ERTH 456 / GEOL 556 Volcanology

– Lecture 06: Conduits–

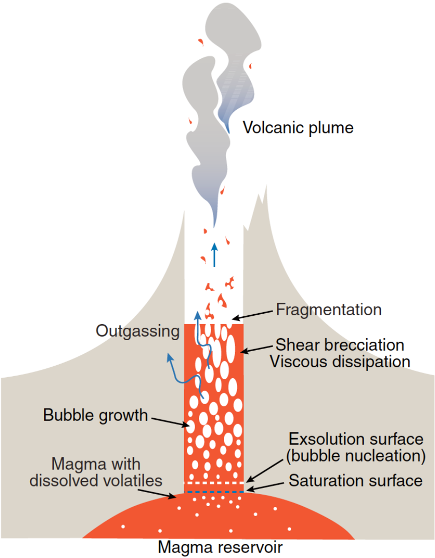
Ronni Grapenthin
rg@nmt.edu
MSEC 356, x5924
hours: TR 3-4PM or appt.

September 12, 2016

How does magma get from source to surface?

What happens along the way?

Volcano Anatomy

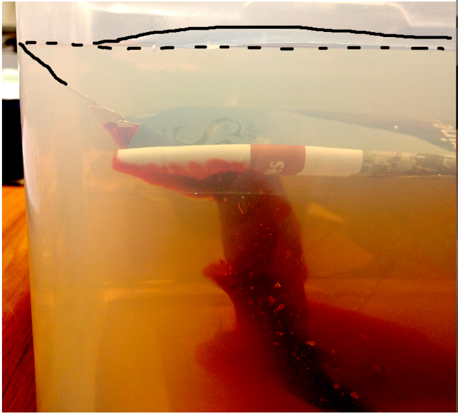


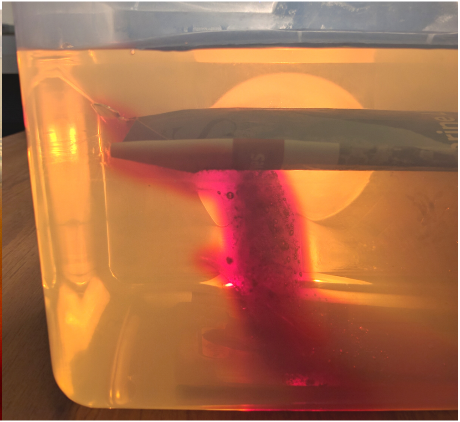
Gonnermann & Manga, 2007

Conduit construction

- poorly understood, through mostly dike driven
- viscosity determines propagation speed (up to m/s for basalt, days-years for silicic magma)
- dike width: controlled by magma pressure elastically deforming wall rock
- delay (hours-days) between eruption initiation & climactic activity suggests full connectivity not established right away (e.g., St Helens, Pinatubo)

Conduit Construction





Us!

Conduit evolution

- evolution in time and space through:

Conduit evolution

- evolution in time and space through:
  - mechanical, thermal erosion
  - magma solidification
  - changing stress conditions

Conduit evolution – Thermal Erosion

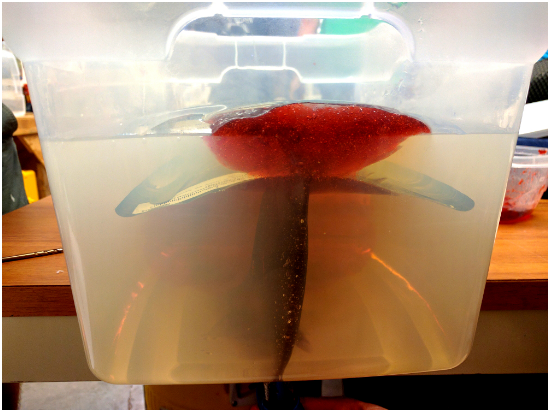
- Basaltic eruptions: “curtain of fire” evolves to localized vents
  - feedbacks of flow, rheology, cooling
  - rapid flow through wide part: heat advection slows / reverses chilled margin growth
  - low flow through narrow part: cooling & solidification promoted

Conduit evolution – Solidification

- degassing and crystallization changes viscosity
- similar effects to low flow rate: cooling & solidification

Conduit evolution – Mechanical Erosion

- likely where dikes change orientation
- brittle deformations, brecciation & dilatation localize flow; generate xenoliths
- xenoliths can be transported to surface



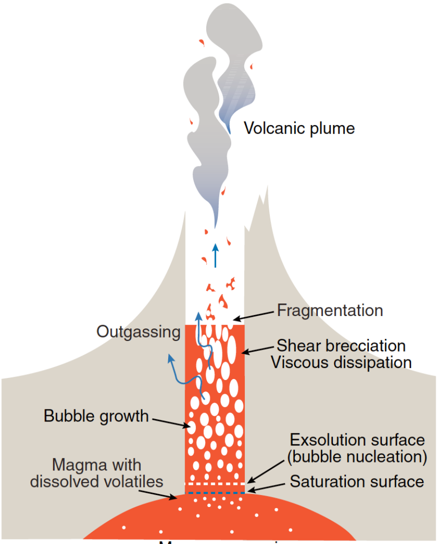
Us!

Conduit evolution – Mechanical Erosion

- shallow levels of explosive vents
- cylindrical near-surface conduits develop if early magma:
  - sufficiently overpressured to excavate conduits
  - sufficiently underpressured to cause wall rock to fail, transported out by explosive flow
- can extend to kilometers into conduit for powerful explosive eruptions

Volatiles, Bubbles & Crystals

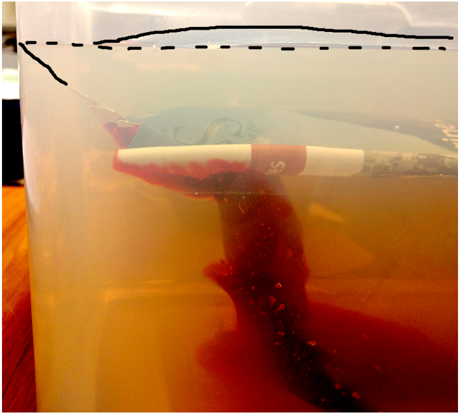
- **volatiles** in silicate melt more soluble at high pressures
- decompression causes exsolution of volatile phase as bubbles (vesiculation)



Gonnermann & Manga, 2007

Volatiles, Bubbles & Crystals

- homogeneous **bubble** nucleation: nucleation within the melt
- heterogeneous bubble nucleation: nucleation on crystal surfaces
- bubble number densities in pumice: homogeneous nucleation
- very high bubble number densities: supersaturation due to rapid magma decompression or rapid crystallization (heterogenous nucleation)



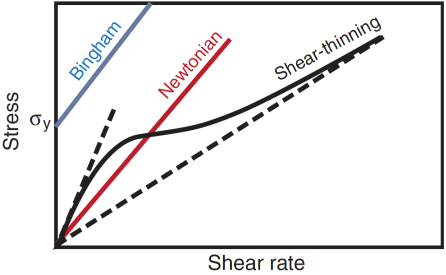
Us!

Volatiles, Bubbles & Crystals

- Number and proportion of **crystals** reflect conditions of magma ascent
- Time required for crystal nucleation / growth in response to water exsolution depends on:
  - melt composition and temperature
  - undercooling (temperature below equilibrium crystallization temperature of a mineral that initiates nucleation)
  - presence / absence of phenocrysts
- experiments show decompression-induced crystallization can occur on eruptive time scales

Rheology

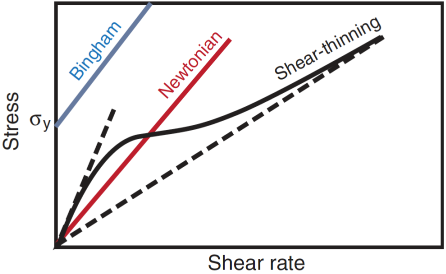
- see Lab 1
- generally Newtonian
- suspended crystals / bubbles can result in non-Newtonian properties (increase in viscosity)
- sufficient crystal content: yield-strength generated, shear-thinning / shear-thickening
- crystal shape: high aspect ratio allows interaction at low volume fraction



Cashman & Sparks, 2013

Rheology

- crystallization due to volatile exsolution during rapid decompression (small elongate plagioclase) can cause apparent viscosity change several orders of magnitude
- viscous rhyolitic glass may repeatedly break and re-anneal during slow shallow ascent: hybrid earthquakes (?)



Cashman & Sparks, 2013

Controls on Eruption Style

- driving force: pressure gradient between magma source and surface
- opposing force(s): friction along walls, degassing / solidification

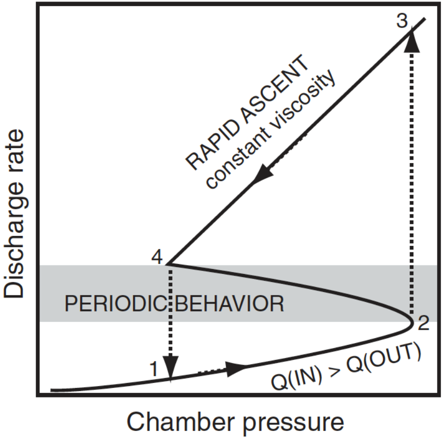
Controls on Eruption Style

- driving force: pressure gradient between magma source and surface
- opposing force(s): friction along walls, degassing / solidification

- ascent rate: controls eruption style; depending on retention of gas
- gas loss: controlled by relative rates of bubble rise, coalescence, permeable pathway development
- bubble rise: controlled by viscosity

Conduit Flow

- numerous interacting factors = variety in volcanic behavior
- Figure: general steady-state solution of feedbacks: magma input, overpressure, output
- small decompression related changes in magma viscosity: 1-2-3-4
- periodic behavior when input in shaded region



Cashman & Sparks, 2013

Gas during Ascent

- after mobilization magma ascents due to volatile exsolution
- bubble velocity: drift velocity
- magma velocity: ascent velocity
- ascent modulated by vesiculation & gas escape, which depends on viscosity
- low viscosity (basalt): bubbles separate from ascending magma when bubbles rise faster than melt

Gas during Ascent – Bubbly Flow

https://www.youtube.com/watch?v=YV_BlnpJvao

Gas during Ascent – Slug Flow

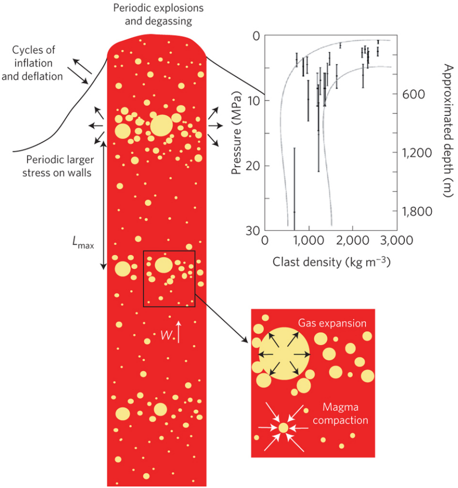
https://www.youtube.com/watch?v=_K1jkp9uCz4

Gas during Ascent – Bubbly Flow

https://www.youtube.com/watch?v=g0eXnEutiaU

Two-phase Flow

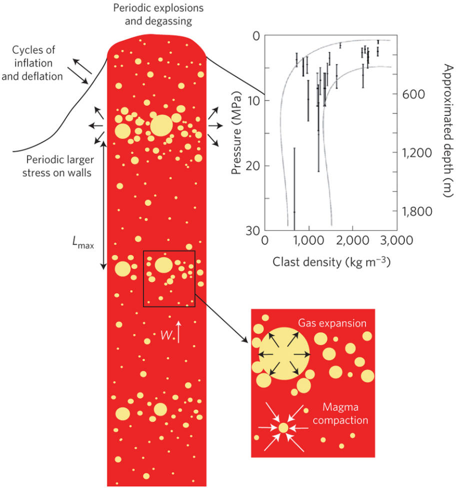
- recent development to move toward numerical models that examine gas-magma flow in large conduits with viscous fluid
- high-viscosity fluids enhance bubble coalescence due to drift velocity decrease



Michaut et al., 2013

Two-phase Flow

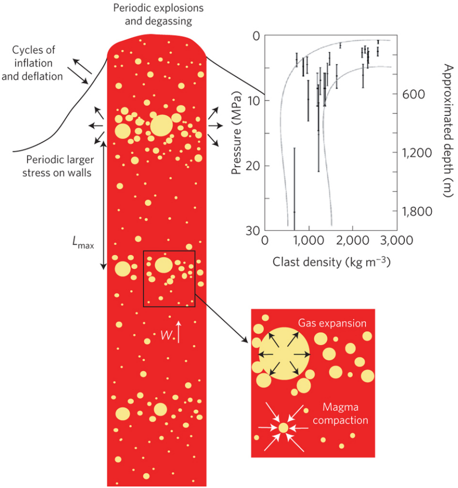
- large, conduit filling bubbles may be dynamically unstable during buoyancy-driven ascent
- cyclic patterns in bubbly magmas may explain pulsing in Hawaiian, Strombolian eruptions



Michaut et al., 2013

Two-phase Flow

- crystals may hinder gas migration if bubbles are trapped
- . . . or help degassing if bubbles coalesce in melt pathways



Michaut et al., 2013

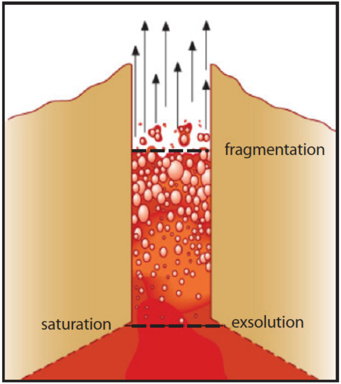
Magma Fragmentation

Fragmentation: transition from melt with included bubbles to continuous gas phase with suspended droplets / particles (Cashman & Sparks, 2013)

Magma Fragmentation

Fragmentation: transition from melt with included bubbles to continuous gas phase with suspended droplets / particles (Cashman & Sparks, 2013)

- can be ductile (low-viscosity, basaltic melts) or brittle (high-viscosity, silicic melts)
- **ductile fragmentation:** instabilities in accelerating liquid phase
- **brittle fragmentation:** magma exceeds critical vesicularity, volatile phase critical overpressure, expanding melt exceeds critical strain rate



Cashman & Sparks, 2013

Conduit Examples - Dike, Reykjanes, Iceland

R. Grapenthin

Conduit Examples - Dike, Kamen, Kamchatka

Conduit Examples - Conduit Zimina, Kamchatka