Volcanoes on Io

Grade Level: Middle to High School
Description: Features associated with active volcanoes on Jupiter's moon Io are studied to determine what they are made of and how they were put in place. Students will use images of Io to determine characteristics of volcanic features.
Objectives: (1) Students will learn how the shape and size of a volcano, as well as the explosiveness of eruptions, is related to the chemical make-up of the magma and lava; (2) students will study the nature of volcanism on Io; and (3) students will understand how and why volcanoes on Io differ from those found on Earth.

Materials: 2 bottles carbonated water, bowls, olive oil, mayonnaise, peanut butter, pencils, rulers, and a calculators (optional)
Vocabulary: Volcano, eruption, magma, effusive vs. explosive, viscosity, silica, tidal heating, plate tectonics.

Introduction

Volcanic eruptions are perhaps the most dramatic events on Earth. Terrestrial volcanoes are important to understand not only as potential hazards, but also as geologic resources, biologic environments, and for their role in shaping the surface of Earth and other planets. Volcanic activity has been significant in shaping the surfaces of the rocky planets in the inner solar system (Mercury, Venus, Earth, Mars), and on some moons in the outer solar system as well. In fact, Jupiter's rocky moon Io is the most volcanically active body in the solar system.

A **volcano** consists of a hole or crack in a planet's surface through which hot, molten rock and gases erupt, and also includes the material that comes out onto the surface. When molten rock, also called **magma**, rises through the Earth's crust it causes a buildup in pressure. When this pressure becomes greater than the strength of the overlying rock, the rock cracks and allows the magma to reach the surface, resulting in a volcanic eruption.

The shape of volcanoes and their deposits (ash and rocks), as well as the chemicals that make up these deposits (their **chemical composition**), provide us with information on how the volcano formed. Based on the study of many volcanoes around the world, scientists have learned that the size and shape of a volcano, and how violently it erupts, is related to its chemical composition and the gas content of the magma.

Part A. The shape of a volcano

The shape of a volcano depends primarily on the chemical composition of the magma. Although magma is made up of hundreds of **chemical compounds**, the relationship between a volcano's shape and its composition can be illustrated by looking at one compound: silica (SiO_2). Silica, made up of one silicon (Si) atom and two oxygen (O) atoms, affects the **viscosity** (i.e., the resistance to flow) of the magma. Scientists have learned that magmas and lavas with high amounts of silica are very pasty, like gravy with too much cornstarch. On the other hand, magmas and lavas with low amounts of silica are runny and flow easily, like olive oil – they have a low viscosity. Because "runny" lava flows are typically long and thin, volcanoes that are built up by many of these flows have a very wide base compared to their height; that is, they have gently sloping sides. These are called **shield volcanoes** because of their resemblance to ancient warriors' shields. Examples of shield volcanoes are the Hawaiian volcanoes Mauna Loa (Figure 1) and Kilauea.

Now consider lava with a "pasty" consistency (i.e., high viscosity). Because "pasty" lavas do not flow as readily they tend to be short and thick. Volcanoes that are built up by pasty lava flows resemble steep-sided mounds. These volcanoes are called **domes**. Figure 2 is a picture of Mt. Elden in Flagstaff, AZ. In addition to the thick, high-silica flows which ran down the sides of the mountain, Mt. Elden was also "inflated" by very pasty magma. Growth through both inflation and external flows is common for volcanic domes.

However, not all volcanoes are shields or domes; other types of volcanoes of course do exist. Lava with a silica content that is between "runny" and "pasty" will have lava flow lengths and slopes that are between those of shields and domes.

Warm-up: Food Viscosity

Food can be used to demonstrate the concept of viscosity. Fill three clear bowls to the same level (e.g., two inches deep), one with olive oil, one with mayonnaise, and the last with creamy peanut butter. Using a stopwatch, time how long it takes a 1/3 pound fishing sinker to move through each of these materials. A material with a higher viscosity (resistance to flow) will require a longer amount of time for the weight to move through it. Low-silica lavas have a viscosity similar to olive oil, while high-silica lavas have a viscosity that is over 1000 times greater than peanut butter.

Part B. Gas Content and Volcanic Eruptions

The amount of gas dissolved in a magma determines how explosive a volcanic eruption will be. In the same way that chemical makeup affects the shape of a volcano, the amount of gas in a magma affects the explosiveness of an eruption. In general, magma with a high gas content erupts more explosively than magma with less gas. Low-gas-content magma tends to erupt non-explosively, with lava quietly running down slope. These eruptions are called **effusive**. When there is a lot of gas present in the magma, or it is trapped and builds up pressure, an explosive eruption, like Mt. St. Helens results.

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Warm-up: Soda Shaker Volcanic Eruptions

The violence with which a volcano erupts --explosively or quietly (i.e., **effusively**) -- depends primarily on the gas content of the magma. This can be illustrated using bottles of soda pop. Soda contains carbon dioxide gas that is dissolved in the liquid. Shake an unopened bottle of soda. When you open the bottle quickly, the soda erupts explosively. Now consider a second (unshaken) soda bottle of the same brand. If you leave the bottle open for several hours the carbon dioxide will escape from the liquid. Now put the lid back on and shake the bottle. Open it, and….nothing happens. The difference was not in the composition, but in the amount of dissolved gas within the soda. Turning back to volcanoes, when a magma erupts that has a high gas content, the gases "shred" the magma producing ash, pumice, and other rock fragments. (These hot fragments are collectively called **pyroclasts**.)

Part C . Silica and Gas Content Combined

The combination of the silica and gas contents of a magma influence a volcano's shape and explosiveness. Runny and *effusive* volcanism produces lava flows that result in shield volcanoes or vast lava plains. Runny and *explosive* volcanism produces steep piles of dark ash that surround the volcanic vent called **cinder cones** (Figure 3). *Pasty* and *effusive* volcanism produces lava domes. Pasty and *explosive* volcanism produces violent eruptions that are often accompanied by large amounts of ash and rock fragments. The explosive eruption of Mount St. Helens (Figure 4) in Washington State in 1980 is an example of this style of volcanic activity. Volcanoes like Mt. St. Helens are called **composite cones** or **stratovolcanoes** because they are made up of alternating layers of lava flows and pyroclasts (ash and rock fragments). In general, pasty (high-silica) eruptions are more explosive than runny (low-silica) eruptions because gas bubbles tend to build up greater pressures in silica-rich magmas.

Volcanoes on other Planets

Volcanoes and volcanic deposits have been identified on planets and moons in the solar system in addition to Earth. Like Earth, the planets Venus, the Moon, and Mars all have examples of effusive and explosive volcanism. Also like Earth, they had a lot of fluid low-silica volcanism, which resulted in vast lava plains and/or shield volcanoes. But unlike Earth, they all have unusual features that resulted either from their unique eruption environments (e.g., atmospheric conditions, gravity) or perhaps from uncommon lava compositions. On Venus, very long (up to thousands of kilometers) lava channels may be signs of emplacement of very fluid lavas, while the relative lack of deposits from explosive eruptions may be due to Venus' thick atmosphere. Figure 5 is a radar image of a shield volcano on Venus. The vertical relief has been exaggerated by 20 times in order to bring out the volcano's presence. On the Moon, the very fluid lunar lavas contain long, curving lava channels (Figure 6) called **sinuous *rilles***. Also, the Moon's lower gravity and lack of an atmosphere result in more powerful explosive eruptions on the Moon compared to Earth. On Mars, the lack of **plate tectonics** may have permitted the development of huge shield volcanoes. Olympus Mons (Figure 7) is a shield volcano that would cover the state of Arizona. And on the icy satellites of the outer planets, exotic processes like ice volcanism (e.g., the eruption of water or ice) appear to have occurred. A possible "ice flow" is seen on Jupiter's moon Ganymede (Figure 8).

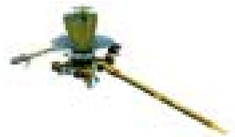
How does having a thick atmosphere (like Venus), or no atmosphere (like the Moon or Io) affect the way volcanoes look and how they erupt? Scientists have studied the volcanoes and volcanic deposits on other planets in order to better understand how planetary environments (in addition to silica and gas content) have affected their size, shape and locations. In general, higher gravity will result in *longer* lava flow lengths, but *shorter* travel distances for materials thrown from a volcanic vent. Materials thrown from a vent will also travel a *shorter* distance on a planet with a thick atmosphere compared to a planet with no atmosphere. A thick atmosphere will also cool lava flows faster than on a planet with a thin or no atmosphere.

Volcanoes on Io

Although volcanic features occur on many planets or moons, *active* volcanic eruptions have been observed beyond Earth only on Neptune's moon **Triton**, and on **Io**, one of Jupiter's four large moons. Volcanic plumes, up to 300 km high, were imaged on Io by the Voyager spacecraft (1978-1981). Images also show Io's multicolored surface, resulting from a wide range of volcanic flows and sulfur-containing deposits (Figure 9). New images from the Galileo spacecraft provide an opportunity to look for surface changes and to gain a better understanding of the types of volcanic activity on Io. We will use these Galileo images to investigate the styles of volcanism on Io.

Part D. Explosive Eruptions

The presence or absence of volcanic **plumes,** or gas jets, is related to the abundance of gas-rich materials on a planet. One of the first images of Io obtained by the Voyager 1 spacecraft in 1979 shows a plume above one of its volcanoes. Since then, the Voyager and Galileo spacecraft have photographed many volcanic plumes on Io. Plumes are the products of volcanic eruptions in which gas-rich magma is explosively shredded by gases as they escape from the magma. On Io deposits resulting from these plumes are often brightly colored. However, plumes on Io also result from lava flows releasing gases from surface materials. As the front of the lava flow moves with time, the location of the plume also migrates. Figure 10 shows a ~140 km high plume, which Galileo observed erupting from the volcano **Pillan** in June of 1997.



Volcanoes on Io

Gravity vs. Gas

Some of Io's eruptions are very explosive. Because Earth's Moon has a lower gravitational force compared to Io, volcanic eruptions on the Moon should have been more explosive (with a wider distribution of deposits) than Io --all else being equal. But Io's eruptions are more explosive! The red circular feature seen in the left side of figure 11 is a ring of volcanic deposits surrounding the volcano Pele. The dark deposit which interrupts this ring in the right side of figure 11 is an Arizona-size deposit from a later explosive eruption. The wider distribution of volcanic deposits on Io compared to the Moon probably indicates that there is something different about the chemical make-up or gas content of Io's eruptions that make them more explosive than eruptions on Earth's Moon. Other observations of lava flows on Io support this hypothesis as well.

Part E. Quiet, Effusive Volcanism

As we have seen, the length of a lava flow is determined by its viscosity. Low-silica lavas are more fluid than high-silica lavas. In addition, high-temperature lavas are more fluid than low-temperature lavas. On Earth, very fluid low-silica lavas have produced the longest recognizable lava flows. Lavas of similar composition are thought to have erupted on the Moon, Venus, and Mars, based on the length (hundreds to thousands of kilometers) and thickness (typically less than a few tens of meters) of the flows. However on Io additional information is available—the temperature of Io's lava flows can be measured.

Taking Io's Temperature

Lava flows on Io are very hot. Instruments on the Galileo spacecraft have obtained temperatures of erupting volcanic materials on Io, including those around Pillan (Figure 10), Pele (Figure 11), and Lei-Kung (Figure 12). The temperatures in these areas range from 1210-1625˚C (2210-2960˚F), which are much hotter than the hottest eruptions on Earth (1080-1180˚C or 1980-2160˚F). These temperatures are more like those of very low-silica lavas which erupted during the early part of Earth's history, over 2 billion years ago. Very hot lavas are very fluid and can easily flow long distances. Alternatively, carbon-dioxide-rich lavas can also have low viscosities that might promote long-distance flow. Although fluid, low-silica lavas on Earth can travel long distances, the fact that very high temperatures were measured on Io near the source of these flows may mean that lavas with unusual compositions (very low silica content, or carbon-dioxide rich) – compared to Earth – may be erupting on Io.

Lava Chemistry

Scientists are interested in determining the chemical make-up or composition of Io's lavas. Long, dark flows that cover large areas producing shield volcanoes or lava plains are common on Io. On Earth, lighter-colored, silica-rich materials with high viscosities form short flows that tend to pile up forming domes and steep volcanoes. The absence of domes or other steep-sided volcanoes on Io indicates that high-silica lavas are not present on Io.

Part F. Surface Changes on Io

Io's surface changes rapidly as a result of the large amounts of volcanic activity. Voyagers 1 and 2 obtained photographs of Io's surface in 1979 and 1980. With the arrival of Galileo at Jupiter in December of 1995, the spacecraft has obtained photographs of Io's surface which are used to search for changes. Surface changes include new volcanoes that have formed, new types of lava flows, or new explosively erupted deposits.

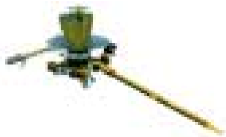
Many changes can be noted in these images. Here are a few: The most obvious is the large circular dark feature just to the right (east) of Pele that has partially covered the red ring of sulfur-rich material (Figure 11). At the center of this dark feature is the volcano Pillan Patera which erupted a plume of material (Figure 10). This dark feature is roughly 400 km (250 miles) across. At the center, the material is dense, and may contain lava flows; away from the center the dark material is diffuse, and may be explosive deposits.

Part G. Io's Heat Source

What keeps Io's volcanoes so hot and so active? The answer is **tidal heating**. Io is continuously pulled and stretched by the massive planet Jupiter on one side, and the icy moons **Europa** and **Ganymede** on the other side, resulting in Io's elliptical orbit. This causes Io's interior to flex, which generates large amounts of heat. This heat melts part of Io's interior, producing the very hot lavas that are observed. The effect of tidal heating can be demonstrated with the exercise **Flexing Muscles and Moons** (http://galileo.jpl.nasa.gov).

Summary

Using data obtained from the Galileo spacecraft, scientists are learning more about volcanism on Jupiter's moon, Io. Io's multicolored surface includes dark low-silica flows and several types of sulfur deposits. Explosive eruptions produce plumes and deposits which travel hundreds of kilometers (farther than on Earth or the Moon). These great distances may be due to unusual lava compositions and/or high gas contents. Very hot lavas that are erupting on Io may be similar to lavas that erupted on Earth billions of years ago. These lavas are very fluid and produce long flows. As we have seen, eruption environments (e.g., gravity, presence and type of atmosphere), lava compositions and gas contents influence the types of volcanic deposits produced. Understanding these differences is key to understanding volcanism on Io, Earth, and other planetary objects as well.



Volcanoes on Io

Graphics .

Figure 1. Mauna Loa, Hawaiian shield volcano

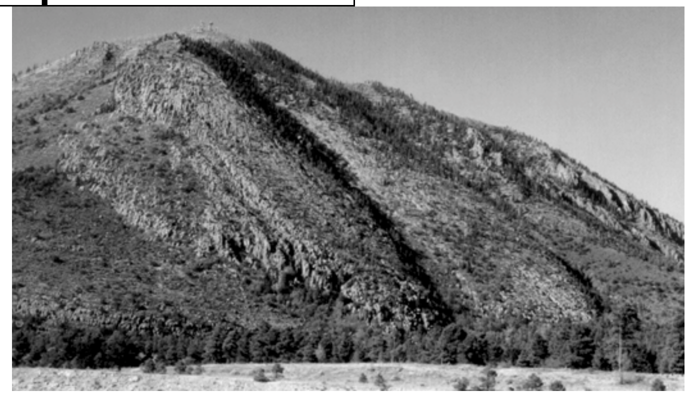


Figure 2. Mt. Elden, volcanic dome in Arizona

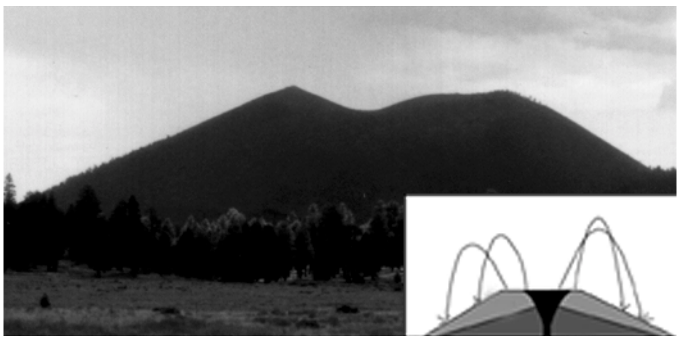


Figure 3. Sunset Crater, cinder cone in Arizona

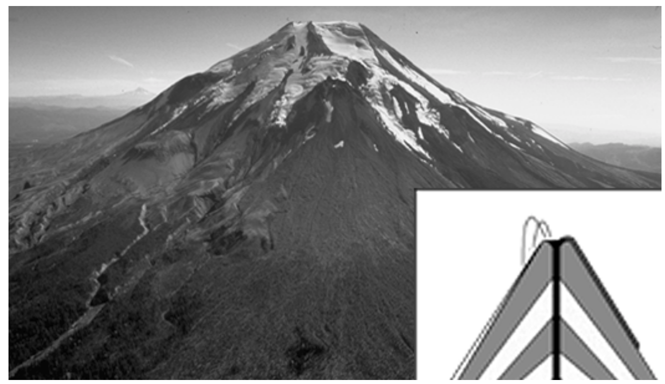


Figure 4. Mt. St. Helens prior to 1980 eruption

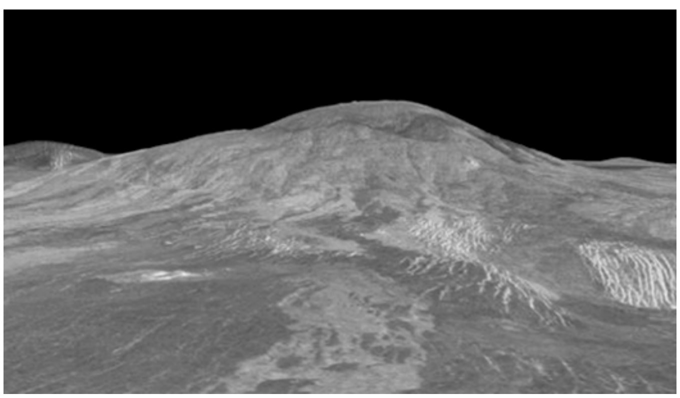


Figure 5. Shield Volcano on Venus

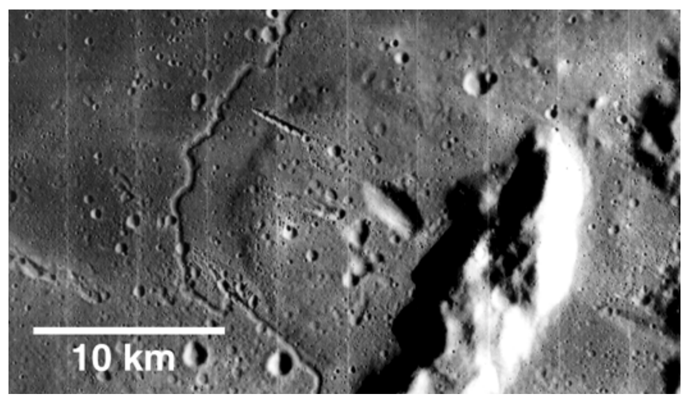


Figure 6. Lava channel (rille) on Moon

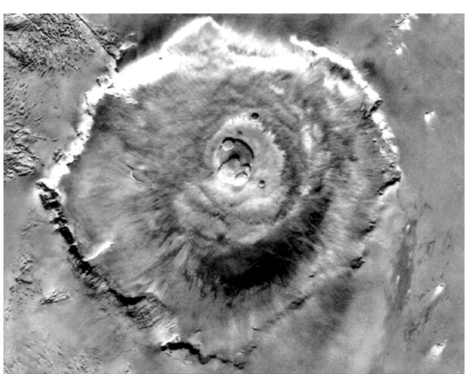


Figure 7. Olympus Mons, martian shield volcano

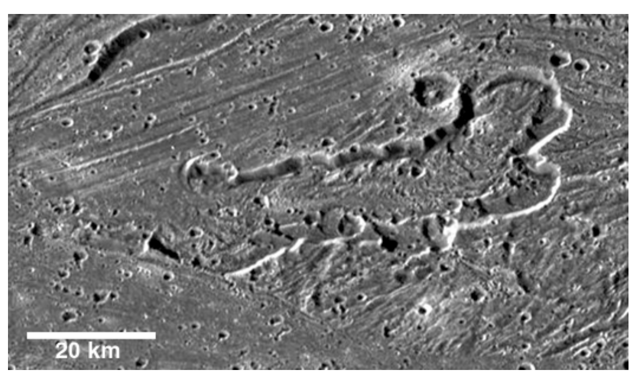
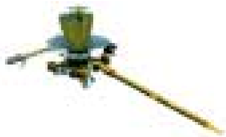


Figure 8. Volcanic depression/flow on Ganymede



Volcanoes on Io

Graphics .

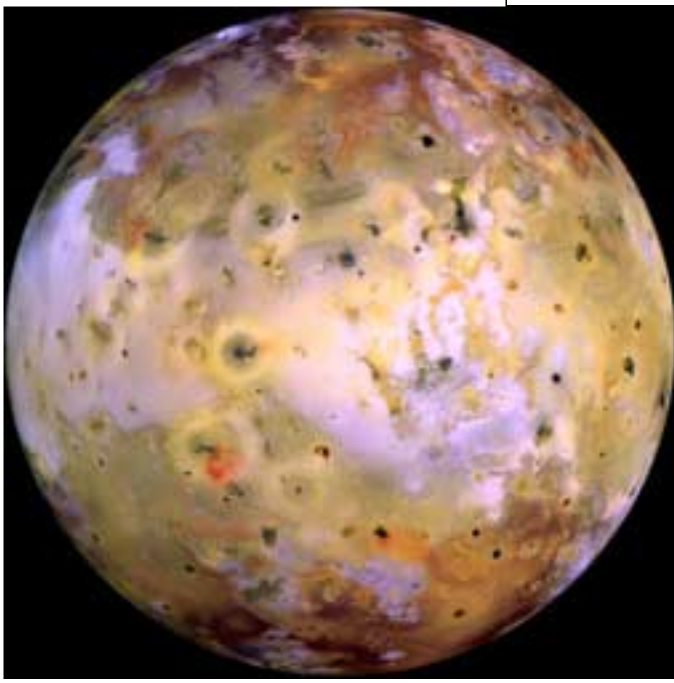


Figure 9. Global Io, imaged by the Galileo spacecraft.

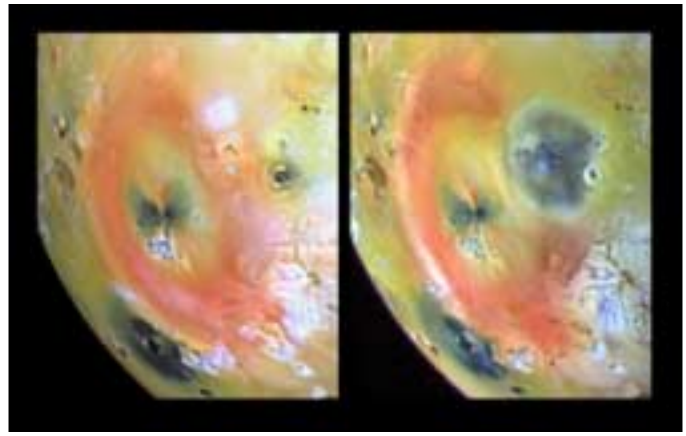


Figure 11. *Left*: Red volcanic ring surrounding Pele. *Right*: Dark, Arizona-size eruption.

Figure 10. Volcanic plume erupting from Pillan Patera

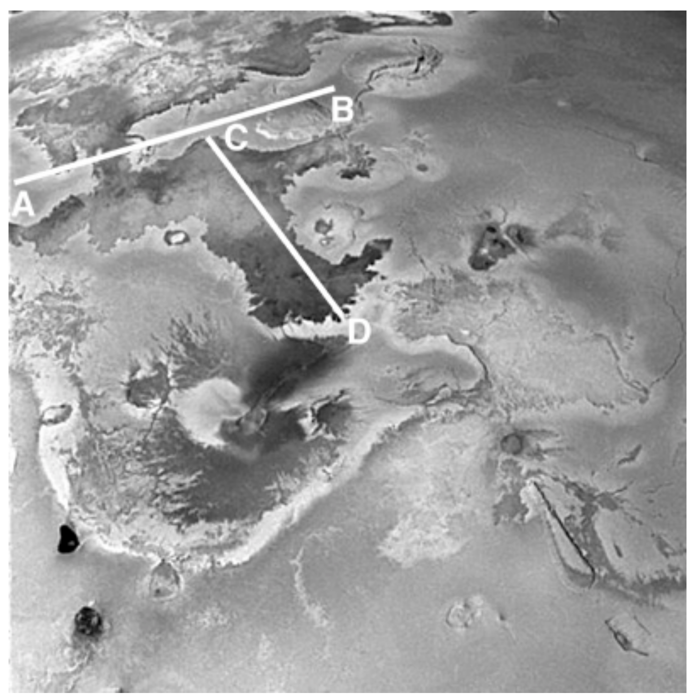


Figure 12. Lei-Kung volcanic region on Io.

Volcanoes on Io

Student Worksheet .

Name:____ **Date:** __________________

Procedure

Part I: Factors in Size and Shape of Volcanoes

The shape of a volcano is determined by how fluid the lava is—which is determined by the amount of the silica present. Silica makes magma or lava more pasty or difficult to flow, and also traps gas, producing more violent eruptions. The gas content of a magma determines whether an eruption is explosive or effusive. For each combination of silica and gas contents in the following table, describe:

a) the violence of the eruption (e.g., explosive or effusive),
b) the erupted materials: lava flows (e.g., long, short, thick, thin, runny, pasty) **or** deposits (e.g., ash, cinders),
c) name a type of volcano associated with each style of eruption,
d) and draw a profile of the volcano produced (use figures 1-4 if necessary).

	Low Silica Content	**High Silica Content**
Low Gas Content		
High Gas Content		

Volcanoes on Io

Student Worksheet .

Part II: Volcanoes in the Solar System (Answer on a separate sheet of paper.)

1. The presence of an atmosphere and the strength of gravity both affect how explosive an eruption will be and how far the deposits will travel. Would you expect an active volcano on Io to be more or less explosive than an erupting volcano (with similar composition and gas content) on Venus? Why? (Hint: How thick is Venus' atmosphere? How does Venus' mass/gravity compare to Io's?)

2. Many explosive volcanic deposits on Io traveled a greater distance from the central vent compared to those on the Moon. If you consider that both moons have similar gravity, and neither has an atmosphere, what does this indicate about the explosiveness of Io's volcanoes compared to the Moon?

A. Explosive Volcanism on Io: Plumes and deposits

3. Based on the observation of volcanic plumes, like the one seen in figure 10, erupting on Io for a period of over 20 years, and presumably for the age of the solar system, what can you determine about the *quantity* of gas-rich materials on Io?

B. Effusive Volcanism: Flows

4. In addition to explosively deposited deposits, Io's surface contains many lava flows. To determine how far some of these lava flows have traveled, use Figure 12, to measure the dimensions of the T-shaped flow (lines A-B, C-D) with a ruler. If 1 cm in the picture = 130 km on the ground, what are the flow lengths in kilometers and miles. (1 km = 0.62 miles).

5. The flows in figure 12 are very long (and thin)! Based on this observation, do you think the lava which produced these flows had a high or low viscosity? Were these lavas high or low in silica content?

C. Surface Changes on Io

6. Two pictures taken of the same area at different times can reveal the types of activity which have occurred. The left picture in Figure 11 is a Galileo image of Pele taken on April 4, 1997, and the right picture is the same area photographed on September 19, 1997, roughly five and a half months apart. Describe all the changes you see, and whether these changes were produced by explosive or effusive activity.

D. Synthesis

7. Based on what you have learned, list at least two factors that are important in whether a volcanic eruption will be explosive or effusive, and how they affect the distance flows or deposits will travel.

8. How do the temperature and composition ranges of lavas on Io compare to those which occur on Earth? List at least one factor that may contribute to this.

9. Are lavas on Io, in general, more or less viscous than those on Earth? List two factors which may contribute to this.

10. Scientists think that the lavas which are erupting today on Io are similar to lavas which erupted on Earth about 2 billion years ago. Therefore, studying Io's lava flows allows us to better understand ancient Earth. What does this suggest about the temperature of the Earth 2 billion years ago compared to today?

Volcanoes on Io

Teacher Notes .

Answer Key

Part I: Factors in Size and Shape of Volcanoes

Chart:

a) Low gas and low silica: effusive; long thin flows; shield volcanoes; shallow slopes
b) High gas and low silica: explosive; cinders; cinder cones; steep sides
c) Low gas and high silica: effusive; short thick flows; domes; steep slopes
d) High gas and high silica: very explosive; ash; composite or stratovolcanoes; steep slopes

Part II: Volcanoes in the Solar System

1. Less explosive. Venus has a thicker atmosphere and higher gravity which both lessen explosiveness.

2. Io's volcanoes are more explosive than those which occurred on the Moon.

A. Explosive Volcanism

3. Gas-rich materials have been and continue to be abundant on Io, both on the surface and in the subsurface.

B. Effusive Volcanism

4. The distance from A to B is about 600 km or 375 miles. The distance from C to D is about 415 km or 250 miles.
5. These are very low viscosity (fluid) flows. High viscosity flows do not flow easily and result in thick flows or dome-like structures—neither of which are present on Io.

C. Surface Changes on Io

6. Answers will vary. The major changes are listed in the exercise, and include the large, dark circular feature that disrupts the red ring (an explosive deposit), as well as the presence/absence of white material (SO_2 frosts) Dark lava flows may be present near the center of the dark circular deposit.

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D. Synthesis

7. Silica content (increases viscosity) and gas content (increases explosiveness) are the two most important. However the presence and density of an atmosphere, as well as gravity, also influence the style of volcanic eruptions.
8. Lava temperatures are generally hotter on Io. Volcanoes on Earth, however, have a wider compositional range—from low- to high silica; volcanoes on Io are thought to be very low silica in composition, with no high-silica lavas present. The higher temperatures and low silica compositions are thought to be caused by the combined affects of tidal heating and radiogenic heating (i.e., heat caused by radioactive decay).
9. Io's lavas have a lower viscosity compared to most terrestrial lavas. This is due to their very high eruptive temperatures and very low silica contents.
10. The temperature of the Earth was higher 2 billion years ago compared to today.

The figures of Io used in this exercise along with the original release captions, may be located at the following URLs:
Figure 9: http://photojournal.jpl.nasa.gov/cgi-bin/PIAGenCatalogPage.pl?PIA02309
Figure 10: http://photojournal.jpl.nasa.gov/cgi-bin/PIAGenCatalogPage.pl?PIA01081
Figure 11: http://photojournal.jpl.nasa.gov/cgi-bin/PIAGenCatalogPage.pl?PIA00744
Figure 12: http://photojournal.jpl.nasa.gov/cgi-bin/PIAGenCatalogPage.pl?PIA00537

Credit:
This activity was developed by Jim Klemaszewski and David Williams of Arizona State University for NASA's Galileo Europa Mission (http://galileo.jpl.nasa.gov).