EXPLOSIVE VOLCANISM ON MERCURY AND THE MOON: INSIGHTS INTO THE NATURE OF SUB-SURFACE MAGMA STORAGE. Rebecca. J. Thomas[1], David A. Rothery[1], Susan J. Conway[1] and Mahesh Anand[1,2], [1]Dept. of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, U.K. (rebecca.thomas@open.ac.uk), [2]Dept. of Earth Sciences, The Natural History Museum, London, SW7 5BD, U.K.

Introduction: On both Mercury and the Moon, pyroclastic deposits and endogenic vents are commonly found within impact craters (e.g., [1], [2]). It has been hypothesized that this co-location results from stalling of ascending magma in the relatively low-density brecciated zone beneath craters prior to explosive volcanic eruption [3–5]. However, the specific localization of vents, the presence or absence of crater floor fractures and the inferred style of explosive volcanism differ on the two bodies, indicating differences in the nature of sub-surface magma storage.

We compare the morphology, scale and tectonic association of pyroclastic deposits and vents in complex craters on Mercury and the Moon. We find that deposits and vents are larger on Mercury, and are consistent with a longer period of higher-pressure magma storage than in lunar cases. We propose that the best explanation of these differences is deeper magma storage resulting from the compressive regime in Mercury's crust, indicating that the regional stress regime may play a significant role in the nature of sub-crater magmatic intrusion on terrestrial bodies.

Site selection and analysis: We selected 16 sites on Mercury and 15 on the Moon where candidate vents occur in impact craters in association with a surrounding diffuse-margined spectral anomaly interpreted to be a pyroclastic deposit (Fig. 1). On Mercury, we selected previously-identified [5] sites where MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) images suitable for photogrammetry were available. We selected lunar examples from previously-identified [1,6] sites where the presence of pyroclastic deposits is relatively uncontroversial. Only sites occurring within complex craters (30–120 km diameter on Mercury, 30–140 km on the Moon) were selected, so that subsurface crater-related structures could be considered broadly comparable across the sample set.

The horizontal extent of deposits on Mercury was determined by observation of a relatively bright, red-sloped spectral anomaly in color composites combining reflectance in MESSENGER Wide-Angle Camera images. Lunar deposit extent was determined by observation of low reflectance at ~1000 nm in M^3 (Moon Mineralogy Mapper) and Clementine data products. By measuring the maximum distance between a vent margin and the outer boundary of the deposit, we determined the maximum ballistic range of particles forming the deposit. Vent volume was calculated by subtracting the topography within the vent from an interpolated surface at the level of the pit margin. Topographic data were derived from stereo images using the Ames Stereo Pipeline [7] for Mercury, and from the USGS global LOLA 118m/px elevation model for the Moon.

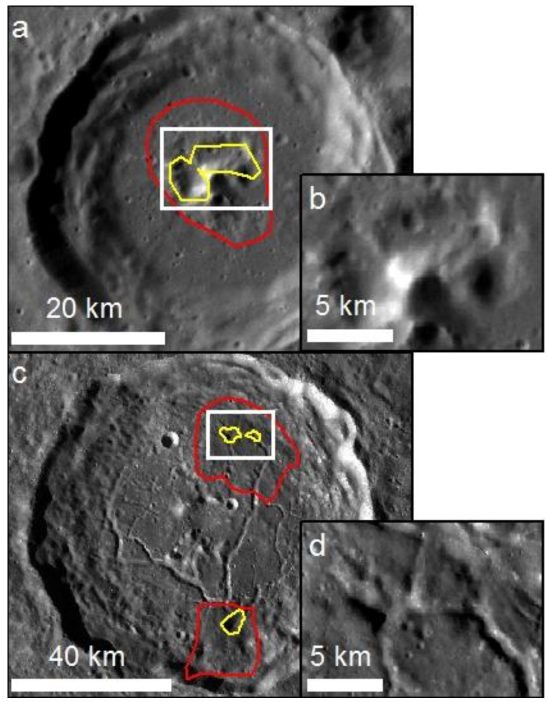

Fig. 1: Characteristic appearance of crater-hosted explosive volcanic vents (yellow outlines) and deposits (red outlines) on a. Mercury (MESSENGER NAC images, NASA/JHUAPL/ Carnegie Washington) and c. the Moon (LROC WAC mosaic), with closeups of vents, b. and d., indicated by white rectangles.

Results and implications for the style of volcanism: Pyroclastic products have a much greater average maximum ballistic range at the sites on Mercury than on the Moon (Table 1). 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 higher velocity on Mercury, indicative of a higher volatile mass fraction in the erupting magma [8]. Additionally, vents are significantly larger on Mercury. If vent-formation is a result of vent wall stripping, this indicates more energetic eruptions on Mercury than on the Moon.

Table 1. Comparison between explosive volcanism within complex craters on Mercury and the Moon.

	Mercury	**Moon**
Sites (total vents)	16 (30)	15 (52)
Median vent volume (summed by site) / km^3	3.61 (11.43)	0.12 (0.65)
Median maximum ballistic range of ejected particles / km	18.6	10.7
Relief of deposits	No relief, or low relief (≤ 3.5°) within 6.5 km of the crater rim, a fraction of the radius of the spectral anomaly.	Low relief (< 2°) over the extent of the spectral anomaly
Tectonic modification of the host crater	Minor thrusts in 2 (compressional)	14 are floor-fractured craters (extensional)
Location within the host crater	Most (14) at crater center. At 3 sites, vents at floor margin.	Most (10) at crater floor/wall margin. 2 at crater central uplift.

Where relief attributed to pyroclastic deposits is observed at the sites on Mercury, it forms an inner region of low relief within a wider spectral anomaly where there is no discernible relief. Modelling of pyroclastic eruption in airless conditions suggest this configuration results from extreme particle-size sorting [9]. This, together with the implied high energy of the eruptions, is most consistent with eruption after sufficiently long residence in a sub-surface magma chamber for the growth of large bubbles and for fractional crystallization to enhance the concentration of volatiles in the remaining melt.

On the Moon, the deposit morphology is as has been observed previously [3] and found to be consistent with vulcanian eruption, a style which is consistent with the observed shorter ballistic range.

Implications for the nature of sub-surface magma storage and controls on its depth: The lunar sites are predominantly within floor-fractured craters (FFCs) [10], with vent-formation in circumferential fractures. This suggests that intrusion of magma has uplifted the crater floor, providing pathways for magma ascent to the surface at the outer edges of the intrusion. In contrast, we detect no floor-uplift or fracturing in the host craters on Mercury, and vents are commonly at the crater center. We have considered several explanations for this disparity, and find that the most probable explanation is that magma storage is deeper on Mercury than on the Moon, despite higher gravity (which would tend to lead to shallower intrusions).

On Earth, upper-crustal magma storage is shallower in extensional than in compressive regimes. In a compressive regime, as has existed on Mercury through much of its geological history, magma is stored deeper and magma chamber rupture occurs only where pre-existing structures are present in the overlying rock [11]. Impact crater central uplifts are thought to be bounded by deep-going, steeply-dipping fractures [12], which would be preferential sites of magma ascent after pressure build-up within such a magma reservoir.

In contrast, the Moon is not in a state of significant global compression [13]. Many of the examples studied here and lunar FFCs in general occur at the margins of mare-filled basins [4]. It has previously been noted that flexural extension due to the mare-load may favor magma ascent from depth at these locations [14]. This comparison with Mercury highlights the possibility that this stress state additionally favors unusually shallow magma storage. This is also consistent with the observation of FFCs with a probable magmatic genesis in areas in extension on Mars [15], e.g. southwest of Isidis Planitia. The regional stress regime is therefore a potential controlling factor on formation of FFCs through shallow intrusion on terrestrial bodies.

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