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Magma transport processes

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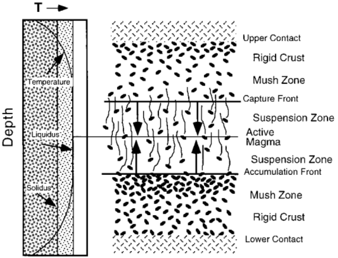
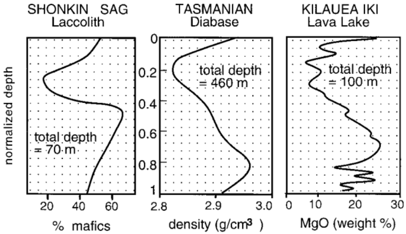
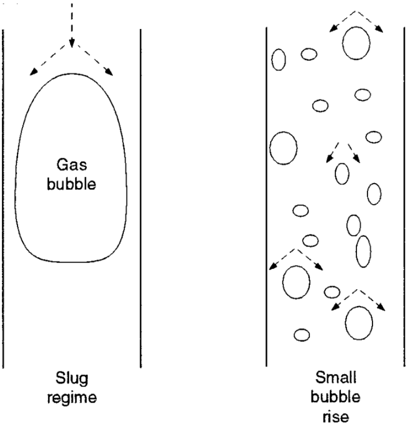
Magmatic transport processes

Viscosity and density control how magma is transported within the Earth's crust
Can consider transport of bulk magma, or fracionation of individual phases

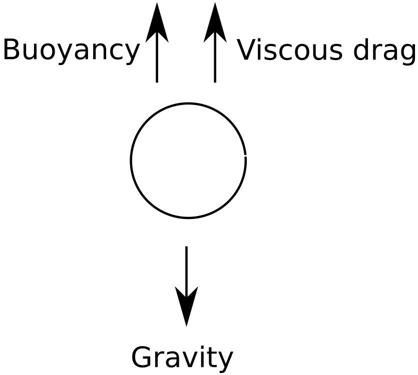






Crystal settling

Sills can contain cumulates - dense regions of crystals which have settled to the base of a chamber



In viscous fluid, three forces act on sphere:

- Gravity $F_g = 4\pi\rho_c r^3 g/3$
- Buoyancy $F_b = 4\pi\rho_m r^3 g/3$
- Viscous drag $F_v = 6\pi\eta_m r v_s$

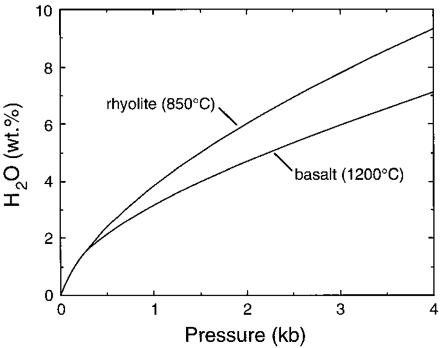
where r = radius, v_s = settling speed

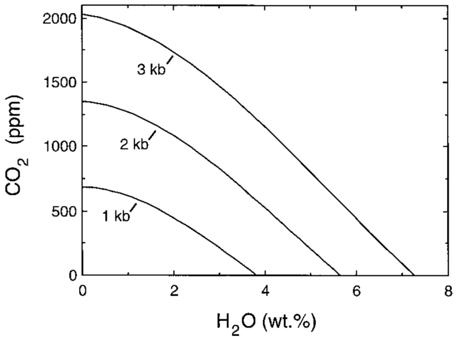
In equilibrium $F_g = F_b + F_v \implies$

$$v_s = \frac{2(\rho_c - \rho_m) g r^2}{9\eta_m}$$

As magma rises, pressure falls and bubble solubility decreases

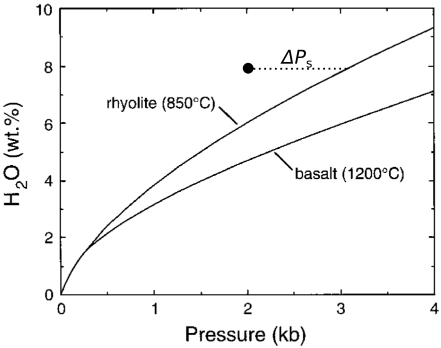
Solubility - Amount of substance that can be dissolved in a mixture





If volatile concentrations exceed solubility, then magma is **supersaturated**

Supersaturation - Difference between actual pressure, and that at which concentration of dissolved volatiles would be in equilibrium



Nucleation - Process by which bubbles initially form

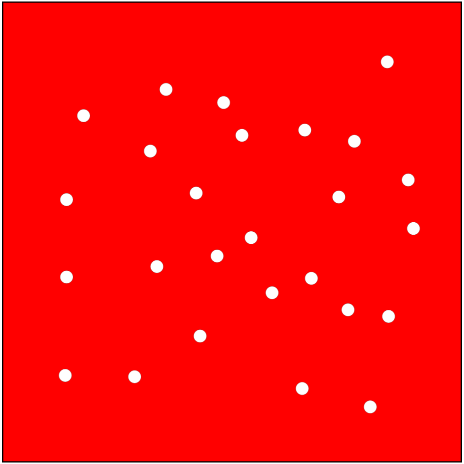
Nucleation creates an interface between melt and volatile

Interfacial tension - Energy created to create an interface between two substances

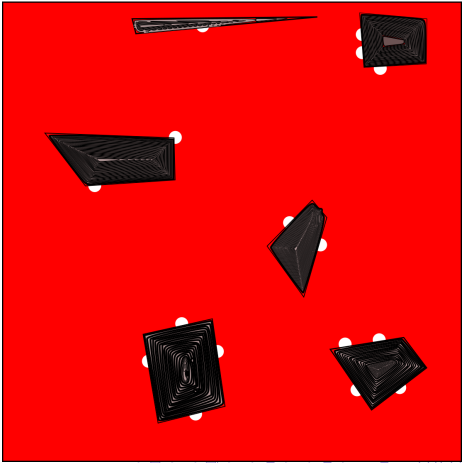
Required amount of supersaturation corresponds to energy needed

Two types of nucleation:

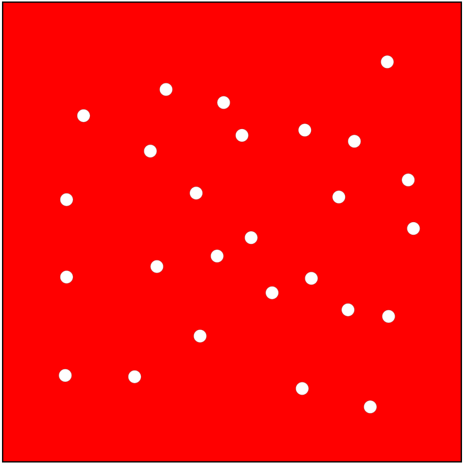
Homogeneous



Heterogeneous



Bubble formation - Homogenous nucleation

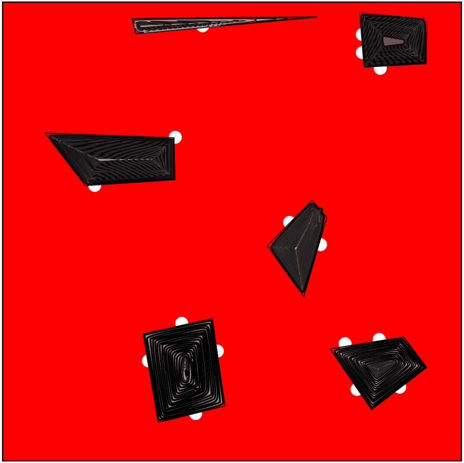


Occurs in the absence of crystals

Bubbles nucleate in the melt

Requires supersaturation of $\sim$ 10-100 MPa

Bubble formation - Heterogeneous nucleation



Interfacial energy between vapour and crystal less than that between vapour and melt

Bubbles nucleate on crystals

Requires supersaturation of $\sim$ 1-10 MPa

$\Longrightarrow$ in presence of crystals, nucleation will almost always be heterogeneous

Bubble growth

As pressure decreases, bubbles grow due to expansion and increasing amount of exsolved gas
3 regimes of bubble growth:

- Viscosity-limited growth
  - Melt viscosity is sufficiently high to slow down bubble expansion
  - Leads to large supersaturation and build up of over-pressure in bubbles (mechanical disequilibrium)
  - Significant for $\eta_{\mathrm{m}} \geq 10^9$ Pa s (silicic melts at shallow depths and low $X_{\mathrm{H_2O}}$
- Diffusion-limited growth
  - Melt diffusivity is too low for oversaturated volatiles to diffuse to pre-existing bubbles (chemical disequilibrium)
  - Leads to nucleation at the expense of growth
  - Results in many small bubbles
- Solubility-limited growth
  - Diffusivity high, and viscosity low, enough to allow mechanical and chemical equilibrium
  - Bubbles can grow unhindered
  - Favoured for low melt viscosity (hot, mafic) and low ascent rates

Bubble rise speed

Bubble rise speed can be estimated by assuming spherical shape and using Stokes law

$$v_b = \frac{(\rho_m - \rho_b) g d^2}{18 \eta_m}$$

Depends on:

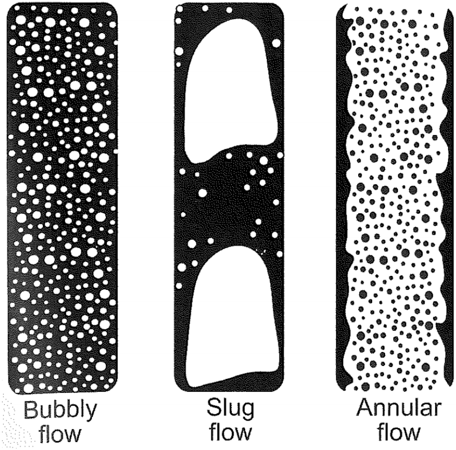
- ρ_m = Melt density
- ρ_b = Bubble density
- d = Bubble diameter
- η_m = Melt viscosity

Other factors:

- Bubble shape
- Bubble concentration ϕ_b
- Crystal fraction ϕ_c

Bubble flow regimes

v_b = Bubble speed, v_m = Melt speed



If $v_b \ll v_m \implies$ **dispersed flow**:

- **Bubbly flow**
- Bubbles dispersed
- Move as passive tracers

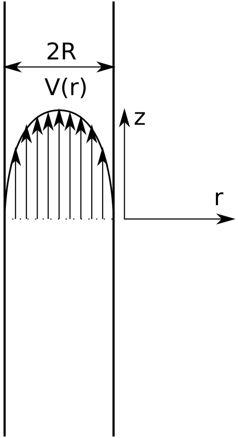
If $v_b \gtrsim v_m \implies$ **separated flow**

- $1 \lesssim v_b/v_m \lesssim 10 \implies$ **slug flow**
- $v_b/v_m \gtrsim 10 \implies$ **annular flow**

Flow regimes are observed for gas flow in a vertical pipe

Application to volcanic conduits remains debatable

Conduit flow



Flow driven by pressure gradient $\mathrm{d}P/\mathrm{d}z$
Velocity profile given by

$$\frac{\mathrm{d}V}{\mathrm{d}r} = \frac{r}{2\eta}\frac{\mathrm{d}P}{\mathrm{d}z}$$

Friction with conduit walls means flow is fastest in centre
Model is valid if flow is NOT separated

Fragmentation

Fragmentation - During explosive eruptions, magma fragements to form **pyroclasts** - ash, lapilli, bombs

- Style of fragmentation depends on magma rheology
- In turn depends on $\phi_{\mathsf{c}}, \phi_{\mathsf{b}}, \eta_{\mathsf{m}}, \dot{\epsilon}$
- Controls style of eruption

Magma mixing and mingling - Magmas of different compositions juxtapose and interact

- Viscosity and density contrasts between magmas inhibit mixing
- Heat transfer fromm hot to cold magma associated with rheological changes
- Style of mixing changes with time