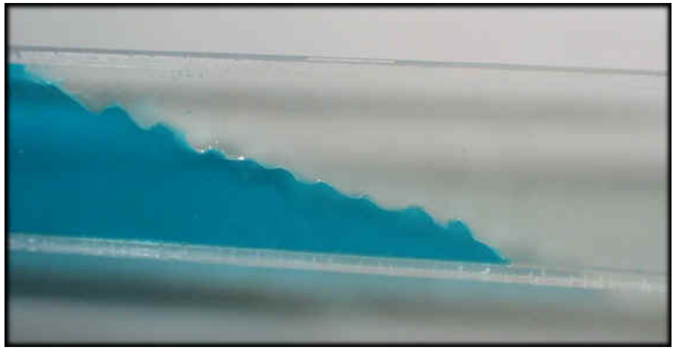
Pyroclastic density currents

L.Pioli

- A Pyroclastic density current is a gravity current composed of gas and pyroclasts

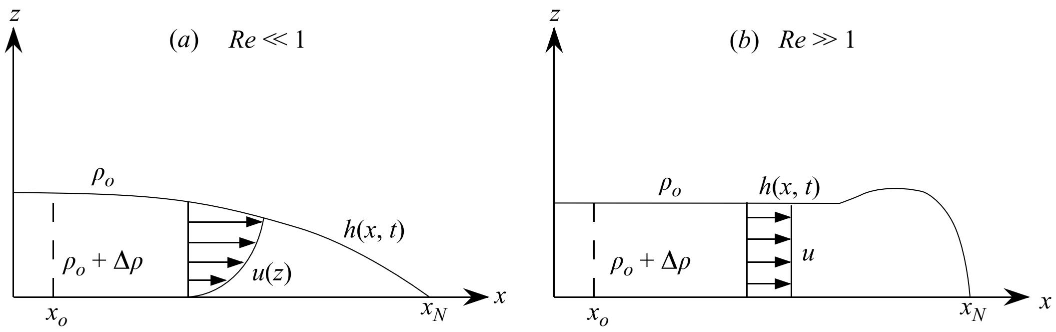
- A gravity current is a primarily horizontal flow which is driven by density differences



- *Which type of natural gravity currents do you know?*

Viscous gravity currents

- lava domes and flows
- Two immiscible fluids (air and lava)



Re is Reynolds number

$$Re = \frac{\rho u h}{\eta}$$

Viscous gravity currents

$$\frac{\partial h}{\partial t} - \frac{\beta}{x^n}\frac{\partial}{\partial x}\left(x^n h^3 \frac{\partial h}{\partial x}\right) = 0,$$

where $\beta = \frac{1}{3} g/\nu,$

$$\int_o^{x_N(t)} (2\pi x)^n h(x,t)\,\mathrm{d}x = q t^\alpha,$$

If Bond number $B=\rho g x_n/\sigma$ is much larger than1

If α=1 the flux is constant

If α=0 the flux is impulsive

Given that :

$$\zeta = (\beta q^3)^{-1/(5+3n)} x t^{-(3\alpha+1)/(5+3n)}$$

Where n=0 in cartesian coordinates
Where n=1 in radial coordinates

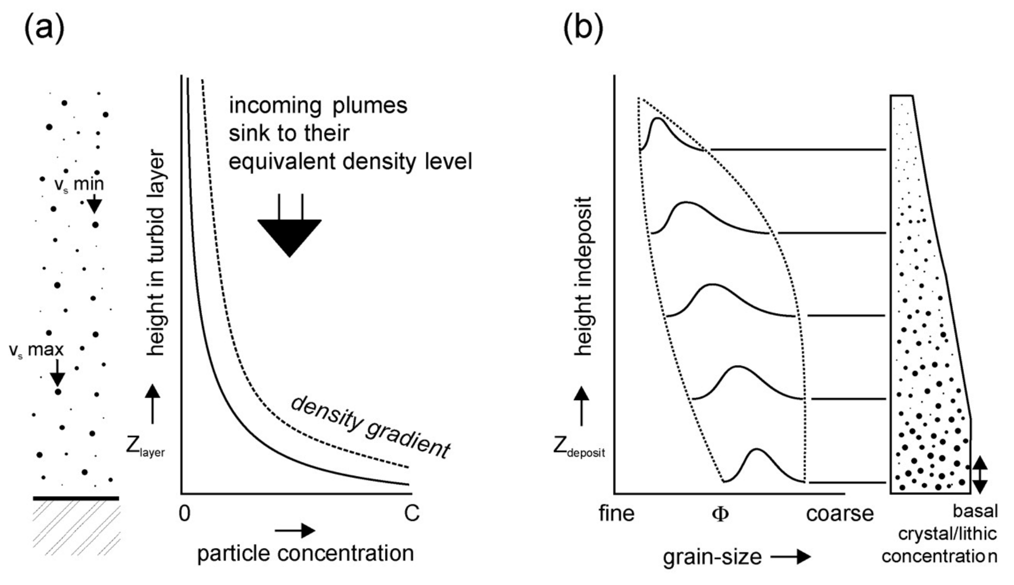
The runout x_N is:

$$x_N = \zeta_N (\beta q^3)^{1/(5+3n)} t^{(3\alpha+1)/(5+3n)}$$

Particulate-laden currents

- Heavy particles drive the flow;

- They fall or rise out of the flow while the driving buoyancy continually decreases



Particulate-laden currents

- High Re: they are sufficiently turbulent to maintain a vertically uniform particle concentration in the main body of the current

- Low Re: particles settle down; vertical and horizontal density gradients develop

Particulate-laden currents

- Particles settle down at the Stokes velocity u_s

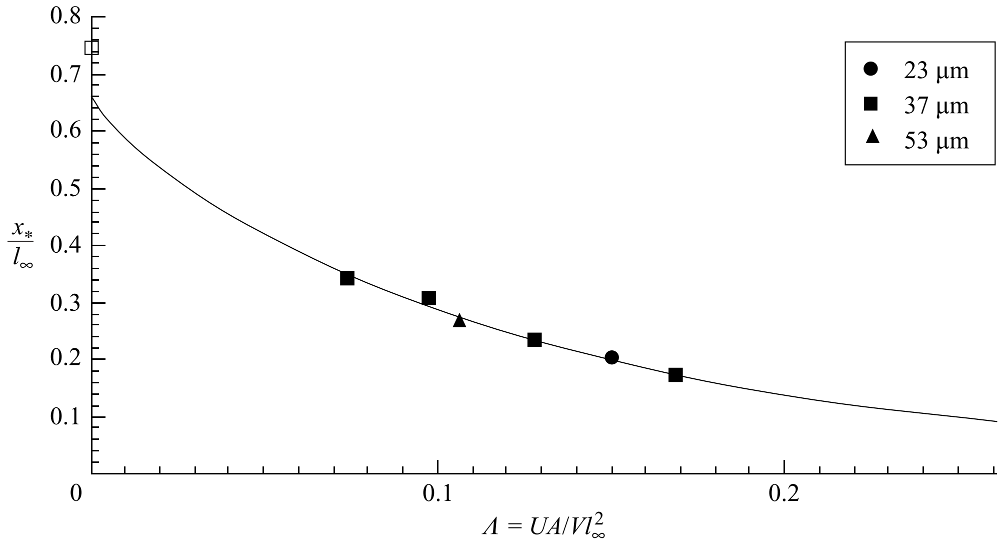
- In a layer of depth h
- $\Delta N_p = -u_s C_0 \Delta t$ where C_0 is the initial number concentration of particles

- If the particles are homogeneously distributed
- $C_0 = N_p/h$

$$\frac{\mathrm{D}}{\mathrm{D}t}\phi \equiv \frac{\partial \phi}{\partial t} + \boldsymbol{u} \cdot \nabla \phi = -V_s \phi / h,$$

Huppert, 2006

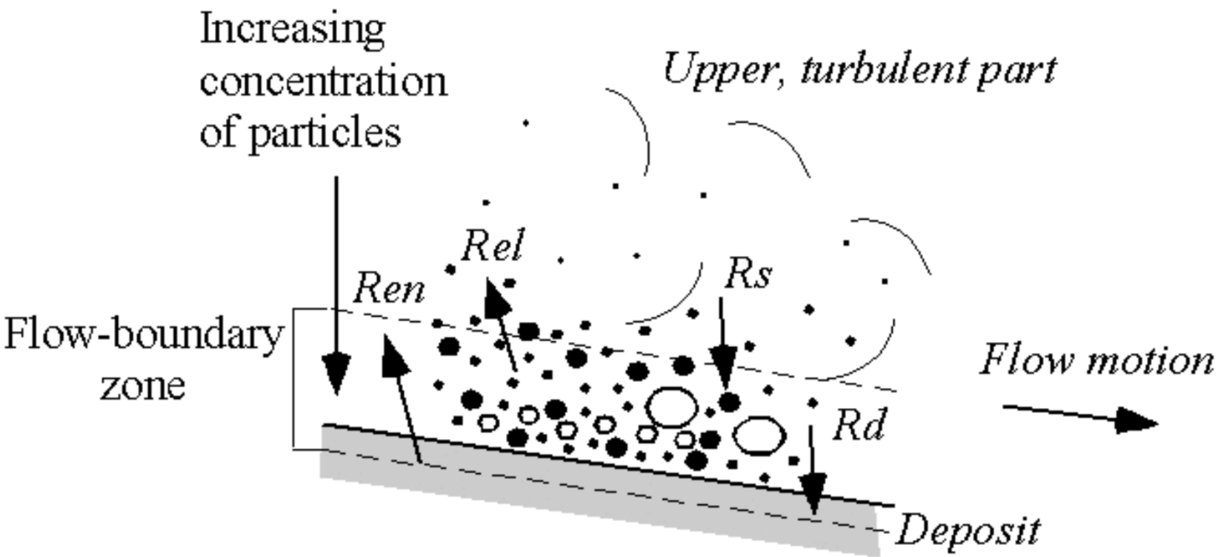
Particulate-laden currents-runout



$$g'_P = (\rho_P - \rho_a) g / \rho_a,$$

$$l_\infty = (g'_P \phi_o A^3 / V_s^2)^{1/5}$$

The lower part of the current where particle-particle interaction dominates the transport mechanisms and promotes deposition is called the flow-boundary zone



Rel= elutriation rate

Ren=re-entrainment rate

Branney and Kokelaar 2002

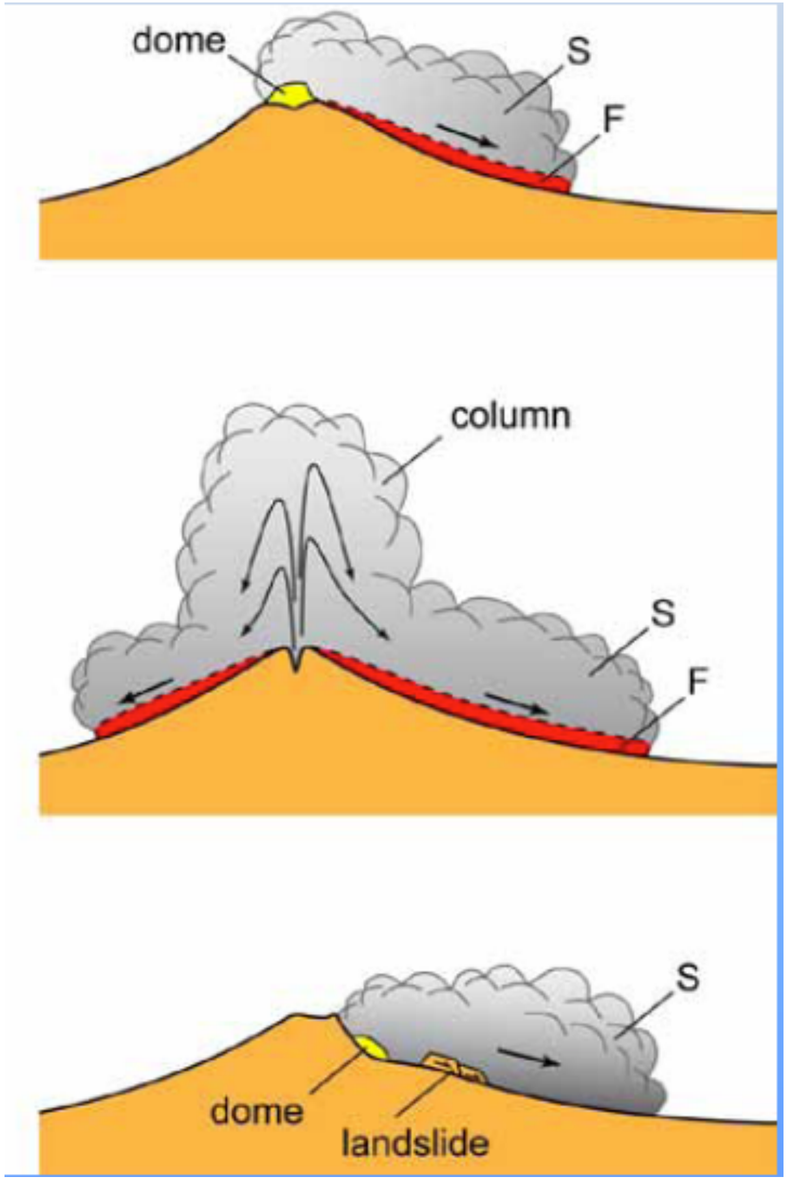
- The rate of deposition (Rd) = mass flux of pyroclasts into the deposit per unit area of the flow boundary.

- The rate of sedimentation (Rs) = mass flux of pyroclasts per unit area supplied to the lowermost concentrated part of the current.

Generation of pyroclastic density currents

PDC originate in different ways and from various sources, during explosive eruptions or gravity-driven collapse of domes.

or relatively long-lived (sustained; i.e. continuously fed)

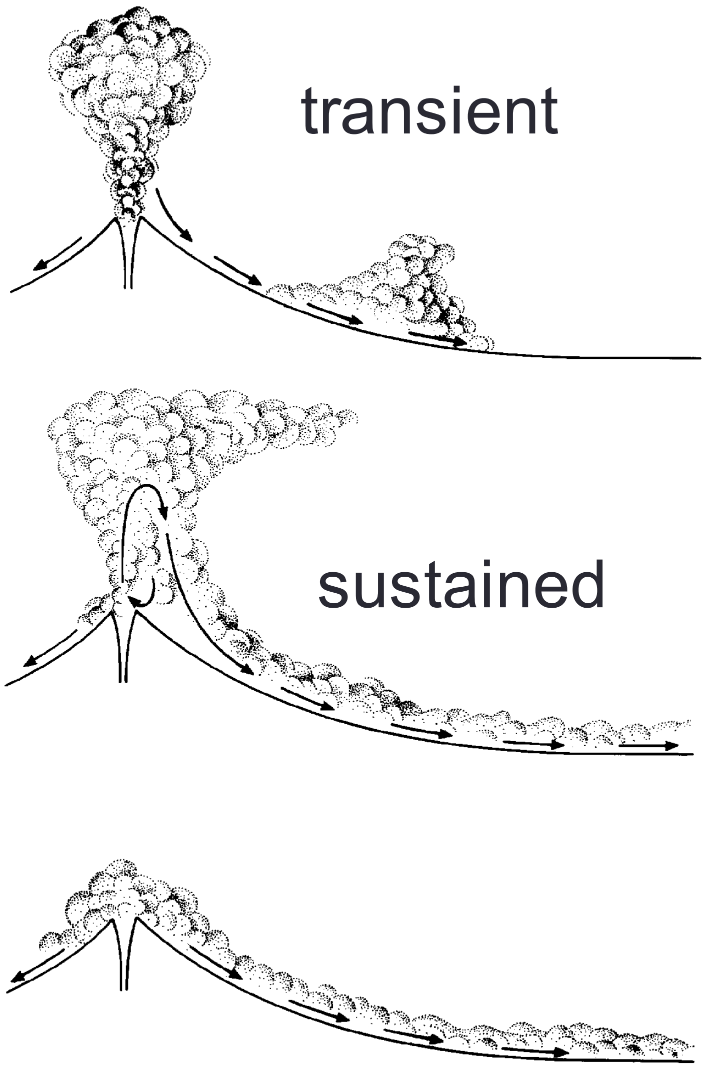


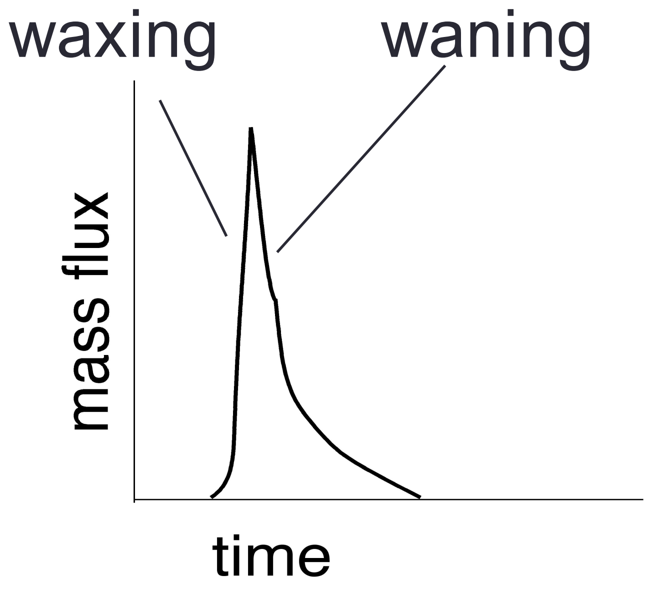
Dome collapses

Column collapses

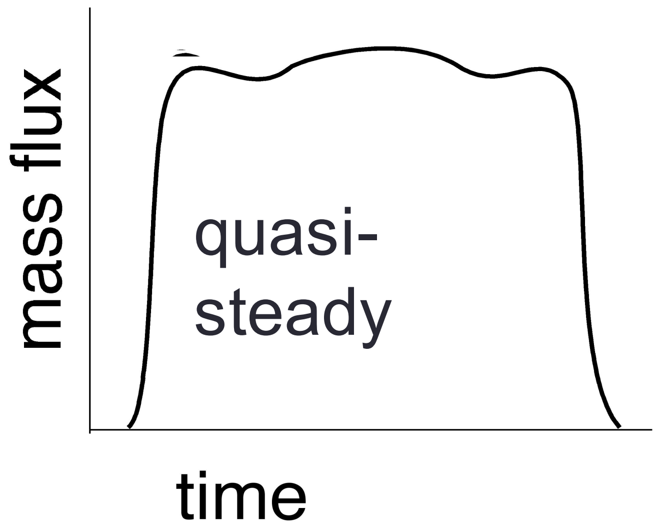
Lateral blast

Eruption style





single surge
rapidly
decaying

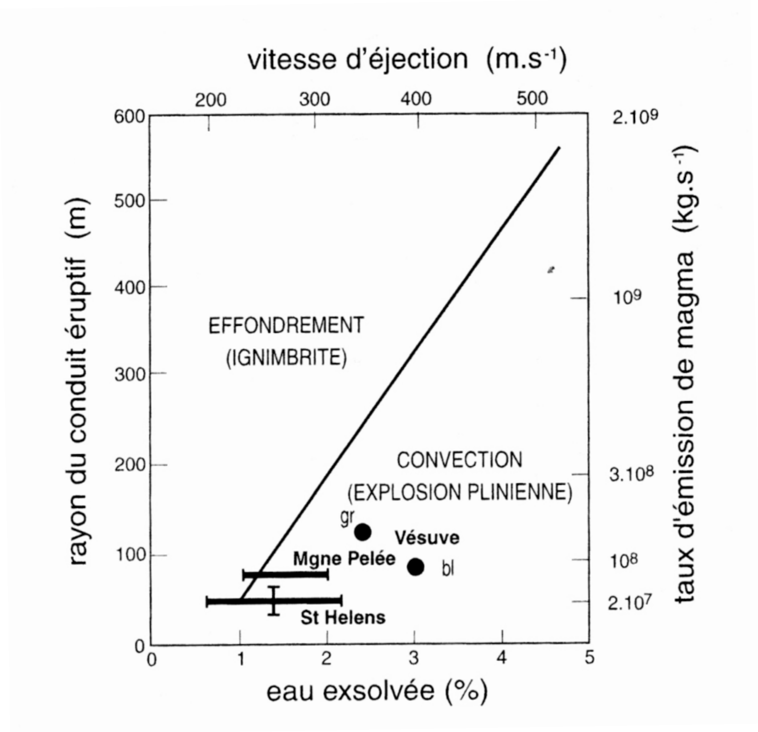


•*Formation of PDC*

•The rising plume does not reach a sufficient decrease in density before the end of the gas thrust zone and then continuously collapse. In the case of boiling over the gas thrust zone is very reduced or absent.

•Few eyewitness accounts (Pliny the Younger was the first) of the largest events

•Very dangerous and catastrophic phenomena.



1. Eruption rate is too high.
2. Not enough gas.
3. Vent is too wide.
4. Eject are too cool or too coarse
5. increasing of density fragment
6. During phreatomagmatic eruption

Pyroclastic density currents

Laterally moving volcanic gas-particle mixtures more dense than the surrounding atmosphere.

Gas: H_2O (99%), SO_2, H_2SO_4, H_2S, CO_2, CO, NH_3, F_2, HCl, HF

Particles:
- Fragment of magma (pumice or scoriae)
- Crystals
- source-derived lithic (from the magma chamber, the conduit)
- accidental lithic (eroded from the substratum)

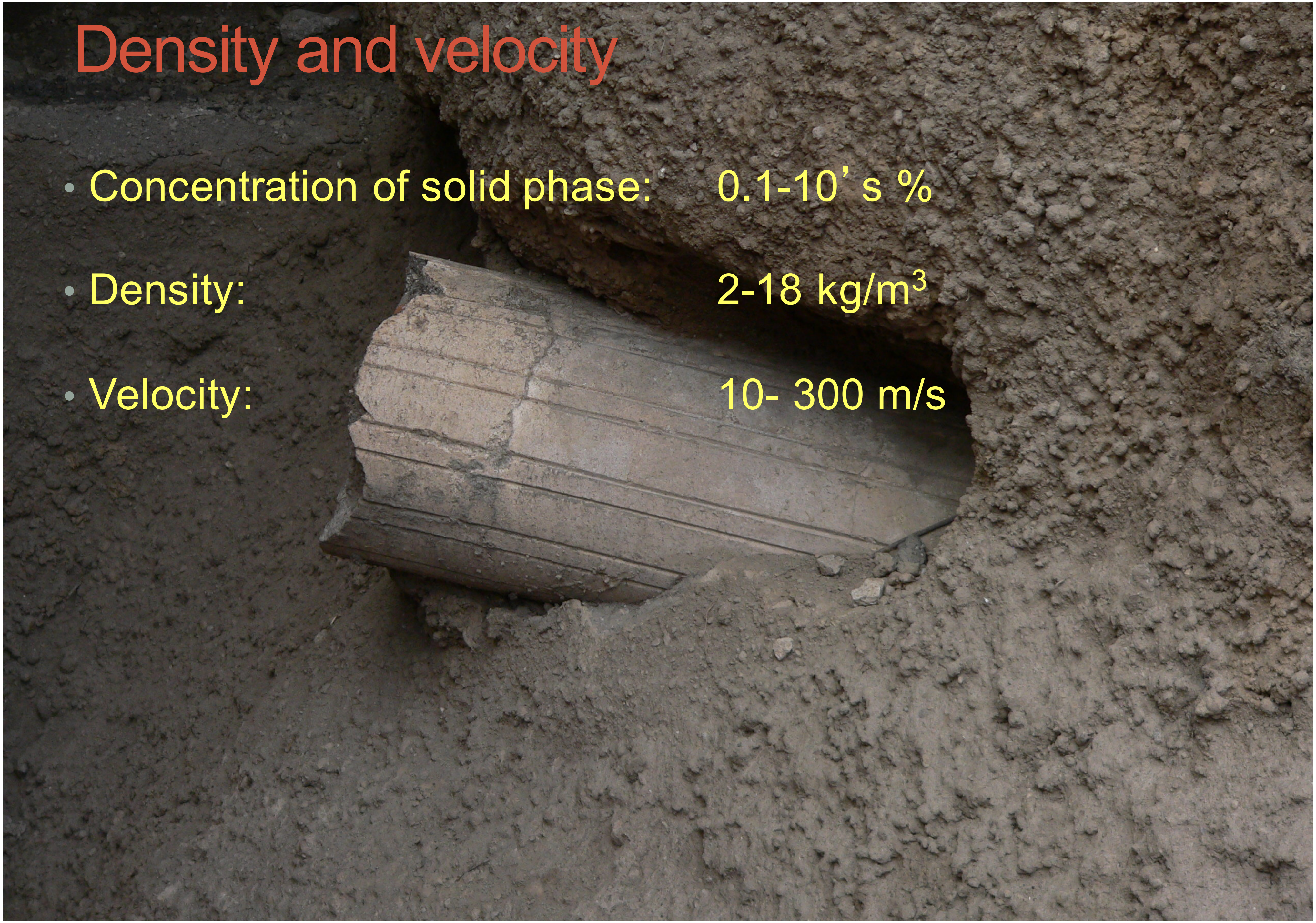
Missiles:
- Logs, bodies, cars, tiles……

Energy sources: gravity (collapse) or laterally directed explosion (blast)

.

Density and velocity

- Concentration of solid phase: 0.1-10’s %
- Density: 2-18 kg/m^3
- Velocity: 10- 300 m/s



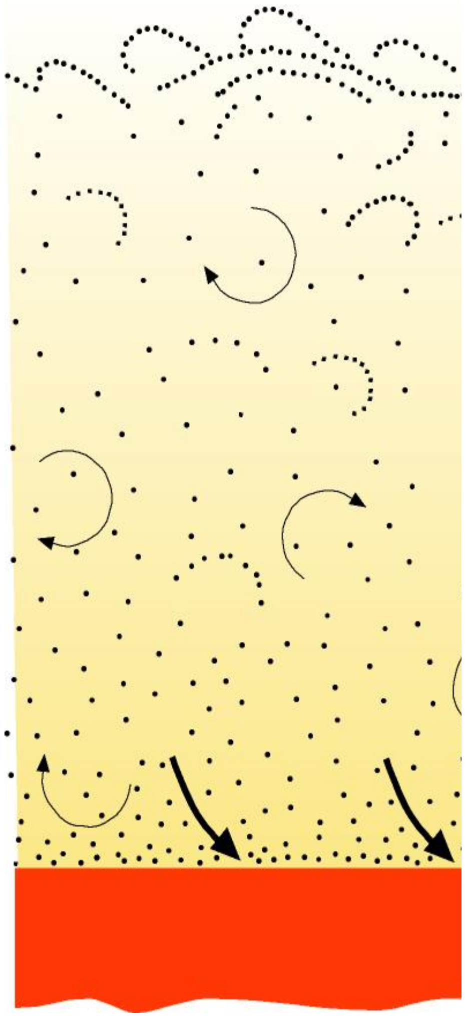
Temperature

Minimum temperature: less than 100˚ C in wet PDC (three-phase system water drops, ash, and vapor) or at the base of PDC for air ingestion (ambient temperature)

Maximum temperature: the magmatic temperature (700-1000˚ C)

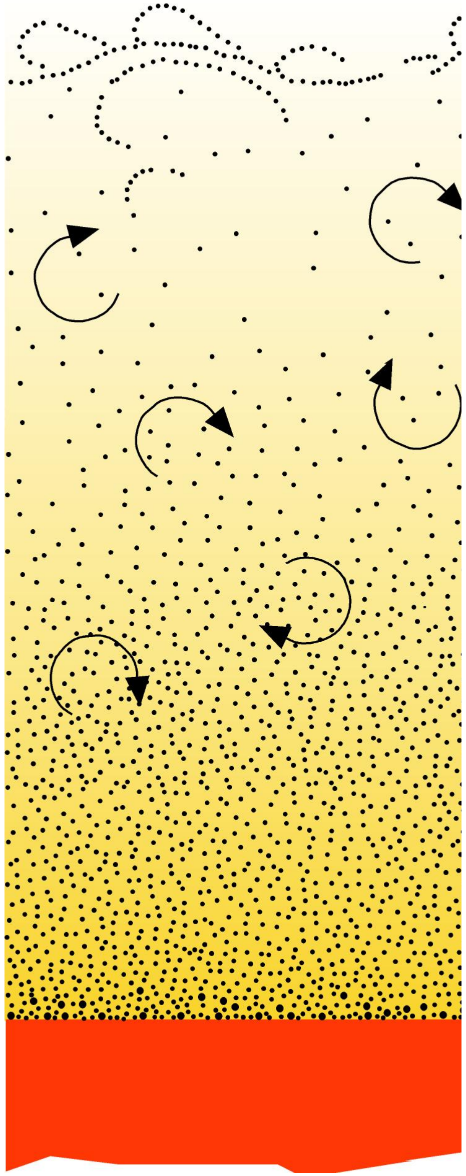
The temperature of PDC, may be a few hundred degrees cooler than the eruption temperature, primarily as a result of the entrainment of air which occurs in the collapsing fountain above the vent.

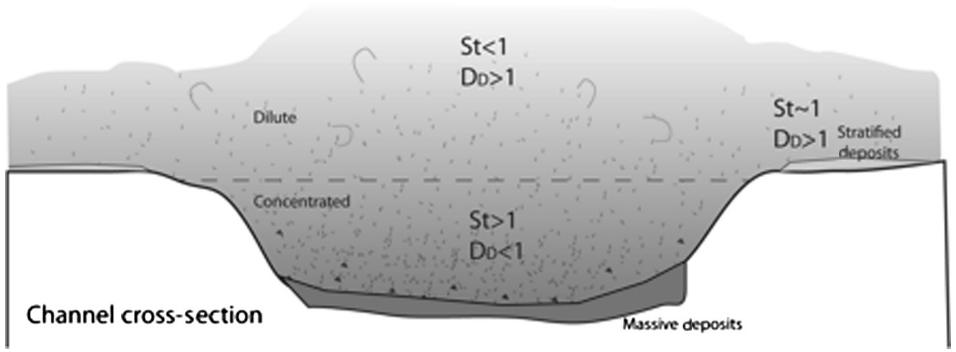
•A first order classification of PDCs can be the division in *diluted and concentrated*.



•*Diluted* PDCs , are those in which gas fraction is prevalent with respect to the solid phase, 0.1 to 1% (vol% solids)

Concentrated PDCs are those in which particle concentration is high and granular interaction predominate, >10 vol% solids





St= Stokes number

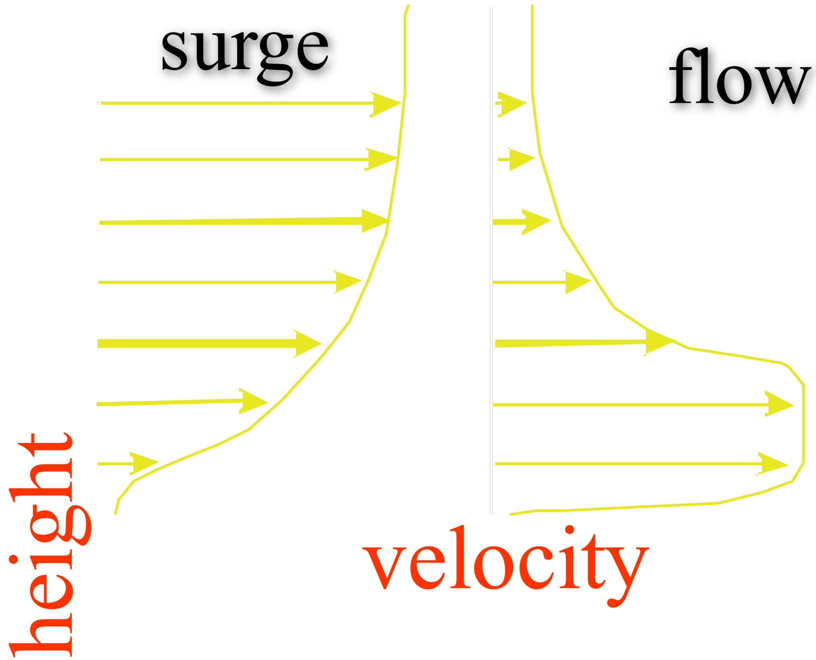
D_D= collisional timescale/particle drag

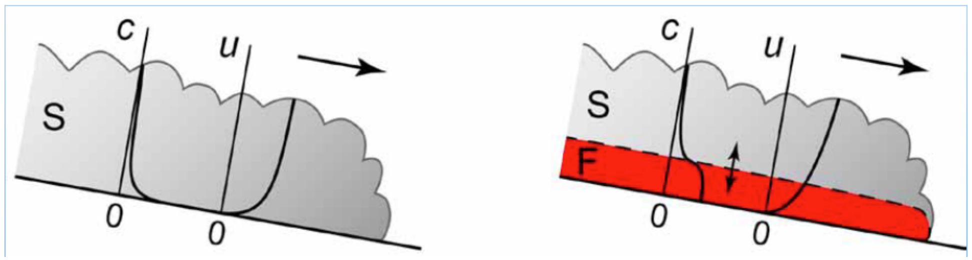
–SURGES:

Low concentrations
non-steady
turbulent
density-stratified
parabolic velocity profile

–FLOWS:

high concentrations
steady
free surface,
plug-like velocity profile





density

Main particle supoprt and segregation mechanisms

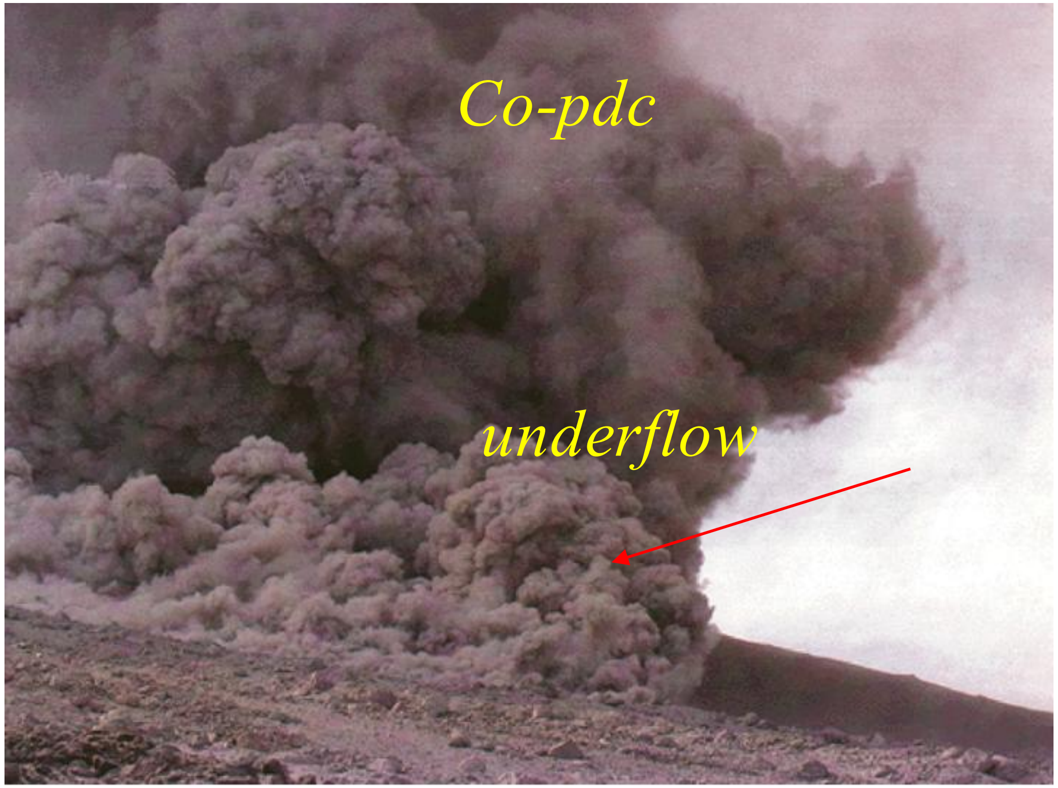
The fluid phase supports the solid particles through different mechanisms:

•suspension due to fluid turbulence,
•intermittent saltation, traction (sliding and rolling)
•fluid support (fluidization)
•particle-particle collisions
•matrix support

The combination of different mechanisms changes in time and space, because a particle that settles through a current experienced different concentrations and shear intensities. Support mechanisms influence the segregation processes, and determine the settling velocity of a particle.

•Regardless they are concentrate or dilute suspensions of gas and particles, PDC consists of two essential and co-pdc plume.

•The underflow is denser than the atmosphere and flows at direct contact with the ground, whereas the co-pdc is less dense than the atmosphere and lofts convectively



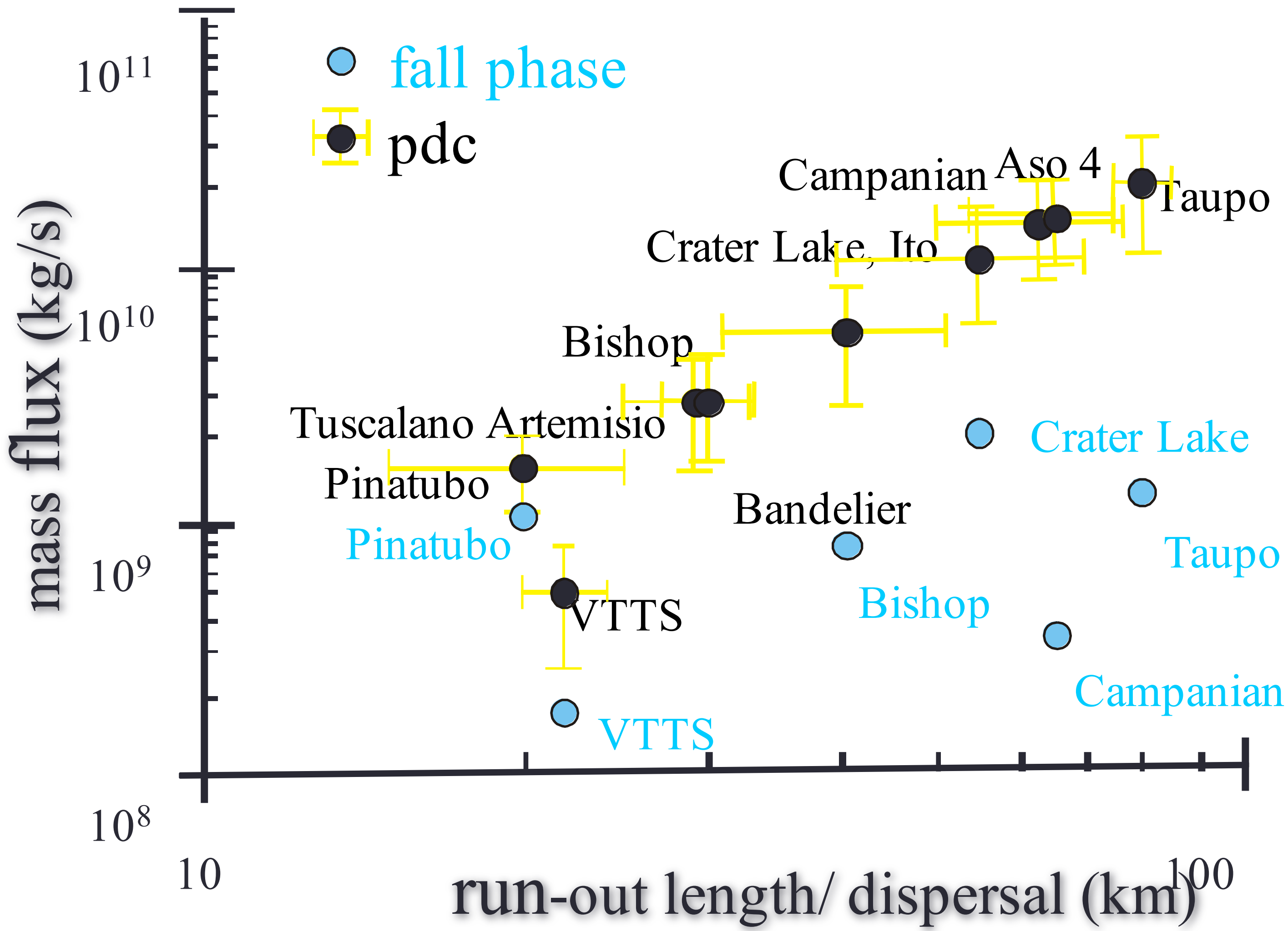
Mass partitioning between the underflow and phoenix changes continuously:

-slope change

-mixing with air

-change in the substrate

Empirical observations on runout



Empirical observations on dispersal

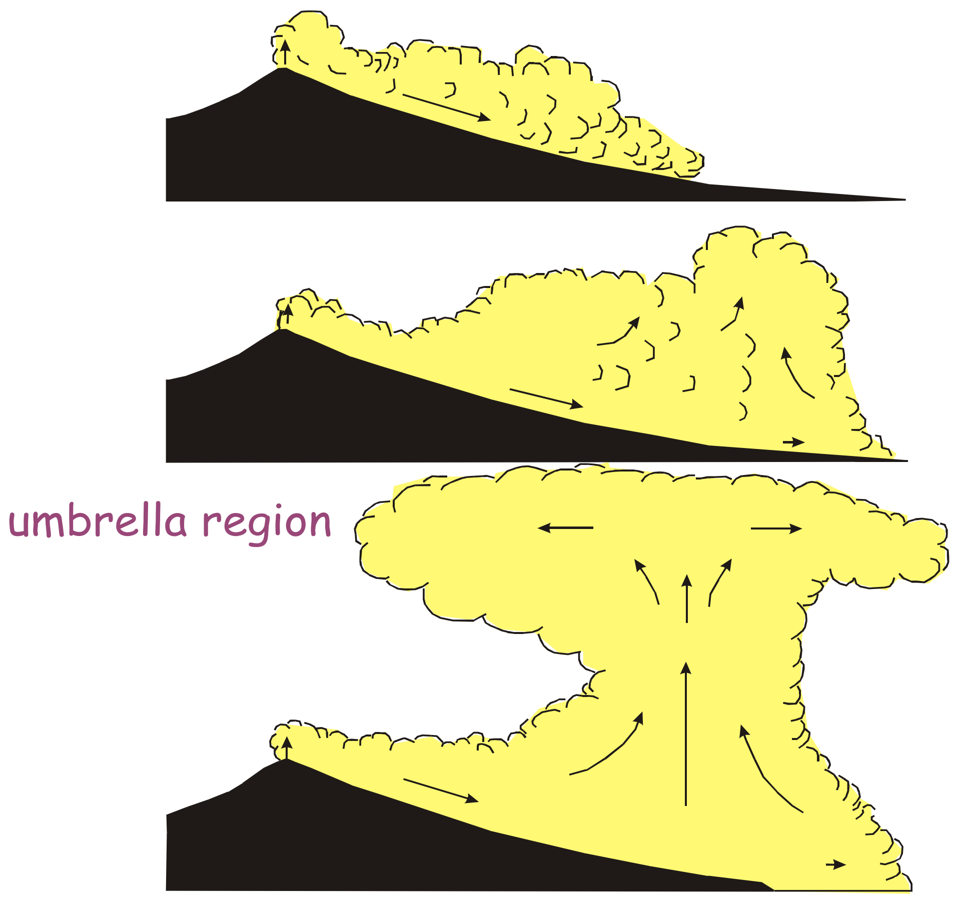
- Covered area: up to 20,000 km^2
  - El Chicon (1982)
  - Mt Pelee (1902) 41 km^2
  - St Helens (1980) 600 km^2
  - Taupo (186 AD) 15,000 km^2
  - La Garita caldera >15,000 km^2
- Volume: > 10 km^3
  - El Chicon (1982) 0.04 km^3
  - Mt Pelee (1902) <1 km^3
  - St Helens (1980) <1 km^3
  - Taupo (1800 y ago) > 10 km^3
  - La Garita caldera 3000 km^3
- Geometry of deposits
  - Sector-confined
  - Radial
  - Valley pounded
  - Draping topography

co-pdc plumes

- Sedimentation and entrainment reduces flow density

- Buoyant lift off begins

- Plume forms from pyroclastic flows



Deposition en masse or aggradational?

In **en-masse freezing** the flow comes to halt abruptly over its entire depth

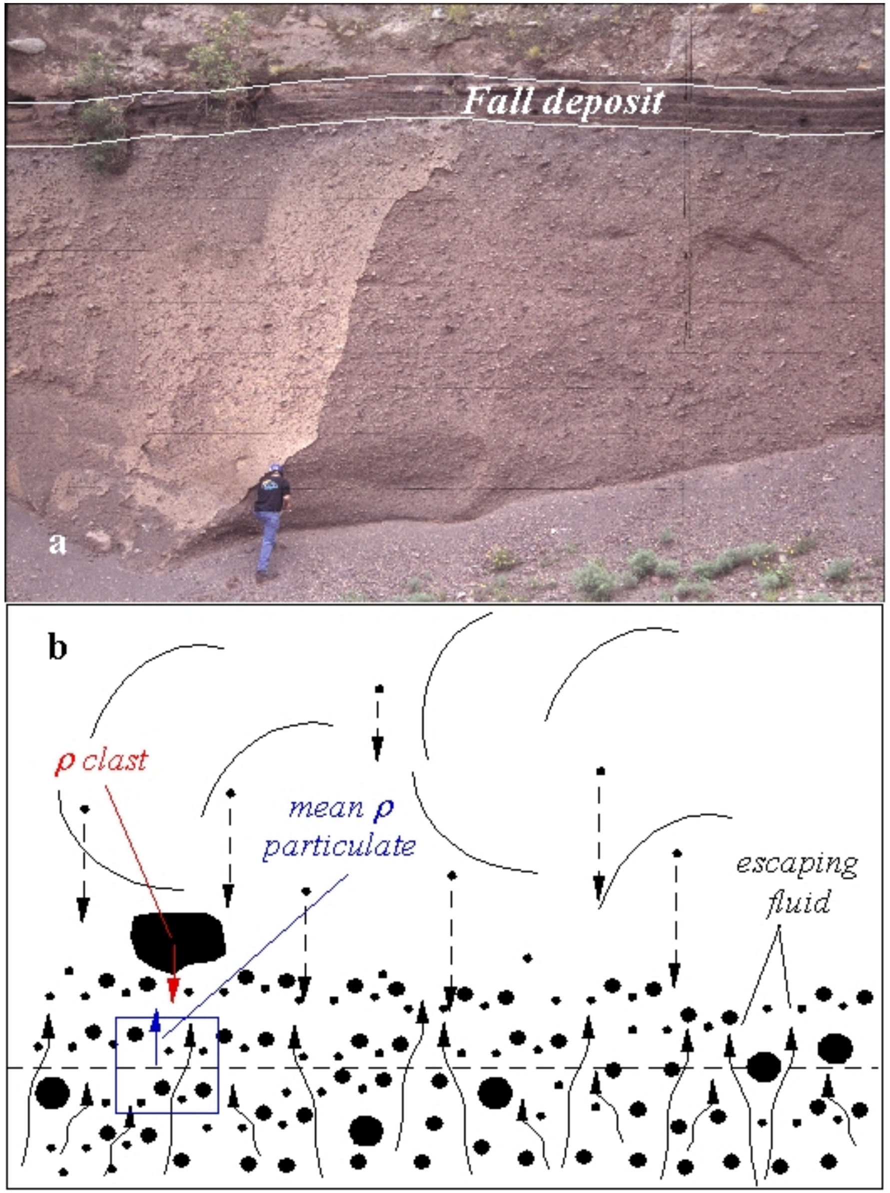
whereas in the **progressive aggradation** model the deposits builds up due to the continuous supply of material from the current through the flow-boundary layer.

Concentrated PDCs: flow compaction

- Poor sorting
- Coarse tail grading
- Massive

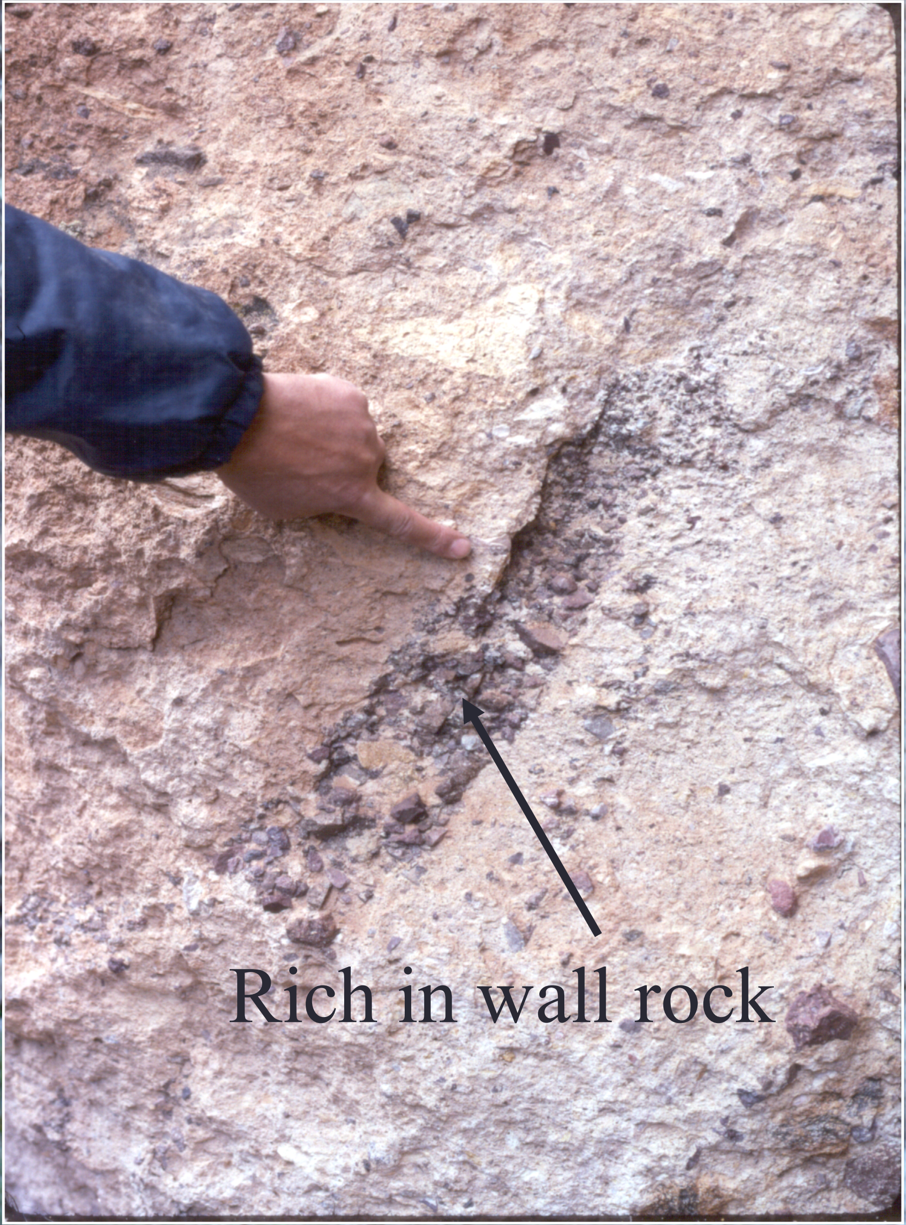
Rapid deposition from a highly concentrated current able to trap a large amount of fine particles.

Concentrated PDCs: flow compaction



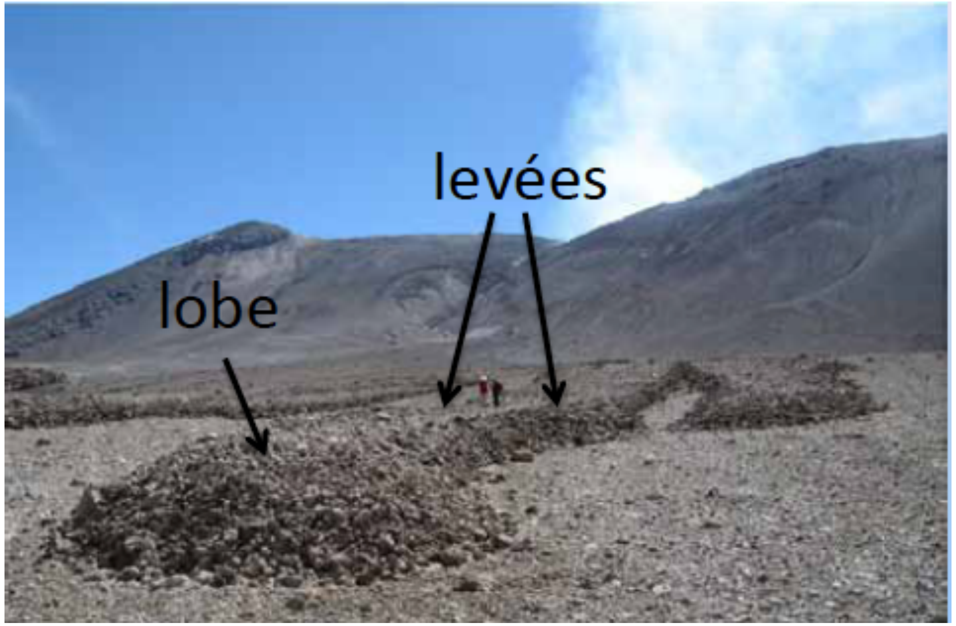
In a flow-boundary zone dominated by fluid escape the clast support is supplied by the expulsion of fluids as consequence of deposition.

Segregation bodies

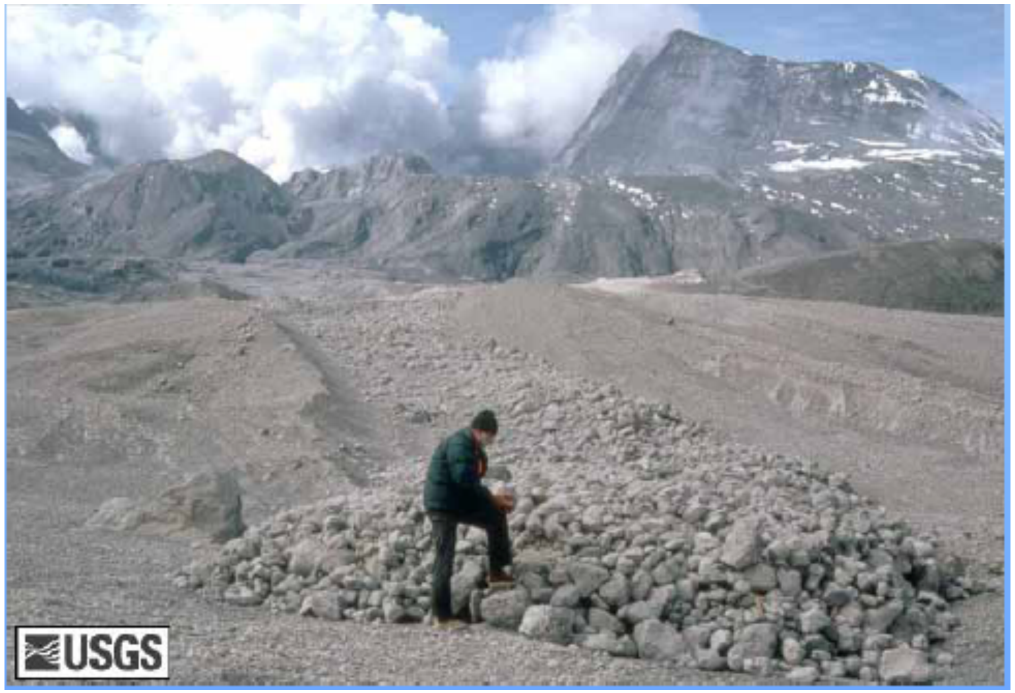


Valley of Ten Thousand smokes

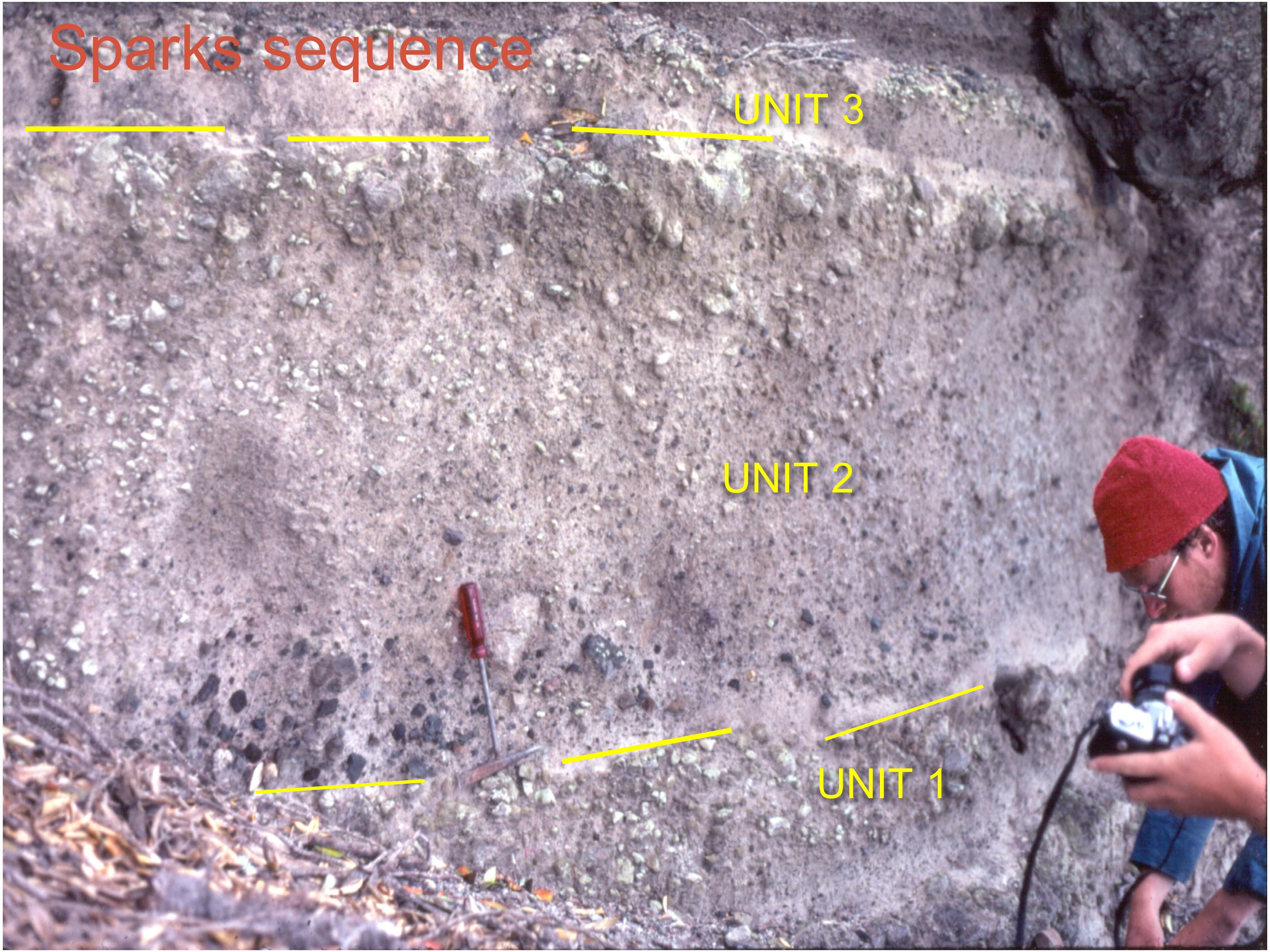
..After the Katmai eruption deposited 13 km^3 of ash flows on 1912



Lascar (Chili)



Mt. St Helens (USA)

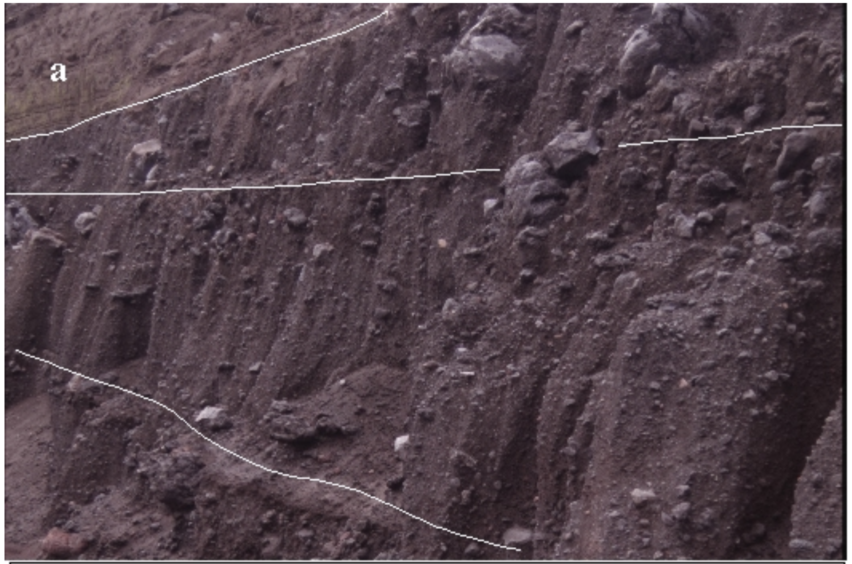

Sparks sequence
UNIT 3
UNIT 2
UNIT 1

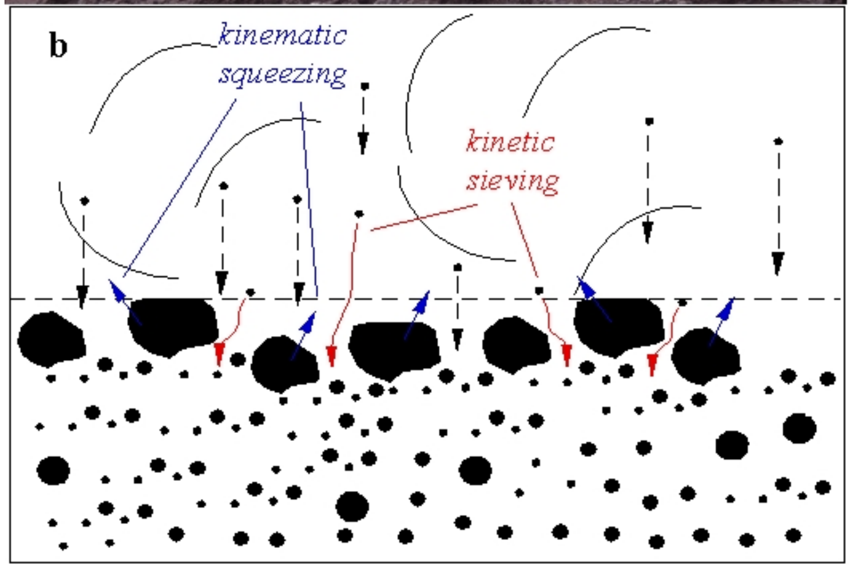
Concentrated PDCs: granular flow

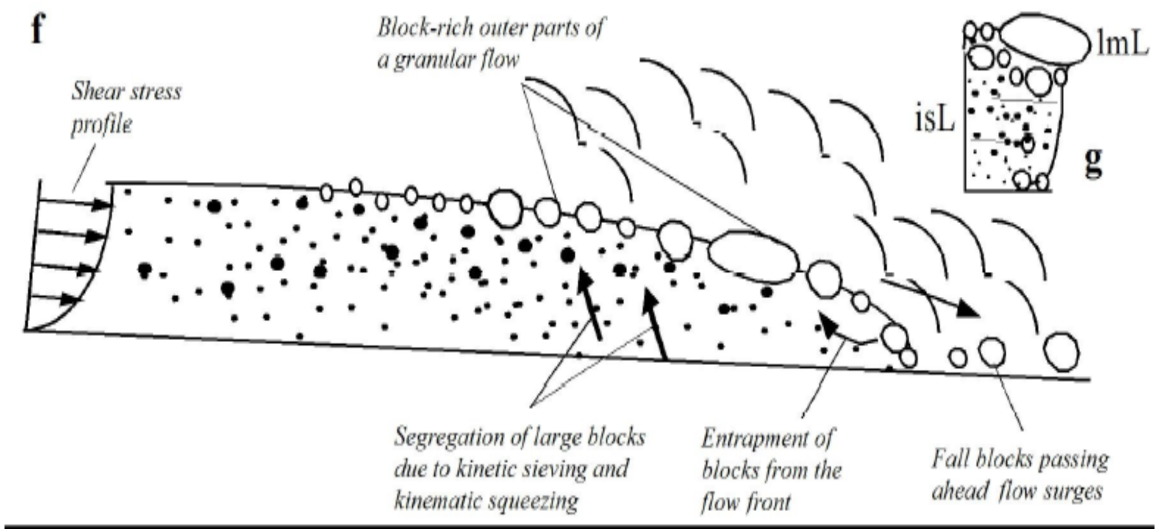
- Poor sorting
- Inverse grading

Rapid deposition from a concentrated current where the particle collision cause kinetic sieving and kinematic squeezing of the large blocks

Concentrated PDCs: granular flow

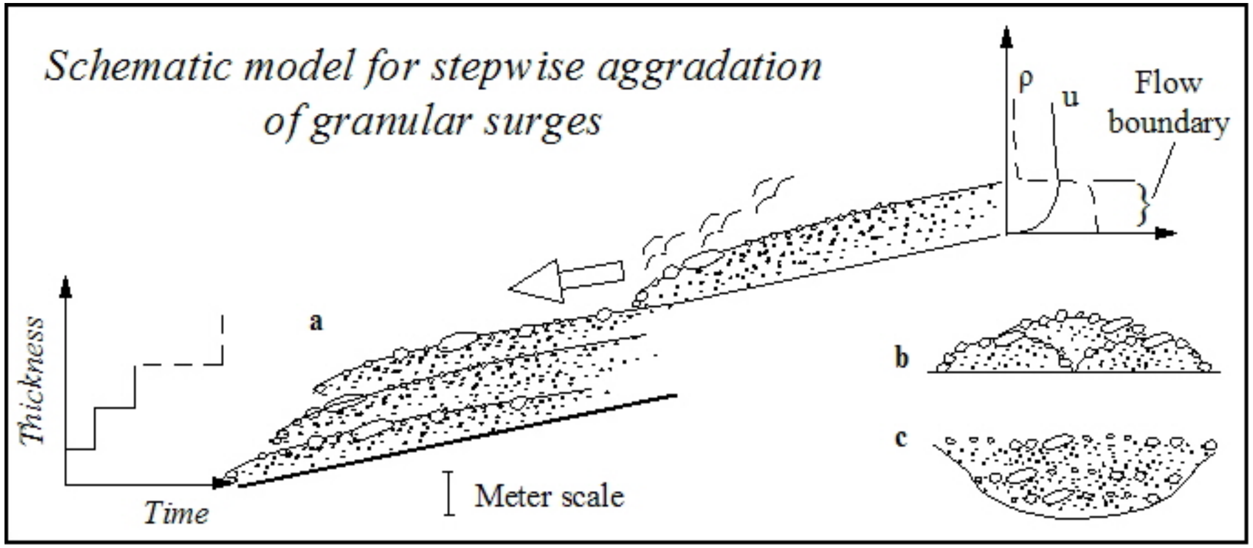


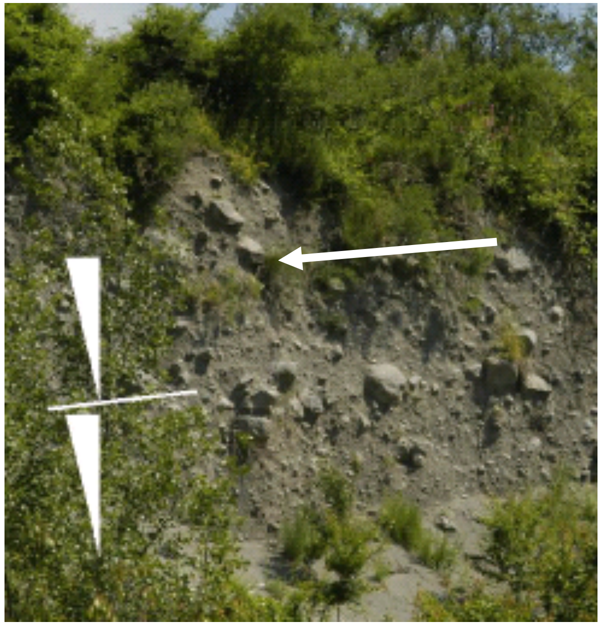


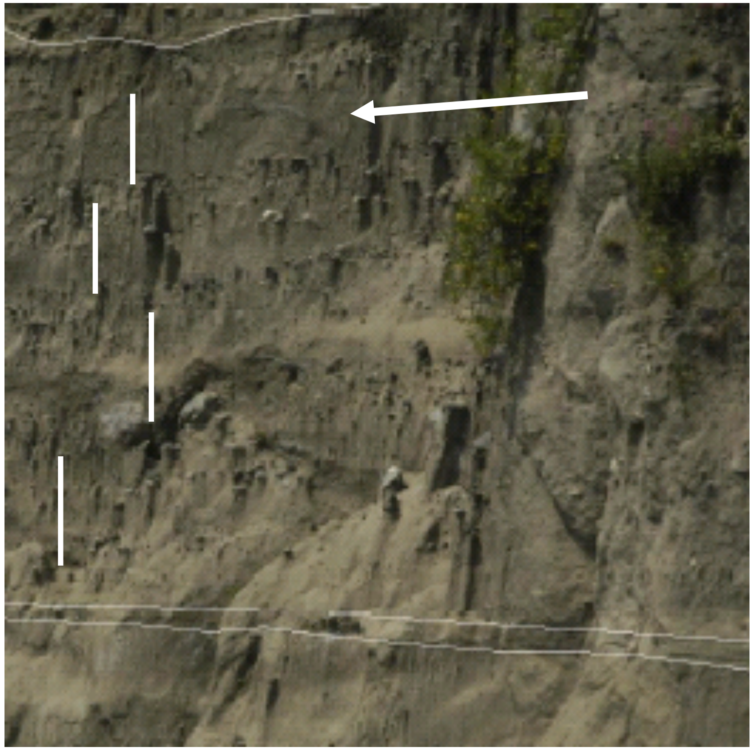


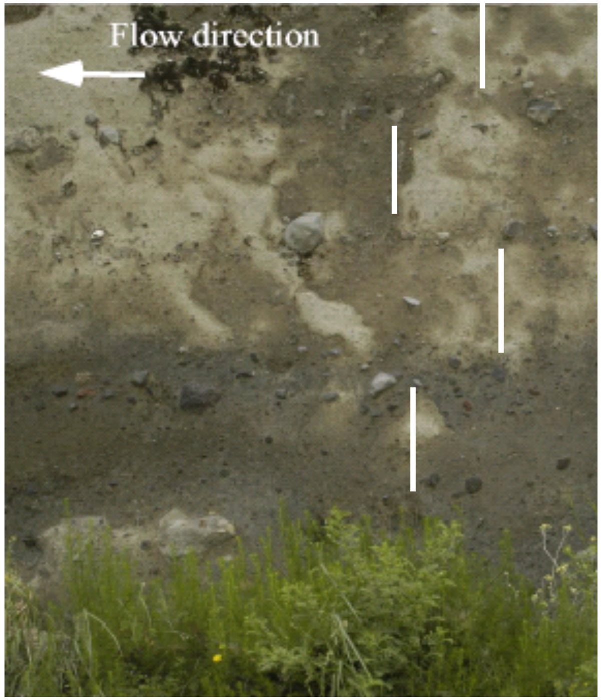
In a flow-boundary zone dominated by granular flows, the clast concentration and velocity are sufficient to sustain grain collisions with time

Multiple surges

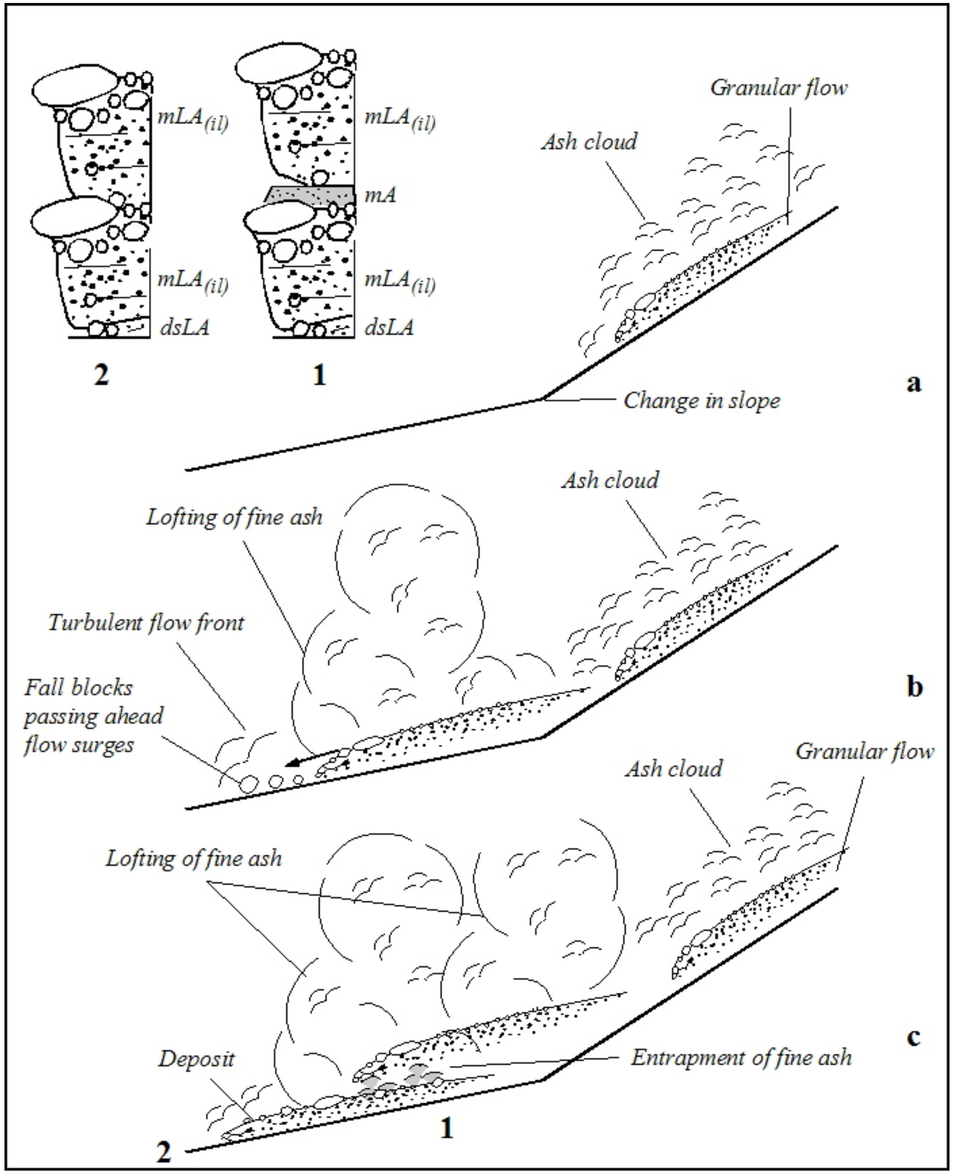




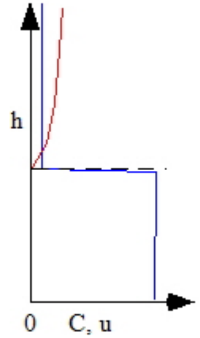


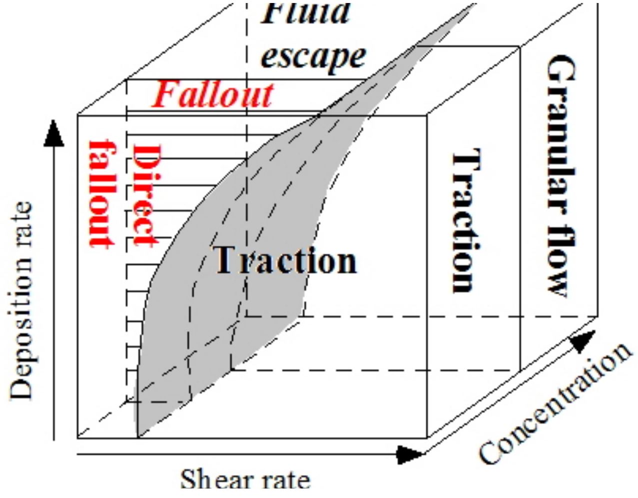


Multiple surges



Diluted PDCs: direct fallout

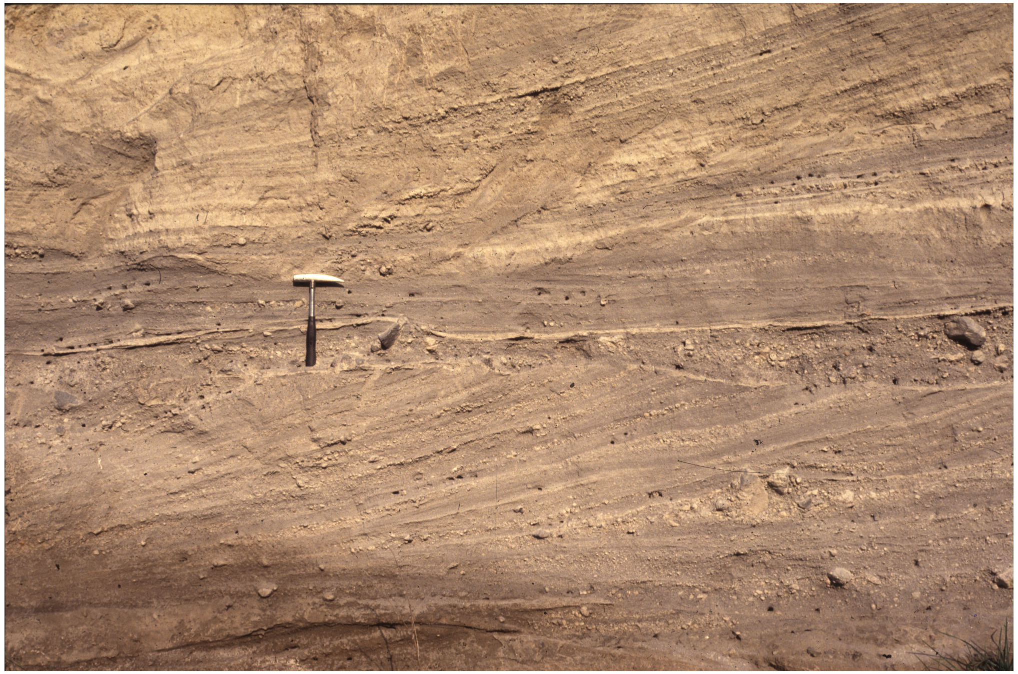




- massive fine ash
- accretionary lapilli

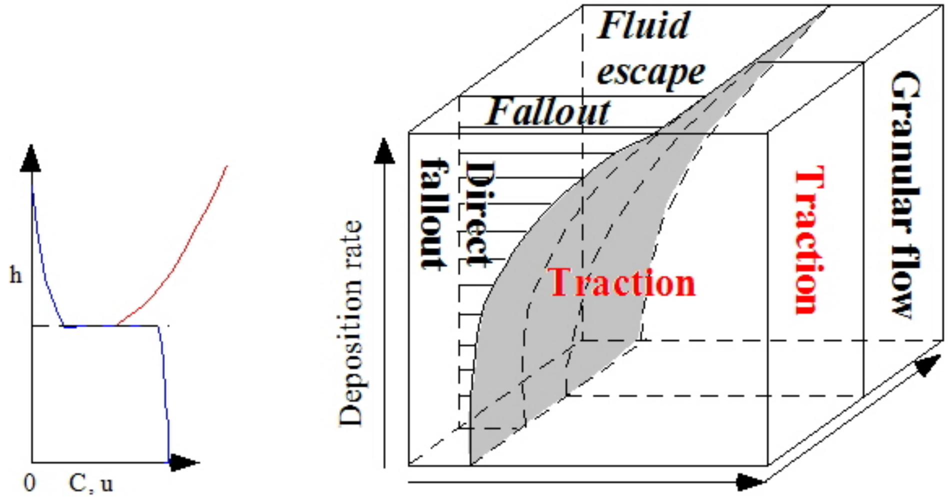
deposition through gentle settling from the turbulent suspension

Diluted PDCs: traction

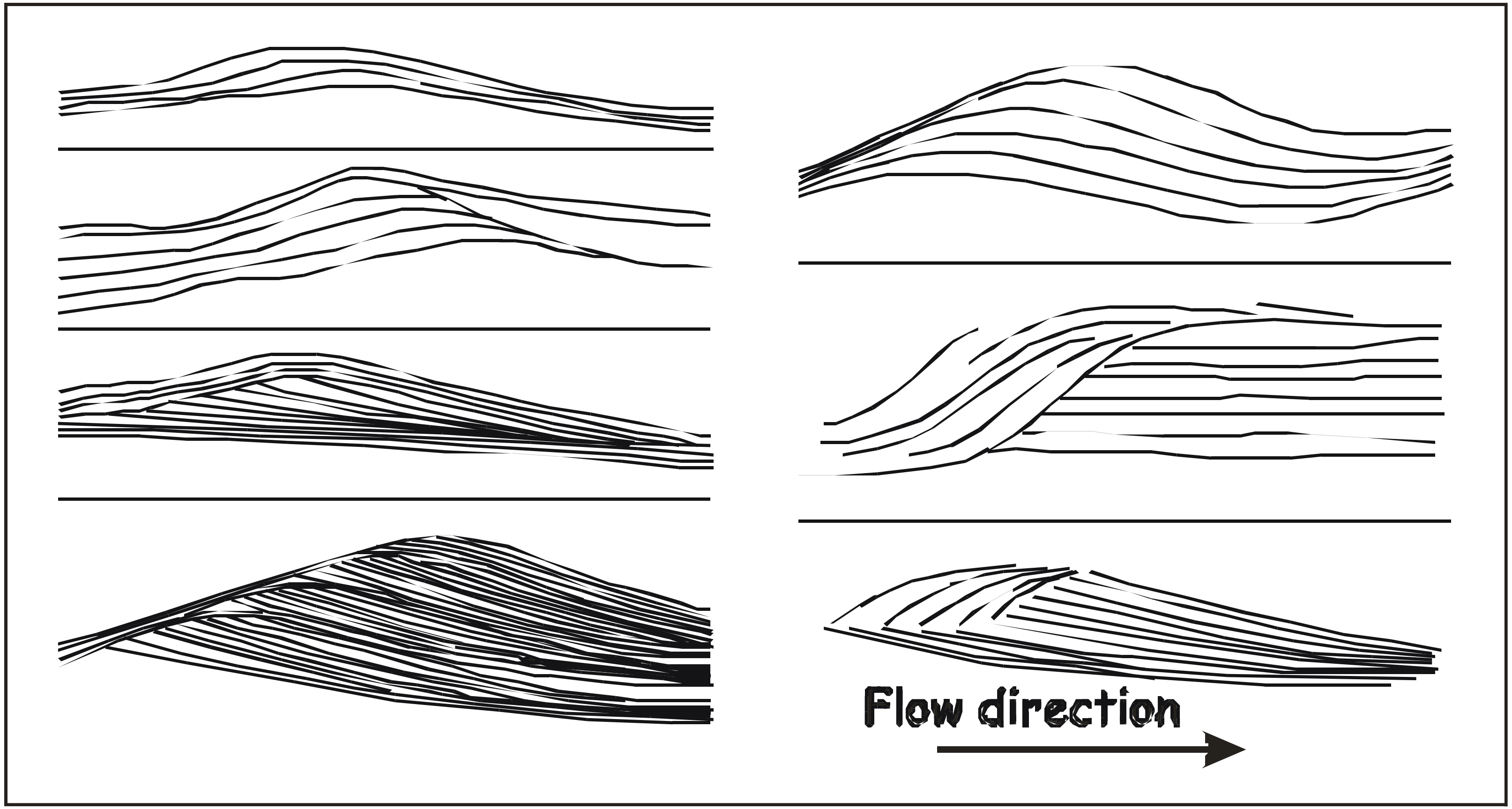


- cross-stratification dune bedded ash
- relatively well sorted
- distribution grading

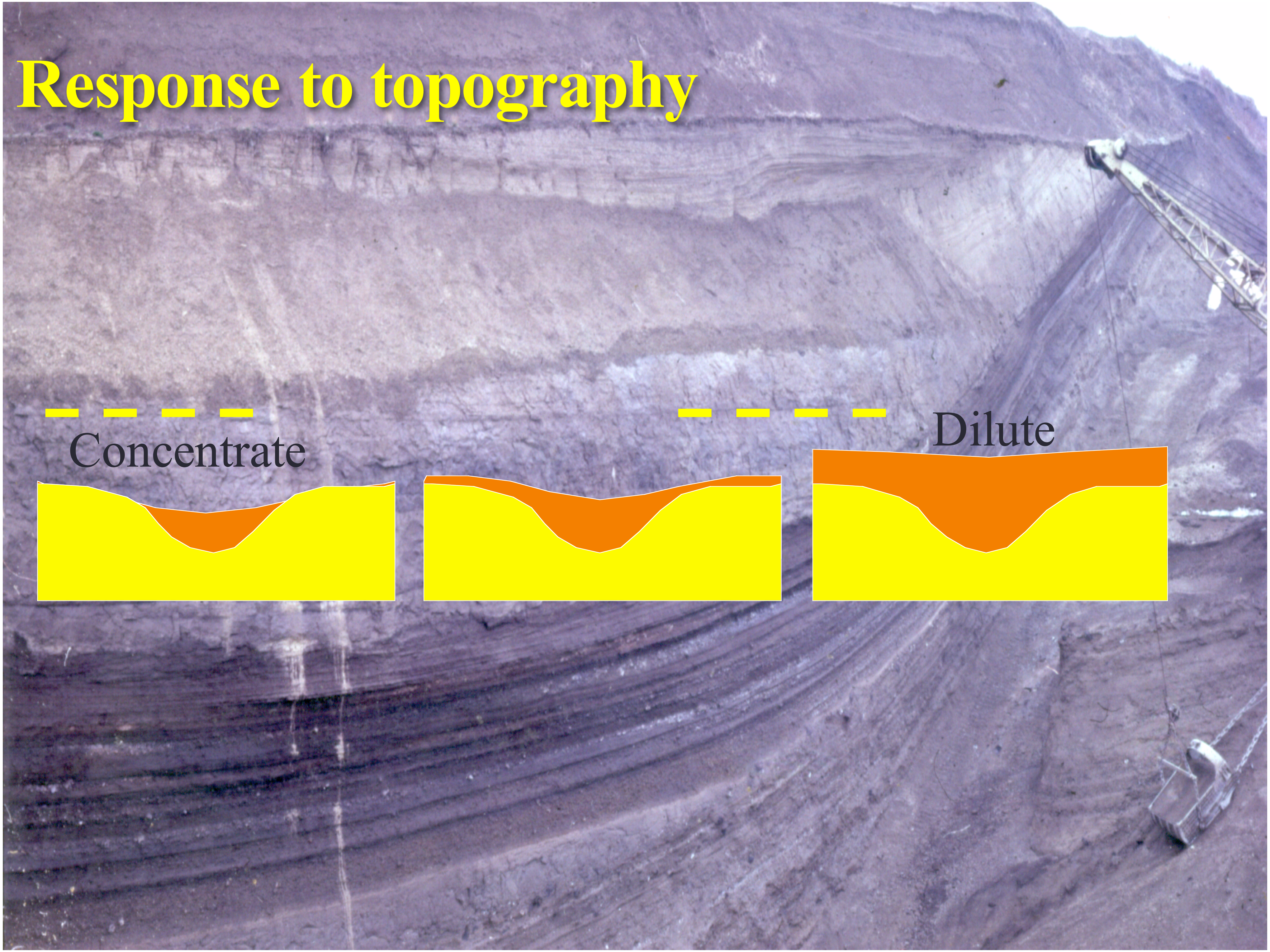
grain by grain deposition from a dilute, turbulent current with flow boundary dominated by traction processes



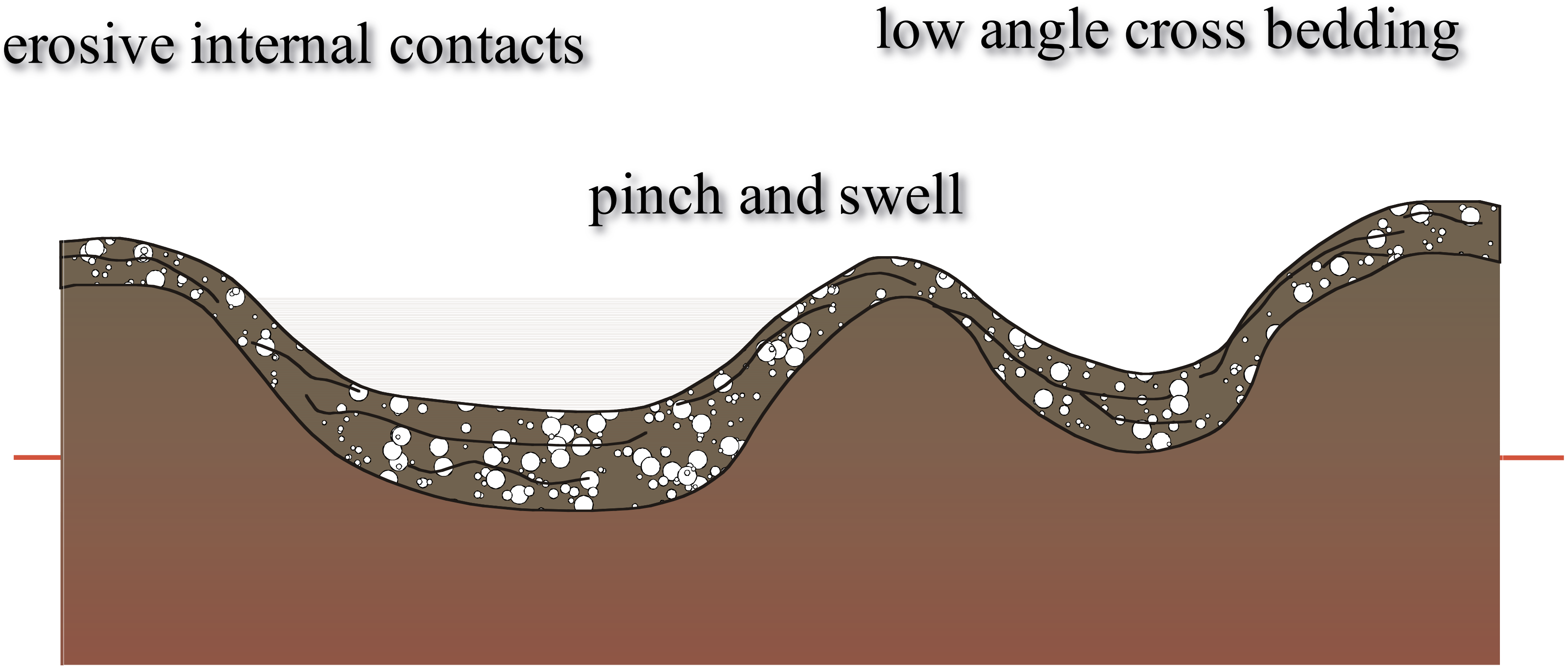
Diluted PDCs: bedforms



Response to topography

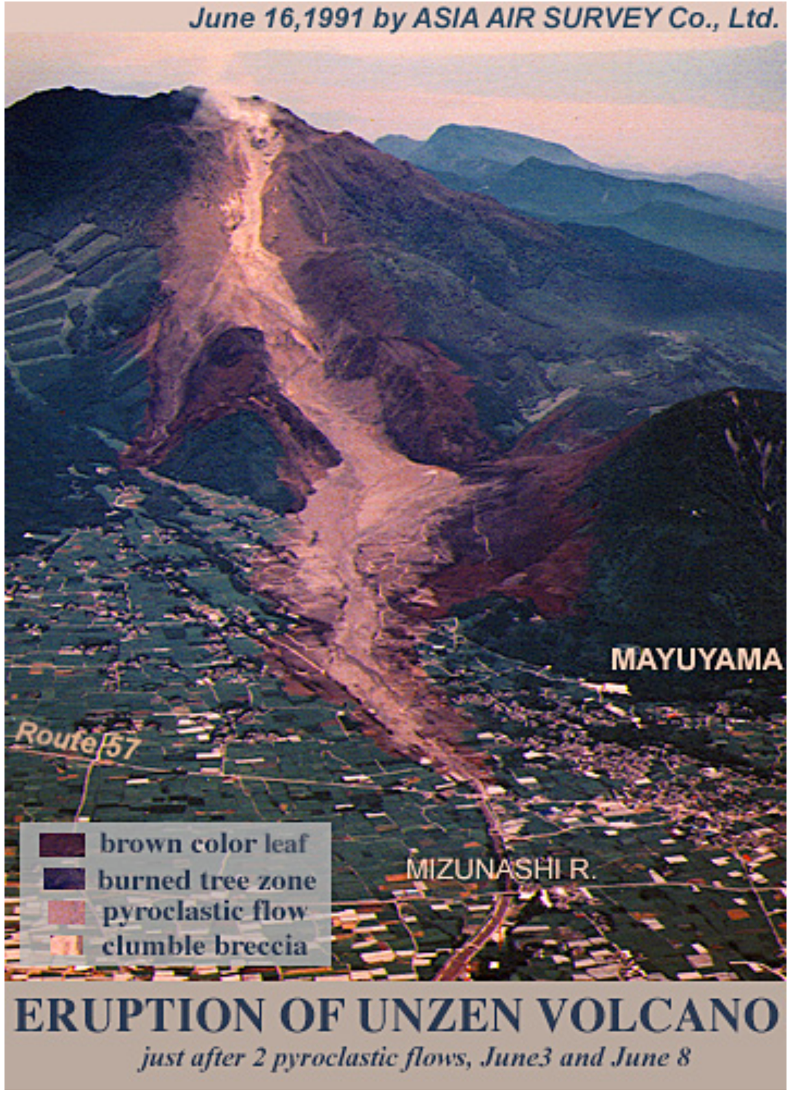


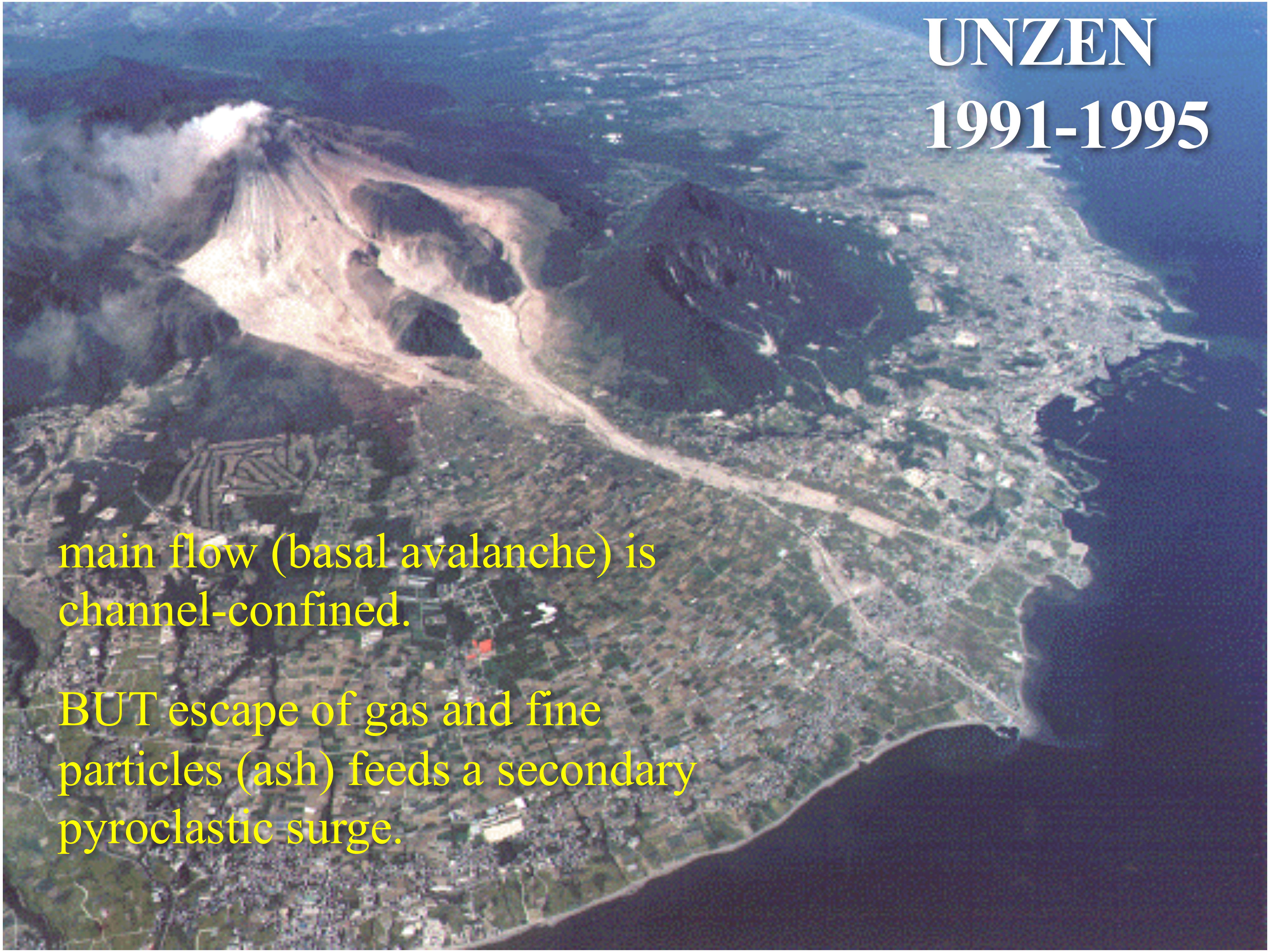
PDC draping



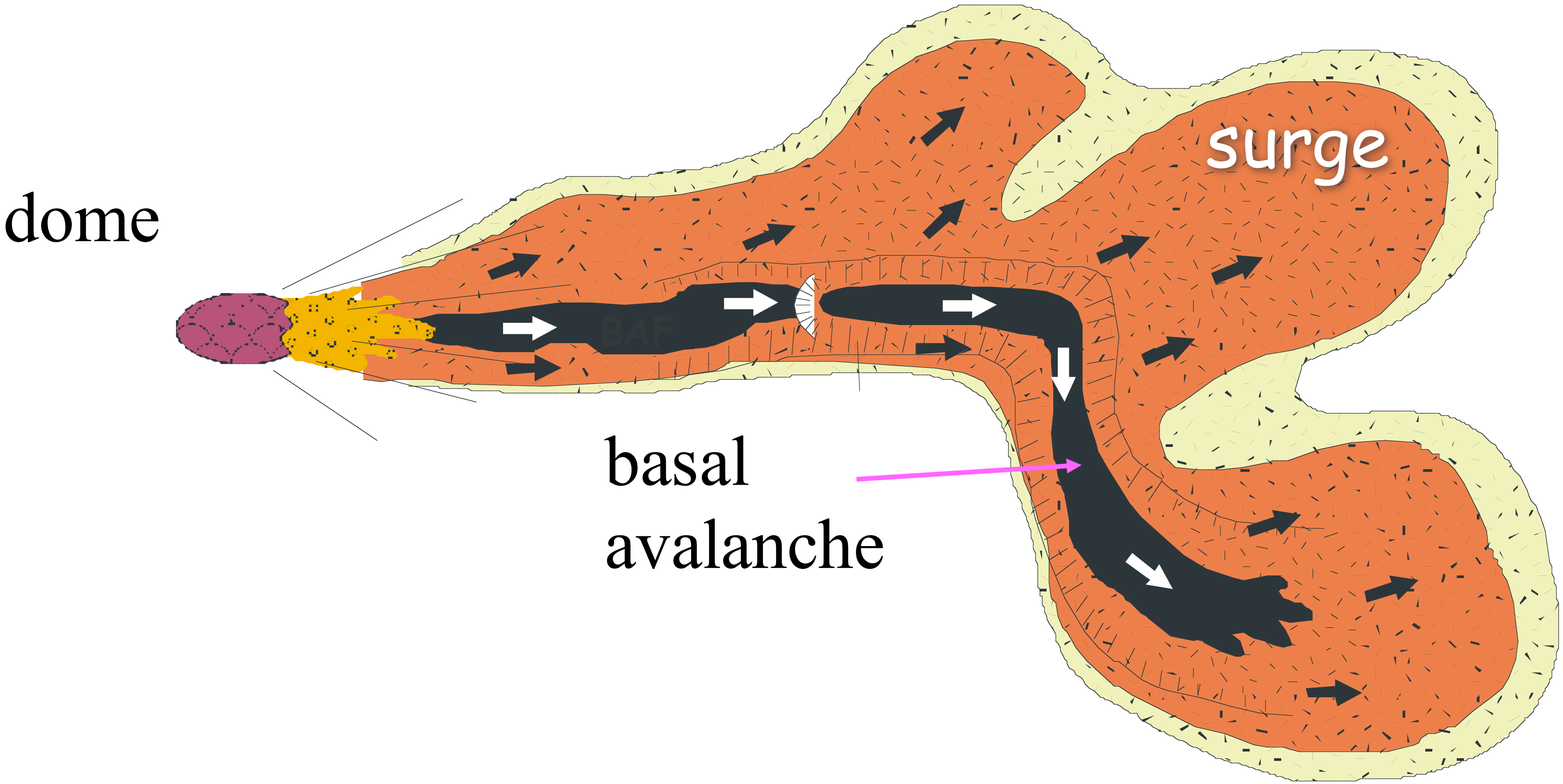
erosive internal contacts
low angle cross bedding
pinch and swell

Unzen 1991 eruption



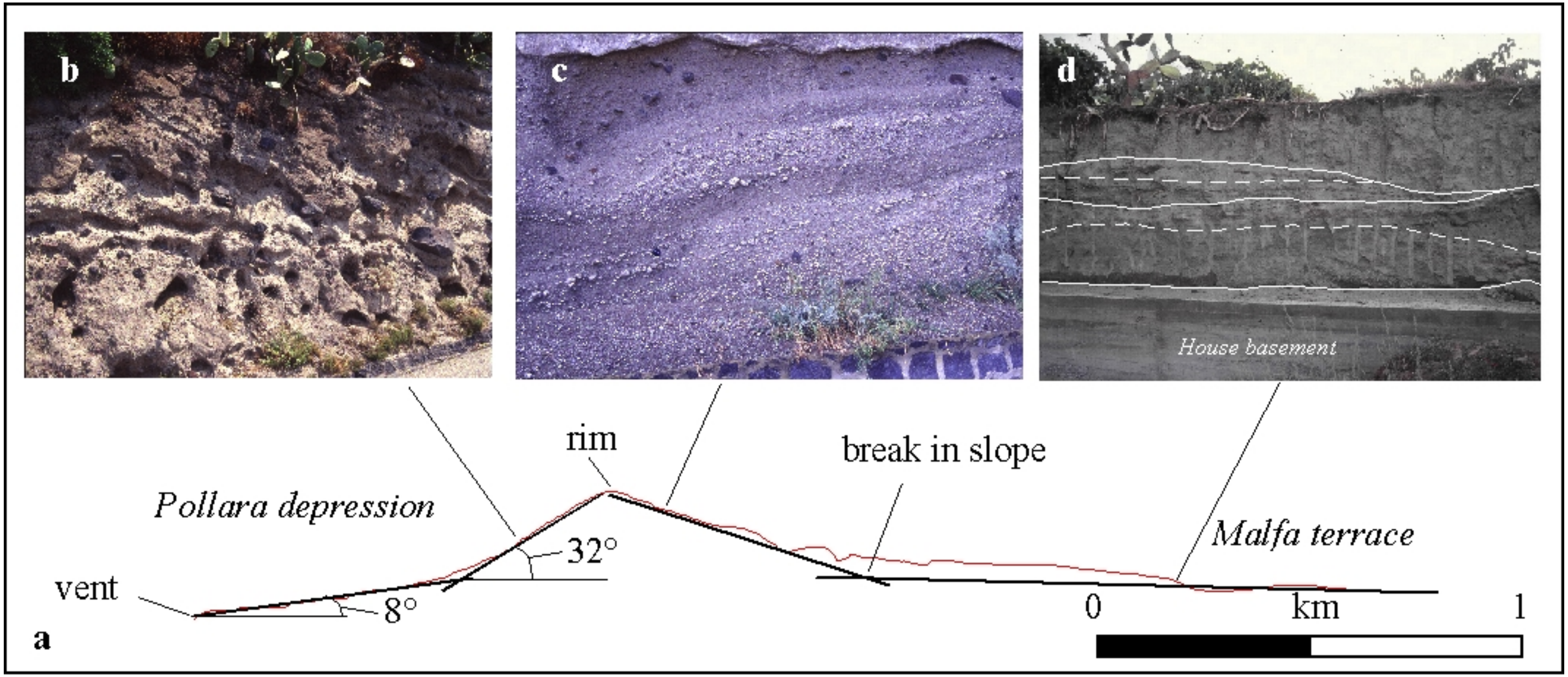

UNZEN
1991-1995
main flow (basal avalanche) is channel-confined.
BUT escape of gas and fine particles (ash) feeds a secondary pyroclastic surge.

Unzen 1991: flow deposits



Ability in surmounting barriers:

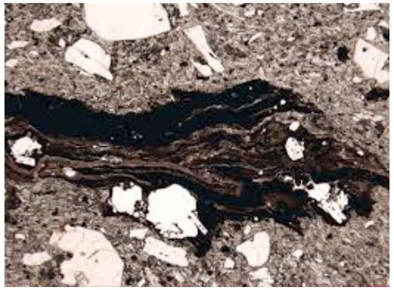
Fisher Caldera, Alaska (Miller and Smith 1977)	500 m
Ito Ignimbrite, Japan (Yokoyama, 1974)	600 m
Campanian Ignimbrite, Italy (Barberi et al., 1978)	1000 m
Taupo Ignimbrite, New Zealand (Wilson, 1985)	1500 m

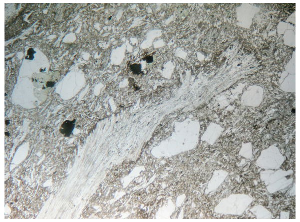


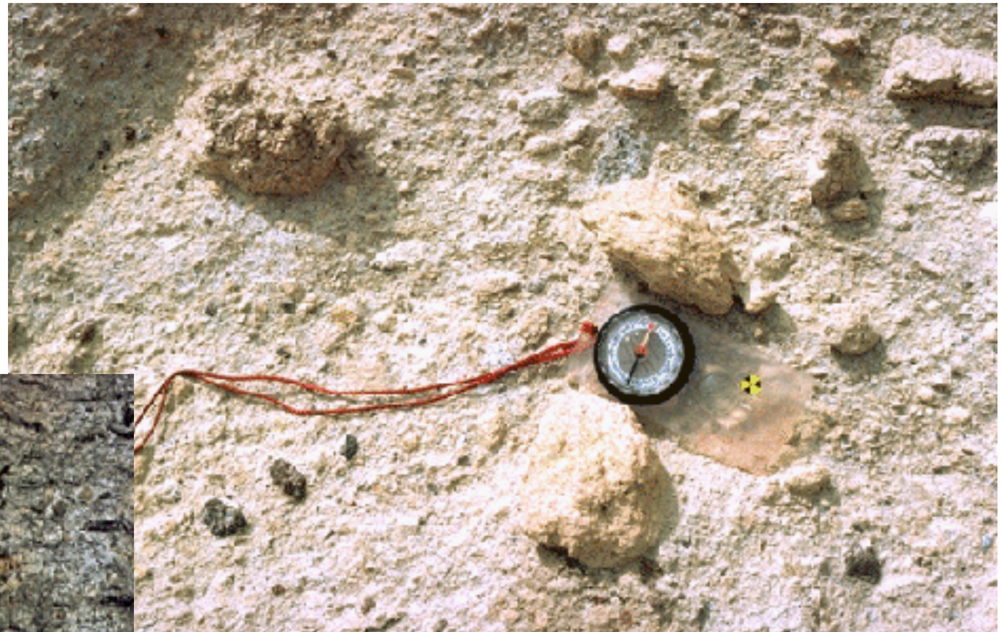
Welding and Compaction of Pumice Pyroclastic Flows

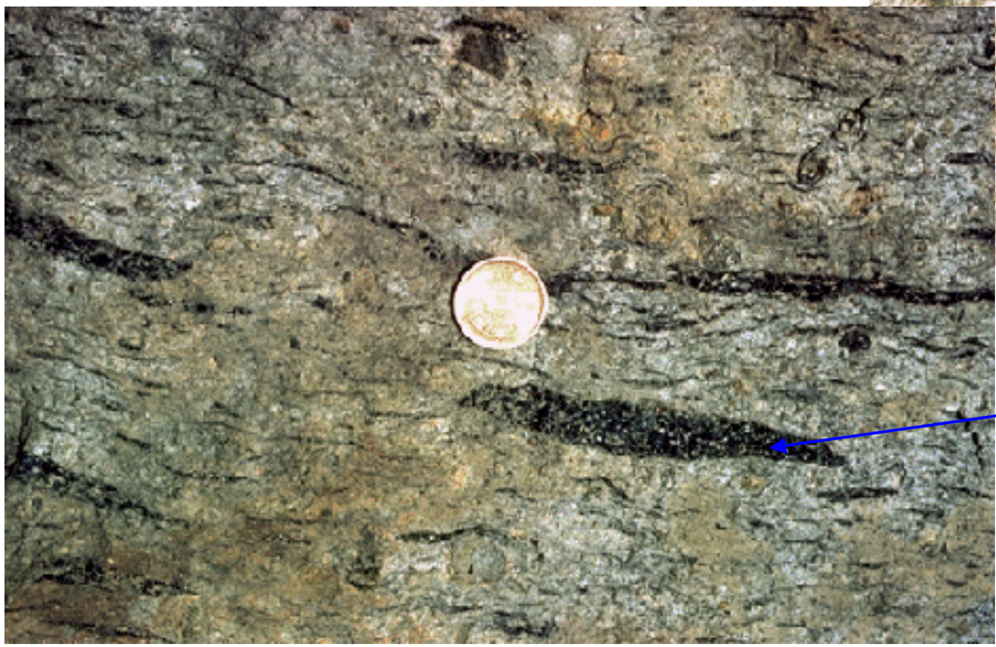
High emplacement temperatures are responsible for some of the main characteristic features of ignimbrites.

Unwelded ignimbrite



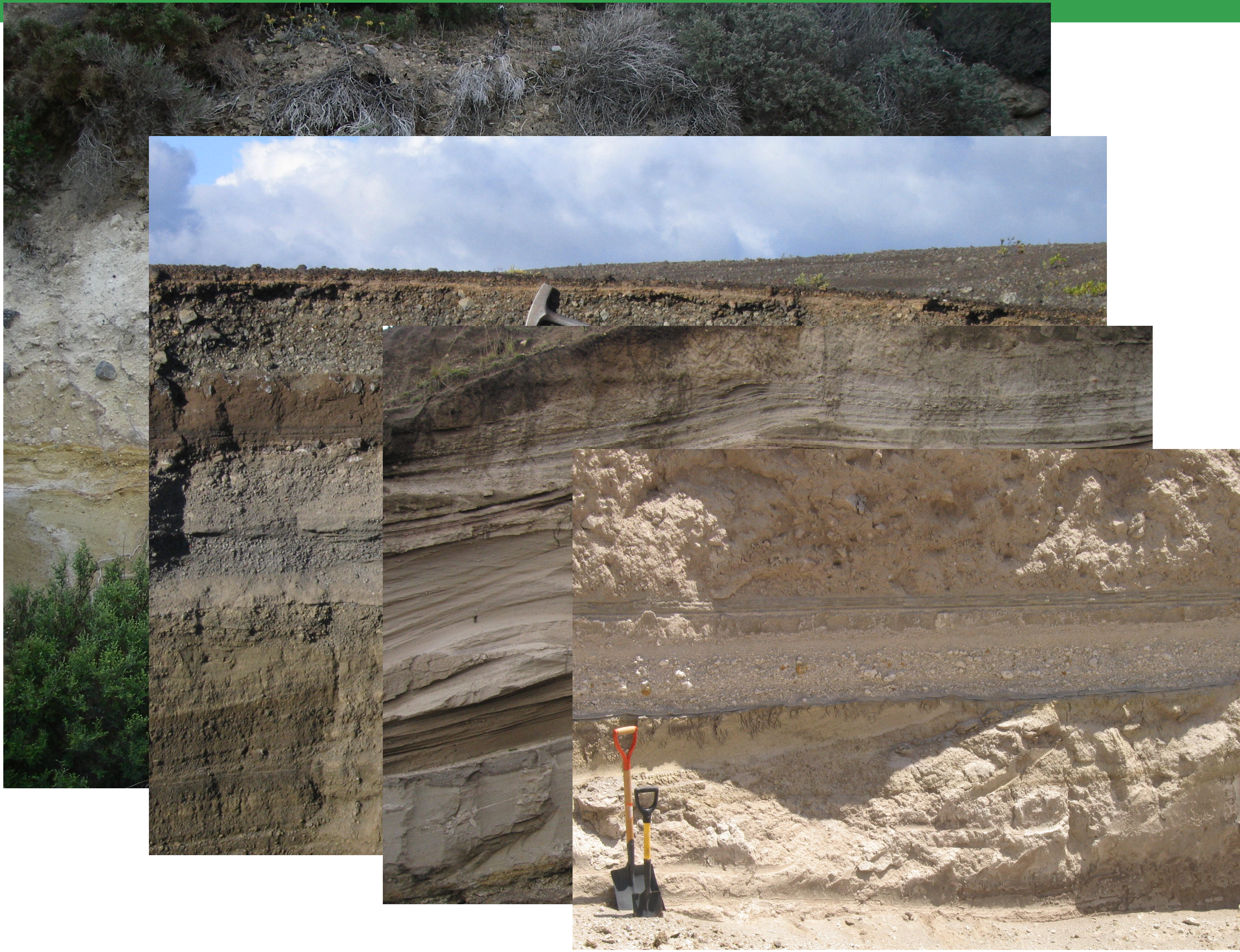






fiamme

Welded ignimbrite



PDC deposits: diagnostic features

- Larger grainsize variation than fallout deposits
- Do not drape topography
- Can be massive or have internal structures related to lateral transport
- Rich in fine material
- Large clasts are rounded
- Can show evidence of high temperature deposition!

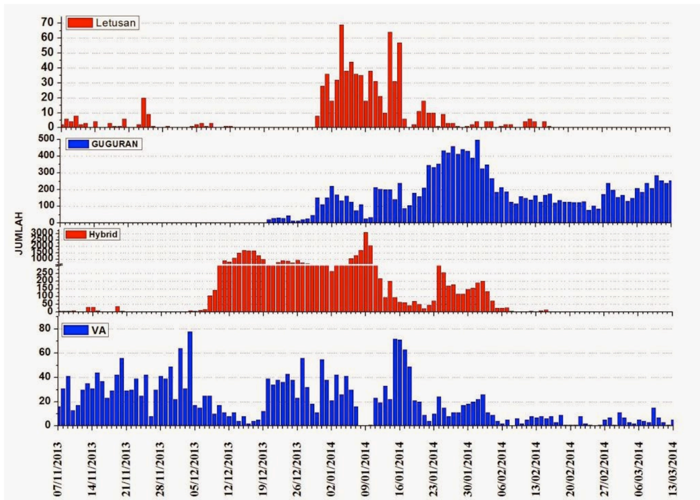
Hazard

Eruption (Name of Volcano, Location)	Year	Casualties	Major Cause
Tambora, Indonesia	1815	92,000	Starvation
Krakatau, Indonesia	1883	36,000	Tsunami
Mont Pelee, Martinique	1902	30,000	Pyroclastic flows
Nevado del Ruiz, Colombia	1985	25,000	Mudflows
Unzen, Japan	1792	15,000	Volcano collapse, Tsunami
Kelut, Indonesia	1586	10,000	
Lakagigar (Laki), Iceland	1783	9,000	Starvation
Mount Vesuvius, Italy	79 A.D.	3,360	Pyroclastic Flow

Mt. Sinabung, Sumatra, Indonesia

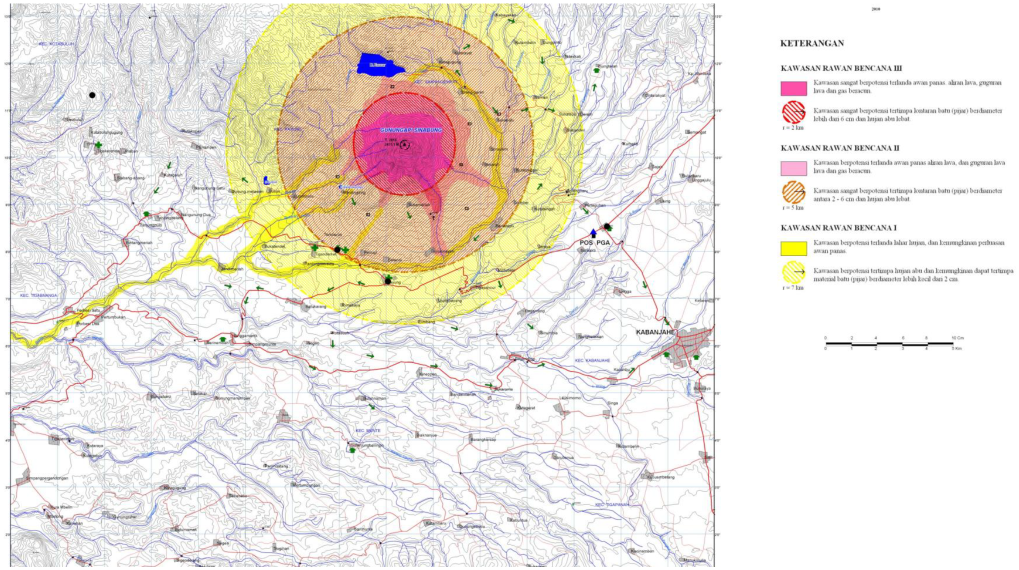
Previous eruption: Sept 2010

15 Sept 2013 start of ongoing eruption- first evacuations
17Sept -17 Dec several ash plumes up to 12 km high
28 Dec   Lava dome
30 Dec first PDC
31 Dec-Feb 2014 Several PDC and ash plumes accompany dome growth and disruption
1 Feb 2014 PDC kills 16 people
5 October 2 km high ash plume and PDCs
Up to now: dome still growing, ash explosion, no PDC, finally people are evacuated.



12 Jan 2014

Mt. Sinabung, Sumatra, Indonesia



Disaster-prone region III (KRB III), is an area with high potential to be devastated by hot clouds, and lava flows, incandescent stones, intense ash fall and toxic gases.
It consists of two parts:
a. Disaster-prone areas of the mass flow (heat clouds, and lava flows), and toxic gases.
b. Disaster-prone areas to ballistic fallout and heavy ash fallout.

Disaster-prone region II (KRB II), is an area potentially stricken by hot clouds, lava flows, lava, ballistic (incandescent) and heavy ashfall. This area is divided into two parts:
a) Areas prone to mass flow (heat clouds, and lava flows).
b) Areas prone to hurl a stone material (incandescent) and heavy ashfall.

Disaster prone regions I (KRB I) is an area potentially devastated by lava and ash fall. If the eruption enlarged, then the area can be potentially affected by incandescent stones with diameters smaller than 2 cm. It is divided into two parts, namely:
a) Areas prone to mass flow (lava).
b) Areas prone to dropping material (ash and rain incandescent stones).

Official document by the Indonesian Geological Service, 2010

Villages at the foothill

Sinabung volcano, Indonesia, 1 February 2014
16 deaths

Merapi Volcano