Lava Flows

Most lava flows are basaltic in composition

Basalt	90%
Andesite	8%
Dacite/Rhyolite	2%

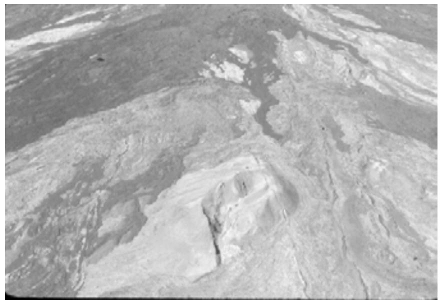
This is because most silicic and intermediate magmas erupt explosively (higher gas content and viscocity) to produce PYROCLASTIC deposits.
Only one rhyolite flow has ever been observed – Tuluman Islands (near Papua/New Guinea) (1953-1957).

There are three main types of lava flow:-

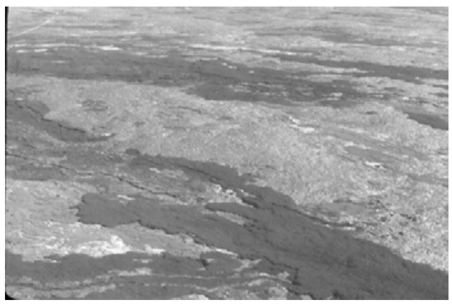
- PAHOEHOE – has a shiny, smooth, glassy surface. It tends to be more fluid (lower viscosity), hence flows more quickly and produces thinner flows (typically 1-3 m).

- AA – a rubbly flow, with a molten core, with higher viscosity (but same composition) which, therefore, tends to move more slowly and produce thicker flows (typically 3-20 m).

- BLOCKY – similar to Aa, but even thicker (>20 m), with a blocky rather than rubbly surface. Andesites, dacites and rhyolites tend to form blocky flows.



Aa and pahoehoe flows on Mauna Loa volcano, Hawaii.



Pahoehoe flows are a silvery gray in color, whereas the Aa flows are a darker gray. This is because the pahoehoe is glassy and the aa is rubbly.

	Basalts	Dacites
Thickness	2 - 30 m	20 - 300 m
Typically	5-10 m	~ 100 m
Hawaii	~ 4 m	
Aspect Ratio (Height/Area)	0.01 – 0.02	0.02 – 0.1
Length	1 – 90 km	0.5 – 10 km
Typically	4 – 5 km	~ 1 km
Hawaii	10 - 25 km	
Volume	0.5 – 1,200 km^3	<< 1 km^3
Hawaii	< 1 km^3	(This may need revising)
Laki (Iceland)	12 km^3	
Roza (CRB)	1,200 km^3	

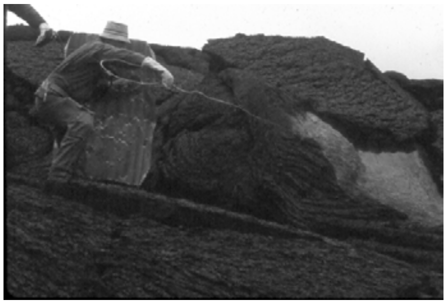
Pahoehoe Flows

Pahoehoe flows on Kilauea Volcano, Hawaii

Pahoehoe close ups

Measuring the temperature of a flow

Famous scientist pokes
flow with a stick!



Pahoehoe lava takes on a variety of shapes and forms - these are examples of ropy pahoehoe

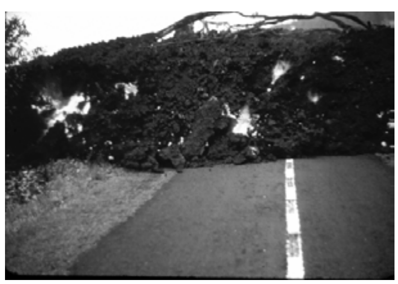
Pahoehoe near the vents is often very gas-rich, inflating to produce shelly pahoehoe. Some bubbles can be quite large!

This type of pahoehoe has the splendid name "entrail pahoehoe" - for obvious reasons.

Aa Flows

Aa flow on Mauna Loa volcano, 1984.

Volcanologist runs away from an aa flow!



Why did the aa cross the road?

The interrior of an aa flow

Measuring the flow temperature

Blocky flows

Blocky lava flow completely engulfs church at Paracutin, Mexico.

House being consumed by lava flow in Iceland. Note, this flow is transitional between aa and blocky in its characteristics.

Blocky lava flows at Newberry Volcano, Oregon (upper left) and Medicine Lake Highland, California.

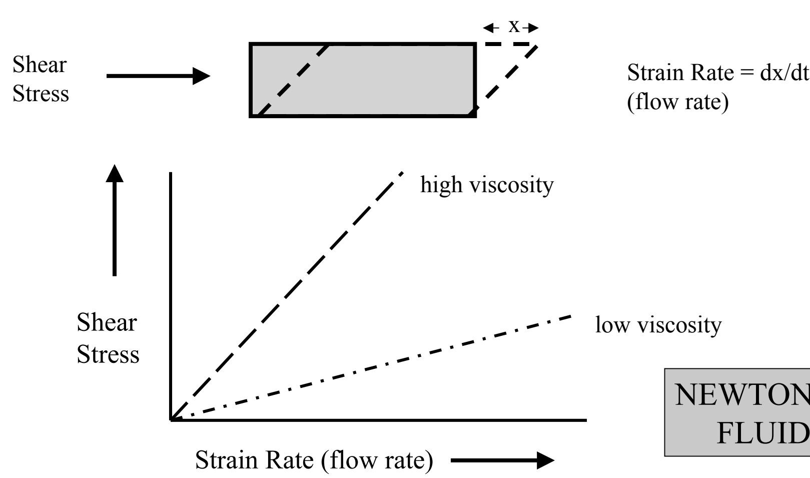
RHEOLOGY – fluid dynamics of lava flows. Viscosity and Yield Strength are the two most important factors that influence:-

- Surface morphology (flow type)
- Size and shape of the flow
- Flow thickness
- Eruption rate
- Flow velocity
- Length of lava flows

Many of these factors are important for evaluating the hazard potential of a flow. Also useful in remote sensing and planetary studies.

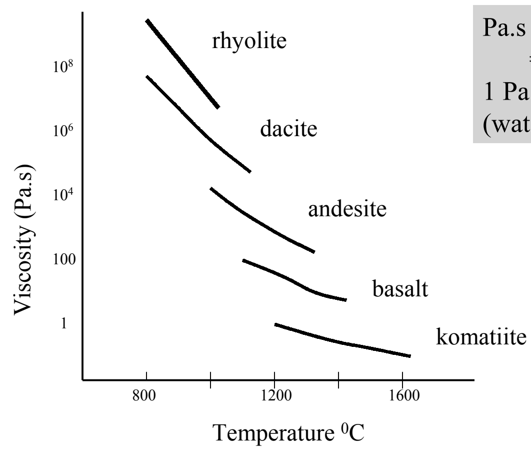
VISCOSITY – is probably the most single important factor and is a measure of how strongly the melt is polymerized.
(Silicic melts are more polymerised than basaltic melts, hence are more viscous)

Viscosity (η) = Shear Stress/Strain Rate



NEWTONIAN FLUIDS

Effects of composition and temperature on viscosity



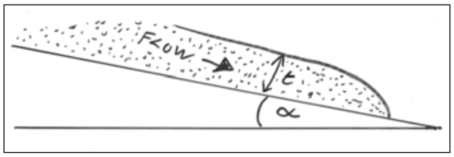
Pa.s = Pascal Seconds
= kg/m/sec
1 Pa.s = 10 poise
(water = 10^{-3} Pa.s

Dissolved water reduces viscosity as does higher pressure

How is viscosity measured?

1. Laboratory – measure the rate of descent of spheres of known weight and size in a melt.
2. Laboratory and field – measure the resistance of a rotating paddle immersed in lava or melt.
3. Laboratory – calculated from the chemical composition of the lava.
4. Field – measure the depth of penetration of a steel spear fired from a crossbow.
5. Field – calculate empirically from the flow velocity or the dimensions of the lava flow (chicken and egg relationship?)

Flow Rate – there is a useful empirical relationship between viscosity and flow rate (velocity).



ρ = melt density
g = gravity (980.6 cm/sec^2
t = thickness (cm)
η = viscosity
α = slope

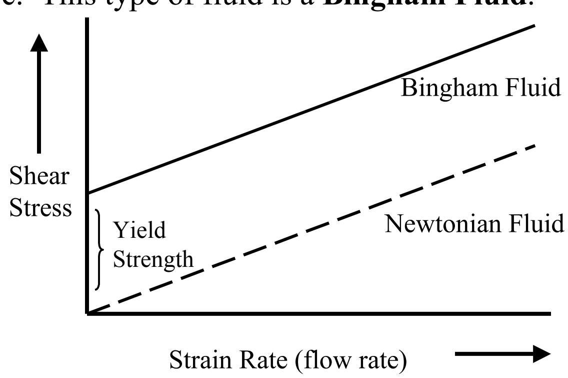
Flow Rate (V) = $\rho g t^2 / 3\eta * \sin(\alpha)$

(Jeffreys equation)

Obviously, the steeper the slope or the lower the viscosity, the faster the flow rate!
Conversely, one can turn this around and estimate the viscosity from a measured flow rate

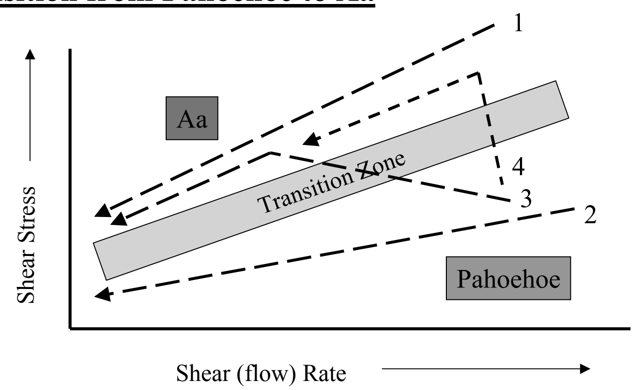
Viscosity (η) = $\rho g t^2 / 3V * \sin(\alpha)$

Most lava flows are not simple liquids, but contain phenocrysts and gas bubbles. Consequently they do **not** behave as Newtonian fluids. They have a threshold value that must be overcome before the flow will move. This type of fluid is a **Bingham Fluid**.



Bingham Viscosity = (Shear Stress – Yield Strength)/Strain Rate

Transition from Pahoehoe to Aa

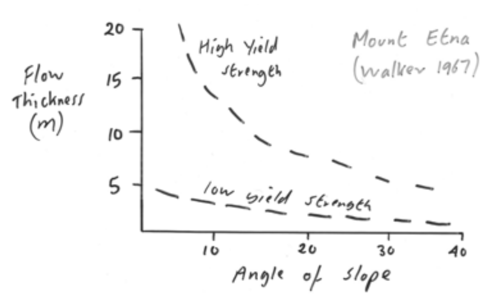


1 and 2 – lavas with different Bingham viscosities and yield strengths follow the paths shown, producing pahoehoe and aa respectively.
3 – usual case, yield strength and Bingham viscosities increase as lava crystallizes and flow rate decreases leading to transition from pahoehoe to aa.
4 – sudden increase in shear stress (slope steepens) also leads to transition from pahoehoe to aa.

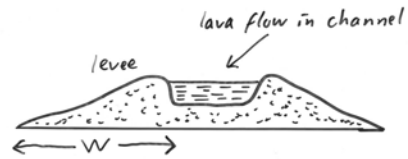
Flow Thickness

Thickness (t) = Yield Strength/($\rho g * \tan(\alpha)$) (Hulme 1974)

- ❑ All else being equal, lavas with high yield strengths will produce thicker flows.
- ❑ Flows will be thinner on steep slopes!



Flow Levees



The width of the levee can be related to yield strength

Width (W) = Yield Strength/($2\rho g * \tan(\alpha)^2$)

(Note that this is also proportional to thickness)

Levee width, and flow thickness have been used extensively in planetary studies to estimate the physical properties (which provide a guide to composition) of extra-terrestrial lava flows

Flow Length - estimating flow length during an eruption is very important because of implications for **hazard** assessment.

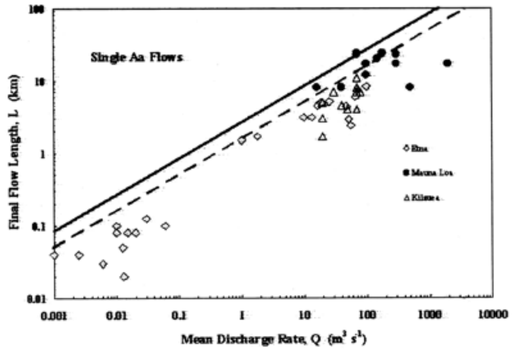
Flows are controlled by topography, so we can predict where they will go. The million $ (or more!) question is how far will they travel.

Several factors have been proposed:-

1. Viscosity and yield strength
2. Total volume
3. Slope
4. Eruption rate (m^3/sec)

George Walker (1973) concluded that eruption rate was the single most important factor.

Laki (Iceland)	~ 5,000 m^3/sec
Mauna Loa (1984)	280 m^3/sec
Dacites	< 1 m^3/sec



Logarithmic plot of flow length vs eruption rate (m^3/sec). Lines are theoretical predictions, whereas symbols represent real data from Etna, Kilauea and Mauna Loa

In this example, Anja will show us how to estimate flow velocities from measurements made on lava channels, such as this one on the Hapaimanu flow on Mauna Loa

Flow Velocity (more realistic?)

Taking into account yield strength as well as viscosity

Flow Rate (V) = $[h\Gamma_b/3\eta] * [1-(3/2)(\Gamma_o/\Gamma_b) + (1/3)(\Gamma_o/\Gamma_b)^3$

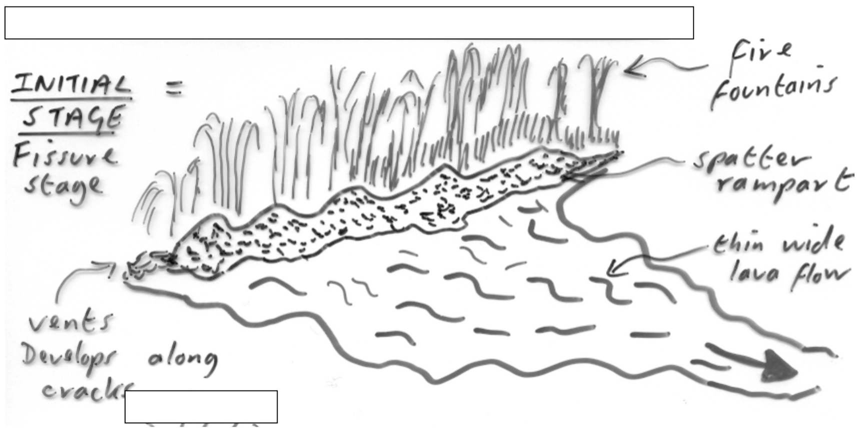
$\Gamma_o = h_o\rho g \sin(\alpha)$ and $\Gamma_b = h\rho g \sin(\alpha)$

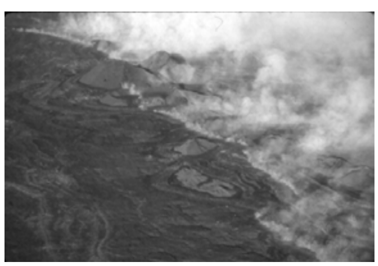
ρ = melt density
g = gravity (980.6 cm/sec^2)
h = thickness (cm)
h_o = critical thickness before flow will move
η = viscosity
α = slope

(Note this is for a wide channel or flow. The constants are slightly different for a semi-circular channel)

Development of a lava flow

Initial (fissure) Stage



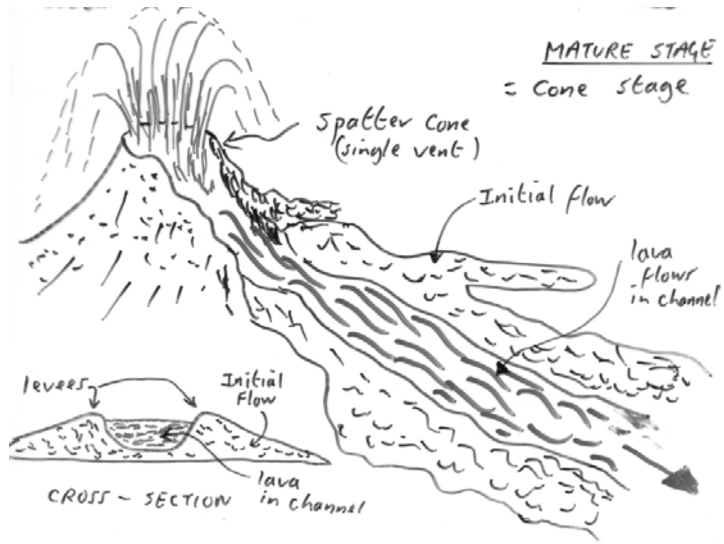



Eruptions from fire fountains feed thin pahoehoe flows


Spatter ramparts are formed along the edge of the fissures

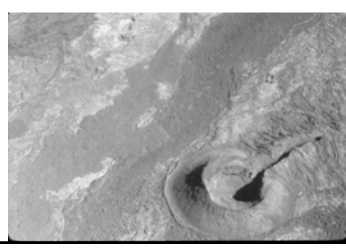
Development of a lava flow

Mature (Spatter Cone) Stage

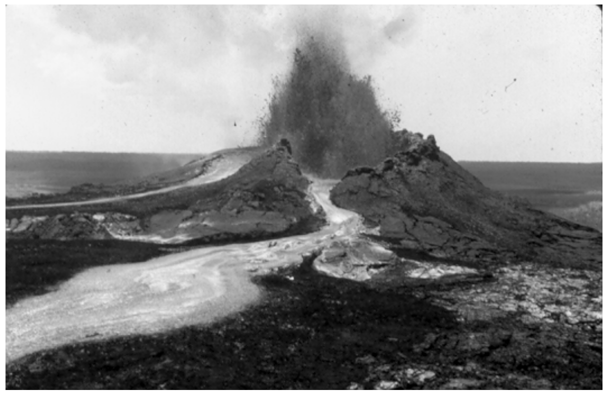


Small spatter cone forming along fissures.

Larger spatter cone produced by a single vent. Note person for scale.



Aerial view of an old spatter cone. Note the lava channel leading away from the cone.



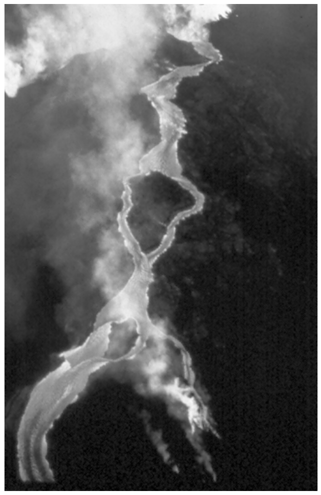
Mature well-developed spatter cone, with lava channels flowing away from the cone.

Length of lava flows (continued)

- Channels – formation of well-developed channels, especially in aa flows, provides efficient transport for lava.

- Lava Tubes – formation of lava tubes or tunnels is typical in pahoehoe flows. Once formed, these tubes insulate the lava, prevent cooling and allow the flow to travel great distances.

Lava Channels



Well-developed lava channels on Mauna Loa Volcano, 1984.

Volcanologist on edge of lava channel about to scoop out a sample.

Lava Tubes

Lava channel "roofing" over to form a lava tube.

"Skylights" looking down into lava tubes.

Sampling lava from a skylight in a lava tube

Kilauea Volcano, Hawaii

Nova - Hawaii, Born of Fire

Lava Flow Hazards

- Lava flows generally travel at slow speeds. (Typical Hawaiian flows move at about 0.25 miles/hr or about 6 miles/day)
- Consequently, it is possible to avoid most flows – resulting in very little loss of life.
- Total deaths from flows (since 1600 a.d.) is about 900.
- Buildings and other structure, of course, are totally destroyed.
- There are, however, exceptions!
  - Maximum speeds for Hawaiian flows is 6-30 m.p.h on steep slopes or for unusually hot and fluid lavas.
  - Nyiragongo (Zaire) – collapse and drainage of a lava lake resulted in a sudden surge of lava traveling at 20-60 m.p.h and resulting in 70 deaths.

- The major problems with lava flows are:-
  - Damage to property.
  - Cuts and blocks transportation.
  - Damages crops and makes agricultural land useless.
- Lava flows are controlled by topography and follow the natural drainage pattern. Hence, the path of flows can be fairly accurately predicted.
- Flows can be very long (Hawaiian flows are typically 10-25 km), therefore the potential for damage is very great, especially in heavily populated areas such as the slopes of Mount Etna in Sicily (e.g. Fornazo).

What can we do about lava flows?

- Build walls and barriers - first attempted on Mt. Etna (1668). Partially successful on Mt. Etna in 1983 and 1992. Not successful in Hawaii (e.g. 1984).
- Divert flow using bombs and explosives - the basic idea is to break levees or lava tubes so that the flow can be dispersed high on the volcano before reaching populated areas. First tried on Mauna Loa in 1935 and 1942. Partial success on Etna in 1983 and 1992.
- Cool flow with water - pumping 2-3 times as much water onto a flow will cool the lava below its melting point, forming internal barriers within the flow. This may divert the flow elsewhere, but it will not stop it. Used in Heimaey, Iceland - but needs a lot of water.