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Memovolc Workshop – Dynamics of Explosive Volcanic Eruptions

Particle Transport and Sedimentation

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Outline

- Processes of volcanic particle transport and sedimentation
- Deposits as the basis of eruption classification

Volcanic Ash Dispersion

Ash dispersion from sustained, co-ignimbrite and short-duration volcanic sources

Common features:

Atmospheric injection

Particles < 64 mm

Particle volumetric concentration is low

Volcanic Ash Dispersion

Scales of motion

$$u_p \sim \left(B_0 N\right)^{1/4}$$

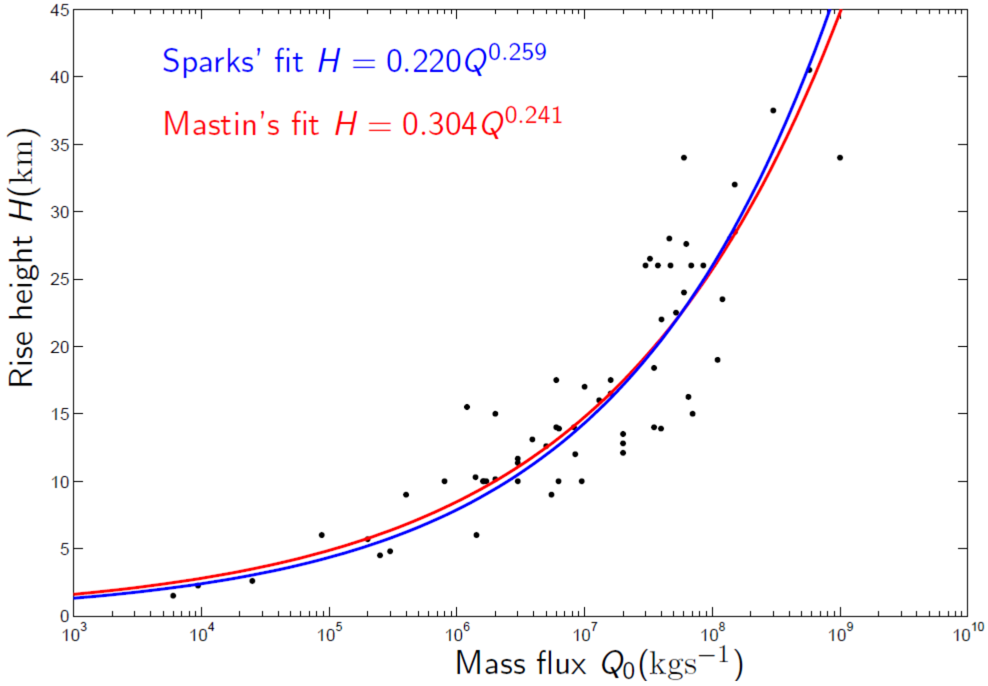
$$t_p \sim \frac{1}{N}$$

B_0 source specific bouyancy flux

N atmosphere buoyancy frequency

Initial Conditions for Ash Dispersion

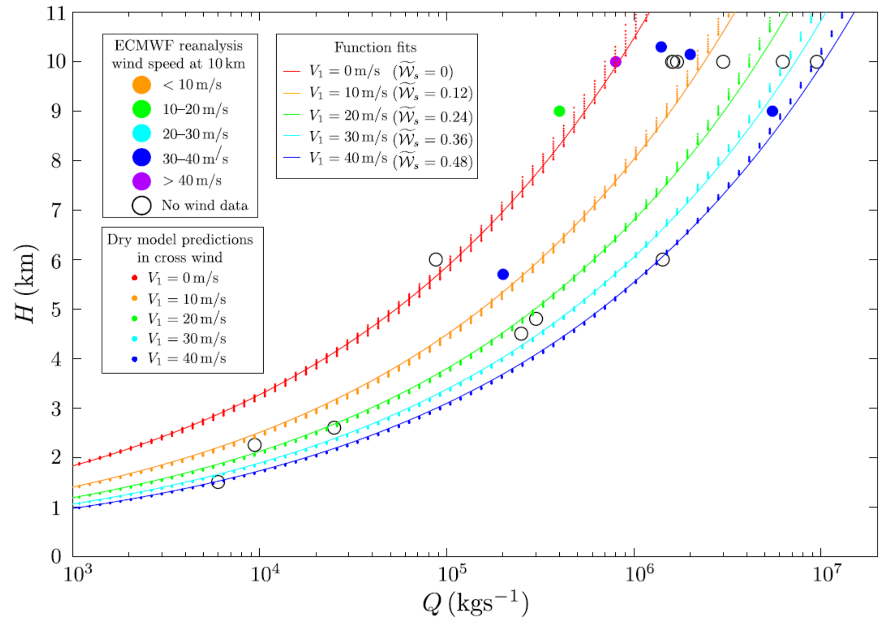

Puhuehue 2011



Sparks 1986; Mastin et al 2009

- Volcanic plumes reach a level of neutral buoyancy controlled by mixing and atmospheric stratification
- Height of injection is correlated to the plume source mass flux

Initial Conditions for Ash Dispersion



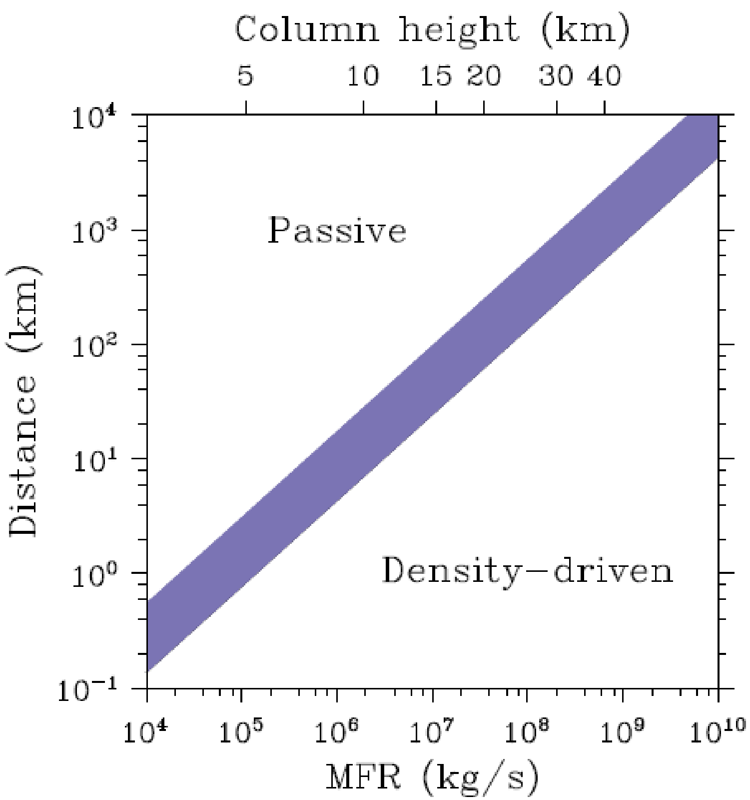
- Volcanic plume intrudes into the atmosphere as an ash cloud
- Initially ash cloud is dispersed by wind and buoyancy; typical Peclet numbers

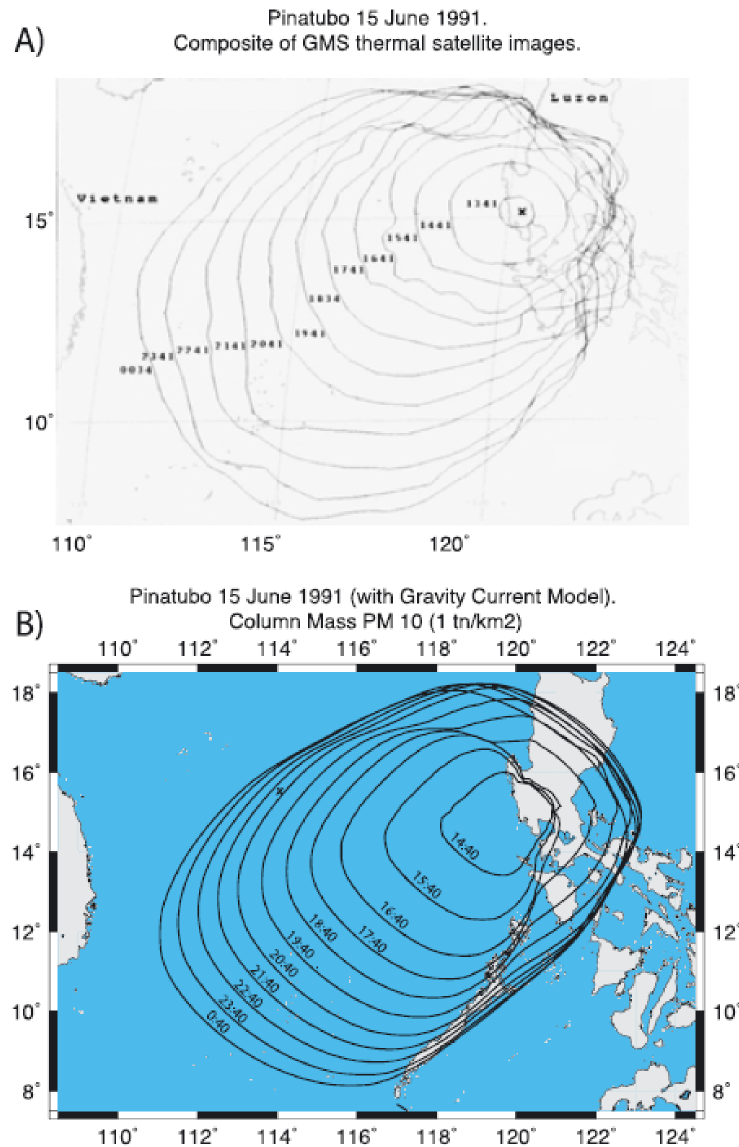
Woodhouse et al 2013

Transition to Diffusive Spreading

The transition from buoyant spreading to ash dispersion by wind advection and diffusion has been identified

Costa et al 2013





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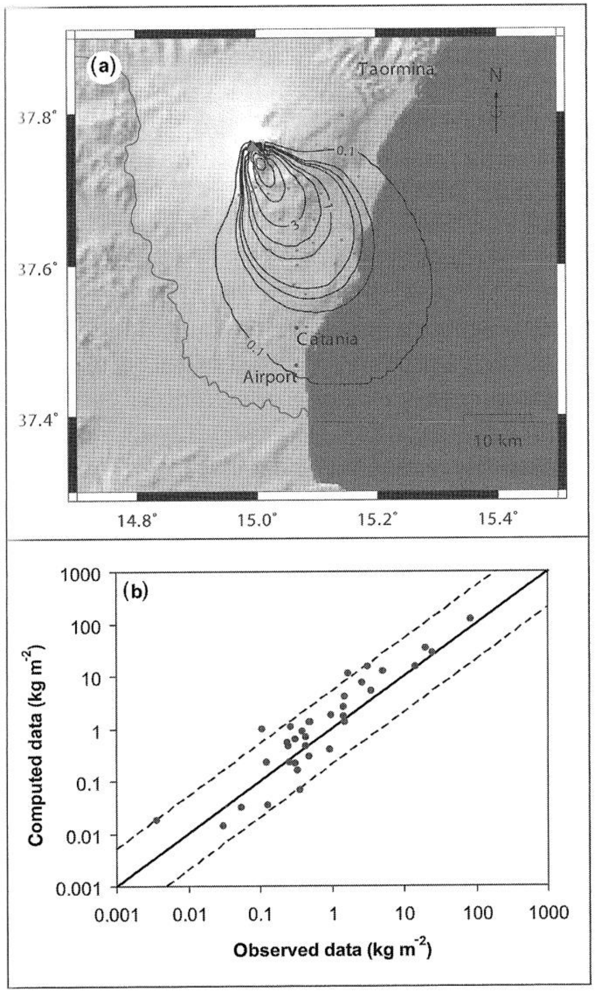
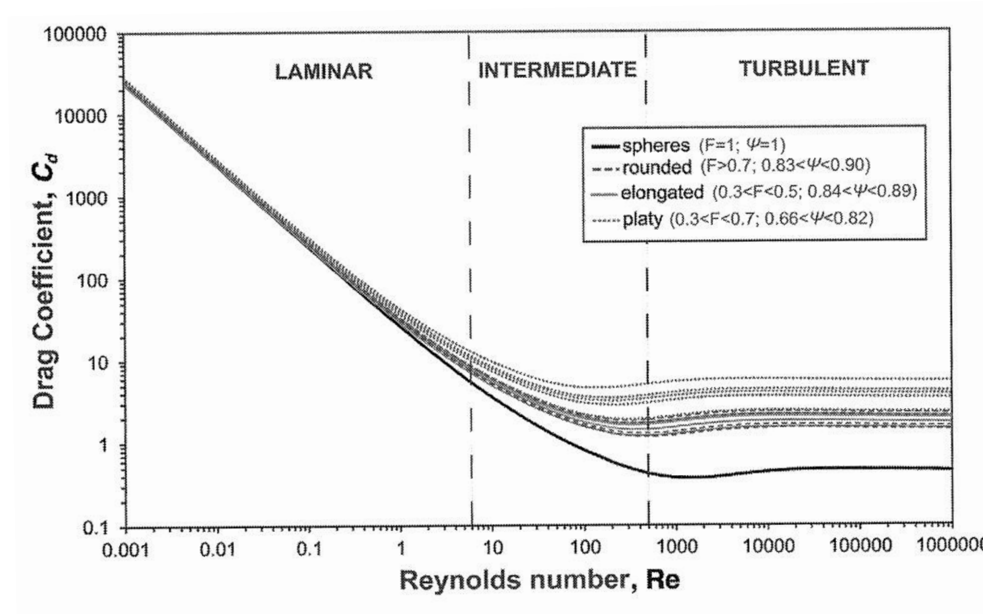
Volcanic ash deposition can be described using combined wind advection, atmospheric diffusion and particle sedimentation





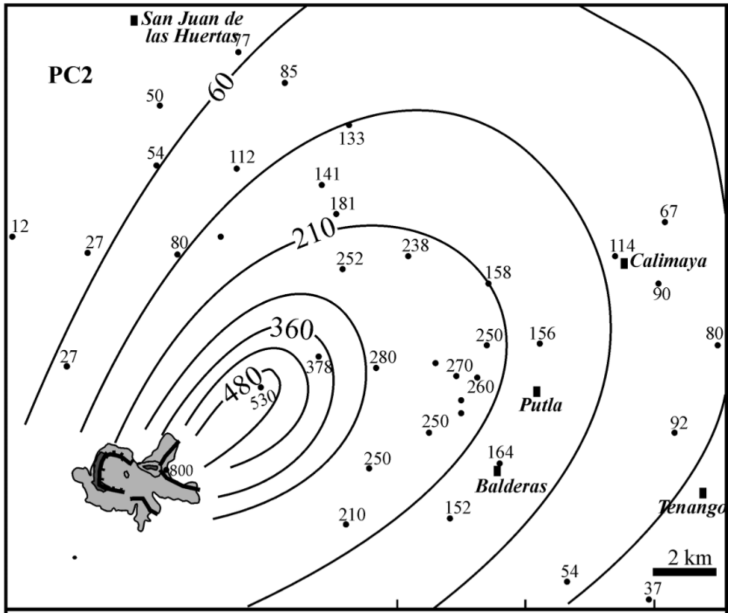
Volcanic particle sedimentation in the atmosphere depends on particle size, density, shape and flow regime

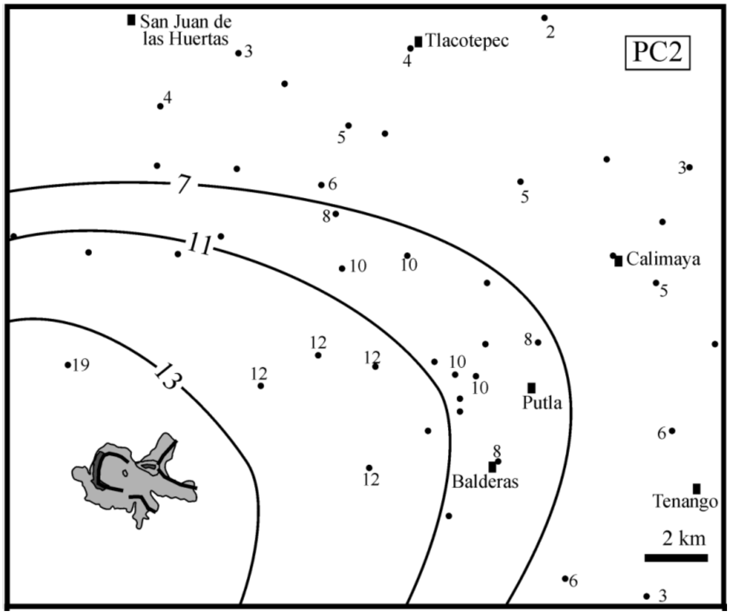
Tephra2 simulation of 1998 Etna eruption

Bonadonna and Costa 2013

Deposits and Thinning Trends

Volcanic airfall deposits show decrease in thickness (thinning) and in maximum clast size with distance from the source





Isopach and Isopleth contours (cm) for 10.5 ka eruption of Nevado de Toluca, Mexico

Arce et al 2003

Deposits and Thinning Trends

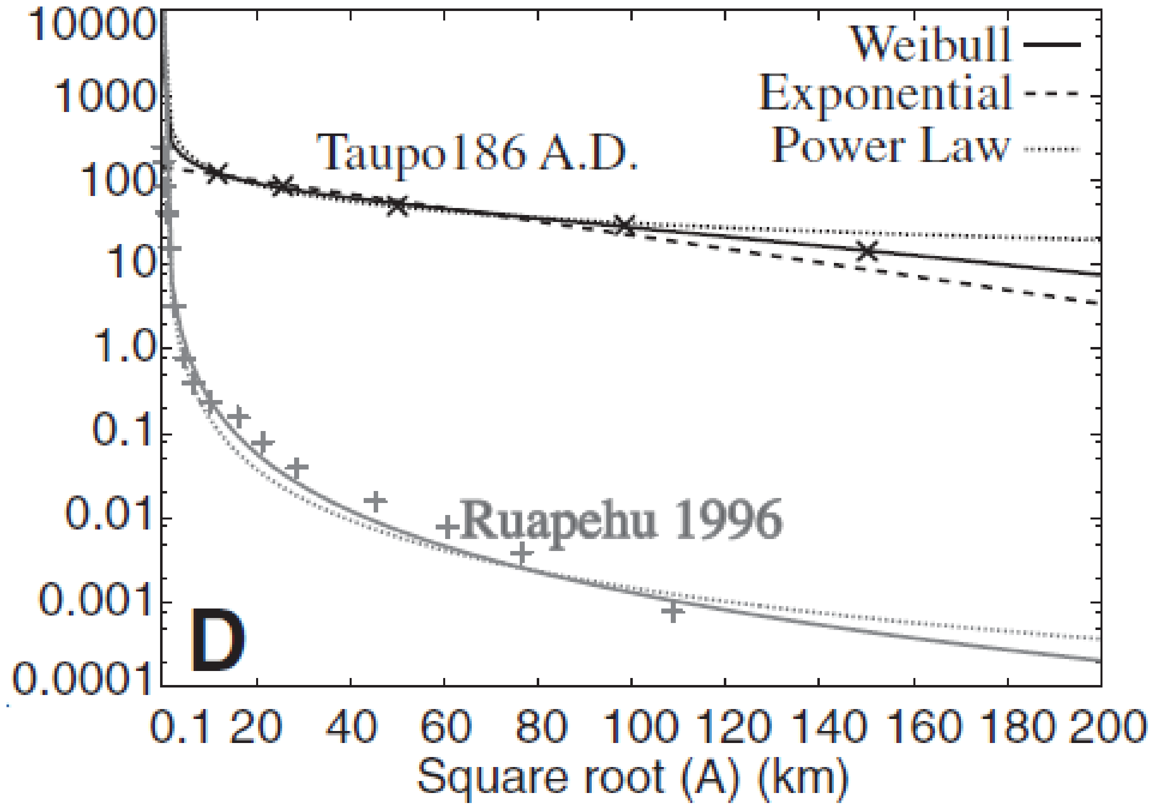
Deposit thinning has been described in terms of a relationship between deposit thickness and square root of area of the isopach enclosing that deposit thickness:

Exponential (Pyle 1989)

Exponential segments
(e.g. Fierstein & Nathenson 1992)

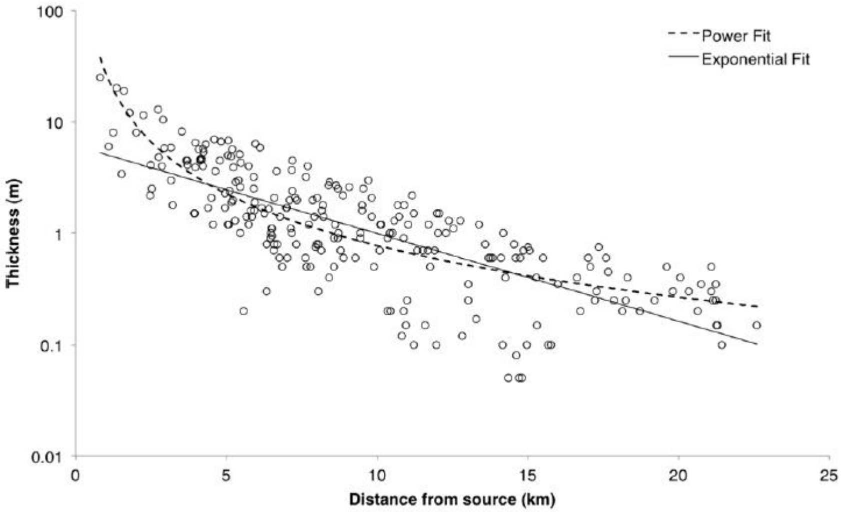
Power-law fits to exponential form
(Bonadonna & Houghton 2005)

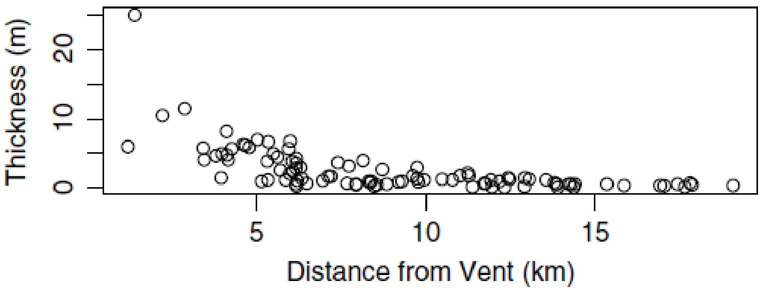
Weibull
(Bonadonna & Costa 2012)

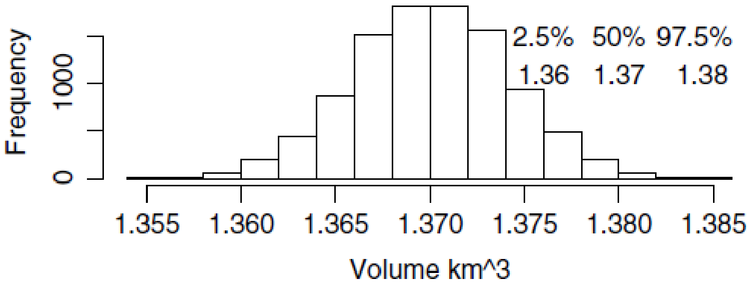


Bonadonna & Costa 2012

Erupted volume can be estimated by integration of thinning trends or by statistical regression on point thickness measurements





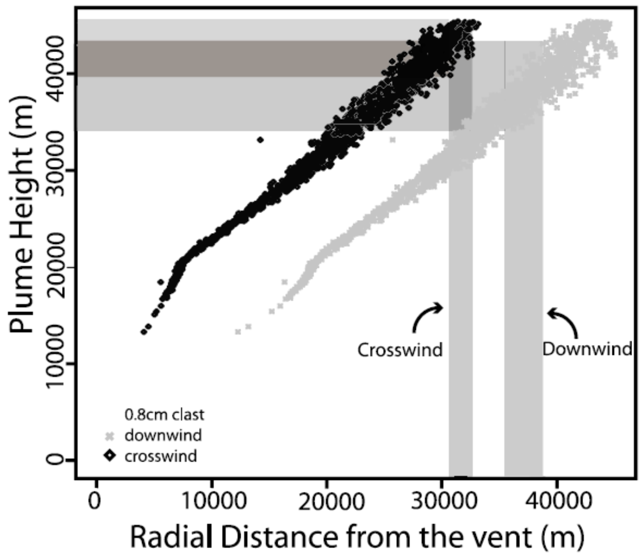


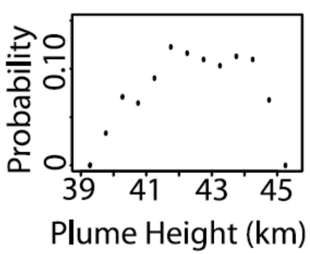
Regression methods show broad agreement with isopach thinning trends

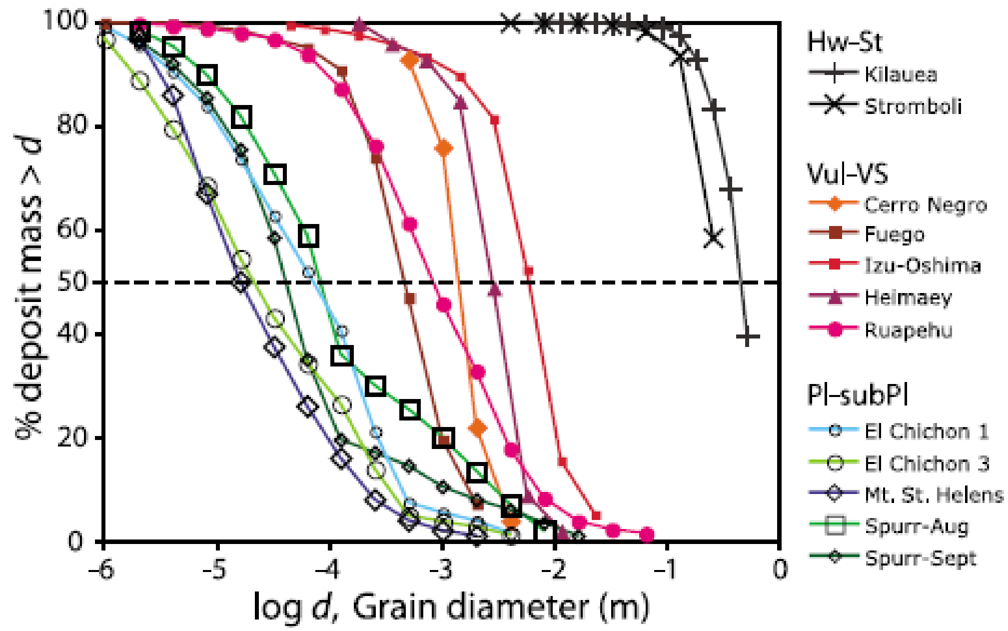
Engwell et al 2013; Burden et al 2013

Deposit Clast Sizes

The maximum clast size at a deposit location can be used to estimate eruption plume height, and hence source mass flux







Rust & Cashman 2011

Proportion of fine material in deposits where total grain size distribution is known has also been used as part of eruption classification

Carey & Sparks 1986
Burden et al 2011

Eruption Classification Based on Transport and Deposits

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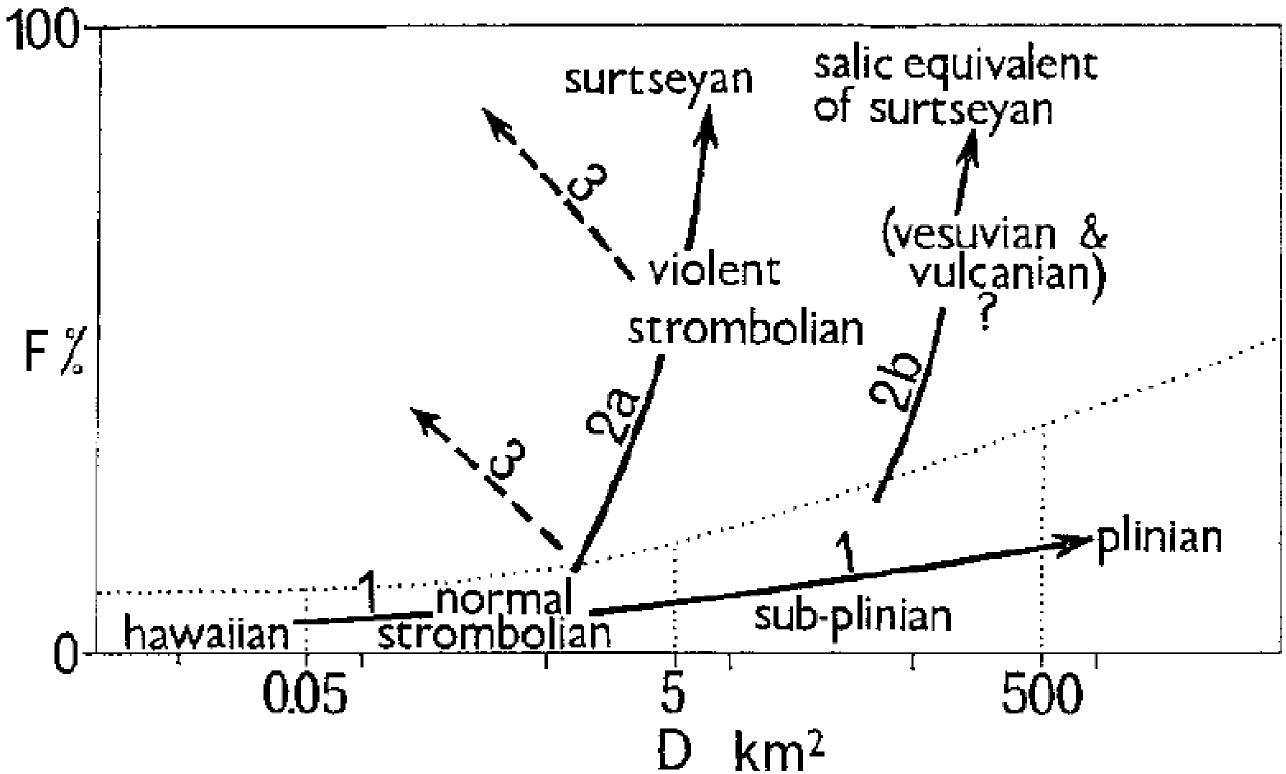
Walker (1973) devised a quantitative eruption classification based on deposit isopachs and grainsize



(D is area enclosed by 1% maximum thickness isopach T_0 ; F is % of deposit finer than 1 mm diameter at intersection of dispersal axis and 1% T_0 isopach)

- D and F are hard to measure!

Eruption Classification Based on Transport and Deposits

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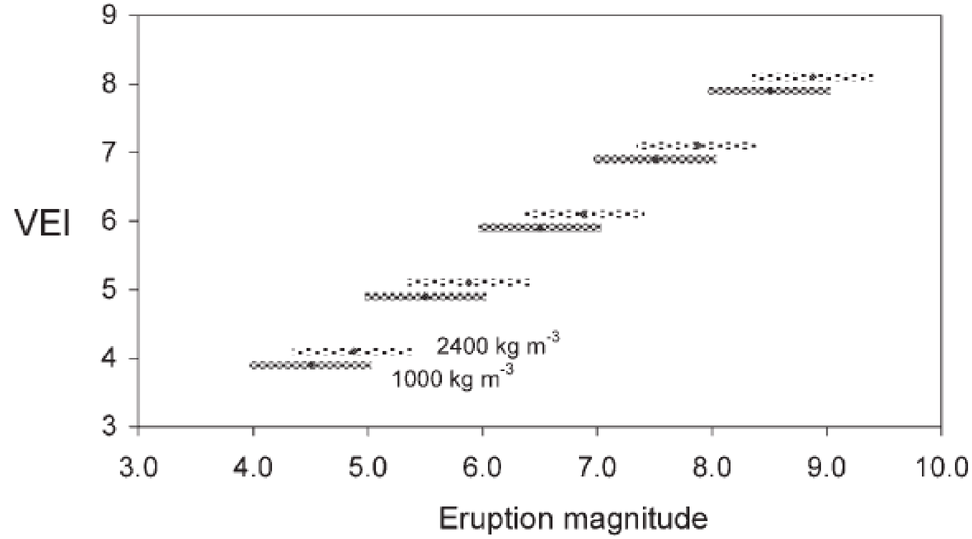
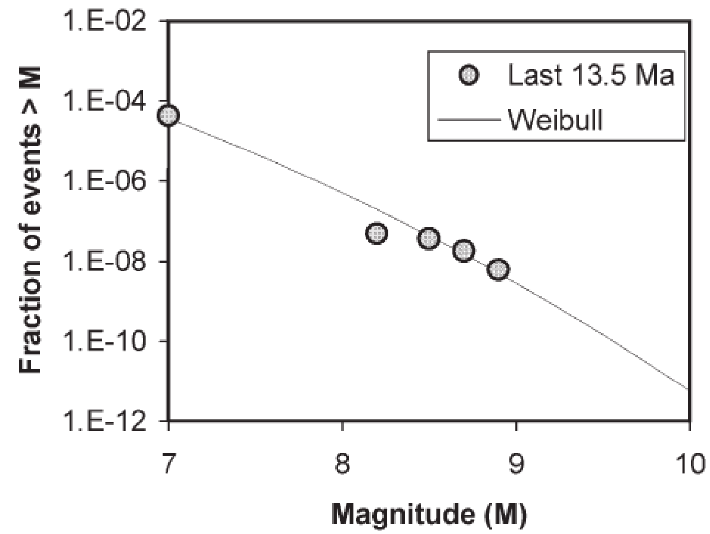
Volcanic Explosivity Index and Magnitude are based on deposit volume and mass

	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)	1×10^4	1×10^6	1×10^7	1×10^8	1×10^9	1×10^{10}	1×10^{11}	1×10^{12}	
Cloud Column Height (km) Above crater	<0.1	0.1-1	1-5						
Above sea level				3-15	10-25	>25 →			
Qualitative Description	"Gentle,"	"Effusive"	← "Explosive" →		← "Cataclysmic,"		"paroxysmal,"	"colossal" →	
				← "Severe,"		"violent,"	"terrific" →		
Eruption Type	← Hawaiian →	← Strombolian →		← Plinian →					
			← Vulcanian →			← Ultra-Plinian →			
Duration (continuous blast)	← <1 hour →				← >12 hrs →				
			← 1-6 hrs →						
				← 6-12 hrs →					
CAVW max explosivity (most explosive activity listed in CAVW)	Lava flow	← Explosion or Nuée ardente →							
	Dome or mudflow	← Phreatic → - - - →							
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



- Magnitude = log (erupted mass) – 7.0

Weibull function is the natural form for a long -tailed distribution with an expected maximum such as Magnitude or VEI



Newhall & Self (1982); Pyle (1995); Mason et al (2004)

Eruption Classification Based on Transport and Deposits

Mastin et al (2009) proposed a classification of eruption 'type' based on a combination of plume height (source mass flux) and deposit volume and particle size fraction

Eruption type	Example (Date as M/D/Y)	H (km) above vent	D (h)	$\dot{M}$ (kg/s)	V (km^3)	m_{63}
Mafic, standard (M0)	Cerro Negro, Nicaragua, 4/13/1992	7	60	1×10^5	0.01	0.05
Small (M1)	Etna, Italy, 7/19–24/2001	2	100	5×10^3	0.001	0.02
Medium (M2)	Cerro Negro, Nicaragua, 4/9–13/1992	7	60	1×10^5	0.01	0.05
Large (M3)	Fuego, Guatemala, 10/14/1974	*10*	5	1×10^6	0.17	0.1
Silicic, standard (S0)	Spurr, USA, 8/18/1992	*11*	3	4×10^6	0.015	0.4
Small (S1)	Ruapehu, New Zealand, 6/17/1996	5	12	2×10^5	0.003	0.1
Medium (S2)	Spurr, USA, 8/18/1992	*11*	3	4×10^6	0.015	0.4
Large (S3)	St. Helens, USA, 5/18/1980	15	8	1×10^7	0.15	0.5
co-ignimbrite cloud (S8)	St. Helens, USA, 5/18/1980 (pre-9 AM)	25	0.5	1×10^8	0.05	0.5
Brief (S9)	Soufrière Hills, Montserrat (composite)	10	0.01	3×10^6	0.0003	0.6
Submarine (U0)	None	0	–	–	–	

Type	Magma type	Historical eruption characteristics
M0	Basalt or other mafic	insufficient historical data to characterize
M1		$H\leq5$ km or VEI≤2
M2		$H=5$–8 km or VEI$=3$
M3		>8 km or VEI≥4
S0	Andesite, dacite, rhyolite or other explosive composition	insufficient historical data to characterize
S1		$H\leq6$ km or VEI≤2
S2		$H=6$–12 km or VEI$=3$
S3		$H\geq12$ km or VEI≥4
S8		active column collapse
S9		active lava dome is present
U0	All magma types	submarine vent with water depth ≥50 m

Challenges

- Transient eruption dynamics are not well-understood – challenge to describe frequent small transient eruptions that feed into ‘cascading’ volcanic hazard
- Lack of detailed understanding of short-timescale meteorological drivers on volcanic ash dispersion and deposition
- Lack of understanding of finest particle processes e.g. aggregation, proximal fine ash deposition

Transport and Deposit Parameters for Eruption Classification

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- Volcanic source flux is a major control on dispersal style

- Plume height alone is insufficient to characterise eruption size because it is partially set by the wind for weak plume eruptions
  - recent advances in mechanistic understanding

- Not clear what information about transient eruption behaviour (short-duration eruption or source fluctuations in continuous eruptions) can be preserved in deposits

- Deposit parameters - area/thickness
  - size/size distribution/density

Optimizing information obtained from deposits; e.g. combining thickness and grainsize information (Bonadonna & Costa 2013)