PRESENT-DAY ENDOGENIC AND EXOGENIC ACTIVITY ON MERCURY AND OPPORTUNITIES FOR FUTURE OBSERVATIONS. E.J. Speyerer, M.S. Robinson, and A.J. Sonke, Arizona State University, Tempe, AZ.

Introduction: The MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission [1,2] provided the first global look at the innermost planet enabling the identification of geologic units at the 100-200 meter scale. A fundamental aspect of interpreting a geologic unit or individual surface feature is understanding its formation age and post-emplacement modification [3-10] While the accumulation and measured density of impact craters are used to evaluate the surface age of geologic units [11-18], the formation rate of impact craters on Mercury is the least constrained of all the inner planets [19].

Furthermore, the surface of Mercury is modified from endogenic activities, and the present-day rate and development of these processes could be better constrained. For example, small, crisp scarp structures are consistent with ongoing tectonic activity in the last 50 Myr [20]. Additionally, clusters of small enigmatic hollows with their characteristic shallow, irregular contours cover about 0.1% of the surface imaged at pixel scales < 180 m/pixel [21] and typically lack superimposed craters supporting a young age and possible continued development [4,21-23].

In this study, we use temporal images collected by the Mercury Dual Imaging System (MDIS) [24] to identify surface changes during the MESSENGER mission to gain insight into the present-day endogenic and exogenic activity. We identified 58,552 time-separated observation pairs (temporal pairs) with similar photometric angles well suited for detecting any changes in the intervening time (minimizing the possibility of false positives due to shadow changes or poor image registration. Normalizing the surface coverage to one Earth year results in an area of 6.27×10^7 km^2.

Surface changes: We identified nineteen quasi-circular surface changes and one linear feature. Most of the detections are in the northern hemisphere, likely due to an observational bias from the eccentric orbit of the spacecraft [1,2,25] with a northern hemisphere periapsis (and thus higher spatial resolution). The center of each surface change has reflectance on average 11% (± 4%) higher than the same area observed in the "before" image. Unfortunately, even at this scale, we could not definitively resolve a crater rim or detailed morphology within these albedo features, likely due to spatial resolution limitations. However, one of the changes located west of Caloris Planitia (38.02°N 115.18°E) has bright rays (reflectance increase of 4%) extending ~20 km SW, consistent with an impact origin.

Assuming an impactor origin for these nineteen surface changes, we estimated the crater diameters of each surface change by evaluating the relationship between the diameter of the high-reflectance ejecta deposit versus the diameter of the primary impact crater for resolved craters seen elsewhere on Mercury. From other small Kuiperian-era craters with diameters between 100 to 400 m, we found that the crater diameter was 30% ± 4% of the proximal high reflectance zone. Therefore, we assume the quasi-circular albedo anomalies correspond to the proximal high-reflectance zone found around craters and use the scaling relationship to approximate the crater diameter. This results in a cratering rate 1000x higher than anticipated [11,12,15,18].

While one surface change had clear ray patterns, the remaining features only show a quasi-circular area of increased surface reflectance lacking any ray-like expressions (Figure 1e-g). Therefore, while some of the remaining changes may be unresolved impact events, others may be the surface expression of endogenic processes such as landslides from faulting or hollow formation. Five observed changes occurred on large (> 10 km) craters and basin walls. Seismic shaking from nearby, active fault structures could induce a landslide on a slope that changes the observed surface reflectance. For example, the change detected at 36.33°S 82.72°E occurs on the wall of a 21 km diameter crater superimposed on the 720 km Rembrandt basin, which is one of the most tectonically complex basins on Mercury. The basin contains a series of extensional and compressional structures and is crosscut by Enterprise Rupes, the largest thrust fault on Mercury [10,20,26].

A second endogenic landform unique to Mercury is the rimless depressions with flat floors, and rounded contours termed hollows [4,21,22]. Hollows preferentially occur in low reflectance material (LRM; ~30% lower than the already dark global average reflectance) [27] and on the floor, central peak, rim, or the ejecta deposit of large craters or basins. Previous studies suggested that hollows could result from the sublimation of volatile-bearing materials such as sulfides, space weathering, outgassing, and pyroclastic volcanism [4,22,28]. Additionally, their crisp features and lack of superimposed craters indicate that they are the youngest non-impact features on Mercury (Blewett et al., 2018).

One such hollow is located along the western terraced wall of Sholem Aleichem crater, which was imaged in 2011 (18 April and 11 October). The temporal ratio image reveals a linear surface change emanating from a hollow and extending down a steep slope. The linear change remains away from the shadow boundary, which remains stationary in the image pair due to the nearly identical lighting geometry. This region was previously mapped as potentially impact-excavated LRM material or a dark spot, a subset of LRM with the lowest average reflectance (0.1-0.2) on Mercury, and proposed to form during the initial stages of hollow formation [23]. A high-resolution MDIS observation acquired on 6 November 2011 shows the hollow and higher reflectance material extending downslope.

Reviewing the other nineteen surface changes, twelve occurred in areas mapped on or near (<25 km) LRM, and six occurred within or on the continuous ejecta deposit of craters containing hollows. One example is a surface change on the ejecta deposit of Lermontov crater, which formed between 13 March and 4 September 2013 and increased the surface reflectance by 8% ± 2% over a 2.9 km^2 region (Figure 3a-b). If this feature was formed from an impact event and we detected the ejecta deposit, we would expect a primary crater 590 m in diameter (based on the crater diameter to bright ejecta relationship discussed above). However, an MDIS-NAC observation acquired in 2014 with a 4× smaller pixel scale (55 meters/pixel) than the original temporal pair shows a cluster of bright haloed hollows and a lack of any resolvable impact crater within the zone of increased reflectance, consistent with an endogenic change associated with the hollows.

Discussion and Future Observations: Temporal imaging analysis of Mercury revealed a collection of new surface changes that formed during the orbital phase of the MESSENGER mission. While some surface changes are the result of exogenic impacts, the location of others suggests an endogenic origin.

The BepiColombo spacecraft [29] will enter orbit around Mercury in 2025 and is equipped with the SIMBIO-SYS [30], a suite of high-resolution cameras. These observations can provide additional detailed images of the changes detected in this study and spur future temporal analysis by comparing SIMBIO-SYS images to the MDIS images collected during the MESSENGER mission, providing a much longer baseline between observations and greater overall temporal coverage. Most importantly, these higher-resolution observations can be used to measure crater rims and confirm assumptions about the formation mechanism.

Recent results from the Lunar Reconnaissance Orbiter Camara [31-33] of contemporary changes seen on the Moon provide an insight into the benefit of follow-up observations. For example, after a significant change or crater is discovered (>30m), we acquire geometric stereo images to help derive digital terrain models (DTMs) [34]. These provide insight into the depth and local slopes and can also be used in photometric modeling that accounts for the local incidence and emission angle. In addition, LROC targets a series of images to create a photometric image sequence over a broad range of photometric angles. Images collected near 0° phase offer insight into the backscattering properties of the surface, while higher phase observations provide insight into the roughness of the surface. Simple ratios of these observations show the slope of the phase curve.

A series of observations covering a broad range of phase angles would reveal the shape of the phase curve that can be used to infer regolith properties. LROC images acquired after the impacts show evidence of how the impact process affects the phase curve and how the curve varies based on distance from the crater.

Further observations of recent changes on Mercury will supply critical insight into the space weathering process and how present-day events affect the properties of the surface (maturity, grain size, roughness, etc.).

References: [1] Solomon et al. (2007) *Space Sci. Rev.*, *131*(1–4), 3–39 [2] Solomon & Anderson (2018), *Mercury: The view after MESSENGER* pp. 1–29. [3] Banks et al. (2015) *JGR: Planets*, 120(11), 1751-1762. [4] Blewett et al. (2011) *Science*, *333*(6051), 1856–1859. [5] Braden & Robinson (2013) *JGR: Planets*, *118*(9), 1903–1914. [6] Ernst et al. (2010) *Icarus*, *209*(1), 210–223. [7] Fassett et al. (2012) *JGR: Planets*, *117*(E12). [8] Ostrach et al. (2015) *Icarus*, *250*, 602–622. [9] Prockter et al. (2010) *Science*, *329*(5992), 668–671. [10] Watters et al. (2009) *Science*, *324*(5927), 618–621. [11] Le Feuvre & Wieczorek (2011) *Icarus*, *214*(1), 1–20. [12] Marchi et al. (2009) *The Astro. Journal*, *137*(6), 4936–4948.[13] Michael & Neukum (2010) *Earth and Planet. Sci. Let.*, *294*(3–4), 223–229. [14] Neukum (1984) [15] Neukum et al. (2001) *Planet. & Space Sci.*, *49*(14–15), 1507–1521. [16] Spudis & Guest (1988) *Mercury*, pp. 118–164. [17] Spudis (1985) *Reports of Planetary Geology and Geophysics Program – Tech. Memo. 87563.* [18] Strom & Neukum (1988) *Mercury*, pp. 336–373. [19] Fassett (2016) JGR: *Planets*, *121*(10). [20] Watters et al. (2016) GRL, *43*(22). [21] Thomas et al. (2014) *Icarus*, *229*, 221–235. [22] Blewett et al. (2013) JGR: *Planets*, *118*(5), 1013–1032. [23] Xiao et al. (2013) *Icarus*, *228*, 260–275. [24] Hawkins et al. (2007) *Space Sci. Rev.*, *131*(1–4), 247–338. [25] Mazarico et al. (2014) *JGR: Planets*, *119*(12). [26] Ferrari et al. (2015) *Geo. Society, 401*(1), 159–172. [27] Robinson et al. (2008) *Science*, *321*(5885), 66–69. [28] Barraud et al. (2020) *Astronomy & Astrophysics*, *605*, A94. [29] Benkhoff et al. (2021) *Space Sci. Rev.*, *217*(8), 90. [30] Cremonese et al. (2020) *Space Sci. Rev.*, *216*(5), 75. [31] Robinson et al. (2010) *Space Sci. Rev.*, *150*(1-4), 81-124. [32] Speyerer et al. (2016) *Nature* 538(7624). [33] Speyerer et al. (2020) LPSC, Abstact #2369. [34] Henriksen et al. (2017) *Icarus* 283, pp. 122-137.