**MODELLING ERUPTION CONDITIONS AT THE PILLAN AND PELE VOLCANOES ON IO.** V. Cataldo and L. Wilson, Environmental Science Department, Lancaster University, Lancaster LA1 4YQ, U.K. (V.Cataldo@Lancaster.ac.uk).

**Introduction:** We have previously modelled steady explosive eruptions of gas and magma at the Pillan and Pele sites on Io [1], both locations being assumed to be associated with very-high temperature hot spots [2]. We modelled the plume activity detected by Galileo at both locations from 1996 to 1997. Before erupting to the surface explosively, the magma is assumed to interact with liquid $SO_2$ at shallow depths. Eventually, $SO_2$ gas condenses onto the volcanic particles and the ground. Condensation is taken to occur at 150 and 250 km from the vent at Pillan, judging by the brightness structure of the upper portions of the Pillan plume as inferred from Hubble Space Telescope (HST) observations [3]. At Pele we use 250 and 500 km based on the distances from the vent at which red and white deposits are found on the surface respectively [2]. The temperature and pressure at which $SO_2$ condensation is likely to commence in the Ionian environment, and the radial distance from the volcanic vent at which the process appears to occur on the surface, are used to derive eruption conditions. The temperature, pressure, and density of the gas-magma mixture are related to distance from the vent using continuity and conservation of energy equations.

**Interaction between magma and liquid $SO_2$:** This interaction causes the initial magma temperature, taken as ranging from 1900 to 2100 K, to decrease to progressively lower values, as a function of increasing amounts of gas incorporated by the magma: the higher the mass proportion of incorporated $SO_2$ within the magma, the lower the temperature. For initial magma temperatures in the mantle of order 1900 K, eruption temperatures range from 1810 to 1170 K, as the amount of $SO_2$ ranges from 5 to 40 wt%. In contrast, if the initial magma temperature is taken as 2100 K, final temperatures lie in the range between 2010 and 1190 K, at the same gas mass proportions within the erupting gas-magma mixture. Based on a survey of the various available temperature estimates for the Pillan and the Pele sites [2, 4, 5] we adopt vent temperatures in the range 1700-1900 K for Pillan and 1200-1400 K for Pele. Values of eruption temperatures as a function of the gas mass proportion within the magma are shown in Table 1, for both the Pillan and Pele sites. Depending on the initial magma temperature in the mantle, gas amounts ranging from 5 to 10 wt% are needed in order to justify observations at Pillan, whereas higher values seem to be required at Pele (25-40 wt%). Recently, some authors have suggested that temperatures up to as much as 1600 K could be possible at Pele [6]. In this case, lower gas amounts (18-25 wt%) could explain current eruptive activity at this site.

**The optically thick portion of the plumes:** We assume that a zone exists, extending a few kilometers outward from the Pillan and Pele vent, within which the number density of magma droplets/pyroclasts is so high that the plume is optically dense (i.e. opaque to the transmission of thermal radiation) [7]. Minimal heat is lost, thus buffering the temperature, while the pressure varies in accordance with a continuity equation. Such an assumption now seems to be supported by some very high-resolution images of an eruption issuing from a fissure vent in one of the calderas of the Tvashtar Catena complex, where fountains of red hot materials (extending ~ 2000 meters outwards) were recently observed [5] and have been successfully modelled as representing such an optically dense particle cloud [8].

The radial extents of the optically dense zones for Pillan and Pele vary as a function of a number of factors, such as the gas mass proportion within the erupting mixture, the distance from the vent at which condensation is taken to occur, and the assumed mean particle size. The extents of optically thick regions increase with increasing condensation distance from the vent and decrease at large mean clast sizes. They also increase with increasing gas amounts incorporated by the magma, except for very high values of mean particle sizes. If mean clast sizes are between 100 and 300 microns, for gas mass proportions within the erupting mixture ranging from 20 to 40 wt%, a reverse trend occurs. At Pele, for particle sizes as large as 1 mm, the larger the volatile amount incorporated by the magma, the lower the radial extent of the optically dense region. In this analysis we have extended the range of mean pyroclast sizes previously considered [1] from 1 micron to 1 mm. Assuming a different magma temperature in the mantle (either 1900 K or 2100 K) affects the mean pyroclast sizes deduced for the Pillan site, whereas this does not seem to be the case for Pele. Here, if we assumed an initial magma temperature in the mantle of order 1900 K, mean particle sizes in excess of 1 mm would be required in order for the optically dense region to exist. Instead, assuming an initial magma temperature of 2100 K would allow the mean pyroclast sizes to be smaller than one millimeter. The latter assumption seems to be more plausible. As a result of our calculations, the maximum extents of these zones could range from ~ 5 km to ~ 15 km at Pele and from ~2.5 km to ~6 km at Pillan.

**Erupted mass fluxes at Pillan and Pele:** We find that deduced mass fluxes vary in proportion with the distance at which $SO_2$ condensation is taken to occur and decrease with increasing amounts of gas incorporated by the magma. At Pillan, the erupted fluxes lie between ~ 1 and 3 x $10^7$ kg/s if the condensation distance is 150 km and between ~ 3 x $10^7$ kg/s and $10^8$ kg/s if the condensation distance is 250 km. We think that the latter distance is more commonly relevant than the former, and conclude that the effusion rate probably lies within a factor of ~ 2 of 5 x $10^7$ kg/s. In the case of Pele the range of eruption rates is 1.2 to 1.7 x $10^7$ kg/s if the condensation distance is 250 km and 4.5 to 6 x $10^7$ kg/s if the condensation distance is 500 km. It is extremely interesting that, despite the great difference in implied amounts of incorporated $SO_2$, both of these eruption sites appear to have similar mass eruption rates. The same rates are also independent of the value assumed for the eruption pressure in the vent.

**Vent pressures and eruption speeds:** In our previous work, we followed the variation of conditions as gas and pyroclasts expanded into a hemisphere centered on a point-source vent, working from the outer edge of the system (outer plume boundaries) inwards by adopting a vent pressure of 2 kPa [1]. In this analysis, we have specified a linked series of values of increasing pressure, decreasing mean pyroclast speed, increasing local sound speed and decreasing radial distances as the vent is approached. We have extended our range of pressure values from 2 kPa up to 2 MPa (taken as an extreme upper value). At Pillan, eruption speeds vary between ~ 570 m/s and ~ 300 m/s, the highest values occurring at lower vent pressures (2 kPa) and particle sizes in the range 10-100 microns. At Pele, we obtain values ranging between ~ 1050 m/s and ~ 450 m/s, the highest values still found as above. For all combinations of assumed exit pressures and inferred gas mass proportion within the erupting gas-magma mixture, eruption velocities are predicted to be supersonic, though they are only just so for the highest gas mass fractions (~ 40 wt%) at the Pele site.

**Vent pressures and vent sizes:** Similar results are calculated for both eruption sites because there is only a very weak dependence of the vent radius on assumed mean pyroclast size. At Pillan, vent sizes appear to be smaller than those found at the Pele site. Values range from a minimum of ~ 10 meters (at both Pillan and Pele), if the exit pressure is extremely high (2 MPa), to maximum values of ~ 800 and ~ 1000 meters at Pillan and Pele, respectively, if the exit pressure is 2 kPa. Inferred vent size is directly proportional to the radial distance from the vent at which condensation is taken to occur on the ground, and is inversely proportional to the square root of the assumed pressure in the vent.

**Summary:**

(1) Eruption temperature estimates for the Pillan and Pele vents have allowed us to estimate the proportions of near-surface $SO_2$ incorporated into the erupting magmas, 5-10 wt% and 25-40 wt%, respectively.

(2) Modelling of the dynamics and thermodynamics of the eruption plumes allows the distances from the vents at which $SO_2$ condenses on the ground to be interpreted in terms of the eruption mass fluxes, probably within a factor of 2 of ~5 x $10^7$ kg/s at both vents.

(3) The sizes of the optically dense, isothermal fire fountains immediately above the vents could be several km but are probably smaller, consistent with mean pyroclast sizes in the one hundred to several hundred micron range.

**References:** [1] Cataldo V. and Wilson L. (1999) LPSC XXX, # 1246. [2] McEwen A.S. et al. (1998) Icarus, 135, 181-219. [3] Spencer J.R. et al. (1997) p.47 in Proc. Conf. on Io during the Galileo era, Lowell Observatory, AZ. [4] Davies A.G. et al. (1999) LPSC XXX, #1462. [5] McEwen A.S. et al. (2000) Science, 288, 1193-1198. [6] Davies A.G. et al. (2000) EOS, 81, F788. [7] Wilson L. and Head J.W. (1981) JGR, 86, 2971-3001. [8] Wilson L. and Head J.W. (2001) Lava fountains from a fissure eruption on Io: implications for dike emplacement mechanisms, eruption rates and crustal structure. subm. to JGR planets.

**Table 1**: The variation of eruption temperatures as a function of gas mass proportions incorporated by the magma at both the Pillan and Pele volcanoes. The values in { } brackets refer to Pillan whereas those in [ ] brackets refer to Pele.

| mass % $SO_2$ gas in erupting mixture | Eruption temps. (K) when initial magma T = 1900 K | Eruption temps. (K) when initial magma T = 2100 K |
|---|---|---|
| 5 | {1817} | 2010 |
| 10 | {1732} | {1918} |
| 15 | 1645 | {1822} |
| 20 | 1555 | {1724} |
| 25 | 1463 | 1624 |
| 30 | [1368] | 1520 |
| 35 | [1270] | [1414] |
| 40 | 1169 | [1303] |
| 45 | - | [1190] |