Determining the Relative Ages of Mercury's Pyroclastic Deposits Using Geomorphological and Spectral Properties

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Introduction: One of the most important, if not unexpected, results of the MESSENGER [1] mission was the discovery of volcanic vent morphologies and associated deposits, which were interpreted as evidence of explosive volcanic activity [2]. While it was long suspected that Mercury hosted significant amounts of effusive volcanic activity, the discovery of explosive volcanic activity provides evidence for the accumulation of volatile species in Mercury’s interior, something incompatible with previous models of Mercury’s formation [3]. Mercury’s pyroclastic deposits, therefore, provide a critical target for understanding the interior and thermal evolution of Mercury.

Crater size-frequency distribution studies of Mercury’s smooth plains deposits suggest that effusive volcanic plains formation largely ceased by ~3.5 Ga [4], during the Calorian period. However, a number of studies focusing on vent morphology and stratigraphy have suggested that vent formation could have occurred as recently as the Mansurian or even Kuiperian periods (~1 Ga) [5, 6, 7].

Here, we present a unified geomorphological and spectral assessment of pyroclastic vent degradation on Mercury, and show clear evidence for a continuous degradation process. These results will allow us to not only place age constraints on the previously observed pyroclastic vents, but also allow for a range of other investigations into the timing and duration of explosive volcanic processes on Mercury.

Geomorphologic Degradation of Vents: Mercury’s pyroclastic vents display a wide range of morphologies and apparent levels of degradation [3, 5, 6, 7]. For example, Nathair Facula (previously NE Rachmaninoff), displays a variety of floor textures, crisp wall morphologies, and even evidence of internal layering and gully formation within the walls (Fig. 1). Although the age of a vent cannot be constrained by the age of its surrounding host crater, the crisp morphologies suggest recent geologic formation. Building upon these geomorphological identifiers for morphologic “freshness”, and adapted from similar morphologic features used in the assessment of relative crater degradation [8, 9], we developed a morphologic degradation classification system for vents on Mercury [10]. For each vent, we used the USGS Planetary Image LOcator Tool (PILOT) to identify the highest resolution MDIS (Mercury Dual Imaging System [11]) Wide Angle- and Narrow Angle Camera (WAC and NAC) images for each vent in the Jozwiak et al. [7] index. The vent morphologies were investigated independently by two different researchers, to ensure robustness in classification. Vents were classified as either heavily degraded (Class 1, oldest), moderately degraded (Class 2), or lightly degraded (Class 3, youngest). Within these categories, we identified 39 Class 1 vents, 68 Class 2 vents, and 10 Class 3 vents [10]. These broad morphologic categories were also subdivided into more- and less-degraded end-members. However, these distinctions are highly qualitative, and strongly dependent on the available image resolution and illumination conditions.

While this classification system provides evidence for explosive volcanic activity occurring across a significant period of geologic time, the classification system is relatively coarse, and allows for only modest comparisons of vent ages and interpretation of relative formation time. In order to more thoroughly investigate the processes associated with vent degradation processes—and by proxy, the ages of vents on Mercury—we incorporated analysis of the spectral characteristics associated with the pyroclastic deposits surrounding the vents.

Spectral Properties of Pyroclastic Deposits: Despite the overall lack of Fe-related mineral absorptions in the MASCS (Mercury Atmospheric and Surface Composition Spectrometer) spectral range, several unique properties associated with Mercury’s pyroclastic deposits have been identified [e.g. 5, 12]. The spectral properties associated with pyroclastic deposits are an enhanced reflectance at 700 nm, and a steep downturn of the spectral slope approaching the UV portion of the spectrum [5, 12]. Observed variations in the strength of spectral properties have been suggested by previous researchers to be related to the age of the deposit, although the exact relationship was unknown [5].

In order to investigate the hypothesis that the strength of the pyroclastic deposit spectral properties is related to the age of the deposit, we investigated the MASCS spectra covering all previously identified pyroclastic deposits. Using the MeSS (Mercury Surface Spectroscopy) Database [13], calibrated spectra covering both the deposit and the regional background material were analyzed. The limits of the spectral deposit...
were defined using the methods described in Leon-Dasi et al. (2023) [14].

We hypothesize that the spectral properties of the deposit are related to the age of the deposit, and therefore the properties should become closer to those of the background region with increasing deposit age due to the combined processes of space weathering and regolith mixing. Using the previously identified geomorphologic degradation as a proxy for vent age, we plot the visible reflectance normalized to the background material (Fig. 2). The results show a distinct trend with the morphologically oldest vents coinciding with vents whose spectral properties are indistinguishable from background material. On the opposite end, the morphologically youngest vents are shown to display the most distinct spectral properties. Most intriguingly, the vents with moderate levels of degradation follow along a trend of decreasing spectral distinctness.

**Results and Ongoing Work:** The results of this analysis strongly suggest that there is a link between the age of explosive vents and deposits on Mercury with their observed spectral properties. Further analysis of the spectral degradation trend identifies two discrete slopes, where spectral degradation of the youngest deposits occurs rapidly, and is followed by a more protracted period of degradation observed at older deposits. We hypothesize that these distinct regions are related to different driving processes. The early, rapid spectral degradation being driven by solar wind irradiation processes [e.g. 15], while the slower protracted degradation is driven by physical weathering of the deposit, including micrometeoroid bombardment and regolith mixing processes [e.g. 16, 17].

These results provide further evidence that explosive volcanism continued into the recent geologic history on Mercury, with important implications for the thermal evolution of the planet. Our ongoing research is exploring the link between deposit size, vent size, and spectral properties, in addition to continued investigation into the processes driving spectral deposit degradation.

**References:**

**Figures:**

Fig. 1: MDIS NAC mosaic of Nathair Facula (35.8° N, 63.8° E). The thin solid arrows identify regions of distinctly preserved floor textures, and the thick dashed arrow identifies preserved layering and structure within the walls.

Fig. 2: Spectral reflectance of pyroclastic deposits as a function of central vent degradation level, where 1.0 is most degraded, and 4.0 is least degraded. The spectral reflectance is normalized to the local background material. The observed trend suggests a link between the age of pyroclastic deposits on Mercury and the strength of the spectral properties in the observed deposit.