OBSERVATIONS OF RIDGES AND LOBATE SCARPS ON MERCURY FROM MESSENGER ALTIMETRY AND IMAGING AND IMPLICATIONS FOR LITHOSPHERIC STRAIN ACCOMMODATION. Maria T. Zuber[1], Grant T. Farmer[1], Steven A. Hauck II[2], J. Andreas Ritzer[2], Roger J. Phillips[3], Sean C. Solomon[4], David E. Smith[5], James W. Head III[6], Gregory A. Neumann[5], Mark S. Robinson[7], Thomas R. Watters[8], Catherine L. Johnson[9], Jürgen Oberst[10], Olivier Barnouin-Jha[11], Ralph L. McNutt, Jr.[11]. [1]Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139-4307 (zuber@mit.edu); [2]Dept. of Geological Sciences, Case Western Reserve University, Cleveland, OH 44106; [3]Southwest Research Institute, Boulder, CO 80302; [4]Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015; [5]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771; [6]Dept. of Geological Sciences, Brown University, Providence, RI 02912; [7]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287; [8]CEPS, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560; [9]Dept. of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada; [10]DLR, Berlin, Germany; [11]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723-6099.

Introduction: The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission [1, 2, 3] has so far executed two flybys of the planet Mercury, during January and October 2008. During flyby 1, the Mercury Laser Altimeter (MLA) [4] ranged to Mercury's surface and acquired 3617 ranges along a 3200-km-long topographic profile in the equatorial region of the planet [5], mostly within the hemisphere of Mercury not imaged by Mariner 10. During flyby 2, MLA acquired 4388 ranges again along an equatorial profile about 4000 km in length in nearly the opposite hemisphere of the planet, where Mariner 10 and MESSENGER images were available. The combination of altimetry from MLA [4] and images from the Mercury Dual Imaging System (MDIS) [6] afford collectively the possibility of assessing quantitatively a variety of geological processes, including strain history and lithosphere structure from analysis of tectonic features.

Observations of Contractional Tectonic Features: Images from Mariner 10 [7] and later from MESSENGER [8, 9] indicate that tectonic structures on Mercury are mostly contractional in nature – including lobate scarps, high-relief ridges, and wrinkle ridges – plausibly the result primarily of a decrease in planetary radius [8-11] that accompanied cooling of the interior [8-13]. The magnitude of contraction provides a constraint on interior thermal history models.

An example of a prominent lobate scarp observed by MESSENGER is highlighted in Figure 1, and an MLA profile from flyby 2 that crosses this feature is shown in Figure 2. The crest of the scarp is about 30 km wide, and the relief of the feature exceeds 1 km. This is comparable to the relief of other lobate scarps on Mercury measured using Mariner 10 stereo derived topography and Earth-based radar altimetry [14]. Relief in excess of 1 km is also comparable to the maximum relief of lobate scarps on Mars [15]. In comparison, wrinkle ridges on Hesperian-aged plains of Mars as mapped by the Mars Orbiter Laser Altimeter [16] have similar cross-sectional shapes but are characterized by surface relief that is less by at least a factor of 3 [17]. The most accepted explanation for these ridge structures is that each represents the surface expression of a reverse fault, perhaps accompanied by multiple splayed minor normal faults near the surface associated with flexural bending of near-surface strata [cf. 18]. Estimation of strain requires knowledge of the dip of the primary reverse fault and the penetration of that fault into the lithosphere. Faulting can be either thin- or thick-skinned [18, 19], depending on the depth of penetration. On Mars, extensive analysis of the ridges of Lunae Planum indicates thick-skinned deformation that implies considerable involvement of the lithosphere in faulting and sufficient strength at depth in the lithosphere to maintain conditions appropriate for faulting [20, 21].

A dynamical model for thick-skinned deformation in Lunae Planum [22] is shown in Figure 3. The figure plots strain rate in a lithosphere with a strong upper crust, weak lower crust, and strong upper mantle. Faulting is simulated via a macroscale localization instability mechanism [23], where significant spatial concentrations of strain rate correspond to likely zones of faulting. Models for Mars suggest upper mantle penetration of localized strain.

Preliminary analysis of four contractional features on Mercury sampled so far by MLA, including that in Figure 1, show that all have elevation offsets that exceed those of the Lunae Planum ridges. The structures imply strain per feature that exceeds that of Martian ridges, and as for Mars, support of the structure is consistent with significant penetration of faulting into Mercury's lithosphere. Modeling can constrain the thermal and rheological properties that characterized Mercury's lithosphere at the time the faults underlying these features were formed and active.

Summary: Altimetry from MLA [4] and imaging from MDIS [6] allow analysis of contractional structural features on Mercury. While global analysis of strain must await hemispheric-scale altimetric mapping of Mercury once MESSENGER enters orbit in 2011, the current study demonstrates the promise for constraining lithosphere structure, and ultimately early thermal state, from surface tectonics. From the albeit limited current data set limits on strain associated with thick-skinned deformation models can be compared to model estimates for global contraction.

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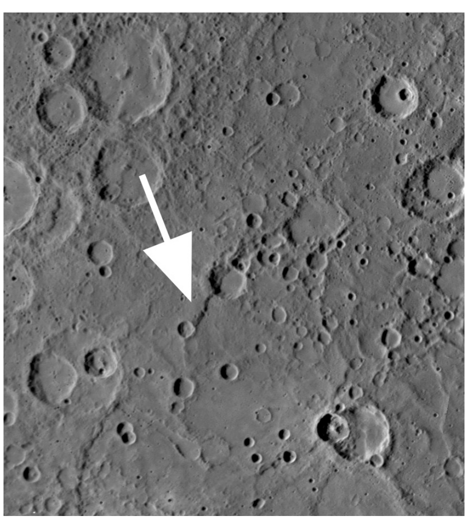

Figure 1. MDIS [6] approach image of a prominent lobate scarp (arrow). The image width is ~500 km.

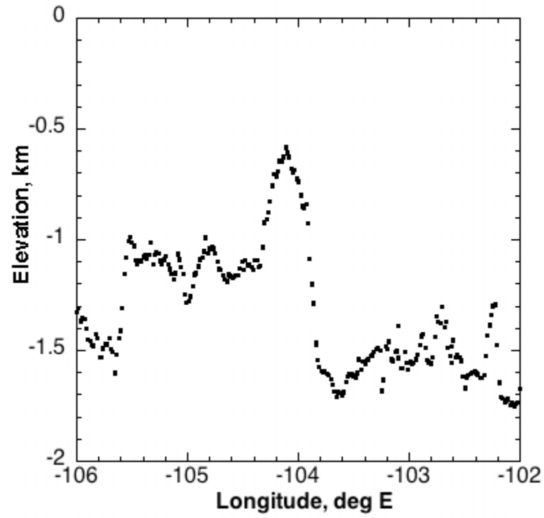

Figure 2. MLA topographic profile from Flyby 2, which is oriented approximately normal to the scarp denoted by the arrow in Figure 1. On Mercury 1° of longitude at the equator is approximately 42 km. The scarp has a vertical expression of over 1 km. The vertical exaggeration in the profile is ~84:1.

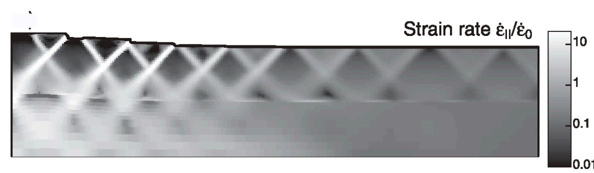

Figure 3. Finite element analysis of the subsurface distribution of strain rate on Mars associated with wrinkle ridges in the Lunae Planum region [20] based on an application of macroscale localization theory [21]. The plot shown is a cross-section of the Martian lithosphere, and the dark, discontinuous near-horizontal line at the approximate midpoint of the mesh corresponds to the crust-mantle boundary, at ~50 km depth. The corresponding horizontal scale in the grid is 3200 km. Light colors indicate high (normalized) strain rates that correspond practically to likely zones of faulting.