Wax Modeling and Image Analysis for Classroom-Scale Lava Flow Simulations

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Why investigating lava flows is important for students: Hazards, physics, geology, and culture.

Figure 1. A small lobe of lava in Hawaii being emplaced exhibits the transition from a fluid to a solid, passing through a semi-solid state. The cooler black rind is stiff and will bend only so much before snapping. The red molten rock is ductile and deforms around irregularities on the surface and squeezes out from under the solid crust above. Lava flows are a captivating subject for study, however, they are typically inaccessible for a classroom of students. Photo extracted from a Lavapix.com video.

Figure 2. Bottles are made from a silicate glass with similar physical properties to lava. Understanding the rheology of fluids is an important part of manufacturing as well as engineering. How properties such as viscosity, surface tension, and crystallinity, change with temperature is important for designing water turbines, controlling mud slides, and studying the magnetic properties of the sun. Image from http://www.ethiogrio.com/newsnow/advt.asp?blurb=38104

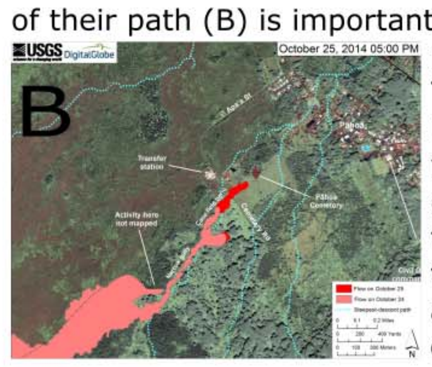


Figure 3. Lava flows consume houses (A), farm land, and infrastructure so the management and prediction of their path (B) is important to communities living near active volcanoes. The fluid properties of the lava determine how fast it flows, how thick it will get, and how far it will travel. Students can play the role of a hazard assessor during an active eruption.

Figure 4. The cultural significance of lava flows sometimes directly conflicts with hazard management practices. This image depicts the claiming of new land created by Kilauea in Hawaii by local residents. Other local residents push for intensive practices like lava diversion which can re-route a flow into other private lands, have extensive costs, and infuriate native Hawaiians. Image from http:/blogs.ei.columbia.edu/2015/11/24/photo-essay-land-lava-people/

Image processing of experimental footage

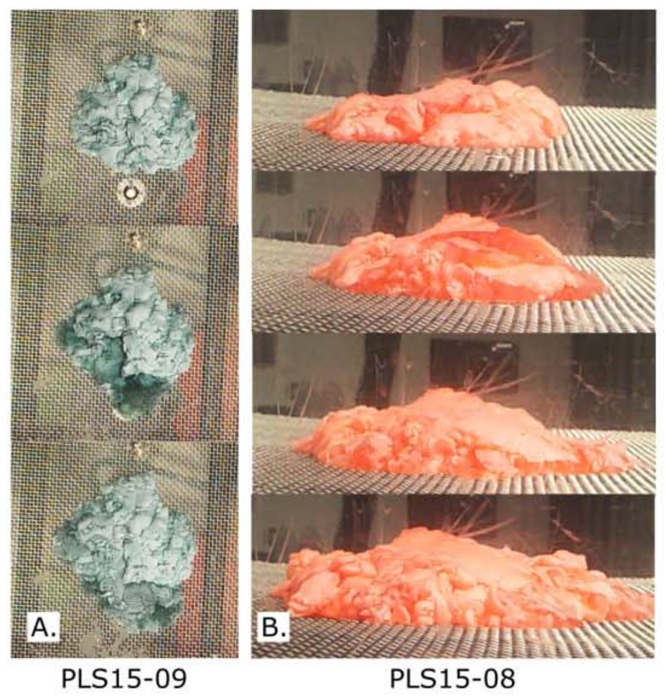


Figure 5. A sequence of top down (A) and side (B) images show how the experiments grow over time with changes in height and area. Free online software allows students to convert video or images into spreadsheets of data that can be graphed (as seen in figure 6), compared, and manipulated.

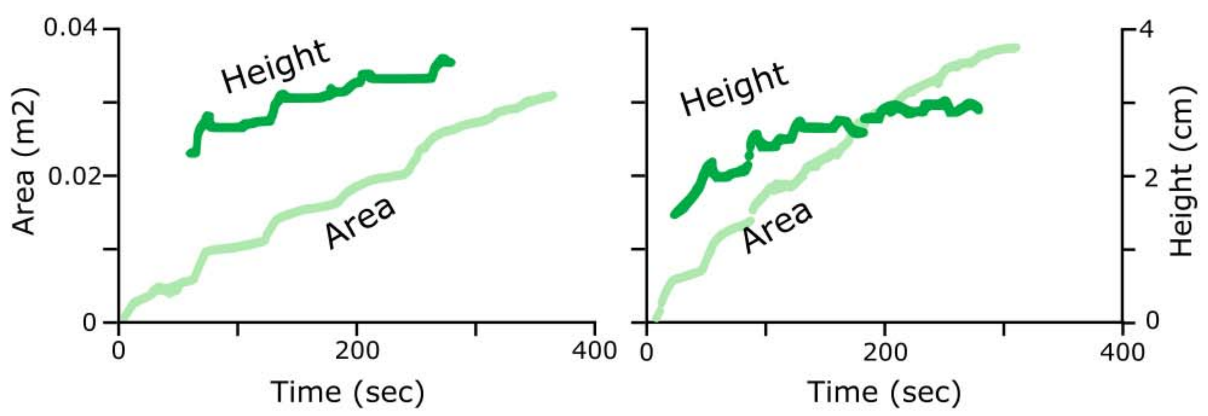


Figure 6. Graphs of two wax eruptions of different temperatures produced by data collected from Tracker and ImageJ. This data illustrates how viscosity affects the way a fluid spreads out. The high viscosity experiment on the left (similar to andesitic lava) becomes thick and spreads out very little, while the low viscosity experiment on the right (basaltic lava) expands to cover much more area but does not grow vertically as rapidly. Graph such as this can also be used in hazard prediction exercises in which students have to forcast evacuations for a diarama that can be placed in the tank during a wax eruption.

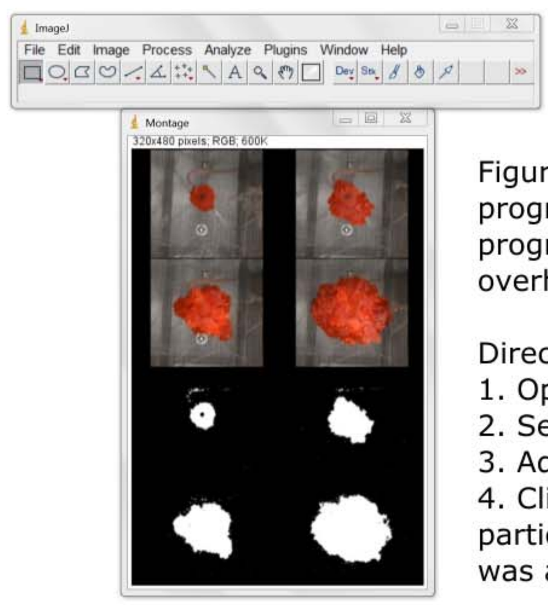


Figure 7. Changes in area are measured with the free open-source program ImageJ found at **https://imagej.nih.gov/ij/**. The program allows students to isolate the outline of flows from overhead images and then measure the surface area.

Directions to process image in ImageJ:
1. Open images and go to Image -> Color -> Split Channels
2. Select one window and go to Image -> Adjust -> Threshold
3. Adjust bars until only the portion you desire is highlighted
4. Click Analyze -> Analyze Particles. You can limit the size of particles, the circularity, display an image of each particle that was analyzed and produce a table of the qualities of each particle.

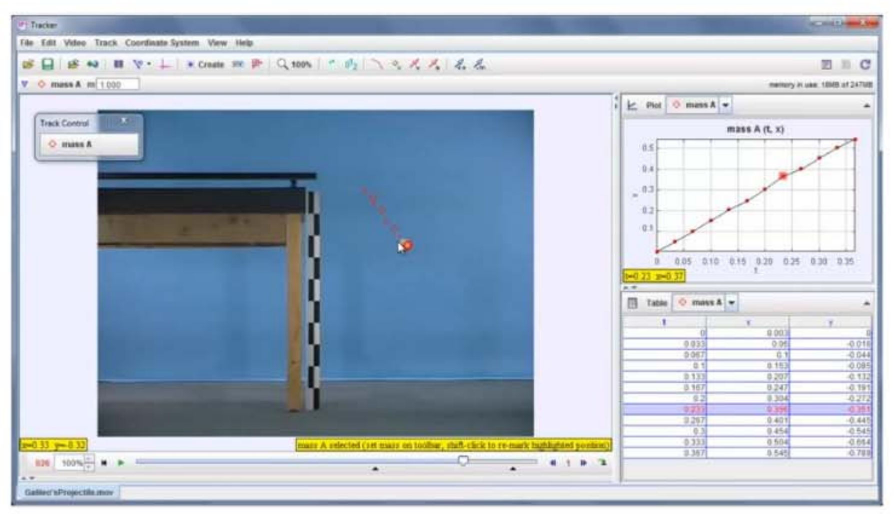


Figure 8. The program, 'Tracker Video Analysis' is an open-source program that continuously measure defined parameters like length, acceleration, or speed. The image on the left shows the video (a falling ball in this case) in a window on the left and the data collection in a window on the right. The program is available at **http://physlets.org/tracker**

Procedure for motion tracking:

The three buttons of importance are calibration tool, axes, and create. See above.
1. Click the calibrations tool button to make a new stick. Match its length to your scale bar
2. Click on axes button to define x and y, + and -. Rotate so +x is up in the video
3. Click on 'Create' -> Point Mass. Hold Ctrl + Shift down while clicking an spot to measure
4. Right click on the new mass in the Track Control box -> Autotracker. Check 'X-axis Only'
5. Click 'Search' to begin measuring the position of your spot along the x-axis.

Tutorials and help documents are also available at the website listed above.

Conclusions:

1. PEG wax successfully simulates basalt crust formation and lava flow behavior.
2. Students can learn about a variety of topics including fluid rheology, planetary geology, volcanic hazard policy through hands-on experiments.
3. Necessary equipment include PEG 600 wax, tank with hole in base, camera(s), tubing, and a "magma chamber".
4. Free software like ImageJ and Tracker can collect data for reports.

How to recreate lava flows in the classroom

Figure 9. A large container to hold the water for the experiment can either be a clear-sided fish tank (A) or even an inflatable kiddie pool (B). With the clear-sided tank, non-water proof cameras can be used for all angles. The soft-sided kiddie pool requires water proof cameras, but the soft bottom can be molded to simulate topography.

Equipment List:
1. Tank or pool
2. Water and ice
3. PEG 600 wax (~70 g per flow)
4. Tubing and clamp
5. Wax reservoir (bottle or beaker)
6. 2 cameras, tripods, ladder
6. Computer with free software downloads
7. Food coloring

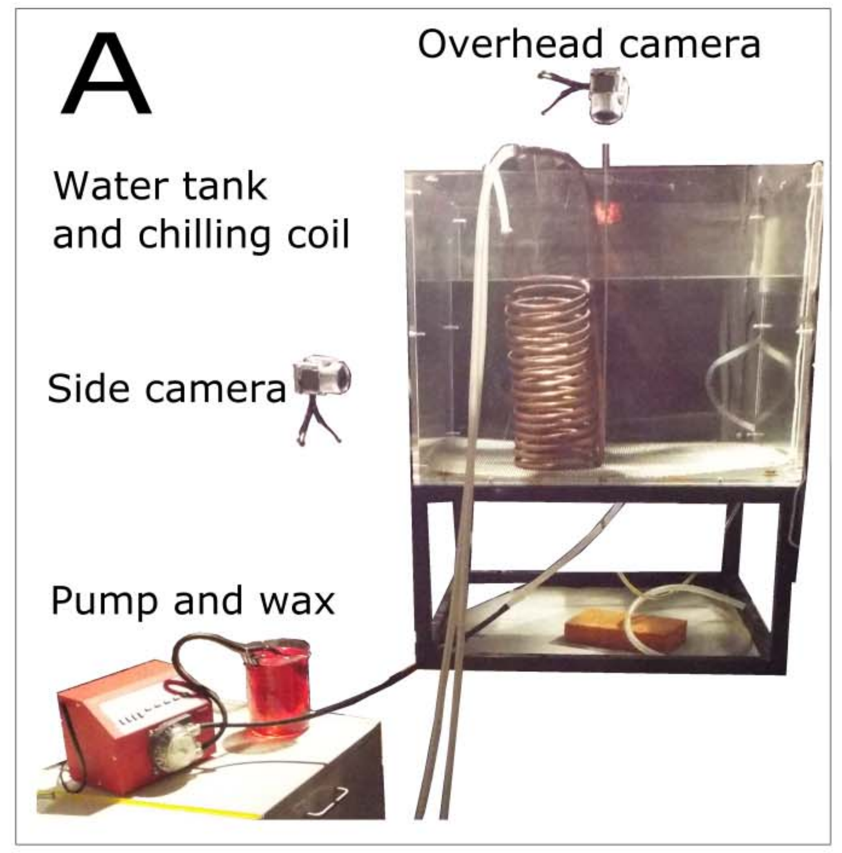


Figure 10. A hole cut in the bottom of the container allows the wax to flow into the tank. Use a clamp on the hose to keep water from flowing out.

Procedure:
1. Fill tank with water and ice to achieve a 0° C mixture.
2. Mix wax and food coloring.
3. Chill wax to ~18-21° C to obtain different viscosities.
4. Place cameras (1 above, 1 side) using tripods and ladders.
5. Connect wax reservoir to the base of tank via clamped tube.
6. Press record on cameras.
7. Raise reservoir above water level in tank and unclamp hose to begin wax flow.
8. Save videos on cameras.

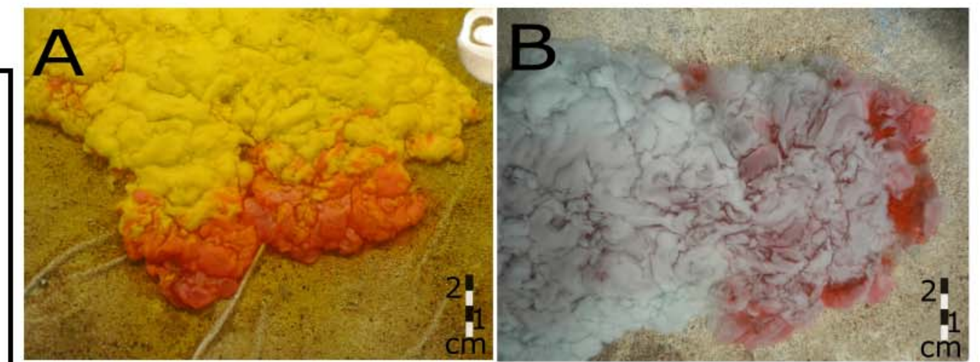


Figure 11. Polyethylene glycol 600 wax is a non-toxic, easily disposed, material available for purchase online. It simulates the formation of rigid crust (A @ ~17.5°C) on the outside of a molten lava flow. As the crust hardens, it becomes opaque and hot translucent wax continues to flow beneath it (B). Many surface textures and volcanic features can be simulated using this type of wax. These features can be examined upon solidification, however the wax will melt at room temperature and absorb water if left in the tank.

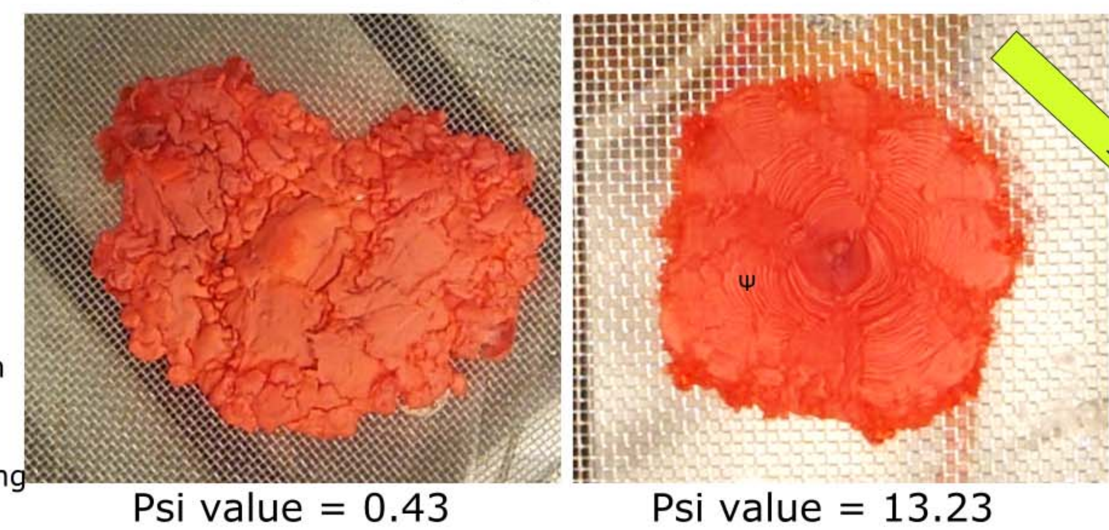
Example experiments for classroom lava flows

Figure 12. The physical parameters controlling the morphology of the wax and lava are captured by the Psi value (equation and parameters below). This equation lets students compare wax experiments to lava flows in the real world by imputing Earth, Mars, or Lunar values.

$$\Psi = \left(\frac{g\Delta p}{\eta}\right)^{3/4} Q^{1/4}\, t_s$$

Variable	Name	Unit
g	gravity	m/s^2
Δp	density difference	Kg/m^3
n	dynamic fluid viscosity	Pa s
Q	volumetric effusion rate	m^3/s
t_s	solidification time	s
Ψ	Psi value	none

Figure 13. Planetary application: Two morphologies to the right were created by changing temperature and eruption rate. Using the Psi value, students can compare the relative eruption rates of lava flows by looking at the surface texture and comparing it to wax experiments.



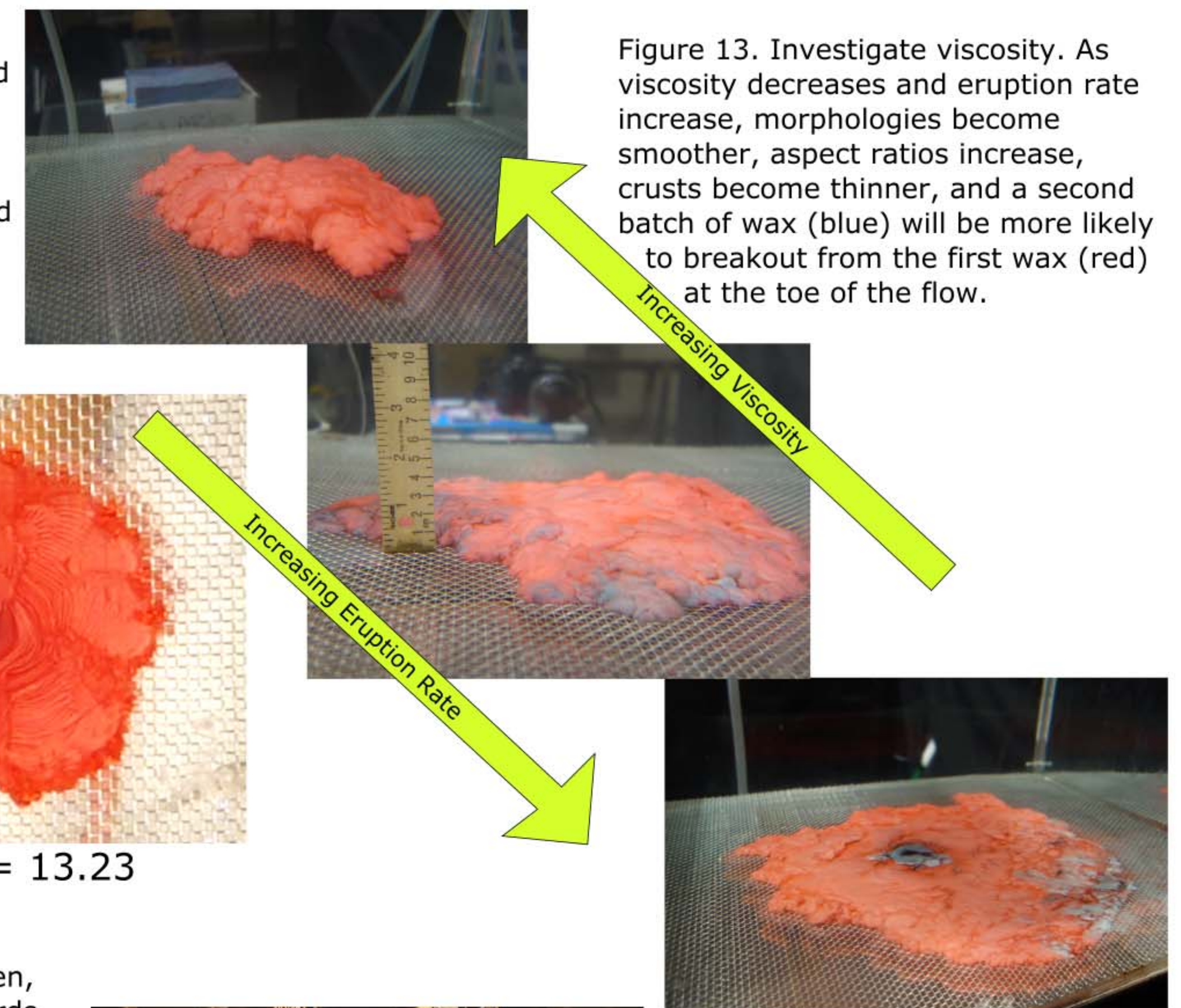


Figure 13. Investigate viscosity. As viscosity decreases and eruption rate increase, morphologies become smoother, aspect ratios increase, crusts become thinner, and a second batch of wax (blue) will be more likely to breakout from the first wax (red) at the toe of the flow.

Figure 14. A cross-section of a wax flow that build up by flowing on top of itself. The thickness of the crust can be measured to see the effect of variable cooling rates and students can examine the interior structure of a 'compound' lava flow.

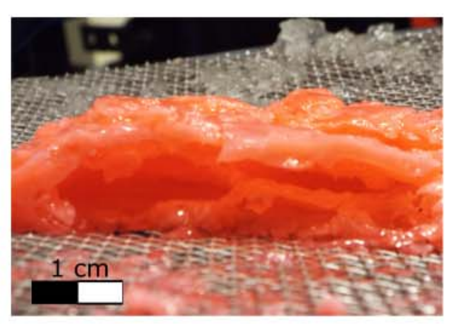


Figure 15. An example of the bottom side of an 'inflated' wax flow. The first wax erupted was dyed yellow, the 2nd bath, red and the last gasp, blue. Students can measure the change in height of an inflating flow to study how lava flows break the rule of superposition in Geology.

Figure 16. Wax dyed green, then red, then blue, records the formation and utilization of a lava tube within a flow. The observation of this phenomena allows students to hypothesize how lava, which cools very rapidly, can travel hundreds of miles.

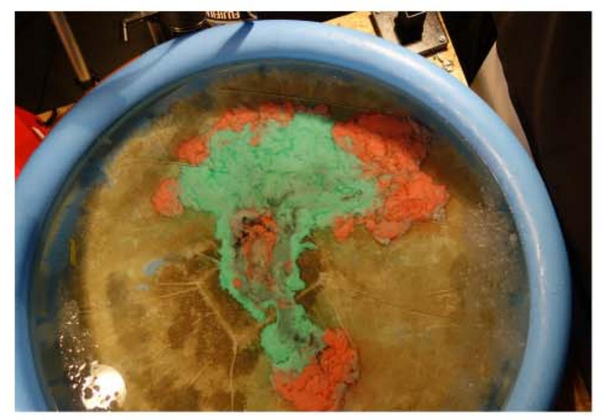


Figure 17. The effect of slight a slight topographic plateau on the shape of a wax flow on the left can be measured and compared to the surface area and shape of lava flows. The importance of micro-topography in lava flow hazard models, and the complications created by lava diversion is a good exercise to include in student role-play in an active eruption scenario.

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References and Additional project ideas:
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