DISTRIBUTION OF PROMINENT LOBATE SCARPS ON MERCURY: CONTRIBUTION TO GLOBAL RADIAL CONTRACTION. T. R. Watters[1], S. C. Solomon[2,3], C. Klimczak[3], M. M. Selvans[1], L. S. Walsh[1], M. E. Banks[1], P. K. Byrne[3], B. W. Denevi[4], C. M. Ernst[4], S. L. Murchie[4], J. Oberst[5], F. Preusker[5], S. A. Hauck, II[6], M. T. Zuber[7], and R. J. Phillips[8]. [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA (watterst@si.edu); [2]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; [5]German Aerospace Center, Institute of Planetary Research, D-12489 Berlin, Germany; [6]Department of Earth, Environmental, and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, USA; [7]Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139, USA; [8]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA.

Introduction: Mariner 10 provided the first view of the distribution of lobate scarps on Mercury from images of one hemisphere obtained during three flybys [1]. The three flybys of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging **(**MESSENGER) spacecraft prior to insertion into orbit about Mercury revealed many more broadly distributed lobate scarps [2]. The global distribution of lobate scarps remained poorly defined, however, because the flyby images were of variable spatial resolution and many had lighting geometries that were less than ideal for the identification and characterization of tectonic landforms. Several MESSENGER orbital imaging campaigns with the Mercury Dual Imaging System (MDIS) wide-angle and narrow-angle cameras have provided global monochrome and high-incidence-angle mosaics along with targeted high-resolution images [3]. These mosaics and images, combined with topography from the Mercury Laser Altimeter (MLA) [4] and stereo imaging [5, 6], have facilitated the production of comprehensive global maps of readily visible contractional lobate scarps and structurally related, though rarer, high-relief ridges. The number and distribution of these large-scale tectonic landforms help characterize the accumulated surface contractional strain on Mercury, their contribution to the decrease in planetary radius, and the degree of heterogeneity of crustal deformation.

Spatial Distribution: Broadly distributed lobate scarps and high-relief ridges are surface manifestations of deeply rooted thrust and reverse faults and deform heavily cratered terrain and intercrater plains emplaced before the end of heavy impact bombardment, as well as younger, Calorian-aged smooth plains [7-9]. Wrinkle ridges, the third type of broadly distributed contractional feature on Mercury that accommodated some portion of global contraction, are likely the expression of more shallowly rooted thrust faults and are generally confined to smooth plains.

Several observations can be made from the number and global distribution of prominent lobate scarps (Fig. 1). Such scarps and high-relief ridges are not uniformly distributed on Mercury. There appears to be a minimum of three pronounced concentrations of scarps and high-relief ridges that occur in longitudinal bands (centered approximately at -110°, -30°, and 120°E) separated by regions where there are distinctly fewer such tectonic features (Fig. 1). The global high-incidence-angle mosaic obtained largely during the third solar day of MESSENGER's orbital mission confirms that some of the gaps in the number of scarps noted in earlier studies [7, 8] are not an artifact of lighting conditions. Within these longitudinal bands, the scarps exhibit a strong tendency toward north–south orientations. At high southern latitudes (south of ~60°S), there appears to be a latitudinal band where orientations are more nearly east–west (Fig. 1). Another distinctive feature of the global distribution of these structures is the difference in number and scale of scarps between the northern and southern hemispheres (Fig. 1). The greatest concentrations of lobate scarps, and the scarps with the largest lengths, are located in the southern hemisphere. The total length of mapped scarps in the southern hemisphere is more than a factor of two greater than the total mapped length in the northern hemisphere.

The distribution of prominent lobate scarps within broad bands suggests that mantle convection may have exerted some control on the localization of strain [7, 10]. Although reductions in estimates for the thickness of Mercury's mantle reduce the expected vigor and longevity of convection [11-13], recent models indicate that mantle convection was nonetheless active over much of Mercury's history [14]. Alternatively, tidally induced despinning may have resulted in an early population of north–south-oriented thrust faults in low-to-mid latitudes that could have been reactivated by post-heavy-bombardment global contraction [15, 16].

Estimates of Radial Contraction: The number and distribution of lobate scarps is clear evidence of widespread contraction of the crust and lithosphere of Mercury. Previous estimates of the global radius change were based on regional values of horizontal shortening and contractional strain extrapolated to the entire surface [1, 8, 17, 18]. It is now possible to estimate the radial contraction using this global population of prominent lobate scarps. The value of the ratio γ of the estimated fault displacement to the measured fault length for large-scale

lobate scarps and high-relief ridges is used to determine the total contractional strain [8, 9, 17]. Updated values of γ obtained by linear fit to fault length and fault displacement, estimated from measurements of scarp relief from MLA [4] and stereo-derived topography [5, 6], range from (~7.1–9.7) × 10^{-3} for values of the fault plane dip θ of 25° to 35° [see 17], with $\gamma \cong 8.2 \times 10^{-3}$ for $\theta = 30°$. For a given θ, the standard deviation of the slope (γ) is (~1.0–1.4) × 10^{-3}. The total length of the mapped lobate scarps and high-relief ridges (assumed to have comparable values of γ) is ~47,000 km, and the areal contractional strain over the entire surface of the planet is estimated to be ~0.06–0.09% (~0.08% for θ = 30°). This range in contractional strain corresponds to a radius decrease of ~0.8–1.1 km (~1 km for θ = 30°). These global values of contractional strain are generally consistent with previous estimates of regional strain and radius decrease by extrapolation to the entire surface [8, 9, 17]. The smooth plains are dominated by wrinkle ridges that likely formed in response to some combination of load-induced flexure and subsidence and global contraction [8]. Thus, a more conservative estimate of the strain accommodated by structures formed from global contraction alone may be obtained by eliminating the area covered by smooth plains, estimated to be ~27% [19]. The total length of the lobate scarps and high-relief ridges outside of and partially crosscutting smooth plains is ~42,000 km, and the areal contractional strain is estimated to be ~0.08–0.12% (0.1% for θ = 30°). This range in the contractional strain corresponds to a radius decrease of ~1–1.5 km (~1.2 km for θ = 30°). Higher estimates of the radius decrease of ~2.4–3.6 km have been recently reported from estimates of contractional strain in an area covering ~21% of the surface and then extrapolated to the entire surface [18]. The difference may be in part because the location of that study area corresponds to one of the longitudinal bands with a large concentration of lobate scarps (~45°E–130°E). If so, then the areal strains appropriate for that longitudinal band need not be for the surface as a whole.

Summary and Conclusions: The estimated contractional strains and range of radius change may be taken only as lower limits because of the conservative approach in mapping only the most prominent lobate scarps and high-relief ridges (Fig. 1). Other landforms lacking definitive evidence of associated faults were not included in the survey. The estimated radius change of ~1.2 ± 0.3 km, although higher than previous estimates [8, 9, 17], does not lessen markedly the mismatch with thermal history models showing that 1–2 km of radial contraction since 4 Ga can be met with at best a limited subset of models [20]. The global contractional strain may be larger than expressed by the population of lobate scarps and high-relief ridges presented here if other landforms not included in this study account for substantial horizontal shortening [21, 22].

References: [1] Strom R.G., Trask N.J. and Guest J.E. (1975) *JGR, 80*, 2478-2507. [2] Solomon S.C. et al. (2008) *Science*, *321*, 59-62. [3] Hawkins S.E., III, et al. (2007) *Space Sci. Rev.*, *131*, 247-338. [4] Zuber M.T. et al. (2012) *Science*, *336*, 217-220. [5] Oberst J. et al. (2010) *Icarus 209*, 230-238. [6] Preusker F. et al. (2012) *EPSC Abstracts, 7*, 2012-528. [7] Watters T.R. et al. (2004) *Geophys. Res. Lett.* 31, L04701, 10.1029/2003GL019171. [8] Watters T.R. et al. (2009) *Earth Planet. Sci. Lett.*, 285, 283–296. [9] Watters T.R. and Nimmo F. (2010) in *Planetary Tectonics*, Cambridge Univ. Press, pp. 15-80. [10] King, S.D. (2008) *Nature Geosci., 1*, 229-232. [11] Smith D.E. (2012) *Science*, 336, 212-216. [12] Hauck S.A., II, et al. (2012) *Lunar Planet. Sci*., *43*, 1170. [13] Hauck, S.A., II, et al. (2012) *JGR*, submitted. [14] Michel, N.C, et al. (2013) *JGR*, in press. [15] Melosh H.J. and McKinnon W.B. (1988) in *Mercury*, Univ. Arizona Press, Tucson, pp. 374-400. [16] Dombard, A.J. and Hauck, S.A., II (2008) *Icarus*, 198, 274–276. [17] Watters, T.R., et al. (1998) *Geology, 26*, 991-994. [18] DiAchille, G., et al. (2012) *Icarus, 221*, 456-460. [19] Denevi, B.W., et al. (2012) *JGR*, submitted. [20] Hauck, S.A., II, et al. (2004) *Earth Planet. Sci. Lett. 222*, 713-728. [21] Dombard A.J. et al. (2001) *Lunar Planet. Sci. 32*, 2035. [22] Byrne P.K. et al. (2012) *Lunar Planet. Sci*., *43*, 2118.

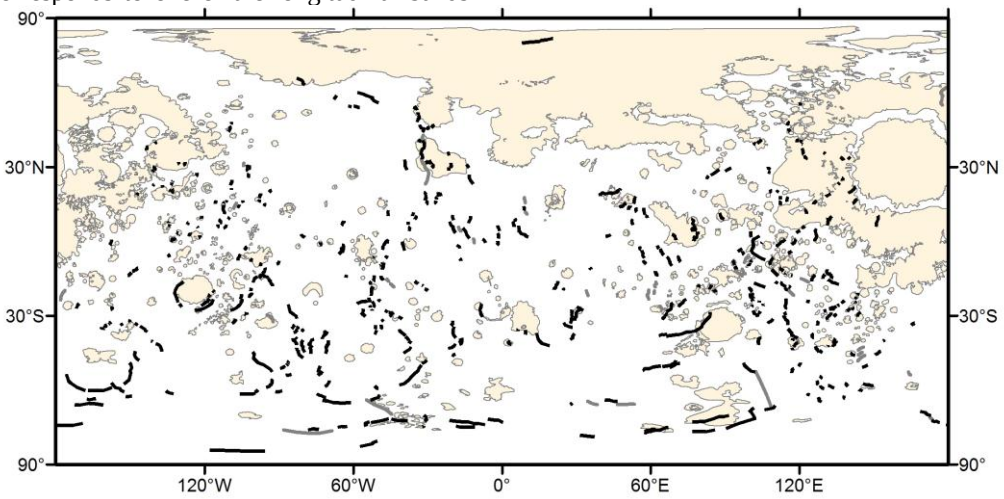

Figure 1. Tectonic landform map of lobate scarps (black) and high-relief ridges (gray) on Mercury. Such features are distributed in broad, longitudinal bands. Smooth plains units [19] are shown in tan.