MESSENGER'S NEWLY GLOBAL PERSPECTIVE ON MERCURY: SOME IMPLICATIONS FOR INTERIOR EVOLUTION. Sean C. Solomon[1], Andrew M. Freed[2], Steven A. Hauck, II[3], James W. Head, III[4], Laura Kerber[4], Roger J. Phillips[5], Mark S. Robinson[6], Thomas R. Watters[7], and Maria T. Zuber[8], [1]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [2]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, USA; [3]Department of Geological Sciences, Case Western Reserve University, Cleveland, OH 44106, USA; [4]Department of Geological Sciences, Brown University, Providence, RI 02912, USA; [5]Southwest Research Institute, Boulder, CO 80302, USA; [6]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA; [7]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA; [8]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02129, USA.

Introduction: As a result of the two flybys of the innermost planet last year by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, coupled with earlier Mariner 10 observations, more than 90% of Mercury's surface has now been imaged at close range. Those images – together with new observations of the planet's internal magnetic field, neutral and ionized exosphere, surface spectra, and topography – are yielding fresh insight into Mercury's tectonic and magmatic history and its implications for the formation and interior evolution of the planet.

Global Contraction: MESSENGER has confirmed the prediction [1], made from Mariner 10 images of less than half of Mercury's surface, that tectonic features on Mercury are dominantly contractional [2,3]. The extent and timing of contraction are important indicators of Mercury's thermal history, including the growth of the planet's solid inner core [4]. Inner core growth is a likely power source for Mercury's magnetic dynamo [5], indicated as the probable source for the planet's internal magnetic field on the basis of the observation that the field is dominated by a dipole nearly aligned with the spin axis [6,7] and the lack of detection to date of crustal magnetic anomalies [8].

The strain accommodated by lobate scarps, the dominant tectonic landforms on Mercury, has been used to infer the amount of global contraction since the end of heavy impact bombardment [e.g., 1]. MESSENGER images of areas imaged by Mariner 10 have revealed previously unrecognized scarps [2,3], a reflection of the sensitivity of feature recognition to lighting conditions. The cumulative length of known scarps in the areas viewed by Mariner 10 and the inferred contractional strain are one third greater than previous estimates, and the contractional strain in newly imaged areas is comparable [2,3]. Both quantities are likely to increase as more of the surface is imaged under lighting conditions favorable to recognizing and characterizing tectonic features. Information on scarp topography from altimetry and new stereogrammetry will also improve estimates of shortening. The inferred strain since heavy bombardment is likely to increase for other reasons as well: (1) Several small craters deformed by lobate scarps indicate horizontal displacements [2,3] greater than would be inferred from previous fault displacement-length relationships [9]. (2) The identification [2,3] of a lobate scarp embayed by smooth plains deposits (Fig. 1) opens the possibility that some scarps formed after heavy bombardment were later obscured by plains, or that faults reactivated after burial by plains have produced scarps that do not reflect full fault displacements. (3) Mechanisms for accommodating contractional strain other than scarp formation remain to be tested [10,11].

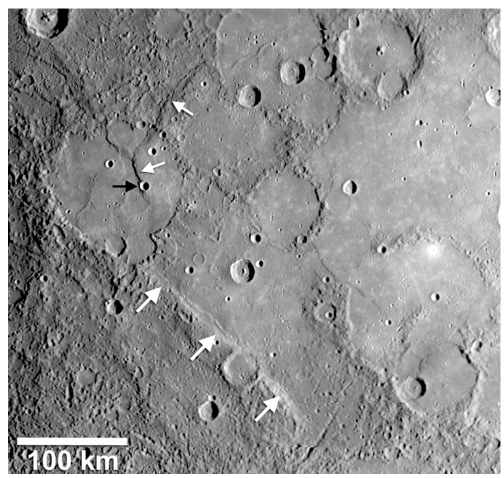

Fig. 1. A lobate scarp embayed by smooth plains (thick arrows), a scarp that deformed smooth plains (thin white arrows), and an undeformed crater atop a scarp (black arrow).

Because a lithospheric stress state dominated by horizontal compression tends to inhibit the ascent of magma [12], the timing of global contraction recorded by the lobate scarps is important for understanding the history of the widespread volcanic and igneous intrusive activity on Mercury documented by MESSENGER [13]. On the basis of scarp distribution and embayment relations, scarp formation began before the emplacement of many smooth plains units and continued until after the youngest expanse of smooth plains material had formed [2,3]. The ubiquity of smooth plains, many of which are volcanic, indicates that compressive lithospheric stress levels were not sufficient to prevent extensive early volcanism [14]. Impact excavation of low-reflectance material [15] interpreted to contain higher quantities of Fe-Ti oxides than other surface material suggests that melt density may have influenced the maximum ascent of some magmas [16].

Basins as Magmatic and Tectonic Foci: Comparatively young impact basins provide important constraints on changes to the lithospheric stress field that accompany basin formation and modification, changes that can be quantified by measurements of topography and gravity anomalies. Basin formation amplifies magma production at depth, by the removal of overburden pressure and the emplacement of impact energy as heat [17]. Basin formation also changes the lithospheric stress state by removing prestress within the basin interior and modifying stress within a damage zone that extends to several basin radii [18,19], both of which processes favor magma ascent and plains formation relative to surrounding areas and can affect the style and timing of deformation within the basin.

MESSENGER observations of several impact basins on Mercury elucidate these ideas. The ~1500-km-diameter Caloris basin [20], the younger ~250-km-diameter Raditladi basin [21], and a newly imaged ~700-km-diameter basin [22] all contain interior smooth plains deposits interpreted as volcanic in origin. These three basins are also the only known sites of extensional deformation on Mercury, the result of a basin interior stress field dominated by horizontal extension at a time when lithospheric stresses were likely compressional elsewhere on the planet. Caloris is surrounded by a broad annulus of smooth plains deposits younger than the basin [23] whose emplacement may have been facilitated by the change in lithospheric stress following impact-induced damage of the crust outward of the basin and loading of the basin interior.

Interior Volatiles: The volatile content of Mercury's interior, if known, would provide an important constraint on models for the planet's formation, thermal evolution, and magmatic history. Evidence for widespread volatile species at Mercury's surface includes the alkali metals Na and K in Mercury's exosphere [24,25], the radar-bright polar deposits interpreted to be frozen volatiles [26,27], and the detection of water-group and sulfur-group ions in Mercury's ionized exosphere [28], but none of these observations strongly constrains volatile levels within the planetary interior. One possible indication that Mercury incorporated volatile material during its formation is its presently liquid outer core [29], which requires the core to contain an element lighter than Fe, such as S, to lower the solidus sufficiently to prevent complete core solidification by global cooling [4].

MESSENGER images have documented examples of volcanic centers surrounded by material interpreted to be pyroclastic deposits [13]. For one of these centers, the radial extent of the deposits constrains the eruption velocity at the vent, and the implied magmatic contents of possible volatiles that drove the explosive eruption are comparable to those of oceanic basaltic magmas on Earth [30]. The extent to which such volatile levels extend through Mercury's interior is not known, but even isolated reservoirs that are not volatile depleted implies that Mercury's accretion included the incorporation of water-rich planetesimals or embryos formed farther from the Sun [31,32] and the preservation of some fraction of original volatiles during whatever process imparted to Mercury its anomalously high ratio of metal to silicate [e.g., 33]. The presence of significant interior volatiles in Mercury extends the predicted duration of melt generation and renders more efficient the process of convective heat transport in the planetary mantle [4].

Conclusions: MESSENGER's first two flybys of Mercury have revealed a planet with a richer history of magmatism, deformation, and impact basin modification than heretofore appreciated, a result consistent with an interior composition that includes a greater volatile content than expected from Mercury's solar distance. A third flyby and the orbital phase of the mission beginning in 2011 will considerably sharpen our understanding of the formation and interior evolution of the innermost planet.

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