Modeling Volcanic Eruptions

New Mexico Adventures in
Supercomputing Challenge
Final Report
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Executive Summary

The goal of this project is to predict the rate at which lava will flow based on some vital characteristics such as the viscosity of the lava, the CO2 emitted prior to an eruption and the dome elevation at the time of eruption. Historical data will be used in conjunction with recent satellite readings to create a simulation model using StarLogo.

Our team decided to look at the damage that is caused by the eruption of volcanoes because many people in the world live with in reach of the lava from the eruptions. In the twentieth century volcanic eruptions took about 80,000 lives (McGuire.12/13/04). The economy was not greatly affected; however the most costly eruption was the 1980 eruption of Mt. St. Helens, which cost almost 1 billion dollars (McGuire.12/13/04). As more was learned about the volcanic eruptions the main focus is going to be the viscosity of the magma. Viscosity is the property of a material to resist flow, which is measured in poise.

Introduction

In the twentieth century volcanic eruptions took about 80,000 lives (McGuire.12/13/04). The economy was not greatly affected; however the most costly eruption was the 1980 eruption of Mt. St. Helens, which cost almost 1 billion dollars (McGuire.12/13/04). As more was learned about the volcanic eruptions the main focus is going to be the viscosity of the magma. Viscosity is the property of a material to resist flow, which is measured in poise.

Societal Effects of Volcanoes

Volcanoes are known for their violent eruptions and lava flows, but there are many benefits that volcanoes provide for society as well. Volcanoes help enrich soil for farming and in some cases provide reservoirs for the storage of ground water. Moreover the earth's valuable resources are formed in volcanoes. These elements include fluorine, sulfur, zinc, copper, uranium, silver, mercury, gold, ect. Society makes use of all of these elements that volcanoes help to provide. Geothermal power is an alternate energy source that is better for the environment and volcanoes provide this to society also. Volcanoes even help us understand past civilizations and cultures. The lava preserves fossils and artifacts that scientists can learn from. The picture below is a fossilized fish that was preserved by volcanoes.

Types of Volcanoes

There are 3 main types of volcanoes and each can produce a variety of eruption forces and lava flows.

Shield Volcanoes

Low viscosity lavas produce shield volcanoes, named after their appearance, which is much like a Roman shield. They have relatively little explosive activity, and are characterized by lava flows, which create their slowly sloping sides. Lava flows are distinguished by the Hawaiian terms pahoehoe, referring to the smooth and curving pattern appearance, created when the top crust of the lava is pulled and twisted by the flow beneath it. Shield volcanoes have broad summit areas because of these flows.

Strato Volcano

High viscosity magmas tend to produce taller, steeper, more explosive volcanoes. The eruptions consist of steaming gases that carry with them pyroclastic rocks which are materials ejected from volcanoes as solid fragments. Strato-volcanoes are also produced by high viscosity magmas. The viscosity level makes the lava more brittle, and while some pyroclastic material is emitted, molten rock also escapes. This combination produces a higher structure. Strato-volcanoes are from multiple eruptions like this, creating a layered and very high structure. Lava domes are formed by the slow extrusion of highly viscous magma. They are usually formed by a large explosion caused by the built-up pressure of the gases trapped in the thick molten rock, but after that, when the gas pressure is decreased, the magma oozes out slowly. Before 1980, Mount Saint Helens was an example of a strato-volcano.

Magma

Magma is composed of silicates which are combinations of other chemical elements with silicon and oxygen. The amount of silica (SiO_2) controls the viscosity. The higher the silica level, the more viscous the magma is. In a magma melt, molecules are polymerized. This means they cluster and form larger complexes. The silicon and oxygen atoms in magma are bonded strongly together molecularly. The more bonds there are, the more viscous the magma is. Therefore, the more silica there is in a magma, the more viscous it is. Temperature is also related to viscosity. The hotter a substance is, the less viscous it is. Viscosity is important because it determines the type of eruption that will occur, and thus what shape or type of volcano will be formed by the eruptions.

Gases are easily released from low viscosity substances. In more viscous magmas, gases are not released easily, and build up. When the pressure builds, a violent eruption can occur

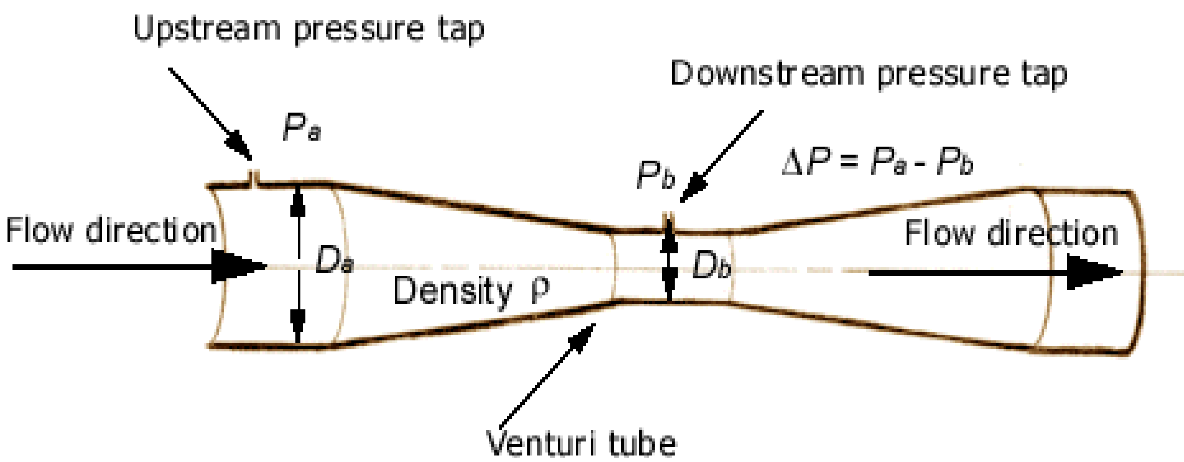
Realistic Models of Viscous Fluid Flow:

Highly viscous fluids movement is mainly a result from gravity, viscosity, damping and friction. There are not many turbulent and rotational behaviors in its movements.

Venturi Flow Rate

A fluid passing through smoothly varying constrictions experience changes in velocity and pressure. These changes can be used to measure the flow rate of the fluid.

To calculate the flow rate of a fluid passing through a venturi, enter the parameters below. (The default calculation involves air passing through a medium-sized venturi, with answers rounded to 3 significant figures.)



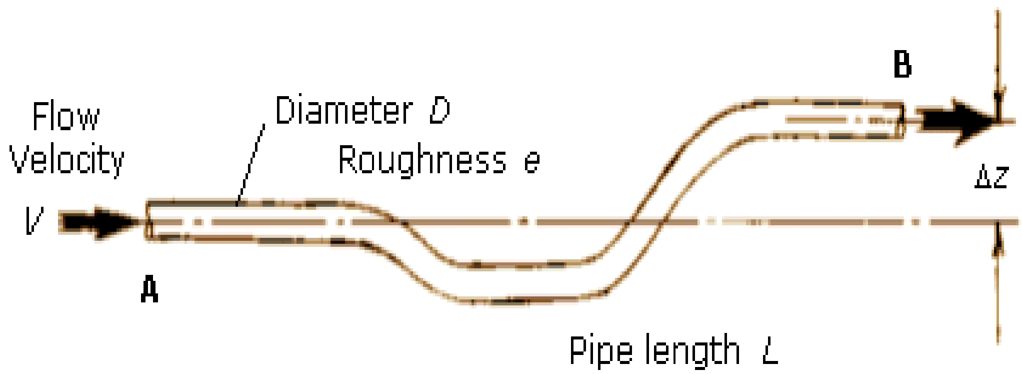
As long as the fluid speed is less than the speed of sound (*V* < mach 0.3), the incompressible Bernoulli's equation describes the flow. Applying this equation to a streamline traveling down the axis of the horizontal tube gives,
From continuity, the throat velocity *Vb* can be substituted out of the above equation to give,

Solving for the upstream velocity *Va* and multiplying by the cross-sectional area *Aa* gives the volumetric flow rate *Q*,

$$Q = \sqrt{\frac{2\Delta p}{\rho}} \frac{A_a}{\sqrt{\left(\frac{A_a}{A_b}\right)^2 - 1}}$$

Wall drag and changes in height lead to pressure drops in pipe fluid flow.

To calculate the pressure drop and flow rates in a section of uniform pipe running from Point A to Point B, enter the parameters below. The pipe is assumed to be relatively straight (no sharp bends), such that changes in pressure are due mostly to elevation changes and wall friction. Note that a positive Dz means that B is higher than A, whereas a negative Dz means that B is lower than A.



Viscosity

To find the viscosity of lava you would use this equation.

$$V = \frac{g h^2 \rho \sin A}{3 \eta}$$

Where V is the mean velocity of the flow, g is the acceleration of gravity, A is the angle of the slope, h is the depth of the flowing liquid, p is the specific gravity of the liquid, and n is the coefficient of viscosity.

The viscosity of pahoehoe lava (the most fluid type of basalt) is usually about 1000 Pascal-seconds. That is about 1 million times as viscous as water. Cooler, more silica-rich lavas are probably up to 10,000,000 to 100,000,000 Pascal-seconds.

Viscosity is measured in Pa s (Pascal seconds), which is a unit of pressure times a unit of time. This can then be turned into poise as 1 Pa s = 10 poise.

Here is a chart for poise to give you a bigger idea of what has more and less poise.

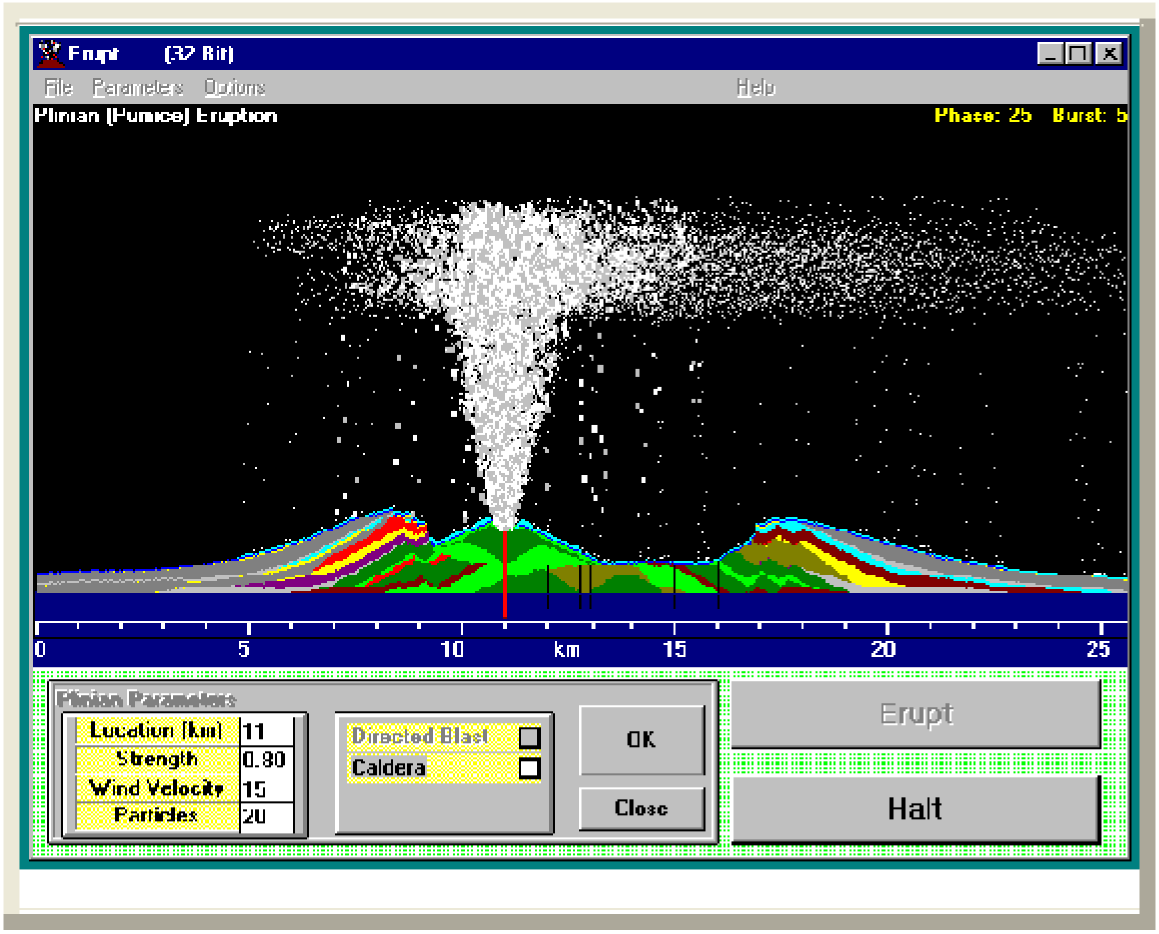
Material	Poise
Water	1
Engine Oil	10
Plasticine	1000
Asphalt	10,000
Basalts (lava)	100 - 1000
Granites (magma)	1,000,000 - 1,000,000,000,000

Math Model

A sample program called Erupt, developed by Ken Wohletz for KWare -Geological Software was studied to help us develop our math model. It is described below.

> "ERUPT is another graphical program that simulates various volcanic eruption types, including Strombolian, Plinian, Vulcanian pyroclastic flows and surges along with Hawaiian fluid lava flows, fumarolic activity, and Peléean viscous lava dome emplacement. Tectonic (faulting), caldera and sector collapse, and erosional events are also simulated. In addition to a greater variety of eruption types, virtual 3-D with topographic and geological maps, and a greatly enhanced user interface, Erupt3 offers the user a built-in updater with web-access and features that make it a much more robust teaching and research tool.

The following image is a reproduction of the screen during simulation.



We want our StarLogo program do work in a similar way but it would not be as complex. Our focus is on how fast flowing lava would reach a nearby town or city and how much time the residents would have to evacuate.

Unfortunately we do not yet have a woking program. It has been a real challenge and we still have many questions that we want to address in or program like:

How would lava flow in different situations? StarLogo requires a math model that breaks lava into chunks like turtles so they move faster downhill due to gravity and is effected by friction as it moves through various terrain. Each lava turtle must move based on laws of physics as it loses heat and energy. So we must know; what is the adhesion of particles at different temperatures? What is the cohesion of different types of lava?

Program Verification

So at this time we have not verified our program, but we expect to have a working model which will be verified by looking at some of the data found at the USGS web site.

Conclusion

In conclusion there is still a great deal of work to be done. Meeting with our mentor is an important part of writing the program since we do not have a computer programming class at our school. Although we have done a great deal of research and learned about the different types of volcanoes, we still need to create the mathematical formulas that will be used in or program.

Acknowledgements

We would like to thank our parents for picking us up late from school every week. We would also like to thank Ms. Loftin for being our sponsor and Nick Bennett for coming to our school to try and help us write our program.

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