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2 **An empirical relation between velocity, mass discharge rate and vent area**
3 **for normal through paroxysmal eruptions at Stromboli**

4
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16
17 **Abstract**

18 Based on published and new data for explosive events at Stromboli (Italy), we propose an
19 empirical relation that links mass discharge rate (MDR) and at-vent gas jet velocity (G_v). We
20 use 65 simultaneous measurements of MDR and G_v and find two trends in both the cross-
21 correlation and rank order statistics. Cross-correlation gives a power law relation: $MDR =$
22 $10^{(0.015G_v+2.434)}$ kg/s, $R^2=0.81$, and applies to ash-dominated emissions. Combining this
23 relation with the conservation of mass equation allows at-vent plume density and/or vent area
24 to be derived from $MDR = G_v \rho A$, ρ being plume density and A being vent cross-sectional area.
25 We find that while a vent radius of 2 m and plume density of 0.35 kg/m^3 fits with the “normal”
26 activity at Stromboli, a 290×2.5 m vent area likely feeds a 10 kg/m^3 jet during paroxysmal
27 activity. Initial tests on available data shows promise in extending the correlation beyond
28 Stromboli and/or to events with higher MDR ($>10^7$ kg/s). However, the exact relation will
29 depend on magma composition, temperature and volatile content, as well as conduit radius and
30 vent overpressure.

31 **Keywords:** Thermal imagery, Eruption intensity, Mass Discharge Rate, Particle Velocity,
32 Gas Jet Velocity, Stromboli

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43 **Conflicts of interest/Competing interests**

44 The authors declare no conflicts nor competing interest

45 **Introduction**

46 Mass Discharge Rate (MDR, kg/s) is commonly used to classify the “explosiveness” of a
47 volcanic eruption, especially through the Volcanic Explosivity Index (Newhall and Self, 1982).
48 Time-averaged MDR can be estimated from the total erupted mass divided by eruption duration
49 (e.g., Mason et al. 2004; Bryan et al. 2010; Pyle, 2015). Peak MDR has also been derived from
50 maximum plume height, as MDR is proportional to plume height to the power-of-four for
51 Vulcanian-to-Plinian eruptions (Wilson et al. 1978). Geophysical signals, such as seismicity,
52 infrasound and Doppler radar (e.g., Brodsky et al. 1999; Freret-Lorgeril et al. 2018; Perttu et
53 al., 2020; Maki et al. 2021), as well as lightning intensity rates (Van Eaton et al., 2016), have
54 also been tested as a proxy for MDR.

55 We propose a further option for deriving MDR from thermal or visible video using an
56 empirical relation between MDR and gas jet velocity (G_v). We initially explore this relation for
57 explosive events at Stromboli (Italy) where there is excellent constraint on the plumbing system
58 (e.g., Bertagnini et al. 1999, 2013; Métrich et al. 2005, 2010, 2021), explosion source
59 mechanisms (e.g., Chouet et al. 1999; Ripepe and Gordeev 1999; Ripepe et al. 2001) and
60 emission dynamics (e.g., Patrick et al. 2007; Scharff et al. 2008; Gurioli et al. 2013). As a result
61 data are available to test a relation between MDR and G_v . Stromboli also displays a range of
62 explosive activity, which are commonly separated into three groups (Barberi et al. 1993). These
63 are, in order of increasing magnitude: normal, major and paroxysmal. Named by Barberi et al.
64 (1993) to describe the typical explosive activity that occurs at Stromboli, “normal” eruptions
65 send $10\text{--}10^4$ kg of bombs, gas and ash to a height of a few 10s to a few 100 m typically ~ 10
66 times an hour (Harris and Ripepe 2007; Patrick et al. 2007; Harris et al. 2013). Major eruptions
67 can occur several times a year, involve $10^5\text{--}10^7$ kg of bombs and ash, and send plumes to around
68 a kilometre in height (Gurioli et al. 2013). Paroxysms are rarer, with four having occurred
69 between 2003 and 2019, and form buoyant ash-rich plumes that ascend to several kilometres,
70 and involve $>10^8$ kg (Rosi et al., 2006; Pistolesi et al. 2011; Giordano and De Astis 2020).

71 The wealth of data for explosions at Stromboli makes it an ideal location to test relations
72 between a variety of eruption source terms (e.g., MDR and vent area) and plume ascent
73 parameters (e.g., emission velocity and plume ascent velocity). We thus use Stromboli to
74 explore an empirical relation between at-vent gas velocity and MDR using published and new
75 datasets for which the two parameters can be simultaneously derived.

76 **Method**

77 We examined 65 eruptive events (59 normal, two major and four paroxysmal) for which
78 suitable data were available (Table 1). Harris et al. (2013) obtained the mass (m) of 21 normal
79 eruptions from thermal video using the amount of energy lost by the bomb field during cooling.

80 However, the duration (t) for these events was not assessed, so we revisited the data to obtain
81 emission duration so that time-averaged MDR could be obtained from m/t . Duration was taken
82 as the time between the first appearance of the plume and the last bomb to exit the vent. Videos
83 used were recorded at 30 frames per second, and in the compressed data 10 frames were
84 equivalent to one second of recording. The uncertainty is five frames (0.5 s), so that
85 (considering the same uncertainty for the start and end of the event) error on duration is ± 1 s.

86 We also used the mass, particle ejection velocity and duration 31 eruptions as obtained by
87 Bombrun et al. (2015) through particle tracking to convert to time-averaged MDR. In addition,
88 we included MDR and gas ejection velocities for transient ash-dominated normal eruptions at
89 Stromboli as derived from thermal and visible imagery by Tournigand et al. (2017).

90 Mass discharge rates for major and paroxysmal eruptions at Stromboli were taken from the
91 literature as follows:

- 92 • For the 8 and 24 November 2009 major eruptions MDR was taken from Gurioli et al.
93 (2013);
- 94 • For the 2003 and 2007 paroxysms, we used the MDR of Rosi et al. (2006) and Pistolesi
95 et al. (2011), respectively;
- 96 • MDR for the July and August 2019 paroxysms were calculated from maximum plume
97 height by Giordano and De Astis (2020) following the equation of Mastin et al. (2009).

98 A theoretical relation between ballistic exit velocity (Bv) and gas exit velocity (Gv) was
99 proposed by Steinberg and Babenko (1978). In this relation, Gv represents the speed of the gas
100 to which the finest particles are coupled, and Bv represents the velocity of particles large enough
101 to be affected by drag, as tested on and applied to normal eruptions at Stromboli by Ripepe et
102 al. (1993) and Harris et al. (2012b).

103 Ballistic velocities are obtained either through particle tracking and given by Harris et al.
104 (2013) and Bombrun et al. (2015) for normal explosions, or ballistic trajectory modeling for
105 major (Gurioli, Colo, et al., 2013; Pioli et al., 2014) and paroxysmal events (Rosi et al., 2006;
106 Pistolesi et al., 2011; Andronico et al., 2013; Giordano & De Astis, 2020). We convert these
107 ballistic velocities (B_v) to gas jet velocities (G_v^b) using equation (8) of Harris et al. (2012b):

$$108 \quad G_v^b = 1.41 \times B_v + 15.3 \quad (1)$$

109 This relation is set for explosions at Stromboli and correlates well with directly measured gas
110 ejection velocities (Fig. 1). The literature-derived database is given in Table 1, and our
111 calculated MDR data are given in Table 2.

112 **Results**

113 The 21 normal explosions at Stromboli recorded by Harris et al. (2013) lasted between 3 and
114 28 seconds, giving MDRs ranging from 32 to 800 kg/s (Table 2). Eruptions from vent NE1
115 lasted longer (average of 18 s) than eruptions from NE2 (average of 6 s). This leads to a wider
116 range of MDR values for events at NE2 than NE1 (Fig. 2a). In Figure 2a, data from Bombrun
117 et al. (2015) fall in a cluster of low MDR and high gas velocities (150–250 m/s, $\text{MDR} < 10^4$
118 kg/s), and data from Tournigand et al. (2017) have high MDR with low gas velocities (< 150
119 m/s, $\text{MDR} \geq 10^4$ kg/s). MDR for these normal explosions show correlations with gas velocity
120 with an R^2 of between 0.5 and 0.83 depending on the data set used (Fig. 2a).

121 MDR for the major and paroxysmal events range between 10^4 and 10^7 kg/s, with gas jet
122 velocities in the range 142–297 m/s (Table 1). The relation between MDR and gas velocity for
123 the six major and paroxysmal explosions shows a positive, linear correlation with an R^2 of 0.79.
124 Eruption magnitudes have a power-law dependence (Pyle, 1998). This can be expressed as a
125 rank order plot, as obtained by sorting the values from the highest to the lowest (Sornette et al.
126 1996). This method can be used to constrain whether the dataset is homogeneous (cf. Schneider

127 and Barbera, 1998) within a single volcanic system. The rank order plot for our Stromboli data
128 shows two trends representing two different populations (Fig. 3). These two populations are
129 apparent in the rank order statistics for both gas velocity and MDR and involve a first group of
130 low gas velocity and MDR, and a second group of high gas velocity and MDR. We thus define
131 two main populations and treat them separately. The first involves ballistic-dominated normal
132 emissions (Fig. 2a). The second includes all major and paroxysmal events, plus one ash-
133 dominated normal eruption, this population being of ash-rich emissions involving plume ascent
134 dominated by buoyancy (Fig. 2b)

135 **Discussion**

136 The two trends apparent for Stromboli in the cross-correlation (Fig. 2) and rank order (Fig. 3)
137 plots result from the different plume types considered and differences in their associated ascent
138 dynamics. Normal explosions at Stromboli are associated with slug flow in the conduit
139 (Gonnermann and Manga, 2012) and are characterized by very low levels of fragmentation to
140 produce bomb-dominated plumes with particles that follow ballistic trajectories (e.g., Chouet
141 et al. 1974; Patrick et al. 2007; Gurioli et al. 2013). In contrast, major and paroxysmal events
142 involve rapid ascent of magma coupled with a gas phase ascending from depths of 7–10 km
143 and are characterized by higher degrees of fragmentation (e.g., Bertagnini et al. 1999; Métrich
144 et al. 2005, 2010, 2021; Pioli et al. 2014). The result is an ash-dominated plume whose ascent
145 is characterized by a longer steady convection-dominated phase (cf. Wilson and Self 1980; Rosi
146 et al. 2006; Harris et al. 2008).

147 Cross-correlation using data for ballistic-dominated normal explosions at Stromboli gives a
148 relation between MDR and G_v of (Fig. 2a, yellow regression line):

$$149 \quad MDR = 10^{(0.003G_v+1.933)} \quad R^2 = 0.50 \quad (2a)$$

150 Considering only a single vent improves the correlation, where the relation for vent NE1 (Fig.
151 2a, blue regression line) is:

152
$$MDR = 10^{(0.004G_v+1.906)} \quad R^2 = 0.83 \quad (2b)$$

153 These two relations are consistent with differences in vent size, gas/particle ratio, crater
154 geometry, overpressure and volatile content between craters and events.

155 Finally, the cross-correlation for ash-dominated normal, major and paroxysmal events gives

156
$$MDR = 10^{(0.015G_v+2.434)} \quad R^2 = 0.81 \quad (3)$$

157 This is the black regression line of Figure 2b.

158 **The next largest event at Stromboli?**

159 Application of maximum likelihood statistics to our rank order plots (cf. Sornette et al. 1996;
160 Pyle 1998) can indicate the most probable MDR and gas velocity for the hypothetical, but next
161 largest, eruption not recorded in our data (i.e., an event larger than the 2003 paroxysm). On this
162 basis an eruption at Stromboli larger than the 2003 paroxysm would have an MDR of $2.19 \times$
163 10^7 kg/s and a gas ejection velocity of 338 m/s. Our current data set for Stromboli is missing at
164 least two paroxysms, i.e., those of 1456 and 1930. Both have been described as being larger
165 than the 2003 paroxysm (e.g., Rosi et al. 2006; Bertagnini et al. 2011; Métrich et al. 2021), but
166 both lack an assessment of MDR and G_v . We thus speculate that the MDR and G_v calculated
167 for the next largest eruption in our dataset are possibly representative of the 1456 and 1930
168 paroxysms.

169 **Vent size during normal and paroxysmal activity**

170 MDR is related to bulk average (V) velocity, gas-particle mixture density (ρ) and vent cross
171 sectional area, A :

172
$$MDR \approx \rho VA \quad (4)$$

173 Given a vent radius typical for Stromboli, i.e., 2 m (Harris et al. 2012b), we use our range of
174 ejection velocities and MDR values to solve for mixture density. We find that the normal gas
175 and ballistic-dominated events fit with a cloud density of 0.35 kg/m^3 (Fig. 2a). This corresponds

176 to the density of water vapor at 650 K. Instead, ash-dominated normal events fit with 10 kg/m^3
177 (Fig. 2a). Note, that these values are for at-vent conditions and are hence in the gas-thrust region
178 of the jet before entrainment of air.

179 The lower and higher limits of the data set for major and paroxysmal eruptions can only be
180 reproduced with a cloud density of 10 and 2600 kg/m^3 , respectively (Fig. 2b). The latter density
181 is close to the dense-rock value of basaltic magma, and does not provide a realistic plume
182 density. For paroxysmal eruptions the conduit radius likely exceeds 2 m. Using the MDR and
183 G_v for the July 2019 paroxysm (Table 1), with a cloud density of 10 kg/m^3 , gives a circular vent
184 radius of ~ 13 m. A 290 m long and 2.5 m wide source also provides a fit for the paroxysmal
185 events. This would represent an eruption from the entire length of a SW-NE trending dyke
186 underlying the crater terrace, and is consistent with emission from all three active craters during
187 a paroxysm (Rosi et al., 2006). It is also consistent with collapse of the crater terrace following
188 paroxysms to create a continuous trench in place of the typical three-crater system that
189 characterizes Stromboli's crater terrace during normal activity (cf. Harris and Ripepe, 2007)
190 and the ejection of meter-sized blocks of the "shattered shallow subvolcanic system" (Renzulli
191 et al., 2009).

192 We calculate the at-vent volume fraction of pyroclasts (f) within the plume using a simple
193 mixture model:

$$194 \quad \rho \approx f \times \rho_{pyroclast} + (1 - f) \times \rho_{gas} \quad (5)$$

195 An average pyroclast density ($\rho_{pyroclast}$) of $\sim 800 \text{ kg/m}^3$ (Pichavant et al. 2022), a gas density
196 (ρ_{gas}) of 0.35 kg/m^3 (Harris et al. 2013), and a plume density of 10 kg/m^3 results in a mixture
197 of ~ 1 % pyroclasts and ~ 99 % gas volumes (respectively ~ 97 % pyroclasts and ~ 3 % gas mass
198 fraction). A low gas weight fraction indicates that the cloud was ejected out of the vent without
199 any mixing with the atmosphere (Wilson and Self, 1980).

200 **Towards a global predictive model for eruption intensity?**

201 At-vent gas and particle velocities vary as a function of vent geometry, over-pressure, magma
202 temperature, volatile content, particle size and gas density (Steinberg and Babenko, 1978;
203 Woods and Bower, 1995). By restricting our consideration to a single system, we limit the
204 variation in volatile content, temperature, crater/vent geometry, pressure, ash/gas ratio, and gas
205 density. Our results for Stromboli indicate that, if eruption types and styles are considered
206 separately according to their dynamics, and measurements of mass eruption rate, gas velocity
207 and particle velocity are available, then an empirical relation relating the three can be derived.
208 We assess whether this can be extended to other, higher magnitude systems by considering:

- 209 • Pinatubo 1991 (VEI = 6; based on the data from Simkin et al, 1981);
- 210 • Mt. St. Helens 1980 (VEI = 5; Venzke 2022);
- 211 • Fuego 2012 (VEI \leq 2; Venzke 2022);
- 212 • Sakurajima 2013 (VEI \leq 3; Venzke 2022).

213 For Fuego and Sakurajima we take the MDR and G_v as derived from thermal and visible
214 imagery by Tournigand et al. (2017). For Pinatubo, an MDR ranging between 6.8×10^8 and 10^9
215 kg/s has been calculated from granulometry (Koyaguchi and Ohno 2001) and satellite data
216 (Koyaguchi and Tokuno 1993). MDR estimates for Mt. St. Helens range from an average of 2
217 $\times 10^7$ kg/s for the whole eruption (Carey and Sigurdsson, 1985; Pyle, 2015), to $2\text{--}6 \times 10^9$ kg/s
218 for the initial lateral blast (Brodsky et al. 1999). In all cases, we use the full range. For Pinatubo
219 whether we calculate gas velocity using the at-vent decompressing jet model (6) or the freely
220 decompressing model (7) of Woods and Bower (1995) is debatable:

$$221 \quad G_v = 0.95 \times (n_0RT)^{1/2} \quad (6)$$

$$222 \quad G_v = 1.85 \times (n_0RT)^{1/2} \quad (7)$$

223 Here n_0 is the difference between melt inclusion volatile concentration (6.4–7 wt %, Rutherford
224 and Devine, 1996) and glass matrix average volatile concentration (1.45 wt.%, Hammer et al.,
225 1999), R is the vapor-gas constant (461.5 J/kg K), and T is the magma temperature (1073 K).
226 The value we obtain is likely a maximum since experimental studies suggested disequilibrium
227 degassing for this eruption (Mangan and Sisson, 2000), which would delay nucleation and thus
228 decrease magma ascent rate and G_v . For Mt. St. Helens we use the range of velocities for the
229 Plinian phase given by Carey and Sigurdsson (1985) and Woods and Bower (1995), i.e., 200–
230 300 m/s. We use velocities as close as possible to the vent-leaving values, where the at-surface
231 decompression of the volcanic jet has the least impact (Woods and Bower, 1995) and where
232 vent-leaving values can be compared between cases.

233 MDR values for Sakurajima, Pinatubo, and Mt. St. Helens are one-to-three orders of magnitude
234 higher than those for Stromboli and Fuego at similar G_v (Fig. 4). However, the relationship
235 between G_v and MDR remains linear and positive. This is consistent with the decompressing
236 jet model of Woods and Bower (1995) for the emission dynamics of gas-particle mixtures,
237 where variations in magma volatile content, over-pressure, vent geometry, and magma
238 temperature account for the differences observed between each system (Fig. 4).

239 **Conclusion**

240 We derive an empirical relationship between gas jet velocity and MDR which applies to
241 explosive events at Stromboli with VEI ranging from 0 to 3. At Stromboli, a network of
242 continuously recording thermal cameras allows measurement of gas jet velocity (Delle Donne
243 and Ripepe, 2012). This means that real-time measurements of G_v can potentially be converted
244 to MDR for the two event types (ballistic and convective emissions) common at this well-
245 monitored site.

246 Extending the analysis to events with higher VEI suggest a wider applicability a linear relation
247 between G_v and MDR. Our argument is thus for a database with simultaneous measurements

248 of MDR and at-vent velocities for a variety of systems, allowing extension of this analysis.
249 Such data requires a video camera network targeting the vent, which is rarely possible. All the
250 same, given the importance of MDR as a key source term in forward modeling (cf. Bonadonna
251 et al. 2011), such a fast and straightforward empirical approach to potentially derive MDR in
252 near-real time shows promise.

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455 **Figure caption listing**

456 **Fig. 1** Comparison between max gas velocity, as derived from ballistic ejection velocity (G_v^b),
457 and directly measured maximum gas velocities (G_v) for major to paroxysmal eruptions at
458 Stromboli. See Table 1 for data and sources.

459 **Fig. 2** Relationships between MDR and maximum gas velocity (data points) and ballistic
460 velocity (colored fields) for (a) normal, and (b) major and paroxysmal eruptions at Stromboli.
461 Gray line gives fit obtained from Equation (4); red dashed lines represent the σ uncertainty
462 envelope. The yellow trend is the fit to the data of Bombrun et al. (2015) and NE1 data of Harris
463 et al. (2013), and the blue trend considers all NE crater data. Both trends look very similar, the
464 difference with the correlation coefficient both lies in the amount of data used for each fit and
465 because the NE2 vent data are scattered around the trendline.

466 **Fig. 3** Rank order representation of Stromboli's normal, major and paroxysmal eruptions in
467 terms of a) the mass discharge rate and b) the maximum gas ejection rate. Both MDR rank order
468 and G_v rank order analyses display a gap between a higher and lower group. The dashed line
469 marks the separation between the higher ranked group composed of paroxysmal, major and ash-
470 dominated emissions, and the lower ranked group of ballistic-dominated normal events.

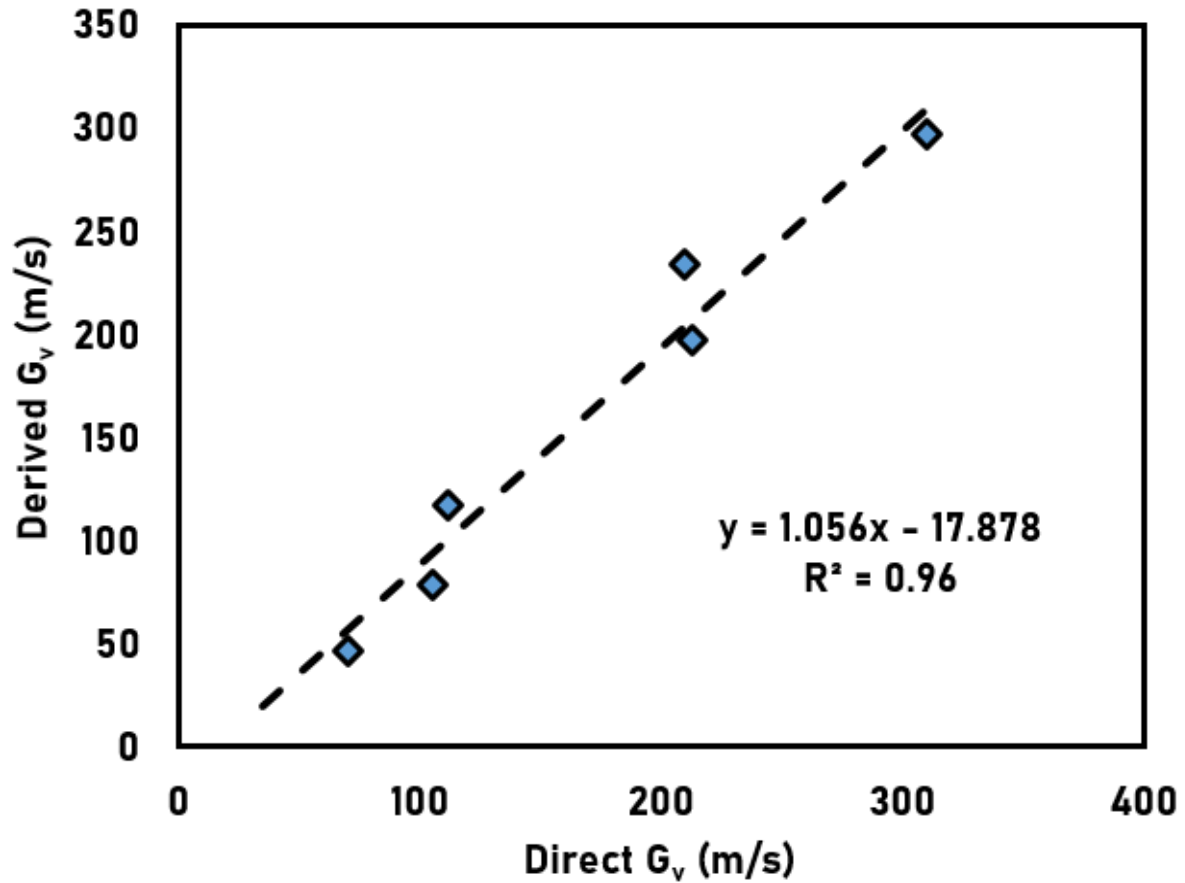
471 **Fig. 4** MDR and G_v relations. Orange field is that defined by the data for ash-dominated
472 emissions at Stromboli, where the positive, linear increase as a function of gas density (d_{gas}),
473 volatile content (C_{vol}), conduit size and vent overpressure (P_{vent}), magma temperature (T) and
474 silica content (X). The blue “Vulcanian-Plinian” field falls on a similar trend but is at a level
475 two orders of magnitude higher than the “Strombolian” trend. Sakurajima, Mt. St. Helens and
476 Pinatubo data fall within this field, all three being volcanoes associated with higher magma
477 volatile content (C_{vol}), silica content (X), conduit size and vent pressure (P_{vent}) than Stromboli.

478

479 **Table caption listing**

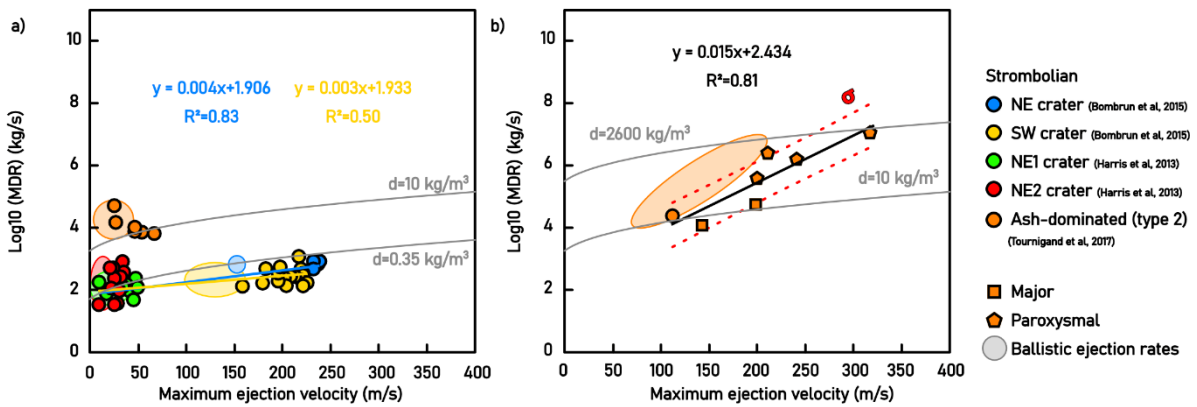
480 **Table 1** Data set for ballistic (B_v) and gas (G_v) velocities and mass discharge rate (MDR) for
481 normal, major, and paroxysmal eruptions at Stromboli. B_v and G_v re-calculated using
482 Equation (8) of Harris et al. (2012) are given in bold.

483 **Table 2** Mass and duration data obtained from thermal video for normal explosions at
484 Stromboli's NE1 and NE2 vents (derived MDR in bold).



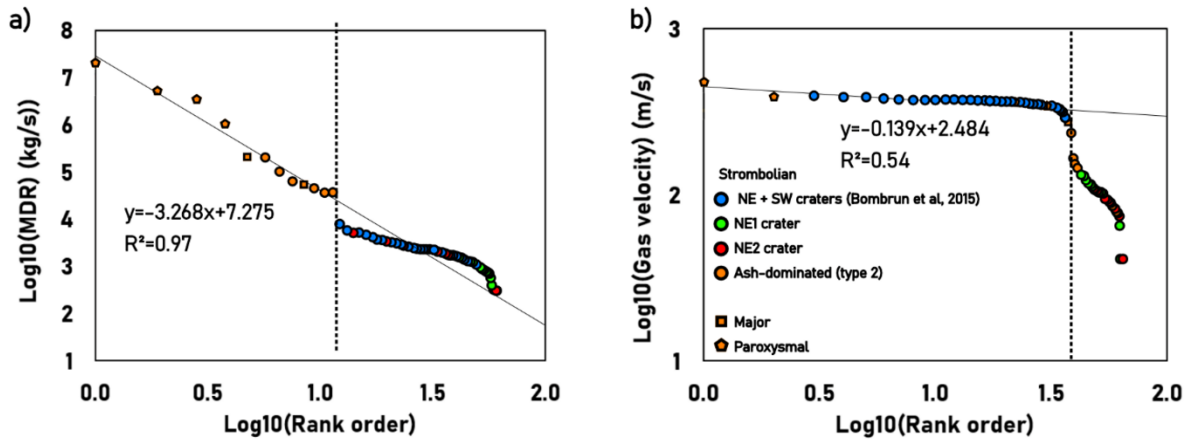
485

486 **Fig. 1**



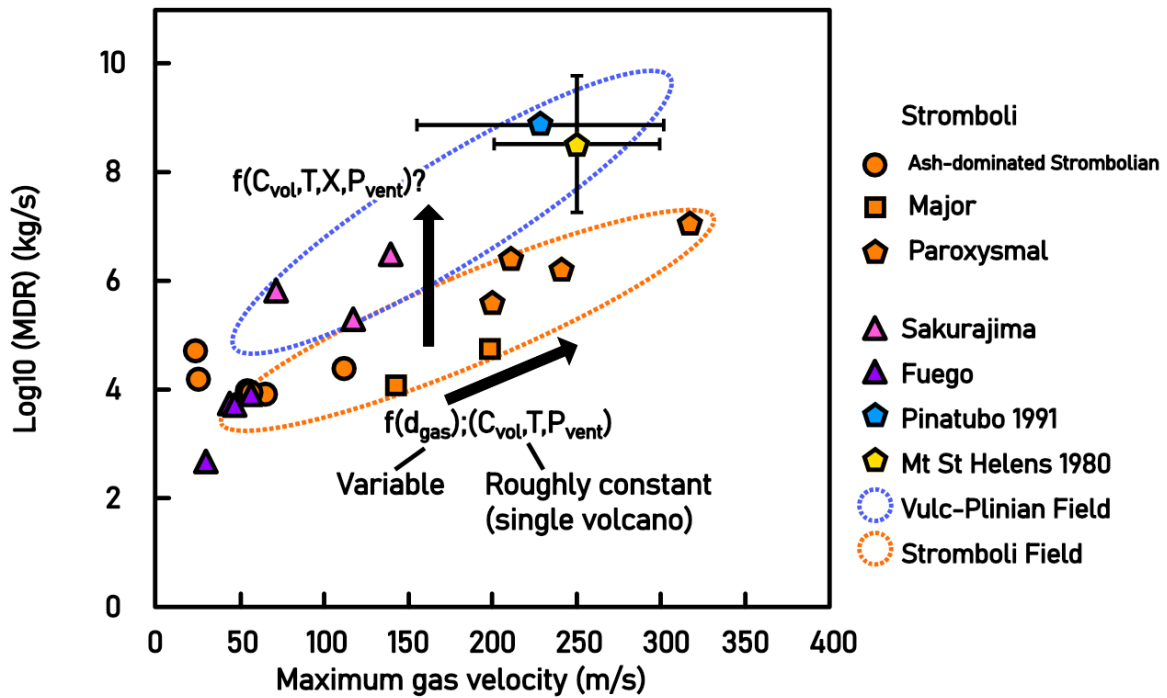
487

488 **Fig. 2**



489

490 Fig. 3



491

492 Fig. 4

493 **Table 1**

Date of eruption	Eruption type	Data type	Method	B_v (m/s)	Direct G_v independent measurement (m/s)	Literature derived G_v calculated (m/s)	Max derived G_v^b re-calculated (m/s)	Max derived B_v re-calculated (m/s)	Max Mass discharge rate (kg/s)	Ref.
4/5/2003	Parox	Radiometer Seismic	Waveform delay time	200	310		297		1.10E+07	Rosi et al. (2006)
4/5/2003	Parox	Radiometer - Seismic	Waveform delay time	185		324	276			Ripepe and Harris (2008)
3/15/2007	Parox	thermal video	Particle tracking	155	210		234		2.20E+06	Andronico et al. (2013), Pistolesi et al. (2011)
11/8/2009	Major	Bomb mapping	ballistic model	130	n.d		199		1.20E+04	Gurioli et al. (2013a), Pioli et al. (2014)
11/24/2009	Major	Bomb mapping	ballistic model	90	n.d		142		5.50E+04	Gurioli et al. (2013a), Pioli et al. (2014)
7/3/2019	Parox	Bomb mapping	ballistic model	160	n.d	200	241		1.40E+06	Giordano and De Astis (2020)
8/28/2019	Parox	Bomb mapping	ballistic model	130	n.d	200	199		3.60E+05	Giordano and De Astis (2020)
6/27/2004	Normal	thermal video	Gas cloud and particle tracking	129	213		197			Harris et al. (2012)
6/2/2010	Normal	thermal video	Gas cloud and particle tracking		8-48			23		Harris et al. (2013a,b)
6/8/2010	Normal	thermal video	Gas cloud and particle tracking		8-35			14		Harris et al. (2013a,b)
6/2004	Normal	thermal video	Particle tracking	3-101			158			Patrick et al. (2007)
9/27/1991	Normal	acoustic sounder	Waveform analysis	20-80			128			Weill et al. (1992)
9/1971	Normal	high speed camera	Particle tracking	2-72	94-112		117			Chouet et al. (1974)
4/2000	Normal	doppler radar	Waveform analysis	44-70			114			Hort et al. (2003)
9/1994	Normal	thermal video	Particle tracking	35-45	40-105		79			Ripepe et al. (2001)
1/29/1988 to 9/8/1989	Normal	thermal video	Particle tracking	16-22	70		46			Ripepe et al. (1993)
10/1/1996	Normal	doppler radar	Waveform analysis	7-13			34			Hort and Seyfried (1998)
27/9/2012 to 18/5/2014	Normal	thermal video	Gas cloud and particle tracking			240			1.30E+03	Bombrun et al. (2015)
26/5/2013 to 26/5/2016	Normal	Visible light and thermal video	Gas cloud and particle tracking			112			5.25E+04	Tournigand et al. (2017)

495 **Table 2**

Crater	Date	Time	Maximum Velocity*	Total Mass*		Duration	MDR	Log ₁₀ (MDR)
	(dd/mm/yy)	(hh:mm:ss)	(m s ⁻¹)	(x 10 ³ kg)		(s)	(kg/s)	(kg/s)
NE1	2/6/2010	11:35:23	16.6	1.1	1.4	18.6	67	1.83
NE1	2/6/2010	11:57:51	39.5	3.5	3.8	22.9	160	2.20
NE1	2/6/2010	12:22:35	8.3	2.7	3	18.2	156	2.19
NE1	2/6/2010	14:08:51	39.5	1.7	1.8	19.0	92	1.96
NE1	2/6/2010	14:38:43	47.8	1.7	1.9	16.4	110	2.04
NE1	2/6/2010	14:59:53	37.4	3.3	3.7	28.1	125	2.10
NE1	2/6/2010	15:48:05	43.6	1.1	1.2	27.2	42	1.63
NE1	2/6/2010	16:08:17	33.3	0.9	1	9.4	101	2.00
NE1	2/6/2010	16:12:11	47.8	1.3	1.4	6.6	204	2.31
NE1	8/6/2010	13:50:46	33.3	1.3	1.4	10.2	132	2.12
Average			34.7	1.9	2.1	17.7	119	2.0
NE2	8/6/2010	12:43:43	22.9	2.3	2.6	5.0	489	2.69
NE2	8/6/2010	13:29:57	29.1	0.4	0.5	5.2	86	1.94
NE2	8/6/2010	14:03:17	20.8	0.32	0.35	3.4	99	1.99
NE2	8/6/2010	14:05:23	35.3	1.9	2.1	5.2	385	2.59
NE2	8/6/2010	14:20:28	27	1.1	1.2	4.8	239	2.38
NE2	8/6/2010	15:08:56	29.1	1.1	1.2	4.6	250	2.40
NE2	8/6/2010	15:19:10	33.3	1.3	1.4	5.0	270	2.43
NE2	8/6/2010	16:32:13	33.3	3.8	4.2	5.0	799	2.90
NE2	8/6/2010	17:00:32	8.3	0.09	0.1	3.0	32	1.50
NE2	8/6/2010	18:03:52	24.9	0.56	0.63	18.6	32	1.50
NE2	8/6/2010	18:20:31	27	0.13	0.15	4.2	33	1.52
Average			26.5	1.2	1.3	5.8	247	2.2

* data from Harris et al. (2013)

