# 9 Hazardous environments

In this chapter you will learn about:

- Hazards resulting from living in areas which have tectonic activity, unstable slopes and **atmospheric disturbances**.
- Primary and secondary effects of hazard events on lives and property.
- The extent to which hazards can be predicted and methods used to monitor them.
- Difficulties involved in managing environmental hazards sustainably and examples where management has achieved some success.

## Terms used in hazard studies

- **Hazard** - a threat that could injure people and damage the built environment. An earthquake in an unpopulated area is a physical event; it only becomes a hazard when people put themselves in danger by moving into the area. Natural hazards occur only where humans interact with the physical world and their severity and frequency depends on human activity.
- **Disaster** - a hazard that causes so much damage and injury that recovery without help is impossible.
- **Risk** - the exposure of people to a hazard event.
- **Vulnerability** - the degree to which conditions make a population more likely to experience a hazard event, which they do not expect, cope with or recover from.
- **Resilience** - how well a population recovers from a disaster.

### Classification of hazards

- Cause:
  - tectonic (geological) - earthquakes and volcanic eruptions
  - geomorphological (processes acting on the land surface) - mass movements
  - atmospheric (meteorological) - tropical cyclones and tornadoes
- Magnitude, scale or size; some types have their own scales
- Frequency of occurrence
- Length of warning time - rapid onset hazards are much more dangerous than slow onset ones
- Spatial distribution.

**RESEARCH** Choose one recent hazardous event and make notes on it. Include date, (local) time, location and size of the event and to what extent these factors influenced the hazardous event's impacts on lives and property. Also note its causes, the methods of and extent to which it was predicted, monitored and its risks perceived. Note its primary and secondary impacts on lives and people and whether they were local, national or global in scale.

## Hazards resulting from tectonic processes

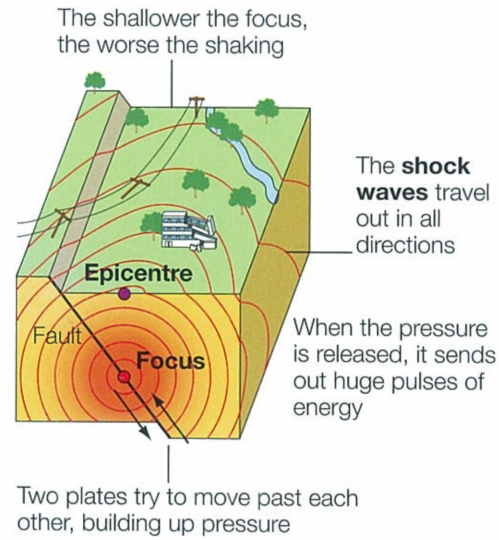


**Fig. 9.1** Three-dimensional block diagram showing how earthquakes occur

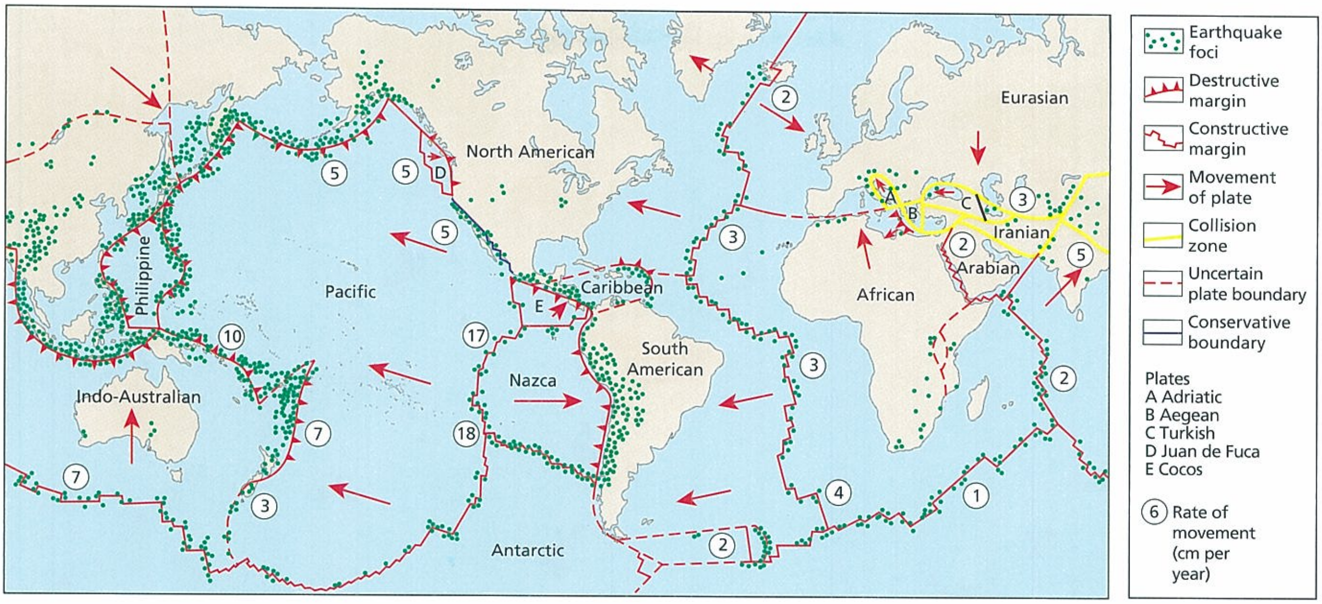


**Fig. 9.2** The global distribution of earthquakes

# The global distribution of earthquakes and volcanoes related to plate tectonics

## Earthquakes

Most earthquakes are tectonic; they occur on all types of plate boundary, at hot spots away from plate boundaries and at **fault** lines. When two plates try to move but become stuck against each other, stress builds up. Eventually, the plates break free along a fault, causing a sudden release of pressure and releasing a tremendous amount of energy, which sends **seismic waves** (shock waves) out from the point of movement - the **focus** or origin of the earthquake. The point on the Earth's surface immediately above the focus is the **epicentre**. Seismic waves are strongest at the epicentre but the greatest damage does not always occur there.

Most earthquake foci occur in narrow zones along plate boundaries but their effects extend far beyond the plate boundary. There are four types of seismic zone:

→ **Destructive** (convergent) plate margins have shallow, intermediate and deep earthquakes inclined along the Benioff zone on the subducting plate where slab pull occurs.

→ Collision boundaries of two converging continental plates, such as between the Eurasian and Indian plates where the Himalayas formed.

→ **Conservative** plate margins where faults, such as the San Andreas in California, have earthquakes but no volcanic activity. Here the North American and Pacific plates are moving side-by-side. Great friction builds up between the plates as they catch against each other which is eventually released in very powerful earthquakes, usually from a shallow focus.

→ Constructive plate margins at mid-ocean ridges where ridge push (slab push) occurs. The lithosphere is too weak and thin for a lot of stress to build up, so large earthquakes do not occur. They are usually shallow focus and occur with volcanic activity.

Some powerful earthquakes may be non-tectonic, caused by human activity putting too much stress on faults. The 7.9 magnitude earthquake in Sichuan, China, in 2008, which killed nearly 70 000 people, was linked to the construction of a reservoir, which added a very heavy weight of water to the surface.

## Volcanoes

A volcano results from the build-up of molten material emitted onto the surface through an opening or fissure in the crust.

**1.** Describe the distribution of active volcanoes in relation to the plate boundaries on Fig. 9.3. Note that the plate boundary to the north of India where two continental plates meet does not have active volcanoes. Note where active volcanoes are found away from plate boundaries.

An **active volcano** has erupted in the last 80 years (some define it as a volcano that has erupted in historic time). **Dormant volcanoes** are inactive but may become active again in the future, whereas **extinct volcanoes** will not erupt again.

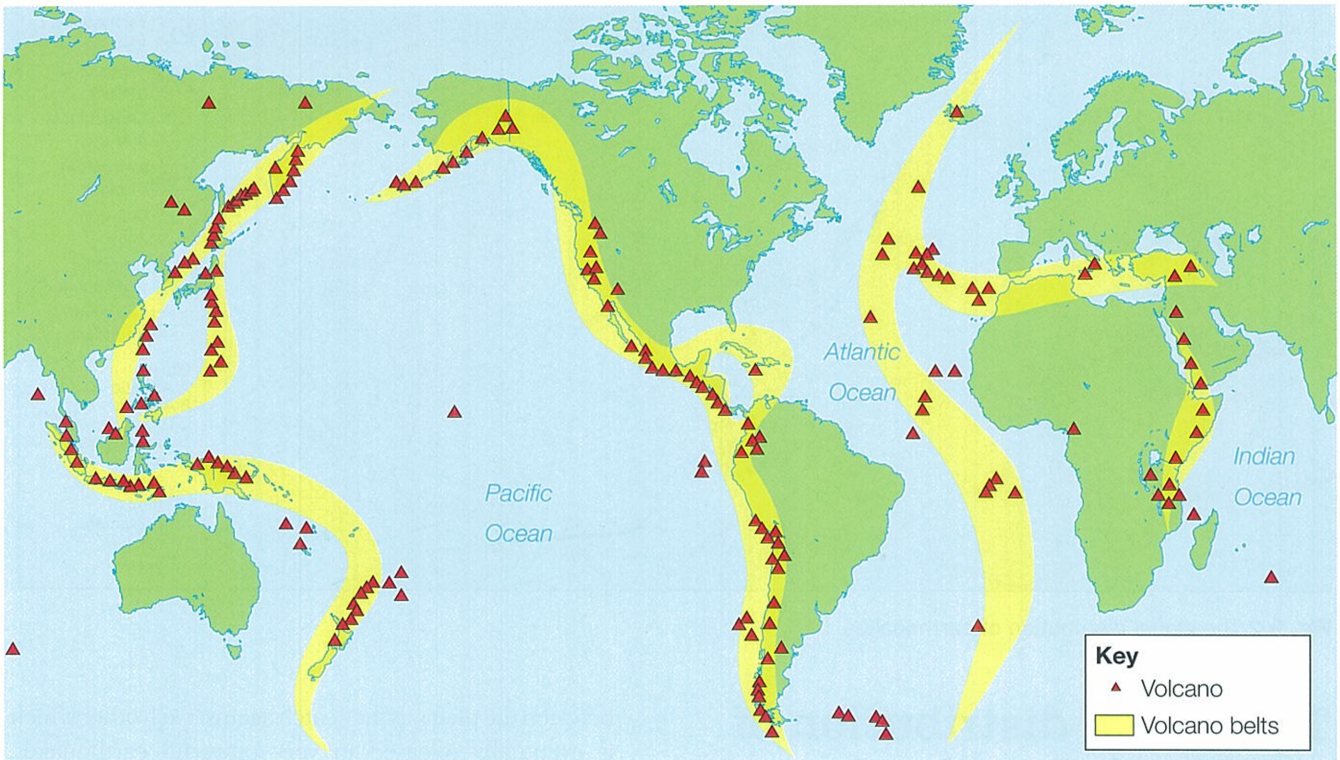


**Fig. 9.3** The global distribution of active volcanoes

# Earthquakes and resultant hazards

## Shaking

Earthquakes send out seismic energy waves, which are recorded by seismographs. **Primary (P) waves** travel fastest and arrive at a place first, followed by **secondary (S) waves**. The slowest waves, **surface waves**, travel along the Earth's surface. Being long waves with large amplitude, they cause most of the damage as they shake the ground most violently.

## Measuring earthquakes

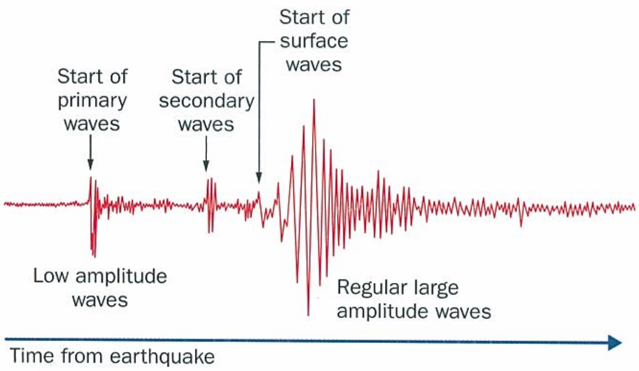


**Fig. 9.4** A seismograph recording of an earthquake

The total amount of energy released, or **magnitude** of an earthquake, was measured on the **Richter scale**. Since 1993, the USGS used the more sophisticated Moment magnitude scale which is similar for medium earthquake values up to 5.0. Both are log scales, so an increase of 1, e.g. from 4.5 to 5.5, produces ten times more ground movement and releases 32 times more energy.

The number of earthquakes increases as their magnitude decreases.

The 12-point **Mercalli scale** measures the **intensity** (amount of physical damage) of an earthquake. Isoseismal

| Magnitude (Moment magnitude scale) | Descriptive term | Average number per year over a recent 50 year period | Effect in populated areas |
|---|---|---|---|
| 8 and above | Great | 1 | Very large-scale devastation with a high death toll. |
| 7–7.9 | Major | 18 | Lots of structural damage and many deaths. |
| 6–6.9 | Strong | 266 | Considerable structural damage and some deaths. |
| 5–5.9 | Moderate | 1319 | Some structural damage but deaths are rare. |

**Table 9.1** Earthquake frequency by magnitude

| Value | Intensity | Description |
|---|---|---|
| 1 | Instrumental | Not normally felt. Animals uneasy. |
| 2 | Feeble | Felt only by a few people at rest |
| 3 | Slight | Vibrations like a lorry passing. Felt by people at rest. |
| 4 | Moderate | Felt indoors by many. Cars rock. |
| 5 | Rather strong | Sleepers awakened. Some windows broken. |
| 6 | Strong | Bells ring. Trees sway. Loose objects fall. |
| 7 | Very strong | Difficult to stand up. People run outdoors. Walls crack. |
| 8 | Ruinous | Ground cracks. Pipes break. |
| 10 | Disastrous | Landslides. Many buildings destroyed. |
| 11 | Very disastrous | Few buildings left standing. |
| 12 | Catastrophic | Total damage. Ground surface rises and falls in waves. Objects thrown into the air. |

**Table 9.2** The Mercalli scale of earthquake intensity

lines on a map can be drawn using Mercalli scale measurements.

The focus (origin) of an earthquake can be up to 700 km deep. Below that the rocks are so hot they bend, rather than break. Deep focus earthquakes are generally not as destructive as shallow focus ones because the thickness of rocks above the focus absorbs the shockwave. Its strength reduces with increased distance from the focus.

Buildings can be destroyed both by shaking and by the ground tilting or subsiding as the shock wave passes.

## Secondary earthquake hazards

Secondary hazards result from the shaking of the ground.

- **Landslides**: in April 2015 a shallow, 7.9-magnitude earthquake struck Nepal with its epicentre 80 km north-west of Kathmandu. Climbers at south base camp on Mount Everest, about 200 km away, reported that after the ground shook there was a massive fall of rocks, snow and ice down the mountain, causing 19 deaths in the camp. Frost-shattered rocks had broken free when shaken and gravity moved them quickly down the steep slopes. Landslides blocked roads, delaying the arrival of aid.
- **Soil liquefaction** occurs when the shaking of the ground makes weak or unconsolidated rocks act as a liquid and flow, leading to the sinking and destruction of buildings. This occurs when groundwater is near the surface and soft sediment like sand mixes with water.
- **Tsunamis** are high, long-period waves in the ocean, resulting from a sudden displacement of the sea bed along a fault. In the open ocean tsunami wave crests are small and wave lengths very long, making them difficult to monitor. When the wave crests reach shallow water at the coast, they slow and rise dramatically in height. The waves then retreat, pulling water back out to sea, before returning to hit the coast with tremendous force. Their height can exceed 30 m and they can flood coasts thousands of kilometres away from the focus.

Coastal areas near earthquake epicentres have little or no warning because a tsunami travels very rapidly. The tsunami generated by the large earthquake off the west coast of Sumatra on 26 December 2004 reached Aceh province a few minutes afterwards, so people fleeing from the earthquake were caught in the flood that surged inland.

### Floods

More damage, injury and death occurs if a shock wave causes a dam wall to collapse or a large landslide to fall into a lake, resulting in sudden flooding down valley.

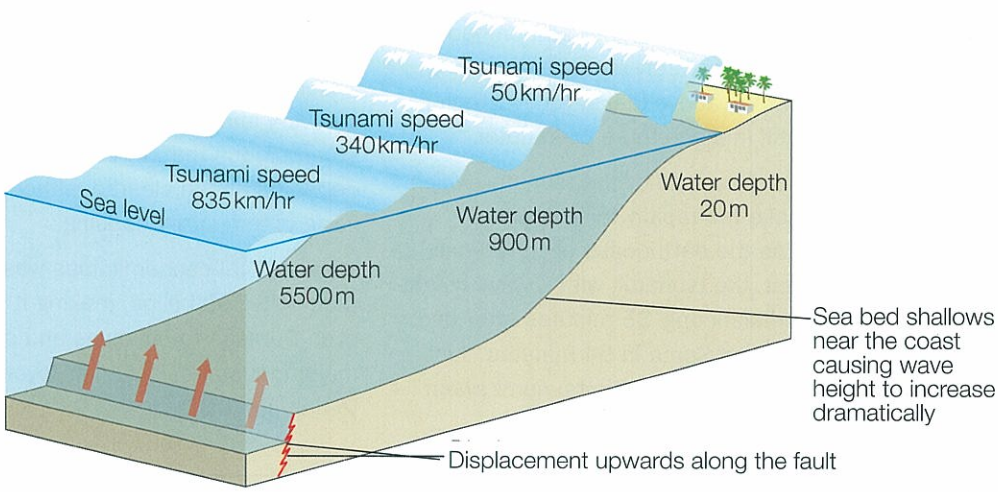


**Fig. 9.5** Three-dimensional block diagram showing how a tsunami forms

# Case study: The Tohoku (Sendai) earthquake and tsunami in Japan, 2011

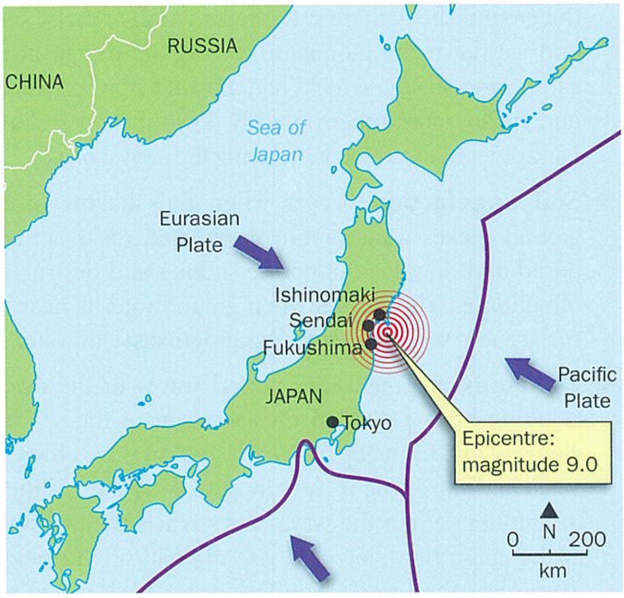


**Fig. 9.6** The location of the epicentre of the Tohoku (Sendai) earthquake

The magnitude 9.0 earthquake occurred at a depth of 32 km off the north-east coast of Honshu, Japan's main island, where the Pacific plate begins to subduct beneath the Eurasian plate at a rate of 83 mm a year. Thrust-faulting uplifted the sea floor by 35 m. The tsunami affected at least 2000 km length of densely populated coastal lowlands. Nowhere in the world was better prepared for earthquakes but the sea defences proved to be totally inadequate, as no one imagined waves as high as 10 m would occur. In fact, a wave nearly 38 m high hit the settlement of Miyagi.

## Effects on lives and property

The earthquake caused fires in all the affected cities and in an oil refinery. Millions of homes were without power, as the Fukushima nuclear power station had to be closed down. It was severely damaged, causing partial meltdown and radioactive leaks. An evacuation zone around it was still in place three years later.

Most of the deaths were caused by the tsunami, which followed the earthquake too rapidly for adequate warning to be given. As the earthquake occurred only 129 km from the coast, the tsunami, with a wave height of 4.1 metres, hit Kamaishi only 35 minutes after and a 7.3 m high wave reached Soma in 64 minutes. Just over an hour after the earthquake, the tsunami swept planes away at Sendai airport.

The configuration of the coast amplified the tsunami, as it funnelled into bays and up estuaries. Rikuzentakata, a settlement with a population of over 23 000, was totally submerged by a wave as high as the third floor of the city hall. Few buildings were left standing in any of the affected cities. The wall of water swept buildings, ocean-going ships, trains and vehicles kilometres inland and piled them up.

In total, the tsunami inundated 561 km$^2$ and destroyed 100 tsunami evacuation sites. The total death toll was 20 896, with more than 5000 injured and 130 000 homeless. Approximately 332 000 buildings, 2000 roads, 55 bridges and 26 railways were destroyed or damaged. A dam collapse near Fukushima destroyed 1800 homes. Most casualties and damage occurred in the cities of Iwate, Miyagi and Fukushima.

**Fig. 9.7** The town of Ishinomaki four days after the tsunami struck

Severe damage to the infrastructure made rescue and recovery immensely difficult but the relief mission was so enormous that, three years afterwards, most of the debris had been cleared, although people were still living in temporary housing.

Japan's total economic loss was estimated to be more than $US 300 billion, making it the costliest disaster ever. Damage to buildings and supply lines caused major industries, including Toyota, Honda and Nissan, to halt production.

| Location | Month/ year | Mg* | Depth of focus (km) | Deaths | Circumstances |
|---|---|---|---|---|---|
| Indian Ocean off the west coast of north Sumatra (3.30 N, 96 E) | December 2004 | 9.1 | 30 | 227 898 (mainly by tsunami) | Release of stress on the subducting Indian plate by a 20 m vertical displacement and a 300 km horizontal rupture along a thrust fault at the boundary with the Eurasian plate, 250 km from the coast. |
| Tohoku (Sendai) off the east coast of Honshu, Japan (38.30 N, 142.37 E) | March 2012 | 9.0 | 32 | 20 896 (mainly by tsunami) | Rock moved 35 m up and a 300 km rupture occurred along a thrust fault at the destructive plate boundary, 129 km from the coast. |
| Off the coast of central Chile (35.85 S, 72.72 W) | February 2010 | 8.8 | 35 | 547 | Horizontal movement along a fault on the subducting Nazca plate, 95 km from the coast. |
| Off the west coast of north Sumatra (2.3 N, 93 E) | April 2012 | 8.6 | 23 | 10 (8 from heart attacks) | Horizontal movement along a fault 434 km from the coast of Sumatra and 200 km from the subduction zone. |
| Off the coast of southern Sumatra (4.44 N, 101.39 E) | September 2007 | 8.5 | 34 | 25 | Movement along a thrust fault on the boundary of the Australian and Indian plates, 130 km from the coast. |

**Mg*** = Magnitude

**Table 9.3** The strongest earthquakes since 2000

| Location | Date | Mg** | Focus depth (km) | Deaths | Effects on lives and property |
|---|---|---|---|---|---|
| Haiti (18.44 N, 72.57 W) | January 2010 | 7.0 | 13 | About 200 000* | 1.5 million people (estimated) homeless in the densely-populated capital city. Damage to airport, port and roads slowed the arrival of aid. |
| Indian Ocean off the west coast of north Sumatra (3.30 N, 96 E) | December 2004 | 9.1 | 30 | 227 898 (mainly by tsunami) | The most deaths ever recorded in a tsunami. Deaths in 14 countries in densely-populated coastal lowlands in south east Asia and one in east Africa. Aceh (Indonesia) was the most affected area. |
| Sichuan, China (103 N, 33 E) | May 2008 | 7.9 | 19 | 87 587 | No aid for days as landslides blocked and destroyed roads. Landslides also buried a train and killed 700 in a settlement. |
| Kashmir, Pakistan (34.53 N, 73.58 E) | October 2005 | 7.6 | 26 | 86 000 | No aid for days as landslides blocked and destroyed mountain roads. Many children died when poorly-built schools collapsed. |
| Bam, south-east Iran (29 N, 58.31 E) | December 2003 | 6.6 | 10 | 31 000 | Landslides in the area around the epicentre trapped people in their poorly-built, mud brick homes when heavy concrete roofs and ceilings collapsed. Houses lacked building regulations. |
| Tohoku (Sendai) off the east coast of Honshu, Japan (38.30 N, 142.37 E) | March 2011 | 9.0 | 32 | 20 896 (mainly by tsunami) | Tsunami – at its maximum nearly 38 m high – caused most of the deaths. Economic loss 300 billion $US. |

* The real total is unlikely to be known. Estimates vary from 316 000 (Haiti government) to 85 000.

****Mg** = magnitude (Moment magnitude scale).

**Table 9.4** Earthquakes causing the most deaths since 2000

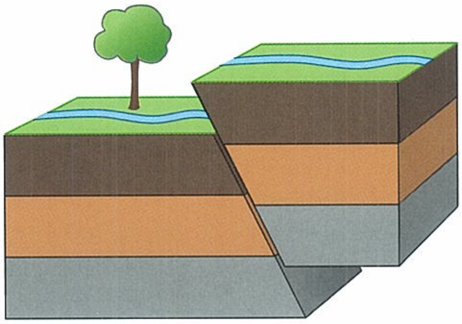

**Fig. 9.8** A thrust fault

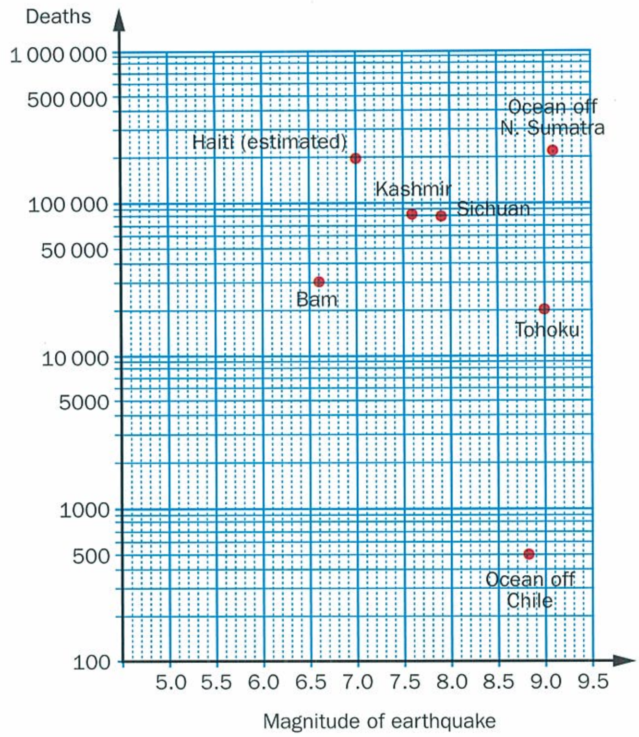


**Fig. 9.9** Semi-log graph showing earthquake magnitude and deaths

Outbreaks of disease occur when survivors are forced to live in camps with insanitary conditions.

## Is there a relationship between earthquake magnitude and deaths?

Although the magnitude in the above data tables can be plotted on a linear scale, the great range of deaths makes it impossible to plot them on a normal linear scale scattergraph. **Semi-logarithmic graph** paper (**log-normal graph** paper), with one linear scale and the other logarithmic, must be used. On Fig. 9.9 the log scale has cycles, each of which is given a value ten times the size of the adjacent lower cycle. The start of the cycles can be 0.1, 1, 10, 100, 1000, 10 000, and so on. As with all scattergraphs, the scales do not need to extend to values below the lowest values in the data. This graph starts at 100 because there are not enough cycles on this paper to show values below 100. The first cycle is subdivided 100, 200, 300, etc.

**2.** (a) Comment on what Fig. 9.9 shows about whether or not there is a relationship between earthquake magnitude and deaths.

(b) Plot another semi-log scattergraph of the same earthquakes to show earthquake deaths and depth of focus. Comment on a conclusion that can be made from your graph.

**3.** (a) Use htpp://usgs.gov/earthquakes to search in the significant earthquake archives for eathquakes with a magnitude of 8.0 or higher that have occurred since 01-01-2000. Choose the map and list format. Print a list of them.

(b) Use the map of the earthquakes to comment on the areas of greatest activity since 2000 and to what extent it is possible to predict where the next very strong earthquake will occur.

**4.** Using evidence from Tables 9.3 and 9.4, explain why two of the strongest earthquakes also resulted in many deaths. To what extent were their death tolls caused by the shock waves passing through?

**RESEARCH** The USGS website (htpp://earthquake.usgs.gov/earthquakes) has a wealth of information. Look up the Real-time earthquake maps to find information about earthquakes that occurred in the last day, week or month and which plate boundaries are most active. Note any earthquakes with a magnitude 8.0 or higher that have occurred since 2013.

# Case study: A comparison of the Haiti and Christchurch earthquakes

| Earthquake location | Date and local time | Magnitude | Depth of focus | Deaths |
|---|---|---|---|---|
| Port-au-Prince, Haiti | January 2012 16.53 | 7.0 | 13 km | 200 000 (estimated) |
| Christchurch, New Zealand | September 2010 04.35 | 7.1 | 5 km | 0 |
| Christchurch, New Zealand | February 2011 12.51 | 6.3 | 5 km | 185 |

**Table 9.5** The Haiti and Christchurch earthquakes

It is clear that the enormous difference in deaths cannot be explained by magnitude, time of day or focal depth. Also, the epicentre of the Haiti earthquake was 25 km from the city whereas that of the 2011 Christchurch earthquake was only 10 km from the city centre. However, Port-au-Prince had a population of 2.5 million, whereas only 400 000 lived in Christchurch.

## The Haiti earthquake

Devastation resulted from a tiny fragment of the Caribbean plate moving eastwards along a fault on the destructive plate boundary with the North American plate. The shallow depth of the movement caused much damage from shaking, which lasted for nearly a minute.

### Effects on lives and property

- The Haiti government's estimate of 316 000 deaths is believed to be too high: other estimates suggest 200 000. As people were buried quickly in mass graves to reduce the incidence of disease, it was difficult to keep proper records. More than 100 000 are estimated to have been injured and up to 1.5 million left homeless.

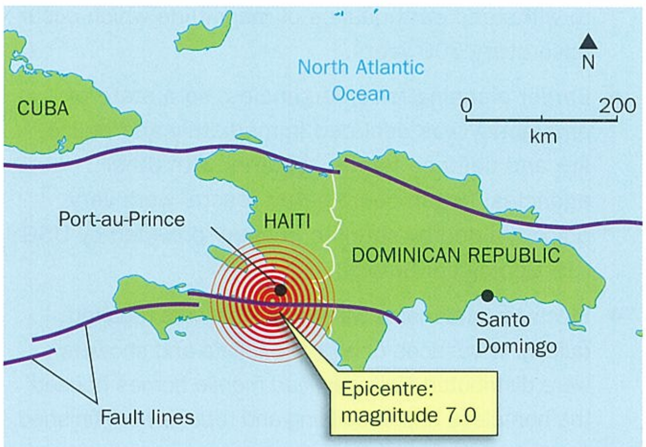


**Fig. 9.10** The Haiti earthquake, January 2010

- Hospitals and government buildings were destroyed, as well as 250 000 residences and 30 000 commercial buildings.
- Power and water supplies were disrupted and phone communications lost.
- Incoming aid was delayed because the international airport's control tower and the port were destroyed and many roads were blocked.
- Looting and violence was a problem for relief workers trying to keep stocks of food and water safe and to distribute them.
- More than 3000 died in 2010 in cholera outbreaks caused by poor sanitation in the temporary tented camps. Outbreaks continued and, by 2015, cholera had killed about 8600 people.

### Reasons for the severity of the earthquake

- It struck the densely-populated capital city.
- Liquefaction: much of the city was built on loose sediments, which allowed the seismic waves to amplify.
- The international airport had only one runway, limiting the number of planes carrying aid and aid workers that could land.
- Haiti is a very poor country and without building regulations, so most infrastructure had been constructed cheaply. Buildings were not reinforced and many had no foundations. Heavy concrete buildings collapsed because they had little steel in their support columns.
- Many people lived in shacks made of flimsy materials on very steep, unstable slopes.
- The earthquake was unexpected and the country unprepared because the last damage from an earthquake was in 1770.

- Haiti had no army and few emergency service vehicles or staff to give immediate assistance.

It is clear that the perception of risk from an earthquake was minimal, but the government acted on the cholera risk by relocating many people to areas with better sanitation.

## Recovery

Haiti had poor resilience as recovery depended largely on overseas aid. Three years after the earthquake, just over half the debris had been cleared and about 280 000 people were still living in camps, some of which lacked flushing toilets. One-fifth of the population lost their jobs because clothing factories, the largest employer, had been destroyed.

Despite the extensive scale of the devastation, the economic cost of the earthquake is believed to be relatively small, less than $US9 billion. Few people were insured against losses, so the biggest cost was for rebuilding.

# The Christchurch earthquakes

Almost all the damage was done by the 2011 aftershock earthquake, partly because the higher magnitude 2010 earthquake had already weakened and damaged structures, so less shake was needed to cause collapse. Some parts of the city had been damaged by liquefaction. Also the 2011 earthquake focus was shallower, closer to the city centre and at Tuesday lunchtime when many people would be out, rather than in bed on a Saturday morning, as in the 2010 event.

Both earthquakes resulted from deformation along different thrust faults at the destructive plate boundary where the Pacific plate subducts beneath the Australian plate.

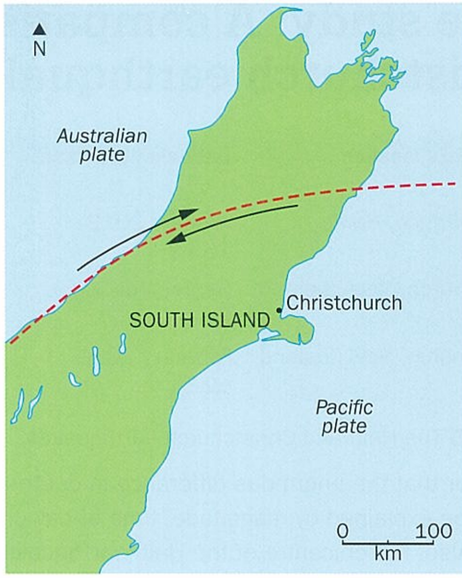


**Fig. 9.11** The location of Christchurch in relation to the plate boundary

## Effects on lives and property of the 2011 earthquake

- Vertical and horizontal shaking at the same time destroyed 1000 major buildings. The shaking intensity was more than four times that in Haiti, and one of the highest ever recorded.
- Liquefaction undermined the foundations of many buildings and destroyed houses built on soft sand by the river in the eastern suburbs. The tallest hotel, the Grand Chancellor, dropped on one side by one metre.
- Numerous aftershocks made recovery difficult.
- More than half the 185 deaths occurred inside the TV building, which collapsed and caught fire. At least 1500 people were injured.
- Most water and sewerage systems were damaged and power cuts affected many homes. However, many services were restored within a week and most within a fortnight. Phone communications were only disrupted for a short time.
- Liquefaction forced road surfaces upwards, slowing rescue efforts.
- The total economic cost of the earthquake is about $US 40 billion, mostly for rebuilding and insurance losses.
- The international airport was undamaged, so overseas aid arrived quickly.

## Perception of the risk

Action by government agencies gave high resilience and considerably less severe effects than in the Haiti earthquake:

- Strict building codes, so modern buildings were built to withstand earthquakes of magnitude which occur once every 500 years.
- Earlier planning for emergencies, so a state of emergency was declared immediately and police, fire and defence forces, together with other agencies, began coordinated rescue work very quickly, aided by satellite imagery provided by USGS (US Geological Survey).
- Electricity and mains water supplies were repaired quickly. Thousands of portable toilets and showers were distributed. Fully-serviced mobile homes housed the homeless until rebuilding and repairs were finished.

All new buildings were made earthquake-proof with a maximum height of 28 metres.

**5.** List the reasons why damage and deaths in earthquakes of the same magnitude in cities in LICs are greater than in cities in HICs.

# Volcanoes and resultant hazards

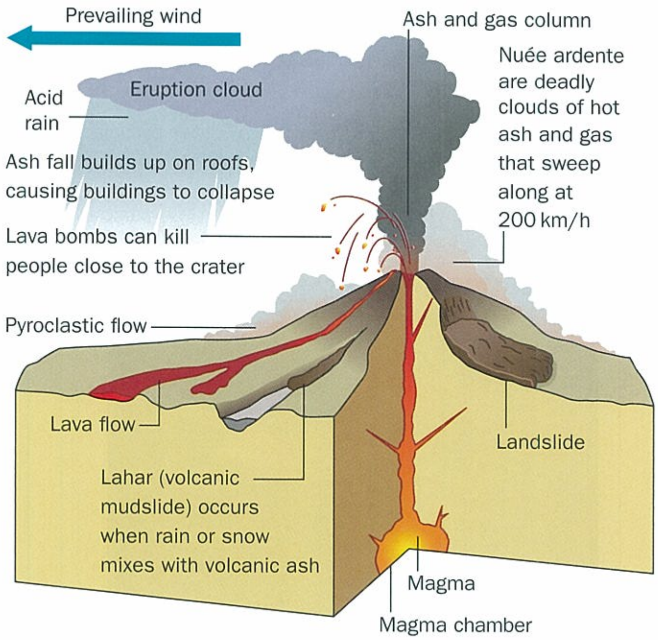


**Fig. 9.12** Three-dimensional block diagram showing primary volcanic hazards that result directly from volcanic eruption

# Volcanic emissions – primary hazards

## Gases

Water vapour constitutes up to 80 per cent of the gases emitted and, after conversion to rain, is responsible for dangerous mudflows and lahars. Other gases include carbon dioxide (an average of 200 million tonnes a year), sulphur dioxide, which can corrode aircraft, and hydrogen sulphide, which is toxic.

A long period of inactivity and highly viscous **magma** causes such a solid plug to grow in the **vent** of a volcano that highly-gas-charged lava eventually explodes sideways out of a weakness in the flank of the volcano in a primary hazard known as a **nuée ardente**. A very hot, incandescent cloud, composed of gas and tiny fragments of solid material, moves very rapidly down the slope, keeping contact with it. Its temperature can reach 1000 °C. Only two people out of 30 000 survived when a nuée ardente rolled down on to the capital town of St Pierre from Mt. Pelée on Martinique in the Caribbean in 1902.

**Fig. 9.13** The crater of Stromboli emits gases frequently, stopping their build-up and preventing violent eruptions

## Liquids

**Lava** is both the liquid material that flows out of the crater of the volcano and the rock it forms when solidified. It originates from magma, molten rock beneath the surface, which rises from a **magma chamber** beneath the volcano through a **vent** to reach the surface. The most dangerous **lava flows** are runny basalts, which occur at constructive plate margins and oceanic hot spots. As they can move at 50 km an hour, anything in their paths is rapidly covered. The fastest basalt lavas are of the **aa** type, formed when a lot of lava erupts quickly. **Aa lava** is thick, up to 10 metres deep, with a surface that breaks into rough clinkers as it moves. Its steep sloping front moves forward as a unit, with sudden, dangerous surges of speed, destroying anything it touches.

Slower-flowing **pahoehoe** lava is less than two metres thick because it forms when low volumes are ejected more slowly. As it solidifies while moving, its smooth surface has curved flow lines, giving it a rope-like appearance. It flows in individual lobes, moving around obstacles, setting flammable objects on fire as it does so. As it is less viscous than aa lava, it cools more slowly and flows further.

**Fig. 9.14** This aa lava flow in Lanzarote buried eleven villages and blocked roads

**Fig. 9.15** This high, steeply-sloping front of a basalt and obsidian lava flow moved down a valley from Newberry volcano, a shield volcano in Oregon USA, and created a lake by impeding drainage

**Fig. 9.16** Ash and cinders piled on top of older pyroclastic material on the lower slopes of Lava Butte

## Solids

**Pyroclastic material** is solid particles that reach the ground in pyroclastic falls (airborne pyroclastic material is also known as **tephra**). Some of it is the shattered remains of the plug that solidified in the vent after the previous eruption. Other pieces form when molten lava solidifies while in the air. Solid materials are categorised by their size and shape: **ashes,** the smallest, are less than 4 mm in diameter while **cinders** are about 4 to 5 mm in diameter and **lapilli** are pebble-sized. **Volcanic blocks** are large angular fragments resulting from the shattering of solid lava during an eruption, whereas **volcanic bombs** are rounded because they form as molten lava cools while spinning through the air.

All ejections of pyroclastic material can be dangerous, as it is usually hot. It is also heavy and even ash can cause roofs to collapse and damage crops, machinery, electronics and people's lungs. Heavier particles, such as bombs, usually fall to the ground within 3 km of the vent, but the lighter particles can rise high into the atmosphere where they can damage aircraft engines. The enormous ash cloud emitted by Eyjafjallajökull in 2010 drifted over Europe from Iceland and disrupted flights for more than a week. More than 100 000 flights were cancelled, costing airlines almost $US 2.5 billion.

When lava domes collapse, hot, dry rock fragments and gases move rapidly away from the vent down slopes and valleys by gravity. These **pyroclastic flows** kill almost half the people who die as a result of volcanic eruptions. Their highly destructive nature results from their high density, fast speed of travel (80 km/hr to 100 km/hr commonly), long distances covered and intense heat (usually 200 °C to 700 °C). The density of materials is lowest at the top of the cloud and greatest in its base flow, which means that the densest part containing boulder - sized fragments moves in contact with the ground and destroys everything with which it makes contact. Above the base flow hot gases keep the ash fragments buoyant. The heat sets nearby buildings, forests

**Fig. 9.17** Cinders, volcanic blocks and bombs on the upper slopes of Lava Butte

and crops on fire and people and animals on the edges of the flows die from breathing in the hot gases. Wide areas are buried by hot pyroclastic debris up to 200 m thick that often welds together. If loose, it can provide material for equally hazardous lahars to occur if water is added to the deposit.

Nuées ardentes, described earlier, are categorised as a special type of pyroclastic flow, being characterised by their incandescent ashes that glow in the dark.

# Types of volcano

## Cinder cones

Cinder cones form when blobs of gas-charged lava are thrown into the air and break into fragments. The inappropriately-named Lava Butte in Oregon is an example. During its growth it blocked and diverted the Deschutes River.

## Shield volcanoes

These are formed of basic lava, containing less than 50 per cent silica. Consequently, it is fluid, flows long distances and solidifies slowly. If it issues from fissures, it forms extensive plateaus, like the Deccan in India, but shield volcanoes result when there is a central vent. These volcanoes are enormous, with very wide bases and gentle slopes of about 5°.

Shield volcanoes form mainly along constructive plate margins - for example in Iceland, which has built up above sea level by layer upon layer of lava. Mauna Loa in the Hawaiian Islands, the largest active volcano in the world, is an example formed at a hot spot - a plume of molten material from the mantle, ejected at the surface far from a plate boundary. From the ocean floor to its summit, it rises 9000 m, which is greater than Mount Everest's height above sea level.

**6.** Comment on the number of volcanic cones in Fig. 9.14 and suggest why this results from the formation of Lanzarote at a hot spot.

## Stratovolcanoes

Stratovolcanoes form at convergent (destructive) plate boundaries where the magma gains added silica as it rises though continental rocks. As the lava is intermediate between acidic and basic, it is more viscous than that of a shield volcano, resulting in steeper sides, which usually steepen towards the summit, giving a concave slope overall. The base is narrower than that of a shield volcano.

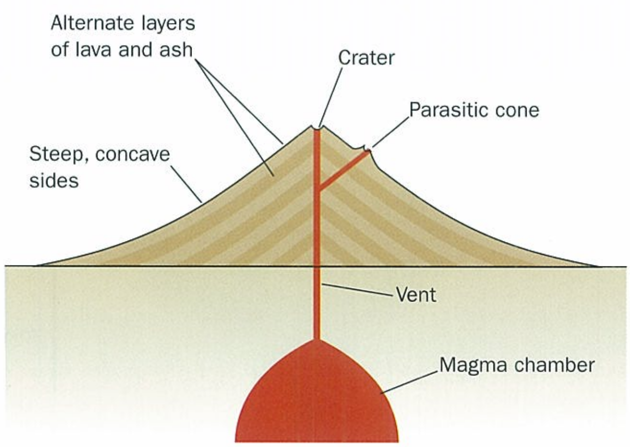


**Fig. 9.18** A cross-section through a stratovolcano

Stratovolcanoes are particularly dangerous because they have long dormant periods, so people are not always convinced that they should heed warnings to evacuate. During dormancy a thick plug of solidified magma builds up in the vent and, as the magma has a high viscosity, a considerable amount of pressure has to build up to unblock the vent, usually culminating in an explosion which shatters the plug into pyroclastic fragments, followed by outpourings of lava.

**Parasitic cones** form on the sides of volcanoes when the main vent becomes blocked and the magma finds another way out.

**Fig. 9.19** Orsorno, a stratovolcano in Chile. Note the small parasitic cones in the form of lava domes on each flank and glaciers at the top, which could lead to flooding and lahars during an eruption

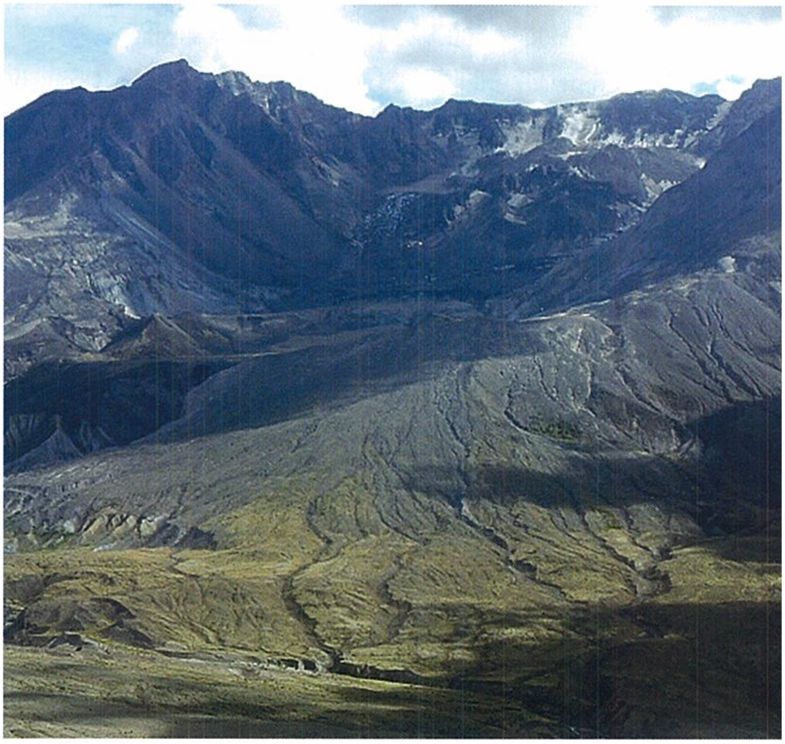

**Fig. 9.20** Since Mount St Helens erupted in 1980, a lava dome has developed in the crater. Gases are rising from the back edge of the dome and thick lahar deposits are seen in the foreground

## Lava domes

These relatively small domes, with steep sides and rounded tops, can form on the slopes of, or in the craters of, stratovolcanoes. They are composed of silicic lava (containing more than 60 per cent silica) which is too viscous to flow far, so it solidifies quickly, forming a thick crust. Domes swell as they grow from within. Very explosive eruptions result when they collapse. Mt Pelée in Martinique developed a lava dome before its 1902 eruption.

# Types of eruption

Volcanoes are classified by the nature of their eruptions.

- Icelandic – fluid basalts issue quietly from fissures at mid-ocean ridges.
- Hawaiian – fluid basalts issue from vents in volcanoes. Gases escape easily and quietly with occasional spurts of gases from lava lakes causing lava fountains.
- Strombolian – less fluid lava and gases escape with moderate explosions in which lava bombs are ejected. Stromboli is known as 'The lighthouse of the Mediterranean' because of its very frequent activity.
- Vulcanian – eruptions are more violent because the more viscous lava solidifies more quickly and traps gases. Ashes and cinders are emitted when pressure is released. Dark, ash-laden clouds rise to form a cauliflower shape.
- Vesuvian – the viscous magma gains a high gas content during long periods of inactivity and a deep plug forms, which can only be blown off after considerable pressure has built up. The violent eruption sends a wide, dark ash cloud into the stratosphere. Ash falls over a wide area. The AD 79 eruption of Vesuvius buried the town of Pompeii under 25 m of tephra.
- Plinean – a very violent explosion of gas, ash and pumice results in a narrower cloud that extends into the stratosphere. The high ash cloud from Mt Pinatubo's 1991 eruption (Fig. 9.54) circulated the world several times in the stratosphere, causing temporary global cooling of about 0.5 °C.
- Peléan – highly viscous magma and a long period of inactivity cause an explosion out of a weakness in the side of the volcano, with a nuée ardente falling down the slope.

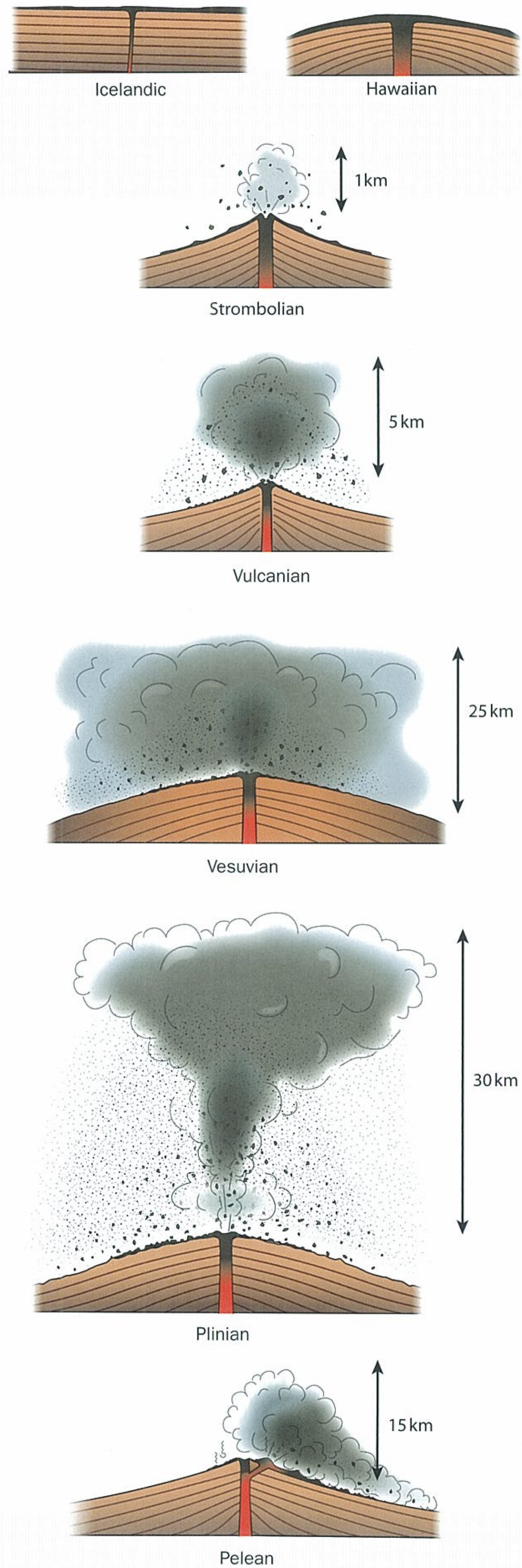


**Fig. 9.21** Types of eruption

## Volcanic explosivity index (VEI)

This scale from 0 to 8 is logarithmic like the Richter scale.

Eruptions of VEI 4 and above send materials into the stratosphere and are capable of global cooling. The largest eruption in historic time was Tambora, Indonesia, in 1815, with a VEI of 7.

| VEI | Volume of material ejected | Eruption frequency | Plume height | Example |
|---|---|---|---|---|
| 1 | >10 000 m³ | daily | up to 1000 m | Stromboli |
| 3 | >10 000 000 m³ | few months | 3–15 km | Nevado del Ruiz |
| 5 | >1 km³ | about 10 years | 20–35 km | Mt St Helens |
| 7 | >100 km³ | about 1000 years | >40 km | Mt Mazoma |
| 8 | 1000 km³ | about 10 000 | >50 km | Yellowstone |

**Table 9.6** Examples of eruptions classified by the volcanic explosivity index

## Secondary volcanic hazards

Secondary hazards result from the primary hazard and usually affect a wider area.

**Fig. 9.22** Crater Lake in Oregon, formed by the eruption of Mt Mazoma 7700 years ago. The summit collapsed into the magma chamber leaving a **caldera** 8 km in diameter and 1.6 km deep, that filled with rainwater to form the lake

### Lahars

Theses volcanic mudflows form when water mixes with loose pyroclastic material, with particle sizes varying from small debris to boulders, forming flows resembling wet concrete down the slopes of volcanoes and into valleys beyond them. The source of the water can be the intense rainfall accompanying the eruption, glacier melt, snow melt or dam failure. Lahars are dense and viscous but flow very fast, reaching speeds of 75 km an hour. The more volcanic material they contain, the faster they flow and the more destructive they are. They are most common on the steep slopes of stratovolcanoes where the downward pull of gravity is strong but can occur on shield volcanoes, as in Iceland. They quickly increase in size as they gain more water and erode more material to carry, but die out as they move away from the volcano.

### Volcanic landslides

These masses of rock and soil moving downslope under gravity can be dry or wet, although they are drier than lahars. With the addition of water as they flow, they can transform into lahars if they contain more than 3 per cent fine clay particles. The landslides originate as large slabs of rock but disintegrate into progressively smaller particles as they move downslope. A volcanic landslide can as huge as 100 $km^3$ in volume and faster than 100 km/hr. Their great size and speed enables them to rise over ridges, as occurred when the north face of Mount St Helens collapsed during the 1980 eruption. The resulting landslide crossed a 500 m high ridge, 5 km from the crater.

Volcanic landslides result when magma forces its way to the surface and pushes outwards, causing the rock to break or over-steepen and collapse by gravity down the high, steep sides of the stratovolcano. They can also be triggered by large earthquakes beneath a volcano.

In turn, volcanic landslides trigger volcanic explosions by removing the 'lid' on the gases and rising magma. They bury valleys and, after coming to rest, cause lahars as water drains down-valley from them. The fastest flow of the Mount St Helens lahars was five hours after the landslide stopped moving and they travelled 55 km further than the landslide. Landslides that do not stop moving but change gradually into a lahar can travel more than 100 km and are the most hazardous.

When landslides block tributary valleys they impound lakes, which can suddenly break through the natural dam and cause further lahars. A large landslide on the coast of Kyushu Island, Japan, in 1792 resulted in a tsunami, causing 15 000 deaths.

## Volcanic hazards and factors influencing them, at different types of plate boundary

Conservative margins have little vertical movement and lack volcanic activity but earthquakes result from horizontal movements.

| **Plate boundary locations** | **Divergent/constructive plate boundaries** (e.g. in Iceland) and **oceanic hot spots** (such as Lanzarote, Galapagos Islands and Easter Island) | **Convergent/destructive plate boundaries** (especially along the Pacific Ring of Fire) |
|---|---|---|
| **Types of volcano** | Shield volcanoes | Stratovolcanoes and dome volcanoes |
| **Magma/lava** | It erupts on the ocean floor, so is mafic (e.g. basalt), basic and fluid. | It rises through silica-rich continents so is more silicic (e.g. rhyolite, andesite), acidic and viscous. |
| **Other emissions** | Effusive: lava flows with fire fountains and ash flows. Routes followed depend on gravity, relief and the viscosity of the flows. | Explosive: pyroclastic flows, nuées ardentes and ash affect wide areas. |
| **Secondary activity** | Floods. Occasional big ash clouds disrupt air traffic (e.g. Iceland 2010). | Lahars, global cooling from atmospheric ash clouds, floods. |

**Table 9.7** Volcanic hazards at divergent and convergent plate boundaries.

# Case study: Nevado del Ruiz, Colombia (an LIC), November 1985

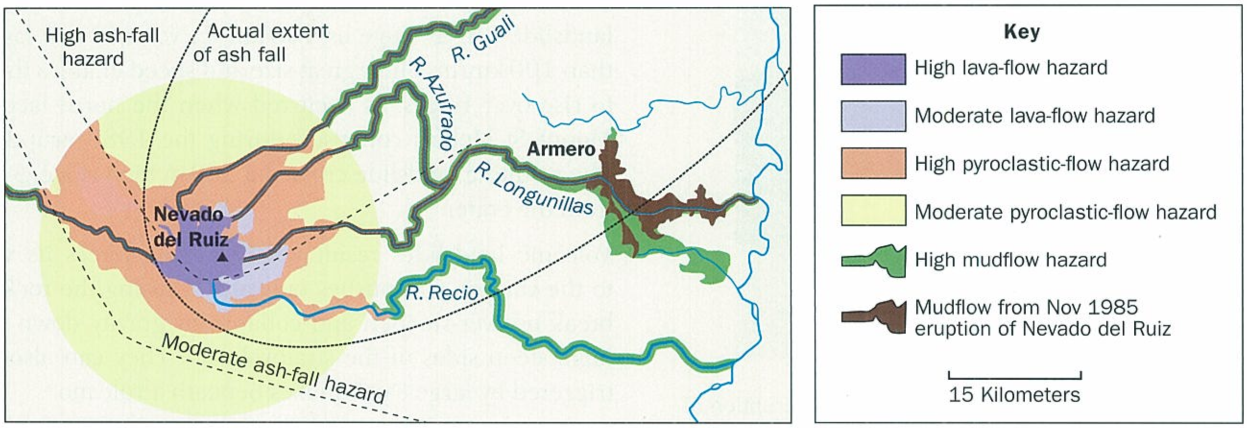


**Fig. 9.23** Nevado del Ruiz hazard map

This stratovolcano in the Andes results from the oceanic Nazca plate subducting beneath the South American plate.

## Prediction and monitoring

- September 1985 – a **hazard map** was drawn up showing locations in danger from ash and rock falls and lahars, including the dangerous location of the town of Armero but many people remained unaware of it, as the map was not well-distributed.
- October – scientists warned of a great risk of lahars and advised local authorities to prepare for an evacuation.
- November 13 – seismographs registered strong earthquakes but the people monitoring them failed to recognise the warnings.

## The eruption hazards

- Ash eruptions started at 15.00 on 13 November but, as they stopped after four hours, people were told to stay indoors rather than to evacuate.
- Soon after 21.00h, a 30 km high ash cloud shot up. Civil defence workers tried to warn officials in Armero but failed to make contact. People in the town were advised locally there was nothing to worry about.
- The eruption melted the summit snow and glaciers, causing thick lahars to race down narrow river valleys at about 60 km an hour, making river volumes four times larger.

## Effects on lives and people

The first lahar, boosted by water from a lake that it passed through, hit Armero only two and a half hours after the eruption. Others quickly followed, including one 30 m deep. People were suffocated by the mud and crushed by collapsing buildings. The eruption caused 23 000 deaths (20 000 in Armero), the second highest from a volcanic eruption in the 20$^{th}$ century after Mt Pelée, and the highest caused by lahars.

Rescue efforts were slow because the mud was very deep and it was impossible to move across it without sinking in. Also, roads and bridges leading to Armero had been cut. Hospitals were overwhelmed and some people died because of the lack of antibiotics to treat infected wounds. The tragedy cost the country $US 7 billion.

## Risk perception

Nevado del Ruiz had been dormant for 69 years and, as there had been no significant eruption for 140 years, officials were reluctant to take expensive prevention measures. Inadequate preparation was the main reason for the deaths, together with a failure to act promptly when it was clear that an eruption was imminent. Also, at the time of the eruption the government and army were busy dealing with a civil war.

# Case study: Mount St Helens, USA (an HIC), May 1980

The magma supplying this stratovolcano results from the subduction of the Juan de Fuca plate beneath the North American plate. The amount of ash ejected by Nevado del Ruiz was only 3 per cent of that from Mount St Helens in 1980. Mount St Helens also produced the biggest volcanic landslide in historical time.

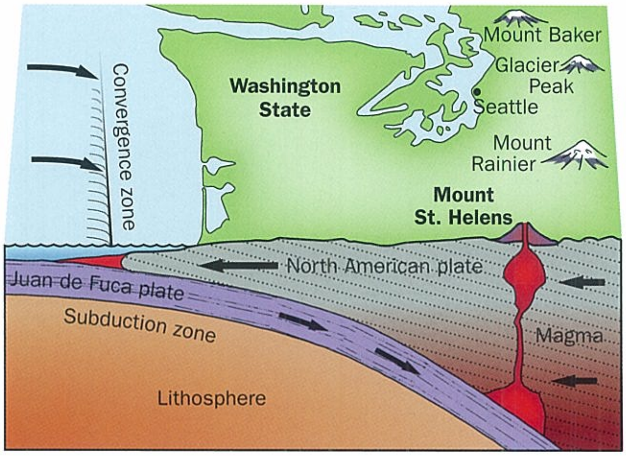


**Fig. 9.24** The location of Mt St Helens

## Prediction, monitoring and perception of risk

The US Geological Survey keeps volcanoes in the country under close observation. They draw up hazard maps and monitor gas emissions. Ground deformation was monitored using lasers in 1980, but is done by GPS now. Many seismometers record the magnitude of earth movements, sending the measurements direct to the University of Washington Geophysics Laboratory. These enable fairly accurate predictions of eruptions.

In March 1980, shallow earthquakes on the north side of the volcano were recognised as being different from the thousands that occur every year. The **harmonic tremor** of continuous rhythmic earthquakes often precedes volcanic eruptions, so extra seismographs were installed and emergency services, guided by the hazard maps, worked on plans to evacuate. Ash eruptions followed for a few weeks and the north flank of the volcano started to bulge. People were not allowed within 13 km of the summit. Most property owners moved away and emergency evacuation plans were made for communities further down the valleys. By the end of April the bulge had grown into a sizeable dome.

## The eruption hazards and their effects on lives and people

- On May 18 the north flank broke open and, with the summit of the volcano, fell downhill as a massive rock landslide 2.3 km³ in volume. It left a new horseshoe-shaped crater, 2 km wide, 3 km long and 600 m deep, open at the north end. (Figs 9.20 and 9.26.) The powerful landslide was channelled down valleys and swept over ridges. Most of the rock was deposited in the North Fork Toutle River Valley (Fig. 9.25).

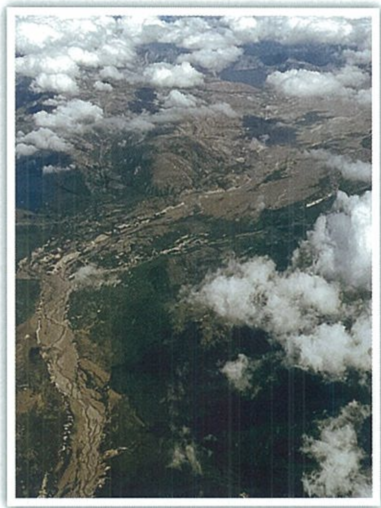

**Fig. 9.25** Lahar material in the North Fork Toutle River Valley in 2013. The summit of Mount St Helens is at the right top of the photograph

- When the landslide stopped moving 22 km from the volcano, its water content, together with melted snow and ice from the glaciers on the slopes of Mount St Helens, rose to its surface and mixed with loose rock material to form destructive lahars, which ripped out eight bridges and cut evacuation routes.
- So much debris reached the Columbia River that ocean-going ships could not sail on it because the previously 200 m wide, deep channel was reduced to less than 70 m wide and 3 m deep.
- Immediately after the landslide, an enormous cloud of gas, rock, ash and ice blasted laterally and

upwards. Hot pyroclastic flows drained rapidly down the volcano's sides, spreading over and beyond the landslide to cover 550 $km^2$.

- Helicopters rescued more than 100 people. Only 57 died, including a geologist monitoring the hazard and people who refused to leave the area.
- Ash had to be cleared from roads.
- People suffered from post-traumatic stress disorder for years afterwards.

**7.** Compare and contrast the main effects of the eruptions of Nevado del Ruiz and Mount St Helens in a table. To what extent are differences explained by the different levels of economic development of the countries?

**Fig. 9.26** The north flank of Mount St Helens 33 years after the eruption. The landslide rode over the ridge where the photograph was taken. The North Fork Toutle River Valley is to the right

**8.** (a) Use Fig. 9.26 to draw a diagram to show the shape of the summit area of Mount St Helens after the eruption and add a pecked line to show its likely shape before it.

(b) The lahar covers the foot of the north flank of the volcano at the headwaters of the North Fork Toutle River. Describe the appearance of the lahar material now and explain why it is different from when it was first deposited. Why is its presence a continuing hazard?

# Primary and secondary impacts of tectonic hazards on lives and property

**Primary impacts** are the immediate results of an earthquake shockwave or of a volcanic eruption; **secondary impacts** happen after the shockwaves or eruptions have finished and are the consequences of the primary impacts. Some continue for a long period.

## Factors influencing the amount of damage caused by the shockwaves of an earthquake

- Amount of energy released, indicated by the Richter scale.
- Depth of the focus - the shallower the focus, the greater the effect. The rocks above absorb some of the energy of deep-focus earthquakes.
- Number and strength of foreshocks and aftershocks. Buildings weakened or damaged by one earthquake may collapse when further damaged by another.
- Distance away from the epicentre. As the distance increases, the strength of the shockwave decreases.
- Nature of the bedrock. If it is solid, damage is limited but where the rocks are weak or loose sands or clays, liquefaction can occur. It can be very destructive, particularly on a slope.
- Population and building density at or near the epicentre. (The above factors are insignificant unless an area is populated.)
- Strength and type of the buildings. Modern buildings in earthquake zones in economically developed countries are usually strengthened against earthquake damage.

The time of day is also significant. During the night there will be fewer deaths in strongly-built homes than at rush hour when people on the streets are likely to be hit by falling masonry. More people are out of their homes during weekdays than weekends. Deaths also depend on risk perception, which leads to the amount of preparation by the population and by emergency services before, during and after the event. This is greater in HICs than LICs, where funding is a problem.

## Managing earthquake hazards

### Earthquake prediction

The New Zealand Earthquake Commission predicts a major earthquake will happen in Christchurch every 55 years. It is not possible to predict exactly when an earthquake will occur or where its epicentre will be. Short-term predictions cannot be made. Most major earthquakes will occur along plate boundaries as a result of a cycle in which strain builds up and is eventually released. The average movement of plates, usually a few millimetres a year, has been calculated but it is not known exactly where in the cycle a particular location is.

Geologists use the **seismic gap theory** to work out where a strong earthquake is likely to occur. 'Gap' refers to the section of an active fault that has not experienced earthquakes for a considerable time compared with other segments along that fault. All parts of the fault are expected to experience the same degree of displacement over time. The location of the 1989 earthquake in the San Francisco Bay area along the San Andreas fault was at a known gap. Using past records, the frequency of earthquakes along part of a fault is calculated to predict the next one and the rate of movement of sections along the fault is also used. The longer the period without an earthquake, the greater the accumulated stress and the greater the likelihood of a strong earthquake.

### Monitoring of earthquake zones

A lot of money has been spent in monitoring, using very expensive instruments, particularly along the San Andreas fault in California, USA.

- Horizontal movements are detected by measuring the change in the time it takes a laser beam to move between two fixed points on either side of a fault.

| Event | Primary impacts | Secondary impacts |
|---|---|---|
| Earthquake | Deaths, injuries, panic and shock caused by collapsing bridges and buildings. Roads are destroyed as vertical movements cause fault scarps to develop or the ground is offset horizontally. | Soil liquefaction, caused by shaking, leads to buildings sinking. Homelessness, lack of shelter and loss of livelihoods occur. People living in temporary tented accommodation or sleeping outside in areas with cold winters or very cold nights can die from hypothermia. Water often becomes contaminated with sewage, leading to disease. Fires and lack of power are caused by the destruction of electricity cables and gas pipes. Water shortages and thirst result from broken water mains. Breakdowns in telephone and internet communications, mudflows, landslides and tsunamis can occur. Famine can be a long-term effect. Theft and other crime can result. |
| Volcanic eruption | Lava flows, ash and tephra falls, pyroclastic flows, release of gases and nuee ardentes. | Lahars, landslides, tsunamis from undersea eruptions, crop damage and famine, loss of homes and livelihoods, disruption to flights where ash clouds occur, long-term cooling of the atmosphere. |

**Table 9.8** A summary of primary and secondary impacts resulting from tectonic hazards

- Changes in slope are detected by a tilt meter, which is like a very sophisticated spirit level.
- Variations in the Earth's magnetic field, resulting from changes in stress in the rocks, are measured by a magnetometer.
- Seismograph records are monitored. Clusters of small earthquakes often precede a large one.
- The amount of radon gas rising to the surface is measured, as it can increase before an earthquake.

Many scientists think reliable prediction will be impossible.

### Hazard mapping

Hazard mapping is undertaken to show areas of ground that are likely to liquefy, fault locations and dates of past movements, past earthquake epicentres with magnitudes and dates and areas where landslides and tsunamis might result. After the 2008 earthquake in Sichuan, which destroyed a school built on a fault, geologists started searching for fault locations to map them as unsuitable locations for development. Ground movements leave earthquake scarps, which need to be mapped, but this vital evidence is often quickly removed by erosion and landslides. However, the authorities in Sichuan could not wait for the maps to be completed before they rebuilt and the replacement buildings are not strong enough to survive an earthquake of the same magnitude. There are now many vulnerable large cities in earthquake belts in China.

### Hard engineering

Engineer geologists know what infrastructures need replacing, moving or strengthening. It is cost-effective to make the necessary changes rather than meet the expense of restoration after a strong earthquake.

### Strengthening buildings

There is little space for building in mountainous Japan, so skyscrapers are built in a pyramid shape for strength. Unfortunately, such measures do add to the cost and builders in some countries make profit, not building regulations, their aim. Even poor rural areas can have safer buildings, using thatch for roofs and mud and straw for walls.

## Land-use zoning

Land uses, such as oil storage depots, that are potential fire or explosion risks are positioned away from homes, and are built on solid rock. Land likely to liquefy is used for playing fields, nature reserves and parks, not buildings.

## Increasing risk perception

Earthquake drills allow people to practise what to do in an earthquake and are regular events in schools and workplaces in many tectonic areas. Japan holds an Earthquake Awareness Day each year so everyone will be able to follow emergency procedures without panic.

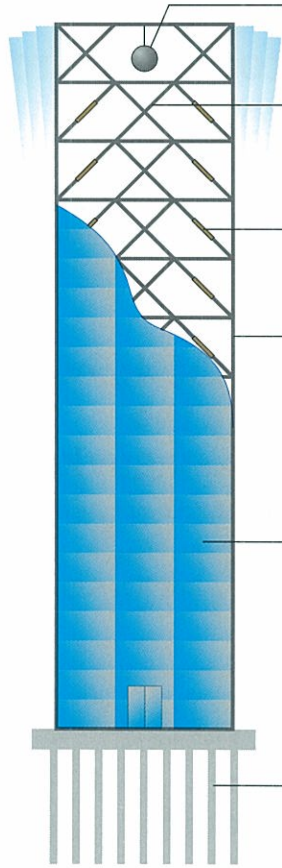


**Fig. 9.27** Earthquake-proof building methods in Japan

Evacuation points, with water, food and medical supplies, are placed in every neighbourhood. People are given maps of routes to follow and leaflets about how to dress and what to take. They are informed how to improve safety in the home, such as by securing furniture to the walls and knowing how to switch off the gas supply. In Japan, gas supplies automatically shut off in an earthquake to reduce the fire risk. People are advised to keep a survival pack near an exit and to have food and drink available to last at least three days.

## Predicting, hazard mapping and monitoring of the tsunami hazard

When a seismic event is detected that could cause a tsunami, a tsunami watch starts. Sea level height detectors confirm if one has been generated. An International Tsunami Early Warning System, operated by NOAA in Hawaii, covers the Pacific Ocean. Seismograph stations and tidal stations spread across the ocean send automatic warnings to Hawaii as soon as the water reaches a certain height. Satellites monitor the tsunami as it crosses the ocean. Communications systems at threatened coasts, warned by the centre in Hawaii, make residents aware of

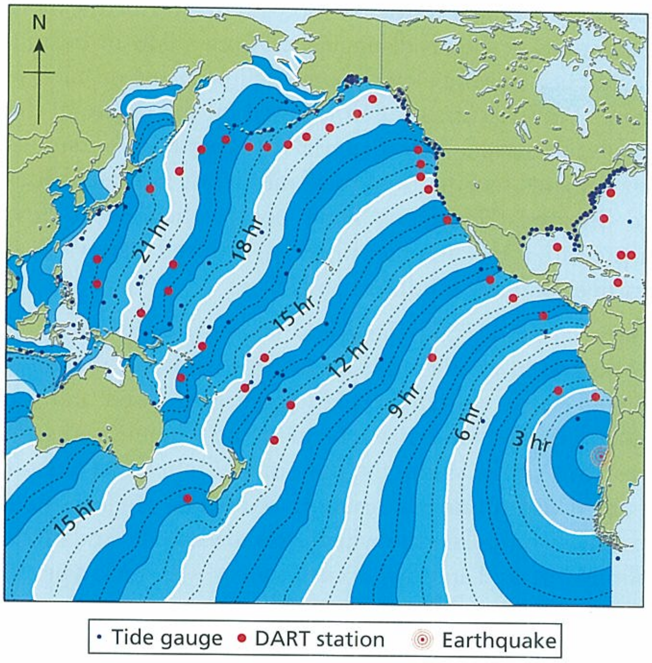


**Fig. 9.28** Isoline map showing travel times of the tsunami wave following the 2010 Chile earthquake

the impending danger by various methods, including text messages, and evacuation procedures are put into place. After the 2004 tsunami, an international warning system was set up for the Indian Ocean.

**9.** Use Fig. 9.28 to state how much warning of possible tsunami danger could be given to San Francisco, New Zealand and Japan after the 2010 Chilean earthquake.

# Managing volcanic hazards

## Predicting and monitoring volcanic eruptions

Remote sensing by satellite sensors detects deformation of the ground surface and temperature changes caused by heating in the ground before an eruption. Gravity meters on the ground detect gravitational changes due to magma movement. Geochemical changes are also indicative of an impending eruption. Thermal waters, such as hot springs on volcanoes, have increased levels of $CO_2$, $H_2$ and He dissolved in them before an eruption. Chemical sensors also measure increased sulphur levels.

## Action taken during eruptions as a result of risk perception

In Iceland and Hawaii cold water was hosed on to lava flows to cool them and reduce their flow length. On Etna lava flows were bombed and diverted away from settlements by channels and in 1992, when the town of Zafferana was threatened, large concrete blocks were dropped into the lava tube from which the lava was flowing. It stopped before reaching the town.

People live near tectonic hazards for a variety of reasons:

- the hazard may not have been predicted
- people may be unaware of the danger if the volcano is dormant or there has been no large earthquake in recent time
- they are reluctant to leave their place of birth, family or friends
- their perception of risk is that it will happen to others but not to them, so they do not accept that they need to take action to reduce risk. People interviewed after a hazard often comment that it is something that happens elsewhere but was not expected to happen to them
- some, such as the Afghan people, take a fatalistic attitude that the hazard cannot be controlled, so it has to be accepted

## Case study: Portland, Oregon, USA – Living with tectonic hazards

The city of Portland developed before seismic gap theory predicted it is likely to experience a magnitude 9.0 earthquake, during which few of its present buildings, bridges, roads and services would escape severe devastation. A map has been published showing the large areas of the city built on ground likely to liquefy and also where **landslips** are a known hazard. The School of Civil and Construction Engineering at Oregon State University is coordinating a programme with representatives of the vital services – transport, gas, electricity and water – to prepare the city. Engineer geologists have begun a race against time to research, plan and undertake hard engineering to hold back steep slopes adjoining main roads and to strengthen structures, such as bridges, where it is cost-effective to do so. Others are likely to be rebuilt away from faults and ground prone to liquefaction. Buildings will need very deep foundations. The whole process could take fifty years.

Public awareness is spread via the media, public meetings and information packs for households about how to prepare for an earthquake and the action to take if one occurs.

Three active volcanoes, Mt Hood, Mt Adams and Mt St Helens, are near but this combination of tectonic hazards does not stop businesses and people from relocating to Portland.

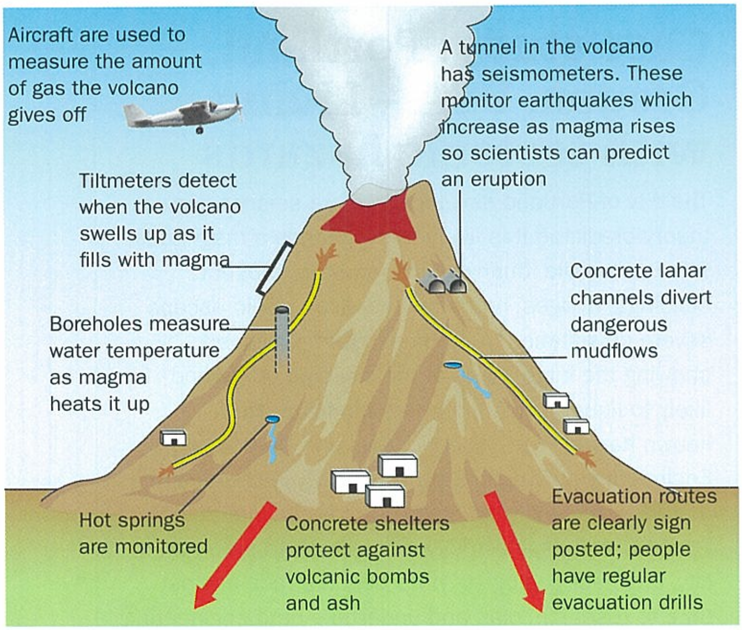


**Fig. 9.29** Some ways in which volcanic hazards are reduced

→ economic reasons, as people are reluctant to leave their jobs. Sulphur is mined from active volcanoes and basic lavas weather to fertile soils suitable for intensive agriculture, as on the densely populated island of Java. Geothermal energy in volcanic areas leads to industrial developments and cheap heating for homes and for crops grown in hothouses, as in Iceland. The dramatic volcanic landscape attracts tourism, which encourages population growth. For such reasons, people believe that the benefits from living in a hazardous area will be greater than the costs of doing so.

# Hazards resulting from mass movements

## Mass movements and resultant hazards: nature and causes

The physical and human causes of types of mass movements are described in Chapter 3. A mass movement which affects people and their property is a hazard, especially when it is unexpected and large-scale but even a single rock fall can be hazardous. Human mismanagement is a prime cause of slope instability.

### Types of hazardous mass movements

Movement is mainly through the air in rock and debris **falls**. **Slides** and **flows** move on the surface both downward and outward. The more rapid ones are the more hazardous. A slide is distinguished from a flow by being a solid mass moving along a single failure plane or fracture zone. Further classification is based on the nature of the material moved. Dry material can produce hazardous movements ranging from rock and debris falls and slides to **slumps**. Hazardous flows occur when earth (fine material) or rock (coarser material) is mixed with water to form earthflows, mudflows and lahars.

Both landslides and landslips (slumps) occur in solid rocks and in weathered material. In a landslide, the plane along which movement takes place is inclined and the material moves in a mass, breaking up where it comes to rest. In a slip or slump the movement is rotational along a curved **slip plane** and results in an arcuate slip face and a relatively unbroken **toe** which rises towards the end of the slipped mass. Landslips occur in areas with rock types of different permeability.

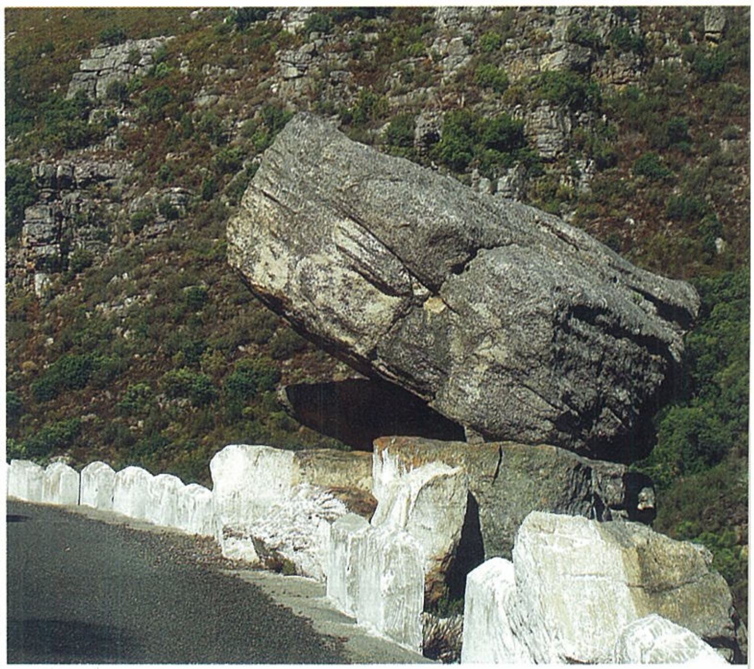

**Fig. 9.30** Rock falls from cliffs are localised hazards along mountain roads

**Fig. 9.31** A small debris slide in the Peruvian Andes