Geo Factsheet

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Why Are Volcanoes Rarely Big Killers?

Introduction

Volcanoes are associated in the popular imagination with violent, spectacular explosions, resulting in instant death and destruction. Whilst this can be true, statistics suggest that these types of events are rare; in fact, since 1900, only two volcanoes have caused large numbers of deaths – Mt. Pelée, Martinique in 1902 and Nevado del Ruiz, Colombia in 1985. This article will examine the nature and occurrence of volcanic eruptions in time and space, and discuss whether societies have learnt to live more successfully with volcanoes, thus reducing their impact.

Deadliest Eruptions

During the past 250 years, there have been only five volcanic eruptions that have each killed over 10,000 people. The nature of these eruptions varied (**Table 1**), and caused total deaths in excess of 200,000 due to a range of causes:

- 30% famine and disease, caused by climate change on a global scale
- 27% pyroclastic flows
- 17% lahars
- 17% tsunamis
- 9% no one major cause identified

Case Study – Nevado del Ruiz, Colombia

The eruption in 1985 was the last volcano to kill significant numbers of people, even though it had a low VEI of 3 and warnings were given. The high death toll was caused by 50m deep lahars, formed when 10% of the snow and ice cover was melted by pyroclastic flows. Water and volcanic debris combined to travel at 60km/hr down existing river valleys on the volcano slopes, making escape impossible, as people were trapped in hot, soft and deep mudflows. Other contributing factors to the disaster were that evacuation notices were too late and not acted upon, as there had been no previous drills and people had nowhere to go or the means to leave. It happened in the dark, and in bad weather. Within 4 hours of the main eruption, 23,000 people in the town of Armero had died.

Table 1 Deadliest volcanoes in the past 250 years

Volcano	Date	VEI	Comments
Laki, Iceland	1783	4	8 months of lava and noxious gas emissions killed >20% (10,000) of Iceland's population, by famine and disease. 60% of livestock died. Environmental impact of sulphur gases caused famine in Europe due to toxic grazing land and death of livestock.
Tambora, Indonesia	1815	7	150km^3 of ash was ejected, up to 1,300km away. Pyroclastic flows and volcanic bombs killed 10,000 people. Magma reacted with seawater to increase ash generation that contaminated water supplies. 82,000 people died indirectly from starvation and disease. Caused global cooling and known as "the year with no summer".
Krakatoa, Indonesia	1883	6	36,000 deaths in one day. Underground magma chamber emptied causing the volcano's centre to collapse. Magma mixed with water to create a massive explosion heard 7,000km away. Volcano collapsed to 250m below sea level destroying two thirds of the island, creating a tsunami that affected neighbouring islands. Global temperature fell 1.2^{o}C. Although less explosive than Tambora, there was a greater impact.
Mt. Pelée, Martinique	1902	4	Pyroclastic flows and a nuée ardente burnt and suffocated 32,000 people in Saint-Pierre. Event marked the start of modern volcanology.
Nevado del Ruiz, Colombia	1985	3	Eruption melted 10% of ice cap, creating a lahar that killed 23,000 in Armero, 40km away.

Eruptions in the last 50 years

Table 2 shows eruptions with higher death tolls in the last 50 years. If Nevado del Ruiz is excluded from the list, only 5,500 deaths have resulted from volcanic activity in this time, including high profile events such as Mt. St. Helens in 1980 and Mt. Pinatubo in 1991. In the last ten years, less than 600 people have died as a direct result of eruptions, a stark contrast to earthquake impacts. No single volcano has ever approached a quarter million deaths, unlike the earthquakes at Tangshen, China, in 1976 and the Indian Ocean tsunami in 2004.

Table 2 Eruptions with highest death tolls in the last 50 years

Deaths	Volcano	Location	Year
87	Volcán Arenal	Costa Rica	1968
5	Mount Hudson	Chile	1971
70	Nyiragongo	D.R. Congo	1977
57	Mount St. Helens	United States	1980
3,500	El Chichón	Mexico	1982
18	Galunggung	Indonesia	1982
23,000	Nevado del Ruiz	Colombia	1985
847	Mount Pinatubo	Philippines	1991
43	Mount Unzen	Japan	1991
9	Galeras	Colombia	1993
19	Soufrière Hills	Montserrat	1997
245	Nyiragongo	D.R. Congo	2002
4	Jebel at Tair	Yemen	2007
473	Mt Merapi	Indonesia	2010
31	Nabro Volcano	Eritrea	2011
57	Mount Ontake	Japan	2014
16	Sinabung 28481	Indonesia	2014

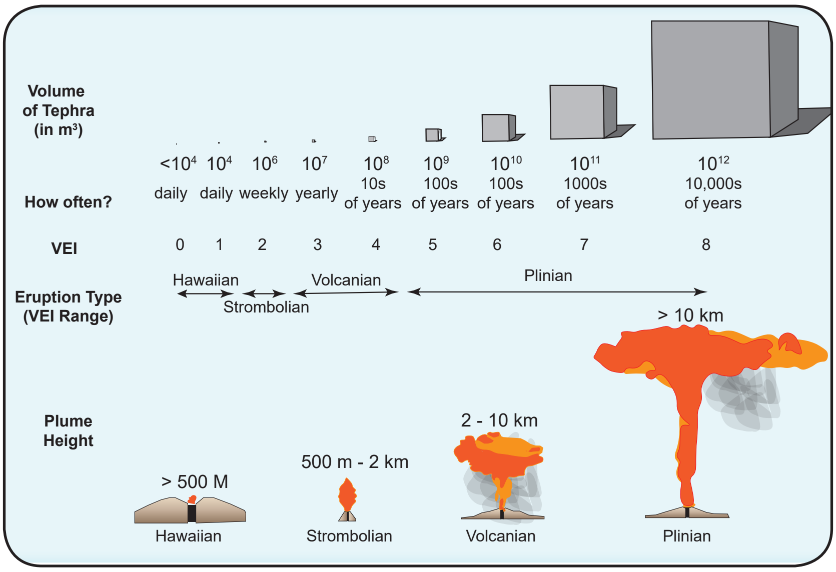
Eruptions in the last 10 years

Large volcanic eruptions (VEI 5+) occur infrequently – only Puyehue-Cordon Caulie in Chile has recorded a VEI 5 in the last decade (**Table 3**). Despite the explosivity, no deaths were reported. This low frequency of destructive events, the slower speed of onset and greater spatial predictability, together with preparedness plans, especially the ability to evacuate, makes volcanoes a relatively easier hazard to manage than earthquakes, although still with their particular difficulties. For example, a typhoon generated lahars which added to the total killed in the Pinatubo eruption.

Volcanic Explosivity Index – VEI

The magnitude of an eruption is measured by the amount of ejected material and the height to which it reaches in the atmosphere, both being a function of a volcano's explosivity. A logarithmic scale of 0-8 is used, each level representing a ten-fold increase of material. In historical times, the most explosive event was Tambora, measuring VEI 7. In geological time there have been 46 eruptions of VEI 8, the last being 600,000 years ago when the Yellowstone supervolcano erupted. The explosivity determines the shape of volcanoes and a classification is shown in **Figure 1**.

Figure 1 Volcanic Explosivity Index (neiu.edu)



Note: The VEI can be closely linked to the nature of the magma (rhyolitic, andesitic, or basaltic)

However, it is not the case that the greater the VEI, the greater the number of deaths and damage, because other factors are involved, such as technological monitoring, population density, awareness and disaster risk reduction measures. The great eruption of Mt. Etna in 1669 destroyed the city of Catania but no one was killed. In contrast a single lahar from melting snow killed 23,000 at Nevado del Ruiz even when the event was correctly forecast. It is clear that accurate and timely information can save lives when a volcano erupts and the UN has done much in recent years in the area of disaster risk reduction to reduce loss of life.

Table 3 VEI 4+ and smaller, notable eruptions in the last 10 years

VEI	Volcanic Eruption	Year	Impact
4	Mt Okmok, Alaska, USA	2008	No deaths reported
4	Chaiten, Chile	2008	1 death
4	Kasatochi, USA	2008	No deaths reported
4	Sarychev Peak, Russia	2009	No deaths reported
4	Eyjafjallajokull, Iceland	2010	Air traffic disruption in Europe
4	Mt Merapi, Indonesia	2010	473 deaths; 350,000 evacuated
4	Grimsvotn, Iceland	2011	No deaths reported
5	Puyehue-Cordon Caulie, Chile	2011	Southern hemisphere air disruption. Biggest eruption in 21st century. No deaths reported
4	Nabro, Eritrea	2011	31 deaths
2	Mt Sinabung, Indonesia	2011	15 deaths
4	Kelud, Indonesia	2014	2 deaths
3	Mt Ontake, Japan	2014	61 deaths
4	Calbuco, Chile	2016	No deaths reported

Decade volcanoes

During the 1990s the UN sponsored the International Strategy for Disaster Reduction (UNISDR) and sixteen volcanoes were identified as Decade Volcanoes. The criteria for selection were:

- A history of destructive eruptions and currently active
- Politically and physically accessible for study
- Large populations nearby who are willing to support the work and participate in awareness programmes, so reducing the severity of impacts

Progress in safety measures has been made at these individual volcanoes, such as the diversion of lava away from the town of Zafferana, on Mt.Etna, using concrete blocks to dam the lava flow. Risk assessments prior to any development and evacuation plans are now standard in many volcanic regions. However, many volcanoes remain unmonitored, mainly due to cost and hence risk of serious impact remains high. Civil unrest in D.R. Congo and Guatemala has hindered research programmes and explosions during research have claimed scientists' lives at Galeras, Colombia and Mt. Unzen, Japan.

Case study of a Decade Volcano – Mt. Merapi

Mount Merapi is one of 16 Decade Volcanoes designated in the 1990s, although monitoring began in the 1920s. Over time, instruments have had to be moved as hazards change spatially on the volcano. Currently, 8 seismometers are deployed to identify centres of tremors, and an area has been identified 1.5km beneath the summit with no seismic activity, thought to be the magma reservoir itself. Slight changes in magnetic field measurements have been associated with eruptions and tiltmeters have indicated the growth of the volcano prior to eruption. One of the greatest dangers on Mt. Merapi are lahars not directly due to volcanic activity, but resulting from the reactivation of pyroclastic material by rainfall; an intensity of 50mm/hr can often generate lahars here.

After a major eruption in 2010 when 473 people died, zones were designated where no-one may live permanently, and 9 villages will no longer have new infrastructure, as the risk of future destruction is too great. A national park was controversially established in 2004, but people have been reluctant to evacuate their homes during subsequent eruptions fearing that the conservation boundaries would be expanded in their absence leaving them homeless.

Monitoring of Volcanic Activity

Seismicity

Seismic activity is always associated with volcanic activity, even at very gentle disturbance levels. Patterns of seismicity are complex and often difficult to interpret but increasing seismic activity, measured by seismometers, is a good indicator of increasing eruption risk (**Table 4**).

Table 4 Seismicity associated with volcanic activity

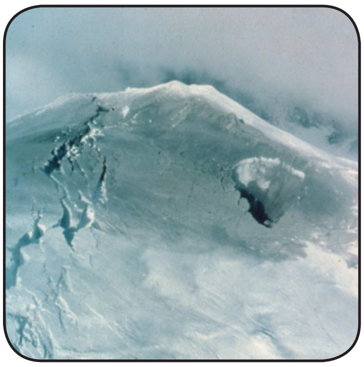
Short period earthquakes	Growth of magma body near the surface.
Long period earthquakes	Indicate increased gas pressure in the magma chamber. When dominant, usually signifies a likely eruption.
Harmonic tremors	Magma moving over subsurface rock sometimes produces a humming sound heard by humans and animals.
Infra-sound waves	This is sub-audible sound below 20Hz. The International Monitoring System has a global network of 60 stations using this technology

There is a link between long period earthquakes and eruption, first noticed during the Nevado del Ruiz eruption in 1985. In December 2000, scientists used this to predict an eruption within two days at Popocatépetl, on the outskirts of Mexico City. Tens of thousands of people were evacuated in time. Despite it being Popocatépetl's largest eruption for a thousand years, no one was killed.

Gas Emissions

CO_2 and SO_2 are the main gases emitted during volcanic activity and they are measured by a multi-component gas analyser system. Prior to an eruption, as magma rises closer to the surface, pressure drops and gases escape. At Pinatubo in 1991, SO_2 levels increased by a factor of 10 before it erupted. It can be the case that SO_2 levels actually drop because rising magma can seal pipes within the volcano, so increasing pressure. Whatever the case, changing SO_2 levels are a clear indication of magma movement underground.

Figure 2 Bulging flank of Mt. St. Helens prior to eruption (USGS)



Ground Deformation

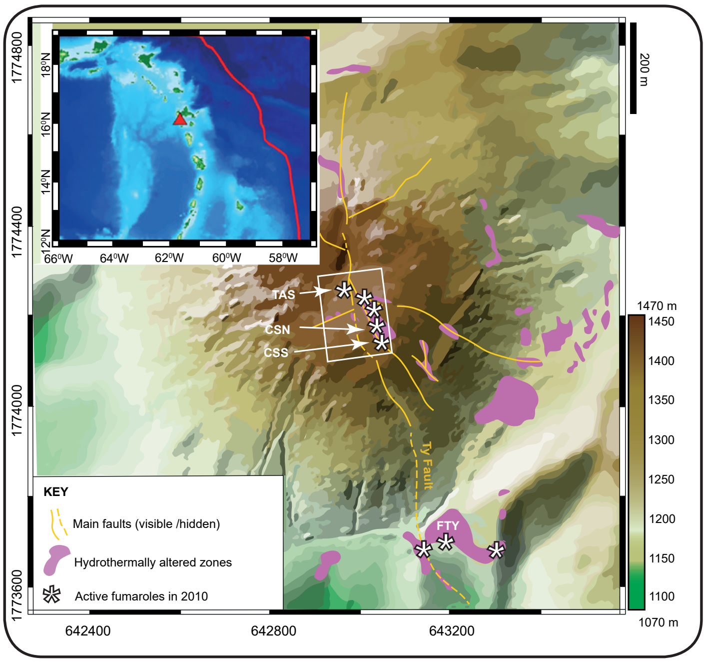
Tiltmeters and measurements by satellites can detect bulging ground. A famous example was the north side of Mount St. Helens that was clearly visible to the naked eye before it erupted in May 1980 (**Figure 2**).

Thermal Monitoring

It has long been known that movement of magma, escaping gases and hydrothermal activity at, and below, the surface can be measured for indications of imminent activity. Reflectance of thermal infra-red wavelength can be measured either by satellite or hand-held instruments to construct heat flux maps.

See **Figure 3**, which shows thermal changes in Mt. Soufriere, Guadalope:

Figure 3 Heat flux map of Mt. Soufriere showing temperature changes on the eastern flank (Gaudin et al., 2016)



Remote Sensing

It has already been mentioned how satellites have been used for decades to monitor individual volcanoes. However, it is now possible to have global coverage of sub-crustal movement of magma, with a pair of satellites within ESA's Copernicus programme using radar to monitor surface displacement to within a few millimetres. This method was used to map the 2014 eruption of Bardabunga, a stratovolcano under Vatnajokull in Iceland. The bulge of magma was tracked as it travelled 47km on an irregular path until emitting vast amounts of lava, equivalent to half of Everest, into a barren, isolated area, causing no damage.

The disadvantage of using technology is that not all individual volcanoes can be monitored, especially in the less developed world. However, as more data is collected, it will be possible to match patterns with actual eruptions and write algorithms to detect where bulges are beginning to develop. For example, recent activity in the Galapagos was studied using this approach and within a day it was possible to establish that the magma was 5km below ground and therefore unlikely to erupt.

Disaster Reduction Preparedness Measures

Alongside instrumental monitoring are preparation measures taken by officials and residents to reduce the risk of a disaster.

Education = Preparedness, Safety and Resilience

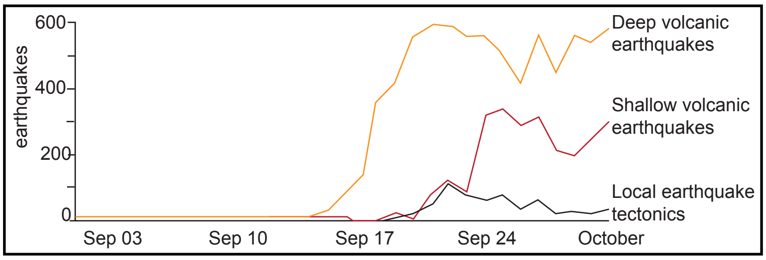
Timely and credible information helps save lives as it motivates residents to become disaster resilient. Risk maps and evacuation plans, together with practice drills, have proven critical to risk reduction. However, the frequency of powerful eruptions of any particular volcano is low, so people often do not have first hand experience as they do in areas, for example, of frequent flooding. Also, whilst the build up to an eruption is relatively long, allowing an orderly management and safe evacuation of people in the area, this long duration of onset creates problems because signs such as tremors and released gases do not necessarily end in an eruption. Judgements have to be made as to the severity of warnings issued and the degree to which the area should be managed.

Case Study – Mt. Agung, Indonesia

Mt. Agung, on the island of Bali, was threatened with a major eruption in September and October 2017, the last one having been in 1963. In 2009 there were earthquakes and satellites detected inflation of one side of the volcano but it subsided without an eruption. Similar activity was noticed in September 2017, and degassing created a plume above the volcano. A 4.2M earthquake at a depth of 5km was felt across – the region, together with a sudden increase of smaller tremors suggesting movement of magma, were measured (**Figure 4**).

A State of Emergency was issued on 29th September and preparedness measures were put in place. However, by early October there had not been an eruption, but 140,000 people had been evacuated. Half were from a 12km radius that was put on the highest alert of an imminent volcanic eruption. Information was disseminated by government officials and warning sirens were installed in the most densely populated areas. This had an impact on tourism and therefore the island's economy, with a 20% fall in October bookings. Five countries put out a travel warning, airlines planned for air traffic disruption and insurance companies refused cover for those seeking travel insurance in the area. The uncertainty also led to locals selling their beef cattle well below market rates.

Figure 4 Earthquake activity, Mt. Agung in September 2017 (Reuters)



Other responses ranged from dredging and deepening parts of the Unda River to increase its capacity. A Hindu ceremony at Bali's most sacred temple, Besakih, within the exclusion zone was held at full moon in October and well-attended, including the Bali Governor.

A decrease in seismic activity at the end of October allowed the National Disaster Mitigation Committee to reduce the risk level and recommend that only 6 villages should remain evacuated and 70,000 people in evacuation centres from outside the red danger zone were told to return home as overcrowded conditions were causing problems. Many refused as they wanted to remain safe. Stress, boredom, irregular eating routines and sleeping on concrete floors resulted in 10,000 people becoming sick. Bali's governor asked countries that had issued a travel alert to remove it and guaranteed safe passage home from other Indonesian islands to any tourists trapped if there was an eruption.

However, Agung became more active again on 21 November and the alert was raised to its highest on 27 November. At the time of going to press, with seismic activity continuing at a level of 700 tremors per day, volcanologists stated that it was more likely than not that there would be an eruption, accounting for the highest alert, although it was impossible to predict the timing and magnitude of an event. A timeline of volcanic activity and human reactions is shown in **Table 5.**

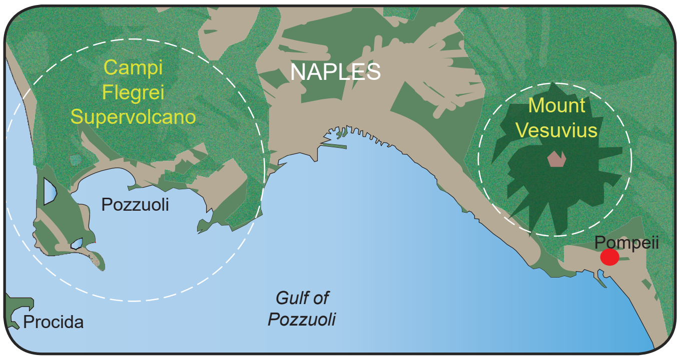
Table 5 Timeline of events at Mt. Agung, 2017

Date	Volcanic activity (bold denotes human response)
17 Sept	Sharp increase in deep volcanic earthquakes
22 Sept	Sharp increase in shallow earthquake activity; 500m plume above volcano. **Level 4 alert issued.**
26 Sept	4.2M earthquake on Bali, at 5km depth
29 Sept	**State of Emergency declared until Oct 12th; extended to Oct 16th, Oct 26th, Nov 9th. Preparedness measures put in place.**
29 Sept	Swelling increases and widening fractures in crater floor.
16 Oct	650 tremors a day.
18 Oct	1000 tremors a day.
24 Oct	Earthquake 6.7M in Flores Sea to north.
25 Oct	5.2M earthquake in Banda Sea to north east.
29 Oct	114 gentle earthquakes.
30 Oct	**Alert lowered from "dangerous" to "high". Only 6 (down from 28) villages now officially at risk. Buses laid on to encourage people to return home. Bali governor asked for travel alerts to be removed. Government insisted decisions were driven solely by the state of the volcano.**
21 Nov	Plume of ash 4000m high and steam (phreatic eruption). No increase in seismic activity.
25 Nov	Magmatic eruption (but not a major one).
27 Nov	Volcanic ash fell on villages and lahars developed due to the rainy season. **Official danger level raised to Level 4. Exclusion zone extended from 7.5km to 10km. 100,000 people needed to leave but only 50% had done so. Aviation warning was upgraded to red - flights cancelled and 60,000 people were stranded at airports.**

Will there be a big killer in the future?

Although Yellowstone, the last supervolcano to erupt, has done so cyclically every 600,000-700,000 years, some volcanologists doubt that it will do so again. Most likely to erupt is Vesuvius, which, when it famously erupted in 79 AD with the destruction of Pompeii, then collapsed, creating an 8-mile-wide caldera. The present-day Vesuvius grew within the caldera and is a very active stratovolcano. It has an eruption cycle of 20 years but has not erupted since 1944. The volcano is unusual because it exhibits a range of explosivity, from Hawaiian-style liquid lava to violent Plinian explosions with pyroclastic flows. The area is further at risk due to the presence across the Bay of Naples of Camp Flegrei (translated "Flaming Fields"), a caldera volcano, lying under Naples itself (see **Figure 5**).

Figure 5 The threat to Naples from Vesuvius and Campi Flegrei



Vesuvius and its surrounds is a very densely populated volcano, with development continuing to increase upslope from the foothills. Nearly 1million people live in Naples and 350,00 live in Campi Flegrei's 100km^2 caldera. Its last eruption 39,000 BP is estimated to be the largest in Europe in the last 200,000 years. Campi Flegrei has been on amber alert since 2012, with concern growing since a number of earthquakes hit central Italy in 2016. The port of Pozzuoli has risen 4m since 1950 due to underground movement of magma.

Italian officials are currently making emergency plans to evacuate 700,000 people, if necessary, from 25 surrounding towns. The aim would be to move all these people within 72 hours by commandeering public transport. Warnings and evacuation orders are a political judgement as well as a scientific one. False alarms have to be measured against complacency. After the L'Aquila earthquake in 2009, six scientists were imprisoned for failure to predict the earthquake. However, an unnecessary evacuation of 40,000 in the 1970s has caused a problem of public perception as residents distrust official advice. Whilst drilling of a 3km borehole would help scientists to make more accurate predictions, the project has stalled due to fears that it might trigger an eruption although that is denied by scientists. Models elsewhere using similar structured volcanoes such as Rabaul, Papua New Guinea and the Soufriere Hills on Montserrat show that energy is not dissipated during periods of rest after activity. Energy is retained in calderas and may lead to an eruption. Three episodes of uplift in the last 70 years, due to magma moving 3km underground, have moved the port of Pozzuoli 3m further out to sea. The difficulty of accurate prediction is that even if ground cracks, molten magma may not pour out because it can become blocked beneath the surface elsewhere.

So historically, people have lived through seismic activity and rapid uplift of ground with no associated eruption, so there is a widespread reluctance to react to warnings as these physical disturbances have not resulted in a disaster in the past.

Conclusion

So whilst volcanoes are rarely big killers, the threat remains and the likelihood of a VEI 8 is possible in the future. Progress in preparing and educating people about risk has improved and has been responsible for much reduced impacts. However, volcanoes are unpredictable hazards and the best of plans may not be sufficient to avoid disasters in future.

Student Activities

1) Draw a diagram of the physical hazard profile of a typical volcano and earthquake. Identify the profile features which explain why most volcanic eruptions are far less of a killer than most major earthquakes. This could include speed of hazard onset, spatial predictability, etc.

2) Look at the photos below and explain how the eruption shown might influence a volcano's capacity to be a killer.

A: Mount Pelée - Rhyolitic eruption

B: Mount Pinatubo - Andesitic eruption

C: Kilauea - Basaltic eruption

3) Refer back to **Table 1** on **Page 1** and assess the importance of secondary factors which may have influenced the number of deaths.

Further Research

Global satellite monitoring:

http://www.bbc.co.uk/news/science-environment-39642372

Volcanic hazards:

http://www.phivolcs.dost.gov.ph/index.php?option=com_content&view=article&id=50&Itemid=86

FAQs: https://volcanoes.usgs.gov/vsc/file_mngr/file-153/FAQs.pdf

For a more detailed case study of the Nevado del Ruiz eruption in 1985, see *Geography Factsheet 348*.

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