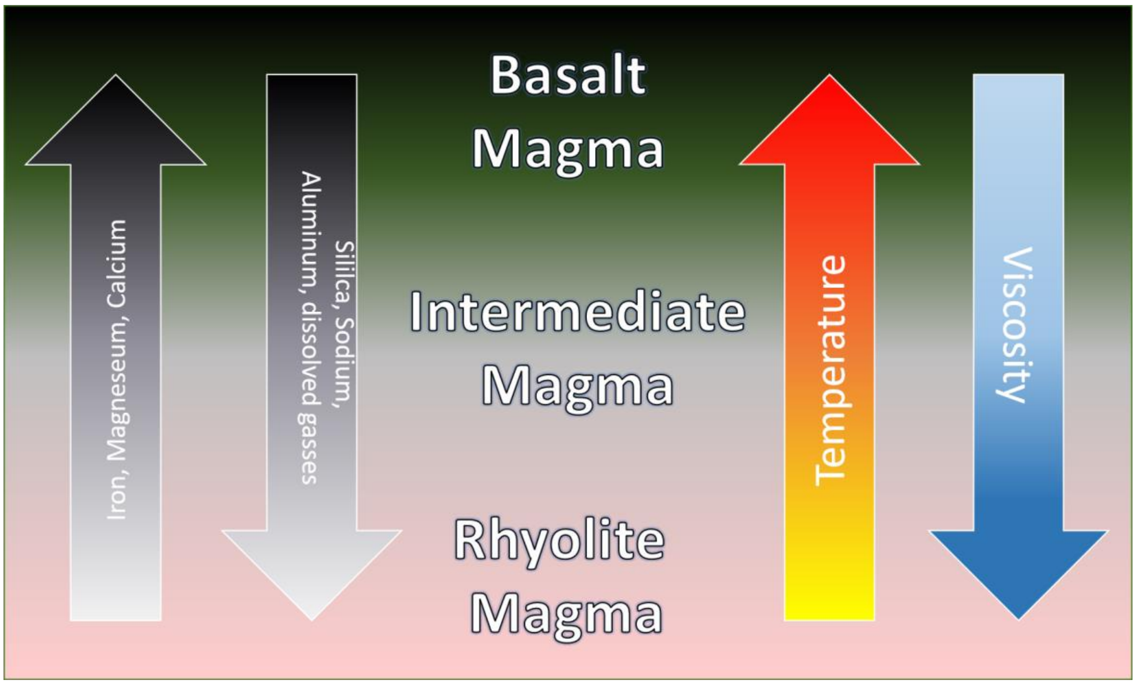
Viscosity and Volcanoes

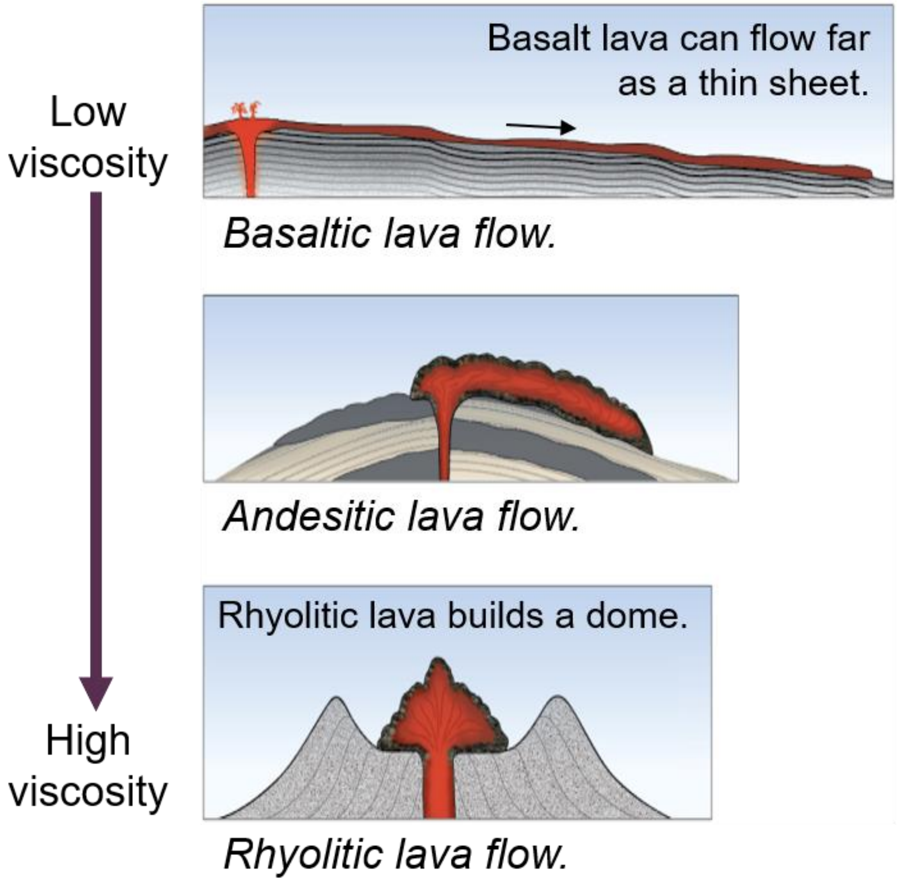
Teacher Background



In the diagram above, we can see three major magma compositions: basalt, intermediate, and rhyolite. These different magmas form from differences in their chemical compositions. Silica content (SiO_2) is the most significant difference when discussing magmas and their viscosity. Some other differences which control the minerals (and therefore rock type) that form are the iron (Fe), magnesium (Mg), calcium (Ca), sodium (Na), and aluminum (Al) content as well. As seen in the diagram, magmas that are rhyolite in composition have higher Al, Na, and SiO_2 and lower Fe, Mg, and Ca content. Whereas basaltic magmas have higher Fe, Mg, and Ca and lower SiO_2, Al, and Na. Also of note, is the total amount of dissolved gasses that are trapped within the magma. Magmas that are more rhyolitic have a higher gas content. This gas content and relative viscosity leads to the more explosive and violent eruptions that occur at composite volcanoes.

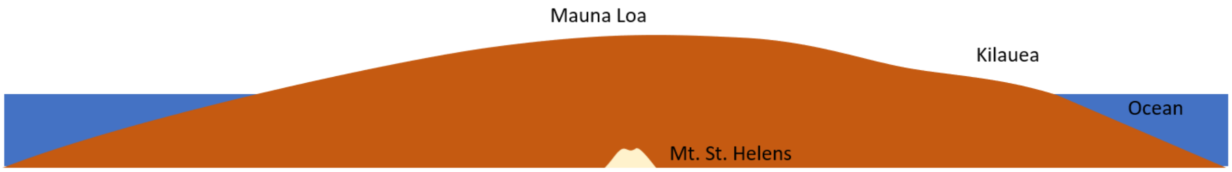
In general, SiO_2 content controls the relative viscosity of a magma. **Viscosity** is the ability of a liquid to resist flowing. This means liquids with a higher viscosity are thicker and do not flow as easily. Compare water to molasses. Which do you think has a higher viscosity? Molasses is a thick, sticky, syrupy liquid that does not flow very easily, especially when its cold (just try pouring it out of the jar!). However, water flows quite easily when a jar is tipped. So, molasses has a much higher viscosity than water. Magmas with a higher SiO_2 content have a higher viscosity. Ultimately, the viscosity of a magma will determine the shape a volcano takes over continued eruptions.

Magma and a Volcanoes Shape



A magma's silica content will not only control the rock type that forms, it also controls the relative viscosity of the magma. Differences in a magma's viscosity will determine the shape a volcano takes. High-silica (basalt) magma has a much lower viscosity. It flows much easier and over longer distances. As low-silica magma cools, it hardens to rock, adding a new thin layer of rock to the volcano. Over time, these long thin layers build up into a volcano that is wide (many are more than 10 miles) with shallow sloping sides. These are called **shield volcanoes** due to their shield-like shape. Each of the Hawaiian Islands is made up of shield volcanoes. The big Island of Hawaii is made of 5 shield volcanoes, with the Kilauea volcano being the only one to erupt since 1984.

In contrast to shield volcanoes, there are stratovolcanoes, like Mt. St. Helens. These volcanoes produce sticky, higher viscosity magma (andesite and rhyolite) that does not travel very far. When layered between ash, this magma will pile up into much steeper sided, conical shaped volcanoes - much like you would imagine a volcano to look like. These volcanoes are actually much smaller than many shield volcanoes. For example, compare the shield volcanoes Mauna Loa and Kilauea to Mount. St. Helens in the diagram below.



Mauna Loa is one of the world's largest volcanoes when measured by its entire size. This volcano is much bigger than what can be seen above the surface of the ocean water. When traced all the way down to the ocean floor, it reaches a height of over 30,000 ft from base to summit! For comparison, Mt. Everest reaches an elevation (above sea level) of just over 29,000 ft, but when measured from its base to summit, it is only 13,600 ft. This means Mauna Loa is more than twice as tall as Mt. Everest! Mauna Loa is only the second largest mountain in the world. The volcano Mauna Kea (also on the Big Island of Hawaii) is even taller!

Magma and Eruption Style

Basaltic Lava

Magma that has a lower viscosity and lower silica content produces the volcanic rock called basalt and forms shield volcanoes. These basalt lava flows are what we find erupting out of the Kilauea volcano today in Hawaii. In general, due to the lower viscosity and lower gas content, eruptions from these volcanoes are relatively gentle in nature. In Hawaii, the lava makes its way to the surface and flows down the side of the volcano in rivers of magma. These eruptions are not very explosive and do not pose as great of a threat to human life. The magma, while lower in viscosity, still moves slow enough to give people plenty of time to evacuate in the event of magma nearby, as happened in Hawaii a few years ago when the largest eruption in recent history occurred. The magma overtook many neighborhoods. While property was ultimately destroyed, no people were hurt.

The basaltic magma erupting in Hawaii produces two distinctly different textures of lava flows. These two types of lava flows are produced as a result of slight differences in the temperature and viscosity of the magma as it erupts!

Pahoehoe (pronounced ‘puh-hoh-ee-hoh-ee’) is the type of lava that most people think of when they picture a lava flow. Pahoehoe has a smooth, billowy look to it. It is nicknamed ‘ropy lava’ because it forms a braided or ropy texture. Pahoehoe lava flows in rivers down the volcano. As the lava is flowing, the part of the flow that is in contact with the air cools quickly into rock. This top crust of hot rock is dragged and folded with the moving lava beneath it and forms the ropy texture. This lava flow forms when basaltic magma is slightly cooler and more viscous.

A’a’ (pronounced 'ah-ah') is the second type of lava that forms. This lava is blocky and forms when the magma cools quickly and large chunks of cooled lava get reincorporated back into the moving flow. These blocks of cooler lava will begin to pile up and slow down the flow. This lava flow forms when the basaltic magma is slightly hotter and less viscous.

Rhyolitic/Andesitic Lava

Magma that has a higher viscosity and silica content produces rocks that are called **rhyolite** and **andesite.** These rocks form Stratovolcanoes (also called composite volcanoes), due to the higher amounts of trapped gasses and the higher viscosity. This leads to an increased pressure beneath the surface as the magma attempts to rise. This ultimately leads to more destructive and explosive eruptions, even though the magma might not travel very far due to its viscosity. Other materials that form during these eruptions are responsible for far-reaching damage. These other volcanic hazards (volcanic products that are a threat to human life) are pyroclastic flows, lahars and volcanic ash. Due to the explosiveness of these eruptions, a lot of ash debris (very small rock and magma pieces) is created. This ash is so fine that it remains suspended in Earth's atmosphere and can travel quite far. This ash can rain down onto roofs causing them to collapse and interfere with air travel. Sometimes, once enough ash is ejected, the ash plume over the volcano becomes too dense and will suddenly collapse and flow down the volcano at a rapid rate. These are called **pyroclastic flows** and are extremely devastating to anything in its path. When pyroclastic flows mix with surface water (streams, lakes, snow, etc.) it turns into a **lahar**. Lahars are volcanic mud flows that are also extremely devastating and can be compared to cement. These lahar and pyroclastic flows create the volcanic rock called **tuff**. Other volcanic rocks that form at composite volcanoes are **pumice** and **obsidian**. These are both volcanic glass which form when magma is instantaneously cooled and no crystals form. Pumice forms when there is a lot of gas present and trapped as bubbles in the magma. Creating a rock that is quite light and even floats in water due to its frothy nature. Once waterlogged though, pumice will sink just like any other rock.

For more information regarding the volcanic hazards present at composite volcanoes, check out our lesson on the eruption of Mt. St. Helens! In this lesson we discuss Mt. St. Helens eruption in 1980 and what made it unique compared to other composite volcanoes.

Lesson Instructions:

This lesson should be broken up into two days if needed. The first day will be spent discussing the different types of volcanoes and showing students the rock specimens. On day two, you will introduce the idea of viscosity and how that controls a volcano's shape.

1. Show students the two pictures of volcanoes: the one of Mt. St. Helens and one showing the big island of Hawaii. Ask the students which one they think is a volcano.
2. Most students will identify Mt. St. Helens as a volcano because of its conical shape. Explain to the students that both are volcanoes and that volcanoes can form many different shapes. You do not need to discuss the reason why they have different shapes yet. That will be discussed on the second half of this lesson. Just introduce the idea and define the different shapes for them.
3. Review the different types of volcano shapes using the diagram provided. Also compare volcano sizes. Explain how large the Hawaiian Island volcanoes are in comparison to Mt. St. Helens.
4. After you discuss that volcanoes look different and are not all conical in shape, you can begin a new discussion on volcanic rocks. Show the students the different rock specimens provided.
5. Let the students handle the rocks and use hand lenses to get a closer look. Have them discuss and make some general observations about the rocks (can they see crystals, rock color, etc.)
6. Ask them if they can guess which rocks were formed from magma and which ones were not. You can go through each one and have the class vote on it. Sort them into categories of what they think is or is not a volcanic rock.
7. Then tell them that they are all volcanic rocks!! Discuss with the class that not all magma is made up of the same material. There are differing amounts of each element within a magma and once that magma cools, different minerals will form depending upon what elements are present in the rocks. For example, basaltic rocks have lower silica and much higher iron content (hence their darker color). Rhyolite magmas have higher silica and form minerals that are lighter in color, resulting in pink to grey rocks.
8. You can now discuss the different types of lava flows. Show them the examples that demonstrate Pahoehoe and A'a' basalt flows. Discuss that the rocks are the same rock type (both basalt) and have the same minerals that make them, but they look different because of the way they flowed on the surface.
9. You can show them videos that demonstrate the differences between how these two types of lava flows.
   A'a' lava flow: https://www.youtube.com/watch?v=CjiGYsWttUc
   Pahoehoe lava flow: https://www.youtube.com/watch?v=-uwt0g9bQXI (the sound in this video is the lava flow! The snap, crackle, pop sounds just like rice crispy cereal, but louder!)
10. Next, discuss with the class stratovolcanoes. Note, again, the difference in shape. Discuss that these volcanoes have much more explosive violent eruptions. Show the students a video of a composite volcano eruption.
    Japan Stratovolcano: https://www.youtube.com/watch?v=HrjiWJWtDuo

11. Discuss with the students how the differences in the magma cause the different shapes as well as the different types of eruptions.

12. Introduce the idea of viscosity and discuss with them how the different magmas have different viscosities.

13. **(Day 2)** Begin by reviewing the discussion from the previous day. Discuss how there are different types of magma. These magmas are different because they contain a different chemical composition (different amounts of silica), which causes them to have different minerals present and results in rocks of different colors. Rhyolites have more silica and form lighter colored minerals, while basalt has less silica and forms darker colored rocks.

14. Next, introduce the experiment. Describe how they will be modeling lava flows using liquids with different viscosities. The liquids will represent the different types of lava flows and they will see how far/easily they flow down a slope.

15. Do the experiment described on the following page and fill out the Viscosity of Liquids: Data Sheet.

16. After students have completed the experiment, have them fill out the questions work sheet describing and interpreting their results.

17. Have a class discussion about their results. Which liquid was the most viscous? Which was the least? How far/fast did each of them flow? Go through their worksheets and discuss/correct their answers.

18. Show them images of the shield volcano and composite volcano and discuss their sizes again. Have the students lead the discussion (asking guiding questions) to lead them to the conclusion that lower viscosity magmas flow farther creating wider, more shallow sloped volcanoes, and that high viscosity magmas do not flow as far and create typical conical steeply sided volcanoes. Discuss how the viscosity of a magma controls both a volcano's shape and the style of eruption. Use the viscosity diagram if needed to reinforce the concept.

19. In knowing this relationship, discuss differences in evacuation procedures that might be implemented at a shield volcano vs. a composite volcano. Composite volcanoes will need a larger evacuation area due to higher gas content, explosive eruptions, and pyroclastic flows, which are much more unpredictable and can cause much more damage to human life. Near a shield volcano, authorities would need to evacuate areas near the lava flow.

Viscosity Experiment

Goals:

This experiment has been adapted from PBS's 'Volcano under a City'. In this activity you will learn about how viscosity controls how far a liquid can travel. This concept directly applies to volcanoes and how their shape is controlled by the viscosity of the magma!

Materials Needed:

- Corn Syrup
- Vegetable Oil
- Water
- Test tubes
- Droppers
- Cookie/sheet pans
- Stopwatch
- Wooden block
- Masking Tape
- Ruler
- 9 paper clips of equal size and weight.

Teacher Prep:

1. Break the students into groups of three.
2. Give each group 3 test tubes, 3 droppers, a stopwatch, 9 paper clips, ruler, masking tape, a wooden block, and a sheet pan.
3. Each group will fill their test tubes with the three liquids to the same height (marked on the test tubes). One tube should be filled with syrup. A second tube with oil. And a third tube with water. Have the students us masking tape to label their tube with the appropriate liquid.

Part 1 Procedure:

1. Have the students observe the three liquids in each test tube. They can gently swirl the tubes. Discuss and predict which liquid you think has the highest viscosity (most resistance to flow) and which has the lowest viscosity.
2. Using the worksheets provided. Have the students predict and order the three liquids from most viscous to lowest viscosity.
3. Have one person hold a stopwatch, and a second person hold a paper clip over one of the filled cups. The paper clip should be held so the bottom is just touching the top of the liquid.
4. Drop the paper clip and have the first person time how long it takes the paper clip to first touch the bottom of the cup. Record that time in the chart.
5. Repeat steps 4 and 5 two more times for the same liquid. You do not need to fish out the paper clip from the bottom of the cup.
6. Calculate the average time of all three trials.

7. Repeat steps 4-7 for the remaining two liquids.
8. Compare the three averages and categorize each liquid from 1 (most viscous) to 3 (least viscous).
9. Does this confirm your original rating from step two? Or are they different?

Part 2:

1. Make a second chart with three columns labelled 'water', 'oil', and 'syrup'. Make five rows beneath the columns and label them from top to bottom 'trial 1', trial 2', 'trial 3', 'Average', and 'Distance'. (Or print the one provided).
2. Place three pieces of masking tape in a row about 25 cm up from the bottom of the sheet pan. Make sure to measure from the inside of the pan, not the rim, and the bottom of the tape should be at the 25 cm mark. If your sheet pan is not big enough to make the space 25 cm, that is ok. Just make sure three pieces of tape are all the same distance from the bottom and measure the distance and record it in the 'distance' row on your chart.
3. Place the end of the sheet pan on a wooden block or book, so that the masking tape is towards the top, and the bottom of the pan is on the table.
4. Have one person ready with the stopwatch again. A second person should have a spoon and cup of liquid.
5. Scoop out one spoonful of the liquid and gently pour it on the pan just above one piece of the masking tape.
6. As soon as the liquid passes the bottom of the tape (the 25 cm mark), the timer should start the stopwatch.
7. Stop the stopwatch as soon as the liquid reaches the bottom of the pan. Record this time on your chart.
8. Continue two more times with the same liquid on the other two pieces of tape and record the times on your chart.
9. Calculate the average time of all three trials for that liquid.
10. Calculate the flow rate of each liquid using this formula: Flow Rate = Distance/average time.
11. Thoroughly clean the liquid off of the sheet pan. Do not remove the tape.
12. Repeat steps 4-11 for the remaining two liquids.
13. Compare your calculated flow rates to their relative viscosity from part 1.
14. Based on your data, how does the viscosity control the flow rate of a liquid?
15. It is known that the lava erupted from Kilauea Volcano flows freely down the side of the volcano, reaching far distances. However, the magma erupting from Mt. St. Helens piles up high into a magma dome and stays inside the volcano's crater. What do you think are the relative viscosity between these two types of magma?
16. How might knowing the viscosity of the magma influence evacuation procedures of towns near the Kilauea Volcano?

Viscosity of Liquids: Data Sheet

Part 1: Paper Clip Drop

Hypothesis: Which liquid do you think will have the highest viscosity? _________

	Trial 1	Trial 2	Trial 3	Average Time*
Liquid 1: Corn Syrup				
Liquid 2: Cooking Oil				
Liquid 3: Water				

*Average Time = (Trial 1 + Trial 2 + Trial 3) ÷ 3

Part 2: Rate of Flow

Hypothesis: Which liquid will flow the fastest? Which will flow the slowest?

	Trial 1	Trial 2	Trial 3	Average Time*
Liquid 1: Corn Syrup				
Liquid 2: Cooking Oil				
Liquid 3: Water				

*Average Time = (Trial 1 + Trial 2 + Trial 3) ÷ 3

Questions:

1. Which of your liquids has the highest viscosity? _________

2. Which of your liquids has the lowest viscosity? __________

3. Look at the two volcanoes below. Do you think the magmas that created them were **viscous** or **not viscous**? Write your answer in the space below each picture.

Shield Volcano (ex. Mauna Loa)

Stratovolcano (ex. Mt. St. Helens)

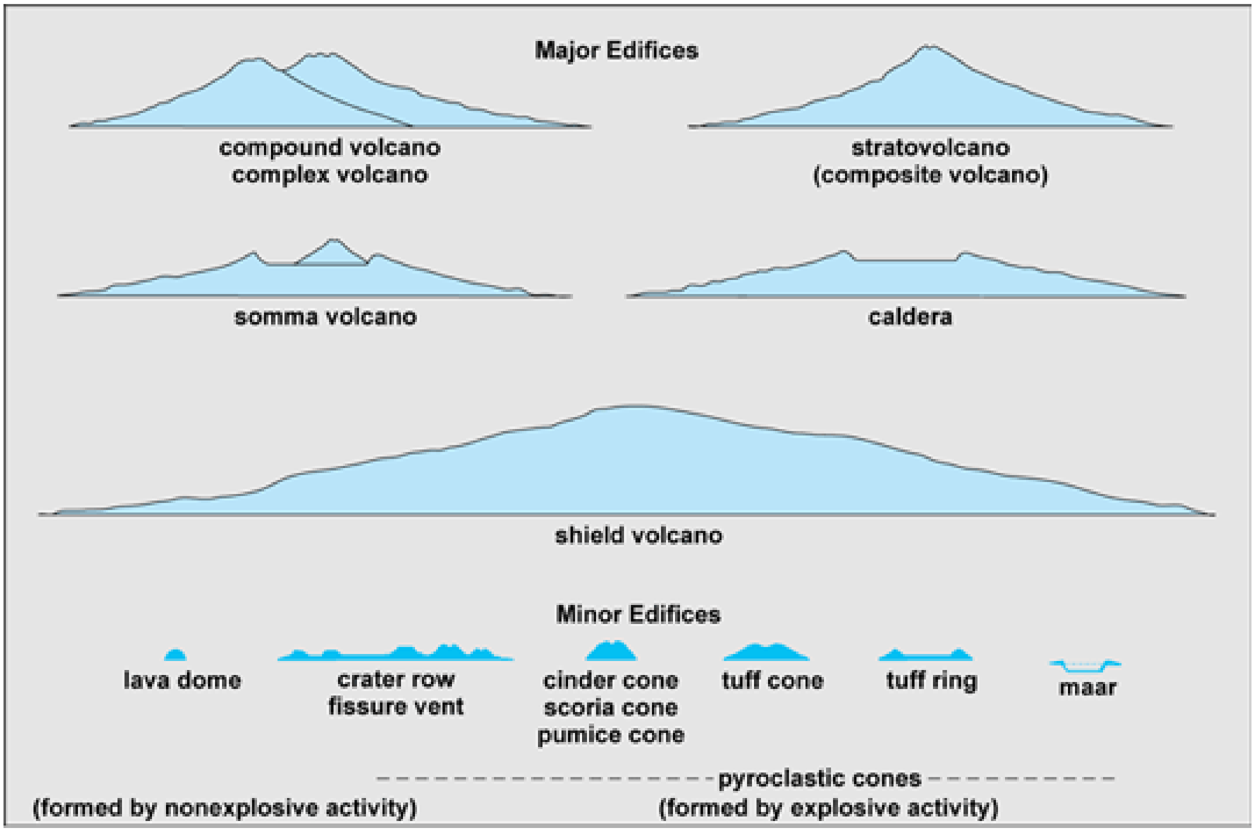
____________________ ____________________

4. When volcanoes erupt, they can erupt either quite explosively with plumes of ash and gas or more gently with flowing rivers of magma.

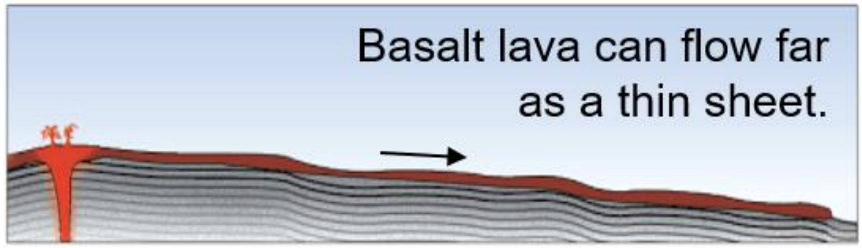
   Will a **more** or **less** viscous magma cause an explosive eruption? ___________

   Will a **more** or **less** viscous magma cause a gentle eruption? ____________

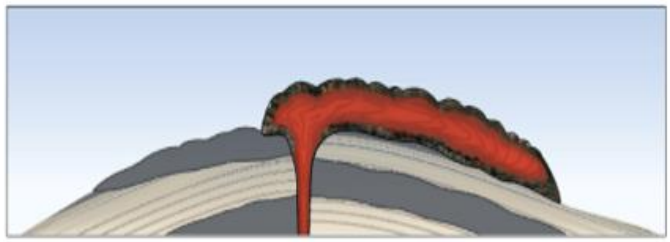
5. Discussion: How might an evacuation plan differ for a volcano with a more viscous magma than one with a less viscous magma?


Major Edifices
compound volcano
complex volcano
stratovolcano
(composite volcano)
somma volcano
caldera
shield volcano
Minor Edifices
lava dome
crater row
fissure vent
cinder cone
scoria cone
pumice cone
tuff cone
tuff ring
maar
pyroclastic cones
(formed by nonexplosive activity)
(formed by explosive activity)

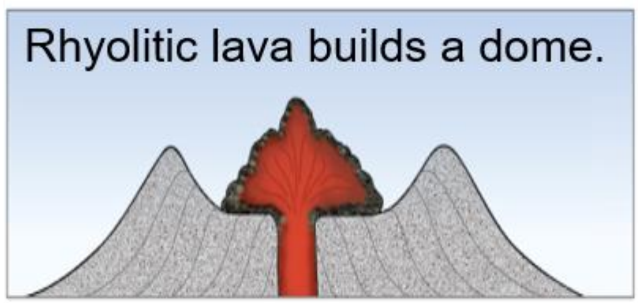

USGS



Basaltic lava flow.



Andesitic lava flow.



Rhyolitic lava flow.