SUMMARY OF MESSENGER ANALYSES OF IMPACT CRATERING ON MERCURY.

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Introduction: The MESSENGER project Science Team is in the final stages of preparing a book (Cambridge Univ. Press) on Mercury in the light of the recently concluded mission. One chapter presents and discusses the findings regarding impact craters and basins. My presentation summarizes some of the conclusions of that chapter and invites discussion.

Basins: According to Fassett *et al*. [1], Mercury has 46 "certain and probable" basins larger than 300 km diameter and 41 more that are "suggested but unverified." (Many more smaller peak-ring basins exist down to ~85 km diameter.) They are not uniformly distributed, with the western hemisphere having double the number of basins of the eastern hemisphere. Mercury's basins cover Mercury even more sparsely than lunar basins cover the lunar surface; GRAIL has demonstrated that even lunar basins are not saturated. But Mercury's basins have impressively shaped Mercury's currently recognized geology, probably influencing the locations of intercrater and smooth plains of volcanic origin.

The simple-to-complex crater transition is near 12 km, or a bit smaller, but not as small as on Mars, despite similar values of *g*; at still larger diameters, complex craters transition to peak-ring basins through an intermediate category of "protobasins". However, the largest basins that would be expected to exhibit multi-ring structures show little evidence of three or more rings, unlike other terrestrial bodies. Mercury is generally dominated by contractional tectonics, but there are extensional features within some basins. A spectacular set of graben apparently radiate from a large crater near the center of the Caloris basin, but the location of the crater is believed to be coincidental.

The chapter provides detailed geological descriptions of some of the larger or more recent basins: Caloris, Rembrandt, Rachmaninoff, Raditladi, and Mozart. Rachmaninoff not only contains the lowest elevation on Mercury but it is also the site of perhaps the youngest plains on Mercury, which were emplaced long after the basin formed and must be of volcanic origin rather than impact melts [2]. Raditladi, on the other hand, is a recently formed basin and it isn't clear if its interior plains are volcanic deposits or impact melts. The uniquely Mercurian small hollows have etched parts of Raditladi's interior.

Morphology of Impact Craters: Simple craters on Mercury have depth/diameter ratios similar to those for craters on the Moon and Mars, but larger, complex craters are deeper, on average. Crater ejecta have morphologies similar to lunar ejecta blankets, but are more compressed toward the crater on Mercury, with secondary crater fields also beginning closer to craters, due to Mercury's higher *g*. In addition to some endogenic craters and depressions (e.g. volcanic vents and hollows), Mercury has various types of impact craters, including elliptical and polygonal craters, as well as "ghost" craters that are visible especially on the Northern Smooth Plains (NSP). Secondary craters are especially numerous on Mercury, including some unusually prominent crater chains radiating away from basins. Crater rays are less common on Mercury than on the Moon, perhaps due to more efficient weathering processes on Mercury, although rays from the large, recent crater Hokusai extend up to 4,500 km away from the crater. There are many examples of solidified impact melt on Mercury, although identification is difficult; the 3x higher average impact velocities of asteroids and comets on Mercury contributes to impact melt production.

Crater Size-Frequency Distributions (SFDs) and Statistics: We adopt, as a baseline for interpretation, the Population 1 (early and Late Heavy Bombardment [LHB]) and Population 2 (post LHB to current) approach of Strom *et al*. [3]. Certainly the older, more heavily cratered terrains on Mercury have SFDs that approximately resemble the crater populations on the highlands of the Moon and Mars. On the other hand, Mercury is relatively depleted in craters smaller than ~40 km diameter, due to extensive intercrater plains volcanism. It is uncertain how much the densities of smaller lunar highlands craters are depressed from the production function by similar degradation processes; certainly smaller Martian craters are degraded by numerous processes on that more active planet.

Strom interprets the end of the LHB to mark the transition between Population 1 and Population 2 cratering on Mercury (and other terrestrial planets), but the timing is debated and even the existence of a "terminal cataclysm" style of LHB is controversial. What is clear about Mercury's more heavily cratered terrains is that their SFDs are somewhat less dense (undersaturated) than the most heavily cratered terrains on the lunar farside, probably due to more extensive competing early volcanism and other crater degradation processes.

A prominent attribute of Mercury's crater SFDs is that the upturn due to the secondary branch often begins near 10 km diameter, much larger than the ~1 km transition seen for lunar and Martian craters. That is, secondary craters are much more common on Mercury than on other Solar System bodies. Indeed, the intercrater plains on Mercury seem to be saturated by older, km-scale secondary craters. This means that the assumption that craters are primaries only is unreliable for relative or absolute dating that involves craters <20 km diameter, so such studies must be restricted to large units.

Dynamical studies have shown that the primary crater-production rate on Mercury is about 3 times that on the Moon. Combined with the greater production of secondary craters, this means that the resurfacing rate – including degradation of large craters and regolith processes – is much greater on Mercury than on the Moon.

Chronology: While the relative stratigraphy of Mercury's broader geological units and widespread features (e.g. lobate scarps) can be determined by relative crater densities and superposition relationships, there are many uncertainties in determining absolute ages for Mercury's surface features. Earlier chronologies were based either on mere assumptions about corresponding epochs between Mercury and the Moon [4] or involved attributes of the impacting asteroid population [5] that are now obsolete and very different from modern results.

We use the chronology of Marchi *et al*. [6], which is similar to that of Le Feuvre and Wieczorek [7], but emphasize the large meta-errors that must be applied. The oldest, most heavily cratered units on Mercury are 4.1 Ga, younger than the oldest lunar terrains [8]. The beginning of the Calorian is difficult to date because of the small sizes of exposures of the rim of Caloris and scaling uncertainties on sloped terrains, but it is about 3.9 Ga by our nominal chronology, followed shortly thereafter by emplacement of the NSP and Calorian interior and exterior plains. Table 1 shows the ages of smooth plains units and of the geological periods on Mercury [9], derived from a variety of published crater counts and applying the Marchi *et al*. chronology. Also shown are approximate R values (spatial densities on R-plots [10]) and approximate cumulative $N(10)$ and $N(20)$ values. The duration of smooth plains emplacement is fairly compressed, ending in just a few hundred million years [11], except in isolated localities.

The absolute chronology could be very different if Mercury were cratered by a Mercury-specific (i.e. "vulcanoid") population, but surveys by MESSENGER and other spacecraft have discounted any significant population of such bodies at the present time and some theoretical considerations argue against an early vulcanoid population.

Table 1. Absolute ages of Mercurian units and periods.

R	*N*(10)	*N*(20)	Age (Ga)	Location
0.02	100	60	3.8	Floor of Rembrandt
0.02	60	25	3.7	Northern smooth plains
0.02	60	25	3.7	Southern smooth plains
0.006	30	15	3.1	Plains inside Tolstoj
0.007	60	10	1.7	Base of Mansurian
0.001	5	1.5	0.3	Base of Kuiperian
0.0003	3	--	0.2	Raditladi rim & inner plains
0.0003	3?	--	0.2	Rachmaninoff inner plains

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