

EXPLOSIVE ERUPTIONS



1868 Vesuvius eruption (Naples, S. Martino Museum)

EXPLOSIVE ERUPTIONS

- **driven by rapid expansion of gas**
 - ∅ fragmentation of magma + wall rock
 - ∅ **PYROCLASTIC** flow, fall, surge deposits
- **gas: exsolution of magmatic volatiles**
 - eg. H₂O, CO₂, sulfur gases, HCl, HF

 - external water ⇒ steam**
 - eg. rain, snow, crater lake, groundwater

EXPLOSIVE ERUPTIONS

- **“dry” explosive:** role of external water H_2O is minor
- **“wet” explosive:** role of external H_2O is very important
phreatomagmatic, phreatic, hydroexplosive
- explosive eruptions can be dominantly dry,
dominantly wet, or
a combination

MECHANISMS (dry)

bubbly foam \Rightarrow particles + gas

1. volatile exsolution

- confining **P** decreases as magma rises
 \Rightarrow dissolved volatiles exsolve (form bubbles)

2. bubble growth

- decompression, continued diffusion, coalescence



Note viscosity control

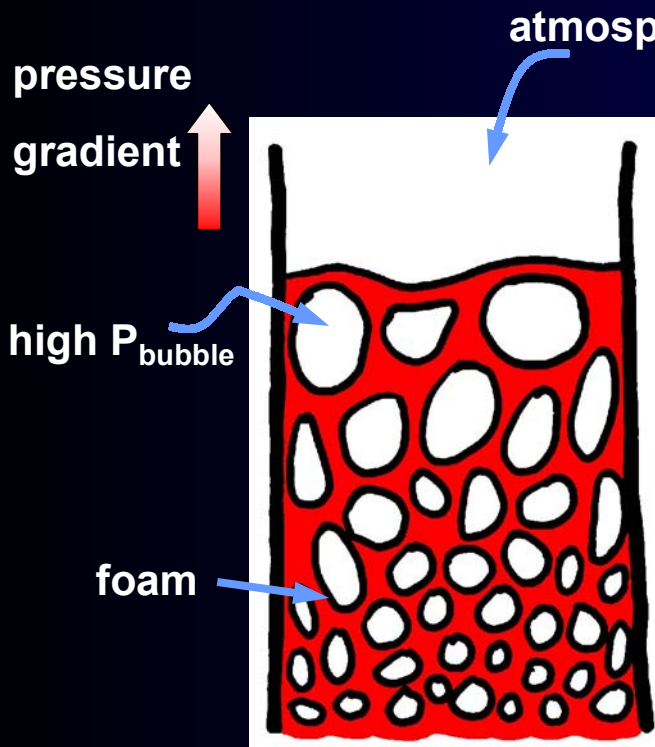
low viscosity: coalescence & rise of bubbles easy

high viscosity: growth & rise inhibited, P build-up

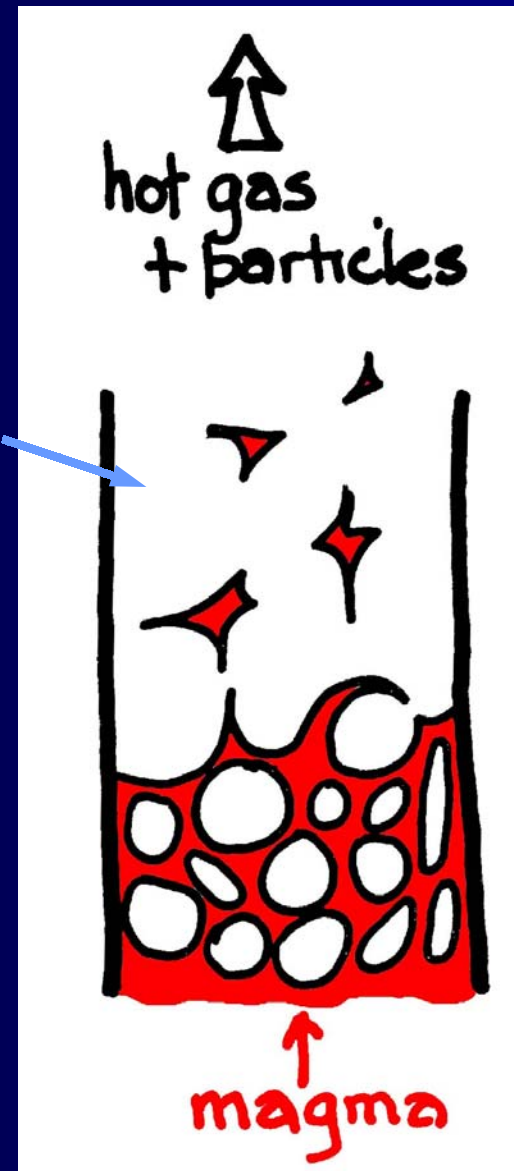
- stops when $P_{\text{bubble}} = P_{\text{volatiles remaining in magma}}$
ie. equilibrium; usually void fraction 70-80 %

MECHANISMS (dry)

3. fragmentation



decompression
and explosive
expansion



fragmentation

eruption column: high-velocity jet of hot gas + hot particles expelled into the atmosphere

- momentum from decompression and expansion of the gas phase

what next?

depends on ρ_{column} cf. $\rho_{\text{atmosphere}}$

- if $\rho_{\text{column}} < \rho_{\text{atmosphere}}$
 - ∅ buoyant eruption plume
 - ⇒ pyroclastic fall deposits
- if $\rho_{\text{column}} > \rho_{\text{atmosphere}}$
 - ∅ eruption column collapses under gravity
 - ⇒ pyroclastic flows and surges

buoyant eruption columns

umbrella

structure: convective plume

gas thrust

gas thrust

- 100's m to a few km above vent
- mean exit velocities 30 to 600 ms⁻¹
 - ie. subsonic to supersonic
- momentum from decompression of gas
 1. slows down: atmospheric drag
 2. expands: from high P_{bubble} to atmospheric P
 3. mixes with air: entrained at base and sides
 4. heat transfer: hot small p'cs $\xrightarrow{\text{heat}}$ gas + air

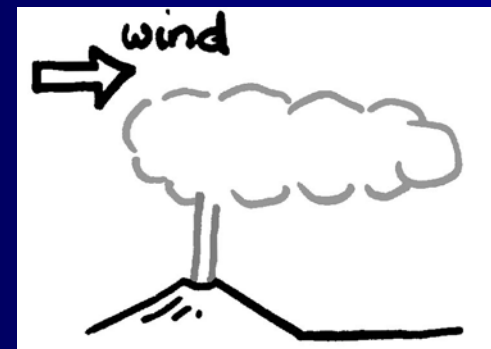
buoyant eruption columns

convective plume

- several km to tens km above vent
- $\rho_{\text{column}} < \rho_{\text{atmosphere}} \Rightarrow$ rises buoyantly

umbrella

- eventually $\rho_{\text{column}} = \rho_{\text{atmosphere}}$
level of neutral buoyancy, H_B
- radial spreading \Rightarrow umbrella cloud or plume
- strong wind \Rightarrow asymmetric expansion; stops up-wind at stagnation point, blown farther downwind



buoyant eruption columns

how high can the column rise?

- total height $H_T = 5.773 (1+n)^{-3/8} [\sigma Q s (t_i - t_a)]^{1/4}$
where, n , vertical gradient of absolute T to lapse rate;
 σ , magma density;
 s , specific heat of magma;
 t_i , initial T of erupting mixture;
 t_a , atmospheric T ;
 Q , volume discharge rate of magma, m^3s^{-1}

most parameters except Q vary only slightly

thus H_T is strongly controlled by Q



Note that $H_T > H_B$ due to overshoot

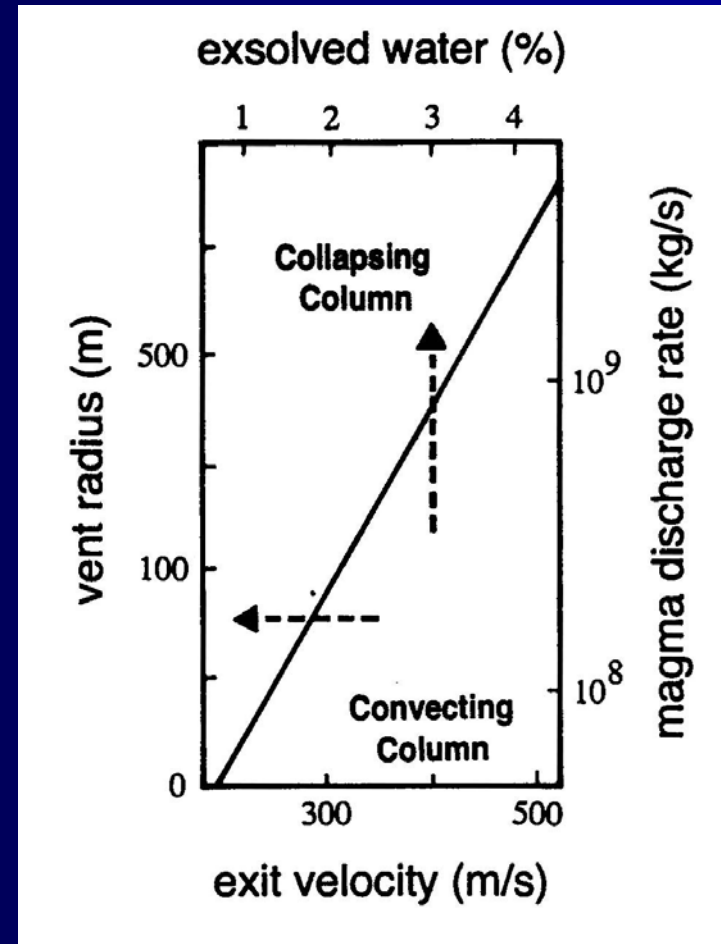
- explosive eruption \Rightarrow buoyant eruption column
 \Rightarrow widespread pyroclastic fall deposits

eruption column collapse

$$\rho_{\text{column}} > \rho_{\text{atmosphere}}$$

- discharge rate is too high or increases
- vent is too wide or radius increases
- gas content is too low or decreases
- clasts are too coarse or too cool

- eruption column collapse
 - ➡ pyroclastic flow deposits (ignimbrites)



TRANSPORT AND DEPOSITION OF PYROCLASTS

pyroclasts: juvenile - **hot** pumice, shards, crystals
lithic clasts - wall rock; warm or cold
range in size, shape, T, ρ

gas phase: **hot** magmatic gas and air

- pyroclast population in erupting mixture:
 1. smallest pyroclasts stay suspended in the hot gas
 2. largest pyroclasts rapidly separate from the hot gas
 3. other pyroclasts are transported or deposited depending on size and density
- deposits: pyroclastic fall, pyroclastic flow, pyroclastic surge

PYROCLASTIC FALL DEPOSITS

1. fallout from buoyant eruption columns

- p'cs fall out when the terminal fall velocity of the clast = local upward velocity of the plume



terminal fall velocity: depends on size, density and shape;
reflects balance of gravitational force \Downarrow and atmospheric drag \Uparrow

- higher eruption column \Rightarrow wider dispersal
- fallout trajectory usually \Downarrow but may be oblique (if windy or very close to source)
- low solids concentration

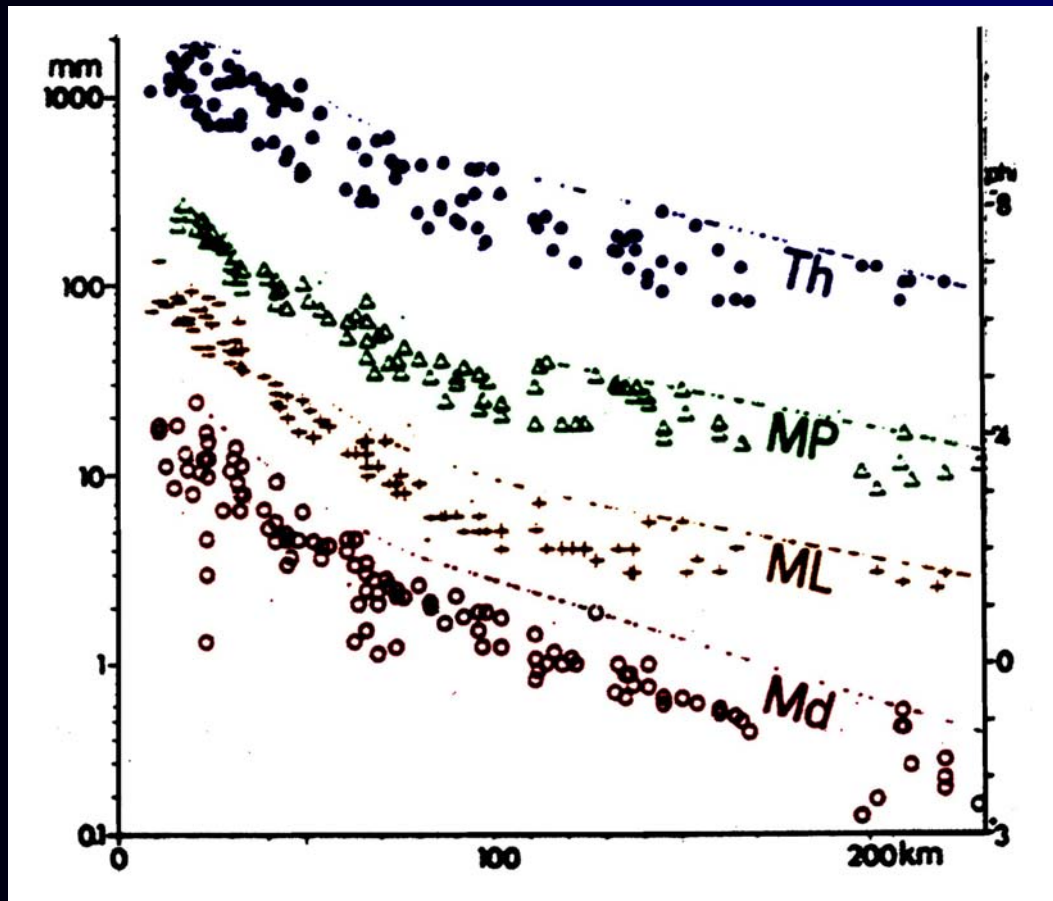
PYROCLASTIC FALL DEPOSITS

thus, typical fall deposits

- are widespread and thin
- are relatively well sorted
- show systematic decrease in grain size, clast density and thickness with distance from source
- show mantle bedding
- consist of angular, ragged clasts
- consist of cold clasts (usually)

PYROCLASTIC FALL DEPOSITS

distance from vent →



Taupo 186 AD
fall deposit

Th, thickness

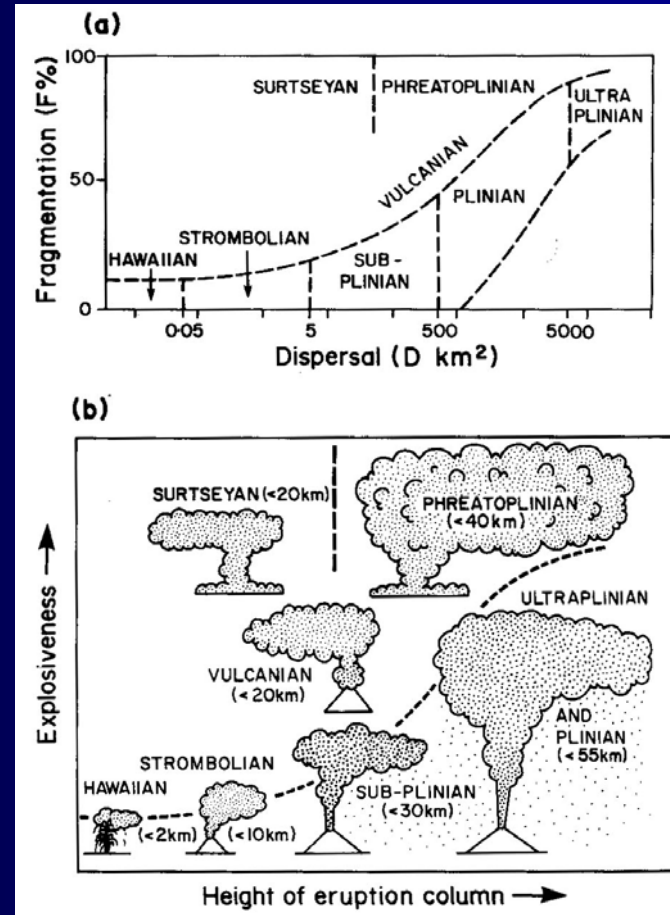
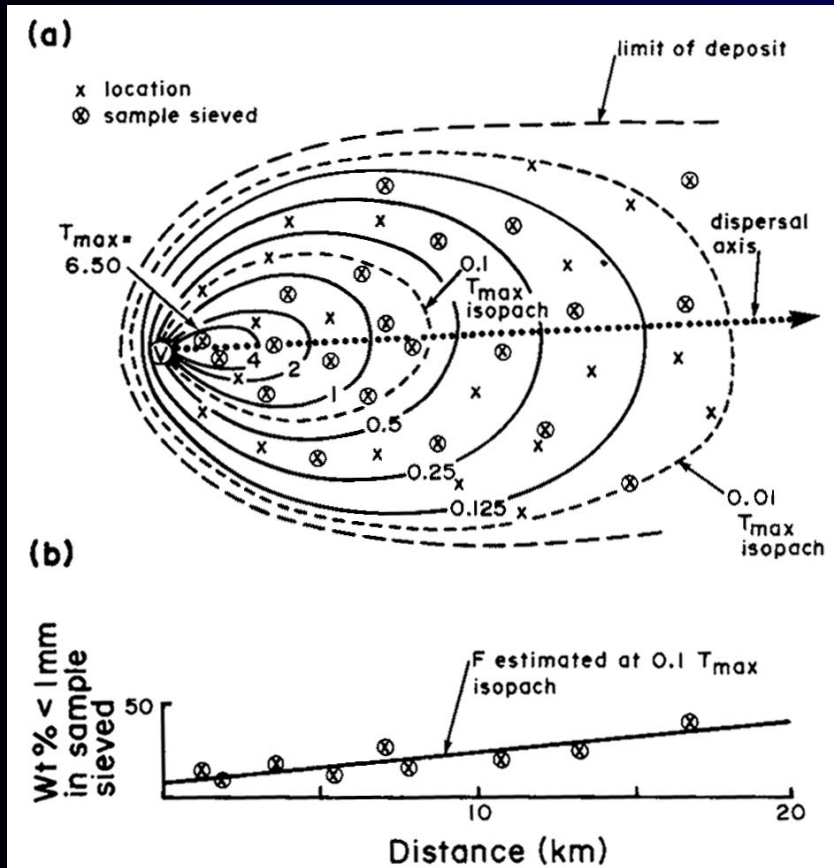
MP, maximum pumice clast

ML, maximum lithic clast

Md, median diameter

Walker 1980

PYROCLASTIC FALL DEPOSITS



(a) Dispersal (area covered) and (b) Fragmentation (grain size)

D-F plot for pyroclastic fall deposits


(Walker 1973)

PYROCLASTIC FALL DEPOSITS

2. fallout from single explosions

ie. no buoyant column



- dominated by ballistic fallout
 - clasts too coarse or dense to be entrained in the gas
 - eg. lithic clasts $\geq 20\text{-}30$ cm
 - pumice clasts ≥ 50 cm (depends on ρ)
- transport distance depends on
 - trajectory 
 - initial velocity (“muzzle velocity”)
 - shape, size, density

PYROCLASTIC FALL DEPOSITS

ballistic fall out deposits

- usually isolated coarse and dense clasts or single-clast-thick layer
- impact sags common
- < 3-5 km from vent, small volumes



Note dispersal is not dependent on Q or H_T

3. classification of pyroclastic fall deposits

- based on F , fragmentation index (grain size)
 D , dispersal (distance from vent)
- plinian, subplinian, strombolian, hawaiian

PYROCLASTIC FLOW DEPOSITS

pyroclastic flow

- hot gas-supported, high particle concentration, laterally moving, gravity-controlled current
- generated by:
 1. eruption column collapse
 - ➔ **pumice flow deposits, ignimbrite;**
usually rhyolite or dacite
 2. upwelling and overflow, no eruption column
 - ➔ **pumice flow deposits, ignimbrite;**
usually rhyolite, dacite or andesite
 3. collapse of lava domes
 - ➔ **block and ash flow deposits;**
usually rhyolite, dacite or andesite

PYROCLASTIC FLOW DEPOSITS

- mobility of pyroclastic flows
 - momentum from collapse height
 - gas-supported
 - denser than air



Note: the flow " the deposit

moving dynamic system

particulate aggregate

typical pyroclastic flow deposits

- poorly sorted
- massive to weakly stratified or graded
- infill topography, flat top surface
- ML (vent-derived) decreases with distance from source

PYROCLASTIC FLOW DEPOSITS

- can be very big up to a few hundred m thick
 cover 100's to 1000's km²
 volumes of 10's to 100's km³
- wide range in emplacement T
 - cool (" 500°C) ⇒ non-welded
 - hot ⇒ welded
 - very hot ⇒ rheomorphic (ie. pyroclasts welded completely and non-particulate flow occurs)
- may show columnar jointing
- glassy components may crystallise or devitrify

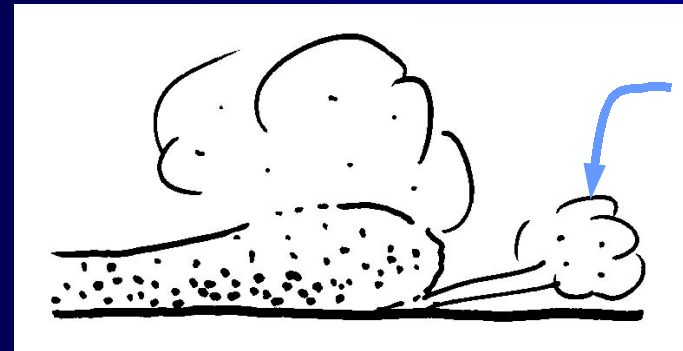
PYROCLASTIC SURGE DEPOSITS

pyroclastic surge

- gas-supported, relatively dilute, turbulent, laterally moving, partly gravity-controlled current
- generated:
 1. directly from the vent
 2. from partial collapse of the eruption column

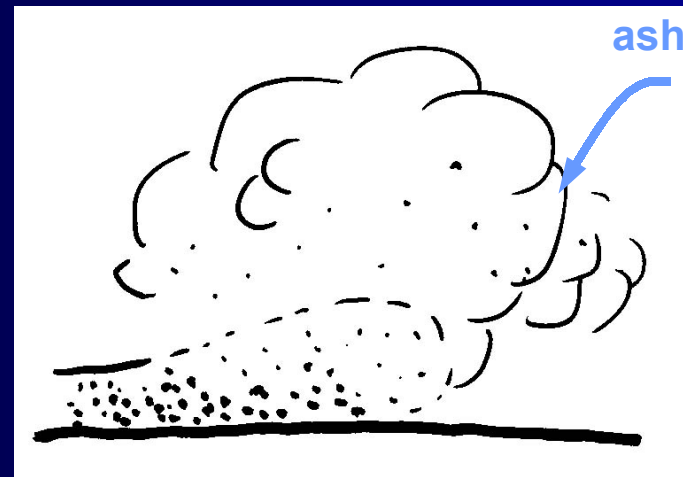
PYROCLASTIC SURGE DEPOSITS

3. associated with pyroclastic flows
⇒ ground surge
in advance of the pyroclastic flow



ground
surge

⇒ ash cloud surge
from dilute top of the
pyroclastic flow




ash cloud
surge

- relatively cool (<100°C) to hot emplacement

PYROCLASTIC SURGE DEPOSITS



typical pyroclastic surge deposits

- moderately sorted
- stratified, commonly very thinly bedded
- unidirectional bedforms 
 - dunes, cross-bedding, cross lamination, pinch-and-swell, wavy bedding, scours
- drape topography
- small volumes, limited extent (vent-derived)
 - bedsets <1 m thick
 - extent <3-5 km from source
 - volumes << 1 km³

TERMS FOR PYROCLASTS



particles produced by explosive eruptions

<i>particle</i>	<i>size</i>	<i>rocks</i>
ash	< 2 mm	tuff
lapilli	2 - 64 mm	lapilli tuff, lapillistone
block 	> 64 mm	p'c breccia, agglomerate
bomb 		

- crystal tuff, lithic tuff, shard tuff
- ignimbrite \equiv pyroclastic flow deposit
- lapilli tuff: mixture of ash and lapilli; rock