**THE MESSENGER MISSION TO MERCURY: NEW INSIGHTS INTO GEOLOGICAL PROCESSES AND EVOLUTION FROM THE FIRST TWO ENCOUNTERS.** James W. Head, III[1], Sean C. Solomon[2], Ralph L. McNutt, Jr.[3], David T. Blewett[3], Clark R. Chapman[4], Deborah L. Domingue[3], Jeffrey J. Gillis-Davis[5], S. Edward Hawkins, III[3], Jörn Helbert[6], Gregory M. Holsclaw[7], Noam R. Izenberg[3], William E. McClintock[7], William J. Merline[4], Scott L. Murchie[3], Roger J. Phillips[4], Louise M. Prockter[3], Mark S. Robinson[8], Brett W. Denevi[8], Ann L. Sprague[9], Robert G. Strom[9], Faith Vilas[10], Thomas R. Watters[11], and Maria T. Zuber[12]. [1]Department of Geological Sciences, Brown University, Providence, RI 02912, USA (James_Head@brown.edu), [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA, [3]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA, [4]Southwest Research Institute, 1050 Walnut Street #300, Boulder, CO 80302, USA, [5]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, USA, [6]Institute of Planetary Research, Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany 12489, [7]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA, [8]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA, [9]Lunar and Planetary Laboratory, The University of Arizona, Tucson, AZ 85721, USA, [10]MMT Observatory, The University of Arizona, Tucson, AZ 85721, USA, [11]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA, [12]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02129, USA.

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission, a part of NASA's Discovery Program, was designed to answer six questions [1]: (1) What planetary formational processes led to Mercury's high ratio of metal to silicate? (2) What is the geological history of Mercury? (3) What are the nature and origin of Mercury's magnetic field? (4) What are the structure and state of Mercury's core? (5) What are the radar-reflective materials at Mercury's poles? (6) What are the important volatile species and their sources and sinks near Mercury? MESSENGER is currently midway through a complex interplanetary cruise phase that involves three flybys of Mercury. The first and second of these, on 14 January and 6 October, 2008, provided important new information relating to several of the questions outlined above [2-19]. Here we give an overview of observations made during the first two flybys that are most relevant to new insights about geological processes operating on Mercury and implications for its history [3, 8-13]. Instruments providing important information on the geological history of Mercury during these encounters were the Mercury Dual Imaging System (MDIS) [14], the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [15], and the Mercury Laser Altimeter (MLA) [16].

Among the many specific questions remaining following the Mariner 10 mission to Mercury (1974-1975) were (1) the level of mineralogical and compositional diversity of the crust that appeared relatively bland in Mariner 10 data, (2) the nature of the rest of the huge Caloris impact basin partially seen in Mariner 10 images and the presence of other new basins in the unimaged portions, (3) the origin of the extensive plains observed on the surface (ponded impact ejecta or extrusive lava flows?), (4) the regional and global extent of magmatic intrusion and volcanic extrusion, (5) the diversity and global distribution of tectonic features disrupting the crust and the implications for strain as a function of time, (6) the spatial and temporal relationships of volcanism and tectonics, and (7) the bombardment chronology and geological history of Mercury [1, 17-19]. The viewing geometry for the first and second MESSENGER encounters of Mercury [1] provided important information on these questions from image and remote sensing data on an additional ~60% of the surface of Mercury unseen by Mariner 10.

The MDIS color data and the geological interpretations from the images helped to address a major question remaining from Mariner 10 [17]: Are the plains on Mercury formed by volcanic flooding, similar to the lunar maria, or did they form by impact ejecta ponding in a process similar to that thought to form the lunar light plains (Cayley Formation)? The new MDIS images show evidence for volcanic edifices and vents around the Caloris basin inner margin [10,13]. Impact crater morphologies and size-frequency distributions derived from the new data [12] show that smooth plains exterior to Caloris display a crater density considerably less than that characterizing Caloris basin interior plains; this is interpreted to mean that the exterior plains are volcanic in origin, and not Caloris impact ejecta. Furthermore, morphologic evidence from regions exterior to Caloris shows that plains were emplaced sequentially inside and adjacent to numerous large impact craters and basins, often to thicknesses in excess of several kilometres [13]. Mercury Laser Altimeter profiles [e.g., 11] indicate that MLA data will be essential in further quantifying the thickness of plains. New images show what are interpreted as ancient craters and basins filled to the rim, with some represented only by circular wrinkle ridge structures (Fig. 1). Evidence for shallow magmatic intrusion was seen in the form of (1) Pantheon Fossae, the radial graben system in central Caloris (a possible radial dike swarm) and (2) a floor-fractured crater, suggestive of shallow intrusion and floor uplift. Taken together, these observations, from geomorphology, stratigraphy, color images, and impact crater size-frequency distributions, support a volcanic origin for several regions of plains and appear to substantiate the important role of volcanism in the geological history of Mercury [20].

MESSENGER MDIS multi-spectral images [8-10] revealed a relatively low-reflectance surface with three broad units identified from reflectance and slope in the wavelength range 0.4 to 1.0 μm. These new data helped to confirm the diversity of color units detected in re-processed Mariner 10 color ratio images [20] and to extend the analysis to much larger areas of Mercury. The reflectance properties of smooth plains could be subdivided into three types: high-reflectance red plains (HRP), low-reflectance blue plains (LBP), and intermediate plains (IP). Combined data from the first two encounters, together with Mariner 10 data, permit global assessment of these units;

smooth plains are widespread on Mercury covering 40% of the surface, and the new data show that their distribution is generally random, in contrast to the distinctive nearside-farside asymmetry of the lunar maria [21]. Of particular interest is moderately high-reflectance, relatively reddish material associated with rimless depressions and located at several places along the southern interior margin of the Caloris basin rim. This material is thought to represent ejecta from pyroclastic eruptions. In addition to the circum-Caloris features, the second flyby revealed numerous other examples located on impact crater floors.

MASCS spectrometer data [9,15] show absorption and spectral slope properties of resolved spectra that are indicative of differences in composition and regolith maturation processes among color units defined by MDIS. Mid-ultraviolet to near-infrared reflectance observations of the surface revealed the presence of a previously unobserved ultraviolet absorption feature that suggests a low FeO content (< 2–3 weight %) in silicates in average surface material. This result is supported by the lack of evidence for a key $Fe^{2+}$ absorption band in spatially resolved spectra taken near the equator.

A comprehensive view of the Caloris impact basin and its surroundings, the youngest known large impact basin on Mercury, was provided by the new MESSENGER data [8,10]. These observations support the interpretation that the surface of the Caloris interior is not composed of an extensive impact melt sheet, but rather has been resurfaced by volcanic plains. Evidence for a volcanic origin for the interior plains includes embayed craters on the basin floor, volcanic constructs, and diffuse deposits surrounding rimless depressions interpreted to be of pyroclastic origin [10,13]. Although the interior of Caloris basin appears similar in many ways to lunar mare basins flooded by mare basalts, the volcanic plains in Caloris are higher in albedo than surrounding basin materials and lack spectral evidence for ferrous iron-bearing silicates. The new data permitted the mapping throughout the basin interior of tectonic landforms observed in the eastern part of the basin by Mariner 10; contractional wrinkle ridges and extensional troughs occur in an annulus around the complete basin interior, but have distributions and age relations different from their lunar basin counterparts, indicating a different stress history. A major discovery of the first flyby was the detection of Pantheon Fossae, an extensive radial graben system located in the middle of the Caloris interior unlike any structure seen in lunar basins, with individual graben radiating hundreds of kilometres. A new basin, ~715 km in diameter, has been discovered and is similar to the Orientale basin on the Moon in that it has been only modestly flooded in its interior by volcanic plains [22]. This example is providing new insight into early basin evolutionary processes.

The global significance of tectonics was further underlined by the new data that revealed numerous extensive scarps and wrinkle ridges of contractional origin; the total contractional strain is significantly greater than that inferred from Mariner 10 images, and newly revealed stratigraphic relationships will permit an assessment of the time dependence of this strain [3].

These data provide new insight into the geological history of Mercury. In addition to improving our understanding of the diversity and character of the crust and the role of volcanism, the size distribution of impact craters on smooth plains matches that of lunar craters post-dating the late heavy bombardment, implying that the plains formed no earlier than 3.8 Ga [12]. The new data from the first two MESSENGER flybys of Mercury, as well as those from the subsequent flyby in September 2009 and from orbital operations, will enable us to relate global contraction to the history of volcanism and impact crater and basin formation [23]. Through the synergism provided by the instruments on the MESSENGER spacecraft [1] we will be able to provide information about the nature and history of the surface, and how this component fits into the larger context of Mercury's dynamic system: a liquid iron-rich outer core, coupled through a dominantly dipolar magnetic field to the surface, exosphere, and magnetosphere, all of which interact with the solar wind.

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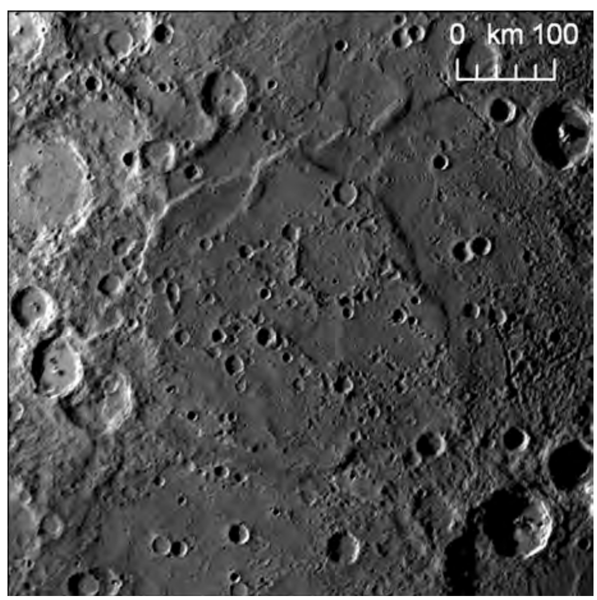


Fig. 1. Circular wrinkle-ridge structure in the first MESSENGER flyby approach mosaic (-17.5°N, -96.4°E). The smooth volcanic plains at the surface are of sufficient thickness, probably several kilometers, to bury completely the original impact structure (D ~ 300 km).