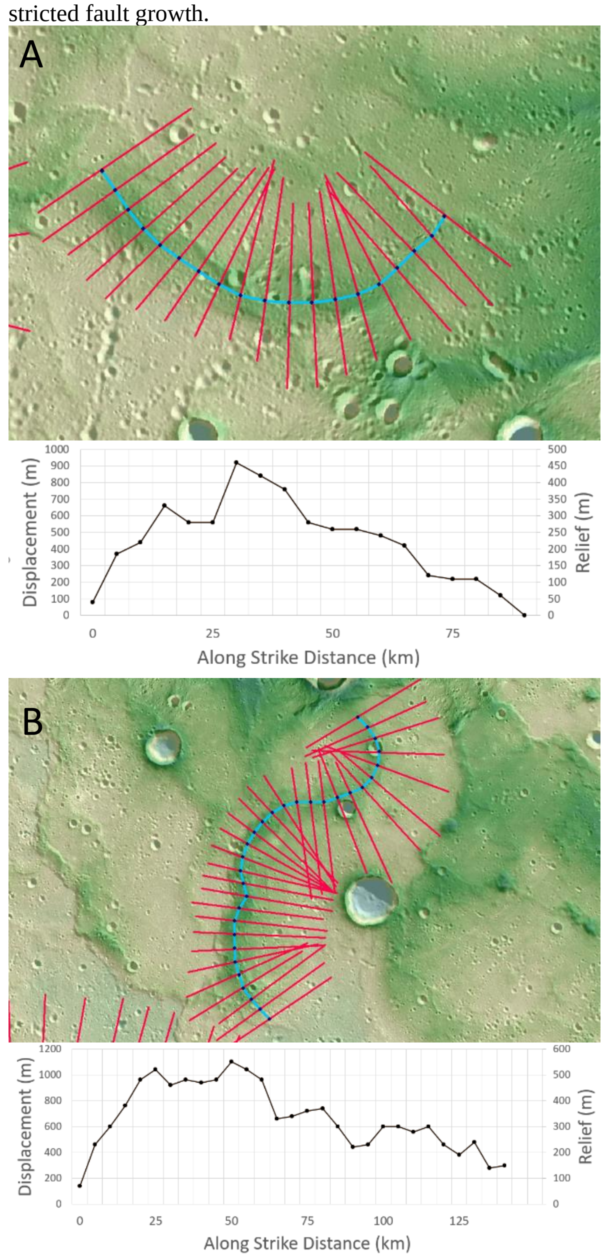

Figure 2: Wrinkle ridge (76.1°N, 83.9°E) in Mercury's northern smooth plains with relief and displacement plotted along length. Relief obtained from elevation data extracted from MLA DEMs. (A) Wrinkle ridge exhibiting a symmetric displacement profile with the area of maximum displacement close to the center of the feature. The ridge is isolated from surrounding tectonic features. (B) Wrinkle ridge (77.6°N, 114.1°E) exhibiting an irregular, asymmetric displacement profile likely due to restricted fault growth.