GLY 431/531: Volcanology
Viscosity

Equipment:

100 mL graduated cylinders (3 per group, or 3 that are shared)
marbles
balance
stopwatches
light corn syrup
water
hair gel
pudding cups
paper plates
rulers or tape-measures
protractors

Goal: To measure the difference between Newtonian and Bingham rheologies, and to measure the viscosities of known fluids.

Part I: Measuring Viscosity

There are several ways to measure the viscosity of a fluid. In the lab, the most common way is to drop a ball of known density and diameter into the desired fluid, and to record the amount of time required for the ball to fall a known distance. Stoke's settling law can then be used to estimate the viscosity.

Stoke's law is given by:

$$v = \frac{2gr^2(\rho_c - \rho_l)}{9\eta}$$

in which v is the velocity, g is gravitational acceleration (9.8 m/s^2 on Earth at sea level); r is the radius of the ball (meters), ρ_c is the density of the ball (kg/m^3), ρ_l is the density of the liquid (kg/m^3), and η is the liquid viscosity (Pa s).

Using the equipment provided, you can determine the viscosity of the 3 fluids presented to you (hair gel, water, and corn syrup). First, you'll need to use the balance and ruler to determine the density of your marble. Recall that the volume of a sphere is $4/3 * \pi * r^3$. Then you'll need to calculate the density of the fluid in question. Finally, measure the velocity of the ball dropped through your fluid. Hint: make the measurement 3 times and take the average.

You'll hand in a sheet with your calculations and answers at the end of the period.

Part II: Newtonian vs. Bingham Rheologies

Recall that the difference between a fluid with a Newtonian rheology and one with a Bingham rheology is the yield strength. A Newtonian fluid will begin to flow as soon as a force is applied; in contrast, a Bingham fluid must exceed a critical force before it will flow. Lavas have been modeled as both Newtonian and Bingham fluids.

Get out the paper plates, pudding cups, corn syrup and water. On the first plate, scoop a large spoonful of pudding near the edge. Keeping one edge of the plate on the table, slowly lift the edge of the plate with the pudding on it, and use the protractor to record the angle at which the pudding finally begins to flow. At the same time, measure the thickness of the flow. (This will work best if one person tilts the plate, another keeps an eye on the underlying slope, and a third watches the flow thickness).

Repeat the experiment with the corn syrup and the water.

The following equation can be used to estimate yield strength from your measurements.

$$S_y = d_c/\rho g \tan(a)$$

where Sy = yield strength; d = thickness at which fluid begins to flow; r = fluid density, g = gravitational acceleration, and a = critical slope (the slope at which the fluid begins to flow).

(Note that you'll need the density of the pudding, which you can calculate from the information on the package—or you can use a graduated cylinder and the balance.)

On a separate piece of paper, answer the following questions:

1. Which fluids have a Bingham rheology, and which have a Newtonian rheology?

2. What are the yield strengths of the Bingham materials? What are the units of yield strength?

3. Do you think lavas are more likely Bingham or Newtonian fluids? Why?