Geo Factsheet

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Volcanoes: Why are some more hazardous than others?

Every year some 60 volcanoes erupt. The vast majority of these eruptions are relatively weak, have a minimal impact on the landscape and do little damage to property or people. Most volcanic activity is submarine, involving the gentle 'oozing' of magma onto the sea floor.

However, every few years a much more violent and potentially life-threatening eruption takes place somewhere in the world. People are evacuated as earthquakes and minor eruptions warn of an impending 'big one'. Scientists monitor the volcano using ground, air and satellite technology and they try to make a forecast. When will the volcano erupt? How big will the eruption be? What will the eruption involve?

In this Factsheet we will examine why only a few of the many volcanic eruptions that take place actually represent a danger to people. We shall attempt to answer the question 'Why are some volcanoes more hazardous than others?'

What is a volcano?

A volcano is a surface landform resulting from the extrusion of **magma** from underground. Lava (liquid), ash, rocks and gases are all erupted in various proportions.

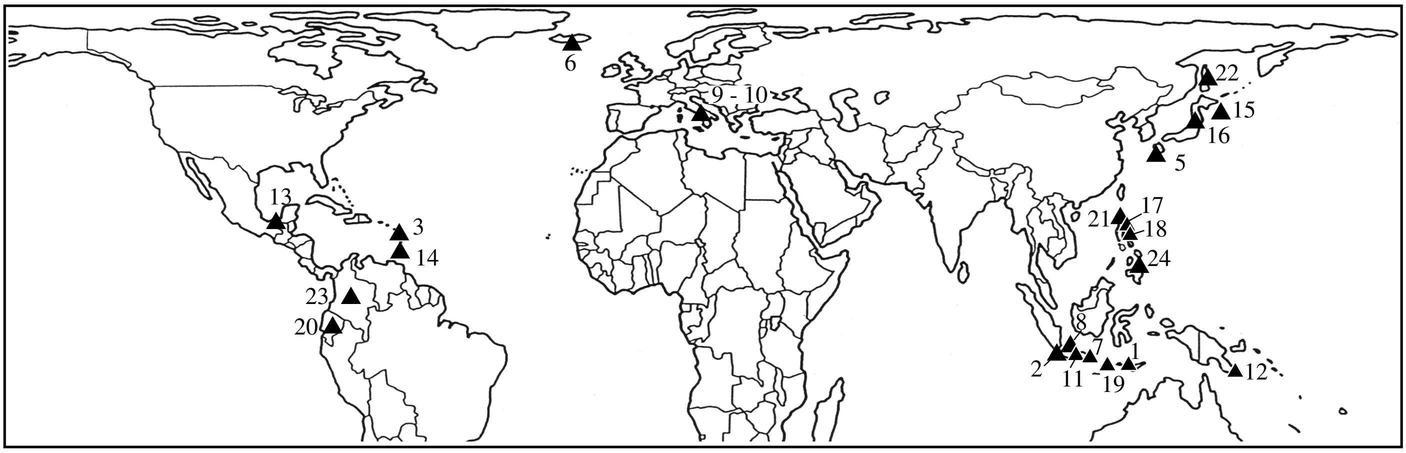
A 'typical' volcano is portrayed as being roughly circular in shape and conical, often rising high above the surrounding landscape. The precise shape of a volcano is determined by the chemistry of the magma and the nature of the eruptions. Whilst for most of us this single vent volcano is the most familiar type, most magma reaches the surface along cracks called fissures. These are very extensive through the Atlantic and Pacific Oceans and also occur in places like Iceland. Here single vent volcanoes are less clearly formed, as lava spreads out from a linear crack rather than a central vent in what is known as a fissure eruption, to form a lava plateau.

What makes a volcano potentially hazardous?

A volcanic eruption is a perfectly natural event; in fact, without volcanic eruptions there would be no atmosphere and no oceans. Volcanic eruptions not only produce gases and water but they also help to build the physical landscape and, in many countries, they provide enormous opportunities for development of geothermal energy and tourism.

However, volcanic eruptions represent a huge potential hazard to people and to human activity.

Fig 1. Most deadly volcanic eruptions



Ref. No.	Deaths	Volcano	When	Major Cause of Death
1	92,000	Tambora, Indonesia	1815	Starvation
2	36,417	Krakatau, Indonesia	1883	Tsunami
3	29,025	Mt. Pelee, Martinique	1902	Ash flows
4	25,000	Ruiz, Colombia	1985	Mudflows
5	14,300	Unzen, Japan	1792	Volcano collapse, tsunami
6	9,350	Laki, Iceland	1783	Starvation
7	5,110	Kelut, Indonesia	1919	Mudflows
8	4,011	Galunggung, Indonesia	1882	Mudflows
9	3,500	Vesuvius, Italy	1631	Mudflows, lava flows
10	3,360	Vesuvius, Italy	0079	Ash flows and falls
11	2,957	Papandayan, Indonesia	1772	Ash flows
12	2,942	Lamington, Papua N.G.	1951	Ash flows
13	2,000	El Chichon, Mexico	1982	Ash flows
14	1,680	Soufriere, St Vincent	1902	Ash flows
15	1,475	Oshima, Japan	1741	Tsunami
16	1,377	Asama, Japan	1783	Ash flows, mudflows
17	1,335	Taal, Philippines	1911	Ash flows
18	1,200	Mayon, Philippines	1814	Mudflows
19	1,184	Agung, Indonesia	1963	Ash flows
20	1,000	Cotopaxi, Ecuador	1877	Mudflows
21	800	Pinatubo, Philippines	1991	Roof collapses and disease
22	700	Komagatake, Japan	1640	Tsunami
23	700	Ruiz, Colombia	1845	Mudflows
24	500	Hibok-Hibok, Philippines	1951	Ash flows

Whilst the death toll for some of the eruptions is very high (the total number of people killed by eruptions from 1600-1982 is put at 238,867), it is worth considering that earthquakes and hurricanes cause considerably more loss of life. For example, the 2003 Iranian earthquake is estimated to have killed some 40,000+ people in the city of Bam.

In order to try to understand why the volcanoes cause such a high death toll, it is helpful to map their location.

From Fig 1:
- Some countries appear more than once, such as Indonesia, Japan and the Philippines
- Several countries in Central and Southern America are represented
- A number of the most deadly eruptions occurred on islands
- Large parts of the world historically appear not to be at huge risk from volcanic eruptions, such as North America and Northern Europe

Volcanic hazards are influenced by several factors:

1. Viscosity of magma
It is the viscosity or thickness of magma that largely determines the nature and power of an eruption and the resultant shape of the volcano.

There are three main factors that determine the viscosity of magma:
- Temperature – the higher the temperature, the lower the density of the magma and the more easily it will flow
- Dissolved gases – the greater the amount of dissolved gases, the more fluid the magma. Gases remain dissolved in high temperature conditions.
- Chemistry – the higher the silica content, the more viscous the magma.

It is possible to identify two extreme types of magma, though essentially each magma chamber is unique.
- **Basic magma** is rich in iron, aluminium and magnesium. It is high temperature magma (1000°C-1200°C), has a high proportion of dissolved gases and a low silica content (44-52%). It is very fluid and has a low viscosity, sometimes likened to melted ice cream!
- **Acid magma** is very rich in silica (66%+) and has a low proportion of ferro-magnesian minerals. It is a relatively low-temperature magma (600C -1000C) and it has a much lower proportion of dissolved gases than basic magma. It is very thick and has a high viscosity, similar to that of toothpaste!

The more viscous the magma, the greater the potential for explosive eruptions and these represent the greatest potential hazards.

2. Plate margins
The vast majority of volcanoes occur at plate margins (Fig 2), as these are the zones where most magma is produced.

At **constructive** or divergent plate margins, where plates are moving away from each other, the magma is produced by the partial melting of the mantle deep below the surface. It is a basic-type of magma and therefore has a low viscosity enabling it to flow easily. Volcanoes at constructive margins, for example along the Mid-Atlantic Ridge, are both central vent and fissure. They erupt frequently but not usually violently and are associated with lava flows and ash.

At **destructive** or convergent plate margins, the plates are moving towards one another. As one plate dives (subducts) below another intense pressures and heat cause melting of the rocks and sediments, which can result in the formation of an acidic magma chamber. Very viscous and resistant to flow, there is often a huge build up of pressure, which results in very violent and dangerous eruptions involving ash and pyroclastics.

Whilst 75% of all volcanic material is erupted at constructive margins, most of the world's active volcanoes (over 80%) occur at destructive margins. It is these that are generally considered to be the most hazardous. Most of the volcanoes in Fig 1 are located at destructive margins.

Volcanoes do not occur at all plate margins. At conservative margins (where two plates slide alongside each other) and collision margins (where two plates collide and buckle) there is no magma produced and consequently no volcanoes. Those volcanoes not directly associated with plate margins, such as those on the Hawaiian Islands, result from isolated plumes of rising magma known as 'hot spots'. The magma is basic in nature and these volcanoes are similar to those associated with constructive margins.

3. Explosiveness of eruption
Given that the strength of an earthquake measured on the Richter scale often determines the extent of the damage, it is reasonable to assume that the power of a volcanic eruption is going to be an important factor in determining how hazardous a volcano is.

The explosiveness of an eruption can be measured by the Volcanic Explosivity Index (VEI). Similar to the Richter scale the VEI is open-ended and ranges from 0, for non-explosive eruptions (less than 10^4 cubic metres of pyroclastics ejected), to 8, for explosive eruptions larger than any in history (10^{12} cubic metres of pyroclastics and a cloud column height of over 25 km). Values higher than 8 can be determined if needed. (See Fig 3 over page).

Fig 2. Plate Margins

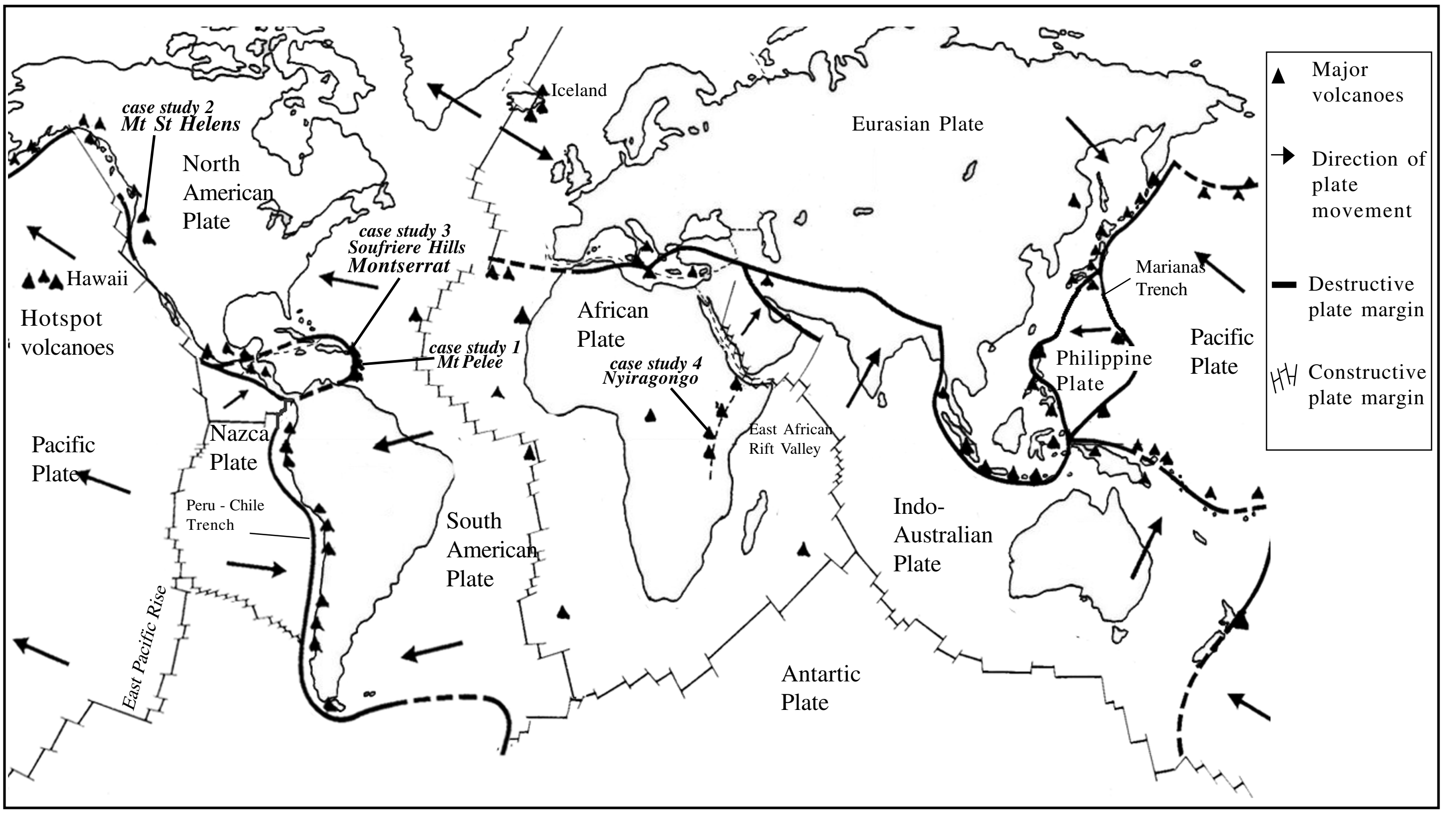


Fig 3. The volcanic explosivity index (VEI)

VEI	Description	Plume Height	Volume of pyroclastics ejected	Duration of continuous blasts (hrs)	Frequency	Number of historic eruptions	Example
0	non-explosive	<100 m	1000s m^3	<1	daily	487	Kilauea
1	gentle	100-1km	1 0,000s m^3	<1	daily	623	Stromboli
2	explosive	1-5 km	1,000,000s m^3	1-6	weekly	3176	Galeras, 1992
3	severe	3-15 km	10,000,000s m^3	1-12	yearly	733	Ruiz, 1985
4	cataclysmic	10-25 km	100,000,000s m^3	1- 12+	10'sof years	119	Galunggung, 1982
5	paroxysmal	>25 km	1 km^3	1-12+	100's of years	19	St. Helens, 1981
6	colossal	>25 km	10s km^3	12+	100's of years	5	Krakatau, 1883
7	super-colossal	>25 km	100s km^3	12+	1000'sof years	2	Tambora, 1815
8	mega-colossal	>25 km	I,000s km^3	12+	10,000's of years	0	Yellowstone, 2 million years ago

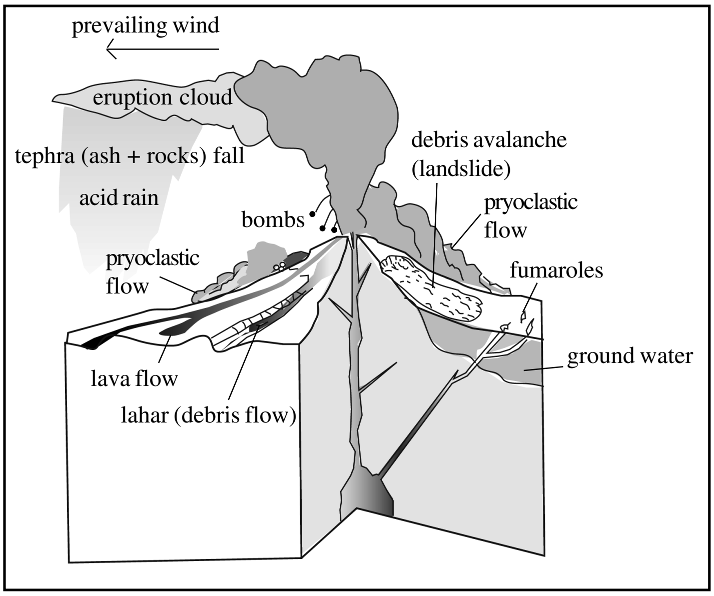
The higher the VEI, the greater the potential hazard. Eruptions with a value of 0 or 1 tend to have very localised effects and are associated with the more gentle fiery eruptions involving mostly lava. Eruptions of 2 and above have much greater effects, with huge quantities of pyroclastics being erupted with the potential of affecting both the immediate area and, through global atmospheric circulation systems, parts of the world much further away. A volcano such as Mt St Helens with a VEI of 5 is potentially far more hazardous than Kilauea on Hawaii with a value of 0.

4. The Materials ejected

There are a number of different hazards associated with volcanic eruptions (Fig 4), however they vary considerably in the danger that they pose to people and human activity.

Non-explosive eruptions tend to produce mostly lava flows, which do not represent a particularly serious hazard to people, although they will destroy farmland and buildings. It is only when large quantities of very fluid lava are released, say when part of a crater collapses that there is a real danger to people (see Case Study on Nyiragongo eruption).

Fig 4. Volcano hazards



Explosive eruptions present a much greater danger to people and human activity. As the magma tends to be very viscous, there is not usually much lava and any that is produced cools and solidifies very quickly indeed. Amongst the greatest threats associated with explosive eruptions are:

- **Ash clouds** – explosive eruptions blast solid and molten rock fragments (called tephra or pyroclastics) into the air with tremendous force. A huge billowing eruption column can reach 20 km in just 30 minutes. Whilst larger rocks tend to fall to Earth within a couple of kilometres of the vent, ash can be carried tens or even hundreds of kilometres.

  Ash clouds pose a considerable threat to aircraft; in the last 15 years 80 commercial aircraft have inadvertently flown into ash clouds and several have suffered engine damage as a result. Ash returning to Earth can cause buildings to collapse and can cause death by asphyxiation; the AD 79 eruption of Mt Vesuvius dumped 3m of ash on Pompeii causing some 2,000 deaths.

- Pyroclastic flows – these are clouds of incandescent gas, ash and rocks, often reaching temperatures up to 800 °C and travelling at speeds in excess of 200kph down the volcano's flanks. They can cause enormous and widespread destruction as occurred with the eruptions of Mt St Helens in 1980 and Mt Pinatubo in 1991.

- Lahars – these are cement-like mudflows consisting of volcanic ash and water, which can travel down river valleys at speeds of up to 100kph. They often occur in the days following an eruption when people are at their most vulnerable and with the capacity to travel up to 300km they represent a massive threat. Many of the people who were killed by the Mt Pinatubo eruption in 1991 perished as a result of lahars.

- **Tsunamis -** When a volcano erupts out to sea, huge waves called tsunamis can be generated. They represent a significant threat to coastal communities often many kilometres away from the volcano. The eruption of Krakatoa in 1883 triggered waves up to 35m in height, which swept along the coast of Java and Sumatra killing over 36,000 people. One of the main issues with tsunami is that they often impact on communities far away from volcanoes who do not consider themselves to be at risk.

5. Proximity to population centres

Whilst some volcanoes are located in remote parts of the world, such as Alaska, a good many are located in areas of dense population or close to major cities. Japan, Indonesia and the Philippines have many active volcanoes and they also have high population densities putting large numbers of people at risk. In Italy, the city of Naples with a population of just over 1million is just a few kilometres from Mt Vesuvius, which will erupt again at some point in the future. Clearly, those volcanoes (particularly the explosive ones) close to population centres are much more hazardous than those located in remote regions.

There are several reasons why people live close to volcanoes. On islands where space is limited, such as in Japan, there is little choice but to be geographically close to volcanoes. Volcanoes can be associated with fertile soils and they bring other benefits for human habitation such as building materials and hot water.

6. Frequency of eruptions and perception of risk
In the Hawaiian Islands some volcanoes erupt virtually continuously and they are even promoted by the local tourist industry. However the threat to property, although relatively minor given the nature of the eruptions, is very real to those who witness the outpouring of molten rock. Mt Etna is another volcano that erupts frequently and it also is a very popular attraction for tourists. There are hotels and cafes on the flanks of the mountain, which, although they periodically get damaged during eruptions, are considered worth the risk to build and maintain.

However, for many people living close to the really dangerous destructive margin volcanoes, eruptions are very infrequent and hundreds of years may elapse between eruptions. For example, Soufriere Hills on Montserrat (see Case Study below) had not erupted for 350 years before it burst into life in 1995. Memories are short and people are less inclined to worry about an eruption from a volcano that has been inactive for many generations. The frequency of eruptions therefore has a profound impact on peoples' perception of the volcanic hazard.

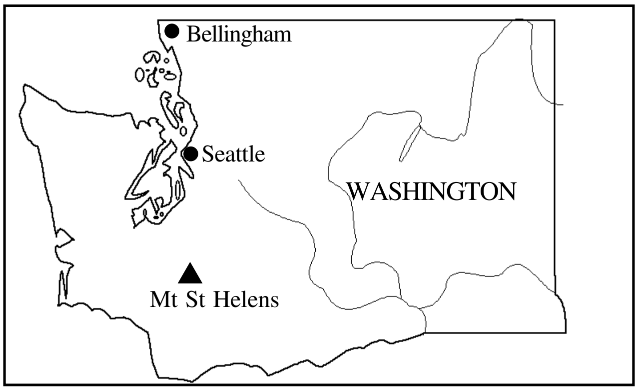
7. Prediction, forecasts and reactions
Nowadays active volcanoes all over the world are monitored using a vast array of scientific equipment. Satellites look for infrared radiation that indicates rising magma and ground instruments measure gas emissions, ground deformation and resulting earthquake activity. Geologists use evidence from past eruptions to suggest likely eruptive scenarios and hazard maps can be constructed to indicate those areas at greatest risk.

Scientists can provide reasonably accurate forecasts of impending eruptions and people can be evacuated from areas considered to be at risk. Such forecasts and evacuations were particularly successful for the Mt St Helen's eruption in 1980 and the eruption of Mt Pinatubo in 1991, and the eruption of Soufriere Hills on Montserrat in 1997.

However, governments do not always respond to scientific predictions and disasters can result. For example, in1985 despite warnings of an impending eruption with associated lahars, the government of Colombia failed to order an evacuation and 25,000 people lost their lives in the town of Armero when the volcano Nevado del Ruiz erupted.

Scientists do not always get it right and sometimes eruptions that seem imminent never actually occur. This reduces the scientists' credibility in the eyes of governments and local people and can cause problems the next time an eruption seems likely.

Case Study 2. Mt St Helens, USA, 1980

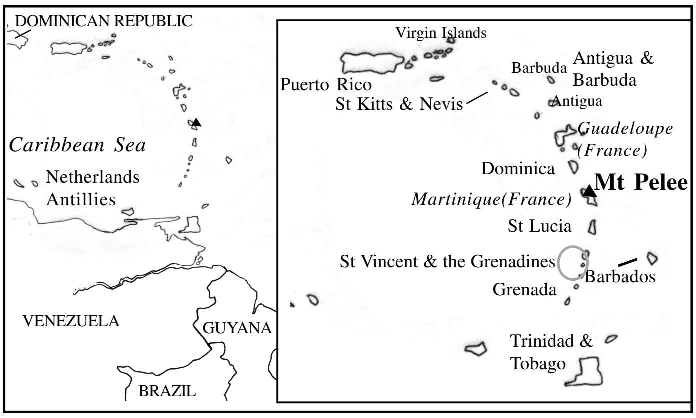


In some ways, the eruption of Mt St Helens in 1980 was similar to that of Mt Pelee. The volcano lies on a destructive plate margin, where the small Juan de Fuca plate is subducting beneath the North American plate. It was a highly explosive eruption, with a VEI of 5 (Fig 3) typical of volcanoes fed by acidic magma.
However, unlike the eruption of Mt Pelee, only 61 people were killed. There were several reasons for this low death toll:

- *Mt St Helens is located in a relatively remote part of southern Washington, 180km south of Seattle. The area was sparsely populated and there were no nearby towns or cities. The main people who were at risk were backpackers.*
- *Much of the blast was directed laterally towards the north when part of the volcano collapsed. Whilst this caused considerable devastation, it tended to be highly concentrated in this remote area.*
- *The volcano had been very thoroughly monitored for months and scientists had extensive historical evidence of past eruptions, which helped them to predict the likely features of the impending eruption. Warnings were issued and areas evacuated. However, the lateral explosion was unexpected and this was the main reason why the death toll was as high as it was.*

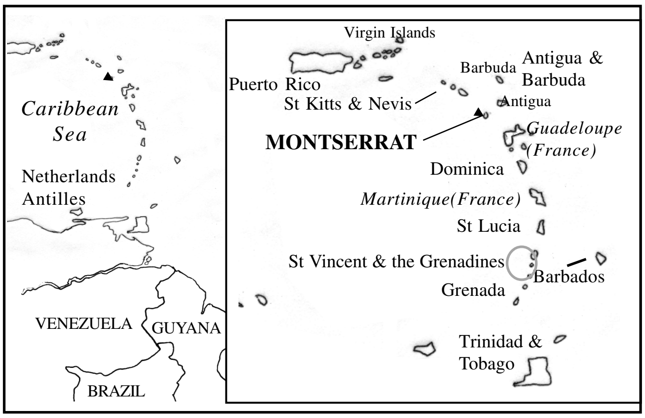
The eruption of Mt St Helens was a major volcanic event and, although the ash falls and pyroclastic flows did a lot of damage to forestry, agriculture and communications, relatively few people perished.

Case Study1 Mt Pelee, Martinique, 1902
The eruption of Mt Pelee on the Caribbean island of Martinique in 1902, which killed 29,025 people claims 3rd place in the table of most deadly volcanic eruptions (Fig 1). There are several factors that can be identified as contributing to the scale of this disaster:



- *Mt Pelee lies on a destructive plate margin, the boundary of the South American plate and the Caribbean plate. The magma is highly viscous.*
- *Eruptions are very explosive in nature, exceeding VEI 5 (Fig 3) and potentially extremely powerful*
- *The products of the eruption of 1902 were pyroclastic flows, which travelled at speeds of 200kph and comprised rock, ash and gas at temperatures of 700 °C.*
- *Most of the people who were killed were residents of the nearby port of St Pierre, which was almost completely destroyed by the blast. Had there not been a big town nearby or if the pyroclastic flows had travelled in a different direction, the extent of the disaster would have been significantly reduced.*
- *In 1902 volcanic monitoring and forecasting was very crude and, although people recognised that an eruption was likely (several people took to boats to escape the dangers), nobody really knew what was likely to happen. There was no coordinated evacuation of vulnerable areas.*

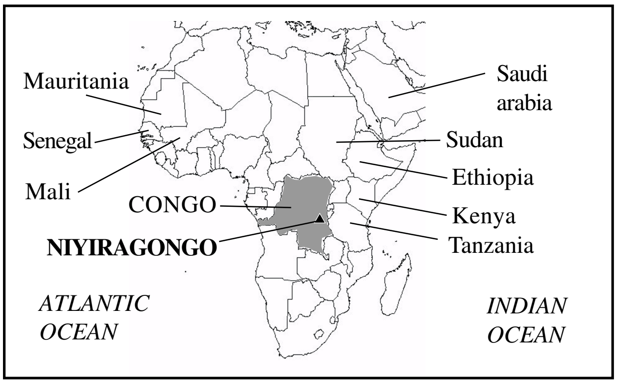
Case Study 3. Soufriere Hills, Montserrat, 1997



The Soufriere Hills volcano on the small island of Montserrat in the Caribbean erupted several times during 1997. It too lies on a destructive plate margin and the highly viscous acidic magma at temperatures of 820-885 °C contained massive amounts of gas, which caused several explosive eruptions from August through to December. Although much of the island now lies abandoned with many of the residents living on other Caribbean islands, remarkably only 19 people were killed and they perished because they returned prematurely to an area identified as being at risk.

The low death toll was largely the result of monitoring and a massive evacuation programme. Scientists correctly predicted the likely hazards (pyroclastic flows and ash falls) and were able to suggest which areas were at greatest risk. Thousands of people were evacuated including the entire population of the capital Plymouth and large areas around the mountain were declared 'exclusion zones'. Had there been no such monitoring and subsequent evacuations, the death toll would have been very much higher.

Case Study 4 Nyiragongo, Democratic Republic of Congo, 2002



One of the most recent volcanic eruptions to hit the headlines was the eruption of previously little-known volcano of Nyiragongo in central Africa. In January 2002 the volcano erupted vast amounts of extremely fluid lava, which flowed rapidly through cracks in the mountainside at speeds of up to 40kph, towards the nearby city of Goma. Much of the city's infrastructure was destroyed by lava, which was up to 3 metres thick in places and hundreds of homes and business premises were razed to the ground. Some 500,000 people fled the city, many becoming short-term refugees in neighbouring Rwanda.

Despite the exceptionally rare rate of lava flow, only 45 people lost their lives, although longer term loses of livelihood and property affected many thousands; for example, some 12,000 families were left homeless. The eruption itself was non-explosive and involved high temperature basic magma escaping from a 'hot spot' deep underground associated with the East African Rift System. The volcano had erupted many times in the past, most recently in 1977, so people were aware of the hazards posed.

Conclusion

It is certainly true to state that some volcanoes are more hazardous than others. It is possible to identify two sets of factors that affect the potential hazards of a volcanic eruption.

The first are to do with the natural event itself: what type of magma is involved and how explosive the eruption is likely to be. Destructive margin volcanoes capable of powerful eruptions emitting deadly pyroclastic flows and ash falls are potentially far more hazardous than constructive margin or 'hot spot' volcanoes where the eruptions are likely to be non-explosive and involve relatively less dangerous lava flows.

However, it is not just the characteristics of the natural volcanic event that determines the degree of hazard, as the case studies above illustrate. The second group of factors are associated with people, their ability to monitor, predict and forecast and their response to the potential dangers. Peoples' perception of the risk, often linked to the frequency of past eruptions, is another key factor.

For the future, it seems likely that the death toll from volcanic eruptions will tend to low, as scientists become better able to predict and make forecasts. Generally speaking it ought to be expected therefore that the human factors will dominate over the natural factors. However, as past eruptions have demonstrated all too clearly, nature has the potential to unleash volcanic eruptions of unimaginable power capable not only of devastating the local environment but having very considerable effects on weather and climate worldwide. As always in geography, it is a matter of scale!

Further research: student ICT activity

Extend your case study knowledge by comparing the eruptions of Mt Pinatubo (1991) and Mt Etna (2002). To what extent and for what reasons could Mt Pinatubo be considered more hazardous than Mt Etna?
To find out more about these two eruptions you should access the Volcano World website at http://volcano.und.nodak.edu/vw.html . Click on 'Volcano Listings' and look up these two eruptions.

- Find out about the effects of the eruptions and make a critical evaluation of the factors affecting the impact on people and human activities.
- Do you consider Mt Pinatubo to be more hazardous than Mt Etna? Explain your answer.

You can use the same website to conduct similar evaluations for other historic eruptions (Nevado del Ruiz in Colombia 1985 is a good one) or for currently active volcanoes (click 'Current Eruptions')

Books
The Volcanic Hazard is well dealt with in several standard texts including:

Bishop, V. (2001) Hazards and Responses Collins Educational
Frampton, S. (Ed.) (2000) Natural Hazards Hodder and Stoughton
Ross, S. (1998) Natural Hazards Nelson Thornes

Websites
There are many good websites as a general search will reveal. Two of the best are:

Volcano World at http://volcano.und.nodak.edu/vw.html

U.S. Geological Survey Volcano Hazards Program at http://volcanoes.usgs.gov/

Smithsonian Institute's Global Volcanism Program at: http://volcano.si.edu/gvp/

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