THE ROLE OF THRUST FAULTS AS CONDUITS FOR VOLATILES ON MERCURY. Christian Klimczak¹, Paul K. Byrne¹, Sean C. Solomon¹², Francis Nimmo³, Thomas R. Watters⁴, Brett W. Denevi⁵, Carolyn M. Ernst⁶, Maria E. Banks⁷, ¹Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA, cklimeczak@ciw.edu; ²Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; ³Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, USA; ⁴The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA.

Introduction: Photogeological data returned by the MESSENGER spacecraft show multiple lines of evidence that volcanism was active throughout a long interval of Mercury’s geologic history, including large expanses of smooth plains interpreted to have been emplaced as flood lavas [1, 2], pits interpreted to be vents for near-surface igneous activity [3], and pyroclastic deposits [4–6]. There is also evidence for widespread contractional deformation of the planet’s surface, manifest by the large number and dimensions of thrust-fault-related landforms (e.g., lobate scarps). Thrust faulting on Mercury is generally attributed to global contraction in response to cooling of its interior [e.g., 7]. Cross-cutting relationships suggest that flood volcanism largely predated the observed contractional deformation [8, 9], indicating that the most voluminous volcanism ceased prior to most global contraction. Indeed, global contraction likely placed Mercury’s lithosphere under an increasingly compressional stress state, such that magma ascent and thus surface volcanism would have been largely inhibited. However, volcanic vents and pyroclastic deposits are widespread on Mercury (Fig. 1) and in many instances are superposed on thrust faults, indicating that at least some volcanism occurred after the onset of global contraction.

Observations:

Pits associated with thrust faults. Pits—rimless, steep-sided depressions—tend to localize at or near weaknesses in impact crater and basin floors, such as central peaks or along peak rings, whereas others are found directly on crater rims [e.g., 3]. Interestingly, many of the craters and basins that host pits are also cut by thrust faults (Figs. 2, 3). In particular, pits frequently appear to superpose thrust faults that cut through the centers of complex craters that otherwise lack an expected central peak. Whereas some pits occur at the fault center, others are frequently found closer to the fault tips near or in regions of step-overs between two different thrust faults (Figs. 2, 3). Many of the pits are also associated with surface materials that show spectrally distinct properties (Fig. 2). Such materials are interpreted as pyroclastic deposits, emplaced by explosive volcanic activity [4–6]. These observations indicate that volcanism continued after the onset of global contraction, and that volatile-containing magma erupted onto Mercury’s surface near or directly along thrust faults.

Global distribution. To quantify the spatial relationship between thrust faults and vents, and to evaluate their paired occurrence at the global scale, we conducted a geospatial survey using the global photomosaic derived from Mercury Dual Imaging System (MDIS) images obtained during MESSENGER’s primary mission. We searched for thrust faults within a radius of 30 km around a pit. We find that of the 115 currently recognized pits on Mercury [2], at least 43 (37%) superpose or are near thrust faults (Fig. 1). The pits associated with thrust faults shown here are likely

Fig. 1. The global distribution of pits and thrust-fault-related landforms (lobate scarps, wrinkle ridges, and high relief ridges) on Mercury, shown on the MDIS monochrome base map between 80°N and S in equirectangular projection.
only a subset of the total population, as MDIS mapping at high solar incidence angle and high-resolution targeted imaging may reveal more examples of both pits and contractional landforms. Moreover, the pits associated with thrusts do not appear to be restricted to particular areas on Mercury (Fig. 1). The large fraction of pits associated with thrust faults and their widespread distribution suggest that this spatial relation is common on Mercury and that the causative process operated on a global scale.

Critically stressed faults: Terrestrial borehole data show that faults can function as conduits for fluids or gases, especially when the structures are critically stressed [10, 11]. Study of critically stressed faults in crystalline rock indicates that fluid migration along faults is particularly facilitated when active faults are oriented at optimal angles to the remote stress field. Applied to a global contraction-induced tectonic stress field, where global horizontal stresses build up isotropically until the onset of faulting introduces regional stress anisotropies, optimally oriented thrust faults on Mercury should occur in conjugate pairs at 30° dip angles, with their strikes close to perpendicular to the most compressive principal stress. The widespread occurrence of pits along faults may suggest that those structures were critically stressed and so allowed volatile-rich magmas to migrate along them. Magma then erupted along zones of greatest near-surface weakness, such as central peaks or faults near rims of impact craters. Future analysis of fault geometry, Coulomb stress modeling, and assessment of the global stress field during global contraction will provide further insight into the role that thrust faults played as conduits for the eruption of volatile-rich magmas on Mercury.

**Significance for volcanism and tectonics on Mercury:** The superposition relations of vents on thrust faults shows that volcanic processes were active after the onset of global contraction, even though background stresses resulting from global contraction would have tended to prevent widespread volcanism. The scenario whereby volatile-rich magmas move vertically along critically stressed thrust faults provides a means for regional volcanism on Mercury within an environment of global contraction. If exsolution served to reduce magma densities markedly, volatile-rich magmas likely were able to erupt regardless of the compressive stresses. However, under such stress conditions critically stressed faults represent preferred pathways for these magmas. Therefore, we surmise that whenever volatile-bearing lavas were emplaced at the surface of an actively contracting planet, their eruption was more likely near faults and other planes of weakness.

![Fig. 2. The pit crater “Glinka” may be seen in the northern part of this MDIS three-color mosaic. The center of Glinka is located at 14.5°N, 247.5°E. Note the relatively bright spectral “halo” surrounding the pit. Inset shows a close-up of the pit superposed on thrust faults (arrows point in the direction of fault dip along each surface break).](image)

![Fig. 3. Pit crater “Geddes” located at 27.0°N, 330.5°E. The pit is collocated with a system of thrust faults (arrows show the down-dip direction along each surface break).](image)

**References:**