LAVA FLOW FIELD AREAS AND CALDERA VOLUMES ON IO: THEIR CORRELATION WITH MAGMA RESERVOIR SIZE AND COLLAPSE EVENTS.

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The Galileo images of Io show numerous large volcanic collapse calderas associated with extensive lava flow fields. Some of these calderas have scalloped margins interpreted as generated by sapping of liquid SO_2 escaping from the base of caldera cliffs onto the surface. However, although the sapping process is likely to occur on Io due to the abundance of SO_2 ice both on the surface and underground, the structural elements of many of these large calderas may rather suggest that plate (piston) subsidence of a relatively coherent floor is involved. On Earth calderas exhibit a range of morphologies [1] which are functions of the exact nature of the subsidence process: piecemeal or chaotic subsidence, plate (piston) subsidence, funnel formation, and hinged downsag. Many calderas are geometrically complex and may contain more than a single structural type and subsidence process. In addition to real diversity among caldera structures, the divergent interpretations of dominant subsidence processes reflect ambiguities resulting from the large dimensions of many calderas, incomplete cross-sectional exposures, and overprinting by post-subsidence structures. Similar problems exist in interpreting the features seen on Io. Of course, ongoing analysis of recently acquired high-resolution images may show structural elements such as ring faults which unambiguously define plate (piston) subsidence, though post-caldera deposits will tend to conceal such details.

Caldera formation above a magma reservoir requires failure of the rocks forming the reservoir roof. This could be initiated by a sufficiently large increase or decrease of the pressure of the magma in the reservoir. It is generally assumed that the commonest case is a decrease in reservoir pressure with the roof failing in tension when the internal magma pressure is less than the lithostatic load above the roof by an amount equal to twice the tensile strength of the roof rocks. A likely source of the pressure decrease is drainage of magma from the reservoir to feed an eruption or intrusion. With the sudden relief of pressure two processes may occur in addition to collapse of the roof. The first is exsolution of any available volatiles from the magma, which could lead to a significant pressure increase again and could drive an eruption through the fractures connecting the reservoir to the surface; however, it is not clear that we expect the mafic to ultramafic magmas implied for Io to contain significant amounts of volatiles. A second process, which can act if the reservoir roof is sufficiently shallow, is contact between liquid subsurface SO_2 and magma, in which case explosive vaporisation may occur, again raising the pressure within the reservoir and aiding eruptive activity.

For caldera-forming eruptions on Earth, a relationship between caldera area and volume of erupted products has been noted by Spera and Crisp [2]. From their data, to a good approximation, a linear relationship

$$V = 0.28\ S^{1.1}$$

is found where V is the volume of erupted material and S is the caldera area. Since we might consider a reservoir as an ellipsoid with horizontal semi-axes a and b and a vertical semi-axis c, the area of the base (equal to the area of the caldera) is $3.14 \times a \times b$, and the volume is $4/3 \times 3.14 \times a \times b \times c$. The ratio between volume of erupted products and caldera area is then $4/3 \times c$, which is thus a measure of the draw-down. The above expression therefore implies that the draw-down in caldera-forming eruptions changes only slowly with reservoir size, a point recognised by Scandone [3]. Why the draw-down should be nearly constant is an issue we are investigating in terms of the stresses around the margins of magma bodies stalled in the crust.

The diameters of calderas on Io are commonly in the range 75 to 100 km with extreme values up to 290 km. For simplicity of calculation we consider the volume of a magma reservoir under a typical 100 km diameter caldera. Depth estimates for such calderas seem to be of order 1 km, so that typical erupted volumes may be of order 10,000 cubic kilometres. Numerous lava flow fields on Io appear to have horizontal dimensions of order 300 km and thus areas of order 100,000 square km, implying that flow thicknesses may commonly be of order 100 m. When the recently acquired high-resolution images of Io are fully calibrated and analysed it will be relatively easy to find accurate flow field areas, but it is less clear that many flow thickness estimates will be obtained.

An important issue for Io is the numbers of lava flow fields associated with caldera collapse events relative to the numbers of flow fields emplaced by elastic deflation of overpressurised magma reservoirs. In an elastic deflation event a reservoir may discharge up to one third of one percent of its initial volume [4]. Even if 100 km diameter reservoirs have vertical extents as large as 20 km (a figure taken from our ongoing modelling of the locations and extents of neutral buoyancy zones in the Io crust [5, 6]), their volumes will not exceed 150,000 cubic kilometres. This means that in elastic deflation events they may discharge up to 500 cubic kilometres of lava, sufficient to cover a 100,000 square km flow field to a depth of 5 metres. It seems very unlikely (based on considerations of heat loss rate relative to flow speed, thickness and substrate slope [7]) that the large flow fields on Io are this thin, and the implication may be that a disproportionate number of large eruptions on Io involve caldera collapse events when compared with the Earth.

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