ERTH 456 / GEOL 556
Volcanology

– Lecture 12: Volcanic Plumes –

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hours: M 4-5PM, R 3-4PM or appt.

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Volcanic Explosivity Index

- Devised by Chris Newhall & Stephen Self in 1982
- “Richter scale for eruptions” (note, we don’t use Richter scale anymore)
- based on volume of tephra, plume height
- often criticized / used for things it wasn’t made to do
- recently revised by Houghton and others (2013, Geology) to account for small explosive events

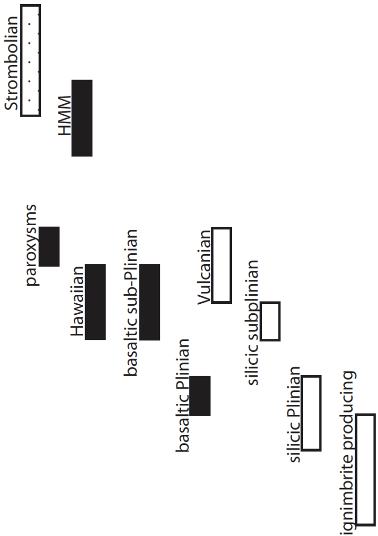
Volcanic Explosivity Index

VEI	0	1	2	3	4	5	6	7	8
General Description	Non-Explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volumn 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" →		← "Cataclysmic," "paroxysmal," "colossal" →				
				← "Severe," "violent," "terrific" →					
Eruption Type (see fig. 7)	← Hawaiian →	← Strombolian →	← Vulcanian →	← Plinian →	← Ultra-Plinian →				
Duration (continuous blast)	← <1 hr →		← 1-6 hrs →	← 6-12 hrs →	← >12 hrs →				
Maximum explosivity	Lava flow / Dome or mudflow	← Explosion or Nuée ardente → ; ← Phreatic →		- - - - - →					
Tropospheric Injection	Negligible	Minor	Moderate	Substantial →					
Stratospheric Injection	None	None	None	Possible	Definite	Significant →			
Eruptions	976	1239	3808	1083	412	168	50	6	0

Newhall & Self, 1982; Siebert et al., 2010

Volcanic Explosivity Index+

New VEI	Old VEI	Volume range m^3	Eruption style
-6	0	1E-2 to 1E-1	
-5	0	1E-1 to 1E0	
-4	0	1E0 to 1E+1	
-3	0	1E+1 to 1E+2	
-2	0	1E+2 to 1E+3	
-1	0	1E+3 to 1E+4	
0	1	1E+4 to 1E+5	
1	1	1E+5 to 1E+6	
2	2	1E+6 to 10E+7	
3	3	1E+7 to 1E+8	
4	4	1E+8 to 1E+9	
5	5	1E+9 to 1E+10	
6	6	1E+10 to 1E+11	
7	7	1E+11 to 1E+12	
8	8	>1E+12	



Houghton et al., 2013

Plume Basics

What's in a plume?

ISS Crew, 2008

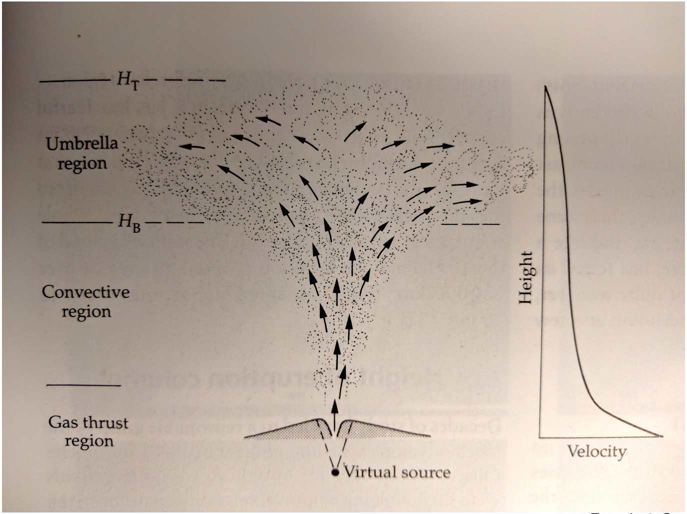
Plume Basics

What's in a plume?

- hot pyroclasts
- magmatic gas
- air

ISS Crew, 2008

Plume Basics



Francis & Oppenheimer, 2004

H_B: height of neutral buoyancy; H_T: maximum plume height
($H_T \approx 1.4 H_B$)

Examples - Karymsky 2008 R. Grapenthin

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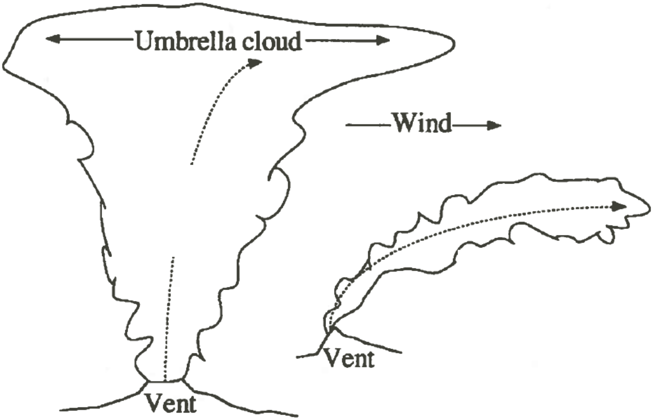
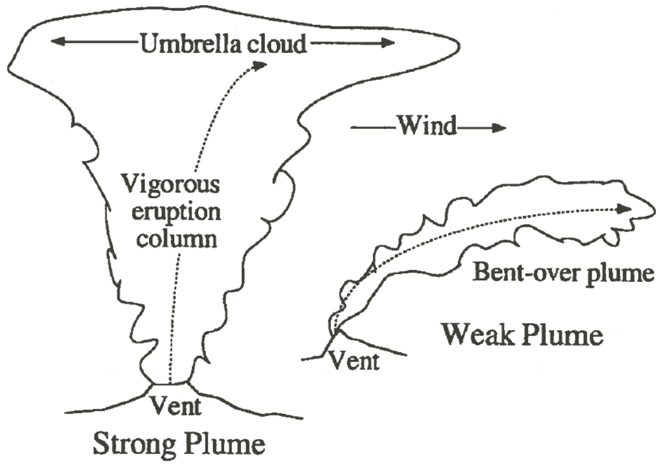
Plume Characteristics



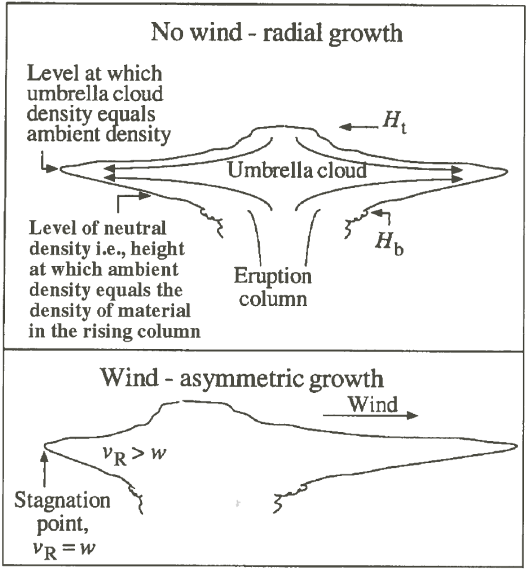
Sparks et al., 1997

Plume Characteristics



Sparks et al., 1997

Plume Characteristics



Sparks et al., 1997

Examples - Karymsky

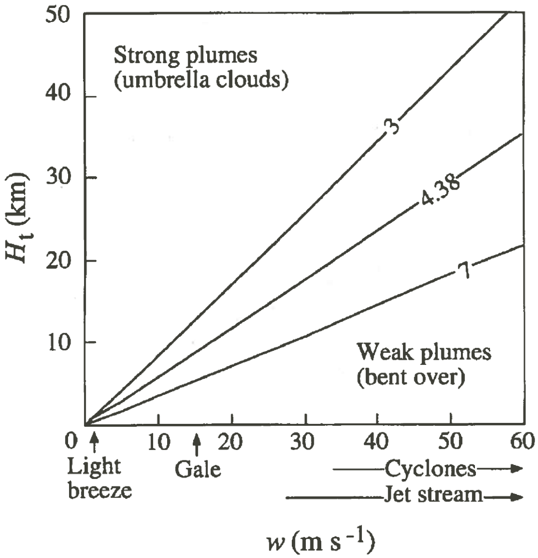

S. Serovetnikov (?)

Examples - Grímvötn" 2011

B. Oddsson

Examples - Kliuchevskoy Group 2010 S. Serovetnikov

Plumes vs. Wind



Sparks et al., 1997

Plumes vs. Wind

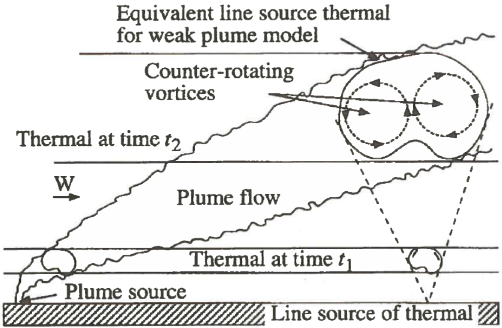


Figure 11.9 Schematic diagram showing the local features of the interaction of a plume with the wind (after Figure 5a of Ernst *et al.* 1994). When the plume is bent over into a subhorizontal orientation, it resembles a thermal in cross-section

Sparks et al., 1997

Plumes vs. Wind

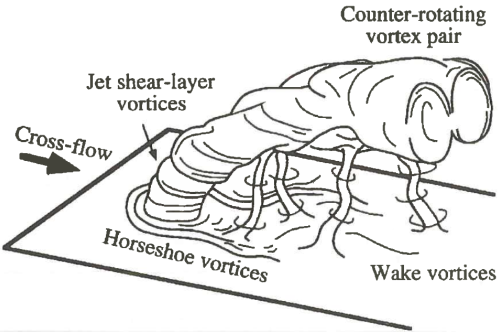


Figure 11.10 Diagram showing four types of vertical vortical structures developed by interaction of a plume or jet with a cross-flow (after Fric and Roshko 1994)

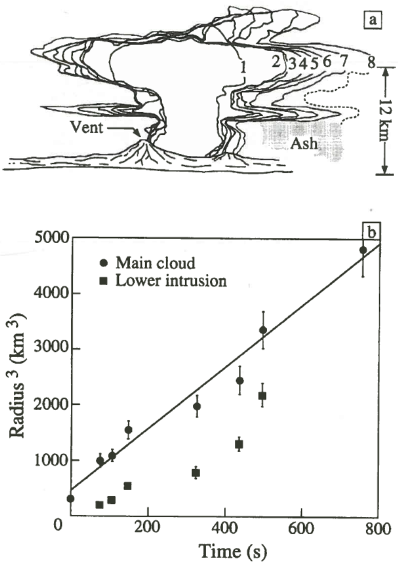
Sparks et al., 1997

Plumes vs. Wind vs. Topography

Figure 11.11 A Landsat image showing the plume of April 3, 1986 issuing from the crater of Augustine volcano, Alaska. (Photograph provided by W. I. Rose.)

Sparks et al., 1997

Plume Dispersal – Redoubt 1990



Sparks et al., 1997

time in minutes

Plume Dispersal – Mt. St. Helens 1980

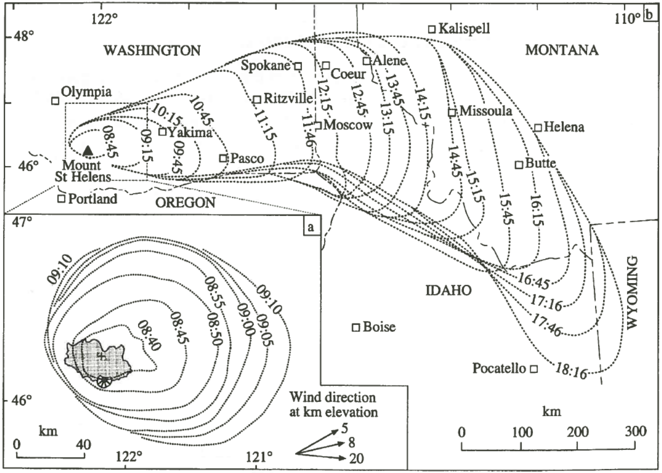
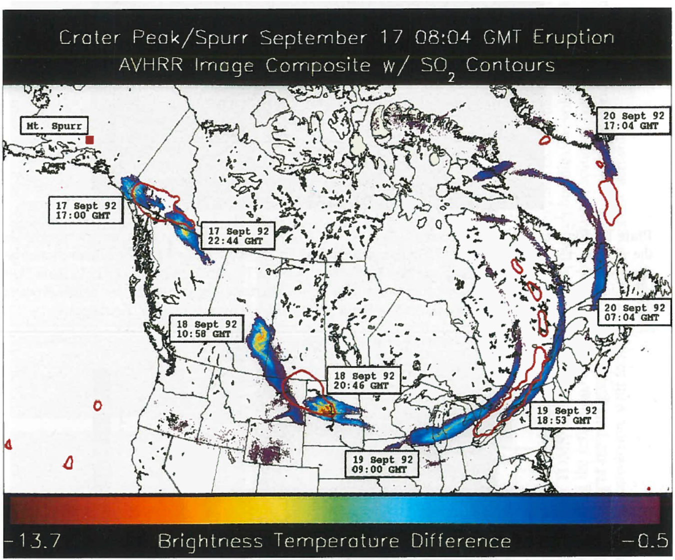


Figure 11.20 (a) Map traced from satellite imagery showing the initial growth of the giant umbrella cloud of Mount St Helens (from Sparks *et al.* 1986). Contours are in five minute intervals labelled with local time in hours and minutes. (b) Map traced from satellite imagery showing the later growth of the May 18, 1980 Mount St Helens plume (redrawn from Sarna-Wojcicki *et al.* 1981)

Sparks et al., 1997

Plume Dispersal – Spurr 1992 (4 days)



Sparks et al., 1997

Plume Dispersal – Pinatubo 1991 (3 months)

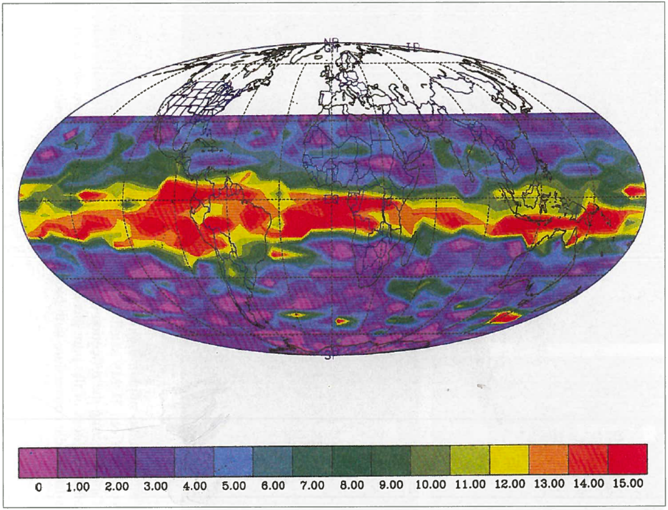


Plate VI Figure 18.10 The global distribution of sulphur dioxide at the 26 km level on September 21, 1991, approximately three months after the Pinatubo eruption (Read *et al.* 1993). The colour bar units are in parts per billion by volume

Sparks et al., 1997

Density Variations in Eruptive Mix

Density of mixture (β) given by:

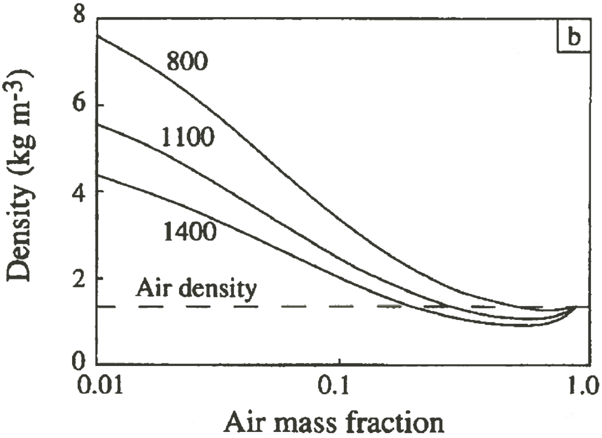
$$\frac{1}{\beta} = \frac{1-n}{\sigma} + \frac{n}{\rho}$$

n, ρ: mass fraction & density of gas
σ: density of pyroclasts
assume gas phase behaves as perfect gas:

$$\rho = \frac{P}{RT}$$

P, T: pressure & Temperature of mixture
R: gas constant, average if gaseous components: air=285 $Jkg^{-1}K^{-1}$, $CO_2 = 185Jkg^{-1}K^{-1}$, water vapor=460$Jkg^{-1}K^{-1}$

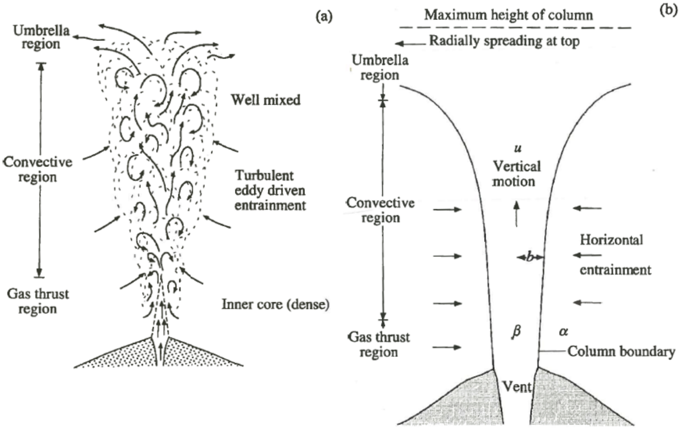
Density Variations in Eruptive Mix



Sparks et al., 1997

Density of mixture (entrained air, pyroclasts, volatiles) function of entrained air; three eruption temperatures given in Kelvin & constant water 3%

Density Variations in Eruptive Mix

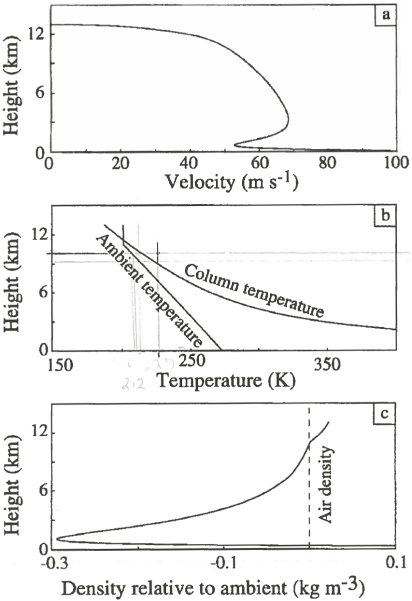


Sparks et al., 1997

entrainment coefficients: jet ≈ 0.06; buoyant plume ≈ 0.09 (more efficient; other models exist)

Density & Temperature Variations

- initial radius: 50 m
- initial velocity: 100 m /s
- eruption temperature: 1000 K
- initial mixtures 3% water (mass fraction)



Velocities vs. Vent Radii

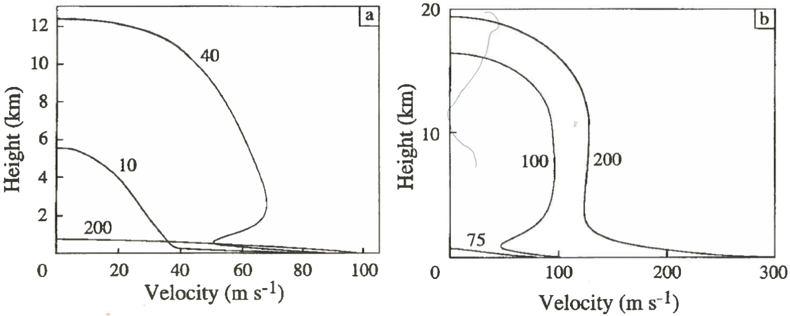
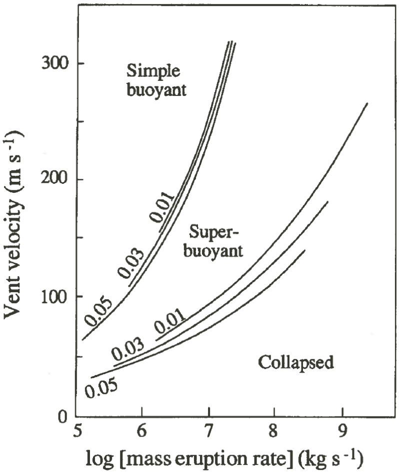


Figure 4.5 Variation of the velocity in the column as a function of the height. Curves are shown for (a) three initial radii, 10, 40 and 200 m with eruption velocity of 100 m s^{-1}, and (b) three eruption velocities 200, 100 and 75 m s^{-1} with a radius of 100 m. The mass fraction of water is 0.03 and the eruption temperature 1000 K. With the larger initial radius (a) or smaller eruption velocity (b) the material takes longer to entrain sufficient fluid to become buoyant, eventually leading to collapse in the case of the 200 m initial radius (a) and 75 m s^{-1} initial velocity (b). The 10 m vent radius (a) and 200 m s^{-1} eruption velocity (b) lead to a monotonically decaying velocity profile, since the material becomes buoyant rapidly. However, the 40 m vent radius (a) leads to a non-monotonic velocity profile, because the column entrains ambient air more slowly, and so the velocity falls off dramatically before the material becomes buoyant. A column with this non-linear velocity profile is referred to as superbuoyant. After Bursik and Woods (1991)

Sparks et al., 1997

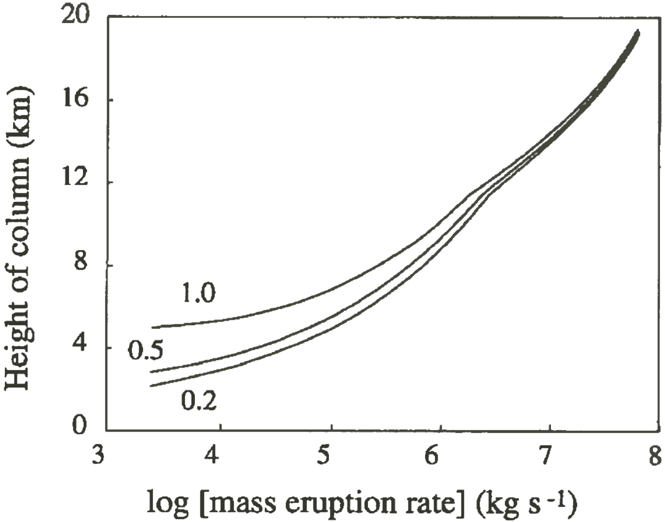
Eruption Regimes: Velocities vs. Vent Radii



Sparks et al., 1997

Solid curves are labeled with initial mass fraction of water

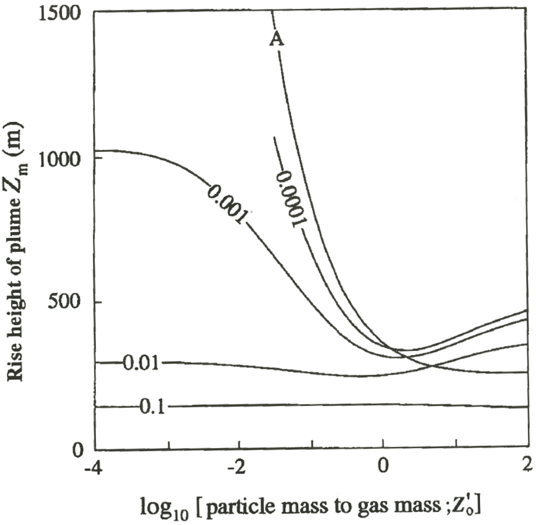
Humidity - Vapor entrainment



Sparks et al., 1997

Solid curves are labeled with different relative humidities

Jet Rise Heights - Vapor entrainment



Sparks et al., 1997

10 m vent diameter with 100 m/s initial velocity, curves for different particle radii in meters