Viscosity experiments: physical controls and implications for volcanic hazards

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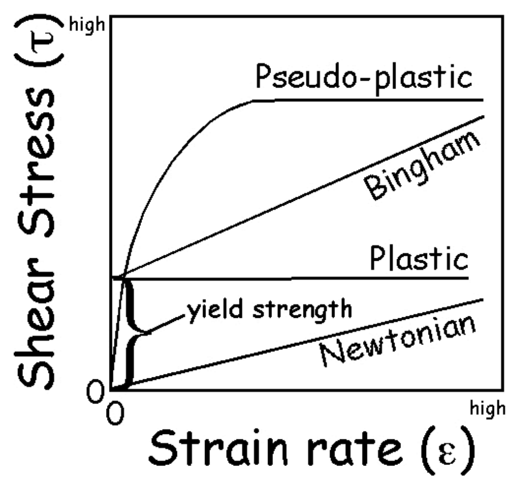
OBJECTIVES OF LAB

- Learn about the rheological property called viscosity and some of the factors that affect it
- Discuss how viscosity controls styles of eruptions and relates to volcanic hazards
- Practice quantitative skills

PART 1. AN OVERVIEW OF VISCOSITY

By definition, viscosity is the "resistance to change of form" (*Handbook of Chemistry and Physics, 61st Edition*) or the "resistance to flow within a fluid" (Fowler, C.M.R, 1990, *The Solid Earth*, Cambridge University Press, p. 462). The viscosity of a substance is a property that determines how rapidly the substance will respond to shear stress; for liquids, this is most obviously reflected in how rapidly a liquid will flow down an inclined surface. For example, water has a **low** viscosity compared to honey; honey has a **high** viscosity compared to water. Liquids that are viscous, or have a high viscosity, flow very slowly. Liquids that are non-viscous, or have a low viscosity, flow relatively more rapidly.



Four different terms are used to describe the ways in which liquids response to shear stress: Newtonian, Bingham, Plastic, and Pseudo-plastic (see figure to the right). **Newtonian** fluids respond instantaneously to shear stress and deform at a constant rate. **Bingham** fluids must experience a critical shear stress, called the yield strength, before they will start to flow; once the yield strength is reached their behavior mimics Newtonian fluids. **Plastic** fluids develop infinite strain rates as soon as their yield strength is reached, while **Pseudo-plastic** fluids deform in a logarithmic fashion until their yield strength is reached.

Viscosity is an important property of magmas for several reasons:

- it determines, in part, how rapidly a magma can move from its source region to the surface of the earth;
- it influences how fast crystals can rise or sink in magma;
- it helps volcanologists predict whether the lava flow from a volcano will move very quickly, and hence be life threatening, or will move very slowly and not be life threatening; and
- it also is an important factor in determining the explosiveness of an eruption.

By completing the activities described below, you will learn about four important factors that can affect the viscosity of magmas and lavas, two very geologically important liquids: temperature, dissolved water, percent of solid material contained in the magma (e.g., phenocrysts, visible crystals in the lava), and the bubble content of the magma.

PART 2. PHYSICAL FACTORS THAT AFFECT VISCOSITY: EXPERIMENTS WITH TEMPERATURE, DISSOLVED H_2O, SOLIDS, AND BUBBLES

A. Experiments

Divide up into four groups; each group will prepare three "lavas" with different viscosities using the clear corn syrup provided. We will discuss as a group towards the end of lab how the viscosity of the "lavas" from each of the groups affects their rate of flow. Circle the heading for the experiments your group is going to conduct.

Set 1: Effect of temperature
Prepare three different temperatures of syrup (hot, room temp, cold).

Set 2: Effects of water
Prepare three different mixtures of water and syrup (1 without water, 1 with a small amount, 1 with a larger amount).

Set 3: Effect of solids
Prepare three different mixtures of syrup and sand (1 without sand, 1 with a small amount, 1 with a larger amount). During the course of this experiment, pick one of the sand grains near the front of the syrup flow and watch how it moves down the slope. Describe with words (or a sketch) the movement of the particle.

Set 4: Effects of bubbles
Prepare three different mixtures of syrup and bubbles using the hand mixer and beating bubbles into the syrups for different amounts of time (1 with no bubbles, 1 with some bubbles, 1 with lots of bubbles).

B. Experimental observations

For the viscosity parameter you are investigating, do the following:

1. Predict which of the three syrups will have the highest/intermediate/lowest viscosities:

Highest viscosity	Intermediate viscosity	Lowest viscosity

2. Prepare the syrups. Try to make equal amounts of each of the three syrups.

3. Once the syrups are prepared, take a straw and conduct the bubble test. The bubble test is a qualitative measure of three things: i) how much force is required to blow a bubble while the straw is pushed down into the syrup, ii) how the bubbles form (e.g., one big bubble versus several smaller bubbles), and iii) how rapidly the bubbles travel from the end of the straw up to the syrup-air interface. Record the results of the bubble test in the table on the next page.

Table 1. Bubble test results.

Syrup parameter (e.g. hot, cold, etc.)	***Relative force required to blow bubbles in syrup***	***Relative time for bubbles to travel up to the syrup-air interface***	***Description of bubble formation (coalescence into large bubbles? many small bubbles?)***

3. Measure the distance in centimeters between the Start and Stop lines on the inclined viscosity test board. Record the number in the box to the right.

4. Now try the experiment. Using the beakers of syrup provided, pour roughly equal amounts of each of the different syrups on the plastic mat [note that the board is at a constant angle of 45 degrees]. In the table on the following page, record how long it takes each type of syrup to reach the bottom of the incline.

Table 2. Experimental results.

Syrup parameter (e.g. hot, cold, etc.)	***Total Time to reach bottom of slope (seconds)***	***Average Velocity (cm/s)***	***Calculated viscosity (poise)***	***Calculated viscosity (Pa s)***	***Log Ave. Viscosity (poise)***

Use the Excel spreadsheet calculator to estimate the viscosities of the syrup based on Jeffreys equation:

$$\eta = \frac{g \cdot \rho \cdot \sin\theta \cdot d^2}{n \cdot V}$$ ***Jeffreys equation***

where η = viscosity in poise (dyne s cm^{-1} = g cm^{-1} s^{-1})*[note that 10 poise = 1 Pascal seconds (Pa s)]*, ***g*** is the gravitational constant (980 cm/s^2), ρ is density (assume this is 1.4 g cm^{-3} for the corn syrup), θ is the angular measurement of the slope (no units), ***d*** is the thickness of the flow (in cm), ***n*** is a constant (3 for broad flows and 4 for narrow, channelized flows), and ***V*** is the measured velocity (in cm s^{-1}).

PART 3. ANALYSIS OF EXPERIMENTAL RESULTS

A. Make sketches of each of the three "lava" lobes in your experiment, showing how the width of the lob varies along its length. Also measure and record the maximum and minimum width for each flow (be sure to include the measured width of each flow in cm).

Sketch 1 Sketch 2 Sketch 3

B. How does viscosity affect flow width?

C. What happens to the width and thickness of the flows when they reach the bottom of the incline?

D. What other observations did you make about your experiments? Look carefully at the surface of the syrup flows and describe any textures you observe.

E. ACH Foods Inc. reports that Karo Light Corn syrup has a viscosity of 22-30 poise at 25˚ C. How do your results compare to the “official” viscosity range?

F. In what ways do you think this experiment is a good model for understanding variations in the viscosity of lava flows? In what ways is it not such a good model?

G. Develop a hypothesis relating the viscosity parameter varied in your experiment to its affect on viscosity. Be prepared to present and defend your hypothesis to the rest of the class, and also write down a few methods that might further test your hypothesis. Circulate around the lab and look at the results from other groups experiments.

PART 4. VISCOSITY AND VOLCANIC HAZARDS

A. Lava flow hazards

Using your newly developed expertise with Jeffrey's equation and information from the graph to the right (based on data taken from Murase and McBirney (1973) Properties of some common igneous rocks and their melts at high temperatures. *Geological Society of America Bulletin*, 84, 3563-3592), estimate velocities of rhyolitic, andesitic and basaltic lava flows traveling down the slopes of a stratovolcano (~20 ˚) versus a shield volcano (~5˚). Assuming you live at the base of the volcano (10 km from the summit), and the lavas erupt from a vent on the summit, how much time would you have to evacuate your home for each of the different lava flows, assuming the flows could travel 10 km before stopping? Record your calculations in the table below.

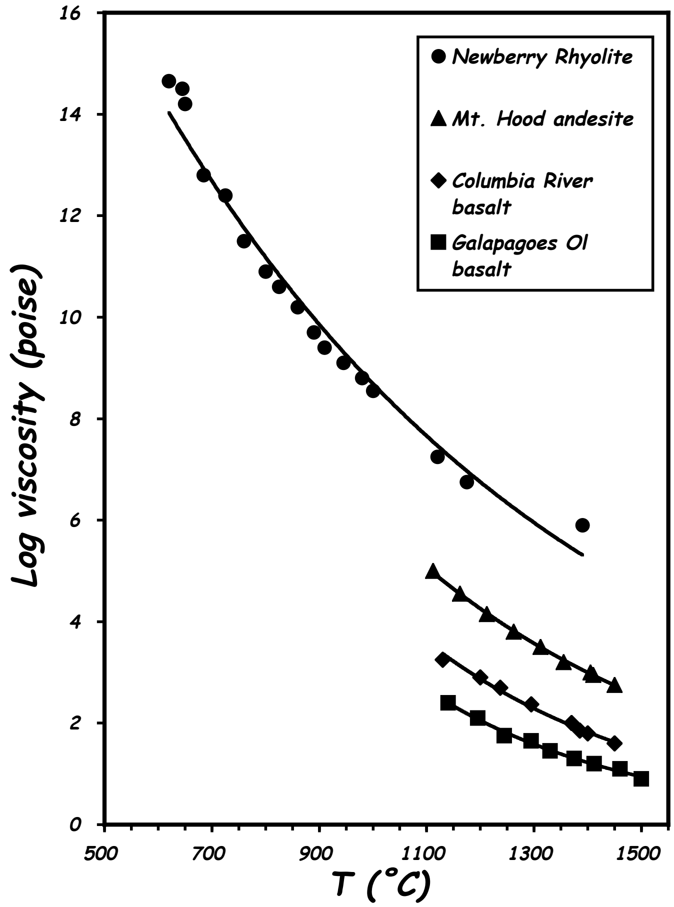


Table 3. Lava flow hazards calculations.

			Stratovolcano		Shield volcano	
Magma type	Temperature	Viscosity	Velocity	Total time to travel 10 km	Velocity	Total time to travel 10 km

B. Explosiveness of volcanic eruptions

Develop a hypothesis that relates changes in viscosity to differences you observed during the bubble test. How easily did the bubbles travel through the liquids? How much "breathe pressure" did you have to exert to blow a bubble in the syrups? Given the assumption that volcanic eruptions are driven by the formation of gas bubbles within magmas, would you predict high viscosity or low viscosity lavas as having the most potential for explosive eruptions?

PART 5. MAGMA VISCOSITY AND DENSITY AS A FUNCTION OF MAGMA CHEMISTRY

A. Effects of variations in chemical composition

1. Choose three rocks from the pulldown menu on MAGMA with SiO_2 compositions that differ by at least 5 wt %. Fill out information in the table below for each sample.

Rock Name			
SiO_2 (Wt. %)			
TiO_2			
Al_2O_3			
FeO			
MgO			
CaO			
Na_2O			
K_2O			
P_2O_5			
H_2O			
Viscosity			
Density			

2. What is the general affect of SiO_2 wt. % on density and viscosity?

3. What other elements show large variations between rock types that might also affect density and viscosity?

B. Effects of changes in temperature, % dissolved H_2O, and % solids.

1. For one of the samples you chose above, fill out the table below to see how changes in temperature, wt. % H_2O, and % solid particles affect viscosity.

Rock Name:	Slope*:	Flow thickness (m)*:	
	Density	Viscosity	Velocity*
T = 1000 C			
T = 1100 C			
T = 1200 C			
T = (your choice)			
Wt % H_2O = 0.5 %			
Wt % H_2O = 2 %			
Wt % H_2O = 5 %			
Wt % H_2O = (your choice)			
% solid = 1			
% solid = 10			
% solid = 20			
% solid = (your choice)			

*use Jeffreys equation and assume a constant slope and flow thickness

1. Make 3 graphs in EXCEL for each of your sets of viscosity calculations (one for effects of T, one for H2O, and one for % solid).

2. Describe the relationship between variations in viscosity and the 3 parameters you varied (i.e., does viscosity change linearly as a function of T or not?).

3. Which of the parameters that you varied seems to have the greatest affect on viscosity? Can you think of why that might be?

4. Speculate on how viscosity might affect the morphology of volcanoes and the degree of explosiveness of volcanic eruptions.