

Characterization of explosive eruptions based on tephra deposits: plume height, mass eruption rate, erupted volume, eruption classification

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PART I: Determination of plume height and Mass Eruption Rate

Objective: determination of 1) plume height and wind speed with the model Rossi et al. (2018), and of 2) MER with the methods of Wilson and Walker (1987), Mastin et al. (2009) and Degruyter and Bonadonna (2012).

1. Please compile an isopleth map based on the document provided and calculate **the height of the plume (above the vent)** and the **wind speed** based on the method of Rossi et al. (2018) using both the nomograms (Fig. 1) and the Matlab script provided. The map represents the largest lithics of the Layer 3 of Cotopaxi volcano (vent height: 5.7 km above sea level). Assume a density of lithics of 2500 kg/m³ and consider an average altitude of sampling above sea level of 3500 m. Before starting, be sure to choose your contour values according to figure 1.

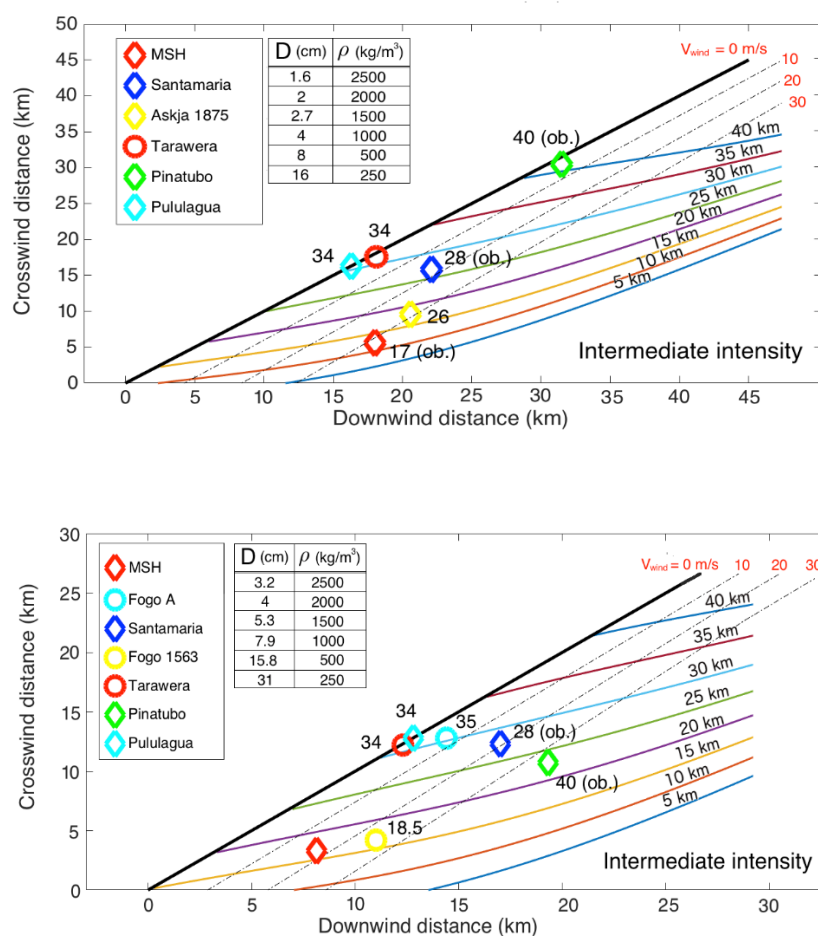


Figure 1: Nomograms of Rossi et al. (2018) to calculate plume height based on particle diameters of 1.6 and 3.2 cm and a density of 2500 kg/m³.

Calculate the plume height (km) and wind speed (m/s) as an average value of the results obtained from the different plots considered. Please also indicate the associated variation (i.e. $\pm(\text{max-min})/2$).

→ Make sure to subtract the average height of sampling from the height obtained with the nomograms in order to derive the height above the vent (i.e. vent height – sampling height)

2. The mass eruption rate (MER, kg/s) can be related to the plume height above the vent (H, km) using the formula of Wilson and Walker (1987):

$$H = 0.236 \times MER^{\frac{1}{4}} \quad (1)$$

The DRE **volumetric flow rate** (Q ; m³/s) can be derived with the equation of Mastin et al. (2009) (with H expressed in km above the vent):

$$Q = \left(\frac{H}{2} \right)^{4.15} \quad (2)$$

Q can be converted in MER based on a DRE density of 2500 kg/m³.

In order to account for the effect of wind, the MER can be calculated from H above the vent (in m) with the formula of Degruyter and Bonadonna (2012):

$$MER = \pi \frac{\rho_{a0}}{g'} \left(\frac{\alpha^2 \bar{N}^3}{10.9} H^4 + \frac{\beta^2 \bar{N}^2 \bar{v}}{6} H^3 \right) \quad (3)$$

assuming $\bar{N} = 0.0156 \text{ s}^{-1}$ (average buoyancy frequency across the plume height), $\bar{v} = 8.7 \text{ m s}^{-1}$ (average wind velocity across the plume height), $\rho_{a0} = 1.2259 \text{ kg m}^{-3}$ (density of the atmosphere), $g' = 45.6525 \text{ m s}^{-2}$ (reduced gravity), $\alpha = 0.1$ (radial entrainment coefficient) and $\beta = 0.5$ (wind entrainment coefficient). Notice that the average wind speed along the plume (\bar{v}) is smaller than the wind speed that you have derived with the method of Rossi et al. (2018), which is the maximum wind speed at tropopause.

Calculate the MER using the average value of plume height **above the vent** obtained from previous exercise and the three formulas 1), 2) and 3). Discuss the difference.

PART II: Erupted volume and eruption classification

Objective: determination of the volume of erupted tephra based on the method of Pyle (1989) and of Bonadonna and Houghton (2005) and classification of the eruption using the method of Pyle (1989)

1. Several approaches exist for the calculation of the volume. Here you will use the exponential method with one segment (Pyle 1989) and the power-law method (Bonadonna and Houghton 2005). Figure 2 shows the isopach map for Layer 3, and figure 3 shows the area^{1/2} vs. thickness plot, with the fits of the different approaches.

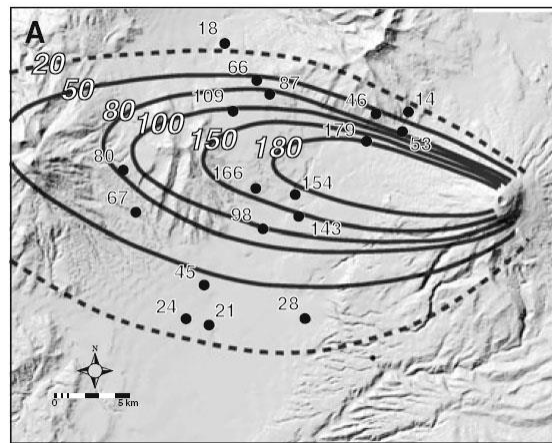


Figure 2: Isopach map (cm) for Layer 3.

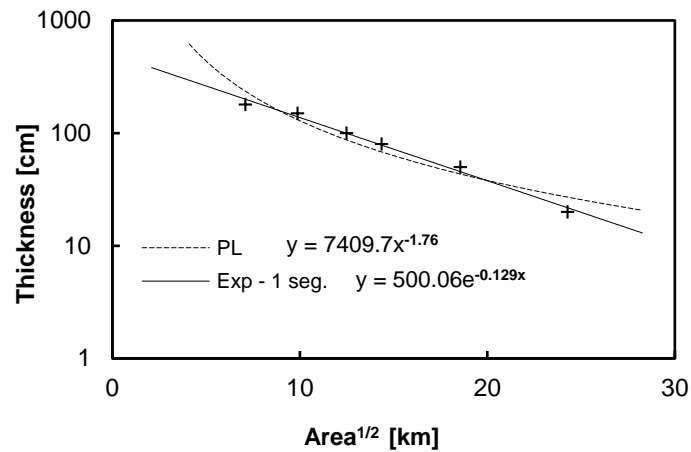


Figure 3: Thickness vs. square root of area.

Exponential method, 1 segment (Pyle 1989)

The exponential fit can be described by the following equation:

$$T = T_0 \exp(-k\sqrt{A}) \quad (4)$$

The expression of the volume integral is given by:

$$Volume = T_0 13.08 b_t^2, \quad (5)$$

where T_0 and b_t are the maximum thickness (intercept) and half-distance thickness respectively, with:

$$b_t = \frac{\ln 2}{k \sqrt{\pi}}, \quad (6)$$

where $-k$ is the slope of the line segment (i.e. exponent of the equation for the exponential best fit). k is a positive value.

Power-law method (Bonadonna and Houghton 2005)

The Power-Law fit can be described by the following equation:

$$T = T_{pl} \sqrt{A}^{(-k)}. \quad (7)$$

The expression of the volume integral is given by:

$$Volume = \frac{2T_{pl}}{2-k} (C^{(2-k)} - B^{(2-k)}). \quad (8)$$

where T_{pl} and k are the power-law constant and exponent in Eq. (7). C and B are two constants of integration. Here, fix B to 4.6 km, and calculate the volumes with $C = 100$ km and $C = 500$ km.

Determine the volume (in km³) using both the exponential method and the power-law method (be careful with units: you need to convert both T_0 and T_{pl} from "cm" to "km"!)

2. Determine the VEI of Layer 3 with figure 4

	0	1	2	3	4	5	6	7	8
General Description	Non-Explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volume of Tephra (m ³)	1x10 ⁴	1x10 ⁶	1x10 ⁷	1x10 ⁸	1x10 ⁹	1x10 ¹⁰	1x10 ¹¹	1x10 ¹²	
Cloud Column Height (km) Above crater Above sea level	<0.1	0.1-1	1-5	3-15	10-25	>25			
Qualitative Description	"Gentle,"	"Effusive"	"Explosive"	"Explosive"	"Cataclysmic," "Severe,"	"paroxysmal," "violent,"	"terrific"	"colossal"	
Eruption Type	Hawaiian	Strombolian	Vulcanian	Plinian	Ultra-Plinian				
Duration (continuous blast)	<1 hour	<1 hour	1-6 hrs	6-12 hrs	>12 hrs				
CAVV max explosivity (most explosive activity listed in CAVW)	Lava flow	Phreatic	Explosion or Nuée ardente						
Tropospheric Injection	Negligible	Minor	Moderate	Substantial					
Stratospheric Injection	None	None	None	Possible	Definite	Significant			
Eruptions (total in file)	755	963	3631	924	307	106	46	4	0

Figure 4: Boundary parameters for VEI classes (Newhall and Self 1982).

3. Considering a density of the deposit of 700 kg/m^3 , calculate the eruption duration (in hours and minutes) using the 3 values of volume obtained in exercise 1 Part 2 and the MER obtained with the method of Degruyter and Bonadonna (2012). Discuss the results.

4. Using the value of b_t calculated in eq. 5 and a value of b_c of 2.8 km, use figure 5 and the method of Pyle (1989) to classify the eruption associated with Layer 3.

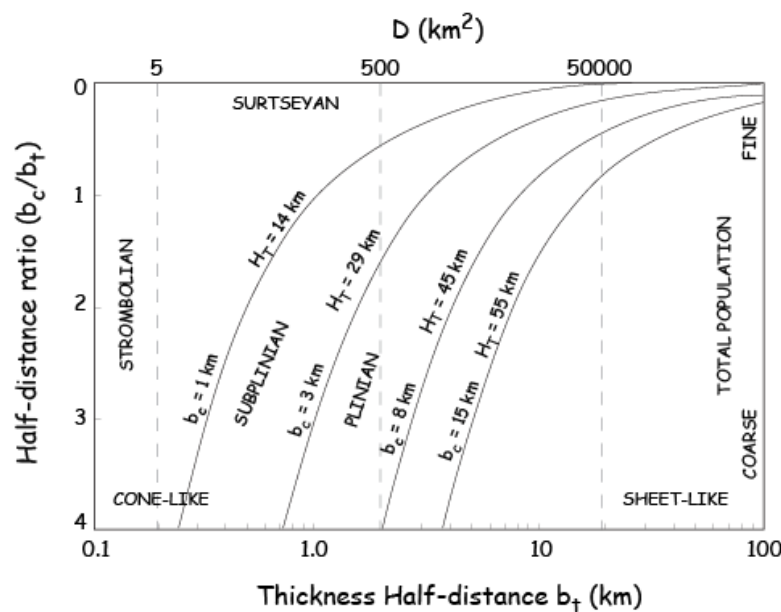


Figure 5: Classification scheme of Pyle (1989).

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