Supervolcanoes

Teal Riley (right) has been digging around in the geological record to find out more about what causes supervolcanoes to erupt.

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What would fill Old Trafford football stadium over 500,000 times, trigger deterioration in global climate, devastate world agriculture, and cause severe disruption of food supplies, and mass starvation? Answer: the eruption of a supervolcano.

Supervolcanic eruptions are not just bigger than 'normal' volcanic eruptions, but are more intense. They have a volume greater than 300 km^3 from a single eruption - (just $1km^3$ would fill Old Trafford stadium 2000 times). In comparison, the eruption volume Mount St Helens in 1980 was $1.2km^3$ and Krakatoa in 1883 was about $10km^3$. Many scientists predict a super-eruption is overdue, and the race is on to discover how they differ from 'normal' volcanoes and the impact they would have on the Earth system.

The recent BBC docu-drama, Supervolcano, used science, drama and computer-generated imagery to show what would happen to the Earth if the sleeping supervolcano beneath Yellowstone National Park in the USA erupted. The Yellowstone supervolcano last erupted approximately 630,000 years ago. Scientists believe that it's now overdue a repeat performance….

Super-eruptions large enough to have a major global impact occur, on average, every 100,000 years, but identifying them in the geological record is not always straight-forward. Myself, Phil Leat and Mike Curtis from the British Antarctic Survey have spent the last 10 years studying two super-eruptions from the geological record of Antarctica. During five Antarctic field seasons, and fieldwork in South Africa and South America, we have pieced together the fragments of two separate super-eruptions. Each Antarctic field season involved three months in special pyramid tents, travelling up to 1500km by snowmobile, dodging crevasses and collecting over a tonne of geological samples.

The first super-eruption we studied is the Chon Aike volcanic province, which extends from southern South America along the length of the Antarctic Peninsula. The rocks are about 170 million years old and the massive series of volcanic eruptions that led to this province took place before the break-up of the supercontinent, Gondwana. The eruption in the Chon Aike Province was highly explosive, like the eruptions of Mount St Helens and Mount Pinatubo (1991). Major explosive eruptions include

Mount Pinatubo 10 years after its massive 1991 eruption.

Nigel Hicks/Alamy

Tambora, Indonesia (1815) and Krakatoa, but in terms of size (tens of cubic kilometres), they don't compare to the volcanoes from South America-Antarctica, where single eruptions were greater than 1000km^3. Despite this, Tambora and Krakatoa had a major impact on the Earth; Tambora caused significant global cooling for two years, leading to widespread crop failure and more deaths than usual. The only super-eruption in historical time is the eruption of Toba, Indonesia, 74,000 years ago. This led to the onset of the last major ice age and is believed to be responsible for the human population being reduced to as few as several thousand people living near the equator 70-80,000 years ago.

We have calculated that the South America-Antarctica super-eruption produced 300,000km^3 of magma over several million years. How could the Earth generate this volume of silica-rich magma? One method is to derive it from a basaltic (low-silica) magma by removing crystals rich in iron, magnesium and calcium, making the magma more silica-rich. But to generate 1km^3 of silica-rich magma (rhyolite), this method would also generate 15km^3 of residue (cumulate), which can't be found in the geological record. And, given the large volumes of rhyolite involved, this isn't a feasible method for major magma production.

Another way to produce rhyolite is to melt the continental crust. But continental crust is typically dry and melting it requires temperatures higher than 1100°C. Large volumes of crust would only melt if it was hydrated, and this would generate large volumes of rhyolite. The location of the Chon Aike Province explains how enormous amounts of water could get into the crust.

The Chon Aike Province crops out on the Pacific margin of Gondwana, under which, for a long time, the Pacific oceanic crust was subducted (sucked down by plate tectonics). Subducted ocean crust is capped by sediment containing water. As the sediment is subducted, it heats up and the water separates, hydrating the continental crust and upper mantle. Over tens of millions of years the crust would become wet and more likely to melt. The trigger for melting would have come from the heat of the mantle plume linked to the nearby Karoo volcanic province and also rifting from the Gondwana break-up.

The second super-eruption occurred 180 million years ago, when, over a few million years, the Karoo-Antarctic flood basalt province erupted over 2 million km^3 of basalt lava across large parts of what is now southern Africa and East Antarctica. The Laki eruption in Iceland of 1783 is the closest modern example of such an eruption. Laki, a fissure eruption lasting about a year, erupted 45km^3 of basalt and pumped over 100 mega tonnes of sulphur dioxide into the atmosphere. This greatly affected the northern hemisphere's environment and climate. Laki's rate of eruption and impact is quite like a flood basalt eruption, except that the cumulative effect of a flood basalt eruption is far greater because it goes on for over 2 million years. The Karoo-Antarctic flood basalt eruption caused about 15% of species to die out. Flood basalt eruptions have long been associated with mantle plumes – unusually hot upwellings from deep within the Earth. The heat from their impact led to widespread mantle melting. However, considerable debate remains regarding the existence of mantle plumes and there is no 'magic formula' to test for their presence.

From fieldwork in the Dronning Maud Land region of Antarctica and laboratory work at the isotope labs in Keyworth we identified dykes (petrified fissure systems that feed the lava flows), which preserve a chemical signature, indicating that the magmas were generated at great depth and at high temperatures. The presence of these chemically unusual and unusually hot materials from deep within the Earth corresponds with many expectations of a mantle plume.

This work allows us to understand the complex mechanisms taking place in the Earth and the havoc super-eruptions can wreak on the Earth system. A frightening prospect, but even following some of the most explosive events, the Earth is remarkably efficient at restoring its balance.

To find out more about what scientists predict for supervolcanoes, go to www.geolsoc.org.uk/template.cfm?name=Super1

Mount St. Helens erupting on 18 May 1980.