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The Pillan volcano, Io: an approach to constrain vent geometry

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1. Explosive volcanic eruptions at the Pillan volcano, Io

In 1997, the Pillan Ionian volcano was home to a fierce explosive volcanic eruption which generated 5600 km^2 of lava flows and a 400-km diameter circular plume deposit (Figure 1). Currently, it is not known whether a circular or a fissure vent fed the 140-km-high plume along with the lava flows at this site [1, 2, 3, 4]. Yet, conduit and vent geometry play key roles in determining eruption style and conditions, and supersonic eruption speeds are required to explain observed plume heights.

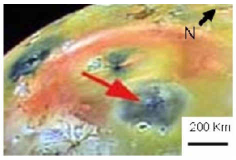

Figure 1: Pillan Patera (red arrow) and dark ring of plume deposits imaged by Galileo in 1997.

2. Modelling upper conduit flow and vent geometry at Pillan

Similar to previous modeling of explosive volcanic activity at this site [5], rising magma is assumed to incorporate 0.5-30 wt% liquid or gaseous SO_2 from crustal deposits. Estimated peak volume fluxes of ~3 x 10^4 m^3/s (based on an eruption duration of 52 days) are used to constrain vent areas [2, 3], and we take an eruption temperature of 1500 K [1]. We adopt a plausible range of exit pressures for the flow exiting the vent at Pillan (0.1 – 10 MPa) and specify a range of pressure gradients within the conduit starting from an assumed maximum depth (1500 m) at which the flow regime changes from subsonic to supersonic. We use conservation of momentum (Equation 1) to calculate conduit cross-sectional area variation with decreasing depth.

$$dA/dz = (A/\rho u^2)\,[(dP/dz)\,(1-M^2) + \rho g + (f\rho u^2/r) \quad (1)$$

Here, dA/dz, where M is the Mach number of the flow, g is the acceleration due to gravity, f is a friction factor, r is the conduit radius, and ρ, P, and u are the density, pressure and velocity of the gas/magma mixture, respectively. At any given depth, the pressure of the gas/magma mixture is taken to be not too different from lithostatic, based on the assumption of steady eruptions [5]. Velocities are calculated according to Equation 2, and start from the sound speed value taken at the depth where the flow regime changes from subsonic to supersonic (M=1).

$$v_f = (1/\rho u)\,[dP/dz + \rho g + (f\rho u^2/r)] \quad (2)$$

2.1 Results

Results are shown in Tables 1, 2 and 3. Fissure half-width is taken to be 15 m (Tables 1, 3) so only fissure length is allowed to vary. Only small conduit wall deflections from vertical are needed to achieve supersonic flow at the vent. Required flaring angles decrease with increasing flow pressures while increasing gas mass proportions in the mixture result in larger vent areas (for a fixed deflection angle). For a 30-m-wide fissure, a deflection angle of ~0.25° from vertical is sufficient to accelerate the erupting mixture to Mach 1.5-1.9 (for gas amounts in the range 10-30 wt% and a vent pressure of 3 MPa) (Tables 1 & 3). By moving the subsonic-supersonic flow transition to a shallower depth (500 m), flow regime turns to transonic at a pressure of 10 MPa (Table 3), but remains supersonic at a pressure of 3 MPa. For a circular conduit, a deflection angle as small as 0.05° may accelerate the flow to Mach 1.5 (Table 2) and geologically plausible scenarios exist for the whole range of exit pressures. In order to explain observed plume heights, exit velocities have to reach ~ 560 m/s. Allowing for further erosion of vent walls and pyroclasts accumulation around the vent, lower gas mass proportions and exit pressures may be required because of the higher exit velocities.

Table 1: Upper conduit flow parameters - fissure scenario. P_v=vent pressure, v_v=vent speed, M_v=Mach n. at vent, θ=flow deflection angle, F.L.=fissure length, S.r.= Sonic radius (M=1) at a depth of 1500 m.

Gas wt%	P_v MPa	v_v m/s	M_v #	θ °	F. L. m	S. r. m
0.5	1.0	108	3.0	0.43	40.0	3.8
0.5	3.0	103	2.3	0.27	21.2	8.0
0.5	10.0	108	1.6	0.09	13.2	12.5
10.0	1.0	331	2.3	0.40	200.0	4.6
10.0	3.0	269	1.9	0.24	84.0	8.8
10.0	10.0	219	1.4	0.08	34.0	12.9
20.0	1.0	463	2.3	0.40	282.0	4.6
20.0	3.0	372	1.9	0.23	118.0	8.8
20.0	10.0	294	1.4	0.08	47.0	13.0
30.0	1.0	568	2.3	0.40	343.0	4.6
30.0	3.0	453	1.9	0.23	144.0	8.8
30.0	10.0	354	1.4	0.08	57.0	13.0

Table 2: Upper conduit flow parameters – point source scenario. P_v= vent pressure, M_v= Mach n. at vent, θ=flow deflection angle, V.r.=vent radius, S.r.=Sonic radius (M=1) at a depth of 1500 m.

Gas wt%	P_v MPa	v_v m/s	M_v #	θ °	V. r. m	S. r. m
0.5	1.0	108	2.9	0.37	19.6	9.9
0.5	3.0	103	2.3	0.15	14.4	10.3
0.5	10.0	108	1.7	0.04	11.2	10.1
10.0	1.0	328	2.3	0.74	43.8	24.4
10.0	3.0	267	1.9	0.26	28.4	21.7
10.0	10.0	219	1.5	0.05	18.1	16.7
20.0	1.0	460	2.3	0.87	52.0	29.1
20.0	3.0	369	1.9	0.30	33.7	25.8
20.0	10.0	293	1.4	0.06	21.2	19.6
30.0	1.0	563	2.3	0.96	57.5	32.2
30.0	3.0	449	1.9	0.33	37.3	28.7
30.0	10.0	352	1.4	0.06	23.4	21.7

Table 3: Upper conduit flow parameters – fissure scenario. Sonic radius (M=1) at a depth of 500 m.

Gas wt%	P_v MPa	v_v m/s	M_v #	θ °	F. L. m	S. r. m
0.5	1.0	75	2.1	0.76	58.0	8.4
0.5	3.0	71	1.6	0.31	31.0	12.3
0.5	10.0	82	1.2	0.08	17.5	14.3
10.0	1.0	262	1.9	0.68	250.0	9.0
10.0	3.0	207	1.5	0.26	109.0	12.7
10.0	10.0	178	1.2	0.06	42.0	14.4
20.0	1.0	369	1.9	0.68	353.0	9.1
20.0	3.0	289	1.5	0.26	153.0	12.8
20.0	10.0	241	1.2	0.06	57.5	14.4
30.0	1.0	452	1.9	0.68	430.0	9.0
30.0	3.0	352	1.5	0.26	185.0	12.8
30.0	10.0	291	1.2	0.06	69.0	14.5

6. Summary and Conclusions

Only small conduit wall deflections from vertical are needed to achieve supersonic flow at the Pillan vent, whether we deal with a fissure or a point source scenario. Yet, more restrictive conditions apply to the fissure case. Our model assumes that the point at which the flow regime changes from subsonic to supersonic is located in the 1500-500 m depth range. Then, we will investigate the fluid-dynamic and thermodynamic conditions in the conduit under which such an assumption is likely to be realistic.

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