

EASC 421 - Volcanology



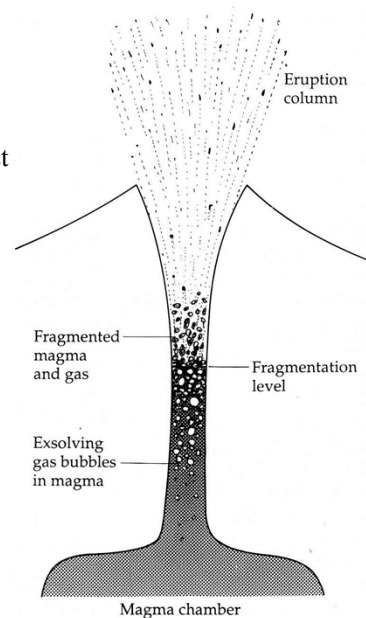
Explosive volcanism I

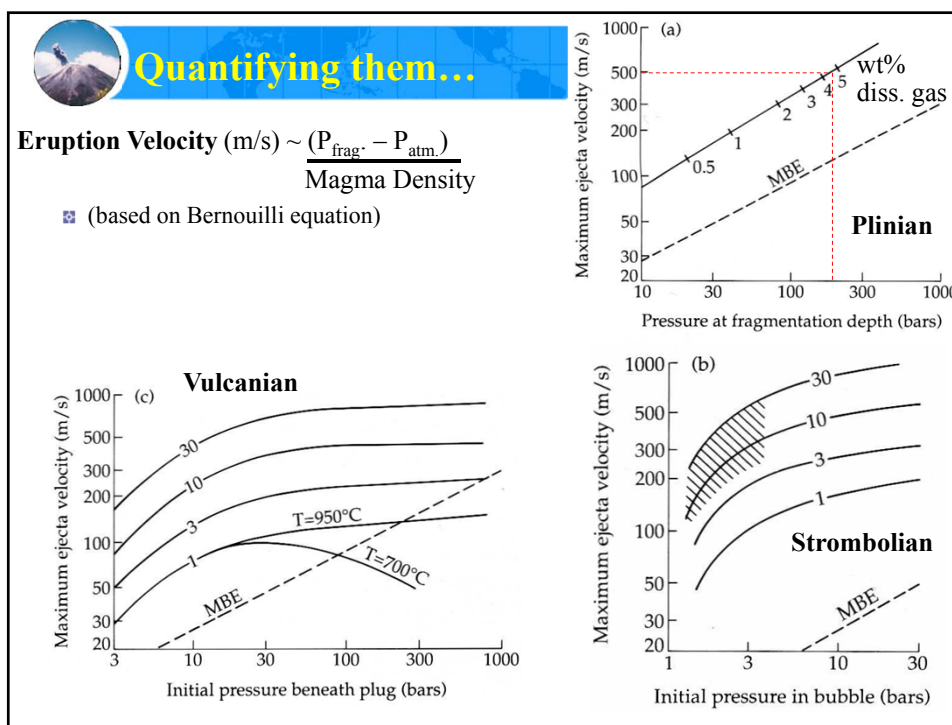
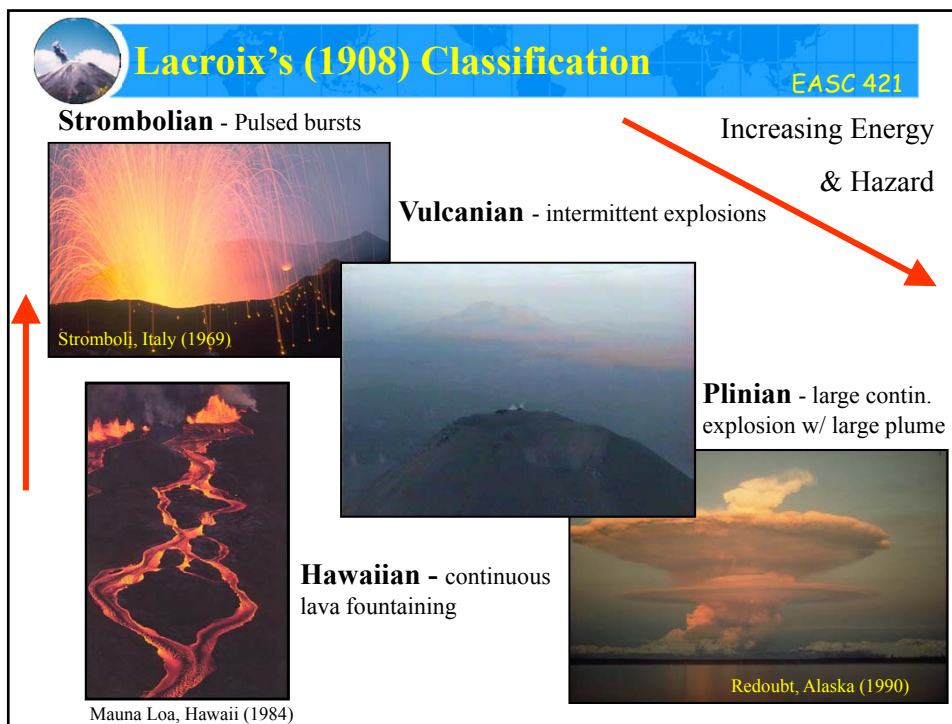


Explosive Eruptions

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- ✦ Volcanic explosions result from catastrophic expansion of **gas phase**
 - ❑ Direct observations difficult (except from afar) & limited – Duh!!
 - ❑ Underlying physics of volcanic explosions must be deduced from:
 - Geologic observations - results of past explosions
 - First principles - laws of physics
- ✦ requires “significant” fragment dispersal (volume dependent)
- ✦ explosion requires a “significant” degree of magma fragmentation
 - ❑ but non-explosive fragmentation to a similar degree also occurs
- ✦ Magmatic (“dry”) explosion driven solely by expansion of steam bubbles



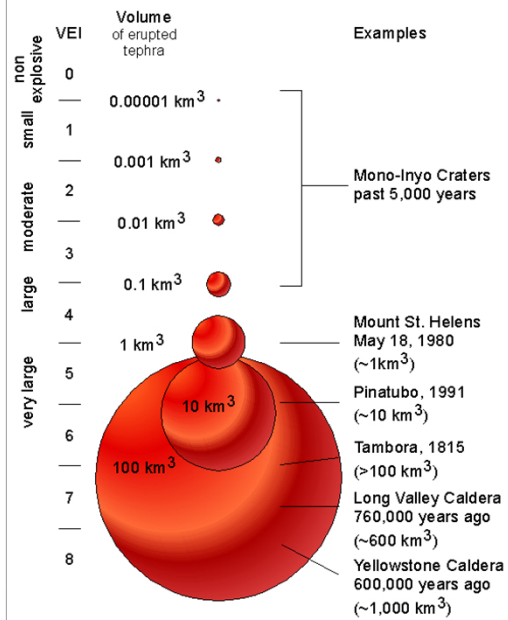
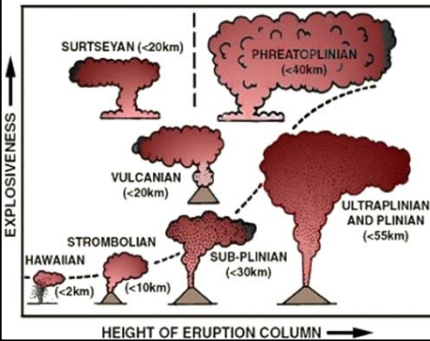




Volcanic Explosivity Index (VEI)

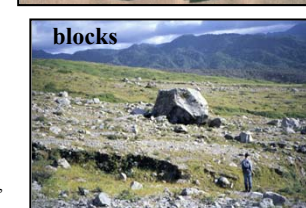
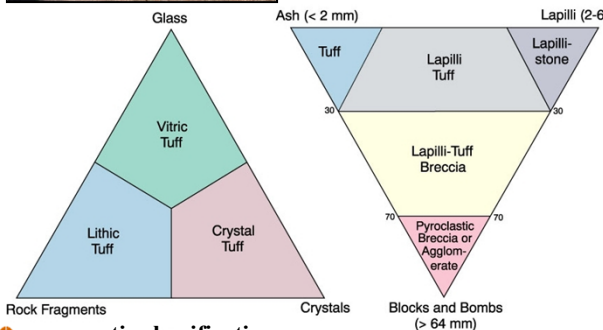
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- proposed in 1982 to describe relative size /r magnitude of explosive volcanic eruptions
- 0-to-8 index of increasing explosivity
 - each step = $\sim 10\times$ increase
- factors include: volume of erupted pyroclastic material, eruption column height, duration in hours & qualitative descriptive terms



Explosive products - tephra

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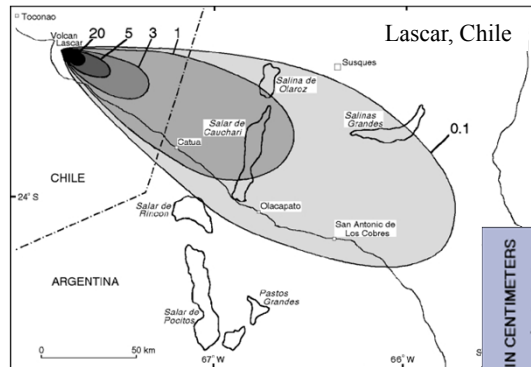
nongenetic classification

- unconsolidated pyroclasts can be welded, compacted, cemented
 - Ash tuff, lapilli tuff, tuff breccia, pyroclastic breccia, agglomerate, agglutinate



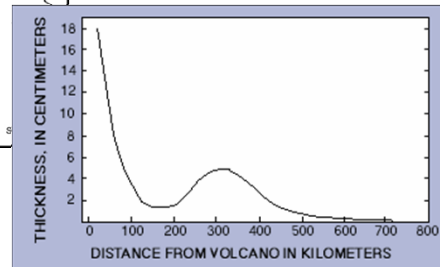
Isopach maps

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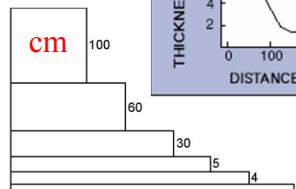
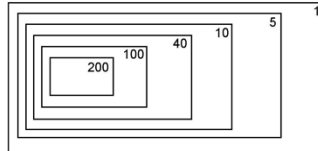
✦ Line of equal tephra thickness

✦ NB. May get compaction over time!



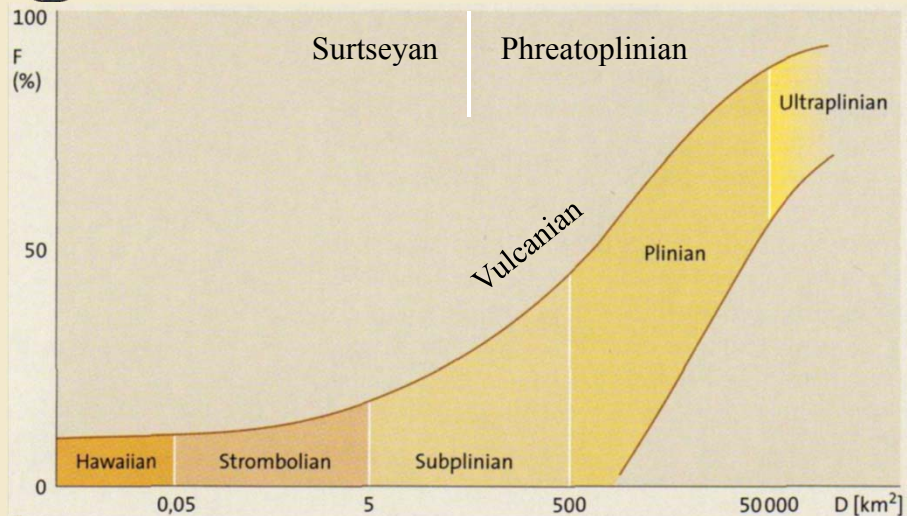
Mount St. Helens

✦ Isopleths??



Explosive triggers

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✦ D = distribution of tephra deposits (area inside isopach = 1% of max. thickness, so $D = 0.01 T_{\max}$)

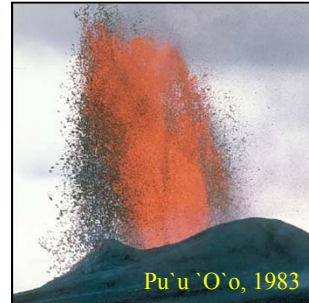
✦ F = degree of tephra fragmentation (% < 1 mm at 1% of max. thickness)



Hawaiian explosions

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- ✦ refers to **fountaining** with magma propelled above surface by expanding gas
 - ❖ may reach 500 m, but 10-100 m more typical
- ✦ high fountaining often announces new eruption/eruptive phase
 - ❖ +/- undegassed magma - subsequent phases show much smaller fountains (or none)
- ✦ gas disrupts magma into “clots”
 - ❖ **ratio of Clot:Gas** was 70:1 in Pu'u O'o
 - ❖ Fragmentation by fluid instabilities in rapidly accelerating jet of magma
 - ❖ Typically produces **Scoria Cones**



Pu'u 'O'o, 1983



Mt. Etna

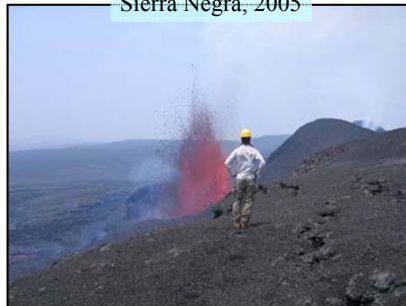


Fire fountains

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Sierra Negra, 2005



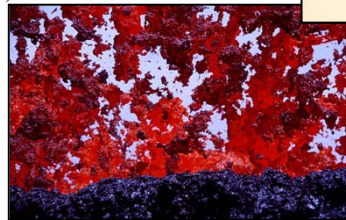
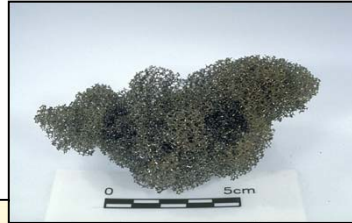
Pu'u 'O'o, 1983



Hawaiian pyroclasts

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- ✦ fountain core may produce highly vesicular **reticulite**
- ✦ fountain margins may be spun in wind to form glass fibres (**Pele's hair**)
 - ▣ Also from lava flows & bursting gas slugs
- ✦ clasts often "fluidal" ash/lapilli
 - ▣ Include angular ash/lapilli
- ✦ coarse spatter can be sticky (agglutinate)



Strombolian Explosions

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Stromboli, Aeolian islands, Italy



- ✦ discontinuous individual explosions repeated at intervals of few per min. to few per hour
- ✦ **Gas:clot ratio** - $10^5:1$
- ✦ 10^{-2} m^3 to 10^2 m^3 erupted/explosion
- ✦ Muzzle velocities $< 100 \text{ m/s}$
- ✦ Results from single large bubble reaching the surface & bursting

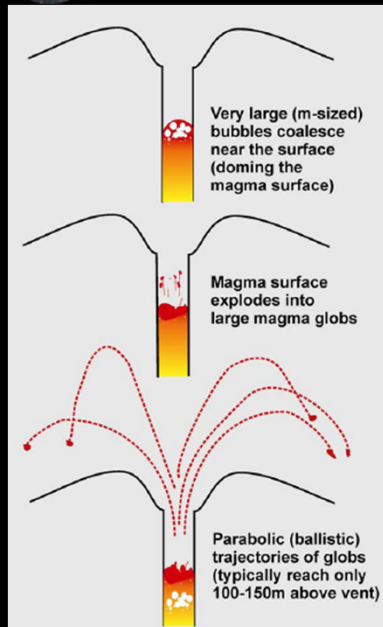
Strombolian Eruption





Fragmentation in Strombolian explosions

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Strombolian pyroclasts

- ❑ mostly coarse (lapilli to block) clasts of variable vesicularity, fluidal & angular
- ❑ variable proportion of (mostly) angular ash
- ❑ bombs (aerodynamically moulded) are common
- ❑ agglutinated spatter & agglutinate (clastogenic) lava flows are common



Vulcanian Explosions

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- ✦ Discrete, very violent explosions
- ✦ Can ejecting enormous blocks & generate atmospheric shock waves
 - ❑ Muzzle velocities ≤ 400 m/s (supersonic)
 - ❑ Speeds suggest 100x overpressure
- ✦ High proportion of non-juvenile material in ejecta
- ✦ May produce ash clouds & PFs

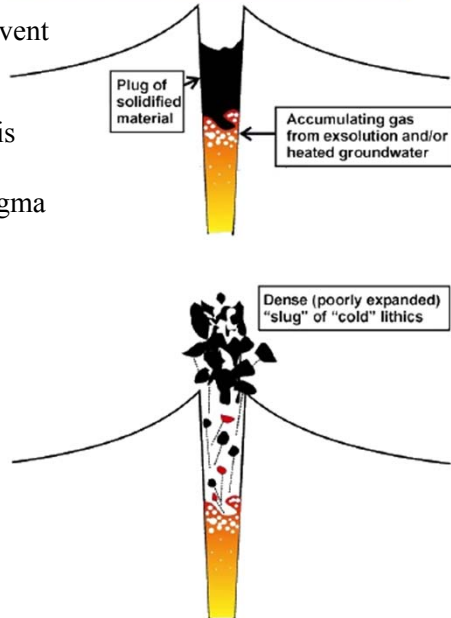
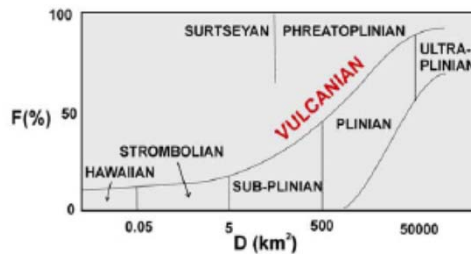




Vulcanian Explosions

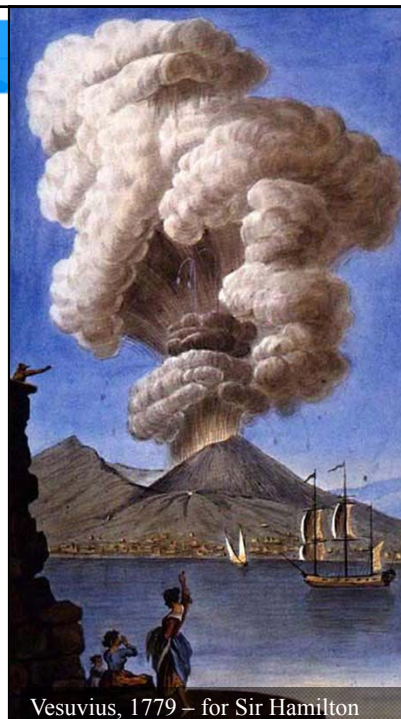
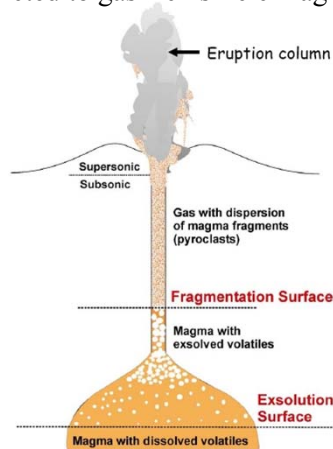
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- ✦ thought to occur when debris blocks a vent & gas exsolved from magma builds up beneath the blockage
- ✦ when strength of block is exceeded, it is ejected!
- ✦ consequent drop in pressure on the magma results in further exsolution
 - ✦ expanding gas propels magma explosively out of the vent



Plinian Explosions

- ✦ Occur when bubbles of exsolving magmatic gas completely disrupt magma
 - ✦ i.e., transformation from bubbly liquid to gas containing fragments of liquid
- ✦ Restricted to gas-rich silicic magmas



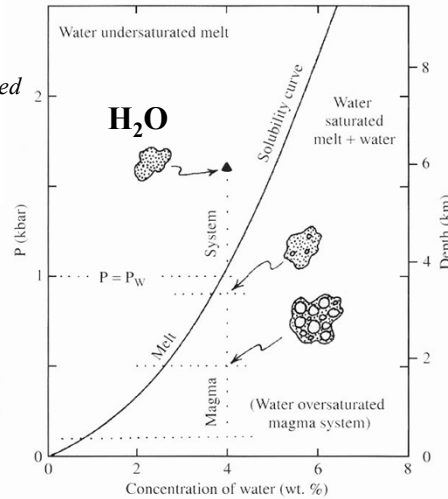
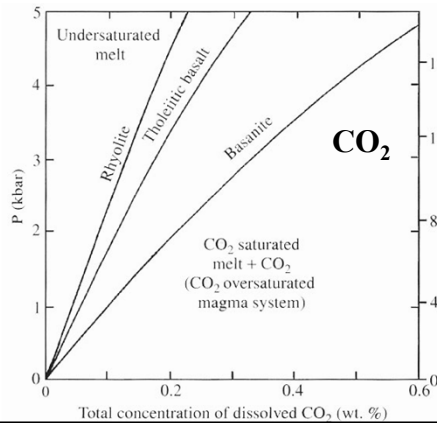


The Physics of it - Gas Exsolution

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- Gas acts as **propellant** in all volcanic explosions

- generally originates as H_2O & CO_2 dissolved in magma
- other sources e.g., ground water can be important - particularly in **vulcanian** explosions



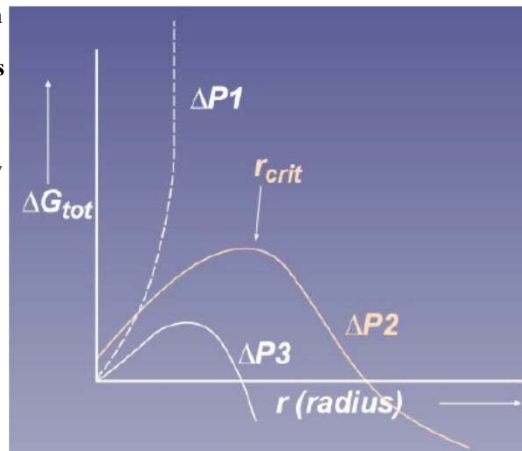
- Relative Solubility in Melt
 $CO_2 < S_{total} < H_2O \leq HCl < HF$



Bubble Nucleation

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- exsolution of gas from magma results in formation of new *phase* (bubbles)
- formation of **interface** between **bubbles** & pre-existing liquid phase
- interface has *interfacial* or *surface free energy*, σ , associated with it
 - must be overcome for a bubble to grow
- Surface free energy between gas & silicate magma is fairly large, requiring significant **supersaturation**
 - rapid bubble formation once necessary ΔG_r is reached
- Surface free energy correlates with **viscosity**
 - so nucleation is more difficult in rhyolite than basalt
- Crystals provide potential sites of bubble nucleation where surface free energy is lower
 - finite surface free energy already exists between crystal & liquid

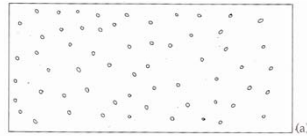


$$\Delta G_{tot} = 4\pi r^2 \sigma + \frac{4}{3}\pi r^3 (\Delta G_r / V)$$

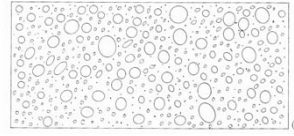


Vesiculation Stages

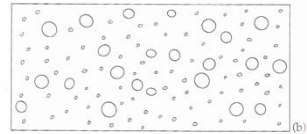
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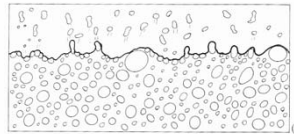
Bubble Nucleation



Froth Saturation

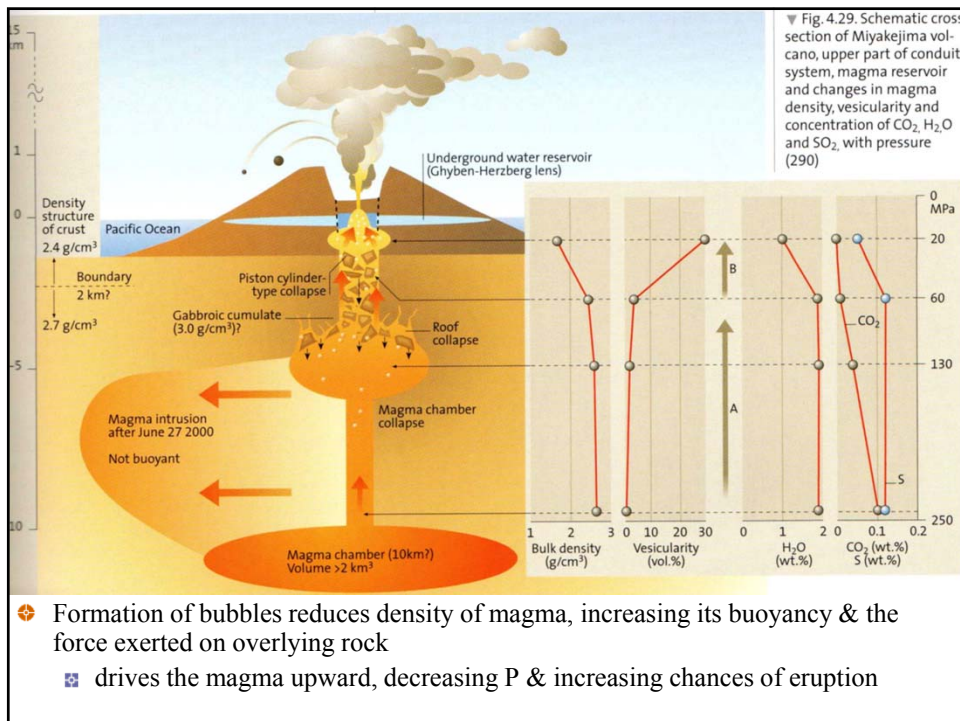


New Nucleii & Growth



Fragmentation

- ✦ **nucleation** will occur at rate: $J \propto D \exp [-(16\pi\sigma^3/3RT \Delta P^2)]$
 - ❑ Leads to strong exponential dependence on supersaturation
- ✦ **growth & nucleation** rates also $\propto$ to diffusion coeff., D , so can be limited by diffusion of gas to bubble surface
 - ❑ Diffusion rates related to viscosity, so bubble growth more likely diffusion limited in silicic lavas than in mafic lavas



- ✦ Formation of bubbles reduces density of magma, increasing its buoyancy & the force exerted on overlying rock
 - ❑ drives the magma upward, decreasing P & increasing chances of eruption



Rise of Bubbles

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Stokes Law:

$$v = \left[\frac{(\rho_l - \rho_g)g}{18\mu} \right] d^2 \approx \frac{\rho_l g d^2}{18\mu}$$

❏ v = velocity, d = bubble diameter (μ = dynamic viscosity)

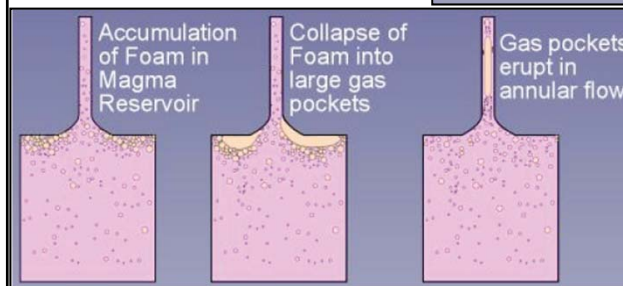
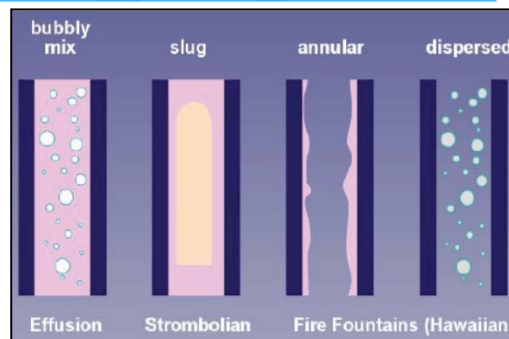
- ❏ For basaltic liquid, 1 mm bubble rises at 0.5 m/h (1 km in 3 months), 1 cm bubble at 50 m/hr
- ❏ For wet granitic liquid, 1 mm bubble rises at 0.4 m/yr, 1 km in 2500 yrs



Conduit Flow Regimes

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- ❏ Yield strength & viscosity key factors in eruptive style
 - ❏ Low viscosity, yield strength favour collapse of foam & also annular flow
- ❏ Higher viscosity inhibits foam collapse
 - ❏ When collapse occurs, slug rise favoured over annular flow



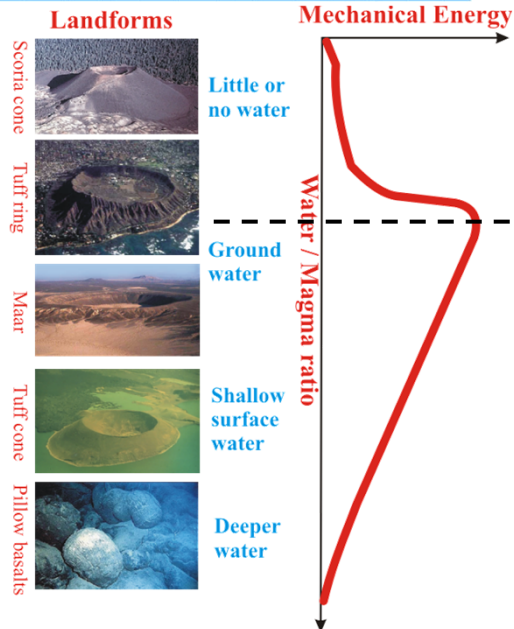
- ❏ Vergnolle & Jaupart models



Landforms & Water-Magma Mixing

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- In experiments simulating magma-water interaction, most explosive interactions occur when water/magma ratio is ~ 0.3
- Explosivity correlates with eruption style, emplacement processes and landforms
- These structures are typically **monogenetic!**

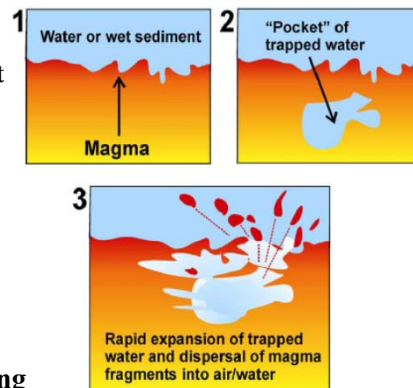


Magma & Water

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Bulk interaction

- envelopment of pockets of water / wet sediment within magma
- Expansion of water generates local explosive fragmentation of magma



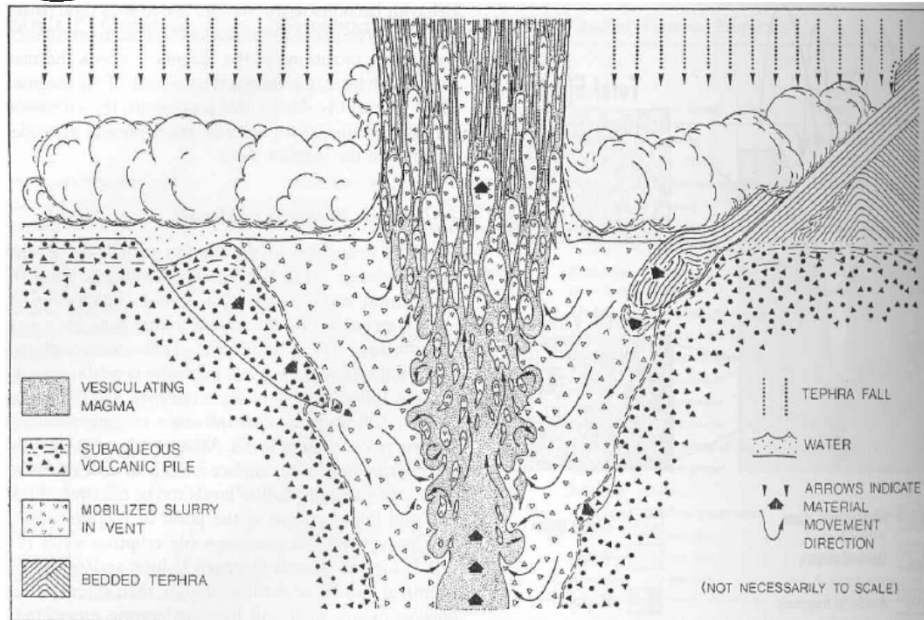
Film boiling

- important because insulates magma from water
- insulation (partly) explains why magma does not always explode on interaction with water
- simultaneous collapse of films can also lead to explosive fuel-coolant interactions!



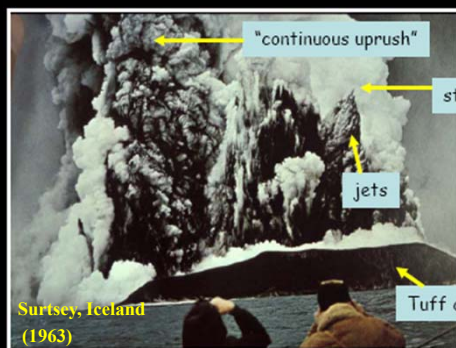
Hydrovolcanic Explosions

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Hydrovolcanic or Surtseyan Explosions

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Ukinrek, Alaska (1977)



Base Surge (Capelinhos, Azores 1957)

- ✦ requires a water/slurry flooded vent
- ✦ weakly energetic (small volumes)
- ✦ Emplacement from ballistic jets & from sustained eruption columns ("continuous uprush"). Lots of associated steam!
- ✦ Fall & Pyroclastic Density Current (PDC) deposition
- ✦ Pyroclasts commonly palagonitized (if basaltic)
- ✦ Most important eruption style in construction of tuff cones, tuff rings & maars



Hyaloclastites

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- ✦ fragmentary, medium to fine-grained rock, consisting of angular shards of black glass clasts (may or may not be vesicular)
 - ❏ most commonly mm to cm across
- ✦ formed by phreatomagmatic eruption or by nonexplosive spalling of pillow basalt rinds by **chill shattering** - quench fragmentation
- ✦ **sideromelane** - water-quenched basalt glass
 - ❏ pure transparent variety of glass – lacks small FeO crystals found in most opaque basalt glass (**tachylite**).
- ✦ **palagonite** - amorphous yellow-to-brown glass formed
 - ❏ formed from hydration / alteration of sideromelane within hyaloclastite
 - ❏ common hydrovolcanic deposit, **palagonite tuff**, contains a mixture of sideromelane shards and coarser-grained fragments of basaltic rock in a palagonite matrix.



Next class...

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Explosive volcanism II