Assignment #1

- Report (2 to 5 pages) on Mt. Nyiragongo
  - Where (geologically) is it located?
  - What is its eruptive history over the last 30 or so years?
    - What has been the social (life & property) consequences of eruptions
  - How, if at all, is it monitored?
  - Why is its lava so fluid?
    - Hint: composition - report on its composition and explain why/how composition affects viscosity
  - Why were lava velocities so high in the 1977 eruption?
    - Factors other than viscosity?
  - What non-geologic factors complicate & amplify the social impact?
What dictates the form and morphology of lava flows?

- Lava flows take on a variety of forms:
  - A’a flows
  - Pahoehoe flows (subvarieties)
  - Coulées
  - Domes
    - Plugs
    - spines
- Why do flows take on such variety of forms?
- What are the key differences?
  - Aspect ratio (length to thickness)
  - Surface roughness
- What governs these properties?

What factors are of importance and interest?

- Effusion Rate (m$^3$/s)
- Flow Velocity (m/s)
- Flow Length (m)
- Flow Direction - governed by topography
- Laminar vs Turbulent?
- Compound vs Single Flows
- Cooling
  - Submarine or subareal?
  - Thick crust or not?
Laminar vs Turbulent

- Two kinds of flow
  - Laminar
  - Turbulent

- For a Newtonian fluid, whether flow is turbulent or laminar depends on the Reynolds No., Re:
  \[ Re = \frac{UR}{\eta} \]
  - Where U is velocity, R hydraulic radius, \( \rho \) density and \( \eta \) is viscosity
  - Flow is turbulent when \( Re > 500 \) to 2000

- For a Bingham Fluid, the critical ratio is the Hampton No:
  \[ H = \frac{\rho U^2}{\tau_0} \]
  - Critical value is 1000

Bottom Line:
- Turbulent vs. Laminar is probably not a factor
- Essentially all lavas should flow laminarly
- Komatiites, carbonatites are possible exceptions

Yield Strength & Flow Thickness

- For a Bingham fluid to flow at all, a minimum force, the yield strength, \( \tau_0 \) must be applied.
- Available force is gravity. Vertical gravitational force is simply \( t \rho g \)
  - \( t \) is thickness, \( \rho \) is density and \( g \) is acceleration of gravity
  - Component of force directed parallel to slope is \( t \rho g \sin \alpha \)
  - Resistance to flow is \( \tau_0 \)

- For flow to occur:
  \[ t \rho g \sin \alpha \geq \tau_0 \]
  \[ t \geq \frac{\tau_0}{\rho g \sin \alpha} \]

\[ t_c = \frac{\tau_0}{\rho g \sin \alpha} \]
Data are actual thicknesses and angles for Mt. Etna lavas measured by Walker (1967). Lines are calculated critical thicknesses for Bingham fluids with yield strengths of 1000 Pa and 20000 Pa.

- Once the thickness exceeds the critical thickness, flow will proceed at a velocity, $V$, given by:

$$V = \frac{\rho g t^2}{B \eta} \sin \alpha$$

- Where $B \approx 3$
- Note dependence on inverse of $\eta$ and square of $t^2$
- Flow velocities measured by Walker on Etna range from 0.5 to 50 cm/s.
- Assumes fluid of uniform viscosity - more complex if crust forms.
Lava Flow Velocities

- Flow fronts generally advance very slowly, usually < 1 km/hr. Hence, they represent little hazard to human life - most of the time!
- An interesting exception is lava flows from Mt. Nyiragongo, D. R. Congo. In a 1977 eruption, lava is reported to have flowed at velocities as high as 60 km/hr killing perhaps thousands.

Mafic Lavas

A’a
Pahoehoe
Pillow Lavas
A’a & Pahoehoe

Pillow Lava
Formation of Pillow Lavas

- Pillow lavas are restricted to submarine and subglacial flows.
- Form where water rapidly quenches a skin or crust that forms a 'balloon' containing liquid lava.
- New pillows form by budding from cracks of parent pillows.
- Restricted to relatively low effusion rates.
  - Pahoehoe-like sheet flows form at high effusion rates.

Morphology of Subareal Mafic Lavas

- Pahoehoe
  - Smooth flow surfaces
  - Flow advances by budding new toes in bulldozer fashion
- A’a
  - Very rough, clinkery, brecciated surface composed of irregular cindery blocks with razor sharp asperities
  - Form as crust breaks and is effectively ground during flow
- Blocky
  - Similar to ‘a’a, but surface blocks are bigger (meters vs. cm to 10’s cm)
Pahoehoe Toes

Entrain Pahoehoe
Ropy Pahoehoe

Active A’a Flow
Pahoehoe & A’a

- Pahoehoe is only observed in relatively low-viscosity lavas
  - Basalts and rarely andesites, never dacites or rhyolites.
  - Suggests viscosity is a factor
- Pahoehoe and a’a lavas often occur on the same volcano; indeed pahoehoe flows can transition to a’a.
  - (But a’a never transforms to pahoehoe).
- What factors dictate the surface morphology?
  - Obviously, composition & viscosity can’t be the sole factors.

Transition from Pahoehoe to A’a
Energy supplied to break the crust vs rate at which crack can be healed is critical factor.

Above a certain critical rate of energy supply and cracking, an a’a crust develops.

Critical value depends on how fast crack can heal by chilling.
In Hawaii, pahoehoe lavas form at low volumetric flow rates and low flow front velocities. Depends on discharge rate and slope.
Silicic Lavas

Coulées
Domes
Spines

Lava Coulée

Lava Coulées, Mono Craters area, CA
Lava Dome

Lava dome, Katmai, Alaska

Lava Spine

Lava Spine, Mt. St. Helens
Formation of Silicic Lavas

- High viscosities lead to very high aspect ratios
  - Rhyolitic lava coulées typically have thicknesses > 50 m.
- Highly viscous lavas effectively do not flow horizontally at all, forming vertically extruded domes.
  - “Spines” represent perhaps the most viscous lavas.

Incandescent Lava Dome of Soufriere Hills, Montserrat, 2003
Evolution of the Mt. Pelee Spine

Aspect Ratio

- Define aspect ratio as: \( t/l \)
  - where \( t \) is thickness and \( l \) is length
  - (note: sometimes defined as ratio of thickness to area)
- Depends on physical properties
  - \( t/l = \tau \eta^{1/4} (g \rho)^{3/4} \)
  - Where \( F \) is effusion rate
Flow Lengths

- Predicting length of a lava flow is complex
  - For an a’a flow, it depends on discharge rate, thermal diffusivity, thermal radiance, strength of the crust, slope, and density:

\[
L = \left[ \frac{1.5 \varepsilon S / \rho g}{\left( \sum \sigma T^4 / (T \kappa \rho c_p) \right)} \right] / \sin^2 \alpha
\]

- \( \sum \) is surface emissivity, \( \sigma \) is Stephan-Boltzmann constant, \( \varepsilon \) is extension before failure of crust, \( S \) is tensile strength of crust