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. H_2O, CO_2, 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 ⇒ particles + gas

1. volatile exsolution

- confining **P** decreases as magma rises

  ⇒ dissolved volatiles exsolve (form bubbles)

2. bubble growth

- decompression, continued diffusion, coalescence

⚠ **Note viscosity control**

low viscosity: coalescence & rise of bubbles easy

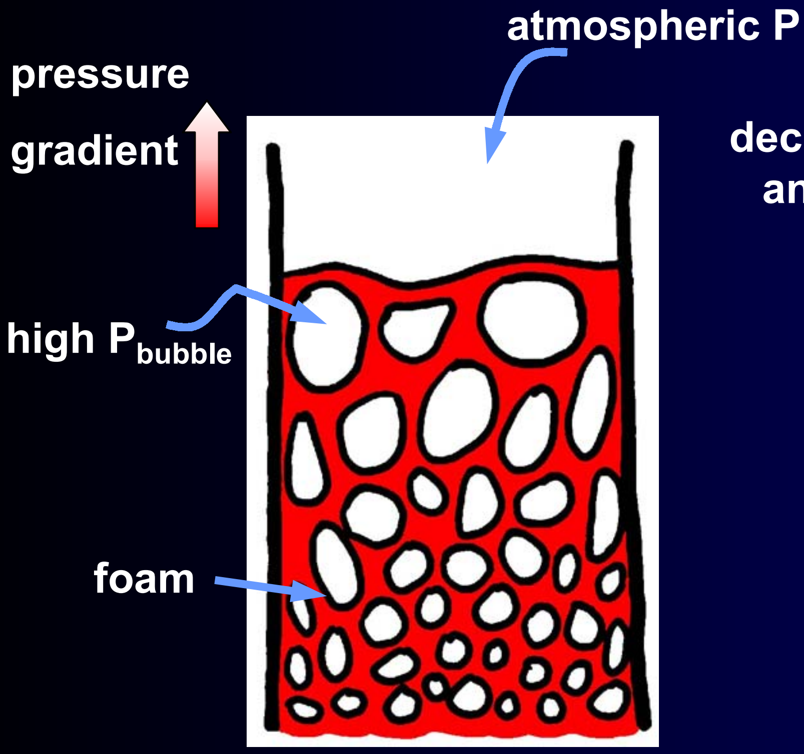
high viscosity: growth & rise inhibited, P build-up

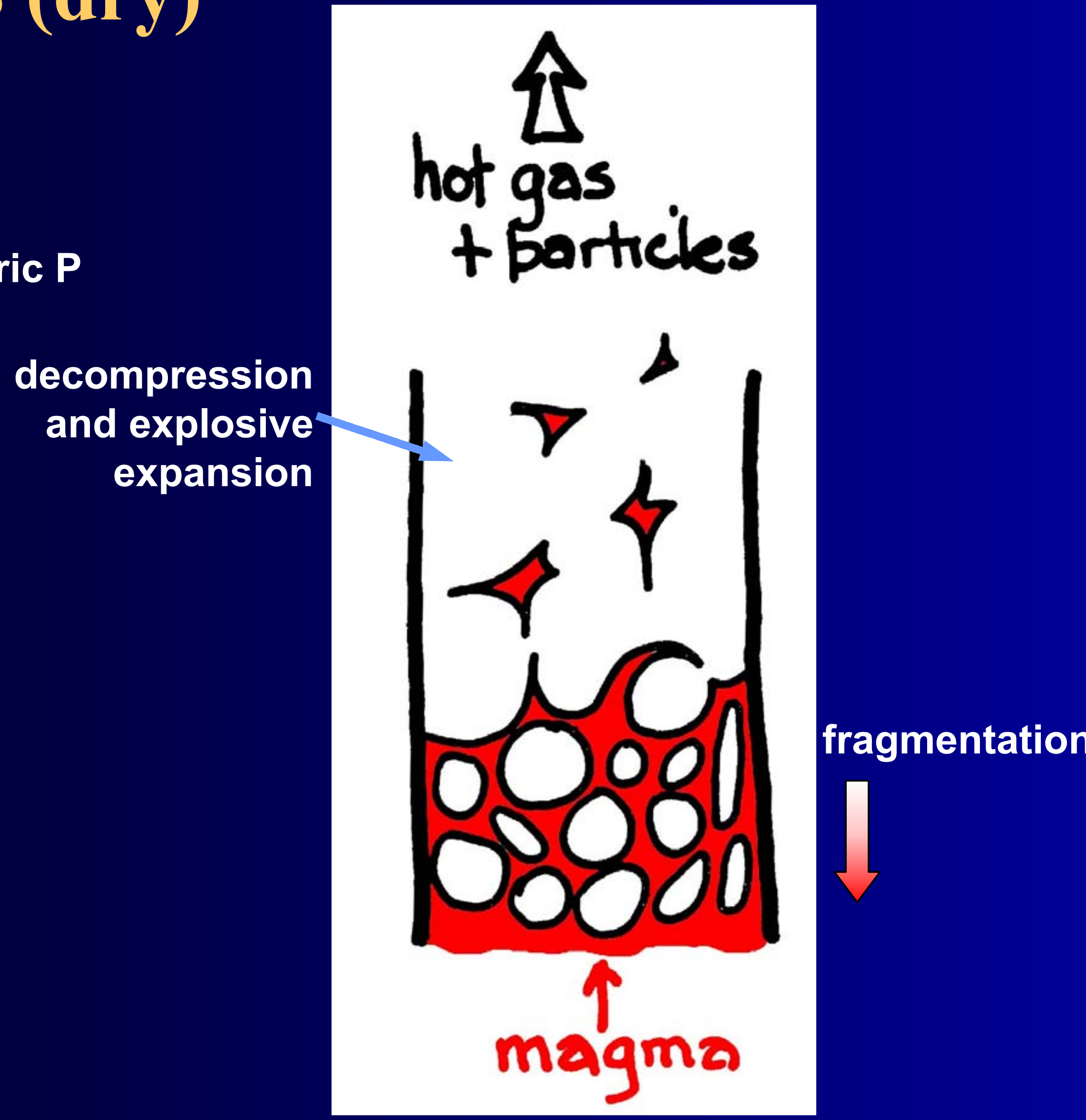
- stops when $\mathbf{P}_{\text{bubble}} = \mathbf{P}_{\text{volatiles remaining in magma}}$

  ie. equilibrium; usually void fraction 70-80 %

MECHANISMS (dry)

3. 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. $\rho_{atmosphere}$

- if $\rho_{column} < \rho_{atmosphere}$

  ∅ buoyant eruption plume

  ➡ pyroclastic fall deposits

- if $\rho_{column} > \rho_{atmosphere}$

  ∅ 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 $\xrightarrow{heat}$ gas + air

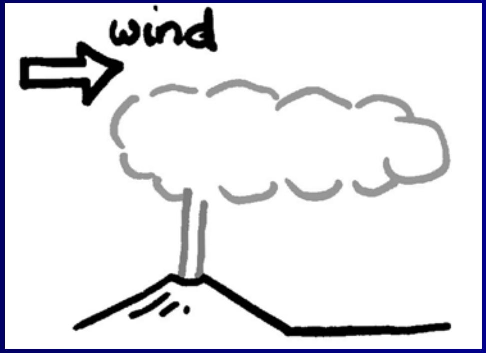
buoyant eruption columns

convective plume

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

umbrella

- eventually $\rho_{column} = \rho_{atmosphere}$
  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 $H_T = 5.773\,(1+n)^{-3/8}\,[\sigma \mathbf{Q} s(t_i - t_a)]^{1/4}$
  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 → buoyant eruption column
  → widespread pyroclastic fall deposits

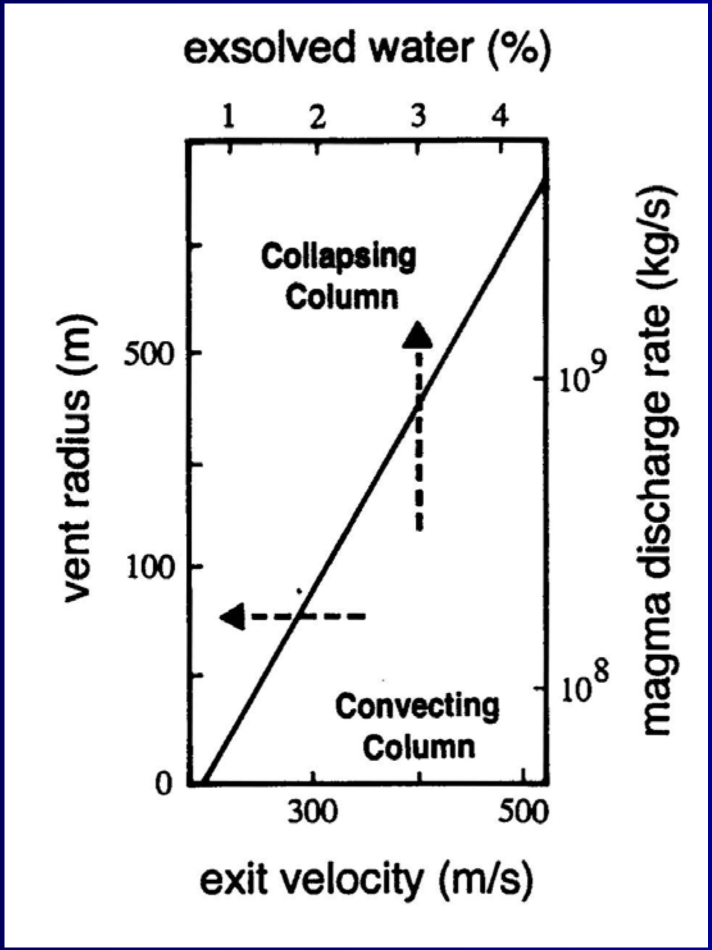
eruption column collapse

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

- 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 ⇓ and atmospheric drag ⇑

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

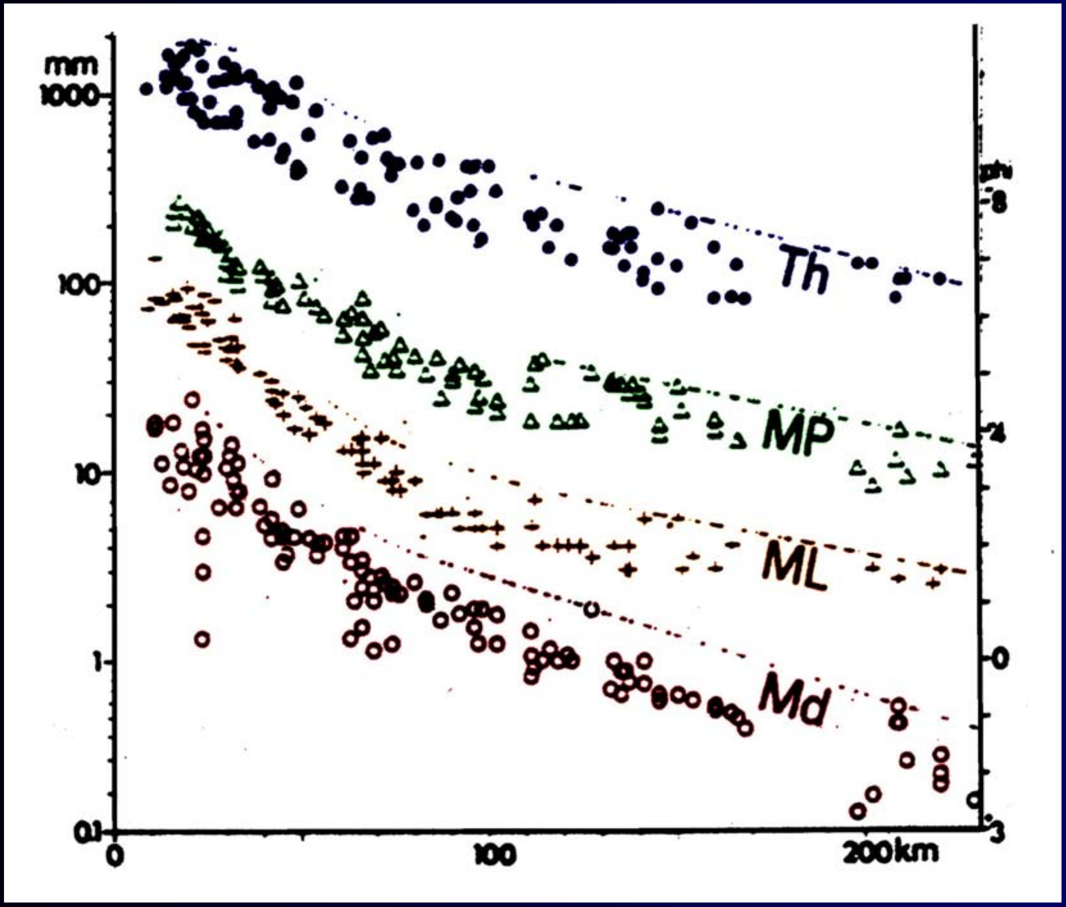
PYROCLASTIC FALL DEPOSITS

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

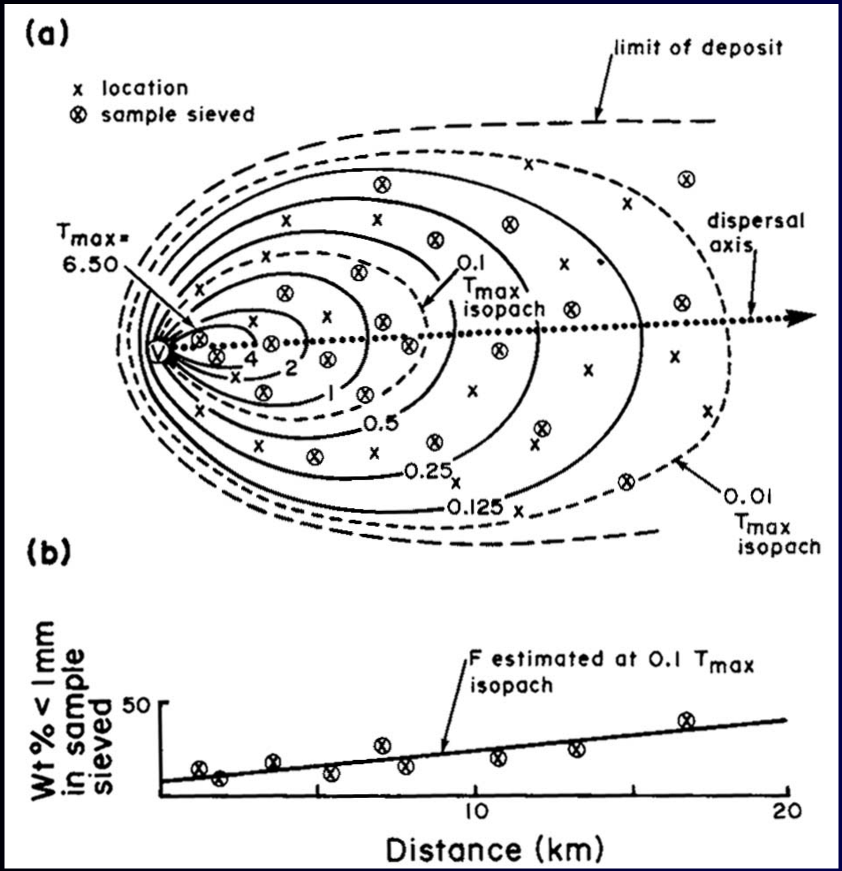
MP, maximum pumice clast

ML, maximum lithic clast

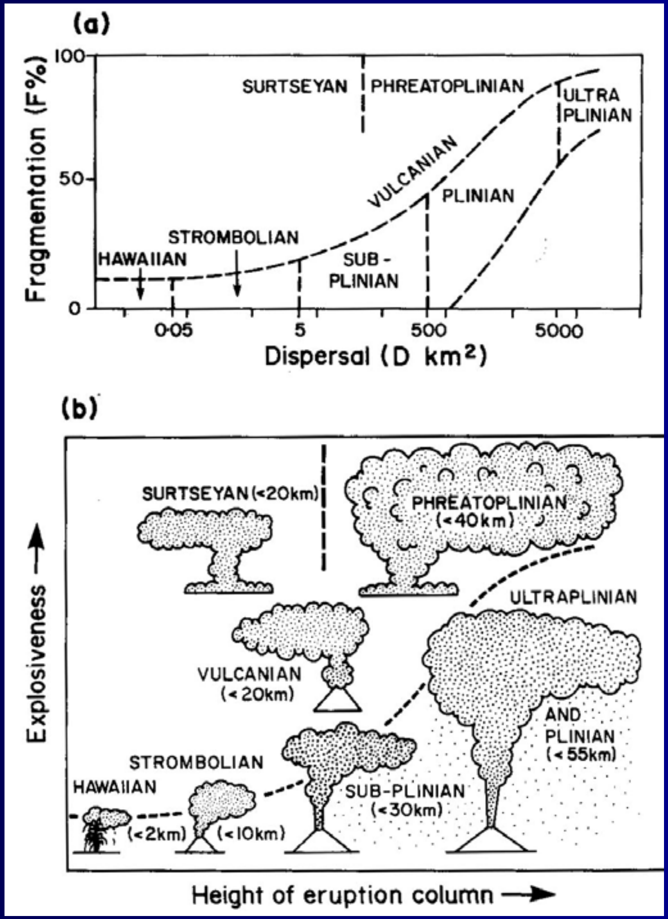
Md, median diameter

Walker 1980

PYROCLASTIC FALL DEPOSITS



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



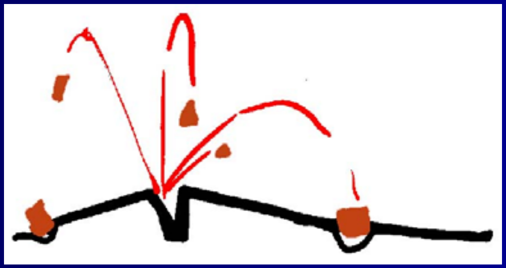
D-F plot for pyroclastic fall deposits

(Walker 1973)

PYROCLASTIC FALL DEPOSITS

2. fallout from single explosions

ie. no buoyant column

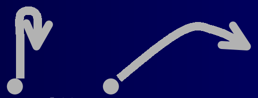


- dominated by ballistic fallout

  clasts too coarse or dense to be entrained in the gas

  eg. lithic clasts ≥ 20-30 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 km^2
  - volumes of 10's to 100's km^3
- 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

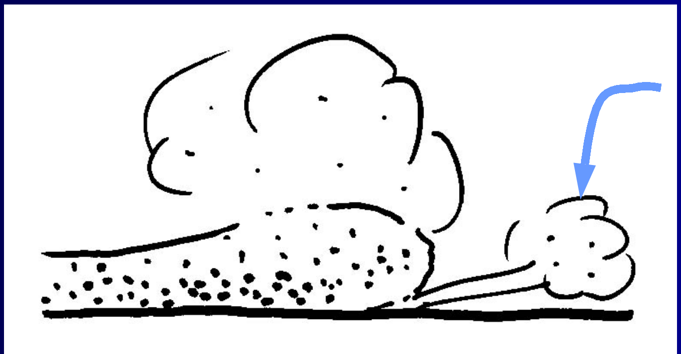
  2. from partial collapse of the eruption column

PYROCLASTIC SURGE DEPOSITS

3. associated with pyroclastic flows

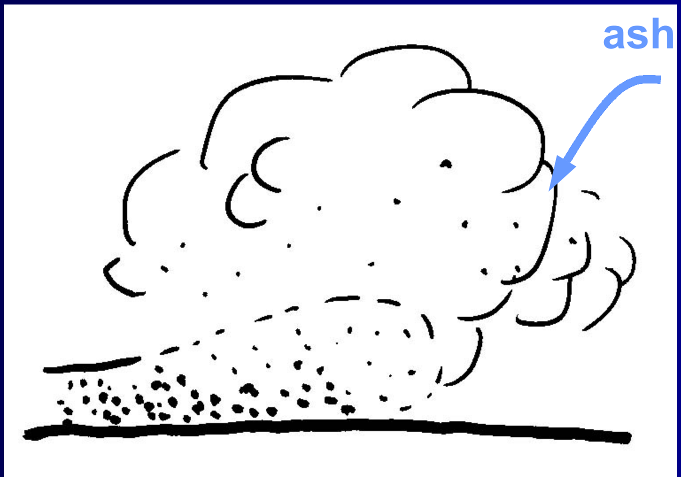
⇒ ground surge

in advance of the pyroclastic flow



⇒ ash cloud surge

from dilute top of the pyroclastic flow



- 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	$<< 1\ km^3$

TERMS FOR PYROCLASTS

particles produced by explosive eruptions

particle	***size***	***rocks***
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 ≡ pyroclastic flow deposit
- lapilli tuff: mixture of ash and lapilli; rock