REVISED AGE CONSTRAINTS ON ABSOLUTE AGE LIMITS FOR MERCURY'S KUIPERIAN AND MANSURIAN SYSTEMS.

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Introduction: On the basis of morphologically distinct basin and crater deposits, [1] subdivided Mercury's surface units into five time-stratigraphic systems. Approximate age limits were suggested for these systems by [1] on the basis of the lunar impact-flux history [2]. From youngest to oldest, these systems are the Kuiperian, Mansurian, Calorian, Tolstojan, and pre-Tolstojan. The recent crater production function and inner solar system chronology of [3] indicates that the oldest surfaces on Mercury date from about 4.0–4.1 Ga during the Late Heavy Bombardment [4], and correspond approximately to the pre-Tolstojan and Tolstojan systems [1]. Widespread smooth volcanic plains were emplaced by about 3.55–3.8 Ga [4], at the end of the Calorian system [1]. Here we focus on absolute age constraints for the Kuiperian and Mansurian systems. High-resolution and multi-band image data obtained by the MErcury Surface, Space ENviroment, GEochemistry, and Ranging (MESSENGER) spacecraft were used to catalogue impact craters interpreted to have formed during the Mansurian and Kuiperian systems. These populations of craters can now be used to constrain revised boundaries for the Mansurian and Kuiperian systems.

Methods and data: The Mansurian and Kuiperian systems are defined by the craters Mansur and Kuiper respectively. Mansurian and Kuiperian craters are morphologically fresh and are characterized by crisp morphologies with well-preserved rims, few or no superposed craters, continuous ejecta with radial lineaments, and well-defined secondary craters [1, 5–6]. Kuiperian craters have bright ray systems and high-reflectance ejecta blankets. Mansurian craters retain fresh morphologies, but their associated ray systems no longer display a reflectance contrast with the local surrounding substrate [1]. For this study we utilize a data set of Kuiperian craters, first presented in [7], which covers 98.4% of Mercury's surface ($n = 472$), and Mansurian craters from the dataset of [8], covering Mercury's surface between 40° north and south latitude ($n = 2604$). Craters were included in the analysis down to sizes of 7 km in diameter. We use the density of fresh craters from these combined datasets, along with the recent production and chronology functions of [3] and [9] to estimate new limits for the boundaries of the two most recent of Mercury's systems. These Model Production Functions (MPFs) were derived from the size distribution of Main Belt Asteroids [3] and Near Earth Objects (NEOs) [3, 9] using crater scaling laws. They differ in the orbital distributions used for the impactors, and the scaling relations used for the strength to gravity and the porous to non-porous transitions in the target material. Since craters used in this analysis are ≥7 km in diameter, expected excavation depths are greater than the the the depth of the porous regime as defined by [9], and thus we use their nonporous strength model.

Results: *Mansurian system*: Using the cumulative density of Mansurian and Kuiperian craters equatorward of 40° latitude [7–8], we obtain an estimated model age for the population of craters that have formed since the onset of the Mansurian of ~2.07 ±0.15 Ga (Figs. 1 and 2) using the MPF of [3]. Using the MPF of [9], we obtain an estimated model age for this same population of ~1.26±0.02 Ga.

Kuiperian system: Using the density of Kuiperian rayed craters covering 98.4% of Mercury's surface (Figs. 1 and 2) [7], we obtain an estimated model age for the population of craters that have formed since the onset of the Kuiperian of ~320±44 Ma using the MPF of [3]. Using the MPF of [9], we obtain an estimated model age for this same population of ~137±4 Ma.

Discussion: We assume our density of fresh craters (all Mansurian and Kuiperian craters combined) is representative of the total population of craters, with diameters ≥7 km, that have formed since the onset of the Mansurian system. A small number of craters or crater rays may have been preferentially eroded, or be unrecognizable in the currently available data, which would lead to underestimated ages. In addition, although obvious secondaries were excluded, large secondaries, particularly large distant secondaries between 7–10 km in diameter, may have been inadvertently included which would lead to overestimated ages. We thus present our results as only estimates for the onset of the Kuiperian and Mansurian systems. An independent

catalogue of Mansurian and Kuiperian craters between 20° N and 20° S yielded similar crater densities to those found here in this study [10] (Figs. 1 and 2). As widespread smooth volcanic plains are estimated to have been emplaced by about 3.6 Ga [4, 11–12], all Kuiperian and Mansurian craters are interpreted to have formed after the associated volcanism had ceased [1], and therefore crater densities from these populations should not have been significantly altered by this process. An age of ~300 Ma for Mercury's rayed craters is supported by recent studies that found optical maturation rates to be up to four times faster on Mercury than on the Moon [8, 13]. In addition, degradation rates on Mercury are expected to be higher than those on the Moon, particularly in regards to erosion from subsequent cratering [1, 9, 14–16]. Therefore, craters of similar sizes and states of degradation are expected to be younger on Mercury compared with those on the Moon. Using the MPF of [3], a particularly good fit for the Mansurian crater size distribution was found for the NEO-derived crater distribution, similar to that found for crater size distributions in younger terrains on the Moon [17].

Altogether, preliminary model ages obtained with the recent crater production and chronology function of [3] and [9] suggest that the Kuiperian system may have begun as recently as ~140–320 Ma and the Mansurian system may have begun as recently as ~1.3–2.1 Ga.

References: [1] Spudis, P. D. and Guest, J. E. (1984) in *Mercury*, Univ. Ariz. Press, 118–164. [2] Shoemaker, E. M. and R. J. Hackman (1962) in *The Moon*, edited by Z. Kopal and Z. K. Mikhailov, pp. 277-339, Academic Press, New York. [3] Marchi, S. S. et al. (2009) *Astrophys. J., 137*, 4936–4948. [4] Marchi, S. S. et al. (2013) *Nature*, *499*, 59–61. [5] Arthur, D. W. G. et al. (1963) *Comm. Lunar Planet. Lab*, *2*, 71–78. [6] Leake, M. A. (1982) in *Advances in Planetary Geology*, Technical Memorandum TM-84894, NASA, Washington, D.C., pp. 3–535. [7] Xiao, Z. et al. (2012) , *Lunar Planet. Sci*., *43*, abstract 2143. [8] Braden, S. E. and M. S. Robinson (2013) *J. Geophys. Res. Planets*, *118*, 1903–1914. [9] Le Feuvre, M. and M. A. Wieczorek (2011) *Icarus, 214*, 1–20. [10] Strom, R. G. et al. (2015) *Research in Astronomy and Astrophysics*, *15*, *3,* 407–434. [11] Denevi, B. W. et al. (2013) *J. Geophys. Res. Planets, 118*, 891–907. [12] Byrne, P. K. et al. (2015) *submitted to AGU*. [13] Kreslavsky, M. A. et al. (2014) *Geophys. Res. Lett.,41*, 8245–8251. [14] Gault, D. E. et al. (1975) *J. Geophys. Res.*, *80*, 2444–2460. [15] Cintala, M. J. (1992) *J. Geophys. Res.*, *97*, 947–973. [16] Domingue, D. L. et al. (2014) *Space Sci. Rev., 181*, 121–214. [17] Kirchoff, M. R. et al. (2013) *Icarus*, *225*, 325-341.
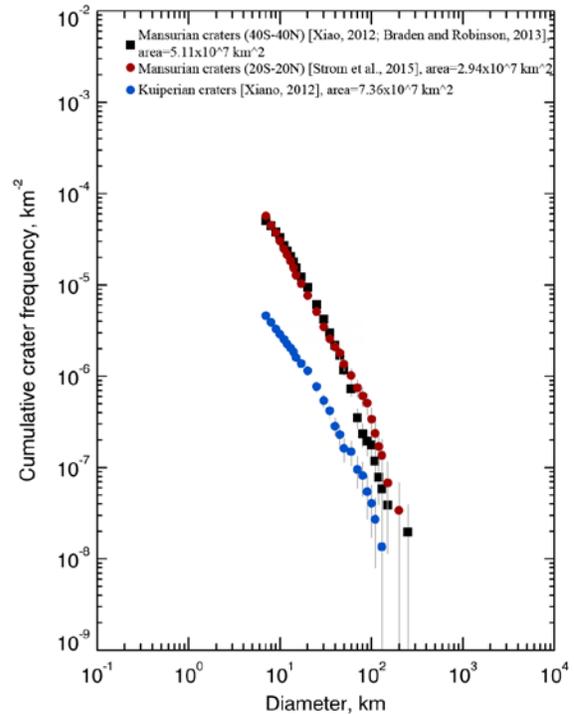

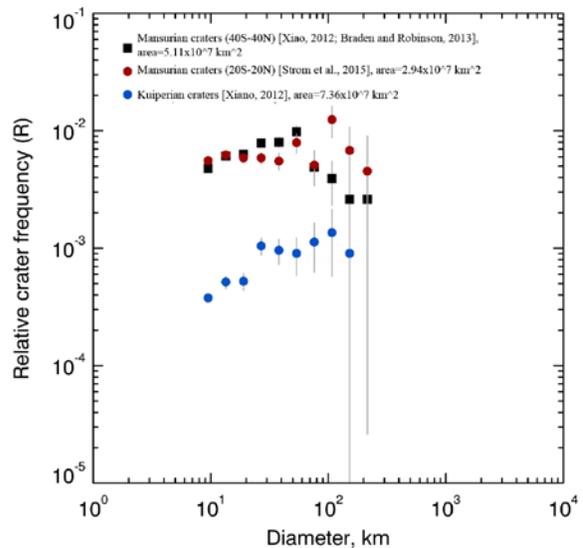**Figure 1.** Cumulative plot for Mansurian and Kuiperian craters [7–8, 10].

Figure 2. Relative plot for Mansurian and Kuiperian craters [7–8, 10].