**THE INTERPLAY BETWEEN VOLCANISM AND TECTONICS ON MERCURY.** Paul K. Byrne[1,2], Caleb I. Fassett[3], Christian Klimczak[4,2], Lillian R. Ostrach[5], Clark R. Chapman[6], Brett W. Denevi[7], A. M. Celâl Şengör[8], Steven A. Hauck, II[9], Alexander J. Evans[6,10], Maria E. Banks[11,12], Thomas R. Watters[11], James W. Head[13], and Sean C. Solomon[10,2]. [1]Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA (paul.byrne@ncsu.edu); [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; [3]Department of Astronomy, Mount Holyoke College, South Hadley, MA 01075, USA; [4]Department of Geology, University of Georgia, Athens, GA 30602, USA; [5]Solar System Exploration Division, NASA Goddard Space Flight Center, MD 20771, USA; [6]Department of Space Studies, Southwest Research Institute, Boulder, CO 80302, USA; [7]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; [8]Department of Geology, Faculty of Mines and the Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469 Maslak, Istanbul, Turkey; [9]Department of Earth, Environmental, and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, USA; [10]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; [11]Center for Earth and Planetary Studies, Smithsonian National Air and Space Museum, Washington, DC 20013, USA; [12]Planetary Science Institute, Tucson, AZ 85719, USA; [13]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA.

**Introduction:** That tectonic activity has occurred on Mercury was confirmed by observations of the planet returned by the Mariner 10 mission in the 1970s [e.g., 1]. Evidence for volcanism having operated on Mercury, however, remained ambiguous following that mission [2,3], but image data acquired by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft during 2008–15 affirmed the volcanic character of the planet [4,5].

The MESSENGER mission generated sufficient data to characterize comprehensively past volcanic and tectonic processes on Mercury (**Figure 1**). Notably, there have been strong spatial, and possibly temporal, correlations between these processes that provide insight into the thermal evolution and geological history of the innermost planet.

**Volcanism on Mercury:** The most prominent volcanic landforms on Mercury are extensive, relatively sparsely cratered effusive basaltic deposits that constitute the majority of mapped “smooth plains” units [6] (**Figure 1**). The largest such deposits are situated in the northern hemisphere and include the northern plains [5] and the plains within and surrounding the Caloris impact basin [7]. Many smaller though still substantial deposits occur inside other impact structures [6], especially in the southern hemisphere.

Notably, all major smooth plains units have relatively similar crater areal density values [e.g., 5,6,8,9], indicating that they were emplaced by about the same time. These values correspond to model ages of ~3.8–3.6 Ga [e.g., 10]. The greatest values for areal crater density for smooth plains [10] approach the lowest values for representative portions of “intercrater plains” [11], the other dominant surface unit on Mercury. The majority of intercrater plains are likely also to be effusive volcanic deposits, their present-day texture the result of sustained impact bombardment (in effect, they are older smooth plains).

Mercury is not without explosive volcanism, however. Diffuse-edged deposits with a distinct reddish color, often found in association with irregularly shaped depressions lacking raised rims, provide evidence for pyroclastic volcanism [e.g., 12]. Sites of explosive volcanism are largely confined to the vicinities of impact craters and basins, although numerous examples are collocated with tectonic shortening structures; few examples are found in smooth plains units [e.g., 13].

**Tectonics on Mercury:** Deformation on the innermost planet is dominated by crustal shortening, manifest as linear to arcuate, positive-relief landforms that occur globally [14] (**Figure 1**). Terms such as “wrinkle ridge” and “lobate scarp” have been applied historically to these landforms on the basis of dimension (with the former having less structural relief and planform length than the latter) [15]. Despite the morphological variety of such landforms on Mercury, they likely resulted collectively from horizontal shortening involving some combination of thrust faulting and folding [e.g., 16,] and are thus forms of fault-propagation monoclines and anticlines [17]. Many such structures may have formed above large-scale décollement surfaces between lava flows and probably along older regolith layers [14].

Larger shortening landforms are typically situated within intercrater plains; their smaller counterparts tend to be localized within smooth plains [14]. There is no globally coherent pattern of tectonic shortening on Mercury, although major shortening landforms show a slight preference toward north–south orientations [18]. Some smooth plains structures may be attributed to subsidence of volcanic loads [15], but the aggregate population of shortening landforms on Mercury likely results from the global contraction of the planet that accompanied interior cooling [1]. The strain accommodated by these structures corresponds to a reduction in planetary radius of as much as 7 km [14].

Shortening structures just hundreds of meters long and with tens of meters of relief have been identified in images from MESSENGER’s low-altitude campaign [19]. The preservation states of these landforms suggest that they developed, and that Mercury continued to contract, geologically recently. Further, superposition relations between craters and shortening landforms show that global contraction was likely underway by ~3.6 Ga [20].

Importantly, extensional tectonic landforms are far less common on Mercury than shortening structures and are located almost exclusively within impact craters partially or almost entirely filled with lavas [e.g., 1,21,22] (**Figure 1**). (Some extensional structures occur along the hinge axes of larger monoclines.) Where they occur within flooded impact features, troughs and graben are likely the result of thermal contraction of ponded lavas [23].

**Volcanic and Tectonic Interplay:** Although heavily shaped by impact bombardment [24], the geological history of Mercury has been dominated by secular cooling as this process controlled the volcanic and tectonic evolution of the planet. Early effusive volcanism, likely responsible for building substantial portions of the crust [25], began to wane as the planet's internal energy decreased [26]. Secular cooling led to a reduction in planetary volume, accommodated in the lithosphere by a global network of shortening structures [14], which in turn inhibited the vertical ascent and eruption of magma [27]. Major effusive volcanism had largely ended by ~3.6 Ga and, although small volumes of effusive [e.g., 28] and explosive [13] volcanism erupted thereafter, such activity was restricted to pre-existing impact and tectonic structures—sites of crustal weakness where compressional stresses from global contraction led to local shortening-perpendicular extension. (The few sites of pyroclastic activity in smooth plains units suggest that those regions mostly lack deep-seated faults along which even volatile-rich magma could ascend.) Yet volcanism also influenced where tectonic deformation occurred, since the majority of extension is localized in lava-filled impact features. The volcanic and tectonic histories of Mercury are thus intertwined, and both processes provide key insights into the thermal evolution of the innermost planet.

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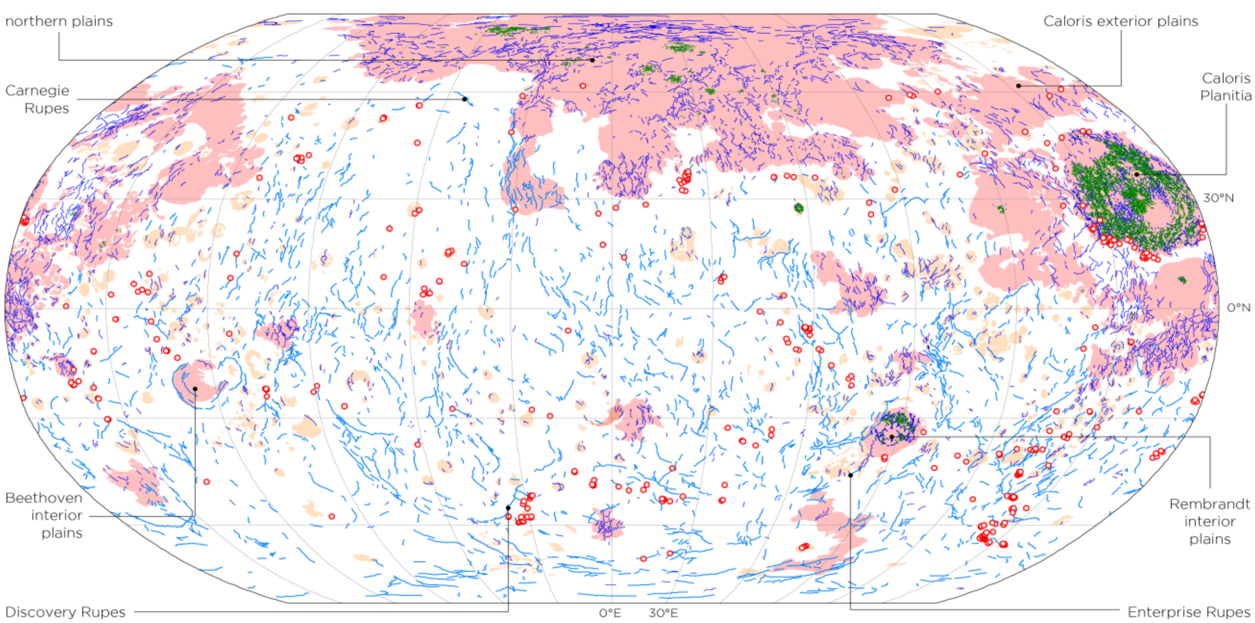


**Figure 1**. Primary volcanic and tectonic landforms on Mercury (with some examples labeled). Mapped smooth plains [6] for which areal crater densities have been determined are shown in red [e.g., 5,6,8–10], with remaining units in orange. Pyroclastic deposits [14] are shown as red circles. Tectonic structures are shown in blue (shortening) [15] and green (extensional) [22,23].