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The role of impact structures in localizing explosive volcanism on a contracting planet: Mercury

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1. Introduction

A long history of global contraction on Mercury is attested to by thousands of ridges and scarps, thought to be the surface expression of thrust faults [1]. The resulting compressive crustal stress presents an obstacle to surface volcanism on the planet, inhibiting magma ascent from depth. Nevertheless, volcanic vents and deposits indicate that explosive volcanism persisted on the planet until as recently as 1 Ga [2]. The common localization of this volcanism within impact craters and inwards of the rims of large impact basins [3] indicates that impact structures play a role in allowing volcanic eruption on this contracting body. By making a comparison with explosive volcanism within impact craters on the Moon, we investigate how ascending magma and impact structures interact on a local scale to facilitate such eruptions on Mercury. Additionally, in light of the surprisingly low number of large impact basins on Mercury [4], we investigate whether the detection of clusters of sites of explosive volcanism can provide evidence for the location of ancient impact basins that are no longer detectable morphologically.

2. Localization within impact craters

2.1 The existing lunar model

Pyroclastic deposits are commonly seen within impact craters on the Moon [e.g. 5-6], and are thought to be sourced from a shallow magmatic intrusion beneath the crater floor. It is hypothesised that ascending magma stalls in the low-density brecciated zone beneath the crater, propagates laterally to the horizontal extent of brecciation, then inflates and fractures the overlying crater floor [7]. These fractures favour magma ascent at the outer floor margins. To determine whether this is a feasible mechanism by which explosive volcanism becomes localized in impact craters on Mercury, we compared the morphology, scale and tectonic association of pyroclastic deposits and vents in 16 complex craters on Mercury and 15 on the Moon.

2.2 Results and implications

We find that host crater deformation and vent location differ significantly on the two bodies. While the floor of the host crater is fractured in all lunar cases, it is neither fractured nor deformed at sites on Mercury. Moreover, vents are commonly near the crater wall on the Moon (10 of 15 sites), but at the crater's central uplift on Mercury (14 of 16 sites).

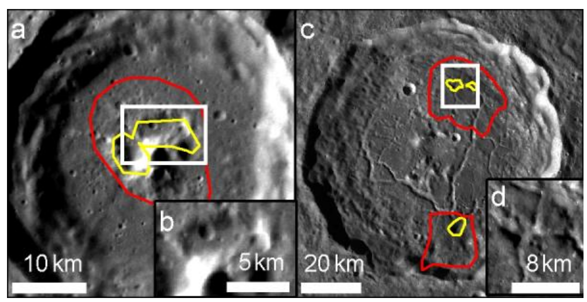

Fig. 1: Characteristic appearance of crater-hosted explosive volcanic vents (yellow outlines) and deposits (red outlines) on a. Mercury (MESSENGER NAC images, NASA/JHUAPL/ Carnegie Institute Washington) and c. the Moon (LROC WAC mosaic), with close-ups of vents, b. and d., indicated by white rectangles.

The scale of vents and deposits indicates a higher energy of eruption on Mercury than on the Moon. The maximum ballistic range (based on deposit extent) is larger at sites on Mercury (18.6 ± 1.2 km) than on the Moon (10.7 ±0.04 km). As both bodies are virtually airless but gravity is greater on Mercury, particles ejected at the same velocity will have a smaller range on Mercury. Therefore, the furthermost particles must have been ejected at considerably higher velocity on Mercury, indicative of a higher volatile mass fraction in the erupting magma [8]. Moreover, vents are much larger on Mercury (average volume 25.0 ± 2.1 km^3 vs. 0.54 ± 0.06 km^3), consistent with more intense erosion of the conduit during higher energy eruption.

The implied high volatile mass fraction powering eruptions on Mercury suggests a period of subsurface magma storage prior to eruption, during which volatiles were concentrated in the melt by fractional crystallisation and/or remobilization of volatiles in the crust. This is supported by the presence of multiple vents at some sites, which are best explained by repeated eruption from a single local source. However, the lack of surface deformation indicates that this storage was at a greater depth than on the Moon. We propose that this results from the compressive stress in Mercury's crust, which hinders magma ascent to a level of neutral buoyancy and favours deep intrusion. On Earth, pre-existing overlying fractures are essential to allow dyke propagation to the surface in such a setting [9]. On Mercury, the common localization of explosive volcanism at the crater central uplift indicates that the deep-going, high-angle faults that are thought to bound such uplifts [10] probably play this role.

3. Explosive volcanism as evidence for ancient impact basins

Sites of explosive volcanism show conspicuous alignments in some regions of Mercury [3]. It has been proposed that the occurrence of such alignments inwards of the putative rims of the large basins Caloris and "b54" indicates that magma ascent there is favoured by the deep structures of the basins [3,11]. We compared the global distribution of sites of explosive volcanism to recently-published maps of elemental abundance [12] and crustal thickness [13] to determine whether alignments of vents occur at the margins of compositional anomalies (which could indicate excavation from depth in very large impacts) and relatively thin crust.

We observe that sites of explosive volcanism do indeed occur along the margins of regions of anomalously thin crust in several regions. One such is the compositionally-defined High-Magnesium Region (HMR), which has been proposed, on the basis of its anomalous composition and low crustal thickness, to be an ancient impact basin (Fig 2) [12]. The occurrence of multiple sites of explosive volcanism along the outer margins of this region supports the basin hypothesis.

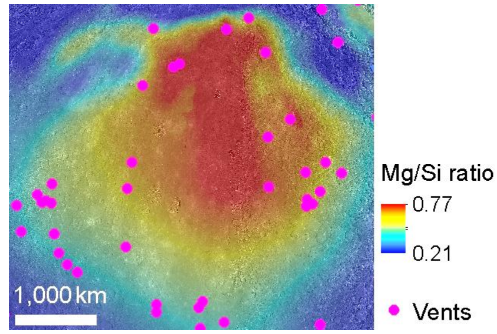

Fig. 2: Sites of explosive volcanism around the HMR. Base image: Mg/Si map [12] centred on 90.4°W, 17.9°N, superposed on MESSENGER global monochrome mosaic V9 (NASA/JHUAPL/ Carnegie Institute Washington).

6. Summary and Conclusions

- The nature of explosive volcanism within impact craters on Mercury and the Moon supports the localization of magma in the brecciated zone beneath crater floors on both bodies. However, deeper magma storage is indicated on Mercury. This is probably due to compressive stress in Mercury's crust and favours energetic eruption.
- A comparison of the distribution of sites of explosive volcanism and composition and crustal thickness data on Mercury provides supporting evidence for an ancient giant impact basin, no longer visible morphologically, in a region with an anomalously high surface Mg/Si ratio (HMR).

References

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