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Intercrater plains on Mercury: Insights into unit definition, characterization, and origin from MESSENGER datasets

Jennifer L. Whitten [a,*], James W. Head [a], Brett W. Denevi [b], Sean C. Solomon [c,d]

[a] Department of Geological Sciences, Brown University, Providence, RI 02912, USA
[b] The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA
[c] Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA
[d] Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA

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ABSTRACT

Orbital observations by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft are used to re-evaluate the nature and origin of the oldest mapped plains deposits on Mercury, the intercrater and intermediate plains units defined by Mariner 10 investigators. Despite the large areal extent of these plains, which comprise approximately one-third of the planetary surface area viewed by Mariner 10, their formation mechanism was not well constrained by Mariner 10 imaging. One hypothesis attributed plains formation to ponding of fluidized impact ejecta to create relatively smooth surfaces. Another hypothesis was that these plains are of volcanic origin. To assess the origin of these older plains and the contribution of early volcanism to resurfacing on Mercury, we have used MESSENGER data to analyze the morphology, spectral properties, impact crater statistics, and topography of Mariner 10 type-areas of intercrater and intermediate plains. On the basis of new criteria for the identification of intercrater and intermediate plains derived from these observations, we have remapped 18% of the surface of Mercury. We find that the intercrater plains are a highly textured unit with an abundance of secondary craters, whereas the intermediate plains are composed of both intercrater and smooth plains. We suggest that the term "intermediate plains" not be used to map the surface of Mercury henceforth, but rather this unit should be subdivided into its constituent intercrater and smooth plains units. We argue that a substantial percentage of the intercrater plains are composed of volcanic materials on the basis of (1) examples of areas where ejecta from a small number of superposed craters have transformed smooth plains deposits of volcanic origin into a unit indistinguishable from intercrater plains; (2) the range in ages of intercrater plains deposits as interpreted from crater size–frequency distributions; and (3) the near-global distribution of intercrater plains compared with the uneven distribution of impact basins and their associated ejecta deposits.

1. Introduction

The first spacecraft images of Mercury were obtained by Mariner 10 (M10) during three flybys in 1974–1975. M10 imaged approximately 40% of the planet's surface (Fig. 1), ~55% of which was covered with several different plains deposits. The earliest geological interpretation of images from the first M10 flyby (Murray et al., 1974) included a regional map showing three distinct geologic units: plains material, hilly and lineated terrain, and heavily cratered terrain. The intercrater plains unit shortly thereafter was identified as a subdivision of this "heavily cratered terrain" marked by level to gently rolling, densely cratered surfaces between craters >30 km in diameter (Trask and Guest, 1975; Trask, 1976). From geologic maps (Trask and Guest, 1975; Schaber and McCauley, 1980; DeHon et al., 1981; Guest and Greeley, 1983; McGill and King, 1983; Grolier and Boyce, 1984; Spudis and Prosser, 1984; Trask and Dzurisin, 1984; King and Scott, 1990; Strom et al., 1990) constructed from M10 images, it is clear that the intercrater plains are the most widespread unit on the portion of the planet imaged by that spacecraft. A distinguishing characteristic of the intercrater plains is their high density of small, superposed craters 5–15 km in diameter (Trask and Guest, 1975; Strom, 1977; Leake, 1981) (Fig. 2). According to Trask and Guest (1975), the majority of these small craters are likely to be secondary impact craters formed from material ejected from larger craters

* Corresponding author. Address: Department of Geological Sciences, Brown University, 324 Brook St., Box 1846, Providence, RI 02912, USA. Fax: +1 4018633978.
E-mail address: jennifer_whitten@brown.edu (J.L. Whitten).

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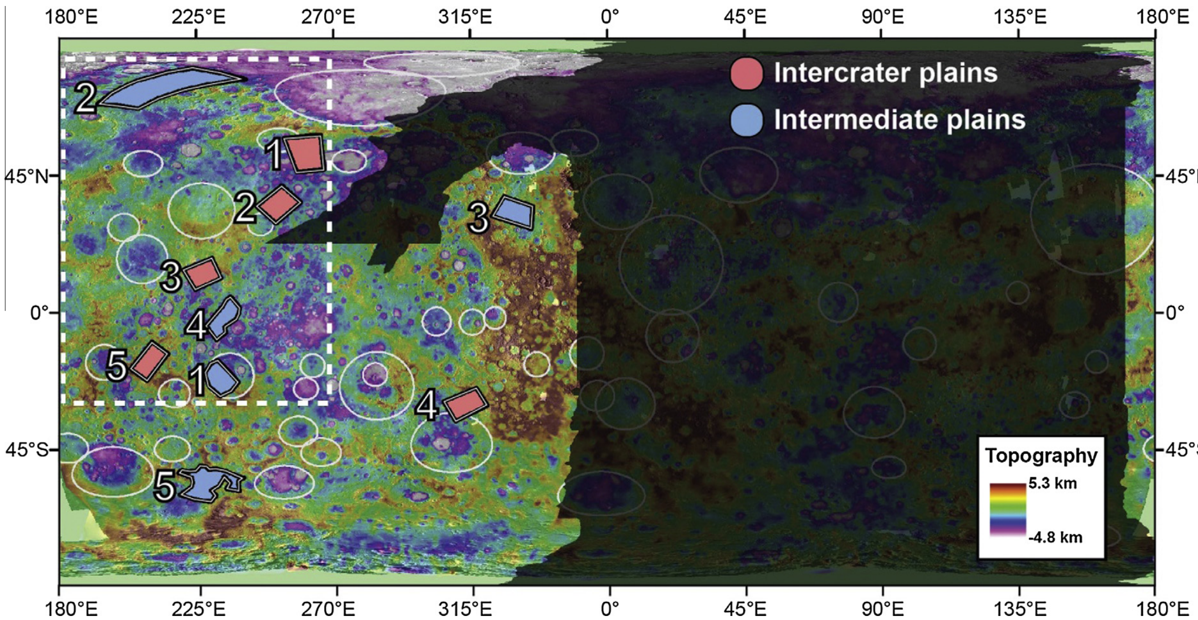

Fig. 1. Map of the study locations in this analysis. Red polygons represent the areas dominated by intercrater plains (ICP), and blue polygons denote the areas dominated by intermediate plains (IP); the numbers are specific identifiers used for reference in the text. The darkened area indicates the part of Mercury that was not imaged by M10. Identified basins (Fassett et al., 2012) are outlined in white. The white dashed box outlines the region mapped in Fig. 8. Overlaid on the MDIS 250 m/pixel mosaic is a model of global topography derived by stereo photogrammetry and referenced to a sphere of radius 2440 km (Edmundson et al., 2011; Becker et al., 2012). Simple cylindrical projection.

(>30 km in diameter) within the heavily cratered terrain. The superposition of these secondary craters was invoked as evidence that the majority of the intercrater plains are older than the heavily cratered terrain (Trask and Guest, 1975). This observed stratigraphic relationship and inferred relative age, combined with the unit extent and crater size–frequency distributions, led to the hypothesis that the intercrater plains are remnants of a volcanic surface that partially predated a period of heavy bombardment of the terrestrial planets (Murray et al., 1975; Trask and Guest, 1975).

The findings from the Apollo 16 mission to the Moon, however, called into question a volcanic origin for plains units on Mercury. Before the Apollo 16 mission, the high-reflectance Cayley plains on which the Apollo 16 astronauts landed were thought to be products of highland volcanism (Milton, 1964; Wilhelms and McCauley, 1971). During the mission (Young et al., 1972) and thereafter (Hodges et al., 1973; Muehlberger et al., 1980), however, the abundance of brecciated material in returned samples (Gast et al., 1973) indicated that these light plains were produced by impact-related processes involving some combination of local, regional, and basin-related material (Eggleton and Schaber, 1972; Head, 1974; Oberbeck et al., 1974). This discovery from the Moon, along with the lack of distinct contrasts in reflectance between surrounding morphologic units on Mercury (Hapke et al., 1975; Rava and Hapke, 1987) and the muted morphology of local wrinkle ridges there (e.g., Strom et al., 1975), prompted some researchers to explore the idea that the intercrater plains on Mercury were emplaced as fluidized ejecta from basin impacts (Wilhelms, 1976; Oberbeck et al., 1977). The surface morphology and reflectance relationships on Mercury matched Cayley plains material more closely than those of the volcanic lunar mare deposits.

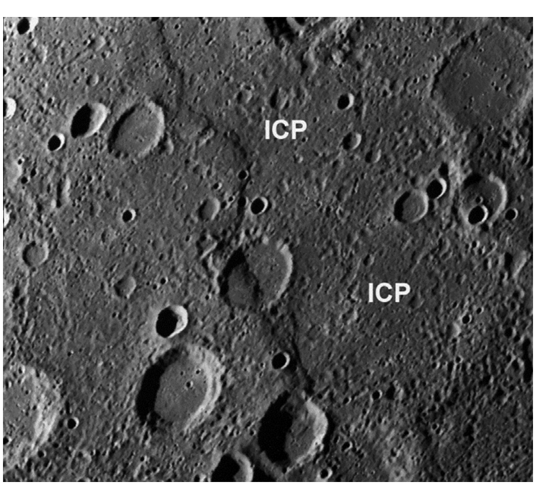

Fig. 2. Example of a Mariner 10 image of intercrater plains (ICP), as defined by Trask and Guest (1975). The lobate scarp Santa Maria Rupes cuts across these intercrater plains from the northwest to southeast. The image is approximately 200 km across; north is up. Mariner 10 frame 27448.

The dominant formation mechanism for the intercrater plains on Mercury continues to be debated, with ideas for the unit's formation focused on two hypotheses: (1) formation as volcanic flows (Murray et al., 1974, 1975; Strom, 1977; Kiefer and Murray, 1987; Spudis and Guest, 1988) and (2) formation by the emplacement of fluidized impact ejecta, an origin similar to that hypothesized for the Cayley plains on the Moon (Trask and Guest, 1975; Wilhelms, 1976; Oberbeck et al., 1977). Another plains unit, the intermediate plains defined in some geological maps constructed from M10 images (Schaber and McCauley, 1980; Guest and Greeley, 1983; McGill and King, 1983; Grolier and Boyce, 1984; Spudis and Prosser, 1984; Trask and Dzurisin, 1984; King and Scott, 1990; Strom et al., 1990), shares many of the same characteristics as the intercrater plains (except that it is less densely cratered), including an uncertain formation origin.

Widespread resurfacing occurred early in Mercury's geologic history, as evidenced by a deficit of craters 20–100 km in diameter compared with the lunar highlands, and at least a portion of that resurfacing is thought to have occurred by the emplacement of intercrater plains (Fassett et al., 2011; Strom et al., 2011; Marchi