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Planet-wide cessation of major effusive volcanism on Mercury

Paul K. Byrne (1,2), Lillian R. Ostrach (3), Brett W. Denevi (4), Clark R. Chapman (5), Caleb I. Fassett (6), Jennifer L. Whitten (7), Christian Klimczak (8,2), Erwan Mazarico (3), Steven A. Hauck, II (9), James W. Head (10), and Sean C. Solomon (11,2).
(1) Lunar and Planetary Institute, Universities Space Research Association, Houston, TX 77058, USA (byrne@lpi.usra.edu); (2) Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; (3) Solar System Exploration Division, NASA Goddard Space Flight Center, MD 20771, USA; (4) The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; (5) Department of Space Studies, Southwest Research Institute, Boulder, CO 80302, USA; (6) Department of Astronomy, Mount Holyoke College, South Hadley, MA 01075, USA; (7) Center for Earth and Planetary Studies, Smithsonian Institution, Washington, DC 20013, USA; (8) Department of Geology, University of Georgia, Athens, GA 30602, USA; (9) Department of Earth, Environmental, and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, USA; (10) Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA; (11) Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.

1. Introduction

The importance of volcanism for the formation of Mercury's crust was affirmed by MESSENGER observations of the planet acquired during its three flybys in 2008–10. Smooth plains units were identified across Mercury, and embayment relations, spectral contrast with surrounding terrain, and morphologic characteristics indicated that most of these plains are volcanic in origin [e.g., 1].

Orbital data have allowed the global distribution of these plains units to be characterized [2]. The largest such deposits are located in the northern hemisphere and include the extensive northern plains (NP) and the Caloris interior and exterior plains (with the latter likely including basin ejecta material). Crater size–frequency analyses have shown that both the NP and the Caloris interior deposits were emplaced, within statistical error, around 3.8 Ga [2–6], for any of the published chronology models for Mercury [e.g., 7]. The areal densities of impact craters (for a given range of crater diameters) for other smooth plains deposits across Mercury are comparable to those for the NP and Caloris plains, implying that these other units are similar in age [2,4,6,8].

To test whether this age marked a period of globally distributed volcanic resurfacing on Mercury, we determined crater size–frequency distributions for six additional smooth plains units, primarily in the planet's southern hemisphere, interpreted as volcanic.

2. Crater Spatial Density Analysis

Each of these six sites hosts two populations of impact craters—one that postdates plains emplacement, and one that consists of partially to nearly filled craters that predate the plains. This latter population indicates that, in each case, considerable time elapsed between formation of the underlying basement and the plains.

The largest region of smooth plains at high southern latitudes we investigated is situated proximal to (and is named for) the Alver and Disney impact craters [9]. Farther west, a smaller patch of smooth plains is not obviously associated with an impact structure and so is termed here the "southern plains." The largest unit of those we examined is located at mid-latitudes in the southern hemisphere and is superposed by the 80-km-diameter Debussy impact crater. In the western hemisphere, smooth plains units within the Beethoven and Tolstoj basins constitute two additional sites; earlier studies have also reported crater density data for Beethoven [2,8]. The northernmost site encompasses, but extends far beyond, the 168-km-diameter Faulkner basin, for which earlier crater density data also exist [2].

3. Results

We give in **Table 1** our crater density measurements for each site in terms of *N*(10), the number of craters 10 km in diameter or greater per 10^6 km^2 [e.g., 6]. This approach has the benefit of allowing direct comparison of disparate sites without the use of a particular model production function. (We give confidence intervals of ± one standard deviation, taken to equal the square root of the number of craters normalized to an area of 10^6 km^2 [e.g., 4]).

The six sites fall into two groups by *N*(10), with higher counts (within error) for the plains at Alver/Disney, Beethoven, and Debussy than for those at Faulkner, the southern plains, and Tolstoj. However, the plains at Faulkner host a greater number of secondary impact craters than at any of the other sites; our efforts to exclude secondaries at Faulkner from our count, on the basis of their occurrence in chains and clusters, may have contributed additional uncertainty to the *N*(10) value we calculated for that site.

Table 1: Smooth plains *N*(10) values from this study

Site	*N*(10)	Area (km^2)
Alver/Disney	132 ± 20	3.4×10^5
Beethoven	100 ± 18	3.0×10^5
Debussy	161 ± 20	4.2×10^5
Faulkner	39 ± 10	3.6×10^5
Southern plains	53 ± 27	7.5×10^4
Tolstoj	45 ± 20	1.1×10^5

Additionally, the southern plains and Tolstoj units are substantially smaller than, and so their *N*(10) values may not be as statistically robust as those for, the other units in this work. Nonetheless, the collective span of *N*(10) we give here is comparable to previously reported values for these and other volcanic smooth plains, and substantially lower than the range found for several intercrater plains units (**Table 2**).

Table 2: Earlier *N*(10) values for plains units

Site	*N*(10)	Ref.
Beethoven	82 ± 19 | 77 ± 24	[2] | [8]
Caloris interior plains	58 ± 13 | 75 ± 7	[2] | [4]
Caloris exterior plains	91 ± 16	[2]
Faulkner	58 ± 18	[2]
Northern plains	67 ± 4	[6]
Rembrandt	103 ± 19 | 110 ± 23	[2] | [8]
Rudaki	51 ± 23	[2]
Intercrater plains	154 ± 34 → 370 ± 53	[8]

Importantly, although small deposits in Rachmaninoff and Raditladi basins may be as young as 1 Ga [10,11], we have yet to identify widespread (e.g., $>1 \times 10^5$ km^2) effusive volcanic deposits anywhere on Mercury with resolvably lower *N*(10) values than those we report.

4. Planet-wide cessation of major effusive volcanism

It has long been noted that many volcanic smooth plains units on Mercury, including the Caloris interior plains and those in Beethoven, Rembrandt, and Tolstoj, are situated within pre-existing impact basins and craters [e.g., 9]. So, too, are many smaller deposits across the planet, at least some of which are likely volcanic. This collocation of many of the youngest effusive volcanic units on Mercury with impact structures is consistent with predictions for a planet undergoing contraction from secular interior cooling [12].

Global contraction induced a state of net horizontal compression in Mercury's lithosphere, inhibiting the vertical ascent and eruption of magma [13]. However, the impact process would not only have deposited impact heat at depth, but would have removed overburden, fractured the lithosphere, and reset stresses locally—making impact structures prime sites for late-stage eruptions in a tectonic regime otherwise generally unfavorable to extrusive activity.

The volcanic smooth plains across Mercury may reflect a peak in magma generation [e.g., 14] or instead may simply have arisen from the rapidly waning impact flux toward the end of the late heavy bombardment of the inner Solar System [15]. Nonetheless, global contraction likely was underway by this time [16] and may, in and of itself, account for the absence of resolvably younger, widespread effusive volcanic deposits on Mercury [13]. If the rate of magma production after the onset of global contraction did not diminish in step with the rate of effusive resurfacing, the ratio of intrusive to extrusive material may be greater for the innermost planet than for bodies with longer histories of effusive surface volcanism [e.g., 17].

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