

**JoVE: Science Education**  
**Volcanic Igneous Rocks**  
--Manuscript Draft--

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**Author Name: Alan Lester, University of Colorado Boulder**

**Earth Science Education Title: Volcanic Igneous Rocks**

## **Overview**

Igneous rocks are the products of cooling and crystallization of magma. Volcanic rocks are a particular variety of igneous rock, forming as a consequence of magma breaching the surface, then cooling and crystallizing in the subaerial environment.

Magma is liquid rock that typically ranges in temperature from approximately 800C to 1200C (figure 1). Magma itself is produced within the earth via three primary melting mechanisms, namely the addition of heat, addition of volatiles, and decompression. Each mode of melt generation tends to produce specific types of magma and, therefore, distinct eruptive styles and structures.

For example, heat addition, often linked to hot spots or to the ponding of high temperature melts in the crust, will generate felsic (silica-rich) magmas in continental settings and mafic (silica-poor) magmas in oceanic settings. Volatile addition is the most common mechanism for melt generation at subduction zones and produces intermediate magmas (intermediate silica abundance), typically leading to island arc or linear volcanic ranges (examples being the Aleutian Islands, the Cascade Mountains (figure 2), and the Andes Mountains). Decompression melting generates mafic magmas and occurs in rift zones. Although rifting can and does occur in continental settings (e.g. East African Rift Valley), this is the primary melt mechanism for the mid-ocean ridges that encircle the globe and stretch through the main ocean basins (Atlantic, Pacific, Indian), these being, by far, the dominant zones of magma generation on our planet.

By way of definition, felsic compositions are rich in aluminum and silica (silicon and oxygen), whereas mafic composition refers to rocks that contain less silica and more iron and magnesium. Quantitatively speaking, felsic rocks contain 60-75% (by weight) SiO<sub>2</sub>; mafic rocks contain 45-60% (by weight) SiO<sub>2</sub>; and intermediate rocks are in the range 55-62% (by weight) SiO<sub>2</sub>. In terms of volatiles, the more common gaseous species are H<sub>2</sub>O, CO<sub>2</sub>, SO<sub>2</sub>, and H<sub>2</sub>S, and although quite variable, felsic magmas by and large tend to have higher volatile concentrations.

**Cooling and Crystallization of Volcanic Rocks:**

Volcanic rocks (figure 3) undergo surface (i.e. rapid) cooling and exhibit textures that are typically marked by either very small grain sizes or mixed grain sizes. Volcanic rocks with very small grains are termed aphanitic (figure 4), and require microscopic investigation in order to see individual crystal grains. Volcanic rocks with mixed grain sizes are termed porphyritic and are characterized by large crystals set in a matrix of fine-grained crystals.

A common scenario for the generation of porphyritic texture is a two-stage cooling process. The initial stage of cooling occurs in the subsurface and is slow, generating larger grains surrounded by still molten magma. The second and final cooling stage occurs when the magma reaches the surface, via volcanic eruption, and results in a rapid quenching of the remaining liquid, producing the finer-grained matrix (or groundmass) that encloses the pre-existing large crystals.

### **Magma Viscosity and Explosivity:**

Viscosity and volatile content are the primary controls on magmatic explosivity. Highly viscous felsic magmas with high volatile contents are likely to produce the most explosive eruptions. In contrast, highly fluid (low viscosity) and low volatile content mafic magmas (e.g. basalt) will generally produce the most quiescent eruptions.

### **Volcanic Products:**

When magma escapes from a volcanic edifice, there are a variety of possible products, including lava and pyroclastics.

Quiescent eruptions allow for magma to pour off the side of the volcano, or outwards from fissures. These are called lava flows. Lava flows rarely travel at velocities greater than a few kilometers per hour. As such, they can result in structural damage, but rarely cause loss of life.

More explosive eruptions will result in mixtures of magma, rock, and gas to be ejected from the volcano. Collectively, this ejected material is termed “pyroclastic.” Pyroclasts can come in a range of sizes from ash (very fine grained material, <2mm, and often of submicroscopic grain sizes) to lapilli (2-64mm), to tephra, and bombs (>64mm).

In some cases, a highly fluidized pyroclastic eruption, containing hot fragments, liquid droplets, and thick gases, will mobilize and move as a rapid mass off the side of a volcano. These events are termed pyroclastic flows (figure 5). They can be on the order of 1000C, and travel at velocities in the range of 100-600km/hr. These are, without doubt, one of the most dangerous volcanic products.

## **Principles:**

Two experiments are presented that relate to the principles of volcanic rock formation. The first experiment demonstrates a key principle of volcanic layering: subsequent deposition of lava, and the principle of superposition. The second experiment is a variant on the frequently-used baking soda and vinegar in a bottle explosion. Although very simple to perform, it shows several important aspects of volcanic eruptions.

## **PROCEDURE**

### 1) Lava Layering

1.1 Warm paraffin on a hot plate so that it becomes a viscous fluid.

1.2 Pour liquid paraffin onto an inclined surface. To approximate a shield-type volcano, use a 5-10 degree incline. To approximate a strato-volcano, use a 20-30 degree incline.

1.3 After the paraffin has cooled and solidified, repeat the process two or three times, in order to simulate successive lava flows.

1.4 Use a flat (non-inclined) surface, and simply pour the liquid paraffin onto a single spot. Several pouring and cooling pairs will generate a simulated volcanic edifice.

### 2) CO<sub>2</sub> volcano

2.1 Fill a plastic container with a thin neck (a 16 oz. soda bottle for instance) about half-full with warm water.

2.2 Bury the bottle beneath modeling clay or dough, leaving just the neck (opening) of the bottle exposed, simulating the structure of a volcano.

2.3 Add a few drops of dishwashing liquid (in order to make the liquid frothy and likely to produce bubbles).

2.4 Using a folded piece of paper as a funnel, add several spoonfuls of baking soda.

2.5 Add red vinegar to the plastic container. If using a 16 oz. soda bottle, add 8-10 oz. of vinegar. Add the vinegar to the container until it begins to effervesce.

2.6 If desired, cork the container for a "violent eruption" or leave it uncorked for a more quiescent eruption.

## **Results**

### **1) Volcanic Layering**

1.1 Note that the layers thin with distance from the magma source.

1.2 Note that subsequent layers can partially melt the underlying layer.

1.3 Note the principle of superposition—older layers on the bottom, younger layers atop.

1.4 The volcanic edifice created by pouring and cooling pairs (over an isolated spot) generate a slope whose angle is related to the viscosity of the paraffin (magma). Highly viscous magmas make steeper slopes (e.g. strato-volcanos) compared to highly fluid magmas with shallower slopes (e.g. shield volcanos).

### **2) CO<sub>2</sub> Volcano**

2.1 Some of the material will flow outwards like a lava flow.

2.2 The frothy nature of the flow is reminiscent of lava that is charged with volatiles.

2.3 Most volcanic eruptions are linked to volatile loss. Those that are particularly explosive will have considerable volatile emanations.

2.4 If the container is corked, then the initial eruption will involve pyroclastic-type material that is ejected into the air above the volcanic edifice.

## **APPLICATION**

Volcanism and associated rocks are of great interest to geologists. Not only do volcanic eruptions pose a threat to nearby communities, it is important to recognize that they can also lead to scenic landscapes, and positively influence soil and agricultural productivity.

Recognizing volcanic rocks in the field, linking them to specific eruptive styles, and ascertaining regions of past activity are part of fundamental geologic assessments for regions in which people live and/or work.

Some examples include:

1) Volcanic rocks are indicators of past eruptive activity.

2) The types of volcanic rocks present can be used to evaluate the severity and explosivity of past eruptions.

3) Understanding the potential types of eruptions (e.g. lava flows, ash, pyroclastic flows) that might occur in a volcanic region are a crucial part of developing mitigation strategies.

4) Volcanic layering can be a window into a “page-by-page” history of a region. Volcanic layers can contain information about past climate, environment, and even life. In particular, volcanic layers are relatively easy to date (unlike sedimentary layers) using isotopic dating techniques. Therefore, volcanic layers are useful time-markers in geologic investigations.

**Legend:**

Figure 1: Fresh lava breakout on Kilauea, Hawaii. Lava is the term for magma that is on earth’s surface.

Figure 2: 3000 foot steam plume from Mount St. Helens on May 19, 1982. Plumes of steam, gas, and ash often occurred at Mount St. Helens in the early 1980s. On clear days, they could be seen from Portland, Oregon, 50 miles to the south. The plume photographed here rose nearly 3000 feet above the volcano’s rim. The view is from Harry’s Ridge, 5 miles north of the mountain.

Figure 3: A crab atop volcanic rocks on the Tortuga Bay, Santa Cruz, in Galapagos. Photographed by professional photographer David Adam Kess.

Figure 4: The smooth texture of this basaltic volcanic bomb is aphanitic.

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For example, heat addition, often linked to hot spots or to the ponding of high temperature melts in the crust, will generate felsic (silica-rich) magmas in continental settings and mafic (silica-poor) magmas in oceanic settings. Volatile addition is the most common mechanism for melt generation at subduction zones and produces intermediate magmas (intermediate silica abundance), typically leading to island arcs or linear volcanic ranges (examples being the Aleutian Islands, the Cascade Mountains (**Figure 2**), and the Andes Mountains). Decompression melting generates mafic magmas and occurs in rift zones. Although rifting can and does occur in continental settings (e.g. East African Rift Valley), this is the primary melt mechanism for the mid-ocean ridges that encircle the globe and stretch through the main ocean basins (Atlantic, Pacific, Indian), these being, by far, the dominant zones of magma generation on our planet.

The type of magma formed in these different settings is linked to the depth of melting, the composition of mantle undergoing melting, and the degree of melting. In general, oceanic environments and continental rift zones generate basaltic (mafic) melts because of asthenospheric mantle melting.

Continental hot spots and subduction zones generate more felsic granitic melts, as a consequence of melting of continental lithosphere. In general, felsic magmas form as a result of high percentage melting of continental crust or continental lithosphere; mafic magmas form during melting of oceanic lithosphere or asthenospheric mantle.

**Comment [A1]:** Why do these 3 modes produce different types? What is the mechanism?

ANSWER--- pretty complex...but I offer a generalization...

By way of definition, felsic compositions are rich in aluminum and silica (silicon and oxygen), whereas mafic composition refers to rocks that contain less silica and more iron and magnesium. Quantitatively speaking, felsic rocks contain 60-75% (by weight)  $\text{SiO}_2$ ; mafic rocks contain 45-60% (by weight)  $\text{SiO}_2$ ; and intermediate rocks are in the range 55-62% (by weight)  $\text{SiO}_2$ . In terms of volatiles, the more common gaseous species are  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{SO}_2$ , and  $\text{H}_2\text{S}$ , and although quite variable, felsic magmas by and large tend to have higher volatile concentrations.

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**Comment [A2]:** Why are felsic magmas more viscous, and why do they produce more explosive eruptions?

**Comment [ml3]:** Magma viscosity is here mentioned... because it controls the explosivity of the magma. BUT the reason for certain magmas being more viscous than others just does NOT seem relevant to the experiment or manuscript.

The REASON has to do with the degree of polymerization of silica tetrahedral within the melt.



More explosive eruptions will result in mixtures of magma, rock, and gas to be ejected from the volcano. Collectively, this ejected material is termed “pyroclastic.” Pyroclasts can come in a range of sizes from ash (very fine grained material, <2 mm, and often of submicroscopic grain sizes) to lapilli (2-64 mm), to tephra, and bombs (>64 mm).

In some cases, a highly fluidized pyroclastic eruption, containing hot fragments, liquid droplets, and thick gases, will mobilize and move as a rapid mass off the side of a volcano. These events are termed pyroclastic flows (**Figure 5**). They can be on the order of 1,000 °C, and travel at velocities in the range of 100-600 km/hr. These are, without doubt, one of the most dangerous volcanic products.

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### 2. CO<sub>2</sub> Volcano

2.1 Fill a plastic container with a thin neck (a 16 oz. soda bottle for instance) about half-full with warm water.

**Comment [A4]:** What is the difference between these types of volcanoes?

**Comment [A5]:** What insight is gained in steps 1.2-1.3 vs. 1.4? What is the difference?

**Comment [ml6]:** The insights associated with 1.1-1.4.... are listed under RESULTS... SEE Results 1.1 – 1.4  
I felt it best to leave INSIGHTS for the results section...and not list these insights here in the procedural section.

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2.3 Add a few drops of dishwashing liquid (in order to make the liquid frothy and likely to produce bubbles).

2.4 Using a folded piece of paper as a funnel, add ~~several spoonfuls~~ 4 teaspoonfuls (appr. 15-20 grams) of baking soda.

**Comment [A7]:** Can you be more specific?

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**Comment [DM8]:** The QC report mentioned imagery for the applications section. The author can provide some volcanic rocks for us to photography at the shoot, and we can recycle these 2 images from earlier in the manuscript. Let me know if this doesn’t suffice and we can search for some additional images.

**Comment [A9]:** What makes volcanic layers easier to date than sedimentary layers?

**Comment [ml10]:** Sedimentary rocks are generally made up of grains that have come from pre-existing older rocks. There are a host of reasons why this makes isotopic dating difficult.... Including issues associated with closure temperatures and isotopic diffusional loss. But, here’s another issue that is perhaps a simpler answer to your question--- Dating a sedimentary rock would be akin calculating an average age for the people in a full auditorium ...and then saying that every individual in the auditorium is of exactly this average age—unlikely the case!

SO, THE REASON THAT VOLC ROCKS ARE BETTER THAN SED ROCKS FOR ISOTOPIC DATING--- is really related to the details of how we do isotopic dating...and this does not seem to be an appropriate focus for this particular video/manuscript on the formation of volcanic rocks.

**Comment [A11]:** What is the copyright status of these figures?

**Comment [DM12]:** Each of these are either public domain or were purchased from one of the stock photo sites we use.