Chapter 5 Hazards

In this chapter you will focus on the atmosphere and the lithosphere (the earth's crust and the section immediately below it – the upper mantle), which intermittently but regularly present hazards to human populations, often in a dramatic and sometimes catastrophic fashion. By studying the origin and nature of these hazards, their impacts and people's responses, you will be exploring some of the relationships between people and the environment in which they live. The study of natural hazards will also give you the opportunity to exercise and develop your observational skills, measurement and geospatial mapping skills, together with data manipulation, interpretation and presentation of statistics.

In this chapter you will study:

- the concept of a hazard in a geographical context and plate tectonics theory
- the background and examples of four types of hazard:
  - volcanic hazards
  - seismic hazards
  - storm hazards and
  - wildfires.

For each type of hazard, you should study one example of the impacts of the hazard and human responses to the hazard. For storms, you need to study a second contrasting example.

Links

There are links to Chapter 8, including The importance of place in human life experience, page 354, and Changing places: meaning and representation, page 364.

5.1 The concept of a hazard in a geographical context

The concept of a natural hazard and its potential impact

A **natural hazard** is a perceived event that threatens both life and property. Natural hazards often result in disasters that cause some loss of life and/or damage to the built environment and create severe disruption to human activities. Natural or environmental hazards include volcanic activity, seismic events (earthquakes) and tropical storms (hurricanes/typhoons/cyclones). All of these can therefore cause disruption to human systems, including death and injury, property and communication system damage and the disruption of economic activities.

These forms of hazard thus pose a risk to human populations. That risk is increased because we build shanty towns on unstable tropical slopes, urbanise volcanic zones, live in areas with active faults and on coasts susceptible to hurricanes and tsunamis. This is also exacerbated by the failure to recognise a potential hazard and act accordingly.

Natural hazards, and their effects on people, tend to have the following common characteristics:

- their origins are clear and the effects that they produce are distinctive, such as earthquakes causing buildings to collapse
- most natural hazards only allow a short warning time before the event (some hardly at all)
- exposure to the risk is involuntary, particularly for populations of less well developed countries. In developed areas, most people who occupy hazardous areas are often well aware of the risks and they choose to minimise or even ignore them
- most losses to life and damage to property occur shortly after the event although the effects of natural hazards can be felt in communities long after that time (disease, disruption to communications and economic activities)

- the scale and intensity of the event requires an emergency response.

Key terms

Adaptation – In the context of hazards, adaptation is the attempts by people or communities to live with hazard events. By adjusting their living conditions, people are able to reduce their levels of vulnerability. For example, they may avoid building on sites that are vulnerable to storm surges but stay within the same area.

Fatalism – A view of a hazard event that suggests that people cannot influence or shape the outcome, therefore nothing can be done to mitigate against it. People with such an attitude take limited or no preventative measures. In some parts of the world, the outcome of a hazard event can be said to be 'God's will'.

Natural hazards – Events which are perceived to be a threat to people and the built and natural environments. They occur in the physical environments of the atmosphere, lithosphere and the hydrosphere.

Perception – This is the way in which an individual or a group views the threat of a hazard event. This will ultimately determine the course of action taken by individuals or the response they expect from governments and other organisations.

Risk and vulnerability

Risk is the exposure of people to a hazardous event presenting a potential threat to themselves, their possessions and the built environment in which they live. People though, consciously put themselves at risk from natural hazards and the question has to be why do they do it?

Possible reasons include the following:

- **Hazard events are unpredictable:** We cannot predict the frequency, magnitude or scale of a natural hazard event.
- **Lack of alternatives:** Due to social, political, economic and cultural factors, people cannot simply uproot themselves from one place and move to another, giving up their homes, land and employment.
- **Changing the level of risk:** Places that were once relatively safe may have become, through time, far more of a risk. Deforestation, for example, could result in more flooding from torrential rain associated with tropical storms and there could also be a greater risk from landslides.
- **Cost/benefit:** There are many hazardous areas that offer advantages that in people's minds outweigh the risk that they are taking. Californian cities, for example, have a high risk from earthquakes, but people see the many advantages of living there as greater than the potential risk.
- **Perception:** see below.

Vulnerability to physical hazards means the potential for loss. Since losses vary geographically, over time and among different social groups, vulnerability therefore also varies over time and space. Researchers at the University of South Carolina have examined all the variables which link risk and vulnerability and have come up with the model shown in Figure 5.1.

This raises the question, is the risk the same for all people in an area? In other words, are some people more

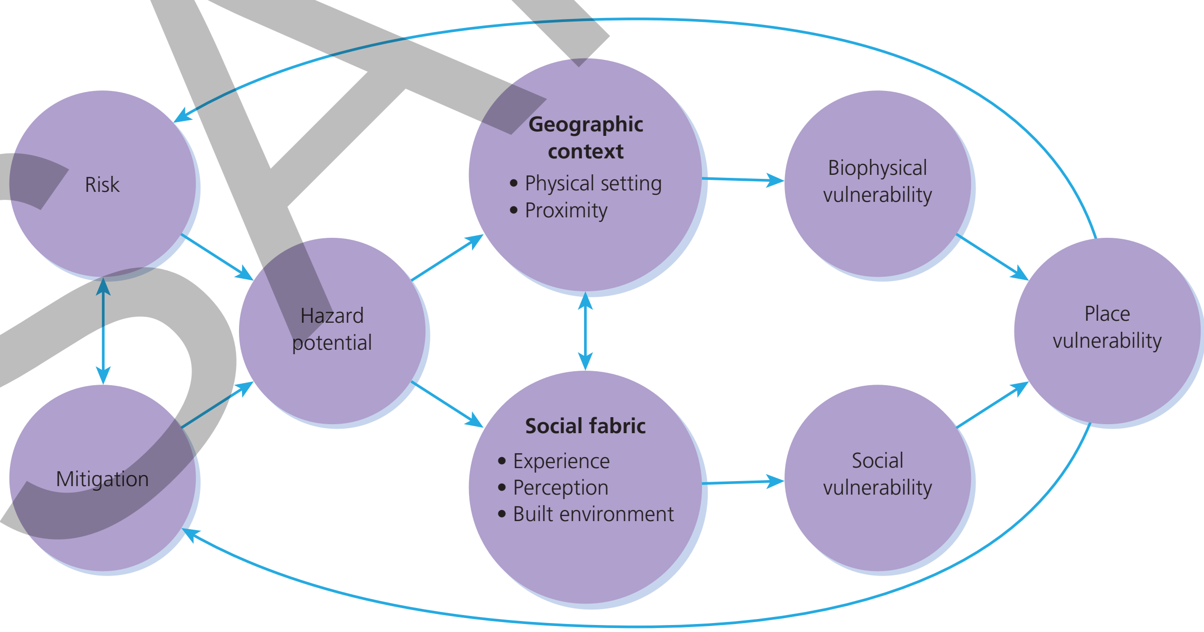

Figure 5.1 Model of vulnerability

vulnerable than others? A similar sized natural hazard event can have widely varying impacts in different parts of the world. People's wealth and the level of technology that they can apply do affect the degree to which the hazard event will impact upon them. Richer people and countries can protect themselves by building sea defences, constructing earthquake-resistant buildings, providing better emergency services, etc. They can also be better prepared by being made more aware of the risk through education. The people of cities in poorer countries are more vulnerable. As such urban areas have grown, more and more people have been forced to live in hazardous areas such as very steep hillsides that are prone to landslides, and in the lowest lying parts where they are at risk from tropical storms and tsunamis.

The perception of natural hazards

People react to the threat of hazards in different ways because of the way in which individuals receive and process information. Perception is influenced by many factors including:

- socio-economic status
- level of education
- occupation/employment status
- religion, cultural/ethnic background
- family and marital status
- past experience
- values, personality and expectations.

Perception of a hazard will ultimately determine the course of action taken by individuals in order to modify the event or the responses they expect from governments and other organisations.

There is often a great difference in the perception of a hazard between peoples of differing levels of economic development. In wealthier areas there is a sense that the better prepared you are, the more able you will be to withstand the impact of the hazard and perhaps even prevent the disaster from taking place. This is usually based upon government and community action, and is backed by capital that will fund technologically-based solutions. The sense of helplessness in the face of natural hazards tends to increase with the level of poverty and the deprivation of the people. Even in wealthier countries there are groups of disadvantaged people who tend to look upon natural hazards as part of their way of life, as they are seen as unavoidable, just as the bulk of people in poorer countries see the impacts of these events as being part of the conditions of poverty.

People may perceive natural hazards in the following ways:

- **Fatalism (acceptance):** Such hazards are natural events that are part of living in an area. Some communities would go as far as to say that they are 'God's will'. Action is therefore usually direct and concerned with safety. Losses are accepted as inevitable and people remain where they are.
- **Adaptation:** People see that they can prepare for, and therefore survive the event(s) by prediction, prevention, and/or protection, depending upon the economic and technological circumstances of the area in question.
- **Fear:** The perception of the hazard is such that people feel so vulnerable to an event that they are no longer able to face living in the area and move away to regions perceived to be unaffected by the hazard.

Management of natural hazards

Key terms

Community preparedness/risk sharing – This involves prearranged measures that aim to reduce the loss of life and property damage through public education and awareness programmes, evacuation procedures, the provision of emergency medical, food and shelter supplies and the taking out of insurance.

Integrated risk management – The process of considering the social, economic and political factors involved in risk analysis; determining the acceptability of damage/disruption; deciding on the actions to be taken to minimise damage/disruption.

Lava – Molten rock (magma) flowing onto the surface. Acid lava solidifies very quickly, but basic lava (basaltic) tends to flow some distance before solidifying (for example, on the Hawaiian Islands).

Mitigation – Long-term action taken to reduce or eliminate the risk to life and property from hazard events. Action is taken before, during and after disasters to break the cycle of damage and repair in hazardous areas.

Prediction – The ability to forecast a hazardous event and then give warnings so that action can be taken to reduce their impact. Improved monitoring, information and communications technology have meant that this has become more important and accurate in recent years.

Resilience – The sustained ability of individuals or communities to be able to utilise available resources to respond to, withstand and recover from the effects of natural hazard events. Communities that are resilient are able to minimise the effects of the event, enabling them to return to normal life as soon as possible.

People respond to natural hazards and the threats that they pose by seeking ways to reduce the risk. Responses can come from individuals, the local community, national governments and international agencies.

Community **resilience** is the sustained ability of a community to utilise available resources to respond to, withstand and recover from the effects of natural hazards. Communities that are resilient are able to minimise the effects of a hazard, making the return to normal life as effortless as possible.

A key feature of the modern approach is that hazards are best combated by efficient management. Modern management techniques, with their gathering of information, careful analysis and deliberate planning, aim to make the most efficient use of the money available to confront natural hazards. A process known as **integrated risk management** is often used. This incorporates:

- identification of the hazard
- analysis of the risks
- establishing priorities
- treating the risk and implementing a risk reduction plan
- developing public awareness and a communication strategy
- monitoring and reviewing the whole process.

The governments of many countries use such schemes. An example developed by the New Zealand government is shown in Figure 5.2.

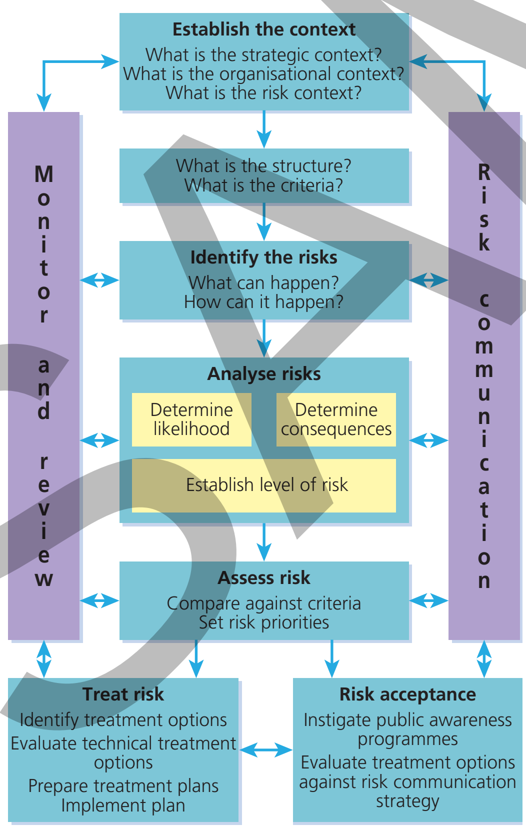

Figure 5.2 The process of risk management

People and organisations therefore try to manage natural hazards in the following ways:

- **Prediction:** It may be possible to give warnings that will enable action to be taken. The key to this is improved **monitoring** in order to give predictions which means that warnings can be issued. The National Hurricane Centre in Florida is a good example of an agency demonstrating how prediction can depend upon monitoring, through the use of information from satellites and land-, sea- and air-based recordings.
- **Prevention:** For natural hazards this is probably unrealistic although there have been ideas and even schemes such as seeding clouds in potential tropical storms in order to cause more precipitation, which in theory would result in a weakening of the system as it approached land.
- **Protection:** The aim is to protect people, their possessions and the built environment from the impact of the event. This usually involves modifications to the built environment such as improved sea walls and earthquake-proof buildings. One way in which governments can act, and people react, is to try to change attitudes and behaviour to natural hazards which will reduce people's vulnerability. **Community preparedness (or risk sharing)** involves prearranged measures that aim to reduce the loss of life and property damage through public education and awareness programmes, evacuation procedures and provision of emergency medical and food supplies and shelters. There can also be attempts to modify losses through insurance (richer areas) and international aid (in poorer regions).

All attempts at management must be evaluated in terms of their success. Successful schemes include the use of dynamite to divert lava flows on Mt Etna and pouring sea water on **lava** flows in Iceland. On the other hand, the well-prepared Japanese government was caught out in 2011 by an earthquake in north-eastern Japan that triggered a tsunami. 15,894 people were killed and 2,500 were reported missing. Hundreds of thousands of buildings were destroyed or badly damaged. According to the Japanese government the final cost was estimated at US $200 million.

Disaster/risk management cycle: This illustrates the ongoing process by which governments, businesses and society plan for and reduce the impact of disasters, react during and immediately following an event, and take steps to recover after an event has occurred. Appropriate actions at all points in the cycle lead to greater preparedness, better warnings and reduced vulnerability or the prevention of hazard events during the next cycle. The complete cycle includes the shaping of public policies and plans that either modify the causes of the hazard events or mitigate their effects on people, property and infrastructure.

One of the main goals of disaster management, and one of its strongest links with development, is the promotion of sustainable livelihoods and their protection and recovery during such events. Where this goal is achieved, people have a greater capacity to deal with disasters and their recovery is more rapid and long lasting.

The Federal Emergency Management Agency (FEMA) was created in the USA in 1978. The agency's primary purpose is to co-ordinate the response to a disaster that has occurred in the United States and that has overwhelmed the resources of local and state authorities. They have created major analysis programmes for floods, hurricanes and earthquakes. Their operations are carried out very much along the lines shown by the disaster/risk management cycle model shown in Figure 5.3.

Disaster/response curve: To show that hazard events can have varying impacts over time, Park (1991) devised his impact/response model (Figure 5.4). This model shows an early stage, before the disaster strikes, where the quality of life is normal for the area. Here people try their best to prevent such events and prepare in case they should happen. When the event happens, the quality of life suddenly drops with people taking immediate action to preserve life and, if possible, the built environment.

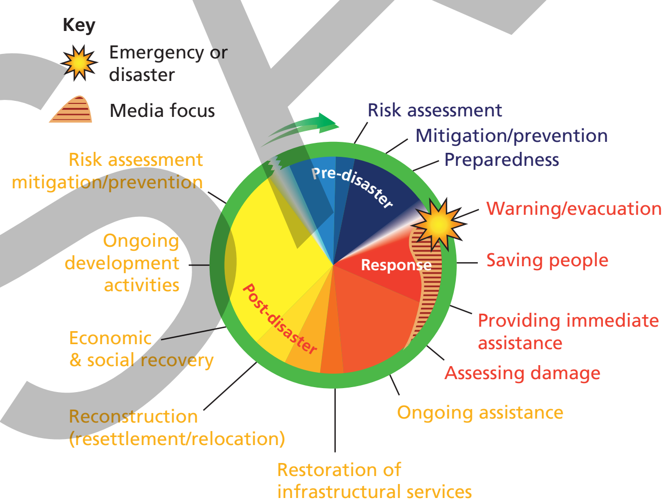

Figure 5.3 The disaster/risk management cycle

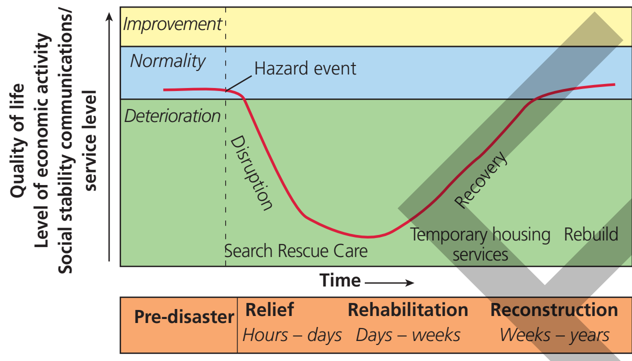

Figure 5.4 The Park impact/response model

The next stage Park called **relief**, where medical attention, rescue services and overall care are delivered. This can last from a few hours to several days if the event has been very damaging. From this point the quality of life of the people of the area starts to slowly increase.

Next comes **rehabilitation**, where people try to return to normal by providing food, water and shelter for those most affected. This period can last anything from a few days to weeks.

Finally comes **reconstruction**, where the infrastructure and property are repaired or rebuilt and crops regrown. At this time people use the experience of the event to try to learn how to better respond to the next one. This period can take from weeks to several years.

Key terms

Frequency – The distribution of a hazard through time.

Magnitude – The assessment of the size of the impact of a hazard event.

Primary effects – The effects of a hazard event that result directly from that event. For a volcanic eruption these could include lava and pyroclastic flows. In an earthquake, ground shaking and rupturing are primary effects.

Secondary effects – These are the effects that result from the primary impact of the hazard event. In volcanic eruptions these include flooding (from melting ice caps and glaciers) and lahars. In an earthquake, tsunamis and fires (from ruptured gas pipes) are secondary effects.

Soil liquefaction – The process by which saturated, unconsolidated soil or sand is converted into a suspension during an earthquake. It is then able to act like a liquid and flow, particularly when under pressure.

Park also showed how different events can have different impacts. This is shown in Figure 5.5 (page 190) by the speed of the drop in the quality of life, the duration of the decline and the speed and nature of recovery. The difference in the three lines could be related to the type of hazard, the degree of preparedness or the speed of the relief effort, and the nature of recovery and rebuilding.

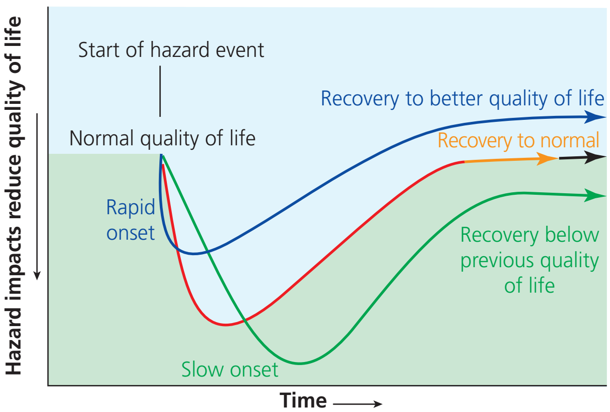

Figure 5.5 Variations within the Park model

Distribution, frequency and magnitude

Distribution refers to the spatial coverage of the hazard. This can refer to the area affected by a single event, some of which can have a very localised effect, while others have a much wider effect, such as tsunamis which can cross large oceans. Volcanic eruptions have been known to have a global effect with the spread of dust in the upper atmosphere and the consequent short-term climatic change. Distribution of a hazard can also refer to the areas where the particular hazard is likely to occur. Earthquakes and volcanoes, for example, are generally associated with tectonic plate boundaries whereas tropical cyclones usually occur between 5° and 25° north and south of the Equator.

Frequency refers to the distribution of the hazard through time whereas **magnitude** assesses the size of the impact. At its most basic level, the frequency-magnitude principle leads us to expect many small insignificant events and fewer large-scale ones.

Skills focus

Crowdsourcing and 'big data' (see page 662) can help in the recovery from a hazard event. Research an example where they have been used and assess their effectiveness.

The effects of natural hazard events

The effects are the impact that an event has upon both the physical and human environments. Some commentators differentiate between primary and secondary effects when considering hazard impacts. For an earthquake, for example, the **primary effect** would be the ground shaking and cracking followed by the **secondary effects** of **soil liquefaction**, landslides, tsunamis and the effects on people and the built environment such as collapsing buildings, fires, flooding and the knock-on effects which could be with the population for a long time. Communication systems could be out of order, the ability to produce food crops may take some time to be restored and the economy of a region may be so damaged that the legacy of the hazard event will be around for years.

Review questions

1 Assess the validity of the statement, 'The richer you are the greater the chance of surviving a natural hazard'.

2 For one example of a hazard, assess the extent to which the Park model can be applied to the impacts and responses to that hazard.

5.2 Plate tectonics

Earth structure

The interior of the Earth is divided into three main components: the crust, the mantle and the core (Figure 5.6, page 192).

The core

The **core** is made up of dense rocks containing iron and nickel alloys. It is subdivided into a solid inner core and a very hot molten outer one, with a temperature of over 5,000 °C. This heat is produced mainly as the result of two processes: **primordial** heat left over from the Earth's formation and **radiogenic** heat produced by the decay of radioactive isotopes, particularly Uranium-238, Thorium-232 and Potassium-40.

The mantle

The **mantle**, the thickest layer, is made of molten and semi-molten rock rich in iron and magnesium (such as peridotite). At a depth of between approximately 700 km and 100 km, the upper part of the mantle becomes hotter and more fluid. This is called the asthenosphere. Above the asthenosphere the mantle becomes solid.

The crust

The outermost layer is called the **crust**. There are two types of crust; a relatively thin layer of dense basalt is found under the oceans and a thicker layer of less dense granitic rock makes up the continents. Table 5.1 summarises the differences between the two types of crust.

Table 5.1 Differences between continental and oceanic crust

	Continental crust	Oceanic crust
Thickness	30–70 km	6–10 km
Age	Over 1,500 million years	Less than 200 million years
Density	2.6 (lighter)	3.0 (heavier)
Composition	Mainly granite; silicon, aluminium, oxygen	Mainly basalt; silicon, magnesium, oxygen

The theory of plate tectonics

Plate tectonic theory was developed in the 1960s. It completely revolutionised the study of Earth Science. The theory emerged from earlier work by the German researcher, Alfred Wegener, who gathered evidence (Table 5.2, page 192) to suggest that just one giant continent (Pangaea) existed about 300 million years ago. He believed that it later split into two smaller continents (Laurasia and Gondwanaland). Today's continents were then formed from further splitting of these two masses. Wegener called his ideas, the theory of **continental drift**.

Key terms

Asthenosphere – Part of the Earth's mantle that lies below the lithosphere, at depths between about 100 and 700 kilometres.

Conservative plate margin – A plate margin where two tectonic plates are moving past one another with no addition or destruction of plate material.

Constructive plate margin – A plate margin where new crust is generated as the plates pull away from each other. These are found at mid-oceanic ridges.

Destructive plate boundary – A plate margin where crust is destroyed as two plates converge. These are usually associated with island arcs or young fold mountains.

Palaeomagnetism – A record of the history of the Earth's magnetic field, preserved in magnetic minerals in volcanic rocks.

Plate tectonic theory – The theory that states that the Earth's crust is made up of several rigid plates moving relative to one another.

Plume – A hot column of magma which rises from deep within the Earth.

Rift valley – A long, deep valley found in the centre of a spreading ridge. It is formed between parallel faults where a block of the crust has sunk down.

Sea-floor spreading – The theory that the ocean floor is moving away from the mid oceanic ridge and across the deep ocean basin, to disappear beneath continents and island arcs.

Tectonic plate – One of a series of rigid sections of the Earth's crust. They float on the upper mantle and move relative to one another.

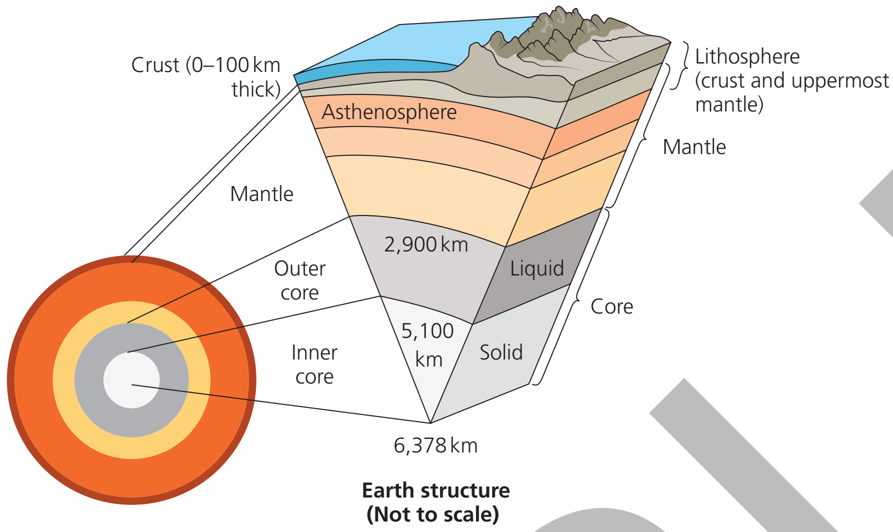

Figure 5.6 The structure of the Earth

Table 5.2 Evidence for the theory of continental drift

Geological evidence	• The 'jigsaw fit' of South America and west Africa • Evidence of similar ancient glacial deposits found in South America, Antarctica and India. They must have been formed together and then moved • Structural faults in rocks in Brazil and west Africa match when the two are compared • Similar rock sequences in northern Scotland and eastern Canada, indicate that they were formed under the same conditions in one location
Biological evidence	• Fossils found in India are comparable with fossils in Australia • Fossil remains of the reptile *Mesosaurus* are found in both South America and southern Africa indicating they were once joined together • Identical plant fossils have been found in the coal deposits of both India and Antarctica

Crustal evolution

Little is known about the early development of the Earth's crust; much of the geological record has disappeared over time as elements of the crust have been recycled. The oldest rocks are approximately four billion years old. It is thought, however, that about three billion years ago there was an increase in the growth of continental crust; rocks of that age are found in the middle of the large continental plates.

Plate movement, as we think of it today, developed about 750 million years ago. It was at this time that Pangaea split up and life on Earth began to evolve rapidly. Deep mountain belts, surface erosion and the recycling of continental crust back into the mantle also developed.

Twenty-first century developments in the theory of plate tectonics suggest that the crust and rigid mantle collectively make up the **lithosphere** and that the lithosphere is divided into seven large continental and ocean **tectonic plates** and several smaller ones (Figure 5.7).

The theory states that the lithosphere is able to slide over the asthenosphere and this allows plate movement. As the lithospheric plates move across the Earth's surface (typically at five to ten centimetres per year), driven by forces that are not yet fully understood, the plates interact along their boundaries where they converge, diverge or slip past one another. Such interactions are thought to be responsible for most of the Earth's seismic and volcanic activity, although earthquakes and volcanoes can also occur in plate interiors. Where plates push together (converge), mountains are formed. Where plates pull apart (diverge), continents break apart and oceans form. The continents within the plates, and the ancient hearts of the continents (cratons), drift with the plates. Over millions of years these movements result in significant changes to the Earth's geography.

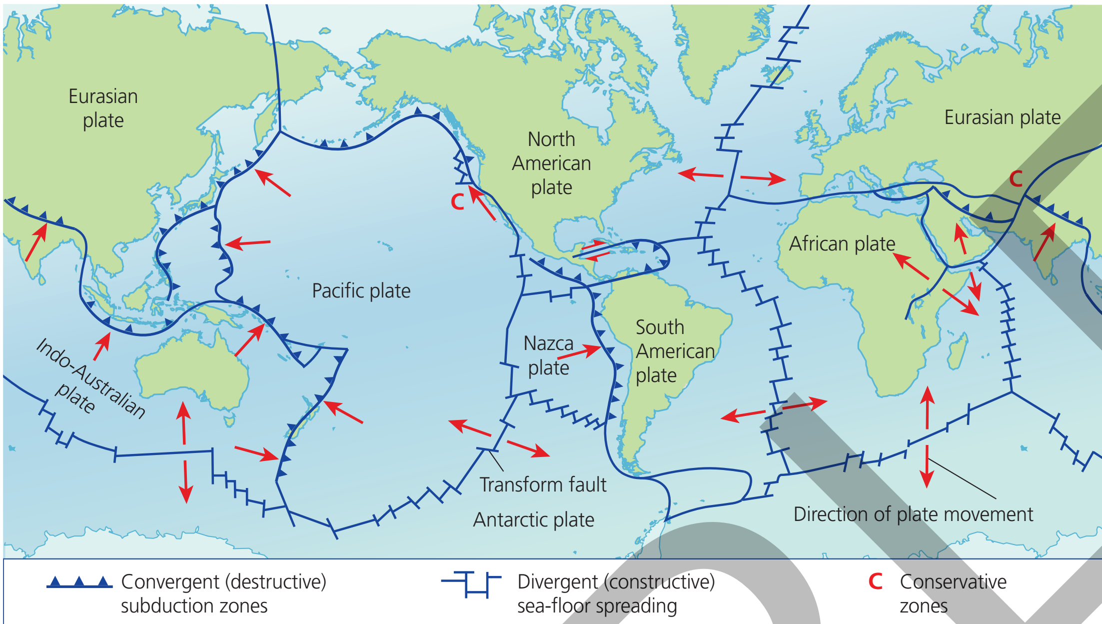

Figure 5.7 Tectonic plates and their margins

Evidence supporting the main theory of plate tectonics was starting to emerge in the 1940s. The mid-Atlantic ridge was discovered and studied along with a similar feature in the Pacific Ocean. A study of the polarity of ancient magnetic particles in the rock (**palaeomagnetism**) found that:

- the polarity of the rock either side of the mid-Atlantic ridge alternated in a striped pattern – that was mirrored on either side of the ridge (Figure 5.8)
- the oceanic crust was slowly moving away from the plate boundary
- the oceanic crust got older with distance from the mid-oceanic ridge (although geologically speaking it is very young, nowhere older than 200 million years).

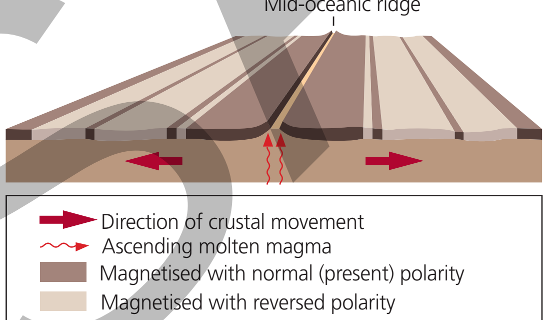

Figure 5.8 Magnetic 'stripes' on the Atlantic Ocean floor

Sea-floor spreading: If the sea floor is spreading, it implies that the Earth must be getting bigger. This is not the case. To accommodate the new crust being created at mid-oceanic ridges, crust must be destroyed elsewhere. Evidence of crust being destroyed was found in huge oceanic trenches where large areas of ocean floor were being pulled downward in a process known as **subduction**.

Plate movement

Convection currents

Lithospheric plates are massive and require huge forces to move them. It was previously thought that **convection currents** within the mantle drove plate movement. Uneven distribution of temperatures towards the base of the mantle caused convection cells which dragged the lithospheric plates with them when the moving mantle reached the surface. This theory has been partly discounted because most of the mantle is not fluid. Scientists now believe that convection currents play only a supporting role in the current dynamic models (ridge push and slab pull) in which plates move as part of a **gravity-driven system** (see Figure 5.9, page 194).

Ridge push or gravitational sliding

At constructive boundaries, less dense, hot **magma** wells up and produces an ocean ridge standing some

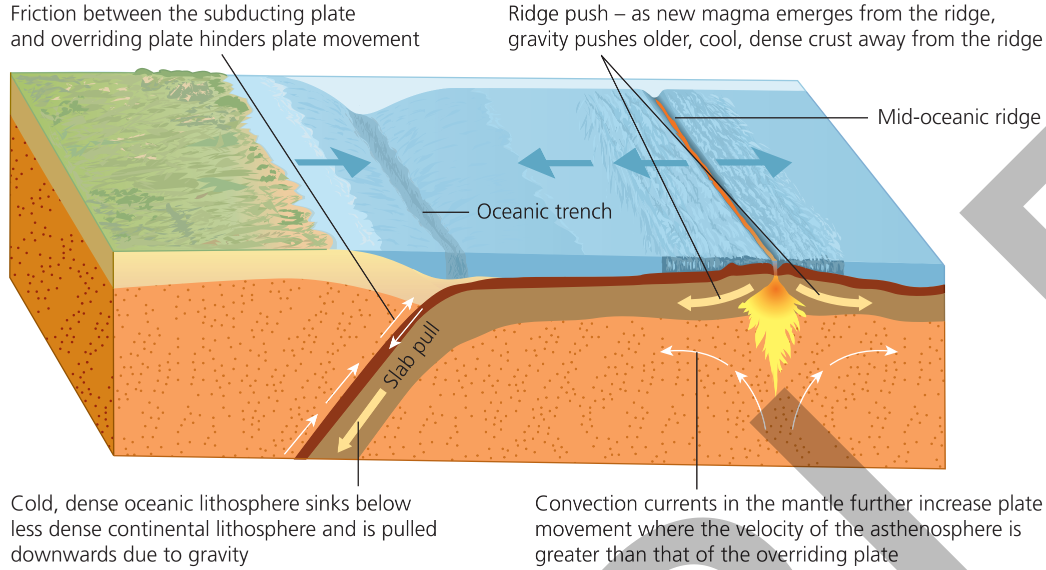

Figure 5.9 Mechanisms contributing to plate movement

two to three kilometres above the ocean floor. As this newly formed rock gets older, it cools becoming denser. Gravity acting on this older, denser lithosphere causes it to slide away from the ridge, down the sloping, semi-molten asthenosphere below. The occurrence of shallow earthquakes, resulting from the repeated tearing apart of the newly formed crust, indicates that there is also some frictional resistance to this force. Some experts prefer to call this process **gravitational sliding**.

Slab pull

At a destructive (subduction) boundary, older, colder oceanic plates are denser than the underlying mantle. As the subducting plate is much colder and heavier than the hotter mantle, it sinks into the mantle due to the downward gravitational force acting on it and pulls the whole oceanic plate down into the mantle. The force that the sinking edge exerts on the rest of the plate is called slab pull.

Currently, although many scientists consider slab pull to be a stronger factor in driving plate movements than ridge push or mantle convection, there are others who disagree and believe ridge pull to be more significant. Each plate moves at its own rate, which suggests that the relative importance of the driving and retarding forces must vary from plate to plate. It therefore seems unlikely that any single mechanism is the sole driving mechanism of plate motion.

Plate margins

As mentioned previously, the lithospheric plates interact with one another at their margins. It is along these margins that most volcanic and seismic activity occurs. The margins are also where distinctive landforms are located. There are three types of plate margin:

- constructive (divergent) plate margin
- destructive (convergent) plate margin
- conservative (passive) plate margin.

Constructive (divergent) plate margins

Ocean ridge system

At constructive plate margins, plates are moving away from one another and new lithosphere is created. Under the oceans, this has produced an extensive **ocean ridge** system, comprising underwater mountains and volcanoes, that stretches for nearly 65,000 kilometres. Over 90 per cent of the mountain range lies at an average depth of 2,500 metres.

The ocean ridge system has different names depending on location (for example, the Mid-Atlantic Ridge (MAR), the East-Pacific Rise, the Juan de Fuca Ridge, and the Galapagos Rise). The MAR is about three kilometres in height above the ocean floor and between 1,000 and 1,500 km wide. Along its length, there are numerous transform faults and an axial rift valley where the crust has partially collapsed into the low-pressure zone left by the erupting magma. Where the magma reaches the surface, volcanoes can grow into islands (such as in Iceland).

Rift valleys

Within continents, constructive margins produce **rift valleys** (Figure 5.10), such as the Great Rift Valley of East Africa which is up to 120 km wide and 1,500 m deep. This is thought to have developed over a hot spot (pages 196–7). Rising magma caused the whole region to be uplifted. This created weaknesses in the crust, through which low viscosity basalts emerged and flooded the area. As with the oceanic ridge, there was a partial collapse of the crust and the development of a deep, steep-sided rift valley.

The two sides of the rift valley are slowly moving apart, and it is believed that it will eventually flood with sea water and become a new ocean separating Africa into two parts.

Destructive (convergent) plate margins

These occur where lithospheric plates move towards one another. The nature of the boundary depends upon the combination of plate types.

Oceanic/continental convergence

The denser oceanic plate is forced under the lighter continental plate in the process of **subduction** (Figure 5.11). The downward displacement

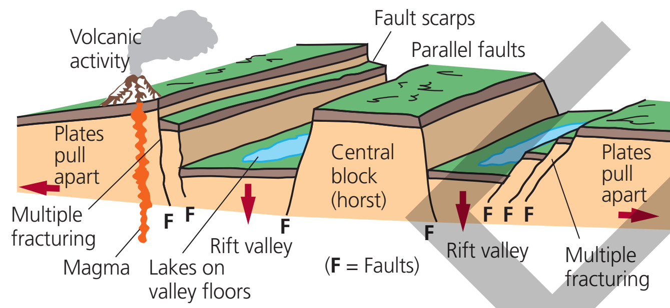

Figure 5.10 Cross section of a rift valley

(downwarping) of the oceanic plate forms a **deep-sea trench** that runs parallel to the plate boundary. The Challenger Deep, in the Marianas Trench, is the deepest part of the ocean at just over 10,900 metres.

During the subduction process, sediments that have accumulated on the edge of the continental plate are deformed by folding and faulting and then uplifted to form **young fold mountains** (such as the Andes). Fold mountains are parallel chains of high volcanic mountains with an inter-montane plateau between them.

Ocean/ocean convergence

Where oceanic crust meets oceanic crust (Figure 5.12, page 196), the more dense oceanic crust subducts beneath the less dense oceanic crust and a line of volcanic islands known as an **island arc** can appear. On the western side of the Pacific Ocean, where the Pacific plate is being subducted beneath the smaller Philippines plate, a line of volcanic islands, including Guam and the Marianas, has been formed from magma upwelling from the Benioff zone.

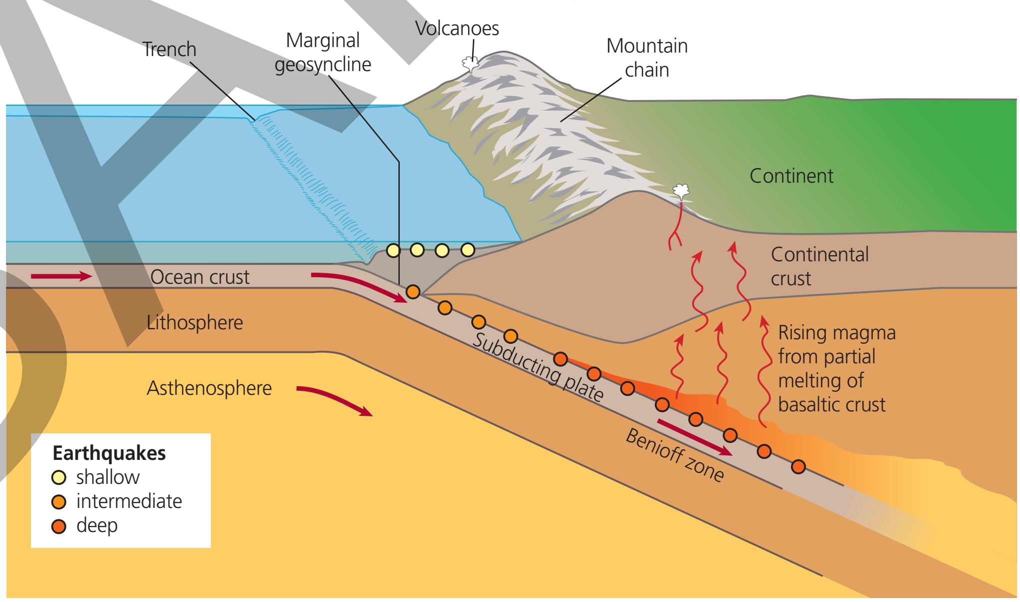

Figure 5.11 Cross section of oceanic/continental plate convergence at a destructive margin

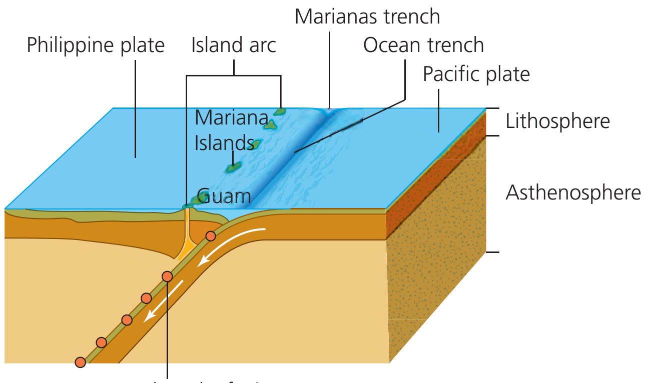

Figure 5.12 Cross section of oceanic/oceanic plate convergence at a destructive margin

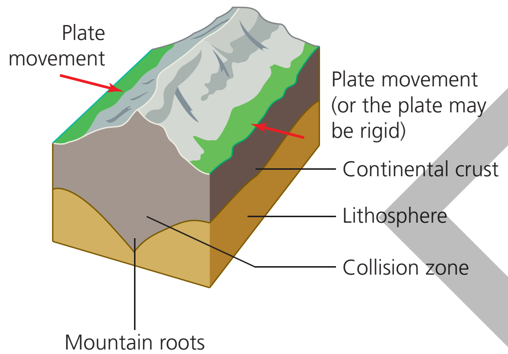

Figure 5.13 Cross section of continental/continental plate convergence (collision boundary) at a destructive margin

Continental/continental convergence (collision boundary)

If two low density continental plates converge, subduction does not occur. Sediments between them are forced up into young fold mountains. This is what is happening where the Indo-Australian plate is being forced northwards into the Eurasian plate, forming the Himalayas. There is no volcanic activity, but the movement can trigger shallow-focus earthquakes (Figure 5.13).

Conservative (passive) plate margins

Where two plates slide past one another, parallel to the plate margins, there is no subduction and therefore no volcanic activity. The movement of the plates does create stresses between the plate margins, particularly when they get stuck. Sudden movements of the plates trigger shallow focus earthquakes. The most well-known example of a conservative plate margin is the San Andreas Fault complex in California, where the Pacific and North American plates move in the same direction but at different speeds. Stresses set up by this movement cause transform faults to develop running at right angles to the main fault (Figure 5.14).

Mantle (magma) plumes

In the 1970s, a theory was developed to explain the presence of volcanic activity away from plate boundaries. It proposed that localised heating at the core/mantle boundary caused a **plume** of magma to rise through the mantle and 'eat' into the plate above the so-called 'hot spot'. Where the lava broke through to the surface, active volcanoes formed above the

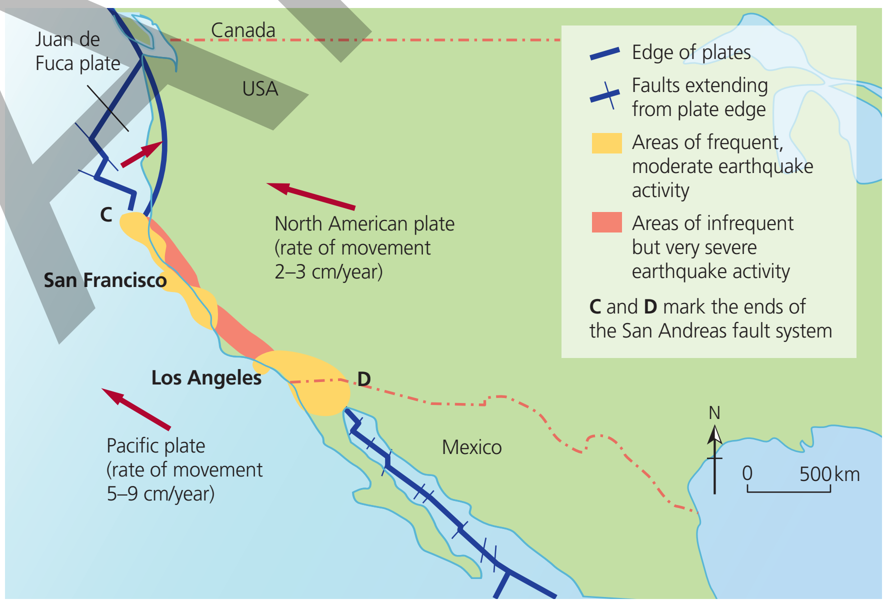

Figure 5.14 The San Andreas Fault system – a conservative plate margin

hot spot. While the hot spots are thought to be fairly stationary, the tectonic plates continue to move. As a plate continues to move away from the hot spot, it takes with it the volcanoes that have formed. These volcanoes cool and subside, and over millions of years a chain of islands, atolls and seamounts (known as hotspot tracks) can form. The volcanoes get progressively older (and become extinct) the further they move away from the hot spot. The youngest and most active volcanoes are found directly over the plume. The Hawaiian Island chain is an example of hot spot activity (Figure 5.15). The Loihi Seamount is a submarine volcano to the south east of Hawaii, formed due to hot spot activity, that will eventually form a new island in the chain.

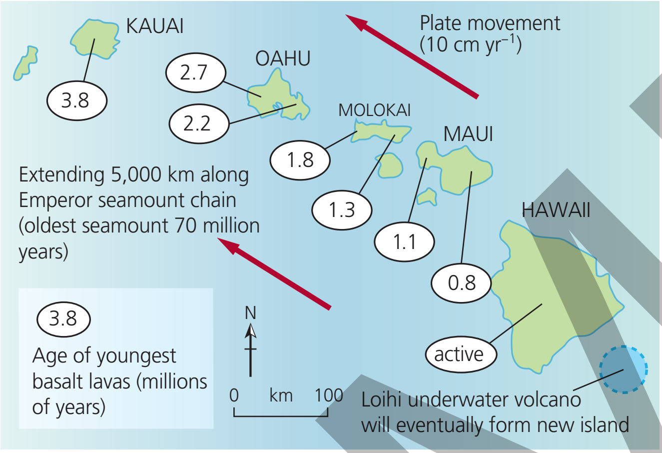

Figure 5.15 The Hawaiian hot spot

The Hawaiian hot spot has been active for around 70 million years. It has created a 6,000 kilometre long chain of volcanic islands in the north west Pacific Ocean. Scientists can use hot spot tracks to study how tectonic plates have moved over time compared to mantle sources.

Whilst the hot spot theory can explain the relationship between age and distance from plate margins for some volcanic chains, it can't be applied to all volcanic activity. There has been some doubt expressed by scientists in relation to hot spot theory about whether hot spots are fixed in position, leading some to believe that other, as yet unknown, processes are at work.

Review question

3 For a named tectonic boundary, outline the links between the nature of the boundary and the landforms found along it.

5.3 Volcanic hazards

Key terms

Ash – Dust-sized particles of rock produced by the explosive eruption of some volcanoes. This material may be carried in the air for long distances from the volcano which formed it.

Composite volcano – Large, steep-sided, symmetrical cone-shaped volcano formed from alternating layers of lava flows, volcanic ash, cinders, blocks, and bombs.

Lahars – Mudflows composed of pyroclastic material and water that flows down from a volcano, usually along a river valley.

Magma – Molten rock that is found beneath the surface of the Earth.

Pyroclastic flow – A high-density mass of gases, hot ash and larger material that flows rapidly down the sides of the volcano.

Tephra – Any type of rock fragment that is forcibly ejected from a volcano during an eruption.

Tsunamis – Giant sea waves generated by shallow-focus underwater earthquakes, violent volcanic eruptions, underwater debris slides and landslides into the sea.

Volcanic bombs – Rocks that are more than 5 mm in diameter that are thrown into the air by a volcanic eruption.

Volcanic explosive index – A scale used to measure the explosiveness of volcanoes.

Nature and distribution

Most volcanic activity is associated with plate tectonic processes and is mainly located along plate margins (Figure 5.17, page 199).

Volcanic activity is therefore found at the following sites:

- Along **constructive plate margins** where plates are moving apart and magma is forcing its way to the surface. In some locations along oceanic ridges, where the lava builds up to the ocean surface, volcanic islands form, for example, Iceland.
  Volcanoes also form within continental rift valleys. The Great Rift Valley in east Africa has created many volcanoes, such as Kilimanjaro, even though they are just outside the valley (Figure 5.10, page 195). Volcanoes formed here have fairly gentle sides because of the low viscosity of the basaltic lava. Eruptions are frequent but relatively gentle (effusive).

- On or near **subduction zones**: The line of volcanoes, or 'ring of fire' that surrounds the Pacific Ocean is associated with plate subduction. The deeper the oceanic plate descends, the hotter the surroundings become. This, together with the heat generated from friction, begins to melt the oceanic plate into magma in a part of the subduction zone known as the Benioff zone. As it is less dense than the surrounding material, this molten magma begins to exploit weaknesses in the crust and rises as columns of magma. The magma collects in huge sub-surface reservoirs called plutons. Eventually, some of the magma reaches the surface and form volcanoes (Figure 5.11, page 195). The andesitic lava, which has a viscous nature (flows less easily), creates complex, composite and explosive volcanoes (compared with the basaltic emissions on constructive margins). If the eruptions take place offshore, a line of volcanic islands known as an **island arc** can appear (Figure 5.15, page 197).
- Over **hot spots**: The Hawaiian Islands (Figure 5.15) in the north Pacific Ocean are examples of shield volcanoes that are located away from plate boundaries over a hot spot. They have low-angled slopes made from low viscosity, basaltic lava that flows great distances from the volcanic vent itself. Two of the world's most active volcanoes – Kilauea and Mauna Loa – can be found on the island of Hawaii. Mauna Loa last erupted in 1984, and Kilauea's last eruption lasted from 1983–2018.

Skills focus

There is no volcanic activity taking place in the British Isles at present but this was not always the case. Consult the geological record to find evidence of past volcanic activity and map this on an outline of the British Isles.

Magnitude and frequency of events

Like all natural phenomena, volcanic events only become hazardous when they impact upon people and the built environment, for example, by killing and injuring people, burying and destroying buildings and infrastructure and bringing agricultural and other economic activities to a halt. The Kamchatka peninsula in the far east of Russia is one of the most geologically active zones on the planet. Despite the fact that there are 300 volcanoes (including 29 that are active) on the peninsula, they are not considered a hazard because so few people live there.

Volcanic eruptions show an enormous variation. The type of volcano and volcanic activity depends upon the nature of the lava, which in turn depends upon the location of the volcano with regard to tectonic plate margins. If the lava is not viscous (a thin fluid), the gases may escape easily. If the lava is highly viscous (thick and pasty), the gases will not move freely and can build up tremendous pressure within the volcano. The resulting explosive eruptions can blow volcanic dust into the high atmosphere, reducing the amount of incoming solar radiation and causing short-term global climate change. The main method of measurement of **magnitude** has been the **volcanic explosivity index (VEI)**, a logarithmic scale running from 0 to 8 (Figure 5.16).

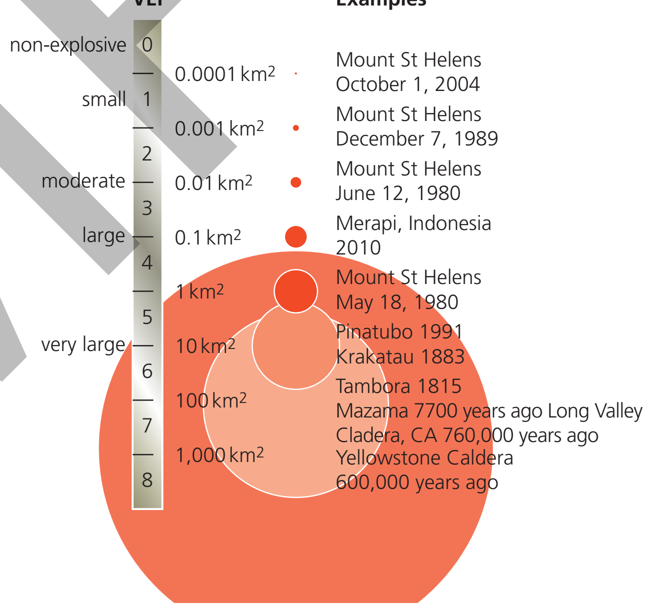

Figure 5.16 The Volcanic Explosivity Index (VEI).
Source: USGS

To determine the **frequency** of eruption of any volcano, its previous history of activity can be interpreted by volcanologists using the deposits associated with the volcano itself and those within the wider region it can effect.

The impacts of volcanic activity

A volcanic event can produce a variety of effects, the impact of which can range from the area immediately

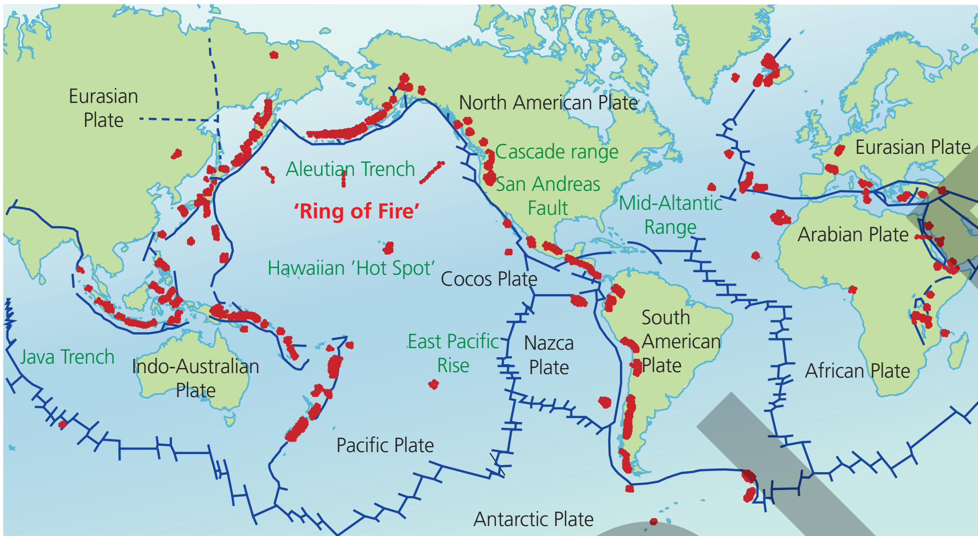

Figure 5.17 Global distribution of active volcanoes

around the volcano to the whole planet. The impact of a volcanic eruption can be categorised into primary and secondary effects.

Primary effects

Primary effects are brought about by material ejected from the volcano and described below:

- **Tephra:** Solid material of varying grain size ranging from **volcanic bombs** to **ash**, all ejected into the atmosphere. Generally, the larger the tephra particles, the shorter the distance of travel from their source. Volcanic bombs as large as a bus are very dangerous, but few people get in their way. At the other end of the scale, fine ash can be thrown high into the atmosphere where strong winds can blow it around the Earth, reducing incoming radiation and cooling the Earth.
- **Pyroclastic flows (also known as nuées ardentes):** Very hot (over 800°C), gas charged, high-velocity flows made up of a mixture of gas and tephra. These usually hug the ground and flow down the sides of the volcano with speeds of up to 700 km per hour. The Roman city of Pompeii (Italy) was destroyed in 79 AD by such flows from Mt Vesuvius.

  Lava flows rarely cause injury to people due to their relatively low velocity. They are, however, often unstoppable and can therefore damage crops and buildings and block roads.
- **Volcanic gases:** These include carbon dioxide, carbon monoxide, hydrogen sulphide, sulphur dioxide and chlorine. In 1986, carbon dioxide emissions from the lake in the crater of Nyos (Cameroon) killed 1,700 people.

Secondary effects

- **Lahars (volcanic mudflows):** Unconsolidated ash from a recent eruption combined with water may be swept down river valleys in the form of a hot, dense, fast-moving mudflow. The water can come from heavy rain, for example, Mount Pinatubo, Philippines in 1991, or from melting snow and ice, for example, Nevada del Ruiz, Colombia in 1985. The mudflow from the Nevada del Ruiz completely destroyed the town of Armero and only a quarter of the 28,700 population survived.
- **Flooding:** When an eruption melts glaciers and ice caps, serious flooding can result. This happened in Iceland in 1996 when the Grimsvotn volcano erupted.
- **Volcanic landslides.** These range in size from less than 1 km^3 to more than 100 km^3. The high velocity and great momentum of landslides allows them to cross between valleys and run up slopes several hundred metres high. For example, the landslide at Mount St Helens in 1980 had a volume of 2.5 km^3, reached speeds of 50–80 m/s and surged up and over a 400 m high ridge located about 5 km from the volcano.
- **Tsunamis:** Sea waves generated by violent volcanic eruptions such as those formed after the eruption of Krakatoa (Indonesia) in 1883. Tsunamis from this eruption are estimated to have killed 36,000 people. (For details on tsunamis see the section on seismic hazards, pages 206–11.)
- **Acid rain:** Volcanoes emit gases which include sulphur. When this combines with atmospheric moisture, acid rain results.

- **Climatic change:** The ejection of huge amounts of volcanic debris into the atmosphere can reduce global temperatures and is believed to have been an agent in past climatic change.

Responses to volcanic hazards

Preparedness

In AD 79, the Roman cities of Pompeii and Herculaneum were overwhelmed by a pyroclastic flow and ash fall resulting from the eruption of nearby Mount Vesuvius. It is thought thousands of people died. Despite being part of a sophisticated civilisation, they had no understanding of the danger that existed on their doorstep. Even in the twenty-first century, people can be caught out (Mt Nyiragongo, 2002, Democratic Republic of the Congo). Thankfully, this is rare as scientists are now able to predict with increasing certainty when a volcanic eruption will occur. Early **prediction** means that people can be evacuated from the danger zone and lives can be saved.

Many earthquakes are now monitored continually, either by local observatories or by satellite. Signs that a volcano may erupt include:

- an increase in the release of various gases, particularly sulphur dioxide and carbon dioxide
- a rise in the level of lava lakes in volcanic craters
- the bulging upwards of surrounding land due to pressure from below
- an increasing number of relatively small earthquakes caused by the rising magma.

A study of the previous eruption history of any volcano is important, along with an understanding of the type of activity produced. Ash, lahars and pyroclastic flows leave characteristic deposits around volcanoes. We can assume that if this type of hazard appeared once, it will be repeated. It is also possible to identify areas at greatest risk and the frequency of eruptions from these layers of deposits.

Mitigation

There are a variety of actions that can be taken before, during and after an eruption to help reduce or eliminate long-term risks caused by volcanoes. **Risk assessments** are one form of mitigation. Governments of countries at risk of volcanic hazards, such as the Philippines, carry out risk assessments and produce a series of alert levels

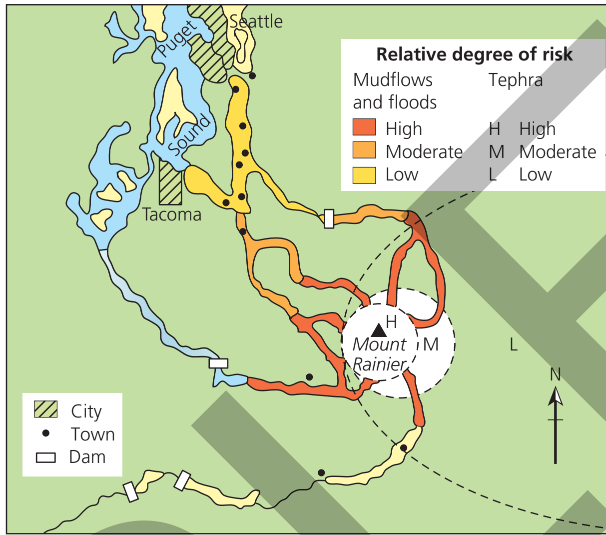

Figure 5.18 Risk assessment of Mt Rainier, Cascade Range USA

(Table 5.4, page 203) to warn the public of the threat. Figure 5.18 shows the risk assessment made for the area around Mt Rainier (part of the Cascade Range in the USA), which is not surprising as 3.5 million people live and work close to it.

During an eruption, some physical actions can be undertaken to reduce the impacts:

- Once viscous lava has started to flow, it may be possible to divert it from the built environment. On Mt Etna in Sicily, digging trenches, dropping blocks into the lava stream and using explosives have been successful in slowing down the flow and, in some cases, diverting it.
- In 1973, the inhabitants of Haeimaey (Iceland) were able to pour seawater on the front of a lava flow to solidify it before it cut off their vital fishing port from the open sea.
- In parts of the Hawaiian Islands, barriers have been built across valleys to protect settlements from lava flows and lahars.

The most common way to reduce the impact on people is to evacuate vulnerable areas when risk becomes intolerable. This comes with its own problems. If an evacuation is carried out needlessly, future evacuations are more difficult to manage. Evacuations have been carried out successfully several times in the Philippines (for example, Pinatubo 1991, Mayon 2018). Sometimes permanent evacuation may be necessary. For example, two-thirds of the Caribbean island of Montserrat is designated an exclusion zone following an eruption of the Soufrière Hills volcano in 1995.

Prevention

There is no way to prevent a volcanic eruption. Disasters can be prevented or reduced by mitigation (see above), particularly evacuation in advance of an eruption.

Adaptation

Perhaps the best response is to move away from the area surrounding the volcano. In the case of Montserrat, this move proved to be permanent for many people and they had to change their way of life, often in a new country. In the east of the Democratic Republic of the Congo, farmers returned to their fields after the eruption of Nyiragongo (2002) and within a short time they were able to change the crops they cultivated, moving from maize to cash crops such as cabbage and bananas. In some cases, their income doubled from before the eruption.

Volcanic event

A recent volcanic event: Mount Mayon, Philippines (2018)

Mount Mayon, at 2,462 m above sea level, is the most active volcano in the Philippines. It is a composite volcano with records of eruptions dating back to 1616. It covers an area of 250 km^2 and, although within a national park, it is surrounded by the city of Legaspi and eight other towns (Figure 5.39, page 225). It is a popular tourist spot and is renowned for its symmetrical conical shape. Its activity is regularly monitored by PHIVOLCS, a Philippine government department dedicated to providing information on the activities of volcanoes, earthquakes and tsunamis.

Mayon is a result of the subduction of the Philippine Sea Plate underneath the Sunda Plate as part of the Pacific Ring of Fire.

Risk and vulnerability

- Large ash emissions from Mount Mayon generally settle within a few kilometres of the volcano and affect the nearby city of Legaspi – the capital of the province of Albay, with a population of almost 200,000 people and a large centre for tourism, education, health, services, commerce and transportation for the region. This ash, made up of fine grains of rock, settles on roofs, often causing them to collapse.
- Ash emissions also settle in the gullies (Figure 5.19) on the flanks of the volcano. The high rainfall amounts in the area (3,432 mm, with January/February being the wettest season), mean there is a high risk of lahars, which destroy anything in their path. In the short term, ash emissions destroy local agriculture, but in the long term they enrich the soil.
- Nuées ardentes (a type of pyroclastic flow) are also concentrated in the gullies. These too destroy anything in their path.
- Lava flows destroy local agriculture

The 2018 event

- Historical data indicates that an eruption event cycle begins with ash emissions and basaltic eruptions, followed by longer term, andesitic lava flows from the central crater. These lava flows travel far down the flanks of the mountain. Pyroclastic flows and mud flows have commonly swept down many of the approximately 40 ravines that radiate from the summit and have often devastated populated lowland areas.
- Mount Mayon has erupted regularly throughout the first 20 years of this century, but the most notable eruption was in 2018. Table 5.3 (page 202) gives a timetable of events.

Figure 5.19 Natural-colour image of Mount Mayon, 15 December 2009. A small plume of ash and/or steam is blowing west from the summit. Dark-coloured lava or debris flows from previous eruptions streak the flanks of the mountain. A ravine on the south-east slope is occupied by a particularly prominent lava or debris flow

Table 5.3 Timetable of events during the 2018 eruption of Mount Mayon

Date	Volcanic activity	Immediate reaction
13 January 2018	• A phreatic (high-pressure steam driven) eruption began that blasted a steam and ash plume approximately 2,500 m into the air for just over an hour and a quarter • Ash fell in many of the surrounding townships and a sulphurous smell was noted in the town of Camalig (Figure 5.20)	• PHIVOLCS raised the alert level of Mayon Volcano from 1 to 2 (Table 5.4) • Approximately 40,000 residents evacuated from a six-kilometre radius
14 January 2018	• Three more phreatic eruptions and 158 rockfall events were recorded • The summit crater began to glow brightly, indicating the growth of a new lava dome and the start of lava flows towards its slopes	• The alert status was upgraded to Level 3
16 January 2018	• Lava flows reached the limits of the six-kilometre evacuation zone	• The province of Albay declared a state of calamity
22 January 2018	• A three-kilometre tall ash column developed • Later that day, lava fountains were observed along with pyroclastic flows, ash plumes, lava bombs and rockfalls	• The alert status was raised to Level 4
23 January 2018	• Intermittent 300–500-metre-high lava fountains and ash plumes developed • Lava bombs and rockfalls could also be observed, along with the sound of explosions	• Schools and colleges were shut • The danger-zone was expanded up to nine kilometres, despite the alert status remaining at Level 4 • Further evacuations took place (eventually totalling 74,000) • Warnings were issued of the possibility of rock falls, landslides and sudden explosions or dome collapse that could generate hazardous volcanic flows • Heavy rains were reported, bringing concerns over the development of lahars
Early February 2018	• The eruption slowly subsides	• Some schools and colleges reopened
March 2018	• Further fall in volcanic activity	• The alert level was dropped to Level 3 and then to Level 2 at the end of the month

Figure 5.20 Ash cloud rising over Mount Mayon on 22 January 2018, as seen from Camalig, Albay

Table 5.4 PHIVOLCS alert levels for Mayon volcano

Alert levels	Main criteria	Interpretation
0: No alert	**Quiet**	**No eruption in foreseeable future**
1: Abnormal	**Low-level unrest**. Slight increase in seismicity	**No eruption imminent**
2: Increasing unrest	**Moderate unrest**. Low to moderate level of seismic activity	**Unrest, probably of magmatic origin;** could eventually lead to eruption
3: Increased tendency towards hazardous eruption	**Relatively high unrest**. Volcanic quakes and tremors may become more frequent	**Magma is close or at the crater**. If the trend is increasing unrest, an eruption is possible within weeks
4: Hazardous eruption imminent	**Intense unrest**. Persistent tremors, many 'low frequency' type earthquakes may occur	**Hazardous eruption is possible within days**
Level 5: Hazardous eruption	**Hazardous eruption ongoing**	Pyroclastic flows (e.g. lava, hot ash or gases) may sweep down along gullies and channels, especially along those fronting the low part(s) of the crater rim. Additional danger areas may be identified as the eruption progresses. Aircraft should stay away lest they encounter potentially dangerous ash clouds

Source: Philippine Institute of Volcanology and Seismology (PHIVOLCS)

Impacts

- Fortunately, nobody was killed during the eruption. This is a testament to the well-organised emergency procedures that had been set up in the Philippines. By 5 February 2018, a total of 86,052 persons had been affected, of which, 64,895 stayed in 58 designated evacuation centres.
- A total of US $3.4 million worth of damages to agriculture (rice, corn and abaca) occurred, affecting more than 10,000 farmers. Some roads were made impassable by landslides and ash falls. Some, but not all, flights in and out of Legaspi were cancelled.

Responses to the eruption

Local and national response

- The Filipino government committed US $1 million for a 'Cash for Work' programme as well as providing hygiene packages for 50,000 families for ten days. As well as this, it provided food packs to evacuees for 100 days.
- The army was called in to help – to enforce the evacuation and to be present if there was any civil disturbance.
- The Philippine Red Cross set up first-aid stations and welfare desks to provide psychosocial support to affected individuals.
- The National Council of Churches in the Philippines provided immediate relief assistance to 3,446 families.

International response

Following the declaration of a Level 3 alert for the volcano, the United States government advised its nationals against travelling to Mayon. Canada and the United Kingdom also discouraged their nationals from visiting the volcano.

The United States government, through the United States Agency for International Development (USAID), committed over US $100,000 which was used to distribute vouchers for families to buy essential items and hygiene kits to help reduce illness in evacuation centres. They also constructed latrines, bathing cubicles and handwashing stations, and promoted safe water and hygiene practices through educational materials.

Volcanic activity has continued on Mayon with further episodes in 2020. It is interesting to note that whilst nobody was killed in the 2018 eruption which reached an alert Level of 4, five people were killed in the eruption in 2013 despite that eruption only being classified at alert Level 2.