Gravity currents in volcanology

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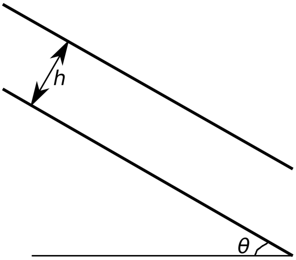
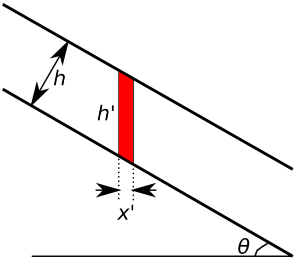
Consider flow of a viscous fluid on a slope



Want to determine shear stress at base of flow

Shear stress = Force per unit area extered on ground

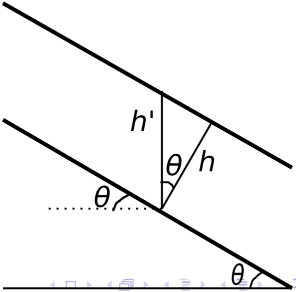


Consider a volume of a thin slice

$$V = h'x'd$$

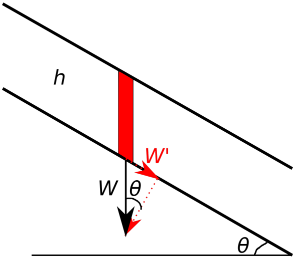
where d = width of flow
So, total weight of column:

$$W = \rho V g = \rho h' x' d g$$



$$h' = \frac{h}{\cos\theta}$$

$$W = \frac{\rho h x' d g}{\cos\theta}$$



Area under column $A = Xd = \frac{x'd}{\cos\theta}$

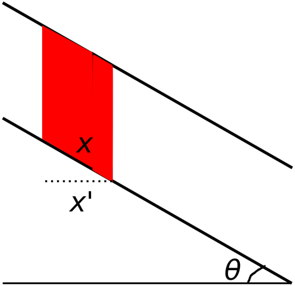
Shear stress:

$$\tau = \frac{W'}{A} = \rho g h \sin\theta$$

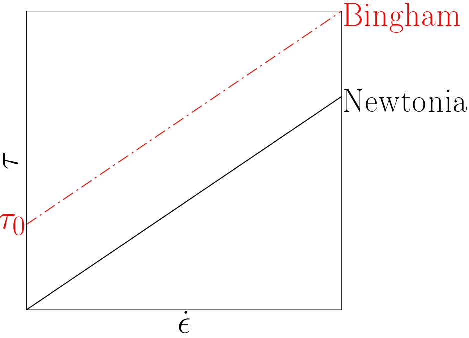
Downslope component of weight:

$$W' = W \sin\theta$$

$$W' = \frac{\rho h x' d g \sin\theta}{\cos\theta}$$



Lava flow rheology



Crystal-free lavas behave as Newtonian fluids

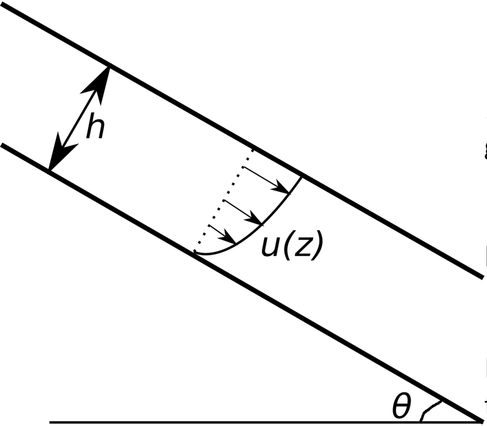
Partially crystallised lavas have a yield stress τ_0

Lavas have a minimum thickness below which they cannot flow:

$$h_0 = \frac{\tau_0}{\rho g \sin\theta}$$

This thickness depends on the topography

Jeffrey's model for lava flow velocity



Mean velocity inside a channel:

$$\bar{u} = \frac{h^2 \rho g \sin\theta}{B\eta}$$

B = constant depending on channel geometry

Expression is valid for a Newtonian lava

More complicated models for Bingham fluids

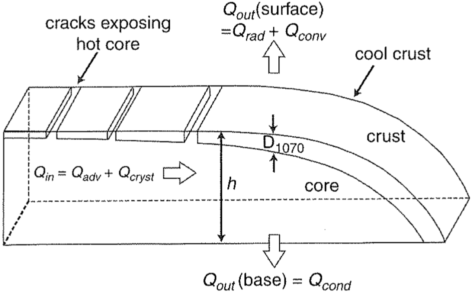
Controls on lava flow

Lava flow rates and morphology depend on:

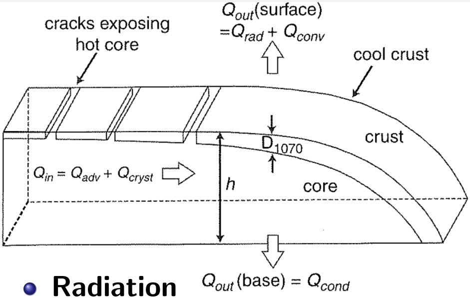
- Topography
  - Slope angle
  - Channel geometry (if it exists)
- Rheology
  - Viscosity
  - Yield stress

Rheology is most difficult to assess - it depends on:

- Composition
- **Temperature**
- Crystallinity
- Vesivularity



Heat loss from the flow



- **Radiation**
  - Emission of heat through EM radiation
  - Flux determined from Stefan-Boltzman law

$$q_{\mathrm{rad}} = \epsilon\sigma(T_{\mathrm{surf}}^4 - T_{\mathrm{a}}^4)$$

  - ϵ = Emissivity
  - σ = Stefan-Boltzmann constant $= 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

- **Conduction**
  - Direct molecular contact
  - Heat flux (W m^{-2}) given by a diffusive term

$$q_{\mathrm{cond}} = -k\frac{\mathrm{d}T}{\mathrm{d}x}$$

  - k = Thermal diffusivity

- **Convection**
  - Heat transported through fluid movement
  - Heat flux given by

$$q_{\mathrm{conv}} = h(T_{\mathrm{surf}} - T_{\mathrm{a}})$$

  - h = Constant

Brecciated surface and basal **crusts**

Coherant **core** which remains fluid during activity

Typically 0.5 - 20 m thick

Clinkers - Broken blocks within the crust

Forms in lavas of higher viscosity

Pāhoehoe

Smooth, glassy, coherent surfaces

Surface folds called **ropes**

Individual units have a **lobate** shape

Individual flow can consist of 100s-1000s of lobes

Normally low effusion rates and low viscosity

Crust is thin but thickens with time

New lobes **breakout** through fractures in crust

Typical thicknesses from 3 - 40 cm

Block lavas

Typical of intermediate to rhyolitic lavas

Crust has large blocky surface

Blocks are relatively smooth compared to ‘a‘ā

Coherent core

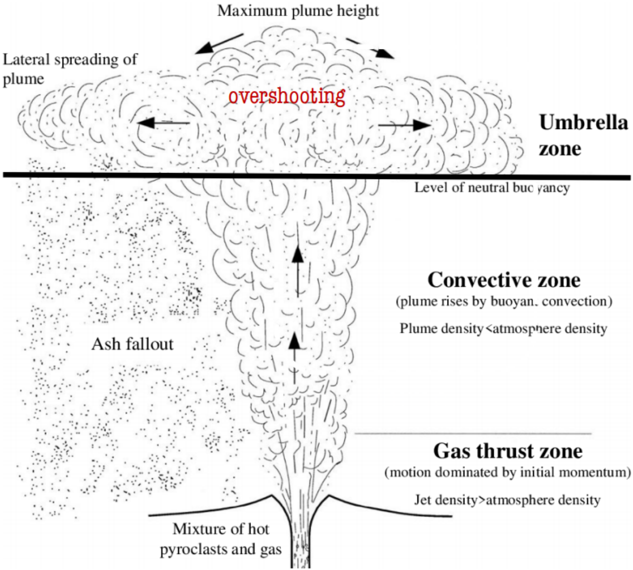
10s-100s m thick

Crystal rich

Lava domes

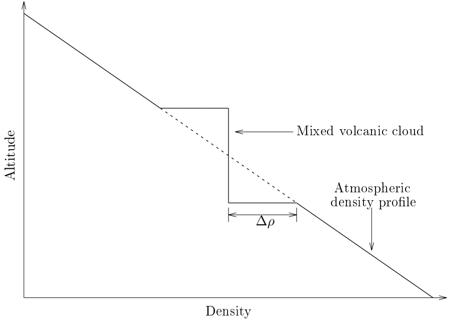
- Mound of viscous lava and rock around the vent
- Can be crystal-poor or crystal-rich
- Crystal-poor domes are rhyolitic
- Crystal-rich domes span compositional spectrum
- Common at convergent margins
- Unstable collapse is a considerable hazard
- Can grow **endogeneously** or **exogeneously**
- Often associated with **vulcanian** explosions

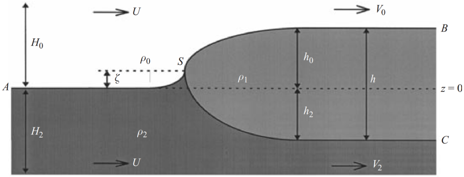
Spreading umbrella clouds



Spreading umbrella clouds

Radially spreading gravity current

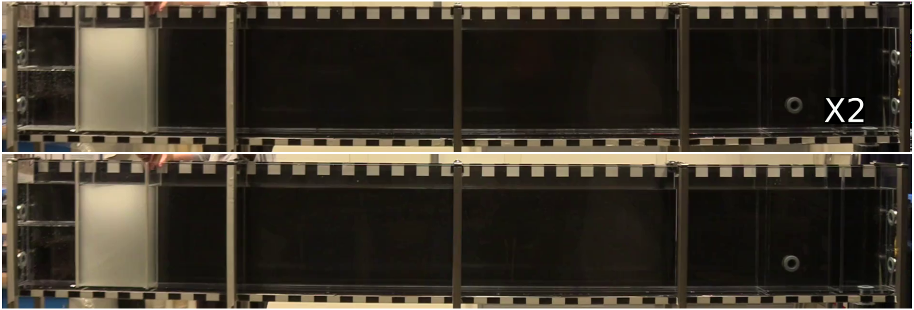




Velocity depends on:

- Flux
- Density of mixture

Spreading umbrella clouds: Experimental modelling

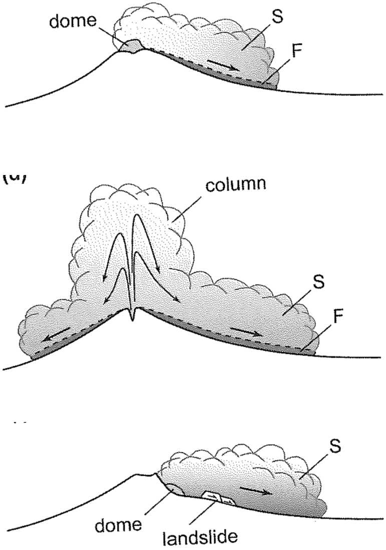


Shear at the base of the cloud can inhibit fallout

Fallout can change density difference

Models of deposition from spreading clouds used to infer eruption parameters from deposit characteristics

Pyroclastic density currents (PDCs): Generating mechanisms



Dome collapse

- Front slope of dome becomes oversteep
- Material avalanches down slope

Column collapse

- Erupted jet doesn't become buoyant
- Material falls back to the ground

Lateral blast

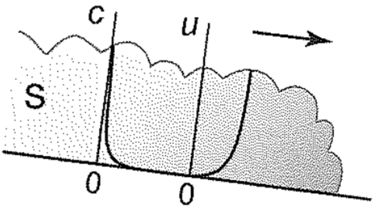
- Ground motion depressurises shallow magma
- Rapid expansion of volatiles mobilises more material

PDCs: Flows and surges

PDCs are a multiphase mixture of solid particles and hot gas

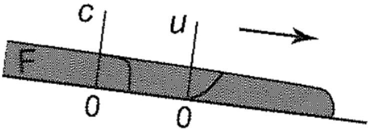
Dilute surges

- Solid concentrations ~ 1 kg m^{-3}
- Concentration increases downwards
- Velocity increases upwards
- Particle interactions negligible except at the base



Dense flows

- Particle concentrations similar to that in the deposit
- Internal velocity and concentration profiles poorly constrained



Surges: Effect of particle sedimentation and mixing

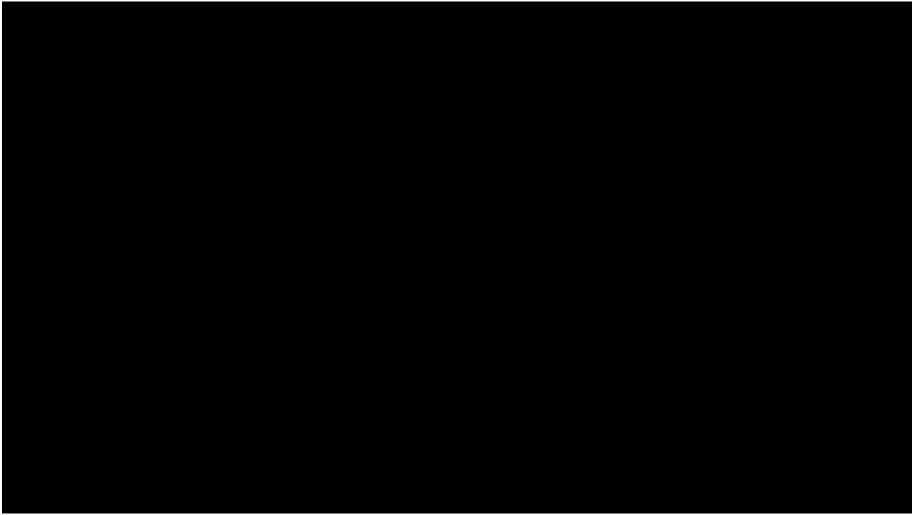
Sutherland et al. (2018)

To model current propagation need to consider conservation of:

- Mass
- Momentum
- Energy

How do particle settling and mixing affect these balances?

Flows: Detailed study on internal structure



Lube et al. (2019)

Flows: Detailed study on internal structure

Lube et al. (2019)

Lahars: Remobilised pyroclastic deposits

Lahars - Mixtures of water and volcaniclastic sediment

Huge variation in:

- Volume: $10^2 - 10^9$ m^3
- Peak discharge: $< 10 - 10^7$ m^3 s^{-1}
- Advance rate: $\sim 2 - 80$ m s^{-1}
- Runout: $< 10- > 100$ km

Lahar triggering

Lahar initiation requires:

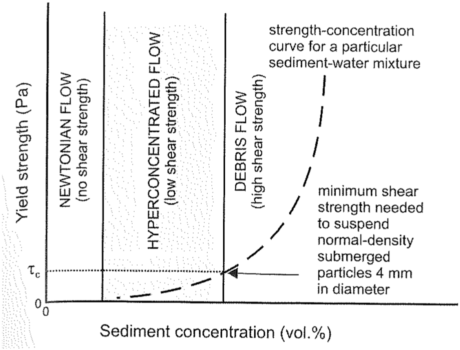
- Sufficient water supply
- Adundant unconsolidated sediment
- Gravitational potential
- Triggering mechanism
  - Rainfall
  - Snow and ice melt
  - Liquefaction

Hyperconcentrated flow

- Solid volume fraction $\sim$ 0.2-0.5
- Bulk density $\sim$ 1.3-1.8 kg m^{-3}
- Density stratified
- Turbulent

Debris flow

- Solid volume fraction $\sim$ 0.5-0.8
- Bulk density $\sim$ 1.8-2.3 kg m^{-3}
- 10^4 - 10^5 times more viscous than water



Conclusions

- Volcanoes are sources for various gravity currents
- Reynolds number Re strongly determines style of flow
- Lava flows have low Re
- Volcanic clouds, PDCs and lahars have high Re
- Multiphase nature of flows exerts strong control on flow runout and deposit morphology
- Hazard and risk assessment requires these flows to be modelled