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Prolonged eruptive history of a compound volcano on Mercury: Volcanic and tectonic implications

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ABSTRACT

A 27 × 13 km 'rimless depression' 100 km inside the southwest rim of the Caloris basin is revealed by high resolution orbital imaging under a variety of illuminations to consist of at least nine overlapping volcanic vents, each individually up to 8 km in diameter. It is thus a 'compound' volcano, indicative of localised migration of the site of the active vent. The vent floors are at a least 1 km below their brinks, but lack the flat shape characteristically produced by piston-like subsidence of a caldera floor or by flooding of a crater bottom by a lava lake. They bear a closer resemblance to volcanic craters sculpted by explosive eruptions and/or modified by collapse into void spaces created by magma withdrawal back down into a conduit. This complex of overlapping vents is at the summit of a subtle edifice at least 100 km across, with flank slopes of about only 0.2 degrees, after correction for the regional slope. This is consistent with previous interpretation as a locus of pyroclastic eruptions. Construction of the edifice could have been contributed to by effusion of very low viscosity lava, but high resolution images show that the vent-facing rim of a nearby impact crater is not heavily embayed as previously supposed on the basis of lower resolution flyby imaging. Contrasts in morphology (sharpness versus blurredness of the texture) and different densities of superposed sub-km impact craters inside each vent are consistent with (but do not prove) substantial differences in the age of the most recent activity at each vent. This suggests a long duration of episodic magmagenesis at a restricted locus. The age range cannot be quantified, but could be of the order of a billion years. If each vent was fed from the same point source, geometric considerations suggest a source depth of at least 50 km. However, the migration of the active vent may be partly controlled by a deep-seated fault that is radial to the Caloris basin. Other rimless depressions in this part of the Caloris basin fall on or close to radial lines, suggesting that elements of the Pantheon Fossae radial fracture system that dominates the surface of the central portion of the Caloris basin may continue at depth almost as far as the basin rim.

1. Introduction

The vent complex on which we focus here is located at 22.3°N, 146.2°E, situated about 100 km inside the southwestern rim of Mercury's Caloris basin. It was discovered in images returned during MESSENGER's first flyby in 2008 (Fig. 1), and described by Head et al. (2008) as a 'kidney-shaped depression' surrounded by a relatively bright deposit with diffuse outer edges that they interpreted to be pyroclastic deposits erupted from the vent area. They referred to it as a 'rimless depression', on the grounds of lacking any trace of a rampart or elevated rim such as surrounds an impact crater. In the then absence of altimetric data, Head et al. (2008) used indirect evidence to infer that the overall structure is a 'broad, low shield volcano'. The inferred pyroclastic deposit centred on the vent was listed as Red Spot 3 (RS-03) by Blewett et al. (2009) in their preliminary analysis of colour trends, and investigated as an example of evidence for unexpectedly high volatile content in the erupting magma (3600–13,000 ppm) by Kerber et al. (2009). With a radius of 24 km, this is the 5th most areally extensive candidate pyroclastic deposit documented during the three MESSENGER flybys (Kerber et al., 2011).

As well as presenting several other examples of volcanic vents, Head et al. (2009) suggested that the scalloped edges of the RS-03 rimless depression are a result of 'successive stages of inflation and collapse of the (magma) reservoir' leading to 'multiple intersecting depressions'. Here we take advantage of higher resolution images and altimetric data acquired during MESSENGER's first three Mercury solar days in orbit to provide a more complete account of this feature. Diverse ages of the individual vents demonstrate a prolonged, or at least complicated, history of episodic eruption involving migration of the locus of eruption to and fro by about 25 km. A hitherto unrecognised vent extends the rimless

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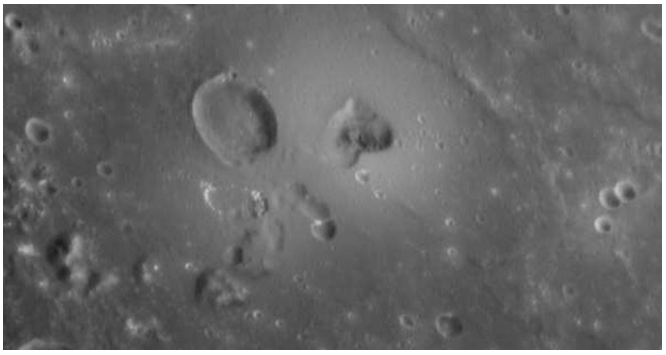

Fig. 1. MESSENGER flyby 1 'discovery' image, as used in Head et al. (2008). The "kidney-shaped" volcanic depression is in the upper centre, a 25 km circular impact crater lies to its west, and several smaller putative volcanic craters lie to the southwest.

depression further west than previously realised, so it can no longer be aptly described as 'kidney-shaped'. We discuss first this main vent complex, and then draw attention to its relationship to other rimless depressions nearby. Because this feature has previously been classified as a 'rimless', we use the term 'brink' rather than 'rim' to refer to the perimeter of the depression.

2. Insights from orbit

2.1. High-resolution imaging

The imaging system on MESSENGER is MDIS, the Mercury Dual Imaging System (Hawkins et al., 2007). It consists of a monochrome narrow angle camera (NAC) and a multispectral wide angle camera (WAC). The RS-03 vent complex was imaged three times by targeted high-resolution NAC acquisitions during MESSENGER's first three solar days orbit, and there are many WAC images that also show more detail than the flyby images. We show in Fig. 2a a WAC mosaic of the region and in Fig. 2b a map of the same area marking the RS-03 vent complex and five other rimless depressions. An inset on the map assigns a letter to each vent within RS-03 for ease of reference.

Spatial resolution in the NAC images is tremendously improved compared to the flyby imaging, and the variety of solar illumination conditions allows many further insights. All three NAC acquisitions were by off-nadir viewing (emission angles between 30 and 46 degrees). Attributes of these images and one particularly useful WAC image are listed in Table 1, and geo-rectified mosaics centred on each are shown in Fig. 3.

The view in Fig. 3a was acquired under conditions of solar illumination similar to those in the flyby image (Fig. 1), with the Sun high in the east. However, its significantly higher resolution reveals very clearly some textural contrasts within the vent complex that could not previously be recognised. The sides and floors of pits occupying the east, north and west of the complex are smooth. These are A–E on Fig. 2b, although A is scarcely distinguishable (the brink of the depression seeming to be at the western edge of B and C) and might not have been recognised if this had been

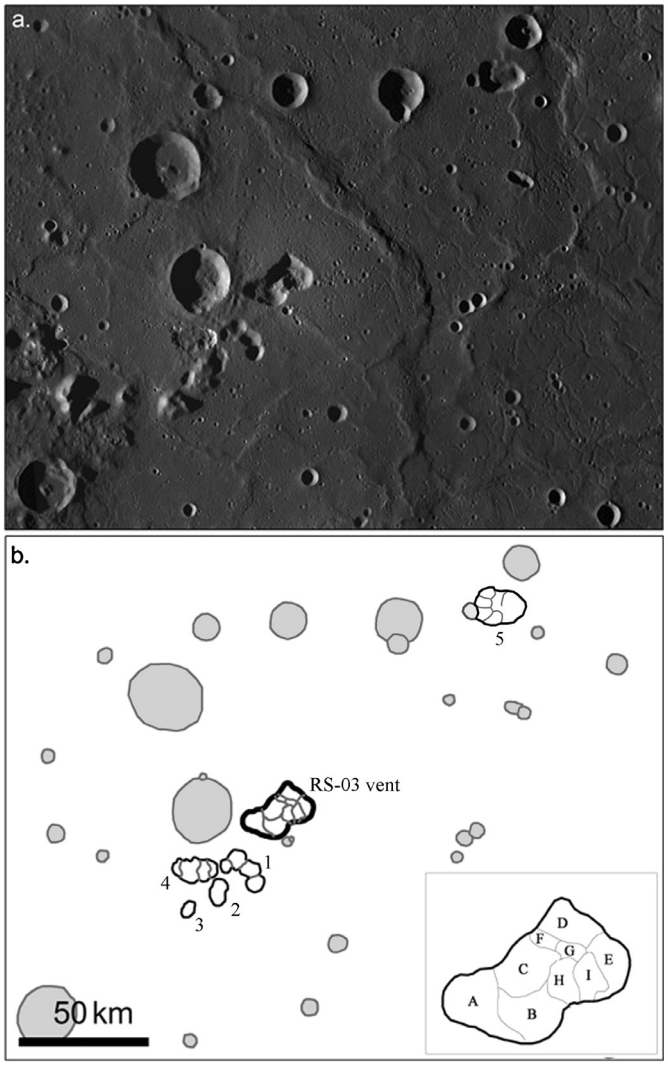

Fig. 2. (a) Regional mosaic of WAC images mapped to a sinusoidal projection centred on the RS-03 vent complex. (b) Sketch map of the area shown in (a), based on NAC and WAC images. The main vent complex (RS-03) is shown with a heavy black outline. Other rimless depressions hosting possible vents are outlined with a finer black boundary, and numbered 1–5. Septa marking the divides between individual vents marked by fine grey lines. Impact craters are shown with a grey fill. The inset shows the main vent complex enlarged, and with letters to identify each vent. The original description as 'kidney shaped' (Head et al., 2008) was based on the outline around vents B–I only, because vent A was not apparent in the flyby image (Fig. 1). Boundaries between vents within vent complex 5 were drawn on the basis of targeted NAC images that became available while this paper was in review; see Supplementary Material.

the only illumination available. We interpret each of A–E as hosting at least one volcanic vent. In the centre of the complex is an area of much finer texture, whose outline and internal morphology suggest that it contains at least four overlapping vents (F–I on Fig. 2b). Cross-cutting relationships demonstrate that these are younger than their smoother-textured neighbours. The rough tex-

Table 1
MESSENGER MDIS NAC and WAC orbital images used in this study.

Image ID	Solar incidence angle (degrees)	Solar azimuth (degrees)	Emission angle (degrees)	Spacecraft azimuth (degrees)	Raw pixel size (m)
EN0215894570M	39.6	133.6	45.5	333.9	28.6
EN0220591242M	74.5	264.8	41.0	359.9	20.7
EN0220850481M	83.7	267.8	30.1	179.0	19.5
EW0220764090G	79.7	266.0	1.6	351.9	125.1