Volcanic panic

15 Mar 2005

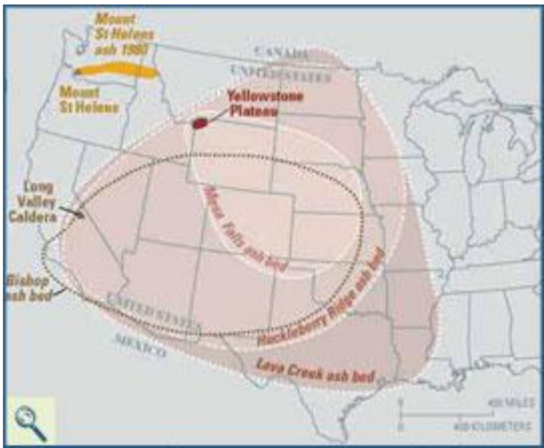
Steamboat is one of Yellowstone's most famous geysers. Eruptions occur sporadically, columns of hot water reach heights up to 100 metres. This is followed by a raucous steam phase that can last for over a day, loudly discharging steam nearly 200 meters into the atmosphere.
U. S. Geological Survey/photo by Tom Cawley

A terrifying new BBC television drama has shown what might happen were the Yellowstone "supervolcano" to erupt. According to the show, much of the US would be wiped out by lava flows and heavy ash-fall. The rest of the world would experience the equivalent of a "nuclear winter", with crops failing due to lack of sunlight. Could these predictions come true?

The two-part documentary – transmitted in March – was developed by BBC television producers working closely with the US Geological Survey, the agency responsible for monitoring the Yellowstone "supervolcano". Situated beneath the state of Wyoming, the giant volcano first erupted 2.1 million years ago, producing a giant crater known as a caldera. Two more have followed, most recently 630,000 years ago. Each eruption has been hundreds of times larger than Mount St Helens in 1980. Evidence suggests if Yellowstone were to erupt again on this scale:

- Sheets of magma and pyroclastic flows would cover the entire Yellowstone region, killing tens of thousands of people.
- An area four times the size of the UK would be thickly covered with several centimetres of ash, while almost all of the US would experience enough ash-fall to cause a serious health hazard.
- 2,000 million tons of sulphuric acid would be ejected into the atmosphere.

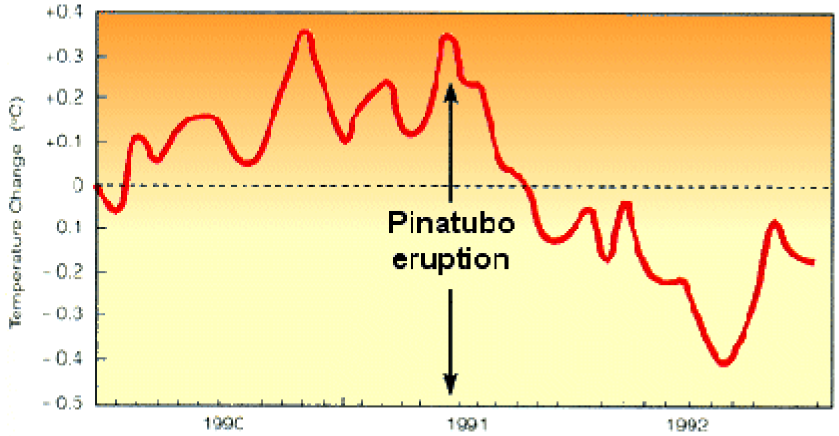
Why would this be a "compound hazard"?



Scientists evaluate natural-hazard levels by combining their knowledge of the frequency and the severity of hazardous events.
U.S. Geological Survey

Compound hazards involve a primary hazard having secondary effects. For instance, the famous Vaiont dam disaster was caused by landslides into a reservoir triggering widespread flooding (Italy, 1960). In the case of an eruption at Yellowstone, some of the most serious effects would be felt months or even years later, due to catastrophic changes to climate. This is because the eruption would create a plume of ash and dust that spreads worldwide, producing a cooling effect on a global scale.

Temperatures might fall by between 10°C and 20°C as the thick blanket of dust would prevent sunlight from reaching the earth's surface, reflecting it back into space instead. Photosynthesis would then be inhibited by the lack of light. Food webs would be severely disrupted and the net primary productivity (NPP) of agricultural and natural biomes would be drastically reduced. Widespread famine could then be expected, with the effects lasting for perhaps four or five years. When Mount Pinatubo exploded in 1991 there was a fall in global temperatures. See below:



What is the evidence for the existence of the 'supervolcano'?

(1) Current geological activity can be observed. Hydrothermal activity (such as hot springs and the Old Faithful geyser) suggests there is considerable magmatic activity below.

(2) Land surveys employing GIS technologies have produced satellite images showing that the mouth of the Yellowstone caldera is 85km long and 45km wide.

Space shuttle image used as the base for annotating the geology to the Yellowstone Caldera.
Image Analysis Laboratory, NASA Johnson Space Center.

(3) Analysis of earthquake shockwaves has allowed scientists to deduce that there is a volcanic chamber beneath, estimated to hold 25,000 cubic km of magma. This modelling technique is made possible because shockwaves travel at different speeds through solid rock and molten (liquid) magma.

(4) Regular swellings and land subsidence are observed by Rangers within the national park above the magma chamber. It is thought that this is caused by convectional currents within the underground lake of molten rock.

(5) Historical evidence of previous eruptions can be found everywhere in Yellowstone. The most recent series of minor eruptions, between 160,000 to 70,000 years ago, extruded more than 20 thick rhyolite lava flows and pyroclastic flows. Lakes have formed where streams were dammed by these thick lava flows, including Shoshone, Lewis, Heart, and Yellowstone Lakes. The last major eruption, around 630,000 years ago, generated 1000 cubic kilometres of pyroclastic materials and airfall tephra, all of which have been mapped by geological surveys.

Obsidian Cliff exposes the interior of a thick rhyolite lava flow that erupted about 180,000 years ago. The vertical columns are cooling fractures that formed as the thick lava flow cooled and crystallized in a previously eroded valley bottom. The flow consists of obsidian, a dark rhyolitic volcanic glass.
U.S. Geological Survey/S.R. Brantley

When will Yellowstone explode?

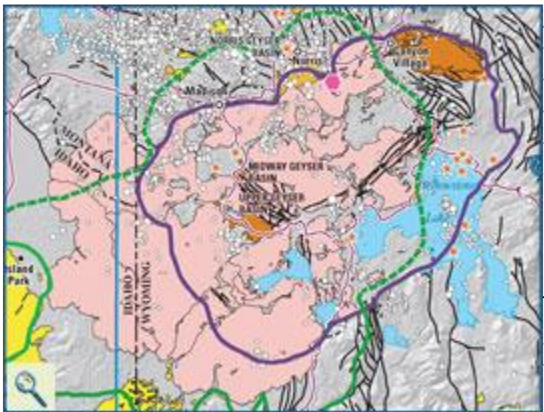
Our recent article on return periods explained how scientists try to predict when known hazards will reoccur. The return period of a natural hazard of a certain magnitude is a statistical estimate of the average time interval before it re-occurs. The higher the magnitude of the event, the longer the return period. *The Times* (09 March 2005) examines the return periods for major volcanic events, clearly displaying the inverse relationship that exists between magnitude and frequency, measured using the volcanic eruption index (VEI).

Volcanic eruption index	**Return period (years)**	**Example**
Level 5 eruption	10	Mount St Helens US 1980
Level 6 eruption	100	Mount Pinatubo Phillipines 1991
Level 7 eruption	1000	Tambora, Indonesia, 1815
Level 8 eruption	50,000+	Supervolcanoes e.g .Yellowstone

This shows us that although there is a one-in-ten chance of a Level 5 eruption occurring somewhere on earth each year, there is less than a one-in-fifty-thousand chance of experiencing a Level 8 eruption (a so-called “super-eruption” such as Yellowstone). The last Level 8 eruption globally occurred 74,000 years ago at Toba in Indonesia. Yellowstone itself has not erupted for 630,000 years, but is known to produce a Level 8 eruption roughly every 600,000 years ago. This is what led one character in the BBC drama to announce that Yellowstone is “overdue”, causing widespread panic.

Yet statistically, *the lack of a recent Level 8 eruption does not actually make it any more likely that one will occur in the near future*. Despite this statistical rule, however, many people are feeling increasingly nervous about Yellowstone. During their research, BBC producers were surprised to find that the US Federal Emergency Management Agency (FEMA) has no contingency plans for a Level 8 VEI disaster, according to *The Independent* (09 March 2005). This reinforces that point that because the likelihood of the event occurring in any one year is so small, it is difficult to justify spending vast amounts of money on disaster planning for such a rare occurrence.

What causes supervolcanoes to form?

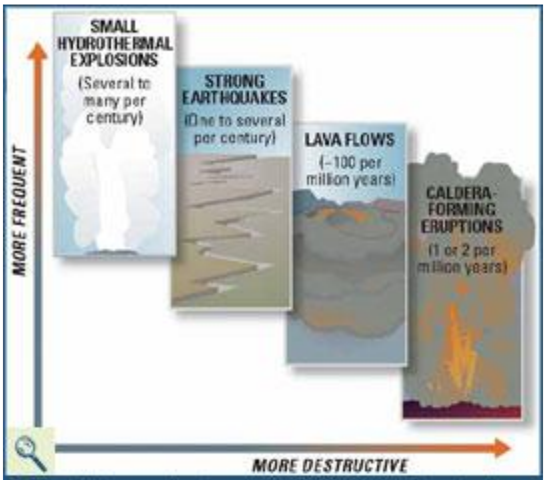


Yellowstone is home to one of the world’s largest active volcanic systems. Cataclysmic eruptions in the past few million years created huge volcanic depressions called “calderas.” U.S. Geological Survey

All volcanoes begin life as a column of magma rising from deep within the Earth. One theory suggests that this is caused by convectional heating, with the long-term radioactive decay of the earth’s core generating the energy required to drive the process. Although most volcanic rocks are generated by convectional activity at plate boundaries, there are a few exceptionally active sites of volcanism within the plate interiors that show up as apparent anomalies on maps of volcanic activity. These regions of anomalous volcanism are called *hotpsots*. For reasons not fully understood, heating of the mantle is uneven and in certain places, far from plate boundaries, giant *mantle plumes* can develop. It is theorised that mantle plumes rise as a plastically deforming mass that has a bulbous plume head fed by a long, narrow plume tail. As the mantle plume reaches the base of the lithosphere, it spreads outward into a mushroom shape with a diameter of around 1000 km.

Under certain conditions, rather than breaking through the surface, the magma pools and melts surrounding parts of the Earth´s crust turning the rock itself into a thick form of *rhyolitic magma*. This process is called *partial melting* and it results in the rhyolitic magma becoming ponded beneath the Yellowstone region in a shallow magma chamber. Rhyolitic magma is very thick and viscous and it traps volcanic gases. As gas pressure increases over thousands of years, stretching and doming of the crust above the inflating magma chamber leads to concentric and radial fracturing and faulting at the surface. Three times in the last two million years, an enormous volume of over-pressurized rhyolitic magma has erupted explosively through the fracture zone, finally releasing the gas pressure.

Once the magma chamber begins to deplete, its roof experiences a piston-like collapse, expelling further extrusive lavas. A giant depression is left behind, known as a caldera. Once the surface layers have cooled and hardened, vegetation can re-colonise the area. Subsequently, the caldera floor may also be uplifted by hundreds of meters in a process known as resurgent doming. This uplift reflects renewed pressure as magma rises again into the magma chamber and two resurgent domes now occupy the caldera floor in Yellowstone. These are the Mallard Lake dome to the west and the Sour Creek dome to the east. Post-eruption processes have therefore rendered the 'sleeping giant' almost completely invisible. Were it not for the hot springs and persistent earth tremors, we might almost forget the awesome forces that are at work beneath Yellowstone.



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U.S. Geological Survey

Spotting hot spots

Yellowstone is one of the planet's hot spots, where a plume of light hot molten mantle rock rises towards the surface. Hawaii and Iceland lie over similar hot spots and there are thought to be around forty in total. Yellowstone is part of a linear system of calderas that becomes progressively older moving from Yellowstone through the Snake River Plateau of Idaho, and ending with the 17-million-year-old McDermitt caldera on the Oregon-Idaho border. Like the Hawaiian islands, a *hotspot track* can be observed. A string of calderas forms when one of the earth's plates, driven by convection currents, moves over a stationary hotspot. Linked like the beads of a necklace, the calderas in Wyoming, Idaho and Oregon help us deduce that the North American plate must be moving in a roughly south-westerly direction with respect to the stationary hot spot deep underneath. The hotspot theory has been highly contested since 2003. See www.mantleplumes.org for more and be sure to read the article 'Volcanic bombshell' from New Scientist 8th March 2003

11-16 curriculum

At KS3, this story could help support teaching of *Unit 2: the restless earth - earthquakes and volcanoes*. It may be particularly well-suited for inclusion in Section *3: what are volcanoes?*

Official advice for KS3 teaching suggests that teachers "arrange for pupils to watch video footage of volcanoes and volcanic activity. Ask them to create 'wordscapes' from selected 'stills' using nouns and adjectives (the pause button allows wordscapes to be constructed on a sketched outline from a television 'still'). Discuss the geographical vocabulary used and identify key words for pupils to define and learn."

As part of this work, pupils could usefully be introduced to the idea of *scale*. Not all volcanoes are the same size, as this news story certainly demonstrates!

AS/A2 exam tips

At AS level, knowledge of hot spots and tectonic activity is required by some examination boards. OCR Spec A and Edexcel Spec A candidates need to be able to answer the following types of question:

(1) Explain why volcanic activity sometimes occurs away from plate margins. **(4 marks)**

(2) Explain what is meant by the term "hot spot". **(4 marks)**

(3) Describe and explain the global pattern of volcanic activity. **(8 marks)**

Examiner's tip: *you will mostly be analysing the distribution of plate boundaries, hopefully distinguishing between constructive and destructive types of activity. But for maximum marks, don't forget to explain the hotspots such as Yellowstone: these are "intraplate anomalies". You would also need to mention that the cause of these anomalies is contested amongst geologists. The New Scientist article 'Volcanic bombshell' is an excellent insight in the alternative theory of the causes of hotspots.*