NOVA

Original broadcast: September 26, 2006

PBS

Mystery of the Megavolcano

PROGRAM OVERVIEW

NOVA details how a group of scientists—each pursuing his own research—pieced together the puzzle of one of the greatest natural disasters ever to occur on Earth.

The program:

- presents ice core research that revealed high concentrations of sulfuric acid in a sample dating back 75,000 years.
- reviews sea core research that indicated a 5° or 6° C drop in ocean temperatures 75,000 years ago.
- profiles a scientist who began receiving chemically similar ash samples from sites separated by more than 6,500 kilometers.
- follows that same scientist's efforts to learn more about the ash and reports on his call to researchers worldwide for ash samples.
- tracks the subsequent detective hunt to try to identify the volcano from which the ash came.
- notes that while one researcher sent in a matching sample from the shores of Lake Toba on Sumatra, there was no clear volcano suspect in the vicinity from which the sample was collected.
- reveals that the volcano was determined to be underneath Lake Toba and established to be so massive that it belongs to a new class of volcanoes known as supervolcanoes.
- recreates how magma may have accumulated for a million years in the Earth's crust underneath the lake before it erupted billions of tons of ash into the atmosphere and formed a caldera that later filled with lake water.
- addresses the question of whether the volcanic eruption could have pushed the planet towards an ice age.
- presents a NASA computer simulation showing how a supervolcanic eruption could activate planetary cooling.
- speculates on what might happen if another supervolcanic eruption were to occur and notes that scientists are seeking to understand the life cycle of supervolcanoes to better predict the next eruption.

BEFORE WATCHING

1 List the following volcanoes on the board: Vesuvius (79 AD, buried Pompeii and Herculaneum); Tambora (1815, largest eruption in historic time); Krakatau (1883, produced tsunami that killed 36,000 people); and Mount St. Helens (1980, major U.S. volcanic eruption). For each, have students research the volcano's location, its largest eruption, the date the eruption occurred, and the amount of debris erupted. Have students then compare the amount of erupted debris to the amount ejected by supervolcanoes (often at least 1,000 cubic kilometers of magma).

2 Organize students into four groups and assign each group one of the following topics to track as group members watch the program: ice core analysis, lake geography, ash and soil analysis, and sea life analysis.

AFTER WATCHING

1 Ask students who took notes on the same topic to meet, review their notes, and present their findings to the class. What was the role of each piece of evidence in identifying Lake Toba as the source of climate change 75,000 years ago? How did the different pieces of evidence support one another?

2 Have students consider some of the different scientists in the film (Gregory Zielinski, climatologist; Mike Rampino, geologist; John Westgate, tephrochronologist; Craig Chesner, geologist; and Drew Shindell, climatologist). What kind of traits would each scientist need to do his job? If students could spend a day with one of the scientists, who would they choose? Why?

CLASSROOM ACTIVITY

Activity Summary
Students use volcanic ash data to determine the source of a possible supervolcanic eruption that occurred in the western United States.

Materials for Each Student
- copy of "CSI: Ashfall Fossil Beds" student handout
- pencil or pen

Materials for Each Team
- copy of "Volcanic Identification" student handout
- copy of "Volcano Suspects: Location" student handout
- copy of "Volcano Suspects: Description" student handout
- copy of "Volcano Suspects: Ash Composition" student handout
- access to print and Internet U.S. map resources

Background
Supervolcanic eruptions are extremely large eruptions that produce at least 1,000 cubic kilometers of magma and pyroclastic material (a hot, dry, fast-moving mixture of ash, pumice, rock fragments, and gas). These eruptions could destroy virtually all life within a radius of hundreds of kilometers from the site and could bury areas as far away as 1,500 kilometers in meters of ash. Very large-scale explosive eruptions of this type produce calderas, large depressions formed by the collapse of the summit or flanks of a volcano.

Volcanic ash consists of rock, mineral, and glass fragments smaller than two millimeters in diameter. Ash is formed by the catastrophic drop in pressure on magma brought about by the volcanic eruption (breaking up of volcanic edifice results in atmospheric pressure inside volcano). This causes gases in the magma to expand violently, fragmenting the magma into tiny pieces, which instantly solidify on ejection into the atmosphere (lower temperature compared to magmatic temperatures).

Ash from a particular volcano has its own unique characteristics, much like a person's fingerprints. These characteristics include chemical composition, and the size and shape of crystals and glass shards. They can be used to determine not only the particular volcano that produced the ash, but the particular eruption from that volcano as well.

The characteristics, along with the age of the ash, help scientists identify the source of material. Volcanic rocks are typically divided into four basic types—basalt, andesite, dacite, and rhyolite—according to the average concentration of major compounds in the rock. These compounds include silicon dioxide (SiO_2), titanium dioxide (TiO_2), aluminum oxide (Al_2O_3), iron oxide (FeO or Fe_2O_3), manganese oxide (MnO), magnesium oxide (MgO), calcium oxide (CaO), sodium oxide (Na_2O), potassium oxide (K_2O), and phosphorous pentaoxide (P_2O_5).

LEARNING OBJECTIVES

Students will be able to:

- describe some of the characteristics of a supervolcanic eruption.
- better understand how additional data can help support or refute a hypothesis.

KEY TERMS

caldera: Large depression formed by collapse of the ground following an explosive volcanic eruption of a large body of stored magma.

pyroclastic flow: Hot, dry, fast-moving mixture of ash, pumice, rock fragments, and gas from a volcano.

supervolcano: A volcano that has produced an exceedingly large explosive eruption involving the ejection of huge amounts of ash into the atmosphere, causing formation of a giant caldera.

tephra: The general term now used by volcanologists for airborne volcanic ejecta of any size.

CLASSROOM ACTIVITY (CONT.)

In 1971, Michael Voorheis, a paleontologist at the University of Nebraska State Museum, made a startling discovery at a farm in northeastern Nebraska. He uncovered the bones of 200 fossilized rhinos, together with the prehistoric skeletons of camels, lizards, horses, and turtles. They had been killed millions of years ago by suffocating amounts of volcanic ash (the site later became known as Ashfall). But there are no volcanoes in Nebraska, nor had there ever been. In fact, there are no volcanoes in the continental United States east of Colorado. So where did the ash come from?

Scientists discovered that the ash originated in an extremely explosive eruption approximately 10 million years ago. By analyzing and comparing ash samples from the Ashfall site to those produced by volcano eruptions of the same age, the scientists were able to identify the source of the eruption as the Bruneau-Jarbridge volcano in southwestern Idaho, some 1,500 kilometers away.

In this activity, students will use real volcanic data to identify the likely source of volcanic ash found in an area of Nebraska.

Procedure

1 Brainstorm with the class about the possible types of information they might need to identify a source of volcanic ash. (The age of a sample is normally a key identifying characteristic; however, because super-volcanic explosions are so rare, knowing the age of the ash sample would allow students to immediately identify the source. Therefore it is *not* included as a characteristic in this activity.)

2 Organize students into teams and distribute copies of the "CSI: Ashfall Fossil Beds" and "Volcanic Identification" student handouts.

3 Ask students to use the information on the "Volcanic Identification" handout to identify the type of ash at the Nebraska site and the type of eruption and volcano that might have produced it.

4 Explain to students that they will be provided with three sets of data, one at a time. (You may want to point out to students that this is actual real volcanic data.) For each data set, they will be asked to analyze the information and—based on that data—eliminate "suspect" volcanoes they think least fit the profile for the Ashfall event. They also will be asked to rate how certain they are of their conclusions. Explain that they will review their conclusions again when all the data are in.

5 Distribute the three data handouts in the following order, having students complete each one before starting the next:

Volcano Suspects: Location
Volcano Suspects: Description
Volcano Suspects: Ash Composition

STANDARDS CONNECTION

The "CSI: Ashfall Fossil Beds" activity aligns with the following National Science Education Standards (see **books.nap.edu/html/nses**).

GRADES 5–8

Science Standard D
Earth and Space Science
- Structure of the Earth system

Science Standard F
Science in Personal and Social Perspectives
- Natural hazards

GRADES 9–12

Science Standard D
Earth and Space Science
- The origin and evolution of the Earth system

Science Standard F
Science in Personal and Social Perspectives
- Natural and human-induced hazards

Video is not required for this activity.

Classroom Activity Author
Margy Kuntz has written and edited educational materials for more than 20 years. She has authored numerous educational supplements, basal text materials, and trade books on science, math, and computers.

CLASSROOM ACTIVITY (CONT.)

6 After students complete each handout in the order given above, have them mark their "Volcano Suspects Table" on their main "CSI: Ashfall Fossil Beds" handout with the volcano or volcanoes they feel is or are the *least* likely suspect(s) based on the data, and rate their confidence level in their answer.

7 After all students have completed all three handouts and filled out their "Volcano Suspects Table," ask them to identify their main suspect and answer the questions listed on their "CSI: Ashfall Fossil Beds" handout. Lead a class discussion about which volcano was the main suspect and why. Did students' opinions change as they got more data? Why or why not? Which data were most relevant? Which were least relevant?

8 As an extension, ask students to research and report on the eruptions of the different "suspect" volcanoes. When did the major eruptions occur at each site? What was the result of those eruptions? Should students be concerned about living in an area where supervolcanic eruptions might have occurred? Why or why not?

ACTIVITY ANSWER

Volcanic Identification

Type of ash at Ashfall: *felsic, because the ash contains a silica content of more than 65 percent*

Type of eruption most likely to have created Ashfall: *highly explosive*

Type of volcano form most likely to have created Ashfall: *caldera or dome volcano*

Volcano Suspects: Location

1 Which volcano is located closest to the Ashfall site? *Yellowstone*

2 Which volcanoes are farthest away? *Mount St. Helens, Lassen, Crater Lake, and Long Valley*

Volcano Suspects: Description

1 The eruptive volume corresponds to the explosiveness of a volcano. Which volcano had the most explosive eruption? Which volcano had the least explosive eruption? *Yellowstone had the most explosive eruption; Mount St. Helens had the least.*

2 Does there seem to be a relationship between the size of a volcano's crater/caldera and an eruption's explosiveness? Why or why not? *Yes, more explosive volcanoes seem to have larger calderas because of the more powerful eruptions they create.*

Volcano Suspects: Ash Composition

1 For each suspect volcano, would you characterize the magma that produced the ash sample as mafic, intermediate, or felsic? Why? *All the given samples correspond to felsic eruptions based on their silica content.*

2 Which ash seems to be most similar in composition to the Ashfall sample? *The Bruneau-Jarbridge ash is most similar in composition.*

CSI: Ashfall Fossil Beds

Student answers will vary but should indicate the following:

Location*: most-distant volcanoes (Mount St. Helens, Lassen Peak) least likely*

Description: *stratovolcanoes (Mount St. Helens, Lassen) and less explosive volcanoes (Crater Lake, Mount St. Helens, Lassen) least likely*

Ash Composition*: those with greatly differing amounts of silica, aluminum, sodium, and potassium from the Ashfall site (Mount St. Helens, Crater Lake, Lassen Peak, Long Valley—and to a lesser extent, Valles Caldera, and La Garita) least likely*

See Sample Volcano Suspects Table on page 6.

ACTIVITY ANSWER (CONT.)

Sample Volcano Suspects Table

Data Set	Mount St. Helens	Crater Lake	Lassen Peak	Long Valley	Valles Caldera	La Garita	Bruneau-Jarbridge	Yellowstone	Confidence Level 1 = low 5 = high
Location	4	3	4	—	—	—	—	—	1 2 3 4 5
Description	4	3	4	2	2	—	—	—	1 2 3 4 5
Ash Composition	4	4	4	4	3	3	—	2	1 2 3 4 5

CSI: Ashfall Fossil Beds Student Handout Questions

1 Most of the listed "suspect" volcanoes have calderas, which are large depressions formed by the collapse of the summit or flanks of a volcano during a large-scale, highly explosive eruption. Why would a caldera-forming eruption be the most likely source of the ash found in Nebraska? *Caldera-forming eruptions are felsic eruptions and would produce massive amounts of ash that could reach a great distance from the source of the eruption.*

2 The most explosive volcanoes have magma with a very high silica (SiO_2) content. Based on this information, which of the suspect volcanoes is most likely to have had the most explosive eruption? *Yellowstone and La Garita*

3 Which volcano do you think was the most likely source of the eruption that killed the animals in Nebraska? Why? *Bruneau-Jarbridge, because the ash is very similar in composition. Even though the caldera is not the closest, it had a very explosive eruption that might have produced enough ash to reach Nebraska.*

Major funding for NOVA is provided by Google.
Additional funding is provided by the Howard Hughes Medical Institute, the Corporation for Public Broadcasting, and public television viewers.

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LINKS AND BOOKS

Links

NOVA—Mystery of the Megavolcano
www.pbs.org/nova/megavolcano
Discover what a supervolcano eruption might mean today, find out what lessons can be learned from the Toba eruption, see the impact Toba had 75,000 years ago, and explore a map of supereruptions around the world.

Ashfall Fossil Beds State Historical Park
ashfall.unl.edu
Features information about the Ashfall Fossil Beds as well as the history and geology of the area.

Smithsonian Institution: Global Volcanism Program
www.volcano.si.edu
Describes volcanoes around the world and eruptions that have occurred during the past 10,000 years.

Books

Volcanoes and Earthquakes
by Susanna Van Rose.
Dorling Kindersley, 2004.
Explains how volcanoes and earthquakes occur.

Volcanoes
by Robert and Barbara Decker.
W.H. Freeman and Company, 1997.
Provides detailed information about the geology of volcanoes.

CSI: Ashfall Fossil Beds

You have been hired to solve a mystery. Which supervolcano killed the creatures found in Nebraska's Ashfall Fossil Beds 10 million years ago? Your job: Use clues from the crime scene to hunt down the volcano responsible.

Procedure

1 Use the data in your "Volcanic Identification" handout to classify the type of ash found at the Nebraska site and determine the type of explosion and the volcano most likely to have produced it.

2 Once you have compiled a profile of the volcano likely to have created the ash at the Nebraska site, your teacher will provide you with three "Volcano Suspects" data sets, one at a time, giving you locations, descriptions, and ash compositions for each volcanic suspect.

3 For each data set (location, description, ash composition), answer the questions listed on each sheet. After you have completed each, mark the table below with the volcano or volcanoes you feel is or are the *least* likely suspect(s) based on the data, and rate your confidence level in your answer.

4 Once you have completed the questions for all three data sets, answer the questions below.

Volcano Suspects Table

Data Set	Mount St. Helens	Crater Lake	Lassen Peak	Long Valley	Valles Caldera	La Garita	Bruneau-Jarbridge	Yellowstone	Confidence Level 1 = low 5 = high
Location									1 2 3 4 5
Description									1 2 3 4 5
Ash Composition									1 2 3 4 5

Questions

Write your answers on a separate sheet of paper.

1 Most of the listed "suspect" volcanoes have calderas, which are large depressions formed by the collapse of the summit or flanks of a volcano during a large-scale, highly explosive eruption. Why would a caldera-forming eruption be the most likely source of the ash found in Nebraska?

2 The most explosive volcanoes have magma with a very high silica (SiO_2) content. Based on this information, which of the suspect volcanoes is most likely to have had the most explosive eruption?

3 Which volcano do you think was the most likely source of the eruption that killed the animals in Nebraska? Why?

Volcanic Identification

Your job is to identify the type of volcano that created the Ashfall Fossil Beds site. First compare the "Ashfall Data" with information about three main types of magma (mafic, intermediate, felsic) listed in the "Magma and Eruption Characteristics" chart. Then fill in the "Ashfall Conclusions" section at right with your conclusions.

Ashfall Conclusions

Type of ash at Ashfall: (circle one)

mafic intermediate felsic

Type of eruption most likely to have created Ashfall:

Type of volcano form most likely to have created Ashfall:

Ashfall Data

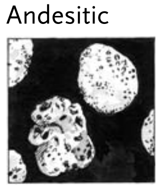
Ashfall Tephra

Ash Composition (percentage by weight)

Aluminum Oxide (Al_2O_3)	Calcium Oxide (CaO)	Iron Oxide (FeO)*	Potassium Oxide (K_2O)	Magnesium Oxide (MgO)	Sodium Oxide (Na_2O)	Titanium Dioxide (TiO_2)	Phosphorous Pentaoxide (P_2O_5)	Silicon Dioxide (SiO_2)
11.80	0.60	2.80	6.30	0.10	2.60	0.20	0.08	75.50

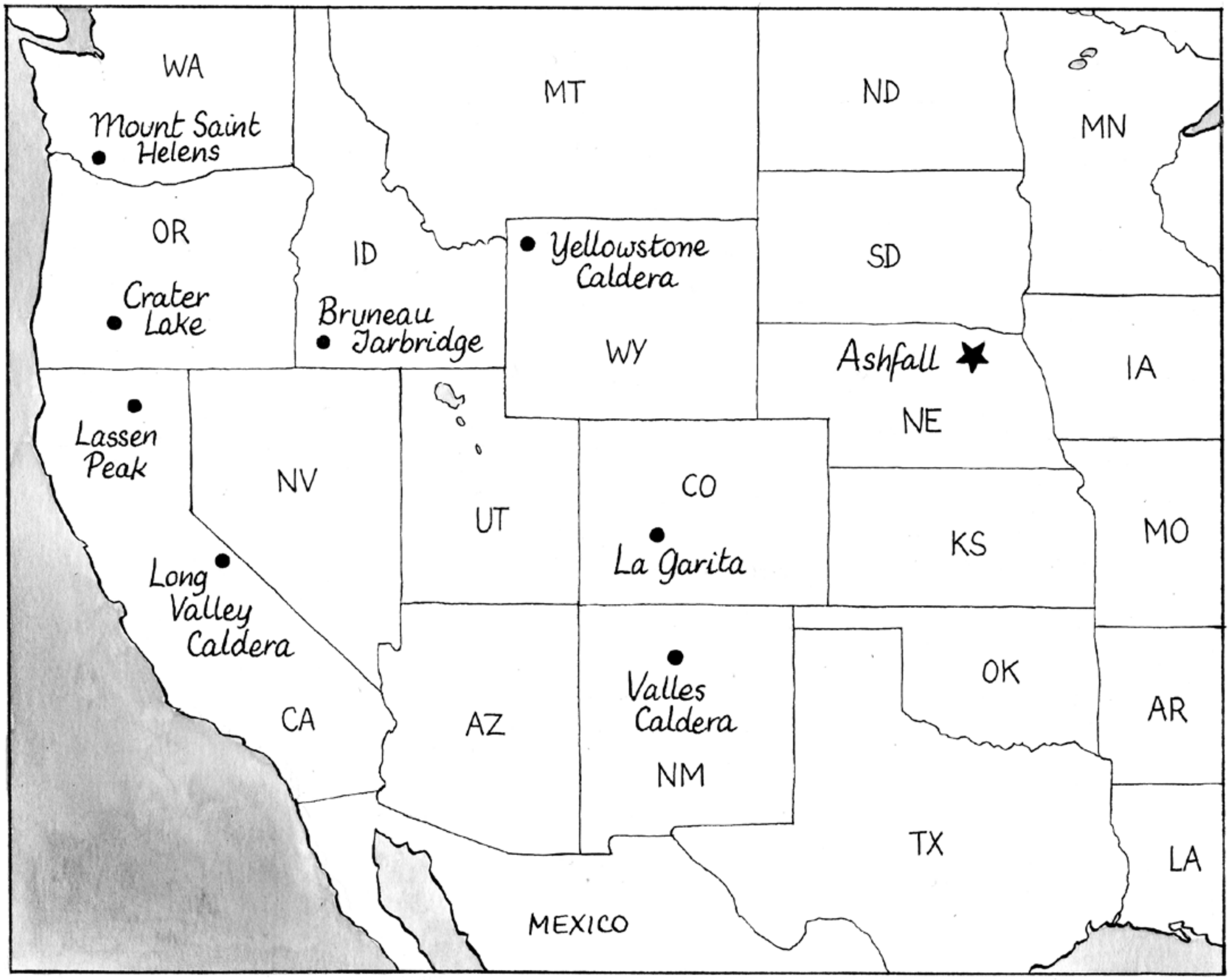
*combined concentration of FeO and Fe_2O_3

Magma and Eruption Characteristics

	Mafic	Intermediate	Felsic
Ash Composition	48–52% SiO_2; high in FeO, MgO, CaO; low in K_2O, Al_2O_3, Na_2O	53–65% SiO_2; moderate amounts of all major compounds	>65% SiO_2; high in K_2O, Al_2O_3, Na_2O; low in FeO, MgO, CaO
Magma Characteristics	High eruption temperature (>1000°C); low resistance to flow (thin, runny lava)	Medium eruption temperature (900°C–1000°C); medium resistance to flow (somewhat thicker, sticky lava)	Low eruption temperature (600°C–900°C); high to very high resistance to flow (very thick, sticky lava)
Eruptive Characteristics	Relatively non-explosive; extensive lava flows	Relatively explosive; pyroclastic flows, ash falls, tephra deposits, volcanic gases, lahars	Highly explosive; enormous dark columns of tephra and gas high into the stratosphere; pyroclastic flows and surges; extensive ash fall
Common Lava/ Tephra Type Produced	Balsitic 	Andesitic 	Dacitic/Rhyolitic 
Dominant Volcano Form	Cinder cones Shield volcanoes	Composite cones (Stratovolcanoes)	Calderas Domes

Volcano Suspects: Location

Use print and Internet resources to determine the approximate distances between the Ashfall Fossil Beds site and each volcano.



Questions

1 Which volcano is located closest to the Ashfall site?

2 Which volcanoes are farthest away?

After you answer these questions, mark the "Volcano Suspects Table" on your "CSI: Ashfall Fossil Beds" handout with the volcano or volcanoes you feel is or are the *least* likely suspect(s) based on the data, and rate your confidence level in your answer.

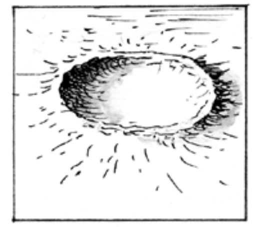
Volcano Suspects: Description

Mount St. Helens

Location: Washington
Volcano Type: Stratovolcano
Summit Height: 2,549 m
Crater/Caldera Size: 2 x 3.5 km
Last Known Eruption: 2006
Largest Eruptive Volume: 1 km^3

Crater Lake

Location: Oregon
Volcano Type: Caldera
Summit Height: 2,487 m
Crater/Caldera Size: 8 x 10 km
Last Known Eruption: ~2500 BC
Largest Eruptive Volume: 35 km^3

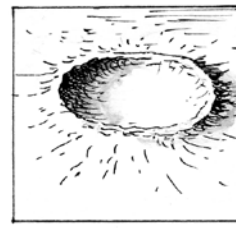


Lassen Peak

Location: California
Volcano Type: Stratovolcano/Dome
Summit Height: 3,187 m
Crater/Caldera Size: 213 x 122 m
Last Known Eruption: 1921
Largest Eruptive Volume: 50 km^3

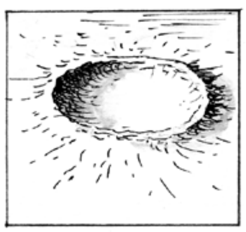
Long Valley

Location: California
Volcano Type: Caldera
Summit Height: 3,390 m
Crater/Caldera Size: 17 x 32 km
Last Known Eruption: Pleistocene Era
Largest Eruptive Volume: 600 km^3



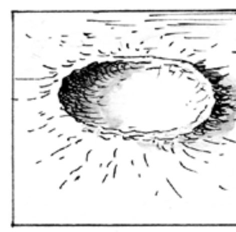
Valles Caldera

Location: New Mexico
Volcano Type: Caldera
Summit Height: 3,430 m
Crater/Caldera Size: 20 x 22 km
Last Known Eruption: Pleistocene Era
Largest Eruptive Volume: 600 km^3



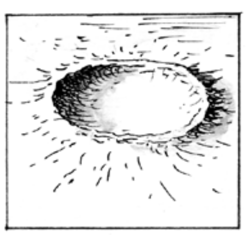
Bruneau-Jarbridge

Location: Idaho
Volcano Type: Caldera
Summit Height: Not Applicable
Crater/Caldera Size: ~80 km
Last Known Eruption: Miocene Era
Largest Eruptive Volume: >1000 km^3



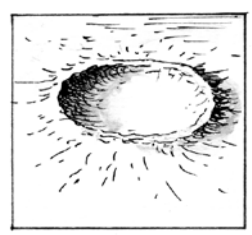
Yellowstone Caldera

Location: Wyoming
Volcano Type: Caldera
Summit Height: 2,805 m
Crater/Caldera Size: 45 x 85 km
Last Known Eruption: Late Pleistocene Era
Largest Eruptive Volume: >2000 km^3



La Garita

Location: Colorado
Volcano Type: Caldera
Summit Height: Not Applicable
Crater/Caldera Size: 35 x 75 km
Last Known Eruption: Oligocene Era
Largest Eruptive Volume: 5000 km^3



Questions

1. The eruptive volume corresponds to the explosiveness of a volcano. Which volcano had the most explosive eruption? Which volcano had the least explosive eruption?
2. Does there seem to be a relationship between the size of a volcano's crater/caldera and an eruption's explosiveness? Why or why not?

After you answer these questions, mark the "Volcano Suspects Table" on your "CSI: Ashfall Fossil Beds" handout with the volcano or volcanoes you feel is or are the *least* likely suspect(s) based on the data, and rate your confidence level in your answer.

Volcano Suspects: Ash Composition

The following represents a breakdown of the average concentration of major compounds (percentage by weight) in the ash from each volcano.

	Aluminum Oxide	Calcium Oxide	Iron Oxide	Potassium Oxide	Magnesium Oxide	Sodium Oxide	Titanium Dioxide	Phosphorous Pentaoxide	Silicon Dioxide
Ash Sample	(Al_2O_3)	(CaO)	(FeO)*	(K_2O)	(MgO)	(Na_2O)	(TiO_2)	(P_2O_5)	(SiO_2)
Mount St. Helens	14.70	1.81	1.39	2.01	0.46	4.45	0.17	0.04	74.80
Crater Lake	14.79	1.58	1.85	2.77	0.32	5.21	0.43	0.09	72.39
Lassen Peak	13.99	2.03	1.99	3.43	0.88	3.64	0.35	0.10	73.47
Long Valley Caldera	13.24	0.40	0.70	5.06	0.07	2.92	0.07	0.01	72.42
Valles Caldera	12.43	0.45	1.52	4.74	0.05	3.74	0.08	0.01	74.77
Bruneau-Jarbridge	11.90	0.80	2.70	6.10	0.10	2.50	0.10	0.08	75.60
Yellowstone Caldera	11.71	0.56	1.90	5.57	0.15	2.75	0.23	0.01	76.49
La Garita	12.50	0.56	1.10	4.80	0.01	2.38	0.10	0.02	77.10

*combined concentration of FeO and Fe_2O_3

Questions

1. For each suspect volcano, would you characterize the magma that produced the ash sample as mafic, intermediate, or felsic? Why?
2. Which ash seems to be most similar in composition to the Ashfall sample?

After you answer these questions, mark the "Volcano Suspects Table" on your "CSI: Ashfall Fossil Beds" handout with the volcano or volcanoes you feel is or are the *least* likely suspect(s) based on the data, and rate your confidence level in your answer.