



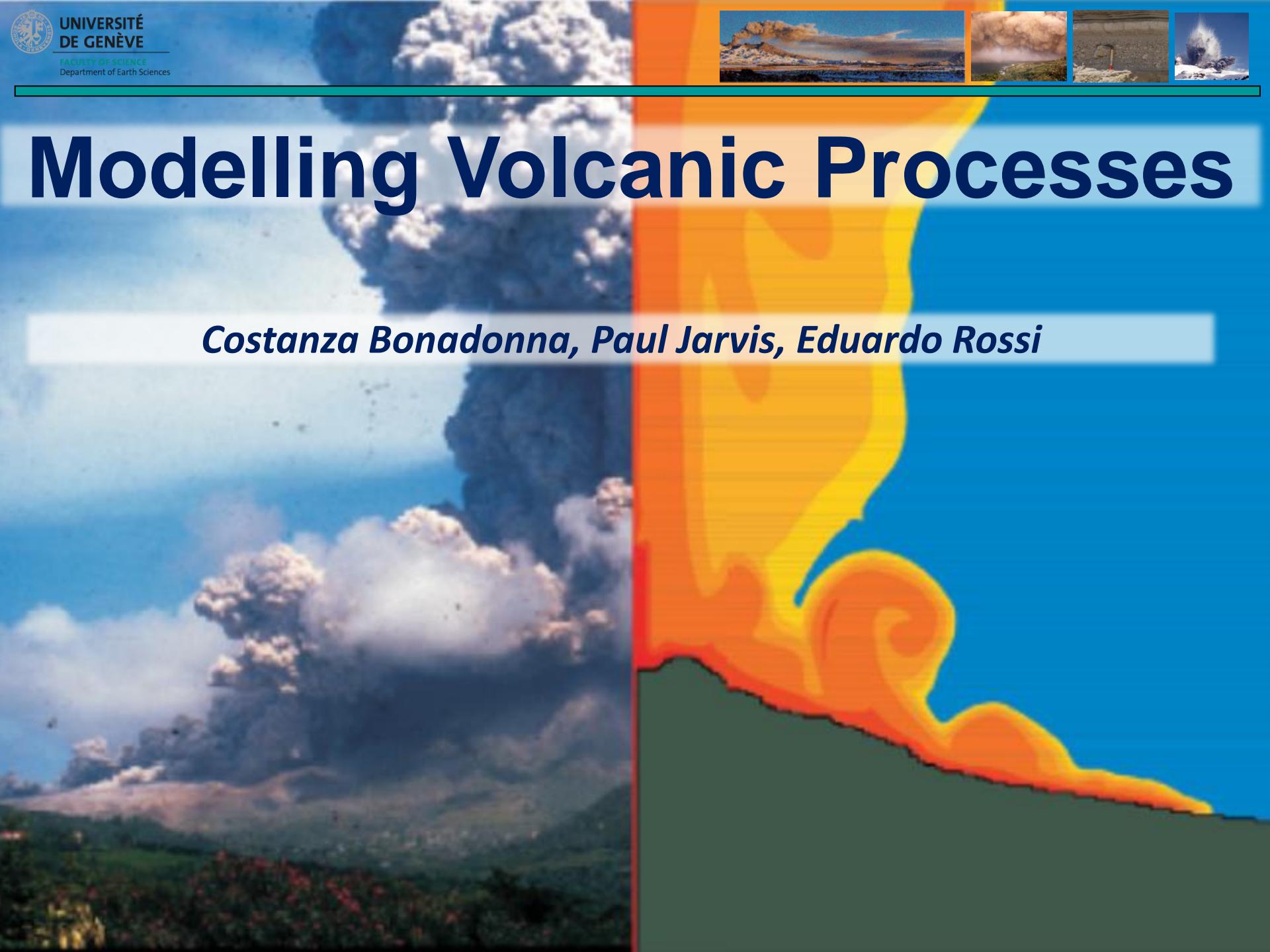
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Modelling Volcanic Processes

Costanza Bonadonna, Paul Jarvis, Eduardo Rossi





MOTIVATION

Volcanic system → range of scales, material property variations, and complex interacting physical and chemical processes

particle transport and dispersal of ultrafine aerosols



eruptive plumes and their interaction with the atmosphere

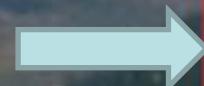
PDCs and their interaction with topography



multiphase high-speed flows in conduits



flow of viscous magma through fractures in the deformable crust



magma chambers deep in the crust





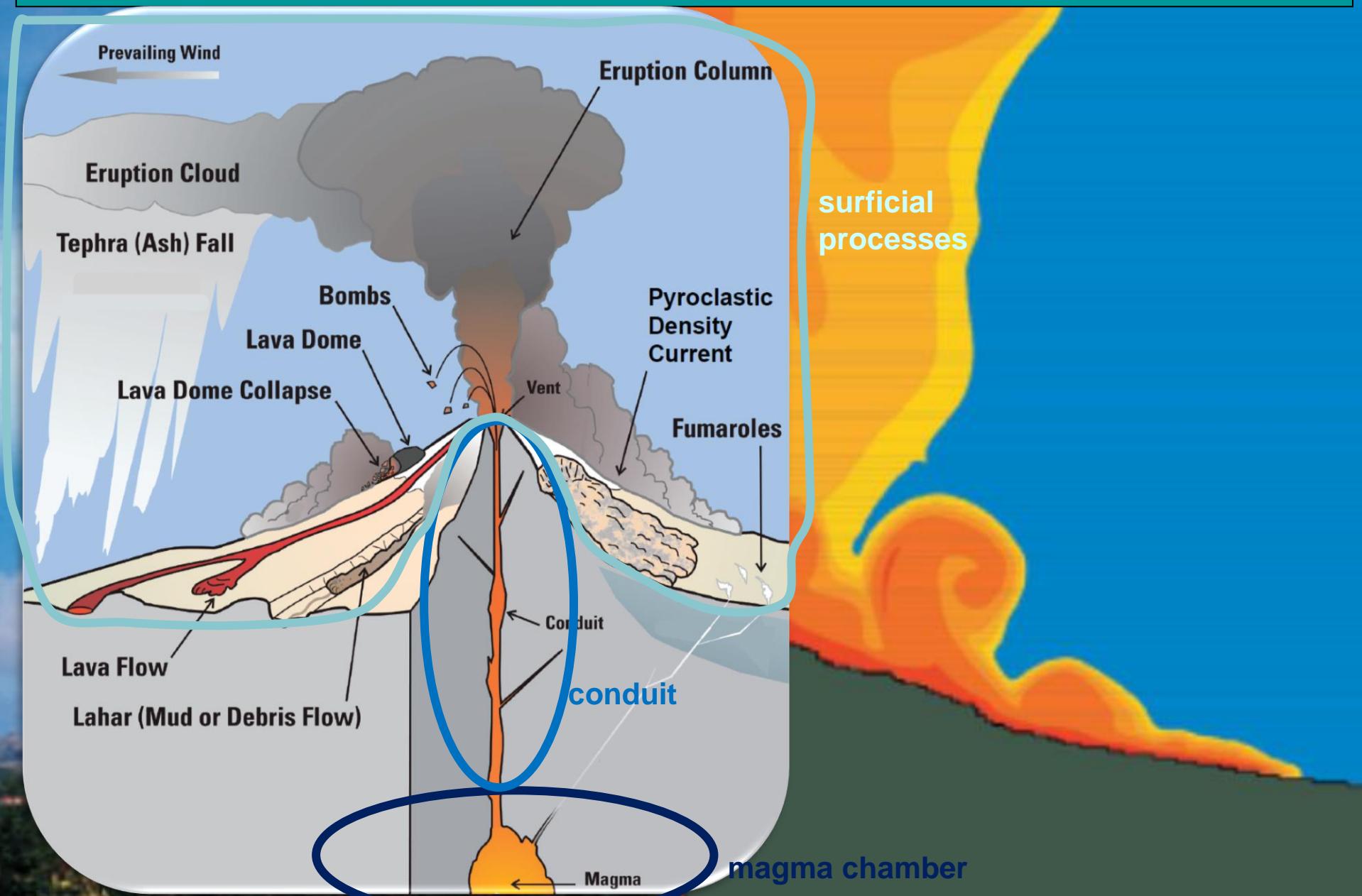
MOTIVATION

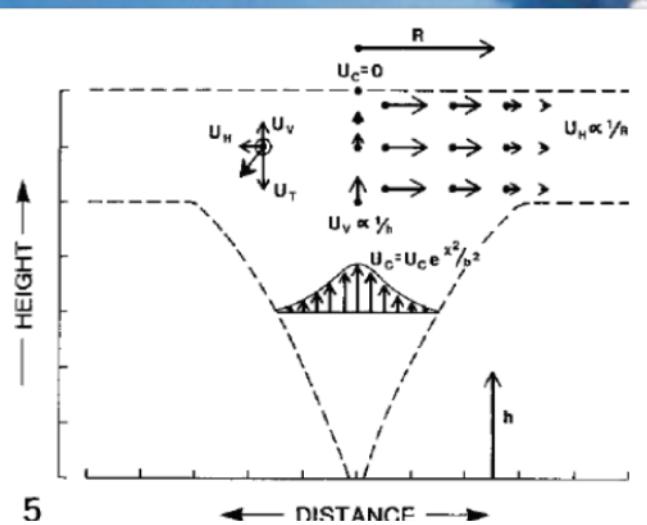
Volcanologists have the drive and the responsibility to progress their science to improve **understanding** and **mitigation** of the effects of volcanic eruptions

Many key volcanic processes cannot be observed and analysed directly

Hazardous processes are required to be analytically and numerically described for both real-time forecasting and long-term risk reduction strategies

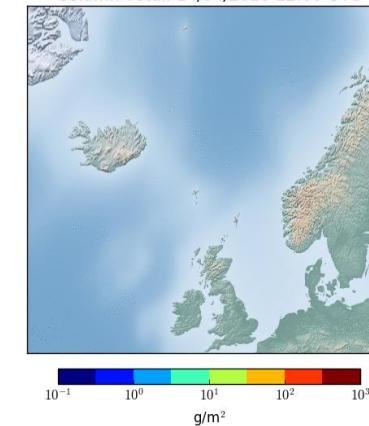
A variety of dedicated models of different complexity needed to be developed at multiple scales that could address different purposes





5

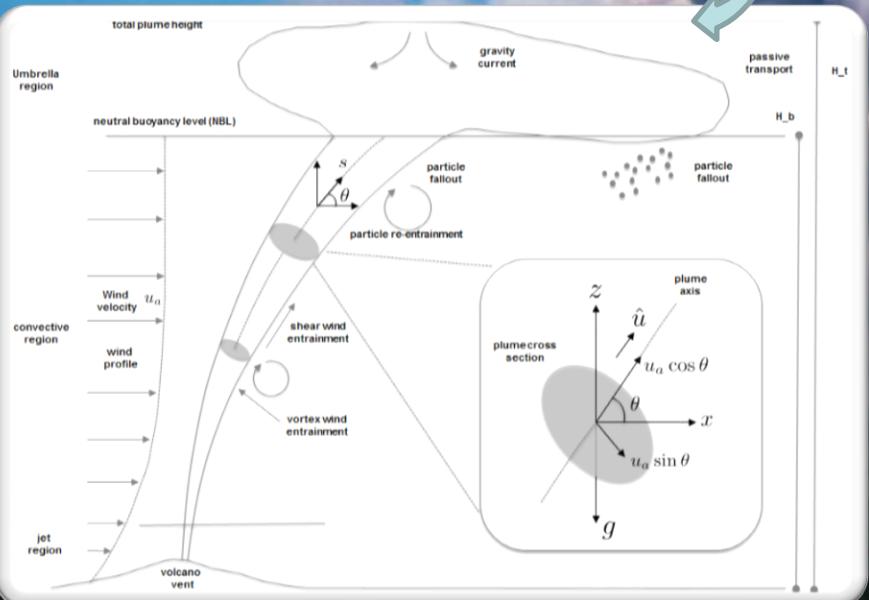
Run name: Mastin
Column Total: 14/04/2010 12:00 UTC



10^{-1} 10^0 10^1 10^2 10^3
 g/m^2

SOURCE: Carey and Spark 1986

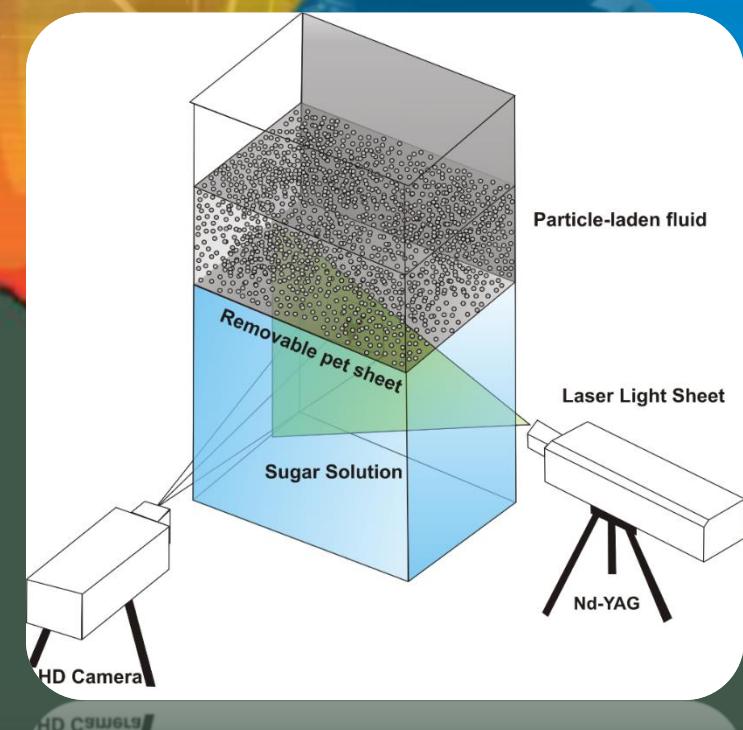
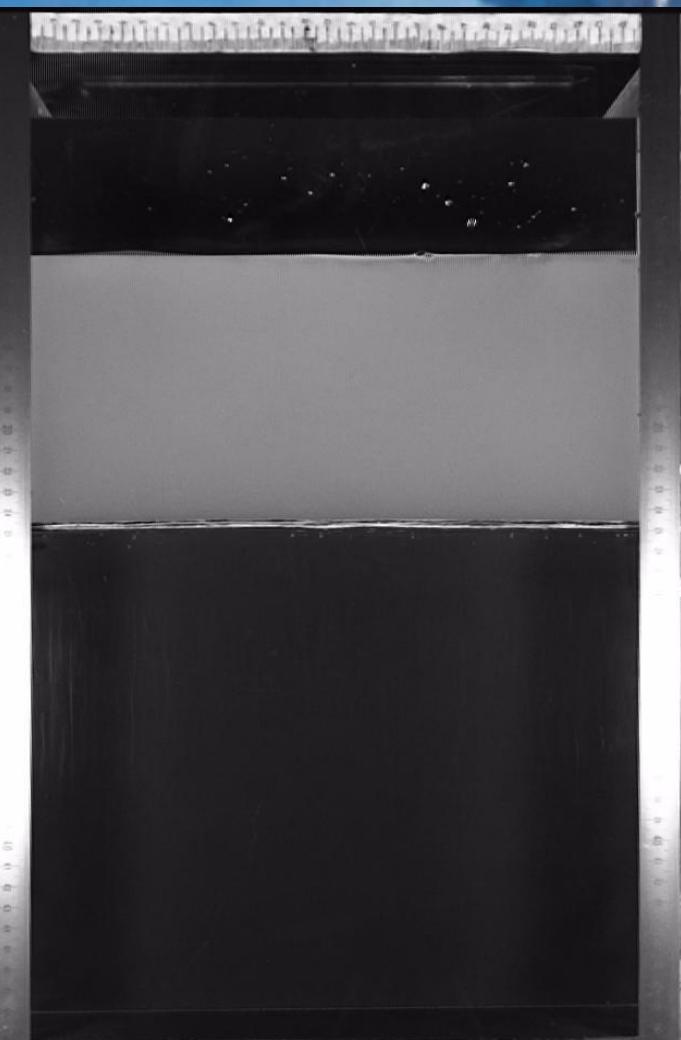
SOURCE: Folch et al. 2011





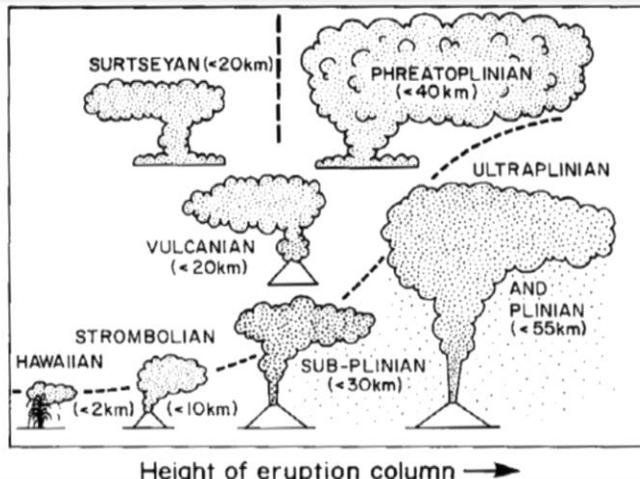
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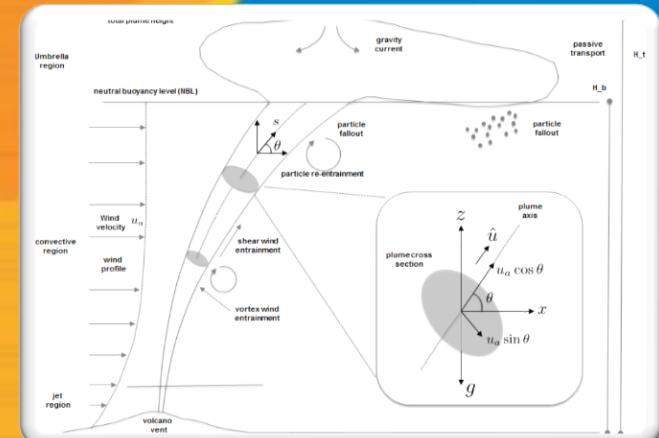
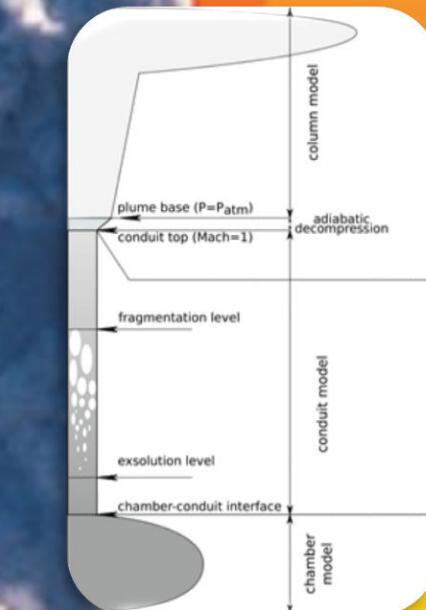




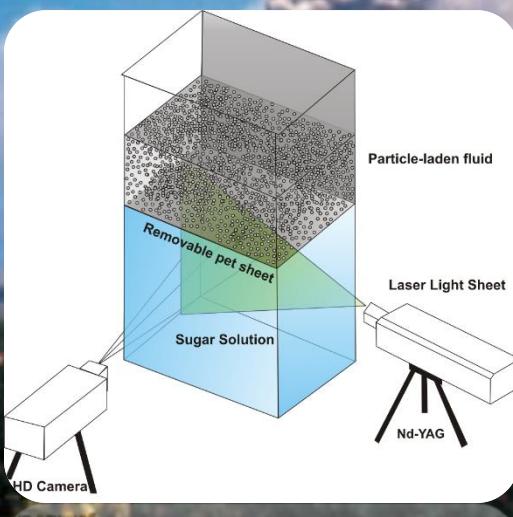
Explosiveness →



PART 1 – ERUPTION CHARACTERIZATION (Costanza BONADONNA)



PART 3 – NUMERICAL MODELLING (Eduardo ROSSI)



PART 2 – CONDUIT DYNAMICS (Paul JARVIS)

PART 4 – EXPERIMENTAL MODELLING (Paul JARVIS)



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PHYSICAL CHARACTERIZATION OF EXPLOSIVE ERUPTIONS

Costanza Bonadonna
Costanza.Bonadonna@unige.ch



MAIN QUESTION:

How well can we constrain explosive eruptions?

**How well can we constrain Eruption Source
Parameters (ESP)?**

→ **Erupted Volume/Mass, Plume Height,
Mass Eruption Rate (MER), Eruption Duration,
Total Grain-Size Distribution (TGSD)**



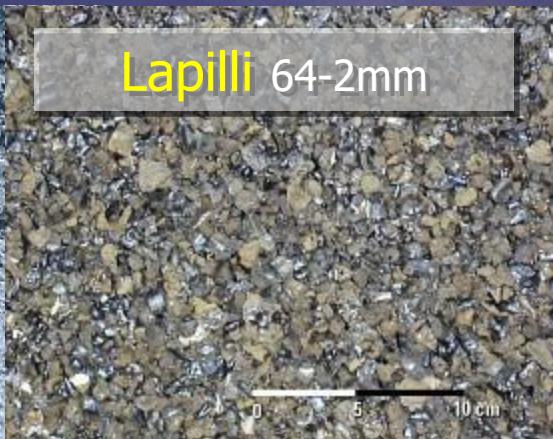
TEPHRA

collective term for airborne volcanic ejecta irrespective of size, composition or shape – *Thorarinsson 1944*

Blocks >64mm



Lapilli 64-2mm



Ash <2mm





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Introduction



TEPHRA

reticulite



Pele's tears



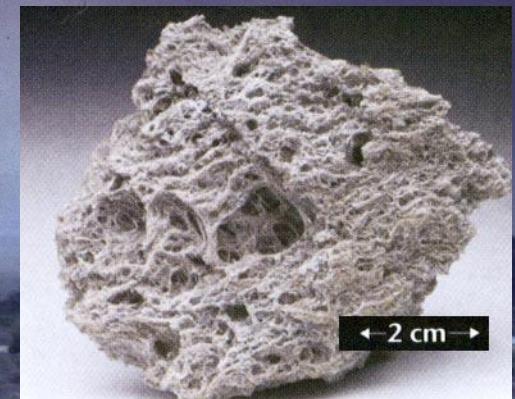
Pele's hair



scoria



pumice





Introduction



TEPHRA

reticulite



Pele's hair

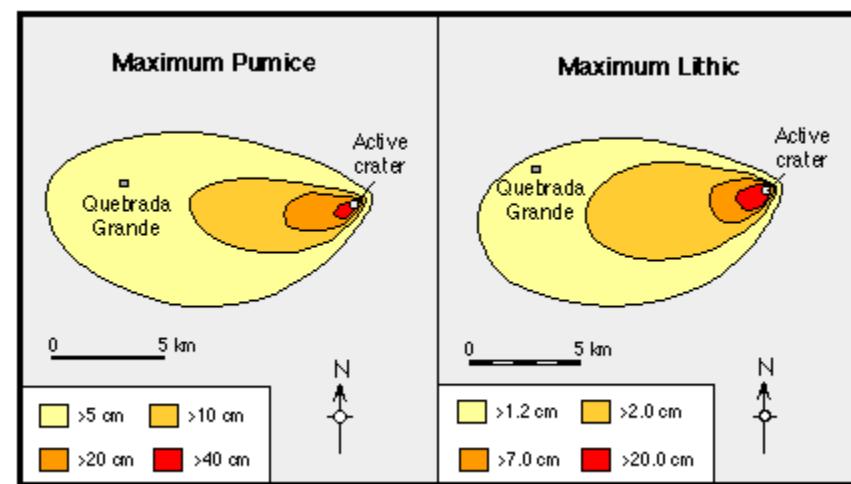
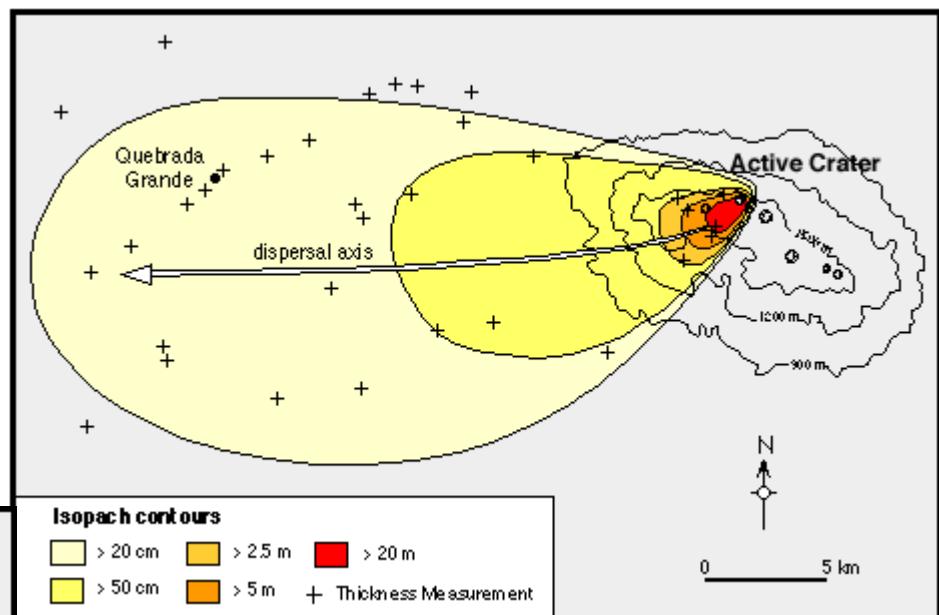
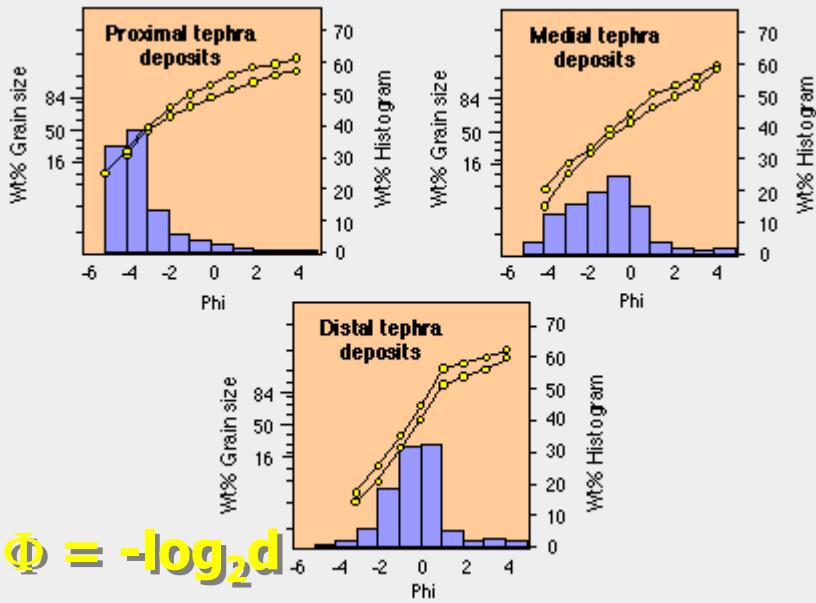
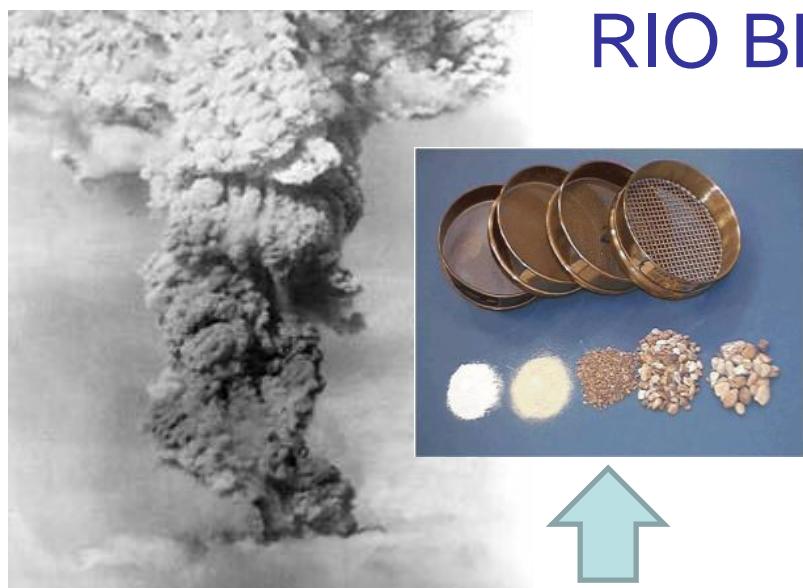


scoria



pumice



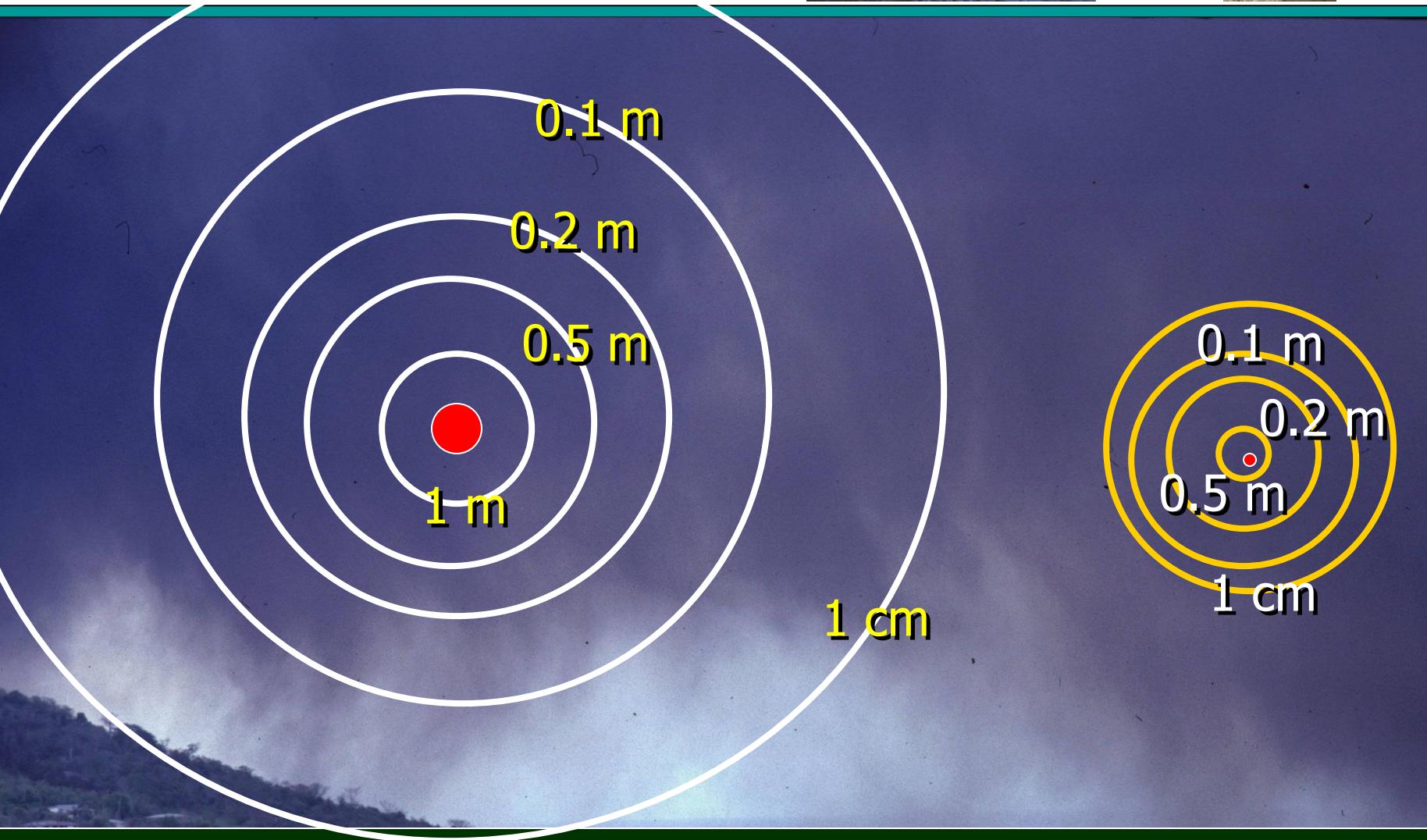
Characterization of
tephra deposits



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Characterization of tephra deposits: Isopach Maps



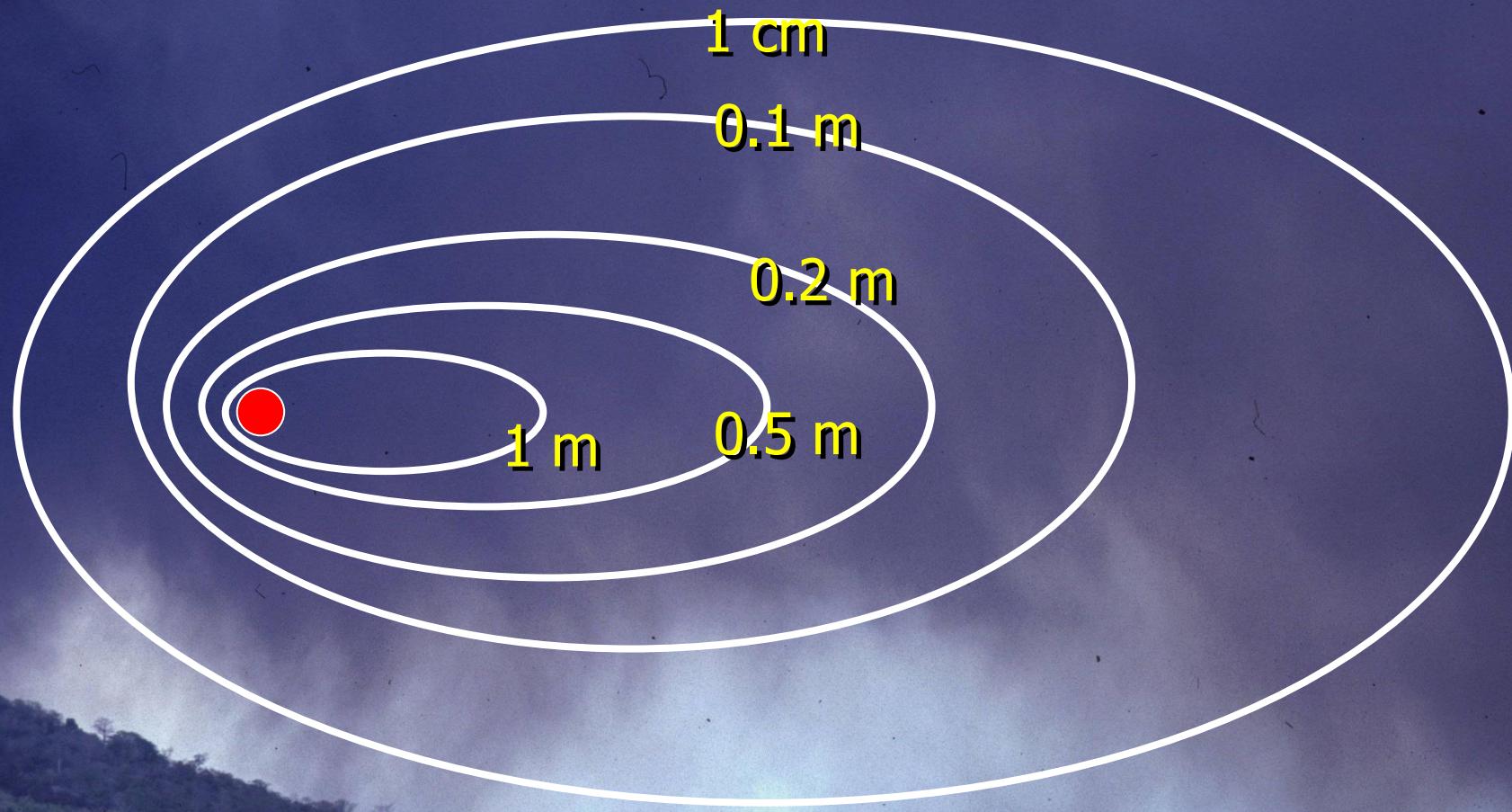
ISOPACH: contrasting intensity



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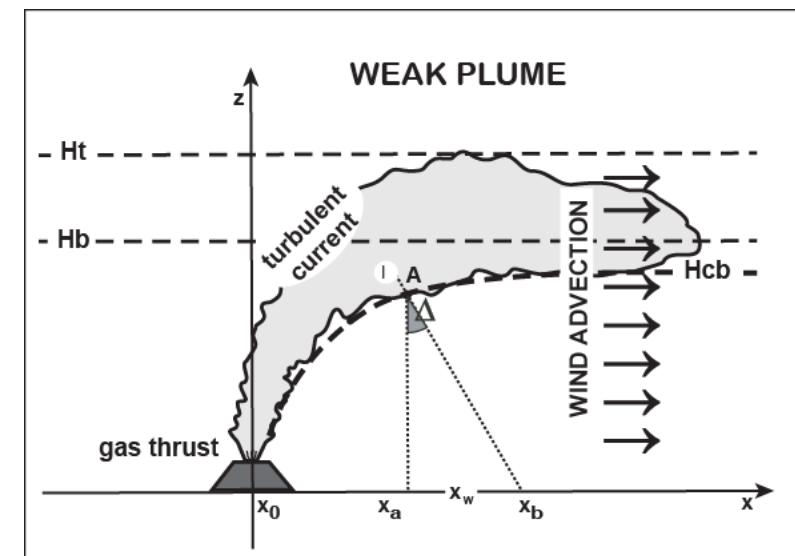
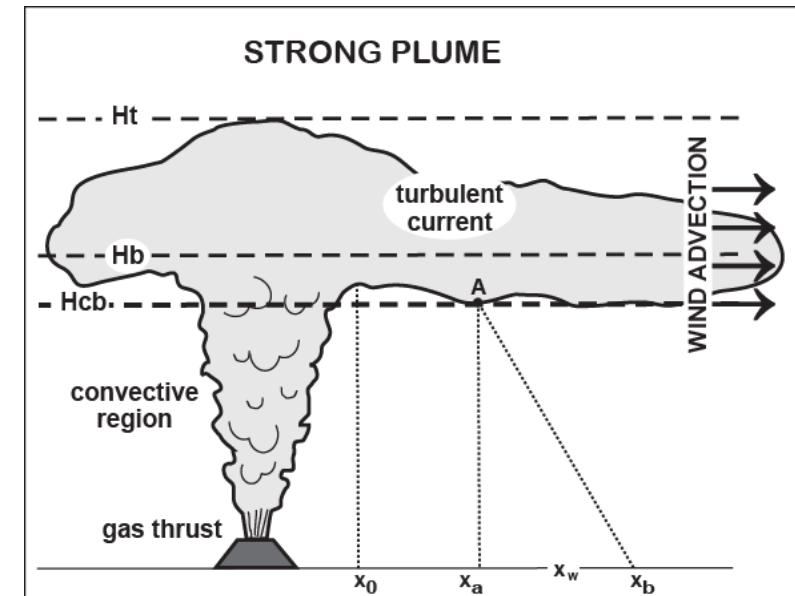
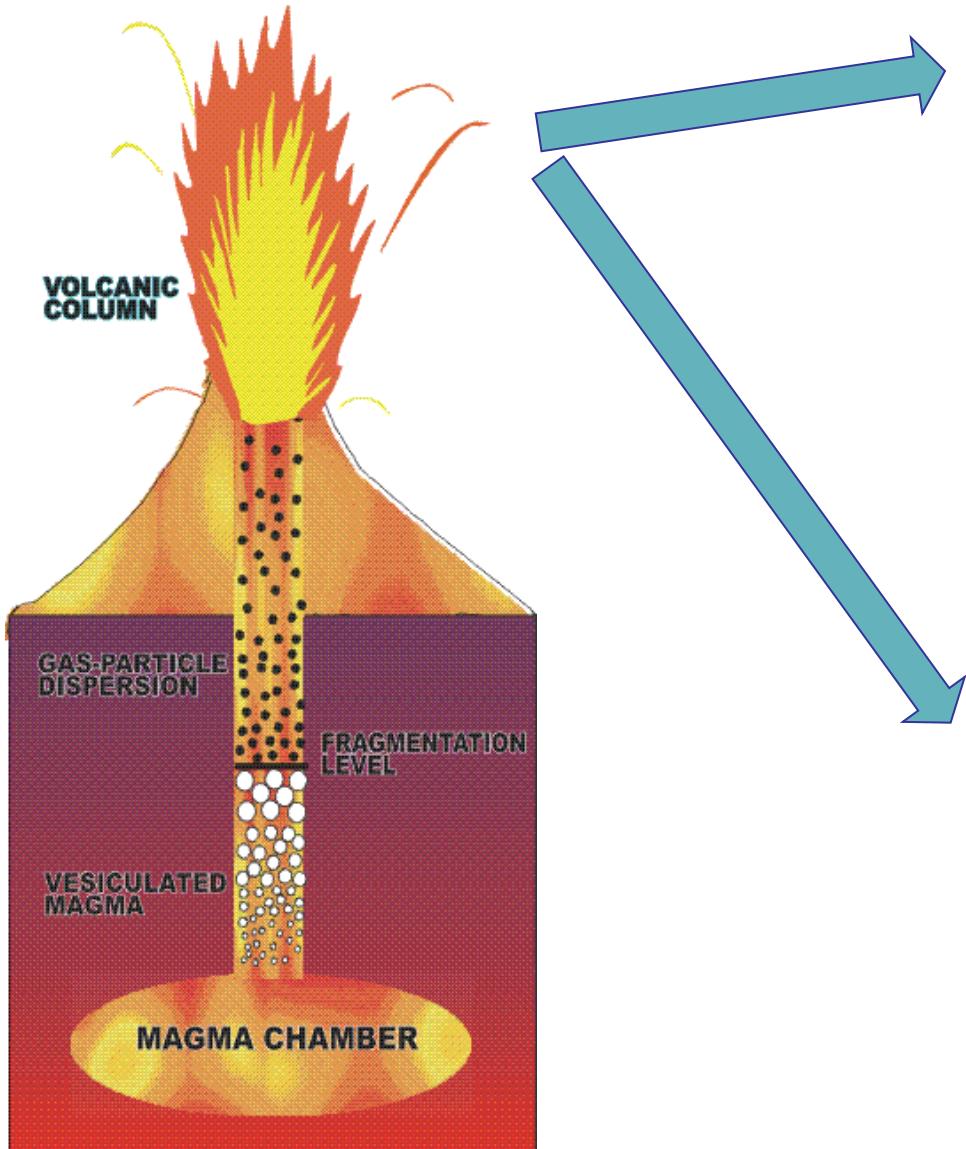
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Characterization of tephra deposits: Isopach Maps



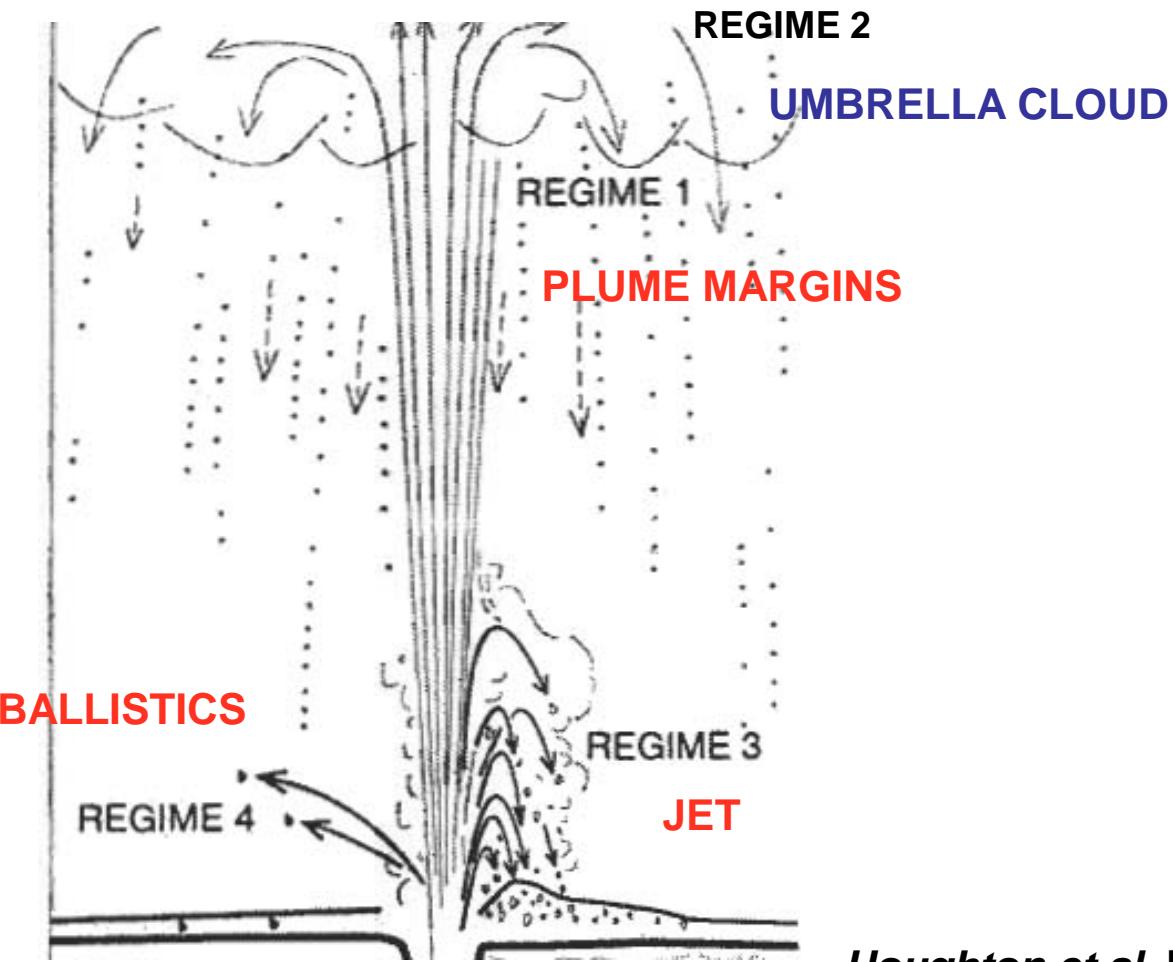
ISOPACH: strong wind

Characterization of tephra deposits: particle sedimentation





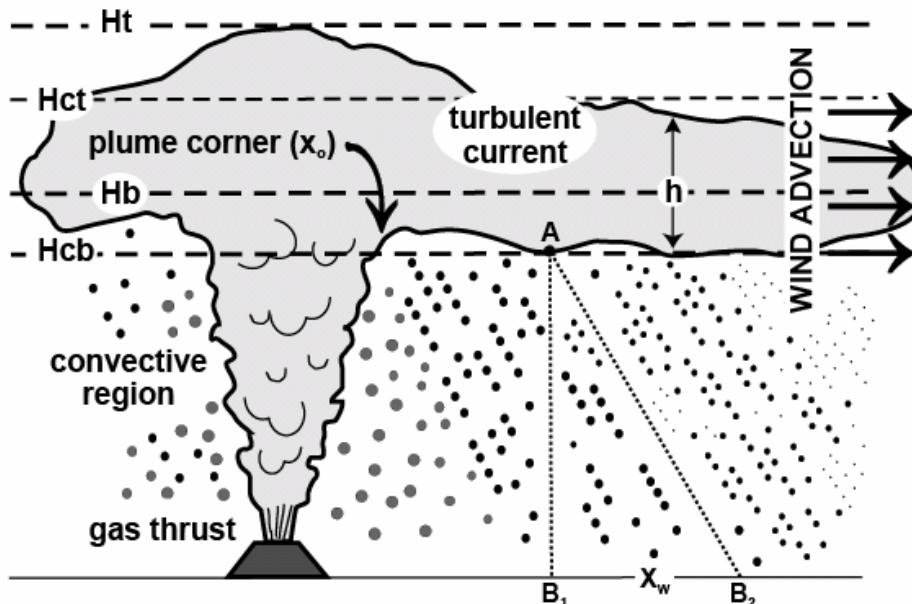
Characterization of tephra deposits: particle sedimentation



Houghton et al. [2004]



STRONG PLUME



Sedimentation from strong plumes

$$X_o = 0.2 H_t$$

CLASS 1 → coarse fragments ejected from the jet (ballistics)
Typically <4km from vent

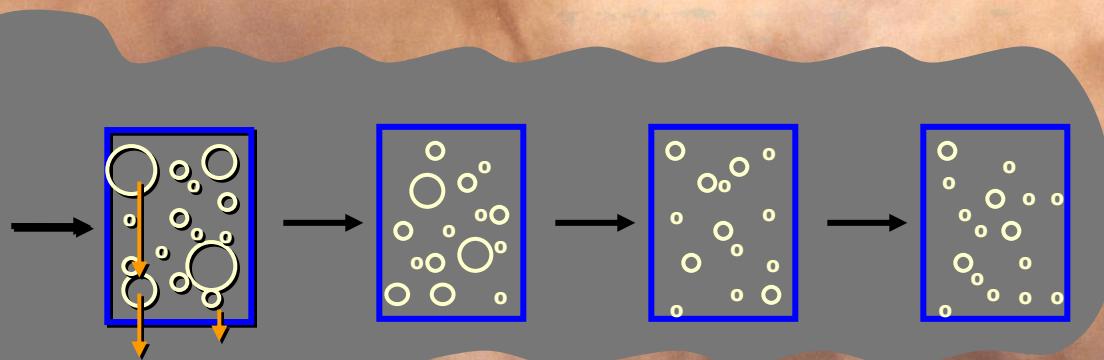
CLASS 2 → convective region. Typically <15km

CLASS 3 → umbrella cloud

CLASS 4 → fine particles dispersed in atmosphere

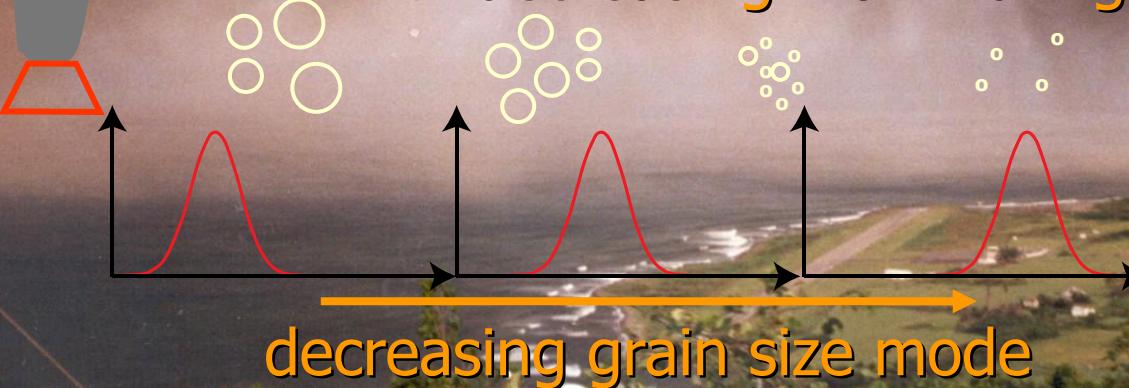


Sedimentation from volcanic plumes



Umbrella fallout

terminal velocity, v_T decreasing maximum grain size



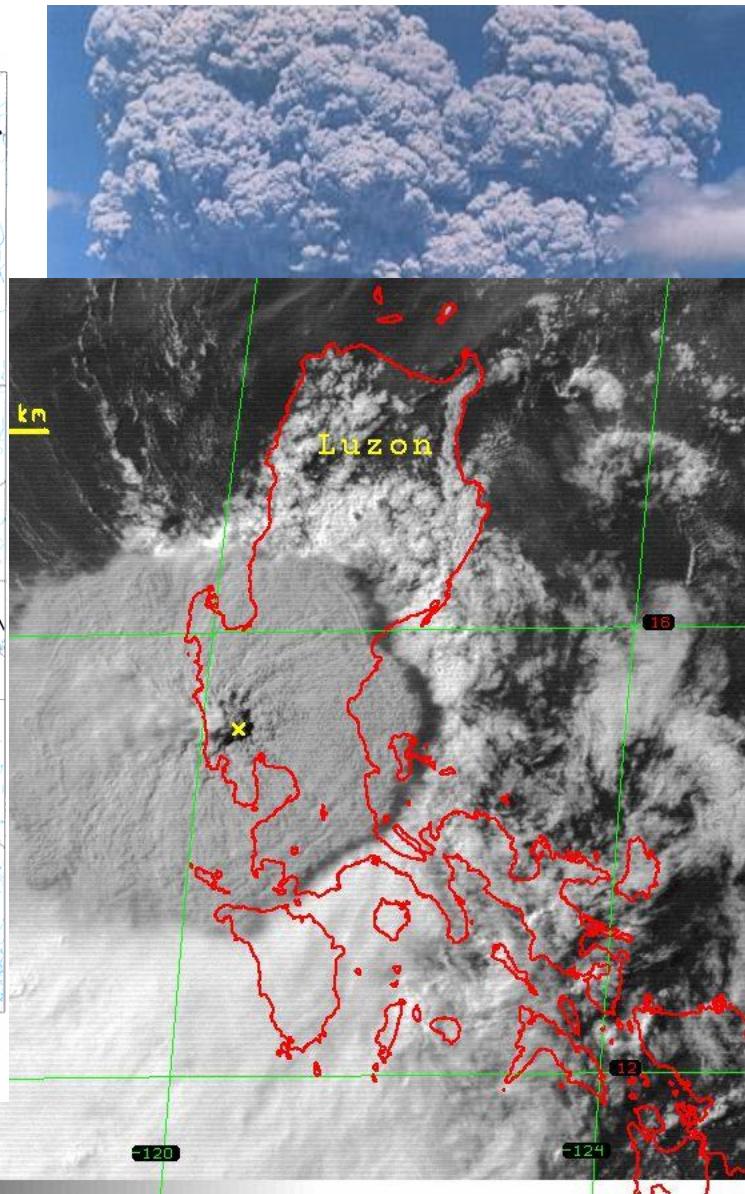
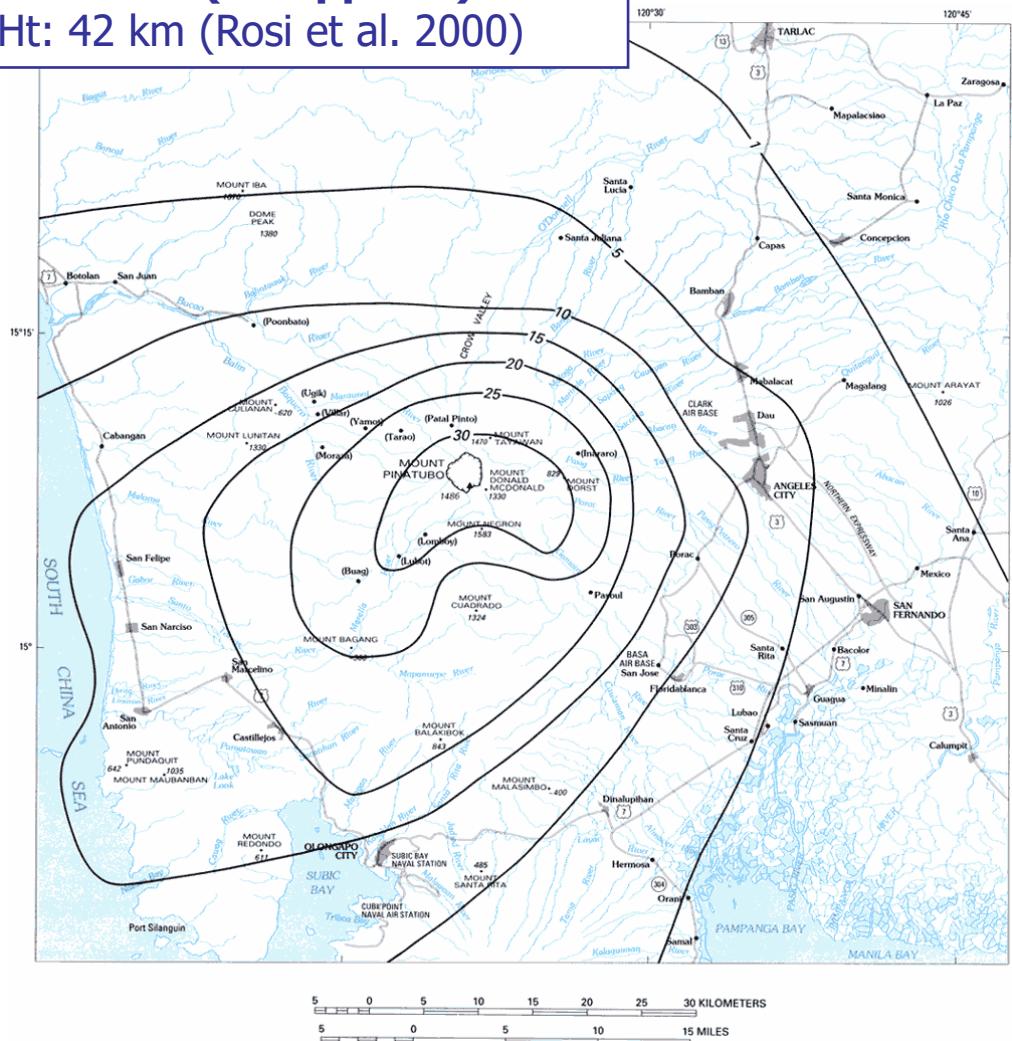


Characterization of tephra deposits: particle sedimentation



Pinatubo (Philippines) 1991

Ht: 42 km (Rosi et al. 2000)



Paladio-Melosantos et al. [1996]

0005 GMS

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Characterization of tephra deposits: particle sedimentation



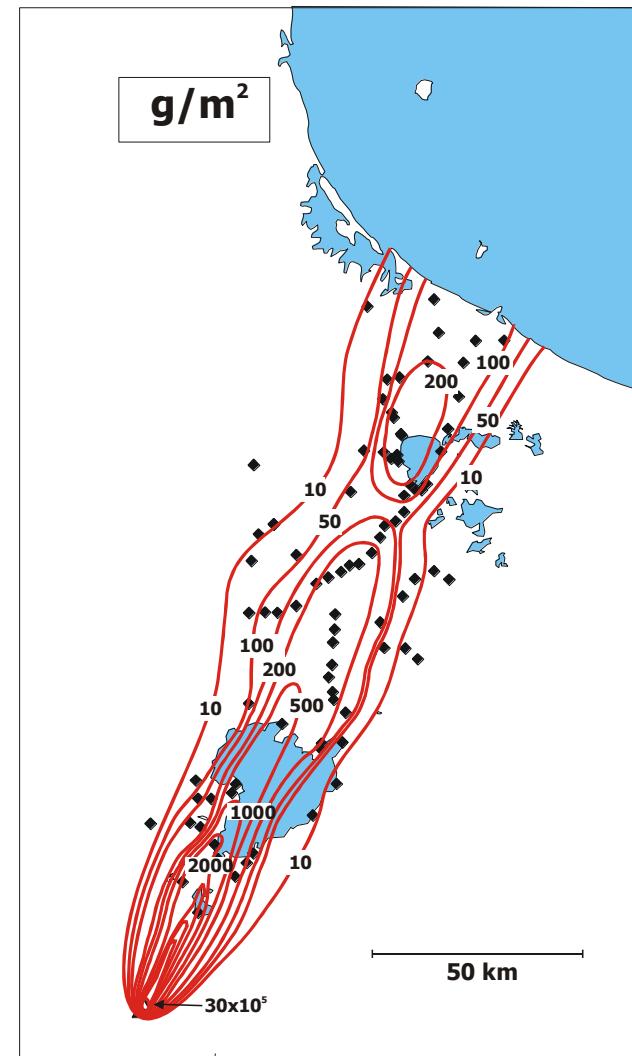
Ruapehu (NZ) 1996

Ht: 8.5 km

Wind speed: 24 m s⁻¹



- no upwind sedimentation
- narrow deposit
- lapilli sedimentation from inclined sector





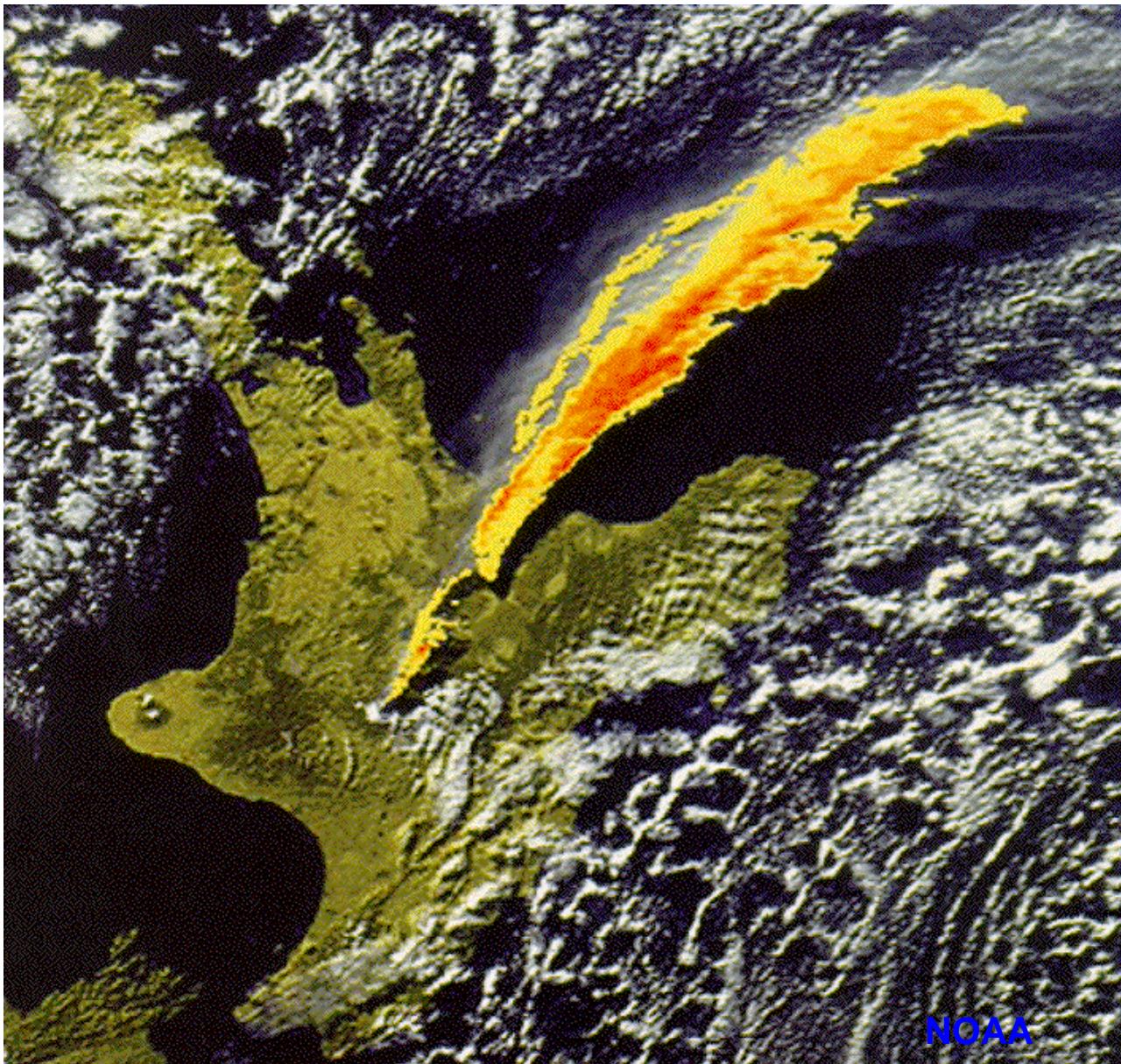
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Characterization of tephra deposits: particle sedimentation



15:30 NZST 17 June 1996





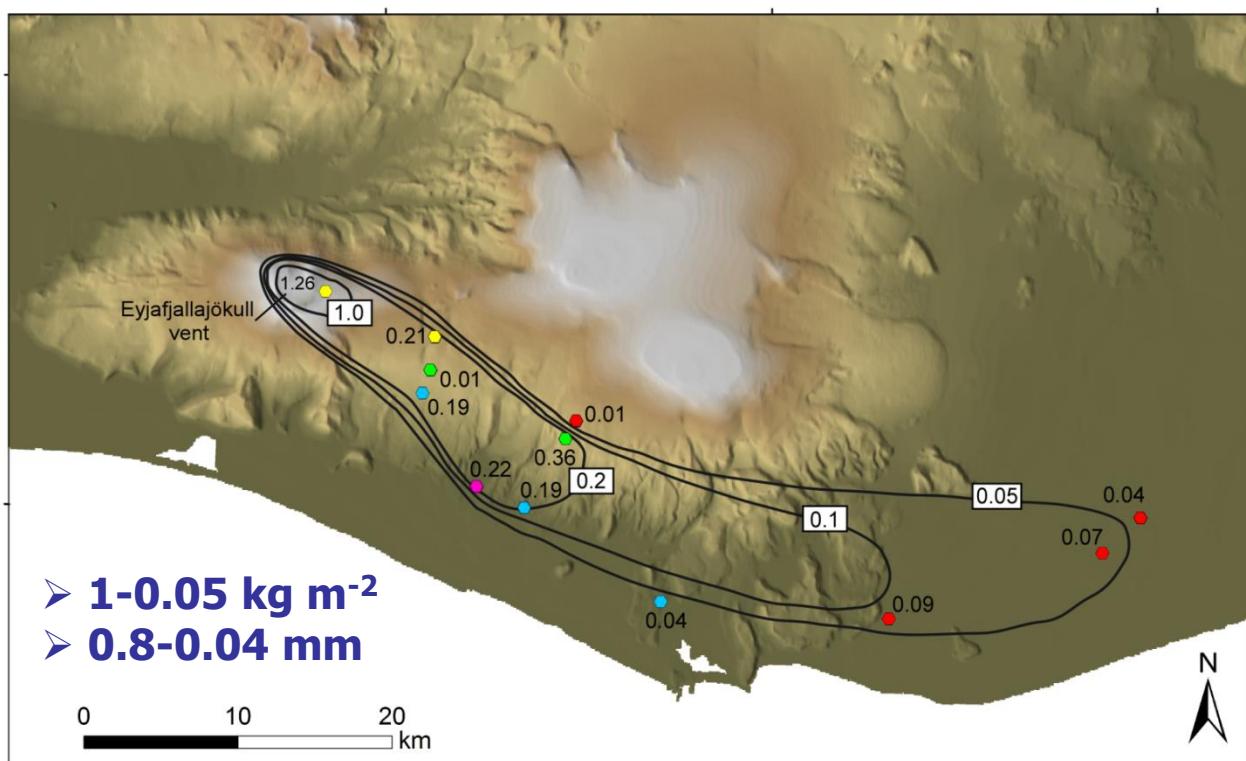
Characterization of tephra deposits: particle sedimentation



Eyjafjallajökull 4-8 Mayo 2010 (Iceland)

Ht: 5-10 km asl

Wind speed: 10-16 m/s



> $1-0.05 \text{ kg m}^{-2}$

> $0.8-0.04 \text{ mm}$

0 10 20 km



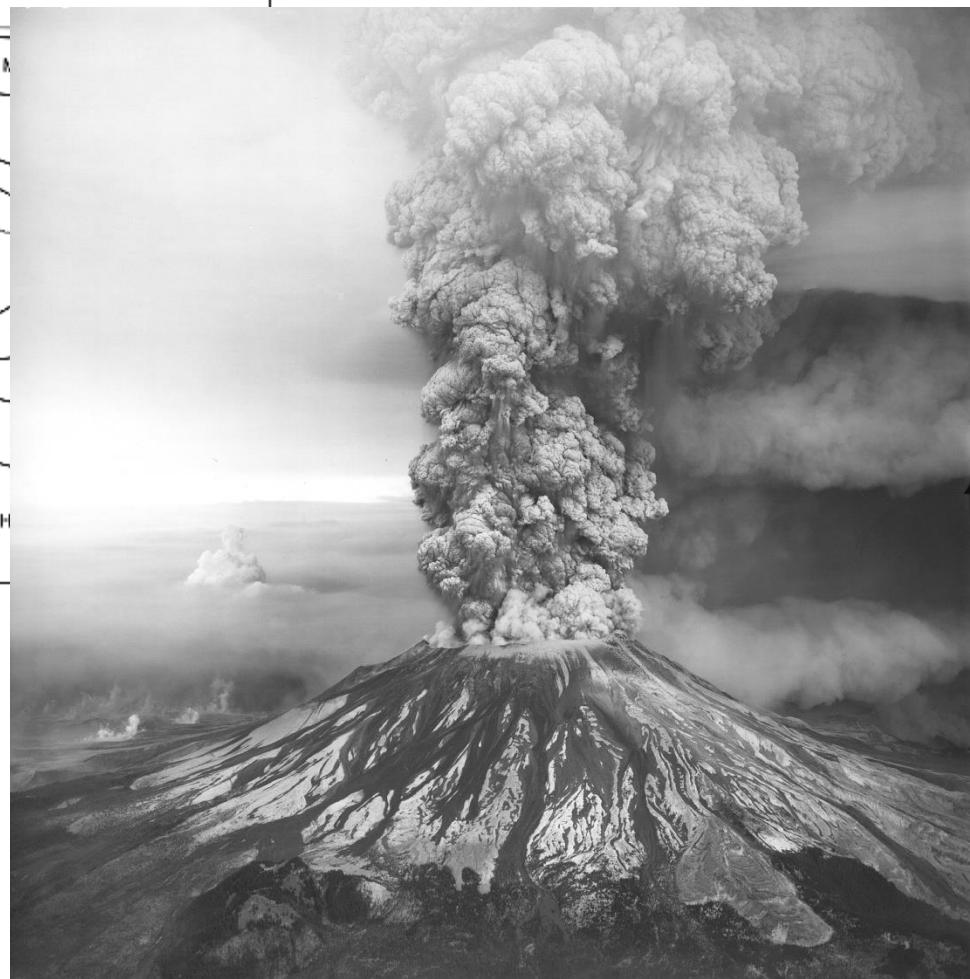
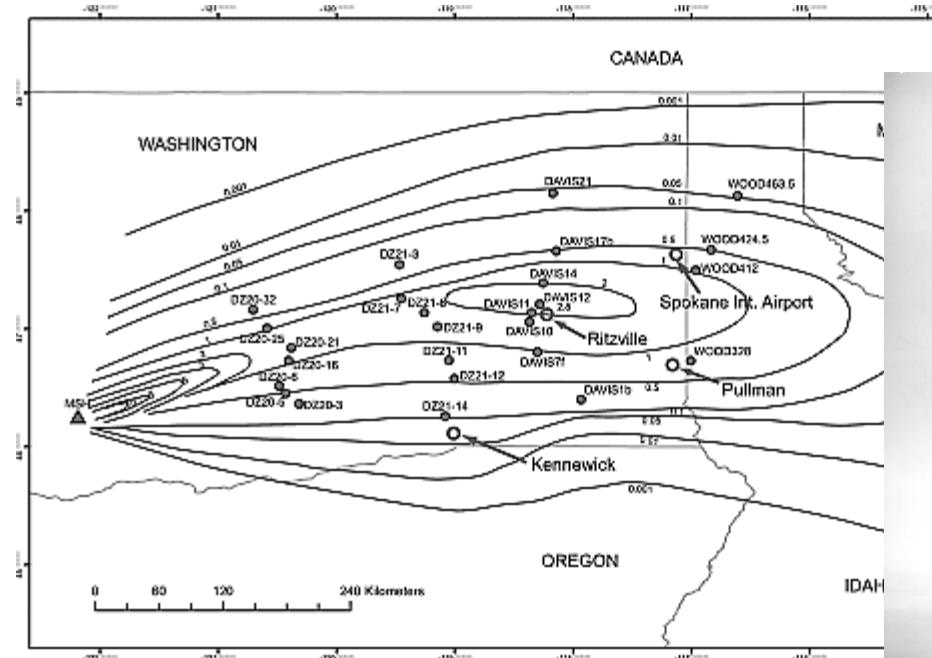
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Characterization of tephra deposits: particle sedimentation

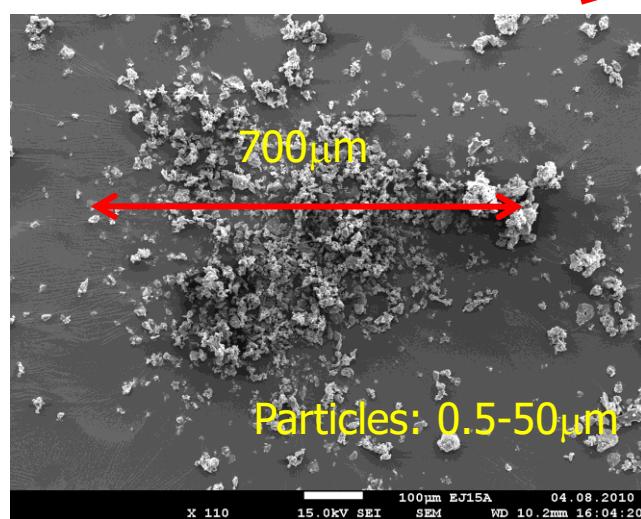
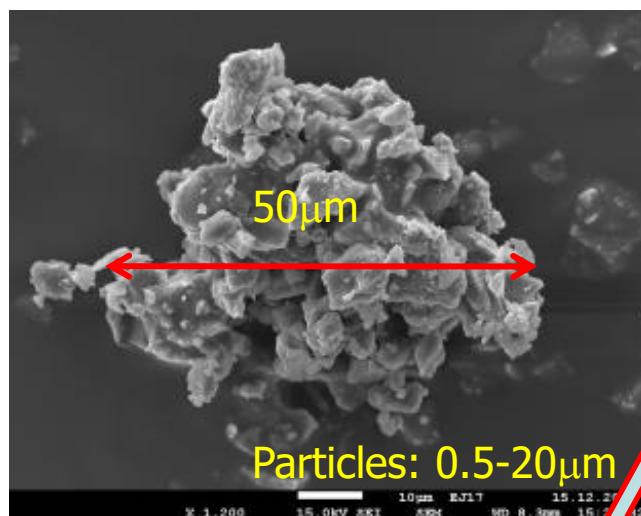


Mt St Helens (18 May 1980)
Ht: 19 km





Characterization of tephra deposits: particle sedimentation



Aggregate type	Typical aggregate size range (diameter)	Particle size range (diameter)
Particle clusters (PC) PCI (ash clusters)	Few 10 s μm up to \sim 10 cm	<1-40 μm : rare particles >200 μm
PC2 (coated particles)	0.05-2 mm	<1-40 μm

PC1 (ash clusters) and PC2 (coated particles) are indicated by red arrows pointing to the corresponding SEM images.

PC1 (ash clusters) is shown in the top SEM image (X 1,200) with a scale bar of 10 μm . The text "50 μm " indicates the size of a cluster, and "Particles: 0.5-20 μm " indicates the size of individual particles.

PC2 (coated particles) is shown in the bottom left SEM image (X 110) with a scale bar of 100 μm . The text "700 μm " indicates the size of a cluster, and "Particles: 0.5-50 μm " indicates the size of individual particles.

PC1 (ash clusters) is also shown in the middle right SEM image (X 600) with a scale bar of 10 μm . The text "130 μm " indicates the size of a cluster, and "Particles: 0.5-10 μm " indicates the size of individual particles.

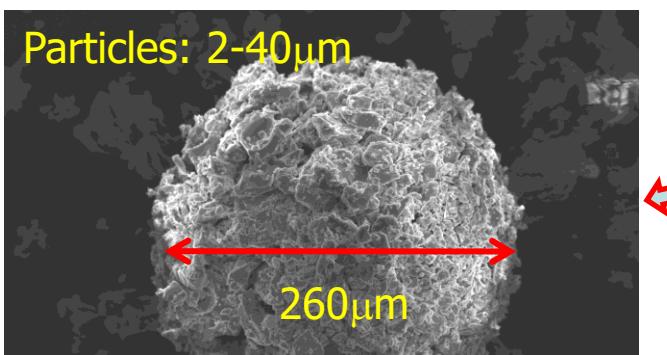
PC2 (coated particles) is also shown in the bottom right SEM image (X 150) with a scale bar of 100 μm . The text "350 μm " indicates the size of a cluster, and "Particles: 0.5-50 μm " indicates the size of individual particles.



Characterization of tephra deposits: particle sedimentation



Particles: 2-40 μm



Aggregate type

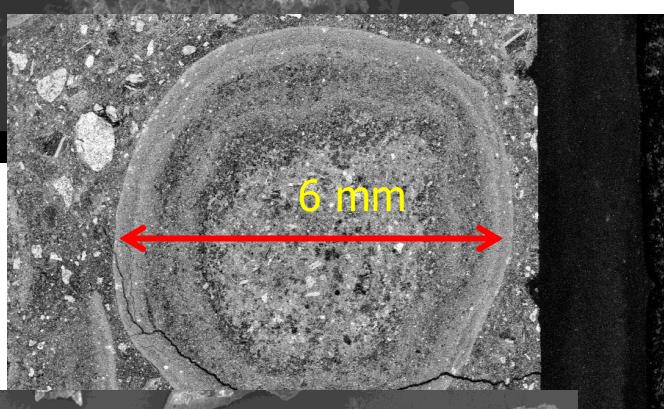
Typical aggregate size range
(diameter)

Particle size range
(diameter)

Accretionary pellets (AP)
AP1 (poorly-structured
pellets)

100 μm up to a few mm

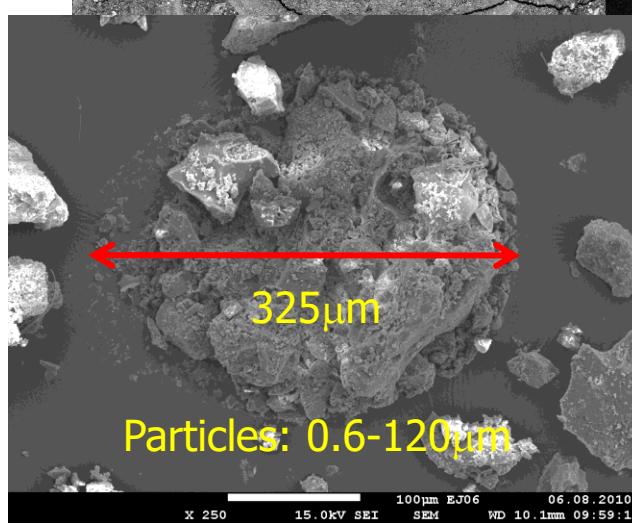
<1-400 μm ; median values
of 30-90 μm ; rare
particles >1 mm



AP2 (pellets with
concentric
structure)

2-15 mm; Rarely >30 mm

Cores: typical median
values of <25-50 μm Rims:
median values of 10-15 μm



AP3 (liquid pellets)

0.1-6 mm

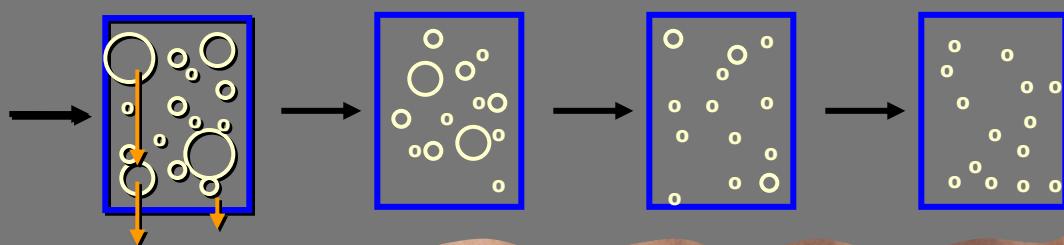
Wide range of particle sizes
(0.001-1 mm)

Particles: 0.6-120 μm

X 250 15.0kV SEI 100μm EJ06 06.08.2010
SEM WD 10.1mm 09:59:10



Sedimentation from volcanic plumes



Umbrella fallout

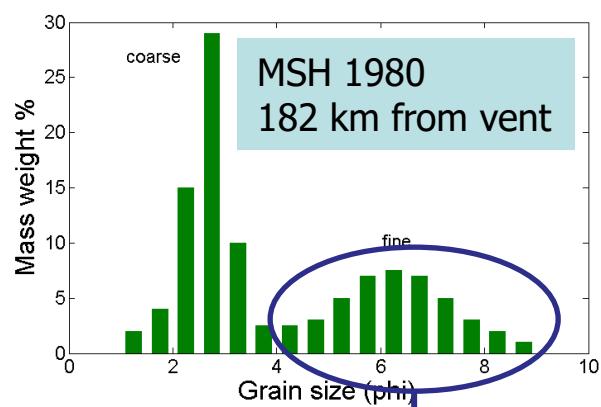
→aggregation





Most particles <125 μm fall within aggregates with greater terminal velocities
→ Premature settling of fine ash from plumes

BIMODAL GRAINSIZE DISTRIBUTIONS



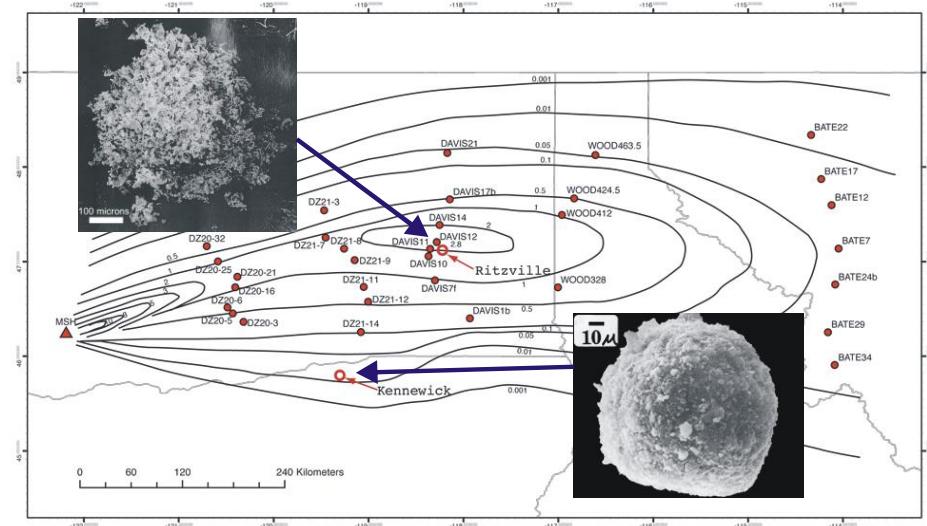
Particles that fell within aggregates

WIDESPREAD PHENOMENON:

Fine mode: <90 µm

e.g., Mt St Helens, Sakurajima, Soufriere St Vincent, Montserrat, Vesuvius, Laacher See Tephra, Tambora, Eyjafjallajökull

DOUBLE SECONDARY MAXIMA OF ACCUMULATION



Isomass map of the MSH 1980 eruption; from Durant et al. 2009

e.g., Mt St Helens 1980, Quizapu 1932,
Hudson 1991



MAIN QUESTION:

How well can we constrain explosive eruptions?

**How well can we constrain Eruption Source
Parameters (ESP)?**

→ **Erupted Volume/Mass, Plume Height,
Mass Eruption Rate (MER), Eruption Duration,
Total Grain-Size Distribution (TGSD)**



GRAIN SIZE PROPERTIES

median, sorting, whole deposit

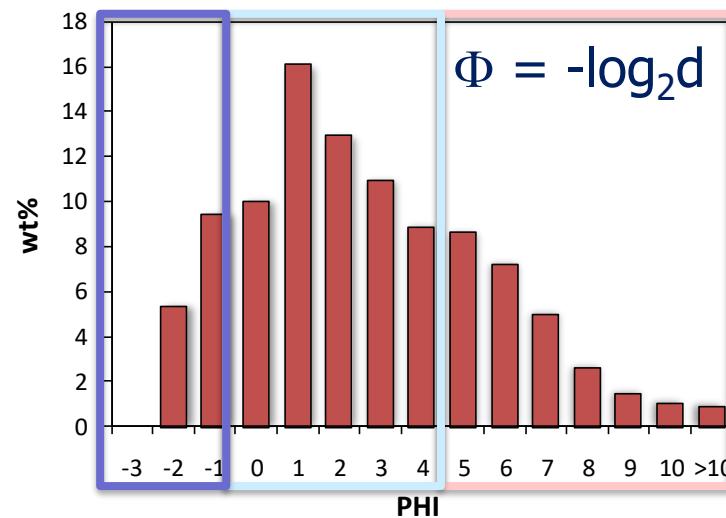




GRAIN SIZE PROPERTIES



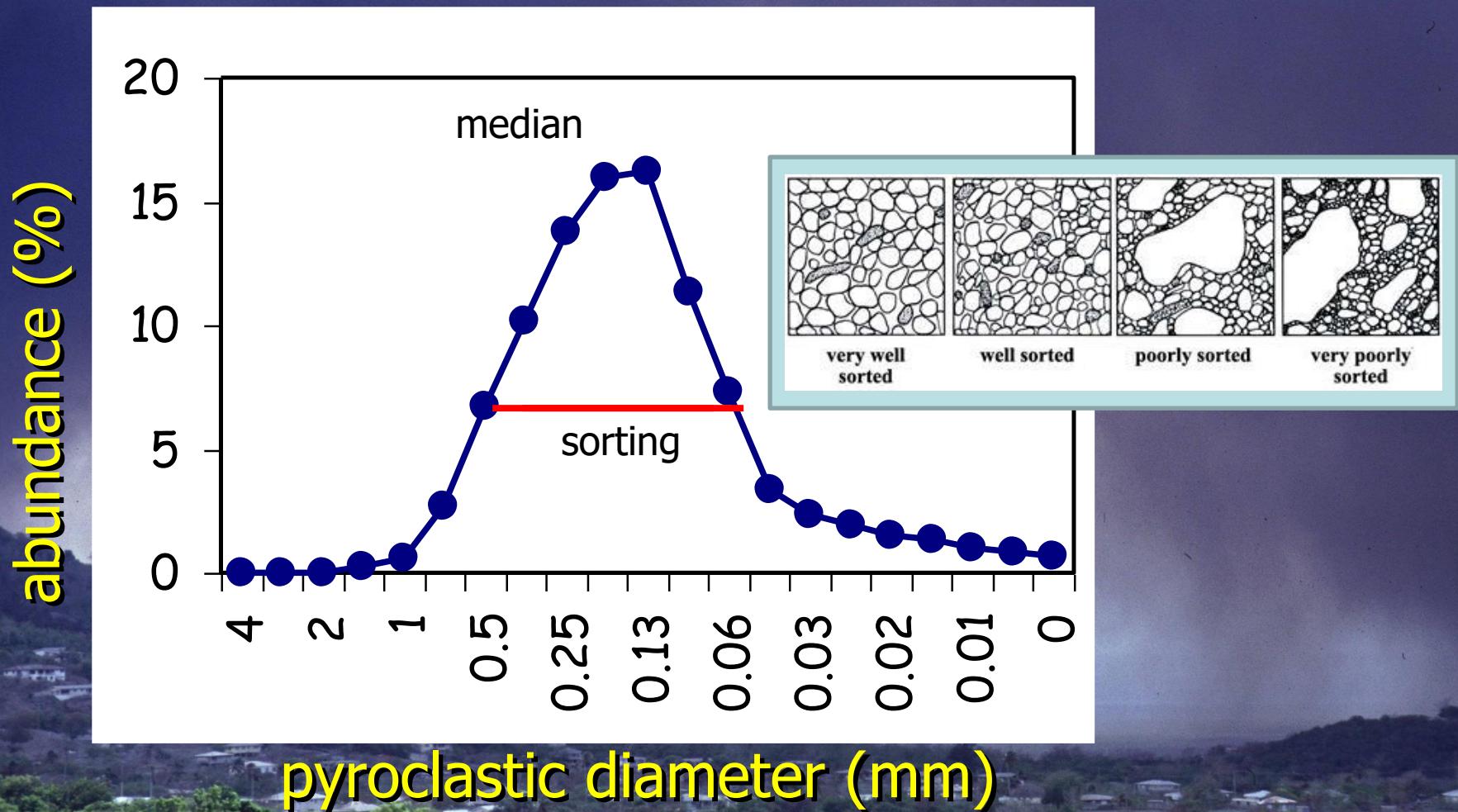
	bombs / blocks	lapilli	coarse ash	fine ash
Diameter	> 64 mm	(64 mm-2 mm)	(2 mm-63µm)	(<63µm)
Residence time	≈ sec	≈ min	≈ hours to few days	several days
Travel distance	proximal <10km	medial <50 km	distal <100 km	very distal <1000 km





GRAIN SIZE PROPERTIES

absolute size = median range of size = sorting





GRAIN SIZE PARAMETERS

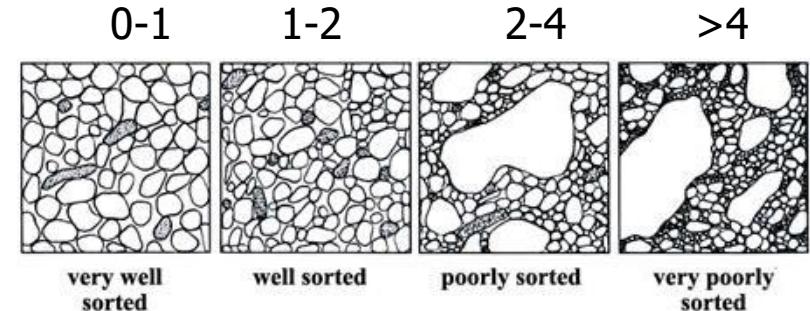
percentiles ϕ 16, 50, 84

Log scale: bin data geometrically ϕ scale = $-\log_2 D$

Inman (1952)

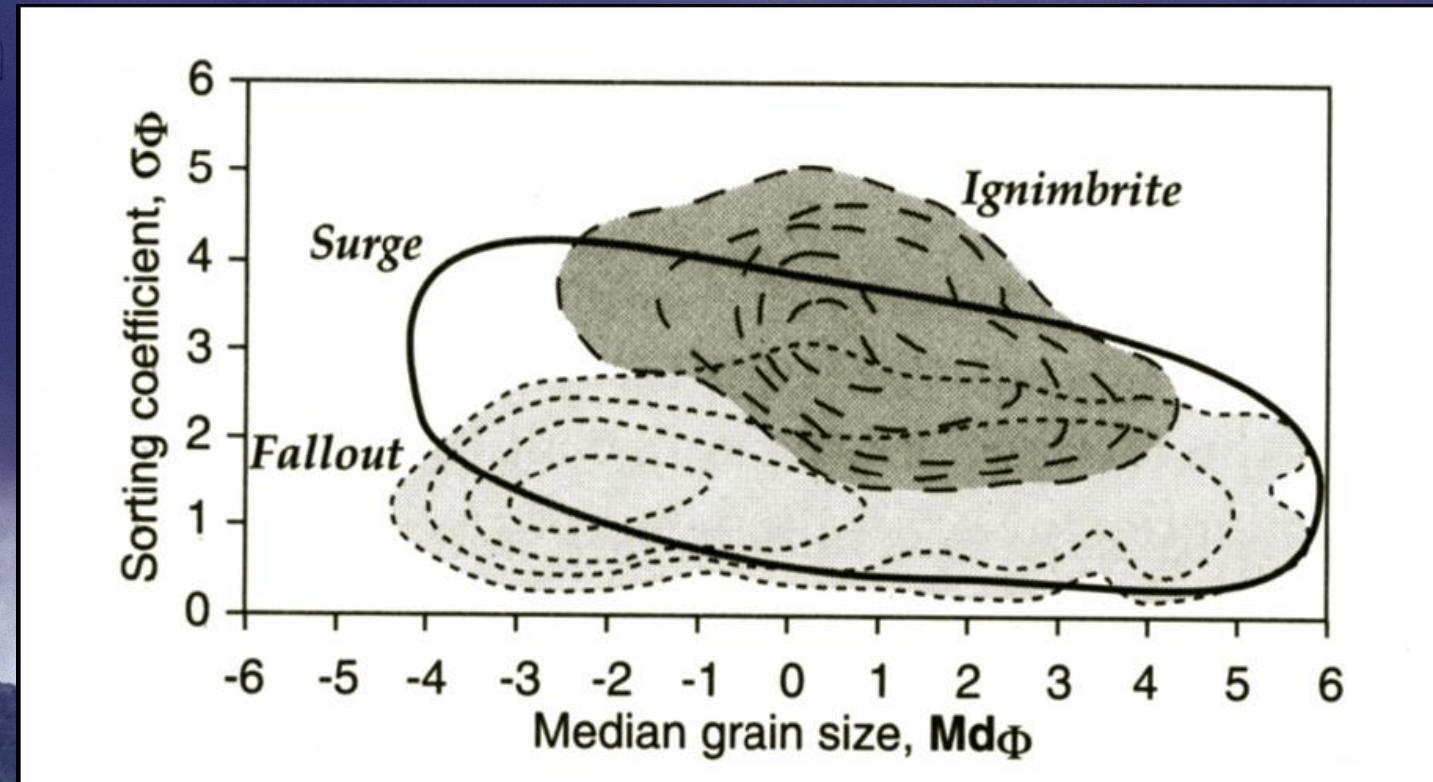
ABSOLUTE SIZE: median (M_d) = $\phi 50$

SORTING: graphic SD (s_G) = $(\phi 84 - \phi 16)/2$





Characterization of ESPs: grainsize distribution





Fall vs. Surge vs. Flow

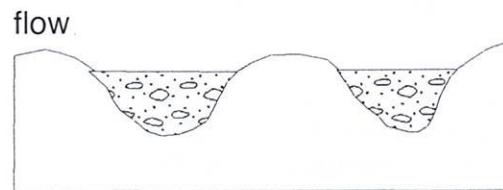
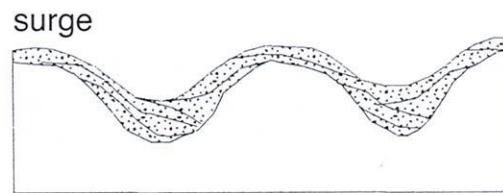
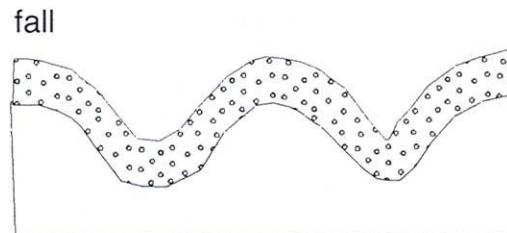


FIGURE 5 Schematic diagram of the archetypal characteristics of the three main pyroclastic deposit types. Fall—mantle bedding, with plane parallel beds and no internal erosion, good sorting (except where water is present; see Section III,E), juvenile clasts with angular to ragged shapes. Surge—nonmantling beds, thickening into low-lying areas, with cross-stratification, pinch-and-swell bedding and scoured contacts, moderate sorting, juvenile clasts with some degree of rounding. Flow—landscape-filling units, generally poorly bedded to nonbedded, poor sorting, rounded juvenile clasts.

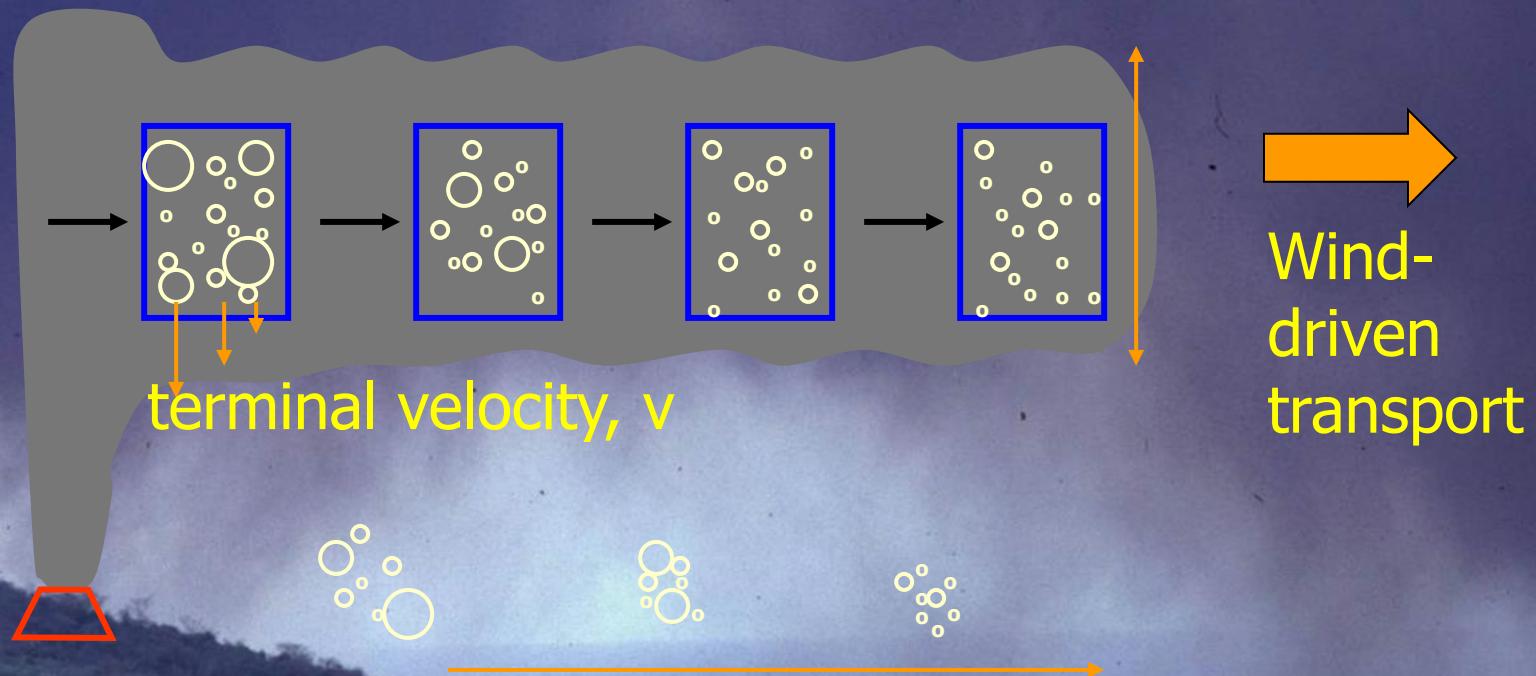
Fall: drape landscape, no cross beds or wave bedforms, well sorted, bedded

Surge: pinch and swell, basal scouring, cross bedding, (i.e., features that express lateral transport), good to poor sorting, sustained high temperatures rare.

Flow: thicken into or are confined in valleys because flow is gravity driven, show basal scouring but lack internal bedforms, poor sorting. Sustained high temperatures (welding) typical. High T indicative of efficient transport (little mixing with ambient air).



FALLOUT





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Characterization of ESPs: grainsize distribution

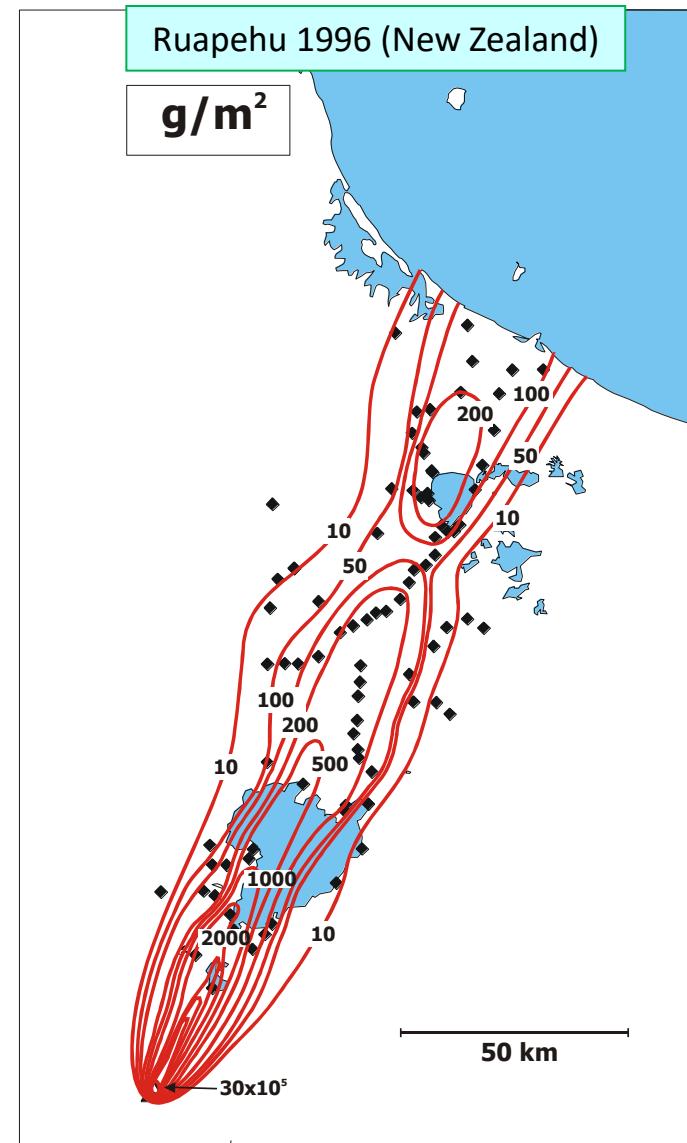
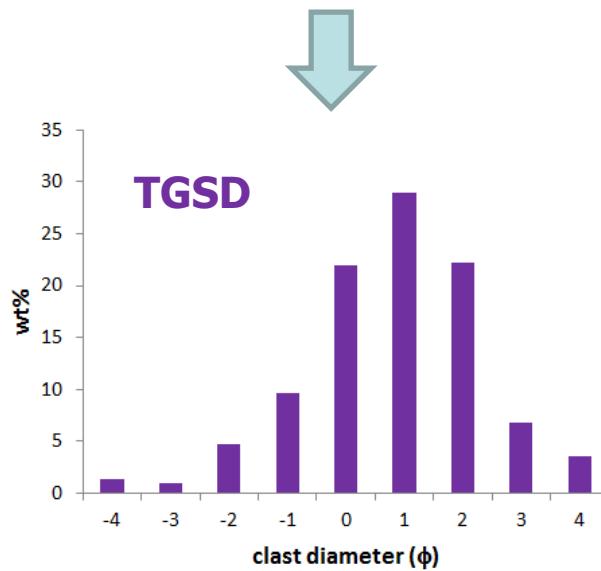
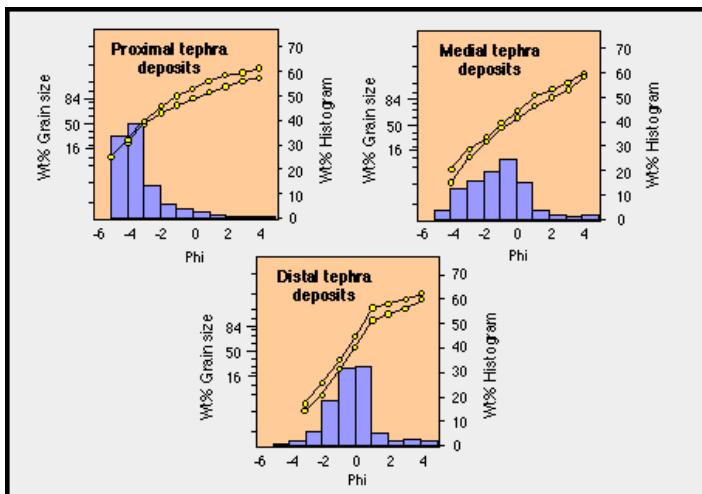




Characterization of ESPs: grainsize distribution



TOTAL GRAINSIZE DISTRIBUTION



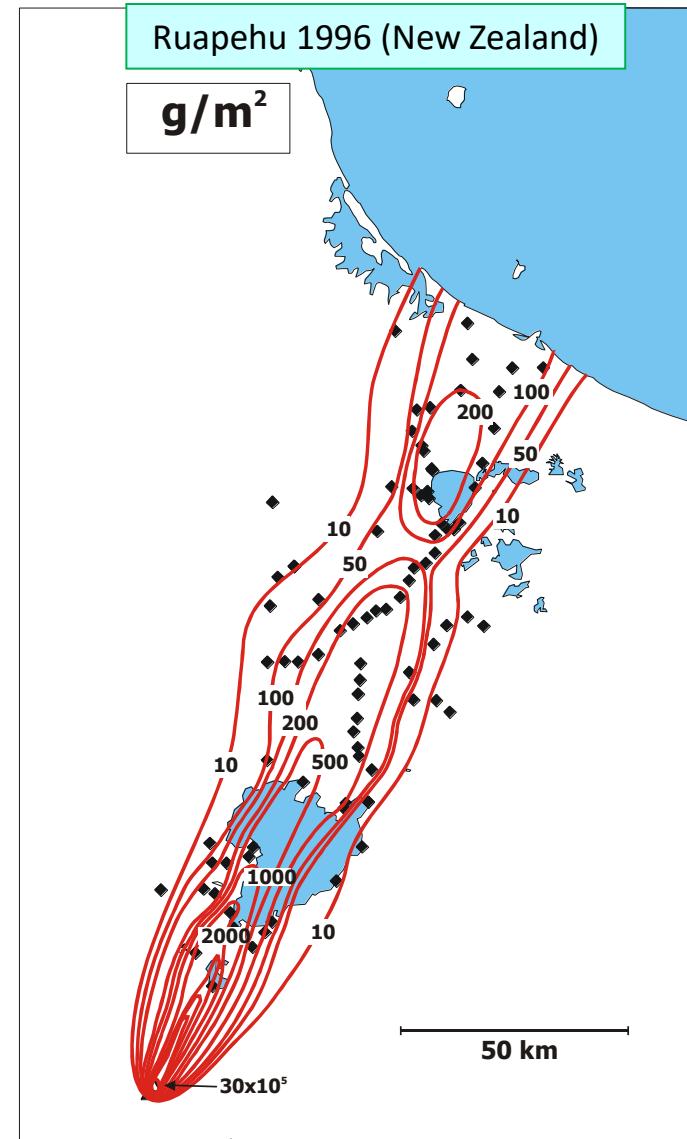


TOTAL GRAINSIZE DISTRIBUTION

The determination of the total grainsize distribution relies on the averaging technique used and on the exposure of the deposit

MOST COMMON TECHNIQUES:

- weighted average
does not deal well with deposits with non-uniform distributions of data
- various types of sectorisation
biased due to the arbitrary choice of sectors





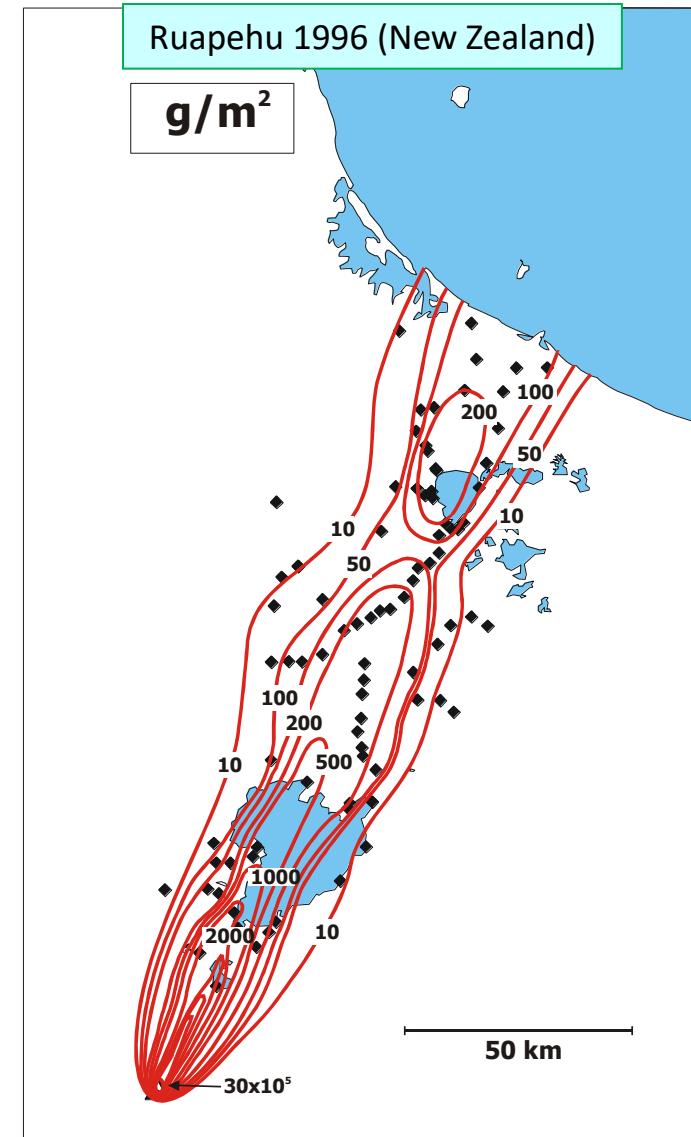
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Characterization of ESPs: grainsize distribution



TOTAL GRAINSIZE DISTRIBUTION





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EXERCISE 1

DETERMINATION OF TOTAL GRAIN-SIZE DISTRIBUTION



MAIN QUESTION:

How well can we constrain explosive eruptions?

**How well can we constrain Eruption Source
Parameters (ESP)?**

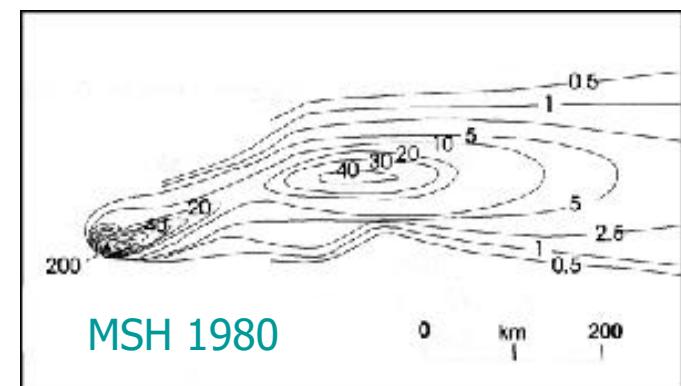
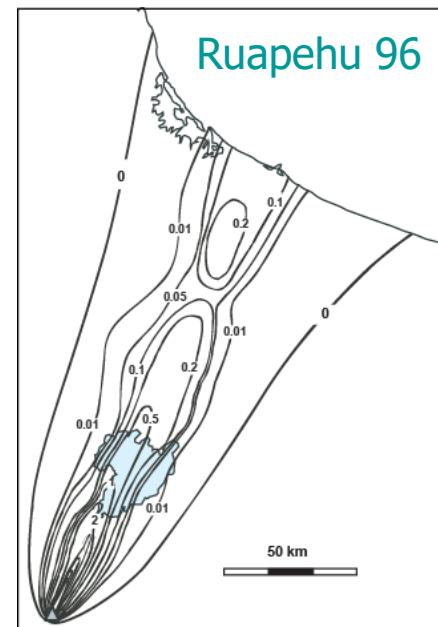
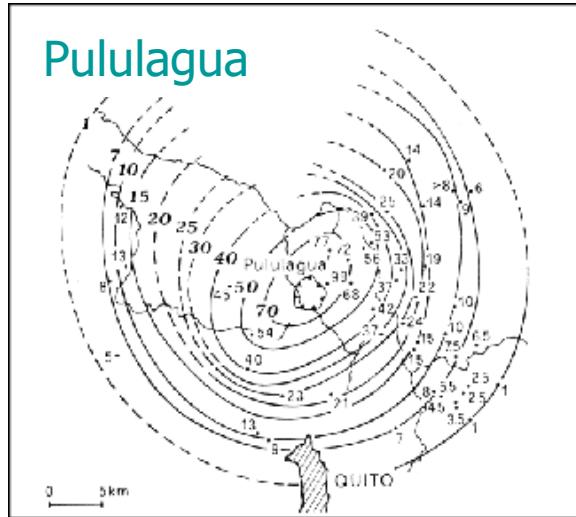
→ **Erupted Volume/Mass, Plume Height,
Mass Eruption Rate (MER), Eruption Duration,
Total Grain-Size Distribution (TGSD)**



ERUPTED MASS/VOLUME

PROBLEMS:

- ✿ Non-linearity of the functions linking thickness and area
- ✿ General scarcity of data
- ✿ Lack of distal and very proximal data



Isopach/isomass maps



ERUPTED MASS/VOLUME

PROBLEMS:

- ✿ Non-linearity of the functions linking thickness and area
- ✿ General scarcity of data
- ✿ Lack of distal and very proximal data

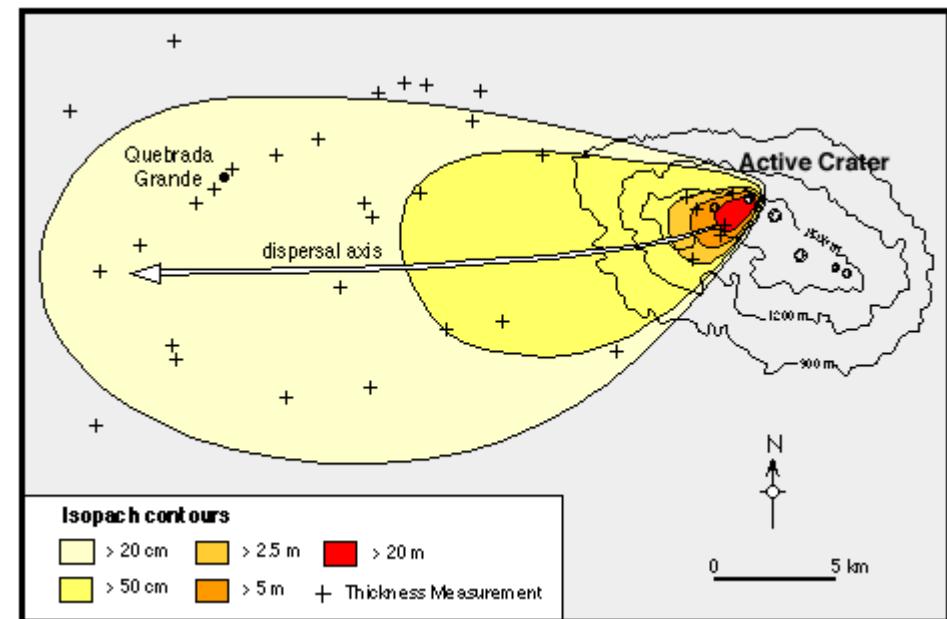
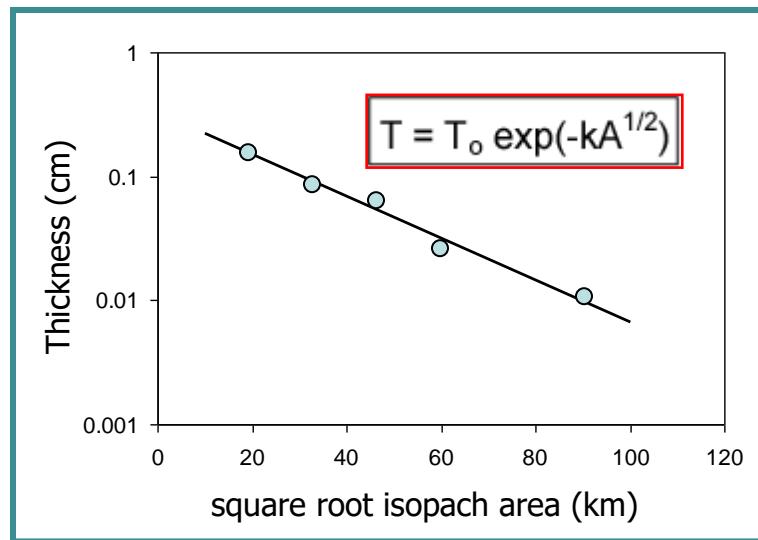
MOST COMMONLY USED MODEL:

→ EXPONENTIAL CURVE FITTING



ERUPTED MASS/VOLUME

EXPONENTIAL FITTING



$$V = T_0 13.08 b t^2$$

$$b t = \ln 2 / (k \sqrt{\pi})$$

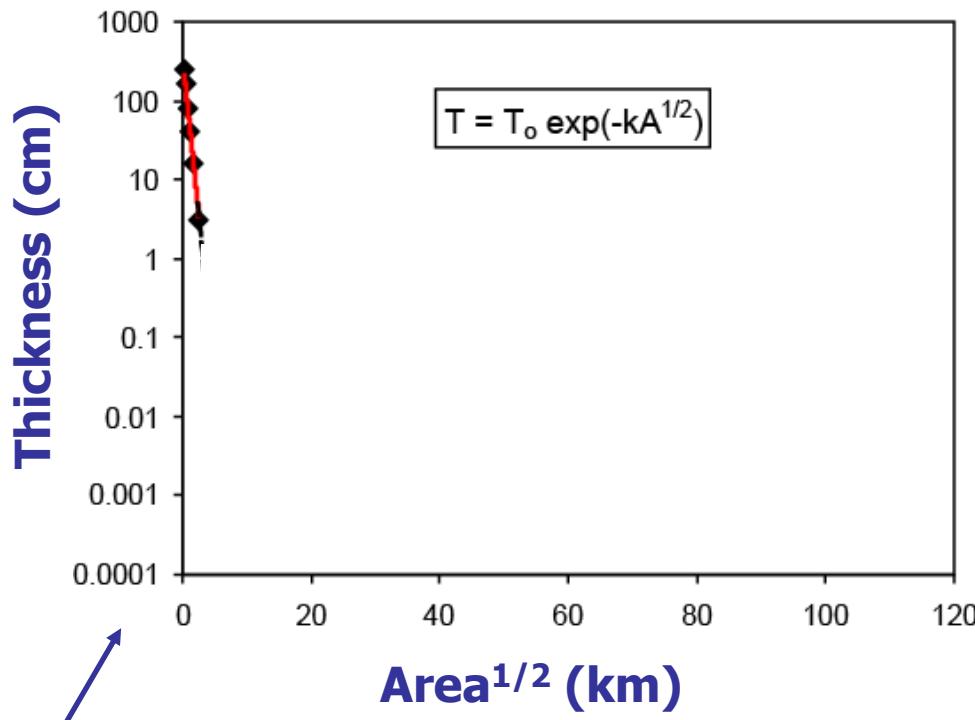
Pyle, 1989



ERUPTED MASS/VOLUME

EXPONENTIAL CURVE FITTING

(1 exp. segment; Pyle 1989)



e.g. Ruapehu 1996 eruption

Empirical and theoretical support:

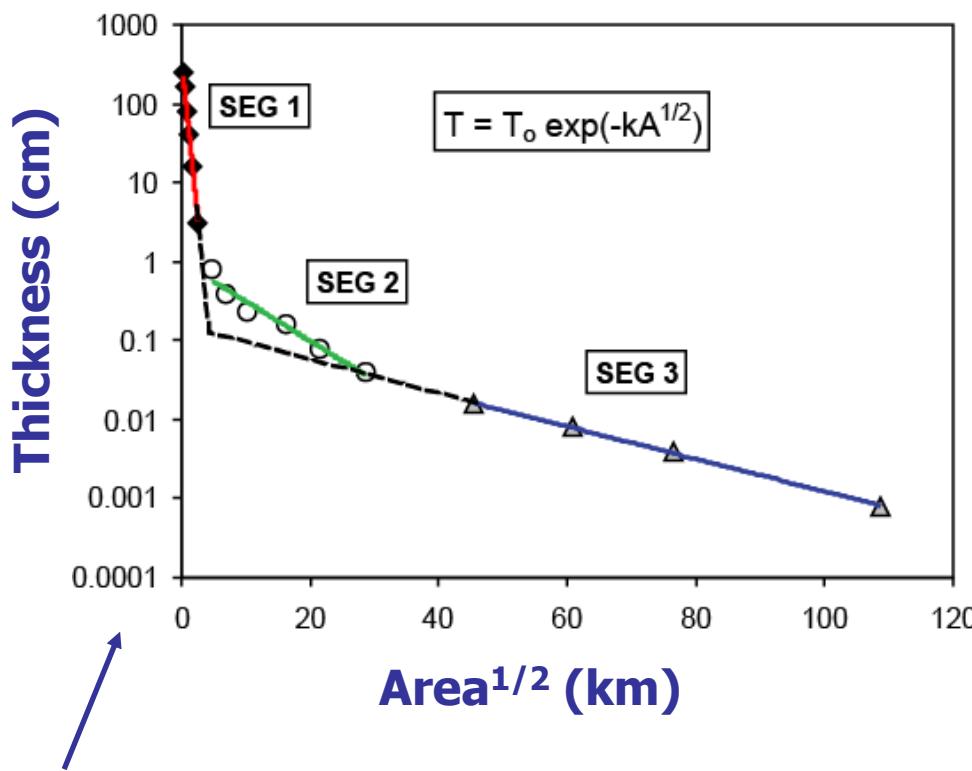
- ★ Thorarinsson (1954)
- ★ Bursik et al. (1992), Sparks et al. (1992)



ERUPTED MASS/VOLUME

EXPONENTIAL CURVE FITTING

(multiple exp. segments: Fierstein and Nathenson 1992; Pyle 1995;
Bonadonna and Houghton 2005)



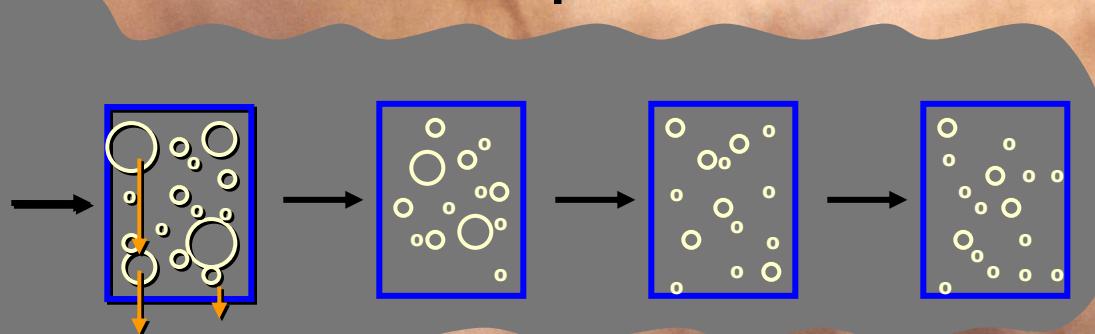
e.g. Ruapehu 1996 eruption

Empirical and theoretical support:

- ✿ Thinning of well exposed deposits
 - e.g. Hildreth and Drake 1992 (Novarupta 1912); Fierstein and Hildreth 1992 (Quizapu 1932); Scasso et al. 1994 (Hudson 1991); Bonadonna and Houghton 2005 (Ruapehu 1996)
- ✿ Rose 1993; Bonadonna et al. 1998



Sedimentation from volcanic plumes



Reynolds number (Re):

$$Re = (d * v_t * \rho) / \eta$$

d = particle diameter (μm)

v_t = terminal velocity (cm/s)

ρ = density of the atmosphere (g/cm 3)

η = viscosity of the atmosphere (g/cm·s)

Umbrella fallout

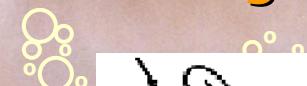
decreasing maximum grain size



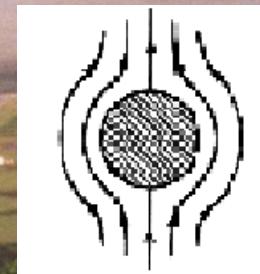
TURBULENT



Turbulent Flow Example. Flow is in upward direction.



INTERMEDIATE



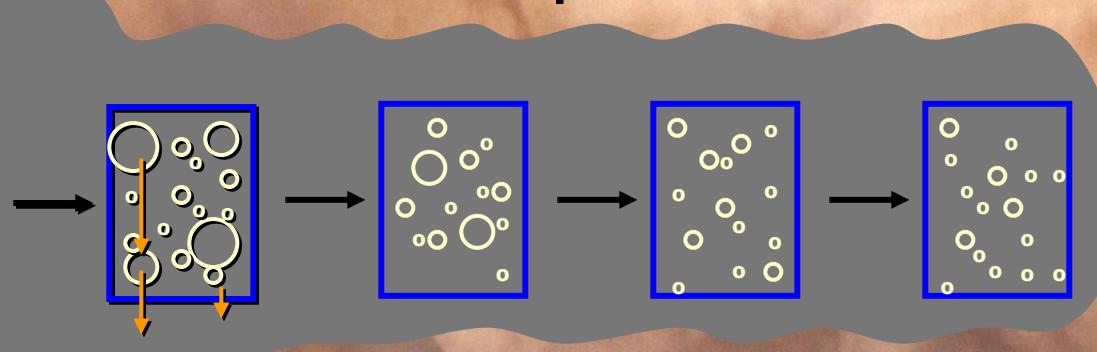
Laminar Flow Example. Flow is in upward direction.

LAMINAR





Sedimentation from volcanic plumes



Reynolds number (Re):

$$Re = (d * v_t * \rho) / \eta$$

d = particle diameter (μm)

v_t = terminal velocity (cm/s)

ρ = density of the atmosphere (g/cm 3)

η = viscosity of the atmosphere (g/cm·s)

Umbrella fallout

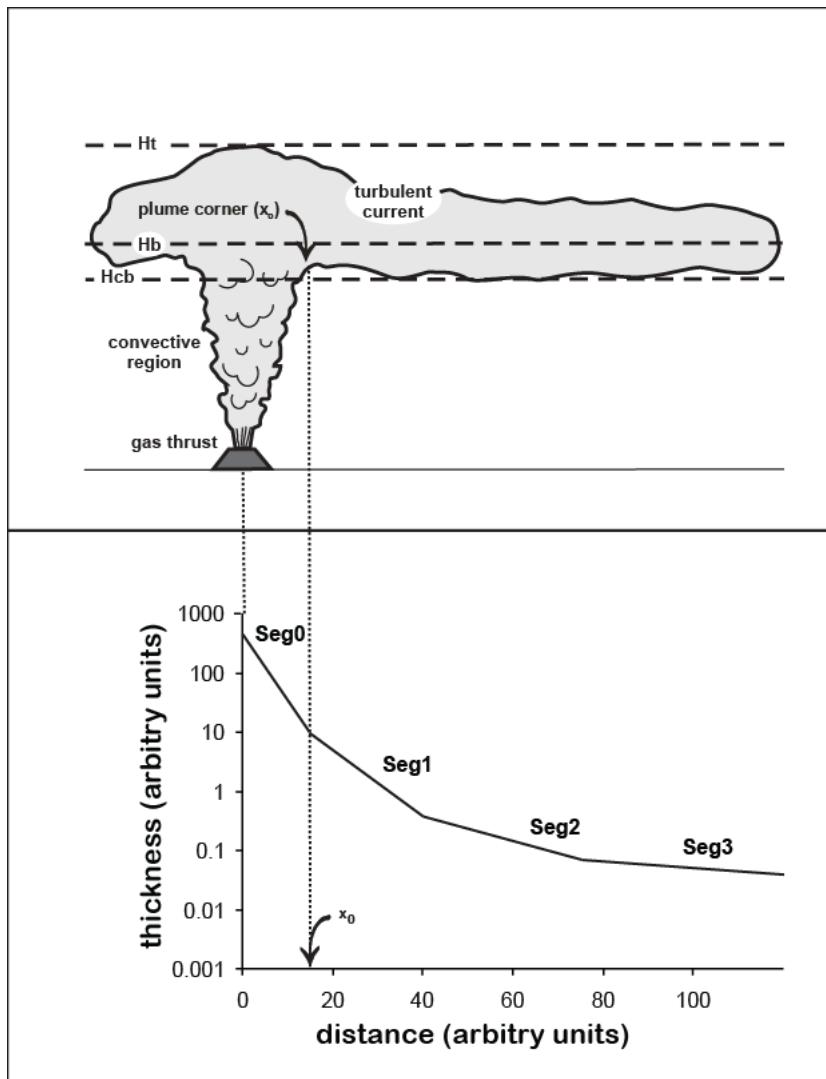
$$v_t \approx (3.1 g \rho d / \sigma)^{1/2} \quad (\text{for Reynolds numbers } 500-200,000)$$

$$v_t \approx d(4\rho^2 d^2 / 225\mu\sigma)^{1/3} \quad (\text{for Reynolds numbers } 6-500)$$

$$v_t \approx (g \rho d^2 / 18\mu) \quad (\text{for Reynolds numbers } < 6)$$



Sedimentation from strong plumes



**Segment 0: sedimentation
from plume margins**

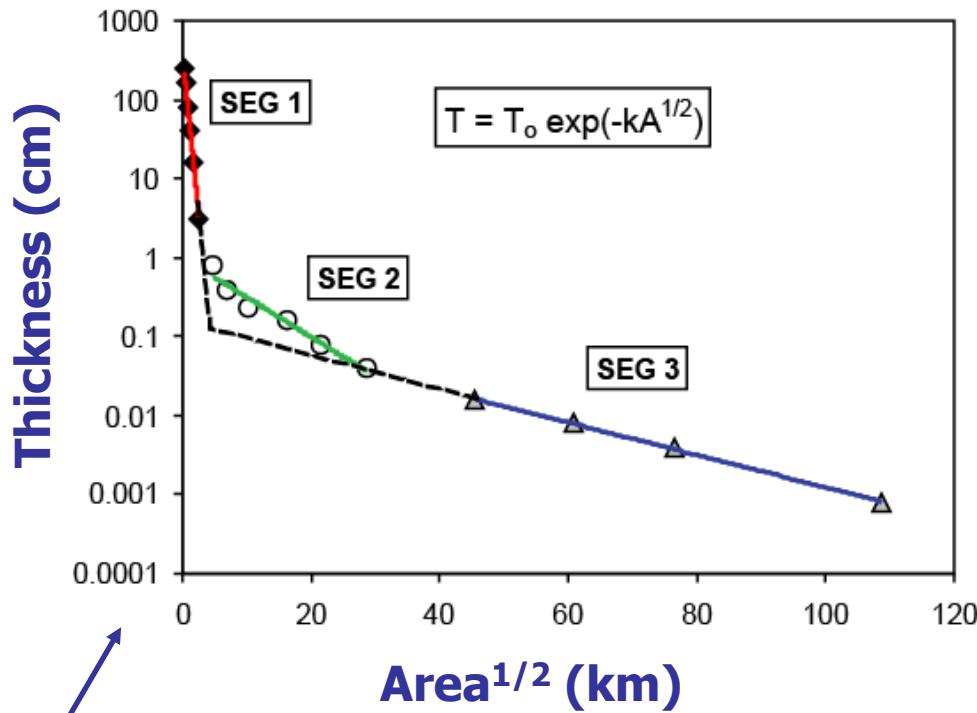
**Segment 1:
high-Re particle settling**

**Segment 2:
intermediate-Re particle**

**Segment 3:
low-Re particle settling**



ERUPTED MASS/VOLUME EXPONENTIAL CURVE FITTING



Variations:

- ★ **1 exp. segment (Pyle 1989)**
- ★ **2 exp. segments**
(Fierstein and Nathenson 1992, Pyle 1995)
- ★ **>2 exp. segments**
(Bonadonna and Houghton 2005)
- ★ **One proximal isopach line**
(Legros 2000)
- ★ **Missing distal data**
(Sulpizio 2005)
- ★ **Thickness measurements**
(Burden et al. 2013)

PROBLEM: underestimation of volume in case of missing distal data

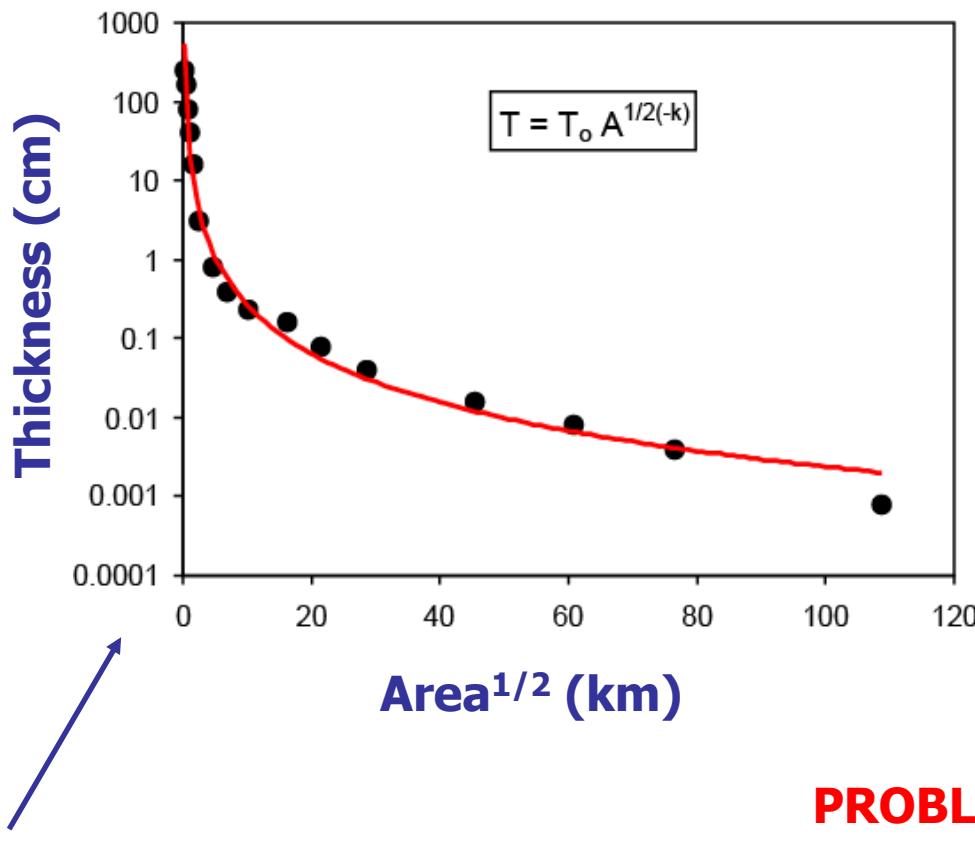
e.g. Ruapehu 1996 eruption



ERUPTED MASS/VOLUME

POWER-LAW CURVE FITTING

(Bonadonna and Houghton 2005)



Empirical and theoretical support:

- ✿ **Thinning of well exposed deposits**
e.g. Hildreth and Drake 1992 (Novarupta 1912); Fierstein and Hildreth 1992 (Quizapu 1932); Scasso et al. 1994 (Hudson 1991); Bonadonna and Houghton 2005 (Ruapehu 1996)

- ✿ **Rose 1993; Bonadonna et al. 1998**

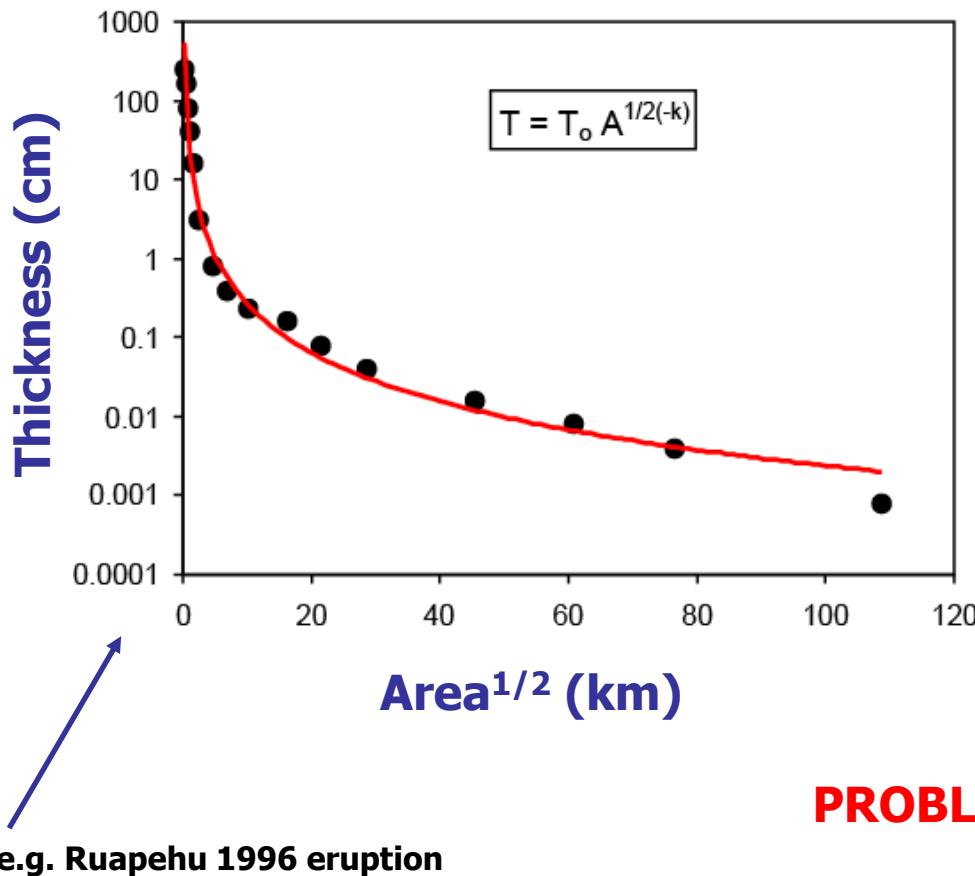
PROBLEM: choice of integration limits



ERUPTED MASS/VOLUME

POWER-LAW CURVE FITTING

(Bonadonna and Houghton 2005)



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

$k > 2 \rightarrow$ rapid thinning \rightarrow small deposit \rightarrow Volume sensitive to prox integration limit

$k < 2 \rightarrow$ gradual thinning \rightarrow large deposit \rightarrow Volume sensitive to distal integration limit

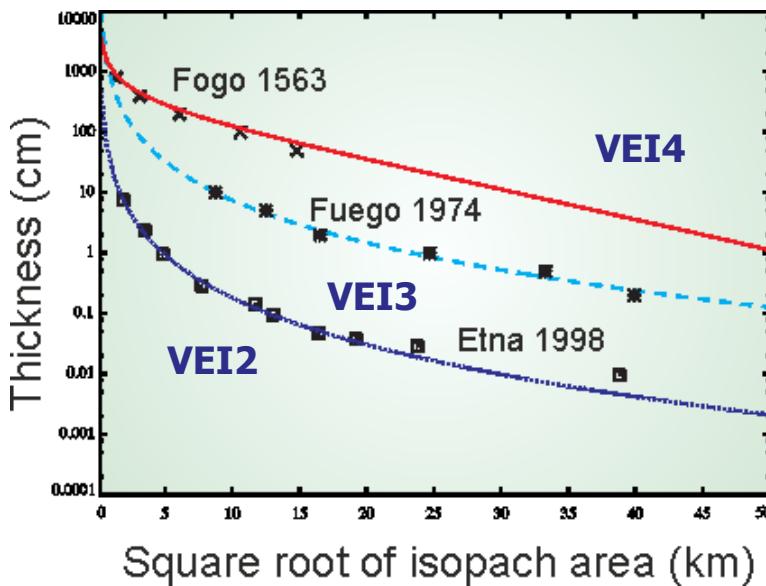
PROBLEM: choice of integration limits



ERUPTED MASS/VOLUME

WEIBULL CURVE FITTING

(Bonadonna and Costa 2012)



$$V = \int_0^{\infty} T dA = 2 \int_0^{\infty} T(x) x dx = \frac{2\theta\lambda^2}{n} \left[1 - e^{-\left(\frac{x}{\lambda}\right)^n} \right]_0^{\infty} = \frac{2\theta\lambda^2}{n}$$

λ : characteristic decay length scale of deposit thinning (km);

θ : thickness scale (cm)



ERUPTED MASS/VOLUME

PROS and CONS

Exponential fit:

- 😊 Easy to apply
- 😊 Can be integrated between 0 and ∞
- 😊 Underestimates the volume in case of missing distal and/or proximal data
- 😊 The choice of exponential segments can be arbitrary and biased by available data

Power-law fit:

- 😊 Easy to apply
- 😊 Can better describe the natural gradual deposit thinning with distance
- 😊 Cannot be integrated between 0 and ∞ (\rightarrow difficult choice of extremes of integration)

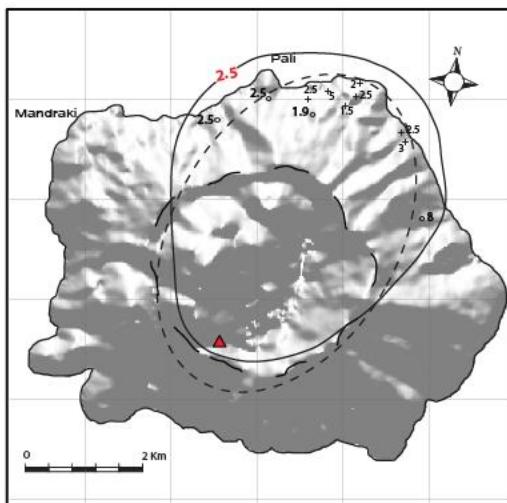
Weibull fit:

- 😊 Can better describe the natural gradual deposit thinning with distance
- 😊 Can be integrated between 0 and ∞
- 😊 Is of more complex application and needs > 3 data points (because it has 3 free par.)

Characterization of ESPs:
erupted mass/volume

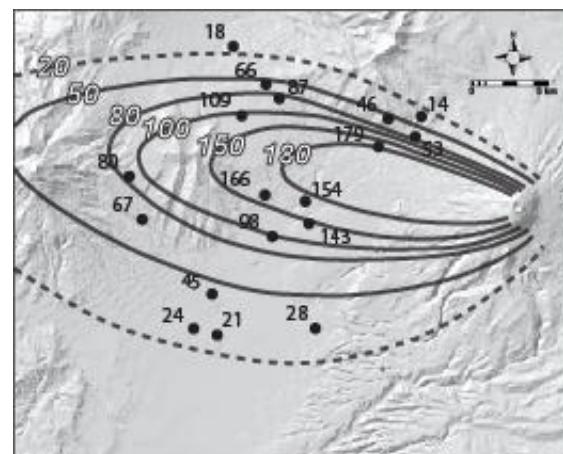
ERUPTED MASS/VOLUME

Lower Pumice, Nisyros (Greece)



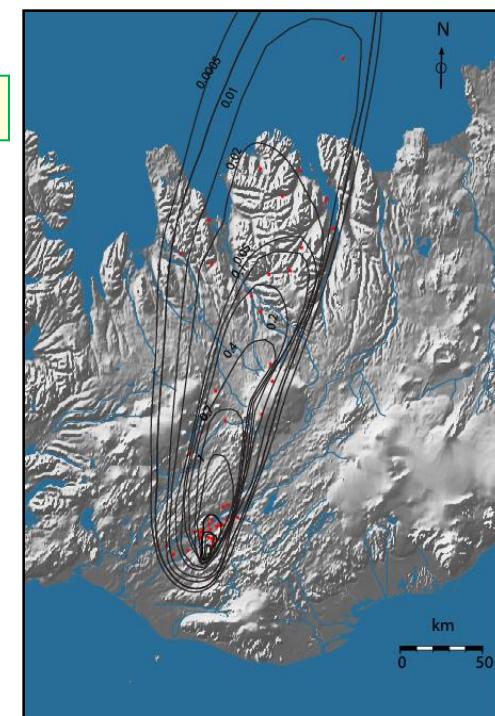
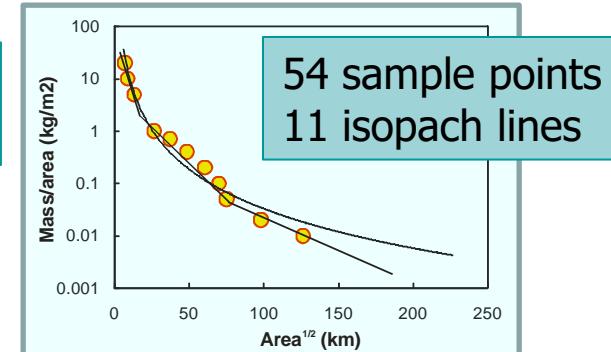
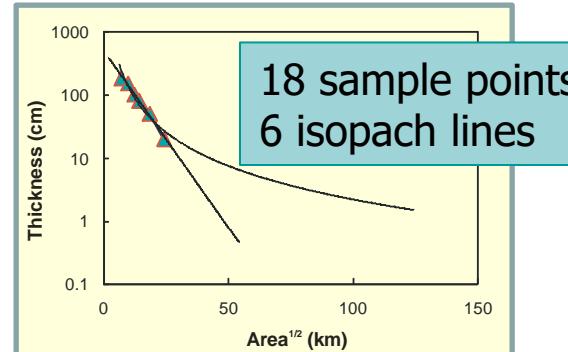
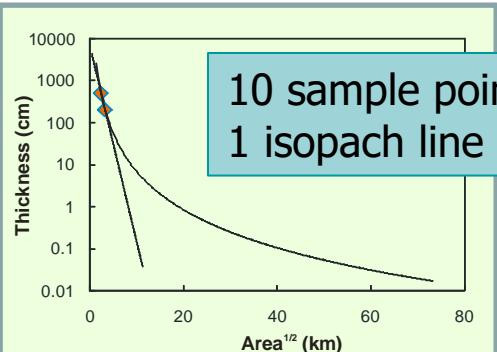
Longchamp et al. , 2011

Layer 3 (820BP), Cotopaxi (Ecuador)



Biass and Bonadonna , 2011

Hekla 2000 (Iceland)

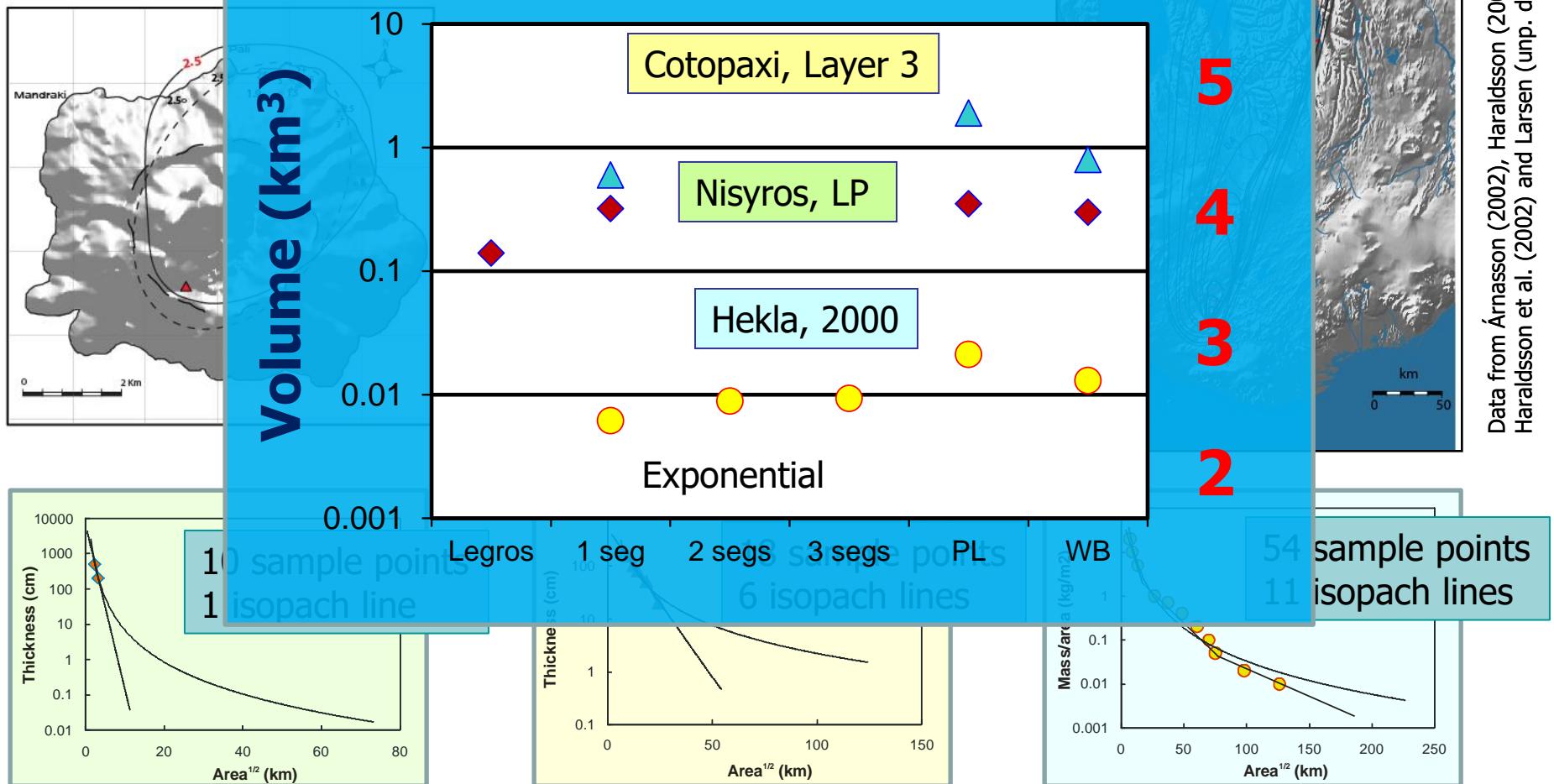
Data from Árnasson (2002), Haraldsson (2001),
Haraldsson et al. (2002) and Larsen (unp. data)



ERUPTED MASS/VOLUME

Lower Pumice, Nisyros (Greece)

Hekla 2000 (Iceland)



Data from Árnasson (2002), Haraldsson (2001), Haraldsson et al. (2002) and Larsen (unp. data)



Volcanic Explosivity Index (VEI)

Volume of ejecta: both tephra and ignimbrite if present

Criteria	VEI:	0	1	2	3	4	5	6	7	8
DESCRIPTION		non-explosive	small	moderate	mod-large	large	very large			
VOLUME OF EJECTA (M ³)		<10 ⁴	10 ⁴ -10 ⁶	10 ⁶ -10 ⁷	10 ⁷ -10 ⁸	10 ⁸ -10 ⁹	10 ⁹ -10 ¹⁰	10 ¹⁰ -10 ¹¹	10 ¹¹ -10 ¹²	>10 ¹²
(TSUYA CLASSIFICATION)*		(I)	(II-III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	
COLUMN HEIGHT (KM)*		<0.1	0.1-1	1-5	3-15	10-25	>25			
QUALITATIVE DESCRIPTION		---"gentle, effusive"---	-----"explosive"-----	-----"cataclysmic, paroxysmal, colossal"-----						
					"severe, violent, terrific"					
CLASSIFICATION			-----"Strombolian"-----			-----"Plinian"-----				
			-----"Hawaiian"-----		-----"Vulcanian"-----		-----"Ultraplinian"-----			
DURATION (hours) of continuous blast			-----<1-----			----->12-----				
				-----1-6-----						
					-----6-12-----					
CAV MAX EXPLOSIVITY**		--lava flows-	-----explosion or nuée ardente-----							
			-----phreatic-----							
			-----dome or mudflow---							
TROPOSPHERIC INJECTION		negligible	minor	moderate	substantial					
STRATOSPHERIC INJECTION		none	none	none	possible	definite	significant			

*If all eruptive products were pyroclastic ejecta

**For VEI's 0-2, uses km above crater; for VEI's 3-8, uses km above sea level.

**The most explosive activity indicated for the eruption in the Catalogue of Active Volcanoes



Volcanic Explosivity Index (VEI)

Volume of ejecta: both tephra and ignimbrite if present

TABLE I. The Volcanic Explosivity Index^a

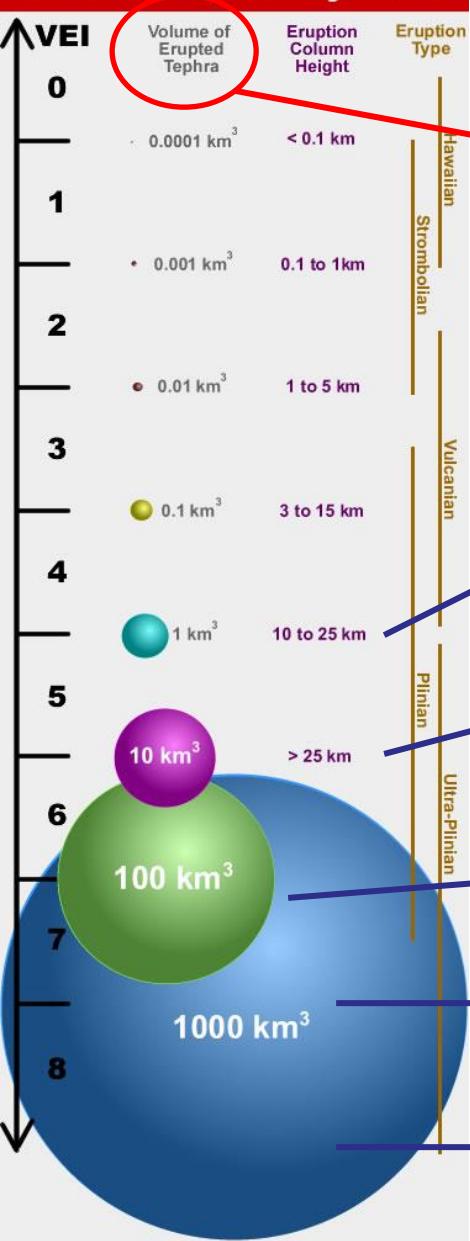
VEI index	0	1	2	3	4	5	6	7	8
General description	Nonexplosive	Small	Moderate	Moderate-large	Large	Very large			
Qualitative description	Gentle	Effusive	← Explosive →		← Cataclysmic, paroxysmal →				
Maximum erupted volume of tephra (m ³)	10 ⁴	10 ⁶	10 ⁷	10 ⁸	10 ⁹	10 ¹⁰	10 ¹¹	10 ¹²	10 ¹³
Eruption cloud column height (km)	<0.1	0.1–1	1–5	3–15	10–25	>25			

^a Adapted from Newhall and Self, 1982.

- ❖ In practice, modern eruptions defined by plume height
- ❖ Ancient eruptions defined by maximum erupted volume
- ❖ Not useful for effusive (lava) eruptions, which by default get VEI of 0, 1



Volcanic Explosivity Index



Volcanic Explosivity Index (VEI)

Volume of ejecta: both tephra and ignimbrite if present

Mono-Inyo Craters (past 5,000 years)

Mount St Helens (May 18, 1980) (bulk deposit = 1.3 km^3 , of which tephra is 1.2 km^3) (VEI 5)

Pinatubo (June 1991) (bulk deposit $\sim 11 \text{ km}^3$, of which tephra is 6.5 km^3) (VEI 6)

Tambora (1815) (bulk deposit $\sim 110 \text{ km}^3$, of which tephra is 101 km^3) (VEI 7)

Long Valley Caldera (760ka) (bulk deposit $\sim 1380 \text{ km}^3$, of which tephra is 300 km^3) (VEI 8)

Yellowstone Caldera (640ka) (bulk deposit $\sim 1000 \text{ km}^3$, of which tephra is 500 km^3) (VEI 8)



Mass vs. Volume of Volcanic Eruptions

Deposit volume depends on deposit vesicularity → deposits with same mass but different vesicularity have different volume

To alleviate this problem → deposit volume is converted to Dense Rock Equivalent volume

This is an estimate of the volume of dense, unvesiculated magma that produced deposit



Dense Rock Equivalent (km³)

Mass deposit = Mass magma

$$\rho_{\text{deposit}} \times V_{\text{deposit}} = \rho_{\text{magma}} \times V_{\text{magma}}$$

$$V_{\text{magma (DRE)}} = \rho_{\text{dep}} \times V_{\text{dep}} / \rho_{\text{magma}}$$



Dense Rock Equivalent (km³)

$$V_{\text{deposit}} = 1.8 \text{ km}^3$$

$$\rho_{\text{deposit}} = 0.9 \text{ g cm}^{-3}$$

$$\rho_{\text{magma}} = 2300 \text{ kg m}^{-3}$$

$$V_{\text{magma}} (\text{DRE}) ?$$



MAIN QUESTION:

How well can we constrain explosive eruptions?

→ Erupted Volume/Mass, Plume Height,
Mass Eruption Rate (MER), Eruption Duration,
Total Grain-Size Distribution (TGSD)

PLUME HEIGHT

- ✿ Direct observations
- ✿ Satellite images (thermal infrared data; cloud shadow clinometry; cloud stereoscopy)
- ✿ Empirical methods (Rossi et al. 2018)
- ✿ Analytical methods (inversion on grainsize)



MAIN QUESTION:

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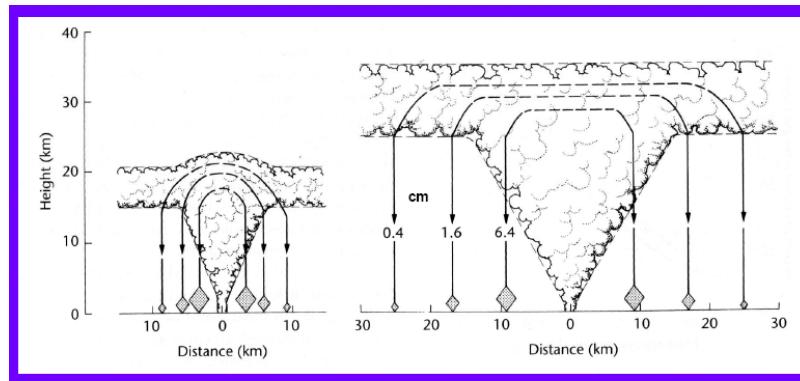
PLUME HEIGHT

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COLUMN HEIGHT

Method of Carey and Sparks (1986)



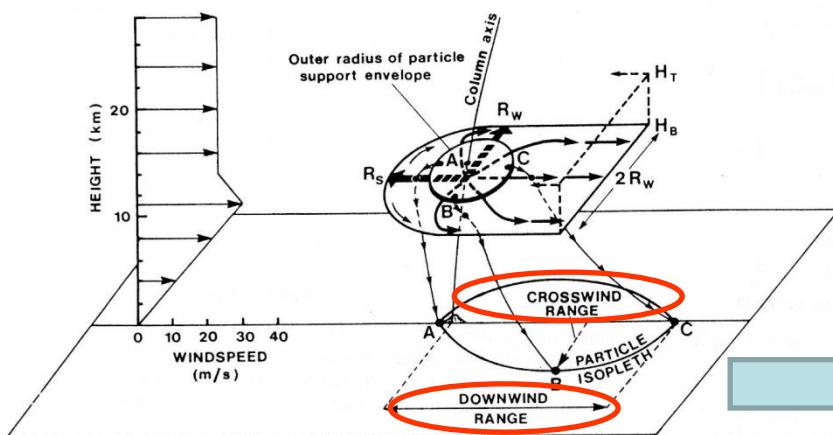
a more intense plume carries a clast higher:

- it takes longer to fall
- the wind carries it further away
- it falls further from the vent



COLUMN HEIGHT

Method of Carey and Sparks (1986)

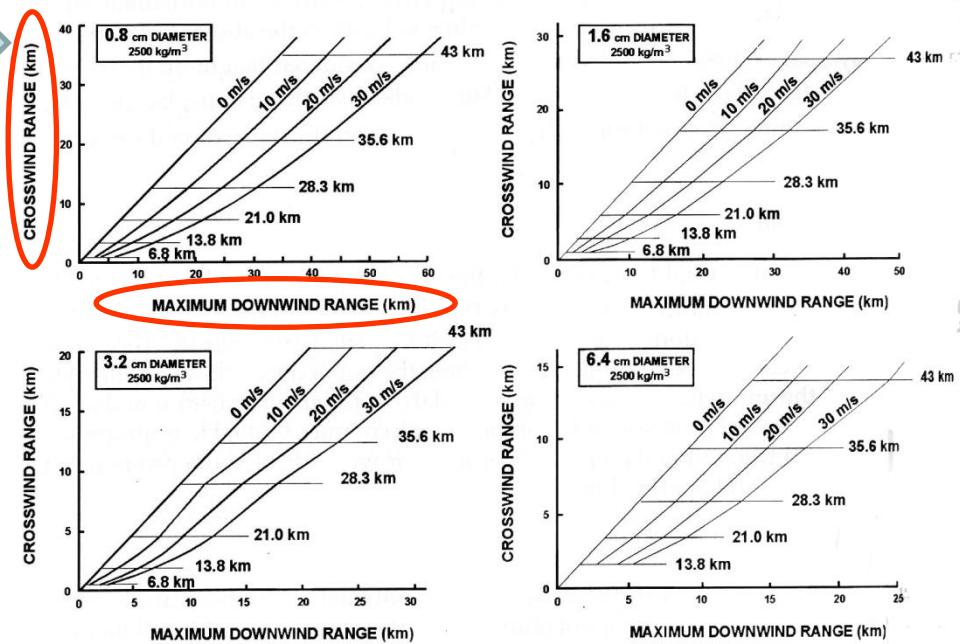


a more intense plume carries a clast higher:

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Main assumptions:

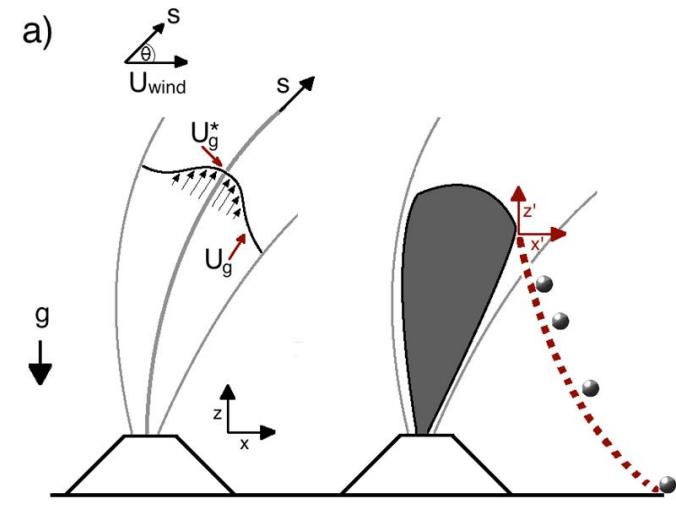
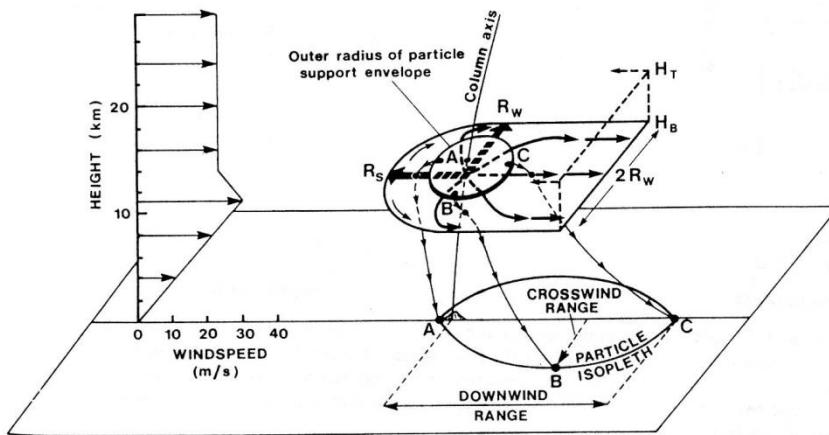
- ★ Sustained strong plumes
- ★ Monotone plume vertical velocity
- ★ Fixed wind profile → trop.=11km





COLUMN HEIGHT

Method of Rossi et al. (2018)



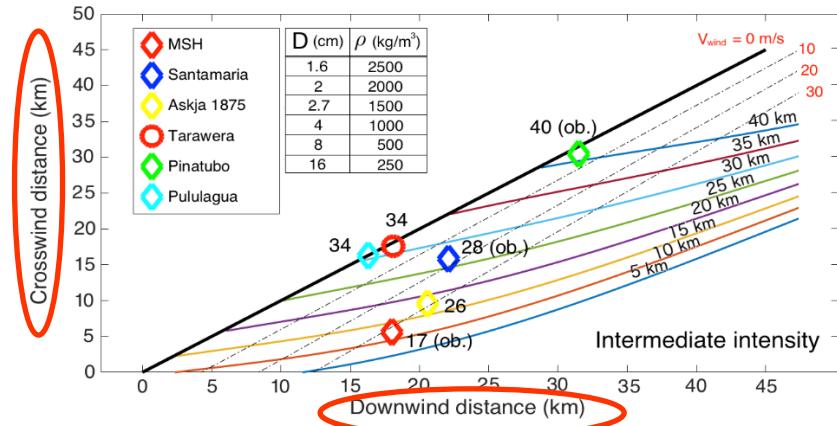
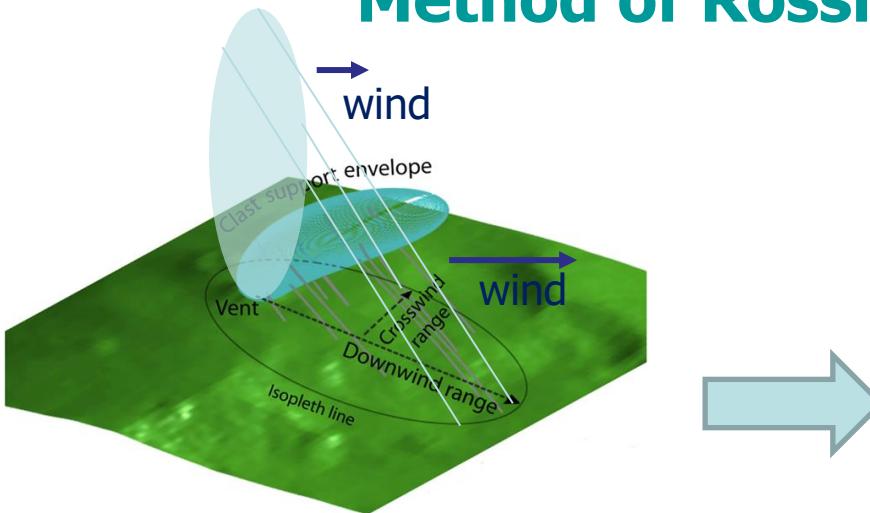
Implementations:

- Better description of plume dynamics (e.g. better description of gravitational spreading) and of the effect of wind on plume rise
- Wind profiles used to construct the nomograms are the same as for C&S86 but real 3D wind profiles can also be considered
- Effect of particle shape on settling velocity

Characterization of ESPs:
height of eruptive column

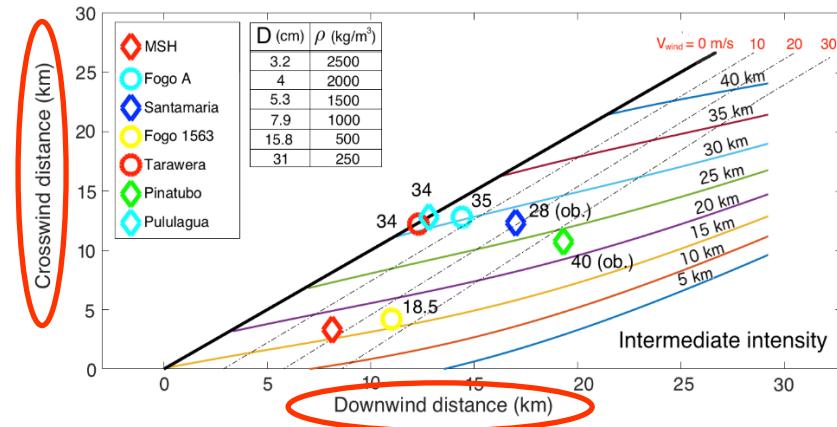
COLUMN HEIGHT

Method of Rossi et al. (2018)



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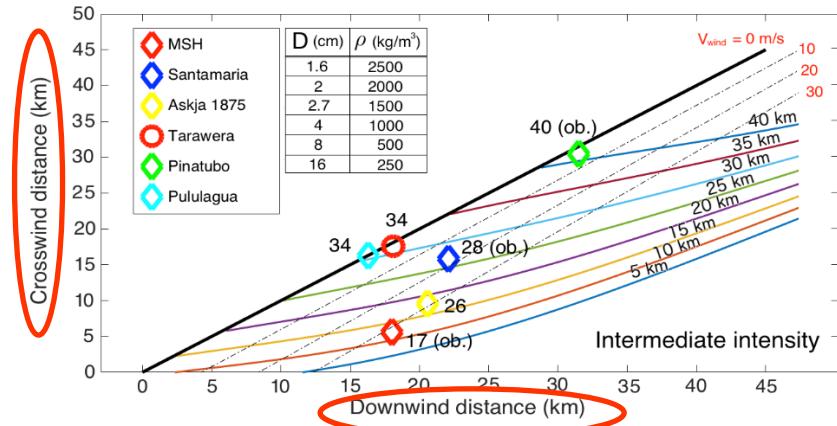
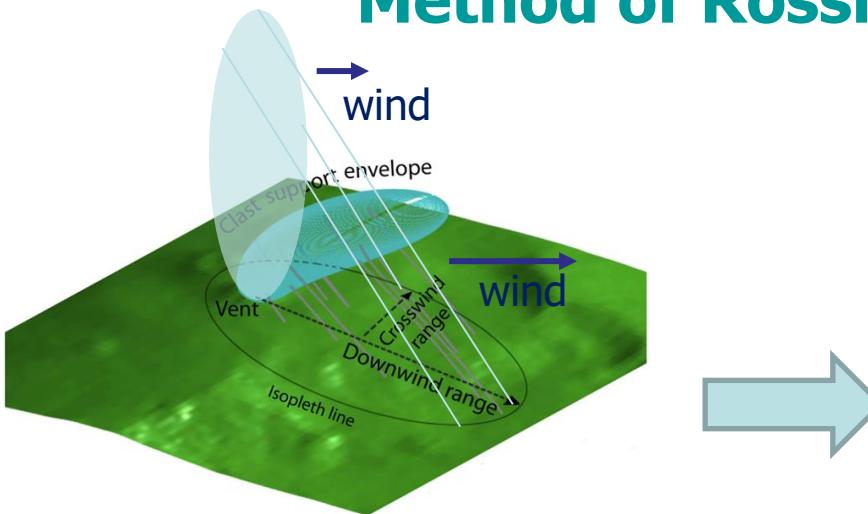


Relation between height and CW range is not longer univocal for a given DW range (effect of wind)

Characterization of ESPs:
height of eruptive column

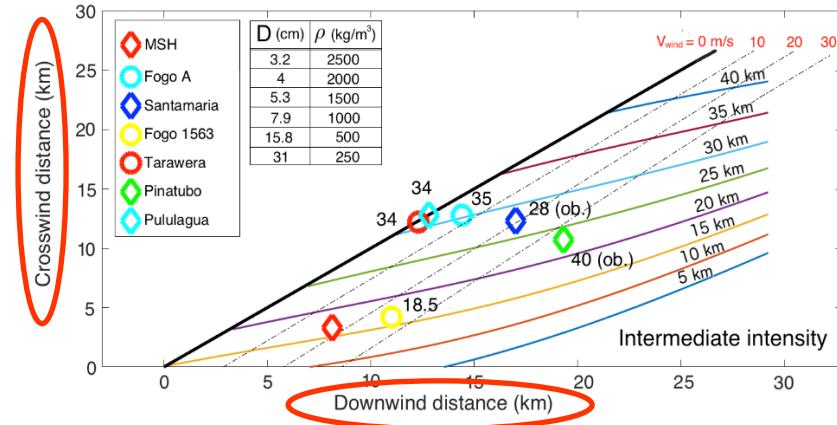
COLUMN HEIGHT

Method of Rossi et al. (2018)



Implementations:

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- Wind profiles used to construct the nomograms are the same as for C&S86 but real 3D wind profiles can also be considered
- Effect of particle shape on settling velocity



Resulting heights are generally lower than those predicted by C&S86 because also the wind is accounted for



MAIN QUESTION:

How well can we constrain explosive eruptions?

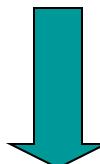
**How well can we constrain Eruption Source
Parameters (ESP)?**

→ **Erupted Volume/Mass, Plume Height,
Mass Eruption Rate (MER), Eruption Duration,
Total Grain-Size Distribution (TGSD)**



MASS ERUPTION RATE

$$H_t \text{ (km)} = K [MER(\text{Kg/s})]^{1/4}$$



Wilson and Walker 1987

$$K = 0.236$$

- Central vent
- Silicic eruptions
- No wind
- Dry atmosphere

$$K = 0.295$$

$$K = 0.247$$

$$K = 0.244$$

Fontana Lapilli (Masaya, Nicaragua); Etna 2001, 2002 (Italy)
Wehrmann et al. 2006, Scollo et al. 2007, Andronico et al. 2008

Characterization of ESPs:
Mass Eruption Rate

MASS ERUPTION RATE

$$H_t \text{ (km)} = K [MER(\text{Kg/s})]^{1/4}$$

Wilson and Walker 1987

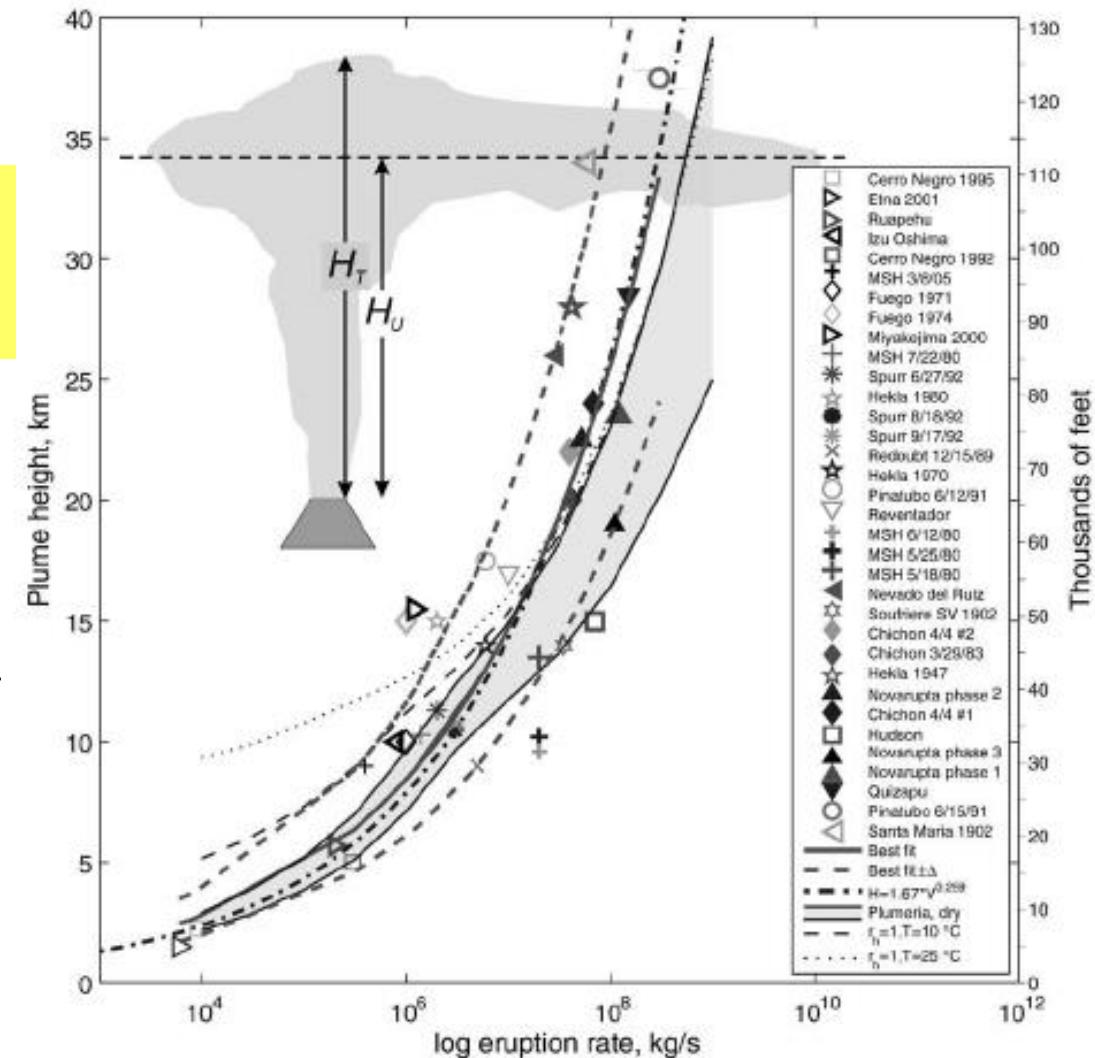
- Mass eruption rate from empirical equations can only be constrained within a factor of 10

$$H_t = 2.00 Q^{0.241}$$

Mastin et al. 2009

 Q =volumetric flow rate (m^3/s) $MER=Q \times \text{magma density}$

$$= Q \times 2500 \text{ kg m}^{-3}$$





MASS ERUPTION RATE

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

H

Plume height

\bar{N}

Average buoyancy frequency across the plume height

v

Average wind velocity across the plume height

α

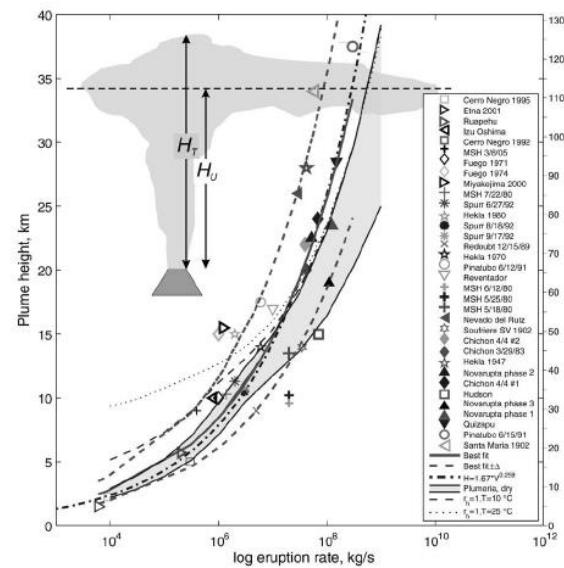
Radial entrainment coefficient (best fit: 0.1)

β

Wind entrainment coefficient (best fit: 0.5)

ρ_{a0}

Density of the atmosphere





MASS ERUPTION RATE

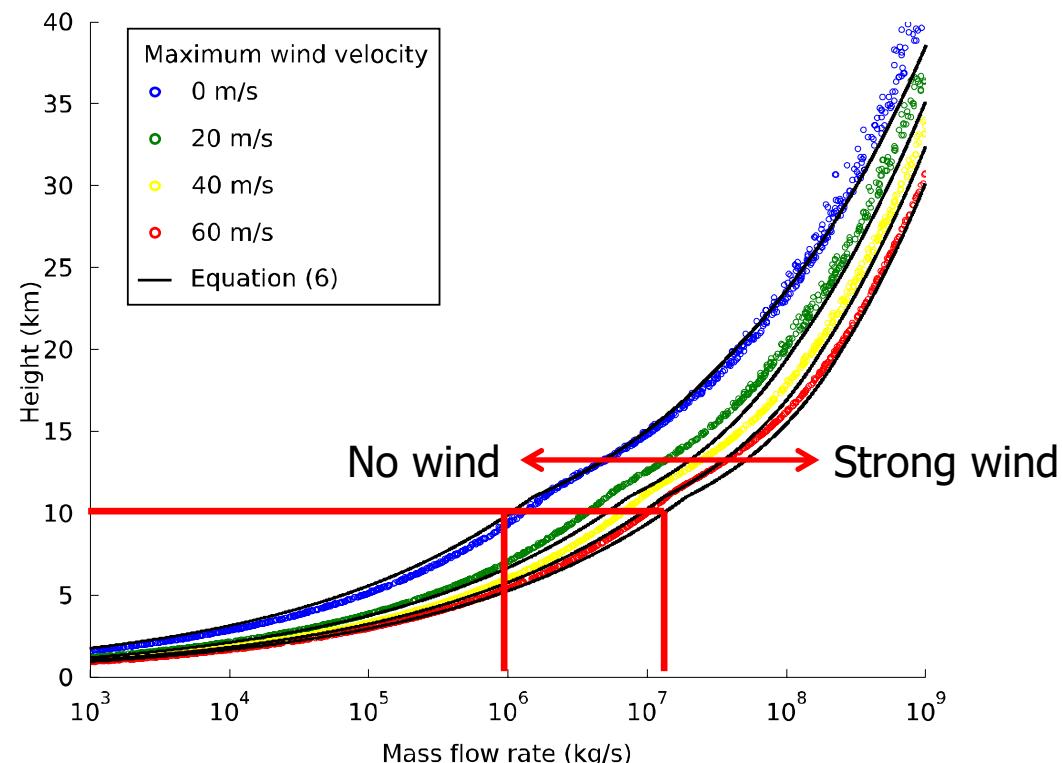
$$MER = \pi \frac{\rho_{a0}}{g'} \left(\frac{\alpha^2 \bar{N}^3}{10.9} H^4 + \frac{\beta^2 \bar{N}^2 v}{6} H^3 \right)$$

- can account for variability of both source and atmospheric conditions
- remains accurate within a factor of two compared with a 1D plume model

$$\Pi = \frac{\bar{N}H}{1.8v} \left(\frac{\alpha}{\beta} \right)^2$$

wind becomes dominant if the height, buoyancy frequency, and radial entrainment are small and the wind speed and wind entrainment are large

$$\Pi \ll 1$$





MASS ERUPTION RATE

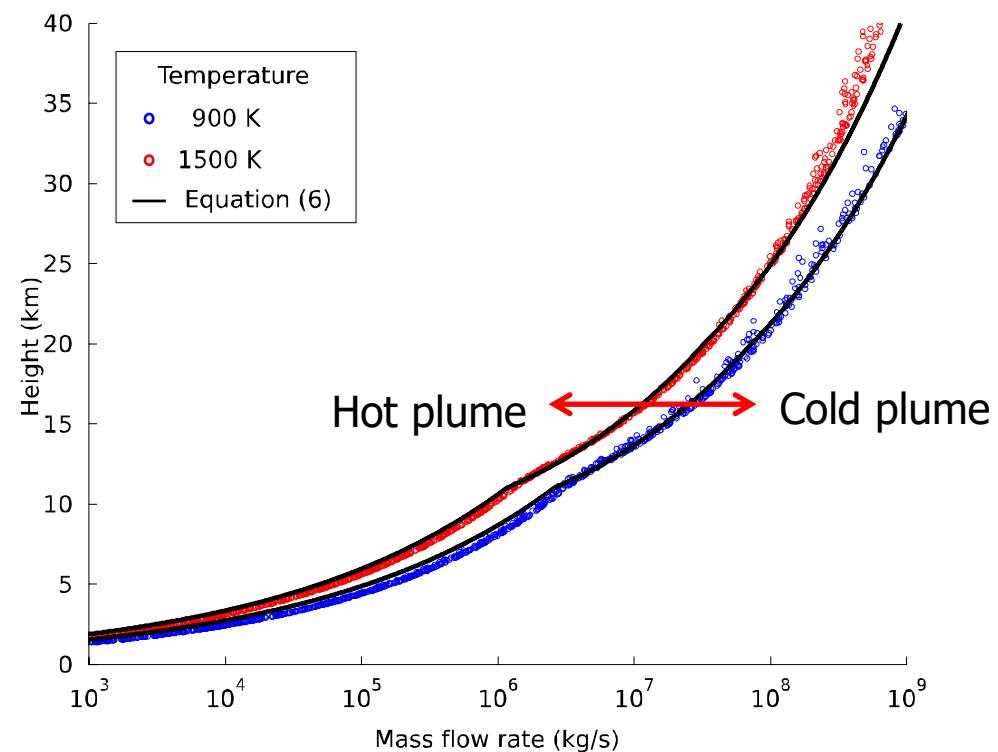
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$$\Pi \ll 1$$





MASS ERUPTION RATE AND DURATION

$$Ht = K \text{MER}^{1/4}$$

Wilson and Walker 1987

$$Ht = 2.00 Q^{0.241} \rightarrow \text{MER} = Q \times 2500 \text{ kg m}^{-3}$$

Mastin et al. 2009

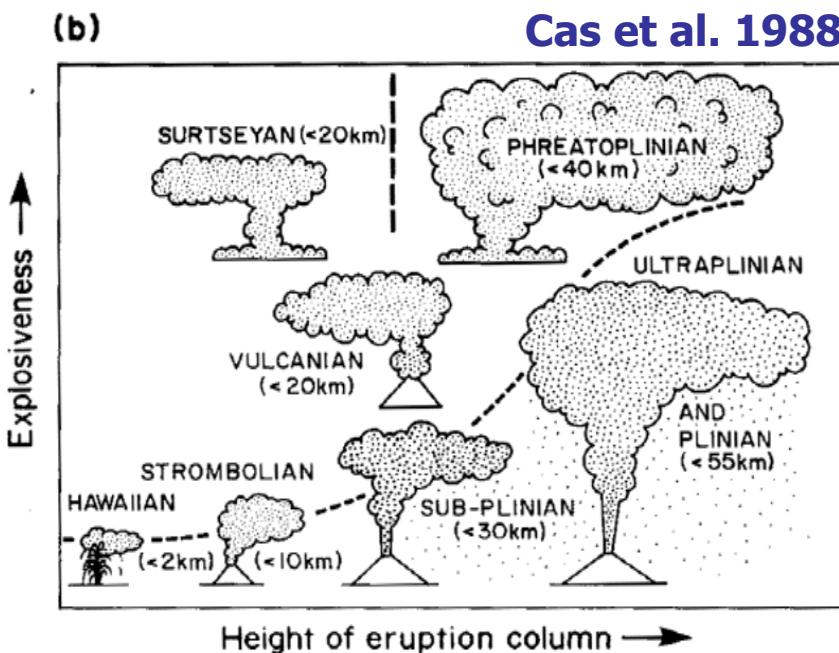
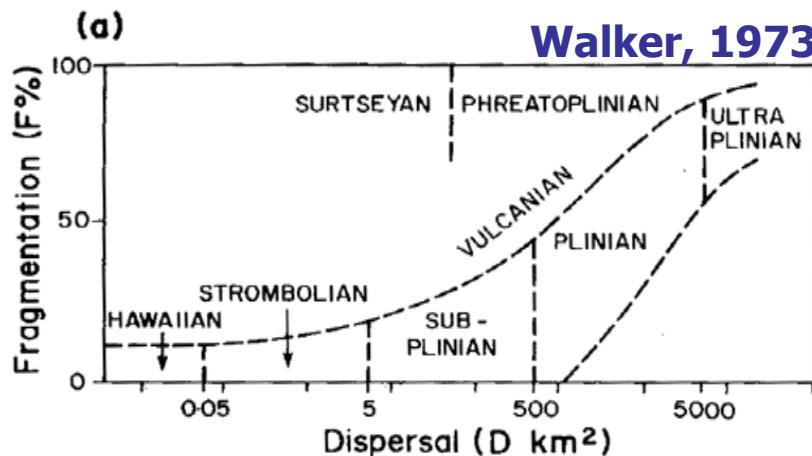
$$\text{MER} = \pi \frac{\rho_{a0}}{g'} \left(\frac{\alpha^2 \bar{N}^3}{10.9} H^4 + \frac{\beta^2 \bar{N}^2 v}{6} H^3 \right)$$

Degruyter and Bonadonna (2012)

Eruption duration (s) = Erupted Mass (kg) / MER (kg/s)



CLASSIFICATION



D (area of pyroclastic dispersal) → indicator of the column height.

Area enclosed by an isopach contour representing 1% of the maximum thickness (0.01 Tmax).

F (fragmentation) → indicator of the explosiveness of the eruption.

Percent of tephra <1mm, measured along an axis of dispersal where the isopach is 10% of Tmax (0.1 Tmax).

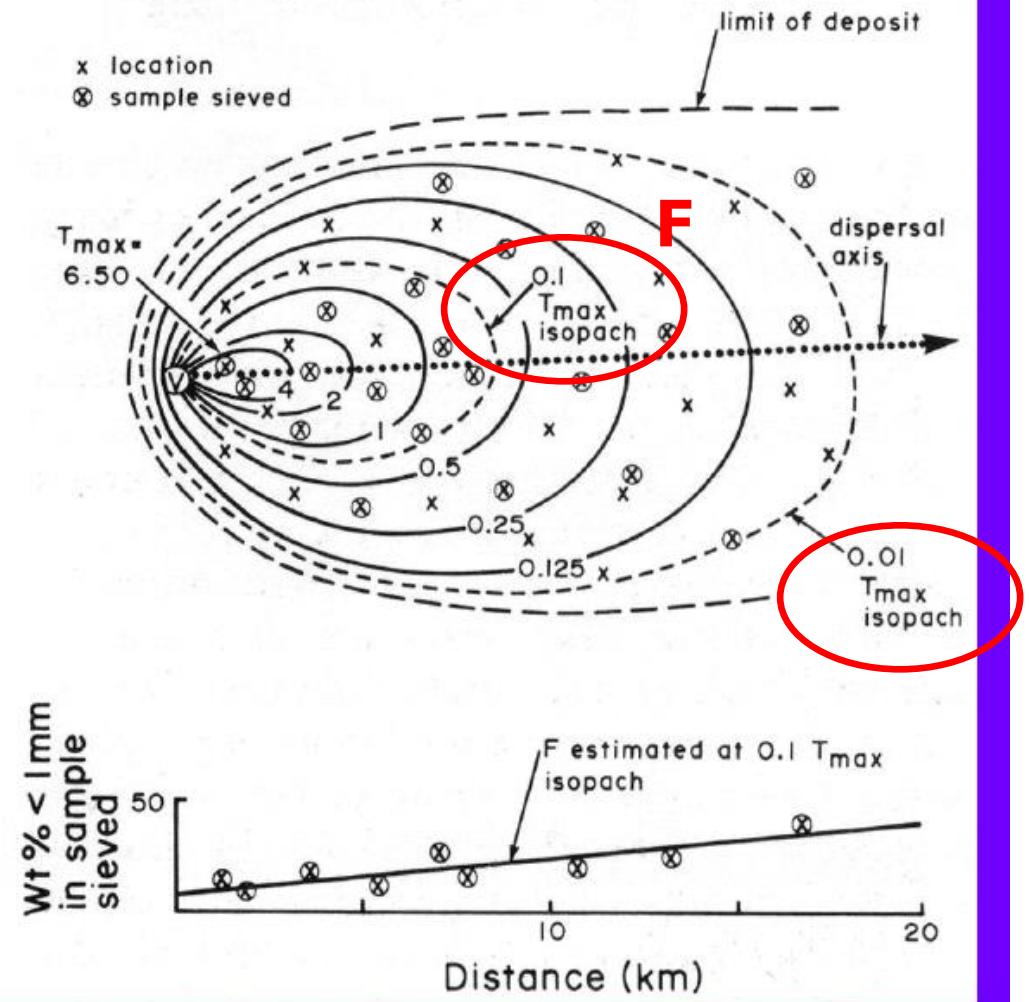


CLASSIFICATION

Fragmentation (F),
a measure of how
thoroughly the
magma is blown
apart.

It's one measure
of the intensity of
an explosion.

Walker, 1973



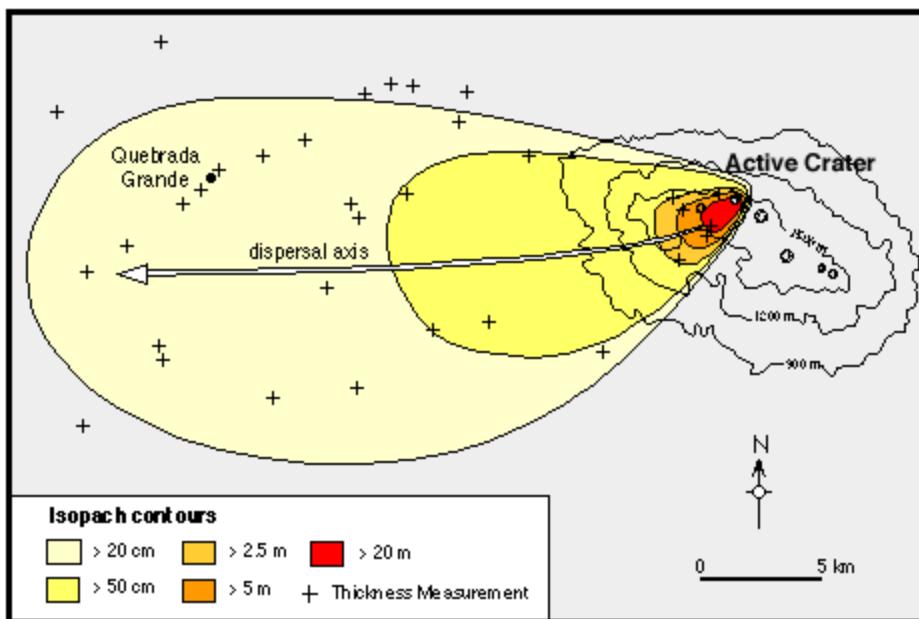
D



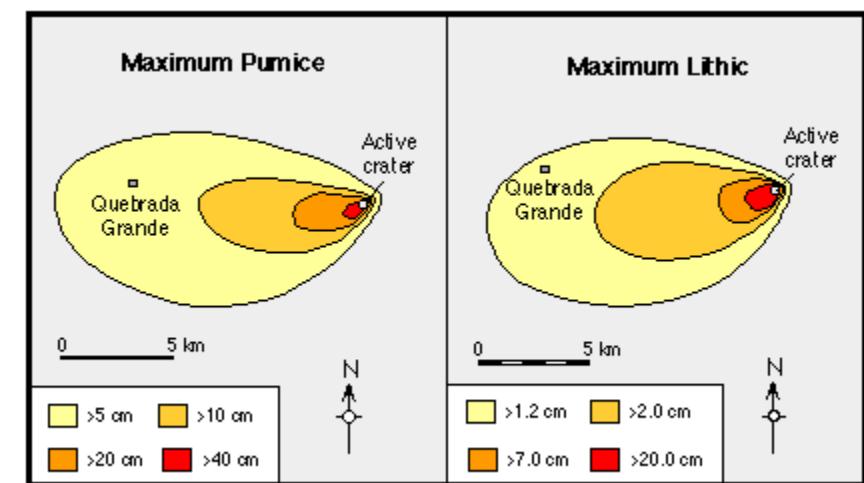
CLASSIFICATION

Pyle 1989

Classification based on the distribution of largest clasts (bc) and on deposit thinning (bt)



Isopach maps



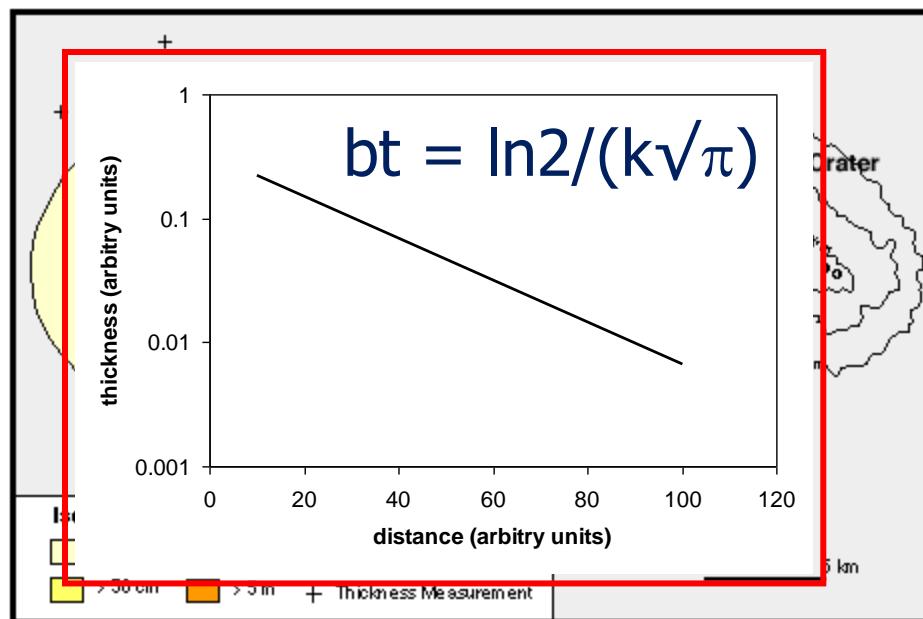
Isopleth maps



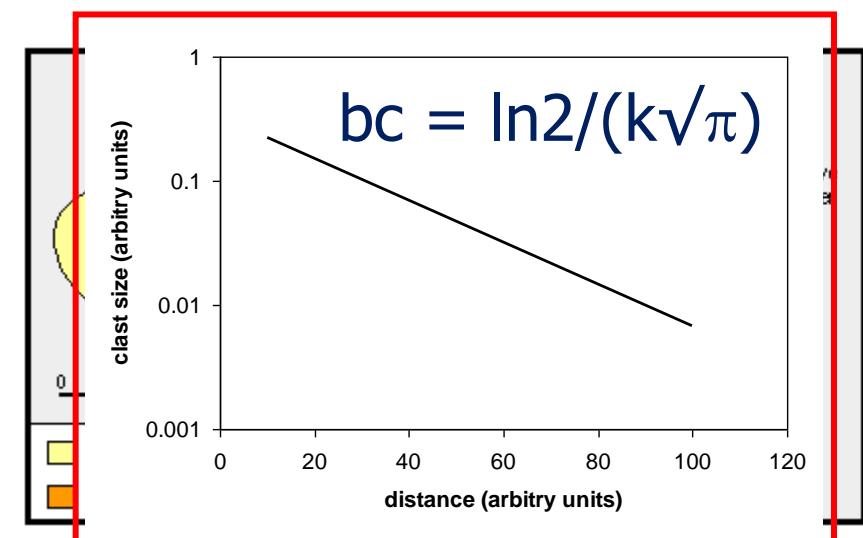
CLASSIFICATION

Pyle 1989

Classification based on the distribution of largest clasts (bc) and on deposit thinning (bt)



Isopach maps



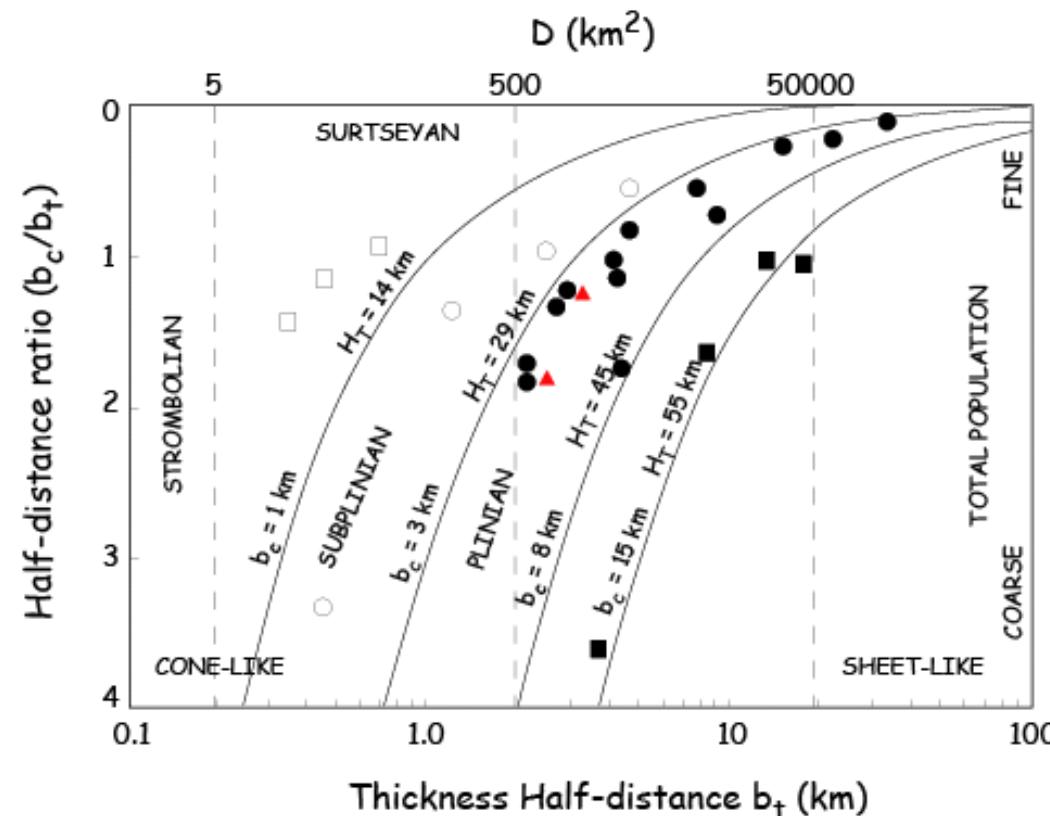
Isopleth maps



CLASSIFICATION

Pyle 1989

Classification based on the distribution of largest clasts (bc) and on deposit thinning (bt)





Physical characterization of explosive eruptions

- **Isopach maps/Isomass maps** → erupted volume/mass (+VEI and DRE) + wind direction
- **Isopleth maps** → Plume height → Mass Eruption Rate → Eruption duration (when combined with erupted mass)
- **Isopleth maps** → Wind speed
- **Individual grainsize distributions** → Total grainsize distribution → Infos on eruptive style and fragmentation efficiency
- **Thickness vs grainsize data** → eruption classification



EXERCISE 2

DETERMINATION OF:
Column height
Mass Eruption Rate
Erupted Volume

ERUPTION CLASSIFICATION



UNIVERSITÉ
DE GENÈVE

FACULTY OF SCIENCE
Department of Earth Sciences



FURTHER READING

DETERMINATION OF ERUPTED VOLUME:

https://vhub.org/resources/531/download/Eruption_Magnitude_and_Deposit_Volume.pdf

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