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Impact craters with ejecta flows and central pits on Mercury

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ABSTRACT

Impact craters with ejecta flows and/or central pits have been found on Venus, the Moon, Earth, Mars, and some icy satellites. Using the MESSENGER camera data obtained during the orbital mission, we found craters with ejecta flows and central pits on Mercury. The ejecta flows differ from normal ballistically emplaced ejecta deposits in their long mobilized distances. They all flowed in downslope directions and exhibited a layered morphology. Analog study suggests that the ejecta flows probably have formed by fluidization in the ejecta deposits. Crustal volatiles are not required to form the ejecta flows on Mercury, although they may have helped. The ejecta flows are most likely to be a type of avalanche features in forms of dry granular flows. Central pits in impact craters on Mercury are located on summits of central peaks when viewing in sufficiently high-resolution images, but some of the central pits may occur on crater floors. The central pit craters are all fresh craters located on smooth plains and intercrater plains. The pits are different from the other forms of rimless and irregularly-shaped depressions on Mercury in the size, morphology, and/or occurrence. Crustal volatiles are not required in forming the central pit craters and they may form in a similar way with the central pit craters on the Moon.

1. Introduction

On airless silicate bodies such as the Moon and Mercury, normal continuous ejecta deposits of fresh impact craters form from ballistic emplacement of impact ejecta (e.g., Osinski et al., 2011). Continuous ejecta deposits start from hummocky terrains near crater rims and grade outwardly into radially ridged facies (Shoemaker, 1965). These two facies exhibit no sharp boundaries and have no superposed secondary crater clusters or chains. Without post-impact disturbances of impact melt flows on continuous ejecta deposits (e.g., Bray et al., 2010), these facies have an exponentially decreasing thickness measured radially from crater rims (e.g., McGetchin et al., 1973). Continuous ejecta deposits on the Moon and Mercury usually have a smooth morphology and a limited extent (e.g., Schultz and Singer, 1980; Xiao et al., submitted for publication), and no ejecta flows occur on continuous ejecta blankets (e.g., Fig. 1).

Crater ejecta that have a fluidized morphology are found on Venus (e.g., Schultz, 1992; Baker et al., 1992), the Moon (Shoemaker et al., 1968; Guest, 1973; Melosh, 1987), Earth (e.g., Osinski, 2004; Kenkmann and Schönian, 2006; Maloof et al., 2010), Mars (e.g., Carr et al., 1977), and some outer Solar System icy satellites such as Europa (Moore et al., 2001), and Ganymede (Passey and Shoemaker, 1982; Boyce et al., 2010). These ejecta have a layered morphology compared with normal ballistically emplaced ejecta deposits. Ejecta flows on Venus were interpreted to form from the entrainment of atmosphere during the ejecta emplacement (e.g., Schultz, 1992). Crustal and/or atmospheric volatiles affect ejecta emplacement on Mars and are possible reasons in forming martian ejecta flows (e.g., Carr et al., 1977; Barlow, 2005; Komatsu et al., 2007). Those on icy satellites were hypothesized to result from the effect of crustal water ice (e.g., Moore et al., 2001). Ejecta avalanches on the Moon were interpreted to be dry granular flows (Melosh, 1987).

Ejecta flows had not been known to exist on Mercury prior to the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER; Solomon et al., 2001) mission. The previous Mariner 10 data covered ~45% of Mercury's surface at an average resolution of ~1 km/pixel. The Mariner 10 data contained a large number of high solar-angle images ($>60^\circ$, measured from horizontal) restricting detailed morphological studies for surface features (cf. Strom, 1979). These factors probably prohibited finding ejecta flows on Mercury in Mariner 10 imagery.

Central pits in impact craters have been found on Mars (e.g., Barlow and Bradley, 1990; Robbins and Hynek, 2012), the Moon and Earth (e.g., Milton et al., 1972; Allen, 1975), and on icy moons, especially Ganymede and Callisto (e.g., Passey and Shoemaker, 1982; Croft, 1983; Schenk, 1993; Alzate and Barlow, 2011). The pits

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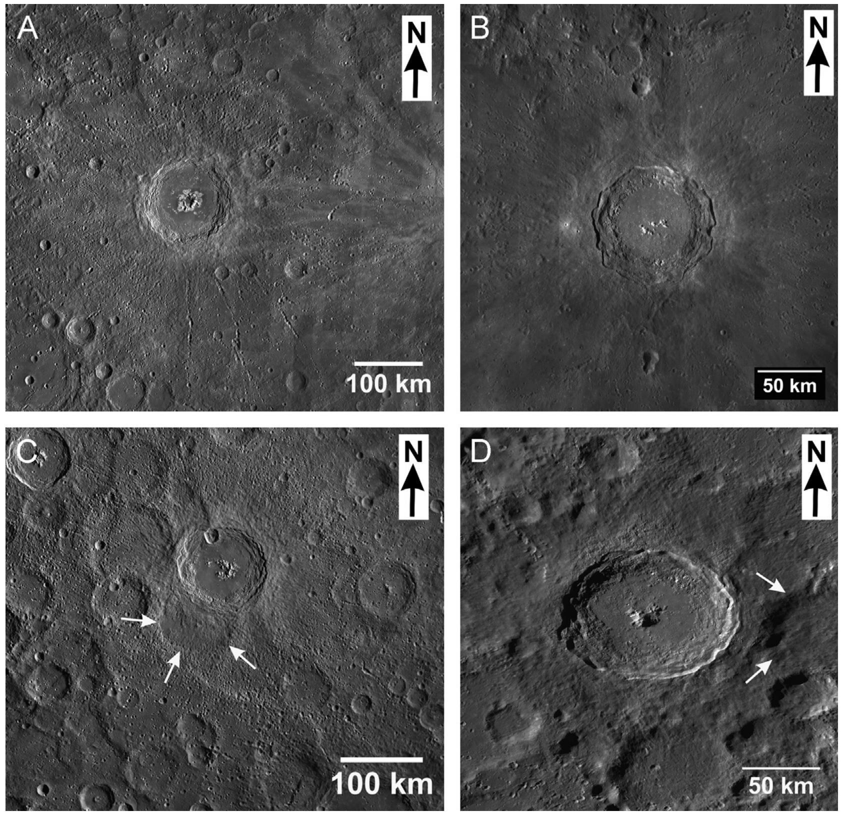

Fig. 1. Ballistically emplaced ejecta deposits of impact craters on the Moon and Mercury. (A) and (C) are the Eminescu (D=130 km; 11 °N, 114 °E) and Amaral (D=109 km; 27 °S, 118 °E) craters on Mercury, respectively. (B) and (D) are the Copernicus (D = 93 km; 10°N, 20°W) and Tycho (D = 85 km; 43°S, 11°W) craters on the Moon, respectively. The base mosaics of (A) and (C) are from the 250 m/pixel global mosaics of Mercury, those of (B) and (D) are from the 100 m/pixel global mosaics of the Moon. The white arrows in (C) and (D) show preexisting topographic lows at the impact sites; impact melt ponded in these areas but no ejecta flows are visible. All the panels are in equirectangular projections.

are either rimless or rimed (Garner and Barlow, 2012; Bray et al., 2012) depressions that are located on summits of central peaks or in centers of crater floors (e.g., Barlow and Bradley, 1990). Previous studies about their origin mostly emphasized the importance of target volatiles during impact processes, which suggested that central pits had formed from either vapor bursts or ice melt drainage (e.g., Barlow and Bradley, 1990; Barlow, 2010; Senft and Stewart, 2011; Bray et al., 2012). Central pits also are interpreted to be caused by impacts into compositionally or rheologically distinct layers at depth (Greeley et al., 1982; Schenk, 1993). The Moon and Mercury generally have been thought to be poor in crustal volatiles (e.g., Lewis, 1972). Central pit craters were not expected to occur on these two bodies (e.g., Elder et al., 2012). Allen (1975) found some craters with central pits on the Moon, but the origin of the pits so far remains unknown due to the assumption of low content of crustal volatiles on the Moon (e.g., Bray et al., 2012). Central pit craters had not been found on Mercury prior to MESSENGER, and the limited coverage and resolution of the Mariner 10 data are possible reasons.

After the three flybys, the MESSENGER spacecraft successfully entered the orbit about Mercury in March 2011. The Mercury Dual Imaging System (MDIS) onboard MESSENGER (Hawkins et al., 2007) has been carrying out systematic global imaging augmented by high-resolution targeted observations. Compared with both the MESSENGER and Mariner 10 flyby data, MDIS orbital images have great improvement in image resolution, coverage, and illumination conditions, thus permitting detailed morphological studies for impact craters.

In this study, we find that several impact craters on Mercury have ejecta flows that are similar in morphology to those on other planetary bodies. Some other impact craters on Mercury have central pits. The ejecta flows and central pits on Mercury provide a complement to similar features on other Solar System bodies, and are therefore useful to understand the formation mechanisms for these features as well as the possible role of volatiles to the impact process.

Here we introduce the morphological and geometrical properties for the ejecta flows and central pits on Mercury. We study their global distribution and compare them with similar morphological features on other planetary bodies. Combining with the geological background and surface conditions on Mercury, we investigate the possible contributing factors in the formation of these features in combination with the geological background and surface conditions on Mercury.

2. Research material

The global monochrome mosaics of Mercury obtained during the MESSENGER orbital mission were used to search for craters with ejecta flows and central pits. The mosaics were composed of MDIS Narrow Angle Camera (NAC) and Wide Angle Camera (WAC) images acquired in the filter centered at 750 nm wavelength. Images in the mosaics were selected and prioritized by resolution, mid to high solar incidence angles, and low emission angles. The mosaics have a resolution of 250 m/pixel and cover over 99.9% of the planet. The detailed information about the mosaics is found at http://messenger.jhuapl.edu/the_mission/mosaics.html. We also made regional mosaics for each of the observed ejecta flows and central pits to measure their geometric properties. The mosaics were in sinusoidal projections and were centered on the centers of the parent craters to preserve accurate areal